COORDINATION OF AGRICULTURAL AND URBAN WATER QUALITY MANAGEMENT IN THE UTAH LAKE DRAINAGE AREA

by

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by

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ABSTRACT

COORDINATION OF AGRICULTURAL AND URBAN WATER

QUALITY MANAGEMENT IN THE UTAH LAKE

DRAINAGE AREA

Like many other urbanizing river basins, the Utah Lake drainage area is faced with serious water quality degradation associated with expanding water use. While the region is not water-short, the downstream water users are encountering water deficiencies. To avoid aggravating these problems, water quality controls will be implemented in the Utah Lake drainage so that its future developments will not be harmfully reflected downstream. A model has been developed which optimized the allocation of water pollution abatement policies among agricultural and urban water uses. In addition, an analysis is made in which water quality management in areas surrounding Utah Lake is coordinated with the alternatives of lake diking and regional desalination. The results indicate that urbanization emphasizes control of urban pollution because of the inherent economies of scale in wastewater treatment facilities. On a basin-wide scale, desalting is shown to be the best strategy for future water quality management.

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KEYWORDS - agricultural wastes, institutional constraints, interbasin transfer, mathematical models, optimization, salinity, urbanization, wastewater treatment, water quality, water resources.

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SECTION I

INTRODUCTION

The management and control of water quality in the streams, rivers, lakes, and reservoirs encompassed by a major river basin implies that efforts must be made to coordinate strategies among various individual segments within the region. Consequently, the quality of water in the upper reaches of a basin must be necessarily managed even though the concentration of harmful pollutants may never be a threat in the immediate area. This conclusion is supported by numerous instances in the Western United States and arid climatological regions elsewhere. A basic characteristic of these localities is a natural pollutant concentrating effect as the flow proceeds towards their eventual sink. As a result, the volume of pollutants, especially salinity, attributable to areas in the upper reaches may produce serious consequences downstream when combined with the natural effects of the region.

One of the regions characteristic of this problem is the Utah Lake drainage area, shown in Figure 1. In this watershed encompassing 3356 square miles in north central Utah, runoff collects first in Utah Lake and then empties

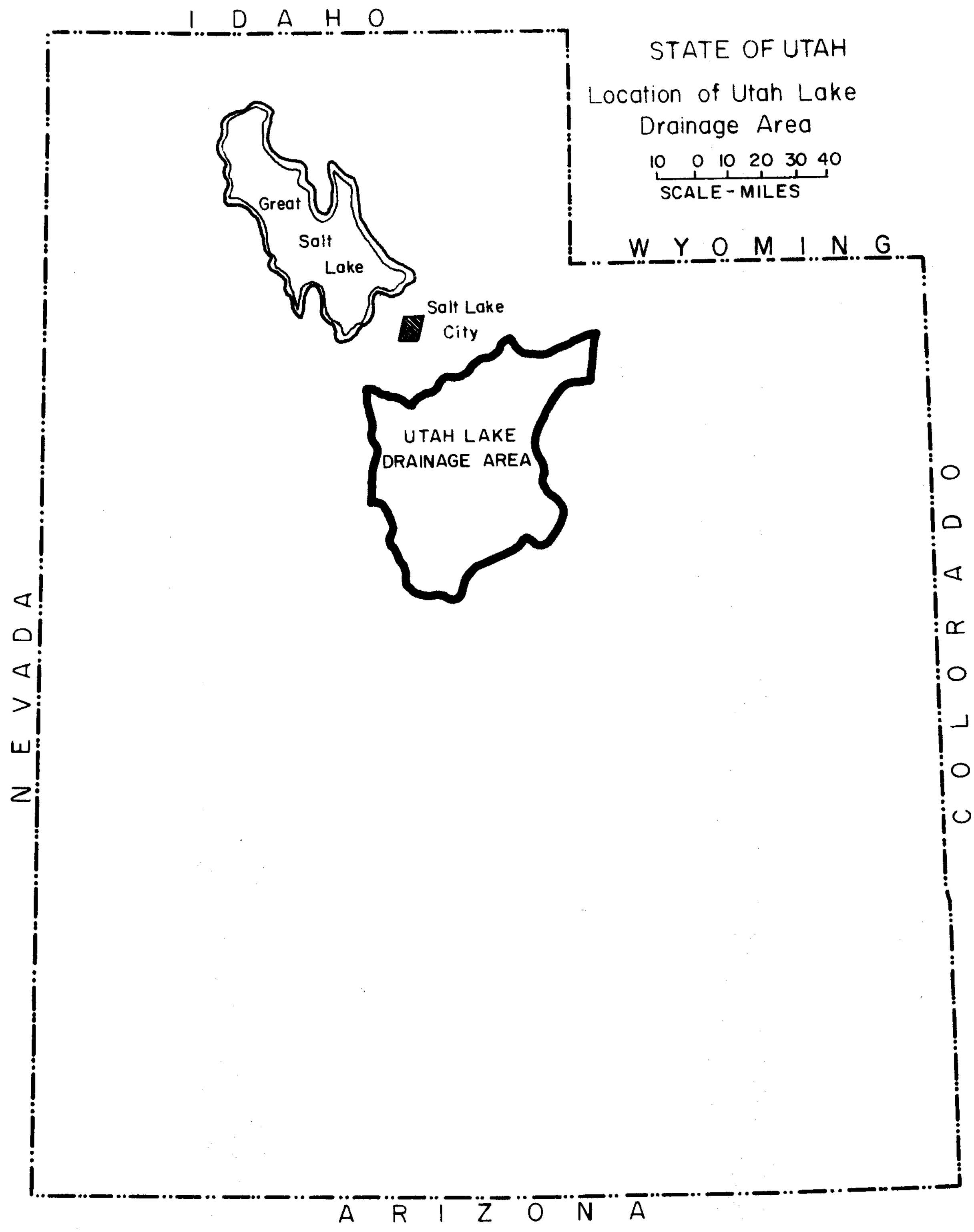


Figure 1. Location of the Utah Lake drainage area.

into the Great Salt Lake via the Jordan River. Between the Great Salt Lake and the Utah Lake drainage area, often referred to as the "Wasatch Front", three-fourths of Utah's more than one million people reside. Consequently, the demands on the water resource are not only for sufficient quantities but also for acceptable qualities. Obviously, if a bulk of the demand is municipal or industrial in nature, the quality parameters must be severely limited. Efforts to minimize water pollution must be regional in scope and thus include an examination of practices and potential treatments in those areas in which quality is really not a problem.

The Utah Lake drainage basin does not have a restrictive water quality problem, but salts picked up in conjunction with the concentrating effects of Utah Lake result in downstream damage and restricts use to those demands insensitive to the poorer water qualities. An important question requiring sound experimental evidence is: "How much control can be acheived in the Utah Lake area and at what cost?" This study is designed to partially resolve this question.

Although the Utah Lake drainage is extensive, the most significant changes are expected in the area immediately adjacent to the lake known as Utah Valley, which will be described more fully in this report. Since this portion of the drainage area contains nearly all of the urban centers and the largest portions of the agricultural section, this study will concentrate on the requirements and effects of water quality control alternatives in Utah Valley. The specific objectives of the investigation include:

(1) Formulation of optimal allocation of water quality controls throughout the study area;

(2) Identification and quantification of institutional constraints restricting implementation of optimal alternative;

(3) Developing strategies for coordinating agricultural and urban water quality control programs; and

(4) Evaluation of the maximum potential for pollution control in downstream reaches resulting from improved water use effectiveness in the Utah Lake drainage area.

The first objective, that of distribution in an optimal fashion of water quality standards on return flows, is a significant addition to current water pollution control technology. In 1965, the Congress of the United States passed Public Law 84-660, "Federal Water Pollution Control Act", requiring states to submit stream standards on their interstate rivers and streams, which has been accomplished. However, the basis for such imposition of standards often lacked analytical basis. A necessary task should have been to optimally allocate wastewater treatment responsibilities throughout a basin in order to achieve a flow quality at a given point downstream. The results of this study indicate a procedure and provide an example in the Utah Lake area.

The need to control and manage water quality levels in the Jordan River releases from Utah Lake to downstream demands suggests that quality standards be placed on the various return flows entering the Utah Lake. Such standards would necessarily require considerable investment into each sector of the area in order to meet the standards. Since the costs of water quality management vary with a number of parameters, it is necessary to employ a systematic approach to determine what standards should be used. This optimization of regional water quality control cost has been undertaken in this research effort to accomplish the first objective of the study.

Water management institutions comprise the vast and complicated array of legal, social, political, and economic structures which accomplish equitable allocation of water resources. Those dealing with water quality control likewise regulate programs for achieving the objectives of the pollution management effort. However, these factors require periodic scrutiny in order for proper modifications to be made which reflect the evolving requirements for efficient water utilization. Consequently, the second major objective of this study is to delineate and evaluate those institutional structures which may restrict implementation of improved water management strategies. To accomplish this goal, the Utah Lake area system will be modeled and optimal solutions obtained for a range of downstream quality requirements. Then the specific institutional constraints which have the greatest effect upon optimal strategy can be evaluated. The costs or value of these restrictions can be computed by comparing the differences between optimal and sub-optimal policies. Finally, the feasibility of changing certain of these institutions can be determined so that decision-makers can make appropriate choices based upon adequate background information.

Even with the development of basin-wide water quality management plans and alleviating institutional barriers, one of the problems remaining is the coordination of urban and agricultural pollution abatement policies. To date this aspect of water management has been somewhat neglected, but its importance in the future must be underscored. In the Utah Lake area, for example, urban demands are approximately 60% of the agricultural needs. As a result, the local investment of funds to facilitate a specified level of quality control is uncertain. The third objective of this study is to perform this analysis in the Utah Lake region. The model which was developed in Part I, "Modeling Water Management Strategies in Urbanizing River Basins" of this projects final reports should prove helpful in evaluating these questions in other regions as well.

The final goal in this study is to evaluate the maximum achievable effects on downstream water quality resulting from a given level of investment in the Utah Lake region. This effort is undertaken to indicate that optimal policies are substantially more effective than a random or non-systematic approach to problem solution.

In the following chapters, these goals will be again reiterated and the success or failure in attaining them discussed. In any event, the results of this study should be helpful to water quality planners in the Utah Lake region in determining plans to minimize the detrimental effects of water pollution, as well as planners in other arid regions facing the conflicts between agricultural and urban water demands.

SECTION II

DESCRIPTION OF AREA

Location

The Utah Lake drainage area, shown previously in Figure 1, is a segment of the drainage system of the Great Salt Lake. Although the area includes only those lands draining into Utah Lake, the boundaries of the drainage fall within five counties (Utah, Sanpete, Juab, Wasatch and Summit), the major part being in Utah County. Hydrologically, the 3,356 square mile drainage area can be divided into subareas, as shown in Figure 2. The size of each subarea has been listed in Table 1, but the area of major concern in this study is Utah Valley.

Geography

The largest subunit in the drainage area is Utah Valley, which is bounded on the east by the Wasatch Mountains and on the west by Utah Lake and the Lake Mountains. The valley opens to the south over a low ridge into Northern Juab Valley and is bounded on the north by the Traverse Range. Utah Valley is divided into four districts in this study, each being supplied from a separate river system. These districts,

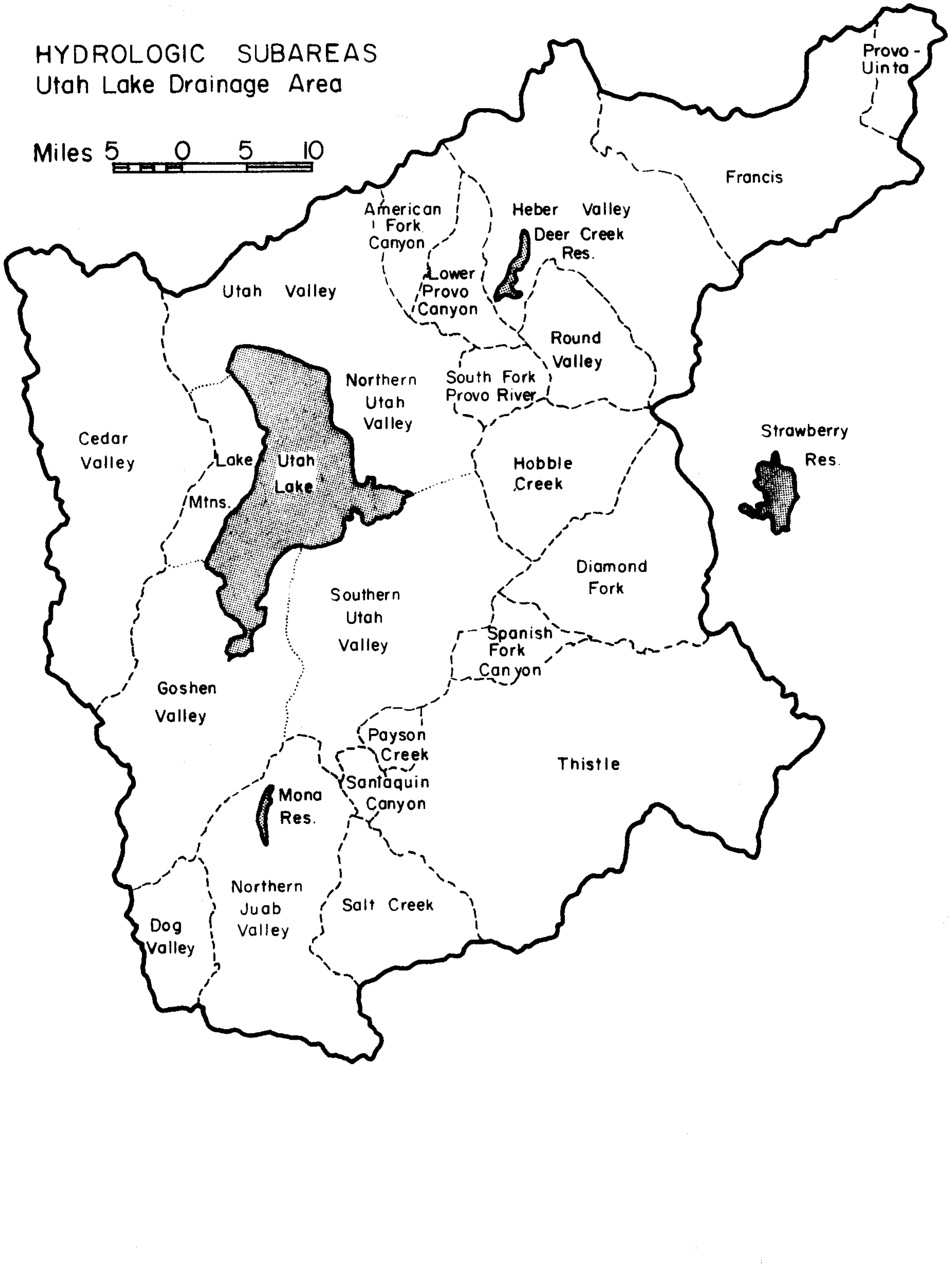


Figure 2. Hydrologic subareas of Utah Lake drainage area.

Table 1. Size of hydrologic areas within the Utah Lake drainage area (Hyatt, et al., 1969)

Hydrologic Area	Area	
	Acres	Sq. Mi.
Francis	129,920	203.0
Heber Valley	163,200	255.0
Utah Valley	612,480	957.0
Cedar Valley	201,600	315.0
Northern Juab Valley	132,736	207.4
Other areas		
Salt Creek	61,184	95.6
Dog Valley	35,776	55.9
Santaquin Canyon	9,344	14.6
Payson Creek	12,032	18.8
Thistle	290,560	454.0
Diamond Fork	93,400	146.0
Spanish Fork Canyon	23,680	37.0
Hobble Creek	67,200	105.0
Provo-Uinta	19,200	30.0
Round Valley	46,016	71.9
South Fork Provo River	19,200	30.0
Lower Provo Canyon	28,800	45.0
American Fork Canyon	201,600	215.0
Utah Lake drainage area	2,147,948	3,356.2

shown in Figure 3, are the Lehi-American Fork district, Provo district, Spanish Fork district and Elberta-Goshen district, supplied by the American Fork River, Provo River, and Spanish Fork River, and Currant Creek, respectively. Currant Creek is supplied by Northern Juab Valley return flows stored in Mona Reservoir. The Elberta-Goshen District consists of the western part of Goshen Valley not supplied by the Spanish Fork River system.

All return flows from the Valley drain into Utah Lake. The lake, which averages only eight feet in depth with a maximum of about twenty feet, has gently sloping shores causing large changes in surface area with small fluctuations in surface elevation. The main body of the lake, located in the valley center, is about 19 miles long in the north-south direction and 10 miles wide. A swampy area called Provo Bay is connected to it on the east side by a narrow channel. The outlet for Utah Lake is the Jordan River, which runs in a northerly direction through Salt Lake County and eventually empties into Great Salt Lake.

Land Forms and Soil

The valley floor was, at one time, part of the Pleistocene Lake Bonneville. As a result, the valley floor consists of lacustrine gravel, silt and clay sediments overlapping

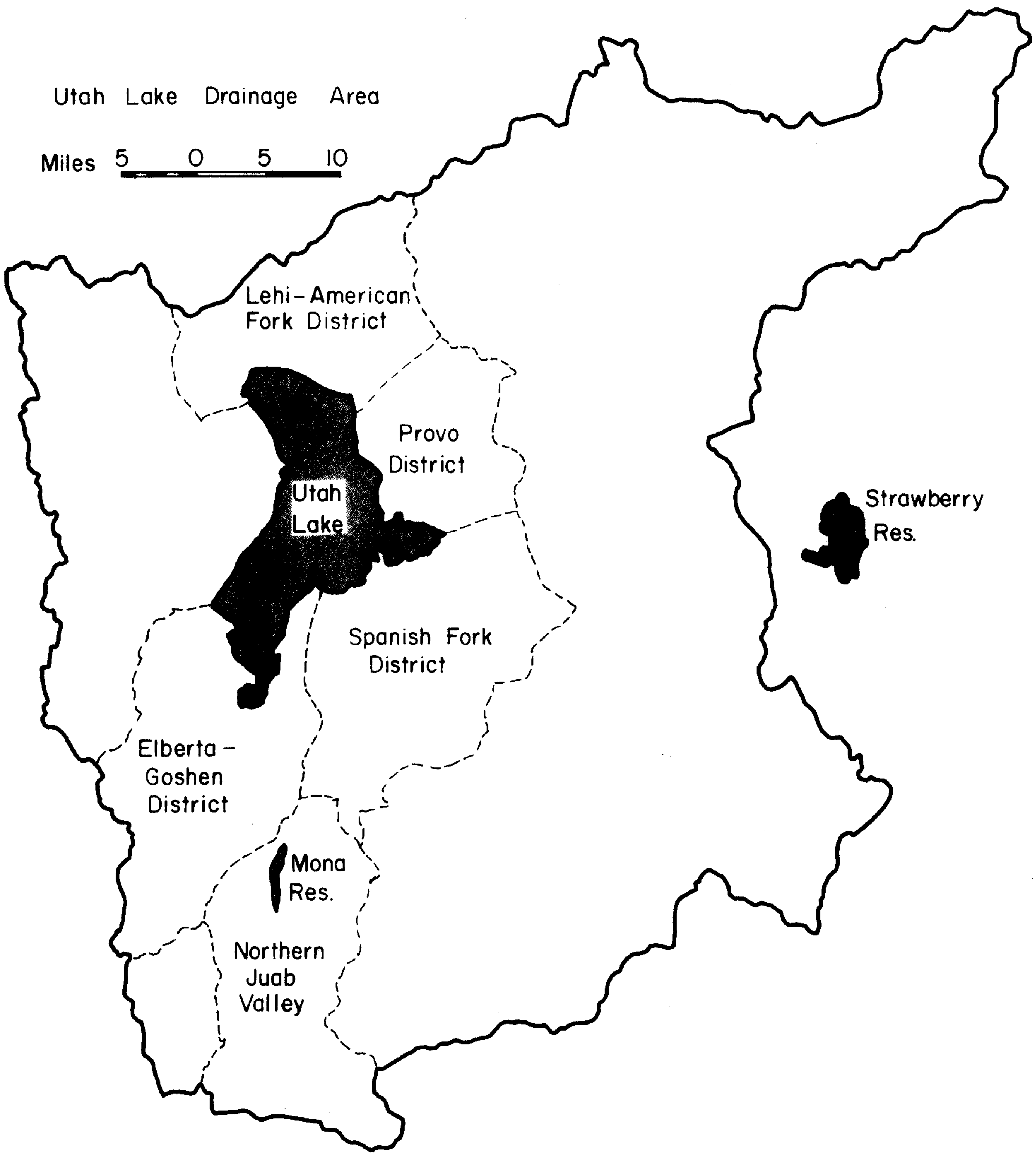


Figure 3. General map of Utah Lake drainage area.

pre-Lake Bonneville alluvial fans spreading out from the mountains. Surface features may be grouped into benches, river bottoms, alluvial fans, and lake bottoms. The benches are wide delta areas of highly permeable alluvium. The flat slope and high elevation of these benches results in these areas being served by separate canal companies. River bottom soils are along major rivers. The soils are permeable alluvium and are set apart from the benches by differences in elevation. Alluvial fans are located at the river mouths and the mountain base. The soil is a well drained alluvium with a lacustrine silt surface. The soils of the lake bottom bordering Utah Lake are primarily silt and clay and are often poorly drained (Hudson, 1962).

Climate

The climate of the Utah Valley may be described as temperate and arid. Low rainfall, low humidity and high evaporation rates result in sparse vegetation. The soils are not leached by rainfall and therefore have not lost the original plant nutrients. Also, the soil is highly calcareous with little organic matter. The summers are usually mild with cold winters, particularly in the higher elevations. The climatological characteristics of the area are summarized in Table 2 (Bureau of Reclamation, 1964, Hyatt, et al., 1969).

Table 2. Climatic characteristics of the Utah Lake drainage area (Hyatt, et al., 1969).

Station	Elevation ft.	Mean Annual Precip., In.	Mean Annual Temp., °F	Median frost free period*	
				Dates	Days
Utah Lake (Lehi)	4497	9.82	48.6	May 16 - Sept 24	132
Provo	4545	12.81	49.6	May 19 - Sept 22	127
Elberta	4690	10.22	50.6	May 14 - Oct 1	141
Spanish Fork PH	4711	16.79	52.0	May 1 - Oct 15	168
Lower American Fork PH	5044	16.45	52.2	April 30 - Oct 21	175
Heber	5593	15.05	44.5	June 19 - Sept 4	78
Snake Creek PH	5950	22.25	43.3	June 10 - Sept 4	87
Soldier Summit	7460	16.09	38.7	June 19 - Aug 13	56

*50 percent probable chance that 32°F will occur or after indicated dates.

Precipitation

Generally, the precipitation decreases moving west of the Wasatch Mountains. In Northern Utah Valley, Southern Utah Valley and Northern Juab Valley, the annual precipitation varies from 12 to 16 inches. In Cedar and Goshen Valleys, it is less than 12 inches. On the high peaks of the Wasatch Mountains, the precipitation is over 30 inches. The mountain valleys receive from 15 to 20 inches of precipitation (Bureau of Reclamation, 1964, Hyatt, et al., 1969).

Wind

The prevailing wind direction varies from southwest to northeast, but in the winter months is generally from the northwest. Violent winds are almost unknown, occurring only for short times during thunderstorms (Bureau of Reclamation, 1964, Hyatt, et al., 1969).

Temperature

The temperature varies with altitude and latitude. There is about 3 degrees Fahrenheit decrease in mean annual temperature for each 1,000 feet increase in altitude and about 2 degrees Fahrenheit decrease for each degree increase in latitude. The mean annual temperature ranges from 40 to 50 degrees Fahrenheit on the valley floor. For the Wasatch Mountains, the mean annual temperature ranges from 35 to 45 degrees Fahrenheit and the Heber-Francis areas vary from 40 to 45 degrees Fahrenheit (Bureau of Reclamation, 1964, Hyatt, et al., 1969).

Agricultural Lands

The 219,658 acres of agricultural land in the Utah Lake drainage area are the largest users of water. Of this acreage, 162,150 acres are irrigated with the rest in dry land farming. Alfalfa, pasture, grain, corn, sugar beets and orchards are representative irrigated crops, with the largest amount of irrigated land being used for alfalfa and pasture. The areas are summarized in Table 3 (Bureau of Reclamation, 1964, Hyatt, et al., 1969).

Municipalities

There are several small cities or towns within the Utah Lake drainage area which constitute a part of the demand on the water supply. The major towns and cities in Utah County are listed with their populations in Table 4. Many smaller towns whose water demands are obtained from wells or springs are not mentioned since their aggregate population and thus, their effect on the hydrology of the Utah Lake area is less than 6%.

Table 3. Agricultural lands in the Utah Lake drainage area (Hyatt, et al., 1969).

Hydrologic Area	Crop Area, acres	Phreatophytes and Native Vegetation, acres
Heber-Kamas	20,682	6,141
Francis-Kamas	1,553	956
Heber	19,129	5,185
Utah Valley	117,760	40,500
Lehi-Am. Frk.	20,492	1,937
Provo	23,495	8,080
Spanish Fork	73,773	17,554
Goshen Valley	15,785	12,929
Cedar Valley	3,328	26
Northern Juab Valley	12,391	550
Other areas	7,989	62
Thistle	5,176	------
Round Valley	2,813	62
Utah Lake drainage	162,150	47,279

Table 4. Estimated population for the major municipalities in Utah County (Templeton, Linke, and Alsup, 1969).

