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A Conceptual Model of the San Pitch River Basin

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A CONCEPTUAL MODEL OF THE SAN PITCH RIVER BASIN

By

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UTAH STATE UNIVERSITY

Logan, Utah

1968

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James Douglas Ballif

A report submitted in partial fulfillment
of the requirements for the degree

of

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in

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James Douglas Ballif

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ABSTRACT

A Conceptual Model of the

San Pitch River Basin

by

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Utah State University, 1969

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To meet future expected needs for water, the State of Utah will have to plan and manage its limited resources in a judicious manner. Comprehensive water resource planning on a river basin basis is necessary to economically plan and develop the best combination of water uses.

Efficient use and management of agricultural water is necessary to maximize the amount available for future needs. Irrigation water management must be improved. Improvements in the organization, storage, distribution, and method of application will be required to meet future demands. Consideration should be given to various combinations of conjunctive use of groundwater and surface water.

The report is a study of the San Pitch River Watershed above the Gunnison Reservoir which is a part of the Sevier River System in Utah. Data are gathered and developed into a mathematical model of the river basin including the whole watershed. The model is in the form that it can be optimized by computer techniques using methods of linear programming by subsequent investigators.

The model is a representative schematic model of water supply, use, storage, and movement of surface and subsurface water through the basin. The report includes gathering of data to evaluate the quantities and costs of associated component parts of the model as well as some of the benefits from the use of water.

(106 pages)

INTRODUCTION

General

The Sanpete Valley is a part of the San Pitch River Watershed located in central Utah, a part of the Great Basin Drainage. The area of the basin is approximately 714 square miles (Plate I, Appendix C).

The Sanpete Valley is situated at the border between the Basin and Range province and the Colorado Plateau province in south-central Utah. The valley is bounded on the east by the Gunnison Plateau and on the west by the San Pitch Mountains. It is drained by the San Pitch River which empties into the Sevier River.

A variety of crops are grown in the valley, and livestock and poultry raising are also important industries.

The climate is semiarid. Irrigation is necessary for the production of crops. Canal systems are supplied by San Pitch River flow. The mountain streams are tapped by ditches near the mouths of the canyons, but this supply is insufficient; consequently, pumping from groundwater is used to supplement the supply (Richardson, 1907). The location of the watershed and its boundaries are shown on Plate I (Appendix C).

Previous studies

Richardson (1907) described the topography and geology of the Sanpete and Central Sevier Valleys in Utah.

Robinson (1964, 1965, 1966) studied the Sanpete Valley in conjunction with Utah State University and the Utah Water and Power Board. He summarized annual pumping rates, groundwater fluctuations, and descriptions of the Sanpete Valley.

The U. S. Bureau of Reclamation (1965) made a reconnaissance study of the Sanpete area and available data in conjunction with the Central Utah Project.

The Soil Conservation Service (1968) has a study in progress that includes the Sanpete Valley. Available data include water budgets, consumptive use estimates for delineated irrigation areas, and possible reservoir sites.

The U. S. Geological Survey made an extensive study of selected wells and springs in the area, including data on discharge transmissibility, drawdown, specific electrical conductance, total dissolved solids, sodium adsorption ratio, percent sodium, geologic formations, pervious depths, and well or spring locations.

TOPOGRAPHY

According to Richardson (1907), the Sanpete Valley is a structural trough filled with wash derived from the adjacent highlands. The valley trends northeast-southwest, and contains numerous relatively small streams. The valley is about 45 miles in length and averages 6 miles in width. The main stream, the San Pitch River, has a number of tributaries, the most important of which flow from the eastern plateaus, where the precipitation is greater than on the relatively low and narrow western highlands. The streams flow perennially within the mountains, where they occupy steep, narrow valleys. At the mouths of the canyons the discharge is largely diverted into irrigation canals. The lower stream courses in the broad lowlands are generally dry except during floods. The chief tributaries of the San Pitch River are Cottonwood, Pleasant, Cedar, Oak, Canal, Ephraim, Willow, Manti, Sixmile, and Twelvemile Creeks, all of which have small drainage basins on the Wasatch Plateau.

The elevation of the Sanpete Valley ranges from about 5,000 feet above sea level in its lowest part to about 6,000 feet at the upper border of the lowlands. The mountains rise from 2,000 to 5,000 feet higher.

The Wasatch Plateau borders Sanpete Valley on the east. The crest of the plateau is underlain by Cretaceous and Tertiary sediments which, on the east form a wall of erosion beyond which the surface slopes to Castle Valley, a lowland underlain by shale which separates the plateau from the San Rafael swell. On the west the Wasatch Plateau slopes toward Sanpete Valley, conforming with a great monoclinical flexure. The Wasatch Plateau is comparatively well timbered and is the source of perennial streams (Richardson, 1907).

GEOLOGY

General

The geology of the Sanpete Valley is favorable for groundwater development. The valley fill consists of permeable material capable of receiving and transmitting water. Groundwater occurs both in confined and unconfined conditions. Certain of the underlying consolidated formations are also capable of receiving and transmitting water.

Most of the water yield occurs through natural avenues as springs and seeps, while a lesser amount has been developed through the installation of pumped wells (U. S. Bureau of Reclamation, 1965).

> There is no evidence available to suggest any loss of groundwater by subterranean routes to points outside the basin. Development and consumptive use of groundwater thus deplete the flow of the San Pitch River. (U. S. Bureau of Reclamation, 1965, p. 84)

The rocks of the Sanpete Valley can conveniently be classified as consolidated "bedrocks" which outcrop chiefly on the highlands, and unconsolidated deposits which occur in the broad central valley. Strata of Mesozoic and Tertiary age occupy the greater part of the highlands. Igneous rocks are found in the extreme southern portion. The valley, on the other hand, is underlain to considerable depths by debris derived from the disintegration of the adjacent highlands. The underground water occurs chiefly in the unconsolidated deposits, but water contained in the bedrocks is locally important (Richardson, 1907).

Figure 12 (Appendix A) shows a structural section at the extreme southern end of the valley.

Jurassic system (bedrocks)

So far as known, the oldest rocks of Sanpete Valley are of Jurassic age. These rocks consist of a considerable, but undetermined, thickness of fissile clay shales, generally drab in color but locally red with some intercalated layers of drab sandstone ranging in thickness from a few inches to a few feet. Lenses of gypsum and rock salt are irregularly interbedded throughout the formation. The hills are practically bare of vegetation and the soft beds have been eroded into a badland topography. These rocks are of no value in the recovery of underground water. They exert, however, an important deleterious influence upon the character of streams with which they come in contact because of the ready solubility of their interbedded salt and gypsum (Richardson, 1907).

Cretaceous system

The Cretaceous system is represented by two divisions, the Colorado and the Laramie. The Colorado strata is thin-bedded buff sandstone, with subordinate drab shale. Because of the limited exposure these rocks also are unimportant in the recovery of underground water (Richardson, 1907).

Sandstones and shales provisionally referred to the Laramie division of the Cretaceous occupy a much greater area. The coal-bearing Laramie beds of Carbon County, which outcrop along the eastern slope of the Wasatch Plateau, are conformably overlain by massive loose-textured buff sandstone with subordinate interbedded buff shale. These rocks locally cap the plateau and outcrop along its middle western flanks east of Sanpete Valley as far as Spring Creek, and are exposed farther south in the valleys of several creeks that have cut deeply into the Wasatch monocline (Richardson, 1907).

The sandstone on the flanks of the Wasatch Plateau is a probable source of artesian water.

Tertiary system

Strata of Eocene age outcrop on the summit and western flank of the Wasatch Plateau, on the summit and eastern part of the Gunnison Plateau, and on the eastern slope of the valley and Pavant Mountains, and also form the low ridges in the Sanpete Valley. These Tertiary sediments consist of at least 2,000 feet of drab green and red shales, buff and reddish sandstones, and whitish freshwater limestones (Richardson, 1907).

The stratigraphy is varied, and even adjacent sections are rarely alike. Younger Eocene strata outcrop in low ridges in Sanpete Valley, extending northward from Manti. They dip westward at low angles and their outcrops are surrounded by Quaternary deposits which conceal relations with the underlying rocks exposed on the flanks of the adjacent plateau. These younger rocks consist of light-colored sandstone, shale, and limestone, including a bed of colitic limestone. The varying stratigraphy of Eocene strata, the prevalence of shale and limestone, and the minor occurrence of more pervious strata render the rocks of little importance as water reservoirs. Yet these relatively impervious beds serve to confine water in the underlying sandstones and conglomerates, and are thus important factors in the occurrence of artesian water (Richardson, 1907).

Igneous rock

Igneous rocks are unimportant as water reservoirs in Sanpete Valley. They occupy small areas and are fine textured and of low porosity. Their occurrence is restricted chiefly to the Sevier Plateau south or east of Richfield, and to the base of the Pavant Mountain Range west of Elsinore. They constitute the northern end of a mass which is well developed farther south. These rocks are for the most part a complex series of lavas that were poured out upon eroded surfaces of the underlying strata at different intervals in Neocene time (Richardson, 1907).

Valley deposits

The broad central floor of Sanpete Valley is composed of fine-textured soils, chiefly sand and clay loam, but toward the highlands the material becomes coarser. The mountains are flanked by alluvial fans and slopes consisting of sand and gravel with subordinate clay. The coarser material preponderates near the mountains. These deposits are derived from the disintegration of the adjacent highlands and transported to the valley by streams. In their mountain courses the volume and velocity of the creeks are considerable, especially during floods, and their carrying power is proportionately large. Upon entering the valley both the volume and velocity of flow decrease. The result is that the coarser materials carried by the streams are dropped near the base of the highlands while the finer debris are carried farther into the lowlands. Alluvial fans, consisting of heterogeneous masses of coarse sand and gravel, are thus formed about the mouths of the canyons. Alluvial slopes accumulate along the base of the mountains between the creeks, chiefly as the result of torrential storms (Richardson, 1907).

These alluvial areas are good recharge sites. The deposits beneath the surface of the broad valleys consist of gravel, sand, and clay, the thickness of which is considerable, but unknown; minium depths in the main part of the valley are about 650 feet in the Sanpete Valley, as shown by wells, in which consolidated rock was not found. Alternating beds of gravel, sand, and clay, from a few inches to many feet in thickness, are encountered in drilling wells (Richardson, 1907).

In general, the coarse material preponderates near the highlands and finer textured debris is more abundant in the lowlands. The inclination of the deposits is toward the valleys in the attitude of deposition. Sections, even of neighboring wells, can rarely be correlated, which implies that the deposits, instead of having wide lateral distribution as homogeneous beds, consists of series of lenses with imperfect connection. These deposits are in large part loose porous, and saturated with water, and constitute the most important underground reservoirs of the region (Richardson, 1907).

HYDROLOGIC DATA

Climatological data

The availability of climatological data for the Sanpete Valley is described in Table 18 (Appendix B). Available data include temperature, precipitation, and evaporation. Plate II (Appendix C) shows a precipitation isohyetal analysis for 1931-1960 data. More detailed and comprehensive meteorological data are recorded at Weather Bureau stations in Milford, Salt Lake City, and Roosevelt, Utah. Table 18 includes location of readings, length of record, type gage (quality), and recording agency. Most of the climatological data are primitive or elementary.

Runoff data

The U. S. Geological Survey has maintained stream flow gaging stations at a number of locations within the San Pitch River Basin. Table 19 (Appendix B) describes the available stream flow records for each of the gaging stations. The locations of some of the stations are shown on Plate III.

Transmountain diversions from the Colorado River Drainage contribute a significant portion of water to the San Pitch Watershed. These diversions are listed and noted in Table 19.

The available data of the irrigation companies in the San Pitch River Watershed are listed in Table 20 (Appendix B). Consumptive use and diversion requirements, per acre foot for adjacent areas, are available from the U. S. Bureau of Reclamation and the Soil Conservation Service.

Snow courses data

A summary of the snow courses in the San Pitch River Watershed is given in Table 21 (Appendix B). A location map of the snow courses is shown on Plate IV (Appendix C). These data are usually primary or elementary. These measurements are usually taken by the Soil Conservation Service, but others also take them. Some of the snow courses include a storage precipitation gage and a soil moisture station.

Chemical quality

The quality of the underground water is generally good for both irrigation and human consumption, with the possible exception of the water from some of the consolidated aquifers. Table 22 (Appendix B) lists the chemical analysis of selected wells in Sanpete County.

The samples of water taken show small amounts of calcium and magnesium. Thus, the water is hard to very hard. The hardness generally exceeds 200 ppm. Only one well (C-19-1) 25cd-2, showed excessive amounts of salts. Total dissolved solids were below 1000 ppm except for the above mentioned well. The sodium absorption ratio (S. A. R.) indicates the groundwaters have a low alkali hazard. Conductivity data shows medium to high salinity hazard. All waters could be considered suitable for irrigation uses. Use of certain waters may require good irrigation management.

