

Drought in Utah:

Learning from the Past—Preparing for the Future



April 2007



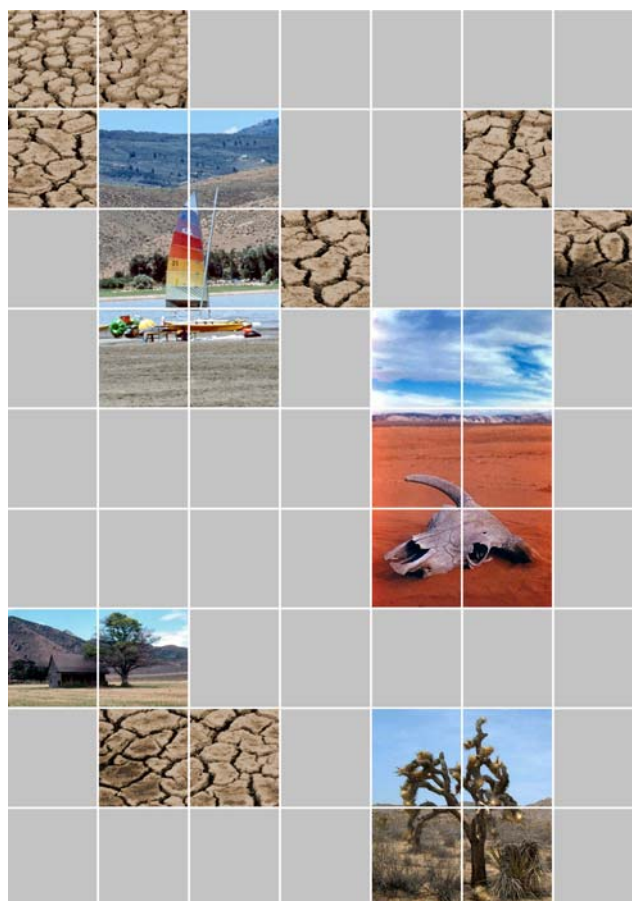
(Revised 2008)

U T A H S T A T E W A T E R P L A N

DROUGHT IN UTAH: LEARNING FROM THE PAST—PREPARING FOR THE FUTURE

April 2007

(Selected data in Chapter 3 revised, April 2008.)



By:

The Utah Division of Water Resources

U T A H S T A T E W A T E R P L A N

ACKNOWLEDGEMENTS

The Utah Division of Water Resources prepared this document with important contributions from the following staff:

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The Utah Division of Water Resources also wishes to express gratitude to the following individuals who provided valuable input during the review process:

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PREFACE

One of the responsibilities of the Utah Division of Water Resources is comprehensive water planning. Over the past decade and a half, the Division has prepared a series of documents under the title "Utah State Water Plan." This includes two statewide water plans, an individual water plan for each of the State's eleven major hydrologic river basins and "special studies" (such as this document). Preparing these documents involves several major data collection programs as well as extensive inter-agency and public outreach efforts. Much is learned through this process. State, local, and federal water planners and managers obtain valuable information for use in their programs and activities, and the public receives the opportunity to provide meaningful input in improving the state's water resources stewardship.

This document is the latest in the "Utah State Water Plan" series and is intended to provide information regarding drought in Utah. It describes drought of the past century (instrumental record) and compares these droughts with pre-instrumental droughts of the not-so-distant past and ancient times, in an attempt to more fully describe drought variability in Utah and the West. It encourages discussion among water managers and decision makers regarding the potential for drought more severe than has been experienced in the past 100 years and strongly promotes a mitigation-based methodology of drought planning and management. It presents and discusses mitigation and response strategies that are currently used, or can be employed, to manage drought and minimize its impacts. This document also makes recommendations that will assist the water community in planning and employing drought mitigation strategies.

In addition to the printed form of this document, the Utah Division of Water Resources has made a "pdf" version available on the Internet. This can be accessed through the Division's home page at: www.water.utah.gov. Such access facilitates better planning and management at the state and local level. It also provides a convenient mode for readers to provide comment and feedback to the division regarding its water planning efforts. Reader comments regarding this publication are welcome.

In April 2008, selected data were revised. Specifically, tree-ring data and analyses presented in Tables 3-2, 3-3, 3-4 and Figures 3-1 and 3-2. Minor modifications were also made in the text to reflect the revised data. Uncertainty in the tree-ring data (fewer tree-ring chronologies) used for analysis increases before approximately 1400 AD. Due to this, additional analysis of the tree-ring data over 1400-1895 AD was conducted and the results added to better reflect drought variability in the recent past (before the start of the instrumental record of drought). This data is also considered more applicable for use in drought planning. The revision was made only to the "pdf" document available on the Division's home page.

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EXECUTIVE SUMMARY

Drought in Utah is a common occurrence and has given rise to various issues, from environmental to societal stresses. This natural phenomenon brings with it impacts that may take years to fully develop and similarly years to recover from. Water in Utah is a limited resource and drought only amplifies this truism. Water development projects and wise management practices are an integral part of Utah’s burgeoning growth and appeal. As the population continues to grow, so too does the demand for water. This growth can potentially increase the state’s vulnerability to drought and result in economically upsetting consequences. In many cases, current management of drought is based upon a response-oriented methodology, which can be a rather costly and sometimes ineffective approach. Management of drought, in general, needs to change from a response-oriented methodology to one of mitigation.

Drought in Utah: Learning from the Past—Preparing for the Future emphasizes the need to plan and implement mitigation strategies—actions taken to ensure a reliable water supply before a drought occurs—in order to satisfy future water demand during periods of drought. Some water suppliers, such as Salt Lake City, have already taken measures to diversify their water supplies and thus mitigate for drought. This document reinforces such actions. Drought can never fully be mitigated and an element of “coping” or “living with drought” will always exist, however, the effects of drought-related impacts can be limited through mitigation. This document also highlights droughts of the past 111 years (the time since weather conditions have been monitored—instrumental record) and compares these droughts with droughts of the not-so-distant

past and ancient droughts (pre-instrumental record—paleoclimatic record) in order to expand current understanding of drought’s natural variability and potential future impacts. It suggests possible mitigation strategies that could be employed and stresses the importance of proactively managing drought using a “risk” management (mitigation) based methodology rather than traditional “crisis” management (response) practices. This document is intended to be a reference to local water planners, managers and decision-makers as they strive to meet water challenges during drought. It will also be of help to those in the general public who are interested in making greater contributions to water-related decisions being made by local, state and federal government officials regarding drought. The following paragraphs summarize the main points of each chapter.

CHAPTER 1

INTRODUCTION: DROUGHT, INDICES AND IMPACTS

The purpose of this report is to:

- Present the significance of historical drought events, drought-related impacts and society’s vulnerabilities to drought.
- Warn of the likelihood of longer-term and more severe drought based upon reconstructed climate records and climate change.
- Discuss mitigation strategies that could be implemented well in advance of drought.
- Make recommendations for action to help manage and mitigate drought.

- Encourage discussion among the water community regarding drought management.

Drought is a dynamic phenomenon and challenging to define; no one definition adequately explains it. Several definitions (meteorological, agricultural, hydrological and socioeconomic) have been developed and when put together, give a better description of drought. Monitoring drought is equally as challenging. Several drought indices have also been developed in an attempt to measure drought severity through comparison of climatological variables to the normal or long-term average (see Box I).

In order to gain a better understanding of drought, its impacts need to be understood. Impacts can be categorized broadly as economic, social and environmental. However, impacts generally are not confined to a single category. Drought impacts can be far reaching and result in economic, social and environmental consequences all at once. In general, Utah’s potential vulnerability to drought and its impacts may increase as the population and demand for water continue to grow. Some water suppliers’ vulnerability to drought has been greatly reduced due to continual planning efforts and actions taken.

CHAPTER 2 HISTORICAL DROUGHT EVENTS FROM THE INSTRUMENTAL RECORD

Utah scientists began to measure and record weather conditions using instruments in the late 1800s. This instrumental record spans a 111-year period (1895-present) and is used in the calculation of drought indices. The Palmer Drought Severity

Index (PDSI), which relies on the data from the instrumental record, was used in this report to identify significant drought periods in Utah. It was chosen due to its relatively long record in comparison to other drought indices’ records (since climate measurements have been recorded) and direct comparability with reconstructed PDSI records (paleoclimatic or proxy records as discussed in Chapter 3).

Utah is divided into seven climatically similar regions. PDSI records exist for each of the seven divisions. Using severity and duration of dry conditions as a guide, the Utah Division of Water Resources identified six drought events in Utah within the instrumental PDSI record. Severity and drought-related impacts varied from region to region and several droughts consisted of consecutive years of mild ($PDSI \leq -1$) to severe ($PDSI \leq -3$) statewide drought conditions. See Box II for the identified drought events and some related impacts.

CHAPTER 3 DROUGHT FROM A PALEOCLIMATIC PERSPECTIVE AND CURRENT CLIMATE TRENDS

Although the instrumental PDSI record yields valuable information on drought, it is limited. This record may be over a century in length, however, drought contained within this time interval does not provide a complete picture of drought variability. Drought occurred years and millennia before the start of monitoring and recording climatic/weather conditions. To gain a broader knowledge and clearer picture regarding drought, analysis of records of longer duration is needed. In order to accomplish this, natural environmental or “proxy” records of

Box I—Drought Indices

Drought Indices:

- Palmer Drought Severity Index (PDSI): based upon meteorological conditions such as temperature and precipitation and weather and climate trends.
- Palmer Hydrological Drought Index (PHDI): also based upon meteorological conditions, however it lacks the “trends” component of the PDSI and therefore becomes a hydrological index.
- Surface Water Supply Index (SWSI): based upon meteorological and hydrological conditions, and takes into account snowpack and stored water supplies.
- Standardized Precipitation Index (SPI): based upon precipitation.

Box II—Drought Snapshots

- 1896-1905: Large cattle operations folded, leaving small operations to fight over what was left of adequate grazing lands. The drought forced settlers to uproot their families as lands were drying up and water rights were inadequate.
- 1924-1936: The “Dust Bowl Years” affected approximately 75% of Utah. Agriculture productivity was decreased to almost half of prior years production and the number of farms significantly decreased.
- 1946-1964: Multiple areas within Utah were declared disaster areas. Statewide, impacts could have been worse but were lessened due to steps taken to enhance the water supply.
- 1974-1979: Conditions in seven of Utah’s counties prompted the governor to request Federal Disaster Declarations for these counties. By the end of 1977 the state and its citizens lost \$41 million (\$132 million in 2005 dollars) due to the drought impacts.
- 1986-1992: Drought blanketed the entire state of Utah for multiple consecutive years. Nationally, 1988 was the most costly drought ever, and until Hurricane Katrina, was the most costly natural catastrophe in U.S. history.
- 1999-2004: The drought produced some of the hottest years and one of the driest years (2002) on record. Statewide reservoir capacity plunged below 50% and farmers and ranchers struggled to make ends meet.

climate variability, such as tree-rings, fossil pollen, sediments and ice cores are used.

Tree rings are commonly used to assess past climate. Patterns and densities of these annual growth rings strongly correlate with regional climatic conditions (wide and narrow growth rings equate to wet and dry conditions respectively). From these growth rings, scientists have been able to reconstruct a long-term PDSI record. This record dates back over two thousand years. Analysis of this record indicates that many droughts, before the advent of the instrumental record, were more severe, more frequent and impacted larger areas. On average, drought contained in the reconstructed PDSI record (roughly 1,900 years before the instrumental record) was approximately 10.9 years in length compared to the average drought duration of 6.8 years during the last 111 years (instrumental record). Geologic records, analysis of lake and eolian (wind-borne) sediments, reinforce this conclusion. Research indicates that prolonged dry periods have occurred in greater frequency than has been experienced within the last century.

These results coupled with the evidence of climate change, suggest that drought within the past century is not a complete subset of drought variability and

that drought similar to episodes of the past (more severe and longer duration) will likely happen again.

CHAPTER 4 MITIGATION STRATEGIES AND DROUGHT FORECASTING

The possibility of decade-long or longer drought occurring in Utah’s future is real. Utah has developed a Pre-Disaster Mitigation Plan that addresses drought (to a degree) and other natural hazards. However, more drought specific planning and action is warranted. Water managers and purveyors can, and do, take several feasible actions to address future droughts. Mitigation or action taken well in advance of any disaster or drought event is a methodology of drought management that should be understood and implemented (see Figure I—Disaster Management Cycle, page xvii). Several existing mitigation strategies can lessen the severity of some future drought-related impacts. Addressing Utah’s vulnerabilities to drought—through mitigation and diversification—is essential to providing a reliable water supply during prolonged periods of drought (decade or longer). Mitigation strategies discussed in this report are listed in Box III.

Box III—Mitigation Strategies

- **Water Redistribution:** transfer of agricultural water (or other water) via a water banking system (“brokering” system) from “willing sellers” to “willing buyers” during times of drought. Large volumes of agricultural water could possibly be available for M&I uses (agriculture to M&I transfers) during prolonged periods of drought or drought of any length.
- **Conjunctive Management:** conjunctive use of surface and ground water supplies. Store water when it is available in surface facilities and/or sub-surface aquifers (aquifer storage and recovery [ASR]), for use when needed, such as during drought. Potential ASR project sites have been identified by the Utah Division of Water Resources and generally cost much less than surface storage.
- **Water System Interconnections:** extensive water networks exist throughout Utah, however many of these are not well-integrated or integrated at all. Increased integration of conveyance networks and implementation of advanced monitoring and control systems can increase efficacy in meeting regional water demands during drought of any length (M&I to M&I transfers). Extensive planning, cooperation, coordination and establishment of agreements between all involved parties would be needed.
- **Water Development:** efficient use of dams, reservoirs and other water systems as well as construction of necessary additional projects currently plays a significant role in satisfying water demands of the projected population growth and in maintaining a reliable water supply during prolonged drought.
- **Water Reuse:** use of treated wastewater effluent (may require new facilities, conveyance, permits, and water rights) for nonpotable uses. Use of this relatively constant and quantifiable source can temporarily lower and/or reduce consumption of potable water used for irrigation and industrial purposes.
- **Demand Management:** more aggressive demand management practices, beyond current water conservation policy, can be implemented to mitigate drought, such as reducing lawn/turf size, eliminating parking strips and requiring water-wise landscapes.
 - **Public Education and Outreach:** use of programs to instill a “water wise” ethic in both children and adults as well as promote possible water use regulatory changes.
 - **Alternative Landscaping:** by encouraging or requiring more efficient landscapes (water wise and more drought tolerant), outdoor water use can be significantly decreased with minimal influence upon everyday life. Aggressive demand management programs such as this could delay the need for additional water development projects.
 - **Incentive Pricing:** effective year-round pricing can help mitigate drought by lowering water use rates.
- **Water Metering and Leak Detection Programs:** billions of gallons of water are lost each day nationwide due to leaks, overflows, pipe bursts and inaccurate or no metering. These system and operational inefficiencies are abundant nationally and throughout Utah. Water suppliers should regularly conduct system water-audits to ensure that the water system is properly metered and in working order.
- **Weather Modification:** the state of Utah views cloud seeding as a cost-effective strategy to supplement the water supply. Additional weather modification projects or improvements to projects already in place should be pursued to help to further mitigate future drought impacts and further research is encouraged.
- **Forecasting (Early Warning System):** although scientists are currently unable to predict future drought, advancements are being made and cooperation at all levels within the state with scientists and drought-forecasting programs is highly encouraged.

These strategies are not a panacea to all future water management challenges, however, when multiple strategies are implemented and managed as one system, with drought components embedded within each strategy, they can serve as long-term mitigation actions or “solutions.” Without drought components embedded within these strategies, they may serve only as short-term drought mitigation solutions.

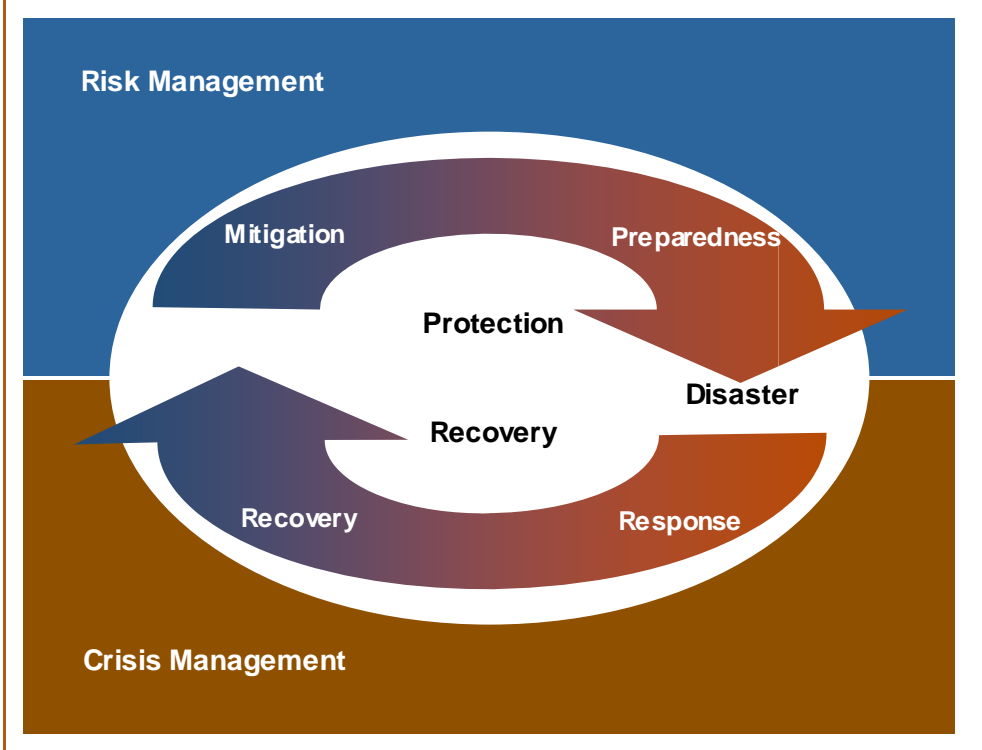
Although current drought forecasting technologies are limited, predicting drought is becoming more and more of a possibility as scientists come to a clearer understanding of the driving forces that underlie most climatic events.

The ability to forecast weather events greatly increases the effectiveness of both mitigation and preparedness activities. Several federal programs are dedicated to drought monitoring, research and prediction; and new programs are being developed that will enhance forecasting abilities. One such program is the National Integrated Drought Information System (NIDIS). The NIDIS Act, which allows the formation of NIDIS within the National Oceanic and Atmospheric Administration, was passed in December 2006.

CHAPTER 5 DROUGHT RESPONSE

Though movement towards drought mitigation is needed, response will always be a part of drought management. Response to drought can take place concurrently with the impacts or after they occur, when needs may be more apparent. Federal relief

FIGURE I
Disaster Management Cycle



Source: Adapted from the National Drought Mitigation Center's "Disaster Management Cycle" figure, University of Lincoln-Nebraska.

has traditionally been the foundation of drought response.

Utah has used such relief during drought, but has done so as an option of last resort. Following its drought response plan, Utah has adequately responded to recent droughts and has employed several drought response strategies (see Box IV).

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

During drought, an already scarce resource becomes even scarcer. Proper management of Utah's finite water supply is the essential aspect of ensuring a reliable supply and environmental integrity during drought. As the population and subsequent water demand continue to grow, so too does society's potential vulnerability to drought.

By using sound mitigation and response strategies, it may be possible to satisfy future water de-

Box IV—Response Strategies

- **Demand Management—Water Use Restrictions:** many water suppliers have developed conservation plans that contain drought management elements. These aspects of water management during drought should ideally be included in separate *contingency plans*. In order to curtail water use during drought and other emergencies, cities, conservancy districts and purveyors may adopt more aggressive water management strategies as set forth in these plans, as is the case with some, such as Salt Lake City's *Water Shortage Contingency Plan*. These management strategies may include water use restrictions and ordinances, limiting water use to certain times of the day and certain days of the week. However these strategies must be monitored for effectiveness. See discussion in Chapter 5 on pages 83-85.
- **Ground Water Use and Temporary Well Permits:** during drought, ground water withdrawals tend to increase as surface water supplies decrease. The Utah state engineer can approve the installation and use of temporary wells in response to water deficiencies. Some temporary wells could possibly be placed near current reservoirs to take advantage of water infiltrated from the reservoir and the nearby conveyance systems. Water rights are a large component in this response strategy.
- **Agricultural Management:** the agricultural sector is generally impacted first and most severely by drought. Management of agricultural resources is therefore paramount during drought and includes land management, crop management and water management. Systems and management strategies have been developed to aid farmers with management decisions and minimize losses during drought.
- **Water Hauling:** when the water supply has been greatly reduced or rendered unusable due to drought, water can be and has been hauled in for public use. Although uncommon, this has recently been done in rural areas affected by drought. Quick and efficient response by local authorities can significantly reduce drought-related impacts.
- **Legislation:** on occasion drought has prompted responses from the Utah Legislature in the form of laws, acts and other actions.

mands without increasing society's vulnerability to drought—even if future droughts are more severe than historic droughts of the 20th Century.

Leaders in the water supply industry, legislators and other community leaders are encouraged to implement the strategies and methods put forth in this publication and adopt a methodology of mitigation rather than one primarily of response to drought. The Utah Division of Water Resources has made recommendations to assist with managing drought and implementing mitigation strategies (see Box V).

Box V—Recommendations

- 1) **Develop Drought Management Plan:** in order to maximize efficiency, cost effectiveness, supply diversification, maintain environmental integrity and ensure a reliable water supply during periods of drought, water suppliers should develop drought mitigation and water shortage contingency components. Mitigation components should detail vulnerability assessments and layout a plan of action to address identified vulnerabilities through the implementation of mitigation strategies. Water shortage contingency components should outline more aggressive response actions that address management of water shortages and can be applied to drought, such as Salt Lake City's *Water Shortage Contingency Plan*.
- 2) **Water Redistribution and Interconnections:** develop a mechanism to facilitate temporary redistribution of agricultural water (or other water) to supplement the public supply during drought. Additional infrastructure may be needed.
- 3) **Agreements on Reservoir Operations:** water users who rely on water supplies from a major reservoir in Utah should craft, a reservoir operation agreement to dictate reservoir operation during drought. In situations where broad segments of the population will be affected by such agreements, a reservoir operation curve (or appropriate indicator) should be developed, posted and regularly updated to help the public understand when and why various operating criteria and water restrictions are triggered.
- 4) **Data Collection:** governing bodies, counties and cities (or appropriate institution) should collect beneficial information that will assist decision makers and the legislative body regarding drought. Survey municipal water utilities, suppliers and conservancy districts throughout and at the terminus of droughts and provide results upon request. Monitor economic sectors (socioeconomic impact data) during and after drought in order to more fully understand and quantify drought impacts. Encourage additional research within state agencies, universities and other institutions regarding climate change and precipitation in Utah. Also support of federal research programs already in place is highly encouraged.

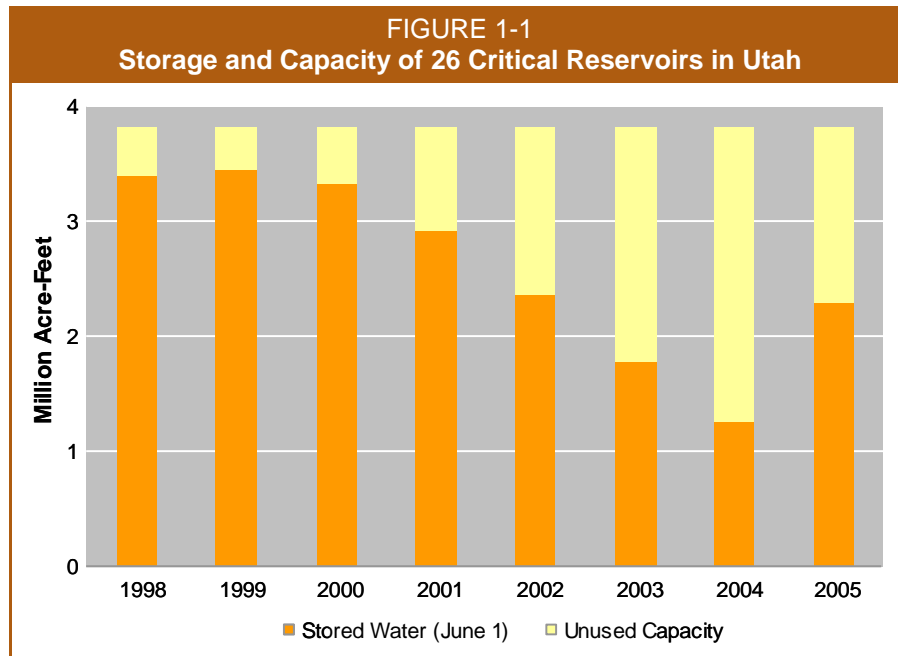
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INTRODUCTION: DROUGHT, INDICES AND IMPACTS

Utah's most recent drought affected parts or all of the state during 1999-2004. At its peak (2002 and 2003), many agricultural water users and municipal water suppliers in Utah encountered difficulties meeting their needs. These difficulties include the following:

- Farmers suffered millions of dollars in losses due to low crop yields and outright crop failure.
- Some ranchers went bankrupt as they were forced to sell off entire herds of cattle and other livestock at a loss.

- Thousands of fish died in East Canyon Creek and water quality standards were compromised when the stream dried up.
- Salt Lake City diverted drinking water into ditches to satisfy century-old exchange agreements with irrigators.
- The Utah State Engineer cut-off several Bear River irrigators (by water right priority) due to low flows.
- City officials in Monticello restricted outdoor watering to once a week to preserve dwindling storage capacity in Lloyds Lake.
- Government officials facilitated the hauling of water to residents of Navajo Mountain as springs went dry.



Source: Utah Division of Water Resources analysis, 2006.

Note: Does not include Lake Powell, Flaming Gorge, Strawberry, Jordanelle and other smaller reservoirs.

As severe as the problems were, they could have been much more widespread had the drought continued a few more years. During each successive year, reservoir levels dropped (see Figure 1-1), ground water levels declined, and the environment became drier and more susceptible to devastating wildfires. When above normal precipitation finally returned to most areas of Utah in 2005, water suppliers breathed a collective sigh of relief—many had avoided what could have

been an extremely adverse situation.

Although most Utahns remember various aspects of the drought, attention has been diverted from this natural climatological hazard to other issues of more immediate concern. It is hoped that this report will again focus some attention on drought and assist decision makers and water managers with mitigating drought and preparing for it well in advance, particularly during wet years.

PURPOSE OF THIS REPORT

The purpose of this document is multifaceted. It:

- 1) Present the significance of drought's influence on society from a historical perspective and how projected growth can potentially make Utah more vulnerable to its impacts.
- 2) Warns about the likelihood of more severe and longer-term droughts in the future based on reconstructed climate and proxy records as well as climate change.
- 3) Explores various strategies to mitigate, prepare for and respond to future drought events.
- 4) Makes recommendations for future action.
- 5) Encourages discussion among decision makers and water managers regarding drought management.

A main objective of the report is to highlight those things that have successfully limited drought-related impacts on society in the past, motivate policy-makers and water managers to continue to implement appropriate measures and move toward a more mitigation-centered water management strategy.

This report compiles a vast array of research and presents new information all into one place—thereby providing a comprehensive view of drought in Utah and what can be done to mitigate and better prepare for future events. Simply put, this document is a word of warning about drought and a strategy for mitigation and preparedness.

WHAT IS DROUGHT?

Drought is unique among natural hazards. Unlike a flood, earthquake, hurricane or tornado, drought is not an easily recognized event. While most natural hazards are sudden and result in immediate impacts,

droughts “sneak up on us quietly disguised as lovely, sunny weather”¹ and can last a long time. As a result, it is difficult to know exactly when a drought begins and equally challenging to pinpoint when it ends.

Drought is a normal, recurrent feature of climate that occurs everywhere to some degree. It is manifested in different ways depending upon the region and the impact it has on human activities. In the most general sense, drought can be defined as “a deficiency of precipitation [or effective moisture] over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector.”² Thus, drought is much more than simply a climatic phenomenon—and can only be fully described in light of its broader impacts on society and the environment.

Over the years, drought experts have developed several different ways to define and measure drought. The following four drought categories³ have evolved:

- Meteorological drought
- Agricultural drought
- Hydrologic drought
- Socioeconomic drought

Although these categories have some unique characteristics, it may make more sense to think of these as “phases” of the same drought (as depicted in Figure 1-2), rather than different types of droughts.

Meteorological Drought

Meteorological drought is determined by measuring climatological conditions, particularly precipitation. It is usually defined by the degree of dryness compared to a “normal” or long-term average.⁴ Defining drought in meteorological terms is the easiest way to gauge drought conditions. If recent precipitation is less than normal, then it follows that meteorological drought conditions exist. The more precipitation amounts are less than normal and the longer this persists, the more severe the drought. While this approach provides a relatively “early warning” of drought conditions, it can also produce false alarms. For instance, a dry period may end before a watershed is seriously affected and water users experience a water supply deficit. Also, after

prolonged drought conditions, a period of above average precipitation may signal an end to the meteorological drought, when in reality the watershed is a long way from recovering, and water supply deficits persist for some time. As long as winter precipitation is adequate, several areas in Utah can endure a meteorological drought during the spring, summer and fall months by capturing available runoff in reservoirs and releasing it as needed during the year. However, in addition to winter precipitation, some areas rely on spring precipitation as a water supply source. For example Alta receives roughly 34 and 31% of total precipitation in the winter and spring, respectively.

A common measure of meteorological drought across the country is the Palmer Drought Severity Index (PDSI). The PDSI, although not a true measure of meteorological drought in the strictest sense, adequately describes it. The PDSI and other drought indices will be discussed later in this chapter.

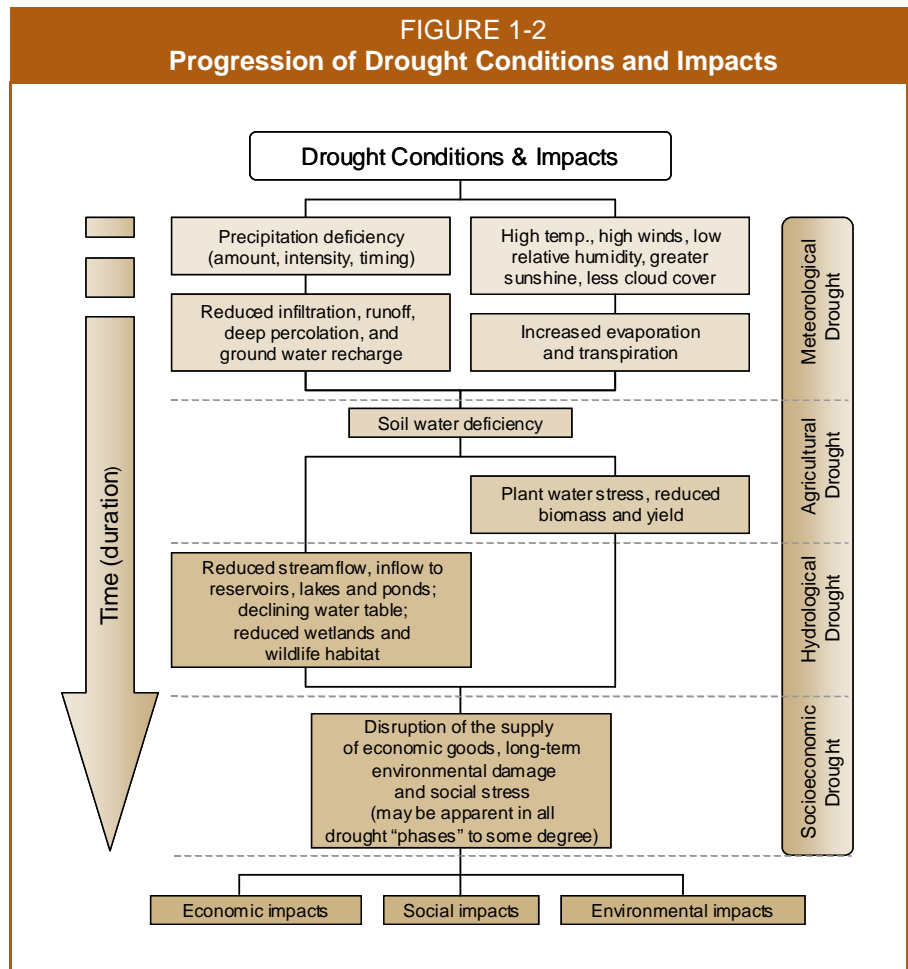
Agricultural Drought

Drought typically impacts agriculture first and most severely. Dry farms, which rely on soil moisture at the beginning of the growing season and precipitation throughout the growing season, are quickly impacted by abnormally hot or dry conditions. While irrigated farms are not immediately impacted by dry conditions—because they rely on streamflows, reservoir storage and ground water to supplement precipitation—they too suffer when drought conditions persist long enough to impact hydrologic conditions. Typically, in the West, agriculture uses

most of the available water supply within a region (81% in Utah). In Utah, only the Salt Lake Valley is an exception to this. Consequently, any water shortage translates directly to economic losses in the agricultural sector. High temperatures associated with drought and decreased water supplies make it difficult to keep up with watering requirements and crop yield subsequently may decrease in amount and/or quality. Energy costs (such as pumping) may also increase and result in negative economic implications.

Hydrologic Drought

Hydrologic drought is determined by the overall water supply (or hydrologic) conditions of a watershed—snowpack, soil moisture, streamflows and reservoir storage. The severity of hydrologic



Source: Adapted from a graphic by the National Drought Mitigation Center found on their web page, "What is Drought? Understanding and Defining Drought." Retrieved from: <http://drought.unl.edu/whatis/concept.htm>, August 2006.

drought is determined by the deviation from normal or long-term average values. While this analysis is more involved and time consuming than the meteorological approach, it provides a more detailed picture. In Utah and other mountainous regions, where water users are largely dependent upon winter snowpack and reservoir storage for their water supply, this approach is quite useful.

In the Intermountain West, several indices are used that adequately describe hydrologic drought: the Palmer Hydrologic Drought Index (PHDI), long-term Standardized Precipitation Index (SPI) and the Surface Water Supply Index (SWSI). These indices will be discussed in more detail later in this chapter.

Socioeconomic Drought

If dry conditions persist long enough and severely impact reservoir storage and ground water levels, drought enters its most disruptive phase: socioeconomic drought. “Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought.”⁵ Socioeconomic drought reaches well beyond the agricultural community and affects community drinking water supplies and consequently many social and economic enterprises. At this stage, long-term damage to vegetation, wildlife habitat and other natural environments is also likely to occur.

A weakness of the socioeconomic drought definition, as well as with the other types of drought, is that no standardized methodology or index exists

that truly measures its severity and impacts. Although attempts have been made in the past to measure total economic costs of drought—which is the most logical way to reflect the severity of socioeconomic drought—these efforts have been inadequate and, thus, not very useful. A consistent methodology for socioeconomic drought impact analysis is needed and warrants further research and development.

Sequence of Drought in Utah

The typical drought sequence (as depicted previously in Figure 1-2) begins with meteorological drought and progresses to agricultural drought. If abnormally dry conditions last long enough, hydrological drought begins and ultimately progresses to socioeconomic drought. While this sequence describes the various “phases” of drought in a logical way that is broadly applicable, in reality the sequence of events is not always so simple and may vary from region to region. In Utah, for instance, agricultural drought only precedes hydrological drought for dry-crop farmers who do not irrigate. Farmers who irrigate and ranchers who water livestock using streamflow or reservoir storage do not experience agricultural drought (to the same degree as dry-crop farmers) until these parameters are affected and hydrologic drought begins. Even then, farmers who have access to or rely solely on ground water may never truly experience agricultural drought, because even prolonged drought may not completely deplete ground water supplies. However, prolonged drought may make it economically infeasible for farmers to pump ground water if levels



After several years of drought, water levels in Echo Reservoir dropped precipitously, exposing vast mudflats in the fall of 1990.

decline far enough.

Another nuance to the sequence of drought is the beginning of socioeconomic drought. Sequentially, socioeconomic drought typically does not manifest itself fully until the duration of the drought becomes very long. However, socioeconomic drought technically begins as soon as any economic loss is experienced and can last the entire duration of a drought and beyond. An example of this could be lack of early snowfall (an indicator of meteorological drought), which prevents ski areas from opening and causes immediate economic loss (socioeconomic drought). While it is often helpful to define drought according to the discussed criteria or phases, drought is almost always a much more complex phenomenon.

DROUGHT INDICES⁶

Over the years, scientists have developed various numerical indices to measure drought. Several of these indices use climatological and hydrological parameters such as precipitation, temperature, streamflow, and lake and reservoir levels, to derive a relationship between instrumental measurements and drought. These indices commonly produce a single digit number that falls within a set range and indicates the severity (which is dependant upon duration and intensity) of the drought or wet period. Water managers and policy makers use these indices to help them make important drought management decisions.

Many of these indices measure the deviation or variation in weather conditions from the observed historical norm. The indices most commonly used in Utah are described in the following sections.

Palmer Drought Severity Index⁷

The Palmer Drought Severity Index (PDSI), also known as the Palmer Drought Index (PDI), was developed in 1965 by W.C. Palmer to measure decreases in moisture based upon supply-and-demand for relatively homogenous regions. The goal of this index is to measure moisture conditions that are standardized to allow comparisons across space and time. The PDSI is used as a meteorological drought index that acts in response to abnormally dry or wet weather conditions. PDSI values generally range from -4.0 to +4.0, which represent extremely dry to

extremely wet conditions, respectively (see Table 1-1). These values are calculated based on precipitation, temperature and available water content in the soil. It does not take into account streamflow, lake and reservoir levels, or other hydrological parameters that require a long recovery time (time needed to overcome deficit and return to “normal” conditions).

The PDSI also attempts to measure the duration of a drought or wet spell. Long-term drought is cumulative⁸ and therefore the index relies upon current weather conditions and patterns as well as the cumulative conditions of previous months (long-term trends) to estimate the intensity of the drought.

TABLE 1-1
Palmer Drought Indices Classifications

Value	Description
4.0 or more	Extremely wet
3.0 to 4.0	Very wet
2.0 to 3.0	Moderately wet
1.0 to 2.0	Slightly wet
0.5 to 1.0	Incipient wet spell
-0.5 to 0.5	Near normal
-0.5 to -1.0	Incipient dry spell
-1.0 to -2.0	Mild drought
-2.0 to -3.0	Moderate drought
-3.0 to -4.0	Severe drought
-4.0 or less	Extreme drought

Although the PDSI was developed for the Great Plains areas of the United States, it is perhaps the most commonly used index across the United States. Monthly values for the PDSI (some dating back to the beginning of the instrumental record in 1895) are available for all climatic regions within the United States.

Palmer Hydrologic Drought Index⁹

“In near-real time, Palmer's index [the PDSI] is no longer a meteorological index but becomes a hydrological index referred to as the Palmer Hydrological Drought Index (PHDI) because it is based on moisture inflow (precipitation), outflow, and storage, and does not take into account the long-term

trend.”¹⁰ The PHDI is an adaptation of the PDSI that indicates hydrological drought and does not incorporate weather and climate trends; it is not “backward-looking” like its PDSI counterpart. Because of this, it generally responds more slowly to weather/hydrologic conditions than the PDSI.

As with the PDSI, PHDI numerical values are generated monthly by the National Climatic Data Center (NCDC)¹¹ and are available nationally. The Palmer Indices:¹²

- Provide information on weather anomalies and related hydrologic conditions for a region.
- Allow scientists to compare recent conditions to those measured by various instruments for more than 100 years.
- Provide valuable comparable spatial and temporal data on historical droughts.

Both of the Palmer Indices have several drawbacks; most notably—for application in Utah—the indices do not recognize the difference between snow and rain. All precipitation is treated as rain in the indices’ calculations. Therefore in regions where snowfall is present, potential inaccuracies in the timing of the PDSI and PHDI values can be created. Snowmelt and rainfall runoff is also not adequately considered and modeled, which generally leads to an underestimation of total runoff.¹³ These indices also do not take into account large topographical differences that are present in the Intermountain West.

Surface Water Supply Index¹⁴

Although the Palmer Indices are widely used across the United States, there are limitations to their application in mountainous regions, which have large topographic (elevation) variations and are largely dependant upon winter snowpack and surface reservoir storage. Shafer and Dezman developed the Surface Water Supply Index (SWSI) in 1982, to complement the Palmer Indices and address such limitations. The SWSI is designed to monitor streamflow and surface water storage conditions, which are dependent upon mountain snowpack. Although the SWSI was originally developed to describe conditions in Colorado, with minor modifications it is also a useful tool to describe drought conditions across other Intermountain states due to their topographical and water supply similarities.

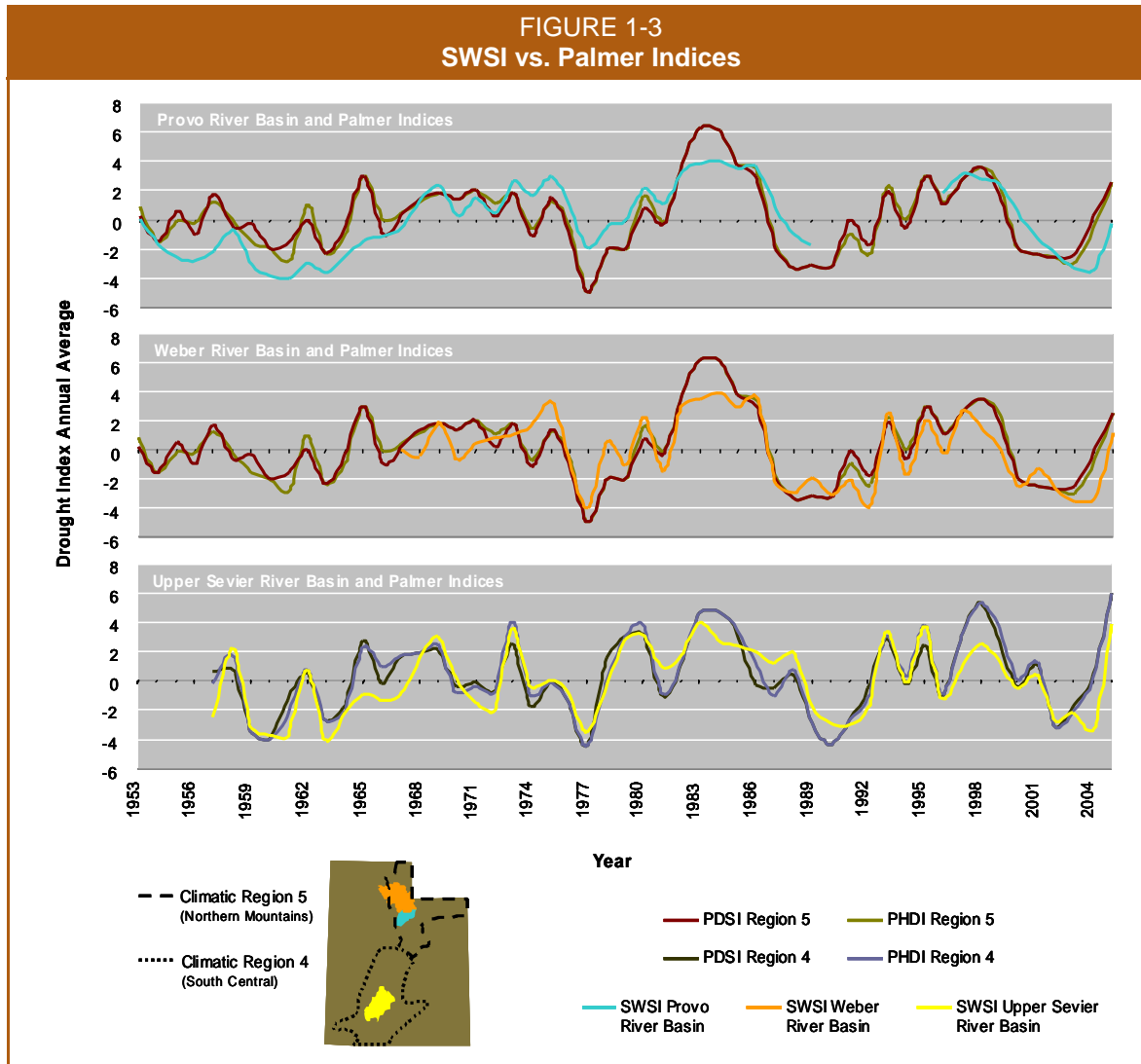
The SWSI integrates hydrological and meteorological elements to generate a numerical index similar to the Palmer Indices’ values and ranges. The SWSI is centered on zero, which indicates normal conditions, and generally extends between -4.2 and +4.2, representing dry and wet conditions respectively. SWSI values are calculated by using snowpack, precipitation and reservoir storage during winter months and streamflow, precipitation and reservoir storage during the summer months.

Utah officials use the SWSI as part of the state’s Drought Response Plan. According to the plan, the SWSI is used to help officials monitor, assess and report drought conditions during early stages and throughout a drought. For more detail regarding Utah’s Drought Response Plan, see Chapter 5—Drought Response.

Despite the advantages of the SWSI for use in Utah, some characteristics limit its application: 1) the SWSI calculation is unique to each basin or region and it is therefore difficult to compare across basins or broader regions; and 2) the SWSI index is dependent upon frequency distributions for selected stream gages and reservoir storage facilities and thus must be recalculated when gages are discontinued, changed, new storage reservoirs are constructed, and after extreme events. As a result, it is difficult to maintain a long-term SWSI time series and only about half of the Utah basins have a series that goes back further than 1980.