Year		1960	1980	2000
Utah County				
U.C.T.S.	(1)		177,200	247,400
U. of U.	(1)	107,001	170,380	233,780
U.C.P.C.	(1)		151,800	196,550
U. of U.	(revised)		195,440	268,130
Provo				
U.C.T.S.			60,000	79,000
U. of U.		36,047	68,000	75,000
U.C.P.C.			56,000	65,250
Orem				
U.C.T.S.			36,000	58,750
U. of U.		18,394	33,500	56,000
U.C.P.C.			30,000	45,500
U. of U.	(revised)		37,000	61,600
Springville				
U.C.T.S.			14,000	21,000
U. of U.		7,913	12,500	18,750
U.C.P.C.			10,900	16,400
American Fork				
U.C.T.S.			12,000	19,000
U. of U.		6,373	11,300	17,900
U.C.P.C.			10,000	15,500
Pleasant Grove				
U.C.T.S.			8,000	10,300
U. of U.		4,772	7,600	9,500
U.C.P.C.			7,000	8,300
Spanish Fork				
U.C.T.S.			11,000	15,000
U. of U.		6,472	10,200	13,950
U.C.P.C.			8,900	12,440
Lehi				
U.C.T.S.			7,000	9,750
U. of U.		4,377	6,600	8,800
U.C.P.C.			5,950	7,550
Payson				
U.C.T.S.			5,800	7,250
U. of U.		4,287	5,600	6,840
U.C.P.C.			5,000	5,800

(1) U.C.T.S. - Utah County Transportation Study.
U. of U. - University of Utah.
U.C.P.C. - Utah County Planning Commission.
U. of U. - Revised - University of Utah studies with minor local additions in some areas and population projections used in this report.

Surface Water

In addition to the major stream systems in the Utah Lake area, storage reservoirs have also been incorporated in the supply system in order to effectively manage the water resource. In this section, a short review of these streams and storage facilities will be given.

Rivers

A summary of the stream flows in the Utah Lake drainage area, listed in Table 5, indicates the importance of two major streams; the Provo River and the Spanish Fork River. The Provo River originates in the Uinta Mountains and empties into Utah Lake, flowing through Kamas and Heber valleys and across Northern Utah Valley. The fully appropriated Provo River in Northern Utah Valley (north of Provo City) yields about 70 percent of the total inflow to Utah Valley, while having less than 40 percent of the irrigated land (Hyatt, et al., 1968). The volume of natural inflow is highly variable with about one-half the annual flow occurring during April through June and one-sixth of the annual flow occurring during July through September (Hyatt, et al., 1969, Bureau of Reclamation, 1964).

The Spanish Fork River begins in the Wasatch Plateau west of Soldier Summit and also discharges to Utah Lake,

Table 5. Mean annual flow of major streams in the Utah Lake drainage area (Hyatt, et al., 1969).

River	Mean Annual Flow, acre-feet
Provo River	
near Kamas	34,300
Duchesne Tunnel	37,200*
Weber-Provo Diversion Canal	56,200*
at Hailstone	214,500
Ontario Tunnel	10,000*
Dry Creek and Fort Creek	20,000
American Fork River	38,200
Battle Creek	4,000
Grove Creek	3,000
Rock Creek	8,000
Hobble Creek	29,500
Spanish Fork River	
at Thistle	56,400
Strawberry Tunnel	60,800*
at Castilla	151,400
Payson Creek	9,400
Summit Creek	8,900
Salt Creek near Nephi	19,300
Currant Creek below Mona Reservoir	15,000
Jordan River	261,000

* Interbasin Transfer

flowing across southern Utah Valley. The natural flow of the river has a high discharge in the months of April through June and a low discharge in the months of July through September, similar to the Provo River. It has two major tributaries, Thistle Creek and the Diamond Fork. The Diamond Fork serves as a conveyance for interbasin transfers to the Spanish Fork area from Strawberry Reservoir.

Reservoirs and Streamflow Regulation

Streamflow regulation has occurred along the Spanish Fork and Provo Rivers with little regulation on any other streams. Fifteen small reservoirs have been developed at the headwaters of the Provo River, which contribute about 8,000 acre-feet of irrigation water annually. The Deer Creek Reservoir, located at the lower end of Heber Valley, releases 96,700 acre-feet annually to the Provo River and provides municipal and industrial water in Salt Lake County through the Salt Lake Aqueduct (Hyatt, et al., 1969). The Strawberry Reservoir, located in the Uinta Basin, provides interbasin exports through the Strawberry Tunnel into the Diamond Fork River.

Mona Reservoir provides the only significant regulation of a minor stream in the drainage area. This reservoir is located on Currant Creek at the northern edge of Northern

Juab Valley. The return flows from Northern Juab Valley and Currant Creek flows are stored in Mona Reservoir to supply the Elberta-Goshen district of the Southern Utah Valley.

Groundwater

The six principal groundwater basins in the Utah Lake drainage area are shown in Figure 4. These basins are Kamas Valley, Heber Valley, Cedar Valley, Northern Juab Valley, Northern Utah Valley and Southern Utah Valley, including Goshen Valley. Kamas Valley and Cedar Valley will not be considered in this study except for the inflow of Cedar Valley water to Utah Lake. Kamas Valley is above the proposed Jordanelle Dam and the outflow from this area is reflected in downstream measurements of the Provo River. Also, Heber Valley outflows are reflected as inflows to Deer Creek Reservoir, which have been previously analyzed (Hyatt, et al., 1968). A summary of the pumping from aquifers in the three main basins indicates that significant increases in these withdrawals have occurred in recent years.

Northern Utah Valley

The Northern Utah Valley groundwater basin, lying north of Provo Bay, extends north to an area east of the Jordan River. Artesian aquifers occur in three unconsolidated deposits, two of Pleistocene age and one of Tertiary age.

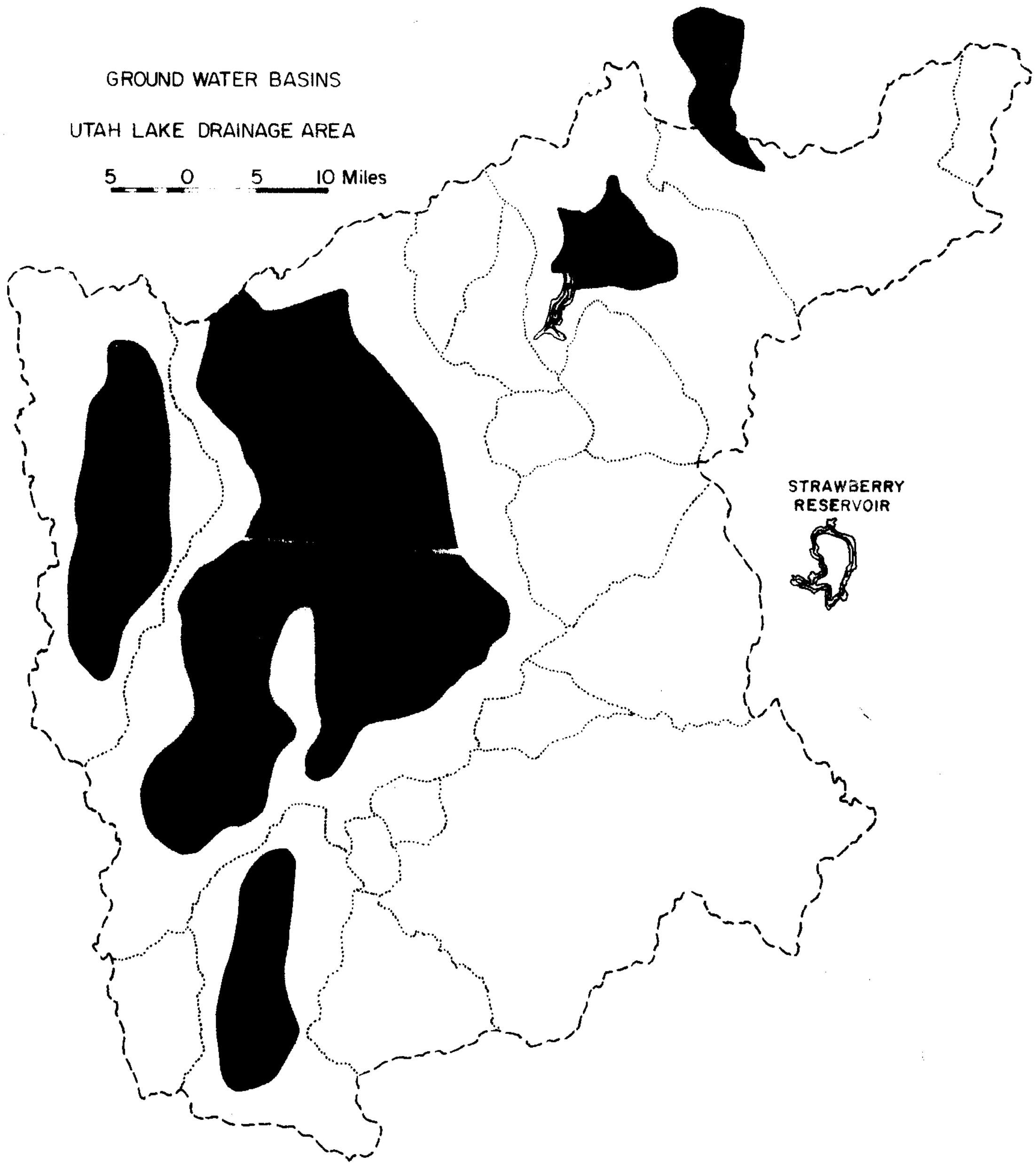


Figure 4. Principal groundwater basins in the Utah Lake drainage area.

The Pleistocene aquifers extend out from the Wasatch Mountains and the Traverse Mountains on the north end of the basin, while the Tertiary deposits are present in and near the Jordan River. Small amounts of water are withdrawn from water table aquifers of the Lake Bonneville deposits. The aquifers are recharged along the eastern edge of the basin along the base of the Wasatch Mountains. Water level contours indicate a general groundwater movement westward toward Utah Lake, while the deep artesian aquifer flows in the northern part of the basin move toward the north, possibly discharging into the Jordan River (Hyatt, et al., 1969).

Southern Utah and Goshen Valleys

The Southern Utah Valley groundwater basin includes the area south of Provo bounded by Utah Lake, West Mountain and the Wasatch Range. Goshen Valley includes the area southwest of West Mountain and is bounded by Long Ridge, the East Tintic Mountains and Utah Lake. These two areas appear to be hydrologically independent (Hyatt, et al., 1968).

The groundwater basins are underlain with unconsolidated deposits to unknown depths. These deposits include four main aquifers - a water table aquifer and three artesian aquifers. Recharge to these aquifers is from seepage, infiltration, and inflow from the bordering mountains.

SECTION III

WATER DEVELOPMENT

Introduction

The Utah Valley area has been modified by its inhabitants from a somewhat barren valley to a rich agricultural-urban complex. During the development of the area, a complicated set of institutional structures were formulated to administer water resources and insure both equitable allocation and profitable enterprise. The history of water development is reflected in present as well as future practices in the area. For this reason, this chapter is devoted to a discussion of historical and present water management practices in the Utah Valley area.

Early Settlement

Padre Francisco Silvestre Velez de Escalante, Padre Francisco Atanasio Dominiguez, and Don Bernado de Miera Pacheco, and a party of seven others plus Indian guides entered Utah Valley by way of Spanish Fork Canyon in September 1776. From a low hill on the south side of Spanish Fork River, which they named Rio de Aguas Calientes, near the mouth of the canyon they saw Utah Valley and Utah Lake. They traveled north as far as the present site of Provo, then west and camped on the shores of Utah Lake, which they referred to as Timpanogotzis, or Timpanoautizis.

In the early 1820's fur hunters including William H. Ashley and Jedediah Smith began to make their place in Utah Valley history. Ashley's Rocky Mountain Fur Company built a fort by Utah Lake, then called Ashely Lake. Jedediah Smith Applied the name "Utah Lake" a short time later. Provo River and Provo City were named for Etienne Provost, one of the colorful fur hunters.

The Mormon settlers in the valley of Great Salt Lake explored the possibilities for establishing settlements in adjacent or nearby areas. Utah Valley was thus explored as early as 1847. In 1849, because of troubles with Indians, Col. John Scott and a company of 31 men moved into Utah Valley and fought with a thieving Indian band encamped at the Pleasant Grove site. Several Indians were killed or wounded in this incident and it is commemorated by the name Battle Creek, the original name of Pleasant Grove, and the name still used for the canyon east of town.

Provo, first named Fort Utah, was settled in 1849 and by the beginning of 1851 had several hundred inhabitants. Pleasant Grove, Alpine (which at first was called Mountain-ville), American Fork (which was called Lake City), and Lehi were settled in 1850. Orem was settled about 1886. All the towns except Orem were located originally alongside or near streams that flow into the valley from the Wasatch Mountains, and the development of Orem followed the construction of a canal to irrigate lands on the Orem bench. In all of Utah Valley, 59 square miles of land were under cultivation by 1877. Because of the sparse rainfall during the growing season, practically all this area was dependent upon water from streams and springs for irrigation.

Agricultural possibilities in the Spanish Fork area were first explored in 1847. Shortly after the Mormon Pioneers arrived in Salt Lake Valley, a scout was sent to inspect the Spanish Fork area, and he returned with encouraging reports of agricultural possibilities. Enoch Reece was the first white man to locate in the Spanish Fork River bottoms, below the present site of Spanish Fork City. Additional land upstream adjacent to the river was broken up that same spring and by fall a settlement was formed. Incident to the first farming operations was the diverting of water from the Spanish Fork river for irrigation of the lands. This was begun in the spring of 1851 when the south ditch was dug. The first water company was organized in the spring of 1852. The first crops planted by these early settlers consisted mainly of small grains and potatoes with moderate yields. Later as more settlers arrived in the area and more land was taken up, additional water was diverted from the river.

The Mt. Nebo Land and Irrigation Company was formed in 1895 to construct Mt. Nebo Dam (Mona Dam) on Currant Creek in Juab Valley. Surplus water from Currant Creek was to be stored in the reservoir created by the dam for subsequent irrigation of about 15,000 acres of land in Goshen Valley near the present town of Elberta. The dam was completed in 1895 and a canal constructed to convey water to the lands. During 1896 and 1897, several families moved from the midwest into the area then called Mt. Nebo. The crops of alfalfa, small grains, pears, and apples were good and the community thrived until 1898, when a water shortage occurred in the newly constructed reservoir. By 1901 the reservoir was dry, and as both land and water had been over-sold, most of the inhabitants were forced to leave. By 1903 the entire project was in receivership. However, by 1905 the reservoir was again filled and the irrigation company was sold as the Utah Lake Land, Water and Power Company. The name of the town was changed to Elberta after a variety of peaches which was prospering in the area.

The first settlers to arrive at Mona were James Bigelow and Andrew Love in February 1852. This early settlement was called Clover Creek. In the spring of 1852 crops were planted and water for irrigation was diverted from the small streams that originate in the Wasatch

Wasatch Mountains to the east. In July of 1853 trouble with the Indians forced the settlers to move to Nephi for protection. The settlement was reestablished in 1860 by Edward Kay and John Vest.

The agricultural development of the Mona-Nephi area, as with the rest of Utah, is located in proximity to available water supplies. There are several small springfed streams emerging from the canyons of the mountains to the east. These streams usually contain large flows during the early spring runoff months, then decrease later in the summer until most are completely dry. These streams make it possible to irrigate only a small part of the arable lands of the area. Because of this lack of sufficient water for all suitable lands, dryland farming is practiced.

The first dry farming on record in Juab Valley, which was also among the first in the intermountain area, was begun in 1881 when David Broadhead successfully raised 15 bushels of wheat per acre on non-irrigated land. Mr. Broadhead then filed on 160 acres with the stipulation that the land was arable. The claim was contested because all the available water had been appropriated and Mr. Broadhead was charged with perjury and sent to jail. He was later acquitted upon proof that the crops were successfully produced in the area without irrigation. The practice of dry farming soon became popular and spread throughout the area.

The dry farming method was uncertain because of unfamiliarity with methods of moisture conservation and crops adapted to these conditions. To help solve these and other dry farming problems, the Utah Agricultural Experiment Station established several experiment farms, one of which was located 5 miles southwest of Nephi adjacent to the southern boundary of the area. This Nephi farm is the oldest experimental dryland farm still in operation in America. Many of the practices of good management now followed by farmers in the intermountain area originated at this Nephi field station.

Water Supply and Delivery System

Utah Lake

Utah Lake was developed as a storage reservoir in 1872 when a low dam was placed across the lake's outlet to Jordan River. A pumping plant was built in 1902 so that the lake water could be lowered below the outlet elevation. The pumping plant has been modified and enlarged several times. Its present capacity is about 1,050 second-feet and it can lower the lake 8 to 10 feet below "compromise level" as defined in the following paragraph. In 1934, the lake was drawn about 12 feet below compromise level by emergency pumps installed at Pelican Point on the west shore of the lake.

With the dam at its outlet, Utah Lake sometimes rises above its normal surface elevation in years of high inflow and floods adjacent lands. This resulted in conflicts between the land owners and lake water users until 1885 when an agreement fixed the compromise level of the lake. The elevation of compromise level is 4,489.34 feet above sea level as related to a recently adjusted datum of the U. S. Coast and Geodetic Survey. Whenever runoff forecasts during the filling season indicate that under controlled operation the lake level will exceed that elevation, the outlet gates are opened prior to and during the high runoff season to permit discharges comparable to natural outflow conditions. The gates remain open until the threat of exceeding compromise level has passed or until the lake has subsided to slightly more than 3 feet above compromise level in the extremely high runoff years of 1922 and 1952. At compromise level Utah Lake has a surface area of about 96,000 acres (150 square miles) and has a storage capacity of approximately 850,000 acre-feet, of which about 830,000 acre-feet can be considered active capacity since it is within a 12-foot drawdown below compromise level.

Water released from Utah Lake is largely rediverted from Jordan River and used for irrigation in Salt Lake Valley and Northern Utah Valley. Some lake water also is used for industrial purposes in Salt Lake Valley. Under exchange agreements, however, lake water used for irrigation replaces some water of mountain streams entering Salt Lake Valley from the east, permitting the latter to be used for municipal and industrial purposes.

Ontario Tunnel

The Ontario Tunnel was constructed in 1891 for the purpose of draining the lower levels of the Ontario, Daly West, and Silver King mines, located near Park City in the Weber River drainage basin. The tunnel was driven from the lower levels of the mines in a south-easterly direction, crossing the divide between the basins of Provo and Weber Rivers, and came out on the Provo side of the divide some 2 miles below the summit. Throughout the greater part of its length of 4 miles, the tunnel receives water from underground sources, so that the volume discharged at its mouth is considerably in excess of the amount that is actually drained from the mines. The mean annual flow from this tunnel is approximately 10,000 acre-feet. A pictorial summary of the water development projects in the Utah Lake drainage area is shown in Figure 5.

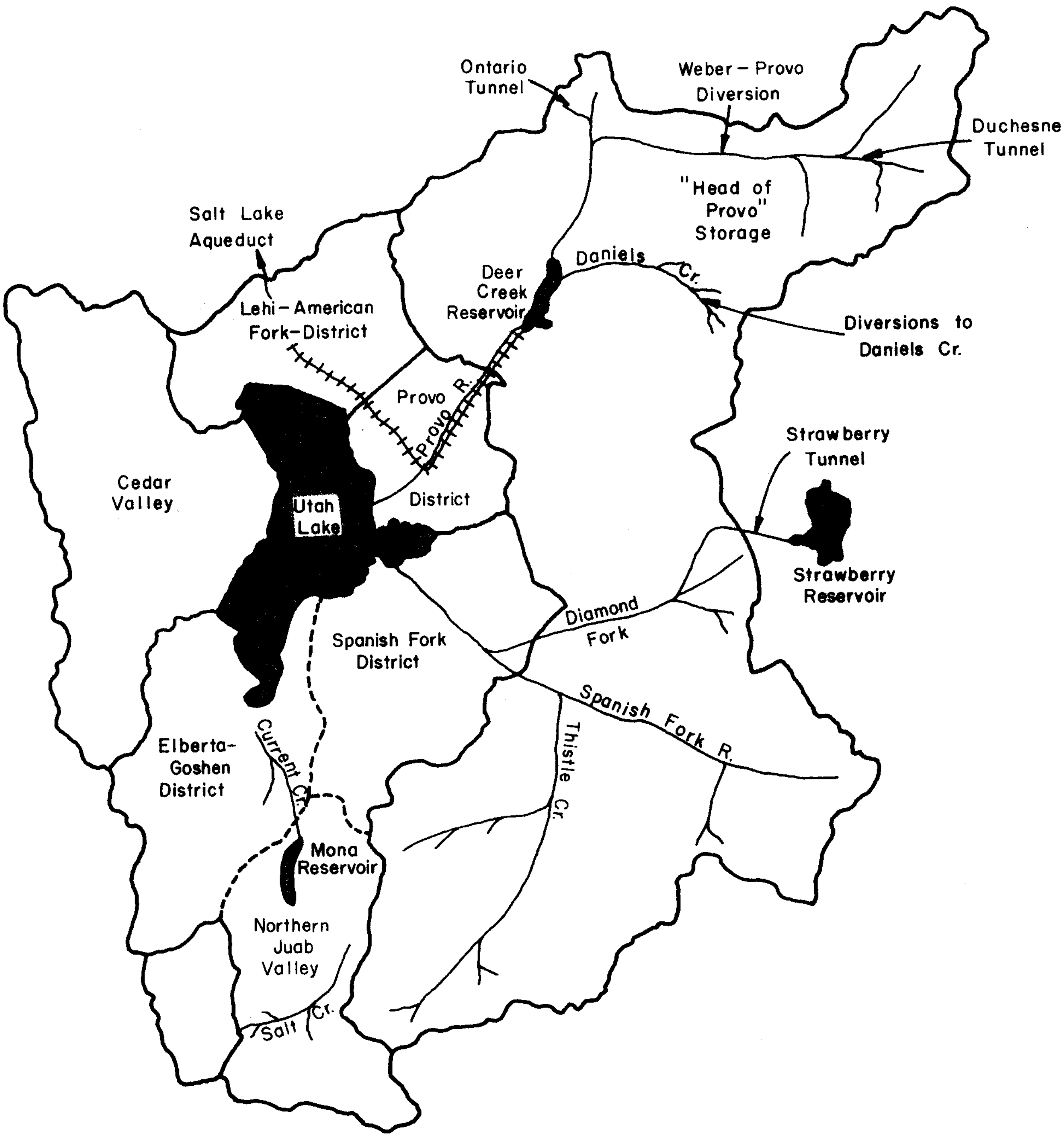


Figure 5. Water developments in Utah Valley.

Diversions to Daniels Creek

There are two canals which presently divert water from the Strawberry River drainage to Daniels Creek. Each canal has two points of diversion. The Strawberry River Canal and Willow Creek Canal were comingled in 1954 to form a single canal entering Daniels Creek. At about this same time, the Upper and Lower Hobble Creek canals were combined to form one canal. The water diverted by the two canal systems is distributed by the Daniels Creek Irrigation Company.

"Head of Provo" Storage

Fourteen small reservoirs at the headwaters of the Provo River were constructed about 1910 by several different interests: the Provo River Reservoir Company, Provo City, and upper basin irrigation companies located in the Francis and Heber Valley subareas. Though each reservoir is separately owned, the group is operated as a unit. Each owner is given credit against the total storage of about 10,111 acre-feet; 4,200 acre-feet of the storage belongs to the Provo River Reservoir Company. In the spring, the reservoirs are filled by snow-melt. When a particular interest wishes to draw some of its water, it informs the river commissioner's office, which, in turn, orders the water released. The water is not necessarily released from the reservoir that the interest built, but rather from the reservoir that is being emptied at the time.

Strawberry Valley Project

The Strawberry Valley project, which diverts water from the Uinta Basin to the Bonneville Basin, is one of the earliest federal reclamation developments. Construction began in 1906 and water was first used in 1915. Water is collected in the 270,000 acre-foot active capacity Strawberry Reservoir formed by a dam on Strawberry River, a tributary of the Duchesne River. Additional water is brought to the reservoir from Indian and Currant Creeks through feeder canals. The Strawberry Tunnel, which is 3.7 miles long, extends from the reservoir to Sixth Water Creek which is tributary to Diamond Fork and thence the Spanish Fork River. Released storage water is rediverted from the Spanish Fork River and used for irrigation primarily in Southern Utah Valley. A small amount of the stored water is conveyed to Goshen Valley. Two small hydroelectric powerplants are located at drops from a canal a short distance below the project's point of diversion from the Spanish Fork River. The Strawberry Water Users Association operates the project.

Weber-Provo Diversion Canal

The Weber River project, constructed in 1928-31, includes the 9-mile long Weber-Provo Diversion Canal that was constructed for project purposes to a capacity of 210 second-feet to convey surplus high flows and some exchange waters from the Weber River to the Provo River. The canal takes water from the Weber River east of Oakley, Utah, transports it 9 miles southward through Kamas Valley, and delivers it to the Provo River near Woodland, Utah. Along the way, the canal intercepts and diverts water from Beaver Creek, a tributary of the Weber. The canal was enlarged to a capacity of 1,000 second-feet after 1947 as part of the Provo River project. The canal operates under water rights in Echo Reservoir, which is located downstream from the canal's intake. During the winter, when surplus water is available, water in excess of the canal's diversions are deposited in Echo Reservoir. In the spring, when all the water is taken by prior claimants, the canal continues to divert water from the Weber River replacing it by releases from its share of Echo Reservoir storage.

Provo River Project

Duchesne Tunnel. The Duchesne Tunnel diverts water from the North Fork of the Duchesne River, a tributary of the Green River and eventually the Colorado River. The intake of the tunnel is 21 miles due east of Kamas. The tunnel itself, which is 6 miles long, is under a spur of the Uinta Mountains. The outlet is into the main stem of the Provo

River, upstream from Kamas. The Duchesne Tunnel was completed in 1953 and began delivering water for the irrigation season of 1954. The capacity of this tunnel is 600 second-feet. The Duchesne Tunnel is dependent upon rights in surplus water for its diversions. In the North Fork of the Duchesne River, at the point of diversion, over 70 percent of the annual flow occurs during May and June. The tunnel usually begins transporting large quantities of water in early May. Substantial diversions, usually about 24,000 acre-feet monthly, may continue through July and occasionally into August. During the rest of the year, the monthly delivery to the Provo is about 500 acre-feet, including some tunnel seepage.