Water rights

Water rights in the San Pitch River Basin are defined in the 1936 Cox Decree. Recent litigation has included the San Pitch River Basin; however, the state engineer has not published notices calling for statements of water users' claims. The proposed adjudication is to update the Cox Decree and define any additional water rights acquired since the Decree.

The Cox Decree divided the Sevier River System into two zones, A and B. This was done for the more efficient use and distribution of the water.

According to the Cox Decree (U. S. Bureau of Reclamation, 1936, p. 186):

> Zone A included all rights above the dam of the Vermillion Canal Company situated in Sevier County, and Zone B included all rights below the dam of the Vermillion Canal Company. The two zones are independent as far as primary, second class, third class, and fourth class rights are concerned. Zone A has no commitments to by-pass water within their direct flow rights to Zone B.
>
> The priority of the primary rights along the river in Zone A starts at the head of the river and proceeds downstream by reaches to Vermillion Dam. Each canal in a reach receives a prorated share up to its water right of the water available. The second, third, and fourth class rights are filled and the priorities start at Vermillion Dam and proceed upstream by reaches. No third class rights receive water until all second

class rights are filled, and no fourth class rights receive water until all third class rights are filled.

Any water in excess of direct flow rights is termed "summer storage water" which, together with the "winter storage water" in excess of stock watering requirements, makes up the storable flows. This water is subject to distribution between Piute Reservoir and Sevier Bridge Reservoir.

The San Pitch River Basin receives water by transmountain diversions from the San Rafael and Price River Basin. It is, therefore, affected by pending general water right adjudication proceedings in those basins.

Essentially all surface water in the San Pitch Basin is appropriated. Most of the applications filed since 1936 have been made to appropriate groundwater. Only during periods of exceptionally high runoff does the San Pitch River water reach the Sevier River. When it does, it is required to meet downstream rights.

SURFACE WATER

Flow of streams

The streams of the Sanpete Valley are of three distinct types: the relatively long master streams, the shorter transverse tributaries, and the canals. The master streams meander in a gentle grade in broad waste-filled valleys of structural origin. The San Pitch River is fed by the direct but varying flow of its tributary streams and by more constant seepage (Richardson, 1907).

The tributary streams are very different. In their mountain courses they occupy narrow, steep-graded, eroded valleys. At the base of the highlands they emerge from their canyon-like courses and enter the broad debris-filled lowland. They flow across the lowland at a lessened grade until they join the master stream. These tributary streams are fed almost entirely by the precipitation on their mountain watersheds through direct and seepage runoff. The discharge is heaviest in late spring and early summer because the main precipitation on the mountains occurs as snow. Discharge during April, May, and June is about 60 percent of the annual runoff (Richardson, 1907).

Conditions are different in each watershed. The discharge varies with the precipitation, topography, vegetation, and soils, and with the care that is taken to prevent fires, excessive grazing, and the destruction of timber. Seepage runoff is greater in valleys of relatively low relief that are abundantly clothed in vegetation. Under these conditions the products of rock disintegration are not readily washed into the valleys. Debris accumulates to absorb a large quantity of the precipitation, which thus escapes flood discharge and seeps slowly into the streams, maintaining their perennial flow (Richardson, 1907).

The tributary streams, in the upper parts of their way across the broad valley, lose flow by evaporation, evapotranspiration, and absorption. While in their lower courses, before they enter the main streams, the stream flow is generally increased by seepage. During the irrigation season the tributaries make small contributions directly to the master streams, because the tributary water at the mouths of the canyons is diverted by canals and distributed over the valley (Richardson, 1907).

Irrigation canals tap both the master streams and tributaries. The canals tap the tributaries at or near the mouths of the canyons, and the San Pitch River at intervals throughout its course. Water is thus distributed over the valley where normally it would not flow.

Irrigation

There are about 106,000 acres irrigated in the San Pitch River drainage during an average year. Pumping from groundwater augments the main supply from small streams and springs. About 64,000 acres of this irrigated land have favorable drainage conditions, and about 42,000 acres have drainage deficiencies of varying degrees. The poorly drained lands are located on the low area along the valley bottom. These lands tend to be saline with salinity increasing toward the south end of the valley (U. S. Bureau of Reclamation, 1965).

The conveyance system consists mostly of earth ditches constructed through porous soils, resulting in high water losses. These water losses may vary from about 30 to 80 percent of the flow, depending on stream size, time of year, and location.

The U. S. Bureau of Reclamation (1965) estimated the direct benefits from irrigation as $22.00 to $27.00 per acre-foot of water, and the estimated payment capacity as $2.50 to $4.00 per acre-foot of water. The anticipated payment capacity is based on long-term average prices paid and received by farmers. Irrigation benefits are based upon increased production of goods and services associated with the increased water supply, less the associated cost.

Table 20 (Appendix B) lists irrigation companies in the Sanpete Valley along with other pertinent data.

Surface storage

Existing storage. Major surface storage in the Sanpete Valley consists of Wales Reservoir (1,480 acre feet), Loggers Fork Reservoir (1,600 acre feet), Patten Reservoir (130 acre feet), Funks Lake Reservoir (700 acre feet), and Gunnison Reservoir (20,000 acre feet). Locations of Wales and Gunnison Reservoirs are shown on Plate I (Appendix C). Loggers Fork, Patten, and Funks Lake Reservoirs are controls for Manti Creek.

Possible future storage. Some possible future reservoir sites and pertinent data are listed below in Table 1.

Table 1. Possible reservoir sites

Site	Capacity (acre feet)	Surface Area (acres)	Estimated Cost (1967)
Black Hills	120	-	$ -
Canal Creek	67	-	118,000
Cottonwood	86	-	56,500
Freeman Allred	291	-	139,000
Moroni	8,000	480	940,000
Jensen	800	36	375,000
Johnson	430	21	195,000
New Canyon	160	-	129,000
Willow Creek	450	18	203,000

General locations of possible sites are shown on Plate I (Appendix C).

GROUNDWATER

Occurrence

The only sources of water are precipitation on the drainage areas tributary to the valley, and transmountain diversions.

The direction of groundwater movement in Sanpete Valley is shown by contours in Figure 9 (Appendix A). The groundwater moves in the same general direction as the surface streams, toward the Gunnison Reservoir in the lowest and southernmost part of the main valley.

The general pattern of the contours indicates that recharge to the west arm of the valley is mostly from the Gunnison Plateau. Recharge to the east arm is mostly from the Wasatch Plateau. Recharge to the main part of the valley is mostly from the Wasatch Plateau and groundwater inflow from the two arms. The water-level gradient in the two arms of the valley ranges from about 10 to 200 feet per mile. In the main valley the gradient ranges from about 2 to 30 feet per mile (Robinson, 1965).

Although data are lacking for estimating the quantity of water available for replenishing the underground storage from the flow of streams, the available data indicate that the amount is considerable. Infiltration from stream beds is the chief source of underground water in the Sanpete Valley. Ephraim Creek on August 30, 1905, flowing

8.2 cfs near the mouth of its canyon, in a course of 0.6 mile over a gravelly bed, lost 0.8 cfs, or 16 percent per mile. Oak Creek on September 18, 1905, flowing 4.88 cfs at a point 3 miles southeast of Spring City, in a course of 2.5 miles, lost 0.46 cfs, or 3.7 percent per mile. Twin Creek on September 19, 1905, flowing 8.1 cfs at a point 3.5 miles southeast of Mount Pleasant, in a course of about 2.75 miles, lost 3.1 cfs, or 13.8 percent per mile. These figures clearly indicate the manner in which the underground supply of the Sanpete Valley is maintained (Richardson, 1907).

The underground water supply of Sanpete Valley is also augmented by the underflow from the bedrock and by the flow of springs from bedrock. A number of springs that issue along fault lines convey water to the valley from a distant source in bedrock. The total discharge of these fault springs amounts to a constant flow of about 95 cfs and absorption of a part of the flow adds an appreciable amount to the underground waters (Richardson, 1907).

In the practice of irrigation, part of the water applied to the fields is absorbed by the soil, percolates below the reach of roots and beyond the sphere of capillary action, and joins the underground supply. The amount thus transmitted varies considerably from place to place, depending on the porosity of the soil and the quantity of water applied to the fields in excess of the irrigation need.

Present development

Robinson (1964, 1965) noted that more than 1,500 wells have been constructed in the Sanpete Valley, most of which are concentrated along the lower parts of the valley between Ephraim and Manti and between Ephraim and Moroni. Most of the large-diameter irrigation wells, which have the greatest discharge, are concentrated near Manti, Ephraim, south of Moroni, south of Fountain Green, or between Spring City and Mount Pleasant.

During 1964, wells in the Sanpete Valley discharged about 16,000 acre feet of water as follows (Robinson, 1965, p. 61):

Irrigation		11,600 AF
Pumped wells (equipped with large turbine pumps)	8,000	
Flowing wells (and wells equipped with small pumps)	3,600	
Public supply (pumped wells)		500
Industry (pumped wells)		400
Domestic, stock, and some irrigation (flowing wells equipped with small pumps)		3,500
TOTAL		16,000 AF

Large seasonal water-level changes occur in the Sanpete Valley, particularly between early spring and late summer.

Water levels were higher in March 1966 than in March 1965 throughout most of the Sanpete Valley (Figure 10). Small water-level declines, however, were registered in three restricted areas of the valley. (See Figure 10, Appendix A.)

Measurements made during March 1966 showed a water-level rise above the March 1965 level of 1 to 3 feet in most of the valley bottom. Rises of 3 to 6 feet were recorded around Manti, on the west side of the valley northwest of Ephraim, and east and southeast of Fountain Green. Rises of from 6 to more than 9 feet were recorded north of Milburn, around Ephraim, and around Mount Pleasant (Robinson, 1966).

Figure 10 also shows water-level changes from March 1942 to March 1966 in 10 wells. Water levels in 5 of the wells rose from less than 1 foot to more than 5 feet. Three of these five wells are in the southern half of the valley. Water levels in the other 5 wells observed, which are in the northern half of the valley, declined from less than 1 foot to more than 2 feet.

Hydrographs of the water levels in two pumped irrigation wells and one small flowing well in the Sanpete Valley are compared to the long-term trend in precipitation at Manti in Figure 11 (Appendix A). As in 1963 and 1964, the amount of precipitation was above normal in 1965. As shown on the cumulative departure curve (Figure 11), the 1965 precipitation was more than 7 inches above the 1931-60 annual normal. The increase in precipitation in 1965 is reflected in the hydrographs for the two irrigation wells. The steep rise of water levels in 1965 resulted in higher levels at the end of 1965 than had been observed in the 31 years of record for the two wells. The water level in the 2-inch flowing well also continued to rise during 1965. The above-normal precipitation caused the rise of water levels by providing a larger amount of surface water for irrigation, thus reducing the need for pumping from wells (Robinson, 1966, p. 59).

Safe yield

Under existing conditions a considerable groundwater yield is available within the valley. Most of the present yield occurs through natural avenues such as springs and seeps while a lesser amount has been developed through the installation of artesian and pumped wells.

The U. S. Bureau of Reclamation (1965) has estimated the total groundwater yield for an average year to be 50,000 acre feet, of which about 16,000 acre feet is developed from wells.

The following 30-year average (1931-60) water budget is from a Soil Conservation Service unpublished report (Soil Conservation Service, 1963):

Items of Supply		
Streams Inflows (Including Transmountain Diversions)		170,100 AF
Precipitation		
	Cropland	50,320 AF
	Wetlands	40,640 AF
	TOTAL SUPPLY:	261,060 AF

Items of Disposal		
Streams Outflows		33,510 AF
Consumptive Use		
	Cropland	109,750 AF
	Wetlands	115,990 AF
Increase in Groundwater Storage		1,810 AF
	TOTAL DISPOSAL:	261,060 AF

Estimated pumpage of groundwater in the Sanpete Valley is around 16,000 AF. Noting the increase in groundwater storage in the above water budget gives an estimated safe yield of 17,800 AF.

Using data collected in the Robinson reports (1964, 1965, 1966) and plotting by the Hill method gives an estimated groundwater safe yield of 18,500 AF with the present pattern of cropland and wetlands (Figure 7, Appendix A).

These values compare favorably and suggest that a modest groundwater development is feasible even with no change in agricultural pattern. By drying up nonbeneficial or marginal value wetlands, more groundwater would be available for development. The safe yield thus could be 20 to 80,000 AF, depending on the amount salvaged.

