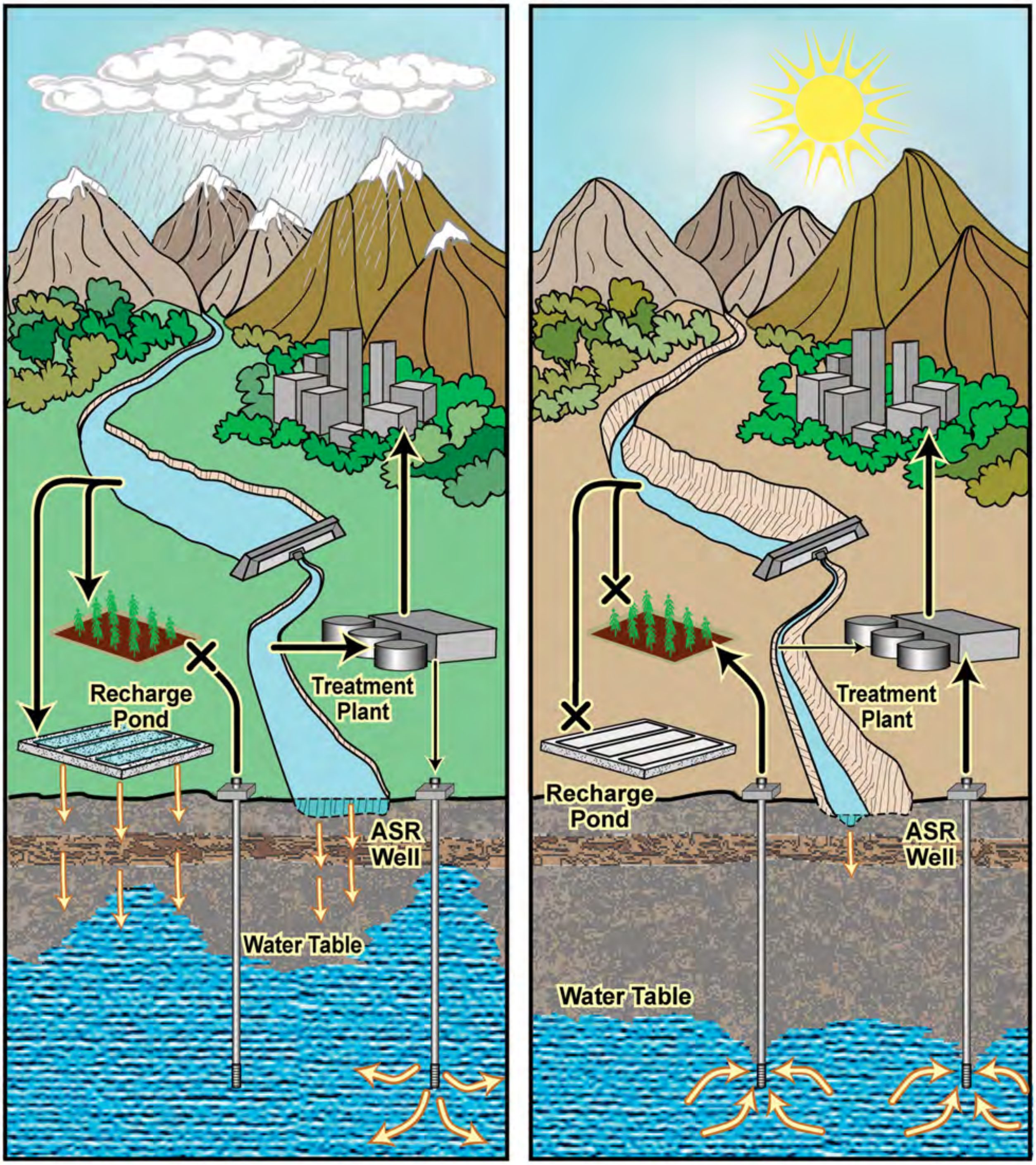
Conjunctive Management of Surface and Ground Water in Utah



July 2005

STATE OF UTAH
NATURAL RESOURCES
Division of Water Resources

UTAH STATE WATER PLAN

CONJUNCTIVE MANAGEMENT OF SURFACE AND GROUND WATER IN UTAH

July 2005

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

This document is also available online at: www.water.utah.gov/waterplan

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PREFACE

One of the major responsibilities of the Utah Division of Water Resources is comprehensive water planning. Over the past 15 years, the Division has prepared a series of documents under the title "Utah State Water Plan." This included a statewide water plan and an individual water plan for each of the state's eleven major river basins. Preparation of these plans involved major data collection programs, extensive inter-agency cooperation and public outreach. Much was learned through this process. State, local, and federal water planners and managers obtained valuable information for their programs and activities and the public provided meaningful input to improve the state's water planning process.

This document is the latest in the "Utah State Water Plan" series and is intended to introduce and promote conjunctive management with aquifer storage and recovery in Utah. It describes some of the problems facing Utah's ground water resources and shows how conjunctive management offers proven methods to mitigate some of these problems and thus more fully utilize the available water supply. In addition to providing a resource to the general public, this document is intended to encourage professionals in the water supply industry to investigate and implement these concepts. It can also help them navigate some of the legal and institutional requirements for actual projects. Another intent is to encourage community and government leaders to facilitate projects through such actions as setting aside lands that are uniquely situated to allow underground water storage. This document explains conjunctive management and aquifer storage and recovery concepts, provides examples of past and present projects, and identifies specific opportunities for future projects. Finally, it provides a guide to project implementation and a valuable list of related information sources to assist in putting these concepts into practice.

In addition to this printed document, a "pdf" version is available on the Internet at the Utah Division of Water Resources, State Water Plan web page www.water.utah.gov/waterplan/. Such access facilitates better planning and management at the state and local level. Web pages also provide 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.

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EXECUTIVE SUMMARY

Utah's surface water and ground water are among its most valuable resources. Water delivered to farms, homes, businesses and other enterprises is essential to the life, health and productivity of Utah's citizens. Rapid population growth and the ever-present threat of drought have brought renewed emphasis to water supply issues in recent years. As a result, water managers and planners are seeking innovative ways to meet future water needs and avoid serious problems. Conjunctive management has received increased attention as a strategy that has the potential to help alleviate problems.

Conjunctive Management of Surface and Ground Water in Utah helps satisfy the need for more detailed information about conjunctive management strategies and its potential to help meet growing demand in Utah and help mitigate other ground water problems. It highlights the successful implementation of various conjunctive management projects throughout the United States and in Utah, and focuses on the important role this technology can play in Utah's future. This document will be a useful guide and reference for local and state decision-makers, water providers, and government agencies interested in conjunctive management. It will also help those in the general public who wish to make contributions to conjunctive management decisions being made by local, state and federal government officials.

The following paragraphs summarize the main points of each chapter:

CHAPTER 1
INTRODUCTION

During the period of 1990 to 2000, Utah grew at the fourth fastest rate of any state in the nation. This growth, coupled with several years of prolonged drought, has brought water supply issues to the forefront of public attention. Because most of Utah's readily available water supplies are already developed, and the population continues to increase, water suppliers will need to implement innovative water management and development strategies to meet future water demands. Conjunctive management is one strategy that has potential to help meet Utah's growing water needs.

Conjunctive management is the coordinated and combined use of surface water and ground water that results in the optimal use of both resources. Elements of conjunctive management include:

- Use more surface water and less ground water when surface water is available during wet periods. (Wet periods include annual spring snowmelt runoff and consecutive years of above-normal precipitation.)
- Store unused surface water above ground and underground during wet periods.
- Take water out of surface and ground water storage during dry periods. (Dry periods include annual summer months and consecutive years of below-normal precipitation.)
- Use more ground water during dry periods when insufficient surface water is available in streams and reservoirs.

Although conjunctive management projects do not always involve storage of excess surface water underground, intentionally recharging aquifers when water is available and recovering it when needed is a common and critical element of most conjunctive management projects. Although this practice, known as aquifer storage and recovery (ASR), is common in many parts of the United States and the world, it has been used only a few times in Utah.

CHAPTER 2
ISSUES RELATING TO AQUIFERS

In addition to growing water demands and drought, there are other reasons for Utah water suppliers to implement conjunctive management strategies. These include the steady decline of ground water levels in several of the state's aquifers, which, if left unchecked, could have serious consequences. These include excessive ground water depletion leading to aquifer compaction and subsidence, surface cracking, damage to buildings and other infrastructure; intrusion of brackish or contaminated ground water into drinking water aquifers; reduced flows to wetlands and other valuable wildlife habitat; and increased costs to pump ground water.

Ground water aquifers in Utah are naturally recharged by precipitation and subsequent runoff in rivers and streams, which infiltrates into the ground. Coarse-grained materials located at the mouth of canyons and near the mountain fronts serve as the primary recharge zones for many of the state's aquifers. Declining ground water levels are the result of many human activities. Diversion of water from streams, urban development in river deltas and other recharge zones, and over pumping all cause ground water levels to decline. In addition to these activities, ground water rights in several aquifers in the state have been over-appropriated, and, if fully developed, could cause ground water levels to decline to critical levels. Although current ground water withdrawals exceed estimated rates of natural recharge in only a few areas, the potential for this exists in several additional areas.

Conjunctive management of surface and ground water can be employed to help stabilize ground water levels and avoid associated problems. While the opportunities for conjunctive management are limited in some areas experiencing problems, this strategy has the potential to improve the situation or avoid problems in other areas. Water managers and policy-makers should seriously consider the benefits of conjunctive management strategies when addressing ground water issues.

CHAPTER 3
CONJUNCTIVE MANAGEMENT: STRATEGIES AND SOLUTIONS

There are two main conjunctive management strategies that can be employed. One strategy is commonly known as conjunctive use—the deliberate, planned and coordinated use of surface and ground water resources (without an aquifer storage and recovery component). Many individual water suppliers that hold significant surface and ground water rights already practice conjunctive use within their own water system by using surface water to meet base demands and ground water wells to meet peak demands. The benefits of this strategy could be greatly increased by several water suppliers within a region jointly coordinating the use of both resources. This helps to optimally utilize all available water resources.

The other main conjunctive management strategy includes conjunctive use, but also employs the concept of aquifer storage and recovery (ASR). This entails intentionally storing surface water in underground aquifers in order to extract it later when needed. It is not always possible to build surface reservoirs and treatment facilities large enough to capture all the available surface water runoff; therefore, when excess surface water is available, ASR can be employed. ASR may also be a more viable option in areas where the water users are unable to work together to employ conjunctive use strategies.

One ASR method involves placing water in surface spreading basins in the primary recharge areas above the target aquifers and later withdrawing that water from locations in the aquifer influenced by the recharge. The best locations for surface spreading include river deltas and at the mouth of the canyons near a water source of sufficient size. A second ASR method employs drilling wells and injecting water into the target aquifer for storage. This ASR well and other wells may then be used to withdraw the water that has been stored underground.

CHAPTER 4
PAST AND PRESENT CONJUNCTIVE MANAGEMENT EXPERIENCES

Conjunctive management has a fairly long history throughout the United States. Water suppliers in Utah who hold significant surface water and ground water rights have employed small-scale conjunctive use for many years.

Investigations into ASR began in Utah as early as 1936. These pioneering studies took place in Davis and Salt Lake counties and demonstrated the feasibility of the concept and laid the groundwork for subsequent projects. The first permanent project was constructed in 1995 in the Salt Lake Valley by the Jordan Valley Water Conservancy District. Since then, viable ASR projects have been implemented in Brigham City and Washington County.

In addition to these existing projects, Weber Basin Water Conservancy District has constructed a pilot project near the mouth of Weber Canyon and Metropolitan Water District of Salt Lake and Sandy is currently planning an ASR project near the mouth of Big Cottonwood and Little Cottonwood canyons.

CHAPTER 5
PROSPECTIVE CONJUNCTIVE MANAGEMENT PROJECTS

The Utah State Legislature became interested in conjunctive management in 1977 during one of the most severe single-year droughts in the state's history. During the legislative session that year, the legislature directed the Utah Division of Water Rights to conduct a feasibility study on artificial ground water recharge along the Wasatch Front. As a result of this legislation, three studies were prepared that identified viable recharge sites from Weber County in the north to Utah County in the south. These studies determined that ASR was feasible, but was not needed at that time due to the availability of other cheaper water supplies. However, these studies still recommended that action be taken to preserve available recharge sites for projects that would be needed in the future. Unfortunately, these recommendations were not followed. As a result, many of the sites identified are no longer available.

The Utah Division of Water Resources believes that conjunctive management is a viable technology that will eventually become more common in Utah. The Division has prepared a list of areas throughout the state that it believes have potential. These areas were determined by the presence of the following conditions: rapid population growth, declining ground water and available surface water supplies. Local water providers interested in pursuing projects in these and other areas will need to carefully consider a variety of issues and local conditions in order to determine the feasibility of such projects.

CHAPTER 6
PROJECT IMPLEMENTATION

Conjunctive management projects can be simple or complex. They all require detailed investigation and planning in order to be implemented successfully. Large conjunctive use projects require coordination of surface and ground water deliveries across jurisdictional boundaries and also may require interconnections between multiple systems in order to fully optimize resource use. Typically, water suppliers that utilize surface water are not the same as those who utilize ground water, which can make it difficult to coordinate management. Such efforts would require careful negotiations and written agreements between all participating entities.

While ASR projects are more technologically complex, they typically do not require the broad participation and cooperation between multiple water supply entities that large conjunctive use projects necessitate. In order for ASR projects to be successful, however, a carefully planned and phased approach is recommended. These phases include: (1) Preliminary Feasibility Assessment and Conceptual Design; (2) Field Investigations and Test Program; and (3) Full-scale Project Development.

ASR projects are subject to regulatory requirements. In 1991, the legislature enacted the Ground Water Recharge and Recovery Act. This act requires that those proposing to store water in an aquifer for subsequent withdrawal obtain a recharge permit and a recovery permit. Also, any stream alteration or new well required by the project will need an associated permit. ASR projects are also subject to the normal water quality regulations that prohibit the pollution of the state's water bodies. While the requirements for surface recharge may be minimal, water put into the aquifer through ASR wells must be treated so as to not degrade the native ground water. Careful monitoring of water quality is required. Modeling of ground water movement may also be necessary to ensure that major project design assumptions prove correct.

There are many funding sources available to assist water suppliers who wish to implement conjunctive management projects. Congress, as part of the Central Utah Project Completion Act of 1992, authorized $10 million for conjunctive management projects. As of July 2005, $8 million of this funding was still available for projects located in Weber, Davis, Salt Lake, Utah and Wasatch counties. These funds require appropriation by Congress. Application for these funds is handled by the Utah Division of Water Resources, and funds are administered by the Central Utah Water Conservancy District. Other federal funding sources include the Bureau of Reclamation, Army Corp of Engineers, and the Department of Agriculture. State of Utah funding sources include the Board of Water Resources, Community Impact Board, and Drinking Water Board.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

While conjunctive management strategies are not completely new to Utah, only a handful of projects have been implemented. In light of the state's continuing population growth, the constant threat of drought, ground water level declines, over-appropriated ground water basins and all the associated problems and challenges, broader adoption of conjunctive management strategies makes a lot of sense.

The Utah Division of Water Resources recommends that local leaders and water suppliers consider conjunctive management strategies as an option to help them meet their future water needs and avoid ground water problems. While conjunctive management may not be able to solve all these problems or be implemented in every area, it can and likely will, play an important role in some areas. Local leaders need to recognize the value of primary aquifer recharge zones and protect the most sensitive areas from unnecessary development. Flood retention reservoirs and debris basins are appropriate structure to locate in these areas, as they will enhance the natural recharge and allow excess runoff to be stored underground for future use.

The Utah Division of Water Resources also recommends that a web page be developed, which contains links to ground water data available from various agencies on the Internet. Once completed, this web page would become a valuable portal to essential data and other technical information that is necessary to begin a conjunctive management project. The Utah Geological Survey is willing to develop and maintain this web page.

1

INTRODUCTION

There is nothing new about the need for water in Utah. What is new is the ever-increasing strain being put on the fixed amount of water naturally available. After 150 years of continuous population increase, in most cases all but the most difficult water sources have been developed. Adding to this challenge is the fact that surface and ground water rights have been granted in excess of the amount of water physically available. As a result, ground water pumping has exceeded natural recharge resulting in ground water level declines in several areas of the state. In some cases this has caused problems for the aquifer. Utah's latest drought has served to heighten awareness of these issues.

This combination of factors has prompted several water suppliers in the state, and the Utah Division of Water Resources, to investigate conjunctive management – the coordinated and combined use of surface water and ground water – to better manage water supplies in order to meet growing needs. In addition, aquifer storage and recovery allows existing water sources to be more fully utilized by using underground aquifers to store excess water supplies until needed. Conjunctive management cannot solve every water supply problem. However, in specific locations and under the right conditions it may be beneficial. When properly applied, this technology improves water system efficiency, increases the total amount of usable water, and makes the overall water supply more reliable. Aquifer storage and recovery can also help mitigate aquifer damage. Details of the situation and these concepts are discussed in this report.

POPULATION GROWTH AND WATER DEMAND

As would be expected, increased population causes increased water demand. This was true in the past and will continue to be true in the future. As indicated by the slope of the lines in Figure 1, Utah's population grew at a relatively modest pace during the first 100 years of the state's history (1850 to 1950). During the next 50 years (1950-2000), the growth was much more rapid. The latest population projections from the Governor's Office of Planning and Budget predict that Utah's population will more

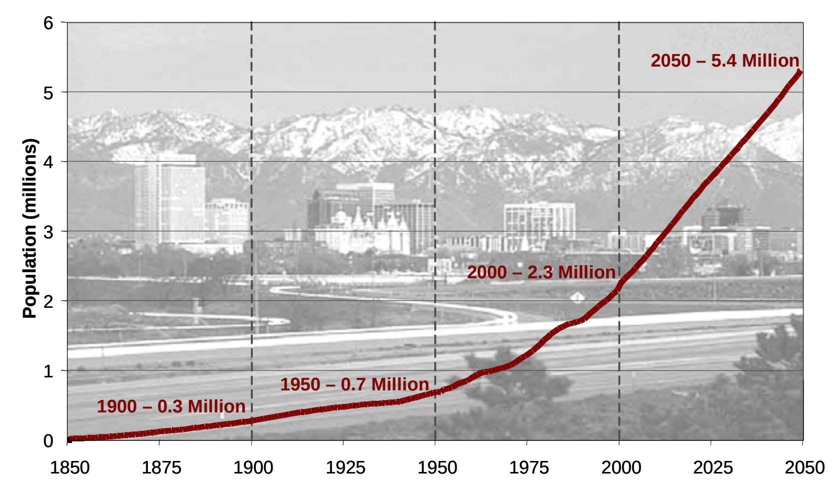


Figure 1, Utah Population Trend and Projection

Source: Utah Governor's Office of Planning and Budget, 2005 than double from 2.3 million in 2000 to about 5.4 million in 2050.

A comparison of the state's projected population growth through 2050, with historic population figures for each of the past half-century increments, shows a significant trend. Table 1, column 4, shows the average annual population increase for each of the four, 50-year increments depicted graphically in Figure 1. Both Figure 1 and Table 1 illustrate the rate at which population has increased in the state during those time periods. Although the yearly rate of increase shown in column 5 has actually decreased from 6.6 percent per year to 1.8 percent per year, the average annual population increase has risen dramatically. The average annual population increase during the current 50-year period (62,708 people/year) is 11.8 times greater than the first 50-year period (5,305 people/year). This steadily increasing growth rate presents a major challenge to meet water demands. Water suppliers need to invest in equipment and distribution systems at a much faster pace today than in the past.

Rankings determined by percentage change in population based on 1990 and 2000 Census figures for states in the U.S.

Figure 2, The Nation's Five Fastest Growing States and Growth Rate Rankings of Other Western States

Source: Census 2000

By way of perspective, during the decade from 1990 to 2000, Utah was the fourth fastest growing state in the country (see Figure 2). In April 2005 the U.S. Census Bureau ranked Utah fifth in the nation for growth rate based on population projections for 2000 to 2030. Utah is part of the nations fastest-growing region, the Mountain West, expected to grow by 65 percent during that time. By contrast, the nation is expected to grow by 29 percent during that time.

Figures 3 and 4, and the related discussions, describe the type and amounts of water withdrawals for the

TABLE 1
Utah Rate of Population Increase Over Time

1 Year	2 Total Population	3 Population Increase During 50-year Interval	4 Average Annual Population Increase People per year	5 Increase Rate Percent per Year
1850	11,380			
		265,369	5,307	6.6 %
1900	276,749			
		412,113	8,242	1.8 %
1950	688,862			
		1,544,307	30,886	2.4 %
2000	2,233,169			
		3,135,398	62,708	1.8 %
2050	5,368,567			

Population data from Utah Governor's Office of Planning and Budget, January 2005.
Analysis by Utah Division of Water Resources, May 2005.

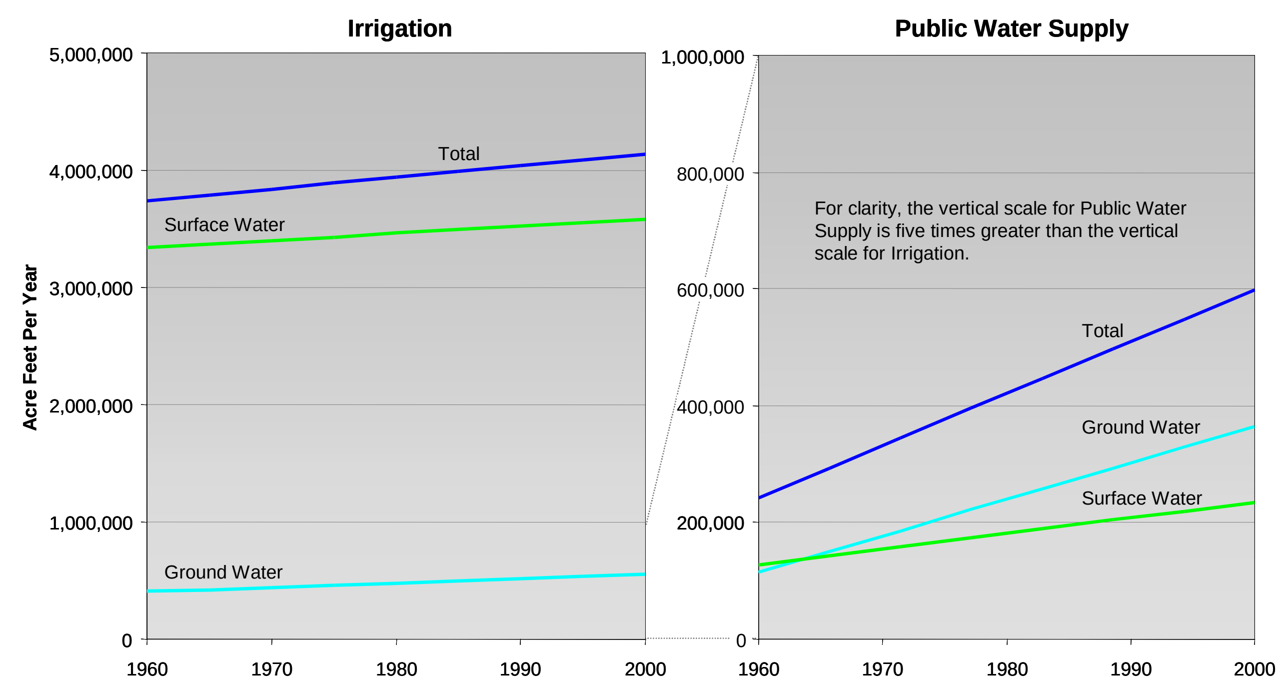


Figure 3, Utah Irrigation and Public Water Supply Withdrawal Trends, 1960-2000

Source: Data from USGS, 2000, analysis from Utah Division of Water Resources, 2005.

state of Utah. The data was derived from a series of reports titled Estimated Use of Water in the United States published every five years by the U. S. Geological Survey.

In 2000, the latest year data is available, total water withdrawals for the year in Utah were 5,561,198 acre-feet. Of this, 5,333,705 acre-feet (96%) was freshwater while 227,494 acre-feet (4%) was saline. Table 2 shows the breakdown of freshwater withdrawals. The saline withdrawals break down to 221,803 acre-feet (97.5%) for mineral extraction and 5,691 acre-feet (2.5%) for industrial purposes.

Water conservation is a very important principle that began to be applied generally nationwide and in Utah in about 1980. The result was an immediate and continuing reduction of both surface water and ground water withdrawals. Conservation and its benefits continue to this day.[1] All of the following analyses include the positive effects of water conservation in Utah.

Figure 3 shows water withdrawals from 1960 to 2000 for irrigation and public water supplies in Utah. Together these account for the majority (94.5%) of the freshwater withdrawals in the state. The intent of this figure is not to show specific data points for each year, but to show the overall trends in water supply withdrawals based on those data. Although actual data points fall above and below the trend lines and the slope of total irrigation water use has undoubtedly flattened in recent years, this graph shows the general direction of water demand. It also shows how much of that demand has been satisfied by surface water and ground water from 1960 to 2000. The slopes of the trend lines indicate how fast water withdrawals are increasing and are summarized in Table 3. The table shows the rate at which the various categories and totals are increasing for the state and the amounts of additional water that must be supplied each year.

Figure 3 and Table 3 provide an important insight into the trends in total amount of water contained in underground aquifers. The increasing demand for

TABLE 2
Freshwater Withdrawals in Utah During 2000

Category	Acre-feet	Percent
Irrigation	4,324,050	81.1 %
Public Supply	714,700	13.4 %
Aquaculture	129,946	2.4 %
Thermoelectric	69,678	1.3 %
Industrial	47,833	0.9 %
Mining	29,462	0.6 %
Domestic	18,036	0.3 %
Total	5,333,705	100.0 %

Withdrawal data, including categories, from U.S. Geological Survey, 2000.
Analysis by Utah Division of Water Resources, 2004.

surface water has been satisfied by diverting more water from streams. Overall streamflow reduction results in less water being available to recharge ground water every year, especially for river delta aquifers. Simultaneously, ground water withdrawals are increasing every year. In other words, less water enters the aquifers and more water is taken out of the aquifers every year. This "double negative" results in an overall withdrawal of more than 9,892 acre-feet per year in the total amount of water in Utah's aquifers. Considering the rate of population increase is itself increasing, this overall rate of decline in aquifer water volume will also increase with time. Such volume declines will occur primarily where population increases take place. Details of the mechanisms involved and the impacts to ground water levels in specific instances will be discussed throughout Chapter 2.

Figure 4 indicates that from 1960 to 2000 the percentage of the state's irrigation withdrawals derived from ground water averaged about 12 percent. This is lower than the national average of 37 percent for that same time period. As shown, this comparison indicates Utah uses a relatively low percentage of ground water to provide irrigation withdrawals. Further, the percentage of the irrigation withdrawals derived from ground water has not changed much over time. Note that this discussion is for the state as a whole. There are areas in Utah, such as Beryl-Enterprise and Milford, where ground water provides a high percentage of the water for irrigation. Such areas will need to give the attention needed to manage and recharge the aquifers to allow their use for the longest possible time.

Figure 4 also indicates that from 1960 to 2000 the percentage of the state's public water supply derived from ground water averaged about 55 percent. This is higher than the national average of 36 percent for that same time period. As shown, this comparison indicates Utah relies on ground water to provide a significant portion of public supplies. Most rural communities rely on ground water exclusively.

WATER SUPPLY AND DROUGHT

Utah receives the second lowest amount of precipitation of all the states in the country, averaging only 13 inches per year. Whether water demands are met using surface water or ground water, the ultimate source of both is precipitation in the form of rain and snow. Reduction or interruption of that natural water supply, caused by drought, has an immediate negative impact. The longer the drought, the greater the impact. Hence, some discussion of drought is appropriate.

If Utah's limited precipitation were available evenly and uniformly from year to year, it would be much easier to match supply with demand. Unfortunately

TABLE 3
Water Withdrawal Rate Increases For Surface Water and Ground Water For Irrigation and Public Supply in Utah, 1960 to 2000

Withdrawal Type	Surface Water	Ground Water	Total
Irrigation	6,124 AF/Year	3,641 AF/Year	9,765 AF/Year
Public Supply	2,666 AF/Year	6,251 AF/Year	8,917 AF/Year
Total	8,790 AF/Year	9,892 AF/Year	18,682 AF/Year

Withdrawal data from U.S. Geological Survey, 1960 to 2000.
Analysis by Utah Division of Water Resources, 2005.

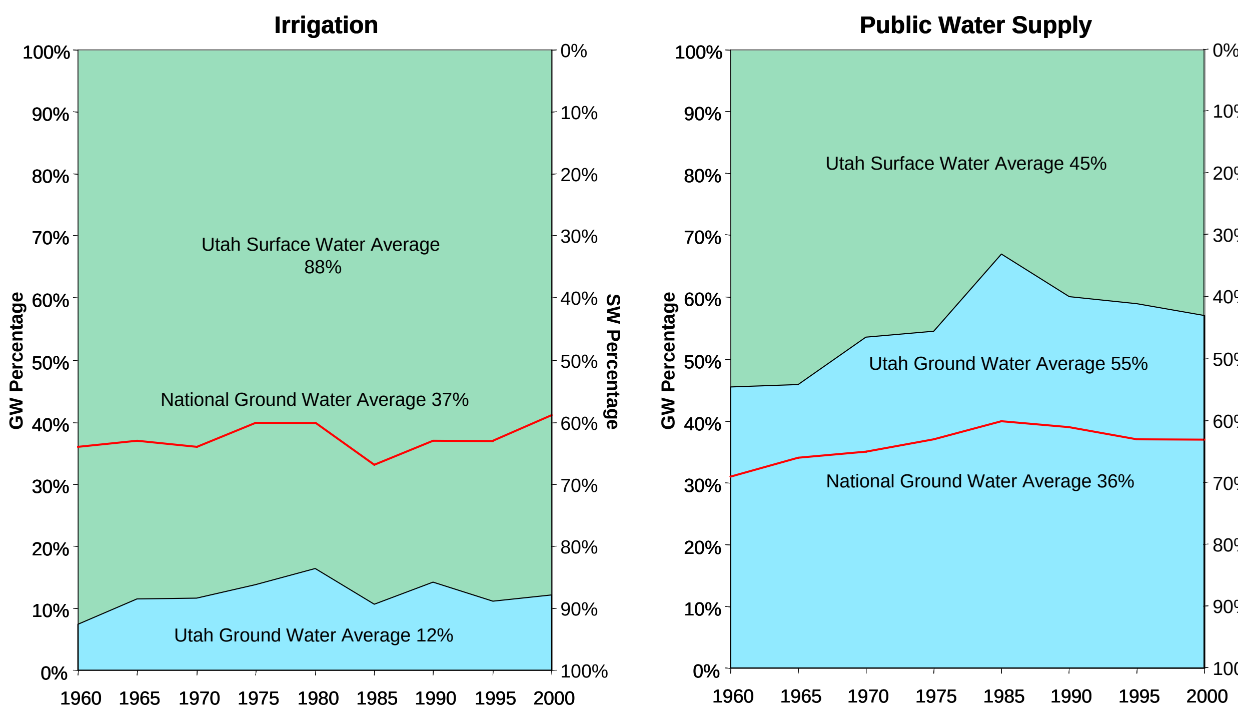


Figure 4, Percentage of Irrigation and Public Water Supply Withd rawals From Surface Water and Ground Water

Source: Data from USGS, 2000, analysis from Utah Division of Wat er Resources, 2005.

precipitation patterns are inconsistent—wet periods of varying length are interspersed with dry periods of different length. While wet periods present few problems in terms of water demand, the dry or drought periods cause significant challenges. During droughts, demand may exceed supply and stored water is consumed to meet needs. Since drought is an inescapable part of water management, a brief description of its nature and effects on water supply is provided.

The National Climatic Data Center has divided Utah into seven climatic regions as shown in Figure 5. Precipitation, temperature, and time are combined to develop the Palmer Hydrologic Drought Index for each region. Figure 6 is a plot of this index for the Northern Mountains region and shows the nature of drought patterns. Other climatic regions in the state exhibit similar patterns. Positive numbers indicate wet years shown in blue. Negative numbers indicate dry years shown in brown. The Palmer Hydrologic Drought Index is simply a record of past history and is not a reliable predictor of specific future events. However, several insights can be gained by analyzing this index.

- Precipitation patterns do not follow any repeating periodic time intervals.
- A period of wet years is typically followed by a period of dry years.
- The length of wet and dry times is variable.
- There are no indicators of when a pattern change might be imminent.

Drought, a prolonged period of dryness, has numerous negative impacts. An examination of drought in the state using the Palmer Hydrological Drought Index is contained in Appendix 1, Brief Analysis of Drought in Utah. Results of this analysis from 1895 are summarized as follows.

- Every region in Utah experiences drought.

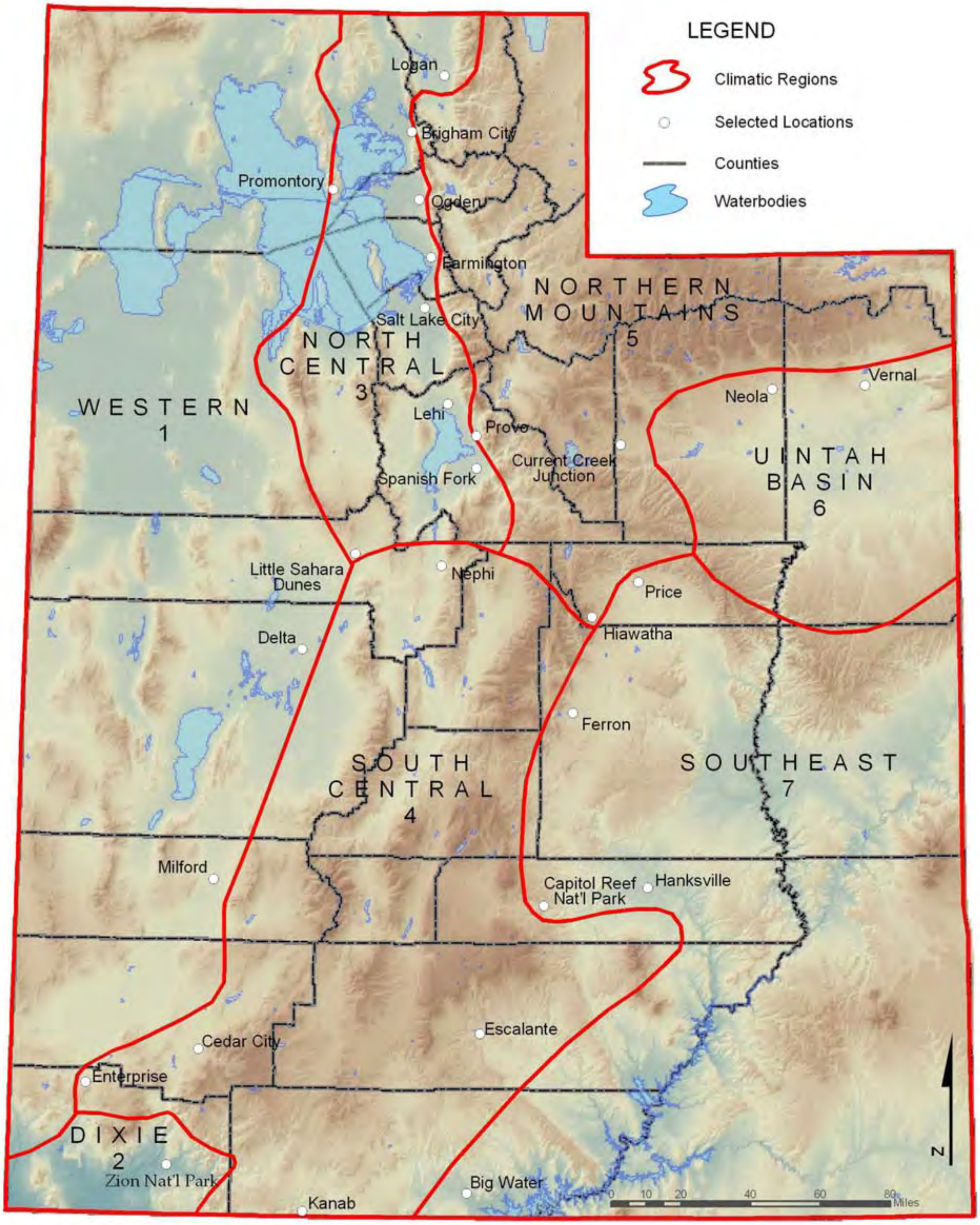


Figure 5, Utah Climatic Regions

Source: National Weather Service, Salt Lake City, 2003

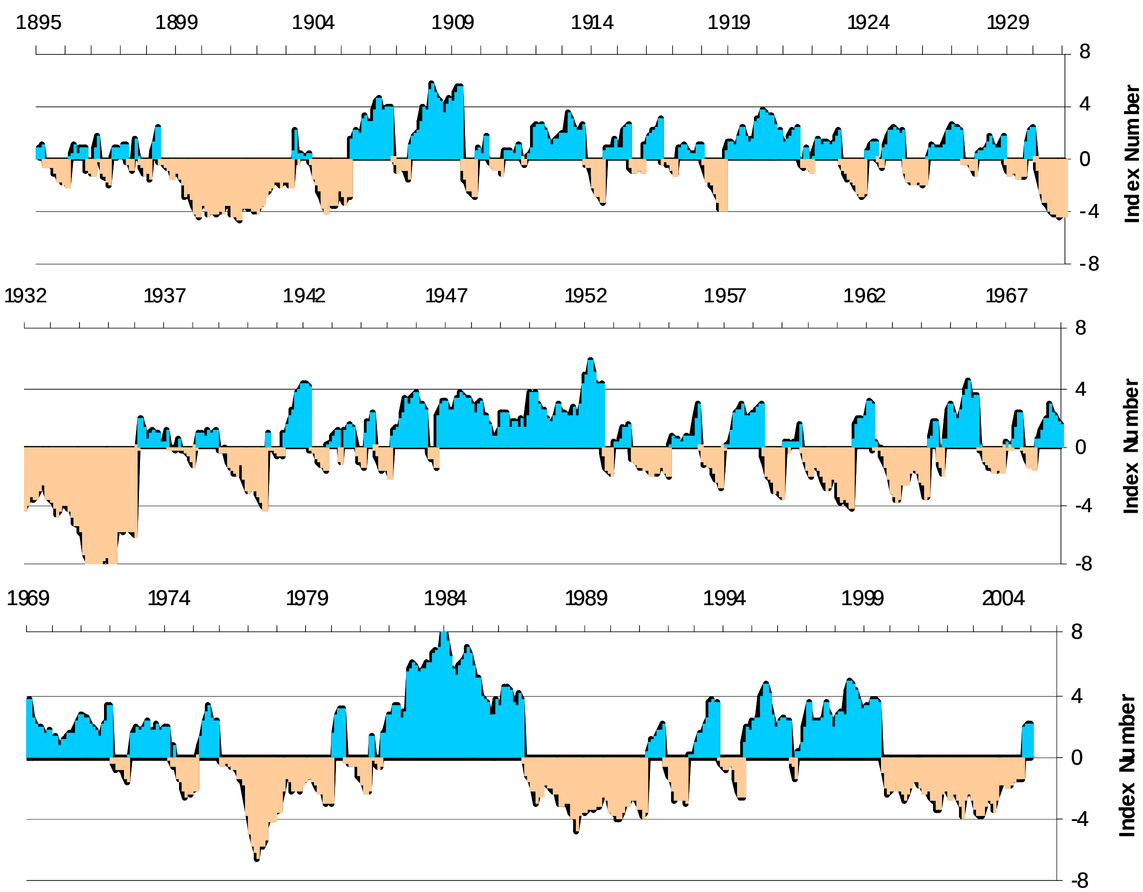


Figure 6, Palmer Hydrological Drought Index for the Northern Mountains of Utah

Source: Utah Division of Water Resources, 2005

- During most drought periods, most regions of the state are experiencing drought simultaneously.
- The average drought lasts from 5 to 7 years, depending on climatic region.
- The five longest droughts lasted from 8 to 13 years, depending on climatic region.
- The interval between extended droughts is quite variable and cannot be predicted.