Deer Creek Reservoir. Deer Creek Reservoir is the major reservoir in the basin. It is located in Provo Canyon, west of Heber Valley. The Bureau of Reclamation began construction of the earth-fill dam in 1938 and completed it in 1941. The reservoir has a usable capacity of 150,000 acre-feet. Natural flows of Provo River are rarely available for storage in Deer Creek Reservoir as all of the normal flows and most of the flood flows are required for prior rights on Provo River and in Utah Lake. The reservoir water is used for power production, irrigation, and municipal purposes. The irrigation water is distributed by previously constructed canals and by the Provo Reservoir Canal that was enlarged as a project undertaking.

Salt Lake Aqueduct. The remaining interbasin transfer is the Salt Lake Aqueduct, also part of the Provo River project, which differs from the other transfers in that the aqueduct takes water from the Utah Lake drainage area to another basin. The aqueduct begins at Deer Creek Dam, runs along the north side of Provo Canyon and the northeast side of Utah Valley, and tunnels through the Traverse Mountains into the Salt Lake Basin. The aqueduct operated by the Metropolitan Water District of Salt Lake went into operation in 1952 and is used to convey its share of stored water for urban purposes. Some water is conveyed by the aqueduct to the city of Orem for its urban water supply system.

American Fork-Dry Creek Watershed

The Soil Conservation Service prepared a watershed work plan in 1958 for the drainage areas of Dry Creek, American Fork River, Grove Creek, and Battle Creek. The plan was developed to reduce sediment and floodwater damages to urban property, irrigation systems, farmland, recreational facilities, and roads and bridges within the watershed; reduce water losses in canals and ditches; improve irrigation efficiencies on the farms and to provide additional late season irrigation water. The structural measures installed consist of four debris basins, an irrigation storage reservoir, canal lining, pipelines, overnight storage ponds, canal construction, drop spillways, desilting basins, and a diversion dam.

Central Utah Project

The water demands in Utah Valley, and the supplies which satisfy them, will change significantly in the future. Population of the industrialized sections of Utah Valley will have tripled by the year 2020 and doubled in the present rural areas. This constitutes a necessary reallocation of the existing supplies from agriculture to municipal uses, resulting in a change in the time distribution of demands as well as changes in absolute amounts of water needed. Increases in irrigation efficiency due to advancing technology, as well as the greater proportions of the water supply going for urban use, will change the water quality throughout Utah Valley. Greater controls will be imposed, in the future, on the water quality because of the urban requirements for "cleaner" water.

Anticipation of problems resulting from these changes has prompted the State of Utah to endorse the Central Utah Project, which encompasses the Utah Lake drainage area. The

Central Utah Project, illustrated in Figure 6, involves transporting water from the Colorado River Basin into Utah Valley to facilitate changing demands in the area, and also to provide water for transfer north to Salt Lake County and south to the Sevier River Basin.

Utah Lake

Utah Lake, affected in a number of ways by the Central Utah Project, will receive additional return flows from increased demands on the new reservoirs and releases for power generation. Although, it will not receive excess flows from the Provo River or the Diamond Fork as it previously did.

The Goshen and Provo bays of Utah Lake will be separated from the main body of the lake by dikes to reduce evapotranspiration losses, and those separate the lake into three parts. The 5.4-mile-long Goshen Bay dike will extend northwest across Utah Lake from Lincoln Point, cutting off an area covering about 27,000 acres at the southern extremity of the lake. Although the deletion of this area will reduce storage capacity in the lake to about 220,000 acre-feet, an emergency outlet will be constructed in the dike to spill lake water into the bay in cases of uncontrollable floods. Goshen Bay will not be reclaimed for agriculture because of

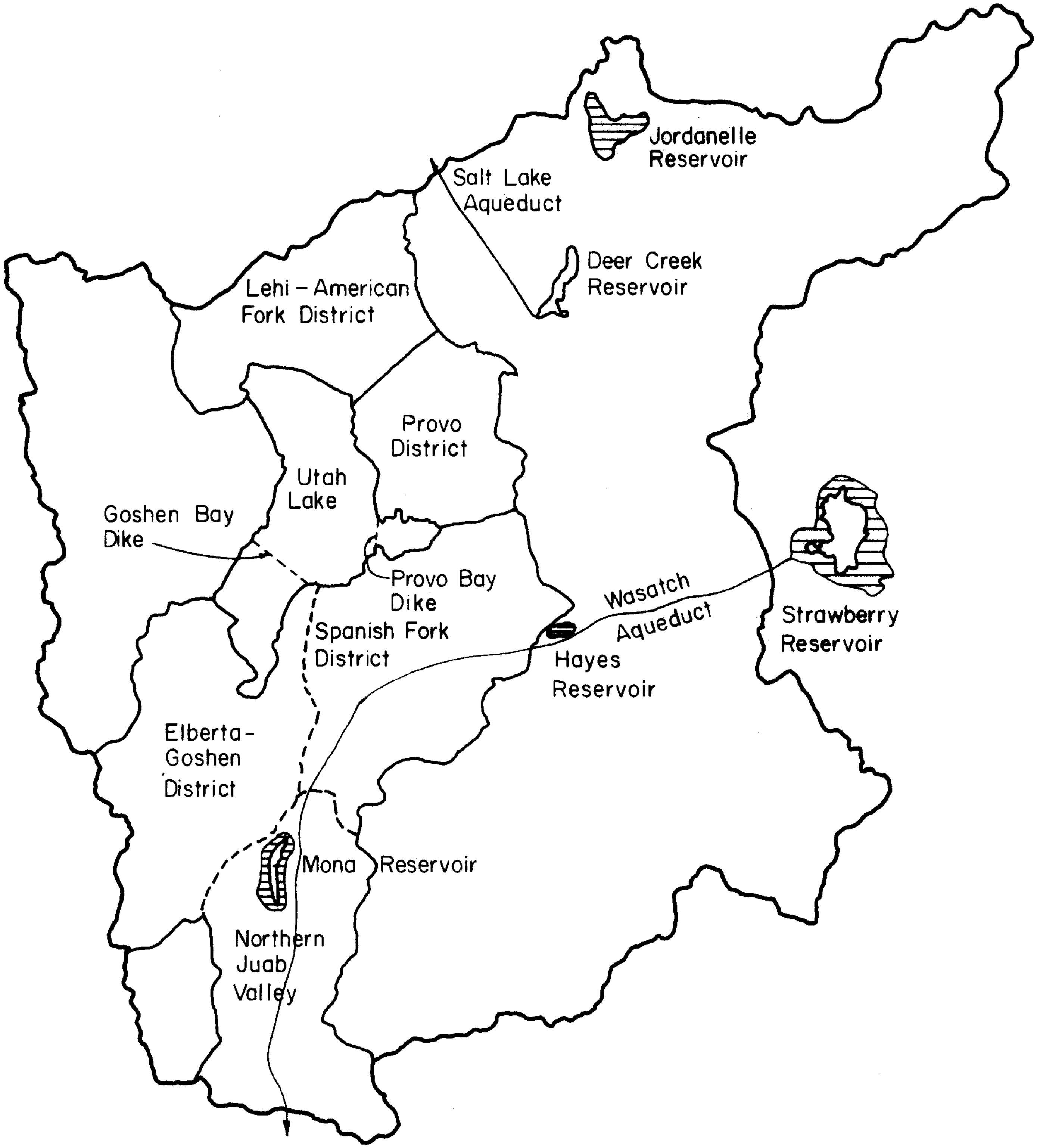


Figure 6. The Bonneville Unit of the Central Utah Project.

the high salt content of the return flows to Goshen Bay and the poor texture of the bay floor, but present planning envisions the bay as a waterfowl refuge. The 6.5-mile-long Provo Bay dike separating Provo Bay from the main body of the lake, excludes about 7,500 acres with a storage capacity of about 23,000 acre-feet from the lake. Facilities will be constructed to divert flood and non-irrigation season flows of Hobble Creek around the bay to Utah Lake, and some of the higher lands in the bay will be reclaimed for irrigation. A closer view of the changes expected in the geometry and operation of Utah Lake is shown in Figure 7.

Jordanelle Reservoir

At the present time, Deer Creek Reservoir on the Provo River below Heber Valley is the only major control structure on the river system. Excess water not required to be delivered to rights on the Jordan River will be stored in the proposed Jordanelle Reservoir, to be located about 6 miles above Heber Valley. Released storage from Jordanelle Reservoir will be available for use in the area extending from Provo City to Salt Lake City. In addition the construction of the Salt Lake Aqueduct will facilitate conveyance of water from Deer Creek Reservoir to Salt Lake County. All existing small storage above Jordanelle Reservoir will be

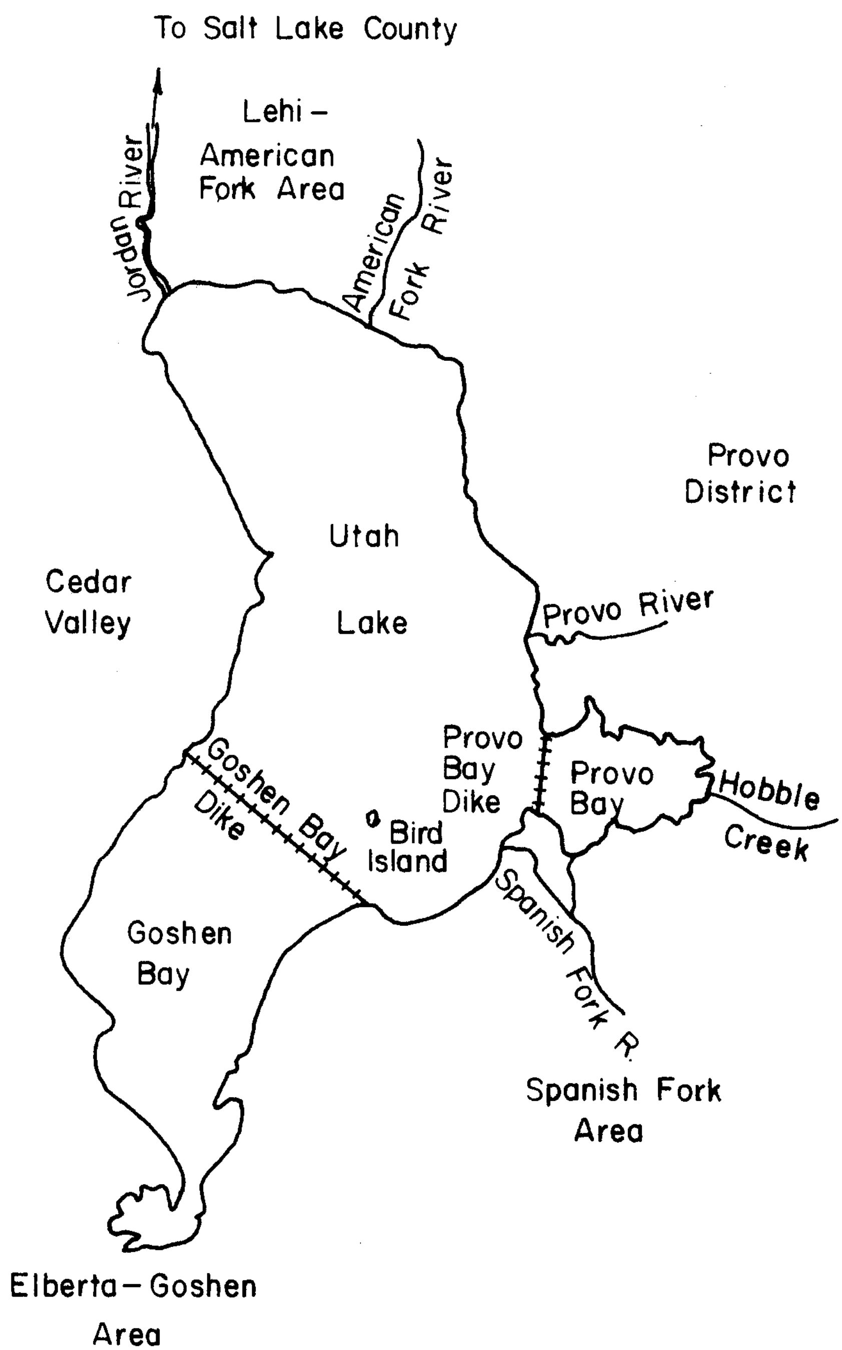


Figure 7. Utah Lake proposed alterations.

replaced except for amounts necessary for irrigation above the reservoir and for fish and wildlife.

Operation of Jordanelle and Deer Creek reservoirs must be coordinated to regulate flow of the Provo River. Deer Creek Reservoir receives return flows from Heber Valley and some small interbasin transfers in addition to the flows of the Provo River. This reservoir will serve to regulate flows from transfers, Heber Valley return flows, and water released from Jordanelle Reservoir to supply water to the Salt Lake Aqueduct and to municipal and agricultural areas in Northern Utah Valley. The interbasin transfers through the Weber-Provo diversion and the Duchesne Tunnel both enter the Provo River system above the anticipated Jordanelle Reservoir site. The Jordanelle Reservoir, planned to have 325,000 acre-feet active capacity, will thus be able to store the interbasin transfers allowing subsequent regulation of Deer Creek Reservoir.

Strawberry Reservoir and Delivery System

The Central Utah Project will provide supplemental Strawberry Reservoir water to all of the Utah Lake drainage area south of Provo Bay. The reservoir will be enlarged to accomodate Colorado River Basin transfers through the Strawberry Aqueduct, which collects flows from several tributaries of the Duchesne River. This water will be released through the Syar Tunnel to the headwaters of the Diamond Fork of the Spanish Fork River and will then travel to the proposed Hayes Reservoir. This reservoir will be located on the Diamond Fork just above its junction with the Spanish Fork River. Also, water may be conveyed to Northern Juab Valley through the proposed Wasatch Aqueduct and the Mona-Nephi Canal. Mona Reservoir will be enlarged to accomodate Strawberry Reservoir water conveyed via the aqueduct in order to supply water to the Elberta-Goshen district.

The three reservoirs in this area must be operated to supply the demands within the area. Hayes Reservoir storage will be used to satisfy Spanish Fork Area demands, which currently exceed the flows of the Spanish Fork River. Spills from Hayes Reservoir will be sent through the aqueduct to satisfy demands in Northern Juab Valley and to supplement Mona Reservoir water. Strawberry Reservoir water, conveyed by the Wasatch Aqueduct, will be used to satisfy demands in Northern Juab Valley, Elberta-Goshen Area, and Spanish Fork Area. A pumping plant at Mona Reservoir will allow water to be pumped out of Mona Reservoir, back into the aqueduct, if necessary. Also, a flow of 36,000 acre-feet per year is to be delivered to the Sevier River Basin through the aqueduct.

In order to accomplish this, the aqueduct must have a capacity of 11,000 acre-feet. Capacities of all physical structures before and after the Central Utah Project, are given in Table 6.

Table 6. Physical restrictions of the system before and after construction of the Central Utah Project.

Structure	Capacity (acre-ft)* Before C.U.P.	After C.U.P.
Strawberry Reservoir	270,000	700,000
Hayes Reservoir	--	43,400
Mona Reservoir	19,200	47,500
Syar Tunnel	--	24,000
Wasatch Aqueduct	--	11,000
Mona Pumping Plant	--	9,000
Deer Creek Reservoir	169,395	169,395
Salt Lake Aqueduct	10,200	10,200
Jordanelle Reservoir	--	325,000

*Reservoir capacities are given as active capacity, conveyance structures are one month flow capacity.

SECTION IV

WATER DEMANDS

Introduction

The characteristic that is most prominent when studying water demands in Utah Valley is that of change. Historically the Utah Valley has been dominated by agriculture, with manufacturing being the primary non-agricultural enterprise. Before World War II, manufacturing accounted for only one-tenth of the labor force, but by 1960 this fraction had increased to one-fourth. About 7300 new jobs were created in manufacturing from 1940 to 1960, with an accompanying increase in service industries. Many of these jobs, especially in the steel mills, have been taken by farmers. This increase in urban living as well as the mild climate and close proximity to recreational areas, has caused a boom in the small cities and towns, which is expected to continue beyond the turn of the century. Competition between agriculture interests and urban demands for the water supply will create a cost structure for water which will force the agricultural sector to become more efficient in their water use. This change from agricultural domination of the water resource to urban use is a basic concern when discussing water demands in Utah Valley.

Agricultural Water Use

Agricultural use of water is an important factor in most western hydrologic studies. In addition to evaluating cropland requirements, characteristics of the soil and the plant rooting systems must be analyzed to determine the moisture holding capacity (moisture storage) and the allowable depletion of this soil moisture to assure proper growth. Application and conveyance efficiencies of irrigation water and leaching requirements are the important parameters determining the demand by agriculture. These factors, which are also important to the management of water quality, are considered below.

Soil Moisture Capacity

The amount of water that may be applied to a given field without losses due to deep percolation is dependent upon the soil type. For example, textured soils tend to retain more water than coarser textured soils. The amount of water held throughout the depth of the soil profile is termed the soil moisture capacity, although the water available for crop use is limited in the first few feet, which may be defined as the root zone. The average percentage of the soil depth occupied by water is determined by considering soil texture and structure throughout the profile. Soil maps have been drawn from which soil types and their associated moisture holding capacities may be estimated.

The soil moisture holding capacities for this study were determined for each subarea (Table 8). In addition, land use maps prepared by Hyatt (Hyatt, et al., 1968) were used to determine crop types and their corresponding acreages. Root depths for these crops were estimated and soil types were obtained from U.S. Bureau of Reclamation soil maps.

Potential Consumptive Use

The amount of water required to sustain proper plant growth is given by the crop potential consumptive use. Consumptive use (evapotranspiration) is the sum of two terms: (1) transpiration, which is water entering plant roots and used to build plant tissue or being passed through leaves of the plant into the atmosphere, and (2) evaporation, which is water evaporating from adjacent soil or water surfaces (Hagan, et al., 1967). The actual consumptive use will vary depending upon the available water supply, but if the crop system is receiving sufficient water to meet its total needs, the actual consumptive use can be assumed equal to the potential consumptive use. The potential consumptive use in this study was approximated by the Blaney-Criddle empirical method.

Application of Water

The agricultural water demand on the supply is dependent upon the efficiency of the system. Specifically, the water use efficiency of the agricultural portion of the system is called the irrigation efficiency. The irrigation efficiency is the ratio of the amount of water required to the amount supplied for irrigation.

The irrigation efficiency is made up of three basic efficiencies; namely, the storage efficiency, the conveyance efficiency and the application efficiency. The storage efficiency is the ratio of the volume of water taken from a storage facility for irrigation to the volume of water delivered to the facility. The conveyance efficiency is the ratio of the volume of water delivered by a conveyance system to the volume of water supplied to the conveyance system. These two efficiencies are dependent upon the water surface evaporation, seepage and phreatophyte uses. The application efficiency is the ratio of the volume of water used for evapotranspiration and leaching to the volume of water delivered to this area (Mizue, 1968). The efficiencies used in this study were about 50% and 80% for application and conveyance efficiencies, respectively.

Total Agricultural Water Demands

The amount of water needed from a supply may be found by determining the water required at the farm and tracing the delivery system back to the point of supply, accounting for all the losses in the system. Components of a typical irrigation system are shown in Figure 8.

A computer program was used to determine agricultural demands for existing efficiencies, and for application efficiencies of 60% and 75%, for each area in Utah Valley. The results indicated there was not enough difference between the answers found in this way and those determined by merely multiplying the existing demands by the ratio of the existing efficiency and the desired efficiency to warrant the extra effort. This is due to the soil moisture storage term always being small enough to have a minor effect on the final answer. Therefore, in following sections, the change in agricultural demands due to changes in efficiency were found by using the ratio of the efficiencies times the demand.

Municipal and Industrial Water Use

Water demands for urban use are determined by population

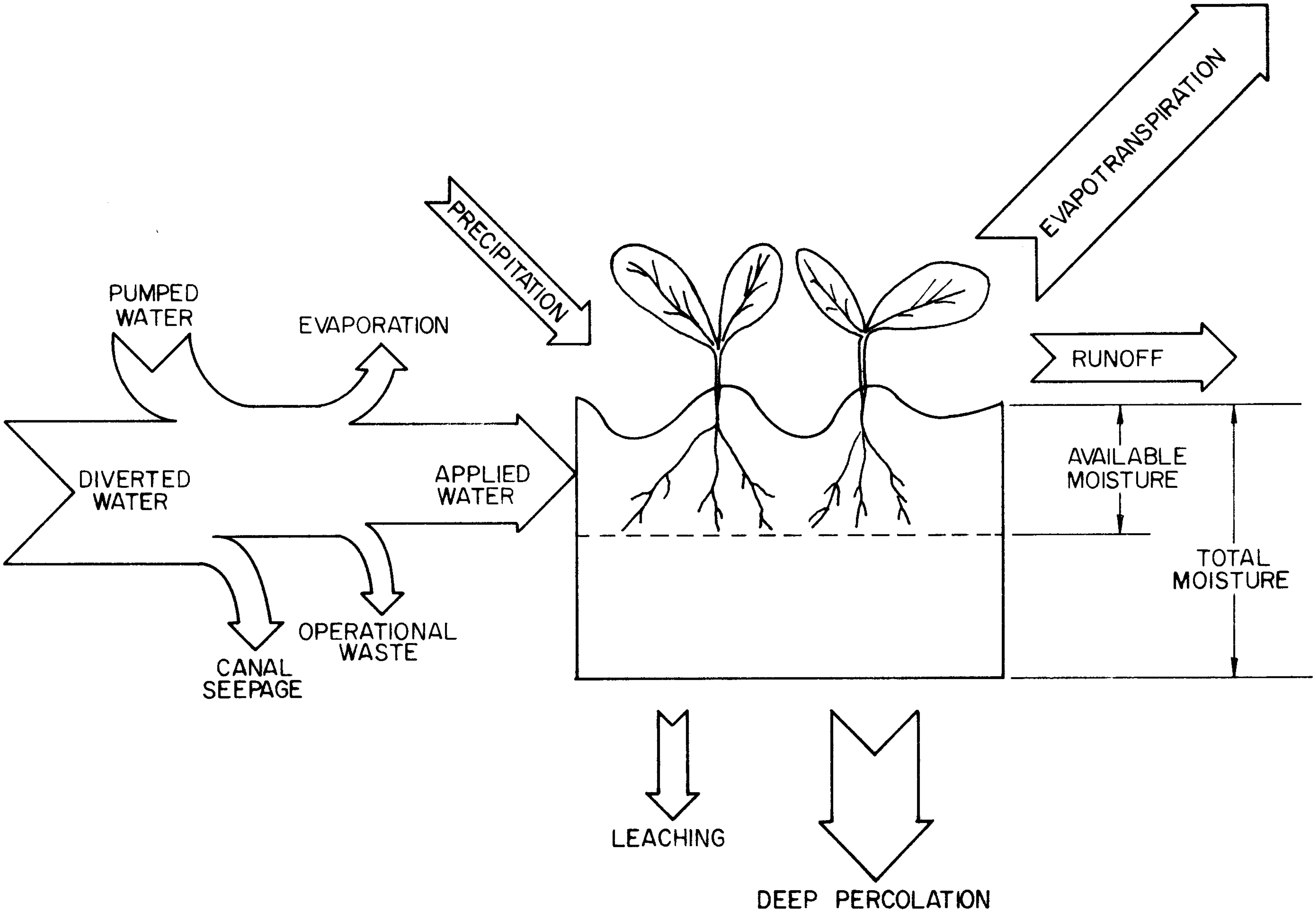


Figure 8. Components of a typical irrigation system.

trends and the industrial expansion within the area. Since Utah Valley roughly covers Utah County, data for this County could be easily adapted to this study. Information collected on the projections of industrial and non-industrial water use were utilized in estimating future urban water demands.

Population Trends

Population projections for Utah County were taken from Economic Research Service data (U.S. Dept. of Agriculture). These projections were then divided into estimates for the Lehi-American Fork Area, Provo Area and Southern Utah Valley, which is called the Spanish Fork Area in the hydrologic analysis. Hudson's book, Irrigation Water Use in Utah Valley, (Hudson, 1962) divided the valley into the desired areas, giving population census data from 1930 to 1960. The census data was then plotted and extrapolated to obtain projected values of population for each area of interest (Figure 9).