Future development

In planning and investigating, those concerned with development of a water supply from groundwater sources must consider the fact that groundwater discharge, both natural and artificial, from aquifers in the San Pitch River Basin is either tributary to the San Pitch River or is consumed by evapotranspiration. The U. S. Bureau of Reclamation (1965) indicates that there is no evidence available to suggest any loss of groundwater by subterranean routes to points outside the basin. Development and consumptive use of groundwater thus deplete the flow of the San Pitch River. Water may be salvaged by reducing nonbeneficial use by phreatophytes in the lower portions of the basin. This water could be exchanged for groundwater developed elsewhere in the basin from the deep or confined aquifers.

A U. S. Bureau of Reclamation plan is as follows:

> A reduction in nonbeneficial use would require a lowering of the water tables in the phreatophyte areas to levels that would allow the eradication of phreatophytes and the substitution of a more beneficial vegetation of either irrigated or dryland varieties with a lower consumptive use. One such program could provide for the development of suitable lands to a more efficient and beneficial use of water and for maintaining the poorer lands in a nonirrigated state. The quantity of water thus salvaged annually would represent the quantity of groundwater that would be available for development from the confined aquifers without depleting the flow of the San Pitch River in exchange for groundwater developed and used elsewhere in the basin. (U. S. Bureau of Reclamation, 1965, p. 84)

Plate V (Appendix C) shows areas of wetlands and areas of contact of alluvial fill and bedrock.

COST EVALUATIONS

Introduction

Cost evaluations are necessary to evaluate the relative worth of various combinations of the conjunctive use of water. They will be used in the objective function of the mathematical model that follows in the text.

Pumping

Nuzman (1967) developed some economic evaluations for pumping which will be used to evaluate pumping costs in this report. Costs are broken down into two basic categories: fixed costs and variable costs. Fixed costs include exploration and development, and all capital expenditures usually made prior to the use of water. Variable costs are all operational costs needed to maintain water production.

Annual fixed costs are given by:

$$FC = \Sigma \left[(CRF)(Iw) + (CRF)(Ip) + (CRF)(Im)\right] + 0.02\ \Sigma \left[Iw + Ip + Im\right]$$

where

CRF = capital recovery factor

FC = annual fixed costs in dollars

Iw = investment cost of well = 19.25 (depth)

Ip = investment cost of pump = 173.3 x (Xp) - 866.6

Xp = size index of pump = $[800 + 0.20\,Q^{0.91}\,H^{0.62}]/100$

Q = discharge in gallons per minute

H = total head in feet

Im = investment cost of electric motor = $341.30 + 23.29(WHp)$

WHp = required water horsepower = $QH/3956$

Q = discharge in gallons per minute

H = total head in feet

The first term in the annual fixed cost equation represents the annual investment cost and the second term represents annual tax assessments and insurance costs.

Annual variable costs are given by:

$$VC = (1.886 \times 10^{-6}\,Ck \times Q \times H \times Th)/Ef + 0.0607 \times Q^{0.47} \times H^{0.26} \times Th^{0.34} + 0.0475 \times Q^{0.84} \times H^{0.40}$$

where

VC = annual variable costs

Ck = cost of electric power in cents per kilowatt hour

Q = pump discharge in gallons per minute

H = total head in feet

Th = season operating time in hours

Ef = overall efficiency of conversion

The first term in the annual variable costs equation represents energy costs and the second and third terms represent operation and maintenance.

Total annual costs are given by:

$$TC = VC + FC$$

where

TC = total costs (annual in dollars)

VC = total variable costs (annual in dollars)

FC = total fixed costs (annual in dollars)

Cost evaluations were made using the following values for variables:

Interest Rate = 7%

Life of Well, Pump, and Electric Motor = 20 years

Depth = 200 feet

Ck = 0.6¢/kwh and 1.12¢/kwh

Th = 2000 hours

Ef = 0.529

H = varies between 20 - 450 feet

Q = varies between 1000 - 4500 gpm

Pumping Season = 100 days

Figure 3 (Appendix A) shows how pumping costs vary with pumping lift for 0.6¢/kwh and for 1.12¢/kwh. The graph also shows how the curves compare with other similar areas, as for the Milford, Utah, area and for southwest Utah.

Artificial recharge

Artificial recharge is defined as the process of replenishment of the water retained in the groundwater storage through works provided primarily for that purpose. Artificial recharge costs vary greatly depending upon geologic, hydrologic, and cultural conditions at the selected site. One of the more important factors governing project operation is the infiltration rate at potential sites.

Frankel (1967) estimates that groundwater recharge costs average approximately $8.00/acre foot. This value is assumed as a representative estimate of artificial recharge costs in the Sanpete Valley. This amount includes land, landscaping, site development, fencing, and hydraulic control works.

Surface storage

The Utah State Engineer (1938) and Brown (1968) have estimated the costs of several possible reservoir sites in the Sanpete Valley. Values in the State Engineer's report were updated to 1967 by the U. S. Bureau of Reclamation index for earth dams, which was begun in 1949. This index rose approximately 0.3 from 1949 to 1967. Estimating the rise from 1938 to 1949 to be 0.2, gives a ratio of 1.5 to multiply 1938 costs by to get 1967 costs. These values were amortized over a 50-year life at a 3 1/2% interest rate.

Table 2 below lists pertinent data for possible future surface storage.

Table 2. Costs of possible surface storage sites

Reservoir Site	Capacity (ac-ft)	Estimated Cost ($)	Annual Cost ($)	Annual Cost ($/ac-ft stor.)
Black Hills	120	-	-	-
Canal Creek	67	118,000	5,040	75.10
Cottonwood	86	56,500	2,415	28.10
Freeman Allred	291	139,000	5,940	20.40
Moroni	8,000	940,000	40,000	5.00
Jensen	800	375,000	16,000	20.00
Johnson	430	195,000	8,330	19.40
New Canyon	160	129,000	5,500	34.40
Willow Creek	450	203,000	8,660	19.20

CONCEPTUAL MODEL

General

The development of systems analysis, operations research, and mathematical programming methods have emphasized a new and perhaps a more efficient method of design of water resource systems. If a mathematical model can be developed that adequately describes the actual physical system and design decision variables, e.g., artificial recharge, pumping, surface and subsurface storage, etc., then the techniques of mathematical programming can be used to develop an optimal plan for development.

If the relationships among variables are linear, then the methods of linear programming can be used. Linear programming can be described as a method of determining an optimal program of interdependent activities in view of available resources. It entails writing an objective function to be maximized or minimized subject to a series of constraint equations that describe physical limitations and requirements of the system. The solution of the set of equations is the optimal plan for development.

One procedure of optimization is the simplex method. This procedure proceeds in systematic steps from an initial feasible solution to an adjacent feasible solution which improves the objective function. More detailed information about this and other methods of optimization is available in a number of tests on linear programming.

It is helpful for visualization to develop a schematic diagram to show the physical relations among variables and their locations in the water resource system. Post-optimal analyses are useful in seeing how cost and benefit coefficients affect the solution. A sensitivity analysis can be performed by varying the cost or benefit coefficients and observing the effect on the optimal solution. This analysis is helpful in management decisions.

Figure 1 is a schematic flow diagram of the water resources of the San Pitch River Basin. Abbreviated items are described in Table 3 which follows.

Linear programming model

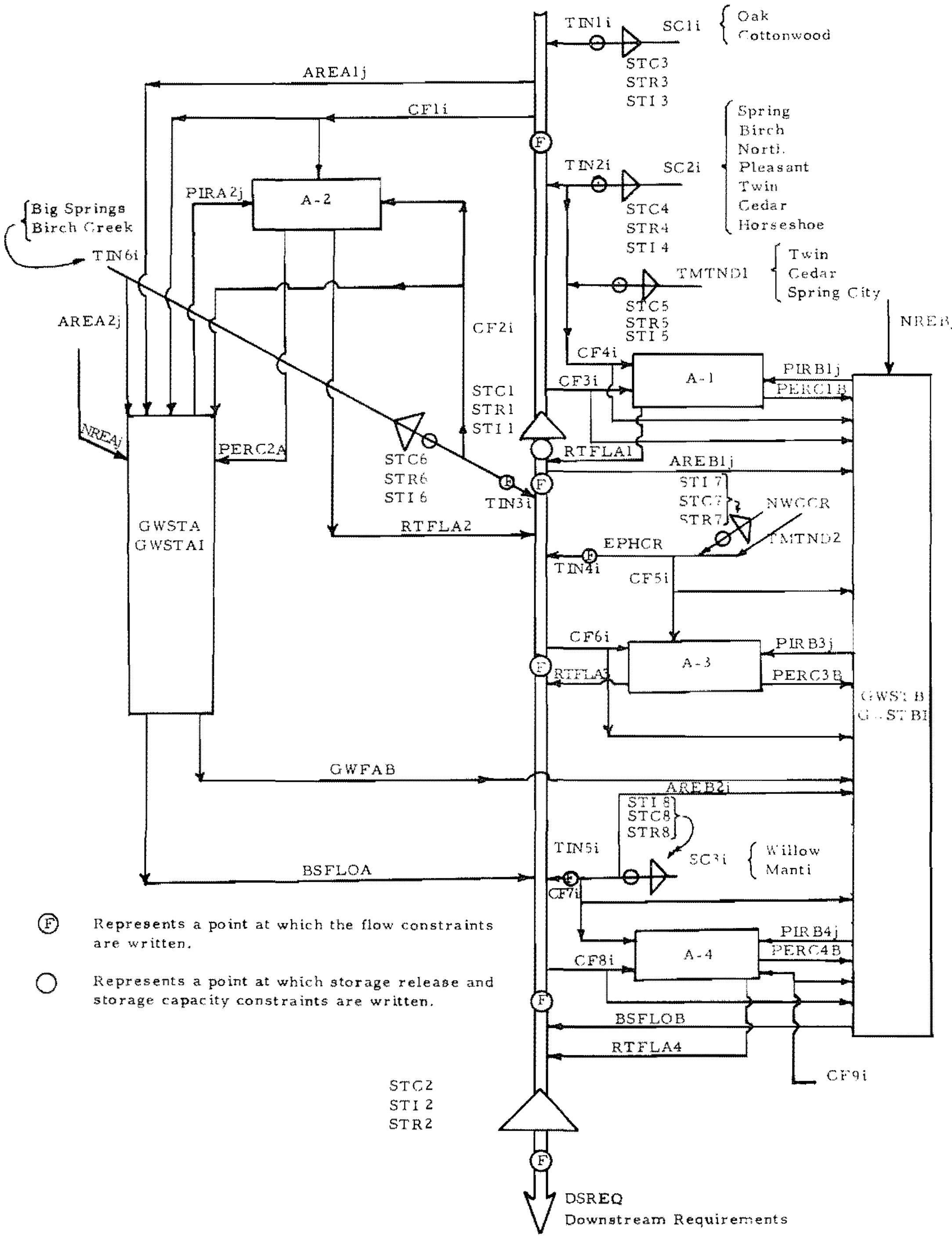
A mathematical model was developed to optimize the conjunctive use of water in the San Pitch River Basin. The model consists of an objective function whose benefits are to be maximized through some combination of conjunctive use of water in the basin, and a series of constraint equations that have to be satisfied and thus, limit the range of feasible solutions.

The preliminary objective function to be maximized is:

$$
\begin{aligned}
\text{OBJTF} = {} & 16.00(\text{IRRA1}) + 16.00(\text{IRRA2}) + 18.00(\text{IRRA3}) + 20.00(\text{IRRA4}) \\
& - 38.00(\text{SHA1}) - 37.00(\text{SHA2}) - 36.00(\text{SHA3}) - 35.00(\text{SHA4}) \\
& - 4.00\text{CF1} - 4.00\text{CF2} - 4.00\text{CF3} - 4.00\text{CF4} - 4.00\text{CF5} - 4.00\text{CF6} \\
& - 4.00\text{CF7} - 4.00\text{CF8} - 4.00\text{CF9} - 8.00\text{AREA1} - 8.00\text{AREA2}
\end{aligned}
$$

SANPETE MODEL

SCHEMATIC FLOW DIAGRAM



Ⓕ Represents a point at which the flow constraints are written.

○ Represents a point at which storage release and storage capacity constraints are written.