Comparison of Drought Indices

Figure 1-3 compares the PDSI, PHDI and SWSI. The figure plots annual average PDSI and PHDI values for the South Central (climatic region 4), and North Mountains areas (climatic region 5) alongside annual values of the SWSI for the Upper Sevier, Provo and Weber River drainages (see inset map and Box 2-1 for division of climatic regions in Utah). The three indices are similar, with the SWSI varying the most from the two Palmer Indices. This is expected since the SWSI relies heavily upon streamflow and surface storage measurements from local streams and reservoirs and generally produces a lag or lead regarding the commencement of a drought when compared to the Palmer Indices as seen in



Source: SWSI data was obtained from the Natural Resources Conservation Service's webpage: www.ut.nrcs.usda.gov/snow/watersupply/swsi.html. PDSI and PHDI data was obtained from the National Climate Data Center's webpage: <http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html>. Utah Division of Water Resources analysis, 2006.
Note: See Box 2-1 for Utah climate divisions/regions.

Figure 1-3. Analysis of these indices also reiterates the fact that while one stage or type of drought, such as hydrological drought (SWSI), can still be underway, another may have terminated, such as meteorological drought (PDSI). This can be seen most notably in the Provo River Basin during the 1950s drought. Also, hydrological drought conditions may not appear to be as severe as meteorological drought conditions (or visa versa), as can be seen in the figure during the 1970s drought.

In addition, and not surprisingly so due to the notable similarities between the two indices, the annual

PDSI and PHDI values for each climatic region in Utah are strongly correlated, with r-values ranging from 0.97-0.98. The closer the r-values are to 1, the stronger the correlation or the more similar compared values are. The monthly values are also strongly correlated with r-values ranging from 0.90-0.93, depending upon climatic region. On the other hand, the Palmer Indices and SWSI are moderately correlated. This is due to the differences in the parameters, calculations of the indices, natural hydrologic factors, and the result of various operational and management factors, which affects streamflows and reservoir levels. Such operational factors may

include retaining water in a reservoir longer or releasing water earlier to compensate for expected runoff conditions and water demands. Additional analysis of drought with regard to the SWSI and comparisons and discussion of these drought indices are in Appendix A—Comparison of Drought Indices. It can be seen in Figure A-3 (of Appendix A) that the SWSI records are quite variable in length. Subsequently it is difficult to obtain spatial information pertaining to early century droughts using the SWSI record.

While water managers and drought experts generally agree that the SWSI is one of the most accurate and meaningful indices to gage the severity of drought in Utah, its limited data set and inability to make spatial comparisons limit its usefulness in analyzing historical drought, which is one of the main purposes of this report. Therefore, in this report, the PDSI is used to define and identify drought events within the instrumental and paleoclimatic records (see Chapter 2—Historical Drought Events from the Instrumental Record and Chapter 3—Drought from a Paleoclimatic Perspective and Current Climate Trends).

Standardized Precipitation Index¹⁵

Another index that is relatively new, developed in 1993 by T.B. McKee, N.J. Doesken and J. Kliest from Colorado State University, is the Standardized Precipitation Index (SPI). This index is based upon precipitation and was originated from the understanding that precipitation deficits impact groundwater, soil moisture, reservoir storage, streamflow and snowpack differently. “The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources.”¹⁶ For example, soil moisture is greatly influenced by short-scale precipitation anomalies whereas changes in groundwater levels, streamflow and reservoir storage are influenced by longer-term precipitation anomalies or events. The SPI therefore can be calculated for various time scales. The purpose of this index is to assign a numerical value relating to precipitation that can be compared across climatic divisions and varying topographies.

The SPI is basically a probability index. It is based upon the probability of measuring a given

amount of precipitation. These probabilities are standardized such that an index value of zero indicates the median precipitation amount over the period of record. Positive values indicate precipitation that is greater than median (normal to wet conditions), and negative values indicate precipitation less than median (normal to dry conditions). Drought events are identified by the SPI when values are continuously negative and reach an intensity equal to or less than -1.0.

The SPI is used extensively in Colorado and by the National Drought Mitigation Center, and merits further investigation for its application and integration in drought-related monitoring and response activities in Utah. Diversifying Utah’s drought monitoring portfolio, by utilizing several indices at once, can enhance Utah’s ability to manage drought effectively.

DROUGHT IMPACTS

Since the impacts of drought are an integral part of defining and understanding drought, a more detailed discussion of these impacts is necessary. Drought impacts vary widely across space, time and economic sectors. While drought can manifest itself in similar ways in various locations—dead lawns in urban areas versus dead crops in a rural setting—the impacts to these areas are vastly different. While dead lawns are unlikely to disrupt many economic activities within a city, dead crops can devastate individual and/or family farms in rural areas. These impacts cannot just be “measured by the crops ruined and cattle sold, but at the cash registers and banks in local towns with effects creeping into the larger economy...”¹⁷ While droughts most directly impact agriculture, intense droughts or droughts of significant duration can produce crosscutting impacts, from farmland to life in suburbia. Impacts can be extremely complex, span several sectors within a region and reach far beyond the area actually experiencing the drought.

Drought impacts can either be direct or indirect.¹⁸ For example, a farmer’s harvest may be reduced due to drought, which is a direct impact; the subsequent loss of income to the farmer, increased prices for food, and unemployment are indirect impacts. Furthermore, drought impacts generally fall into three categories: economic, social and environmental as

TABLE 1-2
Categories of Drought Impacts

Economic	Social	Environmental
Agriculture and Livestock	Nutrition	Wetland
Transportation	Reduced Quality of Life	Animal and Plant
Industry	Health and Stress	Water Quality
Energy	Public Safety	Wind Erosion
Timber Production	Increased Conflicts	Infestation, Insect
Tourism and Recreation	Cultural Values and Sites	Wildfires

Source: Adapted from Cody Knutson, Mike Hayes, and Tom Phillips, "How To Reduce Drought Risk," (1998). Produced by the Preparedness and Mitigation Working Group of the Western Drought Coordination Council.

shown in Table 1-2.¹⁹ Although these categories are used in this document to simplify the discussion, they may not be entirely distinct and separate from one another. Many impacts have economic, environmental, and social aspects, such as drought-induced or drought-enhanced wildfires, thus necessitating consideration of all feasible impacts during planning, mitigation and response actions.

Economic impacts occur more prevalently in sectors that rely heavily upon surface or subsurface water supplies. The economies of agriculture, forestry, fisheries and other related sectors, can be severely impacted by drought due to lower productivity, disease, insect infestations and wind erosion.²⁰ Such impacts commonly cause a ripple-effect. For instance, when farmers lose income, businesses that provide financial support or other services to farmers will also suffer. This can lead to "unemployment, increased credit risk for financial institutions, capital shortfalls, and loss of tax revenue for local, state, and federal government."²¹ Agricultural-based or water-intensive commodity prices may increase as producers try to offset reductions in supply. Hydro-power production may be significantly reduced (roughly 60 hydroelectric plants in Utah) and tourism and recreation can be negatively affected, impacting local, state and even national economies.

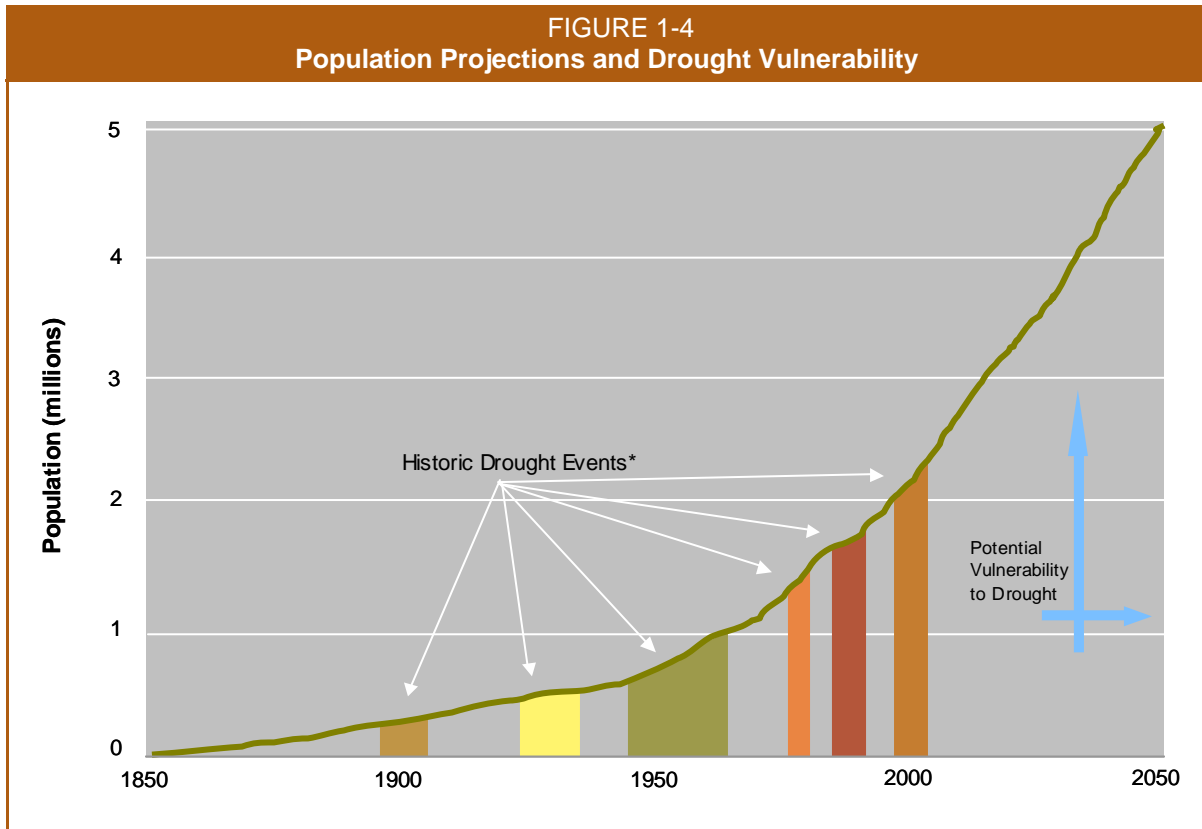
Social impacts of drought include public health, safety and quality of life.²² Drought can also induce

physical and emotional stress and has been the impetus for population migration to less impacted areas, which has occurred in isolated areas in Utah (for instance, many moved from the Abraham area east of Delta during the drought of the 1890s). Such migrations can place increased pressure on the physical and social infrastructure of the area to which people migrate. It also leaves the rural drought-impacted area (from which people have migrated) lacking valuable human resources²³ needed for further economic recovery and development.

Environmental impacts include damage to wildlife habitat, plants, water quality, forests and much more. These impacts can linger for years with devastating effects. Public awareness of the environment, its resiliency and fragility, is steadily growing and demands public officials to direct greater attention and resources to these effects.²⁴ A long recovery time from these as well as other impacts may be required.

Not all drought impacts are negative. Generally agriculture, for example, is hit hardest by drought; however, agricultural producers in unaffected areas may benefit from higher prices for agricultural products and thereby decreasing economic impacts on a larger- or national-scale. A critical part of understanding drought is to understand such impacts. Unfortunately, many drought-related impacts are never quantified and therefore not fully understood. It is important to remember that drought impacts are the result of natural events combined with the vulnerability of society to water deficiencies.²⁵ In order to reduce the effects of drought, we must lessen our vulnerability to it. There is a need for additional monitoring of economic, social and environmental parameters during drought years and a more concerted effort to quantify impacts. For further discussion of assessing drought impacts Refer to Appendix B—Assessing Drought Impacts: The Drought Impact Reporter.

Drought is a natural process that is easily forgotten as it comes and goes at an almost imperceptible pace. Drought and its impacts need to be remembered in order to facilitate preparations and mitigatory actions, which require time and money. See Chapter 4—Mitigation Strategies and Drought Forecasting and Chapter 5—Drought Response, for further discussion on drought mitigation and response.



*Drought periods contained in the instrumental record as defined and discussed in Chapter 2.
 Source: Population data obtained from the Utah Governor's Office of Planning and Budget, 2005.
 Utah Division of Water Resources analysis, 2006.

DROUGHT VULNERABILITY

Throughout Utah's history, water users have been vulnerable to drought and suffered from its impacts. Over the years, water planners and managers have successfully reduced this vulnerability by constructing surface reservoirs, drilling wells and developing other available water sources. This extensive water development has allowed Utah's population to grow significantly and enabled the economy to prosper. In some cases, water development may create "new" vulnerabilities, such as high water use rates. However, through effective management strategies and

public awareness, these "new" vulnerabilities can largely be avoided. While Utah's population and economy are expected to continue their rapid growth, Utah's developable water supplies are limited. In some areas of the state, such water supplies have essentially been fully developed.

As the population increases, so too does societies' potential vulnerability to drought impacts (see Figure 1-4). In order to decrease this susceptibility, water managers will need to implement innovative water management strategies to ensure that Utah's future water supplies are efficiently used and as reliable as possible during periods of drought

NOTES

¹ McKee, Thomas B., Nolan J. Doesken and John Kleist, *A History of Drought in Colorado: Lessons Learned and What Lies Ahead*, (Fort Collins: Colorado Climate Center, 2000), 5.

² National Drought Mitigation Center, "What is Drought?" Retrieved from the National Drought Mitigation Center's Internet web page: <http://drought.unl.edu/whatis/what.htm>, August 2006.

³ For an excellent discussion of these drought categories, see: National Drought Mitigation Center, "What is Drought? Understanding and Defining Drought." Available on the center's Internet web page: <http://drought.unl.edu/whatis/concept.htm>.

⁴ Ibid.

⁵ Ibid.

⁶ Dr. Michael J. Hayes, "What is Drought?: Drought Indices." Retrieved from the National Drought Mitigation Center's Internet web page: <http://drought.unl.edu/whatis/indices.htm#pdsi>, June 2006. The following has been adapted from the NDMC discussion on drought indices.

⁷ Ibid. The following has been adapted from the NDMC discussion on the Palmer Indices.

⁸ National Climatic Data Center, "Climate of 2006 - August U.S. Palmer Drought Indices." Retrieved from the NOAA Satellite and Information Service's Internet web page: <http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html>, June 2006.

⁹ Dr. Michael J. Hayes, June 2006. The following has been adapted from the NDMC discussion on the Palmer indices.

¹⁰ Dr. Michael J. Hayes, "What is Drought?: Drought Indices." Retrieved from the National Drought Mitigation Center's Internet web page: <http://drought.unl.edu/whatis/indices.htm#pdsi>, February 2007.

¹¹ Division of Oil, Gas and Mining, "Precipitation Affects Water Availability." Retrieved from the State of Utah, Department of Natural Resources' Internet web page: <http://www.ogm.utah.gov/coal/water/WEATHER.HTM>, June 2006.

¹² Dr. Michael J. Hayes, June 2006.

¹³ Ibid.

¹⁴ Ibid. The following has been adapted from the NDMC discussion on the SWSI.

¹⁵ Ibid. The following has been adapted from the NDMC discussion on the SPI.

¹⁶ Ibid.

¹⁷ Nebraska's Senator Nelson, "The Drought, A Nebraskan's View." Retrieved from the Internet web page: <http://www.senate.gov/~bennelson/news/details.cfm?id=239387&&>, July 2006.

¹⁸ "Impact of Drought." Retrieved from the NDMC 's Internet web page: www.drought.unl.edu/risk/impacts.htm, June 2006.

¹⁹ Cody Knutson, Mike Hayes, and Tom Phillips, "How To Reduce Drought Risk," (1998). Produced by the Preparedness and Mitigation Working Group of the Western Drought Coordination Council.

²⁰ "Impacts of Drought." June 2006.

²¹ Ibid.

²² Ibid.

²³ Ibid.

²⁴ Ibid.

²⁵ Donald A. Wilhite, "Improving Management in the West: The Role of Mitigation and Preparedness," (Lincoln: National Drought Mitigation Center, 1997), 6.

2

HISTORICAL DROUGHT EVENTS FROM THE INSTRUMENTAL RECORD

To better understand how to manage Utah’s water resources during drought and thereby decrease vulnerability to it, it is prudent for water managers to take a look at and put in perspective historical drought events that have occurred in Utah. Droughts are common in Utah and the state’s natural level of aridity, and limited water supply, compound the effects of drought. Scientists measure drought conditions by using various indices (as described in Chapter 1—Introduction: Drought, Indices and Impacts). These indices, some of which go back as far as 1895, make up the instrumental record of historical drought. From this century-long record, several significant drought events are easily recognized at a national scale as well as within each of Utah’s seven climatic regions (see Box 2-1). This chapter chronicles the severity, areal extent and some of the impacts of each of these droughts in Utah as well as nationally.

UTAH DROUGHTS WITHIN THE INSTRUMENTAL PDSI RECORD

In the late 1800s, scientists began to measure and record weather conditions resulting in an instrumental record, which is widely available today. Generally, the Surface Water Supply Index (SWSI) is used as a drought indicator (which triggers the implementation of a certain drought response actions) in Utah. However, due to the lack of long-term SWSI data and in order to allow a direct comparison of droughts recorded in the instrumental record with droughts of the not-so-distant past and ancient droughts recorded in “proxy records,” the Palmer Drought Severity Index (PDSI) instrumental record is used in this report to identify significant drought periods. In Utah this record spans a 111-year period

(from 1895-present) and contains several monitored weather parameters. This record provides us with “a picture of the short-term behavior and spatial patterns of drought, helping scientists learn more about the character of droughts.”¹

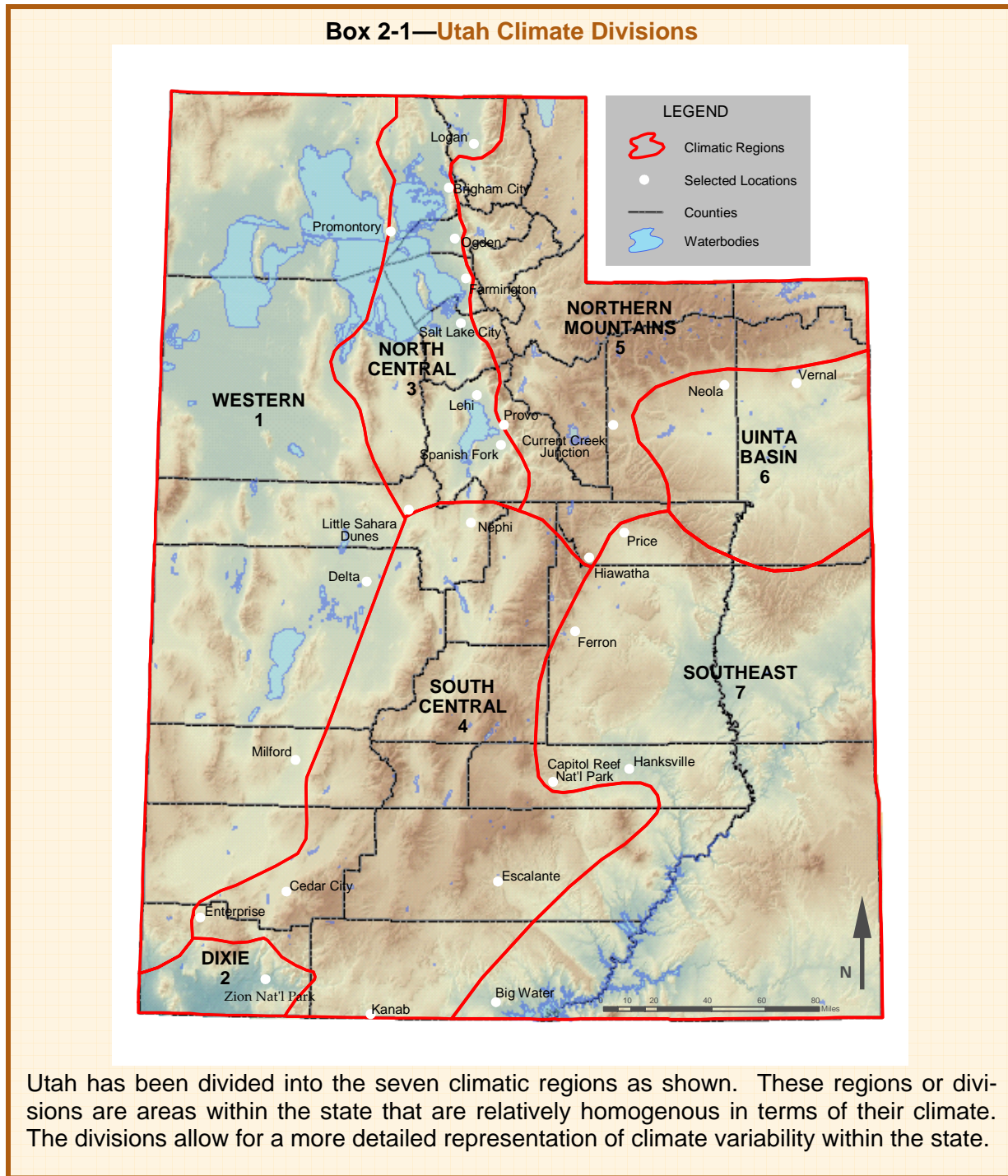
Data reliability of the instrumental record decreases farther back in time due to fewer weather monitoring stations and less dependable technologies. By analyzing the PDSI data graphically, distinct drought periods are easily recognized. These droughts vary in duration, intensity and impacts to the state.

For the purpose of exploring and understanding historical drought contained in the instrumental PDSI record in this document, drought events were defined and identified using the following criteria:

- A drought was considered to have started with **two** consecutive years of annual average PDSI values less than or equal to -1.0 .
- The drought was terminated with **two** consecutive years of near or above normal conditions (annual average PDSI above -0.5).

Refer to Table 1-1 for Palmer Drought Index classifications. Following these basic guidelines, the Utah Division of Water Resources analyzed the PDSI instrumental record.

The term “drought” from this point on, with regard to the instrumental and tree-ring records, refers to drought as defined by these criteria unless otherwise indicated.

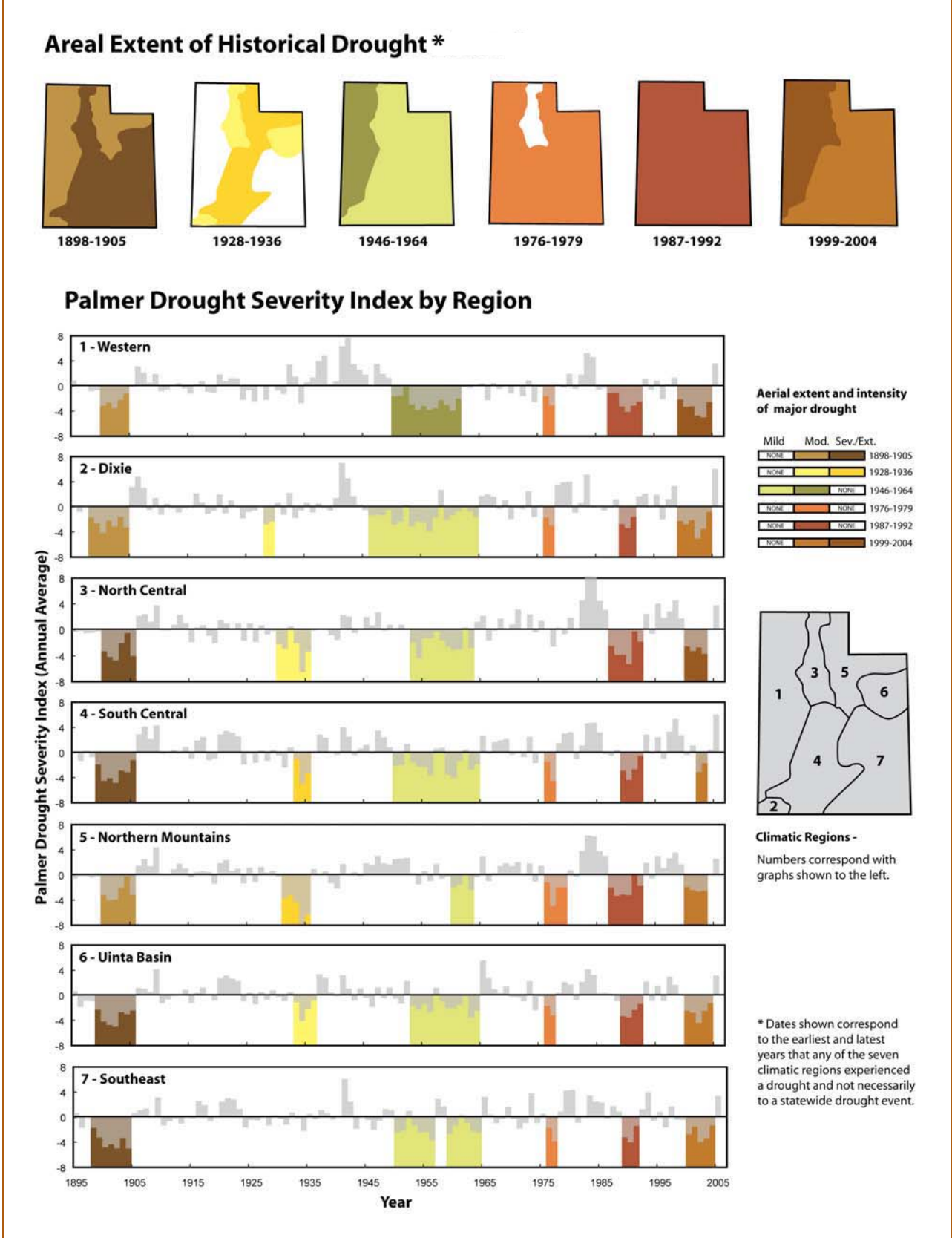


Identification of Utah Droughts

Since the commencement of weather measurements, Utah has experienced several noteworthy droughts. Analysis of PDSI data collected in the state’s seven climate divisions reveals six significant droughts (see Figure 2-1), during 1898-1905, 1928-

1936, 1946-1964, 1976-1979, 1987-1992 and 1999-2004. The state maps in Figure 2-1 represent the cumulative areal extent and intensity of each drought. The graphs also indicate drought intensity as well as drought duration in each of the seven climate divisions.

FIGURE 2-1
Instrumental PDSI Record—Drought Delineation



Source: Utah Division of Water Resources analysis, 2006.

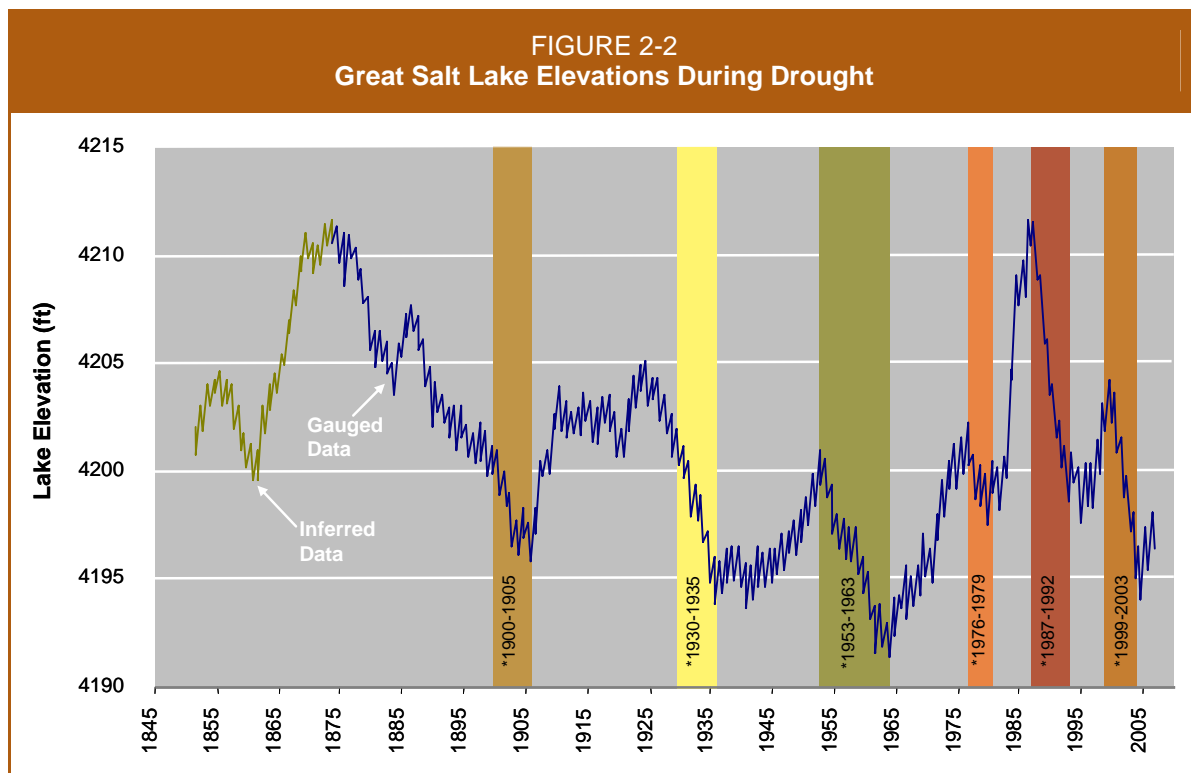
These droughts can also be identified (or verified) using hydrologic data. For instance, these droughts are expressed by fluctuating lake elevations of the Great Salt Lake (see Figure 2-2). Pre-1875 lake elevation data is termed “inferred data” as it was determined from historical accounts. Post-1875 data is gauged or measured data. The Great Salt Lake receives mountain runoff, which is extremely sensitive to precipitation changes and therefore lake levels can be used as a record of regional drought (representing climatic regions 3 and 5). As shown in Figure 2-2, declines in lake elevation coincide quite nicely with droughts identified using the PDSI and defined drought criteria.

Figure 2-3 displays hydrographs of the Virgin River and Ashley Creek, representing climatic regions 2 and 5 respectively. The drought durations identified in these climatic regions (refer to Figure 2-1) by using the PDSI record and defined drought criteria are reinforced by these hydrographs. The horizontal green lines represent the historic average or average annual flow for the entire period of re-

cord. The areas shaded red indicate below average flow and correspond rather well with the PDSI identified droughts. As would be expected, the vast majority of low flow and extreme low flow events take place during these droughts.

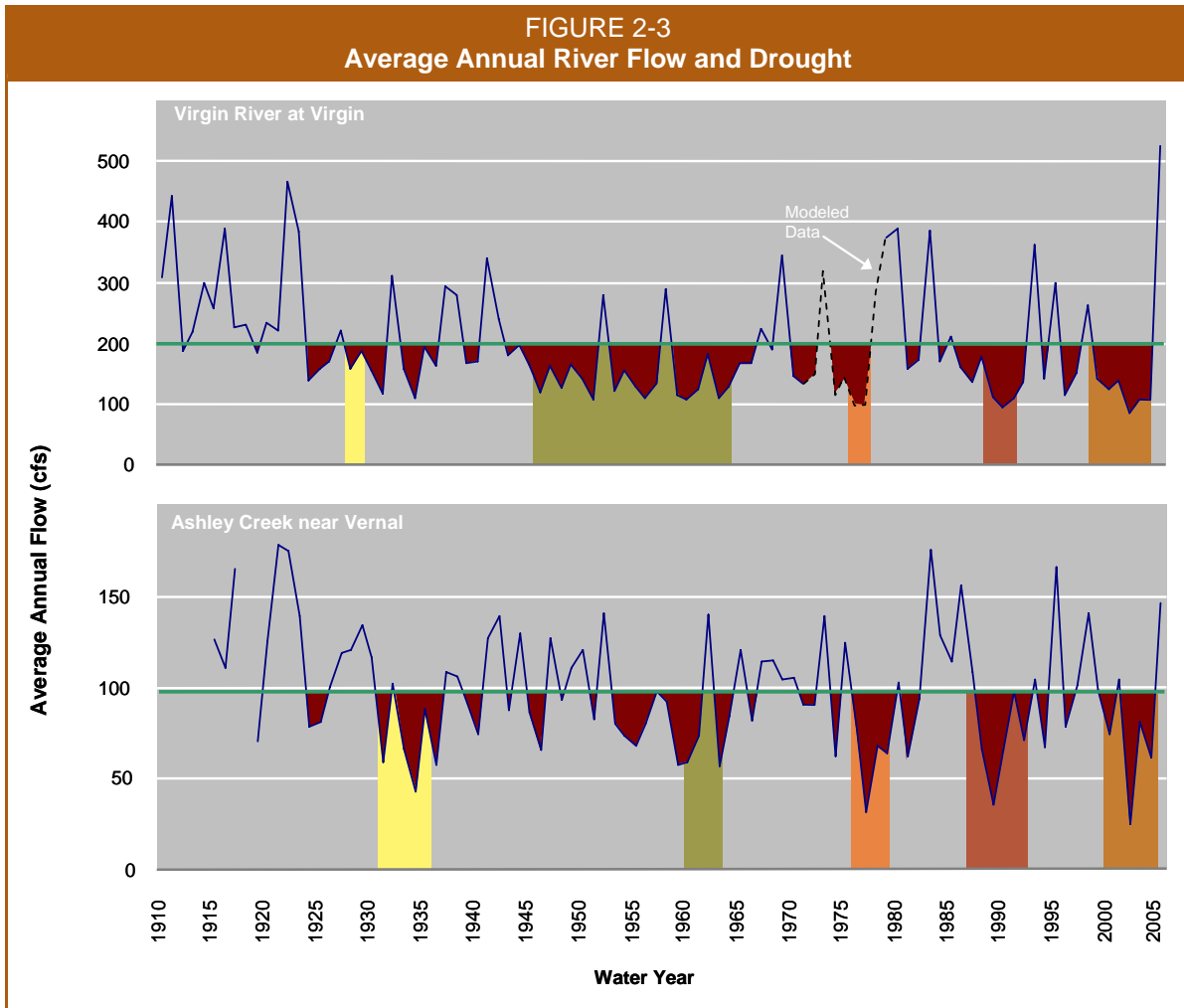
PDSI Parameters—Temperature and Precipitation

As discussed in Chapter 1, the PDSI is largely based upon temperature and precipitation. Figure 2-4 presents statewide precipitation and temperature maps of single years—with the lowest annual average PDSI values—within each drought period and the statewide “normal” precipitation and temperature over 1971-2000. Spatial similarities between precipitation and temperature distribution (Figure 2-4) and areal extent and severity of each drought (Figure 2-1) can be seen. Precipitation decreased significantly statewide during the years shown—the peak of each drought—as large areas of the state received only 0-5 inches of rainfall.



Note: *The duration of each drought period correlates with the cumulative drought durations on Figure 2-1 for climate regions 3 and 5 for each drought. These regions are the main regional areas that contribute to the Great Salt Lake.

Source: Utah Division of Water Resources analysis, 2006.



Note: Virgin River—PDSI drought durations correlate with climatic region 2 (Figure 2-1). Ashley Creek—PDSI drought durations correlate with climatic region 5 (Figure 2-1). Green line indicates annual average flow over the entire record.

Variability of precipitation and temperature between each drought event is also expressed in this figure.

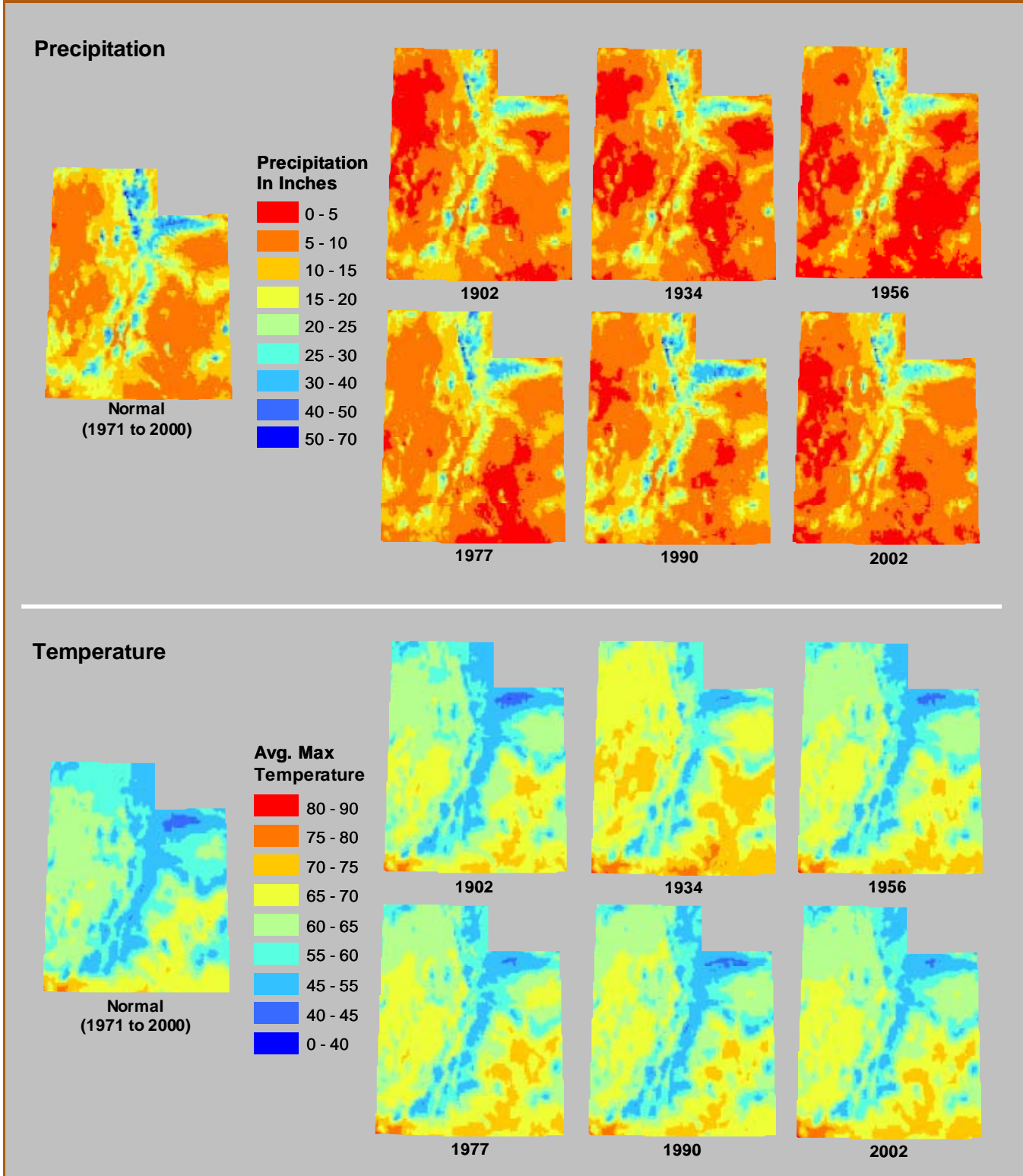
There are several ways to conduct an analysis of drought, which can be done at several scales. It would be prudent to look at drought using multiple indices and indicators at various spatial scales, such as at the watershed or river basin levels. However, the use of climatic regions satisfies the scope of this chapter, which is to give a general overview of regional and local historical drought variability.

Recurrence Intervals and Frequencies of Utah Drought Conditions

Statewide and regional recurrence intervals and frequencies of mild to severe annual drought conditions (see Box 2-2 for definition) are shown in Table 2-1. Recurrence intervals were calculated by dividing the total number of years on record by the number of years where a PDSI value was equal to or less than -1.0, -2.0 and -3.0 for mild, moderate and severe drought conditions respectively. Frequencies were calculated as the number of years where mild to severe drought conditions occurred divided by the total number of years on record.

FIGURE 2-4

Utah Statewide Precipitation and Temperature—Peak of Drought Periods



Note: Single years with lowest annual average PDSI value during each drought compared to the average annual precipitation over 1971-2000.

Source: Utah Division of Water Resources analysis, 2006.

Box 2-2—Drought Conditions: Intervals and Frequencies

Criteria used to calculate recurrence intervals and frequencies of drought conditions differ from the definition of drought used previously (see drought criteria on page 13) in that all years (single non-consecutive years included) with a PDSI ≤ -1.0 were included (resulting in recurrence intervals and frequencies of annual drought conditions, not necessarily droughts per the drought criteria). Therefore drought conditions may refer to a single year.

On average, Utah has experienced moderate to severe statewide drought conditions once every 15.7 to 36.7 years (see Table 2-1) respectively. In reality, years of statewide drought conditions generally occur in groupings of consecutive years (i.e. not equally distributed every “x” number of years) as can be seen in Figure 2-5. Regional recurrence intervals for moderate to severe drought conditions range from 3.7 to 5.2 and 6.9 to 13.8 years, respectively. This means, for example, that regional moderate drought conditions are present one out of every 3.7 to 5.2 years on average (for any given climatic region).

The Western area (climatic region 1) has most frequently experienced mild to severe drought conditions in comparison with the other regions, whereas the Northern Mountains (climatic region 5) has one of the lowest frequency of annual drought conditions.

BRIEF SUMMARY OF THE IDENTIFIED DROUGHTS

The following sections provide a brief summary of the six Utah droughts identified within the instrumental PDSI record. Although details of some early droughts are not well documented, these summaries provide a snapshot of how drought has influenced Utah and its citizens over the past century. A few details regarding regional and national impacts of these droughts are also provided, which adds valuable perspective.

Drought of 1898-1905

In 1898, mild drought conditions developed in the Dixie and Southeast climatic regions. These conditions intensified the next year and spread to other regions, eventually involving the entire state from 1900-1903, and persisted two more years in the South Central, North Central, Northern Mountains and Uinta Basin climatic regions.

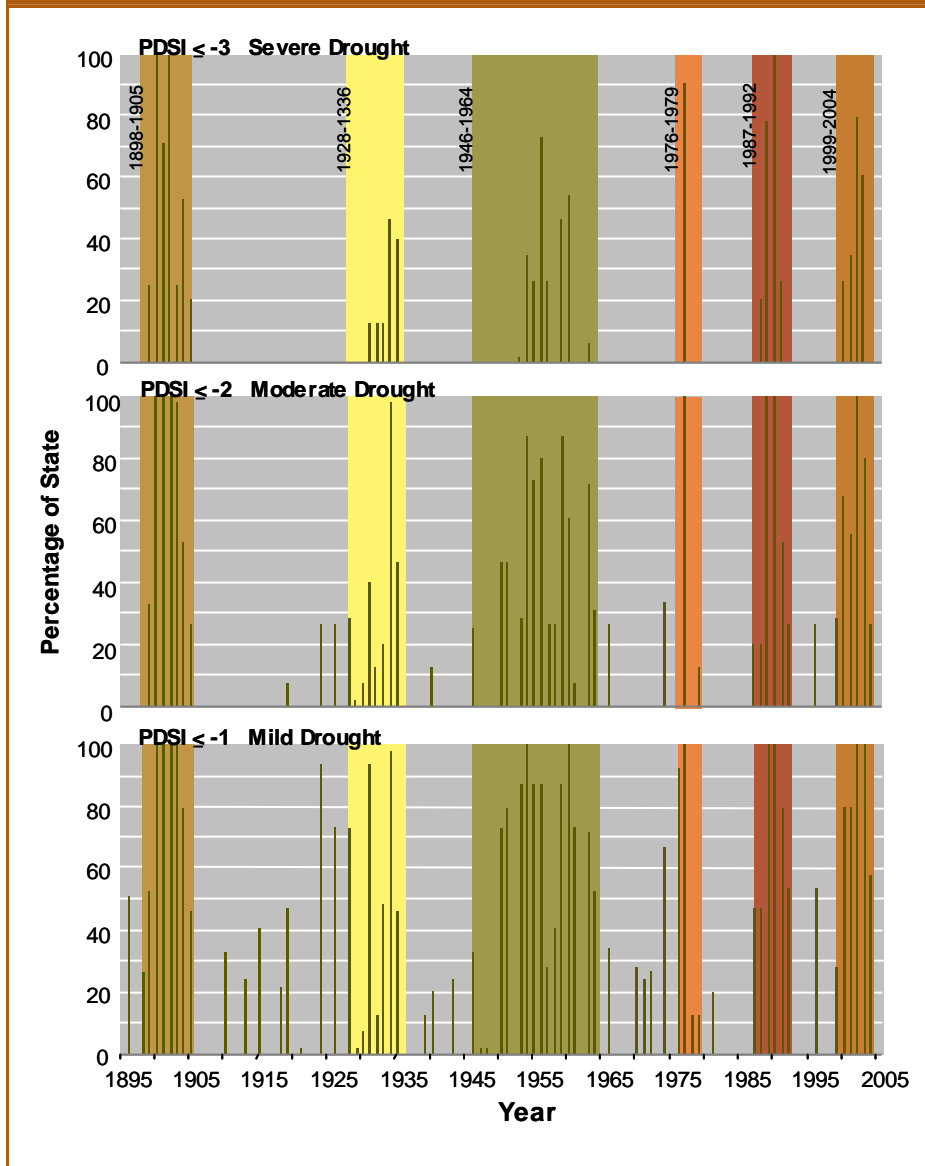
TABLE 2-1
**Recurrence of Mild to Severe Drought Conditions
 Based on the PDSI**

Climatic Region	PDSI ≤ -1		PDSI ≤ -2		PDSI ≤ -3	
	Recurrence Interval (yr)	Frequency (%)	Recurrence Interval (yr)	Frequency (%)	Recurrence Interval (yr)	Frequency (%)
1	2.6	38.2	3.7	27.3	6.9	14.6
2	2.7	37.3	5.0	20.0	13.8	7.3
3	3.1	31.8	4.4	22.7	8.5	11.8
4	3.1	32.7	5.2	19.1	9.2	10.9
5	3.3	30.0	5.2	19.1	8.5	11.8
6	2.9	34.6	4.6	21.8	11.0	9.1
7	2.9	34.6	5.0	20.0	9.2	10.9
Statewide*	10	10	15.7	6.4	36.7	2.7

Note: *Statewide refers to instances where all seven of the climatic regions experience drought conditions simultaneously.

Source: Utah Division of Water Resources analysis, 2007.