Water Use Projections

The Economic Research Service (U.S. Dept. of Agriculture) also provided projections on industrial and non-industrial or municipal water use. Plots indicating these trends for Utah County are shown in Figure 10. These county-wide

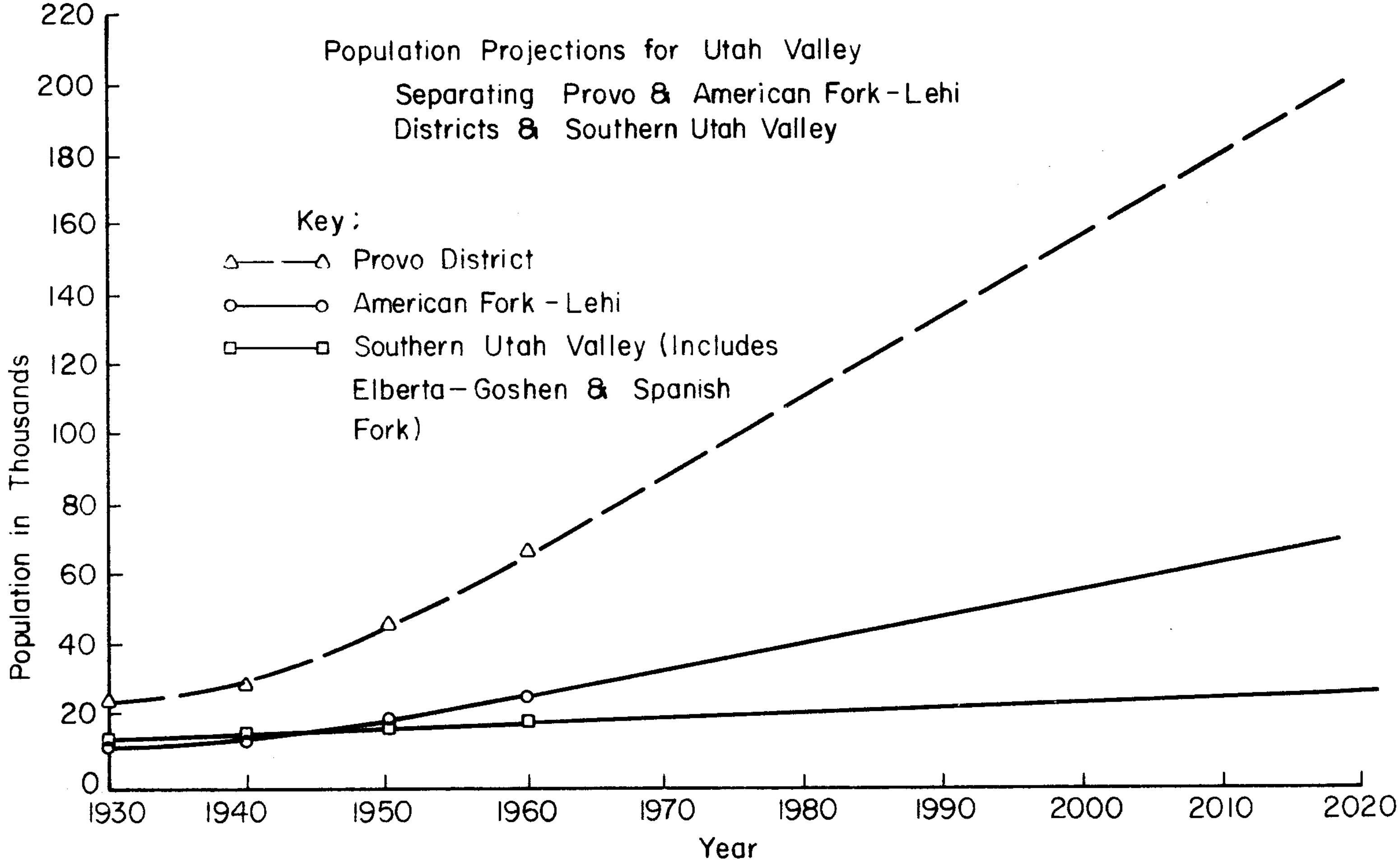


Figure 9. Population projections for Utah Valley.

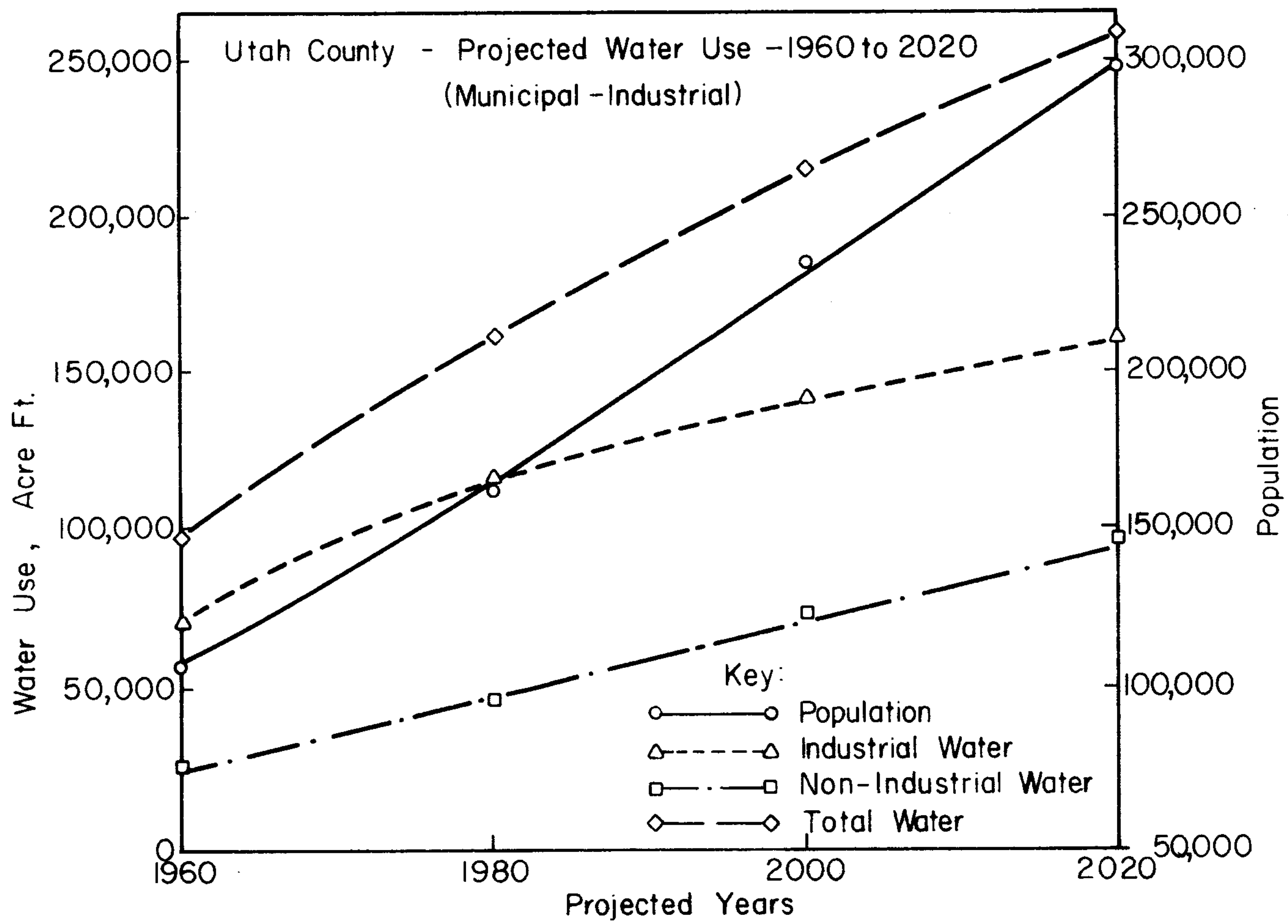


Figure 10. Projected urban water use in Utah County.

projections were then subdivided into estimates for each study area within the county. U.S. Bureau of Reclamation data (Bureau of Reclamation, 1964) divided total urban demand between Northern and Southern Utah Valley. The same relative proportions were used for the Economic Research Service data. The municipal use was divided according to relative proportions of the total population, taken from Figure 10 (Table 7). Then, the resulting municipal demands. were subtracted from the total obtained from the USBR. The industrial water demand for the Lehi-American Fork district had to be estimated. The resulting urban demands are shown in Table 8.

Monthly distribution of the annual municipal demands was then determined. The criteria used for these determinations were obtained from Clark (Clark, et al., 1966), wherein the following statement is made:

> Average daily winter consumption is only about 80 percent of the annual daily average, while summer consumption averages are about 25 percent greater than the annual daily average.

The monthly average was taken to be 1/12 of the annual water demands obtained from Table 8 and the percentages cited above by Clark were applied. The months of May through September were considered as summer months. The peak months of June, July and August were used to balance the total.

Table 7. Population in each area of Utah Valley (U.S. Dept. of Agriculture).

Area	Population 1960	1980	2000	2020
Lehi-American Fork	25000	40000	55500	71500
Provo	65000	111000	158000	204000
Spanish Fork	16000	18800	21800	24300
Elberta-Goshen	1000	1200	1700	2200
Subtotal	107000	171000	237000	302000

Table 8. Mean annual urban water use in the study areas of Utah Valley (U.S. Department of Agriculture).

ANNUAL WATER USE IN DISTRICTS OF UTAH VALLEY

District	1960		1980		2000		2020	
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial
Lehi-American Fork	6,500	1,000	10,700	1,500	17,000	2,200	23,000	3,000
Provo	18,000	64,500	29,800	106,000	48,600	130,000	65,600	144,000
Spanish Fork	2,000	6,000	5,000	7,500	6,700	10,000	7,800	15,000
Elberta-Goshen	250	-	350	-	500	-	750	-

The monthly distribution of industrial use was assumed to be constant.

Salt Lake County water demands were compared with the possible transfers of Utah Valley water through the Salt Lake Aqueduct. The flows of water through the aqueduct were compared with the change in demand in Salt Lake County between each 20-year period. This demand was assumed to occur at a constant monthly rate.

Urban-Agricultural Water Exchange

The future expansion of the urban areas will result in conversion of present agricultural lands to municipal and industrial uses. Increases in land use by urbanization were determined for each subarea by determination of an urban population density. Then, using population data, an acreage increase was determined, which would correspond to an agricultural acreage decrease.

For obtaining population density, Table 9 was used as a quide. A percentage of the total population in each category was assumed. Using the percentages given in the table, the estimated population density (persons/acre) was calculated to be 33.6. If all population expansion is

Table 9. Urban population densities (Clark, et al., 1966).

CATEGORY OF URBANIZATION	Range in number of persons per acre	Number of persons per acre chosen	Percent of total in category
Residential-Single family units	5-35	16	60
Residential-Multiple family units	30-100	Combined 100	20
Apartments	100-1000		
Commercial Areas	15-30	20	20
Industrial Areas	5-15	-	-

attributed to urban growth, an increase in population of 34 persons would result in a one acre decrease in agricultural land. Total acreage decreases due to urbanization are shown in Table 10.

In addition to the decrease in agricultural acreage due to municipal expansion, the Central Utah Project proposes bringing additional land into agricultural production. The proposed additions given in Table 10 will be added to the decreases to obtain a net decrease or increase of agricultural land, also shown in Table 10.

The average monthly potential consumptive use per unit area of agricultural land was determined for each area. This was multiplied by the collective net acreage change in each area to obtain the total change in water demand from 1960 to any projected year.

Phreatophyte Use

The development of improved agricultural practices and the increase in urban development will promote better control and management of water. As a result, the land area occupied by phreatophytes will decrease. The changes in future phreatophyte demands were estimated taking into account the type of development in the area and assuming that urban areas will have better control of water and will demand the elimination of swamp areas.

Table 10. Changes in agricultural acreage due to urbanization and project changes.

URBANIZATION DECREASES

AREA	1960	1980	2000	2020
Lehi-American Fork	0	500	450	450
Provo	0	1350	1350	1350
Spanish Fork	0	89	89	75
Elberta-Goshen	0	6	15	15
Northern Juab Valley	0	63	63	95

NET CHANGE*

AREA	Project acre increase	1960	1980	2000	2020
Lehi-American Fork	none	---	-500	-450	-450
Provo	9500	---	-1350	8150	-1350
Spanish Fork	4600	---	-89	4511	-75
Elberta-Goshen	19270	---	-6	19255	-15
Northern Juab Valley	13090	---	-63	13027	-95

*negative means net decrease

The assumption was made that there would be no change in phreatophyte acreage between 1960 and 1980. In the year 2000, 60% of the phreatophytes in the Spanish Fork and Elberta-Goshen areas are assumed to be eliminated. Phreatophytes in the Provo and Lehi-American Fork districts were assumed to be eliminated by the year 2020 except for the Utah Lake shoreline. The existing acreages of phreatophytes in each area were taken from the 1966 agricultural land use study for the Utah Lake drainage area (Hyatt, et al., 1968). The acreage changes were converted to percentages of the existing acreage (Table 11). These percentages were then multiplied by the existing wetland consumptive use values to obtain the decreases in water use.

Table 11. Phreatophyte acreage in Utah Valley (Hyatt, et al., 1968).

AREA	Phreatophyte Acreage	Percent of Total
Lehi-American Fork	13107	12
Provo	21310	20
Total Northern Utah Valley*	34417	-
Spanish Fork	34206	32
Elberta-Goshen	37142	35
Total Southern Utah Valley	71348	-
Total Utah Valley	105765	-

* Shoreline acreage equals 320 acres.

SECTION V

MODEL INPUT CONDITIONS

Introduction

The ability of any model to provide results, which are representative of a real system, is strongly dependent upon the assumptions made and the input data used in its original development. Generally, when a model of a physical system is developed, it is operated under a given set of conditions, in which the real system results are known, and the model is forced to duplicate those results. Then, different sets of conditions or inputs (e.g., improved water management practices or new wastewater treatment processes) are imposed on the model and new results are generated, which are assumed to be representative of the reaction of the system under the new conditions. Therefore, it is very important that the basic developmental assumptions and the various input conditions be described.

The model used in this study, as in most water resource studies, has a number of interrelated inputs. Annual water balances for the Utah Valley and the associated salt movements are determined for the present and projected future conditions. Also, the assumptions made in operating Utah

Lake to determine lake water quality are discussed. And finally, the methods and assumptions used in obtaining Utah Lake and agricultural water quality control cost functions are presented.

Annual Water and Salt Balances for Utah Valley

A water and salt balance for the Valley was made for each condition imposed. Conditions existing in 1960 and the present (1970) were used in addition to predicted conditions in 1980, 2000 and 2020. Also the balances for 2000 were made using: (1) existing irrigation efficiencies; and then (2) assuming an increase in irrigation efficiency. Original data was used in conjunction with available water quality concentration data and Utah Lake operation studies to obtain preliminary salt and water balances and then adjusted to make the two compatible with each other.

The term "present modified" refers to the water and salt balances having been computed with all present physical facilities in existance throughout the time period of study. Hyatt, et al. (1969) prepared 1960 present modified budgets. Since there has been no major change in physical water facilities between 1960 and 1970, these same budgets have been used in this study as 1970 present modified. The term "future modified" refers to the anticipated physical situation at some time in the future. For example, 1980 future modified water and salt budgets represent balances based upon assumptions regarding the physical situation affecting water demands in the year 1980.

Basic Data

Data for the water balances were obtained from studies by the U.S. Bureau of Reclamation (1964), Hyatt, et al., (1969) and Huntzinger (1971). All the basic data used in the present modified balance was obtained from Hyatt, et al. (1969). In some cases, the available data was given for the entire valley, making it necessary to divide the data among the subareas or districts. When the data was delineated, a balance was prepared for each district, as will be shown later.

The future modified balances utilized data presented by Huntzinger (1971) to obtain the preliminary balances. Changes made in the present modified balance to arrive at the future modified balances are given in Section IV. Agricultural demands used in this study are included in Table 12.

Data concerning the water quality within the Utah Valley study area is not complete and in some cases non-existant. Assumptions and estimates were made a number of times in order to obtain a complete data set. Original data was taken from the U.S. Bureau of Reclamation (USBR), the Utah

Table 12. Annual agricultural demands at 60% farm efficiency.

Area	Annual Demand (Acre-feet)
Lehi-American Fork Area	50,000
Provo Area	66,000
Spanish Fork Area	109,400
Elberta Goshen Area	30,600

State Engineer and the U. S. Geological Survey (USGS), most of which was collected and compiled by Hyatt, et al. (1969). Assumptions made in using the data will be included in the following discussion. Time allotted for this study did not permit an extensive updating of data. Therefore, data not included in Hyatt's study was often not used.

Representative water quality stations were chosen for each subarea in the study. Quality measurements on the major stream in each area at its mouth and above the study area were chosen. Also, a measurement of urban return flow was obtained from a measurement station below each major city water system.

Methods and Assumptions

The present modified water balance was based strictly on Hyatt's study and therefore all inputs and methods of analysis had to be compatible with his water and salt budgets. Total inflows to each area were given, as were diversions to cropland, precipitation and pumped water. However, water diverted for urban use in each area was not given, only a total for the valley. Therefore, urban demands given in Section IV were used to obtain urban diversions. Also, the return flows from agriculture were given. Any given inflows to the area above diversions to urban and agricultural uses were assumed to be excess in the rivers. Urban return flows were found by assuming a water use efficiency (depletion) of 25% for present modified conditions and a 35% efficiency for future modified conditions. Therefore, 75 and 65 percent of the diversions to urban use were returned to the stream.

Wetland use was also given as a total for the area by Hyatt, et al., (1969). Again, this amount was divided according to demands determined by Huntzinger (1971). The values given for wetland demands are potential consumptive use less precipitation.

Yields from the valley floor are those flows which originate as surface runoff and deep percolation from precipitation on non-agricultural lands. Again, a value for the valley as a whole was given. In this case, the quantities used in each area were estimated using total acreages in each area as a guide.

Pumped water was considered to be used for agricultural purposes and was therefore assumed to be used at the same irrigation application efficiency as surface water supplies. The water balance shows a contribution of groundwater from the Provo Area to the Lehi-American Fork Area and from the Spanish Fork Area to the Elberta-Goshen Area. The source of pumped water was derived from an analysis of groundwater recharge. The sum of spills and excesses, agricultural and urban return flows, and yields less wetland use was considered to be inflow to Utah Lake, with no attempt to separate surface and subsurface inflows to the lake.

Future modified water balances incorporated the urban demands described in Section IV with return flows determined by using the assumption of a 35% water use efficiency. Agricultural demands were obtained from Table 19 and converted to the desired efficiency by multiplying table values by the ratio of the desired efficiency and 60%. Year 2000 conditions were analyzed at the 1960 irrigation efficiencies and the assumed irrigation efficiency of 60%. The 2020 balance assumed an agricultural water use efficiency of 75%. Management of pumped water was left unchanged in the Spanish Fork and Elberta-Goshen Areas. Water pumped to the Lehi-American Fork Area from the Provo Area was decreased as the total demand on supplies in the Lehi-American Fork Area was decreased due to increased agricultural efficiency, along with redistribution of water use between urbanization and agriculture. Spills and excesses were estimated using model results from Huntzinger (1971) as a guide. Precipitation on agricultural land was adjusted for the changes in acreage given in Section IV. Yields from the valley floor were held constant throughout the study. Wetland water uses were changed according to assumed acreage changes of phreatophytes. The inflows to Utah Lake were obtained in the same manner as the present modified balance.

The salt balances were obtained by starting with salinity concentration data. Water quality at the mouth of each area's major stream was taken as the total quality of the outflow (inflow to Utah Lake). A measuring station on the major stream above the study area was assumed to be the quality of all excesses and/or reservoir spills from the area. A measurement of the quality of urban return flow was obtained from a station in the sewer outfall below the city. Then, the water quality concentration at the stream mouth was assumed to be the average of the spills, as well as urban and agricultural return flows. Using this criteria, the agricultural return flow quality was estimated. Quality of springs and groundwater were taken from Hyatt, et al. (1969).

The water quality data at the mouth of the American Fork River and at American Fork canyon were used. Data was not available for urban return flows, therefore, the same proportion of salt contributed by urban and agricultural return flows in the Provo district were assumed to exist in this area.

Quality of all return flows to Utah Lake from the Provo area was assumed to be that measured at the mouth of the Provo River. Urban return flow quality was taken as that measured at the Provo sewer outfall. Quality of spills and excesses was assumed to be that measured at the Murdock diversion dam, located below the confluence of the major tributaries of the Provo River. Agricultural return flow quality was then determined by assuming the average concentration of Murdock diversion, Provo Sewer and agricultural return flows to be the concentration at the Provo River mouth.

Measurements of water quality at the mouth of the Spanish Fork River were used as a guide to total return flow quality from the Spanish Fork area. The quality of spills and excess water was assumed to be that measured on the Spanish Fork River at Castilla. Data collected on the Spanish Fork City system was also used as a guide in determining urban return flow quality. However, the data taken on the city system were collected only once and at the mouth only twice. The numbers for these stations are not compatible, as the city return flow is indicated as more than the total for some constituents. This inconsistency is most assuredly due to the difference in the dates of data collection, the city return flow measurement being taken five years previous to other measurements. In the assumptions and changes made concerning the original data, more weight was put on the later collection dates. Where changes were necessary, the proportions allotted to urban and agricultural return flows were based again on those of the Provo Area, making sure the values for Spanish Fork city quality were not increased.

The quality of the total return flow to Utah Lake from the Elberta-Goshen Area was taken as the average of that measured in Goshen Reservoir and South Spring. Total dissolved solids data was taken directly from Hyatt, et al. (1969). Urban return flows from this area are such a small portion of the total, it has little noticeable effect on the total return flow quality. However, to assign some value to the quality of this water, the same numbers were used as in the Spanish Fork district. Quality of spills and excesses in this area were taken as that measured below Mona Reservoir. The quality of agricultural return flow was then determined as in the other areas, assuming the average value of Goshen Reservoir and South Spring to be equal to the average of urban, agricultural and Mona Reservoir concentrations.

The water quality and water balance estimates discussed above were used as a starting point and then readjusted to result in a compatible hydrologic system. Hyatt's study provided concentrations of inflows to Utah Lake and inflows to each area in Utah Valley. Also, values were given for total salt and water inflows to Utah Lake. The water and salt budgets were adjusted to match these values as close as possible.

Concentrations of area inflows, groundwater, yields and urban return flows were assumed to remain constant under the future modified conditions. The agricultural return flows were changed because of the assumptions regarding salt pickup from agriculture. The agricultural salt pickup per acre-foot of return flow was determined from the present modified analysis and held constant for each of the other analyses. Therefore, a decrease in return flow would result in less salt added by agriculture.

Model Inputs

Results of the analysis discussed in the previous portions of this section, shown in Figures 11-15, are used as inputs to the optimization model. In order to understand these figures, definitions of the symbols have been included in Table 13.

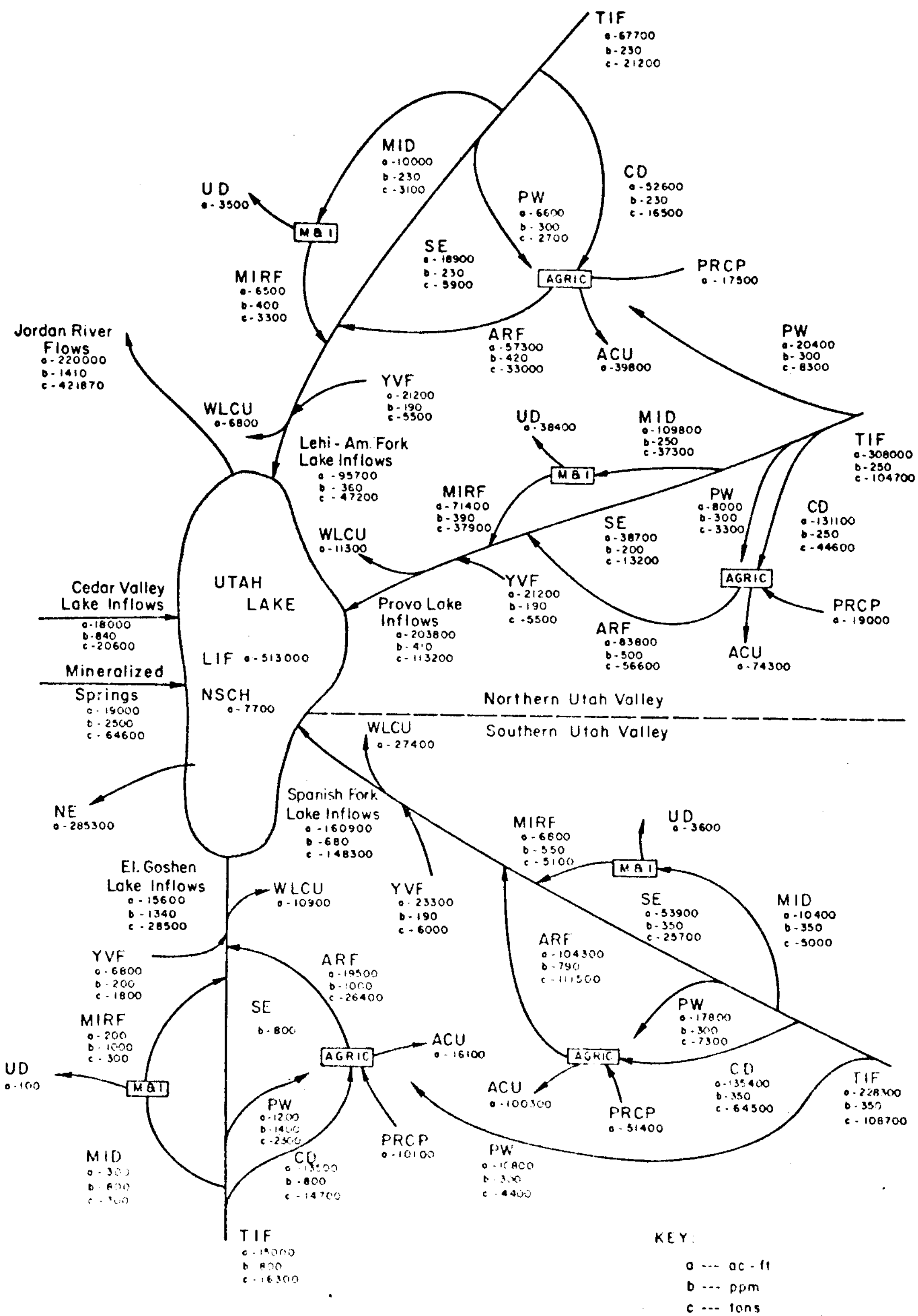


Figure 11. Water and salt balance diagram for Utah Valley under 1970 present modified conditions.