Figure 1. Schematic diagram of Sanpete model

Table 3. Description of schematic items

Feature	Description
A-1	Irrigation Area 1
A-2	Irrigation Area 2
A-3	Irrigation Area 3
A-4	Irrigation Area 4
ST 1	Storage Capacity Reservoir 1
ST 2	Storage Capacity Reservoir 2
ST 3	Storage Capacity Reservoir 3
ST 4	Storage Capacity Reservoir 4
ST 5	Storage Capacity Reservoir 5
ST 6	Storage Capacity Reservoir 6
ST 7	Storage Capacity Reservoir 7
ST 8	Storage Capacity Reservoir 8
STI 1	Initial Storage Reservoir 1
STI 2	Initial Storage Reservoir 2
STI 3	Initial Storage Reservoir 3
STI 4	Initial Storage Reservoir 4
STI 5	Initial Storage Reservoir 5
STI 6	Initial Storage Reservoir 6
STI 7	Initial Storage Reservoir 7
STI 8	Initial Storage Reservoir 8
STR 1	Storage Release Reservoir 1
STR 2	Storage Release Reservoir 2
STR 3	Storage Release Reservoir 3
STR 4	Storage Release Reservoir 4
STR 5	Storage Release Reservoir 5
STR 6	Storage Release Reservoir 6
STR 7	Storage Release Reservoir 7
STR 8	Storage Release Reservoir 8
AREA1j	Artificial Recharge to GWSTA No. 1
AREA2j	Artificial Recharge to GWSTA No. 2
AREB1j	Artificial Recharge to GWSTB No. 1
AREB2j	Artificial Recharge to GWSTB No. 2
GWSTA	Groundwater Storage Basin A
GWSTB	Groundwater Storage Basin B
GWSTAI	Initial Storage in Groundwater Basin A
GWSTBI	Initial Storage in Groundwater Basin B
CF1i	Canal Flow 1
CF2i	Canal Flow 2
CF3i	Canal Flow 3
CF4i	Canal Flow 4
CF5i	Canal Flow 5
CF6i	Canal Flow 6

Table 3. Continued

Feature	Description
CF7i	Canal Flow 7
CF8i	Canal Flow 8
CF9i	Canal Flow 9
SC1i	Sum of Creeks 1
SC2i	Sum of Creeks 2
SC3i	Sum of Creeks 3
TIN1i	Tributary Inflow 1
TIN2i	Tributary Inflow 2
TIN3i	Tributary Inflow 3
TIN4i	Tributary Inflow 4
TIN5i	Tributary Inflow 5
TIN6i	Tributary Inflow 6
TMTND1	Transmountain Diversion 1
TMTND2	Transmountain Diversion 2
M6DIV	Six Mile Diversion
NREAi	Natural Recharge to Groundwater Basin A
NREBi	Natural Recharge to Groundwater Basin B
ETA	Evapotranspiration From Groundwater Basin A
ETB	Evapotranspiration From Groundwater Basin B
RTFLA1	Return Flow From A-1
RTFLA2	Return Flow From A-2
RTFLA3	Return Flow From A-3
RTFLA4	Return Flow From A-4
PIRA2j	Pumping For Irrigation From GWSTA to A-2
PERC2A	Percolation from A-2 to GWSTA
GWFAB	Groundwater Flow From GWSTA to GWSTB
BSFLOA	Base Flow From GWSTA
PIRB1j	Pumping for Irrigation from GWSTB to A-1
PERC1B	Percolation from A-1 to GWSTB
PIRB3j	Pumping for Irrigation From GWSTB to A-3
PERC3B	Percolation from A-3 to GWSTB
PIRB4j	Pumping for Irrigation from GWSTB to A-4
PERC4B	Percolation from A-4 to GWSTB
BSFLOB	Base Flow From GWSTB
NWCCR	New Canyon Creek
GUNSNR	Gunnison Reservoir

$-8.00AREB1 - 8.00AREB2 - 2.30PIRA2 - 2.30PIRB1 - 2.90PIRB3$

$-2.90PIRB4 - (0.00)ST6 - 87.60ST3 - 20.00ST4 - 20.00ST5$

$-5.00ST1 - 107.00ST7 - 19.20ST8 - 0.00ST2$

Note: ( ) These values zero because facilities are existing where coefficients are given in \$/AF and variables are in AF.

Subject to the following constraints:

Sanpete Model--Constraint Equations

I. <u>Flows in all reaches must be nonnegative</u>

1. $TIN1i - AREA1j - CF1i \geq 0$
2. $TIN2i - .94CF3i + STI1 - AREB1j + .04CF4i + 0.1PIRB1j \geq 0$
3. $AREA2j \leq TIN6i$
4. $-.075CF1i + 0.91CF2i - 0.25PIRA2j + AREA2j - STI6 - STI7 + CF5i + CF6i \leq (TMTND2 + TIN6i + EPHCRi + WWCCRi)$
5. $AREB2j + CF7i + CF8i - 0.06CF5i - 0.09CF6i - 0.1PIRB3j - STI8 - 0.1GWSTAI \leq SC3i$
6. $0.15GWSTBI + STI2 + 0.06CF7i + 0.09CF8i + 0.07CF9i + 0.1PIRB4j \geq DSREQ$

II. <u>Releases from storage less than or equal to sum of inflows and initial storage</u>

<u>Surface Storage</u>

1. $TIN1i - STI3 \leq SC1i$
2. $TIN2i + CF4i - STI4 - STI5 \leq SC2i + TMTND1$

3. $CF1i + CF3i + CF6i + CF8i + AREA1j + AREB1j - STI1 - TIN1i - TIN2i \leq 0$

4. $CF2i + AREA2j - STI6 + TIN3i \leq TIN6i$

5. $CF5i - STI7 + TIN4i \leq NWCCRi + EPHCRi + TMTND2$

6. $CF7i + AREB2j - STI8 + TIN5i \leq SC3i$

7. $STI1 + STI2 + TIN1i + TIN2i + TIN3i + TIN4i + TIN5i - AREA1j$

   $- AREB1j + 0.1GWSTAI + 0.15GWSTBI + 0.1PIRB1j + 0.25PIRA2j$

   $+ 0.1PIRB3j + 0.1PIRB4j - 0.93CF1i + 0.09CF2i - .94CF3i$

   $+ .04CF4i + .06CF5i - 0.91CF6i + 0.06CF7i - 0.91CF8i$

   $+ 0.07CF9i \geq DSREQ = 22,000$

8. $CF9i \leq M6DIVi$

Groundwater Storage

1. $0.65PIRA2j - 0.675CF1i - 0.61CF2i - AREA1j - AREA2j$

   $+ GWFAB - 0.9GWSTAI \leq NREAj$

2. $0.5PIRB1j + 0.5PIRB3j + 0.5PIRB4j - AREB1j - AREB2j$

   $- .64CF3i - .76CF4i - .7CF5i - .55CF6i - .7CF7i - .55CF8i$

   $- .625CF9i - .85GWSTBI \leq NREBj$

III. Contents of reservoir at end of season cannot exceed capacity

(Initial storage + inflow - outflow $\leq$ capacity)

<u>Surface Reservoirs</u>

1. $STI3 - STC3 - TIN1i \leq -SC1i$

2. $STI4 + STI5 - STC4 - TIN2i - CF4i \leq -(SC2i + TMTND1)$

3. $STC5 \leq 10{,}000$

4. $STI1 - STC1 + TIN1i + TIN2i - AREA1j - AREB1j - CF1i - CF3i$

   $- CF6i - CF8i \leq 0$

5. $STI6 - STC6 - AREA2j - CF2i - TIN3i \leq -TIN6i$

6. $STI7 - STC7 - TIN4i - CF5i \leq -(EPHCRi + NWCCRi + TMTND2)$

7. $STI8 - STC8 - AREB2j - TIN5i - CF7i \leq -SC3i$

8. $STI2 + STI1 - STC2 - STC1 + TIN1i + TIN2i + TIN3i + TIN4i$

   $+ TIN5i - AREA1j - AREB1j - .93\,CF1i + .09\,CF2i - .94\,CF3i$

   $+ .04\,CF4i + .06\,CF5i - .91\,CF6i + .06\,CF7i - .91\,CF8i + .07\,CF9i$

   $+ .01\,GWSTAI + .15\,GWSTBI \leq DSREQ = 22{,}000$

<u>Groundwater Reservoirs</u>

1. $0.9\,GWSTAI - GWSTA - GWFAB + AREA2j + AREA1j + .67\,CF1i$

   $+ .61\,CF2i - .65\,PIRA2j \leq -NREAj$

2. $0.85\,GWSTBI - GWSTB + GWFAB + AREB1j + AREB2j + .64\,CF3i$

   $+ .76\,CF4i + .7\,CF5i + .55\,CF6i + .7\,CF7i + .55\,CF8i + .62\,CF9i$

   $- .5\,PIRB1j - .5\,PIRB3j - .5\,PIRB4j \leq -NREBj$

IV. Aspired level for initial storage reattainable each year

Surface Storage

1. $\Sigma pi\ TIN1i \leq \overline{SC1} = 13{,}890$

2. $\Sigma pi\ TIN2i + \Sigma pi\ CF4i \leq \overline{SC2} + TMTND1 = 68{,}940D1$

3. $\Sigma pi\ CF1i + \Sigma pi\ CF3i + \Sigma pi\ CF6i + \Sigma pi\ CF8i + \Sigma qi\ AREA1j$
   $+ \Sigma qi\ AREB1j - \Sigma pi TIN1i - \Sigma pi\ TIN2i \leq 0$

4. $\Sigma qj\ AREA2j + \Sigma pi\ CF2i + \Sigma pi\ TIN3i \leq \overline{TIN6}$

5. $\Sigma pi\ TIN4i + \Sigma pi\ CF5i \leq \overline{NWCCR} + \overline{EPHCR} + TMTND2$

6. $\Sigma pi\ TIN5i + \Sigma pi\ CF7i + \Sigma qi\ AREB2j \leq \overline{SC3}$

7. $\Sigma pi\ TIN1i + \Sigma pi\ TIN2i + \Sigma pi\ TIN3i + \Sigma pi\ TIN4i + \Sigma pi\ TIN5i$
   $- \Sigma qj\ AREA1j - \Sigma qj\ AREB1j + 0.1GWSTAI + 0.15GWSTBI$
   $- \Sigma pi\ .93\ CF1i + \Sigma pi\ .09\ CF2i - \Sigma pi\ .94\ CF3i + \Sigma pi\ .04\ CF4i$
   $+ \Sigma pi\ .06\ CF5i - \Sigma pi\ .91\ CF6i + \Sigma pi\ .06\ CF7i - \Sigma pi\ .91\ CF8i$
   $+ \Sigma pi\ .07\ CF9i + \Sigma qj\ 0.1\ PIRB1j + \Sigma qj\ 0.25\ PIRA2j$
   $+ \Sigma qj\ 0.10\ PIRB3j + \Sigma qj\ 0.1\ PIRB4j \geq DSREQ$

8. $\Sigma pi\ CF9i \leq \overline{M6DIV} = 4160$

Groundwater Storage

1. $\Sigma qj\ .65\ PIRA2j - \Sigma qj\ AREA1j - \Sigma qj\ AREA2j - \Sigma pi\ .67\ CF1i$
   $- \Sigma pi\ .61\ CF2i + GWFAB + .1\ GWSTAI \leq \overline{NREA}$

2. $\Sigma qj\ 0.5\ PIRB1j + \Sigma qj\ 0.5\ PIRB3j + \Sigma qj\ 0.5\ PIRB4j$
   $+ 0.15\ GWSTBI - GWFAB - \Sigma qj\ AREB1j - \Sigma qj\ AREB2j$
   $- \Sigma pi\ .64\ CF3i - \Sigma pi\ .76\ CF4i - \Sigma pi\ .7\ CF5i - \Sigma pi\ .55\ CF6i$
   $- \Sigma pi\ .7\ CF7i - \Sigma pi\ .55\ CF8i - \Sigma pi\ .62\ CF9i \leq \overline{NREB}$

V. Constraints describing shortage

1. IRRA1 - 0.4 CF4i - 0.6 CF3i - PIRB1j $\leq$ SHA1ij

2. IRRA2 - 0.5 CF1i - 0.6 CF2i - PIRB2j $\leq$ SHA2ij

3. IRRA3 - 0.4 CF5i - 0.6 CF6i - PIRB3j $\leq$ SHA3ij

4. IRRA4 - 0.4 CF7i - 0.6 CF8i - 0.5 CF9i - PIRB4j $\leq$ SHA4ij

Variables on the left side of the equation are decision variables that are to be solved for in the solution of the model. Variables on the right side of the equation are probabilistic inputs.

In reality, stream flows and natural recharge are probabilistic variables (parameters). Other deterministic variables depend directly on certain probabilistic inputs. Therefore it is necessary to describe probabilistic variates and their corresponding flow in the constraint equations in order to optimize the objective function.

Probability density coefficients

Kim (1968) developed a method of obtaining probability density coefficients from annual stream flow data. His method is used to describe the flow level probability in this report.