FIGURE 2-5
Percent of Utah Experiencing Mild to Severe Drought Conditions
Based on the PDSI



Note: Percentages were calculated using the seven climatic regions and their corresponding areal percentage of the state.
 Source: Utah Division of Water Resources analysis, 2006.

This was the longest drought contained in the instrumental record experienced in the Southeast (climatic region 7), persisting for a 7-year span (see Table 2-2). During this drought, region 7 also experienced the worst multi-year drought PDSI average of

any region at -3.91 followed by the South Central and Uinta Basin (climatic regions 4 and 6) with average drought PDSI values of -3.27 and -3.17 respectively (see Table 2-3).

Many Utah farmers suffered greatly during this drought and were in dire need of assistance. The Relief Society of the Church of Jesus Christ of Latter-day Saints donated nearly 35,000 bushels of wheat in an effort to assist drought-stricken farmers.² Ranchers were not faring well either. Due to overgrazing and drought-related conditions, the majority of “speculative cattle operations folded by the end of the decade...”³ and in 1900, it was reported in the Davis County Clipper (local newspaper) that the honey crop was only one-fifth of previous years due to the drought and resulting lack of flower blossoms.⁴ Many Utahns were forced to find relief from drought-stricken areas and as a result, moved to “greener pastures.” The Abraham area, east of Delta, lost many of its settlers due to this drought and inadequate water rights.⁵ Many of these settlers did not return, leaving the area without crucial human resources.

TABLE 2-2
**Longest Drought on Record by Climatic Region
 Based on the PDSI**

Climatic Region	Years	Duration (yr)	Minimum Annual PDSI Value	Average Annual PDSI Value for Drought Duration
1	1950-1961	12	-3.92	-3.48
2	1946-1964	19	-3.88	-1.39
3	1953-1963	11	-4.34	-1.96
4	1950-1964	15	-4.02	-1.60
5*	1900-1905	6	-4.02	-2.77
6	1953-1964	12	-3.50	-1.62
7*	1898-1904	7	-5.00	-3.91
Statewide	1900-1903	4	-4.29	-3.57

Note: Drought durations were calculated based on the established drought criteria.

*Two droughts were of equal duration; the most severe (lowest average PDSI) is shown.

Source: Utah Division of Water Resources analysis, 2006. See Figure 2-1 for visual representation.

The drought impacted other southwestern states as well. The Salt Lake Tribune reported in 1899, that in New Mexico, “on account of unprecedented drought and the recent order of the Interior department in excluding ranchmen from forest reservations, sheepmen are in a bad plight and sheep are dying by the thousands.”⁶

Drought of 1928-1936

The drought of the late-1920s to mid-1930s, known as the “Dust Bowl Years,” holds a significant place in our nation and state’s history. Although this drought may have been shorter than other droughts in Utah (see Figure 2-1), it boasts the lowest multi-year PDSI average (compared to the other five droughts) contained in the instrumental record of -5.08. This occurred over a 5-year period in the Northern Mountains, climatic region 5 (see Table 2-3) from which the majority of the state’s population received its water supply. The drought’s areal extent covered approximately 50% of the state for three consecutive years, and at its peak in 1934, moderate drought conditions were manifested in 98% of the state (see Figure 2-5) with devastating impacts.

In 1934, Utah’s annual streamflow was only 50% of its mean annual discharge. This lack of water was reflected in crop production. Merely 59% of the 1921-1930 average crop yield was produced.⁷ The U.S. Department of Agriculture’s Statistical Reporting Service recorded that corn yield had dropped to

TABLE 2-3
**Most Intense Droughts on Record by Climatic Region
 (Lowest PDSI Average of Drought Duration)**

Climatic Region	Years	Duration (yr)	Minimum Annual PDSI Value	Average Annual PDSI Value for Drought Duration
1	1999-2004	6	-4.98	-3.48
2	1999-2004	6	-5.02	-2.72
3	1900-1905	6	-4.70	-3.10
4	1899-1905	7	-4.81	-3.27
5	1931-1935	5	-7.76	-5.08
6	1899-1905	7	-4.99	-3.17
7	1898-1904	7	-5.00	-3.91
Statewide	1989-1990	2	-3.98	-3.58

Source: Utah Division of Water Resources analysis, 2006. See Figure 2-1 for visual representation.



Dust storm in Stratford, Texas in April of 1935. This was a common sight as the landscape was ravaged by drought and wind erosion. Photo: credited to NOAA George E. Marsh Album.

Source: <http://www.photolib.noaa.gov/historic/c&gs/theb1365.htm>

17 bushels per acre in 1934 from 32 bushels per acre in 1929. Also, winter wheat production decreased from 22 bushels per acre in 1930 to 14 bushels per acre in 1934. A farmer in the Uintah Basin recorded that at the peak of the drought “our grain burned completely and there was no harvest.”⁸ After the end of the drought in 1936, farm numbers decreased by approximately 3,000 (10%) over a three-year period. Total cattle (including calves and bulls) decreased by 73,000 head from 1934 to 1935, a 15% reduction.⁹

In addition to agricultural impacts, water storage supplies rapidly diminished; Utah Lake contained only $\frac{1}{3}$ of its total volume. During the summer of 1934, many communities established outdoor water use restrictions with lawn watering permitted only twice a week.¹⁰ To help alleviate the impacts of the drought, in 1934 Utah appealed to the federal government and within thirty-six hours President Roosevelt approved a grant for \$600,000 and another for \$400,000 shortly thereafter. That is the equivalent of approximately \$14.6 million in 2005 dollars—dollar amounts, where indicated throughout this chapter, were converted to 2005 dollars using the consumer price index to give a rough estimate of costs. With this funding, several drought response actions were taken: 276 wells were installed, miles

of pipeline were laid, and miles of irrigation ditches were lined.¹¹

This drought impacted the nation and affected an entire generation. Approximately 65% of the country was affected by the drought in 1934.¹² Residents of the Great Plains were overwhelmed by agricultural and economic losses.¹³ As a result, agriculture was abandoned in some areas of the country and large numbers of people relocated to California, impairing the economic substructure that supported agriculture in the Great Plains.¹⁴ “By 1940, 2.5 million people had moved out of the Plains states; of those, 200,000 moved to California.”¹⁵

The environmental impacts were undoubtedly severe and aggravated by poor agricultural practices as farmers struggled to turn a profit. Barren and overgrazed agricultural land perpetuated immense dust storms throughout the mid-West. It was estimated that the federal government provided financial assistance upwards of approximately \$14.1 billion (in 2005 dollars).¹⁶ Additional unmeasured individual economic losses, costs in the form of social distress, and much more certainly raise the toll of the Dust Bowl not only nationally but within Utah as well.

Drought of 1946-1964

In many aspects, the drought that spanned the entire 1950s in most of Utah’s climatic regions rivals the Dust Bowl. In the majority of Utah’s climatic regions, this drought surpasses the Dust Bowl in duration. In the Western and Southeast (climatic regions 1 and 7) the Dust Bowl is exceeded in intensity as well. This period was the longest drought contained in the instrumental record for all regions of the state (with exception of the Northern Mountains and Southeast), averaging 13.8 years. Drought conditions existed statewide during 1954 and 1960 (see Figure 2-5).

During this drought, a significant portion of Utah was declared a disaster area¹⁷ with impacts more

severe than the 1930s drought in some local areas. However, impacts overall (statewide) appear to have been reduced due to action taken and lessons learned from previous drought. Mitigation measures (although not called that at the time) including construction of reservoirs and other water supply projects such as ground water development were pursued and completed. In addition, advancements were made in agricultural practices and land management, and a much stronger economy was in place. Even with such improvements, however, agriculture could not endure the drought unscathed. There was a significant reduction in crop yield statewide. Winter wheat harvest decreased from 22 bushels per acre to a low of 13 bushels per acre in 1952. During the 1950 and 1951 water years (Oct.-Sept.), southern Utah received approximately 57% of the precipitation average of 1921-1945¹⁸ (an average that includes the 1928-1936 drought); however, due to mitigation projects, the impacts were subdued. Without the mitigatory measures taken to develop water resources and stabilize the water supply prior to this drought, its impacts would have been far more severe.

During the early 1950s, just under half¹⁹ of the contiguous United States was affected by drought. Low rainfall and excessively high temperatures characterized this event.²⁰ Millions of cattle died across the Southwest and southern Plains, causing ranchers to relocate their livelihood to other regions of the country.²¹ Crop yields in some areas dropped as much as 50%.²² Due to this and other losses, the federal government estimated that it spent \$3.95 billion (in 2005 dollars), in relief efforts during this drought.²³

Drought of 1976-1979

The period from August 1975 through most of 1977 was one of the driest periods on record. In 1976 the statewide average precipitation was only 7.71 inches²⁴ and mild drought conditions affected 92% of the state and moderate drought conditions were experienced statewide in 1977 (Figure 2-5).

In an attempt to curtail wasteful water use, approximately 36% of the surveyed municipal (or public) water suppliers increased water rates during 1977.²⁵ Seven of Utah's counties were hit especially hard, with 40 to 100%, of the crops lost. In 1977,

Governor Matheson requested Federal Disaster Declarations for these counties.²⁶ The state and its citizens lost millions of dollars from decreased agriculture productivity and reduced recreation activity. From 1976 to 1977, decreased field crop production resulted in a loss of \$13 million (\$38.9 million in 2005 dollars) in potential revenue.²⁷

Winter snowpack was also limited and, as a result, the ski industry greatly suffered, losing millions of dollars. The Utah Ski Association was forced to look into obtaining federal loans for Utah's ski related businesses due to impacts of this drought. By the end of 1977, it was estimated that the state and its citizens lost a total of \$41 million²⁸ (\$132 million in 2005 dollars) due to drought-related impacts. The environment felt the effects of the drought as well. Reservoir levels dropped significantly, resulting in increased water temperatures, subsequent large die-off of fish and other environmental impacts.

Lack of winter precipitation resulted in harsh drought conditions in the West, and at the peak of the drought, affected approximately 35% of the country.²⁹ The Western Governors' Policy Office estimated federal drought response to this short-lived drought cost roughly \$7.62 billion (in 2005 dollars).³⁰ A separate estimate indicated that federal assistance was upwards of \$10.8 billion (in 2005 dollars) for agriculture alone.³¹ The disparity between these two estimates illustrates the need for better drought impact assessments of all economic sectors.

Drought of 1987-1992

In 1987, drought conditions manifested themselves in the western and northern regions of the state. These conditions intensified the following year and spread to other regions of the state, eventually affecting the entire state. In 1989 and 1990 moderate and severe drought conditions, respectively, were statewide (see Figure 2-5). The drought persisted two more years in all climatic regions except for the Dixie and Southeast regions. The North Central region (climatic region 3) recorded the lowest PDSI average for the duration of this drought at -2.89 (relative to PDSI averages for the duration of the drought in other regions). Statewide, streamflows were well below average, however, in 1990 the Colorado River and Wasatch Front Basins were

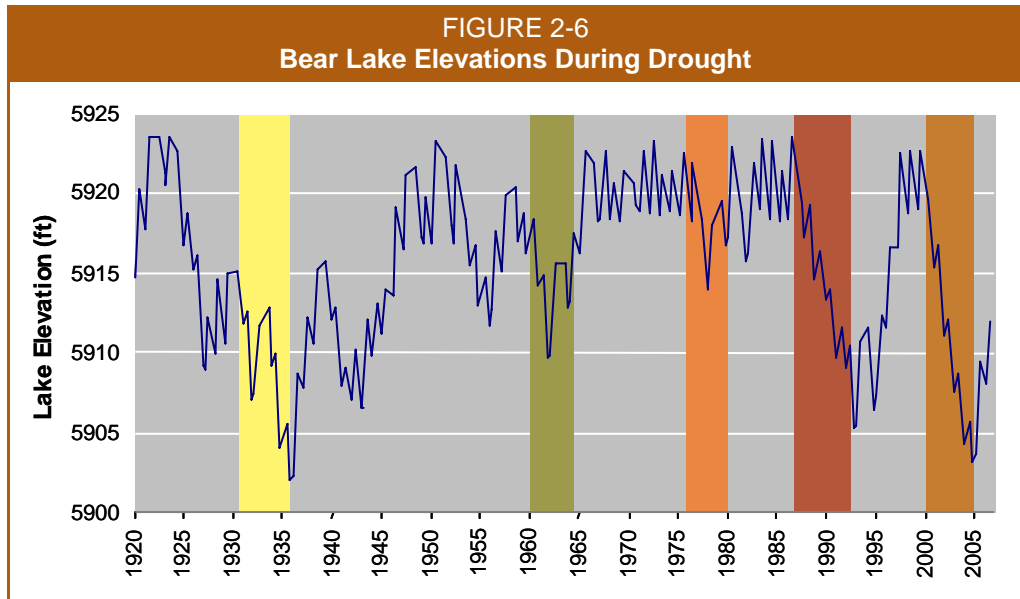
in relatively well condition up to this point with 72 and 77 percent of their respective reservoir capacities.³²

The 1987 water year for the Salt Lake area was sub-par, with total precipitation of only 9.94 inches compared to the average 15.31 inches. Water storage in Bear Lake was well below average as well; indicated by an extremely low

water elevation by the end of the drought. Only during the Dust Bowl and most recent drought (1999-2004) have Bear Lake elevations been lower (see Figure 2-6). Springs and wells in northern Utah dried up and flows in streams and rivers were well below normal,³³ not boding well for wildlife and agricultural activities. It was reported that in certain units throughout the state, up to 80% of the deer population was lost during the winter of 1992 due to the lack of suitable forage in the preceding months. This lack of forage and suitable rangeland was also a problem for cattle and sheep during the drought. In 1988, much of the summer range was diminished due to the drought, most notably in the northern regions of the state, resulting in low cattle and sheep prices as ranchers were forced to thin out their herds.³⁴

Efforts were made to alleviate impacts to the agriculture sector. Temporary water sales, totaling 10,000 acre-feet, were made from Soldier Creek Reservoir to the Central Utah Project for irrigation purposes.³⁵ Other areas of the state enacted water use ordinances and restrictions, as was the case in the City of Price.³⁶

The drought affected approximately 36% of the country.³⁷ The northern and eastern Great Plains, which have greater agricultural productivity and a



Note: Annual maximum and minimum elevations are shown. Color shading indicates droughts per the PDSI instrumental record. The width of the shading correlates to the drought durations for climatic region 5 (Figure 2-1), in which Bear Lake is located.

denser population (relative to the Southwest) were hit hardest by the drought.³⁸ It was estimated that \$6.59 billion (in 2005 dollars) in relief for the agriculture sector was appropriated by the federal government.³⁹ Total cost of the drought from both direct and indirect impacts range from an estimated \$39 billion⁴⁰ to a staggering \$61.6 billion (\$66.9 billion in 2005 dollars).⁴¹ Along with this monetary cost, societal impacts were abundant with approximately 7,500 deaths attributable to the heat wave that accompanied the drought. The drought year of 1988 is the most costly drought-related event on record. Prior to Hurricane Katrina it was the single most costly natural catastrophe in U.S. history.

Drought of 1999-2004

Similar to the 20th Century, the 21st Century was ushered in with drought. The year 2002 was one of the hottest and driest on record, ranking 18th and 7th respectively (as of 2005). Although this drought faded away in Utah during 2005, it lingered on in some areas of the U.S. It is comparable to other major droughts in duration and magnitude.⁴² In the Dixie and Western regions (climatic regions 1 and 2) the drought lasted 6 years and yielded the lowest average PDSI values (for the duration of the drought) relative to past droughts in the instrumental record for these regions (see Table 2-3). Drought

conditions reached a statewide areal extent for two consecutive years, 2002-2003, with moderate conditions in 2003 (Figure 2-5). Although it is comparable to past droughts of the 20th Century in several respects,⁴³ due to the notable increase in population and subsequent increased demand for water, the impacts in some areas of the state were more severe than previous droughts.⁴⁴ This drought would have had much greater impacts had it not been for the many water development (mitigation) projects that were in operation.

The drought first began in the Dixie and Western regions in 1999 and by 2000, except for the South Central climatic region, drought conditions were apparent throughout the state. It is reported to be the worst drought experienced in parts of the Upper Colorado River Basin (the eastern half of the state) in the last 80 years.⁴⁵ The water deficit of the Colorado River (near Cisco, Utah) incurred due to the drought was almost equal to two years of average stream flow.⁴⁶ The National Weather Service (NWS) analyzed flows of six Utah river basins (river headwater gauge volumes) and ranked the driest or lowest 5-year average flows over 1999-2003 (see Table 2-4).⁴⁷ During this 5-year span, the Bear River Basin experienced the lowest 5-year average flow in its period of record (1948-2003) and flows of four other basins experienced averages that fell within the top five lowest, 5-year averages of their respective records.

Statewide temperature rankings for individual years during this drought are presented in Table 2-5. From 1999-2004, statewide annual average temperatures were consistently above normal, which compounded drought conditions throughout the state. In addition, in 2002 statewide precipitation plummeted below normal conditions, lowering surface runoff. Several stream flows in the state were well below their average flow. Small reservoirs profoundly felt the effects as well. Where water once was 30 feet deep there was only a puddle as a 390 acre-foot reservoir near Enterprise, Utah dried up.⁴⁸ Several years of below-normal precipitation lowered levels of numerous large reservoirs as well, resulting in the capacity of critical reservoirs falling below 50% in 2004 (see Figure 1-1 of Chapter 1). Such conditions required three towns, Park Valley, Ponderosa Ranch and Oak City to haul in water⁴⁹ in order to supplement the public water supply.

TABLE 2-4
5-Year Average Flow (1999-2003) Rankings of River Basins

River Basin	Rank
Bear River Drainage*	1
Logan River Drainage	13
Provo River Drainage	3
Sevier River Drainage	5
Virgin River Drainage	4
Weber River Drainage	4

*Example: Bear River had the lowest 5-year average flow—from 1999-2003—in its record, compared to other five-year averages.

Source: Adapted from a presentation given by Brian McInerney, NWS entitled "Comparison of Utah's Current Drought to Past Years," 2003.

Dry-crop farmers were hit exceptionally hard by the drought. One farmer of southern Utah, east of Monticello said that their 5,000-acre farm usually yields 20 to 25 bushels per acre of wheat but in 2002 they averaged only 6 bushels per acre and their corn did not produce a harvestable crop. Governor Leavitt declared a statewide agricultural disaster, which was promptly followed by additional disaster declarations due to grasshopper and Mormon cricket infestations.⁵⁰

TABLE 2-5
Statewide Annual Temperature Rankings—Warmest

Year (Jan-Dec)	Years in Record	Rank	Description
1999	105	6	Much above normal
2000	106	2	Much above normal
2001	107	4	Much above normal
2002	108	16	Above normal
2003	109	3	Much above normal
2004	110	24	Above normal

Source: Compiled data from Annual Climate Review reports obtained from the National Oceanic and Atmospheric Administration's webpage-
<http://www.ncdc.noaa.gov/oa/ncdc.html>

In 2002 alone, state officials estimated that the drought cost Utah agriculture and tourism \$200 million (\$217 million in 2005 dollars). Of this, \$150 million (\$163.3 million in 2005 dollars) was attributable to agriculture losses—\$50 million in hay sales and \$100 million in livestock sales.⁵¹ The drought forced ranchers to liquidate livestock at low prices and during August and September of 2002, ranchers were selling roughly 2,500 animals a week⁵² and many were not turning a profit. The drought-induced low cattle prices were followed by high replacement prices at the end of the drought, hurting the agriculture industry not only as the drought materialized but also as it faded away. In 2003, it was reported that the drought led to increased unemployment with the loss of 6,100 jobs and \$120 million (\$127 million in 2005 dollars) in income.⁵³

Wildfires and Drought

Additional impacts, such as fires—which are pervasive throughout the state during drought—and low water levels in popular lakes and rivers, negatively affected tourism and recreation. This resulted in an estimated additional loss of \$50 million (\$54.3 million in 2005 dollars) statewide.⁵⁴ The frequency of wildfires increased during and after the drought. Wildfires can magnify the economic and social burden borne by communities within drought-stricken areas. Drought exacerbates conditions with explosive results by drying out grasses, trees and other combustibles.

Nationally, from 1995 through 1999, fires burned on average, 4.1 million acres each year. This increased to 6.1 million acres each year from 2000 through

2004 (drought years). The national costs incurred by fire fighting activities increased from \$500 million annually to \$1.3 billion annually (2005 dollars).⁵⁵ While the acreage burned annually increased by 49% during the drought years, the fighting costs increased by 160% nationally. Costs generally increase as fires threaten homes within the “wildland-urban interface” (urban areas bordering wildland) due to the use of additional firefighters, fire engines, aircraft and fire retardant. It is estimated that there are 44 million homes located in the contiguous states within this interface.⁵⁶ A significant portion of Utah’s population is located near this interface. Refer to www.utahfireinfo.gov for information on protecting property from wildland fires.

During a twelve-year period from 1994 through 2005, the Federal Emergency Management Agency (FEMA) authorized federal funds to help Utah fight wildfires seven times. Of the seven Fire Management Assistance Declarations, five were consecutively declared from 2001 through 2005 (see Table 2-6), four of which (2001-2004) were during the drought. Economic costs of these fires reached far beyond the costs incurred through fire suppression. The Mollie fire left hillsides in Utah county near Provo, barren and vulnerable to landslides, which occurred a week later after intense rainfall.⁵⁷ The aftermath of the Mustang fire in northeastern Utah near Dutch John also caused additional costs and environmental damage due to siltation⁵⁸ in streams from the highly erodible and charred landscape.

TABLE 2-6
Fire Management Assistance Declarations

Year	Date	Incident	Homes Threatened/ People Evacuated
1994	08/06	Edgar Fire	-
1994	08/06	Dry Canyon II Fire	-
2001	08/19	Mollie Fire	220 / 80
2002	07/01	Mustang Fire	125 / 200
2003	07/15	Causey Fire	100 / 200 (6 homes destroyed)
2004	06/16	Brookside Fire	500 / -
2005	06/27	Blue Springs Fire	375 / 1200+

Source: Compiled data from the Federal Emergency Management Agency’s webpage-
http://www.fema.gov/news/disasters_state.fema?id=49.

Note: “-” indicates no data.



Hite Marina, Lake Powell, May 2001 (left) and again in May 2004 (right). Photos by Judy Gail.

National Impacts

On a national scale during the summer of 2002, 51% of the contiguous United States was experiencing mild to severe drought conditions. This is third in areal extent only to the 1930s and 1950s droughts.⁵⁹ Regionally, 87% of the West was affected, which is second only to 1934 when 97% of the West was experiencing drought conditions.⁶⁰ In his testimony before the Committee on Commerce of the United States Senate, Dr. Chester J. Koblinsky, of the National Oceanic and Atmospheric Administration (NOAA) said, “In terms of the combined effects of intensity and duration, the 1999-2006 and 1986-1993 western droughts are unprecedented in the 110-year historical record.” Nebraska alone experienced \$1.2 billion in damages during 2001 and 2002 (\$1.3 billion in 2005 dollars), and received only \$138 million (\$150 million in 2005 dollars) in Crop Disaster Payments—roughly 10 cents to every dollar that was lost.⁶¹ Similar impacts were realized in other Great Plains communities. In 2002, Wyoming’s business losses due to the drought’s impact on wildlife ranged from \$65 to \$75 million annually⁶² (\$70.6 to \$81.4 million in 2005 dollars). Fewer outdoor recreation seekers, than compared to previous years, negatively affected all types of business from fuel, food, and lodging to entertainment and outdoor guiding services.

As the drought has loosened its grip upon most of the West and Great Plains, there are two lingering effects: reduced ground water levels and dramatically depleted large reservoirs such as Lake Mead and Lake Powell, which were well below capacity at 56% and 47% respectively (as of March 2007).⁶³

Even under normal conditions it will take several years to reestablish ground water levels and to refill these reservoirs to capacity.

The Colorado River has also experienced its lowest average flow (over the duration of the drought) relative to any drought contained in the instrumental record, averaging only about 9.9 million acre-feet annually from 2000-2004.⁶⁴ Although Utah has largely returned to normal precipitation, drought conditions lingered on in Arizona and New Mexico for another two years with low soil moisture content and large portions of crops in poor conditions.

DROUGHT SNAPSHOTS AND ADDITIONAL IMPACTS

Drought Snapshots

Utah has experienced six major drought events (see Box 2-3) during the 111-years of instrumental record. These droughts affected nearly all parts of Utah, from decreasing agriculture productivity to disrupting every-day life. Each drought event was unique in its climatic characteristics, impacts⁶⁵ and differs from other natural hazards in a significant way: their effects slowly accumulated and took a number of years to be fully realized. Some impacts lingered or even peaked after the drought terminated.

Additional Impacts and Vulnerability

Impacts of drought are strongly linked with severity. Drought severity is dependant upon several factors including duration, intensity and spatial extent. In addition to these, and in some cases less recognized, are human and vegetation demands upon the

Box 2-3—Drought Snapshots

- 1896-1905: Large cattle operations folded, leaving small operations to fight over what was left of adequate grazing lands. The drought forced settlers to uproot their families as lands were drying up and water rights were inadequate.
- 1924-1936: The “Dust Bowl Years” affected approximately 75% of Utah. Agriculture productivity was decreased to almost half of prior years production and the number of farms significantly decreased.
- 1946-1964: Multiple areas within Utah were declared disaster areas. Statewide, impacts could have been worse but were lessened due to steps taken to enhance the water supply.
- 1974-1979: Conditions in seven of Utah’s counties prompted the governor to request Federal Disaster Declarations for these counties. By the end of 1977 the state lost \$41 million (\$132 million in 2005 dollars) due to the drought impacts.
- 1986-1992: Drought blanketed the entire state of Utah for multiple consecutive years. Nationally, 1988 was the most costly drought ever, and until Hurricane Katrina, was the most costly natural catastrophe in U.S. history.
- 1999-2004: The drought produced some of the hottest years and one of the driest years (2002) on record. Statewide reservoir capacity plunged below 50% and farmers and ranchers struggled to continue operations.

water supply of a region. Human demands can exacerbate regional drought impacts and result in water use restrictions and supply shortfalls, which have a negative effect on the economy.

Annually, the national costs of losses due to drought generally fall in the range of \$7.9 to \$10.5 billion (in 2005 dollars).⁶⁶ During the period from 1980-2003, there have been 58 weather-related natural hazards, which have been estimated to cost more than one billion dollars. Of these 58 events, 10 have been droughts.⁶⁷ These droughts “...(17.2% of the total) accounted for \$144 billion (41.2%) of the estimated \$349 billion dollar total cost of all weather-related...”⁶⁸ catastrophes. Three weather-related extreme events hold the distinction of costing over \$40 billion dollars, of which two are droughts. Cost of the 1980 drought year (located in the central and eastern U.S.) due to losses was estimated to be \$52.4 billion (in 2005 dollars) and the societal impacts were extreme with approximately 10,000 drought-related deaths nationwide. The most costly drought year on record, which occurred in 1988, was estimated to cost \$66.9 billion (in 2005 dollars) and played a large role in 7,500 deaths. This was the

most costly natural event ever recorded before Hurricane Katrina, which cost over an estimated \$136 billion (in 2005 dollars) and caused at least 1,800 deaths.⁶⁹

Each year, on average, 12% of the United States (excluding Alaska and Hawaii) is in the severe to extreme category of drought.⁷⁰ Drought is consistently either here or there and management of it and society’s vulnerabilities to it are critical. As water demand and the population continually increase, so too does the potential severity of drought impacts. Drought management needs to be continually improved and drought mitigation strategies need to be implemented in order to lessen the severity of future potential impacts. To do so, a state, county or community needs to assess its vulnerability to drought and reduce its identified “weaknesses.” Drought needs to be better understood by political leaders, water managers and other decision makers in order to make progress towards improving drought management and reducing drought-related impacts. The instrumental record gives us an important piece in the puzzle for understanding drought, however, it is limited by time in its application.

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3

DROUGHT FROM A PALEOCLIMATIC PERSPECTIVE AND CURRENT CLIMATE TRENDS

Droughts have occurred years, centuries and millennia before the start of the instrumental record. In order to obtain a more comprehensive knowledge and better mitigate future drought, a look farther into the past is required. Long before people developed instruments to measure and record weather and climate, natural processes were keeping a record of these events. The resulting records in trees, plants, ice and sediments have been preserved for millennia and can be interpreted today. These records help

describe climatic conditions (or “paleoclimate”) related to drought of the distant and not-so-distant past. This is the primary subject of this chapter.

While the record of weather instruments (primarily temperature and precipitation) provides a rich supply of data extending back into the 1890s, this record is too short to adequately describe many climatic processes and thus provides only a limited understanding of drought.¹ “It is also not [long] enough to allow drought variability to be evaluated during a time when the climate system was not heavily affected by radiative forcing of anthropogenic [human caused] greenhouse gases”² and to adequately consider other natural events and processes that affect climate. In order to obtain a deeper historical perspective and increase our understanding of drought in general, we must also consider the paleoclimatic record.

Paleoclimatology employs the use of natural environmental records known as proxy records, to infer climate conditions of the past.³ A natural proxy is a replacement for, or reflection of, a climate record for the years prior to the time of instrumental records.

Tree rings, fossil pollen, ocean sediments, lacustrine (lake) sedi-



Typical types of proxy records: trees, ice and pollen. Photos courtesy of: PDPhoto.org (tree and flower), NOAA: Peter Brown (tree ring) and Kendrick Taylor (ice).

ments and ice cores are a few of the commonly used proxy records. They show climate variability and enable a better understanding of past conditions. Analysis and interpretation of these records allows scientists to extend records of climatic conditions such as drought, temperature and other natural climate variables.

PROXY DATA TYPES⁴

Tree rings have been used extensively during the past few decades in paleoclimatology studies. Trees are sensitive to climatic conditions and this sensitivity is readily reflected in patterns of ring widths, composition and density—all of which reflect climate variations to some degree (see Box 3-1). Trees normally generate one ring per year and thus yield records of climate with an annual resolution. Temperature, water availability, precipitation and other climatic variables can be correlated to tree-ring characteristics. Samples are taken by boring into live or dead trees to extract a cylindrical core containing tree rings from the outer bark to the center of the tree. Samples from dead trees, in conjunction with live trees, can extend tree-ring records far into the past.

Ice cores are generally collected from the polar ice caps and Greenland. They are analyzed for dust, air bubbles, isotopes of oxygen, and ratios of hydrogen to deuterium.⁵ These parameters vary on an annual basis and can be analyzed similar to tree rings.⁶ Ice records contain several thousands of years of data. They are continuously being deposited and destroyed, a process that has gone on for millions of years. This data can be used to interpret climate conditions over those time periods.

Lacustrine (lake) and ocean sediments are collected by coring into the stratified layers of lakebeds and the ocean floor. The sediments have accumulated from erosion of the surrounding topography and contain fossils, pollen, chemicals, salts and molecular residue from past times. These can be dated and analyzed to interpret past climate conditions. Changes in vegetative cover suggest variations in regional weather conditions at multi-decadal to millennial scales.

PDSI RECONSTRUCTION METHODOLOGY

In order to reconstruct drought or other climate-related parameters from proxy data, a statistical relationship is defined and modeled by calibrating the proxy data with the instrumental record. Usually, part of the instrumental record is withheld from the calibration to test the model. This allows scientists to determine how well the proxy data estimates the instrumental record.⁷ The model is then applied to the full length of the proxy record to reconstruct the pre-instrumental Palmer Drought Severity Index (PDSI) record from the proxy data.

When instrumental records are extended with proxy records, the resulting record provides a much more complete history of past climate than either of them alone, allowing the shorter instrumental record to be assessed in a long-term context. This long-term record and perspective is essential for a more complete understanding of the impacts, severity and duration of droughts. Although severe droughts have occurred during the 20th Century, proxy data indicates those droughts do not completely represent drought variability.⁸ As will be demonstrated in this chapter, proxy data indicates past droughts of greater severity and duration than those of the 20th Century.

Box 3-1—Climate Proxy Requirements for Application to Drought Planning

A proxy must:

- Be highly sensitive to changes in moisture/water supply (drought sensitive)
- Have a broad spatial coverage to adequately capture the spatial patterns of drought
- Have adequate resolution (annually-resolved)
- Be exactly dated
- Provide record long enough to estimate past drought

Source: Edward R. Cook, Richard Seager, and Mark A. Cane, "North American Drought: Reconstructions, Causes, and Consequences," (Earth Science Reviews, 2006), 10.

Tree rings, ice cores, lake and ocean sediment and other geomorphic data “make it clear that the droughts of the twentieth century, including those of the 1930s and 1950s, were eclipsed several times by drought earlier in the last 2000 years...”⁹

TREE RINGS

Tree rings are used in dendrochronology, dendroclimatology and other related scientific studies (see Box 3-2 for definitions). They contain vast records of regional climatic variability, forest fires and additional information helpful in understanding past climate conditions. Tree rings are used to:

- More accurately see and understand past climate conditions.
- Provide recent and present climate with a longer-term perspective.
- Understand current environmental processes, particularly ones that operate at decadal and longer time scales.
- Improve understanding of possible future environmental conditions.

Some experts view tree rings as the only proxy that satisfies all of the climate proxy requirements¹⁰ for application to drought planning (see Box 3-1) and thus provides extremely useful and descriptive records of paleoclimatic conditions.

Scientists have collected tree-ring borings throughout North America for decades. The vast majority of studies indicate that droughts of the 20th Century have been surpassed in severity, duration and areal extent on multiple occasions. Tree rings have been proven to be a reliable record of past climate and can be validated by other paleoclimatic

records. For instance, PDSI values reconstructed from tree-ring data for the Western United States indicate “elevated aridity and epic drought in AD 900-1300, an interval broadly consistent with the ‘Medieval Warm Period.’”¹¹

Tree-Ring Climatic Record—Nationally and the West

Cook et al¹² developed a gridded network to reconstruct drought over the continental United States. Known as the North American Drought Atlas, this network is derived from an expansive collection of tree-ring chronologies¹³ and provides information that is helpful in analyzing past climate nationwide and for a particular region (see Box 3-3).

Several studies throughout North America have been conducted using this tree-ring atlas. In addition, studies of separate chronologies, that in many cases were ultimately included in the atlas, have been conducted. The results of these earlier, regional-specific studies have often been confirmed in the larger drought atlas study. Together, they indicate that drought before the start of weather instrument records in the 1890s was more frequent and in numerous cases more severe across many regions.^{14,15,16,17,18,19} Also, many paleo-droughts are comparable to the severe droughts of the 20th Century. For example, “droughts during the 1750s, 1820s, and 1850s-1860s estimated from tree rings were similar to the 1950s drought in terms of magnitude, persistence, and spatial coverage...”²⁰

The Great Plains area has been hit hard with drought throughout the instrumental record and has been hit even harder by drought before then.

Box 3-2—The Study of Tree Rings

Dendrochronology is the science that uses tree-rings dated to their exact year of formation to analyze temporal (time) and spatial patterns of processes in the physical and cultural sciences.

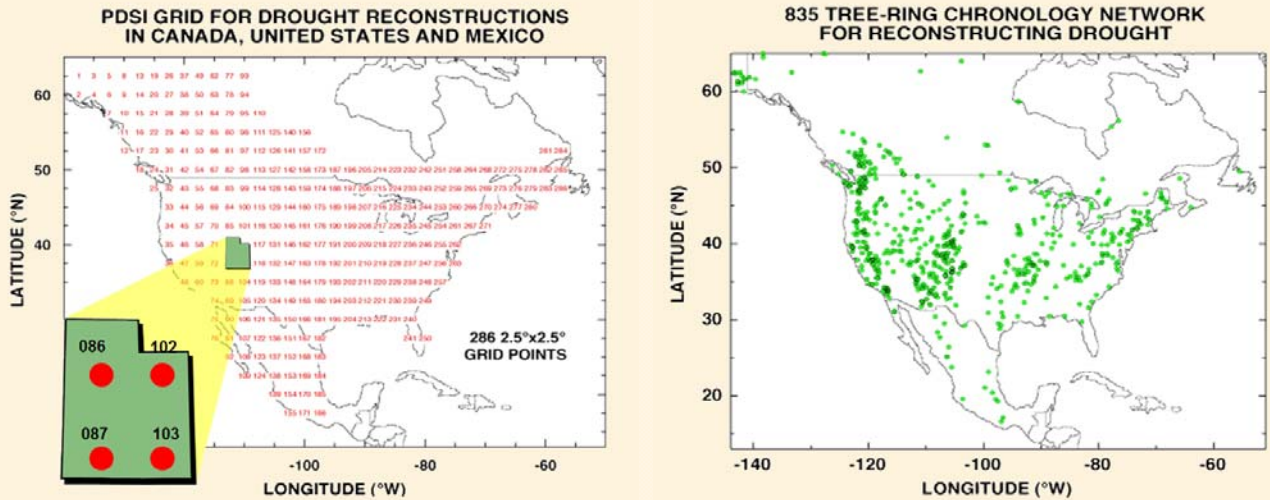
Dendroclimatology is the science that uses tree-rings to study present climate and reconstruct past climate.

Assumption from which tree-ring studies are based—empirical relationships established between tree-ring growth and climate does not change significantly over time.

(Source: Hugo G. Hidalgo, "Climate Precursors of Multidecadal Drought Variability in the Western United States," (Water Resources Research, 2004).

Box3-3—North American Drought Atlas

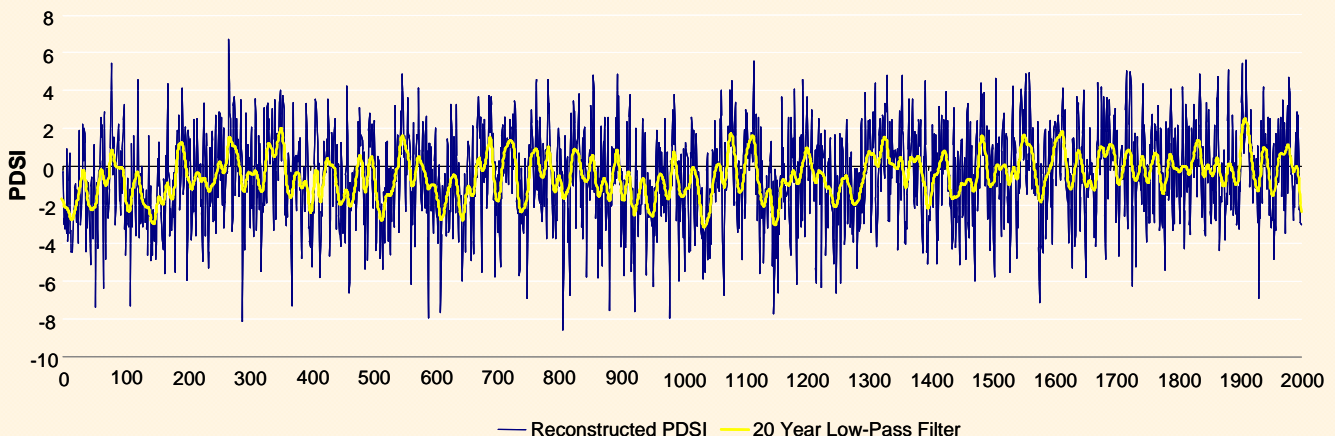
Limitations of instrumental climatic data and the need to more fully understand drought causes prompted the development of a comprehensive history of drought over North America. Cook et al developed the North American Drought Atlas to help educate and inform about drought. It is a collaborative effort based on a network of 835 annual tree-ring chronologies distributed throughout most of North America. The tree-ring chronologies were grouped together through geographic proximity, analyzed, and correlated to PDSI values (by point-by-point regression) resulting in a reconstructed PDSI grid that has a resolution of 2.5 degrees latitude by 2.5 degrees longitude.



The grid is composed of 286 grid points covering much of North America. Tree-ring chronologies used to reconstruct the PDSI are particularly dense in the West. The majority begin before 1700 with many of 400 to 1000 years in length. Reconstructed PDSI records were calibrated using the 1928-1978 period and then validated using the data over the 1900-1927 period of instrumental record.

Utah contains four grid points (086, 087, 102, and 103) relatively evenly dispersed throughout the state. An example tree-ring PDSI reconstruction for grid point 086 located west of the Great Salt Lake is shown below. Smoothed data (20-year low-pass filter) is shown in yellow. The farther back along the timeline, the greater the uncertainty, due to fewer tree-ring chronologies. This uncertainty markedly increases around 1400 AD.

(Figures and text adapted from: <http://iridl.ldeo.columbia.edu/SOURCES/LDEO/TRL/NADA2004/pdsi-atlas.html>)



“The collection of dendroclimatic reconstructions for the Great Plains region suggests that the severe droughts of the twentieth century, although certainly major in terms of their societal and economic impacts, are by no means unprecedented in the past four centuries.”²¹ Droughts comparable to those of the 1930s and 1950s have occurred regularly over the past 400 years.²²



Piñon pine trees dot the landscape. In the background is Stienaker Reservoir located in the northern portion of the Uinta Basin.

Furthermore, during the 16th Century, North America was blanketed by a “megadrought,” a multi-year and sub-continental (major subdivision of the continent) drought that equaled or exceeded the droughts of the 1930s and 1950s in magnitude, duration and extent.²³ This megadrought is thought to be one of the most severe and sustained droughts to impact North America in the past 500 years.²⁴ Analysis of tree-ring chronologies and the subsequent reconstructed summer PDSI “...indicate moderate drought conditions (PDSI \leq -2.0) for 30 years over Northern Mexico from 1560-1589, and mild drought conditions (PDSI \leq -1.0) over most of the United States, southern Canada and Mexico during this same 30-year period.”²⁵ The drought manifested itself first in Northern Mexico and the South-western U.S. and appeared to propagate to the northeast across the U.S.

Another similar megadrought occurred primarily in the West over AD 1140-1162, a 23 year-period. For almost a decade during that time, the average PDSI across North America was below -1.0. This drought was similar to

the spatial pattern of the 1999-2004 drought, but it lasted for a much longer period of time—nearly four times as long.²⁶

Tree-Ring Climatic Record—Utah

A tree-ring study conducted in the Uinta Basin of northeastern Utah indicates that the worst single-years with drought conditions of the 20th Century (1934 and 1977) were likely equaled or exceeded as many as 16 times in the preceding seven centuries. The study covers a 776-year period, from AD 1226 to 2001. Researchers sampled 107 piñon pines to reconstruct the proxy climatic (precipitation) record.

The study indicates that the 20th Century portion of the proxy record contains only 2 out of 39 (5%) of the most severe years of drought conditions. The 16th and 18th Centuries each contained four times as many, or 8 out of 39 (21% each century).²⁷

The proxy record also revealed that the past tended to contain decadal scale dry periods (see Box 3-4) that persisted longer than those experienced in the 20th Century. The only statistically significant dry period of the 20th Century, contained within this proxy record, lasted 12 years in the early 1950s to mid-1960s.²⁸ In contrast, “...[13] significant dry regimes before 1900 averaged 21 years in length.” Four of the periods lasted for at least 28 years.²⁹ These dry periods are based upon precipitation variability and therefore do not strictly follow the drought criteria established in Chapter 2 (based upon the PDSI). However, the information indicates peri-

Box 3-4—Dry Period or Event

A dry period or event refers to an overall dry trend over a time period and does not refer to a specific drought (as defined by the criteria in Chapter 2).

A dry period or event may consist of several droughts and contain years where drought conditions are present. It may also contain one or a few wet years, is not necessarily defined using the PDSI and is generally identified through proxy records (and is not limited to these interpretations).

ods, before the instrumental record, of drought conditions that were more severe.

Table 3-1 shows the reconstructed precipitation values of the 39 driest years from AD 1226 through 2001, from the Uinta Basin study. For comparison, the current average annual precipitation for the basin is roughly 8.5 inches. It is clear from the proxy data that most of those years were significantly drier than the two driest years of the 20th Century. Twenty-one of 39 (54%) were drier than 1934, and 34 of 39 (87%) were drier than 1977.

Additional proxy records also indicate that droughts in the Colorado River Basin and Great Basin have persisted for several decades.^{30,31,32} The previously mentioned megadrought that occurred over AD 1140-1162 (23 year period) was most severe in Utah. The entire state experienced average drought conditions correlating to a PDSI \leq -3.0 (severe to extreme drought) for a period of 10 years (AD 1150-1159).³³ These severe conditions lasted for a period almost twice as long as the most recent drought experienced in Utah (1999-2004).

Using the North American Drought Atlas, paleodrought in Utah can be further analyzed to reveal additional extended dry periods and droughts. Grid point data obtained from this atlas is expressed graphically in Figure 3-1. This data represents grid point 086, located south of the Great Salt Lake (see Box 3-3). The data is smoothed by a 20-year average (kernel smoother) to emphasize decadal variations of the climate and reveals periods of prolonged dry periods and drought conditions. The magnitude or intensity is decreased due to smoothing or averaging of data points as well as the due to the reconstruction process. It is important to note that the farther back along the dataset timeline, the greater the uncertainty or less confidence in the data is present. If using this data, from the North American Drought Atlas, for planning purposes, there should be a “cut off” point; meaning that the data before this point is not used in planning activities due to the decreased confidence in it. For purposes of this document, the chosen cut off point is 1400 AD (see Figure 3-1), however, the entire dataset will still be presented for general informational purposes and comparison.