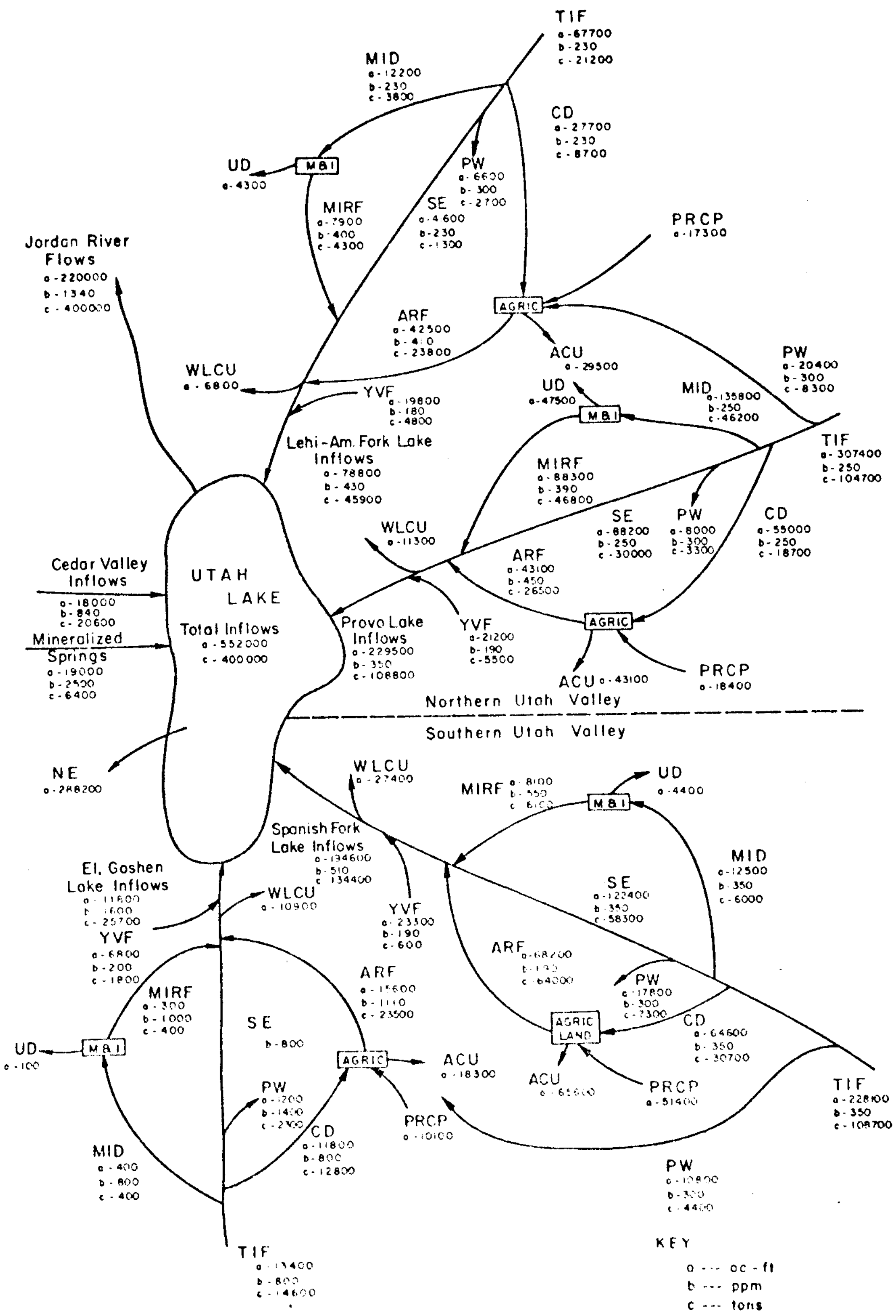


Figure 12. Water and salt balance diagram for Utah Valley under 1980 future modified conditions.

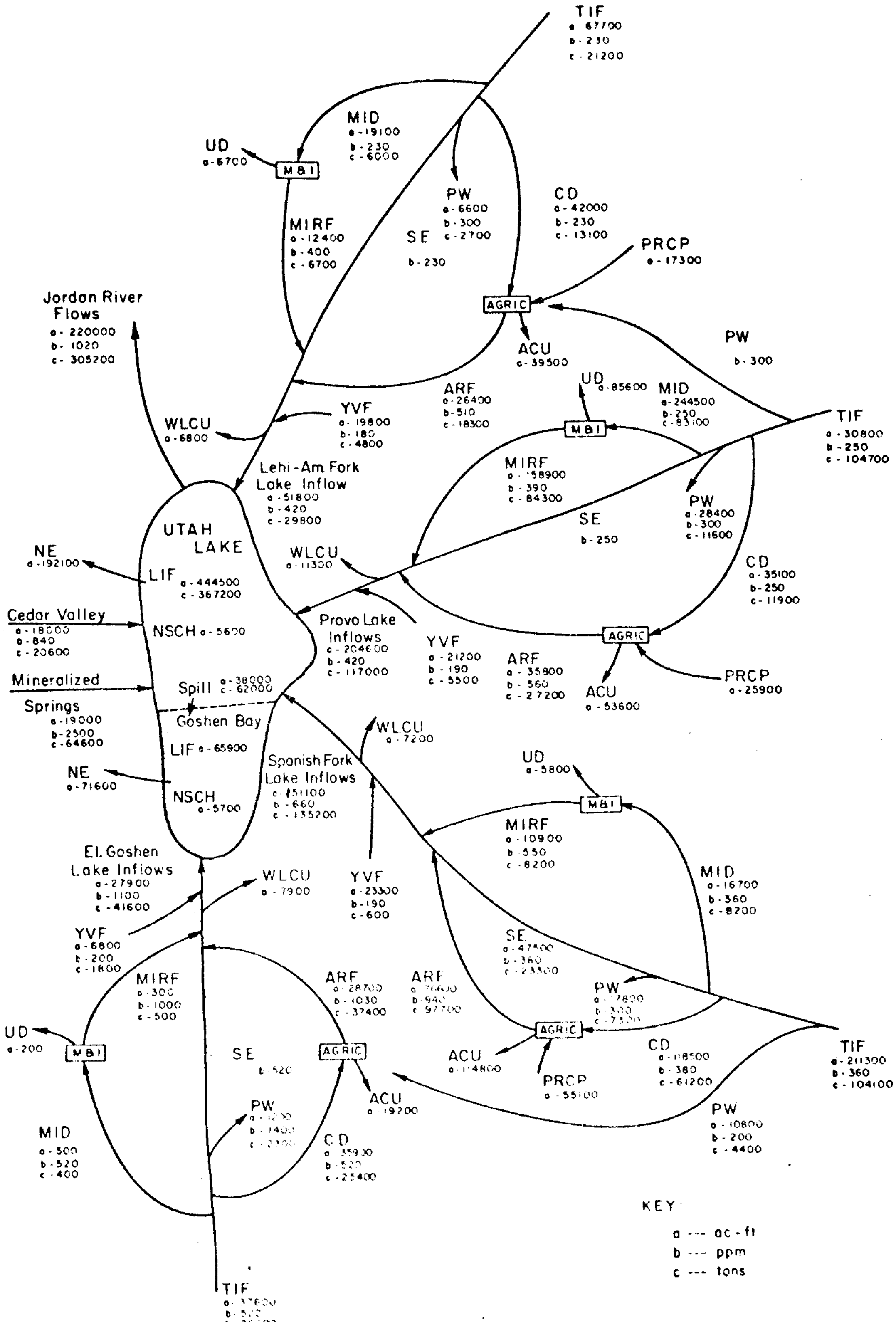


Figure 13. Water and salt balance diagram for Utah Valley under 2000 present modified conditions.

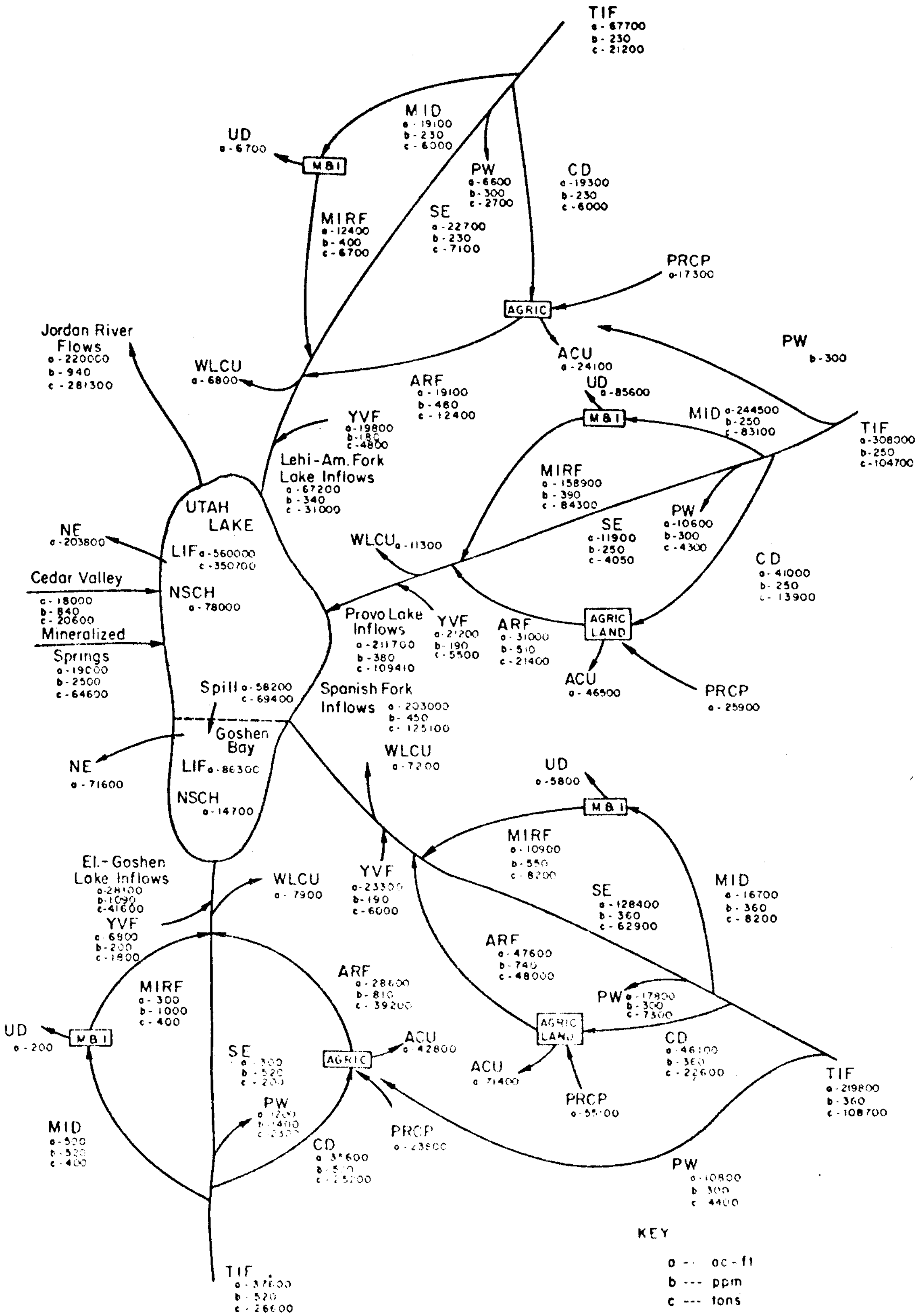


Figure 14. Water and salt balance diagram for Utah Valley under 2000 future modified conditions.

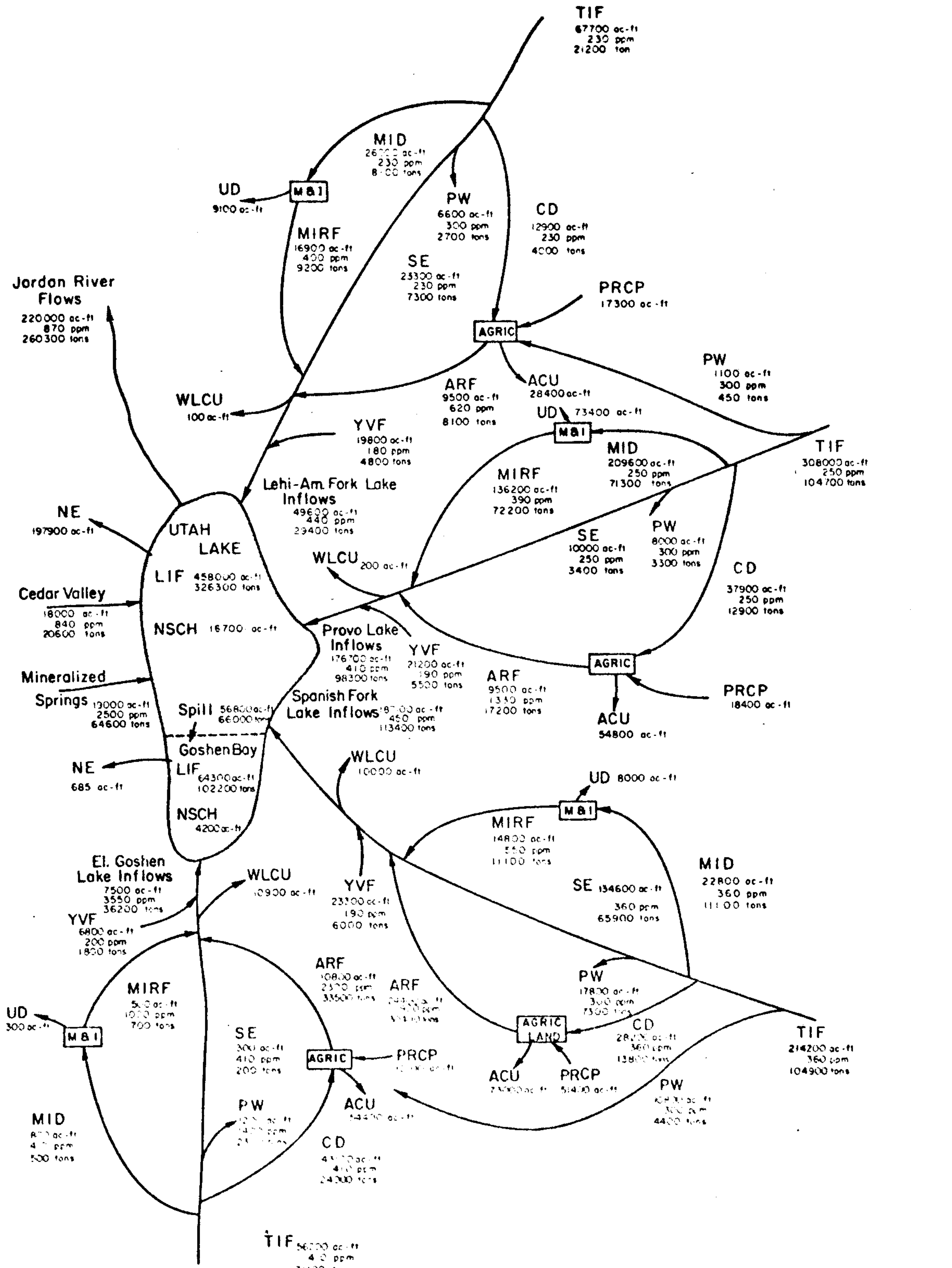


Figure 15. Water and salt balance diagram for Utah Valley under 2020 future modified conditions.

Table 13. Abbreviations in the salt and water balances for Utah Valley.

ACU	Actual agricultural consumptive use
ARF	Agricultural return flow
CD	Canal diversions
LIF	Total Utah Lake inflow
M and I	Municipal and industrial area
MID	Municipal and Industrial depletions
NE	Net evaporation in Utah Lake
NSCH	Net Utah Lake storage change
PRCP	Precipitation
PW	Pumped water
SE	Spills and excesses
WLCU	Wetland net consumptive use
YVF	Yields from the valley floor

Utah Lake Operation

The Utah Lake is the point where all return flows from Utah Valley eventually are deposited. Utah Lake water is then spilled to the Jordan River and transported through Salt Lake County to the Great Salt Lake. Evaporation from Utah Lake is very high because of its shallow depth. Because of this evaporation, the Lake plays a major role in water quality management in the area. The Central Utah Project proposes to dike the lake to separate Goshen Bay and Provo Bay from the main lake in an attempt to decrease the lake evaporation and in turn improve the water quality of the lake contents. The discussion which follows will involve a study of the lake to determine the effects of the diking and changes made by the Central Utah Project on water quantity and quality.

Basic Data

The basic data necessary for studying the water portion of Utah Lake is taken from the Bureau of Reclamation and the study of Utah Valley by Hyatt, et al. (1969) and Huntzinger (1971). Inflows to Utah Lake are obtained from the water and salt balances for Utah Valley, and the additional information on evaporation, such as area capacity curves and evaporation rates, was taken from USBR reports (1964).

Also, the physical characteristics of the spillways at Jordan River and Goshen Bay dike were taken from the same source.

Methods and Assumptions

The starting content of Utah Lake was taken to be the content at the average elevation for October. Content of the undiked lake at the average October elevation of 4484 feet above sea level is 390,000 acre-feet and the diked lake is 300,000 acre-feet. After diking, the Elberta-Goshen return flow was considered as the only inflow to Goshen Bay, with all remaining return flows considered to be inflows to the diked main lake. An intermediate lake and bay content was calculated after the inflows were added and a surface area determined. The net evaporation (evaporation minus precipitation) and Jordan River flows were then taken from the lake content to obtain the final undiked lake content. The Jordan River demand flows were assumed to be 220,000 acre-feet. Any remaining water was considered as net storage change. After the lake is diked, a spill from the main lake to Goshen Bay must be determined. The spill is dependent upon the difference in surface elevation between the lake and bay, as well as the absolute elevation of the lake. In all cases encountered, the maximum possible spill from the lake was more than sufficient to equalize the elevation difference between the two surface elevations. Once the two water levels are equalized, then any additional spills must be conveyed by the Jordan River.

The Utah Lake operation study is not used in the optimization directly. It is necessary to determine the water quality of the lake under each of the imposed conditions. The salt concentration of the lake is then used in the model.

Total Dissolved Solids in Utah Lake

The salt content of Utah Lake plays an important role in water quality management for Utah Valley. Salt concentrations of Utah Lake have a direct effect on the concentrations in the Jordan River, as well as recreational uses and health considerations in the lake itself. Diking the lake by the Central Utah Project is basically an attempt to impound salt loads in Goshen Bay, improving the quality of the remaining lake. An analysis of the actual effects of this diking and other alternatives of controlling salt loads in Utah Lake is explained in the following discussion.

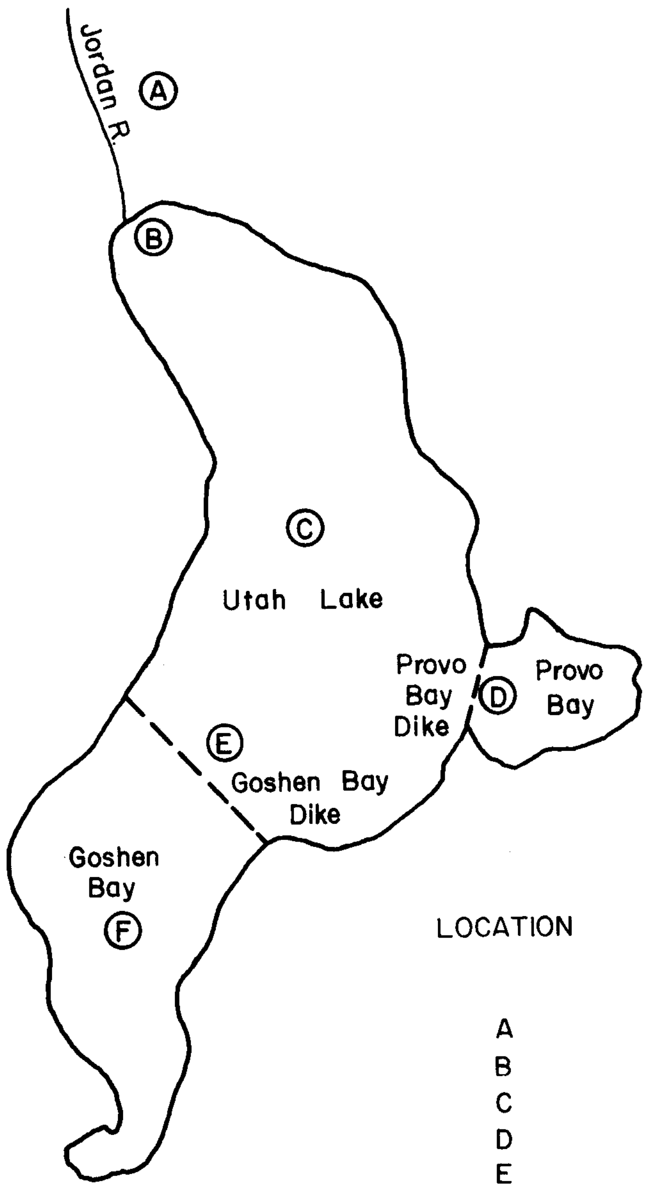
Basic Data

The only information needed for water quality analysis, in addition to the results of the operation study, are the tons of salt coming into the lake from the surrounding area, and the recorded data for water quality at various locations in the lake. The concentrations of salt in the lake were obtained from U.S. Bureau of Reclamation reports. The salt concentrations of Utah Lake are shown in Figure 16.

Methods and Assumptions

The beginning salt content in the lake was determined by using the salt balance for present modified conditions prepared by Hyatt, et al. (1969). The average salt concentration of the Lake was given to be 1400 parts per million (ppm) with a final water content of 422,100 acre feet based upon the operation study described above. Salt balance data on the lake assumes that the salt inflow to the lake is equal to that flowing to the Jordan River. However, it is recognized that this is a simplifying assumption, since there is some precipitation of salts in Utah Lake. From the final water content and the final salt concentration, the total salt load was calculated.

The initial salt load was considered to remain constant for the other imposed future conditions before completion of diking. Also, the assumption that flows of salt to the Jordan River are equal to salt flows into the Lake was retained. Therefore, concentrations of the Lake and Jordan River were



LOCATION	TDS (ppm)
A	1300
B	1600
C	1400
D	1600
E	1500
F	1900
AVG.	1600

Figure 16. Chemical water quality in Utah Lake.

calculated from salt and water flows. Measurements of Goshen Bay concentrations were used to estimate the concentration in Goshen Bay for the imposed future conditions.

After the Central Utah Project diking was imposed, a different technique of determining Lake quality was used. The beginning salt load to the main Lake and Goshen Bay were estimated by using the existing concentrations and the estimated initial water contents. Salt loads obtained were then adjusted so the sum of the two would equal the initial undiked lake salt load. Salt inflows to the main Lake were considered to be all but the return flows from the Elberta-Goshen area, which were considered the only inflows to Goshen Bay in addition to the main Lake spill. Again, the assumption was made that the salt load in the lake was constant. Therefore, the sum of the salt spills both to the Jordan River and to Goshen Bay must equal the salt inflow to the main Lake. A final concentration in the main lake, the Jordan River, and Goshen Bay were calculated from the final salt loads and water flows in each location based upon the operation studies.

Model Inputs

The model inputs from the Utah Lake analysis are the concentrations that result under the various imposed conditions. The concentrations are included in Table 14. Operation study results are not needed in the model study, but are also included in Table 14.

Optimization Cost Analysis

A major component of any optimization analysis is the economic considerations. This section discusses some of the cost estimates required. The costs of improving the quality of agricultural return flows are important. Also, the costs associated with the diking of Utah Lake are necessary to make meaningful water quality management decisions.

Agricultural Water Quality Management Costs

Costs associated with water quality management of agricultural return flows are an integral part of any water management plan. The following analysis results in an estimate of maximum costs associated with agricultural quality management in Utah Valley. The costs involved may be divided into two distinct areas, structural changes and irrigation practice changes. Structural changes are those physical improvements which lead to decreased waste water and better control. Canal and ditch linings, flow measurement devices and land leveling constitute the major costs in structural improvements. Practice changes are those which

Table 14. Operation studies of water and salt flows in Utah Lake.

	1970 Present Modified Conditions	1980 Future Modified Conditions	2000 Present Modified Conditions	2000 Future Modified Conditions	2020 Future Modified Conditions
Main Lake					
Gross inflow (ac-ft)	513000	551700	444500	531600	450400
Contents (ac-ft)	903000	941700	744500	831600	750400
Surface area (acres)	98000	99000	66000	70000	68000
Net evaporation (ac-ft)	285300	288200	192100	203800	197900
Contents (ac-ft)	617700	653500	552400	627800	552500
Spill to Goshen Bay (ac-ft)	--	--	38000	58200	56800
Flow to Jordan River (ac-ft)	220000	220000	220000	220000	220000
Final contents (ac-ft)	397700	433500	294400	349800	275700
*Water surface (feet)	4484	4484	4484	4485	4484
Goshen Bay					
Gross inflow (ac-ft)	--	--	27900	28100	7500
Contents (ac-ft)	--	--	117900	118100	97500
Surface area (acres)	--	--	23000	23000	22000
Net evaporation (ac-ft)	--	--	71600	71600	68500
Final contents (ac-ft)	--	--	84300	104700	85800
Water surface (feet)	--	--	4484	4485	4484
Water Quality					
Utah Lake Ave. (ppm)	1700	1700	1630	1370	1740
Jordan River (ppm)	1410	1340	1020	940	870
Goshen Bay (ppm)	2020	2020	3210	2680	3160

*Compromise elevation is 4489 feet above sea level.

increase water use efficiency through improved irrigation methods and a better knowledge of soil-water-plant relationships.

Structural cost. Canal lining is the major structural cost related to water quality management, which is determined by the total length of canals in each area. The length of canal system in each area and the acreage it served was given by Israelsen, Criddle, and Stock (1940), from which a length of ditch per acre was determined, and from this a total mileage of ditch presently in each area. The Lehi-American Fork and Provo areas both have 0.008 miles/acre and Spanish Fork and Elberta-Goshen areas have 0.002 miles/acre. The Central Utah Project canal mileage in each area was determined from USBR reports (1964).

Total cost per mile of canal is now necessary to obtain a cost for canal lining in each area. Concrete lining was assumed to cost $3 per square yard for 3 inch thickness, non-reinforced lining (Hagan, et al., 1967). The two types of conveyance, project canals and the existing canals were assumed to have average capacities of 310 and 75 cfs, respectively. For these two sizes of canal, the square yardage per foot was computed as 3.8 and 1.9, respectively.

The land leveling costs were estimated on an acreage basis. An average earth moving requirement of one foot cut and one foot fill on each acre at $0.30 per cubic yard was assumed. The total yardage is then 810 yd^3/acre or $240/acre. Land planing and smoothing was assumed to be included in the above figure.

There was assumed to be one flow measurement structure and four control structures for each 160 acres. The measurement structure was estimated at $300 and the control structures at $100 each. On an acreage basis, these structures would cost $4.30 per acre.