This method consists of deriving from the annual stream flow data six discrete points. The points are chosen in the following manner. The minimum annual flow is chosen as the first discrete point. The succeeding discrete points are obtained by adding to the prior discrete point the quotient of the difference of the maximum annual stream flow minus the minimum annual stream flow divided by five. The last and sixth discrete point is the maximum annual stream flow.

A probability density coefficient is obtained for each interval between discrete points by the following equation:

$$\text{Probability Density Coefficient (i)} = \Phi \frac{(X_{i+1} - \overline{X})}{S} - \Phi \frac{(X_i - \overline{X})}{S}$$

$$= \Phi (z)$$

where

i = 1, 2, . . ., 6

X_i = discrete point

$\overline{X}$ = average of annual stream flow data

S = standard deviation of annual stream flow

Φ = functional relation

Now from cumulative standard normal tables for values of $\Phi(z)$, (corresponding to the "z" column in the tables), look up corresponding values of $G(z)$ in the tables which are the probability density coefficients. There is a set of five probability density coefficients for each probabilistic input.

Figure 2 shows an illustrative plot of probability density coefficient vs. corresponding flow. The bar graph approximates the curve shown by the dashed lines. Bar columns are divided by the discrete point intervals. If the period of record for annual flow were infinite, the curve would be a normal distribution. Since the actual length of record is limited, the curve usually is not normal and usually skewed. If the data were infinite, the probability density coefficients would add up to 1.0. In actual limited data this is reduced by the amount in the upper and lower tails of the curve.

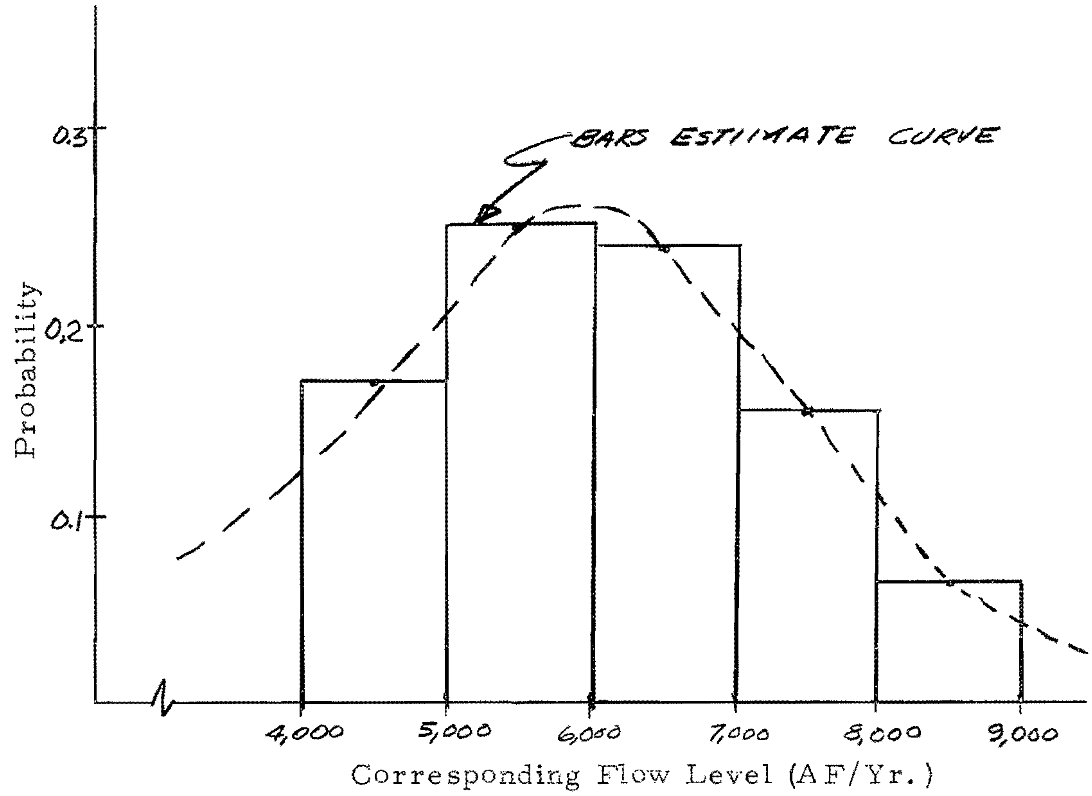


Figure 2. Probability density coefficient vs. corresponding flow level

Probability density coefficients were derived for Twin Creek using both estimated and recorded data. Recorded data on Twin Creek began in 1955. Runoff data for Twin Creek was estimated from 1949 to 1955, by correlation with Ephraim Creek (see Figure 4, Appendix A). The year 1949 is thought by some to be the beginning of a new cycle of hydrologic conditions and for this reason was chosen as the beginning of the base period. Foliage on the range land gives some evidence of being more constant from 1949 to the present. Thus, runoff patterns would be similar for this time base.

Table 14 (Appendix B) lists runoff data. Table 4 lists probability density coefficients derived from the runoff data along with corresponding flows.

Table 4. Twin Creek probability density coefficients

Discrete Point Interval	Probability Density Coefficient	Corresponding Flow
3,540 - 4,588	.163	4,064
4,588 - 5,636	.234	5,112
5,636 - 6,684	.232	6,160
6,684 - 7,732	.160	7,208
7,732 - 8,780	.075	8,256

Probability density coefficients for Pleasant Creek were derived from data from the base period 1949 to 1965. Annual flows for 1949 to 1955 were estimated from Figure 5 (Appendix A), which is a plot of Pleasant Creek discharge vs average of Twin Creek and Ephraim Creek discharge. Table 15 (Appendix B) lists runoff data. Table 5 gives the probability density coefficients and corresponding flows.

Table 5. Pleasant Creek probability density coefficients

Discrete Point Interval	Probability Density Coefficient	Corresponding Flow
7,900 - 10,360	.175	9,130
10,360 - 12,820	.273	11,590
12,820 - 15,280	.256	14,050
15,280 - 17,740	.145	16,510
17,740 - 20,200	.050	18,970

Probability density coefficients for Ephraim Creek were derived from actual data for 1949 to 1963. Table 16 (Appendix B) lists the runoff data. Table 6 below lists the probability density coefficient and corresponding flow.

Table 6. Ephraim Creek probability density coefficients

Discrete Point Interval	Probability Density Coefficient	Corresponding Flow
8,796 - 12,716	.160	10,756
12,716 - 16,636	.234	14,676
16,636 - 20,556	.235	18,586
20,556 - 24,476	.260	22,516
24,476 - 28,396	.077	26,436

Probability density coefficients were derived for Big Springs using estimated data derived from Figure 6 (Appendix A). Data were estimated from 1949 to 1955, and from 1963 to 1966. Actual records were available on Big Springs from 1955 through 1962. This gave a base period of from 1949 to 1966.

Table 17 (Appendix B) lists annual stream flow. Table 7 follows listing probability density coefficients and corresponding flow level.

In order to arrive at probability density coefficients for natural recharge to groundwater basin "A," (NREA), it was necessary to develop an equation describing NREA. The equation estimates annual recharge to the area.

Table 7. Big Springs probability density coefficients

Discrete Point Interval	Probability Density Coefficient	Corresponding Flow
3,431 - 4,555	.142	3,993
4,555 - 5,679	.256	5,117
5,679 - 6,893	.275	6,241
6,893 - 7,927	.196	7,365
7,927 - 9,050	.042	8,489

Natural recharge depends directly upon stream flow and precipitation on the area. Thus, the following equation relating NREA to stream flow and runoff was developed:

$$\text{NREA} = 1.11\ (\text{stream flow}) + 1.06\ (\text{precipitation at Moroni})$$

where values are given in ac.-ft.

Adequate stream flow records have not been kept in the area of groundwater basin "A," so stream flow values were estimated using the following equation:

$$\text{Stream flow} = 0.135\ (\text{Pleasant Creek}) + 0.865\ (\text{Big Springs})$$

where values are given in ac.-ft.

Table 8 shows components of stream flow data. Table 9 follows listing NREA and its component parts, along with its discrete points and statistics of the annual data.

Probability density coefficients for natural recharge to groundwater area "A," (NREA), are listed below in Table 10.

Table 8. Stream flow for NREA in ac. -ft.

Year	Pleasant Creek	Big Springs	2.5/18.5 (Pleasant)	(Big Springs)	Stream flow
1955	11,210	4,260	1,520	3,680	5,200
1956	10,020	5,548	1,350	4,800	6,150
1957	16,030	7,446	2,170	6,430	8,600
1958	16,230	8,760	2,200	7,580	9,780
1959	8,830	5,329	1,192	4,600	5,792
1960	10,330	4,453	1,400	3,860	5,260
1961	7,900	3,431	1,070	2,960	4,030
1962	15,450	6,205	2,090	5,360	7,450

Table 9. NREA and its components

Year	Stream flow	1.11 (Stream flow)	Moroni Precipitation	1.06 (Precip.)	NREA
1955	5,200	6,780	10,540	11,200	17,980
1956	6,150	6,840	7,120	7,550	14,390
1957	8,600	9,550	13,120	13,900	23,450
1958	9,780	10,850	6,400	6,790	17,640
1959	5,792	6,440	8,450	8,950	15,390
1960	5,260	5,850	10,000	10,600	16,450
1961	4,030	4,480	12,390	13,100	17,580
1962	7,450	8,280	9,250	9,800	18,080

$S = 2,950$ Discrete Points:

$\overline{X} = 17,610$

14,390
16,202
18,014
19,826
21,636
23,450

Values checked closely with corresponding items of an unpublished S. C. S. water budget for the area.

Table 10. NREA probability density coefficients

Discrete Point Interval	Probability Density Coefficient	Corresponding Flow
14,390 - 16,202	.180	15,296
16,202 - 18,014	.237	17,108
18,014 - 19,826	.219	18,920
19,826 - 21,638	.141	20,732
21,638 - 23,450	.062	22,544

As with NREA, it is necessary to estimate the natural recharge to groundwater area "B," (NREB), on an annual basis. A base period needed to be established before probability density coefficients could be derived. The following equation was developed relating NREB with stream flow and precipitation:

NREB = 0.218 (stream flow) + precipitation (av. of Manti and Moroni)

where values are given in ac.-ft.

Stream flow was distributed by the following ratio:

$$\frac{\text{Ephraim stream flow}}{\text{Av. Ephraim stream flow}} = \frac{\text{Stream flow}}{\text{Av. stream flow}}$$

where:

Av. stream flow = 81,570 ac.-ft.

Av. Ephraim stream flow (1949 - 1963) = 16,670 ac.-ft.

Table 11 lists NREB and its component parts.

Table 11. NREB and its components

Year	Ephraim	Ratio	Stream flow	0.218 (Stream flow)	Precip.	NREB
1949	18,217	1.1	89,600	19,500	26,000	45,500
1950	13,592	.816	66,600	14,500	23,750	38,250
1951	13,342	.803	65,500	14,270	31,600	45,870
1952	27,054	1.63	133,000	29,000	27,300	56,300
1953	17,621	1.06	86,500	18,820	31,500	50,320
1954	16,780	1.01	82,500	18,000	31,750	49,750
1955	14,586	.875	71,500	15,590	27,400	42,990
1956	12,417	.748	61,000	13,300	23,100	36,400
1957	25,466	1.53	125,000	27,200	44,200	71,400
1958	-	-	-	-	19,530	-
1959	8,796	.529	43,100	9,400	26,850	36,250
1960	13,738	.826	67,500	14,700	28,400	43,100
1961	10,936	.658	53,600	11,700	41,200	52,900
1962	28,397	1.71	139,500	33,000	28,000	61,000
1963	12,204	.735	60,000	13,080	33,100	46,180
			S =	10,220	Discrete Points:	
			$\overline{X}$ =	48,400		36,250
						43,280
						50,310
						57,340
						64,370
						71,400

The following table lists the probability density coefficients for natural recharge to groundwater area "B," (NREB), with corresponding flow levels.

Probability density coefficients were needed for each probabilistic input. See Figure 1, the schematic flow diagram, for locations of

Table 12. NREB probability density coefficients

Discrete Point Interval	Probability Density Coefficient	Corresponding Flow
36,250 - 43,280	.192	39,765
43,280 - 50,310	.265	46,795
50,310 - 57,340	.234	53,825
57,340 - 64,370	.133	60,855
64,370 - 71,400	.047	67,885

probabilistic inputs. Table 3 lists descriptions of the abbreviated components of the schematic flow diagram.

The probabilistic inputs consist of NREAi, NREBi, SC1i, SC2i, SC3i, NWCCRi, EPHCRi, and TIN6i. Transmountain diversions are relatively constant year after year and are not described by probability density coefficients. The flow and storage levels of the other variables will be solved for in the solution to the linear programming model.