Some additional observations regarding drought are relevant to this discussion.

- Records of past droughts give some insight into future droughts.
- Population increases result in each succeeding drought impacting more people.
- Therefore, the impact of drought increases with time.
- Given the limited water supply and population increases, the problem of meeting demand during drought increases with time.

These analyses and observations suggest water suppliers should use all possible methods to optimize water supplies including conjunctive management. Droughts will occur and it is best to prepare now for the next one.

CONJUNCTIVE MANAGEMENT OF WATER

After more than 150 years of expansion, most of the inexpensive water sources in Utah have been developed. With rising water demands, variability of the water supply, drought, and increased environmental concerns, it is clear that achieving the greatest efficiency of water use is essential. Conjunctive management of surface water and ground water can help to achieve this goal. Several factors argue for adoption of conjunctive management; these include:

- Increasing water demand.
- Fewer opportunities to build surface reservoirs.
- Declining ground water levels due to ground water mining.
- Need to maintain minimum stream flows for wildlife and their habitat.

Occasionally, the managing of surface water and ground water has not been a fully coordinated. Sometimes each has been used independently, without consideration of their inter-connection. Using surface water without considering ground water, or vice-versa, is like having a joint checking account and both parties withdrawing funds without discussing it with one another. The risk of overdrawing the account is very high. Likewise, surface water and ground water need to be used and managed together so as not to overdraw the total resource.

In nature, ground water and surface water are very much connected. Figure 7 depicts this along the Wasatch Front. In the mountains, rain and snowmelt contribute to streamflow, and some of all three of those waters soaks into the ground. Thus, the mountains are a ground water recharge area. Sometimes, when streamflow diminishes later in the year, that ground water can flow back into the stream. Sometimes water will leave a stream at one location to become ground water. Then ground water will re-enter the same stream at another location. Thus, at one time, or location, the stream is losing water while at another time, or location, the same stream is gaining water.

When the mountain stream reaches the river delta, porous sand and gravel allows water to be lost from the stream into the ground. In addition, precipitation falling on the mountains at higher elevations, soaks into the ground and flows underground to the delta aquifer. Precipitation also falls directly onto the porous recharge areas along the benches. All of these replenish the delta aquifers from which pumped wells obtain water. Water entering the ground at higher elevations creates flow in the aquifer under some pressure. This often results in ground water finding its way to the surface to become a spring. In addition, a well drilled into an aquifer having enough pressure will allow water to flow without pumping, this is known as a flowing or artesian well. See Appendix 2, Ground Water and Aquifer Concepts, for a more detailed discussion and diagram of these conditions.

Changes in either the surface water or ground water component of the system will affect the other component. One example would be diversions above the delta would reduce flows in the stream resulting in less recharge of river delta aquifers. Conversely, water stored in a reservoir above the delta might release water later in the season and potentially increase recharge to the delta aquifer. Another example would be pumping of wells resulting in diminished flow to nearby springs and artesian wells. Pumping wells can also affect other nearby wells. Both the diversions reducing stream flow and well pumping reducing spring flow could adversely impact stream riparian areas and wetlands. Effective management of the whole system requires consideration of both resources. Utah water law, especially with respect to water rights, fully recognizes the interconnection of surface water and ground water. Also, the State Engineer has developed ground water management plans including the acknowledgement that, "Because of their interrelationship, ground water and surface water systems need to be jointly managed as one system."[2]

Water storage in Utah can be thought of as including three reservoir systems: (1) mountain snowpack, (2) surface reservoirs, lakes, and conveyance systems, and (3) aquifers. Precipitation in the form of snow is stored in the mountains in winter and, when it melts, is captured by dams for use during the dry season. Water storage and delivery systems, namely reservoirs and canals, have been designed largely around the historical snowpack. Aquifers have played a less formal and less recognized role. However, aquifers can and should be used as underground reservoirs and managed accordingly.

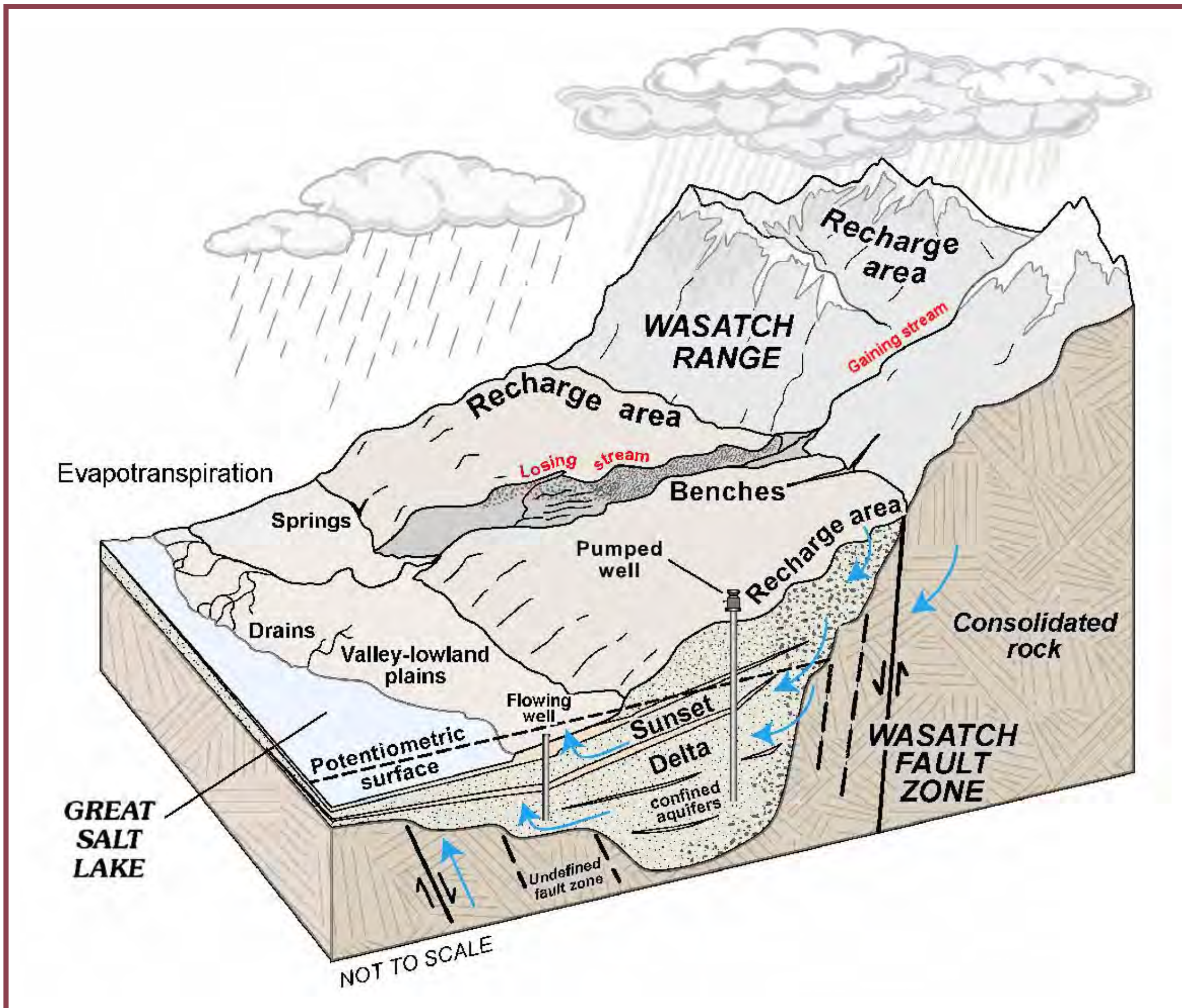


Figure 7, Ground Water and Surface Water Are Interconnected
Source: Utah Geological Survey, 2004, modified from Clark, et. al. 1990.

Definition of Conjunctive Management[3]

In its broadest definition, conjunctive management is the coordinated and combined use of surface water and ground water. It involves using more surface water and less ground water when surface water is available during wet periods. Unused surface water is stored, above ground and underground, during wet periods. Wet periods include the annual spring season snowmelt and consecutive years of above-normal precipitation. Conversely, less surface water and more ground water is used during dry periods when surface water supplies are reduced. Water previously stored, above ground and underground, is taken out of storage during dry periods. Dry periods include the annual summer months and consecutive years of below-normal precipitation. The key point is that unused surface water is intentionally stored above ground and underground in order to have it available when it is needed. This can be accomplished on an annual basis by storing water in the spring and withdrawing it in the summer. It can also be accomplished on a year-to-year basis by storing water during a wet year (or consecutive wet years) and withdrawing it during a dry year (or consecutive dry years). Such coordinated management can change the timing and location of water use to result in greater efficiency. It transfers water from the high supply season to the high demand season. Refer to the cover of this document for a graphical illustration of conjunctive management.

Conjunctive management is intended to increase the available water supply of a region and improve the reliability of that supply. It may be implemented to meet other objectives as well. These include reducing ground water mining and land subsidence, protecting water quality, and improving environmental conditions. It encompasses full utilization of all possible water sources in creative ways that are unique to the location where the water is needed, such as a surface drainage basin or ground water basin.

The terms Conjunctive Use and Aquifer Storage and Recovery (ASR) have both been used to describe storing water underground and later extracting it. This publication, along with many others, uses the term conjunctive management, which is a broader term. "Management" encompasses more than just using water and better describes the overall process involved. Moreover, conjunctive management strategies without ASR have been developed and are presented in the second section of Chapter 3. Aquifer storage and recovery is an important part of conjunctive management and is emphasized in this publication.

There are several components common to conjunctive management projects:

- Use surplus surface water when it is available to increase the amount of ground water in storage. Such recharge may occur through surface spreading, or by using ASR wells. The surplus surface water used for recharge may be local runoff, imported water, stored surface water, or treated wastewater. Recharge water sources and quality will be discussed in the Sources of Aquifer Recharge Water section of Chapter 3.
- Reduce surface water use in dry years or dry seasons by switching to ground water. This use of the stored ground water may take place through direct extraction and use, pumping back to a conveyance facility, or through exchange with another water supply. The aquifer is operated like any other reservoir, alternately filling it and depleting it.
- Implement an ongoing monitoring program to evaluate operations and allow water managers to respond to changes in ground water, surface water, or environmental conditions that could violate management objectives or impact other water users.
- Implement each program for a given location, typically a ground water basin, to deal with the issues of that location.

The Utah Division of Water Rights has used a coordinated approach to managing surface water and ground water for some time. There are ground water management plans for 12 regions in the state. These plans are discussed in the Water Rights Considerations section of Chapter 2.

NOTES

[1] Estimated Use of Water in the United States in 2000, U.S. Geological Survey Circular 1268, 2004, page 41.

[2] http://nrwrt1.nr.state.ut.us/wrinfo/policy/ground.htm , quoted from the Cache Valley Ground Water Management Plan, page 2, November 8, 2004.

[3] These paragraphs are modified from the California Department of Water Resources, *California's Groundwater, Bulletin 118, Update 2003,* (Sacramento: 2003) to fit this publication.

2

ISSUES RELATING TO AQUIFERS

The ground water available in Utah's aquifers is a significant source of water in the state's arid climate. While ground water supplements available surface water in many areas of the state, it is the primary source of water in some areas. Ground water is a valuable source of high-quality drinking water for almost every community in the state. Because of the significance of ground water to Utah's citizens, it is important to understand the condition of the state's aquifers and the problems that can occur if they are not managed properly. This chapter discusses the condition of Utah's aquifers and the issues associated with their management. Topics discussed include the following: reservoirs and ground water, river delta recharge, canals and irrigation, declining ground water, consequences of declining ground water, and water rights problems.

An aquifer is an underground geologic formation or structure that stores water and/or transmits it to wells and springs. The term "aquifer" is usually restricted to those water-bearing structures capable of yielding water in sufficient quantity to constitute a usable supply.[1] The physical characteristics of aquifers are complex and govern the availability and movement of ground water. The types of aquifers found in Utah are shown in Figure 11. Although this chapter does not require a thorough understanding of all the technical details related to ground water, the reader may wish to become more familiar with these and other concepts by reviewing Appendix 2, Ground Water and Aquifer Concepts.

It is important to realize that ground water is derived solely from precipitation that soaks into the ground or otherwise percolates into the subsurface from lakes, rivers and other water bodies. Some of the precipitation percolates down through the ground to replenish the aquifers from which ground water is pumped. Ground water levels in several areas of the state are declining. Ground water declines in some of these areas are the result of pumping that exceeds natural recharge. In these areas, water is literally being mined from the ground like a mineral—it is being removed faster than it can be replaced. Whether surface water or ground water is used to satisfy needs, the ultimate constraint is the limited amount of precipitation that occurs at irregular intervals.

SURFACE WATER AND GROUND WATER RESERVOIRS

The independent use of surface water and ground water has contributed to problems with aquifers. For most areas in Utah, the primary focus of water development has been to build surface reservoirs to capture the seasonal spring runoff for use later in the year and to store this water for use in following years. Normally, reservoirs are drawn down annually to satisfy water needs. However, during consecutive drought years, reservoir levels decline substantially as surface waters diminish. Figure 8 shows how the total amount of water in 24 of the state's major reservoirs has declined during the most recent series of drought years. Details of this drought and comparison to other droughts can be found in Appendix 1, Brief Analysis of Drought in Utah.

The use of ground water usually increases during a drought. While increased use of ground water when

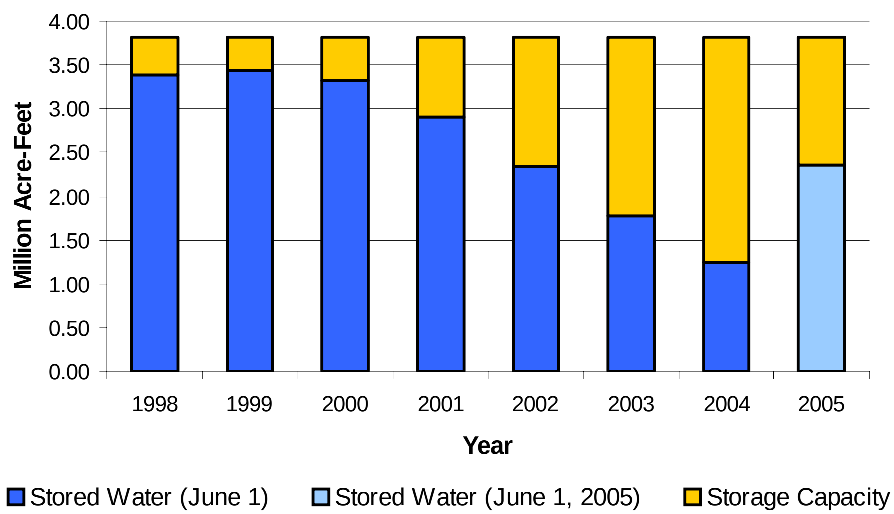


Figure 8, Utah's Reservoir Levels

Source: Utah Division of Water Resources, 2005

surface water is unavailable is a component of conjunctive use projects, this can result in depletion of ground water if no effort is made to replenish the ground water reservoir after the drought is over. In this respect, ground water aquifers are often not managed as storage reservoirs and are susceptible to withdrawals that exceed recharge.

Conjunctive management acknowledges the importance of both surface and ground water reservoirs and utilizes and protects the viability of both storage types within a hydrologic system. When considering the importance of managing aquifers as reservoirs, the following benefits they have over surface water reservoirs are worthy of note:

- Underground water reservoirs are not subject to evaporation losses as are surface reservoirs
- Some people believe surface reservoirs are environmentally unfavorable.
- Sedimentation eventually reduces the capacity of all surface water reservoirs.
- The number of available surface reservoir sites has decreased due to wide-spread urban development.
- The most economic surface reservoir sites have already been built, leaving only the more costly and technically challenging sites.

River Delta Recharge

As discussed earlier, water in rivers and streams constantly recharges aquifers at the river deltas near the mountains. See Figure 7. In addition, high runoff water in the spring of the year is a regular and natural occurrence in nearly every stream in Utah. When water spills out of the riverbanks and onto normally dry lands, the result is a flood. While floods may not occur every year, high water and floods result in additional natural recharge to aquifers. This recharge is particularly important for aquifers in Utah along the Wasatch Front and other locations that are situated beneath the river deltas at the mouth of the canyons. These aquifers receive a large amount of recharge from such events. The large flood of 1952 at the mouth of Weber Canyon shown in Figure 9 shows how such inundations spread water and recharge the aquifer.

With high water lasting several weeks every year, ground water levels increase whether or not there is a flood. Coarse-grained sediments located at the mouth of the canyon allow the water to infiltrate into the unconfined aquifer and then to the confined aquifer. The confined aquifer is the source from which cities along the Wasatch Front and other locations typically get water from wells. See Figure 10. (For a more detailed description and figure showing the differences between confined and unconfined aquifers, see Appendix 2, Ground Water and Aquifer Concepts.)

Today, however, the following human activities have significantly reduced these aquifer recharge events:

In the past, flood waters covering large surface areas provided substantial aquifer recharge.

Figure 9, Flood at the Mouth of Weber Canyon

Source: Deseret News Photo, 1952

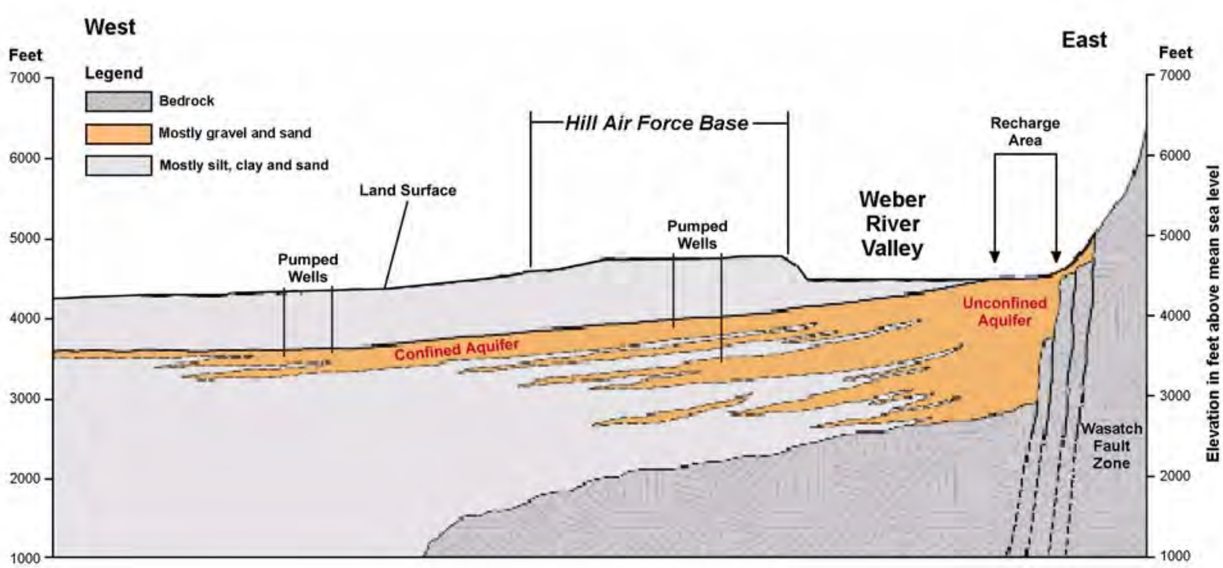


Figure 10, Geologic Profile, Weber Delta Subdistrict, East Shore Area of Great Salt Lake

Source: U.S. Geological Survey, 2003, modified from Clyde, et al, 1984.

- Dams and reservoirs have been built upstream to store water for agricultural, municipal and industrial uses. These reservoirs collect and hold back spring runoff and provide flood control benefits. The resulting reduction of instream flows decreases overall recharge along the stream and reduces the amount of water reaching the river delta.
- With reservoirs holding the water, more time is available for controlled diversions, which allows more water to be taken out upstream. This reduces total annual stream flow and recharge at the river deltas.
- Communities have been built and expanded on the river deltas. This is common throughout Utah since the rivers provide needed water. Buildings have been constructed and roads paved. Water that used to infiltrate into the ground is now channeled away into storm drains. (Depending on local conditions, urbanization reduces infiltration due to rainfall and snowmelt from about 50 % on natural ground cover, down to about 15 % on downtown areas.[2])
- Since high water and floods cause damage to communities on the delta, riverbanks have been built up and waters have been constrained only to the river channel. As a result, river flows rarely spill out onto the flood plains of deltas any more.
- Communities on or near the delta often divert stream flow for indoor and outdoor uses. The wastewater from indoor uses flows by gravity to wastewater treatment plants and is not discharged back to the stream until many miles downstream from the delta.
- Changes in irrigation practices, as described in the next section, have also impacted river delta recharge.

The cumulative result of all these activities has been a substantial overall reduction of natural recharge to Utah's aquifers.

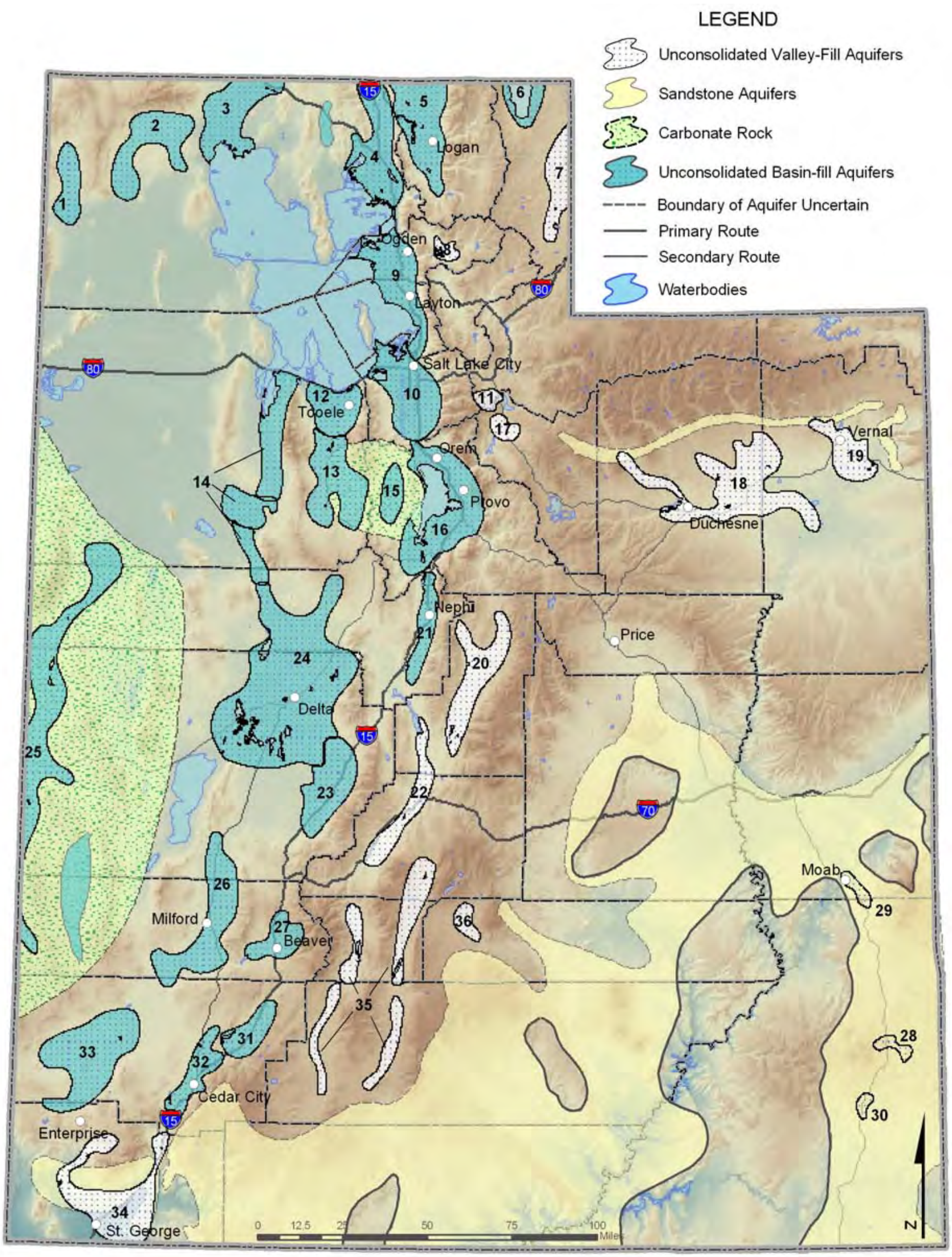
CANALS AND IRRIGATION

Many canals and ditches, which divert water from Utah's rivers and reservoirs, leak water and provide some aquifer recharge. Although not always in the best location to recharge critical aquifers, some water soaks into the ground and becomes ground water. Thus, efforts to reduce water losses from canals and ditches by lining them with waterproof materials or using pipelines also reduces aquifer recharge. Similarly, flood irrigation of crops also provides some aquifer recharge. Some of the water not taken up by crops soaks into the ground. Understandably, irrigators try to be as efficient as possible when watering crops. As a result, sprinkler irrigation has replaced flood irrigation in many locations. In addition, land leveling has reduced the amount of water put on some fields. The overall effect of these efforts to reduce "water loss" is to reduce the amount of water currently recharging Utah's aquifers.

DECLINING GROUND WATER LEVELS

The U. S. Geological Survey monitors and samples about 920 wells throughout the state to keep track of ground water levels. Together with the Utah Division of Water Rights and the Utah Division of Water Resources, they publish an annual report titled, Ground-Water Conditions in Utah, which summarizes findings for designated ground water development areas. The numbers (1 through 36) in Figure 11 identify these areas. Table 4 provides the names of the ground water development areas shown in Figure 11. In addition, Figure 11 shows the type of aquifers found throughout the state. Produced since 1964, Ground-Water Conditions in Utah documents the steady decline of ground water levels in several areas of the state.

One location of interest is the Beryl-Enterprise area in Iron County, (area 33 in Figure 11). Some wells in this area have experienced ground water level declines as much as 110 feet (see Figure 12). These records indicate that ground water levels have been declining continuously since the 1950s. Comparing these water level changes to the Palmer Hydrologic Drought Index for the region shows that the ground water level declines are not affected by changes in precipitation experienced in wet and dry times. This suggests that pumping volumes are very large compared to natural recharge volumes. The Utah Division of Water Rights has determined the average annual well pumping in the Beryl-Enterprise area from 1991 to 2002 was 80,000 acre-feet while the average annual recharge was 33,000 acre-feet. Dur-



Numbered shapes are ground water development areas monitored and reported annually in the publication *Ground Water Conditions in Utah.*

Figure 11, Aquifer Types and Ground Water Development Areas in Utah

Source: U.S. Geological Survey, 1986 and *Ground Water Conditions in Utah, Spring 2004* ing this period, ground water was withdrawn 2.4 times faster than it was replenished. This explains the steady decline in ground water levels.

Another location of concern is the East Shore Area in Davis County near Hill Air Force Base (Area 9 in Figure 11). Recent research by Weber State University indicates ground water levels there have declined up to 100 feet in some locations since 1950.

There are 10 additional ground water development areas that have experienced ground water level declines of more than 20 feet since 1950. Thus, 12 of the 36 areas in the state are experiencing long-term ground water level declines. These declines are summarized in Table 5. Utah Division of Water Rights data indicates these 12 areas have a total of about 5,569 wells that have water rights to withdraw 1,783,872 acre-feet of water annually. These water rights are about 33 percent of the 5,333,704 acre-feet of actual freshwater withdrawals from all sources in Utah in 2000.

The Utah Division of Water Rights defines ground water mining as, "withdrawal of water from an aquifer in excess of recharge which, if continued over time, would eventually cause the underground supply to be exhausted or drop too low to be feasibly

TABLE 4
Ground Water Development Areas in Utah

Basin No. Figure 11	Area Name	Basin No. Figure 11	Area Name	Basin No. Figure 11	Area Name
1	Grouse Creek Valley	13	Rush Valley	25	Snake Valley
2	Park Valley	14	Dugway Area, Skull Valley, Old River Bed	26	Milford Area
3	Curlew Valley	15	Cedar Valley Utah County	27	Beaver Valley
4	Malad-Lower Bear River Valley	16	Utah & Goshen Valleys	28	Monticello Area
5	Cache Valley	17	Heber Valley	29	Spanish Valley
6	Bear Lake Valley	18	Duchesne River Area	30	Blanding Area
7	Upper Bear River Valley	19	Vernal Area	31	Parowan Valley
8	Ogden Valley	20	Sanpete Valley	32	Cedar Valley Iron County
9	East Shore Area	21	Juab Valley	33	Beryl-Enterprise Area
10	Salt Lake Valley	22	Central Sevier Valley	34	Central Virgin River Area
11	Park City Area	23	Pahvant Valley	35	Upper Sevier Valleys
12	Tooele Valley	24	Sevier Desert	36	Upper Fremont River Valley

Source: Ground Water Conditions in Utah, 2005

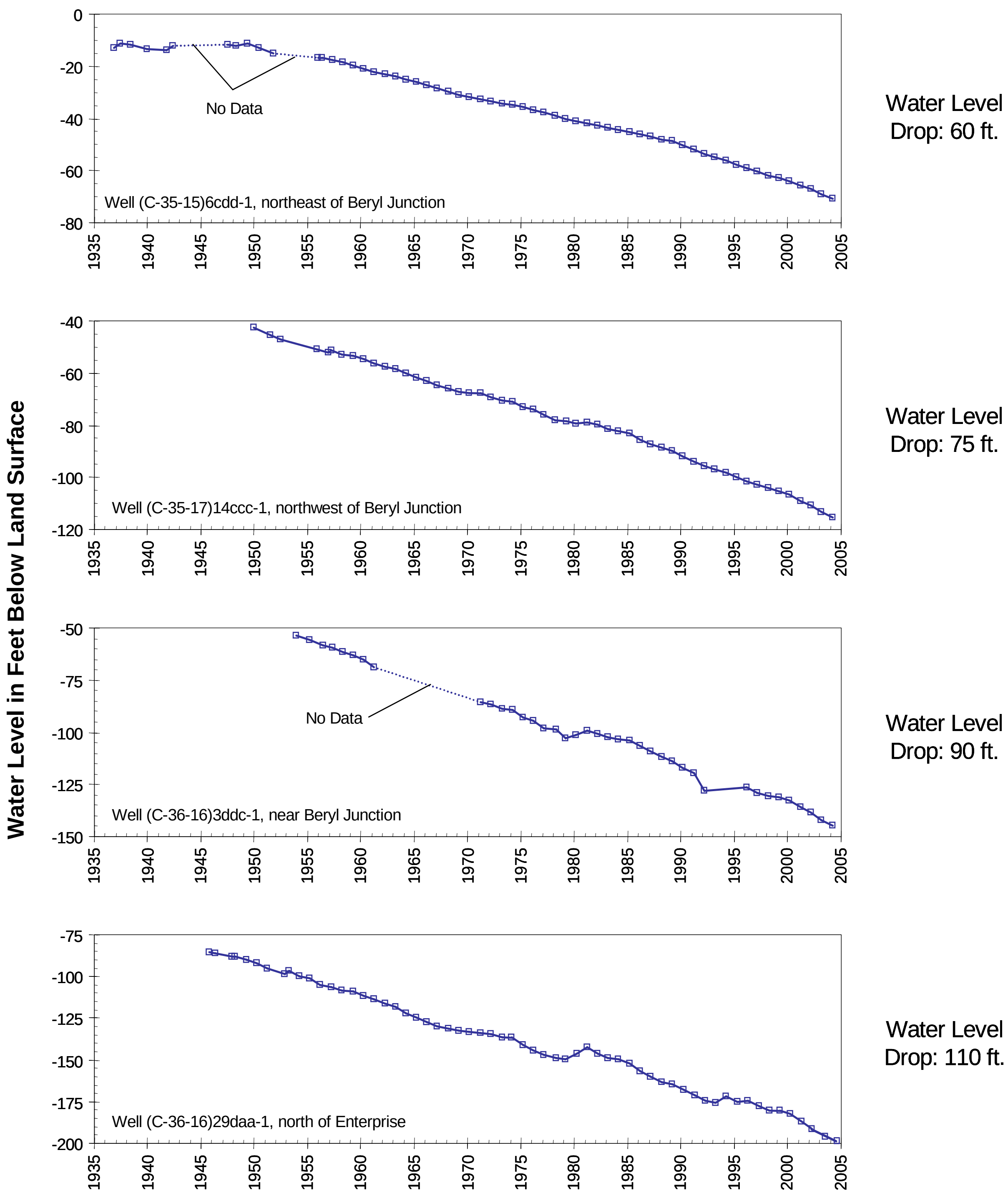


Figure 12, Water Levels in Selected Wells in the Beryl-Enterprise Area

Source: U.S. Geological Survey, *Ground-Water Conditions in Utah, Spring 2004.*

TABLE 5
Ground Water Level Declines in Utah Greater Than 20 Feet. (1950-2004)

Number	Basin Name	Basin Number (Fig. 11)	Water Level Decline (feet)
1	Curlew Valley	3	40
2	East Shore Area	9	37-100
3	Salt Lake Valley	10	36
4	Utah & Goshen Valley	16	21-50
5	Juab Valley	21	65
6	Central Sevier Valley	22	23
7	Pahvant Valley	23	30-56
8	Sevier Desert	24	24-28
9	Milford Area	26	40-55
10	Parowan Valley	31	48-100
11	Cedar Valley, Iron County	32	32-50
12	Beryl-Enterprise Area	33	50-110

The values shown indicate the largest declines observed in wells monitored in each basin and do not represent all wells within the basin.

Source: Ground Water Conditions in Utah, Spring 2004.

pumped."[3] While long-term declines in excess of 20 feet (as shown in Table 5) does not equate to ground water mining, clearly several of the state's aquifers are experiencing long-term water level declines and some of those declines are substantial. Action by the State Engineer to address the issue of declining ground water levels and ground water mining is discussed later in this chapter under "Water Rights Considerations."

CONSEQUENCES OF DECLINING GROUND WATER LEVELS

Long-term declines in ground water levels can have serious consequences. Some of the most important ones are described below.

Economic Costs

When ground water levels drop, pumps require more electrical energy because the water has to be lifted a greater distance. Thus, the cost to pump the same amount of water increases. The following example demonstrates this. Starting with a pumping situation typical for a water supplier, the following calculations show the cost increase due to a 50 ft. drop in ground water level.
Assumptions:

- Pumping rate: 2,500 gpm (5.57 cfs).
- Pump and motor combined efficiency: 80 percent.
- Pump is adequately submerged at all water levels.
- Pump operates during six months of the year (50 percent duty cycle).
- Original pump lift: 250 ft.
- New pump lift: 300 ft.
- Electricity costs: 5 cents per kilowatt-hour.