Several additional dendroclimatology studies reveal similar results. Taken together, they indicate

TABLE 3-1
Driest Years from AD 1226-2001 Reconstructed from Uinta Basin Study

Rank	Dry Year	Estimated Precipitation (in)
1	1270	2.95
2	1460	2.99
	1532	2.99
3	1506	3.07
4	1686	3.15
5	1251	3.31
6	1773	3.35
	1475	3.35
7	1580	3.43
8	1774	3.74
	1234	3.74
9	1871	3.98
10	1399	4.06
	1786	4.06
11	1285	4.09
	1496	4.09
12	1307	4.25
13	1685	4.29
14	1708	4.33
15	1824	4.37
	1316	4.37
16	1934	4.41
	1461	4.41
	1362	4.41
17	1531	4.45
18	1756	4.57
19	1780	4.69
20	1542	4.76
	1474	4.76
21	1544	4.80
22	1442	4.84
	1894	4.84
24	1751	4.92
	1735	4.92
25	1350	5.00
	1585	5.00
	1977	5.00
26	1632	5.04
	1579	5.04

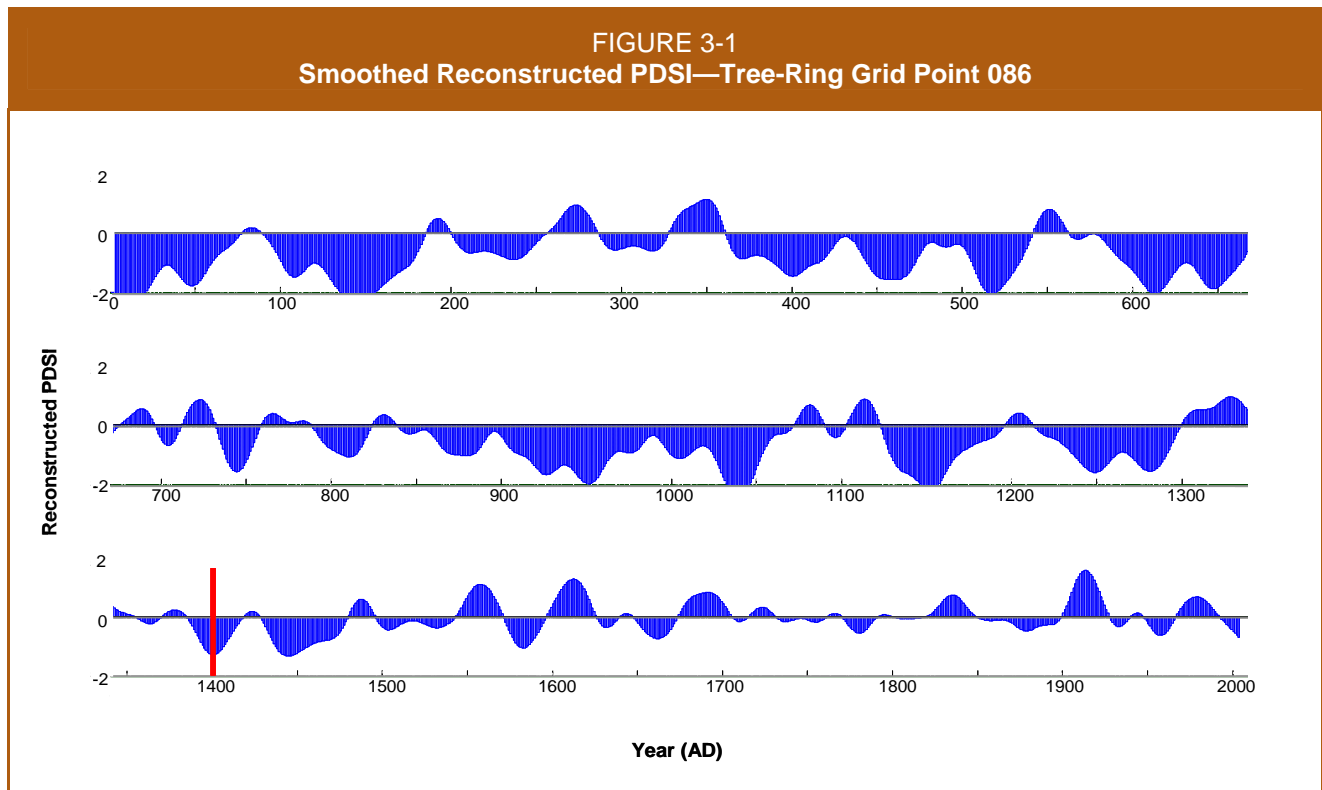
Source: Adapted from table in Stephen T. Gray, Stephen T. Jackson, and Julio Betancourt, 2004.

that on average past droughts were more frequent, of longer duration, and of greater severity than 20th Century droughts and they occurred on a regional scale.

Drought Condition Recurrence Intervals and Frequencies—Utah

Further analysis of the reconstructed tree-ring PDSI and instrumental PDSI records reveals a difference in drought recurrence intervals, frequencies and duration. Utah has been divided into seven climatic regions as shown in Box 2-1 of Chapter 2. The instrumental PDSI record reveals that on average at least one of Utah's climatic regions has experienced mild ($PDSI \leq -1$), moderate ($PDSI \leq -2$) and severe ($PDSI \leq -3$) annual drought conditions 34.2, 21.4 and 10.9% of the time, respectively, during the 111 years since 1895. Frequencies of drought conditions were calculated as described in Chapter 2. Proxy records from the four grid points contained within Utah, reveal that on average at least one quadrant of Utah has experienced mild, moderate and severe annual drought conditions 38, 24.3 and 13% of the time, respectively, in 496 years during 1400-1895 AD (see Table 3-2). The four grid points, 086, 087, 102 and 103 from the North American Tree-Ring Atlas are spaced throughout the four quadrants of Utah, roughly the four corners of the state (see Box 3-3).

Analysis of these proxy records over 1895-2003 yield results that are consistent with the instrumental record. A number of PDSI reconstructions are based on tree-ring data up to 1978 and then rely on instrumental data from 1978 to 2003, so it is likely that some of the same data is being compared between the tree-ring records and instrumental records. This causes the recurrence intervals over 1895-2003 to be more similar. The average recurrence intervals (per analysis of tree-ring proxy records) for this time period (1895-2003) for mild, moderate and severe annual drought conditions are 3.1, 4.7 and 12.2 years, respectively. The corresponding frequencies for mild, moderate and severe annual drought conditions are 33.7, 21.8 and 9.4%, respectively. Compared to the average recurrence intervals for mild, moderate and severe drought conditions obtained from analysis of the instrumental record (over the same time period, see Table 3-2), there is a 5.4, 1.1 and 28% difference, respectively. The percent differences between drought frequencies of the instrumental and tree-ring records for mild, moderate and severe drought conditions are 1.2, 1.7 and 13.8%, respectively; for the 1895-2003 time period.



Source: Data collected from the North American Tree-Ring Atlas. Utah Division of Water Resources analysis, 2006.
Note: The farther back along the record the less reliable the data due to fewer tree-ring chronologies.

TABLE 3-2
Recurrence and Frequency of Mild to Severe Drought Conditions
***PDSI vs. **Tree-Ring Reconstructed PDSI**

Climatic Region	PDSI < -1		PDSI < -2		PDSI < -3							
	Recurrence Interval (yr)	Frequency (%)	Recurrence Interval (yr)	Frequency (%)	Recurrence Interval (yr)	Frequency (%)						
1	2.6	38.2	3.7	27.3	6.9	14.6						
2	2.7	37.3	5.0	20.0	13.8	7.3						
3	3.1	31.8	4.4	22.7	8.5	11.8						
4	3.1	32.7	5.2	19.1	9.2	10.9						
5	3.3	30.0	5.2	19.1	8.5	11.8						
6	2.9	34.6	4.6	21.8	11.0	9.1						
7	2.9	34.6	5.0	20.0	9.2	10.9						
Average	3.0	34.2	4.7	21.4	9.6	10.9						
	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record
	Tree Ring 086	2.9	2.4	34.3	41.3	4.6	3.7	21.6	27.1	8.9	6.2	11.3
Tree Ring 087	2.6	2.2	38.7	46.5	4.2	3.3	23.6	30.0	8.9	6.1	11.3	16.5
Tree Ring 102	2.8	2.3	36.3	44.5	4.5	3.5	22.4	29.0	8.6	6.0	11.7	16.8
Tree Ring 103	2.3	1.9	42.7	51.5	3.4	2.7	29.4	36.7	5.6	4.2	17.7	24.1
Average	2.7	2.2	38.0	45.9	4.2	3.3	24.3	30.7	8	5.6	13.0	18.4

Note: *PDSI is from 1895-2005. **Tree-ring data contains 496 years from 1400-1895 and the entire record is 1,896 years (pre AD 1895).

Source: Data from Tree-Ring Atlas and NOAA. Utah Division of Water Resources analysis, 2008.

TABLE 3-3
Statewide Mild to Severe Drought Conditions Recurrence and Frequency
PDSI vs. Tree Ring

Climatic Region	PDSI < -1		PDSI < -2		PDSI < -3							
	Recurrence Interval (yr)	Frequency (%)	Recurrence Interval (yr)	Frequency (%)	Recurrence Interval (yr)	Frequency (%)						
*PDSI Statewide Average	10	10	15.7	6.4	36.7	2.7						
	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record		
	**Tree-Ring Reconstructed PDSI Statewide Average	3.1	2.6	32.3	38.8	5.1	4.0	19.8	24.7	9.5	7.1	10.6

Note: *PDSI is from 1895-2005. **Tree-ring data contains 496 years from 1400-1895 and entire record pre 1895 AD, 1,896 years, statewide average was calculated using the four grid points located in Utah (North American Tree-ring Atlas)

Source: Data from Tree-Ring Atlas and NOAA. Utah Division of Water Resources analysis, 2007.

TABLE 3-4
Paleo-Drought Duration—
Tree-Ring Reconstructed PDSI

Region	Average Drought Duration (yr)		Longest Drought Duration (yr)		Average PDSI During All Drought Periods		Average PDSI During Most Severe Drought Period	
	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record	1400-1895	Entire Record
Tree ring (086)	6.3	8.9	14	46	-2.05	-2.20	-3.45	-4.95
Tree ring (087)	7.9	10.8	27	52	-2.01	-2.13	-3.54	-3.94
Tree ring (102)	7.6	11.2	27	44	-1.96	-2.13	-3.48	-3.54
Tree ring (103)	9.2	12.6	29	45	-2.29	-2.47	-4.08	-4.10
Average	7.8	10.9	24.3	46.8	-2.08	-2.23	-3.64	-4.13

Note: Tree-ring data contains 496 years from 1400-1895 and the entire record of 1,896 years (pre AD1895).
Source: Data from North American Tree-Ring Atlas. Utah Division of Water Resources analysis, 2008.

Also, the proxy record indicates that *statewide* mild, moderate and severe drought conditions occurred much more regularly than indicated by the instrumental record (see Table 3-3). The difference in *statewide* drought recurrence between the two records is quite dramatic.

It is important to note however, that the tree-ring recurrence intervals and frequencies are based upon data of different spatial resolution—four grid points versus the seven climatic regions. Therefore the results for statewide drought using these tree-ring data sets are likely to be reduced for the more recent several centuries contained on the proxy records due to a “smoothing out” effect of local drought events over the four grid points. Normal to wet conditions in one part of the grid cell tend to compensate for dryness in another area. In the earliest portions of the tree-ring records (pre AD 1250 or so), where the density of tree-ring sites contributing to the reconstructions drops significantly, drought recurrence intervals might be skewed or inflated due to the effects of localized drought events.

Regardless of how the data in Tables 3-2 and 3-3 is viewed, it appears that drought conditions during earlier times have occupied a larger percentage of the time than during the instrumental record.

Drought Duration and Severity—Utah

In order to emphasize drought of longer duration and therefore greater potential of severity, the Utah Division of Water Resources calculated drought duration after modifying the criteria in Chapter 2, as follows:

- A drought was considered to have started with three consecutive years of annual average PDSI values less than or equal to -1.0.
- The drought was terminated when two or more consecutive years of near or above normal conditions existed (annual average PDSI above -0.5).

Following this modified criteria, both proxy and instrumental records were analyzed to generate drought duration data as shown in Table 3-4 and Table 3-5 respectively.

Using the instrumental record as the base, comparison of the averages of the two records reveals the following:

- Average drought duration during the paleo period was 1 year (15%) longer.
- Average of the longest drought durations during the paleo period was 12.3 years (103%) longer.
- Average reconstructed PDSI value of all drought periods during the paleo period was 0.37 (18%) less severe in magnitude.
- Average reconstructed PDSI value during the most severe drought period during the paleo period was 0.07 (2%) more severe in magnitude.

TABLE 3-5
Drought Duration—Instrumental PDSI

Climatic Region	Average Drought Duration (yr)	Longest Drought Duration (yr)	Average PDSI During All Drought Periods	Average PDSI During Most Severe Drought Period
1	6.6	12	-2.60	-3.48
2	8.4	19	-2.02	-2.72
3	7.0	11	-2.56	-3.11
4	7.3	15	-2.63	-3.22
5	5.3	8	-2.58	-5.08
6	7.2	12	-2.18	-3.46
7	5.6	7	-2.56	-3.91
Average	6.8	12	-2.45	-3.57

Note: PDSI is from 1895-2005.
Source: Data from NOAA.
Utah Division of Water Resources analysis, 2006.

This analysis indicates that average paleo-droughts were longer (15%) while the average of the longest droughts was substantially longer (103%). The average reconstructed PDSI value during all paleo-droughts was lower (18% less) while the average reconstructed PDSI value during the most intense paleo-droughts was more severe (2%). The average drought duration over 1895-2003 (per analysis of the proxy records) is 7.7 years, a 12% difference from the instrumental PDSI record (6.8 years) over the same time period.

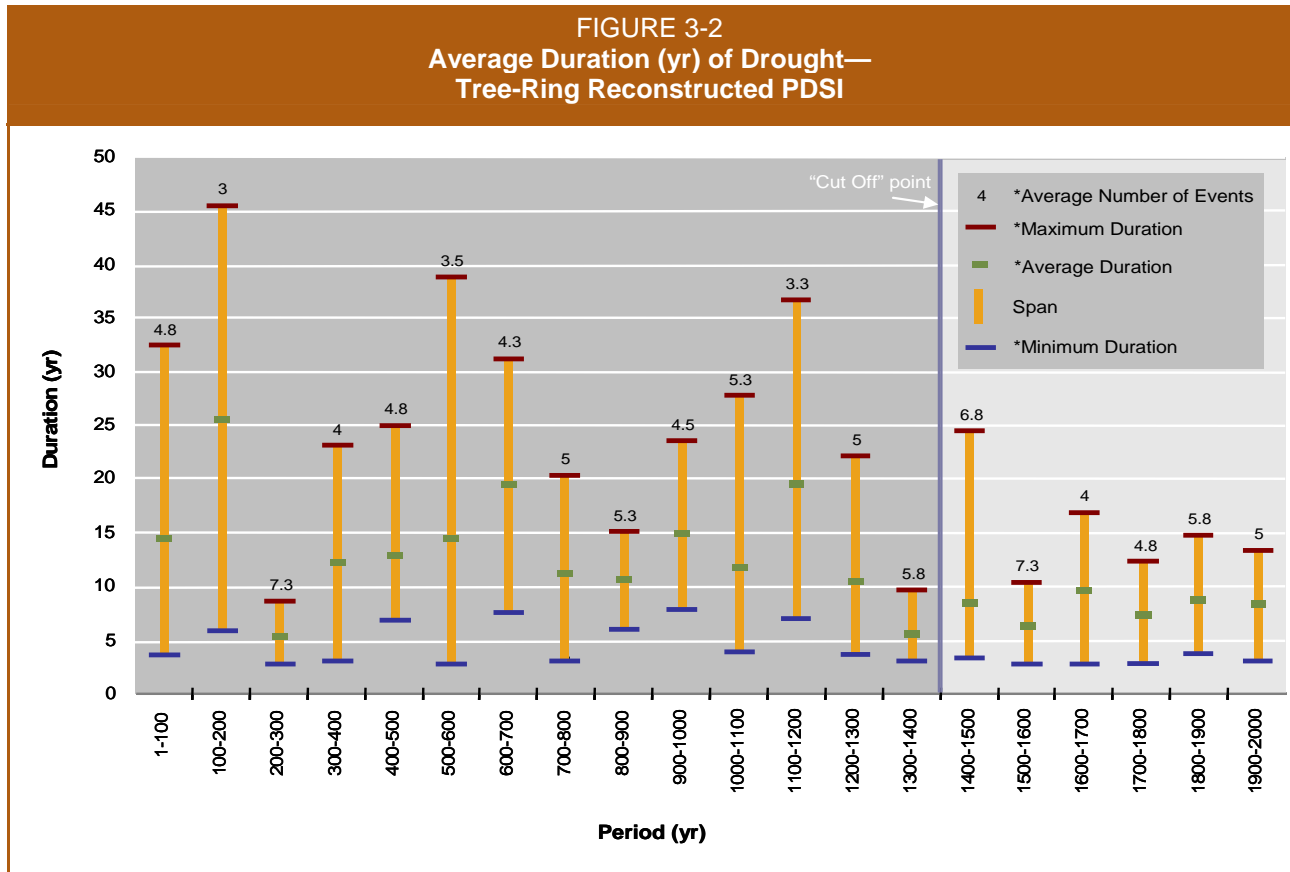
In addition to this drought duration analysis, tree-ring data in Utah evaluated by Herweijer and Seager³⁴ suggests that medieval drought lasted nearly two decades, whereas recent droughts have lasted just under a decade. Drought duration generally tends to increase the farther we look back along the proxy record (see Figure 3-2; this figure indicates the number of drought events in 100-year intervals, maximum and minimum drought duration and the average duration). It must be noted however, that the data also becomes less reliable as there are fewer data points (tree-ring chronologies that span past time periods) the farther back along the proxy record and there are uncertainties associated with intensity and duration of paleo-drought reconstructed from tree-ring data. The 1400 AD “cut off” point is noted on the figure. Drought duration is also influenced by how drought is defined (the drought duration criteria, see page 41). For additional discussion and

comparison of the instrumental PDSI and tree-ring reconstructed PDSI, refer to Appendix C—Instrumental PDSI versus Tree-Ring PDSI.

Based on tree-ring studies, as presented in this report and from scientific literature, it appears drought before the instrumental record has surpassed drought of the 20th Century in duration and in several instances, severity. Such studies also indicate a higher frequency of prolonged drought events. Therefore, the last century’s instrumental record cannot be considered wholly representative of the complete range of drought variability in Utah.

GEOLOGIC PROXIES

Although tree-ring studies are extremely useful and provide information over the past 2000 years, additional proxies are required to provide insight beyond that timeframe. Geologic proxies on the other hand, offer data that is many more millennia in length. Ice cores, marine sediment, lacustrine (lake) sediment and eolian sediments (wind -borne, -deposited, or -eroded sediments) provide us with a look farther back along the paleoclimate timeline. Sediment cores provide us with indirect climate information. Researchers analyze the sediment for such things as plankton shells, fossil pollen, salinity, and signs and types of vegetation, from which climate characteristics can be inferred.



*These are averages of the four grid points (086, 087, 102 and 103)—tree-ring chronologies, which are located in Utah. Source: Grid point data obtained from the North American Tree-ring Atlas. Utah Division of Water Resources analysis, 2006

The slow accumulation rate of sediments results in lengthy records. However, the ability to resolve short-term changes (such as annual variability) is greatly reduced. Thus sediments yield data over time spans of hundreds to thousands of years, often with coarser resolution, from which general climate trends can be inferred.

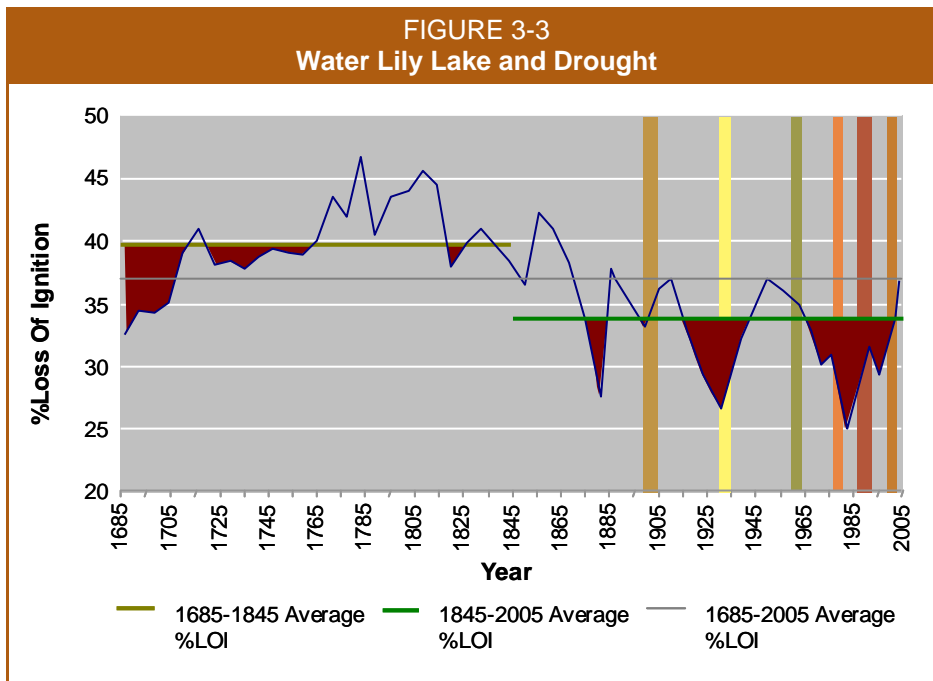
Geologic Proxies and Climate—Utah

Some lake sediment studies have been conducted in Utah and neighboring regions and even though discussion specifically regarding drought is lacking, inferences can still be made. Additional studies in Utah and other topographically related regions are needed in order to add more depth and understanding to Utah’s paleoclimate regimes and drought of the past. Results of a few studies are presented in the following paragraphs.

Analysis of charcoal, indicative of fire, in sediments from Water Lily Lake in the Uintah mountains of northeastern Utah revealed four distinct climatic periods, roughly 3500 to 2750 BC, 2750 to 1000 BC (period that likely featured several droughts and significant drawdown of the lake), 1000 BC to AD 500 (cool moist period) and AD 500 to 1150 (shift back to a warm dry climate),³⁵ indicating long-term regional climatic variability.

The “Loss of Ignition” or LOI, a measure of organic content in the sediment, for this lake, was found to be proportional to lake level.³⁶ Therefore the LOI measurements can be used as a proxy for lake level and compared to the climatic region 5 (Northern Mountains) PDSI identified droughts as shown in Figure 3-3.

Although this particular record is not extraordinarily long, it shows relatively short-term regional climate variability. There also appears to have been a



Source: Data from Collin Rodgers' thesis, "Latest Holocene Environmental Change in the Uinta Mountains, Utah, Based on Analysis of a sediment Core from Water Lily Lake," Middlebury College, 2004.

Note: %LOI—Loss of Ignition is a measurement of organic matter content.

regional or localized climate shift around 1845 to an overall drier regime. In contrast, sediment analysis of another high mountain lake, in the Leidy Park region only 100 km away from Water Lily Lake, indicated different regional climate regimes.³⁷ This emphasizes the fundamental distribution of climate regimes in the Intermountain West. Due to the extreme topographical differences in the West, "microclimates" or regional climates are quite common and may behave differently than the overall climate regime that the West is experiencing. It was also noted that a "boundary" between summer dry/winter wet (Water Lily Lake) and summer wet/winter dry (Leidy Park) appears to bisect the Uinta Mountains,³⁸ further emphasizing climate variability that exists in northeastern Utah and the need for more Utah-based studies.

Geologic Proxies and Climate—Great Plains

Great Plains research is used in this discussion due to the readily available studies and data sets. Great Plains lake sediment reconstructions are similar to tree-ring studies in the conclusion that 20th Century drought is neither representative of past drought variability nor the *potential* range of drought

conditions of the near future.^{39,40} Instrumental records indicate that major droughts, which impacted the Southwest, particularly Utah, in the 20th Century also affected the Great Plains. Thus, evidence of drought in the Great Plains supports the conclusion that such droughts are likely indicators of similar droughts in the Southwest. However, topographical differences and the resulting regional climatic regimes, between the Southwest and the Great Plains areas limit the breadth of inference.

Records spanning the Holocene geologic period, the last 10,000 years, which are driven by changes in orbital patterns or "earth-sun relationships," provide evidence of epic dry periods. In the middle of the Holocene, lake sediments of the northern Great Plains, have recorded 100-year to 130-year and even 160-year long extended dry periods suggesting increased drought frequency. These periods were characterized by decades of productivity followed by decades of drought conditions and erosion.^{41,42} These shifts between wet and dry periods (regime shifts), "...have gone on pretty consistently throughout the last 4,500 years."⁴³

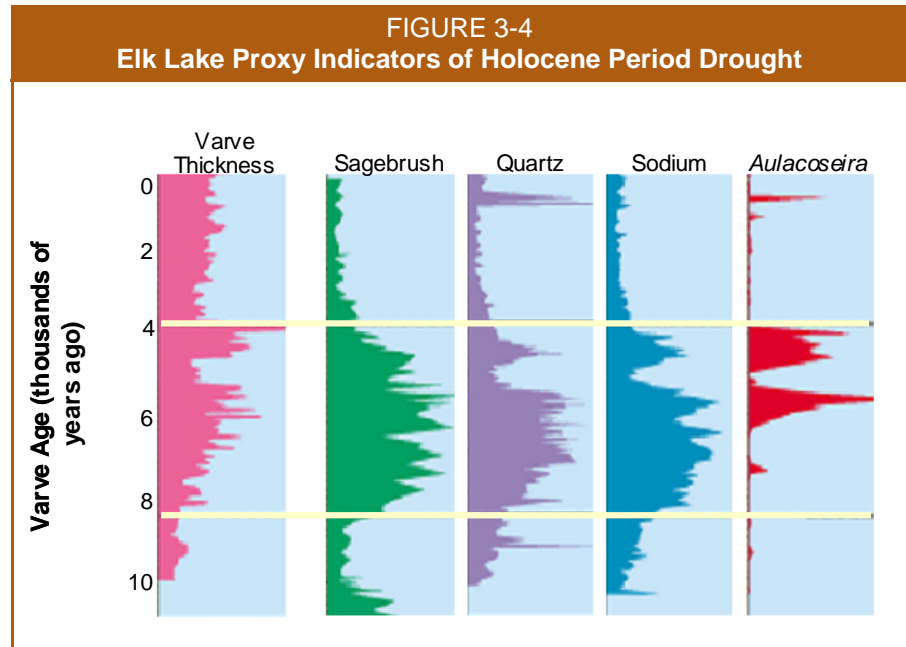
In a similar study, sediments from three Great Plains lakes revealed that the climate of the past 2,000 years was quite complex hydrologically. Large oscillations from wet to dry phases occurred and, prior to AD 1200, severe multidecadal periods of drought conditions were frequent. These were indicated by long intervals of high salinity in the sediment cores.⁴⁴

Similarly, the U.S. Geological Survey presented evidence from various sediments indicating climatic shifts over the last 10,000 years in the upper Mississippi River Basin. Analyses of pollens found in

sediments collected from Elk Lake in Minnesota provide clues to millennial-scale climate regime shifts. A spruce forest once dominated the area after the ice age 10,000 years ago. As the climate warmed, a pine forest replaced the spruce forest and about 8,500 years ago, as the climate became drier, the pine forest was succeeded by prairie vegetation,⁴⁵ see Figure 3-4. This time period, for this geographical location, is known as the “Prairie Period” due to the climatic shift towards conditions favorable to prairie grasses.

Varve (a pair of layers of alternately finer and coarser silt or clay believed to comprise an annual cycle of deposition)⁴⁶ thickness increased during this time due to eolian (wind-borne) sediment deposition indicative of prolonged dryness. Active dune fields were also formed during this time period. Enhanced eolian activity is generally associated with drought conditions severe enough to inhibit and remove vegetation.⁴⁷ This mid-Holocene climatic shift is characterized by elevated dry periods. These dry periods affected much of North America and are thought to dwarf the 1930s dust bowl in several aspects.⁴⁸ The data suggests that these dry periods were expressed during roughly a 4,000-year span, as shown in Figure 3-4. As can be seen, the proxies found within the sediments are quite consistent and reflect that prolonged dry period.

Analysis of eolian sediments in the Wray Dune Field of eastern Colorado and Sand Hills of Nebraska indicates enhanced eolian activity to have taken place within the past 400 years, coinciding with the drought conditions of the late 16th Century;⁴⁹ a significant dry period also indicated by tree-ring studies. Further analysis of the Nebraska Sand Hills by Muhs et al⁵⁰ suggested prior enhanced eolian activity about 800 years ago, which supports and coincides with analysis of lake sediments from



Note: 4,000 to 8,000 years ago, dry conditions prevailed with sagebrush vegetation dominating the region.

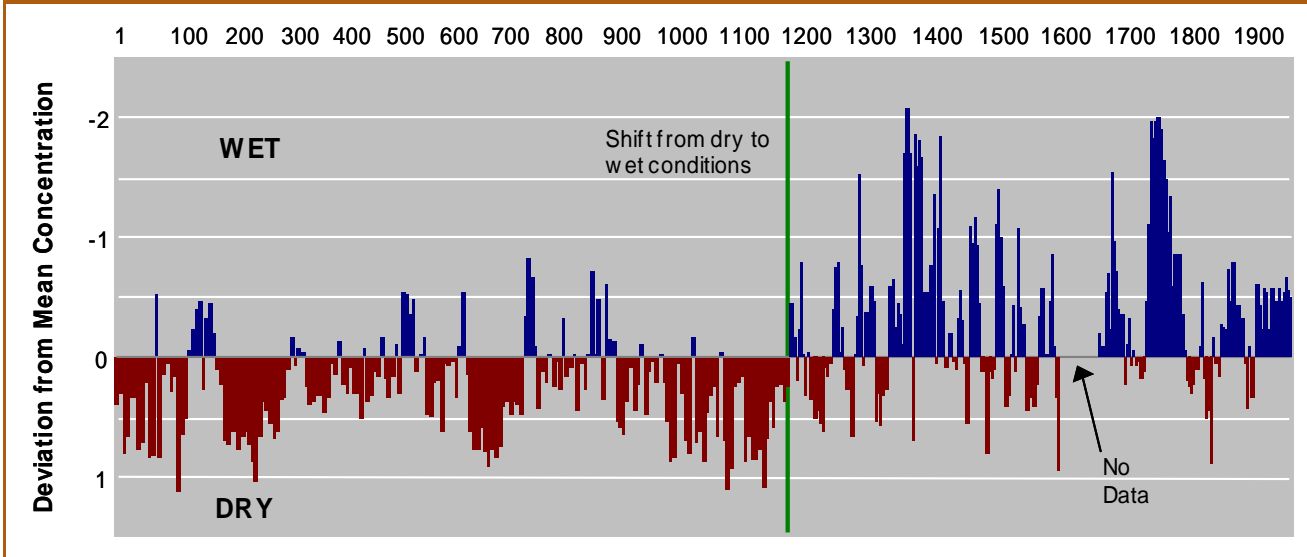
Source: Adapted from Walter E. Dean, "Evidence of Climate Change over the Last 10,000 Years from the Sediments of Lakes in the Upper Mississippi Basin: USGS Fact Sheet FS-059-99." Retrieved from: <http://pubs.usgs.gov/fs/fs-0059-99/>, July 2006.

Elk Lake in Minnesota, indicating a severe and sustained dry period.

In addition to this, another geologic proxy record study indicates a noticeable change in drought characteristics through time. Analysis of sediment salinity (higher salinity concentrations correlate to drier conditions) from Moon Lake in North Dakota indicates a regime shift from predominately dry to wetter conditions, around AD 1200.⁵¹ Droughts before this time were characterized by greater frequency, longer duration and greater intensity when compared to 20th Century drought. Compare the two time periods (pre-1200 and post-1200) as shown in Figure 3-5. Once again, natural records show the most recent century of human existence to be less severe in terms of drought conditions when compared to past times.

In support of this inference, several tree-ring reconstructions in the Great Basin and Southwest reveal a similar shift, however the timing of the shift in these studies is slightly later.⁵² Indications of this regime shift can also be seen in the tree-ring reconstructed PDSI record (Figure 3-1), as prolonged

FIGURE 3-5
Moon Lake Salinity—Regime Shift



Note: High salinity concentrations depict dry periods whereas low concentrations are indicative of wet periods.
 Source: Data acquired from ftp://ftp.ncdc.noaa.gov/pub/data/paleo/paleolimnology/greatplains/moonlake/moonlake_salinity.txt Contributors: Kathleen R. Laird, Sherilyn C. Fritz, Kirk A. Maasch, and Brian F. Cumming. Utah Division of Water Resources analysis, 2006.

drought conditions were more prevalent before AD 1200-1300. In order to adequately describe this event (regime shift) that apparently took place around 700 years ago additional investigation of highly resolved and accurately dated proxy records is required.

FUTURE CLIMATE AND TRENDS

Climate Driving Forces (Climate Forcings)

Tropical Pacific sea-surface temperature (SST) patterns have been found to moderately influence Utah’s climate. The most notable SST patterns are known as El Niño and La Niña and commonly are heard in weather forecasts. El Niño events generally result in dry winters in the normally wet Pacific Northwest and northern Rockies and wet winters in the southwestern United States. The influence of La Niña is the opposite of El Niño and when coupled with a positive Southern Oscillation Index (SOI) (see Box 3-5), dry winters are almost guaranteed in the southwest. “It is the most dependable predictive climate relationship in the United States.”⁵³ El Niño, La Niña and the SOI collectively are referred to as the El Niño Southern Oscillation (ENSO).

In addition to the relatively well-known ENSO, drought may be linked to additional climate variations brought about by changes in SSTs in the Pacific and Atlantic Oceans, known as the Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO). See Box 3-5 for definitions. These oscillations along with El Niño and La Niña events can help explain drought occurrence. AMO causal mechanisms regarding drought are not yet clear, however the PDO appears to be associated with the ENSO as a low frequency component. The PDO and AMO may be linked to prolonged drought periods.

Although much is still yet to be verified, it is reported that up to “52% of the spatial [space] and temporal [time] variance in multidecadal drought frequency over the conterminous U.S. can be attributed to⁵⁴” specific PDO and AMO phases, and increasing Northern Hemispheric temperatures. Across the U.S., in both the instrumental and proxy records, the wettest decadal-scale events are generally associated with a negative AMO and the driest with a positive AMO,⁵⁵ which appears to have influenced the duration of the 1950s drought. This drought appears to strongly correlate with a positive AMO (see Figure 3-6). The Southwest climate

Box 3-5—Definitions

El Niño Southern Oscillation (ENSO) is described by its two phases, El Niño and La Niña and also by the Southern Oscillation.

El Niño is the warming of sea-surface temperatures (SSTs) of the eastern and central tropical Pacific Ocean, which interacts with atmospheric conditions, with 2 to 7 year phases. Generally this results in drier winters in the Pacific Northwest and wetter winters in the Southwest United States.

La Niña events (or cold events) are the cooling of SSTs across the eastern and central tropical Pacific Ocean, which tends to be associated with wetter winters in the Pacific Northwest and drier winters in the Southwest United States.

Southern Oscillation is an inverse relationship in atmospheric surface pressure between Tahiti and Darwin (Australia). When lower than average pressure exists at Tahiti and higher than average at Darwin, El Niño is generally present. The normalized pressure difference between the two locations is known as the **Southern Oscillation Index (SOI)**.

Pacific Decadal Oscillation (PDO) is a long-term El Niño-like pattern of climate variability in the Pacific, with 20-30 year phases. The warm or positive phase is indicative of cooler than average SSTs (in the main Pacific) and warmer than average SSTs near the coast of California, enhancing El Niño effects. The cooler or negative phase tends to enhance weather conditions associated with La Niña.

Atlantic Multidecadal Oscillation (AMO) refers to long-duration changes in the SSTs of the North Atlantic Ocean, with phases lasting 30-40 years. During the warm or positive phases, droughts tend to be more frequent and/or severe.

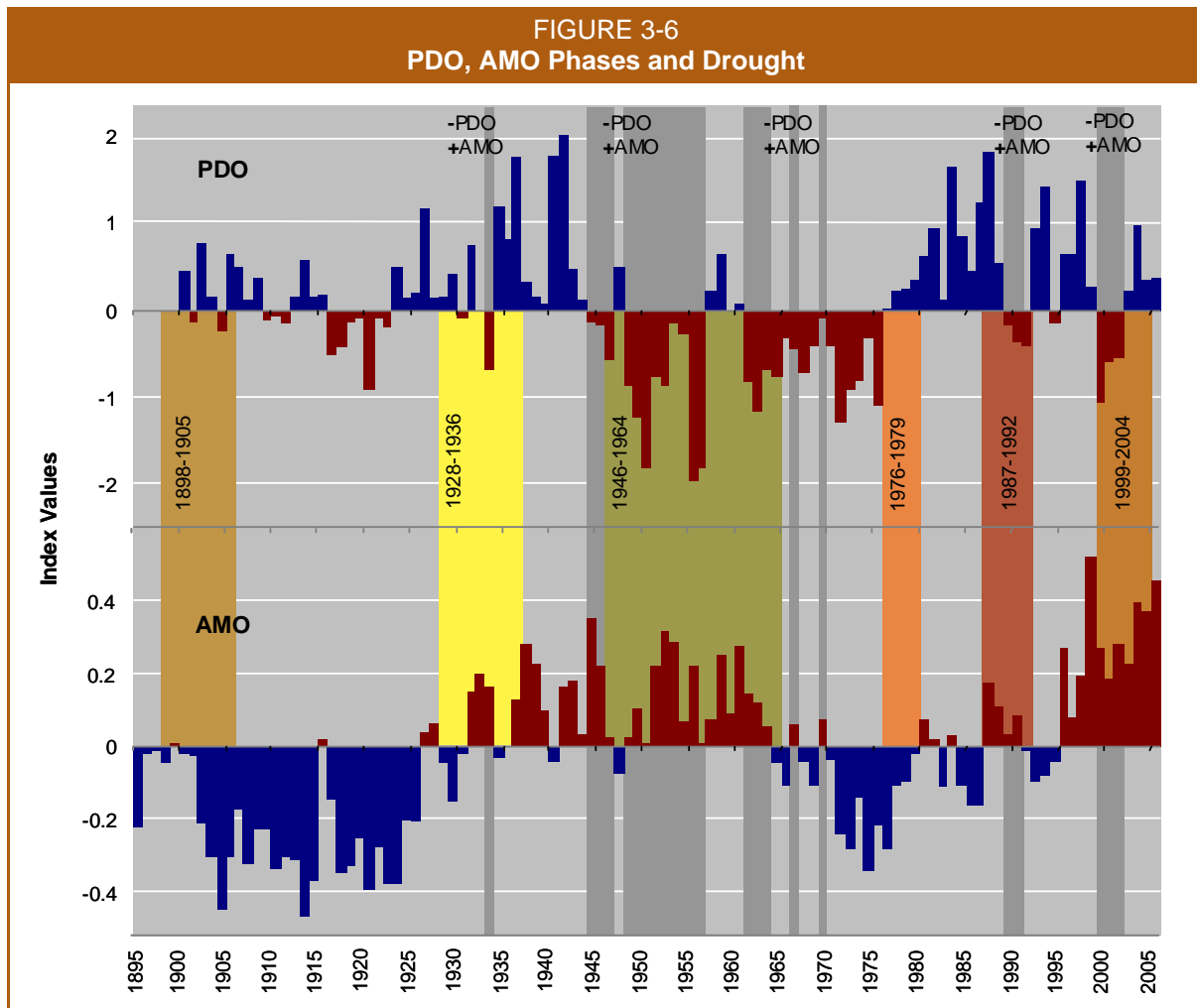
phase also tends to be determined by a positive PDO and negative PDO for wet and dry periods, respectively. Furthermore, the location of a drought epicenter within the western states is influenced by the PDO phase (northern region—positive phase and southern region—negative phase). The first few years of the most recent major drought event, 1999-2004, was associated with positive AMO and negative PDO phases. See Figure 3-6 for phase changes on record in relation to the six identified drought periods from the instrumental record.

This relatively new area of research is leading towards a greater understanding of drought and our climate at both global and regional scales. Every step forward in understanding the mechanisms of natural variability of SSTs brings us closer to being able to forecast and better understand future drought events. While the ENSO, PDO and AMO are

somewhat good indicators of weather conditions and possible drought for many regional areas, Utah, due to its geographical location, falls within a “grey area.” It can be thought of as being on the edge of influence of both PDO and AMO phases, or an area of overlap. Therefore the resulting weather conditions brought about by AMO or PDO phases may not be fully expressed in Utah or the expression thereof may be somewhat unclear.

Climate Change

It is clear that the climate has been changing throughout all of history—it is a natural phenomenon. Some of the changes in the climate during the last 10,000 years, that appear to have had an effect on drought, have been discussed in this chapter. Clearly, there have been changes in wet and dry times as well as hot and cold times on land. Similarly, oceans have experienced changes in tempera-



Note: Annual Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO) time series with Utah droughts shown. Source: Adapted from McCabe, Paleki, and Betancourt, Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States, 2004. PDO data from the University of Washington's webpage- <http://jisao.washington.edu/pdo/PDO.latest>, AMO data from the National Oceanic and Atmospheric Administration's webpage- <http://www.cdc.noaa.gov/Timeseries/AMO/>. Utah Division of Water Resources analysis, 2006.

ture and flow patterns. The ability of people to observe, quantify, monitor and understand climatic processes has been greatly improved with the advent of instrumental records during the last 111 years or so.⁵⁶ Climate change is of great interest since every human activity from how individuals dress to how entire economies function is greatly dependent upon the weather and climate. Undoubtedly, climate change may continue to be examined and discussed far into the future. This section discusses the current state of knowledge on climate change with emphasis on potential impacts to the water supply and drought in Utah.

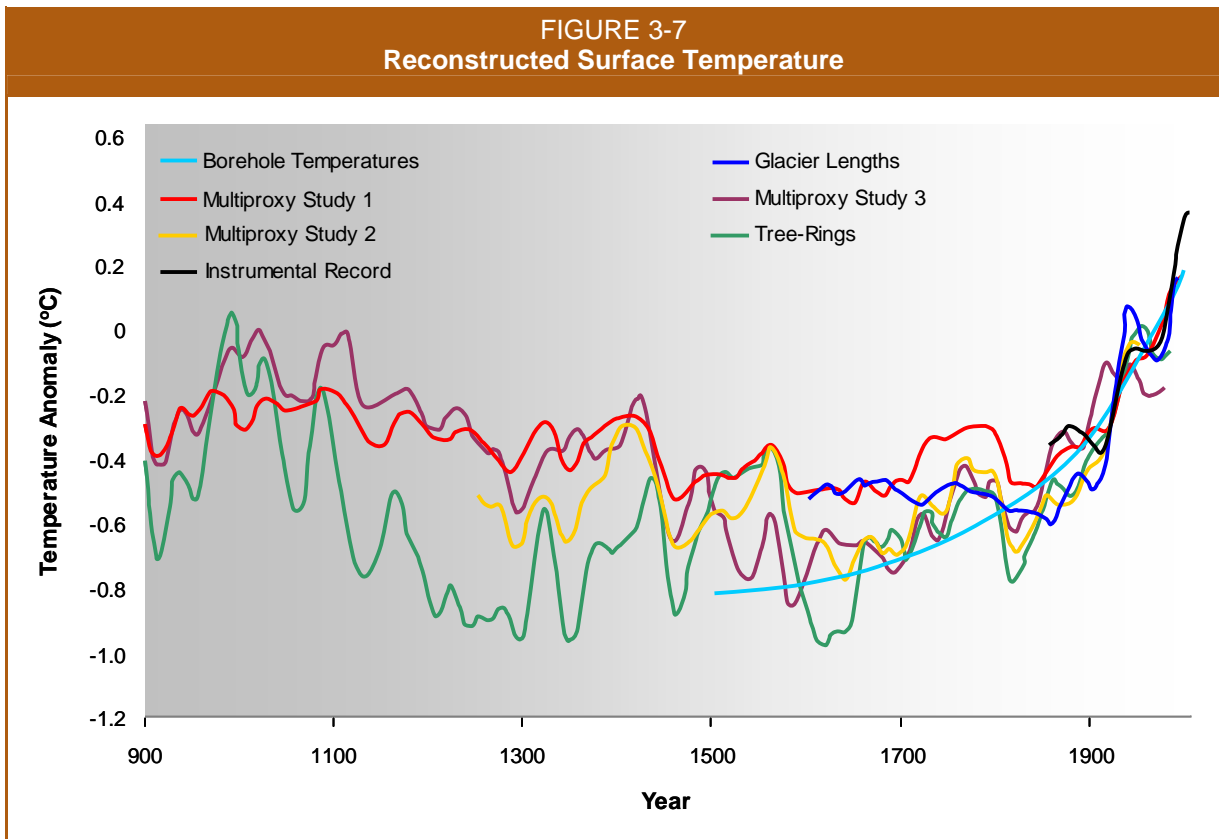
One topic of great interest is whether or not the planet is heating up—the concept of global warming. Today, the anthropogenic influence on climate change is pronounced more than ever before. Greenhouse gases are contributing to overall climate change, however, it looks as though that even with strict regulation of greenhouse gases, climate change will continue and mankind will have to adapt to whatever the resultant climate may be.⁵⁷ Much credible work has been done for decades and serves to illuminate the subject and it is in the interest of Utah water suppliers to gain some knowledge of the matter.