Practice costs. Estimates of salt pickup decrease from irrigation practice changes were assumed to be attained from a solid set sprinkler system. A generalized system was then used for a 160 acre unit and expressed on an acreage basis. The design estimates are shown in Table 15. Insight into costs of the various components of the system were obtained from the Sprinkler Irrigation Association's text "Sprinkler Irrigation" (1969). Investment capital was assumed available at 8 per cent interest, a representative figure for such investments.

The total agricultural management costs are given in Table 16.

Table 15. Cost estimates for change in irrigation practices.

Capital Investment

	Cost	Life	Remarks
Pipe	$600/acre	20 years	solid set installed based
Pumping Plant	20/acre	15 years	on 160 acre system
Sprinklers	100/acre	10 years	

Annual Operation and Maintenance (all based on 160 acres)

	Remarks	Cost
Fuel (diesel)	3½ gal/hr., 110 days at 18¢/gal.	$1800/year
Maintenance (pump)	$15/100 hrs., 2650 hrs.	$400/year
Maintenance (system)	1% of investment	$7/acre/year
Taxes and insurance	2% of investment	$14/acre/year
Labor (operating)	10 min./acre/irrig. at $3/hr.	$5.50/acre/yr
Professional Assist. (soil samples, scheduling)		$6.50/acre/yr

TOTAL ANNUITY

Pipe	$61.00
Pumping Plant	2.00
Sprinklers	10.20
Fuel & Maintenance (pumping plant)	14.00
Maintenance (system)	7.00
Taxes and Insurance	14.00
Labor (operating)	5.50
Professional Assistance	6.50
Total per Acre	$120.20

Table 16. Total agricultural management costs.

Area	Total Fixed Cost*	Annual Cost
Lehi-American Fork		
Canal Lining	$5,086,200	$396,720
Land Leveling	5,080,100	304,810
Measurement & Control	38,100	3,310
Total Structural Improvements		$704,840
Practice Improvements		$2,544,270
Provo		
Canal Lining	$7,090,600	$553,070
Land Leveling	5,959,200	357,550
Measurement & Control	44,700	3,890
Total Structural Improvements		$914,510
Practice Improvements		$2,984,570
Spanish Fork		
Canal Lining	$4,496,400	$350,720
Land Leveling	$15,685,200	941,110
Measurement & Control	117,600	10,230
Total Structural Improvements		$1,302,060
Practice Improvements		$7,855,670
Elberta-Goshen		
Canal Lining	$4,123,200	$321,610
Land Leveling	3,390,500	203,430
Measurement & Control	25,500	2,220
Total Structural Improvements		$527,260
Practice Improvements		$1,698,070

* Annual cost on structures was based on 100 year life at 6% interest.

Cost Function for Utah Lake Water Quality Management

The following analysis is undertaken in an effort to obtain a general relationship between construction cost and the resulting decrease in salt concentration in Utah Lake. Two points on a representative curve can be found quite easily. A near maximum point, or the ultimate construction cost and its accompanying lake concentration change is taken directly from the U.S. Bureau of Reclamation (1964). Studies conducted by the USBR resulted in a concentration of 0.8 tons/acre foot with all project construction completed and a concentration without the project of 1.16 tons/acre foot, or a 30% reduction in lake concentration with the total project. Therefore, a 30% reduction in concentration is the maximum that can be expected. However, it was stated that the Provo River portion of the project resulted in no appreciable change in lake concentration, and its cost should be deleted from the 30% cost just discussed.

A second point can be found by determining the effect of the Goshen Bay dike alone. Existing data collected in the Lake indicates a representative concentration for the Lake in 1960. If the Lake is then operated as if the dikes were constructed under 1960 conditions, a new Lake concentration can be estimated. It should not be expected that this analysis will be compatible with the earlier operation study, as different averages were used here to accomodate

USBR estimates. The estimated operation study is shown in Table 17.

The total cost less the Provo River features is $195,700,000 as shown in Table 18, which results in a 30% decrease in salt concentration. Also, the cost of Goshen Bay alone is $40,780,000, which results in a 24% decrease in salt concentration. Therefore, the cost function must pass through these two points as well as the zero point. In the following optimization analysis, the function is more efficiently utilized if presented as an annual repayment cost, so the two known points are converted to annuities at 6% interest for 100 years. The annual cost at 30% decrease in salt is $11,742,000 and at 24% decrease is $2,446,800. The cost function that results is shown in Figure 17.

Table 17. Utah Lake operation comparisons with and without dikes.

Starting content with no dikes

485,500	acre-feet	average end of month contents
+328,700	acre-feet	USBR measured evaporation
813,200		
-540,000	acre-feet	annual inflow (Hyatt, et al., 1969)
273,200		estimated starting content

The corresponding elevation is 4482.5 ft. Goshen Bay elevation must be the same if it is assumed the diking does not change the water surface elevation.
Then:
Diked lake starting content is 220,000 acre-feet. Diked Goshen Bay starting content is 53,200 acre-feet. Starting salt load of diked lake from USBR is (220,000) (1400) (.00136) = 418,800 tons.

Diked Lake Operation

Water inflow to main lake	= 524,400 ac-ft
Main diked lake evaporation	= 126,300 ac-ft
Content	= 618,100 ac-ft
Concentration	= 1024 ppm
Elevation of lake	= 4489 feet
Goshen Bay inflow	= 15,600 ac-ft
Goshen Bay evaporation	= 32,500 ac-ft
Goshen Bay content	= 36,300 ac-ft
Spill to Bay	= 63,700 ac-ft
Salt to Bay	= 95,050 tons
Spill to River	= 220,000 ac-ft
Salt to River	= 284,570 tons
Salt in lake	= 481,660 tons
Water in lake	= 334,400 ac-ft
Concentration of lake	= 1058 ppm
Concentration without project	= 1400 ppm

Table 18. Cost of Central Utah Project features.

	1960-62 Cost	Present Adjusted
Jordanelle Reservoir	$23,860,000	$42,710,000
Provo Bay and Assoc. Features	18,630,000	33,350,000
Goshen Bay Dike	22,780,000	40,780,000
Hayes Dam and Reservoir	11,930,000	21,350,000
Mona Dam and Reservoir	4,040,000	7,230,000
Wasatch Aqueduct and Laterals	19,610,000	35,100,000
Beer Creek Dike and Assoc. Features	1,190,000	2,130,000
Mona-Nephi Pumps and Assoc. Features	8,640,000	15,470,000
West Mona Canals	510,000	910,000
Elberta Canals	2,440,000	4,370,000
Mosida Pumps and Assoc. Features	10,780,000	19,300,000
Pelican Point Pumps and Assoc. Features	3,550,000	6,350,000
Total Project less Provo Bay and Assoc. Features		$195,700,000

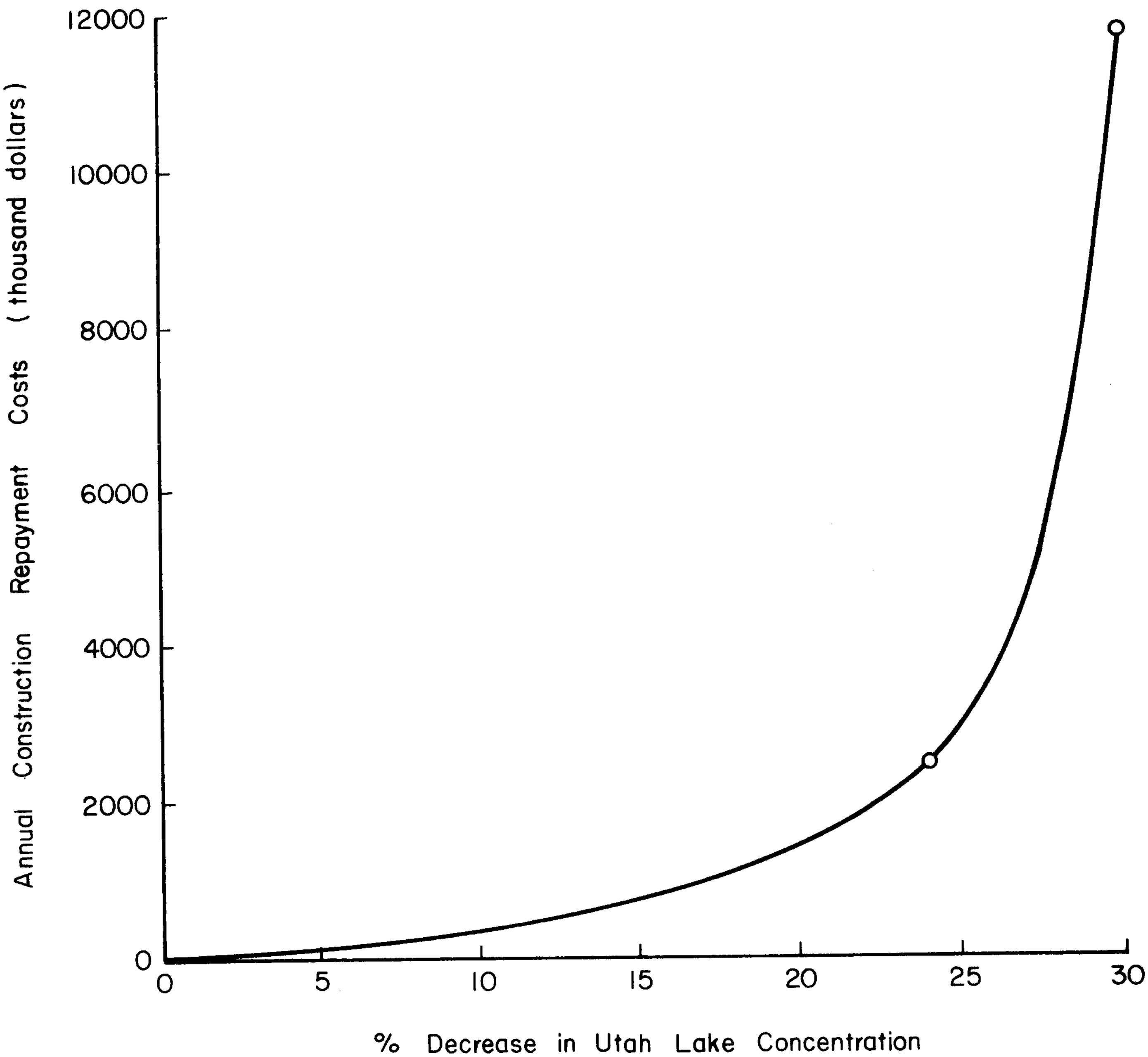


Figure 17. Annual costs of decreasing total dissolved solids in Utah Lake.

SECTION VI

INSTITUTIONAL FACTORS AFFECTING WATER MANAGEMENT IN THE UTAH LAKE DRAINAGE AREA

Introduction

The Utah Lake drainage area lies immediately upstream from the Jordan drainage area, which encompasses the Salt Lake City metropolitan area. Many of the institutional factors important to water quality management for the Denver area (which were listed in the previous report, "Evaluation of Water Management Policies in the Denver Metropolitan Area," hereinafter referred to as the "Denver Report"), would also apply to Salt Lake City. However, the Utah Lake drainage area offers a unique setting for study.

Water Quality Situation

The high mountainous regions of the Utah Lake drainage area and the interbasin transfers (e.g., Weber-Provo Diversion Canal, Duchesne Tunnel, and Strawberry Tunnel) produce substantial quantities of good quality water. A portion of the interbasin transfers to the Provo River (Weber-Provo Diversion Canal and Duchesne Tunnel) are transported via the Salt Lake Aqueduct to the Salt Lake City urban water supply. Other interbasin transfers such as those to the Spanish Fork River, which are flows transported via the Strawberry Tunnel, are used for irrigation and urban uses in Utah Valley.

The primary water quality problems occurring in Utah Valley result from both urban and agricultural water uses. The principal urban water quality problems occur in Northern Utah Valley because of population concentrations in this area, as well as rapid urbanization. The population growth in Southern Utah Valley is slow in comparison with Northern Utah Valley. The water supplies reaching Southern Utah Valley are primarily used for irrigation.

The return flows from urban and agricultural water uses in Utah Valley eventually reach Utah Lake. This lake, which is shallow and has a large surface area, loses half of the inflows to evaporation. Consequently, the concentration of total dissolved solids (TDS) leaving Utah Lake and entering the Jordan River is twice as great as the average inflow TDS. Thus, evaporation from Utah Lake is the greatest single contributing factor to increased TDS levels in the Jordan River.

The water quality problems faced by water users in the Utah Lake drainage area are relatively minor in comparison with the water quality problems to be faced by downstream users. Thus, in contrast with the optimal water quality management solutions involving water supply, distribution, and wastewater treatment for the Denver metropolitan area (or the Salt Lake City metropolitan area, if studied), water management decisions in the Utah Lake drainage area will be primarily dictated by downstream water demands.

Future water demands in the Salt Lake City metropolitan area have been projected to increase dramatically. However, studies have not been made to date which determine the degree that additional water supplies from the Utah Lake drainage area might be utilized, or the necessity for recycling. Studies have been made of additional potential storage developments on nearby mountain streams which pass through Salt Lake City. Another important consideration is the future use of the Jordan River. Plans are underway to convert the Jordan River and adjacent lands into a recreational greenbelt. If this should become a reality, then more stringent water quality standards would have to be placed upon the Jordan River.

As mentioned above, water management requirements in the Utah Lake drainage area will be highly dependent upon downstream water quantity and quality demands. Much of these requirements will be transposed into water management criterion for urban and agricultural water users in Utah Valley. For example, water management will be dictated by either the water quality standards imposed on the "Jordan River at Narrows," or the outlet from Utah Lake. At the same time, standards could be placed upon Utah Lake to insure its suitable use for recreational purposes. Another likely possibility would be to place effluent standards on return flows, particularly urban wastes. In order to control irrigation return flows, influent standards might be imposed upon the canal diversions from the rivers.

The uniqueness of Utah Valley is the dependency of effective water quality management programs on both urban and agricultural water users. Northern Utah Valley is rapidly urbanizing through the conversion of agricultural lands to urban uses, while Southern Utah Valley will remain an agricultural area in the foreseeable future with additional irrigation water supplies being transported to Southern Utah Valley as a part of the Central Utah Project.

Federal and State Activities

Much of the discussion regarding federal activities in water quality management presented in Section III of the "Denver Report" is equally pertinent to Utah, including the Utah Lake drainage area. Therefore, this material will not be reiterated in this report. Also, much of the material regarding water rights would also apply to Utah. Therefore, the reader is requested to review Section III of the Denver Report before proceeding with the following discussion.

Utah's water quantity and quality regulatory functions are organized in much the same manner as Colorado's. Water pollution regulation is handled within the Utah

Division of Health under the Department of Social Services, while water quantity regulation is accomplished by the State Engineer's Office under the Department of Natural Resources. The Utah Division of Water Resources (similar to the Colorado Water Conservation Board), which is a part of the Utah Department of Natural Resources, is responsible for water resources planning and development. Like Colorado, Utah's water quantity regulatory agency is administratively responsible to a different department of State government than the water quality regulatory function.

The record of Utah's water quality regulatory agency in attaining secondary treatment of municipal wastes from cities surrounding Utah Lake is quite impressive. As shown in Table 19, seven trickling filter plants were constructed near Utah Lake between 1953 and 1959. The total design population for these plants is 120,000. A review of federal legislation shows that Utah was responsive to federal programs in the 1950's. Two additional plants, having a total design population of 12,000, were constructed in Utah Valley during the 1960's.

Urban Water Management

The listing of wastewater treatment plant construction in Utah Valley is indicative of the organizational framework for both the water supply and wastewater functions. In other words, each municipality handles its own

Table 19. Construction of secondary municipal wastewater treatment plants in Utah Valley.

Year Operation Began	Community	Type of Plant*	Design Population	Flow, mgd
1953	American Fork	TF	10,000	1.50
1956	Pleasant Grove	TF	8,000	1.00
1956	Provo	TF	31,500	12.00
1956	Springville	TF	8,000	2.00
1957	Lehi	TF	5,000	0.50
1959	Orem	TF	45,000	5.60
1959	Spanish Fork	TF	10,000	1.80
1964	Salem	TF	2,000	0.20
1968	Payson	TF-2S	10,000	1.25

*TF is trickling filter and TF-2S is two-stage trickling filter plant.

requirements for additional water supplies, as well as construction and operation of a wastewater treatment plant.

Many of the municipalities in Northern Utah Valley will be receiving additional water supplies when the Central Utah Project is completed. The Salt Lake City metropolitan area will receive a mean annual water supply of 50,000 acre-feet, while the cities in Northern Utah Valley will receive 20,000 acre-feet.

In addition to Central Utah Project Water, there are numerous possibilities available to municipalities in the Provo District and American Fork-Lehi District for acquiring additional urban water supplies. Besides developing additional good quality water supplies at upper elevations in the nearby watersheds, considerable quantities of water could be acquired by purchasing agricultural water rights. There are two very important factors in Northern Utah Valley which facilitate the conversion of agricultural water rights to urban water uses. First, excessive quantities of water are diverted to irrigated lands in the Provo District; and second, agricultural lands are being converted to urban uses. Adjudication of water rights in the Provo District, along with enforcement of beneficial use, would provide significant quantities of water for other uses. Also, for lands being converted from agricultural to urban use, a policy requiring developers to deed the associated water rights to the municipality serving the new development would result in maintaining a better balance between competing water demands.

This particular report is concerned with optimal water quality management in the Utah Lake drainage area. The only effect of downstream water users (Salt Lake City metropolitan area) is reflected in the water quality standards imposed at the outflow from Utah Lake. If the study area included both the Utah Lake drainage area and the Jordan drainage area (which contains the Salt Lake City metropolitan area), then the optimal water quality management solutions would be similar to the results developed for the Denver metropolitan area. This would likely place more stringent water management requirements upon the Utah Lake drainage area, since downstream water demands would be many times greater than the demands in Utah Valley.

Each of the major cities in Utah Valley have their own individual secondary wastewater treatment plant. As populations increase, there will be a growing need to expand these facilities. Eventually, questions will arise regarding economies of scale in expanding each treatment plant, as compared with having a regional wastewater treatment plant. This will be particularly true for Northern Utah Valley, which is experiencing rapid urban growth. This same "economies of scale" presently results in a much heavier per capita tax burden for the smaller communities to construct and operate a wastewater treatment plant.

If more stringent water quality standards were to be placed on urban effluents in the future, then tertiary treatment would likely be required. If advanced wastewater treatment processes were required, then a greater necessity would exist for one or two regional wastewater treatment plants. Again, if the Salt Lake City metropolitan area was included in this study, then optimal water quality management solutions could include tertiary treatment for Utah Valley, with the effluent being recycled into the urban water supplies for Utah Valley, or transported into downstream urban water supply systems.

Agricultural Water Management

Analysis of agricultural water management in Utah Valley is complicated. There are numerous irrigation entities which have been formed under the State laws of Utah. Of the approximately 75 irrigation entities, many of which serve overlapping needs, 29 irrigation companies serve the vast majority of irrigated lands receiving surface water supplies. Lands served from groundwater supplies were analyzed separately.

As described earlier in this report, Utah Valley can be subdivided into Northern Utah Valley and Southern Utah Valley. Northern Utah Valley contains the Provo District (lands served by water from the Provo River) and the American Fork-Lehi District; while Southern Utah Valley is further subdivided into the Spanish Fork District and

Elberta-Goshen District. Northern Utah Valley is "water rich" (particularly the Provo District), while Southern Utah Valley has an inadequate water supply. The enlargement of Strawberry Reservoir as a part of the Central Utah Project will result in additional interbasin transfers to the Spanish Fork River to satisfy irrigation demands in Southern Utah Valley.

Of the two water quality parameters selected as indexes of water pollution in these studies, total dissolved solids (TDS) is very pertinent to agricultural water management. Earlier sections of this report have shown that Northern Utah Valley contributes only small quantities of salt pickup, with the major salt pickup occurring in Southern Utah Valley. Thus, optimal agricultural water management policies for Southern Utah Valley are a major concern both because of inadequate water supplies and the salt contribution to Utah Lake.

Besides the separate irrigation companies which were formed for each canal that was constructed to divert water from a natural water course, additional irrigation entities were formed to accomplish major water development projects. For example, the construction of Strawberry Reservoir resulted in the formation of the Strawberry Water Users Association, which contracted with the U.S. Bureau of Reclamation for the repayment of construction costs. In turn, the Strawberry Water Users Association is responsible for delivering project water to each of the irrigation companies in the Spanish Fork District which have stock in Strawberry Reservoir. A very similar example is the Provo River Water Users Association, which was formed as the responsible agency for repaying the construction costs of the Provo River Project.

The construction of the Central Utah Project, which is presently underway, has resulted in the formation of the seven-county Central Utah Water Conservancy District. Both Utah County (which includes Utah Valley) and Salt Lake County are included in this conservancy district. Of particular significance to this study is that the water supplies developed by the Bonneville Unit of the Central Utah Project are nearly equally divided among urban water users and agricultural water users. Thus, this conservancy district has been placed in a role where nearly equal concern should be given to both urban and agricultural water management.

There is considerable difference in the water rights held by each of the 29 major irrigation companies analyzed as a part of this study. Since the water duty (acre-feet of water diverted from a river for each acre of land served) differs to such an extreme, questions naturally arise as to maximizing the benefits from available water supplies. First of all, how could water supplies be redistributed in Southern Utah Valley to maximize agricultural benefits? Or better yet, what would be the effect of various improved water management practices upon alleviating water supply shortages in Southern Utah Valley? Will the Bonneville Unit of the Central Utah Project essentially alleviate water supply shortages? What is the best long-range use of excess water supplies in Northern Utah Valley?

Although it was never intended that this particular study should answer all of these questions, it is readily apparent that answers are needed. In fact, the construction of the Bonneville Unit of the Central Utah Project will impose a major change upon the water system, which is also an opportune time for achieving institutional changes which would facilitate improved water management practices.

SECTION VII

ANALYSIS OF WATER QUALITY MANAGEMENT STRATEGIES

Introduction

In the Utah Lake drainage area, the most serious water quality problem is the concentration of total dissolved solids, or salinity. However, because of the increasing population in the area, an important consideration is the maintenance of water quality which supports the wide range of recreational activities. These uses of water are mainly affected by the organic pollutants such as BOD and fecal coliforms stemming from urban water utilization. In addition, some exotic pollutants such as pesticides, herbicides, and fertilizers from agricultural return flows and the heavy metals, acidic wastes, and brines from industrial demands are also contributors to water quality deterioration. As a result, the optimal management of water quality necessitates programs which coordinate both agricultural and urban pollution control efforts.

Aside from the aesthetic and recreational factors, water quality management in the Utah Lake area is prompted largely by the sensitivity of downstream users to the concentrations of the pollutants. Although water shortages are experienced locally due to poor distribution within the basin, most uses are adequately supplied well into the future and as such, water supply is not a problem. Such is not the case downstream, however, and the large urban centers in the Salt Lake Valley rely heavily on the flows from the Utah Lake drainage area. Thus, the conditions in the Salt Lake City area are very much similar to those analyzed in the Denver area in the previous report "Evaluation of Water Management Policies in the Denver Metropolitan Area," submitted as part of this project. This study therefore, answers important questions on a larger scale concerning water management in urbanizing areas.

Water quality management in the Utah Lake region can be broadly classified in three categories. First, the reduction of both organic and inorganic pollutants in individual hydrologic subunits of the area. These have been termed districts in this study so this first category can be referred to as district water quality management. Two water quality parameters are used in this study as indicators of organic and inorganic pollution. These are BOD and TDS which were selected because they are commonly utilized in designs and monitoring investigations.

The second classification of water quality management is the coordination of pollution control activities between the four principal districts adjacent to the Utah Lake. Since each district is characterized by a different mix of urban and agricultural uses, it is necessary to optimally select the policies of water quality control in each district which gives the best overall cost-effectiveness in the area. Each of the districts lie in Utah Valley which extends along the eastern shores of Utah Lake. Consequently, this phase of the study can be termed the Utah Valley water quality management.

Finally, the water quality control throughout this region includes at least two other alternatives: (1) lake diking and (2) desalination. On the basin-wide scale, therefore, it is important to optimize the policies for pollution control by comparing each alternative method and selecting the best combination achieving the goals set for the effluents from the drainage areas.

In order to accomplish the objectives of this study, mathematical models were prepared for each segment of the management process. These models were presented in the report entitled "Mathematical Modeling of Water Management Strategies in Urbanizing River Basins." Data outlined in this report was then applied to the models to generate these results.

District Water Quality Management

At the district level, water quality management is a problem of coordinating agricultural and urban efforts in an optimal manner. Since BOD is generally not an important water quality parameter in agricultural return flows, the control of this pollutant is based on urban wastewater treatment and act as fixed costs in the optimization of district policies. The concentrations of TDS, common to both sectors, is thus selected as the parameter linking together agricultural and urban water pollution control efforts.

Before discussing the results of coordinating agricultural and urban salinity control, it is probably helpful to review the characteristics of each sector. Then, after the results are presented, the institutional factors will be examined. And finally, a discussion of district water quality management policies in the future will be given.

Agricultural Salinity Control

In any salinity control program, the primary objective is to minimize the concentrations of TDS in the return flows. To achieve this goal, the basic alternatives are either to reduce unnecessary evaporation and transpiration, alleviate conditions in which salts are added to the flow system, or physically remove the salts from the flows. Agricultural salinity control is concerned almost exclusively with the salts which are leached from soils and aquifers.

To minimize the effects of agricultural water use (primarily irrigation), it is necessary to reduce the quantities of water which seep from canals and ditches, percolate through the root zone, and flow off the fields into wasteways, marshes, and ponds. A useful indicator in this regard is called the irrigation efficiency; the percentage of the diversions for agricultural purposes which is beneficially used by the croplands. Increases in irrigation efficiency may be accomplished by rehabilitating the irrigation system to more effectively handle water, by improving the irrigation practices in an area to best reflect the conditions required for efficient water application, or by a combination of both.