Using formulae provided by PacifiCorp, the Utah Division of Water Resources determined that pumping costs at the original 250-foot water level would be about $20,586 per year. Pumping costs at the lower 300-foot level would be about $24,747 per year—and increased cost of approximately $4,161 per year for a single well. These increased costs continue indefinitely unless water levels are restored to their original level. It is important to note that the cost increase is directly proportional to the water level decline. That is, a 20 percent drop in water level results in a 20 percent increase in pumping costs.[4]

This cost increase occurs gradually just as the ground water level drops gradually. Power costs may vary through the year and typically increases over the years. These variations, especially over a long time period, obscure the increased electrical costs due to declining ground water levels. One water conservation district was surprised to find that from 1950 to 2004, eight of their wells had experienced pumping cost increases on the order of 70 percent. Ground water levels in the aquifer utilized by the district had declined an estimated 47 to 60 feet at the rate of from 0.5 percent to 2 percent per year. The district did not notice the cost increases over the 54-year period until ground water level declines were determined and calculations made.[5]

Other economic costs that are not easily measured may be incurred due to declining ground water levels. These include the following:

- The need to re-drill and deepen wells when the water level declines below the bottom of the well. Pumps may need to be reset to greater depths and larger pumps may be needed.
- Compaction of the aquifer resulting in land subsidence and damage to well casing, canals, roads and other structures.
- Eventually, complete loss of the ground water when the level declines below the point of economic recovery.

Environmental and Water Quality Costs

Ground water level declines can also negatively impact the environment and water quality. Some possible impacts are listed below:

- Reduction or loss of flow to springs fed by the aquifer.
- Reduction or loss of flow to streams and wetlands fed by the aquifer.
- Ground water contamination due to surface runoff entering the aquifers directly through ground cracks. Water treatment to remove such contaminants can be costly.
- Loss of artesian pressure in flowing wells.
- Risk of saltwater intrusion for those aquifers bordering the Great Salt Lake. (The Utah Division of Water Rights has implemented a ground water management plan that considers this possibility in the Salt Lake Valley.[6] The Utah Division of Water Resources believes saltwater intrusion into the Weber River Delta aquifer could possibly occur in 25 to 30 years if ground water levels continue to decline at present rates. This was determined by comparing the decline in water pressure of two artesian wells within a mile of the lake to the average lake level.[7])

Aquifer Compaction and Land Subsidence

While the negative impacts of aquifer compaction are somewhat intuitive, the subsequent land subsidence that such compaction can cause is serious enough to justify elaboration. The impacts of land subsidence can be significant, if not dramatic. The following are some examples of these impacts in other areas of the country (italics added for emphasis):

- Aquifer system compaction and land subsidence have accompanied ground water depletion in many areas where unconsolidated basin-fill deposits constitute the principal aquifer systems. Subsidence is an ongoing concern in numerous areas of California, the Houston-Galveston, Texas area, Las Vegas Valley, Nevada, and throughout south-central Arizona.[8] *(Note in Figure 11, that 22 of 36 of the ground water development areas in Utah are in this type of aquifer.)*
- Ground subsidence can be dramatic and have disastrous consequences in areas of high ground water withdrawal. In Houston, Texas 10 feet of subsidence resulted in tens of millions of dollars of property damage and the loss of 31 square miles of land. One suburb had to be abandoned completely because of flooding.[9]
- *Even though water levels have recovered significantly, aquifer compaction and land subsidence have continued*. Historic overdrafts in the Eloy, Arizona area are responsible for the continued dewatering of aquifers and subsequent land subsidence. Interstate 10 has been repeatedly repaired due to an earth fissure that intersects the highway. Farmers have seen earth fissures cut through fields and subsidence destroy canals in Eloy.[10] *(See Figures 13 and 14.)*
- Land subsidence causes many problems including: (1) changes in elevation and slope of streams, canals, and drains; (2) damage to bridges, roads, railroads, storm drains, sanitary sewers, canals, and levees; (3) damage to private and public buildings; and (4) fail-

ure of well casings from forces generated by compaction of fine-grained materials in aquifer systems.[11]

The effects of excessive ground water withdrawal on the subsurface materials is described as follows:

> Overdrafting of aquifers is the major cause of subsidence in the southwestern United States, and as ground water pumping increases, land subsidence also will increase. In many aquifers, ground water is pumped from pore spaces between grains of sand and gravel. If an aquifer has beds of clay or silt within or next to it (see Figure 15), the lowered water pressure in the sand and gravel causes slow drainage of water from the clay and silt beds. The reduced water pressure is a loss of support for the clay and silt beds. Because these beds are compressible, they compact (become thinner), and the effects are seen as a lowering of the land surface. *The lowering of land surface elevation from this process is permanent*. For example, *if lowered ground water levels caused land subsidence, recharging the aquifer until ground water returned to the original levels would not result in an appreciable recovery of the land-surface elevation*.[12]

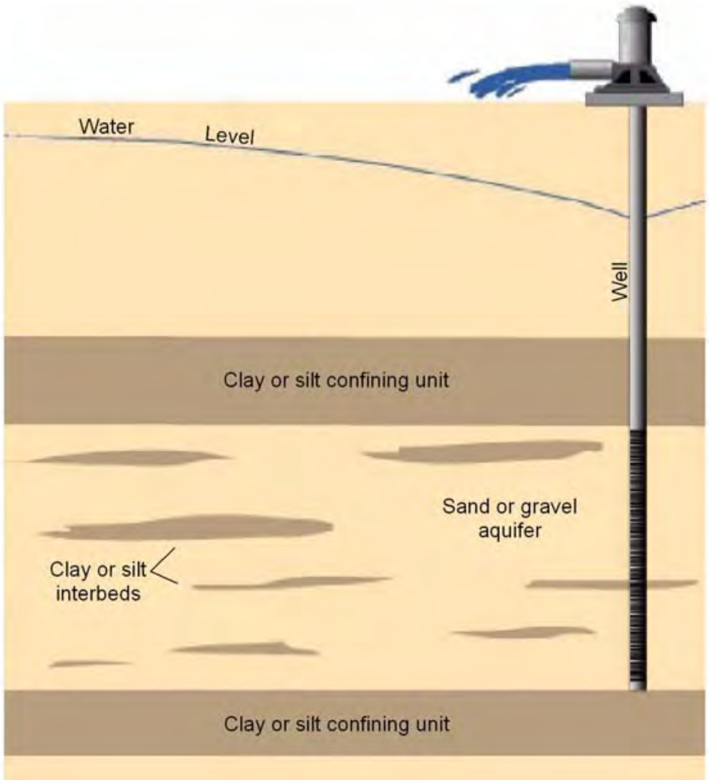
Utah's Wasatch Front and other locations have aquifers that are geologically similar to the other areas of the country described above that have experienced problems. Figure 15 illustrates an aquifer system that is susceptible to compaction and subsidence. Many of Utah's aquifers are very similar to such a system. The cross-section of the Weber River Delta aquifer near Hill Air Force Base shown in Figure 10 is typical of the aquifers along the Wasatch Front. Comparison of Figures 10 and 15 shows the similarities. As ground water levels in such aquifers decline, the risk of land subsidence and subsequent damage to the communities and associated infrastructure located above them increases.

This assessment is confirmed in the following geologic assessment of the Salt Lake Valley (Jordan Valley):[13]

Figure 13, Earth Fissures Caused by Aquifer Compaction and Subsidence, Eloy, AZ
Source: USGS, *Ground Water Atlas for the U.S.,* 1995

Surface contaminants flow directly into the ground water aquifer through these fissures.

Figure 14, Earth Fissures Enlarged by Erosion
Source: USGS, *Ground Water Atlas for the U.S.,* 1995



Release of water from clay and silt confining units and interbeds causes a reduction in thickness of these compressible sediments.

Figure 15, Aquifer System Susceptible to Compaction and Subsidence
Source: USGS, *Land Subsidence From Ground-Water Pumping.*, 1999

Hydrologic literature contains many references to land subsidence that has occurred because of compaction of aquifer materials after they were unwatered or artesian pressures were drastically lowered. Wherever subsidence has been studied, a correlation between the amount of subsidence and the decline of water levels has been found. The aquifer materials in Jordan Valley, occurring in strata with different particle sizes and containing considerable quantities of silt and clay, are similar to those in areas where subsidence has been observed. Hence, some subsidence probably would accompany any future large decline of water levels in Jordan Valley.

In general, compaction of sand and gravel is small and is chiefly elastic and temporary; but compaction of silt and clay is greater and is chiefly inelastic and permanent. For this reason, large fluctuations of water level near the east and west sides of Jordan Valley probably would induce only slight subsidence, but similar fluctuations in the central part would induce greater subsidence.

A review of the literature suggests that permanent land subsidence probably has begun in parts of the valley where declines have been greatest. Subsidence effects have not yet been recognized and may be too small to be easily measured. In the central and northern parts of Jordan Valley… aquifers contain thick beds of fine-grained sediments and are most susceptible to compaction, with consequent land subsidence.

Action by the Utah State Engineer to address this concern is discussed later in this chapter under "Water Rights Considerations."

In 2000, unpublished research by the Salt Lake City office of the U.S. Geological Survey[14] showed that 94 percent of ground water wells in Utah withdrawal water from unconsolidated basin-fill aquifers. Five percent of Utah's wells withdraw water from alluvial fill aquifers and one percent from sandstone bedrock aquifers. Unconsolidated basin-fill aquifers are the most susceptible to ground subsidence and associated problems. The continued reliance on these aquifers (see Table 5 and Figure 11), with the compaction and subsidence concerns discussed previously, provides compelling reasons to manage these ground water resources carefully.

Surface Cracks

A major concern of subsidence is the formation of cracks in the earth, which "provide a path for surface contaminants to move downward to an aquifer and pollute native ground water."[15] It is important to understand that cracks begin forming in the aquifer and move upward to the land surface. Once the crack appears, there is a direct connection between contaminated surface runoff and the ground water.[16] Surface water in streams contains animal waste and decomposed plants and animals. These are most undesirable to introduce into a clean ground water supply. Once introduced, these are very difficult to remove and can migrate and contaminate other portions of the aquifer. Drinking water extracted from such contaminated aquifers requires additional treatment before use.

Once pollutants have entered the ground water, the aquifer itself provides a means for transporting them. "Frequently, ground water is used without treatment because of the perceived filtering action of solution flow through porous media. It is now recognized, however, that bacteria and viruses can travel considerable distances in aquifers and saturated soils, thus posing a contamination threat to surface waters and well waters."[17]

Since 1970, the study of ground water microbiology has grown tremendously. Work in this area has established that naturally-occurring subsurface bacteria remain alive, viable, and able to reproduce even after long periods of time underground.[18,19] Fortunately, the underground environment of aquifers is conducive to killing off surface bacteria and viruses. One laboratory investigation in 2004 used raw and pasteurized water and simulated aquifer conditions in order to determine survival rates of two groups of fecal indicator bacteria and three groups of fecal indicator bacteriophage. Giardia and cryptosporidium parasites were also evaluated.[20] The shortest times for 99 percent reductions were for fecal coliform in one to two weeks, while the parasites took the longest at 7 months.[21] Different microorganisms will survive at different rates and survival rates under actual field conditions will be different than those in a laboratory, so site-specific monitoring of attenuation under particular circumstances is recommended.[22]

Pumping a well draws down the ground water level around the well resulting in water moving horizontally and vertically to replace the removed water. Thus, water movement is toward the well. This enhances pollutant transfer from surface cracks to the wells. The likelihood of surface water pollutants ending up in a given well due to surface cracks depends on several variables. These include whether subsidence cracks actually form, ease of water transport within the aquifer, and distance from the well to the crack. However, most of Utah's ground water development areas are in unconsolidated basin-fill aquifers that convey water relatively easily and quickly (see Figure 11). As discussed earlier, a large majority of the state's ground water supply is from such aquifers, primarily along the Wasatch Front. Finally, increased population density has resulted in many wells that are closely spaced. Should subsidence cracks develop, the opportunity for contamination will be increased.

Aquifer Damage in Utah

Having examined aquifer compaction, land subsidence and surface cracking in general, it is appropriate to consider actual conditions in Utah. Although ground water levels have declined over broad portions of some aquifers, fortunately, relatively little damage has occurred so far.

Beryl-Enterprise

A 1982 study of the Escalante Desert near Beryl-Enterprise showed ground water level declines of 40 to 60 feet over an area of about 90 square miles.[23] Another study of the same area 18 years later showed ground water levels declines of at least 40 feet over 100 square miles.[24] For perspective, the towns of Beryl Junction, Enterprise, and Newcastle are all located within this area and within 12 miles of one another. A third study noted several surface cracks near Newcastle in the same area just described. The most likely cause of these cracks is the compaction and subsidence accompanying drying and consolidation of the fine-grained materials in the aquifer due to lowering of the water table.[25] First noticed in 1975, these cracks varied in length from several tens of feet to about 100 feet. Surface water flow and grazing animals have subsequently eroded these cracks. Erosion channels concentrate local surface runoff and direct it into the cracks, which carry it to the subsurface. Shallow modern drainages through the area are likely developed along cracks.[26]

In January 2005, additional earth fissures totaling about 1,300 feet were discovered in the Beryl Junction area. Fissures caused a fracture across Highway 56 about one-half mile east of Beryl Junction. The crack came within 50 yards of a home and the road had to be closed for repairs. Crack width sizes varied from a pencil width to 15 feet across.[27] Subsequent investigation by the Utah Geological Survey determined that the ground in the area had subsided in the range of two to four feet since 1940. The subsidence area coincided with, and was centered above, an approximately 100 square mile area where ground water levels have declined over 75 feet. There appears to be a direct correlation between ground water withdrawals and subsequent ground subsidence resulting in formation of earth fissures causing minor damage to human structures.[28]

In March 2005, KSL television did a news story of this situation including interviews with local people and Utah Geological Survey personnel. Apparently, the January 2005 floodwaters that flowed over the fields revealed previously undetected cracks by causing extensive erosion into them. During the flood, people saw large volumes of surface runoff water flowing across fields, including an animal feedlot, and pouring into the cracks.[29] These contaminated waters flowed down to the underlying aquifer. Figure 16 shows several aspects of the situation.[30] These conditions are analogous to those previously described in other parts of the country; compare Figure 16 to Figures 13 and 14.

Milford

Subsidence cracks due to ground water withdrawals have also been found in the Milford area. The town of Milford is about 60 miles northeast of Newcastle. The cracks that were discovered are several hundred feet long and vary in width "from a fraction of an inch to more than 1 foot wide." In addition to fissures on the ground surface, "water from storm runoff collects in a small channel and disappears into a fracture on the bottom of the normally dry Beaver River Channel." This aquifer is also susceptible to pollution. In addition, ground subsidence has broken a well discharge pipe and its associated pipeline. An area of about 32 square miles has experienced ground water declines of 20 to 30 feet from 1950 to 1972 in the Milford area.[31] The existence of subsidence cracks, along with the ground around wells dropping, is evidence aquifers in the Milford and area have compacted and subsided.

Other Areas

It would appear that, so far, only limited damage has occurred and this is confined mainly to the sparsely populated desert basins of southwestern Utah. No damage has been detected in Utah's urban areas.

The likelihood of aquifer subsidence and compaction depends on local geology and the magnitude of ground water decline. As discussed previously, there has been some damage in Utah where levels have declined the most. One-third of the ground water basins in the state have water levels that have declined anywhere from 20 to 110 feet. Increased ground water withdrawals in those areas could result in ground water mining and increase the risk of damage in both rural and urban areas. So far, the state has not experienced major impacts due to declining ground water levels. Considering these factors, it is important to reiterate that most of Utah's ground water development areas are in the same type of aquifer as those in other areas of the Western United States that have had serious and costly problems. When Utah's ground water levels decline far enough, similar problems are possible.

Since aquifer compaction, land subsidence and surface cracks cannot be restored, it is clearly better to prevent or minimize such occurrences. Conjunctive management of Utah's water resources could help prevent such problems.

WATER RIGHTS CONSIDERATIONS

The State Engineer's office is well aware of the issues related to declining ground water levels in Utah. That agency took action several years ago to address the situation by developing Ground Water Management Plans for 12 designated areas of the state.[32] The intent of these plans is to protect existing water rights, provide for maximum beneficial use of water resources, and address other issues unique to a particular ground water basin.[33] Approaches to ground water management include:[34]

Aerial View showing the January 2005 flooding in the Escalante Valley

Earth fissures caused by land subsidence and subsequently enlarged by water erosion.

Figure 16, Beryl-Enterprise Area Ground Subsidence and Cracking
Source: Utah Geological Survey, 2005

- Many basins are closed to new appropriations.
- Conditional approval of new appropriations in some areas.
- Guidelines in place for change applications.
- Restrictions to prevent the spread of ground water contamination.
- Addressing illegal ground water diversion.

The Ground Water Management Plans typically include comparisons of the estimated natural recharge into the ground water basin to natural discharge and human withdrawals out from the basin. Approved water rights for wells are part of human withdrawals. From such comparisons has come the concept of "over-appropriation." Ground water basins with approved water rights that exceed the amount of natural recharge physically available are considered to be "over-appropriated." In some cases, the water rights have been fully developed and in other cases they have not. As approved water rights in these areas are developed and perfected, the ground water not used so far will be put to use. Table 6 summarizes the magnitude of over-appropriation as well as the degree of current development in the affected ground water basins in Utah. All of the over-appropriated areas listed are also included in Table 5 and already have the indicated levels of ground water level decline. Two of them, Bountiful Sub-Area of East Shore Area and Salt Lake Valley, are along the Wasatch Front.

Details of each ground water management plan can be found on the Utah Division of Water Rights Internet website:

nrwrt1.nr.state.ut.us/wrinfo/policy/ground.htm.

The status of the ground water management plans and other ground water policy in Utah is summarized by Figure 17. About 27 percent of the state, including the heavily populated Wasatch Front, is completely closed to new ground water appropriation. Most of the rest of the state, 47 percent, is restricted in ground water development according to the parameters set by the State Engineer. Thus, about three-quarters of the state, 74 percent, is closed or restricted to further ground water appropriation. Only 26 percent of the state's land area is open to further ground water appropriation. However, even in the open areas, applications larger than small domestic are closely reviewed and may not be approved.

The State Engineer is currently (2005) working with the Utah Legislature, water suppliers, and the public to address the ground water issues described here. A special Legislative Task Force Studying Water Issues has been formed as part of that effort.

TABLE 6
Ground Water Over-appropriation in Utah

Basin Name	Basin Number (Figure 12)	Approximate Degree of Over-Appropriation	Degree of Water Right Development
Bountiful Sub-Area of East Shore Area	9	70 %	Partial
Salt Lake Valley	10	500 to 600 %	Partial
Pahvant Valley	23	23 %	Full
Milford Area	26	50 %	Full
Beryl-Enterprise Area	33	140 %	Full

Source: Utah Division of Water Rights, December 2004.

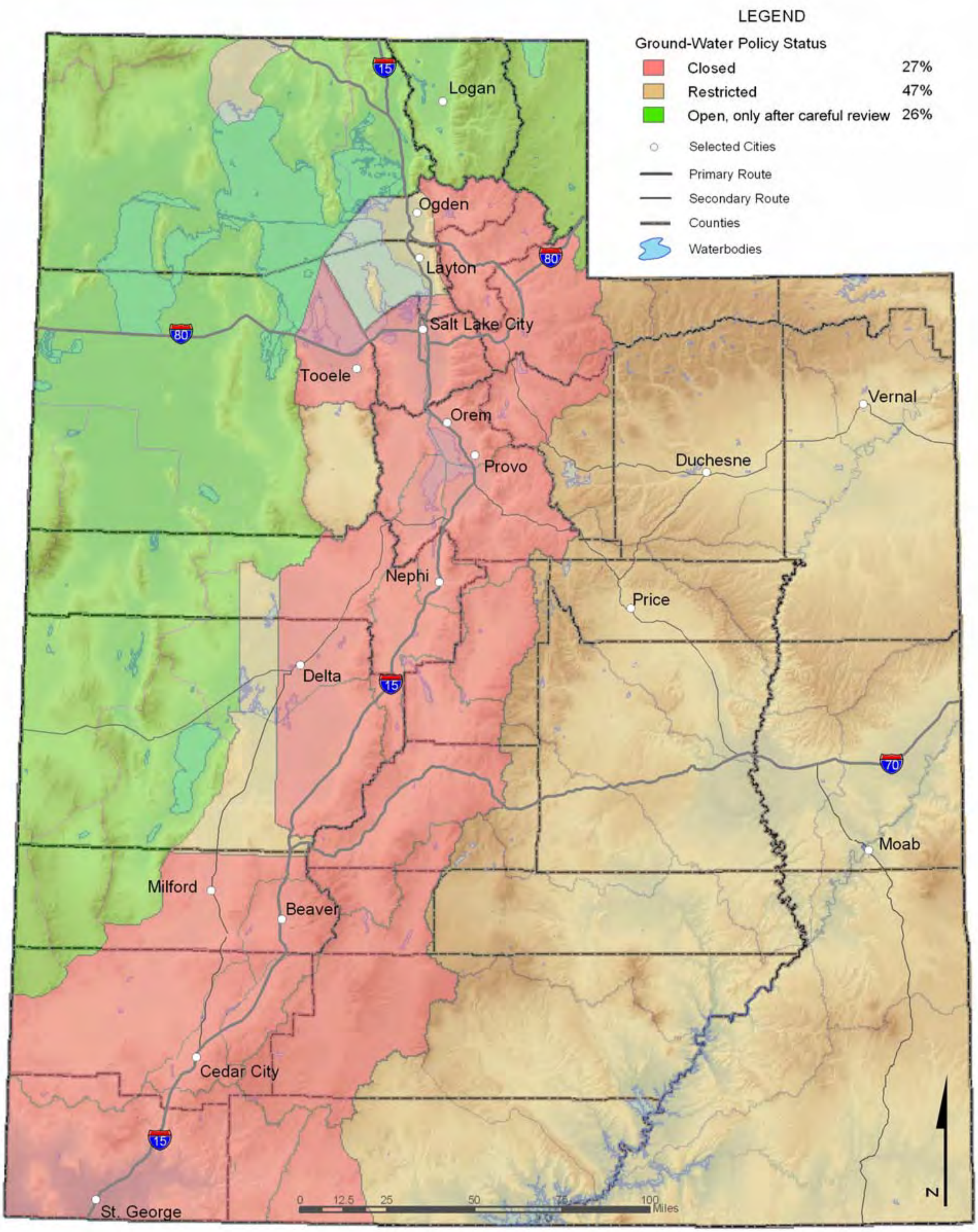


Figure 17, Ground Water Policy in Utah

Source: Utah Division of Water Rights, 2005

NOTES

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[3] *Dictionary of Water Words*, State of Utah, Department of Natural Resources, Utah Division of Water Rights, April 2000, page 15.

[4] Utah Division of Water Resources calculations, confirmed by PacifiCorp, September 2004.

[5] Estimated by the Utah Division of Water Resources as part of a detailed analysis of ground water declines in the East Shore area, May 2004.

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3

CONJUNCTIVE MANAGEMENT: STRATEGIES AND SOLUTIONS

There are two conjunctive management strategies that can be employed. The first is conjunctive use—the deliberate, planned and coordinated use of surface and ground water resources with the intent of balancing those resources. The second strategy is conjunctive use, as just explained, coupled with aquifer storage and recovery (ASR). This entails intentionally storing surface water in underground aquifers in order to extract it later when needed. Most conjunctive management projects include ASR. Details of both strategies are presented in this chapter.

Conjunctive use alone may use existing facilities only, or it may require additional construction. Many individual water suppliers holding surface and ground water rights already practice conjunctive use within their own water system by using surface water to meet base demands and ground water wells to meet peak demands. The benefits of this strategy could be greatly increased by several water suppliers within a region jointly coordinating the use of both resources. This helps more fully utilize all available water resources. When excess surface water is available that cannot be captured in surface reservoirs or treated in water treatment facilities, ASR can be employed. ASR may also be a more practical option in areas where the water users are unwilling or otherwise unable to work together to employ conjunctive use strategies.

These distinctions are similar to those found within the California Water Code, Section 79171, which defines conjunctive use to mean:

> The temporary storage of water in a ground water aquifer through intentional recharge and subsequent extraction for later use. Storage is accomplished by either of the following methods:
>
> "In-lieu recharge" means increasing the amount of ground water available in an aquifer by substituting surface water supplies to a user who would otherwise pump ground water.
>
> "Direct recharge" of an aquifer by conducting surface water into the ground by various means, including spreading ponds and injection wells for the purpose of making water stored in the aquifer available for extraction and later use in drier years. [1]

California is a leader in the implementation of various conjunctive management strategies. In 1999, the state made $200 million in grants available, "for feasibility studies, project design, or the construction of conjunctive use projects on a pilot or operational scale."[2]

Water rights must be carefully and thoroughly considered when contemplating conjunctive management projects. Because the water rights issues associated with any given project are unique and can be quite complex, it is beyond the scope of this document to provide a detailed discussion regarding water rights issues associated with any type of project. Chapter 6, Project Implementation, describes in general terms the water rights permits and other regulatory requirements for conjunctive management projects. The recommendations provided there supply some background on water rights considerations.

Consultation with the Utah Division of Water Rights is an important and necessary part of implementing every conjunctive management project.

CONJUNCTIVE USE WITHOUT AQUIFER STORAGE AND RECOVERY (ASR)

Whenever there is an exclusive, predominant, or even primary reliance upon either surface water or ground water in an area, a move to fully coordinate both water sources is the best way to most efficiently use the available water. The conjunctive use of surface and ground water sources allows for a more complete utilization of the available water supply and improves the reliability of that supply. Undoubtedly there will be issues to be overcome such as water rights, water quality, and physical location (availability) of surface and ground water supplies. However, it is beneficial for individual suppliers and the entire water community to strive for such a balance. The following paragraphs discuss suggested strategies to achieve those ends.

Perhaps the most simple, and inexpensive, conjunctive use strategy is to maximize deliveries of treated surface water during the spring runoff months accompanied by the reduction or elimination of ground water pumping while surface flows are available. This strategy involves the maximum utilization of surface storage reservoirs, in accordance with the respective reservoir administration plan. Fully utilizing surface water sources in this manner allows the ground water aquifer to "rest" and naturally recharge its capacity. This results in "water banking" with no added construction cost. In order for this strategy to work, water suppliers providing the treated surface water might need to lower prices as an incentive for local communities to buy more surface water and reduce their ground water pumping.

The ideal circumstances for implementation of conjunctive use without aquifer storage and recovery would be a single water supplier with adequate surface water rights and ground water rights, along with adequate surface reservoir and aquifer capacity. This combination allows independent and unrestricted management of the total water supply to achieve optimum efficiency and reliability. Such a combination is definitely possible, as demonstrated by the three operating conjunctive management projects described in the Current Utah Projects section of Chapter 4. This combination was a contributor to implementing these projects. However, such a combination might be difficult to achieve in a given locality. Often, surface water users are not the same as ground water users in Utah. See Figure 4, which shows that, statewide, irrigation users take about 88 percent of withdrawals from surface water and 12 percent from ground water. The figure also shows that, statewide, public water suppliers take about 45 percent of withdrawals from surface water and 55 percent from ground water. Thus, agricultural users are predominantly surface water users while public drinking water supplies come almost half from surface water and just over half from ground water. Most of Utah's rural communities get their drinking water supplies exclusively from ground water sources. Utah's public water supplies that come from surface water sources are largely the metropolitan areas along the Wasatch Front. While not impossible, it would be difficult for these water-user groups to cooperate in mutually beneficial conjunctive management projects. The interests, water use patterns, water quality issues and operating politics of these groups are quite different.

In some areas, agricultural users are already employing conjunctive use practices. Streams are used until they have inadequate water and then irrigators turn to ground water wells to meet demand. Surface storage reservoirs have been employed throughout the state and investments in wells have been made where needed. If it makes sense economically, in general, it is already being done. One example can be found near Nephi where surface flows of Salt Creek are conveyed to the Nephi Irrigation Company canals, when those flows are available in the spring of the year. Later in the year, when Salt Creek flows are insufficient to meet demands, five wells owned by the irrigation company are used to provide irrigation water.[3] It is clear from the location of the wells, on the stream channel just downgradient of the mouth of Salt Creek canyon, that the stream provides the natural ground water recharge from which the wells draw water.

Due to the complexity and cost of storing water underground, there is little incentive for agricultural water users to invest in such a project. Thus, it appears that the greatest opportunities for conjunctive management in Utah is not with the agricultural community, but with public water suppliers.

When agricultural lands are converted to urban lands, the surface water rights associated with those lands become available to a city. This helps create the ideal situation described earlier since the city now has both surface water and ground water rights. This allows greater flexibility to conjunctively manage the two supplies. However, the municipality would likely need to change the management approach from past practices of relying primarily on ground water and move toward relying on surface water when it is available and only using ground water when surface water supplies are insufficient. This might take the form of using the former irrigation surface water by treating it for drinking water supply, using the surface water directly in a secondary system, or possibly using the raw or treated water for an aquifer storage and recovery project.

One potential approach in the Salt Lake Valley would be for suppliers that obtain water from the mountains to sell treated surplus surface water during the high runoff period to communities in the valley that rely on ground water. Those communities would then not pump their wells as long as treated surface water was available, thus preserving the ground water resource. Actually, any surface water supplied to those relying on ground water that resulted in not pumping as much, would be an enhancement to the overall water supply and a benefit to the aquifers. Of course, several issues would need to be addressed, among them are physical connections to water supplies and agreement on water prices.

The following collaborative actions among water providers can promote conjunctive management on a local or even a regional basis. Such cooperation can result in a win-win situation for all parties, including the overall benefits described earlier. In the following discussion, the parties could remain as separate entities with contractual agreements between them, one entity could buy out the other entity, or they could form a cooperative.

One water provider may have more water rights to surface supplies than to ground water supplies. Another provider may have more water rights to ground water supplies than to surface supplies. Perhaps these providers are totally surface-supply or totally ground water-supply dependent. These providers could work together to balance both of their "portfolios" and achieve an equal reliance on surface and ground water. There would be challenges to such an agreement. Theses include working out the value of the several water rights that would be exchanged. Perhaps leasing arrangements would be necessary. While the Utah constitution allows the exchange of water rights and sources of water supply, it does not currently allow a municipal corporation to sell or dispose of water rights and sources of supply. Depending on physical locations, additional pipelines might be needed to exchange the water from one supplier to another. Perhaps ongoing payments according to the volumes of water exchanged would be appropriate. The needed construction might be less costly than building new surface reservoirs or adding more wells. Another advantage could be the postponement of constructing new facilities by either or both providers. It would be worth looking into and considering such arrangements. Such exchanges could include raw water as well as treated water.

A simple example illustrates the above proposal. Suppose a city is reliant exclusively on ground water wells for their culinary supply. The city could purchase raw surface water from a nearby provider to supply a secondary water system for a new subdivision being added to the city. That would reduce the city's need for ground water and reduce the use of culinary-grade water for lawn and garden purposes.

Another example would be for two cities with unbalanced portfolios to interconnect their respective drinking water systems and balance the supply between them. Treated surface water would be available to both cities when surface supplies were available. Ground water would then be available to both cities when surface supplies were limited. This pooling of resources would benefit both parties and, again, improve the efficiency of water use and increase the utilization of the available supply.

One more example would be the sharing of water between suppliers. That is, when one supplier is unable to meet demand using existing supplies, they obtain water from another supplier having a surplus. Numerous suppliers might participate on a basin- or region-wide basis thus balancing the water supply to the greatest extent possible. Water is thus moved from points of supply to points of demand, regardless of whether it is ground water or surface water. While two suppliers might easily agree, adding more parties to the mix increases complexity. Each must be willing to sell their surplus water at agreed-upon prices and be willing to physically interconnect the systems to appropriately move the water. There would also be management issues to change what were independent suppliers into what amounts to a water-supply cooperative. The benefits of such arrangements would have to be compared to the drawbacks to determine whether or not to proceed.

Given the steadily increasing demand for water, and the cost and difficulties in developing new water sources, there could be real advantages to taking this approach. Such cooperation could be the least-cost option to expand the overall water supply. In this scenario, water becomes a "free-wheeling" commodity similar to electricity, and the use of surface and ground water supplies is optimized. These principles may ultimately become common and essential practices within Utah's water-supply industry.

CONJUNCTIVE USE WITH AQUIFER STORAGE AND RECOVERY

As described earlier, intentionally storing water in underground aquifers in order to extract it later when needed is known as aquifer storage and recovery or ASR.

Areas where ASR has potential application are as follows:

- Increasing population resulting in increasing water demand.
- There is a need to optimize water utilization.
- Declining ground water levels.
- Geology is favorable to ASR.
- Water is available for recharge. Quantity and quality must be adequate to justify the project.
- Physical sites are available for surface spreading ponds or ASR wells.
- A water conservancy district or other water supplier is available and willing to sponsor the project.
- Economic feasibility.

Investigation of these criteria would be the responsibility of the organization investigating ASR in any given locale. Typically this would be a water conservancy district, city, or other water supplier looking to improve efficiency, save money, and increase the available water supply. Consulting firms providing services in these areas might study the criteria in order to develop business with such suppliers. Government agencies interested in developing water resources might also investigate them.

Quantification of population increases leads to better definition of future water demands in an area. This enables planning for capital investment to satisfy the demand. Conjunctive management, including ASR, is one of many water supply options that should be considered. An aquifer with declining ground water levels can be looked upon as an empty reservoir just waiting to be filled and emptied, the same as a surface water reservoir. However, the empty aquifer is already "built" and need only be developed and put to use. Full aquifers do not inhibit ASR projects; they can be used by first removing water and later refilling.

For perspective, the volume of a 50-foot thick, 50 square-mile, unconsolidated basin-fill aquifer having 20 percent voids and yield, would be about 320,000 acre-feet. That is about 86 percent of the total capacity of Jordanelle Reservoir. These conservative numbers give an approximation of the volume of water storage available in most of Utah's aquifers.

Without favorable geology and available water, no ASR project can be implemented. In every case, detailed studies will be necessary to determine whether the proposed project is geologically feasible. Similarly, the proposed project must have water with a chemistry suitable for the geologic formations involved and of sufficient quantity to make the project worthwhile. There must be a location suitable for the surface spreading pond or ASR well in order to get water into the ground.

Finally, there must be an organization willing to expend the time, energy, and money to investigate whether or not the project is feasible. Part of that investigation should include a fair comparison of ASR to other available water development prospects. ASR has been shown to be very competitive. Early water development projects were simple and less costly. Today's environment requires more complexity and greater cost. Conjunctive management is a worthwhile option, but is relatively new in

Utah; therefore it may require new thinking by those developing the state's water supplies.

There are additional or secondary reasons to implement aquifer storage and recovery that are often quite compelling and result in numerous benefits. The following list describes both primary and secondary reasons to implement aquifer storage and recovery.[4]

1. **Seasonal Storage.** Water is stored during wet months when it is available, and recovered during dry months when it is needed.
2. **Long-term Storage.** Water is stored during wet years, and recovered during drought years. This is sometimes referred to as "water banking."
3. **Emergency Storage.** Water is stored to provide a strategic reserve to meet demands when the primary source is unavailable. This is particularly appropriate for water systems that rely heavily on a single source and a long transmission pipeline. Given Utah's earthquake risk this could be useful.
4. **Disinfection Byproducts (DBP) Reduction.** Aquifer storage can reduce concentrations of DBPs, such as trihalomethanes (THMs) and haloacetic acids (HAAs), and also their formation potential.
5. **Restore Ground Water Levels.** A small percentage of the stored water can be left in the aquifer each year, or increased storage during wet years can be accumulated. This reverses ground water mining and reduces pumping costs.
6. **Reduce or Prevent Land Subsidence.** This phenomenon and its consequences were described previously.
7. **Maintain Distribution System Pressure.** Aquifer storage at those locations within a utility distribution system that experience seasonal low pressures can help maintain these pressures by recovery during peak demand months.
8. **Improve Water Quality.** This includes pH stabilization or adjustment, THM and HAA reduction, iron and manganese reduction, hydrogen sulfide reduction, arsenic reduction, and softening. Nutrient and coliform reduction may also occur where these are present in the recharge water.
9. **Prevent Saltwater Intrusion.** ASR wells in a line parallel to intruded portions of an aquifer can prevent further movement of the saltwater intrusion front, while also meeting seasonal peak demands. Areas along the Great Salt Lake might benefit from this.
10. **Reduce Environmental Effects of Streamflow Diversions.** ASR systems primarily divert water during high flow when the amount diverted is a small percentage of the total stream flow. This reduces the environmental effects of diversions and facilitates environmentally sound use of surface water sources. It also offers some flood control.
11. **Agricultural Water Supply.** ASR has been used for irrigation water as well as public water supplies. Fresh or brackish aquifers are potentially useful for such purposes. Regulatory and technical issues must be addressed where recharge water quality may not meet all potable standards.
12. **Nutrient Reduction in Agricultural Runoff.** Storage of agricultural runoff can reduce nitrogen concentrations through bacterial denitrification. Also, some aquifers can reduce phosphorus concentrations through physical-chemical and bacteriological mechanisms. This reduces eutrophication of lakes and reservoirs.
13. **Defer Expansion of Water Facilities.** Since water systems are designed to meet peak loads, it is frequently possible to more efficiently use existing treatment and conveyance capacity by operating these facilities in an ASR mode at full capacity throughout the year. Water facility expansion can be deferred and downsized. This often justifies ASR projects.
14. **Reclaimed Water Storage for Reuse.** High quality reclaimed water may be stored seasonally in fresh or brackish aquifers for recovery to meet irrigation demands.
15. **Hydraulic Control of Contaminant Plumes.** In portions of the aquifer that are threatened by movement of contamination plumes, it is sometimes possible to control movement of these plumes through the appropriate use of ASR wells.
16. **Diurnal Storage.** In situations where daytime demands exceed supply, ASR wells

have been used to store water at night for recovery during the day.