In August 2006, the National Academies of Science published a report titled, “*Surface Temperature Reconstructions for the Last 2,000 Years.*” This was done in response to a request by the United States Congress to “describe and assess the state of scientific efforts to reconstruct surface temperature records for the Earth over approximately the last 2,000 years and the implications of these efforts for our understanding of global climate change.”⁵⁸ The report discusses results from six different research projects, each from different authors. These projects examined and analyzed “proxy evidence from sources such as tree rings, corals, ocean and lake sediments, cave deposits, ice cores, boreholes, glaciers and documentary evidence.” The results are graphically summarized in Figure 3-7.⁵⁹ This graph shows that global air temperature has been increasing over the last several centuries. Most notably the rate of increase, or slope of the curves, itself has been increasing over the last 150 years. A similar

report, which focuses on the Colorado River Basin, supports these findings by stating that mean temperatures in the Colorado River Basin have been increasing and goes on further to say that, “there is no evidence that this warming trend will dissipate in the coming decades, with many different climate model projections pointing to a warmer future for the Colorado River region.” It also states that in recent years, “the Colorado River basin has warmed more than any region of the United States.”⁶⁰

As with every scientific endeavor, “*Surface Temperature Reconstructions for the Last 2,000 Years*” contains many caveats and conditions on interpretation of the data. However, the following points from the report’s summary are relevant to the purpose of investigating drought in Utah. Based on these observations, global air temperature is rising.

It can be said with a high level of confidence



Note: Smoothed reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from six different research teams (see Academy of Sciences report for references) are shown along with the instrumental record of global mean surface temperature. Uncertainties generally increases going backward in time, as indicated by the gray shading. This set of reconstructions conveys qualitatively consistent picture of temperature changes over the last 1,100 years, and especially the last 400.

Source: Adapted from the National Academy of Sciences.

that global mean surface temperature was higher during the last few decades of the 20th century than during any comparable period during the preceding four centuries. This statement is justified by the consistency of the evidence from a wide variety of geographically diverse proxies.⁶¹ Based on the analyses presented in the original papers by Mann et al. and this newer supporting evidence, the committee finds it plausible that the Northern Hemisphere was warmer during the last few decades of the 20th century than during any comparable period over the preceding millennium.⁶²

The report concludes by encouraging further work on surface temperature reconstructions and encourages investigation into, “other climatic variables, such as precipitation, over the last 2,000 years [that] would provide a valuable complement to those made for temperature.”⁶³

The overall implications of a warmer environment are many and varied—and not yet completely understood. A consensus has not yet been reached pertaining to the affect climate change will have on precipitation in Utah. Currently there is no significant annual precipitation trend in Utah that has been projected or detected. Through statistical analysis of Utah’s snowpack, conducted by Randall Julander of the Natural Resources Conservation Service, no statistically significant trends with regard to snowpack accumulation, melt or ablation have been identified. This conclusion is reinforced, as precipitation trends have not been identified in the Colorado River Basin as well.⁶⁴ However, many studies do introduce potential consequences of increasing temperatures, of which several have been documented as occurring in the West.⁶⁵ These potential consequences are as follows and warrant consideration in water management and planning activities:

- The growing season will likely begin earlier and last longer.
- Evapotranspiration will likely increase.
- Snowpack will likely be less (largely due to higher evaporation rates) and melt earlier.
- Summer precipitation could decrease while in the fall and winter a greater percentage of precipitation could fall as rain rather than snow.

- Future Colorado River and tributary streamflows will likely decrease and “contribute to increasing severity, frequency, and duration of future droughts.”⁶⁶

The National Oceanic and Atmospheric Administration’s Earth System Research Laboratory presents a possible scenario for the future. Through recent research, to be published in the *Regional Impacts of Climate Change, An Assessment of Vulnerability, 4th Assessment* (by the Intergovernmental Panel on Climate Change in 2007), the following preliminary data regarding Utah is as follows. All projections are statewide, unless indicated and are to occur by about 2060:

- Air temperature is projected to increase in Utah by 5.4 to 6.3 °F. The Northern Mountains and Uinta Basin, climatic regions 5 and 6 are projected to be the national epicenter of temperature increase. The Colorado River Basin has already warmed more than any other region in the United States.
- Annual precipitation is projected to change within a range of -1.2 to +1.2 inches. Precipitation in the Dixie area, climatic region 2, is projected to decrease by 1.2 to 2.8 inches.
- Annual evapotranspiration is projected to increase by 5.1 to 6.7 inches. Evapotranspiration in the Dixie area, climatic region 2, is projected to increase by 6.7 to 7.9 inches.
- Annual water balance (precipitation minus evapotranspiration) is projected to decrease by 30%, indicating a deficit in the water balance—higher loss than recovery.
- Drought, due to the estimated air temperature increase, is projected to be more severe early on in the 21st Century (severe drought = PDSI_≤ -3), on average have an areal extent that will affect 50% of the Interior West and on average last for 12 years (similar to severe droughts expressed in the reconstructed PDSI records).

This is one possible scenario among many. The data shown are the averaged preliminary results of over 40 computer models. As expressed in this scenario, droughts could become more severe in terms of duration and intensity, similar to droughts contained in proxy records.

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4

MITIGATION STRATEGIES AND DROUGHT FORECASTING

Water managers and suppliers are encouraged to consider drought in the context of historical records, proxy records and climate change, as presented in the previous chapters, and re-evaluate their drought management strategies. In order to better plan for drought and alleviate its impacts, water managers and suppliers are also encouraged to move toward and implement a more mitigation-oriented drought management methodology. The possibility of decade-long or longer drought in Utah's future is sobering. The socioeconomic impacts of such a pernicious natural event would be enormous. Although it is difficult to predict exactly what kind of drought to expect in the future, based on historical and paleoclimatic data, the evidence suggests that droughts of longer duration and greater intensity have occurred and therefore could occur again. When this understanding is coupled with the current scientific understanding of climate change and global warming, the prospects for the future become even more sobering.

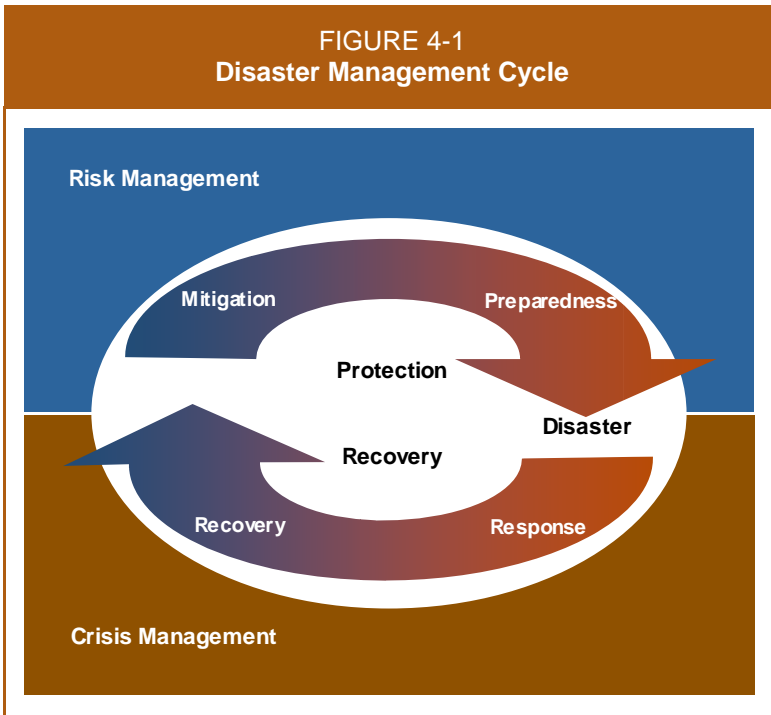
All this begs an important question—is there anything that society can do to effectively mitigate such future drought? While the answer to this question for the “worst case” scenario is *possibly* “no,” for the events of shorter duration that are more likely to occur the answer is *certainly* “yes.” The means and methods of mitigating, preparing for and responding to prolonged drought are the topics of this and the next chapter. While the prospects are challenging and an element of “coping” with drought will likely be required, practical solutions, which can be implemented while maintaining environmental integrity, are available to deal with more extreme drought

events than society has experienced in the past century.

DEFINING MITIGATION

Often mitigation is erroneously considered synonymous with response. It is important to understand the distinction between the two. Response is action taken after a disaster has commenced and impacts are already felt. Due to the long duration of drought events, response can at times take place concurrently with ongoing impacts. The impacts, however, commenced first and the response followed. In this document, mitigation is defined as effort, planning and work done in advance of a disaster or drought, to lessen, or in some instances eliminate potential impacts. Frequently, mitigation for the next disaster follows closely on the heels of a recent disaster and occurs concurrently with ongoing response efforts. The distinction is that while the response efforts are addressing the impacts of the recent disaster, mitigation efforts are directed at the potential impacts that could result from future events, in kind of a “lesson-learned” approach.

Mitigation can also be confused with preparedness. To correctly understand the distinctions between mitigation, preparedness, response and recovery, refer to the Disaster Management Cycle as depicted in Figure 4-1. Before a disaster occurs, the planner is concerned with managing the risk presented by a potential disaster. Hence, this portion of the cycle is known as Risk Management. After a disaster has occurred, and impacts evident, planners and community leaders are concerned with manag-



Source: Adapted from the National Drought Mitigation Center, University of Lincoln-Nebraska “Disaster Management Cycle.”

ing the crisis, hence this portion of the cycle is known as Crisis Management. Crisis Management (response and recovery) is “backward-looking” in the sense that it addresses impacts that have already taken place. Risk Management (mitigation and preparedness) is “forward-looking” in that it is planning ahead for future disasters. For additional discussion and understanding of mitigation and preparedness, see Box 4-1 for an illustrative example.

The Economics of Risk Management

Because some mitigation strategies can be expensive, it is important for communities to carefully consider not only what mitigation strategies will be implemented, but also what is an “acceptable-level-of-risk.” Cost-benefit analyses should always be conducted. If funding were not an issue, and a community had at its disposal an unlimited supply of money with which to mitigate, then a community could mitigate for impacts of every possible natural hazard. If such were the case, in some cases the cost of mitigation could possibly exceed the actual cost of the potential impacts, had the impacts actually been allowed to occur unmitigated. The logical extension to this hypothetical situation is that there is a point of diminishing returns, at which the dollars

spent on mitigation will begin to exceed the dollars saved in reduced impacts. Consequently, and because communities don’t have unlimited funds with which to mitigate, it is incumbent upon local planners to carefully weigh mitigation strategies against potential impacts in order to determine what is the acceptable-level-of-risk. This reasoning further supports the need for accurate estimates of economic losses and quantitative impacts.

UTAH’S MITIGATION PLAN

Utah’s Pre-Disaster Mitigation Plan

The Utah Division of Emergency Services and Homeland Security (a Division of the Utah Department of Public Safety) is the state’s designated coordinating agency for disaster preparedness, emergency response and recovery, and hazard mitigation programs. In November of 2004, the Utah Division of Emergency Services published “*The State of Utah Pre-Disaster Mitigation Plan.*” This plan is the culmination of three years of mitigation planning and was undertaken to meet the requirements of the federal Disaster Mitigation Act (DMA) of 2000. This act details mitigation and planning requirements for state, local and tribal governments. These requirements mandate governments to complete a mitigation plan that identifies natural hazards, risks and vulnerabilities.

The DMA is the latest federal legislation that provides funding for disaster relief, recovery and some hazard mitigation planning. The new legislation reinforces the importance of mitigation planning and emphasizes planning for disasters before they occur and established a Hazard Mitigation Grant Program (HMGP), which fosters close coordination and integration of mitigation planning activities within local governing entities. The DMA specifically addresses mitigation at the state and local levels, identifies new requirements that allow HMGP funds to be used for planning activities and increases the amount of these funds available to states that have developed a comprehensive or enhanced mitigation plan prior to a disaster. State and local communities must have an

Box 4-1—Flood Mitigation and Preparedness—An Illustrative Example

The difference between mitigation and preparedness can be illustrated by considering the example of an impending flood. Days before the river reaches flood stage, residents can prepare by placing sand bags along the river banks and get pumps, hoses and other equipment ready. Mitigation, on the other hand—which targets the threat of flooding—could have been accomplished months or even years earlier by building an engineered berm, landscaped dike or flood wall and non-engineering options such as flood plain buy-outs.

This example illustrates a very important point about mitigation. Often mitigation is expensive, such as, an engineered dike or flood wall. This is especially true when comparing the cost of constructing a permanent dike with the cost of having volunteers place sand bags. Obviously, if a community knew that there would only be one flood, and they knew when it would happen, the most economically viable option would be to place sand bags at the appropriate time. But in reality, floods are reoccurring phenomena and can occur without warning. Although mitigation can be expensive, it is often the best long-term solution to reoccurring natural hazards.

While the example of a flood was used here because it easily illustrates the difference between mitigation and preparedness, the principle is the same with regard to drought. When a drought is in its early stages precautionary measures can be taken to prepare for a worsening drought situation. Mitigation on the other hand should be planned and accomplished long before the drought commences.

approved mitigation plan in place prior to receiving both pre- and post- disaster funds.¹

An important aspect of hazard mitigation planning is to obtain input from skilled professionals who work with specific hazards and their associated impacts. Through such input, the hazard mitigation planner can plan for those conditions, which cause an unacceptable threat to life and property. Identifying what constitutes an acceptable or unacceptable risk is an essential component of any mitigation plan.² In addition to its own assets and expertise, the Utah Division of Emergency Services and Homeland Security has established an inter-agency technical team, which provides disaster mitigation assistance. The team includes representatives from:

- Utah Division of Water Resources
- Utah Division of Water Rights
- Utah Division of Drinking Water
- Utah Division of Forestry, Fire and State Lands
- Utah Geologic Survey
- Utah Division of Oil, Gas and Mining
- National Weather Service
- U.S. Geologic Survey

- Bureau of Reclamation
- National Resources Conservation Service (NRCS)

Utah's mitigation plan addresses the following seven natural hazards: earthquake, flood, landslide, wildfire, dam failure, drought and severe weather. The plan also identifies which communities and counties in the state have developed mitigation plans that have been approved and are in place. The state plan is supplemented by six hazard mitigation plans completed by county-formed associations of government. All of these plans are available online at <http://dhls.utah.gov/nathaz/plans.htm>. Within these hazard mitigation plans, drought mitigation goals and objectives are detailed at the state and county levels (goals of cities within their respective county) as shown in Table 4-1 and Table 4-2, respectively.

The state and counties have addressed drought from several angles, including the following: water development, agricultural use improvements, secondary water systems, public education/outreach—in which the vast majority of counties have taken an active role—and promotion of efficient water use, especially outdoor use.

TABLE 4-1
State Drought Mitigation Goals, Objectives and Example Projects

Goal	Objectives	Possible Projects
Conserve existing water resources in all sectors	<p>Educate the public about water conservation.</p> <p>Adopt strict water conservation practices in all state buildings.</p> <p>Conserve water within the agriculture sector.</p>	<p>Provide printed and broadcast material; teacher education; and public speakers to promote conservation.</p> <p>Retrofit buildings with water saving devices; educate employees; and use water conserving landscaping (xeriscape).</p> <p>Develop and demonstrate conservation practices for agricultural use and promote the use of treated wastewater effluent.</p>
Reduce the impact of development on water resources	<p>Enhance building codes for new construction in areas where potable water supply is a problem.</p> <p>Develop demonstration projects to show the public how they can retrofit their property with appropriate conservation technology.</p> <p>Require all public water systems to have drought contingency plans.</p>	<p>Modify existing building codes or adopt new ones; require water-conserving landscape; and require water-conserving appliances and fixtures.</p> <p>Construct demonstration gardens; water-wise public facilities; etc.</p> <p>Provide technical assistance for drought contingency planning.</p>
Improve public water infrastructure	<p>Reduce water loss within public water infrastructure.</p> <p>Reduce water use by consumers.</p> <p>Increase efficiency through shared system management.</p> <p>Expand and improve existing potable water systems.</p> <p>Support the State's Drought Mitigation Plans and initiatives.</p>	<p>Identify and correct leakage from water mains.</p> <p>Meter all water usage within water systems and set water rates that encourage conservation and cover O&M costs.</p> <p>Develop incentives for public water systems to conserve their resources.</p> <p>Enhance the productivity and efficiency of existing raw water extraction methods and develop new well fields or surface water sources for public supply.</p> <p>Support the State Department of Natural Resources, Water Resources Division in updating the state drought plan.</p>

Source: Tabulated information from the Utah Division of Homeland Security web page: <http://dhs.utah.gov/nathazplans.htm>, State Natural Hazard Mitigation Plan.

TABLE 4-2
Drought Mitigation Programs and Measures of Cities within the Listed County

County	Develop/Promote Conservation Measures (public education and outreach)	Limit Unnecessary Water Consumption/Enforce Laws	Encourage Development of Secondary Water Systems	Protect Aquifers	Develop New Water Storage Facilities	Develop New Water Sources	Upgrade Irrigation Systems	Enforce Rate Policies that Encourage Conservation	Address Agricultural Shortages and Water Practices
Beaver	X	X			X		X		
Carbon			X		X	X			X
Daggett	X	X			X		X		
Duchesne	X	X			X		X		
Emery	X	X			X		X		
Garfield	X				X	X		X	
Grand	X				X	X		X	
Millard	X		X						
Morgan	X		X						
Salt Lake	X	X	X	X	X	X	X	X	X
San Juan	X				X	X			
Sanpete	X		X						
Summit	X		X						
Tooele	X			X				X	
Uintah	X	X			X		X		
Utah	X		X						
Wasatch	X		X						
Washington	X	X				X	X	X	

Source: Adapted and modified data from the Utah Division of Homeland Security web page: <http://dhsis.utah.gov/nathazplans.htm>, Hazard Mitigation Plans. Note: Only the 17 counties out of the total 29 that have addressed drought mitigation within the hazard mitigation plans are included.

Some of these goals or mitigation strategies, along with additional strategies, are discussed in detail in the following sections. Concerted drought mitigation efforts put forth by the state, its counties and its communities can undoubtedly reduce impacts of drought in all sectors of the economy and social construct.

DROUGHT MITIGATION STRATEGIES

As the state continues to grow in population, so does the demand for water. In order to satisfy or modify this demand year-round (especially during periods of drought) and maintain a reliable water supply, Utah has, and can, employ several mitigation strategies. These strategies include, but are by no means limited to the following: water redistribution, conjunctive management, water system interconnections, water development projects, water reuse, demand management (alternative landscaping and incentive pricing), water metering and leak detection programs, weather modification projects and forecasting.

These mitigation strategies are not viewed as a panacea to all future water management challenges. However, when multiple strategies are implemented and managed as one system, with drought components imbedded within each strategy, they can serve as long-term mitigation strategies. It is also important to note that without drought components, such as a mechanism to store water for use during drought, the strategies presented in this document may only mitigate drought in the short-term, until the water which was “freed up” by the implemented strategy is required by the growing population. Successful implementation of each strategy as a means to mitigate drought must be based on this understanding. These strategies developed in concert and managed as a whole will likely produce more beneficial results and more effective drought management possibilities.

Water Redistribution

In the event of a decade-scale drought, the water supply industry will not be able to conduct “business as usual.” A major challenge during such a drought will be simply to obtain enough water to meet basic municipal and industrial demands, let alone agricultural demands. As a result, a temporary redistribu-

tion of water supplies may be needed. This would most likely involve voluntary leasing and/or selling of agricultural water (and/or other water) to satisfy public demand. Such water redistribution can be done during a drought of any length. Current water use patterns in Utah suggest such a redistribution could take place. To some degree this is already occurring to satisfy growing urban demands.³ The vast majority of surface water supplies in Utah are used for agricultural purposes. Use percentages of subsurface and surface water supplies are as follows:

- In 2000: 81.1% of freshwater withdrawals were for irrigation.
- Average from 1960 to 2000: irrigation—88% surface water.
- In 2000: 13.4% of freshwater withdrawals were for public supplies.
- In 2000: public supply—58% ground water.
- Average from 1960 to 2000: public supply—45% surface water.

Given that drought impacts the agricultural community first, and most severely, the agricultural sector will likely be in dire conditions during a prolonged drought. Although some surface water will be available each year, the reduced amounts could make the economic viability of raising crops and livestock for many farmers extremely challenging. Under such circumstances, selling irrigation and livestock water to thirsty cities could be more profitable for farmers and ranchers than producing minimal crop yields.

While most Utah cities rely more on ground water than surface water for drinking water, many may still be challenged to provide an adequate water supply. Many municipalities have yet to “prove-up-on” (show beneficial use of water allotted via water rights) and fully develop existing ground water rights, which will likely be put into service. However, several ground water basins, including Salt Lake Valley and Bountiful East Shore Area, are over-appropriated (approved water rights exceed natural recharge) and have declining ground water levels.⁴ Furthermore, all the major metropolitan areas in Utah, except for Cache and Rich Counties, are closed to additional ground water applications due to lack of sufficient recharge.⁵

Given these and other factors, a logical option for municipalities faced with prolonged drought might be to turn to the agriculture community for needed, and potentially available, surface water supplies. Moreover, the large percentage of agricultural withdrawals suggests a relatively large volume of water available to meet demand during prolonged drought. As of 2000, total agricultural water use in Utah was approximately 4,221,000 acre-feet per year (see Table 4-3). During drought, agricultural water available for redistribution would be less. Statewide the total municipal and industrial (M&I) or public water requirement is approximately 714,720 acre-feet per year. Some basins where large quantities of water are used for agricultural purposes are also locations of substantial M&I water demand, for example, Bear River, Weber River and Utah Lake (Figure 4-2). Water redistribution may be best suited in such areas. One method that can be employed to help facilitate water redistribution is water banking.

A water bank is an “institutional mechanism that facilitates the legal transfer and market exchange of various types of surface, ground water and storage entitlements.”⁶ Water banks are not new and have been used in the western states in various forms for decades. The common goal of these banks is to

TABLE 4-3
Agricultural Water Use by Basin

Basin	Agricultural Water Use in 2000 (acre-ft/yr)
Bear River	858,000
Sevier River	767,000
Uintah	745,000
Utah Lake	523,000
Weber River	322,000
West Colorado River	284,000
Cedar/Beaver	268,000
West Desert	204,000
Kanab Creek/Virgin River	92,000
Jordan River	85,000
Southeast Colorado River	73,000
Total	4,221,000

Source: Division of Water Resources, *Utah's Water Resources: Planning for the Future*, 2001, State Water Plan.

bring “willing sellers” and “willing buyers” together and mediate or broker the deal. Providing such a mechanism for locating and transferring water rights during periods of drought can reduce the potential severity of drought impacts.

The greatest challenge to such redistribution would be physically transferring the water. As can be seen in Figure 4-2, urban and industrial areas are in many cases adjacent to or within close proximity of actively irrigated agricultural lands. In order to physically facilitate water transfers, new infrastructure may be needed. There are, however, numerous reservoirs and pipelines existing between agricultural and urban locations that could be used to convey water from where it is available to where it is needed. It would be advisable for public water suppliers to formulate plans and put in place agreements and develop infrastructure that allow water transfers, before they are needed. See Box 4-2 for an example of an effective water redistribution program in California. The effectiveness of this strategy is not only contingent upon proximity of available water for transfer but also the quality of it and ability to meet treatment needs. If the water cannot be diverted for treatment then its application is greatly limited to secondary distribution systems. Also, potential environmental impacts must be evaluated such as erosion potential of fallow fields and decreases in return flows (runoff from agricultural fields) to receiving water bodies and ecosystems. Considerable effort and cooperation among several agencies would be required in order to negotiate any potential legal restraints and water rights issues.

Conjunctive Management

Conjunctive management is another useful management tool for mitigating droughts of any length in Utah. While there are many components to this tool, the most important is also the most straightforward: store water when there is a surplus in order to have it available when it is needed. Utahns have been successfully storing water in surface reservoirs in this manner for over a century. Although often equally feasible, and even less expensive, storing water underground has not been applied nearly as much.

Conjunctive management concepts are simple as follows⁷ (See Figure 4-3 for an illustrative representation):

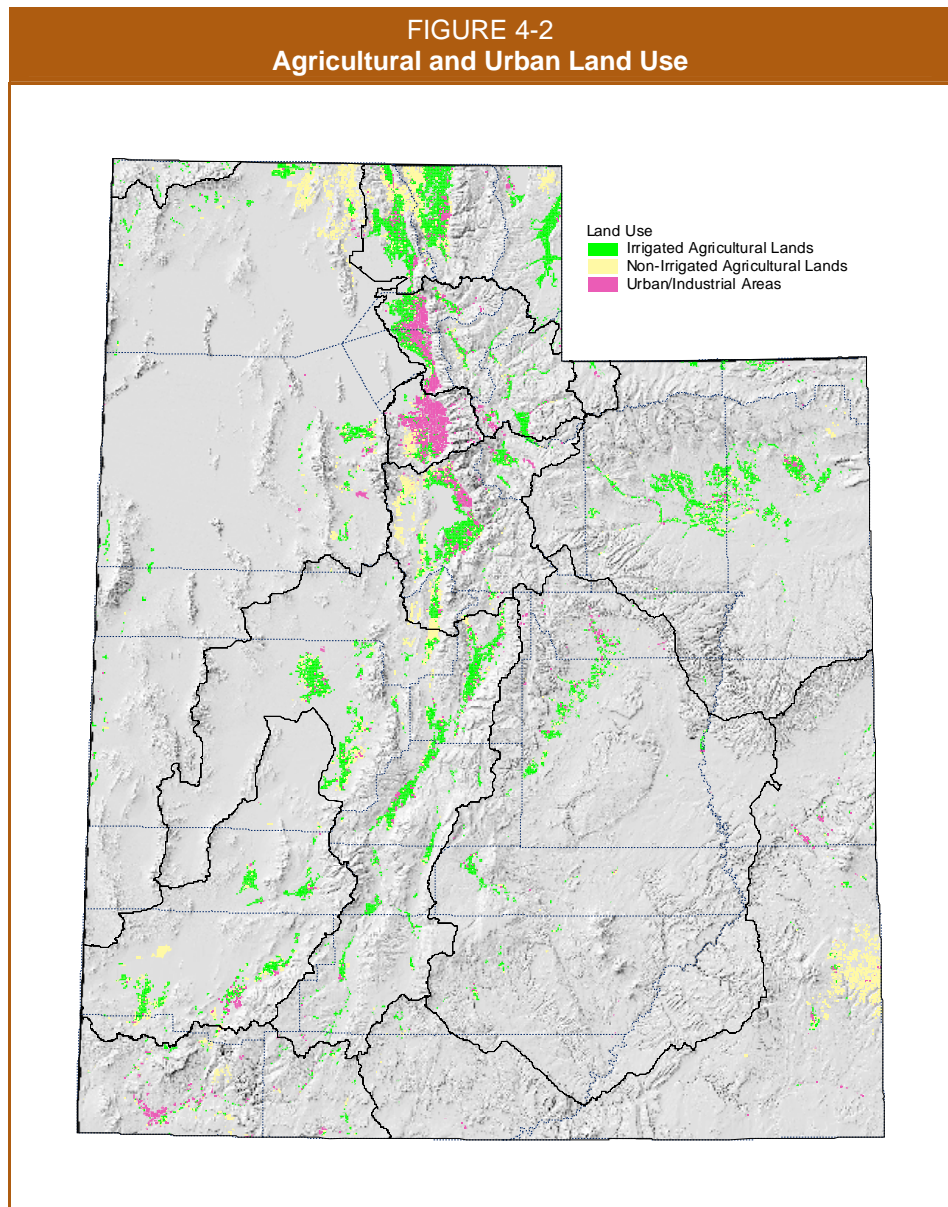
- Use more surface water and less ground water when surface water is available during wet periods.
- Store unused surface water above ground and underground (managed or artificial recharge) during wet periods.
- Wet periods include the annual spring season snowmelt and consecutive years of above-normal precipitation.
- Conversely, use less surface water and more ground water during dry periods when surface water supplies are reduced.
- Take water out of surface and ground water storage during dry periods.
- Dry periods include the annual summer months and consecutive years of below-normal precipitation (droughts).
- Protect natural recharge zones.

The key point is that unused surface water, during normal or wet years, is intentionally stored above ground and underground in order to have it available when it is needed. Aquifer storage and recovery (ASR) is one way of doing this. An aquifer can be regarded as an “underground reservoir.” This reservoir can be operated just like a surface reservoir, without the large evaporation losses

inherent to surface reservoirs. Water can be recharged to the aquifer by two methods: 1) spreading untreated water on the ground in favorable locations and allowing gravity to draw the water down, and 2) using ASR wells to inject water into the target aquifer.⁸ Both options are typically less expensive, costing 50% to 90% less, than surface reservoirs.⁹ Several water sources for ASR are available including stream floods, springs, storm runoff, reclaimed water and converted agricultural water.¹⁰

When employed specifically for long-term drought mitigation, a good strategy would be to put

FIGURE 4-2
Agricultural and Urban Land Use



Source: Utah Division of Water Resources, 2006

Box 4-2—California's Water Redistribution Program

This agriculture-to-urban water redistribution concept (or water banking) has been implemented in various forms in California since 1991. Initially, water redistribution was prompted by a five-year drought, a relatively rare occurrence in that state. The two primary infrastructures for moving water were experiencing difficult times due to greatly reduced water supplies. "The State Water Project had limited deliveries to municipalities to ten percent of contract entitlements and deliveries to agricultural users had been suspended. The Central Valley Project system also was cutting back deliveries to 75 percent [25% reduction] for Sacramento River water rights and San Joaquin exchange contractors, 50 percent [50% reduction] for municipalities, and 25 percent [75% reduction] for agricultural users." In response, the state government established a water bank to "obtain water from voluntary transfers to supply water to "critical needs" of the state." The California Department of Water Resources negotiated water purchase contracts and water sales contracts, monitored compliance, secured permits and coordinated deliveries. "The goal was to create 'new' surface water through the implementation of three types of contracts." Over 820,000 acre-feet of water was provided under 351 contracts in 1991. Dry conditions in succeeding years necessitated the reactivation of the water bank in 1992 and 1994. A total of 330,000 acre-feet of water was provided during these two years.

Success of the water banks and requests from water users throughout the state resulted in the establishment of a permanent, Dry Year Purchasing Program. Under this program, "the [California] Department of Water Resources negotiates a Memorandum of Understanding (MOU) with potential buyers to estimate water demand, and then enters into separate agreements with sellers to purchase water on behalf of the participants of the MOU. This program is available in years with less than normal hydrologic conditions. Water can be purchased through two different types of contract structures: 1) dry-year option contract, or 2) direct purchase contract." During the years 2001, 2002, and 2003 some 172,211 acre-feet of water was provided under this mechanism. When a drought of any length occurs, California is well positioned to redistribute water throughout the state to match supplies with demands. A similar system in Utah would help water suppliers lessen the impacts of drought on their customers.

Washington State Department of Ecology and West Water Research, Inc., *Analysis of Water Banks in the Western States*, July 2004, Publication No. 04-11-011, pages 40-46.

more water in the aquifer every year than is extracted, thus building up a storage surplus over a long time. This strategy would need to be done in cooperation with the Utah Division of Water Rights and the Utah Division of Water Quality since there are regulatory requirements for ground water recharge and recovery.¹¹

The greatest opportunities for conjunctive management in Utah are with public water suppliers.¹² That is an advantage since the greatest need for water is for an increasing population, primarily in urban locations. When using ASR wells, the storage location could be the aquifer directly beneath the city that needs such a facility. Several locations having favorable geologic conditions have been identified and are listed in the Utah Division of Water Re-

source's report: *Conjunctive Management of Surface and Ground Water in Utah* (available online at: www.water.utah.gov). Depending on local geologic conditions, agricultural water users could also employ conjunctive management; however, the opportunities are fewer primarily due to cost.

At any level of use, above ground storage/infrastructure will likely be required in order to retain surplus water until it can be introduced into an aquifer via injection wells or infiltration.

Besides managed recharge, protecting natural recharge areas would enhance and/or maintain natural recharge rates. In many cases these environmentally sensitive areas are within or adjacent to developed areas. Measures should be taken to protect these

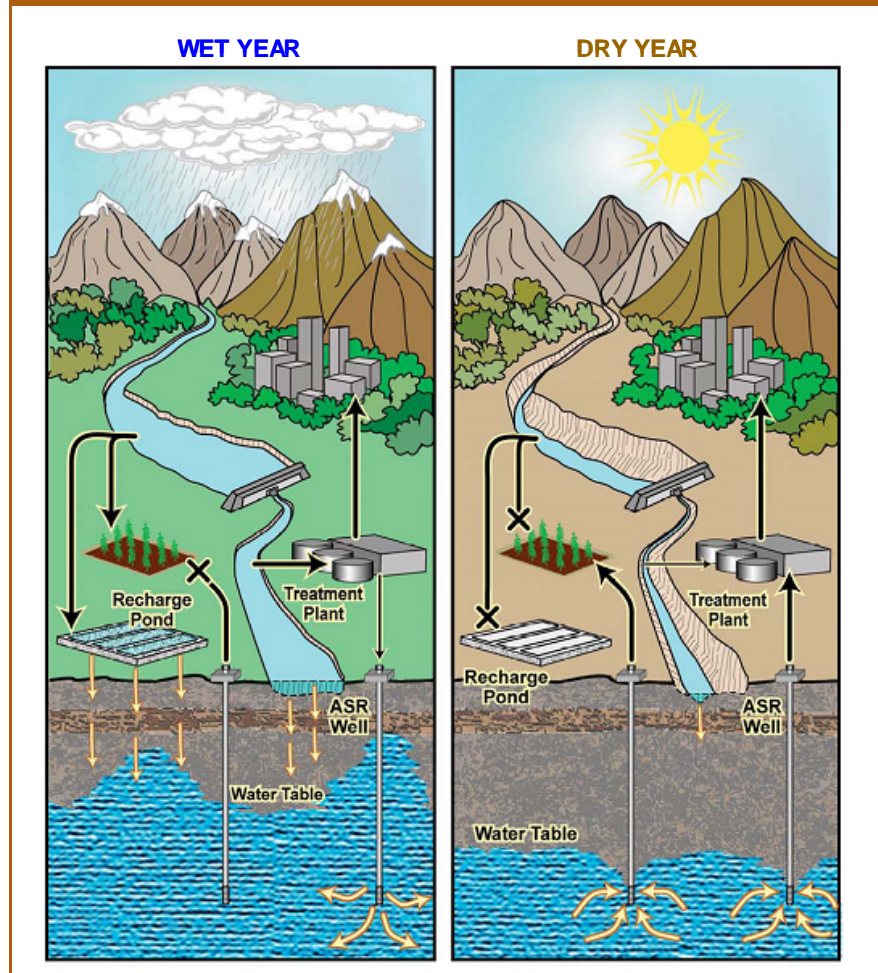
areas in order to maintain water quality standards and facilitate adequate recharge. Maintaining instream flows is also a concern when implementing conjunctive management and/or managed recharge.

Water System Interconnections

Many independent water systems exist throughout Utah. Connecting these systems together, as inferred in the sections on water redistribution and conjunctive management, will be required to distribute water to the user as needed during prolonged drought and other emergencies. Individual communities are generally “plumbed” from the water source or treatment plant, to the individual homes or businesses. In most cases, this plumbing system is not well integrated with neighboring systems to meet regional water demands and management requirements. Increased integration of conveyance networks and implementation of advanced monitoring and control systems (such as supervisory control and data acquisition, or SCADA systems¹³) can increase water suppliers’ ability to meet regional water demands during drought. If during drought, the demand on a particular system is lower than the supply and a surplus exists, that surplus can be distributed to the neighboring network through such an integrated and managed system (M&I to M&I transfers).

During the summer of 2000, drought conditions coupled with a 12-25% increase in water demand from the previous year in Jordan Valley Water Conservancy District and Salt Lake City, prompted water managers to implement cooperative management adjustments through mechanisms already in place. System adjustments and aqueduct capacity transfers

FIGURE 4-3
Conjunctive Management



Source: *Conjunctive Management of Surface and Ground Water in Utah*, 2005, Utah Division of Water Resources.

made it possible to distribute water throughout Salt Lake County without shortages.¹⁴ Such cooperation and management adjustments are to be commended and highly encouraged.

Connecting water systems together is a viable mitigation strategy that requires extensive planning, cooperation and coordination between all parties involved, however it may be limited by the commonality of water sources. For example, if neighboring systems use the same drought impacted water source, the likelihood of water to be available for transfer from one system to the other is greatly diminished. Water suppliers should investigate such opportunities and develop agreements and physical interconnections (substantial monetary investment likely required) that would allow such transfers to

take place when needed. Water districts and other purveyors should explore the prospect of forming a committee to facilitate and create the opportunity for dialogue among one another to discuss interconnections and managing water systems as a whole, especially during drought.

Water Development and Inter-Basin Transfers

Development of Utah's water supply has been an ongoing effort since the early days of the pioneers. Water development is inseparable from Utah's prosperity and appeal. Many projects were initiated to bolster the water supply during drought. Through the drought of the 1930s, it became apparent that development of water sources was essential to supplement the water supply and increase reliability. The Provo River Project, an idea that had previously been considered, was thrust into the spotlight in a concerted effort to alleviate future drought impacts. After seeking federal aid and approval, construction was started in 1938 and completely finished in 1958.¹⁵ Water was first made available in 1941. This multi-use, multipart project included the dam; a collection system of smaller dams and diversions, a tunnel, and canals; the Salt Lake Aqueduct and tunnels; the Deer Creek Division structures; and the Deer Creek power plant.¹⁶

The water supplies developed by the Provo River Project and other similar projects have been invaluable



Deer Creek Dam and Reservoir completed in 1941 as part of the Provo River Project, supplying water to many of Utah's residents. (Photo courtesy of Bud Rusho)

resources for communities throughout the state providing benefits to domestic, M&I uses, irrigation, recreation, wildlife, fish and flood control.¹⁷ In addition, these projects enabled water purveyors to provide a timely and adequate water supply during droughts.

Impacts of the 1950s drought were mitigated due to this and other projects. Many projects have been initiated in order to mitigate deficiencies, which have become more apparent in times of drought. Agriculture-based projects are sized to meet the agricultural water demand and generally do not provide water to meet M&I demand during drought unless the water is redistributed. The Jordanelle Reservoir is another project that helped mitigate the drought of 1999-2004 as it came online in the mid-1990s before this drought. If built earlier than needed, these projects can greatly mitigate drought until the growing population's water demand regularly requires the available water.

Current water development projects are at various stages of implementation and evaluation such as the Central Utah Project, Bear River Project and Lake Powell Pipeline. These projects and other water development projects will effectively supplement the water supply and help mitigate drought, and are important to the development of a sustainable water supply for the state. Some water projects in the state contain over a years worth of storage. When economically feasible, this type of storage capacity should be considered. The large capital costs, immense planning efforts and feasibility studies (which can take several years to accomplish) must be considered when assessing and implementing this strategy.

In addition, reservoir operations may also involve inter-basin transfers (the movement of water from one drainage basin or watershed to another) or interstate transfers (from state to state). Such transfers could be used more during drought to lessen the impacts of water deficiencies. These transfers often involve water rights and possibly intergovernmental dealings. When basins or

watersheds cross state boundaries, interstate compacts are needed to regulate the sharing of the water source and any potential transfers from one state to the other. It would be beneficial to have mechanisms or agreements in place to facilitate such transfer in the event of a drought. Also, system efficiency can be improved and should continually be assessed. Digital modeling to understand and improve the efficiency of large systems, possibly entire river basins with multiple dams, is of great value and should be pursued where appropriate.

Besides capital cost and the time needed to enact this strategy, potential environmental impacts need to be carefully considered. Action must be taken to limit such impacts when executing water development plans and projects. Environmental values, or vulnerabilities, are always changing as public opinion and understanding of the environment evolves; thus necessitating continual vulnerability and environmental assessments.

Water Reuse

Large volumes of wastewater are generated daily from residences, commercial establishments and industries. This water traditionally has been discharged to natural waters after treatment or disposed of in evaporation ponds. However, in recent years, this water is being viewed as an additional supply to be reused after treatment. Water reuse, “the direct or indirect use of effluent for a beneficial purpose,”¹⁸ is a water management strategy that can provide a community with an additional water source during normal and dry years by providing “once-used water” for specific, nonpotable uses. Such a water source is extremely reliable and is available perennially in predictable quantities.

Water reuse can serve as a mitigation strategy by developing a relatively under-utilized water source, which can temporarily reduce the consumption of potable or “better quality” water for irrigation and industrial purposes. Potable supplies can be left in an aquifer, or sur-

face waters formerly used for other purposes can be used for reservoir and aquifer recharge.

In Utah, water reuse regulations have been developed that specifies water quality standards and acceptable uses (see Utah Administrative Code R317 and Table 4-4 for reuse water types and uses). The quantity of community effluent is fairly constant on a daily basis and is available year-round and proportional to population. This can make it difficult to fully utilize effluent for irrigation purposes unless storage facilities are developed, making industrial processes with a more-constant demand desirable. In any case, small storage reservoirs/facilities are typically required for water reuse in order to provide a buffer for varying demands and other reasons. Wastewater treatment plants situated near farmland may provide reuse water for agricultural uses and incur relatively low development costs since little piping may be required to transport the reuse water where it is needed and land is available for small retention ponds.



The Central Valley Golf Course receives approximately 0.6 million gallons per day of reclaimed water from the Central Valley Water Reclamation Facility to irrigate its greens and fill the various decorative ponds. (Photo courtesy of Central Valley Water Reclamation Facility.)

TABLE 4-4
Acceptable Uses for Treated Effluent

Secondary	Type II	Type I
	Irrigation of sod farms, silviculture (tree farming), limited access highway rights-of-way, and other areas where human access is restricted or unlikely to occur.	All Type II uses listed.
At the Plant Site:	Irrigation of food crops where the reclaimed water is not likely to have direct contact with the edible part, whether the food will be processed or not (spray irrigation not allowed).	Residential irrigation, including landscape irrigation at individual homes.
Chlorinator injection water for wastewater chlorination facilities.	Irrigation of animal feed crops other than pasture used for milking animals.	Urban uses, which includes non-residential landscape irrigation, golf course irrigation and other uses with similar potential for human exposure.
Water for hosing down wastewater clarifiers, filters and related units.	Impoundments of wastewater where direct human contact is not allowed or is unlikely to occur.	Irrigation of food crops where the applied reclaimed water is likely to have direct contact with the edible part. Type I water is required for all spray irrigation of food crops.
Irrigation of landscaped areas around the treatment plant from which the public is excluded.	Cooling water. Use for cooling towers that produce aerosols in populated areas may have special restrictions imposed.	Irrigation of pasture for milking cows.
Other uses approved by the Water Quality Board on a case-by-case basis.	Soil compaction or dust control in construction areas.	Impoundments of treated effluent where direct human contact is likely to occur.

Source: *Utah Administrative Code, Rule R317-1-4.*

For some communities, reuse of effluent might require obtaining water rights, permits, building facilities and infrastructure such as treatment facilities, pumping plants and storage ponds, and finding an appropriate application. Other communities may have to perform only minor modifications to existing treatment facilities and connect to existing irrigation pipelines. The most viable reuse projects will, of course, be those with the most reasonable costs.

At present, only a few projects in Utah reuse effluent to supplement their water supplies. The Tooele reuse project produces Type I effluent (see Table 4-4) for use on a golf course and in the nearby Overlake subdivision. It currently produces 1,904 acre-feet of reuse water each year. Another project, in the Heber Valley, operated by the Heber Valley

Special Service District produces 1,568 acre-feet per year for alfalfa.

Environmental and public health elements must be factored into the development of such projects. Water reuse potentially can reduce instream flows considerably if not properly managed and implemented. Such decreases can adversely affect aquatic wildlife as well as downstream junior water users' ability to withdraw the amount of water they are accustomed to. Balance between water reuse and instream flows must be achieved in order for this strategy to be truly effective. For a more thorough look at water reuse and projected volume of water available for reuse see the report, *Water Reuse in Utah* online at: <http://www.water.utah.gov/>.

Demand Management

Through increased awareness, individuals and communities are making wise choices and taking responsibility to use water resources efficiently. Even during wet years, many of Utah’s residents can and do implement water conservation practices as they sensibly use this precious resource.

It is important, however, to understand that the state’s current water conservation goal or policy (at least a 25% reduction in per capita use, by 2050, as a means to meet future demand) cannot stand alone as a sole solution to drought and is not intended as such. Water conservation is an “ethic” and is practiced regardless of drought. However, one of the many benefits of conservation practices is that it can help to mitigate drought, which is discussed in this section. The term “demand management” is used in order to make a distinction between the current water conservation goal and more aggressive practices.

In the context of drought mitigation, these demand management practices (achieved through stricter measures than currently used) beyond the state’s current water conservation goal (achieved largely through public education) may be needed and are

already implemented by several water management entities. Demand management practices can result in negative effects during drought if not properly employed. An example of this can be seen by examining limitations of demand management as presented in Box 4-3. On the other hand, it can result in a “surplus” that can be drawn upon during drought and other emergencies as well as put to use as the population grows. Withdrawing less water due to demand management practices also leaves more water in rivers, streams and reservoirs for fisheries and other environmental values.

Public Education and Outreach

The implementation of more aggressive demand management practices is a function of public education, perception and willingness to follow more aggressive management measures such as reducing lawn/turf size, eliminating parking strips, requiring water-wise landscapes (alternative landscaping) and *year-round* incentive pricing. A successful program will utilize outreach programs to continuously educate and inform the public regarding efficient water use practices. These programs not only need to reach school children, but adults as well, and do so at multiple stages—repetition is an important facet

Box 4-3—Limitations of Demand Management

If a water system has a water supply of 10,000 acre-feet per year and delivers that water to end-users who waste it to the tune of 2,500 acre-feet per year, then the system has an inefficiency of 25 percent. When the service area is impacted by a drought that reduces the supply by 20 percent, eliminating wasteful practices can easily mitigate that reduction. If, however, the system has through aggressive demand management efforts already increased its efficiency to say 95 percent, then a drought that reduces supply by 20 percent will have a much bigger impact.