NREAi and NREBi are described by the probability density coefficients derived for them. SC1i and SC2i are represented by the average of Twin and Pleasant Creeks probability density coefficients. EPHCR, NMCCRi, and SC3i are described by the probability density coefficients derived for Ephraim Creek. TIN6i is described by the coefficients derived for Big Springs.

Table 13 lists the probabilistic inputs and the corresponding sets of probability density coefficients for these variables.

Table 13. Probability density coefficients for stochastic inputs

Stochastic Input	Probability Density Coefficients	Flow
NREAi	.180	15,296
	.237	17,108
	.219	18,920
	.141	20,732
	.062	22,544
NREBi	.192	39,765
	.265	46,795
	.234	53,825
	.133	60,855
	.047	67,885
SC1i	.169	9,720
	.254	12,200
	.244	14,630
	.253	17,180
	.063	19,700
SC2i	.169	45,900
	.254	52,200
	.244	69,100
	.253	81,000
	.063	92,800
SC3i	.160	18,700
	.234	25,500
	.235	32,300
	.260	39,200
	.077	46,100
EPHCRi	.160	10,756
	.234	14,676
	.235	18,586
	.260	22,516
	.077	26,436
NWCCRi	.160	(5,270)
	.234	(7,190)
	.235	(9,100)
	.260	(11,010)
	.077	(13,000)

CONCLUSIONS

On the basis of data presented, there is sufficient water available for irrigation of all irrigable lands in the Sanpete Valley if care is taken in planning and developing water use.

The estimated groundwater safe yield has not been reached. On the basis of the estimated safe yield of 17,800 AF/yr, an approximate additional 2,000 AF of groundwater could be developed even with no change in agricultural pattern. Harold Brown of the Soil Conservation Service estimated about 20 additional wells could be drilled in watershed A-1 (Plate VI, Appendix C).

A reduction in nonbeneficial use would require a lowering of the water table in the phreatophyte areas. This would allow the eradication of the phreatophytes. Conjunctive use of water throughout the Sanpete Valley and consolidation of irrigation companies would increase the efficiency of water use. Comprehensive water basin planning and management should be considered as water demands increase on a fixed supply.

Using the groundwater basin for storage of water in underground reservoirs along with planned, controlled pumping in conjunction with surface distribution may increase the efficiency of use greatly. By drying up nonbeneficial or marginal value wetlands, more groundwater would be available for development. The safe yield thus could be 20,000 to 80,000 AF, depending on the amount salvaged.

To best manage the water resources of the basin may require a consolidation of the separate entities into a central basin authority. Under this authority conjunctive use of water could possibly be best implemented. Water from surface supplies may best be used in the uplands and areas adjacent to the hills. Pumping may be best suited for the lowlands and central valleys. Water tables could be lowered to levels to provide for best use of underground storage. Injured parties should receive fair compensation.

Solving the linear programming model of the San Pitch Basin in subsequent studies at the Utah Water Research Laboratory will yield optimal solutions to the equations given previously in this report. These studies will optimize the conjunctive use of water in the basin. The interested reader should consult these subsequent studies.