One possible approach in the Salt Lake Valley would be for water suppliers on the east side of the valley to "bank" surface water underground in an aquifer storage and recovery project over a multiple-year period. Aquifers on the east side have a good potential for such projects. When available water supplies and treatment plant capacity both exceed current demand, the excess water could be treated and banked in the aquifer. Sufficient existing water rights would be necessary. The banked water could then be withdrawn during dry years to satisfy demand. Stored water could also be sold to cities and towns in the valley. Those communities would then not pump their wells, thus preserving the ground water resource. Of course, several issues would need to be addressed, among them are physical connection to water supplies and agreement on water prices.

Given the need to treat water before using an ASR well to store it in an aquifer, there is little economic incentive for agriculture water users to invest in such a project. And since surface spreading requires an ideal geologic location combined with a nearby water supply, there are not many irrigators in a position to employ such methods. Furthermore, the costs of such projects would be challenging to most irrigators.

SELECTION OF RECHARGE PROCESS

As shown in Figure 18, there are two principal methods to manage ground water recharge. The first is spreading water in recharge basins and allowing it to infiltrate into the ground. Notice the mound of water formed beneath the recharge basins. The second method is injecting water treated to drinking water standards under pressure directly into the designated aquifer using a recharge well. Details of each method will be discussed in the following sections. "If land availability and hydrogeology are favorable, surface recharge is usually the most cost-effective recharge approach. Where either of these factors become limiting, then well recharge should be considered. In some cases, a combination of the two recharge approaches offers operating flexibility while also fully utilizing the available recharge flows and storage capacity in the area."[5]

The geology at the prospective site is a major factor that must be considered when choosing which method to employ. This includes the geologic formations from the land surface down to, and below, the aquifer in which water will be stored. Potential storage zones can be confined, semi-confined, or unconfined aquifers that contain fresh, brackish or salty water. See Appendix 2, Ground Water and Aquifer Concepts for a discussion and diagram regarding aquifers.

There are likely to be multiple objectives in each project and each objective may influence which recharge method is chosen. The entire project needs to be reviewed. "Getting the water into the ground is usually only part of the process. Equally important is the ultimate potential use and value of the stored water at the point of recovery. Recharge economics should therefore consider not just the cost of getting the water into the ground, but also the overall cost for achieving (all) local water management objectives."[6]

Recharge Using Surface Spreading

Surface spreading of water is accomplished by putting aquifer recharge water into constructed recharge basins or ponds. This is especially effective along rivers in delta formations at the mouth of a canyon. An explanation of Wasatch Front river delta geology is needed to understand this advantage. See Figures 7, 10, and 19. As rivers cut down through the mountains they carry a sediment load of boulders, gravel, sand, silt and clay. In the mountains, the river slope is steep and the river flows rapidly; there is enough energy to carry all sediments down the channel. However, when the river reaches the delta region, the slope becomes flatter and the river flow is much slower. This results in less energy to carry sediments, causing deposition of these material in the delta. As the sediments are deposited they are progressively sorted. Larger, heavier particles stop first while the smallest particles are carried furthest. Generally speaking, the boulders and gravel stop at the mouth of the canyon, sand and silt are carried further, and clays are carried furthest down the river channel. Historically, along the Wasatch Front, rivers flowed into ancient Lake Bonneville and the lake level fluctuated over geologic time. This resulted in the shoreline moving closer to and farther

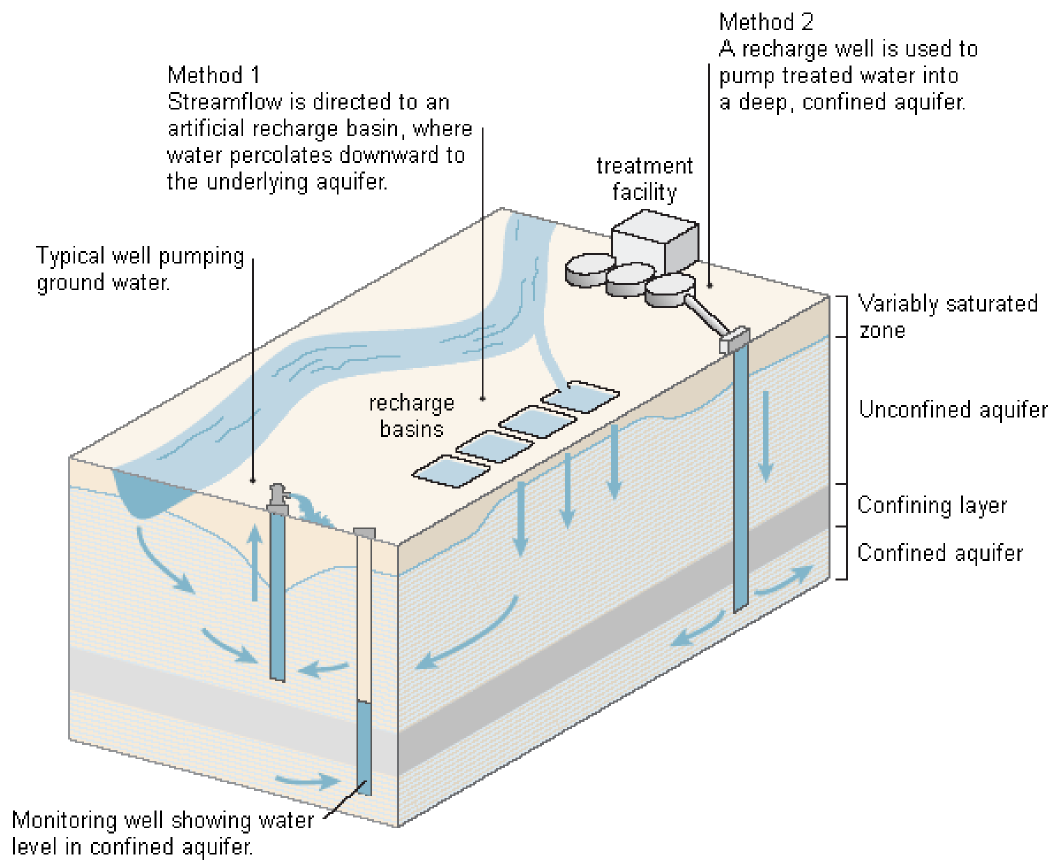

Figure 18, Techniques to Artificially Recharge Ground Water Aquifers

Source: USGS, *Evolving Issues and Practices in Managing Ground Water Resources,* 2003.

from the mountains. This produced layered formations and created river deltas with the geologic cross-section shown in Figure 10. Notice the relative location of confined and unconfined aquifers.

Figure 19 is a map view of the Weber River Delta. Location of the "river delta primary recharge area" and "river delta secondary recharge area" shows the result of the sediment sorting described above. Notice that the primary recharge area extends out in a "tongue" shape at the mouth of the Ogden and Weber Rivers. This is typical for river canyons along the Wasatch Front. This tongue area has a large percentage of boulders, gravel and sand; little or no silt and clay is present. This means water on the surface easily seeps into the ground and into the deeper aquifer. This tongue area is designated an "Unconfined Aquifer" and is shown as the "Recharge Area" in Figure 10. Water flows by gravity vertically downward through the unconfined aquifer, which also pushes the water horizontally sideways into the down-gradient confined aquifers. Confined aquifers are comprised of gravel and sand layers, with silt and clay above and below them. This mechanism of surface water flowing through the unconfined aquifer into the confined aquifers, is a principal source of ground water recharge in the river delta. Many communities along the Wasatch Front derive a significant portion of drinking water from these deep, confined aquifers. Again, see Figure 10. Notice the relative locations of pumped wells in Figure 10.

Surface spreading with recharge basins located above the unconfined aquifer is an ideal way to manage recharging confined aquifers. As indicated in Figure 19, land area located in the tongue at the mouth of river canyons is very small compared to the rest of the delta recharge area. Being small, and

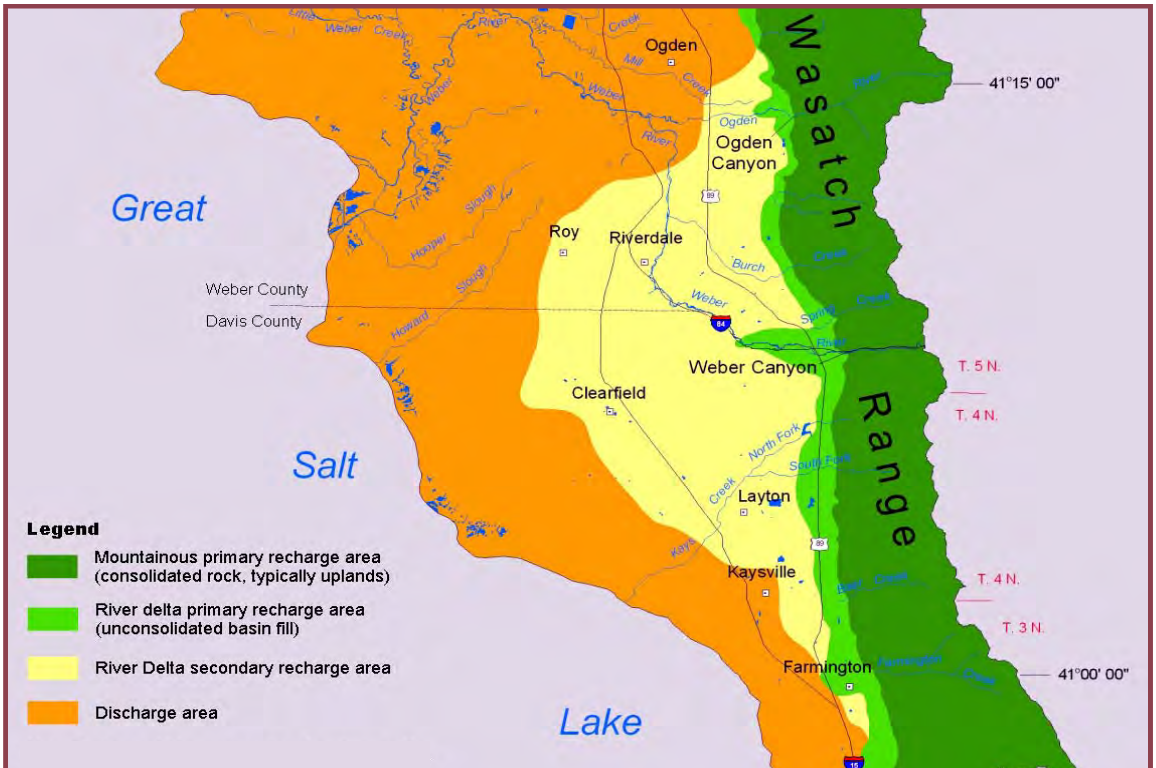

Figure 19, Weber River Delta Recharge & Discharge Areas

Source: Utah Geological Survey, 2004

a principal recharge source, makes them very valuable from a ground water standpoint. These areas need be preserved to allow natural recharge to continue and to accommodate managed recharge in the future. Community expansion in the tongue area reduces natural recharge and renders the land unavailable for surface spreading of water. Additional challenges are created since land values rise to where surface spreading becomes too costly. Creating open areas, such as a park or golf course, on the tongue can preserve the area for possible future aquifer recharge use. Provision can be made to incorporate recharge ponds directly as an integral feature or the park or golf course could surround the ponds.

Often commercial gravel pits are placed at the mouths of canyons since that is where sand and gravel deposited are prevalent. Gravel pits that no longer produce gravel, and are located above the unconfined aquifer, usually make ideal recharge ponds. Many Utah towns and cities have contemplated just what to do with gravel pits that are no longer in operation. Such pits are sometimes perceived as an eyesore and a liability. A viable option is to use them for aquifer recharge. Even gravel pits located further away from the canyon mouth can be suitable for recharge if mining has proceeded deep enough to remove clay layers and thus provide an uninterrupted path for recharge waters to reach the confined aquifers.

Wherever the recharge pond is located, the infiltration rate for the location must be adequate to put the required amount of water into the ground. Sufficient land area, at a reasonable cost, must be available to make surface spreading a viable option. If the recharge pond is located appropriately, recovery of the stored water can be done using existing withdrawal wells. Alternatively, new withdrawal wells may be drilled to intercept waters coming from the recharge site. “Evaporation losses from infiltration systems are much less than the amounts that infiltrate into the ground, and evaporation is often ignored.”[7]

Another surface spreading option is the construction of a surface reservoir specifically for recharge. These can be located directly on the stream or water can be diverted to a suitable off-stream reservoir site. In addition to being a traditional storage reservoir, Sand Hollow Reservoir in Washington County, Utah is an example of an off-stream aquifer recharge reservoir. As with every reservoir, evaporation losses should be considered during the design.

All instances of using recharge ponds involve maximizing the infiltration rate or amount of water entering the ground in a given time. This results in using the minimum land area and achieving the lowest operating costs. Considerations for operating recharge ponds to minimize clogging include:[8]

- Pretreatment to remove sediment.
- Controlling algae growth.
- Determination of optimum pond water depth.
- Determination of methods to remove clogging materials.
- Schedule of pond flooding, drying, and cleaning.

Another surface spreading option is the use of inflatable dams and other adjustable structures that can be raised and lowered to hold back water. Such dams increase the area over which water is ponded in the river channel and thus enhance aquifer recharge. They are used as stream water is available such as during spring runoff. These are used on the Santa Clara River in southern California.[9]

Another creative and promising variation to surface spreading is the use of perforated pipe that is buried at shallow depths. This is basically a subsurface distribution system (drain field) that provides a large underground area for the water to infiltrate into the unconfined aquifer.[10] The main advantage of this method is it can be installed in the primary recharge area even though urban development prevents installation of large surface spreading ponds. Similarly, pipelines to supply ASR wells might not be feasible in urban areas. Extensive recharge using a drain field is potentially feasible in spite of such development. Many miles of perforated pipe could be installed along highway, road, and street rights-of-way and in recreation areas such as golf courses, parks, and horse and hiking trails. Another advantage is the system is completely out of sight and does not interfere with other activities. Depending on location and the amount of water available, pipe diameter could vary from a several inches to several feet. This method has not yet seen wide application. Considerations for use include getting water to the available locations and access to the pipe for maintenance and cleaning. The Utah Division of Water Quality would regulate this method of storm water recharge.

Surface recharge systems can sometimes be combined with recreational and educational facilities to enhance and enrich the community. The town of Gilbert, Arizona has created a place known as "Water Ranch." It occupies 110 acres of prime real es-

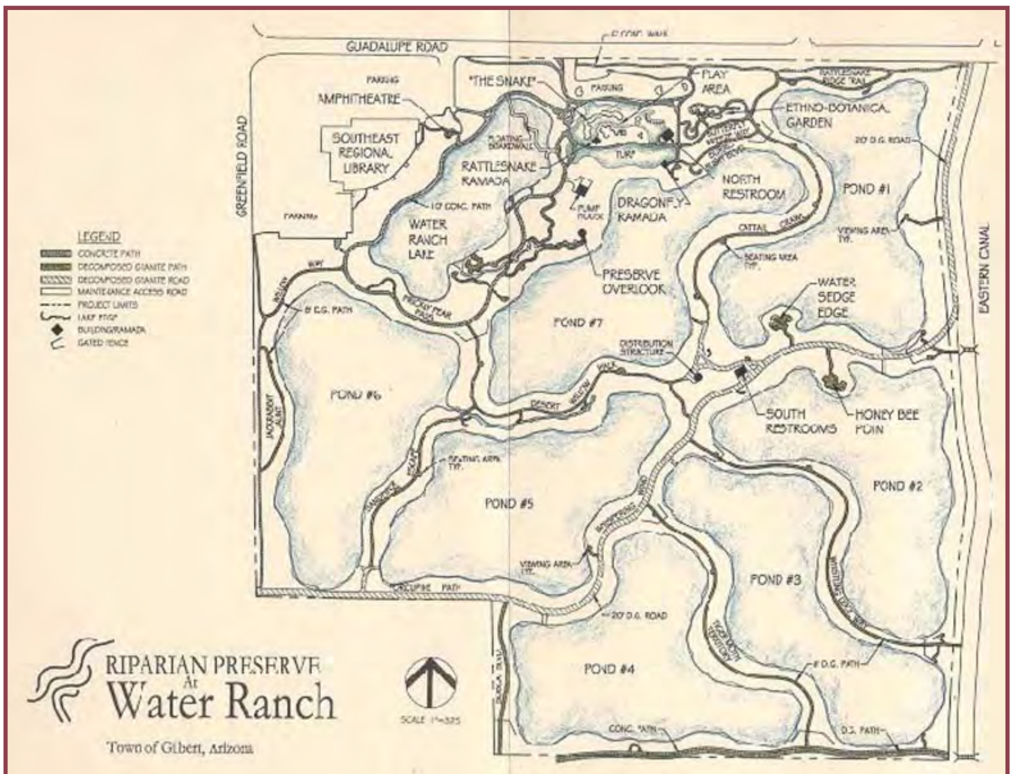

Figure 20, Riparian Preserve at Water Ranch, Gilbert, AZ

Source: Water Ranch, 2003

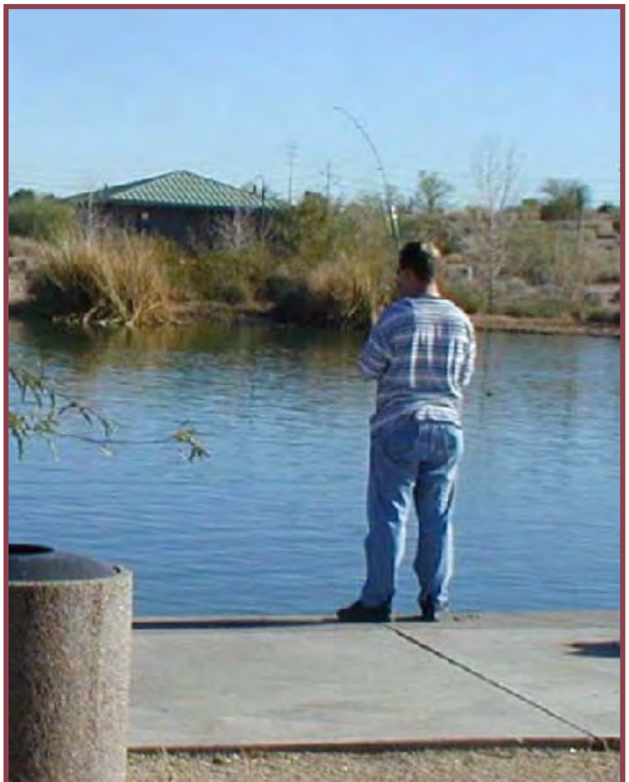

Figure 21, View of Urban Recharge Basin at Gilbert, Arizona

Source: Utah Division of Water Resources, 2003

tate within the city limits and is surrounded by urban, single-family dwellings. It is a multipurpose facility that includes ground water recharge basins, a community wildlife sanctuary, and recreational areas including fishing ponds (that are not drained), playgrounds, bike paths and the new city library. See Figures 20 and 21. Las Vegas, Nevada has a similar facility.

Recharge Using ASR Wells

Another, very popular, method of managing recharge is to pump water into the aquifer using ASR wells. One well is used for the dual purposes of getting water into the ground and recovering stored water at the same location.[11] ASR wells are intended to prevent plugging through proper well design, operation, and maintenance. Many publications are available on these subjects. Very little land area is needed for ASR wells and that is an important advantage in populated areas where land is expensive. See Figures 22 and 23.

"The first ASR well began operation at Wildwood, New Jersey in 1969, and this system is still in operation."[12] Aquifer recharge using ASR wells has proven popular and there are currently about 70 projects having over 290 wells operating in the United States. More are operational throughout the world. The technology is considered mature.

> Aquifer storage and recovery (ASR) wells are dual purpose wells that can recharge, store, and recover ground water. Such wells are typically constructed similar to production wells (screens, gravel envelopes, grouting, etc.), although greater screen lengths and diameters may be provided to increase recharge rates and reduce clogging. The water for well recharge needs to be treated to: (1) remove suspended materials, entrained air, and possibly dissolved gases; (2) remove nutrients and biodegradable organic carbon from waters of poor quality; and (3) disinfect or otherwise in-activate microorganisms to prevent physical and biological clogging of the aquifer or filter material around the screen or open portion of the well, and to prevent entry of pathogens into the aquifer. Also, undesirable compounds such as toxic and non-biodegradable organic chemicals may have to be removed prior to well injection.
>
> Because of the high cost of wells, pretreatment of the water before recharge, and required maintenance, ground water recharge by wells is usually more expensive than ground water recharge by surface infiltration, except in areas of high land costs or unsuitable soil conditions.[13]

Although ASR wells are typically more expensive than surface spreading, both are often less expensive than other surface water storage options. Economic details are discussed in the Benefits of Conjunctive Management section of this chapter. Where possible, existing withdrawal wells can be retrofitted to accommodate ASR, thus reducing the overall cost of the recharge project. Stored water can be recovered from the ASR well and also from wells located down-gradient of the ASR well.

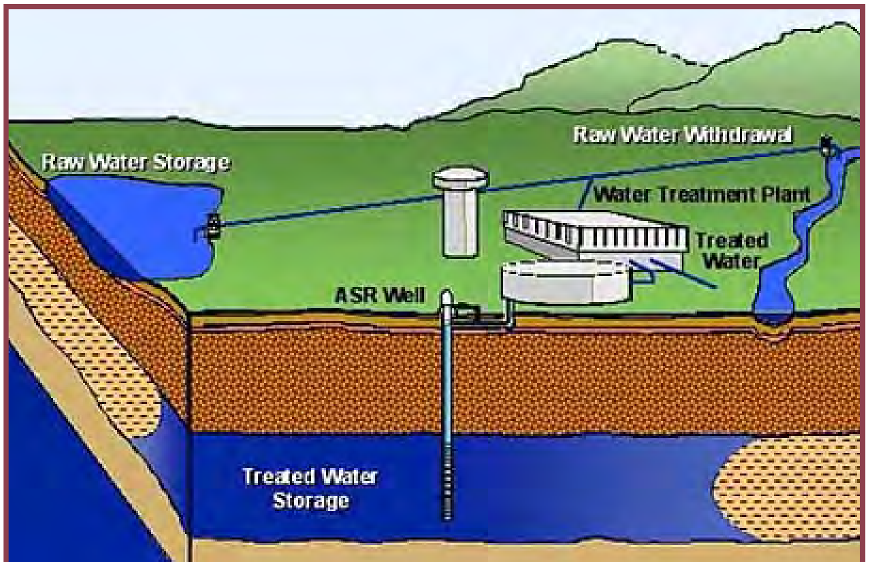

Figure 22, Municipal Water System With ASR Well

Source: www.asrforum.com, January 2005

usually occurs during April, May and June. For instance, as shown in Figure 24, the volume of water flowing in the Weber River during those three months is 54 percent of the total annual volume. More than one-half the annual flow volume occurs during one-fourth of the year. The percent will be different for each stream, and for each year, but this comparison can be considered representative.

During the peak runoff, the amount of water available often exceeds the amount that can be used or stored with existing facilities. Even though water rights may be available, the water cannot be captured. This "excess water" passes on downstream without being put to beneficial use. Often that water goes into the Great Salt Lake or other water body where much of it may not be utilized. About 52 percent of the area of Utah is drained by streams that flow to lakes without any outlet. These areas are located north of Washington and Kane Counties and west of the Wasatch Mountains, and include the most populated areas of Utah. This region is outside the Colorado River drainage. A

SOURCES OF AQUIFER RECHARGE WATER

While there are several possible sources of recharge water, all sources will not be available at all locations. When considering implementing aquifer storage and recovery, it is worthwhile to take an in-depth look at all potential sources. Although any one source might be relatively small, several sources could be combined to come up with enough water and thus maximize efficiency. "Typically, ground water storage projects can operate with fairly high levels of source unreliability."[14] Another consideration is using different recharge sources at different times to even out the quantity over time. Some areas in Utah do not have a sufficient quantity of water even when combining the following suggested sources. Beryl-Enterprise may be such an area.

Streams

Seasonal spring runoff in streams is perhaps the most likely source of aquifer recharge water. Rivers in Utah typically have very high spring runoff when compared to flows during the remainder of the year. Peak runoff

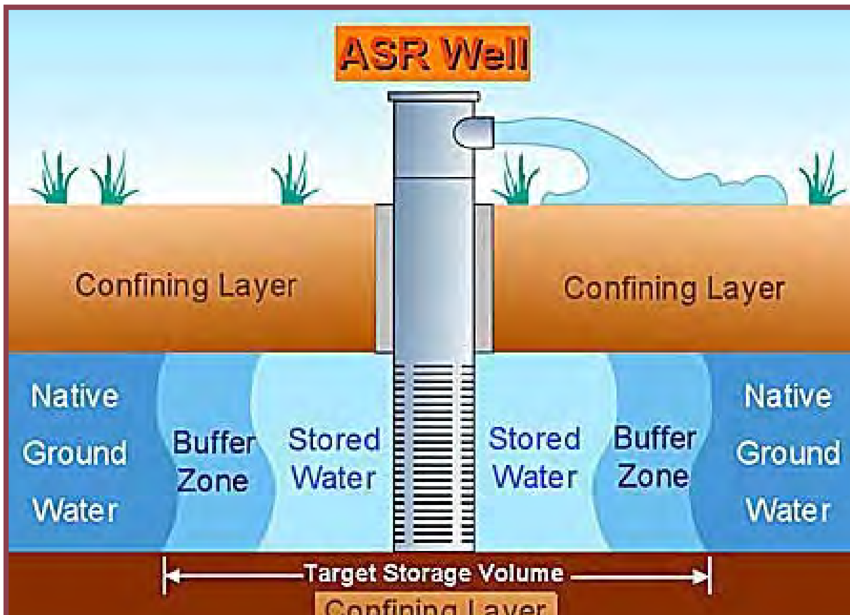

Figure 23, ASR Well

Source: www.asrforum.com, January 2005

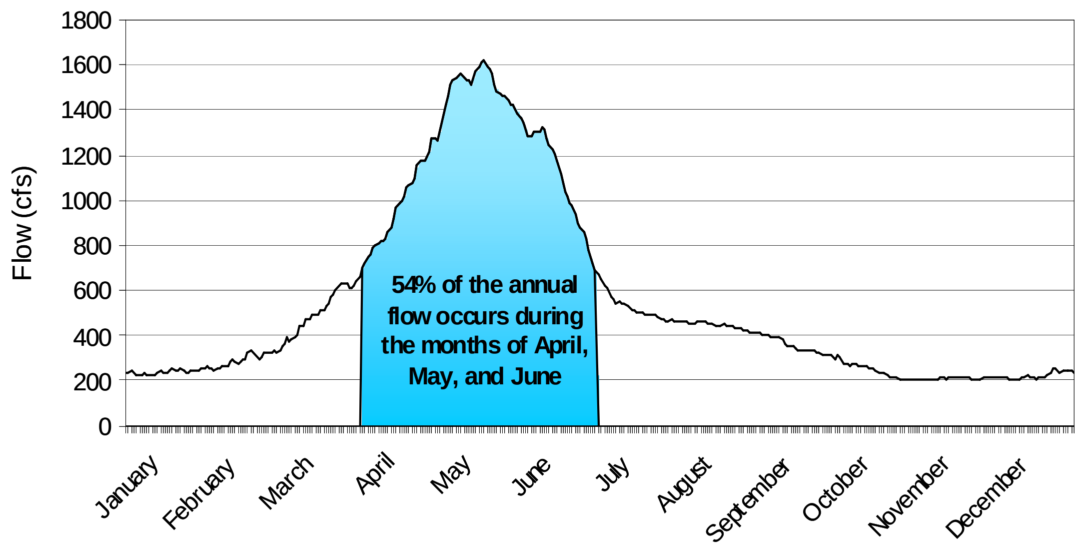

Figure 24, Weber River Average Annual Flows, 1920 to 2003

Source: Utah Division of Water Resources, 2005.

large portion of the water there is lost to evaporation without any discernable benefit. Evaporation in the Salt Lake City area exceeds 30 inches per year while in the St. George area it exceeds 50 inches per year.[15] The magnitude of evaporation water losses can be appreciated by seeing the total surface area of a lake and removing those depths of water. Instead of being lost to evaporation, a portion of that water could be stored underground to be used when needed.

Consequently, there may be a significant volume of seasonal runoff water available in some of the state's rivers and streams. These surplus flows can be used to recharge ground water aquifers and conjunctively manage the total water resources. The actual volumes available will depend upon the drainage area size and runoff characteristics, and stream size. Figure 24 depicts the long-term average flows in the Weber River. In any given year, actual flows will be above or below average. Similar flow patterns can be expected in other Utah streams.

In 1995, the Central Utah Water Conservancy District (CUWCD) determined, "Opportunities may exist for more complete utilization of direct flow surface water supplies. The difficulty in using these supplies is that approximately 60 percent of the annual flow volume of the creeks is available during the short three-month period of April, May and June of each year. This is a huge amount of water for a relatively short period."[16]

Their analysis is shown in Figure 25 and summarized below. These numbers are for an "average year."

150,000 acre-feet	Total Available Supply
- 58,000 acre-feet	Currently Utilized Stream
- 43,000 acre-feet	Potential Conjunctive Use Benefits
49,000 acre-feet	Remaining Available Water

The "Potential Conjunctive Use Benefits" amount shown in Figure 25 was limited by the capacity of existing water storage and treatment facilities. Also, those potential benefits were derived from specific conjunctive management actions, described previously, that did not include aquifer storage. This analysis indicates that seasonal runoff water in streams is available and can be used to recharge aquifers even in one of Utah's most populated regions. The Jordan Valley Water Conservancy District uses seasonal runoff in a project which is described in the Current Utah Projects section of Chapter 4. Also, the Metropolitan Water District of Salt Lake and

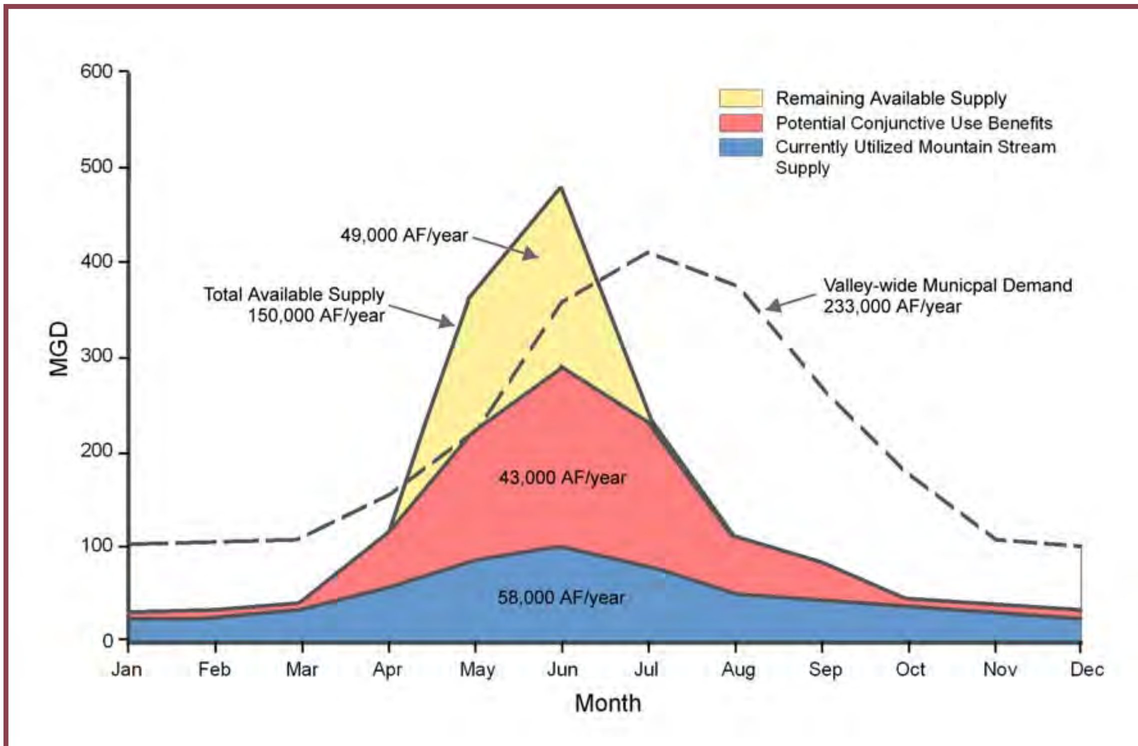

Figure 25, Potential Conjunctive Use Benefits, Salt Lake Valley

Source: Central Utah Water Conservancy District, 1995

Sandy is considering using stream flows for an aquifer storage and recovery project.

Owners of water treatment plants supplied by streams have a considerable advantage that should encourage the use of ASR wells for aquifer storage and recovery.

> "Municipal water systems are usually designed to meet peak day demands during some future year. The typical ratio of peak day to average annual demand is about 1.3 to 2.0, although ratios as high as 5.0 are known. Consequently it is not uncommon for water systems to have a substantial amount of idle capacity during periods when demands are below the peak demand. This capacity can be utilized for storage of water underground during off-peak months, using recharge facilities."[17] (See Figures 22 and 23.)

A simple and inexpensive way of using seasonal spring runoff for aquifer recharge is the use of properly placed debris basins. Such basins were constructed by many communities along the Wasatch Front after the high stream flows and flooding during the early 1980s. Rocks and trees were washed down the channels causing considerable damage. Installation of catchment basins allowed debris to accumulate in accessible locations where it could be removed. Locating debris basins on the primary recharge area along the mountains achieves the added benefit of allowing more stream flow to recharge the aquifer. This practice should be employed whenever possible. Precautions need to be taken to insure that recharge from the catchment basins does not raise the local water table to the point that water seeps into the basements of the adjacent homes or negatively impacts land that is down-gradient of the basin.

Such debris basin sites can also be used for recreation in urban areas. Notice in Figure 26 the parking area with adjacent picnic tables and trails around the basin and along the stream. However, also note the housing and paved areas that greatly reduce the ability of natural precipitation to infiltrate the aquifer recharge area. Depending on local conditions, urbanization reduces infiltration due to rainfall and snowmelt from about 50% on natural ground cover, down to about 15 % on downtown areas.[18] Such urbanization also increases peak stream flows and runoff volumes. Storm water volumes from impervious areas are about three times that of the pre-development runoff volume from storm events.[19]

For a variety of reasons, some agricultural water is no longer being put to beneficial use. Often this water comes from stream flows. Assuming rights to this water could be obtained, such unused water could be used for aquifer recharge. As with any beneficial use of water, maintenance of downstream water rights must be considered. A further benefit of using spring runoff waters is reduction of flood flows.

Springs

Another potential source of water for aquifer recharge is spring water. Consider the "Valley-wide Municipal Demand" curve shown in Figure 25. The peak demand months are June, July and August while the rest of the year demand is considerably lower. This occurrence of a few months of high demand followed by many months of low demand is typical for most areas of the state. In contrast, many springs flow all year long with peak flows occurring in the spring season. Spring water can be stored in aquifers during the lower demand times for later withdrawal during the high demand times. In 2002 Brigham City, Utah implemented a project to recharge excess spring water; details are discussed in Chapter 3, under Current Utah Projects.

Storm Runoff

Another potential source of water for aquifer recharge is storm water runoff discharged through storm water drainage wells. "Storm water drainage wells are Class V, Underground Injection Control wells used to remove storm water or urban runoff (rainwater and melted snow) from impervious surfaces such as roadways, roofs, and paved surfaces to prevent flooding, infiltration into basements, etc."[20] "By definition, a Class V injection well is any bored, drilled, or driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system."[21] Although inventories are not complete, the Environmental Protection Agency has determined that about 81 percent of the documented storm water drainage wells in the United States are located in the seven Western States of Arizona, California, Wash-

Figure 26, Debris Basin at the Mouth of Big Cottonwood Canyon

Source: Utah Division of Water Resources, February 2005.

ington, Oregon, Idaho, Montana, and Utah. Of the seven states, Utah has the fewest: 2,890 wells.[22]

These wells are regulated by the Utah Division of Water Quality (DWQ) and, after required conditions are met, can be Authorized-by-Rule as part of the Underground Injection Control (UIC) Program. As of April 2005, DWQ is working to standardize the use of storm water runoff added to surface waters and to ground water. Contact information is provided in Chapter 6, Project Implementation.