If this system eliminated wasteful practices (the 2,500 acre-feet) and did not experience an accompanying growth in demand, then its supply of 10,000 acre-feet per year will satisfy its demand of 7,500 acre-feet per year and although a drought may reduce the supply by 20 percent the system would remain fully supplied. However, most of Utah’s communities are growing. If a water supply system becomes 95 percent efficient and the system also allows its demand, through growth, to rise to within say 90 percent of its annual supply, this system would be very susceptible to drought impacts. A drought that reduced this system’s supply by 20 percent would have serious impacts and demand management, in this case, has not served as mitigation against drought. In order for aggressive demand management strategies to truly serve as a drought mitigation tool it is important for planners to understand the susceptibility of their supplies to drought, and to maintain an appropriate balance between the demand and supply that will adequately address potential drought impacts on the water supply.

to implementing successful programs. Education and outreach programs need to be continually fine tuned and supported. An example program is that of public education gardens. The state, as well as some water conservancy districts and other institutions, have developed public education gardens, with the purpose of promoting alternative landscaping and other water-wise practices.

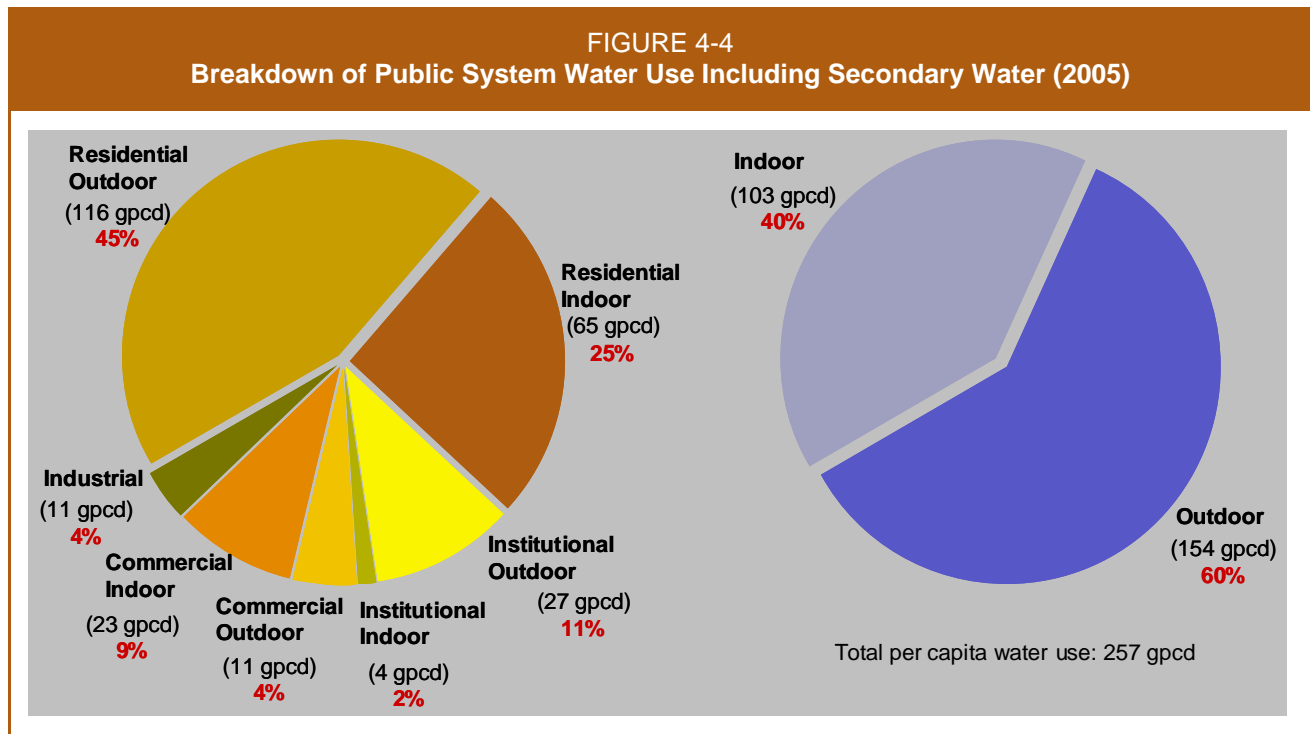
Alternative Landscaping

Green lawns are what Utahns are used to; it is the norm. Lawns are prolific in Utah because sufficient water has been obtained to allow them to be maintained at a relatively low cost. Although much of Utah is a desert environment, it has an ample source of storable water nearby—mountain snowpack. Water use for lawns—outdoor water use—is the main use of the public water supply. Currently outdoor water use is approximately 60% or 154 gallons per capita per day [gpcd], of the total public water use (see Figure 4-4). Of this 154 gpcd, 75% or 116 gpcd is residential outdoor use (watering lawns, etc.). As the population grows, developments continue and as long as green grass is an expectation throughout Utah, outdoor water use will likely continue to be the largest portion of both the total and residential

uses of the public supply. The obligation to use water respectably coupled with projected climate change and ever present potential for prolonged drought, begs the question, “Will the average landscape survive during *prolonged* periods of water deficiency?” The answer to this question is likely “no,” as there could be only enough water available to satisfy indoor needs.

Changing landscapes to contain more native and adaptive species (water efficient species) that can survive in warmer conditions and during prolonged drought is an excellent mitigation strategy.

During a severe drought, when mandatory restrictions are instituted, the first things to “go” in an urban environment will likely be green lawns, and if the drought is prolonged and restrictions required over consecutive years, lawns may not recuperate and reestablish. Transitioning current landscapes using proven alternative landscaping techniques to a more drought tolerant landscape should be considered at all levels—county, city and residential. This does not mean that lawns are to be replaced with rocks and cacti but lawns should be reduced in size and vegetation with lower water requirements planted—an aesthetically pleasing landscape can be



Source: Utah Division of Water Resources, 2006.



Utah Department of Natural Resources' alternative landscaped grounds.

replaced with another of a different kind. Not only are water-wise landscapes environmentally friendly, they are economically sound. Consumers who implement alternative landscapes will likely save money, as outdoor water use will decrease and maintenance requirements could decrease depending upon the chosen and installed landscape.

Transitioning to an alternative landscaping would definitely take time and could be phased in for established communities. For example, first, replacing grass along parking strips—the buffer between the sidewalk and the street—with water efficient vegetation, rock and wood chips while maintaining aesthetic aspects should be required. This could be followed by additional requirements as needed and deemed appropriate. Incentives could also be offered to the homeowner to encourage such action. New landscaping activities at new developments or individual homes should be required and are encouraged to pursue and utilize alternative landscaping methods. A significant amount of water that is currently used for outdoor water use can potentially become available through alternative landscaping and used in periods of drought—temporarily lessening drought impacts and delaying the need for additional water development activities.

Several cities, including Sandy, West Jordan, South Jordan and West Valley, have adopted landscaping ordinances that promote water efficient landscapes and irrigation systems. Thus far these ordinances have been viewed as water conservation practices; however, this also is a good initial step in transitioning from current landscapes to alternative

ones to survive prolonged drought. Cities are encouraged to adopt similar and more aggressive landscaping ordinances that can be implemented. These ordinances outline requirements for residential and commercial landscapes as well as irrigation methods. A model-landscaping ordinance can be found on the Jordan Valley Water Conservancy District's webpage: <http://www.slowtheflow.org/programs/ordinances.asp>. While these ordinances emphasize water efficient and native plants and efficient irrigation systems, they do not restrict lawn size with any regularity. Restrictions on lawn size, in an urban environment, according to available open space or irrigable land within a lot should be considered. Alternative landscaping is encouraged and should be viewed as an acceptable landscaping practice across the board (residential and commercial). Several other potential water saving regulatory actions could be implemented as mitigation strategies that are not discussed in this document, such as land use regulations, cooling tower regulations and other industry related regulations.

Incentive Pricing

Effective water pricing can help mitigate drought impacts by lowering water use rates, however, simply raising water rates may not be the best solution to using less water. Implementing a pricing strategy, *year-round*, that provides incentives to customers for efficient and wise water use can “free up” existing supplies for use elsewhere or during drought until the surplus is once again required by the growing population. Rate structures should also be designed to provide sufficient income to finance system maintenance and improvements and avoid capital short-

falls as lowered water use reduces revenue. A few of the possible water pricing strategies that provide incentives to customers are listed and briefly discussed below.

- Increasing Block Rates—this pricing structure has a base fee, which must be paid whether or not any water is used (and sometimes a fixed amount of water is made available at no additional cost). The price of subsequent increments of water supplied then increases in a step-wise fashion. This rate structure encourages efficiency and less water use only if the steps in the incremental price are sufficient to discourage excessive use.
- Seasonal Block Rates—this rate structure also has a base fee and is similar to the increasing block rates structure, however, instead of rate increases based upon the volume of water used, rates are set according to seasons. The summer price is set strategically to encourage consumers to be more conscious of watering habits and general water use during the months of peak demand. If desired, a spring and fall use rate can also be applied to help reflect the rising and falling costs associated with typical use patterns within the water system.
- Increasing Seasonal Block Rates—this rate structure is a combination of the increasing block and seasonal rates. Like the seasonal rate, it has a price for each unit of water delivered in winter that is lower than for water delivered in the summer. However, instead of a flat rate for a given season, the increasing seasonal block rate has an increasing block rate for each season.
- Target Block Rates—this rate structure requires that a target use be established for each customer. This target is based on the water needs of the landscape and the number of people in the home or business. Landscape water need is determined by using evapotranspiration rates for turf grass from local information sources and landscape size. Then, each unit of water is priced in such a way so as to reward the consumer for using no more than the target use for their individual property or penalize the consumer for using amounts that exceed the target use.

Water Metering and Leak Detection Programs

According to the American Water Works Association (AWWA), “40 billion gallons of water are processed by U.S. water utilities each day, 6 billion gallons [15%] are lost due to problems such as main leaks, tank overflow, pipe bursts, improperly open drains, system blow-off, inaccurate or no metering or unauthorized use.”¹⁹ This water loss (water leaving the system and not being used as intended) is significant. System and operational inefficiencies are abundant nationally and Utah is no exception.

Although a totally leak-free water system (collection, treatment, storage, conveyance and in-house plumbing) is not an achievable goal, even for the best-managed and maintained systems, leaks and other system losses can be minimized through metering and repair. Metering water systems allows for accurate quantification of the volume of water and rate at which it is escaping the system. Regular maintenance and replacement of aging water meters and distribution pipelines is an essential component of a properly functioning and efficient water system.

Effective metering allows water suppliers to better monitor operations of their system. For example, Logan City was unaware of the inefficiencies of its system due to inadequate system metering. During upgrades to the system—to increase water capacity for distribution—the supplier uncovered a substantial leak in a water tank, which was undetectable by the metering network in place. After repairing the tank, the system’s efficiency significantly increased and more water became available for distribution.

In addition, California has successfully implemented leak detection and repair programs by employing “acoustic leak detection” technologies. California achieved half of the targeted potential water savings at a price of \$100 per acre-foot. California was also able to achieve 80% of the potential water savings at a cost of \$200 per acre-foot (“saved” water)—the extra 30% cost an additional \$100 per acre-foot.²⁰ Water suppliers should regularly conduct system water-budgets and ensure that the water system is properly metered and in working order. This has the potential to dramatically increase system efficiency and save money in the long run, however, maintenance costs may increase.

Weather Modification (Cloud Seeding)

Weather modification, or cloud seeding, has long been recognized as a means to enhance existing water supplies. Utah first investigated cloud seeding in the 1950s and has provided funding for cloud seeding programs since the early 1970s. Cloud seeding enhances existing water supplies by increasing natural precipitation. Cloud seeding is a process that introduces water droplet-forming nuclei into a cloud at the appropriate time and place, usually in mountainous areas, to aid in the formation of precipitation and increase snowpack during winter months. Typically silver iodide is released into the air via ground-based generators or in some cases aircraft; propane gas is also used. These particles attract moisture from the surrounding air and form water droplets and ice crystals that fall to the earth as rain and snow.

Cloud seeding is most effective when it is continued during several consecutive years (wet and dry). This increases soil moisture, reservoir storage, ground water levels, spring flows, and helps sustain base flows in streams and rivers. In a study con-

ducted by the Utah Division of Water Resources, cloud seeding projects within the state were found to have increased total precipitation by an estimated 1.3 to 20% (depending upon project location, number of generators and weather conditions) in the target areas, over the years that the projects have been in operation.²¹ This water has helped supplement existing water supplies of many Utah communities, translating into a 2.3 to 18% increase in April 1st snow water content.²²

Cloud seeding is currently viewed by the state as a cost-effective strategy to supplement the state’s water supply. In 2005 it was estimated to cost \$1.69 per acre-foot and increase total runoff by 222,800 acre-feet.²³ Additional weather modification projects or improvements to projects already in place should be investigated.

Additional Mitigation Strategies

Additional mitigation strategies are available (see Table 4-5) that can be integrated into water management methodologies. Several of the mitigation strategies require structural components, however, there are viable strategies that require only minimal or no structural elements. Some of these are briefly highlighted in the following discussion.

Vulnerability Assessments

Vulnerability assessments are a fundamental part of mitigation planning. They provide “a framework for identifying the social, economic, and environmental causes of drought impacts. [They bridge] the gap between impact assessment and policy formulation by directing policy attention to underlying causes of vulnerability rather than to its result, the negative impacts, which follow triggering events such as

TABLE 4-5
Drought Mitigation Strategies

Structural	Minimal to Non-Structural
Improvement of Water System (distribution-pipes and pumps)	Vulnerability Assessments
Desalination Projects	Legislation
Consolidation of Utilities	Protection of Aquifers and Recharge Areas
Over-drilling Wells (where appropriate, to avoid lowering the intake later)	Protection of Ecosystems (Water Quality)
Upgrading Wells (lower intake)	Remove Water-Loving Invasive Species
Urban Runoff Management	Education and Outreach Programs
Ground Water Remediation Projects	Interagency Cooperation
Development of Livestock Watering Locations	Water Law Revisions
	Develop an Early Warning System
	Improve Monitoring System
	Floodplain Management
	Watershed Management
	System Optimization (Digital Modeling)

Source: Utah Divisions of Water Resources, 2006.

drought.”²⁴ In order to improve drought mitigation planning efforts, societal vulnerabilities to drought need to be identified and the root causes of these vulnerabilities addressed. Recommendation 4, of Chapter 6, could be used to help identify such vulnerabilities. In addition to this, planners and water managers are encouraged to refer to the report published by the Western Drought Coordination Council, Preparedness and Mitigation Working Group entitled, *How to Reduce Drought Risk*, which can be accessed online at: <http://www.drought.unl.edu/plan/handbook/risk.pdf>. “Step 4” within the report specifically gives guidance on conducting a vulnerability assessment. The entire document should be used as a reference in developing a drought mitigation plan (see Recommendation 1 of Chapter 6—Conclusions and Recommendations).

Remove Water-Loving Invasive Species

Many invasive species exist along Utah’s waterways. Removing “water-loving” invasive species such as tamarisk does not require structural components. These trees consume large quantities of water compared to the natural riparian vegetation that it has displaced. Projects are currently underway in southern Utah to remove tamarisk using biological control methods. Beetles that feed upon tamarisk foliage have been released and appear to be quite effective in controlling tamarisk growth and ultimately killing it. Removing invasive species such as tamarisk not only is beneficial to the water resources community but also to the riparian environment and ecosystems.

Watershed Management

“Watershed management is the process of evaluating, planning, managing, restoring, and organizing land and other resource use within an area of land that has a single common drainage point.”²⁵ It is finding and maintaining a balance between human needs and ecological integrity. From a water resource perspective it can potentially improve capture and storage of runoff, water quality and reduce flooding potential. For example, by improving and maintaining natural vegetation, more snowmelt can be captured, which can lead to increased summer base flows and less erosion, which improves water quality.²⁶

Only a selected few of the possible mitigation strategies have been presented in this report, however all strategies need to be evaluated by decision-makers in order to better manage this precious resource during times of drought as well as in years of surplus. No matter the chosen strategy, environmental integrity must be maintained. Riparian buffers, aquifer recharge areas and sensitive ecosystems, should be continuously evaluated throughout any project and protected, not only to address water quality but wildlife and recreation concerns as well.

Another important mitigation strategy discussed in the following section is that of forecasting and improving monitoring of drought indicators in order to develop an “early warning” system. This can prove to be extremely helpful in maintaining a reliable water supply to satisfy both municipal and agricultural demands.

DROUGHT FORECASTING

Many climatic calamities are visually apparent in their development and give clear indications of their impending arrival; they are predictable. Therefore, impacts of such climatic events can be alleviated through preparation and the use of mitigation strategies employed in advance. The ability to forecast weather events greatly increases the effectiveness of both mitigation and preparedness activities. Drought on the other hand is a climatic event that does not provide many obvious hints of its onset. There are various federal programs dedicated to drought monitoring, research, and developing methods of predicting or forecasting drought. The focal point of many of these programs include understanding weather patterns and trends and researching hydrological aspects such as streamflows, ground water levels, soil conditions. Collectively, the research conducted by these programs is used to better understand drought and ultimately more accurately forecast the arrival of drought events. In a paper titled, “Pacific and Atlantic Ocean Influences on Multidecadal Drought Frequency in the United States,” (published in Proceedings of the National Academy of Science [PNAS], 2004), McCabe et al stated:

Although long considered implausible, there is growing promise for probabilistic climatic forecasts one or two decades into the future based on quasiperiodic variations in sea-

surface temperatures (SSTs), salinities, and dynamic ocean topographies. Such long-term forecasts could help water managers plan for persistent drought across the conterminous United States.

Researchers' breadth of understanding of climate forcings and teleconnections (see Box 4-4) is continually expanding. In recent years, a probable link between the spatial and temporal variability of drought and SST oscillations from warm to cold or cold to warm in the Pacific and Atlantic Oceans has been identified.

At first, analyses and forecasting of precipitation in the U.S. has largely utilized the Pacific SST anomalies and the El Niño Southern Oscillation (ENSO). However, as climatology has progressed through the maturation of scientists' understanding, variations in the Atlantic SST are now being incorporated thereby strengthening the potential of forecasting drought. As described in Chapter 3, phases of the Pacific Decadal Oscillation (PDO) and Atlantic Multidecadal Oscillation (AMO), which amplify or diminish El Niño and La Niña-like effects, influ-

ence the development or termination of drought conditions globally and in the Southwest. Forecasting drought greatly depends upon our understanding of these oscillations. Researchers have found that the probability of summer drought in the West is increased during positive phase of the AMO. Additionally, during such periods (positive AMO) it has been found that the phase of the PDO is likely associated with the location (northern, positive phase or southern, negative phase) of the drought center in the West. Furthermore, analysis of paleo-droughts contained in proxy records, reveal that several of these droughts relate to the "spatial signature" of the 1930s and 1950s droughts and the spatial extent of these droughts may be explained by the relationship between the PDO and AMO.²⁷

Use of Proxies

An increased understanding of the causes of severe and multiyear drought events is a necessary step in developing dependable forecasting methods. Using proxy records, such as tree rings, in addition to the meteorological instrumental record increases the opportunity to test and research forcing mechanisms as those described. Analysis of tree rings revealed

multiple oscillation modes for climate variability, ranging from bidecadal (oscillation expressed in approximately two decades) to pentadecadal (oscillation expressed over a period of approximately five decades) and longer.²⁸ This reinforces the likelihood of drought prediction. However, drought behavior is not in the strictest sense of the word oscillatory (does not recur over well-defined intervals) and the oscillation modes mentioned are only a piece of the picture needed in order to forecast drought. Additional climate trends, embedded within the proxy and instrumental records are also being considered in forecasting drought.

Box 4-4—Definitions and Acronyms

Climate Forcing—mechanism that "forces" the climate to change by disrupting the global energy balance (balance between incoming energy from the sun and out going energy from the earth). The earth's orbit, ocean circulation and changes in the earth's atmospheric composition are examples of climate forcings.

Teleconnections—recurring and persistent large-scale pattern of pressure and circulation anomalies that span vast geographic areas (relationship between oscillations and surface temperatures).

SST—Sea Surface Temperature.

Refer to Box 3-4 for definitions of:

ENSO—El Niño Southern Oscillation

PDO—Pacific Decadal Oscillation.

AMO—Atlantic Multidecadal Oscillation.

Climate Trends

To enhance drought prediction capabilities, climate trends are continually being investigated. “Climate across much of the U.S. has been getting warmer for about 20-25 years, especially in the winter and spring. These conditions contribute to drought by increasing the rate of snow melt in the spring and early summer, and also by increasing water evaporation.”²⁹ Climate models developed by the National Oceanic and Atmospheric Administration (NOAA) simulate the current warming trend and indicate that this trend will continue for the rest of the 21st Century.³⁰

Presently, there is a level of ambiguity concerning how and when (how far into the future) there will be a significant climatic response to elevated concentrations of greenhouse gases. However, observations have been made that indicate demonstrable changes are taking place. The exact effect that such a warming trend will have in Utah is uncertain, however, increased temperatures will likely, “...result in less winter snowfall, more winter rain, and faster, earlier spring snowmelt” and lower streamflows and lake levels in the summer³¹ as discussed in Chapter 3. Understanding climate trends adds a key component to current and future drought forecasting models.

The Drought Monitor and Seasonal Drought Outlook

NOAA, with support of various other government agencies and public and private institutions, provides current and potential drought conditions via the Drought Monitor (see Figure 4-5) and Seasonal Drought Outlook (see Figure 4-6), respectively. Both of these systems utilize multiple drought indices, hydrological indicators such as streamflow and soil moisture, agriculture conditions and impacts, and other resources to describe drought conditions. The Seasonal Drought Outlook describes potential drought conditions approximately 3 ½ months into the future. A modified Seasonal Drought Outlook model is being developed that will display probable drought conditions and changes over a longer time period.

Recently, the Seasonal Drought Outlook has accurately predicted development of drought conditions. In December 2005 drought expanded into the South-

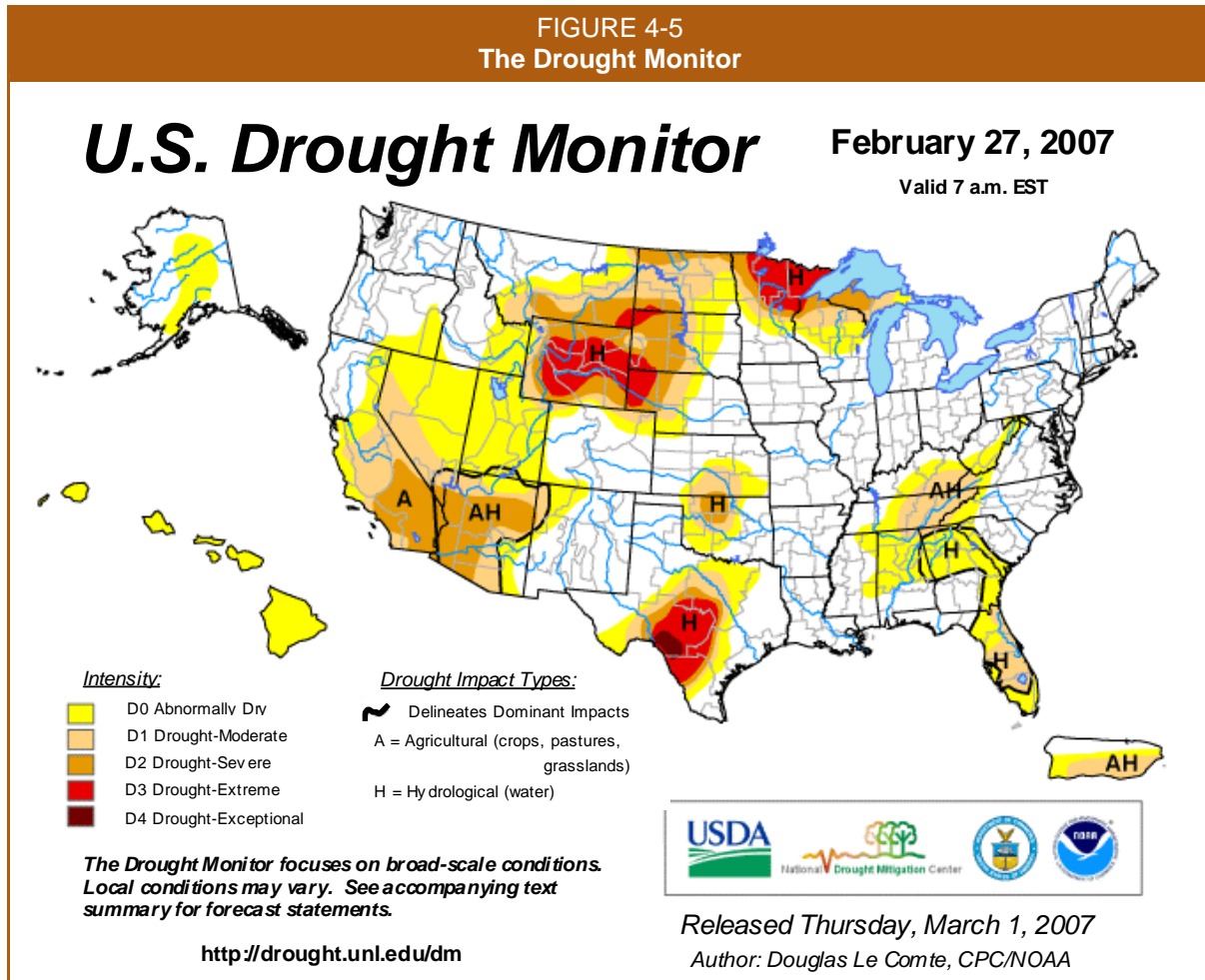
ern Plains and Southwest as predicted. Also, “the mid-January [2006] Outlook accurately projected that drought would expand into Kansas and the Southwest, and this occurred by mid-March leading to problems with winter crops and pastures and increasing the danger of wildfires.”³² There have been inaccurate projections of drought and the process is still somewhat tenuous, however, these tools are useful and aid in agriculture management decisions as well as in the distribution of federal aid to impacted areas. As input parameters and data collection methods are refined and improved, the capabilities of these models will greatly expand.

National Integrated Drought Information System

NOAA is currently expanding its drought forecasting or “early warning” capabilities through the creation and implementation of the National Integrated Drought Information System (NIDIS). The NIDIS Act, approving the creation of this system was passed in December 2006. In an oversight hearing on drought, Dr. Chester J. Koblinsky, director of NOAA’s Climate Program Office stated:

NIDIS is an ambitious program to significantly enhance the Nation’s ability to monitor and forecast drought. It will establish a modern, dense network of observing locations to observe and monitor all aspects of drought and enhance stakeholder access to information on drought conditions, impacts, and forecasts. NIDIS, in turn, will be supported by a focused drought research program. NIDIS will create a national drought early warning system to enable the Nation to move from a reactive to a more proactive approach to drought. The vision is for NIDIS to be a dynamic and accessible drought information system that provides users with the ability to determine the potential impacts of drought and their associated risks and also provides the decision-support tools needed to better prepare for and mitigate the effects of drought.³³

This program will assist several sectors with mitigating and preparing for drought in a timely and effective manner. Benefits will be manifested through more efficient agriculture production and municipal water allocations, as well as better emergency decla-



Source: The Drought Mitigation Center's webpage- <http://www.drought.unl.edu/dm/monitor.html>.

ration decisions and distribution of relief. The implementation of NIDIS will also provide improved "...climate and water assessments, more reliable forecasts at various timescales, better decision-support tools, and more timely communication of this information to decision makers through an interactive delivery system [and] will greatly enhance management of water and other natural resources."³⁴ It will benefit Utah water suppliers and the state to support and continue to support NIDIS and educate themselves regarding its development.

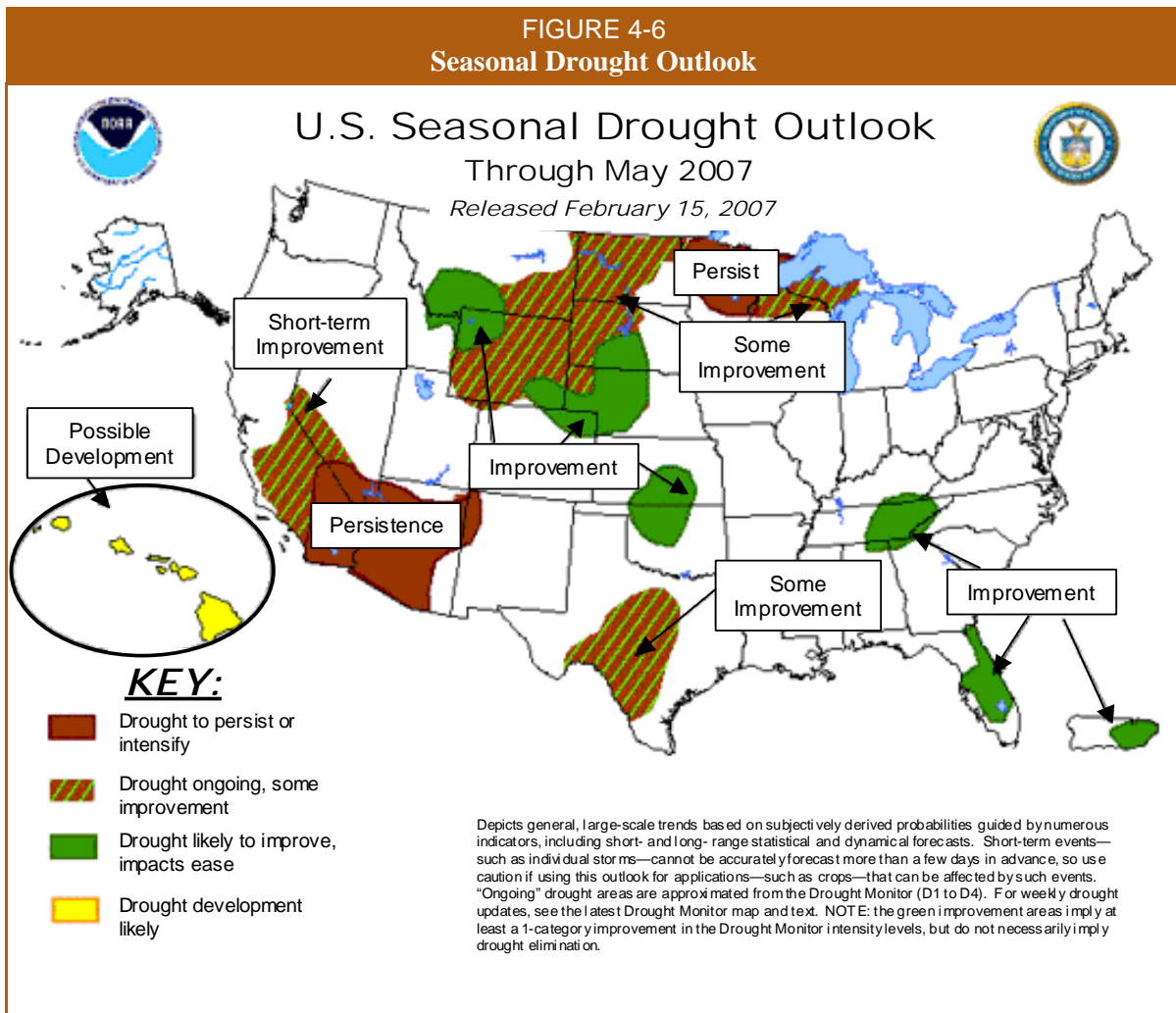
FUNDING AND OTHER ASSISTANCE FOR DROUGHT MITIGATION

Utah has funded many water development projects through several loan assistance programs. This funding effort managed by the Utah Division of Water Resources continues to provide low interest

loans. The federal government also provides funding to support drought mitigation programs.

Utah State Water Resources Development Funding

Since the early 1900s state funding has been available to help local communities and water users fund water development projects. These were relatively minor amounts until 1947 when the legislature created the Utah Water and Power Board and established the Revolving Construction Fund with an appropriation of \$1 million. Since that time, state-funding assistance has grown. The Utah Board of Water Resources oversees three revolving funds that provide low interest loan assistance for water development projects. Since 1947 to the end of the fiscal year 2006, the board has provided over \$500 million to applicants through these three funds for the construction of 1,270 water projects. These state spon-



Source: The National Oceanic and Atmospheric Administration’s webpage—http://www.cpc.noaa.gov/products/expert_assessment/seasonal_drought.html

sored and funded projects have never really been touted as drought mitigation projects, however, in many instances that is precisely what they are. Many of these projects came about because of shortages experienced during droughts. These projects include reservoirs and other water storage facilities that make it possible to store surplus flows. Releasing the water during dry periods in essence mitigates or eliminates drought-related impacts.

An example of such a project funded by the Board of Water Resources is Ken’s Lake, an approximately 2,610 acre-feet capacity reservoir located in the upper Spanish Valley, 10 miles southeast of Moab. Originally touted as a flood management and agricultural irrigation project, it has provided additional

benefits to the community. Before the completion of this \$4 million project in 1981, Moab City had experienced several years of water restrictions. After its completion there have been no major restrictions enacted. Such state funded projects have greatly benefited Utah’s communities and will continue to do so.

Federal Mitigation Assistance

The Federal Emergency Management Agency (FEMA), through the Pre-Disaster Mitigation (PDM) program provides funds to states, territories, Indian tribal governments, communities, and universities for hazard mitigation planning and the implementation of mitigation projects prior to a disaster

event. Funding these plans and projects reduces overall risks to the population and structures, while also reducing reliance on funding from actual disaster declarations.

PDM grants are awarded on a competitive basis. Funding is dependent upon a yearly appropriation from Congress. The Utah Division of Homeland Security reports that from 2002 to 2006, Utah has received approximately \$1.267 million dollars for mitigation planning and \$7.941 million for mitigation projects through this competitive grant program. The majority of the project grants have been for seismic retrofits of local and state critical facilities that include water treatment facilities. Future mitigation planning funds may be provided to help identify drought mitigation strategies. The Utah Divi-

sion of Homeland Security manages the PDM in Utah.

In a study conducted by the National Drought Policy Commission in 2000, it is reported that from 1990-2000, 88 drought-related federal programs had been funded; 42 were related to drought mitigation.³⁵ The Bureau of Reclamation, U.S. Army Corp of Engineers and U.S. Department of Agriculture annually provide funding for mitigation and water supply development projects.

Several additional federal programs exist that are geared toward disaster or drought relief, emphasizing mitigation and monitoring of climatic anomalies. Refer to Appendix D—Federal Drought Assistance Programs—for a compilation of selected federal programs.

NOTES

¹ Utah Division of Emergency Services, "Pre-Disaster Mitigation Plan," (2001), 1.

² Ibid.

³ Division of Water Resources, *Conjunctive Management of Surface and Ground Water in Utah*, July 2005, pages 4 & 5.

⁴ Ibid.

⁵ Ibid, 23.

⁶ Clifford, Peggy and Clay Landry and Andrea Larsen-Hayden, *Analysis of Water Banks in the Western States*. Publication No. 04-11-011 (Washington Department of Ecology, July 2004). ii.

⁷ Division of Water Resources, *Conjunctive Management of Surface and Ground Water in Utah*, July 2005, page 9.

⁸ Ibid, 34-38.

⁹ Ibid, 49.

¹⁰ Ibid, 39-44.

¹¹ Ibid, 80-81.

¹² Ibid, 30.

¹³ Melissa J. Stanford, "Water Supply Assurances and Drought Mitigation: Options for State Regulatory Commissions and Key Stakeholders," (Columbus: The National Regulatory Research Institute; Ohio State University, 2002), 16.

¹⁴ Leroy Hooton, "Conjunctive Water Management." Retrieved from the Salt Lake City's Internet web page: <http://www.ci.sl.c.ut.us/Utilities/NewsEvents/news080100.htm>, November 2006.

¹⁵ "Dams, Projects & Powerplants: Provo River Project." Retrieved from the Bureau of Reclamation's Internet web page: <http://www.usbr.gov/dataweb/html/provoriver.html>.

¹⁶ Ibid.

¹⁷ Ibid.

¹⁸ Utah Division of Water Resources Staff, *Water Reuse in Utah*, (Salt Lake City: State of Utah Department of Natural Resources, Division of Water Resources, 2005), xv. Special study in conjunction with the Utah State Water Plan.

¹⁹ Melissa J. Stanford, "Water Supply Assurances and Drought Mitigation: Options for State Regulatory Commissions and Key Stakeholders," 41.

²⁰ "Leak Detection Frequently asked Questions." Retrieved from the California Department of Water Resources' Internet web page: <http://www.owue.water.ca.gov/leak/faq/faq.cfm>, October 2006.

²¹ Ann Merrill, Todd Adams and Dave Cole, "Utah Cloud Seeding Program Increased Runoff/Cost Analyses," (Salt Lake City: Utah Department of Natural Resources, Division of Water Resources, 2005), 6 (Table 2).

²² Ibid, 6.

²³ Ibid., 10.

²⁴ Cody Knutson, Mike Hayes, and Tom Phillips, "How to Reduce Drought Risk," (1998), Produced by the Preparedness and Mitigation Working Group of the Western Drought Coordination Council.

²⁵ California Department of Water Resources, *California Water Plan Update 2005 A Framework for Action*, Volume 2, (Sacramento: 2005), 25-1.

²⁶ Ibid.

²⁷ Hugo G. Hidalgo, "Climate Precursors of Multidecadal Drought Variability in the Western United States," (Accepted by the Water Resources Research, in 2004).

²⁸ Ibid, 8-9.

²⁹ Dr. Chester J. Koblinsky, "Written Testimony of Dr. Chester J. Koblinsky, Director Climate Program Office." Retrieved from the U.S. Department of Commerce, United States Senate's Internet web page: <http://commerce.senate.gov/pdf/koblinsky-042706.pdf>, August 2006. From an oversight hearing on drought, April 27, 2006.

³⁰ Ibid.

³¹ Climate and Policy Assessment Division, "Climate Change and Utah," (Washington D.C.: United States Environmental Protection Agency, 1996).

³² Dr. Chester J. Koblinsky, from an oversight hearing on drought, April 27, 2006.

³³ Ibid.

³⁴ Ibid.

³⁵ National Drought Policy Commission, "Preparing For Drought in the 21st Century," (U.S. Department of Agriculture's Office of Communications, 2000), 16.

5

DROUGHT RESPONSE

Through mitigation, communities and the state as a whole greatly improve their ability to endure drought. In an ideal situation, drought mitigation would prohibit drought's negative impacts to society and thus no response would be necessary. However, in most situations drought mitigation will only reduce the severity of drought impacts and some type of response will still be required. Response to drought can take place concurrently with the impacts or after the fact, when needs may be more apparent. Although added attention should be placed upon Risk Management (mitigation), Crisis Management (response) should not be over-looked. Crisis Management is an important part of water management in Utah as steps are taken towards a more proactive Risk Management approach—thereby further reducing vulnerability to sustained droughts.

Significant droughts "...are usually far enough apart that we have forgotten about them, or we choose to ignore them. So when drought happens to us again, we perceive it as a whole new and surprising experience."¹ Spawned from this perception and similar views, Crisis Management has predominated in the planning arena. At the crux of Crisis Management is drought assistance and relief, primarily from the federal government. Once the state has proved that there is a need for assistance and has followed proper procedures, relief in the form of money is disseminated through appropriate channels to sectors in need. Although federal relief is needed, its effects are two-fold; it hurts and helps at the same time. "It has been demonstrated that crisis management responses, such as drought relief, actually decrease self-reliance and, therefore, increase vulnerability to future drought episodes."²

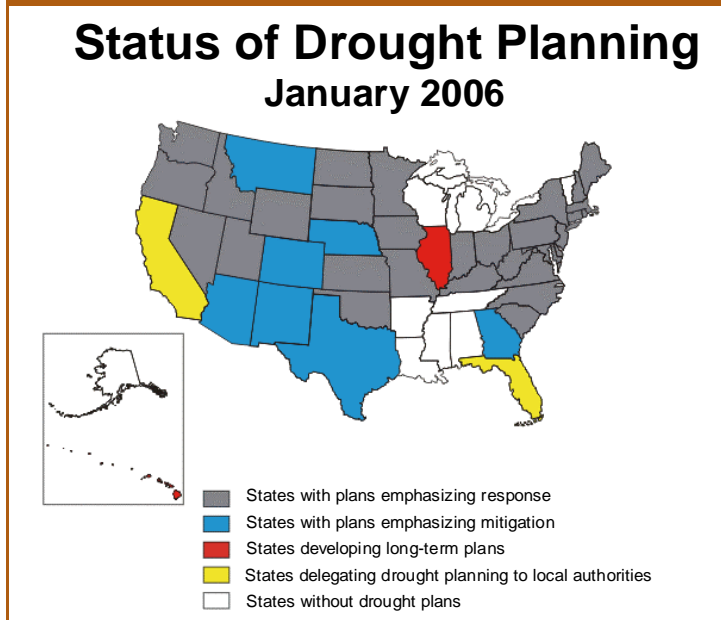
Federal relief should be requested as an option of last resort when needed. Historically, Utah has done just that. The state has developed a drought response plan involving multiple sectors, which draws upon federal relief only when absolutely needed. The state's multidisciplinary plan promotes coherent coordination and communication between organized committees and ultimately funnels collected information of import to the Governor to aid with decision-making and drought management.

UTAH'S DROUGHT RESPONSE PLAN

Drought plans are a relatively new facet of the planning process and are being developed nationwide. In 1982 only 3 states had drought plans. This number has significantly increased as 38 states currently have developed plans³ (Figure 5-1). Utah developed its drought response plan in 1993 and made minor revisions to it in 2003. The purpose of the plan is to provide an effective and systematic way for the state to deal with emergency drought problems⁴ through monitoring, impact assessment, and preparedness and response mechanisms.

Each element of the plan is activated by set "triggers" or designated values of the Surface Water Supply Index (SWSI) (described in Chapter 1). Calculated values of the SWSI, published monthly by the National Resources Conservation Service (NRCS), correspond with a sequence of actions described in the plan. For further details, the *Utah Drought Response Plan 1993 (Revised – 2003)* can be accessed at: www.homelandsecurity.utah.gov/pdf/nathaz/Appendix_G.pdf. Triggers are an essen-

FIGURE 5-1
Drought Plans by State



Source: National Drought Mitigation Center, University of Lincoln-Nebraska (Text enhanced by the Utah Division of Water Resources)

trusted with the primary purpose of monitoring the water supply. This committee assesses snowpack, soil moisture, reservoir and ground water levels, precipitation, temperature and streamflow in an effort to quantify, compare and track the water supply through time.

Assessment⁷

The assessment aspect of the plan continues to utilize the WSAC and, if conditions worsen, additional committees and task forces are activated. Six different impact task forces cover the following water-related areas:

- Municipal water and sewer systems
- Agriculture industry
- Commerce and tourism
- Wildfire protection
- Wildlife
- Economic

tial aspect of monitoring and defining drought as stated below.

...public declarations of drought are often triggered by specific and well-defined conditions, such as a specific reservoir elevation on a specific date. In some cases, there are well-defined exit points that trigger a resumption of normal activity. These “drought triggers” become the practical definition of drought for a particular region and for specific issues. Defining these triggers is an inseparable part of planning for and responding to droughts. Once these triggers are defined, a region is much better able to estimate the costs, expected frequency, and risks of drought response.⁵

Monitoring⁶

The Utah Division of Water Resources continually monitors climate conditions via the SWSI and other resources that can “warn” of impending drought conditions. When mild drought conditions occur, the Water Supply Availability Committee (WSAC), which is chaired by a representative of the Division of Water Resources, is activated and en-

The impact task forces are activated and specifically structured as described in the response plan. Their primary goal is to identify existing and potential drought-related issues and assess the prospective impacts on the public within their respective areas. Additional task forces may be organized as needs arise. The task forces report their findings to the Drought Review and Reporting Committee (DRRC), which compile the information from which recommendations are made.

Response⁸

In the event that state response actions are warranted, the Drought Response Committee (DRC) is activated. The DRC is designed to operate as a centralized point of coordination to handle un-met needs identified by each task force, ensure interagency coordination and determine when deactivation should occur. State involvement/response takes place when local capabilities are exceeded and local response has become inadequate. In the event that action is needed beyond the state’s response, “...an existing state program would facilitate preparation of requests for federal assistance.”⁹ The organization of Utah’s drought assessment and response is depicted in Figure 5-2.