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APPENDICES

Appendix A

Figures

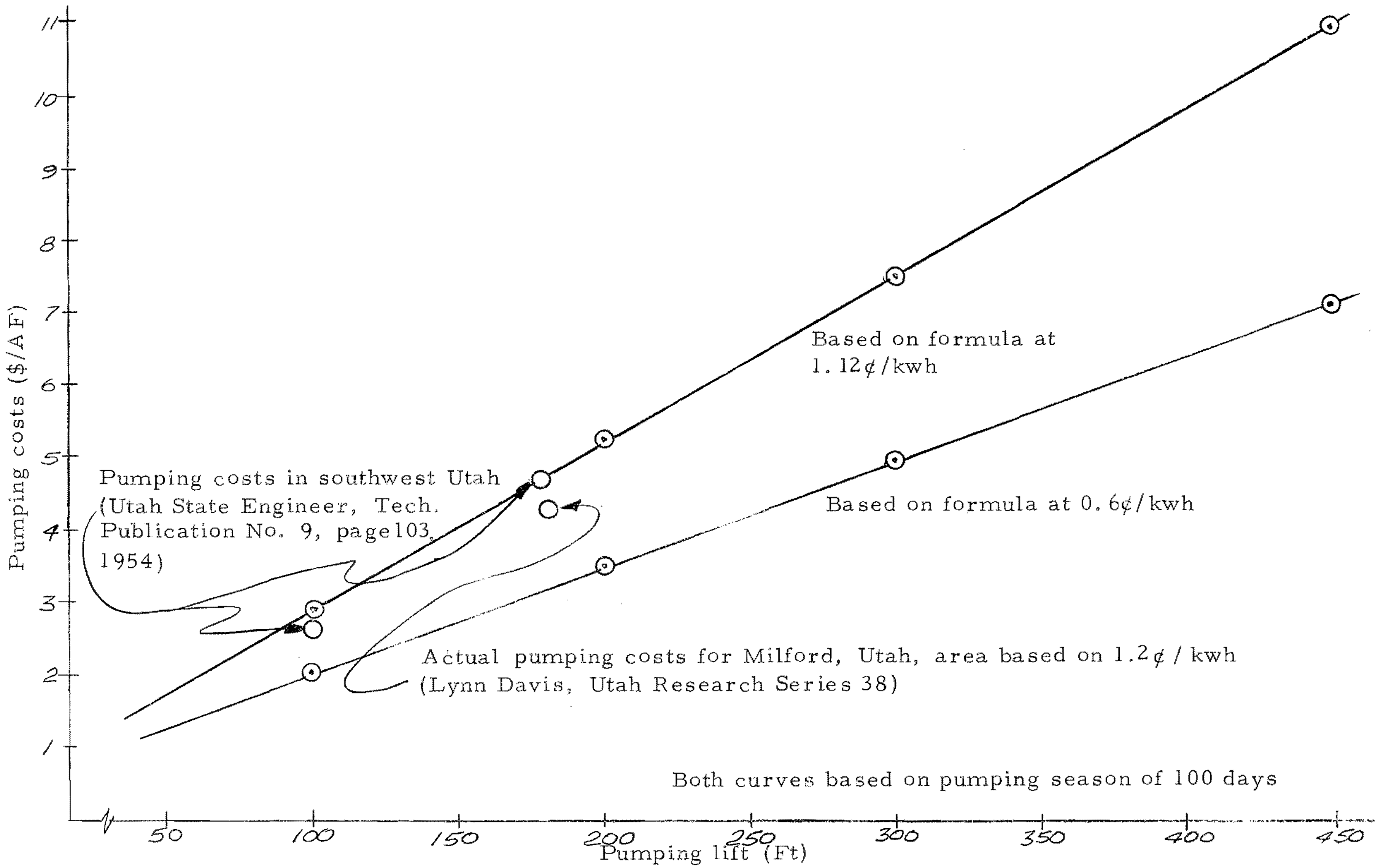


Figure 3. Pumping costs vs. pumping lift

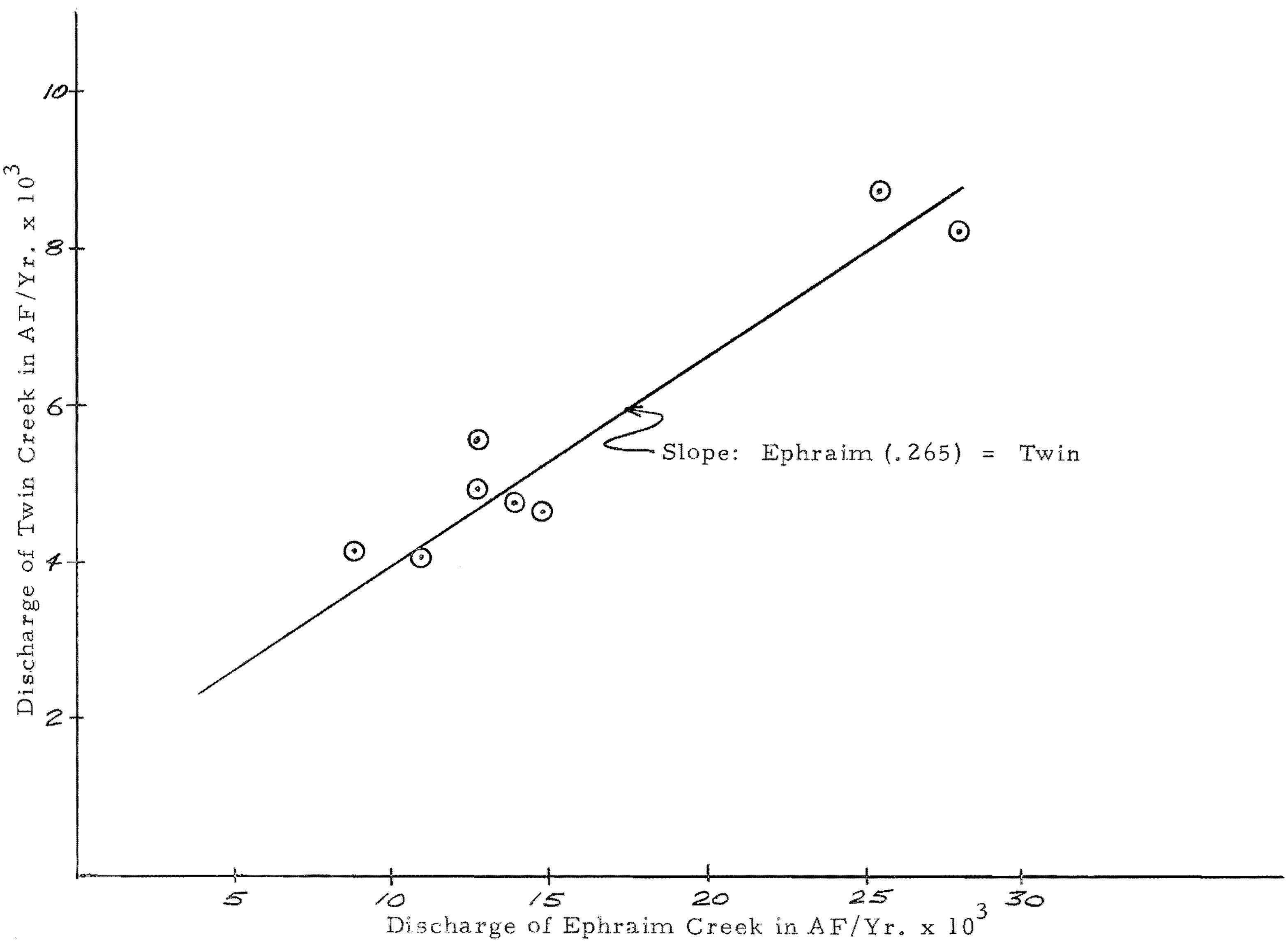


Figure 4. Discharge of Twin Creek vs. discharge of Ephraim Creek

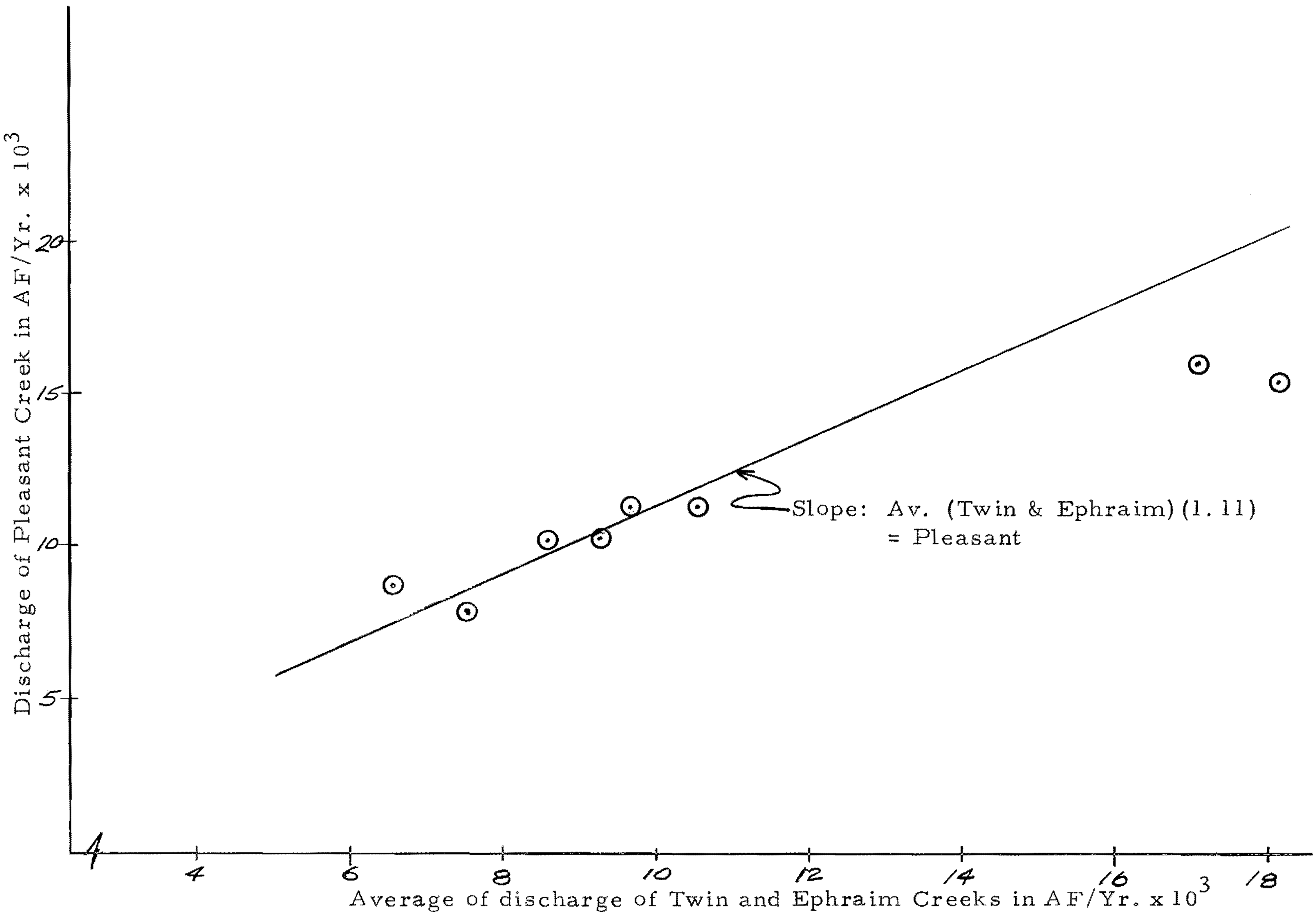


Figure 5. Discharge of Pleasant Creek vs. average of discharge of Twin and Ephraim Creeks

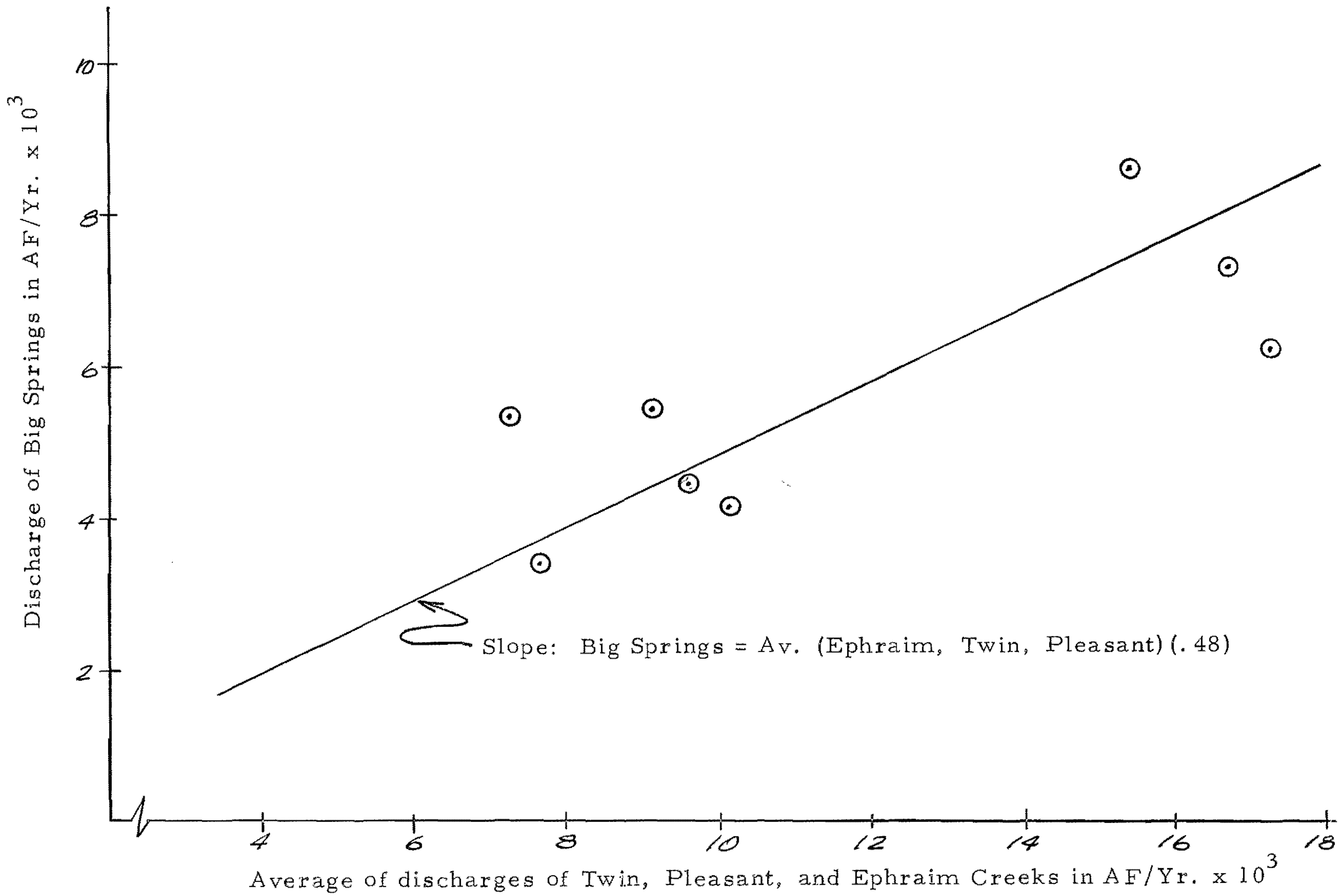


Figure 6. Discharge of Big Springs vs. av. of discharge of Twin, Pleasant, and Ephraim Creeks