The water quality industry has recognized Best Management Practices (BMP) which serve to minimize the impact to ground water from storm water infiltration through these wells. Such BMPs are effective and inexpensive. These practices include construction, operation, maintenance, and monitoring and sampling. Construction practices can incorporate a sediment trap and an oil/water separator to clean the water before it enters the well. Sediments can contain contaminants. Operation practices include a regular inspection and cleanout program to maintain the effectiveness of the well.[23]

Depending on where the runoff water originates, it can contain potential contaminants such as heavy metals, organics, coliform bacteria, herbicides, pesticides, and other constituents.[24] However, locations can be found that contain few contaminants. In general, studies have found that private residential property runoff is relatively clean and less likely to contaminate ground water.[25] In Utah there are many residential communities already built in the primary aquifer recharge areas adjacent to the mountains. A series of storm water drainage wells located along aquifer recharge areas would provide continual replenishment to the aquifer. Storm water runoff could also be directed to water spreading recharge basins as described previously. Otherwise, as is now the case, large volumes of storm water will continue to be lost to storm sewers and wasted. Storm water volumes from impervious areas are about three times that of the pre-development runoff volume from storm events.[26] While safeguards are necessary, Utah has a regulatory program that allows storm runoff water to become a viable option to recharge ground water aquifers.

Reclaimed Water

Another potential source of water for aquifer recharge is reclaimed water from wastewater collection systems. Such water must receive tertiary treatment including chlorination and denitrification to prevent contamination of the ground water. The city of Gilbert, Arizona has used such a system for over three years. See Figures 20 and 21. The facility is designed to recharge at the rate of 8 million gallons per day (12.4 cubic feet per second). Considerable attention must be given to make sure the reclaimed water meets quality standards before using it to recharge ground water. Referring to using reclaimed water for aquifer storage and recovery purposes, one reference indicates:

> "For a growing number of water users, the reliability of this source, its high quality, rising competition for limited available water supplies and regulatory pressures to conserve water provide four good reasons to incorporate reclaimed water into long-term water supply plans."[27]

There have not been any projects in Utah that introduce reclaimed water into the ground water specifically for aquifer storage and recovery. However, the Utah Division of Water Quality is willing to consider such projects and details of their requirements are discussed in Chapter 6, Project Implementation. In April 2005, the Utah Division of Water Resources published a report titled, "Water Reuse in Utah," which provides information on many aspects of water reuse, including aquifer recharge.

Converted Agriculture Water

When a piece of irrigated farm land changes to urban use, the city may require the agricultural water rights associated with the land to be transferred to the municipality as a condition of approving the development. Although water rights determinations affect the actual transfer rates, the amount of water required per acre of land for irrigated agriculture is about the same as the water required for urban development on the same acre. Several municipalities in Utah have implemented this requirement.

Applying such water conversions to aquifer storage and recovery might be complex. Irrigation diversions typically apply only during the growing season whereas communities need water all year long. Some communities with secondary water systems could use irrigation water during the growing season. Irrigation points of diversion may not be located convenient to the municipal water treatment plant. Still, it would be beneficial to investigate the possibility of using these agricultural waters. The water formerly used on farm fields could be used in a city's secondary water system. Although potentially costly and inconvenient, it could also be piped directly to the community water treatment works and used to provide municipal and industrial water to people via the existing distribution system. Another option would be to store the water available during the irrigation season in the local ground water aquifer. Raw water might be put into spreading basins or treated water might be injected using wells. Then the water could be withdrawn using existing wells, or ASR wells, and distributed via the existing water distribution system. That is, conjunctively manage the irrigation water by storing it underground until needed for public water supplies.

Recharge Water Quality

Because of the risks to public health that can be associated with water supply, the entire "chain of water" from the initial source of recharge water to the final consumer must be carefully monitored and controlled.[28] "The number of samples of the recharge water needed will vary with the type of source. A larger number of samples will be needed if the source water quality is expected to vary seasonally. Review of these samples should indicate if additional sampling is required."[29]

Regardless of source, aquifer recharge water quality must be thoroughly tested and quantified. This is necessary to be certain the water will not contaminate the aquifer itself or the water subsequently drawn from the aquifer. Table 7 lists the contaminants commonly found in the proposed recharge waters. There are many harmful pollutants and potential chemical interactions making analysis of water chemistry a very technical field. Specialized consultants will be necessary to assist in this aspect of conjunctive management projects. While not comprehensive, the following general cautions apply.

- Recharge water chemistry should be compared to the existing aquifer water chemistry. Potential chemical interactions need to be understood. The results could be negative or positive.
- Recharge water chemistry should be compared to the geologic formations of the aquifer. Materials in the water, dissolved or suspended, can react with the minerals in the ground through which the water passes. The results could be negative or positive and must be understood.
- Potential contaminants associated with the recharge water source need to be identified. While not a complete listing, Table 7 contains contaminants commonly associated with recharge water sources.

> "Source waters not suitable for recharge or not meeting quality standards can be improved by providing treatment prior to recharge. However, provision for disposal of the by-product of treatment must also be made. If adverse geochemical reactions are expected, pre- and post-treatment may be sufficient to correct the problem."[30]

As mentioned earlier, the underground environment of aquifers is conducive to killing off surface bacteria and viruses. Other contaminants are similarly mitigated. Therefore, it is important not to measure compliance at the ASR well. Rather, a separate monitoring well located about 1,200 feet from the ASR well should be used to provide a more accurate indicator.[31]

TABLE 7
Contaminants Associated with Recharge Waters

Recharge Water Source	Likely Contaminants
Streams	Fertilizers, pesticides, coliforms, animal waste
Springs	Dissolved minerals
Storm Runoff	Metals, organics, coliforms, herbicides, pesticides, fertilizers, oil, grease.
Reclaimed Water	Coliforms, organics, large number of household chemicals & pharmaceuticals

Timing and Volume of Ground Water Recovery

Every aquifer storage and recovery project includes consideration of the time interval between recharge and withdrawal. Water stored underground can be recovered during the same year it was stored or it can be stored long-term and carried over to subsequent years. Which method can be implemented depends on aquifer characteristics. Free-draining geologic formations, such as unconfined gravels and sands, are conducive to short-term storage. Tighter geologic formations, such as sandstone and carbonate rocks, are more conducive to long-term storage. Other factors determining whether short- or long-term storage is employed include regulatory issues, such as the State Engineer's decisions on the project, and water demand patterns.

Each aquifer storage and recovery project is dependent on local geology. However, a recent investigation by the U. S. Geological Survey may prove helpful when considering recharge to withdrawal times for projects in the Salt Lake Valley. Since the geology of the Basin and Range Province extends all along the Wasatch Front, these studies might possibly be indicative of conditions elsewhere along the province. Several researchers and ground water models indicate the primary recharge areas for ground water are located along the east side of the valley adjacent to the mountains.[32] Ground water flows generally from east to west with much of the discharge area being along the Jordan River. Tritium and tritium/helium-3 analysis shows, "On the east side of the valley, the youngest water is generally in the primary recharge area. Water becomes older with distance from the mountain front, the oldest water being in the discharge area."[33] The time taken for ground water to flow from recharge area to discharge area varies from 20 years to over 50 years, depending on location in the valley.[34] See Figure 27. The analysis indicates "a typical age gradient of about 7.5 years per mile, corresponding to an average linear ground water velocity of about 1.9 feet per day."[35] This is in general agreement with other researchers who determined an average linear velocity median value of three feet per day, although values ranged from 0.06 to 144 feet per day.[36] The time intervals indicated in Figure 27 and the ground water velocities provide some insight into how fast recharge water might travel through the Salt Lake Valley principal aquifer.

Water moves through the sand and gravel aquifers in the Salt Lake Valley as indicated above. Water injected under pressure becomes a part of the underground regime and flows in a similar manner. However, it takes time for the water to move away from the well head. As water is continually injected into the aquifer, the flow is initially taken up more by water going into aquifer storage than by an immediate increased flow in discharge areas. Similarly, as water is continually pumped from the aquifer, initially more water comes out from aquifer storage than from decreased flow in the discharge areas. This principle, combined with the above flow rates, suggests an ASR well aquifer storage and recovery project would operate most efficiently and effectively with storage times of no more than 4 or 5 years, with shorter times being better.

The amount of recharge water recovered from the aquifer can vary. Water stored in confined aquifers using wells to inject and recover the water is typically 100 percent recoverable. Water put into an unconfined aquifer using wells or recharge ponds, and later recovered using wells, presents a more complex set of circumstances. Each project is unique due to the geology involved and the goals of the sponsoring agency. Apparently these conditions were contemplated in the Utah Ground Water Recharge and Recovery Act that was enacted in 1995. Some of its provisions include:

- Recoverable water -- State Engineer to determine.
  A person who holds a recovery permit may recover the amount of water stored by the recharge project which the state engineer determines has reached the aquifer and remains within the hydrologic area of influence.
- Application for a recharge permit -- Required information. (Among other things) (1) The source and annual quantity of water proposed to be stored underground and (2) the percentage of anticipated recoverable water.

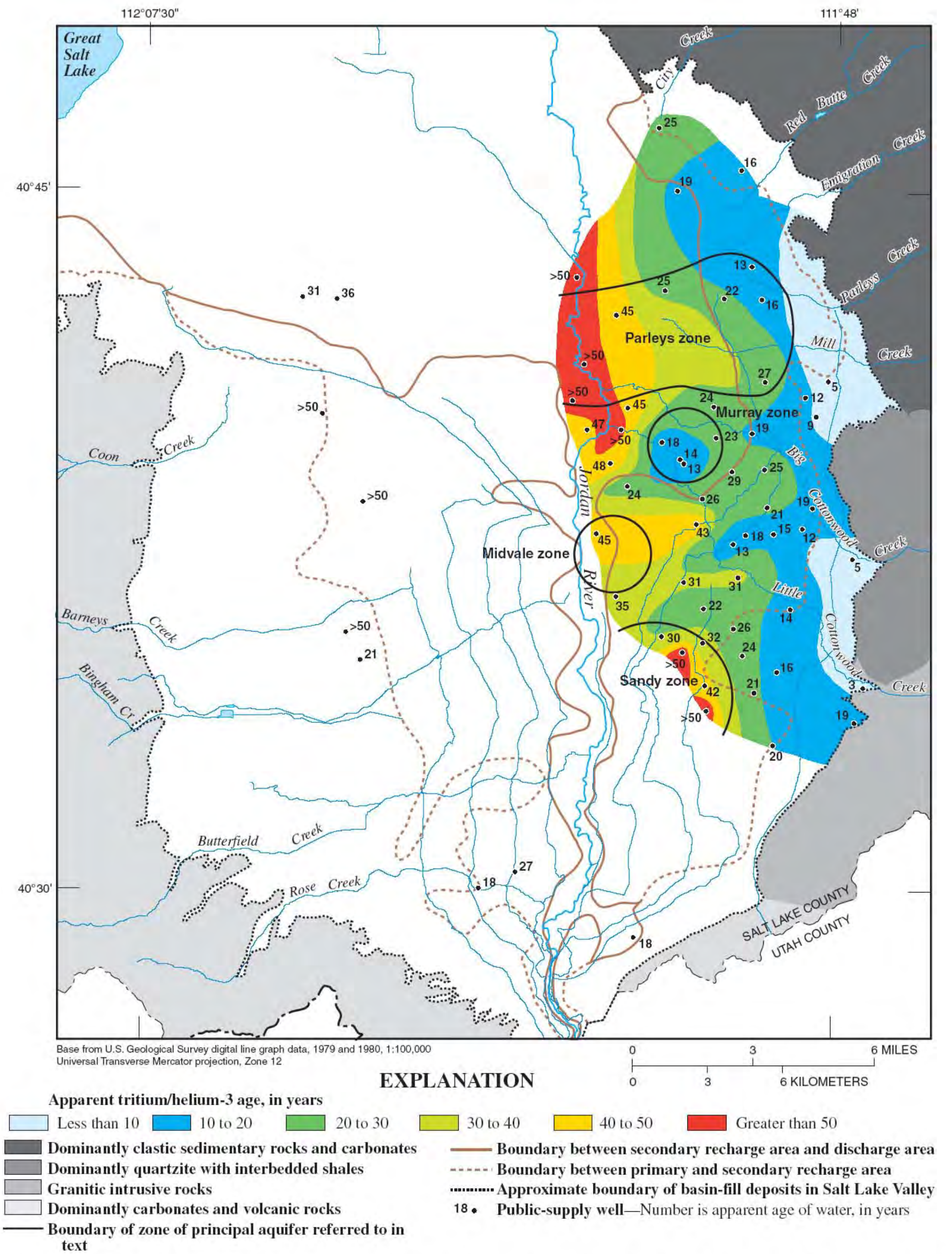

Figure 27, Tritium/Helium-3 Age in Salt Lake Valley Principal Aquifer, 2000-2001

Source: U.S. Geological Survey, *Water Quality in the Great Salt Lake Basins,* Circular 1236, 2004.

A number of beneficial aspects of conjunctive management projects are related to water recovery. The American Society of Civil Engineers indicates: "Aquifers can be used to store, convey, and distribute recharged water. If wells are drilled where the water is to be used, perhaps to supply a local distribution system, large surface conveyance and distribution systems may not be needed because the water can flow underground in the aquifers from the source of recharge to the point of use."[37]

In a similar vein, "Some situations may arise where it is desired to recharge at one location and recover at another location. This uses the aquifer as a means of conveyance and also long-term storage. Water injected at point A is recovered from the same aquifer at point B, even if the distance between the two points is such that the travel time may be hundreds of years or more. The net volume of water in the aquifer, and associated water levels, are maintained through recharge practices. This is a sound water management approach; for example, such a practice is legal in California, Arizona, and Texas…"[38]

When recharge occurs at one location and withdrawal occurs at another location, the organization putting water into the aquifer can be concerned that other well owners will withdraw "their water." All well owners are allowed to withdraw only the amount approved in their respective water right. And the entity doing the recharging has the right to withdraw the water that was recharged. Still, the recharge water keeps ground water levels higher than they would otherwise be and thus benefits everyone using the aquifer. Allowing recovery of the full recharge amount eliminates this concern of recharge water being withdrawn by well owners other than the entity that did the recharging.

Considering these factors, it would be desirable in unconfined aquifers to design and build systems that recharge a given amount of water at one point in the aquifer and recover the same amount of water at another point in the aquifer. Benefits of such a system include:

- Convey and distribute water without the cost and disruption of constructing pipeline systems.
- Achieve longer water storage time as the water moves through the aquifer.
- Blend recharge water with natural aquifer water.
- Maintain water volumes in the aquifer and reduce water level declines.
- Recover the full amount of water that was recharged.
- Eliminate the concern of recharge water being withdrawn by well owners other than the entity that did the recharging.

Interestingly, there was one Utah project that intended to implement this concept. In November of 1946 the City of Bountiful submitted an application to the State Engineer's office for approval of a project described as follows:

> "…divert 1500 acre feet of water from Barton Creek…[and] convey it by means of two canals… to recharge areas located as follows…(location described). The water will be spread over the land by a system of contour terraces and checks and allowed to percolate into the underground supply to commingle with the natural waters of the basin. The water thus put into the underground basin will be exchanged for a like quantity of water which will be diverted from the basin by means of three wells which are located [¼ to 1¼ miles away]. From the wells the exchanged water will be pumped directly into the present distribution system and its extensions and used each year from January 1 to December 31 inclusive for municipal purposes in Bountiful City."[39]

In a similar manner, the currently operational Jordan Valley Water Conservancy District aquifer storage and recovery project is permitted to recharge water into the aquifer from any of its wells and also to withdraw water from any of its wells.[40] There are 19 wells located from 7000 South to 10100 South and from 700 East to 2800 East, resulting in an overall well field size of about 4.5 miles north-south and about 3.4 miles east-west. With the any-to-any combination of recharge and withdrawal of water, it appears water injected at point A in the aquifer can be accounted for by withdrawal at point B. However, this project does have a restriction in the amount of water recovered. As expected, recovery cannot exceed recharge. But, if the water is recovered within the first 12 months of recharge, 100 percent can be recovered. If the water is recovered between 12 and 24 months of recharge, 90 percent can be recovered. And so on in succeeding years, there being a 10 percent per year reduction in the recovery amounts for each year. The Recharge and Recovery Act indicates the State Engineer determines recovery amounts based on the parameters for each individual project. Thus, recovery percentages for one project are not determined by any other project.

BENEFITS OF CONJUNCTIVE MANAGEMENT

Increasing the Usable Water Supply

Implementing conjunctive management and utilizing the several water sources described earlier simply results in the greatest possible water use efficiency. Water that evaporated or was otherwise lost may be put to beneficial use. Each completed project benefits those being served. As more projects are finished, more benefits accrue. The paramount advantage is an increase in the amount of water available.

Economics

Overall, aquifer storage and recovery (ASR) has been found to be more cost effective than aboveground options to develop water. As with all water projects, there is a need to compare options on a project-by-project basis to determine which option is the most cost effective. The following quotes[41] provide the particulars. Additional considerations are provided in parenthesis.

> ASR [well] feasibility has been demonstrated at a growing number of operational sites in the U.S. It is a practical, cost-effective, and environmentally acceptable water management alternative. When compared to surface storage reservoirs, aquifer storage is very low cost, since land requirements are minimal and the storage capacity is provided by nature for the relatively low cost of a few ASR wells (or recharge ponds). In addition, water transmission and treatment facilities can be operated more efficiently with ASR systems, often requiring less capacity and construction costs.
>
> Most utilities can use ASR to meet water system expansion goals while achieving significant cost savings. However, feasibility must be confirmed through satisfactory completion of an ASR test program, with all associated permitting, legal, economics, water rights, environmental, and other issues resolved. This typically requires two to three years to complete, after which it is appropriate to begin adjusting water system expansion plans to accommodate the new ASR technology and begin to realize the associated cost savings. Until an ASR test program is completed, it is recommended that ongoing expansion plans be continued. Therefore, maximum savings from application of ASR technology can best be achieved by starting ASR feasibility investigations at least three, and preferably five years before any major decision regarding investment of capital and sizing or location of facilities.

In order to better understand ASR economics, construction and engineering cost data from nine ASR well sites in six states were obtained and analyzed. The following conclusions, expressed in 1993 dollars, were drawn.[42]

1. Unit costs for ASR facilities range from $200,000 to $600,000 /MG/day of recovery capacity, with an overall average of about $400,000/MG/day. Higher unit costs are typically associated with the first new ASR well at any sites, sites requiring extensive piping to tie them in to the existing water systems, and sites with low recovery capacity per well. Lower unit costs are associated with retrofitting existing wells at sites close to existing piping facilities, higher yield wells, and also with multiple-well ASR expansion projects.

2. Unit costs for the second and subsequent ASR wells at any site are typically lower than for the first well, reflecting generally reduced efforts to obtain regulatory approval. The first ASR well incurs additional cost in order to demonstrate ASR feasibility. The reduction in unit cost is typically in the range of $100,000 to $200,000/MG/day.

3. When comparing capital cost per unit of new capacity, ASR typically is less than half the cost of other water supply and treatment alternatives. In some cases, the cost savings approach 90 percent. This savings reflects the efficient use of major facilities such as pipelines, pumping stations, and treatment plants, and the relatively low cost of using underground storage capacity when compared with a similar storage volume provided by surface reservoirs.

4. Annual operating costs range from about $6,000 to $40,000/MG/day of recovery capacity, although data availability is sparse. This includes the marginal cost for power and chemicals during recharge and recovery, plus an allowance for operation and maintenance.

"When comparing ASR to other water management alternatives, it is important to compare them on the same basis. When comparing capital costs, an appropriate comparison is usually the cost/unit production capacity since ASR increases system peak capacity even though it may only recover water for a few months each year. It is usually inappropriate to compare capital costs on the basis of dollar per acre-foot or any other volume measurement, since total annual production from ASR facilities may be small, depending upon the duration and extent of the peak demand period. Similarly, when comparing operating costs, it is more appropriate to compare the annual costs/unit production capacity rather than dollars per unit volume, since ASR wells typically are not in operation all year."[43]

"If recharge is the sole objective, surface recharge, if feasible, is the lowest cost approach to getting water into the ground. If recharge is the sole objective but surface recharge is not feasible because of hydrogeologic constraints, high land costs or other issues, then ASR wells can also achieve this objective at a higher unit cost due to the probable need for a higher level of water treatment prior to recharge. If the objective is to recover and use the stored water within a few years at or near the same site, then ASR well systems will probably be more cost-effective than surface recharge systems because no additional facilities will be required for recovery, treatment, and use."[44]

Table 8 shows a comparison of capital costs for five water utility systems having comparable service levels, with and without ASR. In some cases, the savings with ASR is due to reduction or elimination of surface reservoir storage. In other cases, the savings is in terms of a major pipeline or treatment plant. In all cases, the savings is greater than 50 percent. This appears to be typical for most ASR systems placed in operation to date. With these kinds of savings, the ASR system can respond to a variety of technical, regulatory, and other challenges and still provide cost-effective service to the owner and consumer.[45]

The opportunity exists for marginal cost pricing of water using ASR technology. Inexpensive water can be bought during winter months of low demand and stored underground. That same water can then be sold during summer months of high demand for a higher price. An analysis conducted for Green Bay, Wisconsin indicated water potentially available for 7 cents per 1000 gallons in the winter and worth $1.29 per 1000 gallons in the summer. Comparing the sell price to the buy price yields: $1.29/$0.07 = 18.4 times.[46]

Water suppliers needs to look at all available options, including ASR, when considering system ex-

TABLE 8
Comparison of Capital Costs, With and Without Aquifer Storage and Recovery (ASR)

Location	Expansion Cost With ASR (Million Dollars)	Expansion Cost Without ASR (Million Dollars)	Percent Savings
Wyoming, MI	9	31	71 %
Peace River, FL	46	108	57 %
Manatee County, FL	2	38	95 %
Florida Keys, FL	3	38	92 %
Kerrville, TX	3	30	90 %

Source: Ground Water Recharge and Wells, A Guide to Aquifer Storage and Recovery, R. David G. Pyne, 1995, page 221 pansion. When the options are identified, costs evaluated, and equal comparisons made, the most attractive option will be identified.

Environment

As mentioned earlier, aquifer storage and recovery can be used to maintain minimum stream flows and thus enhance stream riparian corridors. Such flows can benefit wetlands along the stream as well as marshes and wildlife refuges around lakes and reservoirs. This is accomplished by intentionally storing a quantity of the spring runoff for the specific purpose of recovering that water and returning it to the stream during low flows later in the year. High water flow damage to such areas is reduced, and harm to these areas due to low or non-existent flows is prevented. In addition, fish, bird, and aquatic wildlife habitat is preserved. Where multi-year water storage is practiced, such restored flows could prevent permanent loss of such habitat during prolonged drought years. Restoring water taken from the stream, back to the stream, is a good way to provide considerable environmental benefits. These benefits should always be included when considering using stream flow for an aquifer storage and recovery project. Such a project is being developed at Squaw Valley, California to maintain minimum stream flows and preserve brown trout habitat during the summer.[47] A related perspective is provided as follows.

> "By increased reliance upon water sources during times of high flow and low demand, and upon storage of the water primarily in confined aquifers with no impacts upon surficial water levels, the environmental effects of ASR operations are positive in that they help to sustain human welfare without adversely impacting aquatic and terrestrial ecosystems. This benefit has been widely recognized by environmental interest groups."[48]

Other Significant Benefits

Conjunctive management also has other significant benefits, including:

- Stabilize ground water levels and prevent further decline.
- Increase ground water levels in some instances.
- Improve ground water quality, depending on aquifer water and recharge water chemistry.

Mitigation of ground water mining effects. Avoidance of negative consequences include:

- Reduced pumping cost increases to lift the water higher.
- Reduce the need to re-drill and deepen wells or buy larger pumps.
- Reduce flow reduction or loss of flow to springs fed by the aquifer.
- Reduce flow reduction or loss of flow to streams and wetlands fed by the aquifer.
- Reduce or eliminate compaction of the aquifer, land subsidence, or contamination of aquifer water.
- Reduce the loss of aquifer water-holding capacity.
- Reduce or defer the loss of the ground water since levels may not decline below the point of economic recovery.
- Reduce the risk of saltwater intrusion for those aquifers bordering the Great Salt Lake.

Negative Impacts

- Regardless of the water source used for aquifer storage and recovery, the improved efficiency can result in an overall reduction of in-stream flows. This has the potential for injury to riparian and wetland areas. Such potential should be considered and avoided for every project.
- Similarly, overall reduction of in-stream flows can adversely impact down stream water users. While appropriate water rights are required for every conjunctive management project, there may still be impacts. As mentioned earlier, water rights are an important consideration to every project.
- Surface recharge ponds, debris basins and storm-water drainage wells are designed to increase the amount of water going into the ground and raise the local water table. Depending on location, these conditions could harm nearby residential and commercial buildings, promote landslides, or impact other human enterprises such as an open ex-

cavation, pipeline, canal or highway. Such potential should be considered and avoided for every project.

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[20] http://www.epa.gov/ogwdw000/uic/classv/pdfs/stw-fact.pdf , April 2005, page 1.

[21] http://www.epa.gov/ogwdw000/uic/pdfs/fact_class5_stormwater.pdf , April 2005, page1.

[22] See note 20.

[23] See note 19, page 2.

[24] http://waterquality.utah.gov/UIC/CLASSV/ClassVSubclasses.htm , April 2005, page 1.

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4

PAST AND PRESENT CONJUNCTIVE MANAGEMENT EXPERIENCES

This chapter provides a historical perspective to the concepts involved in conjunctive management, particularly aquifer storage and recovery (ASR) using surface spreading and wells. It includes a brief description of the earliest known project in the world and a review of work in several countries. This is followed by a brief compilation of projects in the United States as well as a history of early work and existing projects in Utah.

WORLDWIDE

The first known intentional recharge of water to an aquifer and subsequent withdrawal of that water occurred several hundred years ago in the Kara Kum Plain on the southeast shore of the Caspian Sea in Turkmenistan. The area has less than 4 inches of rain per year. Nomads in the area dug long trenches to direct water away from areas having a shallow clay layer that prevented recharge, to known recharge areas that supplied dug wells. The nomads used a series of wells closest to the recharge to provide lesser quality water for livestock and additional wells farther down-gradient for domestic needs. Some of the underground reservoirs were used routinely while others were reserved for use only during severe droughts.[1]

Today, ASR systems are operating in the United States, United Kingdom, Canada, Australia, South Africa and Israel. Several other countries, including the Netherlands, New Zealand, Thailand, Taiwan and Kuwait are in the process of developing operational projects.[2] The forces that drive the need for water operate throughout the world and implementation of conjunctive management has been similarly widespread.

UNITED STATES

As of May 2004, there were 68 known operating aquifer storage and recovery systems in the United States.[3] The distribution is shown in Table 9. Details of these systems, including persons to contact for further information, are available at http://www.asrforum.com/frames/wherefr.html. There are another approximately 100 systems in various stages of development nationwide.

These systems include surface water spreading and ASR well recharge systems. Surface recharge systems vary in size. One of the largest is the Orange County Water District (OCWD) system, located in southern California, which is described as follows:[4]

> The Orange County Water District is responsible for managing the underground water reserves that supply about 500 wells within district boundaries. At the present time about 270,000 acre-feet of this water is pumped for use each year… Ground water reserves are maintained by a recharge system, which replaces water that is pumped from wells. OCWD's facilities have a recharge capacity of approximately 300,000 acre-feet per year. About two million people depend on this source for more than three-quarters of their water.
> The district has 1,500 acres of land for use in its recharge program. Water that flows

TABLE 9
Known Operating ASR Systems in the United States

State	Number
Arizona	6
California	11
Colorado	2
Florida	13
Iowa	1
Idaho	2
Kansas	1
New Jersey	9
Nevada	2
Oregon	6
South Carolina	4
Texas	3
Utah	3
Virginia	1
Washington	3
Wisconsin	1
TOTAL	**68**

Source: http://www.asrforum.com/frames/forumfr.html

down the Santa Ana River, together with supplies imported from the Colorado River and from the State Water Project, is channeled into nine recharge basins. These lakes and ponds, with depths ranging from 50 to 150 feet, were formed in years past by sand and gravel mining operations. (See Figure 28)

OCWD is a leader in ground water management and provides tours and briefings for visitors from local college classes, water agencies and international leaders from around the globe.

ASR well recharge systems also vary in size. Las Vegas Valley Water District (LVVWD) has a large-scale, long-term managed program to satisfy anticipated water demand using a 50-year planning horizon. Aquifer storage and recovery wells are an essential tool to enable using stored water until other water sources are developed and brought on line over time. Seventeen years ago LVVWD began storing water and as of July 2005 has about 285,000 acre-feet as a reserve. The system is the largest well recharge and recovery project in the world. A description of the LVVWD system follows:[5]

- The system was started in 1988 and has cost over $50 million.
- Growing population and water demand had resulted in ground water declines of 300 feet. Severe and costly subsidence problems had occurred.
- Initially, the huge pressure to supply water resulted in rapid expansion of the well field. The first ASR well was a conversion of an existing production well for $5,000. During the following four years 69 new wells were installed. The system now has over 100 wells with plans to expand over the next 20 years.
- 75 percent of the wells pump directly to the distribution system. Optimizing the pump systems and pumping during low demand times (night) resulted in a 40 percent overall reduction in electrical power needs.
- Water is stored mostly in confined aquifers.

Figure 28, Anaheim Lake Recharge Facility
Source: Orange County Water District, California

If needed, 12,000 gpm can be injected underground. Only potable water is injected; no reclaimed wastewater is injected.

- A crucial element to the success of the project was the establishment of the Southern Nevada Water Authority. This resulted in the essential cooperation between the various stakeholders.
- A portion of Nevada's Colorado River allotment is used to "bank" enough water in aquifers for a several-year supply.
- Wells were located and water was stored where the water was needed. The result was considerable savings in capital expense since existing infrastructure was used during off-peak daily and seasonal periods. When demand is low, water is injected. When demand is high, water is withdrawn.
- LVVWD has become a recognized leader in ASR well design, construction, and operation. They have published numerous articles on these subjects.

LVVWD's ASR well project may not be the largest project of its kind for long, as a very large ASR program to restore the Everglades of southern Florida is in the planning stages. It is expected to have over 300 wells storing and recovering up to eight billion gallons per day.[6] Once completed, this would become the world's largest ASR well system. New York City is in the initial stages of developing a 225 million gallon per day ASR wellfield.[7]

EARLY UTAH EFFORTS

This section presents a short summary of investigations into the feasibility of conjunctive management projects in Utah, most of which have involved aquifer storage and recovery. While not comprehensive, the efforts described here are representative of past endeavors. Together they show a substantial history of investigations that started in 1936. It is impressive that water professionals in Utah were among the earliest to experiment with this innovative technology.

Salt Lake Valley

In 1936, A. J. Lazenby was the engineer in charge of wells and investigations for Salt Lake City's Department of Water Supply and Waterworks. This early leader in aquifer recharge undertook three noteworthy tests on the east bench just south of Parleys Creek (see Figure 29). The motivation for aquifer recharge then was much the same as it is today, to provide for future higher demand due to population increases and to, "conserve and increase" the available water supply.[8] In addition, the report notes drought as an incentive for the experiment: "Primarily because of the low annual precipitation from 1929 to 1934, the flow from springs and flowing wells throughout the state decreased considerably."[9] These were the beginning of the "Dust Bowl Years" which represent the worst recorded drought in the history of the state.

The first test involved simply running water from Parleys Creek into an old unused reservoir and observing the results on the ground water levels in the area. Using a nearby canal Lazenby directed varying flows of 2.5 to 4.5 cfs into the reservoir from January 14 to February 18, 1936. This time of year was chosen to avoid interference with natural recharge, seepage from Parleys Creek, or irrigation. The response in 7 wells and 12 springs was then monitored. Four of the wells and all the springs were located down-gradient of the reservoir. Water levels and spring flows were measured for over a month before beginning the experiment to obtain baseline data. Monitoring continued until the following spring when natural recharge was observed.

Graphs of the water levels in the wells all showed pronounced increases shortly after introduction of water into the reservoir. The graphs also showed response to variations in the rate of flow into the reservoir. Those furthest from the reservoir showed the greatest time lag. Total increases in water level varied from 0.77 feet in the furthest well, 5,399 feet southeast, to 7.58 feet in the second closest well, 800 feet west. Water levels raised an average of 3.60 feet.[10] Measured spring flows increased from 18 to 457 percent, with an average increase of 75 percent. Lazenby concluded that:

> The data obtained indicated that artificial recharging of the ground-water basin is not only possible and practicable, but beneficial to owners of wells and springs.

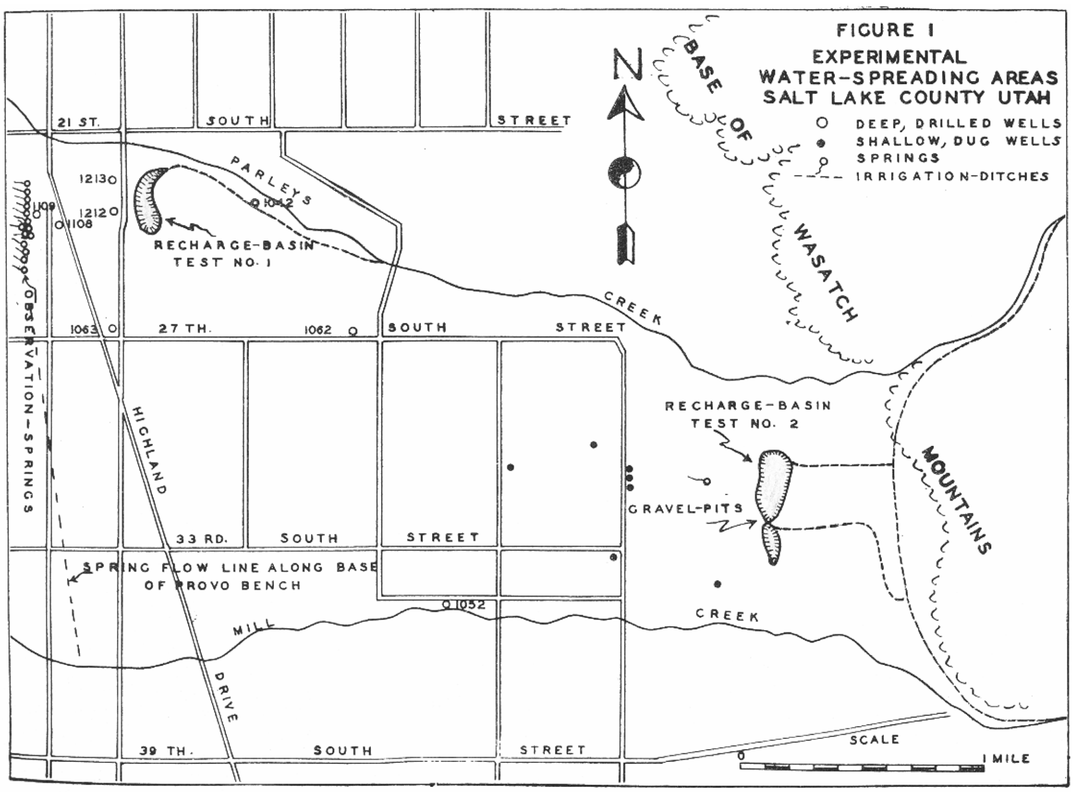

Figure 29, Experimental Water-Spreading Areas, Salt Lake County, Utah
Source: A. J. Lazenby, *Experimental Water Spreading for Ground Water Storage in Salt Lake Valley, Utah, 1938*.

The location of the test-area was so close to the zone of ground-water discharge that the storage-period of some of the water recharged is comparatively short. Water placed in storage by artificial recharge-methods over areas more remote from the zone of ground-water discharge—in this instance, over areas closer to the base of the mountains—will be retained in the ground longer. Because of the relatively slow movement of ground-water, it would probably appear at the zone of ground-water discharge several months and possibly a year or more after it was spread over the area recharged. Thus it is desirable to use spreading areas as high upon the ground-water recharge-area as is possible.[11]

The second test involved again running water from Parleys Creek, but this time into an abandoned county gravel pit and observing the results on the ground water levels in nearby wells. These wells "were shallow and probably receive their supply from a perched water-table. No wells penetrating the main ground water table could be located near the pit." The pit had an area of about two acres and a depth of about 24 feet… The bottom of the pit was about 16 feet below the impervious clay layer forming this perched water table and the water run into the pit during this experiment naturally seeped to a lower water table." Water was turned into the pit over two time periods and results were the same for both attempts, "The pressure in the wells and the flow from the springs did not change enough from their natural trend to tell whether or not this recharge was affecting them."