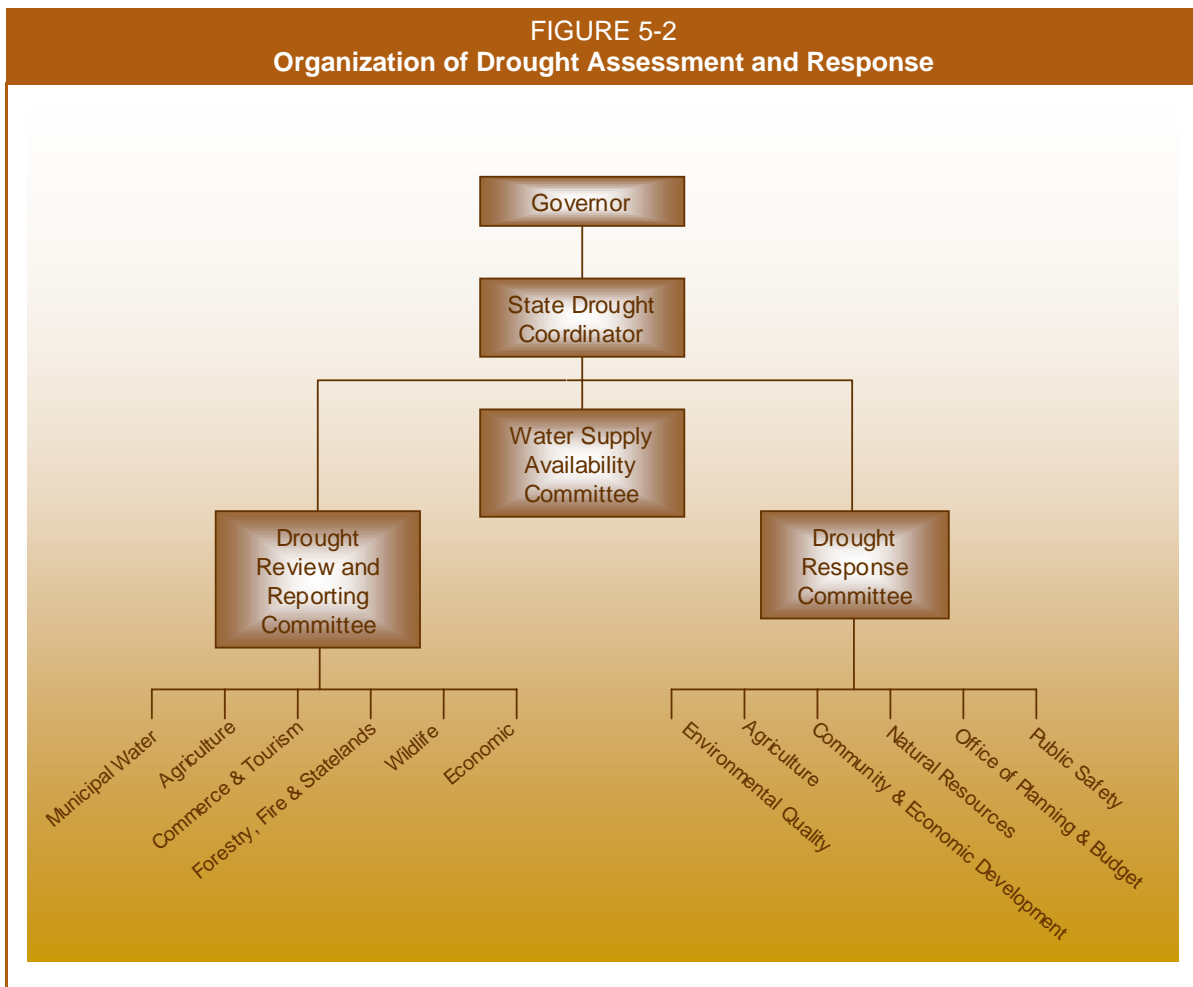
DROUGHT RESPONSE STRATEGIES

Depending on several factors such as drought severity, location and condition of the water supply, there are many avenues that response to drought can take. These vary from large-scale state projects to personal water use choices. Utah has historically responded well to drought, satisfying deficiencies in the water supply and infrastructure that become apparent during severe and sustained periods of drought, by establishing water use restrictions, wisely using groundwater, using agricultural best management practices, hauling in water and enacting drought-related legislation. The following discusses and provides examples of some of these selected response strategies.

Demand Management—Water Use Restrictions

Water use restrictions can help reduce the severity of drought impacts by lowering normal rates of water use, which allows less water to “stretch farther” within a well-managed system. In 2005, per capita water use in Utah (refer to Figure 4-4) was second only to Nevada and was primarily used for outdoor purposes. In order for water restriction efforts to be an effective response to drought, these restrictions must focus on reducing outdoor use, which can be accomplished in several ways.

In Utah, some of the most common water use restrictions are specific responsive elements embedded within municipal water management plans to be enacted when more aggressive actions are needed. Restrictions are also commonly suggested and/or mandated by governing bodies in response to water deficiencies:



Source: Adapted from the Utah Drought Response Plan 1993 (Revised - 2003)

Traditionally, managing water resources during droughts has been based on immediate reactions to a current crisis. The focus of most action is to reduce the daily demand for water, and local governments usually are responsible for reducing water demand within their jurisdictions.¹⁰

Drought (Water Shortage) Contingency Plans

In the event of a drought, it is beneficial for water suppliers to have a plan of action already in place—a drought contingency plan. Currently, water suppliers with more than 500 connections are required (by the Water Conservation Plan Act) to prepare and submit a water conservation plan to the Utah Division of Water Resources and update the plan every five years.¹¹ The Board of Water Resources also requires that all state funded water projects complete and submit a water conservation plan prior to receiving funding. These plans contain general conservation methods and goals and many directly address drought. Several of the plans deal with water use restrictions beyond common conservation practices that may be implemented as a response to periods of drought or other water shortages. These drought response elements should be viewed as being separate from common conservation practices and ideally be included in drought or water shortage contingency plans rather than conservation plans.

In order to curtail water use during drought, cities, conservancy districts and other water purveyors may adopt water management strategies as set forth in their respective plans. These more aggressive efforts generally include water use restrictions and penalties for water waste.

Salt Lake City has developed a *Water Shortage Contingency Plan*. Although not a drought specific plan, it is applicable to drought and outlines the initiation, notification and termination of water shortage stages and associated responses. In addition to supply, these stages are also dependant upon changes in demand. The stages progressively increase in both import and response as conditions worsen. Trigger, target, objectives and termination qualifiers describe each stage. For example, Stage 3—Moderate, is triggered by a 30% reduction of the average annual water supply (available water supply is 70% of average), conditions have not improved

from previous stage and the demand levels indicate the need for additional response to manage the situation. The target or ideal result of enacting this stage is a 15% reduction in total daily or average annual water demand. The objectives are as follows:

- Achieve target by restricting water users.
- Ensure adequate supply is available for public health and instream flows.
- Minimize hardship on the public while meeting targeted consumption decrease.
- Promote equity; establish restrictions that affect all water users/customers.

This stage is terminated when conditions, which triggered entering this stage, have improved and ultimately cease to exist for a time period deemed appropriate.¹²

The development of drought or water shortage contingency plans or components that can be integrated into a larger management plan is highly encouraged. The effectiveness of these plans or components greatly depends upon public involvement. The public needs to be aware of the condition of the water supply and why certain actions are implemented—what the triggers are. Such information could be posted online and made easily accessible to the public (see Chapter 6, Recommendation 3 for further discussion on drought indicators/triggers for public use and understanding).

Emergency Outdoor Watering Restrictions or Declarations

During sustained drought, outdoor watering guidelines such as those mentioned and time-of-day watering declarations are quite common. For all approved and funded projects, the Utah Board of Water Resources requires that a time-of-day watering guideline be in place always, not just during drought. Such watering guidelines can be established in emergency situations to aggressively lower water use rates. In the 1930s, turf irrigation was limited to twice a week in some communities.¹³ During Utah's most recent drought, Governor Leavitt asked cities to pass an ordinance setting times during the day when watering could take place¹⁴ and many communities did so. Some cities also established penalties for wasteful use of water.¹⁵ The City of Nephi adopted an ordinance setting a time-of-day

watering schedule with penalties up to \$750.¹⁶ Theoretically, outdoor watering time-of-day guidelines promote more efficient water use by limiting watering to established times of the day when evaporation is minimized; however, it has not been shown to “save” water in some instances and other restrictions or ordinances may be more appropriate.

In order for temporary watering ordinances and outdoor water use restrictions to be effective, the public must perceive that there is a problem—that the water supply is limited. Ordinances and restrictions cannot reduce water use alone; the public’s willingness to be involved and enforcement of such restrictions are critical for the success of these programs. If the consumer does not “buy into” the need to limit water use, then water use may actually increase because the consumer may take advantage of the “day on” (day allowed to water) and over-use water to compensate for the “days off” (days of restricted use).

Ground Water Use and Temporary Well Permits

Utah is heavily dependant upon winter precipitation (snowpack) for its water supply. The runoff is captured in reservoirs, recharges ground water supplies, and is diverted for municipal, industrial and agricultural uses. In Utah, about 80% of total withdrawals are from surface water sources. The state’s public water supply is a mix of ground water (55%) and surface water (45%). According to the U.S. Geological Survey, Utah’s percentage of drinking water that originates from ground water sources ranks 10th highest in the nation. This heavy reliance upon ground water can be a mitigating factor, if managed properly, since surface water supplies diminish first during periods of drought.

Agricultural and rural communities with heavy reliance upon surface water and/or limited surface storage capacities are generally hit hardest by drought and are forced to seek supplemental water sources. The Utah State Engineer can authorize the installation and use of temporary wells (generally good for one year) in response to such water supply deficiencies. Due to drought conditions in the 1970s and late 1980s-90s, the number of approved well permits increased dramatically,¹⁷ contributing to an approximate 26% increase in ground water withdrawal (from 1970-1980) for agricultural purposes

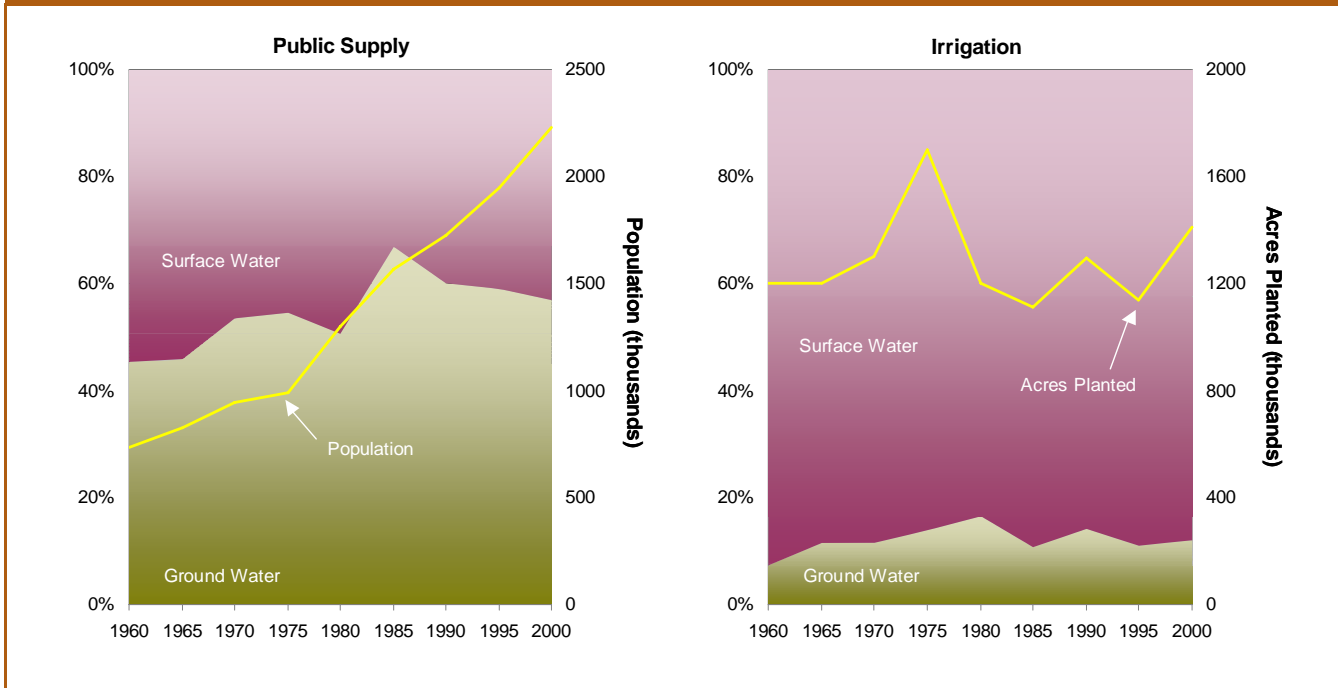
statewide. This translated to a 6.5% increase of the ground water fraction of the total water supply used for irrigation (see Figure 5-3). These supplemental ground water withdrawals can increase stress on already depleted aquifers resulting in a decline in ground water levels, as was the case in the most recent drought (1999-2004).¹⁸ “Lower ground-water levels are the result of both decreased recharge and increased withdrawals; however, it is difficult to determine which causes the greater effect.”¹⁹ Efficient well management and management of supplemental ground water withdrawals are key factors in maximizing the available water supply and ensuring its sustainability during drought and beyond. Existing wells can also be lowered, drilled deeper, into the water table in response to declining ground water levels. This has been done in Beaver, Iron, Washington and Kane counties.

Temporary Well Placement

Potentially, one of the most reliable and probably cost-effective ways to get ground water from temporary wells is to drill them under and adjacent to existing reservoirs. This available water supply would be valuable to municipal, industrial and agricultural interests. The water could be pumped right into the reservoir to take advantage of existing distribution systems. Utah has 135 surface reservoirs with capacities ranging from 1,000 to 1,370,000 acre-feet. The total capacity of those reservoirs is approximately 5,155,000 acre-feet.²⁰

Being built on pervious ground, water from every reservoir continually infiltrates into the earth. Over the many decades these reservoirs have been in operation, large volumes of water have been “lost”—from a reservoir storage standpoint due to this infiltration. In reality that water is not actually lost. It is stored in the ground beneath and adjacent to each reservoir. The volume of water contained underground as a result of infiltration from a reservoir is difficult to quantify. It depends on numerous geologic factors unique to each individual reservoir. However, it can be assumed that a significant quantity of water is available beneath every reservoir in the state. This water is a significant untapped source located throughout Utah and could prove to be advantageous to water suppliers during drought. This underground reservoir capacity could supplement surface waters for some time—depending on local

FIGURE 5-3
Water Use: Percentage of Ground Water and Surface Water for Public Supply and Irrigation



Source: Data from USGS, <http://water.usgs.gov/watuse/50years.html>. Utah Division of Water Resources analysis, 2006.

runoff and demand, possibly many years—and could be extremely important during prolonged drought.

Agricultural Management

The agricultural sector is impacted immediately and most severely by drought of any length. The NRCS website provides advice to farmers and ranchers to mitigate and prepare for drought by employing sound management practices. NRCS discussion pertaining to drought can be found at: <http://www.nrcs.usda.gov/feature/highlights/drought.html>. Several of the recommendations are included below.

Land Management

- Use conservation tillage (crop residue left on the field after harvest) to increase soil moisture and reduce evaporation.
- Use conservation practices that reduce runoff and encourage infiltration of water into the soil.
- Closely monitor soil moisture.

- Maintain and establish riparian buffers, filter strips, grassed waterways, and other types of conservation buffers near streams and other sources of water.
- Know livestock’s forage needs. Contract early to ensure enough hay is obtainable during dry times or find alternative feed sources.

Crop Management

Drought can negatively influence a farmer’s crop in several ways. Increases in soil salinity and sodicity, due to higher evaporation rates and lower quality irrigation water can degrade soil condition and stresses from dryer and hotter weather can stunt growth and limit yield. Alleviating the impacts of drought on crop yields requires proper crop management.

Suggestions for managing one of Utah’s main crops, alfalfa, are as follows (from the NRCS):



Agricultural land in Southeast Colorado River Basin. Strip cropping, leaving fields fallow, is a management strategy that can be used when the water supply is low due to drought.

- Irrigate normally as long as possible and delay harvesting until full bloom—this will increase yield however quality will be lowered.
- As water becomes limited, irrigate the highest yielding fields—it is better to fully irrigate a smaller area (producing a higher quality and fuller yield) than to insufficiently irrigate multiple areas.
- Fields should be grazed rather than harvested if harvest costs cannot be recouped through sale of the crop.
- Plant crops with lower water requirements such as small grains, oats, forage peas, and corn silage.

Additional methods have also been applied in Utah during drought, such as planting fewer crops, planting more drought-tolerant crops and employing available technologies to improve watering and general crop management strategies. It is important to note that each crop is unique. Some crops are annuals and need to be planted each year. Perennials, on the other hand, generally take more time to establish and may not tolerate large water reductions without serious damage to their production. Some crops can go dormant, such as alfalfa, while others cannot, such as fruits and nuts. These factors need to be taken into account when managing crops during drought.

Water Management

- Evaluate all types of appropriate irrigation systems and choose the one that will lose less water to evaporation, percolation, and runoff.
- Look for ways to make the existing irrigation system more efficient and easier to maintain.
- Build a water storage system that holds water for use during the irrigation season.
- Install water measurement devices and keep track of water use.

The type of irrigation management used by Utah farmers during drought depends upon the water source. If the water supply source is forecasted to ensure at least some water is available throughout the season, postponing irrigation until soil moisture levels indicate that irrigation is required is an efficient use of the water supply. If the water supply is extremely variable and is likely to be reduced as the growing season progresses (such as a small stream), it is advantageous to store as much water as possible in the soil when it is available by watering early in the growing season to increase the surface soil moisture content. After harvesting the crop, delaying subsequent irrigation pending development of a leaf canopy reduces leaf scalding and evaporation.

Efficient Irrigation and Agricultural Management Systems

The Utah Water Research Laboratory in cooperation with the Department of Economics of Utah State University (USU) is developing a program that will greatly assist farmers during drought times²¹ and during normal conditions. Knowing the projected conditions of the water supply and local market and economic conditions will enable a decision on the most profitable crop to cultivate and irrigation practices to adopt in a given year. Users enter information, which includes the following:

- Irrigation system: center pivot or gravity.
- Well or canal water delivery.
- Estimated amount of water available.
- System power source: electricity, diesel, or natural gas.
- Production costs including chemicals, labor, and energy.

- Soil type and area of land in the field.
- Crop type: alfalfa, sunflower, wheat, hay and others.
- Local economic conditions such as demand for food crops and crop sale prices.

The program outputs include when to irrigate and how much water to apply for each crop type, expected optimal profit and risk exposure based on fluctuating local market conditions. Farmers input their own individual variables and select alternative crops to see how to make the most profit with the water available. The system is intended to enable farmers to make their own decisions after seeing the results of various options. It enables such decisions down to an individual field level. Although this system may initially take hold in the agricultural community through response to drought conditions (as farmers search for management assistance during such times), it is also a viable mitigation strategy that can be employed and integrated into agricultural management to improve annual efficiency and productivity as well as promote conservation of agricultural resources.

The system will eventually be set up to operate as a stand alone system operating on the Internet allowing users to better manage agricultural lands. Initially developed for Utah, it has the potential to be applied throughout the country. This system is expected to be completed by Fall 2008.

Water Hauling

Although not a common practice, in some rural areas where the potable water supply has been greatly reduced or rendered unusable due to drought, water has been hauled in for public use. When other measures are ineffective or rapid response is needed and the water supply has decreased to severely low levels, supplemental water can be trucked in from other sources. This was the case in several towns during the peak period of the most recent drought (1999-2004), pointing out the need for improving the water supply in those areas. Water hauling for use by livestock is more common. In Carbon and Emery counties, it is a common practice to haul in water for cattle during periods of drought.

As reported in the San Juan Record newspaper on August 8, 2006, in southeastern Utah, drought has

directly and indirectly impacted the water supply of the town of Navajo Mountain. The area's primary water source, a natural spring, had been severely depleted due to years of drought and the landscape had been scarred by drought-induced wildfires. As a result of heavy rains and the lack of ground vegetation, muddy and sediment laden runoff overwhelmed filters on the water system's storage tank and damaged sections of the pipeline resulting in a contaminated and unusable water supply. In response, water was trucked in at a cost of \$1,200 per truck with a need of six trucks per day. This continued for a few weeks until the pipelines were repaired and the water treatment system resumed production of potable water. However, the community is still at risk during rain events and severe drought until a more permanent long-term solution is completed. Quick and efficient response by local authorities to this incident significantly reduced its impacts on the community.

Legislation

On occasion drought has prompted responses from the Utah Legislature in the form of codified laws, acts and other actions. In response to the 1976-1979 drought, a drought that developed rapidly and caught much of the state off-guard, in 1977 the Utah legislature:

- Appropriated a supplemental \$3 million to the Utah Division of Water Resources Revolving Construction Fund.
- Created the Governor's Emergency (drought relief) Culinary Grant Fund (\$1 million) to assist water suppliers.
- Appropriated \$5 million for special drought assistance:
 - Of which \$2 million was allotted to the then newly created Emergency Water Resources Act, Utah Code 73-20 to provide "financial assistance to commercial farmers and ranchers within the state who own or lease commercial farms or ranches and who are engaged primarily in the production of basic livestock herds in conjunction with such agricultural activity to enable them to provide adequate water supplies for the maintenance and preservation of such herds."²²

- \$2 million was allotted to the Revolving Construction Fund
- \$1 million was appropriated to the Cities Water Loan Fund

Of the \$2 million appropriated for the Emergency Water Resources Act, \$300,000 was requested and used, and the remaining \$1.7 million was transferred to the Revolving Construction Fund.²³ During this time great effort was put into enhancing ground water development via temporary well installation and drilling existing wells deeper.

Due to the most recent drought (1999-2004), water reuse issues and possibilities have been re-examined. As mentioned in Chapter 4, in 2006 the legislature revised the Wastewater Reuse Act, Utah Code 73-03c, which defines water reuse and sets protocol. In part because of drought, water reuse is emerging as a useful water management strategy in Utah through continued research, legislative discussion of its application and implementation of small-scale reuse projects.

State Assistance

The state also offers several financial assistance programs in response to drought such as loans, grants and other monetary relief. Selected programs are presented in Table 5-1.

Federal Assistance

The federal government has been a security blanket for many in times of crisis by providing direct relief. Due to national droughts and other calami-

ties, the federal government has strengthened its emergency-assistance programs. There are many federal programs that offer some form of monetary assistance in response to drought. In addition to monetary aid, the federal government assists by donating needed supplies. Refer to Appendix D, Table D-3, for drought response federal assistance programs.

The state, regional entities and individuals can request federal assistance. Generally, farmers are the beneficiaries of federal government aid in times of drought as their livelihood is adversely affected. In Utah, the federal government has hauled in feed and powdered milk supplements for livestock and also has opened previously closed ranges for grazing purposes as resources have been strained during long periods of drought. In the 1930s, 25% of rural families in Utah ended up on federal relief despite local charitable donations.²⁴ Also during this time, the federal government purchased 155,000 cattle and 250,000 sheep from Utah farmers and ranchers in effort to ease the impacts of the drought.²⁵ When disseminated and used properly in response to drought, federal aid can be extremely beneficial to satisfy immediate needs. However, it must not be relied upon to “bail out” unprepared communities. Additional mitigatory and preparatory steps should continually be taken at the state, local and individual levels. Federal aid may also be limited by long-term (decade-scale) widespread drought due to the resulting volume of applicants and not enough aid to meet total needs.

**TABLE 5-1
State Assistance Programs (Response)**

Program	Assistance	Agency	Customers Served	Triggering Event
Agriculture Resource Development Loan Program	The Agriculture Resource Development Loan Program primarily deals with water and soil conservation and development of rangeland. Loans can be made at 3% interest with a maximum term of 12 years.	—	Farmers and agriculture agencies	—
State Drought Related Assistance Programs	The Governor has authority to declare an emergency, effective for 30 days. The Governor's emergency powers include the purchase or lease of necessary materials. Food and other items are specifically mentioned, including lands, but not water. However, water rights are similar to the property interest in land, and arguably the Governor could expropriate and reallocate water. Appropriate compensation would be required and determined under eminent domain statutes.	Department of Public Safety, CEM	General Public	Governor's declaration of emergency
Utah Emergency Act of 1981	This act authorized by Comprehensive Emergency Management (CEM) to coordinate disaster mitigation, preparedness, response, and recovery covering "natural phenomenon", which specifically includes drought. Drought response therefore falls under the general State Emergency Response Plan.	Division of Emergency Services and Homeland Security	General Public	Governor's declaration of emergency
Revolving Construction Fund (Also serves mitigation purposes)	The Revolving Construction Fund was established in 1947 to provide technical and financial assistance to nonprofit irrigation companies and water companies. Board funding is provided at 0% interest. This program provides the best opportunity for the state to provide assistance to irrigation companies experiencing problems during the drought.	Department of Natural Resources, Division of Water Resources	General Public	—
Cities Water Loan Fund (CWLF)	The Cities Water Loan Fund is used to provide funding to political subdivisions of the state for upgrading and/or replacing its municipal water systems. During the 1977 drought, several communities received funding through this program to help drill wells.	Department of Natural Resources, Division of Water Resources	Residents of affected communities	—

Source: Compiled from the United States Department of Agriculture's webpage: <http://www.fsa.usda.gov/drought/finalreport/appendices.htm>

NOTES

¹ David W. Echhoff, "Drought Happens: Get Used To It, Will Technology Help Us To Survive?" Retrieved from the University of Utah Library's Internet web page: www.lib.utah.edu/services/prog/gould/2002/lecture.html, July 2006. From the Gould distinguished lecture series in technology and the quality of life.

² Dr. Donald A. Wilhite, "Senate Subcommittee on Disaster Prevention and Prediction Drought Hearing," (Lincoln: National Drought Mitigation Center, University of Nebraska, 2006), 2.

³ Ibid, 6.

⁴ Utah Department of Natural Resources and Division of Emergency Services and Homeland Security, *Utah Drought Response Plan 1993 (Revised -2003)*, (Salt Lake City), 1.

⁵ National Drought Policy Commission, *Preparing for Drought in the 21st Century*, (U.S. Department of Agriculture's Office of Communication, 2000), 4.

⁶ Utah Department of Natural Resources and Division of Emergency Services and Homeland Security, 2003.

⁷ Ibid.

⁸ Ibid.

⁹ Ibid, 1.

¹⁰ W.R. Walker, M.S. Hrezo, and C.J. Haley, *Management of Water Resources for Drought Conditions*, (National Water Summary 1988-89 Hydrologic Events and Floods and Droughts, United States Government Printing Office, 1991), 149.

¹¹ Utah Division of Water Resources, *Utah's M&I Water Conservation Plan, Investing in the Future*, (Salt Lake City: Department of Natural Resources, 2003), 9. Can be accessed on: <http://www.conservewater.utah.gov/Final71403AACC.pdf>

¹² Salt Lake City, "Water Shortage Contingency Plan." Retrieved from the Salt Lake City's Internet web page: http://www.ci.slc.ut/utilities/cs_watershortageplan.htm, October 2006.

¹³ Fred May, "Utah Drought Mitigation Plan," (unpublished, 2000).

¹⁴ Myrna Trauntvein, "Watering restrictions are put in place for outside use, both culinary and irrigation supplies." Retrieved from the Times News of Nephi's Internet web page: <http://www.nephitimesnews.com/0502/051502/1.htm>, August 2006.

¹⁵ Jed Boal, "Are Water Penalties Effective?" Retrieved from the KSL TV's Internet web page: <http://water.ksl.com/index.php?nid=3&sid=32910>, August 2006.

¹⁶ Myrna Trauntvein, August 2006.

¹⁷ Chris D. Wilkowske, David V. Allen, and Jeff V. Phillips, "Drought Conditions in Utah During 1999-2002: A Historical Perspective," (Salt Lake City: USGS, 2002), 5.

¹⁸ Ibid.

¹⁹ Ibid.

²⁰ Utah Division of Water Resources, unpublished internal investigation in cooperation with the Utah Division of Water Rights, April, 2005.

²¹ Jagath J. Kaluarachchi; Professor, Civil and Environmental Engineering; Head, Water Engineering Program; Utah State University, Utah Water Research Laboratory; 1600 Canyon Road, Logan, Utah 84321; jkalu@cc.usu.edu ; (435) 797-3918

²² Utah Legislature, "Utah Code--Title 73--Chapter 20--Emergency Water Resources." Retrieved from the State of Utah's Internet web page: http://www.le.state.ut.us/~code/TITLE73/73_1B.htm, August 2006.

²³ Utah Division of Water Resources, *State of Utah Sixteenth Biennial Report of the Division of Water Resources to the Governor of Utah*, (Salt Lake City: Department of Natural Resources, 1979), 2-3.

²⁴ , "Changes and Challenges: A Century of Utah Agriculture." Retrieved from the Utah State University's Internet web page: http://extension.usu.edu/AITC/teachers/secondary/pdf/changes_challenges/cc30.pdf, August 2006.

²⁵ Ibid.

6

CONCLUSION AND RECOMMENDATIONS

Water is a scarce resource in Utah's semi-arid climate. During periods of drought this resource becomes even more limited and the potential for severe water management difficulties increases. As the population continues to grow, the demand for water and potential strain on the water supply will also increase and likely compound future drought impacts. By employing sound mitigation projects and efficient response strategies, Utah's increased future water demand, may be satisfied without increasing society's current susceptibility to drought. In certain situations it may be possible, through mitigation, preparedness and response to reduce the socioeconomic impacts of future droughts; even these that exceed Utah's historic droughts of the 20th Century in intensity and duration.

MITIGATION AND RESPONSE TO DROUGHT IN UTAH

Drought has affected Utah on numerous occasions, straining the water supply. During the 111-year instrumental record (Palmer Drought Severity Index [PDSI] record), Utah has experienced six significant droughts, varying in duration, intensity and impacts. Some communities have been devastated, experiencing drought-related impacts across many sectors, while others have endured unscathed. The state has responded to drought through several avenues, from the installation of temporary wells to hauling water. However, a more proactive management approach toward drought is needed. Vulnerability to drought should be assessed both locally and statewide, and mitigating actions should be taken to bolster water supplies—reducing suscepti-

bility while emphasizing wise-use of these supplies and environmental awareness.

Efficient management of Utah's finite water supply is an essential aspect of ensuring a reliable supply and environmental integrity during drought. This can be accomplished through effectively incorporating mitigation strategies within management efforts. From experience gained during past droughts, communities must take action in mitigating and preparing for drought. (Table 6-1 lists some of the mitigation and response actions that can be and are used.) Movement in this direction is taking place and needs to continue.

Problems resulting from drought often go unrecognized until they become substantial, producing a stark contrast from the "norm." With the exploration of drought contained in this report, it is clear that naturally-occurring conditions and the resulting problems encountered will eventually force change in water management strategies at all levels—state, local and individual. Mitigating before the drought can be less expensive and less painful than only responding after a drought is under way. Leaders in the water supply industry, legislators and other community leaders are encouraged to implement the strategies and methods put forth in this publication and adopt a methodology of mitigation in addition to one of response to drought.

Utah will continue to face drought and the demand for water will increase as the population grows. It is paramount that past drought episodes be remembered and paleo-drought, as well as climate

TABLE 6-1
Drought Mitigation and Response Actions

Mitigation	Response
Water Redistribution	Drought Response Plan
Conjunctive Management (ASR)	Water Conservation
Reservoir Construction	Publicity and Communication
Water Reuse	Water System Operations
Public Outreach and Education	Public Outreach and Education
Protect Aquifers (recharge areas)	Increased Ground Water Use
Drought Contingency Plan	Crop Management
Fund Water System Improvements	Legislation
Early Warning System (monitoring)	State and Federal Assistance

Selected response and mitigation activities, Utah Division of Water Resources, 2006.

change, considered when developing a baseline from which future water management decisions are made. More significant droughts are evident within the proxy records and there is no reason to believe that such droughts will not occur again.

RECOMMENDATIONS

There are several actions, in addition to what is already being done, that must be taken in order to decrease Utah’s vulnerability to periods of water deficiency, while maintaining environmental integrity. These include and are not limited to: increasing storage capacity through surface and sub-surface reservoirs, integrating distribution systems, water transfers and economic impact assessments. An underlying element of these and other actions is that of public education and outreach. Public perception and approval is fundamental to the success of any program or action taken. Education and outreach programs must continually be executed and fine-tuned.

Some water suppliers/purveyors have and are taking such actions. The following recommendations are primarily geared toward water managers, suppliers, and local and state governing bodies to assist with efforts to manage the water supply during drought.

1: Develop Drought Management Plan

- The Utah Division of Water Resources in cooperation with other state and local agencies will develop a model drought management plan. This plan will consist of two main components: one that addresses drought mitigation, and one that addresses response to water shortages (contingency plan).¹
- Utah water suppliers should develop a drought management plan that contains drought mitigation and water shortage response components. This plan can be used in conjunction with or separate from existing water management plans.

The drought mitigation component should contain results of a vulnerability assessment and outline a plan of action to address these results or identified “weaknesses.” Mitigation strategies discussed in Chapter 4, and other strategies, should be incorporated into this mitigation component, thereby adding to water supply diversity and helping to ensure a reliable water supply during prolonged drought. Potential projects incorporating any mitigation strategy or strategies not only need to be assessed individually but as a unit or combination to maximize efficiency, cost-effectiveness, supply diversification and maintain environmental integrity. These drought mitigation components are separate from the State’s pre-disaster mitigation plan (discussed in Chapter 4) and the association of governments’ hazard mitigation plans, but should compliment these broader plans by adding area specific detail.

The *water shortage response component* (or contingency plan) is intended to differ from components within current management or conservation plans in that they layout more aggressive demand management actions to be taken in response to drought or other emergency water shortages. This contingency plan should compliment and add to current management plans with regard to potential prolonged water shortages. Response strategies outlined in Chapter 5 could also be used in the development of this contingency plan.

Several water suppliers include drought response as part of conservation plans; however, it may be beneficial to address drought and water shortages separately or in more detail. See Salt Lake City's *Water Shortage Contingency Plan*. Although Salt Lake City's plan is not specifically a drought contingency plan, it encompasses water shortages, which includes drought and sufficiently satisfies the water shortage contingency component of this recommendation. Other states, such as Texas, have made this a statutory requirement for all retail public water suppliers (in addition to their water conservation plan requirement).

2: Water Redistribution and Interconnections

- Water suppliers within common regions should initiate discussion on how to develop a mechanism, such as a water bank and system interconnections, to facilitate water redistribution (or water sharing) when needed, thereby minimizing future time, effort and potential disagreements.

As discussed in Chapter 4, temporary redistribution of agricultural water (or other water) to supplement the public supply is a viable method to help alleviate impacts of prolonged regional and local drought.

Institutional collaboration (especially during drought when water resources are limited) between districts to share water and develop interconnections and needed infrastructure is highly recommended. A "committee," with appropriate regional representation, could be formed in order to create an opportunity for dialogue and cooperation.

3: Agreements on Reservoir Operation

- Water users who rely on water supplies from a significant reservoir in Utah should craft a reservoir operation agreement to implement during drought.

This is currently underway for the Colorado River and its major reservoirs, Lake Powell and Lake Mead. The potential agreement involves reservoir operations during drought; certain reservoir levels trigger specific operational strategies and the distri-

bution of shortages among Colorado River water users when supplies are limited.

- In situations where broad segments of the population will be affected by such agreements, a reservoir operation curve (or appropriate indicator) should be developed, posted and regularly updated to help the public understand when various operating criteria and water restrictions are triggered.

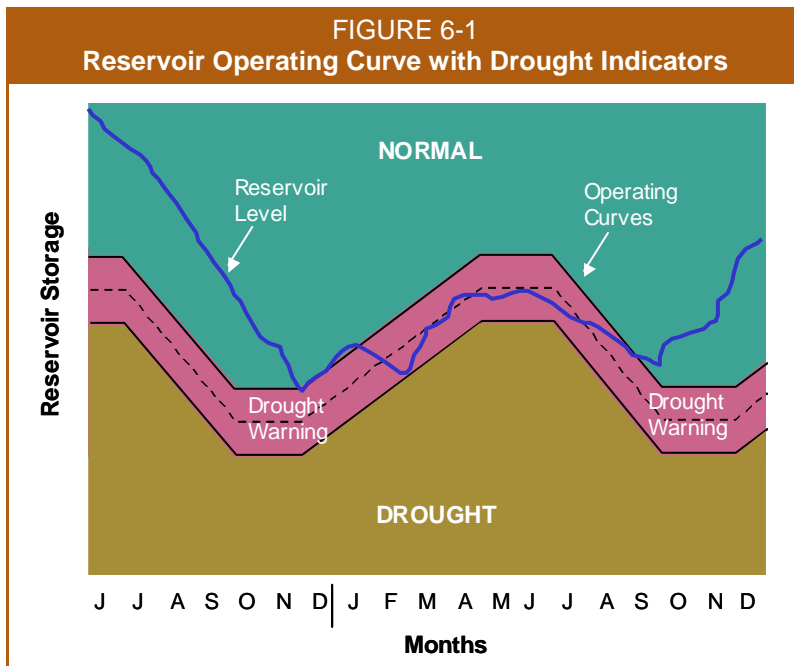
Figure 6-1 is an example of a generic operating curve. The zones of operation, normal, drought warning and drought are easily identified and comparable to the actual operating conditions—water levels—of the reservoir.

Public accessibility and understandability of such a curve (or appropriate indicator) is of utmost importance to the design. These indicators are visual representations of "real-time" data and conditions that may trigger certain responses in operational activities of the reservoirs and overall management of water resources during drought. Using understandable terminology to describe drought conditions will increase the indicator's effectiveness. Drought descriptions such as phase 1 and phase 2 are not easily understood by the public. Instead, words that describe the resultant action should be used such as drought warning, alert, or water rationing. Such indicators can provide information to the public, explaining why certain measures such as watering restrictions, are enacted. These indicators could also be publicized during drought by local media and public education and outreach programs.

4: Data Collection

- Governing bodies, counties and cities (or appropriate institution) should regularly collect information in an effort to assess drought (and other water shortages) impacts more effectively and guide future water management decisions.

Some suggestions are as follows:



Example operation curve with drought indicators. Adapted from: Page 31, U.S. Geological Survey, 1986, National water Summary 1985-Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper.

Survey

A survey of municipal water utilities, suppliers and conservancy districts should be conducted each year during a drought and results provided upon request.

Possible survey question topics include: 1) emergency funding to supplement water supply; 2) water use restrictions; 3) water supply versus demand; and 4) population growth.

Such surveys and other data gathering activities will provide qualitative and quantitative information regarding drought and will help to evaluate the effectiveness of mitigation and response activities. Also, areas with specific needs may be identified for future assessment and water development projects.

Socioeconomic Impact Data

Large and significant data gaps hinder the quantification of drought impacts in all sectors of the economy and society. There is a need for additional monitoring of economic sectors during and after drought in order to more fully understand drought impacts and their associated costs. Tax revenues and other potential economic indicators of drought impacts should be monitored at the city, county, regional and state levels to better evaluate and understand drought impacts. Economic sectors—agriculture, recreation, tourism and other industries—should also be evaluated individually in order to identify and address any specific needs that may arise.

Additional Research

While some research regarding climate change in Utah has been conducted, more such research is needed in order to better understand the interplay between increasing air temperatures (climate change) and precipitation (the ultimate source of all the state's water supplies). Water planners and managers will then have more information from which to devise strategies and options to address the potential impacts of climate change on the state's water supply. Research within state agencies, universities and other institutions is encouraged. Federally funded research should also be supported by those in the water resources community and where practicable should participate in such research. Cooperation with ongoing programs such as the National Integrated Drought Information System is highly encouraged.

NOTES

¹ To view example drought contingency plans, see:

—Salt Lake City's *Water Shortage Contingency Plan*, available online at:

http://www.ci.slc.ut.us/utilities/cs_watershortageplan.htm and,

—Water Supply Division, Texas Commission on Environmental Quality, *Handbook for Drought Contingency Planning for Retail Public Water Suppliers*, Austin, TX: April 2005, Appendix B & C. Available online at:

http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-424.html

Appendix A

COMPARISON OF DROUGHT INDICES

Presented within this appendix are comparisons of the Palmer Drought Severity Index (PDSI), Palmer Hydrologic Drought Index (PHDI) and the Surface Water Supply Index (SWSI) for the State of Utah. Climatic regions and statewide annual averages are used to compare the data.

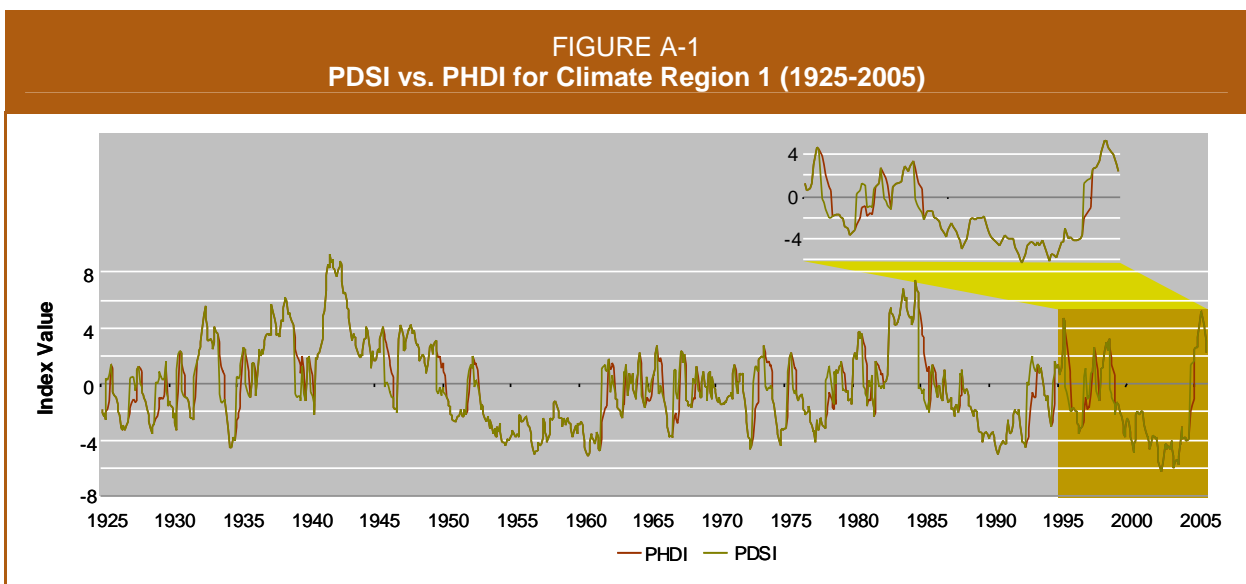
PDSI VERSUS PHDI

The PDSI and PHDI have the same primary inputs (soil moisture, temperature and precipitation). The main difference between the two is that the PDSI has a “backward-looking or back-tracking” component that takes into account dry/wet/neutral trends in the analysis. Due to this there is a slight difference in calculated values for each index but the strong correlation between the two indices regarding the magnitude and duration of wet and dry periods is of no

surprise. The PHDI is a simplified version of the PDSI.

There is a slight offset (see Figure A-1, Index data for Climatic Region 1) present in the PHDI data (commencement and terminus of the drought periods) relative to the PDSI data; however, this offset is not sufficient enough (less than six months in most cases) to significantly influence the correlation/similarities between the two (Table A-1).

The two indices are very similar through time, most notably during extreme weather events (wet and dry periods). This strong correlation (r-value—as value approaches 1 the correlation or “likeness” increase; the closer to 1 the stronger the correlation) between the two indices suggest that for the purpose of this document, the use of either of the two would



Division of Water Resources analysis, 2006.

TABLE A-1
PDSI and PHDI R-Values

Utah Climatic Regions						
1	2	3	4	5	6	7
Monthly						
0.93	0.92	0.92	0.93	0.93	0.91	0.90
Annual						
0.98	0.97	0.97	0.98	0.97	0.97	0.97
Statewide Annual						
0.97						

Source: Utah Division of Water Resources analysis, 2006.

be appropriate, however, since proxy reconstructed data is universally presented using PDSI values, we have chosen to use the PDSI records throughout this report.

PALMER INDICES VERSUS THE SWSI

As aforementioned in Chapter 1, the Surface Water Supply Index (SWSI) shows more variability relative to the Palmer Indices (see Figure 1-3) due to the hydrological and operational variables at play. Although the SWSI may be the most appropriate indicator for drought in Utah, due to the relatively short record (ranging from 22 years in the Virgin River Basin to 54 years for the Provo River Basin) and lack of direct comparability to the reconstructed PDSI records, it was deemed inadequate for the scope this study.

Figure A-2, presents visual comparison of the three drought indices. Droughts are highlighted and identified using the drought criteria presented in Chapter 2. For the most part, droughts identified in each of the indices occur during the same time frame or overlap one another. The most notable differences between the compared regions and indices are the lack of the drought in the 1970s (orange color) and the extended duration of the 1950s drought (green color) in the SWSI data versus the PDSI and PHDI data. Although dry years are present during the 1970s in the SWSI data, they do not satisfy the drought criteria set forth in Chapter 2. What was deemed a shorter drought in climatic region 5 by the PDSI and PHDI records was much longer in the SWSI data for this region (Provo River Basin). The Palmer drought indices indicate that meteorological

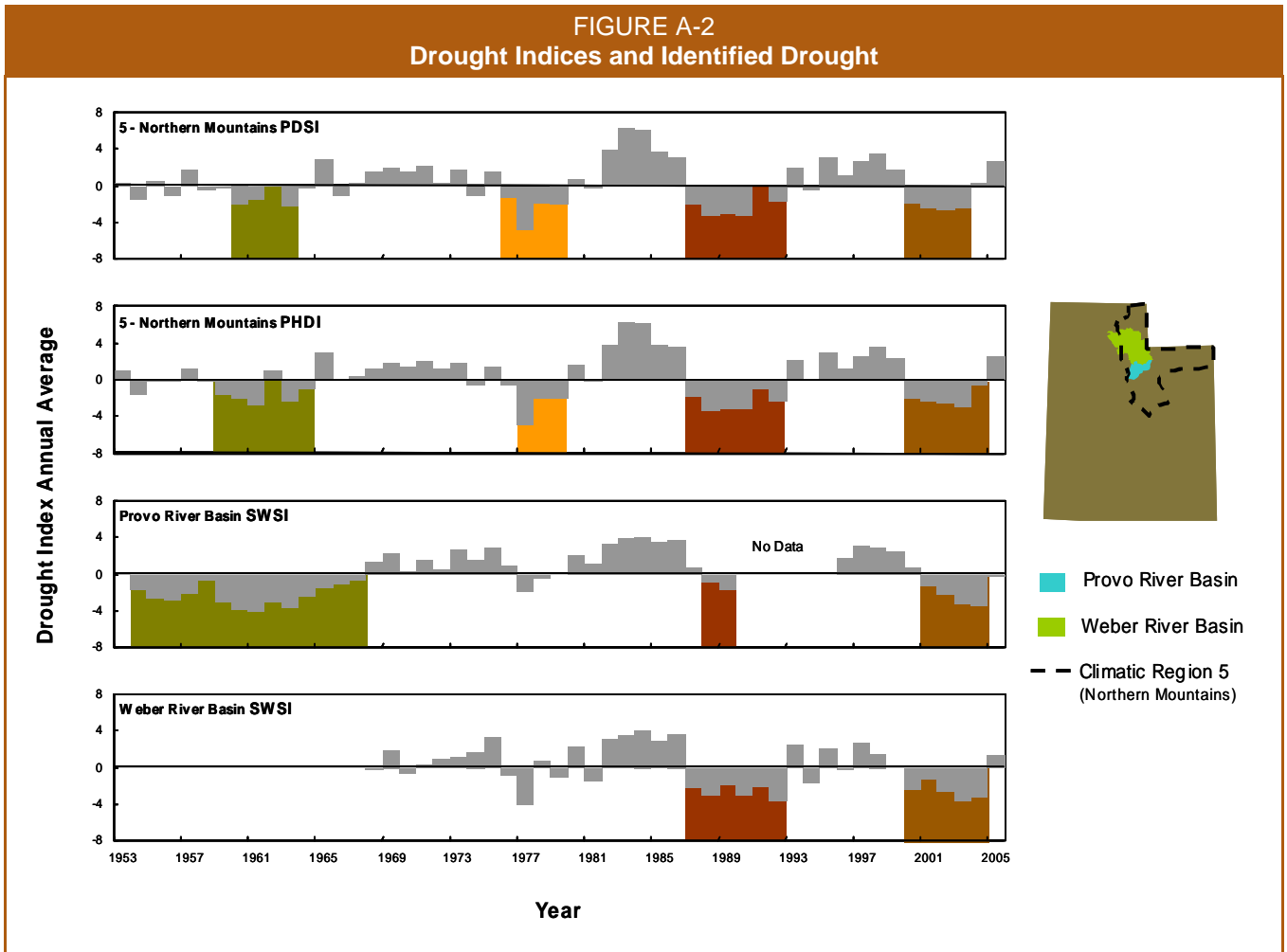
drought conditions were of much shorter duration than hydrological drought conditions expressed by the SWSI during this drought.