In the modeling report noted previously, the effectiveness of these two alternatives were discussed, but it is helpful here to illustrate again the functions utilized to evaluate agricultural salinity control in the districts of Utah Valley. These functions, shown in Figure 18, indicate the cost-effectiveness distribution which can be realized by treating a specified portion of the area. For example, if 50% of the system was rehabilitated structurally (linings, measuring structures, control structures, etc.) about 30% of the salts currently being picked up would be eliminated. These functions thus represent the distribution of costs within each alternative and are based on the assumption that initial expenditures will achieve more effectiveness than later spending simply because the most detrimental problem would be fixed first.

An estimate was made of the total costs necessary in each district to treat 100% of each area with structural and practice improvements. These costs were based on the feasibility studies in the Utah Lake area conducted as part of the Bureau of Reclamation's Central Utah Project,

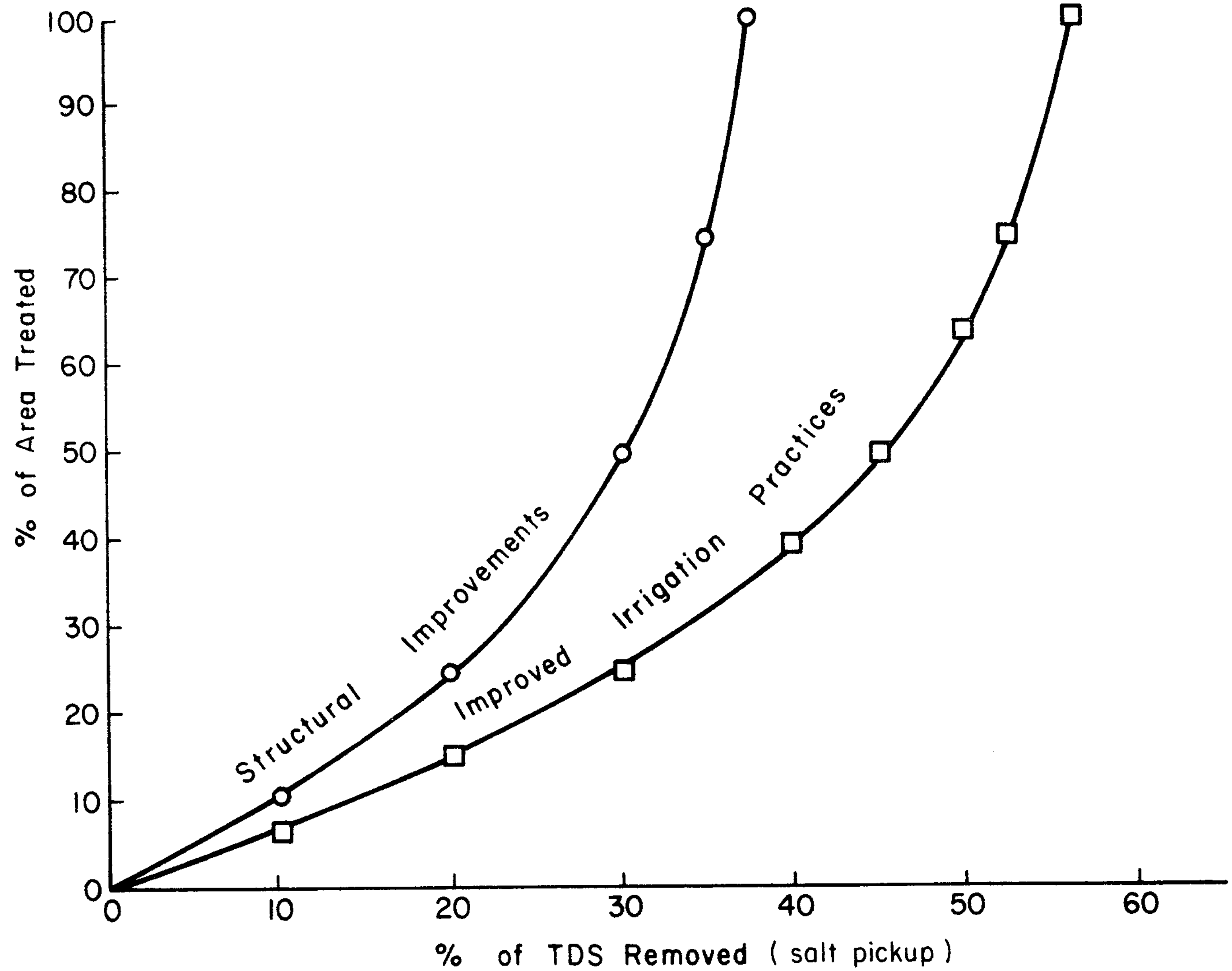


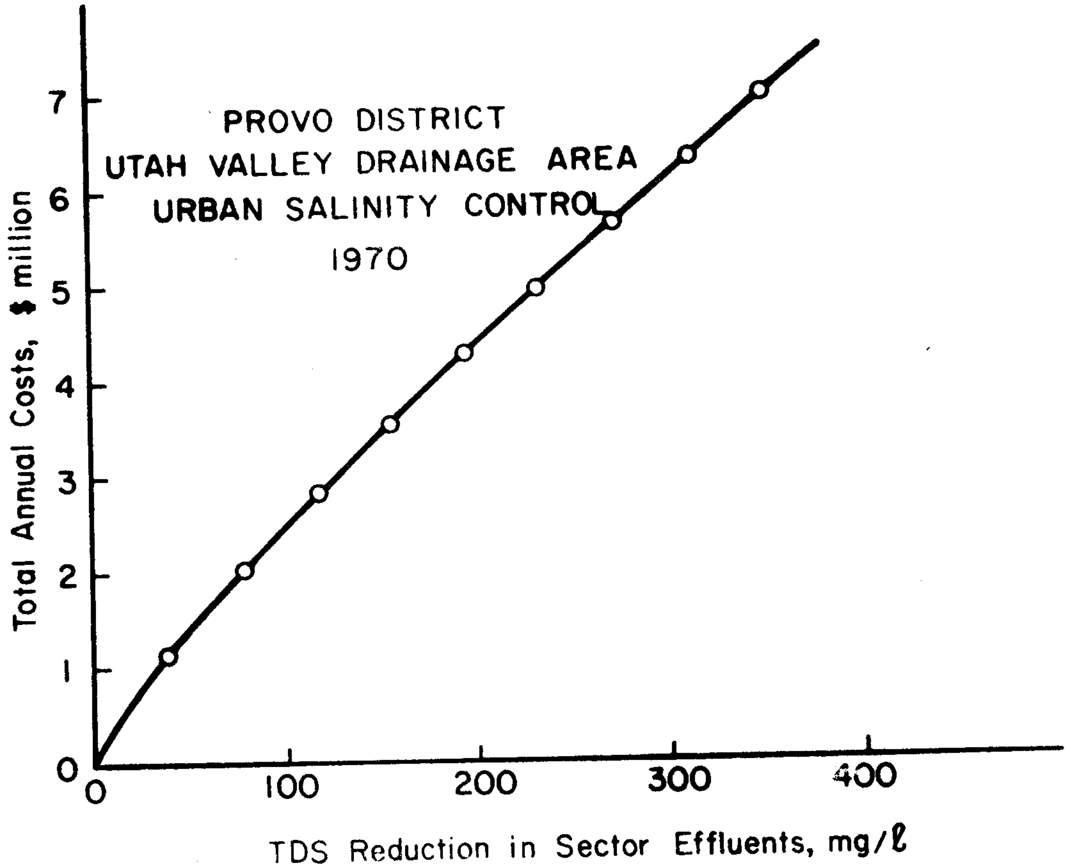
Figure 18. Cost-effectiveness distributions for agricultural salinity control.

the State of Utah's state water plan, and the Soil Conservation Services' ongoing programs for local assistance. A summary of these estimates are given in terms of annual 1970 dollars in Table 17.

Each of the distributed cost-effective relationships exhibit increasing marginal costs with scale, indicating that an optimum combination of the two alternatives must be selected for each level of salinity control. This optimal value for each treatment will occur at the point where the marginal costs are the same. As an illustration, the agricultural salinity control costs for the Provo District were optimized and presented in the lower half of Figure 19. It is observable from this plot, that between a 20 and 30 mg/l reduction in the TDS concentrations in the agricultural return flows, an abrupt transistion is made. This characteristic, common to each district, results when a combination of structural improvements and practice improvements is optimal. Before this point, the marginal costs of one alternative are always less than the associated values of the other, the specific case being dependent on the values in Table 17.

Urban Water Quality Management

Included in the upper half of Figure 19 are the costs of TDS removal from aggregate urban effluents of the Provo District. Of immediate interest is that urban salinity control is characterized by decreasing



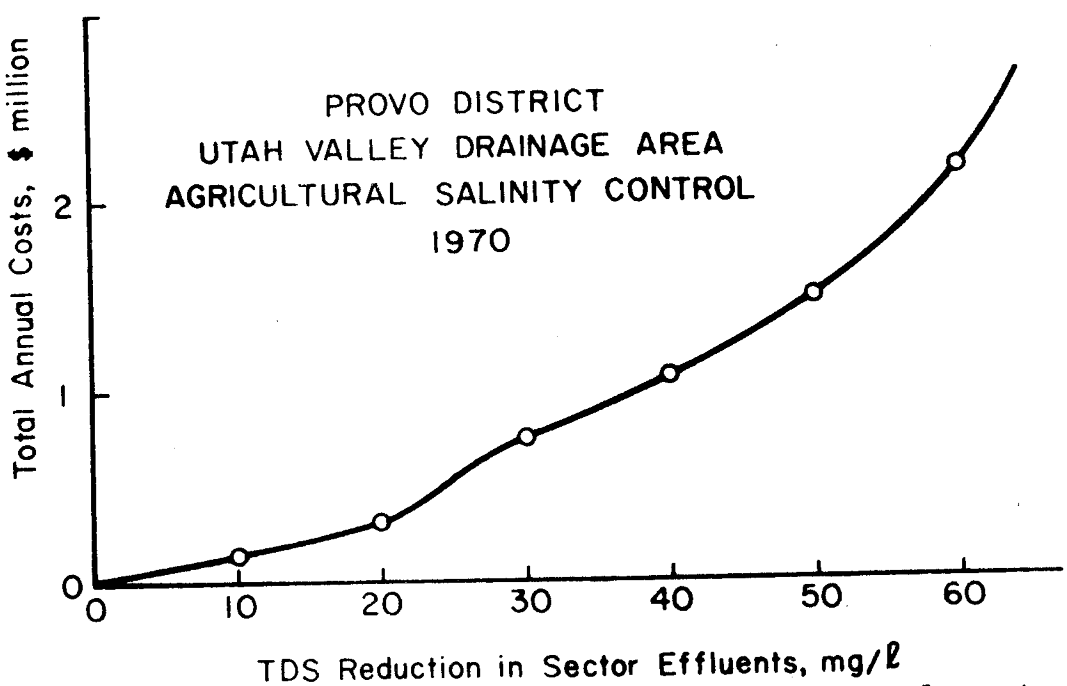


Figure 19. Agricultural and urban salinity control costs as a function of the effect on the sector effluents of the Provo District.

marginal costs with scale. In addition, since salts are being removed from the effluents by physical processes, the effectiveness of TDS removal in the urban sector is 6 to 7 times greater than achieved in the agricultural sector at comparable costs.

Urban salinity control in this study is achieved by treating the effluents with a tertiary process to remove materials which would plug the membranes of the electro-dialysis desalting plant. In the modeling reports, the cost functions for this process were given, and will not be repeated herein. The BOD control in these treatments was also varied to test the effects on the strategies developed later and were shown to be fixed costs in this operation of the model.

Coordination of Agricultural and Urban Water Quality Management

If the average TDS concentration in the return flows from a district were to be reduced by a specified amount, a question of considerable impact would be "how to accomplish the goal at least cost?" One alternative would be to implement desalting of urban effluents to achieve the desired mix, and another would be to invest enough into the agricultural sector to achieve the same result. There are, however, reasons why a combination, an optimal combination, of a portion of each alternative would be better than either by itself. First, if the district effluent is to be improved only slightly, then neither the urban or agricultural investment would be high. However, the marginal costs of the agricultural alternative at low levels of control are much less than the values for the urban system and as a result the best policy is likely to be agricultural in nature. If the salinity control is to be substantial, then it is obvious that the reverse is true. As a result, the specific strategy depends on the standards set on the district effluent.

The objective of modeling the interaction of agriculture and urban water use at the district level is to identify the characteristics of the optimal water quality management strategies. In this study, this was accomplished for each district for a wide range of conditions. Standards were superficially imposed on the effluents of each district ranging from current conditions to the calculated maximum pollutant removal. In order to demonstrate these results without becoming too lengthy, the Provo and Spanish Fork districts will be examined in detail.

The Provo District is the only district in the study area which presently has urban water demands of comparable magnitude to the agricultural demands. This district contributes about 40% of the water in the basin and 27% of the salts. The policies for salinity control for this area, illustrated in Figure 20, were optimized. In the left part of the figure, the total annual costs are plotted against the TDS reductions achieved in the district

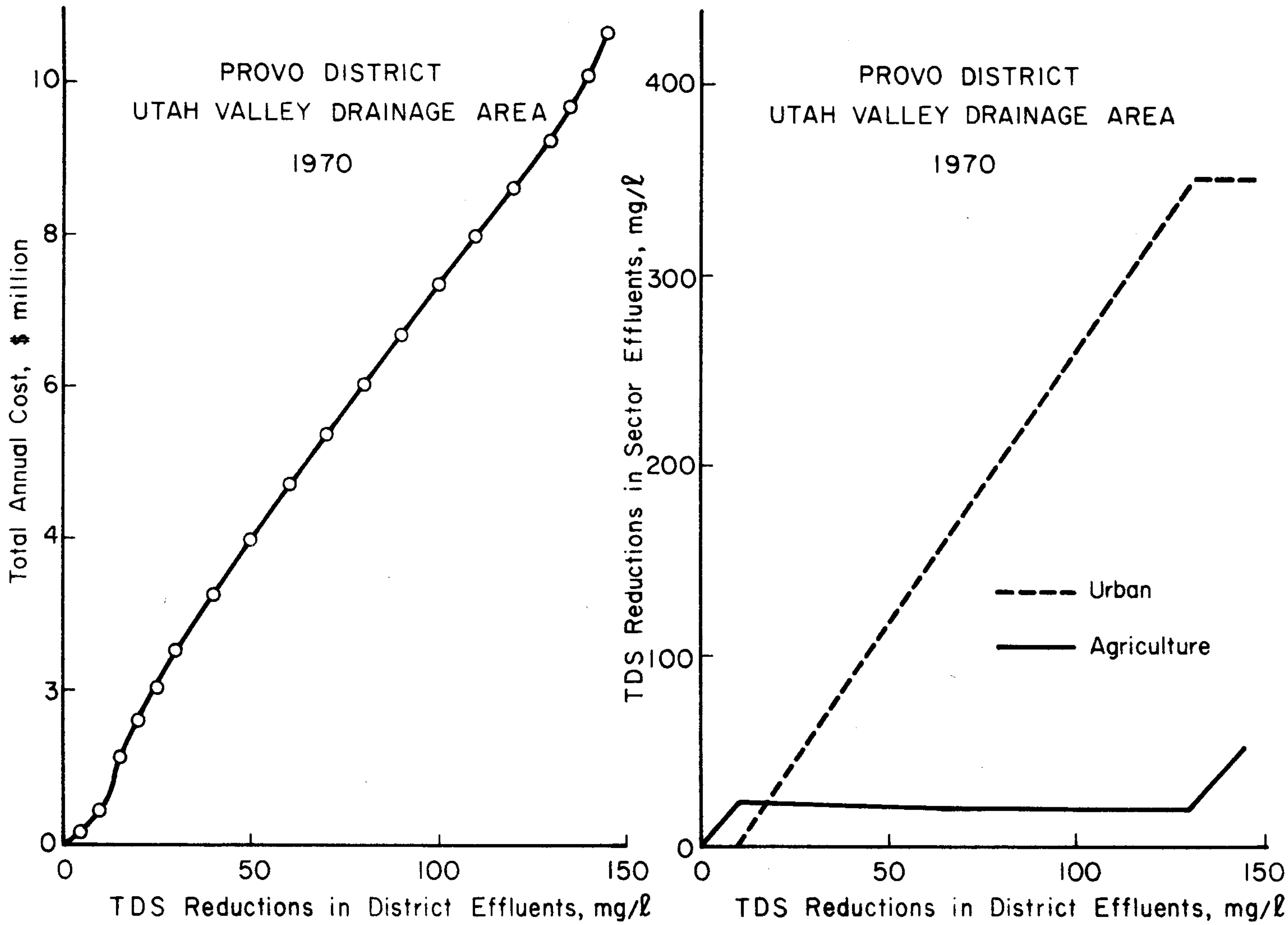


Figure 20. Optimal policies for salinity control in the Provo District.

effluents. The right portion of Figure 20 indicates the optimal policies for agricultural and urban water quality control. For TDS concentrations less than 10 mg/l in the district effluents, salinity control is primarily an agricultural policy. However, as the necessity for TDS removals push past this point, agricultural controls remain essentially fixed as urban policies are implemented. Finally, the TDS controls are rigid enough for both alternatives to be in force. The cost curve reflects the alternating policies, which indicate increasing and then decreasing marginal costs characteristic of the controls in the agricultural and urban sectors.

The Spanish Fork District, representing 31% of the flows and about 34% of the salts in the Utah Lake area, is an area which is predominantly agricultural in nature. It is obvious therefore that water quality management should be primarily concerned with managing the agricultural sector. A plot of total annual costs versus TDS reductions in the district effluents, shown in Figure 21, substantiates this conclusion. The curve represented in Figure 21 has two points where the curves change shape that are of importance. At a value of TDS reduction of about 75 mg/l, the noticeable break in the curve indicates the shift from one alternative in the agricultural sector to a combination of both structural improvements and improving practices. The undulation in the curve at about 130 mg/l, however, indicates the point where urban effluent

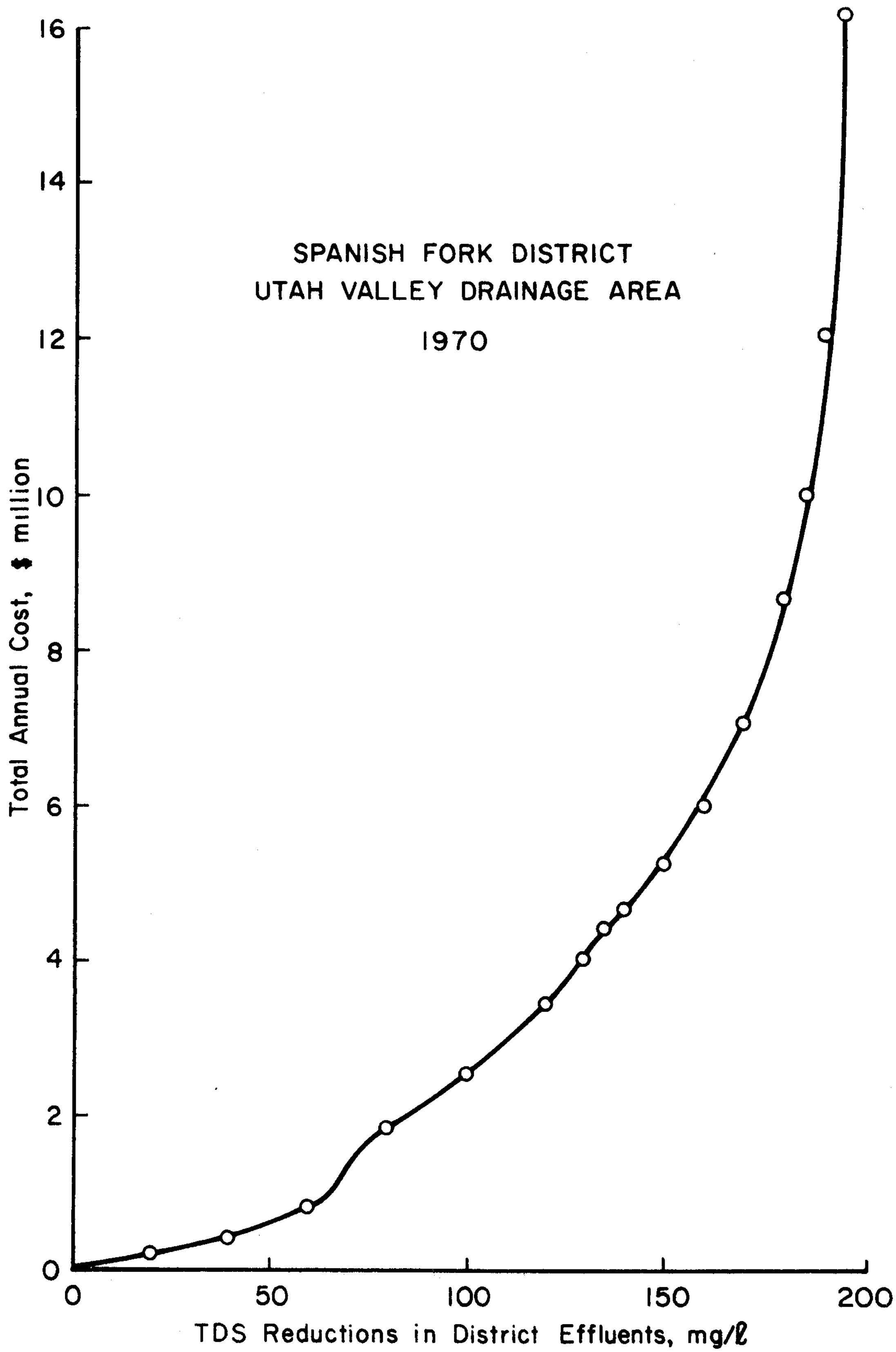


Figure 21. Total annual costs for salinity control in the Spanish Fork District.

desalting is introduced. An examination of the policy, illustrated in Figure 22, reveals that the implementation of desalting is almost immediate for all of the urban effluents. Beyond this point, salinity control is achieved by treating the agricultural sector.

A comparison of the results for the Provo and Spanish Fork districts emphasizes the need to evaluate the optimal strategies. If, for example, the conclusions drawn from the Spanish Fork District were uniformly applied to the conditions of the Provo District, the costs would be substantially higher than are shown. The basic policy, however, can be tentatively stated. If TDS reductions in the district effluents are small, it is likely that the best investment is in the agricultural sector. In addition, if complete control is desired, it is obvious that all measures must be undertaken in their entirity. In the middle ground, the decisions are much less apparent and should be evaluated for each set of conditions.

Institutional Factors

In the preceding paragraphs, the analysis has taken an aggregated district view, while in reality, urban and agricultural interests in these areas are numerous. From much of the investigation presented in the modeling and Denver reports, it is economical to consolidate urban wastewater treatment responsibilities to take advantage of the economies of scale inherent in such physical facilities.

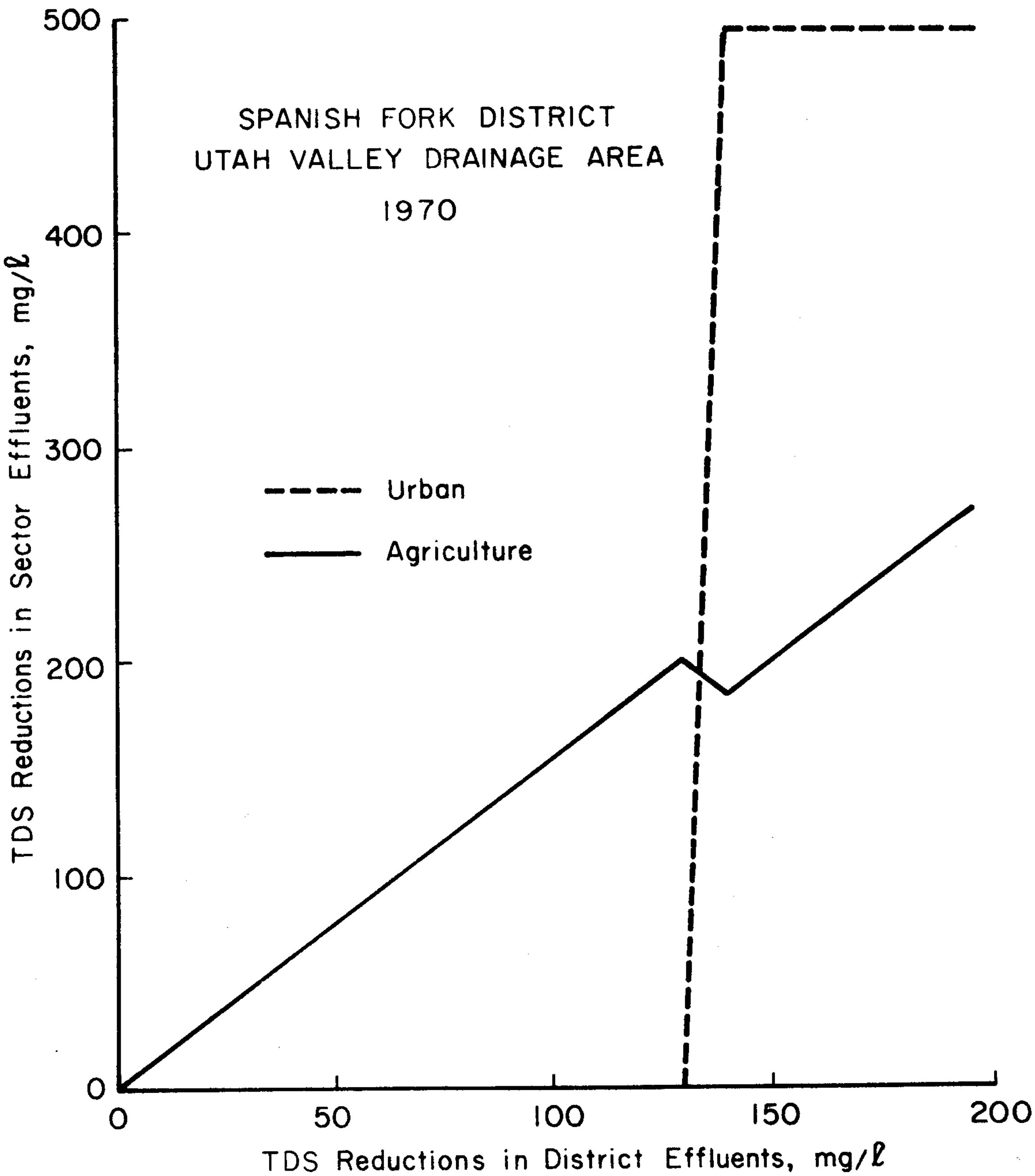


Figure 22. Optimal policy for reducing the concentrations of TDS in the return flows of the Spanish Fork District.