The last test involved measuring the flow rates at three points in the canal supplying the water to the second experiment. An initial weir was installed at the canal intake; a second weir was installed at the point the canal reaches the bench lands; and a third weir was installed at the gravel pits. Readings from each weir showed a loss of 550 gpm per mile for the first portion of the canal and 800 gpm per mile for the second section. The test ran for 38 days (October 28 to December 5, 1936) with an average flow rate of 1,840 gpm (4.1 cfs). These significant seepage rates represented a 74 percent loss of the total flow diverted over a distance of two miles. The report then cites the results of several canal seepage studies made during 1934 by other investigators. There is a note indicating these figures vary with the amount of water flowing in the ditches, although the flow rates are not given. It was initially believed that the ditches had accumulated silt and were no longer losing water. These data provided insight into just how much ground water recharge was provided by unlined irrigation canals. In almost all cases the seepage loss was found to be large and the ditches were ultimately lined with concrete.[12]

The conclusion for the last experiment was:

> Seepage tests… indicate that the canals and ditches used to convey water to points of recharge, or for irrigation-use, act as recharging conduits the same as pits and reservoirs.[13]

At the end of the report, the final conclusions included:

> From the combined results of the experiments made, there appears to be no question that the ground-water basin can be artificially recharged by surface-runoff, and that the increased recharge from water spreading would increase the yield of the wells and springs accordingly… Water-spreading should not be left until the discharge has become greater than the recharge, but should be begun at once. With proper study of recharge with respect to discharge, the level of water in the ground-water reservoir can be controlled until there would be practically no danger of drawing more water from the ground-water reservoir than the recharge will supply.
>
> Water-spreading has a definite place in the ground-water supply of the State of Utah, and a more complete study should be made at an early date to determine other problems and factors not encountered in this experiment.[14]

Near Bountiful

In 1937, an attempt to store water with the intent of later withdrawal was undertaken near Bountiful on the Provo Terrace of the old Lake Bonneville, south of Centerville Creek. This was an experiment in managed aquifer recharge that was intended "to show a way in which surplus waters may be stored in ground water reservoirs for future use." The study was conducted under supervision of the Intermountain Forest and Range Experiment Station of the U.S. Forest Service. During 1937, a recharge basin (approximately a half-mile long and a maximum width of about 75 feet) was constructed. Water was diverted into the basin during the non-irrigation season every year from 1937 to 1947. The amount of water diverted ranged from 185 to 415 acre-feet per year with an average of 310 acre-feet per year. A total of 3,095 acre-feet were diverted during the decade.[15] The literature does not indicate the motivation for this experiment. However, as with the Salt Lake Valley investigation that occurred the previous year, the experiment took place right after the "Dust Bowl Years" from 1931 to 1936.

"During the first few years the spreading basin absorbed the water as rapidly as it could be delivered, a maximum rate of 3.0 cfs. Gradually, however, silt and fine sand particles accumulated in the basin and the rate of percolation diminished until in some years there was flow over the spillway at the south end of the basin."[16] There was "a general rise of artesian pressure in wells throughout the Bountiful district from 1936 to 1938, and available data are inadequate to discriminate the beneficial effect of the artificial recharge in this general rise." Further, the "positions and changes of the piezometric surfaces of the respective aquifers under natural conditions prior to 1937… is not available." Thus, the outcome of the experiment was uncertain. The conclusion was, "the beneficial effect must be inferred from the reports of several well owners that the flow of their wells was increased after the water spreading…"[17]

City of Bountiful

Another attempt at managed aquifer recharge was conducted by the City of Bountiful in 1941. It is possible that, in addition to the drought, the nearby first experiment and success in Salt Lake City gave encouragement for this recharge effort. "The City of Bountiful… has increased in population to the point where existing water supplies from wells, springs, and streams are inadequate to meet the summer demand. The city lies near the eastern edge of a natural ground water reservoir … which is tapped by hundreds of wells. In recent years the city has endeavored to increase the storage of water in this artesian reservoir by artificial recharge from a canyon stream during the non-irrigation season, with the intention of constructing wells to divert this stored increment into the municipal water system during periods of peak demand."[18]

The approach to recharge was a little different this time. A portion of the flow of Barton Creek was diverted into a 1,200 foot-long canal. Eleven outlets allowed water to flow from the canal onto the ground. This resulted in no observable silting problems during the 7 years of operation. Water was diverted during the non-irrigation season every year from 1941 to 1947. The amount of water diverted ranged from 75 to 425 acre-feet per year with an average of 280 acre-feet per year. A total of 1,960 acre-feet was diverted during the seven years.[19]

While this experiment had good intentions, the underlying geology was not well understood. The recharge water went to the shallow ground water aquifer. The result was substantially increased flow from local drains. Apparently little or no water was added to the lower aquifer from which the city was drawing water and there was no evidence of increased storage in that aquifer.
The report observes, "It is concluded that where artificial recharge is for the specific purpose of storing water that is to be diverted subsequently from a certain aquifer by means of wells, it is essential that proof be obtained that the water does reach that aquifer. This proof requires an adequate knowledge of the geologic and hydrologic conditions, supplemented by detailed observations of the effects of the artificial recharge."[20]

Apparently there was no follow up to these early endeavors. However, the results showed the concept of managed aquifer recharge of ground water aquifers was viable. It also showed the need for adequate understanding of the geology of such projects.

Weber River Delta Near Hill Air Force Base

Some revealing studies to determine the feasibility of managed aquifer recharge of the Weber River Delta were done by the Bureau of Reclamation in the 1950s. Results of the experiments are quoted as follows:[21]

> In February and March 1953, recharge experiments were made near the mouth of Weber Canyon by running surplus flows of the Weber River into a pit having an area of 3-1/4 acres and a depth of 30 feet. The two experiments lasted a total of 7 weeks, and about 2,170 acre-feet of water infiltrated into the pit, equivalent to a continuous flow of 7 cfs per acre. The recharge affected the water level in test well 1 of the Bureau of Reclamation 3 days after the experiment began, and the water level rose 34 feet during the experiment. Test well 1 is a quarter of a mile west of the recharge pit; therefore, under unconfined conditions, the velocity of the water was about 440 feet per day.
>
> A third recharge experiment was attempted from December 1954 to March 1955. Exceptionally cold weather froze the recorder floats in the observation wells and froze the water in the delivery canal. Later, high-stage turbid waters interfered with recharge by depositing silt in the pit.

The figure accompanying the first three experiments shows plainly discernable spikes indicating water level increased 25 to 30 feet each time water was recharged into the aquifer. It is clear the recharge water entered the aquifer, moved through it, and raised the water level at the monitoring well. A fourth experiment conducted at the site is described below:

> From November 11, 1957, to February 11, 1958, about 1,500 acre feet of water from the Weber River was put into a recharge pit at the mouth of Weber Canyon, and the effects on water levels or artesian heads were measured in nearby wells. The increases in head… were measured in the various wells after the initial ground-water mound in the recharge area had dissipated. These data show that the average rise measured was 5.5 feet in the unconfined (water-table) zone and 3.5 feet in the confined (artesian) zones. The tabulated data shows ground water level increases in two water table wells and six artesian aquifer wells.

The discussion of these experiments noted that the recharge experiments showed that the area is definitely one in which natural recharge occurs and in which managed aquifer recharge of the primary drinking water aquifer is possible.

CURRENT UTAH PROJECTS

As of July 2005, there are three aquifer storage and recovery projects operating in Utah. These projects are sponsored by Brigham City, Jordan Valley Water Conservancy District, and the Washington County Water Conservancy District. These projects are described below to provide other water suppliers with perspective and to serve as examples of how future projects could be implemented. The following descriptions provide a contact person for each project. These people, and the respective agencies, are willing to advise those contemplating conjunctive management projects.

Brigham City[22]

The Aquifer Storage and Recovery (ASR) project in Brigham City is a good example of a successful project. With capital costs of only $180,000, it is the smallest and least costly of the three current projects. It is an excellent example of how conjunctive management can solve problems for an individual city. The project includes three existing production wells that were retrofitted to inject water into the aquifer during low demand months and draw it out during high demand months. Injected water is obtained from springs that otherwise are not fully utilized during the winter months. Construction was begun in 1998 and completed four years later in 2002.

One of the issues prompting investigation into ASR was poor water quality due to high concentrations of iron and manganese in the aquifer supplying the city. This prompted numerous customer complaints, especially late in the summer. Another issue was ground water levels in the aquifer were steadily declining. The last consideration leading to the project was the city owning several large, high-quality springs located in the Mantua Valley. Water from these springs was unused much of the year. The excess supply was about 4 to 6 million gallons per day (Mgd) of high quality water.

Initially, the city hired a consultant to study the possibilities of ASR. Then the city implemented a pilot project to determine whether or not a full-scale project was warranted. In addition to demonstrating the feasibility of storing surplus water and later recovering it, the city hoped the pilot project would reduce the high iron and manganese concentrations in the aquifer that impaired their ability to fully utilize their existing wells.

The pilot project consisted of a short-term test and long-term test. Water levels and water quality were monitored throughout both tests. A long-term test was then conducted between January and October of 1999. Approximately 86 million gallons (267 acre-feet) were injected, stored and recovered over this 10-month period. All findings confirmed the results of the short-term test, namely:

- Injected water was easily recovered.
- Recovered water quality was greatly improved. Iron and manganese concentrations dropped to about one tenth the original values. Further cycles would only better condition the aquifer.
- Recovered water could be utilized without pre-treatment, greatly reducing costs.
- Contrary to expectations, a slight increase in well pumping efficiency was experienced.

Results of both cycles clearly favored continuation of the project. The findings also indicated the ASR well system could be expanded to two other wells owned by the city. Consequently, the city retrofitted these other wells and incorporated them into a full-scale project in 2002. The State Engineer will allow Brigham City to recover 100 percent of the recharged water regardless of when it is recovered. Thus far, Brigham City has recovered somewhat less than the amount recharged resulting in year-to-year storage, or banking, of the recharged water. This has raised ground water levels.

The project had some complications. Brigham City adds fluoride to all its drinking water, and the concentration of fluoride in the injected water exceeds the State Ground Water Protection Standards. However, an exemption was granted by the Utah Division of Water Quality based on ground water modeling that indicated no interference with other water rights or downstream uses. Other issues typical of ASR well projects were encountered, these included: retrofitting the pump stations, air entrapment, operation, education and training, and record keeping.

Successes of this project include:

- Nearly 1,400 acre-feet of water per year is injected into and recovered from the three wells. The system can inject up to 2,484 acre-feet per year.
- Water is stored during the low-demand season and recovered during the high-demand season.
- Water quality has been improved to the point that iron and manganese cannot be detected.
- Ground water levels have returned to where they were five years before the project began.
- Expansion of water supply facilities has been deferred.
- Water resources have been conserved and overall water use efficiency is greatly improved.

For further information regarding this project, contact Brigham City's Water Department Superintendent, Blair Blonquist at (435) 734-2001.

Jordan Valley Water Conservancy District[23]

The Jordan Valley Water Conservancy District (JVWCD) has spent $20 million dollars to implement an ASR project and upgrade their water distribution system in the southeast part of the Salt Lake Valley. The project consists of 13 existing production wells that were retrofitted to accommodate ASR operation as well as six new ASR wells. The wells are located from 7000 South to 10100 South and from 700 East to 2800 East, resulting in an overall well field size of about 4.5 miles north-south and about 3.4 miles east-west. Water for storage is derived from the spring season high runoff of nearby streams draining from the Wasatch Mountains. The water is treated to drinking water standards before storage. The project also includes a new 30-inch pipeline and a new 20-inch pipeline for the distribution system to handle increased water flow. A new bi-directional booster station was added to handle those flows. In addition, the regional treatment plant was upgraded to twice the previous peak capacity, 10 Mgd to 20 Mgd. Since there is no surface storage, this increased treatment capacity allows capture of more of the spring runoff from the streams. There is also an on-line microorganism toxicity monitoring station.

The project was prompted by difficulty meeting peak demand during the summer months; in particular, the aqueduct supplying the district was at capacity. In addition, ground water levels were declining in several locations resulting in increased pumping costs. Finally, the availability of a $5,000,000 cost-share grant available through the Central Utah Project Completion Act (1992) made action at the time more attractive.

JVWCD first began to study ASR as early as 1983. A 1986 study and pilot project was partially funded by the U.S. Bureau of Reclamation under the High Plains States Ground Water Demonstration Program Act. It involved two ASR wells, two recovery wells, three monitoring wells and an in-line filtration process. The demonstration lasted three seasons from 1991 to 1994. A full-scale project was not completed until 2002, 19 years after studies were first begun.

Although JVWCD's full-scale project has been in operation several years, it has not realized its full potential because the lack of excess supplies during the recent drought. Spring runoff volumes have been mostly taken up by existing demands. Still, the treatment plant allows greater utilization of surface water runoff and the aquifers have had less ground water drawn out of them. Thus, many conjunctive use benefits have already been realized. Although some water has been stored underground, it is much less than the project design. Another challenge for the project has been the clogging of wells due to iron and sulfate reducing bacteria. Operation methods have been continually revised to manage this and other problems. Despite these setbacks, JVWCD expects to realize a greater benefit from the project in coming years when available runoff increases. Streams that contribute flows to this project include: Provo River, Middle Fork Dry Creek, Little Cottonwood Creek, South Fork Dry Creek, Bell Canyon Creek, Rocky Mouth Creek and Big Willow Creek.

The project is permitted to recharge water into the aquifer from any of the wells and also to withdraw water from any of the wells. Also, this project can recover 100 percent of recharged water if recovery takes place during the first 12 months. After that there is a 10 percent per year reduction in the recovered amount. This provides JVWCD an incentive to recover the water during the year it was recharged. The State Engineer determines recovery amounts based on the parameters for each individual project. Jordan Valley Water Conservancy District constructed this project in lieu of other water storage projects that were considered by the district, but were determined to be less attractive.

This project was the first "bona fide" ASR project in the state and existing laws proved inadequate. One of the most significant outcomes of this project was that it prompted passage of the Utah Recharge and Recovery Act covering this method of managing surface water and ground water resources. Being new, the project received considerable scrutiny. As a result, numerous geologic and engineering studies were performed. The result was a greatly increased understanding of Salt Lake Valley aquifers and an institutional acceptance and regulatory mechanism for such projects.

For further information regarding this project can be obtained by contacting Jordan Valley Water Conservation District's Chief Engineer, Richard Bay at (801) 565-4300.

Washington County Water Conservancy District[24]

The Sand Hollow Reservoir and Recharge Project, sponsored by the Washington County Water Conservancy District, is the last of the three managed aquifer storage projects in Utah to be completed. The total cost of the reservoir and individual recharge project components was over $35,000,000. The project has multiple uses and a separate cost for the aquifer storage and recovery portion has not been calculated. Project uses include operation as a surface storage reservoir, operation in conjunction with Quail Creek Reservoir, recreation (it is a state park), a surface spreading recharge and recovery project, and the end point for the future Lake Powell Pipeline.

The reservoir is an off-stream impoundment that results in surface spreading of water which recharges the Navajo Sandstone Aquifer upon which it is built. Water is recovered from the aquifer using five production wells and an 18-inch pipeline. A million-gallon storage tank and chlorination treatment plant are included in the project. Future production wells to recover water from the aquifer are planned. Fifteen monitoring wells track ground water levels of the project. Water to fill the reservoir comes from the Virgin River between October and April each year via the Quail Creek Diversion. Water flows by gravity from Sand Hollow Reservoir to Quail Creek Reservoir via a 60-inch pipeline. Water can also be pumped in the reverse direction enabling the two reservoirs to be operated together to satisfy water needs. Originally conceived in 1990, construction of the dam, pipeline, and pump house was begun in March 2000, and the reservoir began filling in March 2002. From conception to completion, the project took a total of 12 years to complete.

Sand Hollow Reservoir is located approximately 5.5 miles southwest of Hurricane and 3.5 miles south of Quail Creek Reservoir. It has a capacity of 50,000 acre-feet and a surface area of about 1,300 acres. It is unique in that it is the only surface-spreading project in the United States on fractured bedrock. Recharge is estimated at 15,000 acre-feet per year with the annual water yield available estimated at 10,000 acre-feet. Two dams create the reservoir; one is 3,000 feet long and 97 feet high while the other is 7,500 feet long and 57 feet high.

The reservoir was originally conceived as a surface storage reservoir to help meet growing water demand brought on by extremely rapid population growth in Washington County. However, early hydrogeologic studies indicated potential benefits from expanding it into a surface spreading aquifer storage and recovery project. A preliminary study in 1992 determined that the floor of the reservoir consisted of Navajo Sandstone with high porosity and permeability ratings. Surrounded by wells, this type of formation could provide a vast underground storage volume. The U.S. Geological Survey, U.S. Bureau of Reclamation, and numerous engineering firms have studied the project extensively. These studies have taken an in-depth look at the geology, sensitive species, and archeology of the site as well as the economics and recreation needs of the project.

As required by the State Engineer, the District developed a monitoring program to define changes in the aquifer as a result of the recharge. Monitoring includes determination of recharge amounts, its lateral extent, the quantity of water that can be credited to the project, and water quality. No detrimental effects have been found thus far, and collection of water level measurements and water quality data is planned to continue throughout the existence of the project.

In addition to the new water supply develop by this project, the following benefits have been realized:

- Water resources have been conserved and overall water use efficiency is improved. This is due to operation as a surface reservoir and a surface spreading aquifer storage and recovery project.
- Virgin River water flows that would otherwise be unavailable are utilized.
- More water is available to meet demands due to population growth.
- Ground water levels are increased.
- The area is managed as a Utah State Park.
- Fish and waterfowl habitat are greatly increased.
- Additional recreational facilities have been created (including fishing, boating and camping).
- Revenues to the local economy are increased. Depending on the number of visitors, these are estimated to be over $4,000,000 per year.
- A terminus for the future Lake Powell Pipeline is available.

For further information regarding Washington County Water Conservation District's conjunctive management project, contact the district's General Manager, Ron Thompson at (435) 673-3617.

OTHER PROJECTS BEING INVESTIGATED

Weber Basin Water Conservancy District

The Weber Basin Water Conservancy District (WBWCD) is conducting a pilot project and related study to define the area of hydrologic impact and demonstrate feasibility for a surface spreading aquifer storage and recovery project near the mouth of Weber Canyon. This area was identified as a successful area for ground water recharge in previous research and testing conducted in the Weber River Delta. In its pilot project, WBWCD has recharged the aquifer by putting raw water from the Weber River into four small recharge basins, thereby allowing it to soak into the ground. This is basically an enhancement of a naturally-occurring process since the river normally loses water to recharge the underlying aquifer. The basins are located above the unconfined portion of the aquifer and consequently recharge the confined aquifer. Eventually, withdrawal will be accomplished by pumping from existing or new production wells. This is the first project of this in Utah type (spreading basins at the mouth of a river delta) and will serve as a useful example for other future projects. See Figures 9, 10, 18 and 19. The project is located at the mouth of Weber Canyon, just northeast of Hill Air Force Base.

First conceived in 2002, the project now has four ponds (recharge basins) occupying about 3.8 acres in a former gravel pit. The ponds are enclosed by three-foot high berms. Water is conveyed by gravity from the river into an existing ditch and down to the ponds. The first pond provides sediment removal as well as recharge. There is a 300 foot deep observation well adjacent to the ponds to monitor changes in ground water levels and provide access for water chemistry sampling. The main water table is about 230 feet below ground level. From March to July of 2004 about 800 acre-feet of water were put into the ground. Infiltration rates varied from 1.3 cubic feet per second per acre at the beginning to 0.9 at the end. One aim of the study is to determine optimum sediment removal methods and a basin cleanout schedule. Recharging began again in March of 2005. WBWCD has not yet withdrawn any of the water it has recharged into the ground.

WBWCD is conducting its pilot project in cooperation with the U.S. Bureau of Reclamation, Utah Division of Water Resources, Utah Geological Survey and Weber State University. Thus far this project team has completed a preliminary study of the project site and purpose. The team will also complete a final report summarizing the results of the pilot project in late 2005. Ultimately the project could include one or more of the large gravel pits located closer to the mouth of the canyon, which would provide a mechanism whereby it could store a substantial amount of water underground. Recharge rates in these pits are expected to be much higher and the recharge capacity much greater. In addition, recreational development in cooperation with the town of South Weber is anticipated as part of the project.

The U.S. Bureau of Reclamation has provided approximately $250,000 in federal funding to help WBWCD investigate the potential for managed aquifer recharge. So far, WBWCD has invested about $500,000 in this project and the other agencies involved have also contributed significant cost match and technical support. The Utah Division of Water Quality and Utah Division of Water Rights have provided regulatory oversight. Weber State University has contributed to the project and expanded their research by developing a comprehensive ground water model of the aquifer systems in the Weber River Delta. Similarly, the University of Utah has contributed to the project and expanded their research on microgravity. Using field measurements on the ground, this work has provided insight into how the ground water mound forms under and moves away from the recharge ponds. This project is a good example of the collaboration necessary for successful water development in the complex environment found in today's world.

If WBWCD is able to construct a full-scale project, the following benefits would be realized:

- More water available for the entities within the Weber River Delta area and increased reliability.
- Greater flexibility in how to meet peak demands during the summer and shortages during drought.
- Slow and possibly reverse groundwater level declines in the Weber Delta aquifer. (These range from 37 to 100 feet.)
- Reduce and possibly eliminate the threat of ground subsidence.
- Reduce the risk of salt-water intrusion from the Great Salt Lake.
- Increased flood protection from peak flood flows.

Metropolitan Water District of Salt Lake and Sandy

In August 2003, the Metropolitan Water District of Salt Lake and Sandy (MWDSLS) completed a feasibility assessment and conceptual design for aquifer storage and recovery (ASR) projects in the Salt Lake Valley.[25] Recent success by other water supply agencies and the latest drought prompted the district to revisit the possibility of using aquifer recharge to meet their goals. Objectives in pursuing these systems include:[26]

- Develop a "strategic water reserve" or "water bank" that can be accessed to meet future demand requirements for the district or its member cities. Utilization of this water reserve would be critical to the viability of the district's system during times of drought.
- Develop seasonal storage and recovery capabilities to help meet peak summer demands.
- Enhance and improve well field production for partnering agencies through restoration of depleted ground water levels in the Salt Lake Valley aquifer.
- Optimize the district's water conveyance and treatment system by more fully utilizing the facilities year round.

Potential water supplies include raw (untreated) water and treated water. Raw water sources include Deer Creek Reservoir, Little Cottonwood Creek, Big Cottonwood Creek and other local mountain streams. Treated water sources include the Little

Cottonwood Water Treatment Plant, Jordan Valley Water Treatment Plant, South East Regional Water Treatment Plant, and the future Point of the Mountain Water Treatment Plant. Water rights are available through the district and its partnering agencies.[27]

Hydrogeology, as well as water quantity and quality, have all been investigated and indicate likely success for the project. The district anticipates a combination of recharge basins and ASR wells will eventually be used. Five alternative sites, located in the primary recharge zone, and totaling 55 acres have been identified for recharge basins. Depending on hydraulic loading, these can recharge from 9 to 89 percent of the water available for recharge. Three alternative schemes for ASR wells have been identified to use the remaining amount of water available for recharge. These include combinations of retrofitting existing wells and installing new wells. Implementation and operation and maintenance costs have been identified for the various alternatives, including cost per acre-foot.[28]

The study recommended a phased approach, including field investigations, data collection and pilot testing for this project. The study also incorporates virtually all aspects of aquifer storage and recovery as discussed in this document and serves as a good example for water suppliers to follow when considering managed aquifer recharge options.

In the spring of 2005, the district received a $300,000 Water 2025 grant to construct the initial phases of this project. Included are an ASR well and surface spreading facilities. For further details regarding this grant, see the Project Funding section in Chapter 6.

NOTES

[1] Ground water Recharge and Wells, A Guide to Aquifer Storage and Recovery, David G. Pyne, 1995, CRC Press, Inc., Lewis Publishers, page 9.

[2] http://www.asrforum.com/frames/wherefr.html, April 2005.

[3] Ibid.

[4] http://www.ocwd.com/_html/recharge.htm, (August 1, 2004)

[5] Personal communication from Tom Morris, Hydrologist, Las Vegas Water District Operations Department, February 2004 and updated July 2005.

[6] http://www.asrforum.com/frames/wherefr.html, (August 1, 2004)

[7] David G. Pyne, author of *Ground Water Recharge and Wells, A Guide to Aquifer Storage and Recovery*, Communication to Utah Division of Water Resources, June 2005.

[8] A. J. Lazenby, *Experimental Water Spreading for Ground Water Storage in Salt Lake Valley, Utah*, 1938. From National Research Council, Transactions of the American Geophysical Union, Nineteenth Annual Meeting, April 27 to 30, Washington, D.C.. page 402.

[9] Ibid. page 403.

[10] Ibid. page 407.

[11] Ibid. page 408.

[12] Ibid. page 411.

[13] Ibid. page 411.

[14] Ibid. page 411.

[15] Ground Water in the East Shore Area, Utah, Technical Publication No. 5, H.E. Thomas and W.B. Nelson, 1948.

[16] Ibid.

[17] Ibid.

[18] Artificial Recharge of Ground Water by the City of Bountiful, Utah, H. E. Thomas, August 1949.

[19] Ground Water in the East Shore Area, Utah, Technical Publication No. 5, H.E. Thomas and W.B. Nelson, 1948

[20] Ibid.

[21] Lake Bonneville: Geology and Hydrology of the Weber Delta District, Including Ogden, Utah, J. D. Feth, L. G. Moore, R. J. Brown, and C. E. Veirs, U. S. Geological Survey Professional Paper 518, 1966.

[22] Data for the Brigham City ASR project provided by Brigham City, July 25, 2004.

[23] Data for the Jordan Valley Water Conservancy District ASR project was provided by the district, August 6, 2004 and from Salt Lake County High Runoff Treatment and Storage Project Via Artificial Ground Water Recharge, Feasibility Study, Salt Lake County Water Conservancy District, October 1996.

[24] Data for the Sand Hollow Project provided by the Washington County Water Conservation District, July 16, 2004.

[25] Metropolitan Water District of Salt Lake and Sandy, *Phase 1 Feasibility Assessment and Conceptual Design for Aquifer Storage and Recovery Project*, August 2003, Title Page.

[26] Ibid. page ES-1.

[27] Ibid. page ES-2.

[28] Ibid. page ES-5.

5

PROSPECTIVE CONJUNCTIVE MANAGEMENT PROJECTS

Several reports were reviewed to identify aquifer recharge sites throughout the state that could be developed in the future. The sites are located primarily along the Wasatch Front where future water demands will be the greatest. See Figure 30. This chapter presents a brief summary of reports from 1977 to the present including sites recently investigated by the Utah Division of Water Resources. This information is provided to assist water suppliers near the locations identified who might not otherwise have considered conjunctive management. Those interested in pursuing any given location are advised to obtain the referenced study and read it for particulars. Some of the studies are difficult to find, but those referenced in this chapter are available at the Utah Division of Water Resources. This chapter simply identifies prospective projects, all of which have concerns; each will need the detailed investigations described in Chapters 3 & 6 to establish feasibility.

WASATCH FRONT LOCATIONS

In 1977, the Utah State Legislature instructed the Utah Division of Water Rights to conduct a feasibility study on artificial ground water recharge along the Wasatch Front.[1] The 1977 drought was one of the most severe drought years in Utah's history. Three investigations covering Salt Lake, Utah, Box Elder, Davis and Weber counties resulted from this directive. A summary of each report follows.

Most of the prospective sites discussed in the following reports are stream deltas at the mouth of a canyon. When considering aquifer storage and recovery projects in such locations, it is well to realize that the larger the stream drainage, the greater the opportunity for a project. The 2,344 square miles of the Weber River drainage[2] has produced a delta region of about 450 square miles and a thickness of 500 to 800 feet.[3] Tremendous amounts of rock, gravel, and soil have been moved from the mountains to the valley. This large volume aquifer has potential for underground water storage. At the other extreme, a small stream will also have a delta at the mouth of the canyon, but the size will be proportionate to the size of the drainage, and consequently less potential for underground water storage. Whenever possible, the largest drainages should be considered first.

Salt Lake County

The first study, by Keith L. Hansen, was a comprehensive analysis of the Salt Lake Valley. Every one of the potential sites identified has since been rendered unavailable for surface spreading aquifer recharge by urban development and construction of buildings. However, given their location above the unconfined aquifer, those sites are still viable for ASR wells which require only small surface areas. Further, the methodology of the investigation and general observations could prove helpful to those considering such projects today. Today's decision makers can also learn from the recommendations in the study that were not implemented. Loss of those opportunities has contributed to the difficulty of locating surface spreading recharge sites in the Salt Lake Valley today.

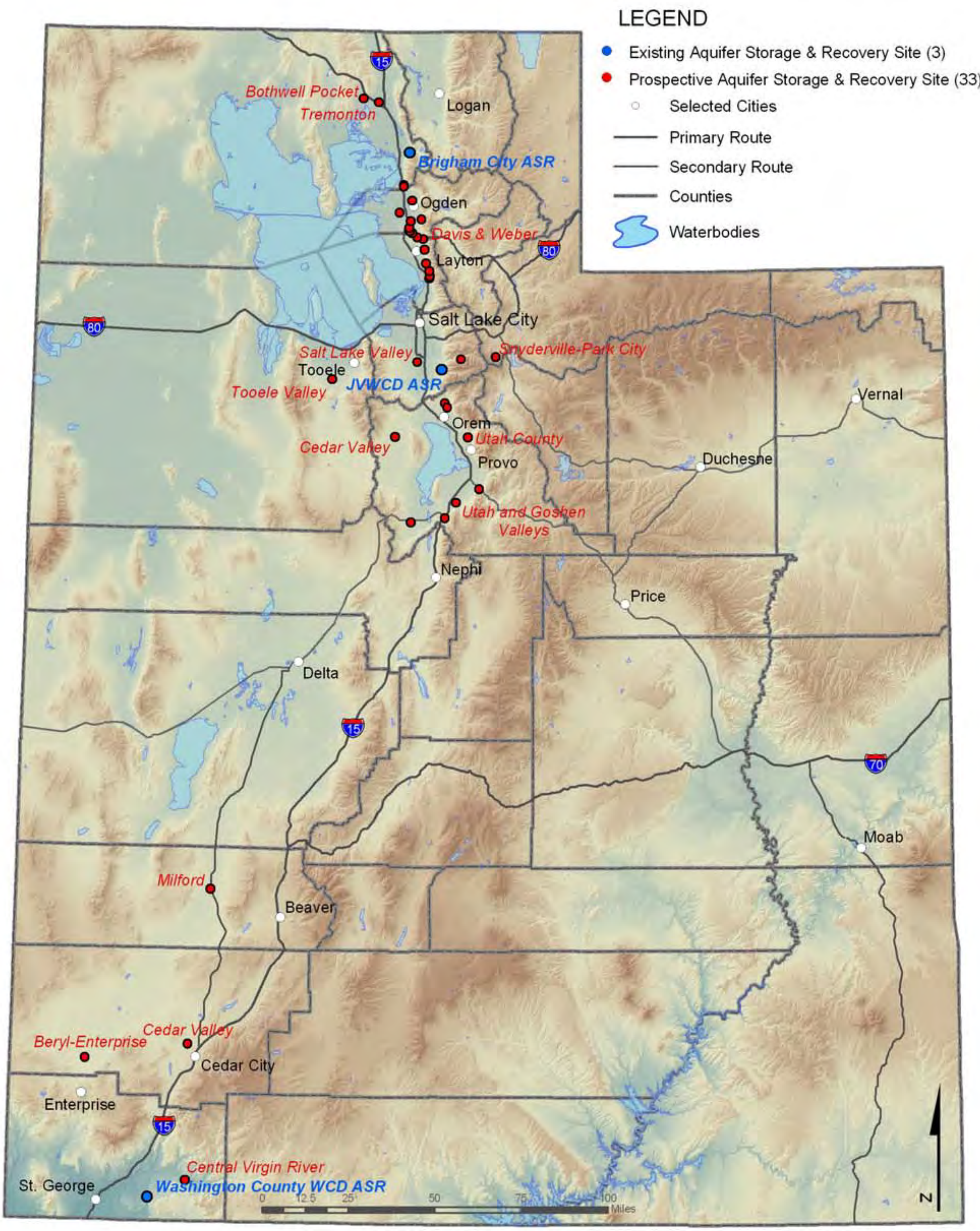

Figure 30, Existing and Prospective Conjunctive Management Areas in Utah
Source: Utah Division of Water Resources, 2005

The study looked at the following.

- Previous Investigations
- Climate
- Geology
- Ground Water
- Methods of Artificial Recharge
- Selection of Sites for Artificial Recharge
- Estimated Cost to Conduct Recharge Project
- Water Rights Affected by Recharge Diversions
- Observation Wells
- Identification of Water For Artificial Recharge
- Recreational Benefits
- Problems Associated With Artificial Recharge

The logical conclusion was that the best recharge areas are located on the pervious benches of the ancient Lake Bonneville, adjacent to streams and to hillsides near the mountains. "The location most favorable for artificial recharge to the confined aquifer is near the mountains where thick coarse-grained deposits are prevalent. The unconfined aquifer of Salt Lake Valley is deep and extends throughout the valley at the edges of the surrounding mountains."[4] A map, included in the study, indicates a "Deep Unconfined Aquifer and Principal Recharge Area" along the perimeter of the Salt Lake Valley.[5] That is, next to the Wasatch Mountains on the east, next to the Oquirrh Mountains on the west, and next to the Traverse Mountains on the south (north of the Utah County line). Some of these general locations may prove viable options today. If urban development has taken surface recharge sites, ASR wells may still be a viable option.

Four specific sites were identified as a result of this study. Sites 1 and 2 were located in the streambed of Big Cottonwood Creek southeast of Knudsen's Corner. This is in the southeast quadrant of the valley about 1 to 3 miles from I-215. These sites were chosen on the basis of studies showing the stream lost 32 percent of its volume while flowing across these areas. Aside from the study and more recently, Figure 26 shows a debris basin that was constructed on Big Cottonwood Creek that provides recharge not far from sites 1 and 2. The debris basin could be enlarged to enhance recharge if the Utah Department of Transportation warehouse and yard shown in the figure were moved. Of course, this would be costly and involve considerable interagency cooperation. This area is located on 3000 East Street south of the Old Mill Golf Course. That golf course would make an excellent surface spreading recharge site for either recharge ponds or a subsurface drain field.

Site 3 is located in the streambed of Little Cottonwood Creek immediately northwest of the Little Cottonwood Water Treatment Plant (LCWTP) at the mouth of Little Cottonwood Canyon. Once again the site was selected based on loss of streamflow in the area. Site 4 is located southwest of the same water treatment plant on the bench area. Consistent with the Hansen study, in 2004 the Metropolitan Water District identified LCWTP properties as a viable option for development of managed aquifer recharge basins.

Hansen's study concluded with the following recommendations, none of which were implemented.

- The State of Utah should purchase the property at all proposed recharge sites for use at a future date. Property values will never be lower than at the present time.
- Lease Sites Nos. 1 and 2 as sand and gravel operations with proper supervision and design, to be completed as needed for recharge pits. The royalty received will offset purchase costs.
- If Sites 1 and 2 are not required as recharge pits upon completion of the sand and gravel excavation, they should be developed into public parks that would still be functional as recharge sites when needed.
- Incorporate Site No. 3 into the existing golf course, to be utilized at a later date when recharge is required.
- Drill test and observation wells at Site No. 4 to determine if recharge water will enter the aquifer or if it will resurface at Site No. 3.

Utah County

The second 1977 study was done by Carl H. Carpenter of Nielsen, Maxwell & Wangsgard, Consulting Engineers. It covered the "Utah Valley portion of the Wasatch Front from the Point-of-the-Mountain on the north to Santaquin on the south. The study includes the identification of rechargeable formations, evaluation of the water supply available for recharge, and investigation of sites where recharge by artificial means appears feasible."[6] As in other studies, the Lake Bonneville benches at the mouth of canyons were identified as most likely areas for managed aquifer recharge. Sites were selected based on the following criteria.[7]

- Good permeability in stream channels.
- Large areas for spreading operations not in conflict with existing developments.
- Extensive unsaturated zone above regional water table to provide large storage capacity.
- No evident perched or shallow water table.
- Situated in areas where construction of conveyance and diversion facilities will be minimized.
- Compatibility with existing land uses.

The study indicated that, in 1977, "Utah Valley generally has an abundant supply of ground water and does not suffer from overdevelopment.[8] There is no need for artificial recharge in Utah Valley to raise water levels, increase aquifer yields, reduce land subsidence, or maintain quality."[9] Nevertheless, the study went on to identify the following potential ASR sites. The assessment following each site is based on review and evaluation of 2004 satellite imagery. The sites have not been field checked.

<u>Dry Creek channel between Alpine and Lehi</u>.[10] It is located about 1 ½ mile southwest of the town of Alpine in the Dry Creek streambed. Homes built along the banks of the Dry Creek channel in the immediate vicinity of this site probably will preclude the construction of any surface pond, but aquifer storage and recovery (ASR) wells remain a viable option for this site.

<u>American Fork River channel downstream from the canyon mouth for 2 miles thru part of the Tri-Cities golf course</u>.[11] "The basins could be landscaped and incorporated into the golf course parkway at site 1 and part of the Tri-Cities Recreational Complex at sites 2 and 3." Subdivision construction in the vicinity of sites 2 and 3 will probably preclude the construction of a surface pond or ASR wells. Site 1 remains undeveloped and a viable option for either ASR wells or surface spreading.

<u>Provo River channel approximately 1 mile downstream from the canyon mouth</u>.[12] This site is about one mile south of Highway 52 and one-half mile west of Highway 189. Commercial Development, including extensive paved parking facilities, at this site will probably preclude the use of this site for ASR.

<u>Spanish Fork River channel near the canyon mouth</u>.[13] This site is located between the Salem Canal and the Bottoms Road, immediately west of their intersection. A golf course has been built over this site. The course includes ponds which could be used for surface spreading. ASR wells could also be used at this site.

<u>Peteetneet Creek channel near the mouth of Payson Canyon</u>.[14] This site is about one-half mile southeast of the fairgrounds. This site has homes built in the vicinity, but may still be viable as a surface spreading or ASR well site.

<u>Summit Creek channel near the mouth of Santaquin Canyon</u>.[15] This site is immediately southeast of Highway 91 and extends in the stream channel along the access road into Santaquin Canyon. A portion of this site has been developed with homes, but the remainder of the site could still be to build ponds for surface spreading, or ASR wells could be used.