R-values between the PDSI and SWSI as well as the PHDI and SWSI are presented in Table A-2; annual averages of each index were used. The Weber River Basin SWSI moderately to strongly correlates with the Palmer Indices while the Provo River Basin SWSI is moderately correlated. Drought appears to be slightly more variable (see Figure A-3) in the SWSI records than indicated by the PDSI and PHDI records. However, due to lack of a significantly long and consistent SWSI record, as shown in Figure A-3, the PDSI gives a better idea of drought throughout the past 100 years (instrumental record) as well as beyond (reconstructed or paleoclimatic record).

TABLE A-2
SWSI versus Palmer Indices' R-Values

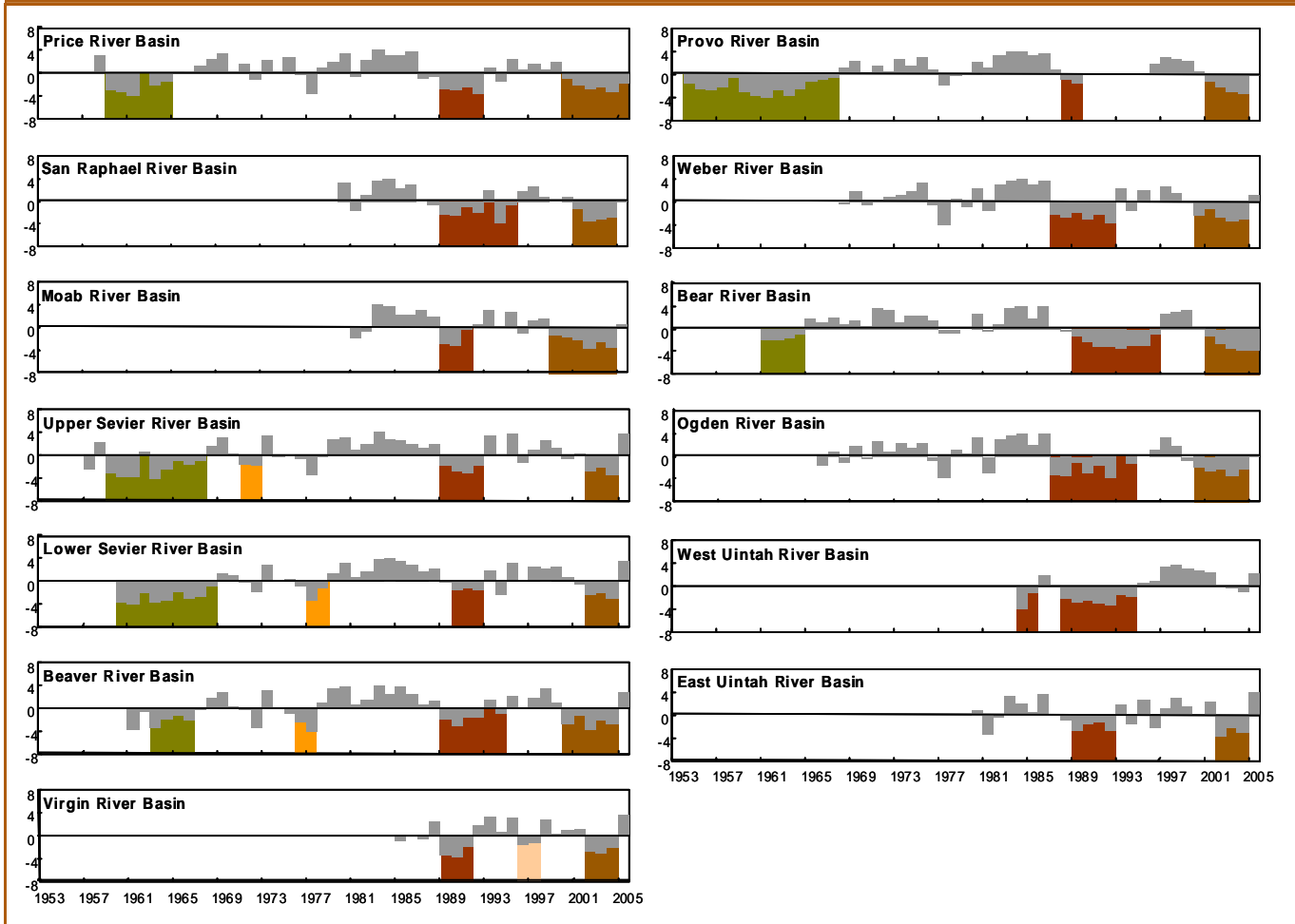
SWSI Region	PDSI Region 5	PHDI Region 5
Provo River Basin	0.68	0.73
Weber River Basin	0.84	0.87

Source: Utah Division of Water Resources analysis, 2007.



Source: Utah Division of Water Resources analysis, 2007.

FIGURE A-3
Surface Water Supply Index and Identified Drought



Source: Utah Division of Water Resources analysis, 2007.

Appendix B

ASSESSING DROUGHT IMPACTS: THE DROUGHT IMPACT REPORTER

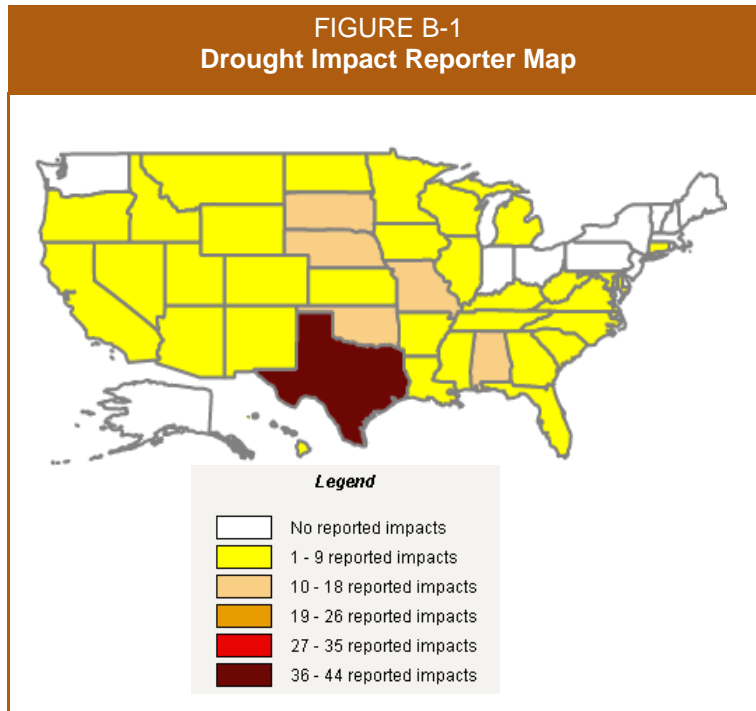
Drought related impacts are woefully under-assessed. This is largely due to the complexity of such impacts. Drought impacts cut across several sectors (ripple effect) of the economy and are extremely variable as discussed in Chapter 1. Currently there is not a consistent methodology for assessing drought impacts. The National Drought Mitigation Center (NDMC) is attempting to address this issue through the development of an online Drought Impact Reporter. “The principal goal of the Drought Impact Reporter is to collect, quantify, and map reported drought impacts for the United States and provide access to reports through interactive search tools.”¹ The Drought Impact Reporter is currently in its infancy. However, as more people become aware of it and utilize it, more timely information regarding severity, spatial extent (location) and impacts of droughts will be available for use in managing drought by means of risk management-based (mitigation) methodologies. Impact information will help assess vulnerabilities, thereby aiding policy and decision makers in taking appropriate action and establishing mitigation programs before drought occurs.

The Drought Impact Reporter relies heavily upon online articles, scientific journals, newspapers (over 5,000 such online sources), public input, media and government agencies for information regarding drought impacts. The NDMC staff members review all submitted impacts for acceptance. There may be biases embedded within the reported impacts, however as the Drought Impact Reporter is continually fine-tuned, it will progressively come closer to providing and maintaining a consistent methodology for assessing drought impacts.

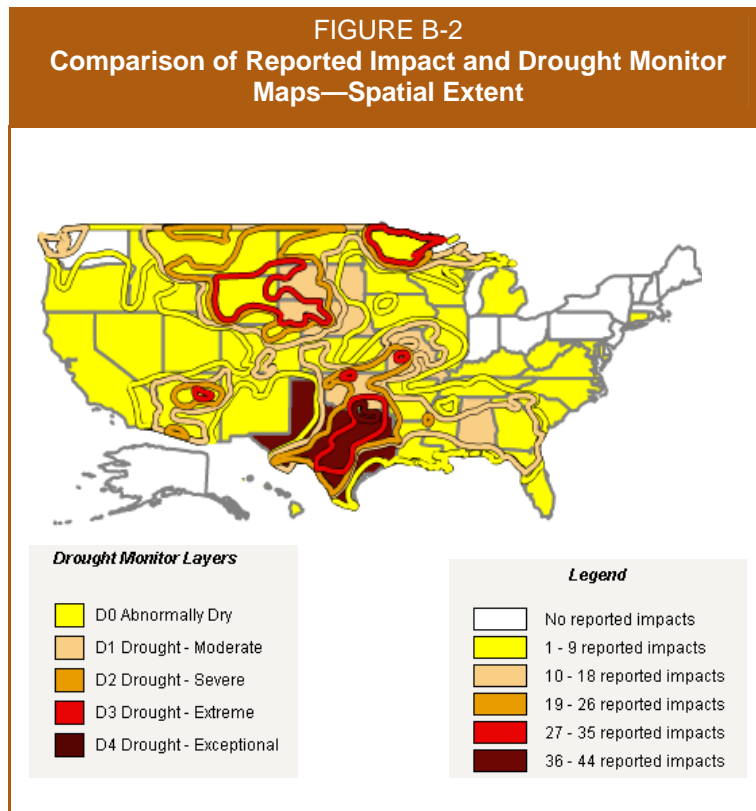
The Drought Impact Reporter can be accessed online at: <http://droughtreporter.unl.edu>. The reporter consists of an interactive map (Figure B-1) of the United States. Impact information can be obtained on national, state and county levels. Local leaders, in assessing drought impacts, can use the county level of resolution to identify vulnerable areas and act appropriately through response or the development of future mitigation actions.

The impact map can be very useful in showing areas where impacts linger after the physical nature of drought has passed. It also serves as “ground truth” for drought indices, which do not always reflect reality. The impact map may not match the Drought Monitor map by nature of direct and indirect impacts (Figure B-2). Impacts can easily be submitted online and are categorized into six areas: agriculture, water/energy, environment, fire, social and other.

The state as well as counties, cities and individuals are encouraged to use this resource and report drought related impacts. This will aid in identifying deficiencies and vulnerabilities, disseminating relief and mitigating future droughts.



Adapted from the Drought Impact Reporter webpage:
<http://droughtreporter.unl.edu>, October 2006.



Drought Impact Reporter map overlaid with the Drought Monitor map.
 Adapted from the Drought Impact Reporter webpage:
<http://droughtreporter.unl.edu>, October 2006.

NOTES

¹ National Drought Mitigation Center, "Drought Impact Reporter." Retrieved from the University of Nebraska-Lincoln's Internet web page: <http://droughtreporter.unl.edu>, October 2006.

Appendix C

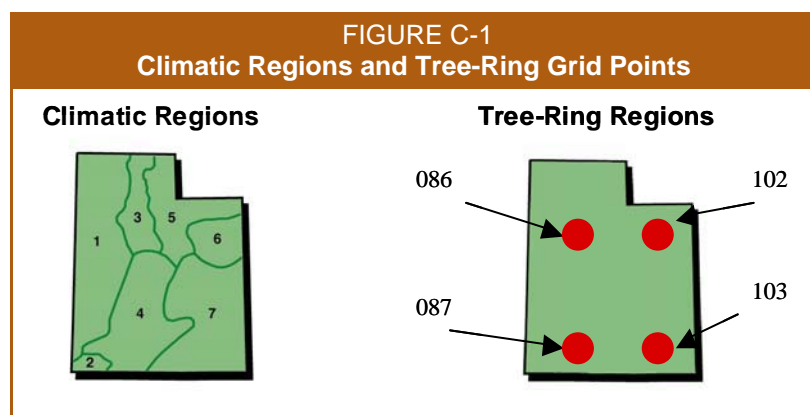
INSTRUMENTAL PDSI VERSUS TREE-RING PDSI

The utilization of tree-ring chronologies to unlock the door to past climate is a complex mathematical process that has become extremely useful. It not only broadens our understanding of past climate, but also that of future possibilities. The tree-ring reconstructed PDSI records used in this document were obtained from the North American Tree-Ring Atlas as previously discussed (see Box 3-3). Four grid points, representing a composite of tree-ring chronologies in proximity of each respective grid point, are located in Utah and provide four reconstructed PDSI records. Comparing the reconstructed PDSI records with any of the seven climatic regions' instrumental PDSI records (see Figure C-1) yields r-squared values (degree of correlation; stronger correlation as value approaches 1.0) ranging from poor (0.31) to moderate (0.68). Overall, the reconstructed PDSI and instrumental PDSI correlate rather well given the variability of natural events, both spatially and temporally.

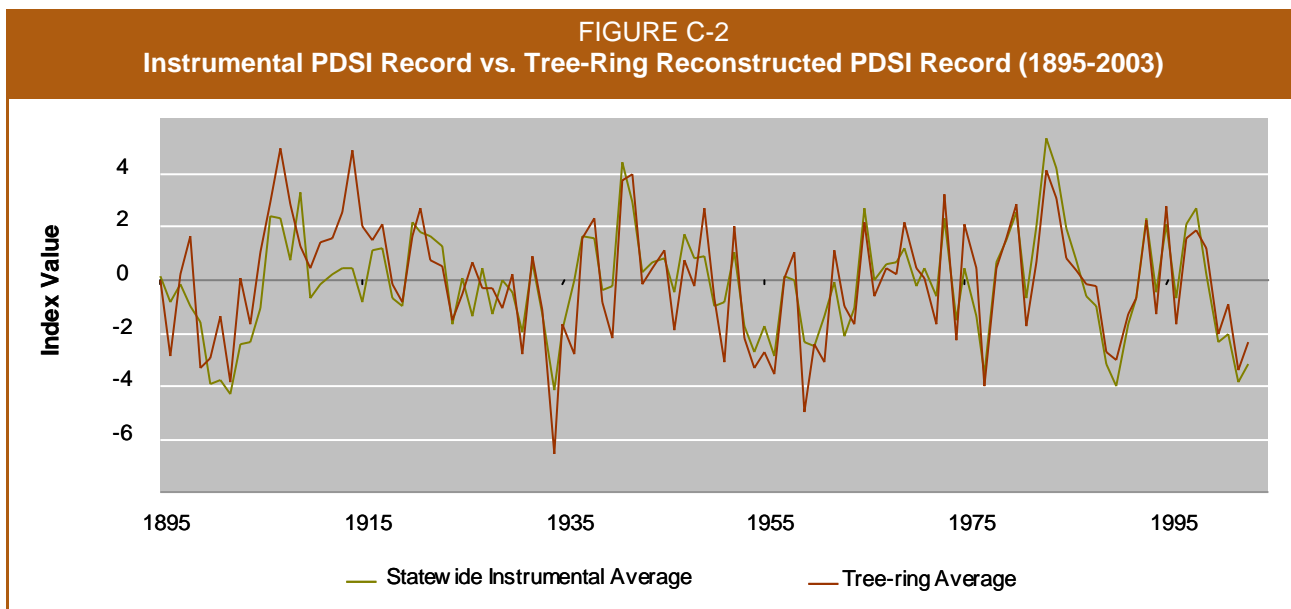
The variability between the two record types is gen-

erally expressed through the magnitude of the respective PDSI values. The two records, overall, indicate similar, if not the same, dry (drought) and wet periods (duration—commencement and termination) throughout the compared 108-year period (1895-2003). The similarities and differences can be seen in Figure C-2, where the average of the four reconstructed PDSI records and the average of the seven instrumental records are graphically compared. The r-squared value of the two averaged data sets is moderate at 0.68.

It is important to note that there is a distinct spatial difference between the two records. The instrumental record consists of seven areas (climatic regions) that represent the state whereas the reconstructed record consists of four quadrants that roughly represent the state (quadrants may also cross state boundaries). This spatial difference was not factored into the analysis and comparison of the records. Also, many tree-ring PDSI records are reconstructed up to the 1970s and from then rely heavily upon the instrumental PDSI record, which likely results in the two records being more similar from then on.



Utah Division of Water Resources, 2006.



Source: Instrumental PDSI data obtained from: <http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgr.html>. Tree-ring data obtained from the North American Drought Atlas. Utah Division of Water Resources analysis, 2006.

Appendix D

FEDERAL DROUGHT ASSISTANCE PROGRAMS

There are many programs designed to provide disaster relief and promote the implementation of mitigation strategies. Selected federal programs, aimed at disaster and drought mitigation (Table D-1), monitoring (Table D-2), and response (Table D-3) are comprised within this appendix.

List of Acronyms used in Tables D-1, D-2 and D-3:

Army COE—Army Corps of Engineers
APHIS—Animal and Plant Health Inspection Service
ARS—Agricultural Research Institute
BEA—Bureau of Economic Analysis
BIA—Bureau of Indian Affairs
BLM—Bureau of Land Management
BXA—Bureau of Export Administration
CPC—Climate Prediction Center
CSREES—Cooperative State Research, Education, and Extension Service
DOC—Department of Commerce
DOI—Department of Interior
EDA—Economic Development Administration
EPA—Environmental Protection Agency
ERS—Economic Research Service
FCIC—Federal Crop Insurance Corporation
FEMA—Federal Emergency Management Agency
FSA—Farm Service Agency
FS—Forest Service
FWS—Fish and Wildlife Service
NASS—National Agricultural Statistical Service
NCDC—National Climatic Data Center
NCEP—National Centers for Environmental Prediction

NESDIS—National Environmental Satellite, Data, and Information Service
NIST—National Institute of Standards and Technology
NOAA—National Oceanic and Atmospheric Administration
NPS—National Parks Service
NRCS—Natural Resources Conservation Service
NWS—National Weather Service
OAR—Office of Arctic Research, currently part of the Climate Program Office
OAS—Organization of American States
OFCM—Office of the Federal Coordinator for Meteorology
OGP—Office of Global Programs, currently part of the Climate Program Office
RD—Rural Development
RMA—Risk Management Agency
SBA—Small Business Administration
USBR—United States Bureau of Reclamation
USDA—United States Department of Agriculture
USGS—United States Geological Survey

TABLE D-1
Federal Assistance Programs—Mitigation

Program	Federal Assistance	Agencies	Customers Served	Eligibility Criteria	Limitations
Federal Crop Insurance (FCIC)	Financial assistance to manage risk for agricultural producers in order to improve the economic stability of agriculture. Crop insurance helps farmers to recover from crop losses, secure operating loans, and financial assistance to manage risk for agricultural producers in order to improve the economic stability of agriculture. Crop insurance helps farmers to recover from crop losses, secure operating loans, and aggressively market a portion of their crop. Recent changes in farm policy have increased the risk borne by individual producers; to help them acquire the risk management skills needed to compete and win in the global marketplace, RMA has been providing education and educational grants in production risk, legal risk, marketing risk, financial risk and human resources risk.	USDA-- RMA, FCIC	All farmers	RMA provides a risk management program that protects against production losses due to unavoidable causes such as drought, excessive moisture, hail, wind, hurricane, volcano, tornado, lightning, etc.	Losses from drought are calculated on a share, or producer/farm basis. To be eligible for payments, a farmer must have purchased crop insurance before the sales closing date established for the 70+ crop insurance programs covered.
Livestock Indemnity Program (LIP)	Financial assistance for losses of eligible livestock from natural disasters occurring during specific periods.	USDA-- CCC, FSA	Livestock producers who suffered livestock losses	Natural disaster, including drought, that has been proclaimed in a Secretarial or Presidential disaster declaration	Livestock producers must have possessed a beneficial interest in eligible livestock which were lost as a result of the disaster condition in the Presidential or Secretarial disaster declaration.
Livestock Assistance Program (LAP)	Financial assistance for grazing losses suffered by livestock producers in calendar year 1998 in counties that have suffered a 40 percent or greater loss of normal grazing as a result of a natural disaster.	USDA-- CCC, FSA	Livestock producers who suffered grazing losses	Natural disaster, including drought, that has resulted in a 40 percent or greater grazing loss for 3 consecutive months	Livestock producers in an approved county must have suffered at least a 40 percent loss of normal grazing for a minimum of 3 consecutive months for the producer's eligible livestock. Livestock must have been owned or leased for at least 3 months.
Cooperative forestry Assistance	Financial and technical assistance to State Foresters	USDA-- FS	State Forestry Fire programs	States receive assistance for preparedness	Limited to resources/funds
Watershed Management Program	Technical assistance includes: 1. Water use conservation and restrictions at government-owned offices, garages, employee housing, fire retardant bases, livestock watering tanks and irrigation of pasture. 2. Construction and operation of water storage ponds for wildfire suppression. 3. Measurements of snowpack, rainfall, streamflow, groundwater levels, air temperature and other meteorological parameters at hydroclimatic stations on national FS lands in over 500 locations, often in support of NRCS and NOAA programs.	USDA-- FS, NRCS	All sectors and customers that depend upon water supplied from the 192 million acres of national forests and grasslands, without restriction or discrimination	1. Data on below-normal precipitation, low soil moisture, and fine fuels buildup are collected at hydroclimatic stations by any agency. 2. Increasing risk of wildfire triggers restrictions on outdoor burning and outdoor recreational and access activities (road and trail closures) which can affect people's use of the national forests and grasslands and, for a few, affect their ability to access their buildings, water facilities, microwave towers, etc. located on these lands and waters.	No special funds, staffs, or agency priority are normally assigned to drought mitigation or response until drought becomes very severe.
Emergency Conservation Program (ECP)	Financial assistance to make cost-share payments to agricultural producers who carry out emergency measures to control wind erosion on farmlands or to rehabilitate farmlands damaged by wind erosion, floods, hurricanes or other natural disasters when, as a result of the foregoing, new conservation problems have been created that (1) if not treated, will impair or endanger the land; (2) materially affect the productive capacity of the land; (3) represent damage that is unusual in character and, except for wind erosion, is not the type that would recur frequently in the same area; and (4) will be so costly to rehabilitate that federal assistance is or will be required to return the land to productive agricultural use.	USDA-- FSA, NRCS	Farmers and ranchers	In the event of a natural disaster, ECP may be implemented to rehabilitate farmlands and conservation facilities. ECP provides cost-share assistance to eligible producers.	ECP is limited to funds which are generally made available by emergency supplemental appropriation, and staff available to handle requests. There is no annual appropriation.
Conservation Reserve Program (CRP)	Financial and technical assistance to cost-effectively reduce water and wind erosion, protect the nation's long-term capability to produce food and fiber, reduce sedimentation, improve water quality, create and enhance wildlife habitat, and other objectives including encouraging more permanent conservation practices and tree planting. Under the CRP, Commodity Credit Corporation (CCC) will enter into contracts with eligible participants to convert eligible lands to a conserving use for a period of not less than 10 years and not more than 15 years in return for financial and technical assistance.	USDA-- FSA, NRCS, FS, ERS; EPA; DOI-- FWS	Farmers and ranchers	The Food Security Act of 1985, as amended, authorizes the Secretary in the case of drought and other similar emergency to permit haying and grazing of CRP acreage.	Limited to CRP participants. Emergency haying and grazing must be conducted in a manner protective of all CRP stakeholders and purposes, including soil erosion control, water quality, and wildlife.
Plant Materials Program	Technical assistance through plant science technology to NRCS field offices for transfer to end users (e.g., landowners and land managers). The program functions in this capacity by providing vegetative solutions for natural resource problems. It develops plant releases (i.e., materials) and information technology on how to establish and manage plant species.	USDA-- NRCS	NRCS field offices receive technical information and transfer it to end users (e.g., farmers and ranchers).	The program is limited to conservation cooperators' properties in conjunction with Soil Conservation Districts, State Agricultural Experiment Stations, and State Cooperative Improvement Associations	The program emphasizes field testing to determine a plant's value and restoration techniques. It is limited to conservation cooperators' properties in conjunction with conservation districts, State Agricultural Experiment Stations, State Crop Improvement Associations and other federal and state agencies. Plants or seed are not provided to the general public, and the public is not eligible to participate in the program.

TABLE D-1 Continued
Federal Assistance Programs—Mitigation

Program	Federal Assistance	Agencies	Customers Served	Eligibility Criteria	Limitations
Environmental Quality Incentives Program (EQIP)	Technical and financial assistance and education are provided to eligible farmers and ranchers to help them address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. This program provides assistance to farmers and ranchers in complying with federal, state, and tribal environmental laws and encourages environmental enhancement. The purposes of this program are achieved through the implementation of structural, vegetative, and land management practices on eligible land.	USDA-- NRCS, FSA	Farmers and ranchers located in locally chosen areas where significant natural resource concerns exist.	The program can be used by farmers and ranchers to apply natural resource conserving practices, such as improved irrigation water management, which provide long-term benefits that may reduce impacts from future droughts	The program does not provide emergency drought relief. However, if a practice fails for reasons beyond the producer's control, payments are offered for reestablishment. Cost-share and incentive payments are limited to \$10,000 per person per year and to \$50,000 per person per year contract.
Economic Adjustment Program (Sudden and Severe Economic Dislocation [SSED] Components)	Financial assistance. Grants to qualified economically distressed areas, a nonprofit organization, an economic development district, or a state or political subdivision thereof, to prevent serious economic dislocations or to reestablish employment opportunities after a sudden and significant dislocation occurs. Grants can fund public infrastructure business loans or technical assistance.	DOC-- EDA	Communities which could experience or have experienced sudden major permanent job losses	Disaster declaration	Absent a federal disaster declaration, an affected area would have to meet the agency's criteria for economic distress. Grants usually provide 50% of project cost; supplemental grants depend on level of distress. Need improved ability to plan for drought disasters, as by early warning of objective indicators such as low reservoir levels, etc.
Natural Disaster Reduction Initiative	This technical assistance is a DOC strategy for natural disaster reduction involving mainly NOAA, NIST, and EDA. Goal is to reduce the cost to society and commerce of natural disasters and to reduce the risk to human life, personal property, infrastructure, and natural resources. Program elements include: hazard identification; application of new technologies to warning and dissemination systems; improved predictions; technology transfer; training, education, and outreach; strengthening state, local, federal, and industry disaster mitigation capabilities; enhancing post-disaster response and recovery; and export of natural disaster reduction technologies.	DOC-- NOAA, EDA, NIST, BEA, BXA	General public, business	N/A	N/A
ARS National Research Program	Technical assistance to develop new and improved drought preparedness and mitigation approaches and technologies	USDA-- ARS	Drought-impacted communities	N/A	A science-based action plan is needed that will accelerate both the development and adoption of drought preparedness and mitigation approaches that have the potential to reduce the impacts of drought on rural communities. Current program on drought monitoring could be strengthened by taking advantage of recent advances in technology.
Farm Labor Housing Loans and Grants	Financial assistance for project grants; guaranteed or direct loans to provide decent, safe and sanitary low-rent housing and related facilities for domestic farmworkers	USDA-- RD	Family partnerships, family farm corporations, or an association of farmers	Grants are available to eligible applicants only when it is doubtful that such facilities can be provided unless grant assistance is available.	NA
Rural Housing Site Loan	Financial assistance for direct loans for the purchase and development of adequate sites, including the necessary equipment which becomes a permanent part of the development; for water and sewer facilities if not available; payment of necessary engineering and legal fees and closing costs.	USDA-- RD	Public or private nonprofit organizations or state or local governments interested in providing sites for housing	No deadline limits for public or private nonprofit organizations that provide the development sites to qualified borrowers on a cost of development basis in own county and towns of 10,000 population or less, or population up to 25,000 under certain conditions.	Loan limitation of \$100,000 without national office approval; loan funds may not be used for refinancing of debts or for payment of any fee or commission to any broker, negotiator or other person for the referral of a prospective applicant or solicitation of a loan; no loan funds will be used to pay operating costs or expenses of administration other than actual cash cost of incidental administrative expenses if funds to pay those expenses are not otherwise available. Repayment of the loan is expected within 2 years.
Reclamation Wastewater and Groundwater Study Program	Financial cost shares or grants	DOI- USBR	Any nonfederal entity is eligible; municipalities are the most common	A nonfederal entity must meet certain requirements before money may be released; 1) a feasibility report is required, 2) the nonfederal entity must demonstrate capability to finance its share of the project costs, and 3) a cost-share agreement is required.	Stakeholders may be seeking the authorization of additional projects.
Reclamation States Emergency Drought Relief Act of 1991, Title I	Under Section 101, non-financial assistance to willing buyers in their purchase of available water supplies from willing sellers. Participation in water banks established by states, under Section 102, the Secretary may permit the use of Federal Reclamation projects for the storage or conveyance of project or non-project water for use both within and outside an authorized project service area.	DOI- USBR	Any state or tribal entity within the States identified in section 1 of the Reclamation Act (Act of June 17, 1902, 32 Stat. 388).	The programs and authorities under Title I, Section 104, shall become operative in any Reclamation state only after the Governor or Governors of the affected State or States, or on a reservation when the governing body of the affected tribe has made a request for temporary drought assistance.	Stakeholders who qualify under Title II of PL 102-250 have suggested that the law be amended to allow emergency assistance, under Title I, to be provided to all 50 states and U.S. territories. Customers have also suggested that loans should be provided at a low-interest rate rather than requiring interest rates based on Treasury rates.

TABLE D-1 Continued
Federal Assistance Programs—Mitigation

Program	Federal Assistance	Agencies	Customers Served	Eligibility Criteria	Limitations
Emergency Well Construction and Water Transport	Secretary of the Army can authorize the construction of wells or the transport of water to farmers, ranchers, and political subdivisions of those areas determined to be drought distressed.	Army--COE	Local and state governments, individual farmers and ranchers	A written request for assistance may be made by any farmer, rancher or political subdivision within a distressed area.	This is a program of last resort. The law requires that all other reasonable means must be exhausted before the Corps has authority to help. Corps assistance is supplemental to state and local efforts. Long-term solutions to water supply problems are the responsibility of state and local interests. The authorities are not to be used to provide drought emergency water assistance in cases where an owner of livestock has other options, including raising funds from private sources through a loan, selling all or part of the herd, or relocation of the animals to an area where water is available. Federally owned equipment must be used to the maximum extent possible. Assistance can be made available to transport water for consumption. The cost of transporting water is provided by the Corps; however, cost of purchasing and storing water is the non-federal sponsor's responsibility. Assistance can also be provided to construct wells. Federal costs associated with well construction must be repaid.
Drought Contingency Water	When available, the Secretary of the Army can sell storage in Corps reservoirs to provide surplus water to a state or political subdivision which agrees to act as wholesaler for all of the water requirements of individual users. Water stored for purposes no longer considered necessary can be considered "surplus." Water may also be considered "surplus" if it could be more beneficially used for M&I purposes and its use would not significantly affect the authorized purpose. The local government determines who is entitled to shares of this surplus water based on assessments of local needs. The price for drought contingency water supply will be determined in the same manner as for surplus water, but it will never be less than \$50 per acre-foot per year. Section 322 of the Water Resources Development Act of 1990 gives the Assistant Secretary of the Army limited discretion to authorize a lower price for low-income communities. All revenues from drought contingency agreements will be deposited in the Treasury of the United States as miscellaneous receipts.	Army--COE	State or local government	May be used only for water supply vulnerability revealed by droughts. Water can be provided only if surplus water is available in a Corps reservoir. Where the governor of a state has declared a state of emergency due to drought, Corps project managers may approve withdrawals from 50 acre-feet of storage or less. This water can be made available for domestic and industrial uses but not for crop irrigation. If the Corps reservoir has an approved Drought Contingency Plan, the District Commander can approve emergency demands that require less than 100 acre-feet of storage, and the Division Commander can approve demands that require from 100 to 499 acre-feet. The term of the agreement will not exceed one year. Requests for larger amounts and agreements that do not follow the standard should be submitted to HQUSACE (CECW-A).	The Corps can do the same thing in advance of the drought, so that the water supply is in place and the emergency never develops.
Planning Assistance to States	States may obtain Corps water resources planning expertise in 50-50 cost-shared studies to develop plans related to the overall state water plan.	Army--COE	States	This program can be used to develop state drought contingency plans, or local and regional plans that support state water plans.	Half the study costs are paid by the Corps, half are paid by the state. Nationwide, annual funds cannot exceed \$10 million; actual funding has been somewhat less. Not more than \$500,000 per state can be spent in any year. This is a popular program used to provide Corps planning expertise to support state water plans for all things, not just drought.
Drought Contingency Plans for Corps Reservoirs	Plans for the release of water from Corps reservoirs during a drought.	Army--COE	All persons & entities affected by releases from Corps reservoirs	For each Corps reservoir, there is a drought contingency plan which contains information that may be useful to those relying on water in or releases from Corps reservoirs during droughts.	Good program that can be a source of information for people depending on a Corps reservoir during drought.

Source: National Drought Policy Commission, "Preparing for drought in the 21st Century", Appendix B, (USDA's Office of Communications), May 2000.

TABLE D-2
Federal Assistance Programs—Monitoring

Program	Federal Assistance	Agencies	Customers Served	Eligibility Criteria	Limitations
National-Fire Danger Rating System	Technical assistance as a means of monitoring and predicting conditions for wildland fires throughout the fire season. The data on 1000-hour fuel (i.e. large, dead fuel), moisture, and energy release component are most closely related to drought. National Fire-Danger Rating System uses daily input from some 1,500 weather stations that comprise the Fire Weather Network to run various models and algorithms to create maps, graphs, and tabular products, which yield predictions of fire danger.	USDA--FS, DOI--BLM, NPS, BIA, FWS, OAS, and DOC--NWS	Federal, state, county, and local government agencies engaged in wildland fire control and planning	N/A	Interpretation requires knowledge of spatial and temporal context of normal and drought conditions.
Vegetation Greenness Maps	Technical assistance to produce Greenness maps to assess the condition of live vegetation over time. Actively photosynthesizing biomass, or vegetation "greenness," is used to assess relative fire danger in forests and grasslands.	USDA--FS; DOI--BLM, NPS, BIA, FWS, and OAS; DOC--NWS	Federal, state, county, and local government agencies engaged in wildland fire control and planning	Maps are used throughout the fire season as a means of monitoring conditions for wildland fires. Drought places stress on live vegetation that can be monitored using these maps. FAO uses data in maps for early warning of food shortages (see www.fao.org/giews/english/windisp/windisp.htm).	1. Uses AVHRR satellite imagery. Provides only coarse (1 km) resolution. 2. Best viewed as time series to detect and monitor change. 3. Clouds may totally or partially obscure certain portions of the images.
Farmland Protection Program (FPP)	Technical assistance: Each farm under a purchased agricultural conservation easement (PACE) is required to have a conservation plan. Part of that conservation plan should contain a drought section that includes mitigation actions, should a drought occur.	USDA--NRCS, CCC	State, local and tribal agricultural protection entities that in turn purchase easements from farmers	Farm is accepted into a state, local, or tribal farmland protection program and conservation easements are recorded.	Limited CCC technical assistance funds are available for maintaining the conservation plans for farms under the FPP.
Drought Monitor	Technical assistance. Map and text describing location of drought across the country. Drought/dryness areas classified by intensity and primary impact. Forecast trend changes indicated. Available via Internet and NWS dissemination channels.	DOC--NOAA, CPC; USDA-- National Drought Mitigation Center	Primarily public, media, executives	N/A	While offering a concise summary of drought, may not meet the needs of local and regional interests, where impacts are often dependent on origin of water supplies. Intended as a national summary of drought. Not detailed enough in all cases to serve local interests.
Western Regional Climate Center	Technical assistance. Produces a section on its Web site (www.wrcc.dri.edu/monitor/quarterly.html) under "WGA/WRCC Quarterly Reports and Information" that includes western climate and water status reports.	DOC--NOAA, NESDIS	General public, business	N/A	N/A
National Climatic Data Center	Technical assistance. Publishes Climate Variations Bulletin that documents anomalous weather in the U.S. monthly and seasonally, including drought. Also publishes Climatic Extremes and Weather Events on NCDC/NOAA Web site that documents major droughts and other significant events.	DOC--NOAA, NESDIS, NCDC	General public, business	N/A	N/A
NWS Hydrologic Information Center	Publishes drought statements issued by NWSFO's and water resource statements for affected areas issued by NWS River Forecast Centers.	DOC--NOAA, NWS Office of Hydrology	General public, business	N/A	N/A
CEOS Disaster Management Support Project	Technical assistance. The Committee on Earth Observation Satellites (CEOS), created in 1984 as a result of the international Economic Summit of Industrialized Nations, serves as the focal point for international coordination of space-related Earth observation activities. The Disaster Management Support Project was initiated in 1997 to foster improved utilization of existing and planned Earth observation satellite data. Toward this goal, the Project has assembled a number of hazard teams tasked with providing recommendations. The drought team has made several recommendations on the use of future satellite systems. In an interim report published in 1998, the drought team concluded that accurate drought prediction as well as early warning of drought onset can reduce drought-related loss of life as well as human suffering.	DOC--NOAA, NESDIS (primary U.S. NOAA participants). Also NOAA-OGP, OAR, OFCM, NCEP/CPC	Policy makers	N/A	N/A
Long-Range Climate Outlooks	Technical assistance. A probabilistic ("tilt of the odds") forecast of the likelihood of above- or below-normal average temperature and total precipitation during the following calendar month and all 3-month periods for the ensuing year. The forecasts are issued shortly after the middle of each month and are analyzed across the contiguous 48 states.	DOC--NOAA, NWS Climate Prediction Center	USDA, NOAA, other federal and state government offices, private industry (primarily agriculture- and energy-related), educational and research institutes, military.	The precipitation outlooks present the odds that long-term precipitation will be above or below normal for all locations across the contiguous 48 states. They are primarily useful in looking at areas already approaching or experiencing drought conditions.	Not as useful at forecasting drought prior to the onset of at least minimally dry conditions; no quantitative precipitation forecasts. Use the long-lead forecasts to produce drought forecasts (see Experimental Drought Outlook). Needs: 1) sufficient research and verification data; 2) greater ability to communicate the meanings and limitations of the forecasts to users; 3) flexibility to tailor forecasts to specific user needs, and/or educate users sufficiently so that they can obtain information pertinent to their interests from the forecasts.
Seasonal Drought Outlook	Technical assistance. A map depicting areas where drought is expected to persist, weaken, or intensify over the next 1 to 2 seasons. Largely based on the CPC long-range outlooks.	DOC--NOAA, NWS Climate Prediction Center	Available on the CPC Web site	N/A	Based on subjective interpretations of seasonal forecasts of precipitation and temperatures as well as model forecasts of soil moisture.
Western Region NWS Drought Program	Issuance of Water Supply Summaries by NWS offices when Drought Program in active status. Each Western Region office implements a Drought Program. The MIC (Meteorologist-in-Charge) of each office is designated as the Drought Information Officer (DIO) for that office's county warning area. The DIO works closely with the River Forecast Centers in monitoring and assessing drought conditions	DOC--NWS	General public. Also, the Water Supply Summaries include drought conditions for the entire state and serve as a primary source of briefing material for state and federal inquiries about the situation.	Less than 60% of normal precipitation for the season or the current water year (Oct-Sep) and/or water supply less than 60% of normal	N/A
National Streamgauging Program	Technical assistance to monitor streamflow, groundwater levels, and reservoir contents. Comparison with previous droughts, drought studies, and service on drought-emergency committees. Information and advice concerning hydrologic conditions.	DOI--USGS	Cooperators (partners) in the NSP, NWS, emergency managers, planning agencies, reservoir operators, media representatives and the public	N/A	N/A

Source: National Drought Policy Commission, "Preparing for drought in the 21st Century", Appendix B, (USDA's Office of Communications), May 2000.

TABLE D-3
Federal Assistance Programs—Response

Program	Federal Assistance	Agencies	Customers Served	Eligibility Criteria	Limitations
Emergency Watershed Protection (EWP)	Technical and financial assistance to undertake (with sponsors) emergency recovery measures to relieve imminent hazards to life and property created by natural disasters.	USDA--NRCS	Sponsoring local organizations (usually units of government)	FSA declares a drought.	Efforts must be defensible and sponsors must contribute a 25% cost-share.
American Indian Initiative	Technical assistance to individuals or community units in Indian country. Indian communities as well as Indian farms and ranches should have conservation plans developed and facilitation provided to address the rapid response.	USDA--NRCS, FSA, APHIS	Individuals on private lands belonging to recognized tribes and tribal governments	A nationally or regionally declared drought emergency or the intent to prepare drought contingency plans.	Indian lands are not all included in conservation districts, and field offices are not staffed adequately. Cultural differences may also hinder timely assistance and acceptance of that assistance
Emergency Community Water Assistance Grants	Financial assistance to the residents of rural areas that have experienced a significant decline in quantity or quality of water to obtain adequate quantities of water that meet the standards set by the SDWA (42 U.S.C. 300 f et seq.). Grants can be made to alleviate a significant decline in quantity or quality of the water available from water supplies in rural areas that occurred within two years of filing an application for assistance.	USDA--RD	Public bodies and private nonprofit corporations serving rural areas	Decline occurred within two years of the date of the application with RUS. Does not apply to grants for repairs, partial replacement, or significant maintenance on an established water system.	Grants cannot exceed \$500,000. Grants for repairs, partial replacement, or significant maintenance on an established water system cannot exceed \$75,000.
Public Assistance Program (Emergency Measures)	Financial assistance in the form of cost-shared grants; technical assistance	FEMA	State and local governments	Presidential Emergency or Major Disaster Declaration	In keeping with the agency's mission, this program provides for the general public's emergency needs directly related to drought: the need for food and for potable drinking water.
Small and Limited-Resource Farmers	Financial and technical assistance for conservation plans and rapid response that should address drought impacts and corrective actions.	USDA--NRCS, FSA, RD, CSREES, NASS	Small and limited-resource farmers	Because of being underserved, many believe they are too small to receive assistance.	Many needing help are not identified. Pride or distrust may limit the acceptance of help.
SBA Disaster Assistance Program	SBA offers financial assistance with low-interest working capital loans to small businesses and small agricultural cooperatives which have suffered substantial economic injury as a result of an agricultural production disaster. Agricultural enterprises are NOT eligible.	SBA	Small non-farm businesses and small agricultural cooperatives which have suffered substantial economic injury as a direct result of a declared agricultural production disaster	Declaration of agricultural disaster by the Secretary of Agriculture	Loan amount is limited to the amount needed to meet necessary financial obligations which the business could have met under normal conditions, but is unable to meet as a direct result of the disaster. Maximum loan amount is \$1.5 million. Only those businesses determined to be unable to obtain credit elsewhere are eligible.
Reclamation States Emergency Drought Relief Act of 1991, Title II	Under Title II, the Secretary is authorized to conduct studies to identify opportunities to conserve, augment, and make more efficient use of water supplies available to Federal Reclamation projects and Indian water resource developments in order to prepare for and better respond to drought conditions. The Secretary is authorized to provide technical assistance to states, local and tribal government entities to assist in the development, construction and operation of water desalinization projects.	DOI--USBR	Any of the 50 states and U.S. territories, including tribal, county, public, and private entities	Willingness expressed by a state, tribe, county, public or private entity in developing a comprehensive drought contingency plan; activities are primarily limited by funding.	Expand authority to allow financial incentives to be provided to stakeholders. Customers have also expressed concern that a specific fund is not available to fund drought contingency plan implementation.

Source: National Drought Policy Commission, "Preparing for drought in the 21st Century", Appendix B, (USDA's Office of Communications), May 2000.

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