Consequently, an important institutional factor in implementing water quality control programs in the Utah Lake area is the integration of municipalities into regional administration. The cost advantage of constructing and operating one tertiary and desalting plant rather than a host of them must be weighed against the costs of transporting the sewage effluents to a central location. If such consolidation is not possible because of infeasibility, or the inability to coordinate municipal wastewater treatment among the individual cities, then the optimal policies will be to add these special treatments to the largest urban centers and omit the smaller ones. This type of policy tends to be an inequitable distribution of water quality management responsibility.

In the agricultural sector, consolidation for water quality management is undesirable because of the large diseconomies with scale. Recalling that the costs were distributed in this sector to take advantage of treating the most detrimental water quality effects first, the more disaggregate the agricultural sector is, the more this assumption is valid. Since water distribution is a collective enterprise, structural improvements and more efficient practices should be engaged at the irrigation company or district level. On the other hand, irrigation practice improvements are best facilitated at an individual farm level.

It should be noted that these results do not suggest disaggregating management and operational responsibilities, but rather the disaggregation of investment to manage water quality. The distinction to be made is that when costs indicate economy of scale, consolidation needs to be considered. If such scale effects are in reverse, consolidation is discouraged. For example, it may be feasible to consolidate irrigation systems into a single management unit to reduce the duplication of many services. However, if money is to be spent controlling salinity, the most serious problem should be treated first. Consequently, policies should not be implemented uniformly in each locality. If seepage is the most serious problem in one area, while excessive deep percolation losses is the major problem in another area, optimal strategies would not suggest complete seepage reduction or minimization of deep percolation losses throughout the area.

To facilitate policies which achieve the greatest cost-effectiveness, it is necessary to coordinate local efforts at all levels. Institutional barriers which prohibit such strategies must therefore be closely examined to see if changes are warranted.

Future Conditions

The Utah Valley area is expected to witness significant growth in its urban population in the next four decades. Nearly all of this growth will be centered in the Provo District, an area already predominantly urban in character. As a means of assessing this urbanization upon water quality management decisions of the future, the projected data for the year 2000 was applied to the Utah Lake models. The results were then analyzed in accordance with the preceding sections.

Because agricultural water quality management is largely directed at alleviating conditions leading to excessive concentrations of salinity, the future costs (in terms of 1970 dollars) do not change significantly. What changes that do occur result from diminishing agricultural acreage. The implementation of new technology has not been considered, nor has any of the other unpredictable events which have historically improved the standard of living.

Urban water quality management costs will increase significantly. Total desalting of urban effluents in the Provo District would increase from $7 million annually in 1970 to over $13.5 million annually by 2010 as the urban effluents are slightly more than doubled. The American Fork-Lehi District will also realize a two-fold increase in urban demands by 2000, but in comparison with the Provo District, these increases are relatively small.

The effects of urbanization at the district level will increase the importance of desalting. Desalting not only exhibits significant economies of scale, but also allows for much more potential control on the district effluents.

When the policy for the Provo District for example was plotted, almost no agricultural water management was involved until the ultimate district control was suggested. The important institutional factor is thus the consolidation of urban wastewater treatment systems.

Utah Valley Water Quality Management

Once the individual districts have been optimized for any specified effluent standard, the next major issue is "if the entire Utah Valley area was to be controlled by various aggregate standards, what would be the optimal policies for coordinating the water quality management among the districts?" The answer to this question is extremely important from state or federal planning view points. All interstate streams have had stream standards imposed to manage water quality, but the methods for setting such standards included slight, if any, optimization philosophies. Consequently, the standards were set according to a "equitable" formula and probably do not represent optimal regional water quality management strategies. This analysis is directed at coordination of water pollution control activities regionally.

Present Conditions

Each of the district models were conjunctively operated to achieve a range of aggregate TDS standards in the return flows from Utah Valley. The results, presented pictorially in Figure 23, indicate some interesting characteristics of regional water quality management.

When TDS reductions from Utah Valley are a relatively small fraction of the potential control, the Spanish Fork District is the primary area where funds are invested to meet the standards. Recalling that when TDS controls were slight, the low marginal costs in the agricultural sector directed efforts in that direction, the optimal policies for achieving the standards at minimum cost reflect these conditions. When the standards on Utah Valley require TDS reductions of about 60 mg/l, the marginal costs in the Spanish Fork District increase until it is more economical to employ extensive control in the Provo District, which consists primarily of desalting the urban effluents.

Two other observations may also be of interest. First, the contribution from the small districts, American Fork-Lehi and Elberta-Goshen, is insignificant. This would lead to the conclusion that the large areas be attended to primarily, which is not an unexpected result. The second detail is somewhat related to the first. By optimizing water quality management regionally, it is apparent that the cost-effectiveness is enhanced. This characteristic is observable in the curved upper boundary of Figure 23 representing the total annual costs. Consequently, on a regional scale, water quality management

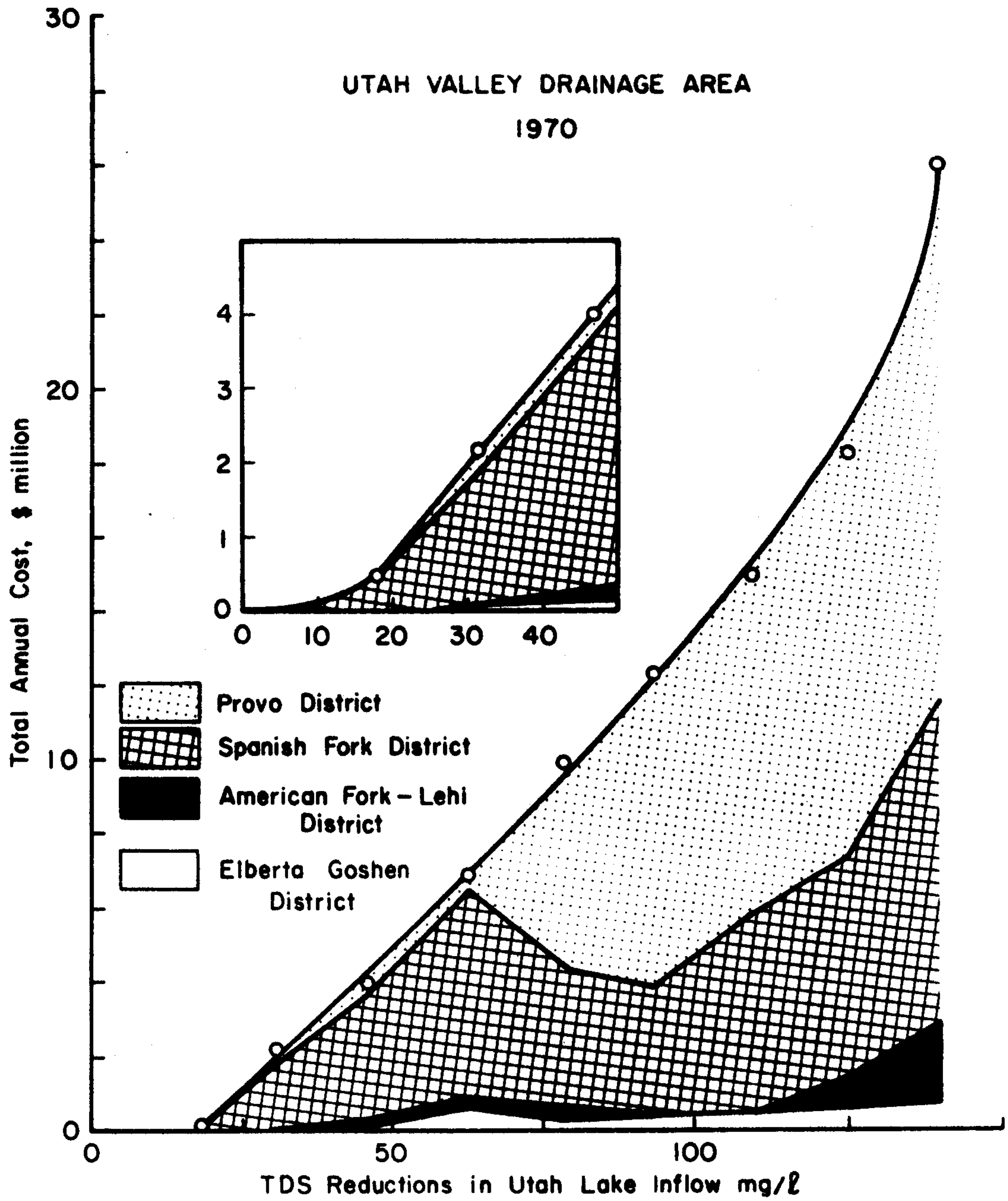


Figure 23. Optimal water quality management policies in the Utah Valley area.

should show increasing marginal costs with scale indicating that the more detrimental effects are corrected first.

Future Strategies

By the year 2000, when the primary water use in the Provo District will be urban in nature, the optimal regional strategies will be significantly altered. The results of this analysis are presented numerically in Tables 20 and 21 and can be examined to assess the changes which are expected to occur.

The price advantage of treating the agricultural pollution sources is substantially reduced for assumed future conditions, again because after some TDS reduction, the scale effects associated with urban wastewater treatment are effective enough to introduce these policies into the regional strategy. The total annual costs are therefore also reduced by these economies of scale.

The effect of urbanization on water quality management decisions will be to increase the emphasis on urban wastewater treatment and decrease the restrictions on agricultural water uses. The specific nature of these decisions, however, depends on the ultimate requirements for pollution control. The less restrictive strategies will encourage agricultural water quality management until the marginal costs of urban wastewater treatment are reduced sufficiently with scale to modify the overall policy. Since the exact requirements for an area such as the Utah

Table 20. Optimal water quality management policies in the Utah Valley area in the year 2000.

TDS Reduction In Valley Effluents mg/l	TDS Reduction in District Effluents, mg/l			
	Provo District	Spanish Fork District	American Fork-Lehi District	Elberta-Goshen District
0	0.0	0.0	0.0	0.0
22	0.0	15.6	0.0	6.4
45	0.0	37.2	0.0	7.8
67	44.6	15.6	0.0	6.8
89	71.4	14.9	0.0	2.7
112	93.0	14.9	0.0	4.1
134	116.0	13.4	0.0	4.6
156	125.0	26.0	0.0	5.0
178	125.0	47.6	0.0	5.4
201	127.0	53.5	13.4	1.1
208	134.0	59.5	7.4	0.0

Table 21. Annual costs of optimal water quality management policies in the Utah Valley area in the year 2000 (1970 dollars).

TDS Reduction In Valley Effluents mg/l	Annual costs in each district, $ million				
	Provo District	Spanish Fork District	American Fork-Lehi District	Elberta-Goshen District	Total
0	0.00	0.00	0.00	0.00	0.00
22	0.00	0.72	0.00	0.66	1.38
45	0.00	4.12	0.00	0.70	4.88
67	7.25	0.72	0.00	0.66	8.63
89	10.71	0.65	0.00	0.16	11.52
112	13.34	0.65	0.00	0.24	14.23
134	16.05	0.53	0.00	0.45	17.03
156	17.07	2.38	0.00	0.48	19.93
178	17.07	5.89	0.00	0.57	23.53
201	17.33	7.95	3.69	0.65	29.62

Valley would not be known until water quality management policies has been optimized on a basin-wide or even state-wide scale, the specific structure of pollution control strategies would not be known. In the following analysis, these factors will be defined to a limited extent.

Basin-wide Water Quality Management

In order to satisfy the water quality requirements of the uses below the Utah Lake drainage area, the flows in the Jordan River would necessarily be subjected to a maximum concentration of TDS. To meet such a constraint optimally, an appropriate combination of controls in Utah Valley would be set along with a reduction in the surface area of Utah Lake and a desalting capacity for treating the outflows.

The effect of Utah Lake is the most detrimental deterioration in water quality in the region. In evaporating half of the inflows, it doubles the concentrations of salts. Consequently, outflows which would ordinarily be about 500-700 mg/l are presently 1200-1300 mg/l. The water pollution control alternative of lake diking is therefore worth substantial examination. From the relationship plotted in Figure 17, it is apparent that this measure also exhibits large economies with scale.

Desalination of Utah Lake outflows to satisfy growing urban demands along the Wasatch Front has been studied in some detail by Haycock, Shiozawa, and Roberts (1968). A favorable conclusion from that particular study led to the inclusion of a desalting alternative in this study. However, the objective here is not to amend some flows for the more sensitive demands, but all flows to a quality sufficient to satisfy all downstream requirements.

TDS standards were imposed on the Utah Lake outflows which would require an average reduction in the concentration of salts from 0-950 mg/l. These standards would result in TDS levels in the Utah Lake outflow ranging from the 1300-1400 mg/l at present to about 400 mg/l if extreme measures were taken. The results have been included in Figure 24 and include the optimal policies as well as the minimum costs.

From the results presented in the previous paragraphs, these results are probably not surprising. However, the conclusion that the Utah Valley area not be included in any salinity control programs is a very significant result. This would indicate that urban pollution control be limited to organic substances such as BOD in order to facilitate local recreational uses. In addition, the BOD removals should be accomplished on an aggregated basis, with the largest urban centers included first. Another important result indicated here is that the current plans for lake diking as part of the Central Utah Project are too extensive. Even though these diking projects are being planned more for saving water rather than

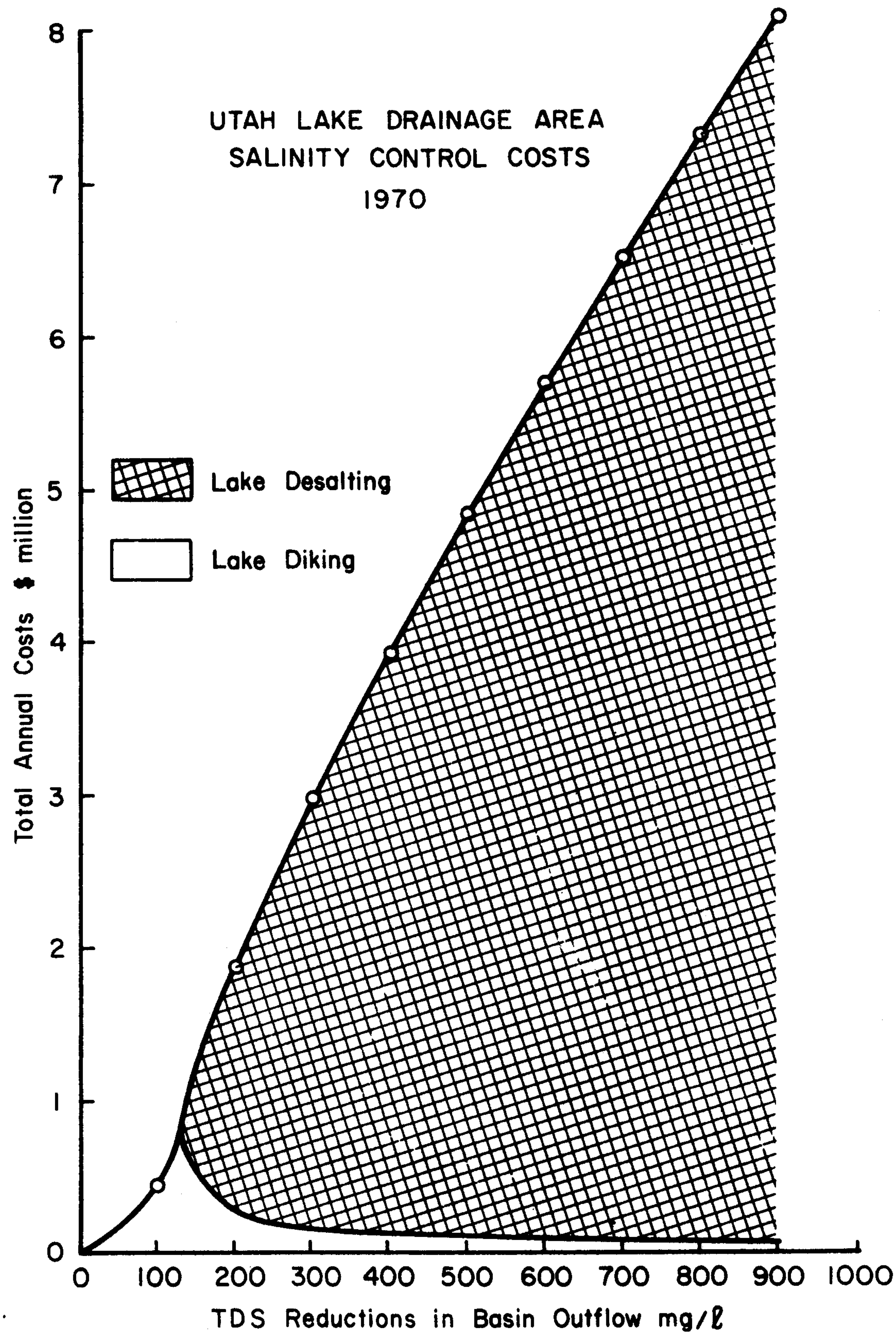


Figure 24. Optimal water quality management strategies in the Utah Lake drainage area.

water quality control, more usable water supplies could be obtained for less investment with desalting.

If the TDS concentrations in the flows from Utah Lake were to be reduced 200 mg/1, it would cost approximately $12 million annually to accomplish this goal in Utah Valley and about that much with diking. Under the optimal strategy suggested by these results, the same effect could be achieved at a cost of $1 million annually (assuming a 50 year repayment period and about 6% interest). The point to be made here is the enormous savings to be realized by small optimization analyses. Water quality management need not be excessively expensive unless the measures selected to curtail degradation are not carefully planned.

SECTION VIII

SUMMARY AND CONCLUSIONS

Introduction

Water quality degradation is a serious threat to the utility of existing water resources. Wastewater inputs and decreasing dilution capacities have jointly emerged as the causes of this deterioration. Efforts to control water pollution and effectively preserve water for future use will require regional insights and coordination among polluters. To accomplish this type of integrated water quality management, standards need to be set and policies generated which best meet these goals. Institutional constraints must be carefully evaluated to test the feasibility of resolving their restrictions in order to implement strategies which reflect current and future needs. This report has attempted to shed some light on certain questions concerned with problems of regional water quality management.

Summary

The Utah Lake drainage area is the headwaters of the Jordan River system encompassing the Salt Lake City metropolitan area, where most of Utah's municipal and industrial water demands are located. Owing to the sensitivity of these demands to water quality, implementation of effective water management policies is essential for continued expansion. The high mountainous regions of the Utah Lake drainage area, along with interbasin transfers from the adjoining Colorado River Basin, produce large quantities of good quality water for needs in the immediate area, as well as the Salt Lake City metropolitan area. However, the urban and agricultural water uses in the Utah Valley area, along with the evaporative depletion of Utah Lake degrades the quality of the area outflows so as to be unsuitable for urban water supplies. Thus, in order to protect downstream users while continued development occurs in the Utah Lake drainage area, and to in fact improve the qualities of the outflows for the more sensitive urban uses in the Salt Lake City area, water quality controls will be imposed in the Utah Lake region. Of critical importance is the strategies with which such controls are implemented. In addition, the effect of institutional constraints must be reconciled with optimal policies in order to best achieve the goals of the water quality control measures. This study was initiated to resolve some of these significant questions. To do so, an extensive hydrologic and water quality inventory was conducted to define the flow systems in the area. Then these results were incorporated into water quality management models whereby optimal policies could be evaluated. In the following paragraphs, a summary of these efforts is presented.

Hydrologic Analysis

Previous to this study, a number of detailed evaluations regarding water flow systems in various segments of the Utah Lake drainage area were conducted. The results of these studies were collected and analyzed. Then, a comprehensive budgeting procedure was undertaken to coordinate the segmental results of these previous studies into a complete quantification of the water flow network for the drainage area. Once this effort had been accomplished, water quality parameters consisting mainly of total dissolved solids (TDS) and biochemical oxygen demand (BOD) were added to the flows.

The hydrologic budgeting analysis was extended from the 1960 historical condition to 1980, 2000, and 2020 projected conditions. In addition, the expected improvements in water use efficiencies and the development of the Central Utah Project were incorporated into the models. These results indicate substantial urbanization occurring in the Utah Valley area surrounding Utah Lake. This region (Utah Valley) was divided into four principal districts (American Fork-Lehi, Provo, Spanish Fork, and Elberta-Goshen) in which the policies for water quality management were evaluated.

As a final determination, an exhaustive operation study on Utah Lake was made to examine the alternative salinity control measures of evaporation suppression by diking or implementation of regional desalination to improve the water quality in the Utah Lake effluents.

Modeling Water Quality Management Policies

A four level water quality management model was formulated which was used to select the optimal water quality control measures for achieving a specified water quality standard on the area outflows. TDS was selected as the quality parameter in the model since salinity is the most pressing basin-wide problem. However, the growing demand for recreational water uses was included in the modeling by considering BOD removal in urban effluents. The first level of the model considers optimal strategies for reducing salinity in urban and agricultural return flows. The urban treatment process involves desalting a portion of the effluents in order to achieve a desired level of TDS in the urban outflows. The agricultural salinity control measures are structural rehabilitation and improving irrigation practices to minimize the quantities of water entering the groundwater basin where salts are picked up from contact with the soils and groundwater aquifers.

In the second level of the model, optimization of combined urban and agricultural water quality management policies is accomplished. This procedure is repeated on each district of Utah Valley in order to reflect individual differences between the agricultural-urban mix in each district. Then, the next level coordinates and optimizes water quality controls among the districts. These results are significant in that they illustrate the effects of local urbanization and the influence of one area's water quality control on anothers'.

Finally, the model optimizes water quality control on a basin-wide scale by evaluating the best combination of control in the Utah Valley, including lake diking and regional desalination.

Each of these four levels of optimization produce interesting and important results relating to the best strategies for controlling water quality deterioration in regions where urbanization is occurring.

Conclusions

District Water Quality Management

At the district level, water quality management involves the optimal coordination of agricultural and urban treatments. Since BOD is generally not associated with agricultural return flows, district policies are independent of this parameter because the costs are fixed by the BOD standard on the district outflows.

Agricultural salinity control costs exhibit increasing marginal costs with scale since it can be assumed that the more detrimental salinity effects in the area can be treated first. Consequently, initial investments in the agricultural sector are more "cost-effective" than are later expenditures. This is a most significant characteristic because it indicates that agricultural pollution controls should be limited to the areas where substantial results can be achieved. Although this conclusion must be limited to the conditions in the Utah Lake drainage area, it is nevertheless important to note that this basic characteristic may be found in other areas as well.

The removal of salts from urban effluents is principally accomplished by desalting, which is characterized by decreasing marginal costs with scale. Thus, the larger desalting facilities exhibit greater cost-effectiveness. In addition, since salts can be removed in excess of the urban contribution, a great deal more water quality management flexibility is associated with desalination.

The optimal coordination of agricultural and urban water quality control policies is dependent on the characteristics of the respective cost functions. In addition, the relative magnitudes of the two uses also determines the nature of such optimal policies. However, the basic structures of these strategies are the same. Initial salinity control measures are largely agricultural in nature because of the low expenditures necessary to accomplish significant TDS reductions. As the removal requirements the increased, the marginal costs of the agricultural alternatives surpass those for the urban sector and an abrupt change occurs in which primary emphasis is directed towards desalination. Eventually, both measures are incorporated to achieve water quality standards.

Regional Water Quality Management

After the individual districts have been optimized for any specified effluent standard, the next question is the optimal allocation of pollution control responsibilities among the districts. Solutions to this problem give important direction for setting water quality standards in order to equitably charge polluters. Also, these solutions clearly illustrate the effects of urbanization upon water management strategies.

The results of optimizing strategies for water quality control among the districts closely follow these results indicated in the previous paragraphs. For example, the Spanish Fork district is primarily agricultural in nature, while the Provo district is substantially urban. As the water quality standards on aggregate Utah Valley return flows become increasingly stringent, initial salinity control centers in the Spanish Fork district but gradually shifts to urban treatments in the Provo district. An analysis of this type for future conditions indicated the same general policy, but as the urbanization in the Provo and American Fork-Lehi districts occurred, the initial investments into the agricultural area were substantially reduced. Consequently, the effect of urbanization is to increasingly stress urban water pollution where cost advantages can be gained by the inherent economies of scale associated with urban wastewater treatment.

These results have implicitely assumed regionalization of urban wastewater treatment facilities. Important institutional constraints need to be resolved so that consolidation can be achieved. Agricultural water quality control on the other hand is assumed to be as disaggregated as possible in order to invest in controls with the maximum cost-effectiveness. As a result, institutional constraints are only minor in nature.

Basin-wide Water Quality Management

In order to satisfy potential demands on the outflows of the Utah Lake drainage area, standards on the flows in the Jordan River would be required. Then, the Utah Lake area could devise and implement a least cost strategy for meeting the goal. Three basic alternatives would be involved. First, controls could be imposed on the aggregate return flows from Utah Valley. These controls would then be distributed according to the optimal policies generated previously. Since the effect of Utah Lake is to double the TDS concentration of the inflows to the lake because of large evaporation losses, reduction in the evaporative losses by diking segments of the lake would also be considered. Finally, the economies of scale noted previously regarding desalination suggests that desalting some flows and then mixing these with the total outflows would be a realistic water quality management tool.

Optimization of these three alternatives were not surprising in retrospect. Initial controls involved the alternative of lake diking but rapidly shifted to desalination. This typical policy, indicated at all levels of the Utah Lake study, suggests the need for renewed emphasis on physically removing salts rather than attempting to prevent their inclusion in water resources.

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