<u>Other Potential Sites</u>.[16] Sites on the following streams were considered during the study, but not explored for a variety of reasons. These might be reevaluated in today's environment of limited water supplies. Suitable sites might be found for surface spreading and ASR wells. Due to the general nature of the description, satellite imagery was not explored for these streams. Streams include, Fort Creek, Grove Creek, Battle Creek, Rock Canyon, Slate Canyon, Hobble Creek, and Maple Creek.

With the need for water clearly evident in 2005, it may still be worthwhile to pursue these sites or others nearby. The underlined site identifier is taken from the report. All sites contemplated a combination of a settling pond and ASR wells. Detailed geologic studies will be needed; these can also serve to determine whether or not wells are appropriate.

Box Elder, Davis and Weber Counties

The third 1978 study was done by Valley Engineering and included Davis County (7 sites), Weber County (6 sites), and Box Elder County (2 sites).[17] As in other studies, the Lake Bonneville benches at the mouth of canyons were identified as most likely areas for managed aquifer recharge. In fact, the general area map in this report shows that virtually any side canyon draining from the mountains onto the ancient lake benches is a candidate location for recharge. While not every canyon will be ideal, with today's situation of urban development all along the Wasatch Front, these may still prove to be viable options. The underlined site identifier is taken from the report. The assessment following each site is based on review and evaluation of 2004 satellite imagery. The sites have not been field checked. The following information was determined for each site.

- Location
- Ownership
- Geologic Description
- Source of Water
- Point of Diversion and Method of Application
- Existing Wells in Area
- History of Fluctuations
- Possibilities of Success
- Estimated Cost

Davis Recharge Site No.1.[18] About one mile south of Farmington, adjacent to Davis Creek, about one-quarter mile east of Highway 106. Expanding residential development in the immediate vicinity may soon preclude the use of this site for surface spreading

Davis Recharge Site No. 2.[19] Immediately south of Farmington, adjacent to Steed Creek, about one-quarter mile east of Highway 106. This site still appears to be viable for both surface spreading and/or ASR wells.

Davis Recharge Site No. 3.[20] Immediately north of Farmington, adjacent to Farmington Creek, about one-half mile north of Highway 106. This site still appears to be viable for both surface spreading and/or ASR wells.

Davis Recharge Site No. 4.[21] In the Fruit Heights area, adjacent to Baer Creek, about 2,300 feet east of Highway 89. Expanding residential development in the immediate vicinity may soon preclude the use of this site for surface spreading.

Davis Recharge Site No. 5.[22] In the East Layton area, along side the South Fork Creek, about 1,300 feet east of Highway 89. Expanding residential development in the immediate vicinity may soon preclude the use of this site for surface spreading.

Davis Recharge Site No. 6.[23] In the South Weber area, south of I-84 and west of Highway 89. This site is the existing Parsons gravel pit. This site still appears to be viable for both surface spreading and/or ASR wells.

Davis Recharge Site No. 7.[24] In the South Weber area, between I-84 and the Weber River, about one-half mile west of the I-84/Hwy.89 interchange. This is in the flood plain of the Weber River. This site still appears to be viable for both surface spreading and/or ASR wells.

Weber Recharge Site No. 1.[25] South of Washington Terrace, between I-84 and the Union Pacific Railroad. This site is in the Weber River riverbed. This site still appears to be viable for both surface spreading and/or ASR wells.

Weber Recharge Site No. 2.[26] Southwest of Washington Terrace, between the Weber River and the Union Pacific Railroad. This site is in the Weber River riverbed. This site still appears to be viable for both surface spreading and/or ASR wells.

Weber Recharge Site No. 3.[27] Between Riverdale and Washington Terrace, between the Weber River and the Union Pacific Railroad, immediately south of the Highway 91 overpass. This site is in the Weber River riverbed. Development along the river at this location may preclude surface spreading at this location.

Weber Recharge Site No. 4.[28] Just west of Ogden, between the Weber River and the railroad freight yards, just south of 33rd Street. This site is in the Weber River riverbed. This site still appears to be viable for both surface spreading and/or ASR wells.

Weber Recharge Site No. 5.[29] East of Ogden, at the mouth of Taylor Canyon. This site still appears to be viable for both surface spreading and/or ASR wells.

Weber Recharge Site No. 6.[30] Southwest of North Ogden, just west of Mountain Road, east of 2100 North Street. This site still appears to be viable for both surface spreading and/or ASR wells.

Box Elder Recharge Site No. 1.[31] One-half mile east of Highway 89, one and one-half mile north of the Weber / Box Elder County line. This is in a gravel pit and the topographic map shows several gravel pits in the area that might make suitable recharge sites. This site still appears to be viable for both surface spreading and/or ASR wells.

Box Elder Recharge Site No. 2.[32] South of Willard, one-quarter mile east of Highway 89. This site is in a gravel pit. This site still appears to be viable for both surface spreading and/or ASR wells.

In 1980, two years after the reports commissioned by the legislature were completed, the Utah Division of Water Resources made the following recommendation. "The three studies are helpful in verifying the value of artificial recharge to the aquifers in the respective study areas. The evidence provided in all three reports show that present-day drafts of the ground water do not justify the cost of artificial recharge now. But, in order to fully develop and efficiently utilize our ground water resources, plans should be made now rather than procrastinate until the crisis is upon us. This means that with the rapid growth of building over the Wasatch Front the more favorable injection areas are being occupied and land costs are increasing continuously each year. So, now is the time to purchase the necessary lands. The Utah Division of Water Resources in consultation with the Utah Division of Water Rights should assist the state, counties, municipalities, conservancy districts, and water users associations to understand the need to acquire recharge areas now before they are lost to urban development. "[33]

OTHER UTAH LOCATIONS

The work involved in creating this publication suggested taking a broad look at the state to identify locations that had potential for managed aquifer recharge projects. The following paragraphs briefly describe the locations identified. In all cases the investigations described previously in Chapter 3 will need to be accomplished. Many of the following suggested locations have been the subject of geologic investigations by the Utah Geologic Survey; these are available at the Department of Natural Resources Library in Salt Lake City.

Malad-Bear River Valley

The Malad-Bear River basin (area 4 in Figure 11) is in the northeast corner of Box Elder County and includes Bothwell, Tremonton, and Brigham City. The area has been the focus of ground water exploration under the guidance of the Bear River Water Conservancy District, and two regional studies have been completed. Water is produced from both fractured rock and basin fill.

A possible recharge project was investigated in the Bothwell Pocket, using winter water to be delivered by the Bear River Canal. Bear River water would require treatment for ASR well use. Infiltration ponds in abandoned gravel pits is possible, but the water would need to be lifted several hundred feet.

The towns of Thatcher and Riverside have been identified as having managed aquifer recharge potential. A detailed study is available for those wanting to pursue those options.[34]

East Shore

The East Shore system (area 9 in Figure 11) is a structural basin containing up to 10,000 feet of lacustrine and alluvial deposits. A series of coalescing deltas at the mouths of canyons draining the Wasatch Range serve as natural recharge areas. The previously described report by Valley Engineering outlines areas suitable for augmentation of recharge by water spreading.

The largest of these, the gravel delta of the Weber River, has been proposed as a site for managed aquifer recharge since the 1950s. Declining water levels in the Delta Aquifer have created a large potential reservoir. The Weber Basin Water Conservancy District project described at the end of Chapter 4 is investigating the feasibility of managed aquifer recharge at the mouth of Weber Canyon.

Salt Lake Valley

The Salt Lake Valley (area 10 in Figure 11) is a structural basin containing up to 5000 feet of unconsolidated lacustrine and alluvial deposits. Coalescing deltas and alluvial fans border it on both the east and west. Aquifers are recharged naturally on the east and west margins near the range-fronts, and discharge to the Jordan River in mid-valley.

As the first large-scale ASR project in Utah, the Jordan Valley Water Conservancy District has been injecting off-peak (winter) water delivered by the Deer Creek Aqueduct, and recovering it in the summer. The aquifer is open to the Jordan River, so water continually migrates down-gradient to the Jordan River. On the west side of the valley, the extensive alluvial apron and deep water table implies a large empty reservoir, which could be recharged by either wells or infiltration basins. Conveying water from sources on the east side of the valley (for example, Central Utah Project or Deer Creek water) to recharge locations on the west side of the valley could involve substantial pump lifts. Recharge and recovery could be complicated by contamination plumes near the Kennecott Copper Mine.

Snyderville-Park City

The Snyderville-Park City area (area 11 in Figure 11) is a relatively thin alluvial cover that overlies complexly folded and faulted bedrock. Most aquifers are full, with ground water at the surface. However some areas of deep fractured rock or Tertiary gravel could be explored as potential recharge areas.

Tooele Valley

Tooele Valley (area 12 in Figure 11) is a structural basin containing up to 5000 feet of unconsolidated lacustrine and alluvial deposits. Coalescing deltas and alluvial fans ring the valley on the west, south, and east, and it is open to the Great Salt Lake on the north. The 1983 report by Bhasker and others provides a model for optimizing the conjunctive use of surface and ground water. A recent description of the ground water flow system and budget is in Steiger and Lowe, 1997.

The basin fill is recharged naturally at the mouths of canyons where streamflow infiltrates streambeds and percolates downward, eventually migrating toward the center of the valley and emerging as springs and seeps near the shore of the Great Salt Lake. This natural system could be enhanced by water-spreading in suitable areas or augmented with reclaimed municipal wastewater. The aquifers extend out beneath the lake, where artesian pressure prevents the intrusion of brine. To fully utilize the ground-water basin for long-term storage it may be necessary to construct a salt-water intrusion barrier using ASR wells.

Cedar Valley (Utah County)

Cedar Valley (area 15 in Figure 11) is a structural basin containing up to 2000 feet of unconsolidated lacustrine and alluvial deposits. It is bordered on all sides by coalescing alluvial fans. The basin fill is recharged naturally near the margins, and is believed to discharge in the subsurface to Utah Lake. CUP water that is not yet fully utilized could be stored here using infiltration basins, but would require a pump lift of several hundred feet to get it over Coyote Pass. Utah Geological Survey, Special Study 109 has information for this area.

Utah and Goshen Valleys

Utah and Goshen Valleys (area 16 in Figure 11) comprise a complex structural basin containing up to 10,000 feet of unconsolidated lacustrine and alluvial deposits. Coalescing deltas and alluvial fans ring the valley on the west, south, and east. The basin fill is recharged naturally at the mouths of canyons where streamflow infiltrates streambeds and percolates downward, eventually emerging as springs and seeps near the shore of Utah Lake. Alluvial aquifers are mostly full and spilling, except in Goshen Valley. The alluvial apron at Mosida might provide a site for recharging CUP water that is not yet fully utilized.

Milford

Milford (area 26 in Figure 11) occupies a deep basin containing sand and gravel where the Beaver River entered ancient Lake Bonneville. Declining ground water has left a substantial volume of empty aquifer. Natural recharge by the Beaver River could be enhanced by spreading or by infiltration basins. In some areas, however, surface gravel is underlain by impervious clay strata. There is a potential opportunity to recharge using reclaimed M&I water.

Cedar Valley (Iron County)

Cedar Valley (area 32 in Figure 11) is a structural basin containing about a 2,000-foot thickness of unconsolidated lacustrine and alluvial deposits. It is bordered by coalescing alluvial fans. The basin fill is recharged naturally near the margins, and is believed to discharge in the subsurface westward to the Escalante Valley, and possibly southward to the Ash Creek drainage. In the past century, ground water levels have declined as much as 40 feet, creating some space to accept natural or managed recharge. Spring runoff waters from Coal Creek were diverted to existing gravel pits in 2005 in order reduce flood flows; this also recharged local aquifers.

In most places, the alluvium is fine-grained, making recharge by either wells or basins difficult, but there are a few suitable areas underlain by fractured volcanic rock and gravel of Tertiary age. Recharge water could come from Coal Creek or other drainages, reclaimed wastewater, or the possible future Lake Powell Pipeline. Some of the surface waters may have high sulfate content which could limit the suitability for recharge due to aquifer contamination. Utah Geological Survey, Special Study 103 has information for this area.

Beryl-Enterprise

A large structural basin containing a great thickness of unconsolidated lacustrine and alluvial sediment underlies the Beryl-Enterprise area (area 22 in Figure 11). Natural recharge is limited because few perennial streams enter the basin. However, investigation into the use of spring flood flows might prove worthwhile. Ground water levels have declined due to agricultural pumping, creating an empty reservoir of substantial size.

Central Virgin River

The central Virgin River (area 34 in Figure 11) is characterized by shallow alluvium and large fractured rock aquifers, primarily Navajo Sandstone and basalt. The newly completed Sand Hollow reservoir is recharging the Navajo aquifer for future recovery. Other small areas of sandstone or basalt may be suitable for storing winter water or flood flows.

NOTES

[1] Keith L. Hansen, *Artificial Recharge: A Feasibility Study for Using Storm Water and Surplus Stream Flow as a Source for Artificial Recharge to the Ground Water Aquifer in Salt Lake Valley*, June 1978, page 2.

[2] Utah Division of Water Resources, *Utah State Water Plan, Weber River Basin*, May 1997, page 3-2.

[3] Mike Lowe, Janae Wallace, and Matt Butler, *Ground Water Sensitivity and Vulnerability to Pesticides, East Shore Area of Great Salt Lake, Davis and Weber Counties, Utah*, Utah Geological Survey, MP04-1, 2004, page 8.

[4] Ibid. page 12.

[5] Ibid. Figure 5, page 14.

[6] Carl H. Carpenter, *Potential for Recharge of Aquifers in Utah Valley by Artificial Means*, June 1978, page 1.

[7] Ibid. page 11.

[8] Ibid. page 5.

[9] Ibid. page 28.

[10] Ibid. page 14

[11] Ibid. page 16.

[12] Ibid. page 19.

[13] Ibid. page 21.

[14] Ibid. page 23.

[15] Ibid. page 25.

[16] Ibid. page 27.

[17] Valley Engineering Co., *Water Spreading Feasibility Study, Davis, Weber, and Box Elder Counties, Utah*, June 1978.

[18] Ibid. page 3.

[19] Ibid. page 4.

[20] Ibid. page 5.

[21] Ibid. page 6.

[22] Ibid. page 7.

[23] Ibid. page 8.

[24] Ibid. page 9.

[25] Ibid. page 10.

[26] Ibid. page 11.

[27] Ibid. page 12.

[28] Ibid. page 13.

[29] Ibid. page 14.

[30] Ibid. page 15.

[31] Ibid. page 16.

[32] Ibid. page 17.

[33] *Memorandum: Analysis, Conclusions and Recommendations Of Three Reports on Artificial Recharge To Ground Water*, From S. Bryce Montgomery, To Paul L. Gillette, January 18, 1980.

[34] Mariush Kemblowski, Tom Lachmar, and Richard Peralta, *Potential for Aquifer Storage and Recovery in Box Elder and Cache Counties*, Utah State University, January 1999, pages 5 to 7.

6

PROJECT IMPLEMENTATION

At first glance, a conjunctive management project might appear to be a relatively simple endeavor. Simply take some of the excess spring runoff and allow it to pond up in an abandoned gravel pit or existing debris basin. However, as with any water project, such a simple approach is not likely to provide the desired benefit and could easily become entangled in legal, environmental and other problems. Therefore, a successful conjunctive management project must be more deliberate and follow the appropriate planning, design and development process of any modern water project. For a list of common impediments to conjunctive management projects, see Appendix 5.

This chapter contains the key elements the Utah Division of Water Resources and others feel are important in developing a successful conjunctive management project. Although the information presented does not cover every potential problem or obstacle, it does provide a firm foundation upon which projects in Utah can be built. The exact requirements for any given project will depend greatly on its desired objectives and the local conditions encountered during preliminary investigations. Managed aquifer recharge projects are very site specific. Therefore, it is important that such projects start small, learn as you go, and expand as appropriate.[1]

PROJECT DEVELOPMENT PHASES

Experts in the conjunctive management field strongly recommend utilizing a phased approach in the development of projects. Three commonly used phases are as follows:[2,3]

Phase 1: Preliminary Feasibility Assessment and Conceptual Design
Phase 2: Field Investigations and Test Program
Phase 3: Full-Scale Project Development

Following this approach allows project sponsors to manage the risks of the project by clearly defining the level of effort and associated financial investment that is required at each phase without overcommitting themselves to subsequent stages that may not be feasible.[4]

The natural tendency to forego the initial investigations in phase 1 (Preliminary Feasibility Assessment and Conceptual Design) and move immediately into field-testing at a selected site is risky. Although success is possible, many project sponsors who have ignored or only partially considered this important phase have "encountered significant problems" that have hampered the project or led to its abandonment.[5] Phase 1 should include initial contact with state regulatory agencies (Utah Division of Water Quality and Utah Division of Water Rights) and typically culminates in a preliminary feasibility report that clearly defines the objectives of the conjunctive management project, summarizes essential hydrologic and geologic data, and contains a conceptual design for the project. This report is often vital to obtain financial, political and environmental support for subsequent phases.

The objective of phase 2 (Field Investigations and Test Program) is to collect important field data that is needed and begin a test program at a large enough scale in order to determine whether or not a full-scale project is feasible. An important element of phase 2 is to monitor the aquifer system before, during and after recharge operations in order to obtain essential hydraulic and water quality information. In many cases, modeling the aquifer may also be desirable, especially if there is a good chance that water recharged into the aquifer will migrate away from the areas where it will be recovered. If the results of phase 2 are positive, project sponsors can then proceed with confidence into phase 3 (Full-Scale Project Development), where the largest financial commitments and risks are incurred.

TECHNICAL EXPERTISE

Conjunctive management projects require specialized knowledge and technical expertise. Project sponsors can increase the probability of successfully implementing a conjunctive management project by assembling a multi-disciplinary technical team that includes a balance of engineers and hydrogeologists with expertise in the following areas:[6]

- Hydraulics
- Well and pump station design
- Water quality and water treatment
- Hydrology
- Geology
- Hydrogeology
- Aquifer simulation modeling
- Geochemistry

Other individuals who can properly address environmental, legal, regulatory and political issues may also be required. Failure to consider all of these issues at the planning and conceptual design stages of the program can lead to costly mid-course corrections, or possible program failure.[7]

One last, important consideration is to obtain actual ASR well expertise. While production wells that remove water from the ground and injection wells that put water into the ground have common elements, they cannot simply be combined to design an ASR well. Select a person experienced in ASR well design.[8]

PERMITS AND OTHER REGULATORY REQUIREMENTS

Conjunctive management projects in Utah are subject to a variety of permitting and regulatory requirements. These requirements deal primarily with important water rights and water quality issues and are discussed briefly in the following sections. Local governments may also have specific requirements that should be followed. For federally funded projects, additional environmental review may also be required. Appendix 3, Internet Websites, contains contact information for the various agencies involved in permitting actions.

Ground Water Recharge and Recovery Act

In response to Jordan Valley Water Conservancy District's aquifer storage and recovery proposal, the Legislature enacted the Groundwater Recharge and Recovery Act in 1991. The full text of this act can be found in Appendix 4, Utah Ground Water Recharge and Recovery Act. In essence, the act defines the State Engineer's authority, as director of the Utah Division of Water Rights, to permit and regulate conjunctive management projects, which contain an aquifer recharge and recovery component. Essential permits required by this act and other related permits that may be required by the Utah Division of Water Rights are summarized below.

Recharge Permit

According to the act, no entity may "artificially recharge a groundwater aquifer without first obtaining a recharge permit."[9] The entity applying for a recharge permit must also have a valid water right to the water proposed for recharge or an agreement to use the water proposed for recharge with another entity or individual who has a valid water right.

As part of the application for a recharge permit, the entity must provide a plan of operation that includes the following:

- Description of the project
- Design capacity of the project
- Detailed monitoring program
- Evidence of financial and technical capability

- Hydrologic study demonstrating: (1) Area of hydrologic impact, (2) hydrologic feasibility of the project, (3) assurance that the project will not cause unreasonable harm, and (4) assurance that existing water rights will not be impaired.

In addition, information regarding the quality of the recharge water and the quality of the water in the receiving aquifer must be submitted as well as evidence that all applicable water quality permits have been obtained. These permits are discussed later under the title “Water Quality Protection Laws.”

Recovery Permit

According to the act, no entity may “recover from a groundwater aquifer water that has been artificially recharged unless [they] first obtain a recovery permit.”[10] The entity applying for a recovery permit will only be allowed to recover that portion of the recharge water that the State Engineer determines has reached the aquifer and remains within the hydrologic area of influence. Ground water modeling may be necessary to demonstrate that the recharge water will not leave the project area.

The entity applying for a recovery permit need not be the same entity that holds the recharge permit. However, if the entities are not the same, the entity applying for the permit must have a written agreement with the holder of the recharge permit to recover and use the water.

Well Permit and Stream Alteration Permit

In addition to the key permits mentioned above, most conjunctive management projects will need a well permit and a stream alteration permit from the Utah Division of Water Rights. A well permit will be required for any monitoring wells that are needed to monitor the project and for any new well that will be used to inject water into the aquifer or recover water from the aquifer. In simple projects, the monitoring, ASR and recovery wells may be the same well and require only one permit.

If the project proposes to divert water from a new location on a stream, which is the case with many surface recharge proposals, a stream alteration permit will also be required. The regional engineer with the Utah Division of Water Rights can help with these processes.

Water Quality Protection Laws

Ground water quality is subject to the federal Drinking Water Act of 1994 and subsequent revisions. The Utah Division of Water Quality and the Utah Division of Drinking Water administer this law at a state level. Typically, the Utah Division of Water Quality handles most of the requirements that would affect a conjunctive management project. Under current state guidelines, the specific requirements for a given project that must be followed depend upon the type of project to be implemented (surface spreading or ASR well). These differences are discussed briefly below.

Surface Spreading

A conjunctive management project that proposes to recharge an aquifer through surface spreading may be required to apply for a permit under the Utah Division of Water Quality’s Ground Water Quality Protection Program. However, since this program was intended to protect aquifers from recharge by polluted water sources, the detailed requirements of this program may only be necessary in such cases where natural filtration from the ground surface to the aquifer would not be sufficient to improve the water quality. A permit may also be necessary if the water proposed for recharge were imported from another area far removed from the proposed recharge area. Due to potentially negative geochemical reactions that could occur, the Division may require that water quality be monitored closely to assure no degradation.

The Utah Division of Water Quality did not require the Weber Basin Water Conservancy District to obtain a Ground Water Quality Protection Permit for their aquifer storage and recovery pilot project located near the mouth of Weber Canyon in Davis County (see Chapter 4). Instead, the Division issued a "Permit by Rule" because the project proposed only to enhance natural recharge by diverting the Weber River into an abandoned gravel pit located in the rivers floodplain. Even so, the district has monitored water quality carefully throughout the duration of the pilot project and has not observed any ground water quality degradation.

ASR Well

A conjunctive management project that proposes to recharge an aquifer through an ASR well is required by law to apply for a Class V Injection Well permit under the Utah Division of Water Quality's Underground Injection Control (UIC) Program. To obtain a permit, the applicant must submit a technical report that outlines pertinent information about the proposed well and its operation. Some of the things that are required as part of this report include:

- Piezometric map of all ground water in the area.
- Description of the receiving aquifers hydraulic and geologic characteristics.
- Water quality characteristics of recharge water.
- Water quality characteristics of ground water in the receiving aquifer.
- Assessment of the potential for geochemical interactions between recharge water and receiving aquifer water and geologic matrix to cause degradation of water quality of receiving aquifer.

Since the UIC Programs intent is to prevent degradation of ground water, the water to be injected into the aquifer must be of equal or higher quality than the receiving ground water. Thus, for many aquifer storage and recovery operations, the recharge water will need to be treated to potable (drinking water) standards. Careful monitoring of potential chemical and biological contaminants may also be required.

As mentioned earlier, the underground environment of aquifers is conducive to killing off surface bacteria and viruses. Therefore, it is important not to measure compliance at the ASR well. Rather, a separate monitoring well located about 1,200 feet from the ASR well should be used to provide a more accurate indicator.[11]

Local Government Requirements

In addition to the state regulations mentioned above, local governments should be consulted as part of the planning of a conjunctive management project. Most communities have zoning laws and permitting requirements for any land use or construction activity within their boundaries. Typically, these include such things as a special use permit and a construction permit.

PROJECT FUNDING

Many funding sources are available to help finance conjunctive management projects. The Central Utah Project Completion Act (CUPCA), for instance, authorized $10 million in 1992 for such projects along the Wasatch Front—approximately $8 million of this amount is still available as of July 2005. This and other potential funding sources are described in Table 10; additional discussion of the most significant sources is provided in the paragraphs that follow.

Central Utah Project Completion Act

Of the $10 million that was authorized in CUPCA for conjunctive management projects, $5 million was used on the Jordan Valley Water Conservancy District for their aquifer injection and recovery system located in southeast Salt Lake Valley. There is currently $8 million in federal funds remaining in the program ($5 million plus yearly indexing), which could be used for the construction of eligible projects with a mandatory matching 35% local (non-Federal) cost share. While the Central Utah Water Conservancy District (CUWCD) administers these funds, project proposals must be submitted to the Utah Division of Water Resources for approval. Once the Division approves the proposal, it is forwarded on to CUWCD so it can request federal appropriation. In conjunction with this report, the Utah Division of Water Resources will solicit proposals for additional projects. The Division hopes that several water suppliers along the Wasatch Front will be able to implement projects that demonstrate the feasibility of a variety of conjunctive management strategies with the remaining funds.

CUWCD plans the budget at least 30 months in advance to allow time for CUPCA funds to be approved by the U.S. Congress. While Congress has already authorized the funds for this purpose, these funds must be appropriated on an annual basis before they can be distributed. Since this is a lengthy process, it is wise to prepare proposals at least three full years before monies are actually needed. Importantly, this funding source will no longer be avail-

TABLE 10
Potential Federal and State Funding Sources for Conjunctive Management Projects

Agency or Board	Fund or Program	Purpose	Type
Federal Government			
Department of Agriculture	Rural Development Fund	Water supply and wastewater disposal projects for rural communities	Grants & Loans
Army Corps of Engineers	Civil Works	Flood control, water supply and recreation projects	Cost-Share
	Section 595	Environmental infrastructure, resource protection and water development projects	Cost-Share
Bureau of Reclamation	Water 2025	Collaborative water conservation, efficiency, and banking projects	Grants Cost-Share
	Technical Assistance to States	Environmental, economic, engineering, land use, and social analysis	Grants
	North and South Utah Geographically Defined Programs	Water reclamation projects	Cost-Share
Central Utah Water Conservancy District	CUPCA Section 202(a)(2)	Conjunctive use of surface and ground water	Cost-Share
	Unexpended funds made available to the Water Conservation Credit Program	Water recycling, conjunctive use and other purposes	Cost-Share
State of Utah			
Board of Water Resources	Revolving Construction Fund	Irrigation projects, wells and rural drinking water systems	Loans
	Cities Water Loan Fund	Municipal water projects for cities, towns and districts	Loans
	Conservation and Development Fund	Multipurpose dams and large municipal irrigation and drinking water systems	Loans
Community Impact Board	Permanent Community Impact Fund	Planning, construction and maintenance of public facilities for communities impacted by resource development on federal lands	Grants Loans
Drinking Water Board	State Revolving Fund	Drinking water projects for cities, towns and districts	Grants Loans
	Federal State Revolving Fund	Privately and publicly owned drinking water systems	Grants Loans

able upon completion of the Central Utah Project, which is estimated to be about 2016.

CUPCA money is available to study the feasibility of conjunctive management and to develop operational projects. The required cost share is 50-50 (federal-local) for feasibility studies, and 65-35 (federal-local) for development. Feasibility includes the first two phases recommended for projects mentioned previously: Phase 1- Preliminary Feasibility

Assessment and Conceptual Design and Phase 2 - Field Investigations and Test Program (pilot or demonstration project). Development includes the final phase recommended: Phase 3: Full-Scale Project Development (construction of the project). In order to qualify for available funds, the project sponsor must demonstrate:

- Economic feasibility as indicated by costs versus benefits analysis.
- Clearance by the National Environmental Policy Act (NEPA). Depending on the scope of the project, this might be a simple categorical exclusion, an Environmental Assessment, or a full Environmental Impact Statement.
- Approval of pertinent state agencies.
- Hydrologic feasibility.
- The project is in an approved location (Weber, Davis, Salt Lake, Utah or Wasatch county).

In 2002, CUPCA was amended to also allow certain unexpended funds authorized for the Central Utah Project to be used for water conservation projects through the Water Conservation Credit Program ("Credit Program"). This amendment is significant for conjunctive management projects, not only because of the unexpended fund provision, but because the definition of conservation measures that can receive existing funding through the Credit Program was expanded to include conjunctive use. Applications to the Credit Program can be made at anytime during the year, however, feasibility studies must be submitted prior to a yearly deadline in May in order to be eligible for review during that calendar year. Entities interested in obtaining funding through the Credit Program should contact D. Heath Clark, Credit Program Manager, at CUWCD for more information.

U.S. Bureau of Reclamation

In the past, one of the major funding sources for ASR projects has been the U.S. Bureau of Reclamation (USBR). The High Plains States Ground Water Demonstration Program studied the potential for artificial ground water recharge in 17 Western States and demonstrated artificial recharge technologies under a variety of hydrogeologic conditions. Demonstration sites were located in areas having a high probability of physical, chemical and economic feasibility for recharge. In the early 1990s, JVWCD received funds from this program through specific legislation to conduct a demonstration project. The success of this pilot project led to the construction of their permanent project discussed previously.

As of July 2005, the USBR had only limited funding available through this program. Funds are for general planning and pilot studies, and not for construction. The required cost-sharing is 50 percent federal to 50 percent non-federal. This means a sponsoring agency could must use money from local sources to match USBR funds.

Water 2025 Initiative

In 2003, the Department of Interior began the "Water 2025 Initiative: Preventing Crises and Conflict in the West" to help western states meet growing water needs. This initiative, overseen by the USBR, identified 12 areas in the west where the potential for water conflicts in the future were "highly likely." Two of these twelve areas are in Utah—the Wasatch Front and the St. George area. Water projects proposed in these areas are more likely to qualify for funding.

Through the Water 2025 Initiative, the Interior Secretary hopes to achieve the outcomes identified during the public meetings held throughout the West. A focus of the program is to fund projects that emphasize water conservation, encourage water efficiency, create water banks and other markets and encourage collaboration. Projects which best leverage federal dollars and that can be completed within 24 months receive the highest priority.

As part of the 2025 Water Initiative, the "Water 2025 Secretarial Challenge Grant" fund was created. During the Fiscal Year 2004, only $4 million was made available to this fund and three projects in Utah received funding (limited to $250,000 per project). During Fiscal Year 2005, over $20 million was made available and 11 projects in Utah received funding (limited to $300,000 per project), including a conjunctive management project proposed by the Metropolitan Water District of Salt Lake and Sandy. Once completed the district's project will contain an ASR well, infiltration pond and infiltration trench to enable it to store an estimated 300 acre-feet per year of water in the Principal Salt Lake Valley Aquifer. The district plans to work with its member agencies to develop a water bank to market the stored water.

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers has funds available to help fund conjunctive management R projects in Utah. Cost sharing of 75 percent federal to 25 percent non-federal is required and "design and construction assistance may be provided only for projects that are owned by public entities." This program authorizes the expenditure of $25 million. As with other Federal programs, while funds may already be authorized, they must also be appropriated by Congress. To obtain Corps funds, it is necessary to plan at least 30 months in the future to allow time for the funds to be approved by the U.S. Congress. It is probably wise to start application to COE at least three full years before funds are actually needed to begin construction.

Funding is provided under the Water Resources Development Act (WRDA) of 1999, Section 595. This was amended in 2003 to provide direct assistance for design and construction projects. Projects may include:

- Wastewater treatment and related facilities;
- Water supply and related facilities;
- Stormwater collection and related facilities; and
- Environmental restoration and surface water resource protection and development.

This program is intended for rural projects only, thus projects located in Weber, Davis, and Salt Lake counties, as well as portions of Utah and Washington counties, are not eligible.

Utah Board of Water Resources

Funding is available for projects that conserve, protect, or more efficiently use present water supplies, develop new water, or provide flood control. There are three revolving loan funds from which finances might be obtained:

- The Revolving Construction Fund is for incorporated groups and water companies. Funding is available for irrigation projects up to $500,000, culinary projects up to $250,000, and dam safety upgrades.
- The Cities Water Loan Fund is for municipal projects for political subdivisions.
- The Conservation and Development Fund is for projects for incorporated groups, political subdivisions, or Indian Tribes.

Utah Community Impact Board

The Community Impact Board (CIB) is a program of the Utah Division of Community Development. It helps state and local agencies and entities that are, or may be, directly or indirectly impacted by mineral resource development on nearby federal lands. The board provides assistance through grants and low-interest loans for the planning, construction, and maintenance of public facilities. The funds also help community agencies provide public services. This is primarily a rural program and Salt Lake and Utah Counties are not eligible.

Utah Drinking Water Board

Low interest loans and limited grants are available to all qualified public drinking water systems. The Utah Division of Drinking Water administers two financial assistance programs: the State Revolving Fund and the Federal State Revolving Fund.

The State Revolving Fund program was created by the Utah State Legislature in 1984 and is governed by the Water Development Coordinating Council. It is a state-funded program. Only political subdivisions (cities, towns, districts) are eligible for these funds.

> It's interesting how there's never enough money to prevent problems, but we always find the money to correct problems.
>
> --Unknown Author

The Federal State Revolving Fund program was created under the 1996 amendments to the Federal Safe Drinking Water Act. Most of the funds in this program originate from the federal government. These funds are available for privately and publicly owned community water systems and nonprofit non-community water systems.

NOTES

[1] Herman Bouwer, former Chief Engineer and Director of the U.S. Water Conservation Laboratory, communication to Utah Division of Water Resources, June 2005.

[2] Pyne, R. David G., *Groundwater Recharge and Wells—A Guide to Aquifer Storage and Recovery,* London: Lewis Publishers, 1995, page 24.

[3] Environmental and Water Resources Institute, *Standard Guidelines for Artificial Recharge of Ground Water,* Reston, VA: American Society of Civil Engineers, 2001, 7.

[4] Ibid, page 24.

[5] Ibid, page 25.

[6] Ibid.

[7] Ibid.

[8] Tom Morris, Hydrologist, Las Vegas Valley Water District, personal communication to Utah Division of Water Resources, June 2005.

[9] *Utah Administrative Code, 73-3b-103,* Salt Lake City: State of Utah, 1992.

[10] Ibid.

[11] David G. Pyne, author of *Ground Water Recharge and Wells, A Guide to Aquifer Storage and Recovery*, Communication to Utah Division of Water Resources, June 2005.

7

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Utah has a history of investigating conjunctive management and aquifer storage and recovery (ASR) technology. Starting in 1936 and continuing intermittently to the present, numerous experiments and studies have been conducted. Conjunctive management strategies were employed in some areas simply because it made sense to do so. Despite this history only three specific projects involving managed aquifer recharge have been put into operation. This can probably be explained by over a century of steady implementation of surface water development projects. This includes such far-reaching undertakings as the Central Utah Project and the Weber Basin Project. Further, conjunctive management and managed aquifer recharge require an understanding of ground water conditions, which can be difficult. Ground water is out of sight, out of mind, and can be hard to define and understand. In the past, this complexity has been something of an impediment to ground water development. It is reasonable that surface water development would come first and ground water development would come later. However, continuous development over time has brought improved pumping and underground investigation technology, expanded geologic exploration throughout the state, and the introduction of managed aquifer recharge technology. These have all made conjunctive management much easier to implement. It has also been demonstrated to be very cost effective compared to surface water development alternatives.

Moreover, the possible overdraft of aquifers has created concern. Yet the demand for water increases and will continue to increase. Action today is needed to be ready for tomorrow. As discussed earlier, conjunctive management is a proven technology employed throughout the world, including about 70 ASR projects, with over 290 ASR wells, operating in the United States. Many more are in various stages of development. Conjunctive management strategies are among the next logical steps to more fully develop Utah's water resources.

Current projects have met with success and have encountered challenges. The Brigham City project is generally regarded as positive achievement. Given that the other two projects were brought on-line during the recent six-year drought, their full success has yet to be realized. This document is intended to encourage further implementation of conjunctive management. Following the recommendations below will advance the technology over the next several decades.

Water is owned by the state and the Utah Division of Water Rights regulates its use. These agencies, along with the Utah Division of Water Resources, Utah Division of Water Quality and Utah Geological Survey, have supported development of the three existing managed aquifer recharge projects in the state. It is logical and appropriate that these agencies continue working together to assist water suppliers interested in implementing conjunctive management projects. This is consistent with an Executive Order by Governor Scott Matheson in 1984 which stated, "The Division of Water Resources and the State Engineer shall encourage conjunctive use operations where more efficient use of the water resources can be demonstrated." Coordination with other Federal, county, and city governments, and local water suppliers would be done as needed.

RECOMMENDATIONS

In the course of developing this document, it became apparent that there were several actions that could be taken to increase the utilization of Utah's usable available water supply. Therefore it seemed logical and judicious to follow through and make two recommendations.

The first recommendation is a collection of suggested actions to be taken by leaders in cities and towns, counties, water conservancy districts and water suppliers. The second recommendation will be implemented by the Utah Geological Survey as part of their ongoing support.

First: Take Immediate Action to Facilitate Conjunctive Management.

The following suggested actions could be taken immediately to keep options open for implementing conjunctive management. These apply to leaders in cities and towns, counties, water conservancy districts and water suppliers. The Utah Division of Water Resources, (801) 538-7234, is available for assistance.

- Investigate the applicability of conjunctive management strategies to increase the water supply in your location. Initially, this might include discussions with the Utah Geological Survey about local geologic conditions. Discussions with technical consultants would also be likely. Such firms can be located through the American Council of Engineering Companies of Utah, www.acecutah.org Search their directory for firms with the specialty of "hydrogeology." Implement conjunctive management where appropriate.
- Visit existing aquifer recharge sites in Utah, and surrounding states to learn from their experiences.
- Set aside lands that are uniquely situated for storing water underground. These are valuable and cannot be used after the land is put to other uses. This especially includes gravel pits located above the unconfined aquifer at the mouth of canyons. If subsequent study determines aquifer recharge cannot be accomplished, the lands can then be developed otherwise. These areas are typically well suited for temporary or permanent multiple uses such as parks and recreation.
- Investigate the status of aquifers. This includes declining ground water levels and potential contamination risks. Take action based on what is found.
- When agricultural land is converted to urban use, investigate the options of directly putting former irrigation waters into the community water supply or developing a conjunctive management project to store those waters in aquifers.
- Require new subdivisions, annexations, or additions to provide the water needed by those entities.
- Require urban developers to install storm water recharge basins with every new development.
- Flood retention reservoirs are routinely installed on mountain streams to reduce the peak runoff. Investigate and locate the aquifer recharge sections of the stream and build the flood retention reservoirs at these locations.
- Locate debris collection basins as described above for flood retention reservoirs.

Second: Develop An Internet-Based, Consolidated Ground Water Information List.

Numerous state and Federal agencies have developed information directly related to ground water. This includes ground water levels over time, water chemistry over time, aquifer contamination records, and geologic descriptions of the aquifers. These sources constitute a large and valuable compilation of data. Unfortunately these data are contained in numerous, yet disconnected locations. This results in considerable difficulty in gathering data for projects. A great deal of time is spent and relevant data is often completely missed. It costs more to gather the data and often less accurate decisions are made. Many people are simply not aware of the many information sources.

Considerable benefit would be derived if a consolidated ground water information list was developed that provides Internet links to the several agencies. This would be a one-time effort that provides a simple answer to a complex problem; some maintenance would be needed to keep the list current. This would be accomplished by:

- Identify the agencies.
- Compile a table indicating the agency, types of information available, and an Internet link.
- Provide this table to the agencies.
- Request the agencies include the table on the Home Page of their Internet website.
- Annually review the list and provide updates to the agencies.

It was necessary to interact with the following agencies while developing this document. This list identifies most of those having ground water data and indicates the wide variety of data sources.

- Utah Division of Water Rights
- Utah Division of Water Resources
- Utah Division of Water Quality
- Utah Division of Oil, Gas, and Mining
- Utah Division of Drinking Water
- Utah Department of Agriculture and Food
- Utah Geological Survey
- Utah State University Water Research Laboratory
- U.S. Geological Survey
- U.S. Bureau of Reclamation
- U.S. Army Corps of Engineers

In cooperation with the Utah Division of Water Resources, the Utah Geological Survey is willing to compile and maintain a web page with links to online ground water related data.

Appendix 6, Bibliography, provides recommended reading for professionals in the water supply industry, as well as community and government leaders, interested in conjunctive management. Appendix 3, Internet Sites, provides related information for the same audience.

As with any worthwhile endeavor, there are commensurate challenges. In 1998, the National Water Research Institute, in cooperation with the Association of Ground Water Agencies and the Metropolitan Water District of Southern California, conducted a workshop to determine the greatest obstacles to implementing a cost-effective conjunctive management program in California. Workshop participants identified the 10 most significant impediments and these are included in Appendix 5, Impediments to Conjunctive Management Projects. These should be regarded as normal and anticipated problems to be overcome while pursuing projects.

IN CLOSING

As Utah's population increases, the demand for water increases, and recurring drought brings added challenges. The overall water supply is restricted to that which falls from limited precipitation. The main ways to increase the water supply are constructing new development projects, conservation of existing supplies, conversion from agricultural uses to public uses, and implementing effective management strategies to maximize efficiency. Conjunctive management falls into that last category and effectively increases the amount of water available and the reliability of the supply.

This document has presented the details of the situation and gone on to provide ways to deal with and improve that situation. Water development was easier in the past; today's projects are more difficult and expensive to implement. Nonetheless, there is a great deal that can, and will, be done to more fully utilize the available water supply. As water suppliers and government leaders implement these recommendations, they will continue a long-standing heritage of providing adequate water for Utah's people and business in a timely manner.

Appendix 1

BRIEF ANALYSIS OF DROUGHT IN UTAH

Figure 6 is a plot of the Palmer Hydrologic Drought Index (PHDI) for the Northern Mountains climatic region of Utah. This region is comprised of the Uinta and northern Wasatch Mountains. This region was chosen for analysis since it receives the highest precipitation in the state. It is also representative of the mountains where much of the state gets its water. See Figure 5 for the location of this and other climatic regions in the state.

The PHDI was developed by the National Climatic Data Center based on temperature and precipitation records at weather recording stations in the described area. It is available nationwide. The index was developed to quantify the long-term hydrological effects of drought on reservoir levels and ground water levels. Hydrological effects of drought take longer to develop than meteorological effects and it also takes longer to recover from them. This index was chosen for analysis since water for irrigation and public water supplies are obtained from reservoirs and from ground water. It also has the important benefit of having records dating back 110 years to 1895. Positive numbers indicate wet years shown in blue. See Figure 6. Negative numbers indicate dry years shown in brown. Drought is quantified under the PHDI as follows:

- 0 to –0.5 Normal
- -0.5 to –1.0 Incipient Drought
- -1.0 to –2.0 Mild Drought
- -2.0 to –3.0 Moderate Drought
- -3.0 to –4.0 Severe Drought
- Greater than –4.0 Extreme Drought

Analysis of the PHDI data used to develop Figure 6 shows some interesting history for the five longest dry periods. Both length and severity are variable. See Table Appendix 1-1.

As the demand for water increases with time, the impacts of an extended drought also increase. The most extreme and most extended drought of the 1930s would be even more devastating to Utah today than it was then. The population has increased, more people would be affected and economic losses would be much greater. Similarly, the recent 1999 to 2004 drought had a significant impact on the state even though it's the third longest and least severe (for both minimum and average index values) for the period of record.

PHDI charts similar to Figure 6 for Utah's seven climatic regions (Figure 5) were analyzed to determine the maximum length of droughts in those regions. The results are summarized in chronological order by region in Table Appendix 1-2. Several insights regarding Utah droughts come from this table. These insights should impress water suppliers to prepare for such droughts knowing they have occurred in the past and will occur

TABLE Appendix 1-1
Longest Droughts on Record for Northern Mountains of Utah

Years	Duration In Months	Duration In Years	Duration Rank	Minimum Index Value	Minimum Index Rank	Average Index Value	Average Index Rank
1899-1904	53	4.42	4	- 4.62	4	- 3.14	2
1931-1937	72	6.00	1	- 9.01	1	- 4.63	1
1976-1980	43	3.58	5	- 6.59	2	- 2.79	3
1987-1993	71	5.92	2	- 4.64	3	- 2.61	4
1999-2004	58	4.83	3	- 3.81	5	- 2.36	5

Source: Data from National Climatic Data Center,
http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html April 2005
Analysis by Utah Division of Water Resources, April 2005.

again in the future. Historical perspective along with anticipated future demands should help water suppliers make better decisions.

- Every region in Utah experiences drought.
- During most drought periods, most regions of the state are experiencing drought simultaneously. Large areas and many people are impacted.
- The average drought length is from 5 to 7 years, depending on climatic region.
- The five longest droughts lasted from 8.2 to 13 years, varying among climatic regions.
- The interval between extended droughts is quite variable and cannot be predicted.
- Except for the 1999 to 2003 drought, the time periods are not exactly the same in all regions. There is overlap between most regions for the time periods.

TABLE Appendix 1- 2
Extended Drought Periods for Utah Climatic Regions Based on PHDI

Western	Dixie	North Central	South Central	Northern Mountains	Uinta Basin	Southeast
1898-1905 **7.2 yr**	1898-1905 **7.1 yr**	1899-1906 **6.4 yr**	1889-1905 **7.2 yr**	1899-1904 **4.4 yr**	1898-1906 **8.2 yr**	1898-1905 **8.2 yr**
1952-1961 **9.5 yr**	1945-1957 **13 yr***	1928-1936 **8.7 yr**	1932-1936 **3.8 yr**	1931-1937 **6.0 yr**	1953-1957 **3.8 yr**	1953-1957 **4.3 yr**
1987-1993 **6.5 yr**	1989-1992 **3.1 yr**	1982-1991 **4.7 yr**	1953-1957 **4.6 yr**	1987-1993 **5.9 yr**	1988-1993 **4.7 yr**	1988-1992 **4.2 yr**
1999-2003 **4.8 yr**	1999-2003 **4.6 yr**	1999-2003 **4.2 yr**	1988-1992 **4.2 yr**	1999-2003 **3.9 yr**	1999-2003 **4.2 yr**	1999-2003 **4.1 yr**
Average **7.0 yr**	Average **7.0 yr**	Average **6.0 yr**	Average **5.0 yr**	Average **5.3 yr**	Average **5.2 yr**	Average **5.2 yr**

* There were 10 months of positive index numbers averaging +1.78 scattered through this time. However, they did not last long enough to alleviate the drought conditions.

Source: Data from National Climatic Data Center,
http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/main.html November 2003
Analysis by Utah Division of Water Resources, November 2003.

Figure 6 also demonstrates that naturally occurring weather patterns do not follow any repeating periodic time intervals. Further, it shows that a period of wet years is typically followed by period of dry years. However, the length of wet and dry times is highly variable. Just because a wet or dry period has lasted a number of years is no indication that a change is imminent. Also, the PHDI is simply a record of past history. It has no ability to predict the length of future wet or dry times or when such events might occur again.

If the wet years are wet enough, there is water available in excess of that which is needed. In dry years, however, there may not be enough water to meet the needs. The challenge for water suppliers is to capture available excess water during the wet years for use during the dry years. This process can be considered the essence of water management in this semiarid state. Averaging only 13 inches of rainfall per year, Utah has the second lowest average precipitation of all the states in the country. Managing this scarce and valued resource has been, and will continue to be, both challenging and rewarding.

Appendix 2

GROUND WATER AND AQUIFER CONCEPTS

This appendix[1] presents general concepts relating to the occurrence, movement, and quantity of ground water. The concepts will be useful in providing the nontechnical reader with a basic understanding of ground water.

Ground Water Occurrence

Ground water is the water occurring beneath the earth's surface that completely fills (saturates) the void space of rocks or sediment. Given that all rock has some open space (voids), ground water can be found underlying nearly any location in the State. See Figure 11. Several key properties help determine whether the subsurface environment will provide a significant, usable ground water resource. Most of Utah's ground water occurs in material deposited by streams, called alluvium. Along the Wasatch Front, this alluvium consists of coarse deposits, such as sand and gravel, and finer-grained deposits such as clay and silt. The coarse and fine materials are usually coalesced in thin lenses and beds in an alluvial environment. In this environment, coarse materials such as sand and gravel deposits usually provide the best source of water and are termed aquifers; whereas, the finer-grained clay and silt deposits are relatively poor sources of water and are referred to as aquitards. See Figures 10 and 15. Utah's ground water basins usually include one or a series of alluvial aquifers with intermingled aquitards.

Ground Water and Surface Water Interconnection

Ground water and surface water bodies are connected physically. See Figure 7. For example, at some locations or at certain times of the year, water will infiltrate the bed of a stream to recharge ground water. At other times or places, ground water may discharge, contributing to the base flow of a stream. Changes in either the surface water or ground water system will affect the other, so effective management requires consideration of both resources. Although this physical interconnection is well understood in general terms, details of the physical and chemical relationships are the topic of considerable research.

Physical Properties That Affect Ground Water

The degree to which a body of rock or sediments will function as a ground water resource depends on many properties, some of which are discussed here. Two of the more important physical properties to consider are porosity and hydraulic conductivity. Transmissivity is another important concept to understand when considering an aquifer's overall ability to yield significant ground water. Throughout the discussion of these

[1] This entire appendix is derived from *California's Groundwater, Bulletin 118*, Update 2003, Chapter 6,and adapted to fit Utah circumstances.

properties, keep in mind that sediment size in alluvial environments can change significantly over short distances, with a corresponding change in physical properties. Thus, while these properties are often presented as average values for a large area, one might encounter different conditions on a more localized level. Determination of these properties for a given aquifer may be based on lithologic or geophysical observations, laboratory testing, or aquifer tests with varying degrees of accuracy.

Porosity

The ratio of voids in a rock or sediment to the total volume of material is referred to as porosity and is a measure of the amount of ground water that may be stored in the material. Porosity is usually expressed as a percentage and can be classified as either primary or secondary. Primary porosity refers to the voids present when the sediment or rock was initially formed. Secondary porosity refers to voids formed through fracturing or weathering of a rock or sediment after it was formed. In sediments, porosity is a function of the uniformity of grain size (sorting) and shape. Finer-grained sediments tend to have a higher porosity than coarser sediments because the finer-grained sediments generally have greater uniformity of size and because of the tabular shape and surface chemistry properties of clay particles. In crystalline rocks, porosity becomes greater with a higher degree of fracturing or weathering.

As alluvial sediments become consolidated, primary porosity generally decreases due to compaction and cementation, and secondary porosity may increase as the consolidated rock is subjected to stresses that cause fracturing. Porosity does not tell the entire story about the availability of ground water in the subsurface. The pore spaces must also interconnect and be large enough so that water can move through the ground to be extracted from a well or discharged to a water body. The term “effective porosity” refers to the degree of interconnectedness of pore spaces. For coarse sediments, such as the sand and gravel encountered in Utah’s alluvial ground water basins, the effective porosity is often nearly equal to the overall porosity. In finer sediments, effective porosity may be low due to water that is tightly held in small pores. Effective porosity is generally very low in crystalline rocks that are not highly fractured or weathered.

While porosity measures the total amount of water that may be contained in void spaces, there are two related properties that are important to consider: specific yield and specific retention. Specific yield is the fractional amount of water that would drain freely from rocks or sediments due to gravity and describes the portion of the ground water that could actually be available for extraction. The portion of ground water that is retained either as a film on grains or in small pore spaces is called specific retention. Specific yield and specific retention of the aquifer material together equal porosity. Specific retention increases with decreasing grain

TABLE Appendix 2-1

Porosity of Soils and Rock Types, in Percent

Material	Porosity	Specific Yield	Specific Retention
Clay	50	2	48
Sand	25	22	2
Gravel	20	19	1
Limestone	20	18	2
Sandstone	11	6	5
Granite	0.1	0.09	0.01
Basalt	11	8	3

Source: *California’s Ground Water Bulletin 118*, Update 2003, page 85.

size. Table Appendix 2-1 shows that clays, while having among the highest porosities, make poor sources of ground water because they yield very little water. Sand and gravel, having much lower porosity than clay, make excellent sources of ground water because of the high specific yield, which allows the ground water to flow to wells. Rocks such as limestone and basalt yield significant quantities of ground water if they are well-weathered and highly fractured.

Hydraulic Conductivity

Another major property related to understanding water movement in the subsurface is hydraulic conductivity. Hydraulic conductivity is a measure of a rock or sediment's ability to transmit water and is often used interchangeably with the term permeability. The size, shape, and interconnectedness of pore spaces affect hydraulic conductivity. Hydraulic conductivity is usually expressed in units of length/time, such as: feet/day, meters/day, or gallons/day per square-foot. Hydraulic conductivity values in rocks range over many orders of magnitude from a low permeability unfractured crystalline rock at about 10^{-8} feet/day (0.00000001 feet/day) to a highly permeable well-sorted gravel at greater than 104 feet/day. Clays have low permeability, ranging from about 10^{-3} to 10^{-7} feet/day (0.001 to 0.0000001 feet/day).

Transmissivity

Transmissivity is a measure of the aquifer's ability to transmit ground water through its entire saturated thickness and relates closely to the potential yield of wells. Transmissivity is defined as the product of the hydraulic conductivity and the saturated thickness of the aquifer. It is an important property to understand because a given area could have a high value of hydraulic conductivity but a small saturated thickness, resulting in limited overall yield of ground water.

Aquifer

An aquifer is a body of rock or sediment that yields significant amounts of ground water to wells or springs. In many definitions, the word "significant" is replaced by "economic." Of course, either term is a matter of perspective, which has led to disagreement about what constitutes an aquifer. As discussed previously, coarse-grained sediments such as sands and gravels deposited in alluvial or marine environments tend to function as the primary aquifers in Utah.

Aquitard

An aquitard is a body of rock or sediment that is typically capable of storing ground water but does not yield it in significant or economic quantities. Fine-grained sediments with low hydraulic conductivity, such as clays and silts, often function as aquitards. Aquitards are often referred to as confining layers because they retard the vertical movement of ground water and under the right hydrogeologic conditions confine ground water that is under pressure. Aquitards are capable of transmitting enough water to allow some flow between adjacent aquifers, and depending on the magnitude of this transfer of water, may be referred to as leaky aquitards.

Unconfined and Confined Aquifers

In most depositional environments, coarser-grained deposits are interbedded with finer-grained deposits creating a series of aquifers and aquitards. See Figure Appendix 2-1. When a saturated aquifer is bounded on

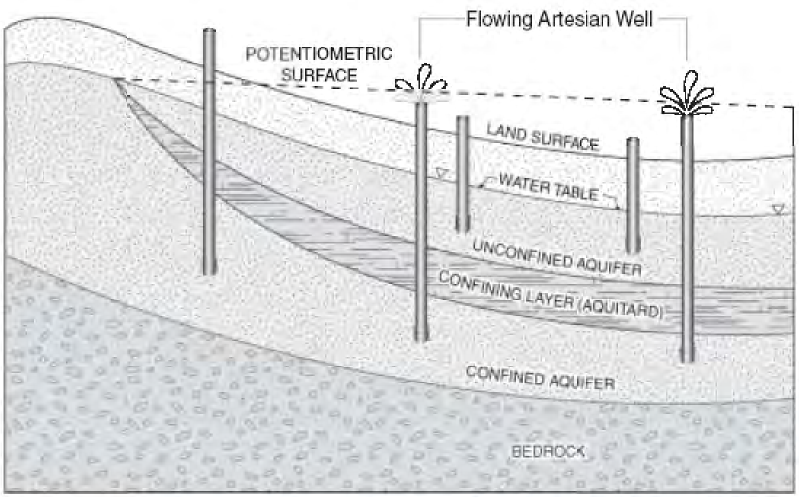

Figure Appendix 2-1, Interbedded Aquifers With Confined and Unconfined Conditions

Source: *California's Ground Water Bulletin 118,* Update 2003, page 87.

top by an aquitard (also known as a confining layer), the aquifer is called a confined aquifer. Under these conditions, the water is under pressure so that it will rise above the top of the aquifer if the aquitard is penetrated by a well. The elevation to which the water rises is known as the potentiometric surface. Where an aquifer is not bounded on top by an aquitard, the aquifer is said to be unconfined. In an unconfined aquifer, the pressure on the top surface of the ground water is equal to that of the atmosphere. This surface is known as the water table, so unconfined aquifers are often referred to as water table aquifers. The arrangement of aquifers and aquitards in the subsurface is referred to as hydrostratigraphy.

In some confined aquifers ground water appears to defy gravity, but that is not the case. When a well penetrates a confined aquifer with a potentiometric surface that is higher than land surface, water will flow naturally to the surface. This is known as artesian flow, and results from pressure within the aquifer. The pressure results when the recharge area for the aquifer is at a higher elevation than the point at which discharge is occurring. The confining layer prevents the ground water from returning to the surface until the confining layer is penetrated by a well. Artesian flow will discontinue as pressure in the aquifer is reduced and the potentiometric surface drops below the land surface.

<u>Ground Water Basin</u>

A ground water basin is defined as an alluvial aquifer or a stacked series of alluvial aquifers with reasonably well-defined boundaries in a lateral direction and a definable bottom. Lateral boundaries are features that significantly impede ground water flow such as rock or sediments with very low permeability or a geologic structure such as a fault. Bottom boundaries would include rock or sediments of very low permeability if no aquifers occur below those sediments within the basin.

<u>Ground Water Movement</u>

The movement of ground water in the subsurface is quite complex, but in simple terms it can be described as being driven by potential energy. At any point in the saturated subsurface, ground water has a hydraulic head value that describes its potential energy, which is the combination of its elevation and pressure. In an unconfined aquifer, the water table elevation represents the hydraulic head, while in a confined aquifer the potentiometric surface represents the hydraulic head. Water moves in response to the difference in hydraulic head from the point of highest energy toward the lowest. On a regional scale this results in flow of ground water from recharge areas to discharge areas. Pumping depressions around extraction wells often create the discharge points to which ground water flows. Ground water may naturally exit the subsurface by flowing into a stream or lake, by flowing to the surface as a spring or seep, or by being transpired by plants.

Ground Water Storage Capacity

The ground water storage capacity of an individual basin or within the entire State is one of the questions most frequently asked by private citizens, water resource planners, and politicians alike. Total storage capacity seems easy to understand. It can be seen as how much physical space is available for storing ground water. The computation of ground water storage capacity is quite simple if data are available: capacity is determined by multiplying the total volume of a basin by the average specific yield. The total storage capacity is constant and is dependent on the geometry and hydrogeologic characteristics of the aquifer.

Total ground water storage capacity is misleading because it only takes into account one aspect of the physical character of the basin. Many other factors limit the ultimate development potential of a ground water basin. These limiting factors may be physical, chemical, economic, environmental, legal, and institutional. Some of these factors, such as the economic and institutional ones, can change with time. However, there may remain significant physical and chemical constraints that will limit ground water development.

Appendix 3

INTERNET WEBSITES

All the following internet websites were current and correct as of May 2, 2005.

Utah Division of Water Rights

http://www.waterrights.utah.gov/
Main Page

http://waterrights.utah.gov/contact.asp
Main Office and Regional Office Listing

http://nrwrt1.nr.state.ut.us/wrinfo/policy/wrareas/default.htm
Map of Regional Areas in Utah

http://nrwrt1.nr.state.ut.us/gisinfo/maps/agwpol.pdf
Ground-Water Policy Map

http://nrwrt1.nr.state.ut.us/wrinfo/policy/ground.htm
Ground Water Management Plans

http://waterrights.utah.gov/cgi-bin/wuseview.exe?Startup
Public Water Suppliers List

http://geology.utah.gov/bookstore/wrtechpb.htm
Publications

http://nrwrt1.nr.state.ut.us/gisinfo/maps/default.asp
Maps

Other Utah Agencies

http://www.water.utah.gov/
Utah Division of Water Resources

http://www.waterquality.utah.gov/
Utah Division of Water Quality

http://www.drinkingwater.utah.gov/
Utah Division of Drinking Water

Utah Geological Survey

http://www.ugs.state.ut.us/
Utah Geological Survey

http://www.ugs.state.ut.us/utahgeo/water/index.htm#resources
Detailed ground water information for the state of Utah.

U. S. Geological Survey

http://www.usgs.gov/
Home Page

http://ut.water.usgs.gov/WR.UT.html
Utah District Offices and Personnel

http://ut.water.usgs.gov/publications/pub_Site/reportsplain.html
USGS Reports in Utah

http://water.usgs.gov/local_offices.html
USGS offices with water information

http://capp.water.usgs.gov/gwa/gwa.html
Ground Water Atlas of the United States.
Overview of Utah's aquifer systems, including maps & diagrams.

Aquifer Storage and Recovery (ASR)

http://www.asrforum.com/frames/forumfr.html
ASR Forum. Description of ASR and related topics.

http://www.iah.org/recharge/
International Association of Hydrogeologists, Management of Aquifer Recharge

http://www.ngwa.org/

National Ground Water Association.

This professional organization has classes in ASR and a large database of information on ground water.

Miscellaneous Ground Water Information

http://www.thehydrogeologist.com/index.htm

The Hydrogeologist's Home Page. Especially see Organizations and Institutes.

http://www.engineering.usu.edu/uwrl/uwj/main.htm

Utah Water Journal, Utah State University

Appendix 4

UTAH GROUND WATER RECHARGE AND RECOVERY ACT

73-3b-101. Short titles**.**
This chapter is known as the "**Groundwater Recharge and Recovery Act."**

73-3b-102. Definitions.
As used in this chapter:
(1) "Artificially recharge" means to place water underground by means of injection, surface infiltration, or other method for the purposes of storing and recovering the water.
(2) "Division" means Division of Water Rights.
(3) "Recharge permit" means a permit issued by the state engineer to inject water into an underground aquifer for the purpose of storing the water.
(4) "Recovery permit" means a permit issued by the state engineer to withdraw from an underground aquifer water that has been injected and stored in the aquifer pursuant to a recharge permit.

73-3b-103. Prohibitions.
(1) A person may not artificially recharge a ground water aquifer without first obtaining a recharge permit.
(2) A person may not recover from a ground water aquifer water that has been artificially recharged unless he first obtains a recovery permit.
(3) A person holding a recharge or recovery permit may not operate a ground water recharge or recovery project in a manner that is inconsistent with the permit conditions set by the state engineer.

73-3b-104. Rulemaking power of state engineer.
The state engineer may make rules to administer this chapter in accordance with Title 63, Chapter 46a, Utah Administrative Rulemaking Act.

73-3b-105. Administrative procedures.
The administrative procedures applicable to the issuance, modification, suspension, or revocation of recharge and recovery permits are those set forth in Title 63, Chapter 46b, Administrative Procedures Act, and Sections **73-3-6**, **73-3-7**, **73-3-14**, and **73-3-15**.

73-3b-106. Water right for recharged water -- Change of use of recovered water.
(1) A person proposing to recharge water into an underground aquifer must have:
(a) a valid water right for the water proposed to be recharged; or
(b) an agreement to use the water proposed to be recharged with a person who has a valid water right for the water.
(2) A person who holds a recovery permit may use or exchange recovered water only in the manner in

which the water was permitted to be used or exchanged before the water was stored underground, unless a change or exchange application is filed and approved pursuant to Section **73-3-3** or **73-3-20**, as applicable.

73-3b-107. Recoverable water -- State engineer to determine.

A person who holds a recovery permit may recover the amount of water stored by the recharge project which the state engineer determines has reached the aquifer and remains within the hydrologic area of influence.

73-3b-201. Application for a recharge permit -- Required information -- Filing fee.

(1) The application for obtaining a ground water recharge permit shall include the following information:

(a) the name and mailing address of the applicant;

(b) the name of the ground water basin or ground water sub-basin in which the applicant proposes to operate the project;

(c) the name and mailing address of the owner of the land on which the applicant proposes to operate the project;

(d) a legal description of the location of the proposed project;

(e) the source and annual quantity of water proposed to be stored underground;

(f) evidence of a water right or an agreement to use the water proposed to be stored underground;

(g) the quality of the water proposed to be stored underground and the water quality of the receiving ground water aquifer;

(h) evidence that the applicant has applied for all applicable water quality permits;

(i) a plan of operation for the proposed recharge and recovery project which shall include:

(i) a description of the proposed project;

(ii) its design capacity;

(iii) a detailed monitoring program; and

(iv) the proposed duration of the project;

(j) a copy of a study demonstrating;

(i) the area of hydrologic impact of the project;

(ii) that the project is hydrologically feasible;

(iii) that the project will not:

(A) cause unreasonable harm to land; or

(B) impair any existing water right within the area of hydrologic impact; and

(iv) the percentage of anticipated recoverable water;

(k) evidence of financial and technical capability; and

(l) any other information that the state engineer requires.

(2) (a) A filing fee must be submitted with the application.

(b) The state engineer shall establish the filing fee in accordance with Section **63-38-3.2**.

73-3b-202. Issuance of recharge permit -- Criteria -- Conditions.

The state engineer:

(1) shall issue a ground water recharge permit if:

(a) the applicant has:

(i) the technical and financial capability to construct and operate the project; and

(ii) (A) a valid water right for the use of the water proposed to be stored underground; or

(B) an agreement to use the water proposed to be stored underground with a person who has a valid water right for the use of the water; and

(b) the project:

(i) is hydrologically feasible;

(ii) will not cause unreasonable harm to land;

(iii) will not impair any existing water right within the area of hydrologic impact; and

(iv) will not adversely affect the water quality of the aquifer;

(2) shall condition any approval on acquiring the applicable water quality permits prior to construction and operation of the project; and

(3) may attach to the permit any conditions he determines are appropriate.

73-3b-203. Lapse of recharge permit.

A ground water recharge permit will lapse if the recharge project is not completed within five years from the date of approval, unless the applicant requests an extension of time to complete the project and the state engineer approves the request.

73-3b-204. Application for a recovery permit -- Required information.

(1) If a person intends to recharge and recover water, the recovery application and permit may be filed and processed with the ground water recharge application and permit.

(2) The application for obtaining a recovery permit shall include the following information:

(a) the name and mailing address of the applicant;

(b) a legal description of the location of the existing well or proposed new well from which the applicant intends to recover stored water;

(c) a written consent from the owner of the recharge permit;

(d) the name and mailing address of the owner of the land from which the applicant proposes to recover stored water;

(e) the name or description of the artificially recharged ground water aquifer which is the source of supply;

(f) the purpose for which the stored water will be recovered;

(g) the depth and diameter of the existing well or proposed new well;

(h) a legal description of the area where the stored water is proposed to be used;

(i) the design pumping capacity of the existing well or proposed new well; and

(j) any other information including maps, drawings, and data that the state engineer requires.

(3) (a) A filing fee must be submitted with the application.

(b) The state engineer shall establish the filing fee in accordance with Section **63-38-3.2**.

73-3b-205. Issuance of recovery permit -- Criteria -- Conditions.

The state engineer:

(1) shall issue the recovery permit if he determines that:

(a) the proposed recovery of stored water will not impair any existing water right;

(b) the applicant of the recovery permit, if he does not hold the recharge permit, has a valid agreement with the owner of the recharge permit to divert and use the recovered water; and

(c) the recovery point of diversion is located within the area of hydrologic impact of the project, as determined by the state engineer; and

(2) may attach to the permit any conditions he determines are appropriate.

73-3b-206. Lapse of recovery permit.

A recovery permit will lapse if the recovery project is not completed within two years from the date of approval.

73-3b-207. Assignment of permits.

(1) A person who holds a recharge or recovery permit may not assign a permit to another person without the written approval of the state engineer.

(2) The state engineer must approve an assignment if the proposed assignee meets the requirements of Section **73-3b-202** or **73-3b-205**, as applicable.

73-3b-208. Proposed new well -- Compliance with water well construction rules.

An applicant for a recovery permit who intends to construct a new well to recover stored water must comply with Section **73-3-22** and Sections **73-3-24** through **73-3-26**, and rules adopted under those sections, regarding the construction of water wells.

73-3b-301. Storage account -- Monitoring and reporting required.

(1) The state engineer shall establish a storage account for each ground water recharge and recovery project for which a permit has been issued.

(2) In accordance with specifications of the state engineer, any person holding a ground water recharge or recovery permit shall:

(a) monitor the operation of the project and its impact on land, the ground water aquifer, and water rights within the project's area of hydrologic impact; and

(b) file reports with the state engineer regarding:

(i) the quantity of water stored and recovered; and

(ii) the water quality of the recharged water, receiving aquifer, and recovered water.

73-3b-302. Fee.

(1) The state engineer shall assess an annual fee, in accordance with Section **63-38-3.2**, on each person who holds a ground water recharge or recovery permit.

(2) The fee shall reflect the division's costs to administer and monitor ground water recharge and recovery projects.

73-3b-303. Modification of recharge or recovery permits.

(1) The state engineer, on his own initiative or at the request of any person holding a recharge or recovery permit, may modify the conditions of the respective permit, if he finds that modifications are necessary and will not impair existing water rights or the water quality of the aquifer.

(2) Before any permit condition is modified, the state engineer may require notice to potentially impaired water users if he finds that the modification under consideration may impair existing water rights.

73-3b-401. Revocation or suspension of recharge and recovery permits.

The state engineer may:

(1) periodically review a project to determine if the person who holds the recharge or recovery permit is complying with the conditions of the permit; and

(2) permanently revoke or temporarily suspend a permit for good cause after an investigation and a hearing.

73-3b-402. Penalty.

(1) A person who violates Section **73-3b-103** is subject to a civil penalty in an amount not to exceed $10,000 per day.

(2) An action to recover damages under this section shall be brought by the state engineer in the district court in the county in which the violation occurred.

Enacted by Chapter 146, 1991 General Session, Amended by Chapter 28, 1995 General Session.

This law is available on the Internet at http://www.le.state.ut.us/~code/TITLE73/TITLE73.htm

Appendix 5

IMPEDIMENTS TO CONJUNCTIVE MANAGEMENT PROJECTS

In 1998 the National Water Research Institute in cooperation with the Association of Ground Water Agencies and the Metropolitan Water District of Southern California conducted a workshop to determine the most significant impediments to implementing a cost-effective conjunctive management program in California. The results were published in California's Ground Water, Update 2003, Bulletin 118, April 2003, page 48, and are included below.

1) Inability of local and regional water management governance entities to build trust, resolve difference (internally and externally), and share control.

2) Inability to match benefits and funding burdens in ways that are acceptable to all parties, including third parties.

3) Lack of sufficient federal, state and regional financial incentives to encourage ground water conjunctive use to meet statewide water needs.

4) Legal constraints that impede conjunctive use, regarding storage rights, basin judgments, area of origin, water rights, and indemnification.

5) Lack of statewide leadership in the planning and development of conjunctive use programs as part of comprehensive water resources plans, which recognize local, regional, and other stakeholders' interests.

6) Inability to address quality differences in "put" versus "take"; standards for injection, export, and reclaimed water; and unforeseeable future ground water degradation.

7) Risk that water stored cannot be extracted when needed because of infrastructure, water quality or water level, politics, and institutional or contractual provisions.

8) Lack of assurances to prevent third-party impacts and assurances to increase willingness of local citizens to participants.

9) Lack of creativity in developing lasting "win-win" conjunctive use projects, agreements, and programs.

10) Supplemental suppliers and basin managers have different roles and expectations in relation to conjunctive use.

Appendix 6

SELECTED BIBLIOGRAPHY

Standard Guidelines for Artificial Recharge of Ground Water, American Society of Civil Engineers, Standard EWRI/ASCE 34-01, 2001. This can be ordered from www.asce.org or www.civilbookstore.com or other sources. This is an excellent objective overview of the subject including project considerations and implementation.

Ground Water Recharge and Wells, A Guide to Aquifer Storage and Recovery, R. David G. Pyne, 1995, CRC Press, Inc., Lewis Publishers. This edition is out of print, however, a second edition went to press in May 2005. See the following Internet website for details: www.asrforum.com/frames/forumfr.html or contact dpyne The table of contents of this book is included below to indicate subject matter. This book is a classic on the subject of ASR injection wells.

Chapter 1- Introduction
Chapter 2- ASR Program Development
Chapter 3- Design of ASR Systems
Chapter 4- Selected ASR Technical Issues
Chapter 5- Geochemistry
Chapter 6- Selected ASR Non-Technical Issues
Chapter 7- Alternative ASR Applications
Chapter 8- Future Directions
Chapter 9- Selected Case Studies

Design, Construction and Maintenance for Sustainable Underground Storage Facilities, American Water Works Association Research Foundation Report, Project 3034. This report is in preparation as of July 2005.

Ground-Water Conditions in Utah, Spring of 2004. The U.S. Geological Survey in cooperation with the Utah Department of Natural Resources, Division of Water Resources and Division of Water Rights prepares this annual publication. Thirty-four local areas of the state are defined and their ground water development is described. See Figure 11 for a map of the areas. Each section has a brief narrative, map of the local area, and graphs showing ground water level changes over time. Graphs showing precipitation and ground water withdrawals over time for the area are also provided. Some areas also have graphs showing changes in ground water chemistry over time.

This publication was begun in 1964, although many records are included which begin as early as 1935. Copies of all reports are available on the Utah Division of Water Rights Internet web site, http://www.waterrights.utah.gov/. Click Publications -> Click View Publications -> Click Publication Type -> Select Ground-Water Conditions in Utah from the Publication Series choices -> Click List Publications -> Click on the report of interest (usually the most recent) -> Click View Publication. The report is presented for review and can be printed.

Printed copies of recent reports are available from the Utah Department of Natural Resources Bookstore, 1594 West North Temple, Salt Lake City, UT, 84114. Printed copies of older editions are available for review only in the Utah Department of Natural Resources Library located at the above address.

California's Ground Water, Update 2003, Bulletin 118, Department of Water Resources. This is available free of charge from: www.groundwater.water.ca.gov/bulletin118/index.cfm

Applied Hydrogeology, C.W. Fetter, 2001, Prentice-Hall, Inc. This text is a comprehensive review of ground water and associated principles. The table of contents of this book is included below to indicate subject matter.

Water Management Improvement Studies, Report on the Study of Coordinated Operations, Central Utah Water Conservancy District, October 1995. The table of contents of this book is included below to indicate details of the subject matter.

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