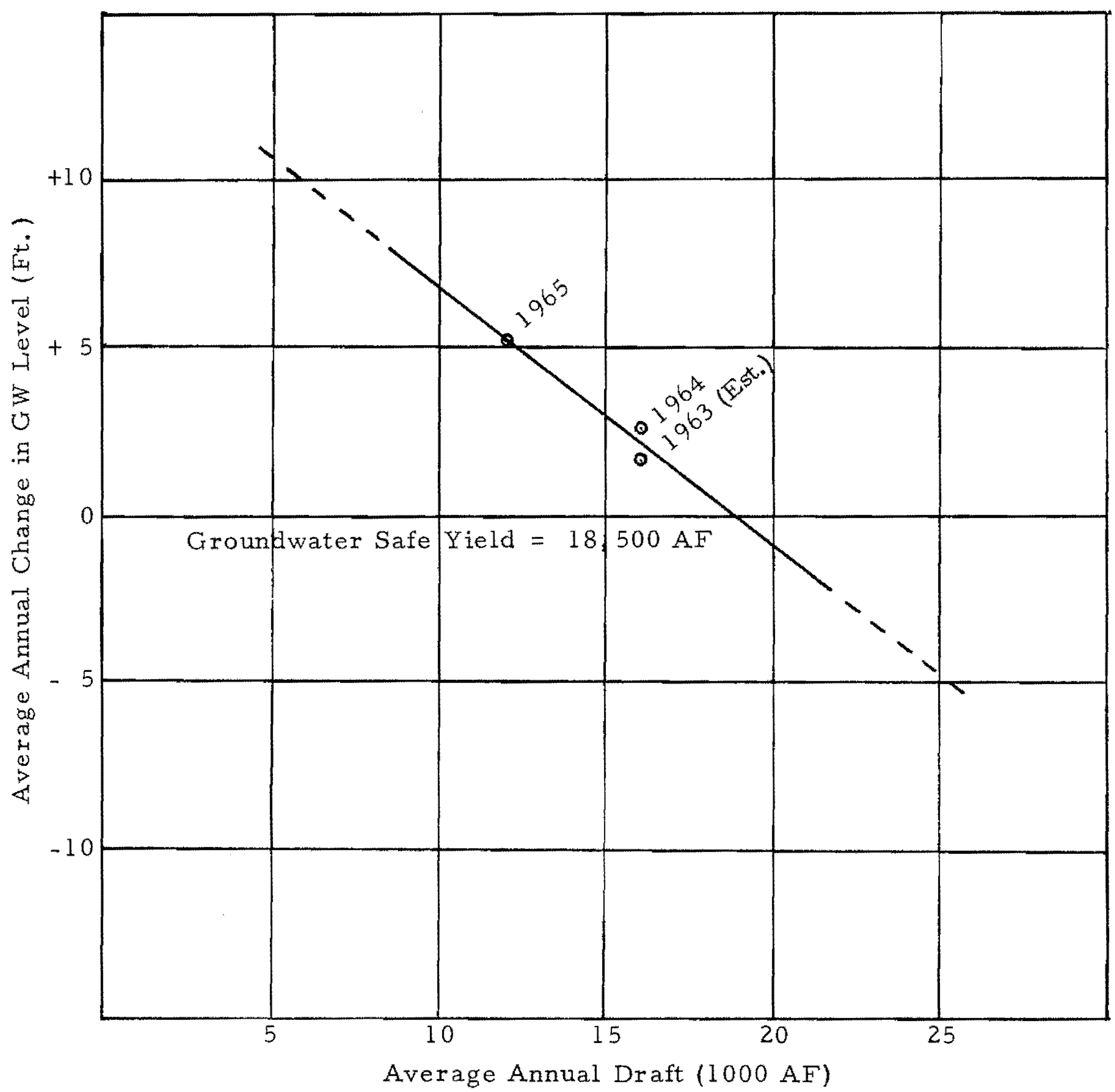


Figure 7. Safe yield by Hill method

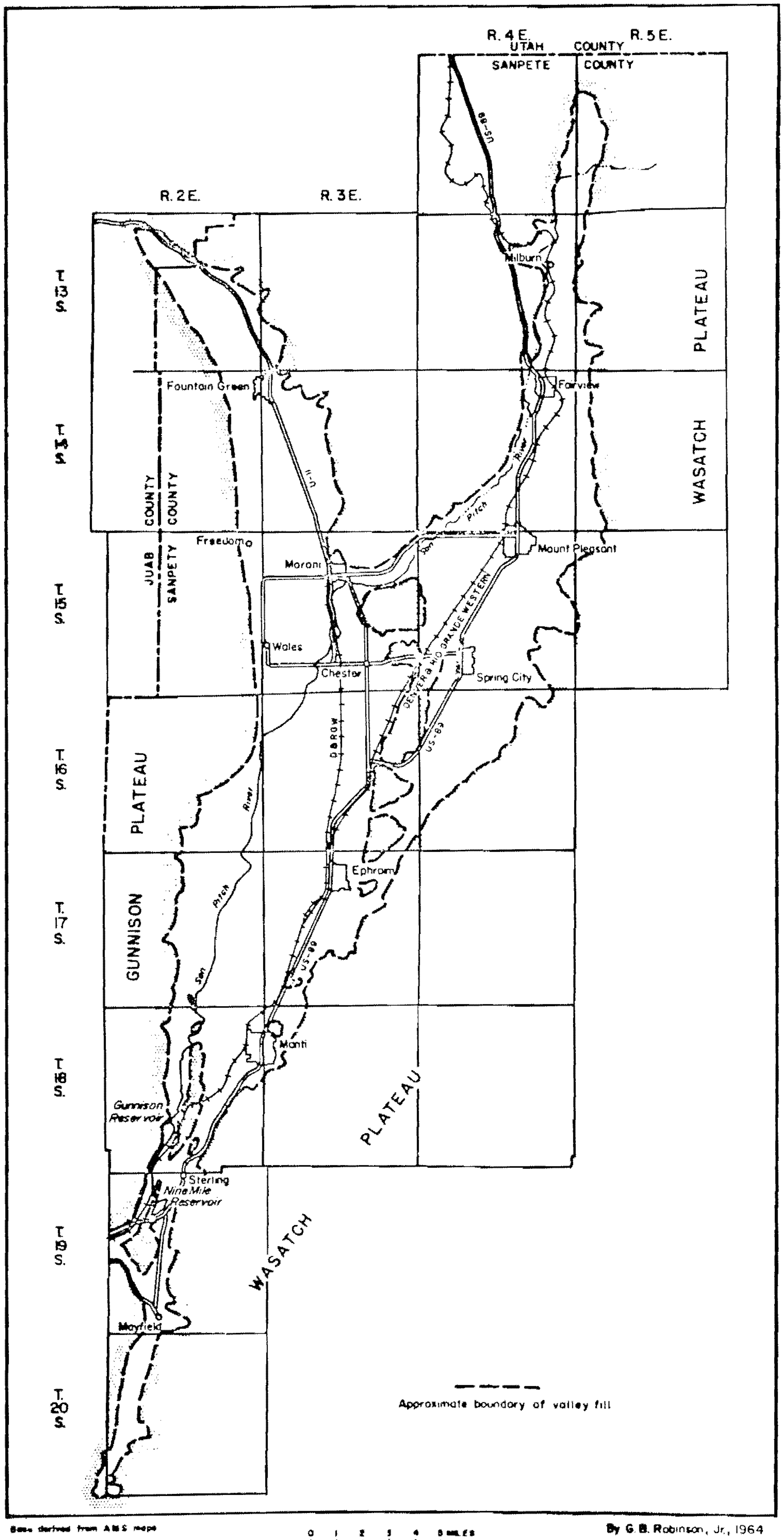


Figure 8. Map of Sanpete Valley

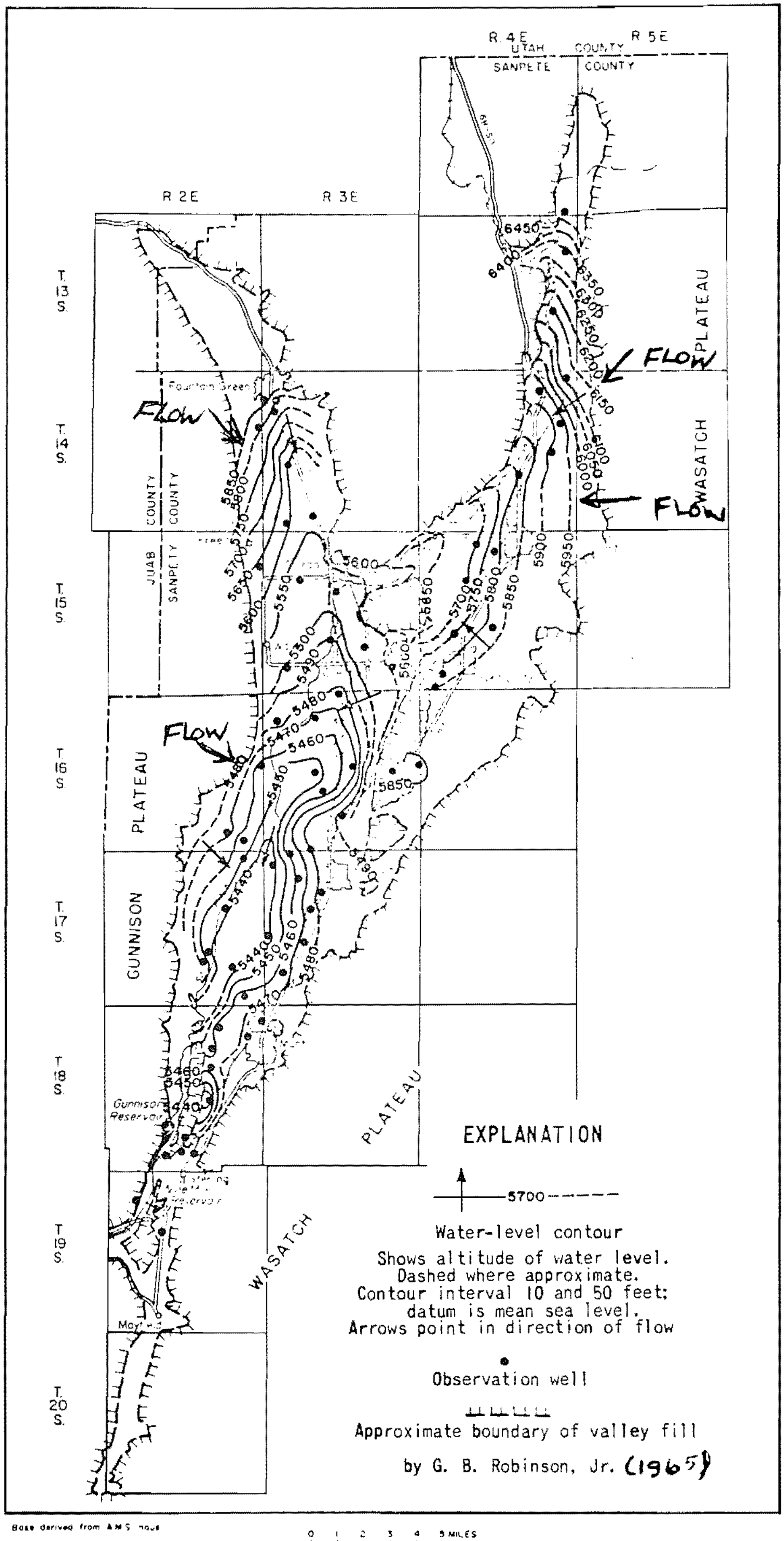


Figure 9. Map of Sanpete Valley showing water-level contours, March 1965

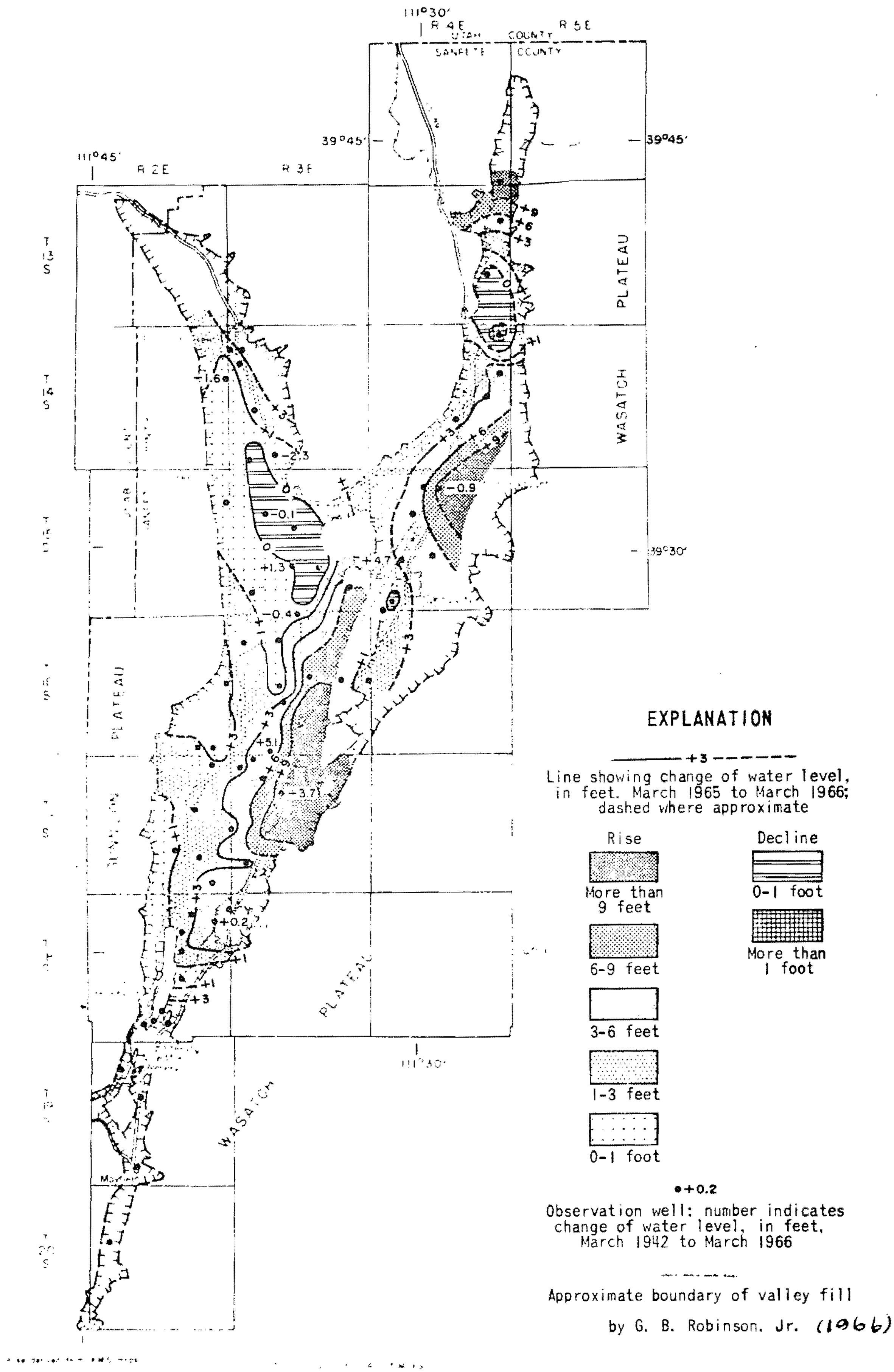


Figure 10. Map of Sanpete Valley showing change of water levels, March 1965 to March 1966

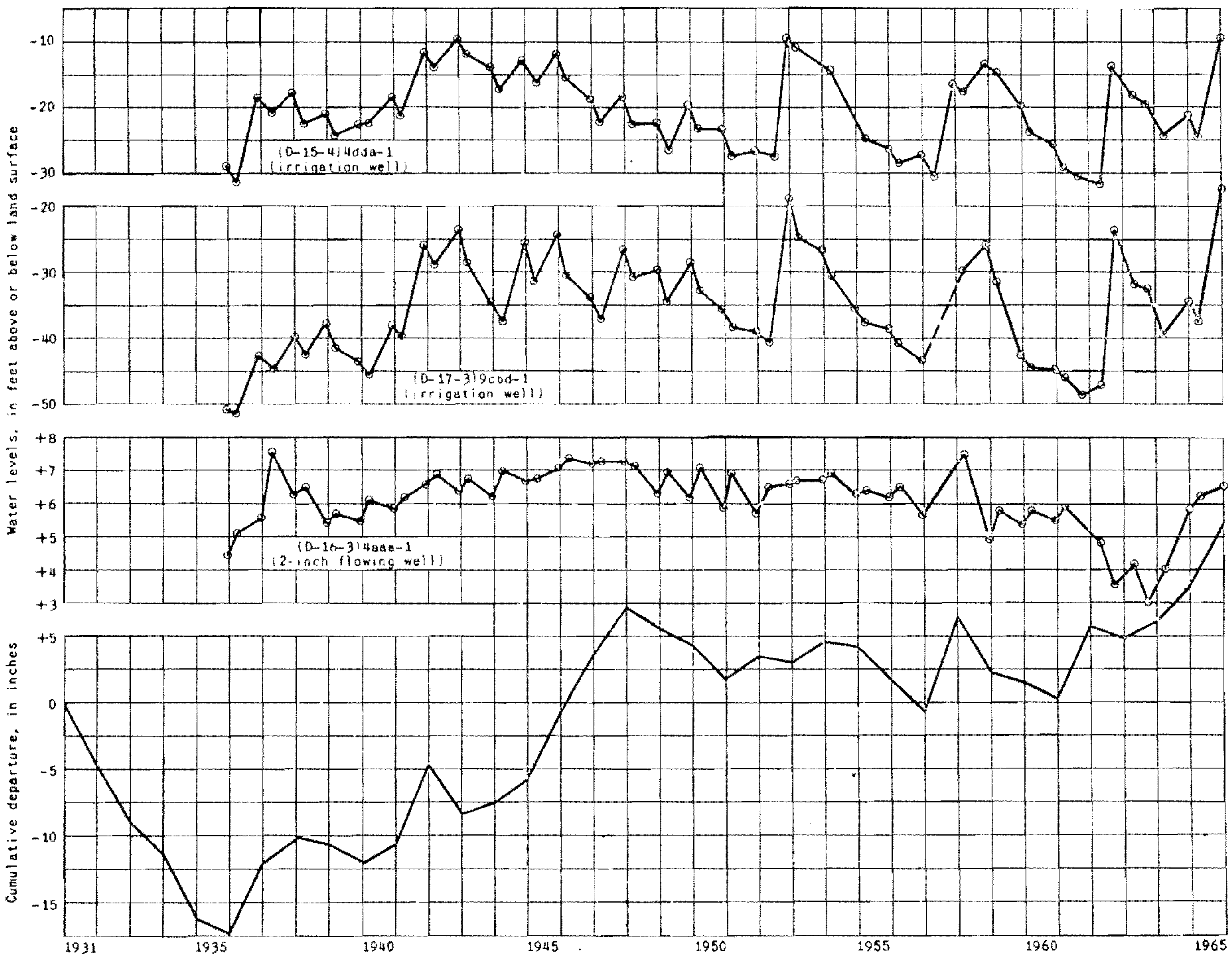
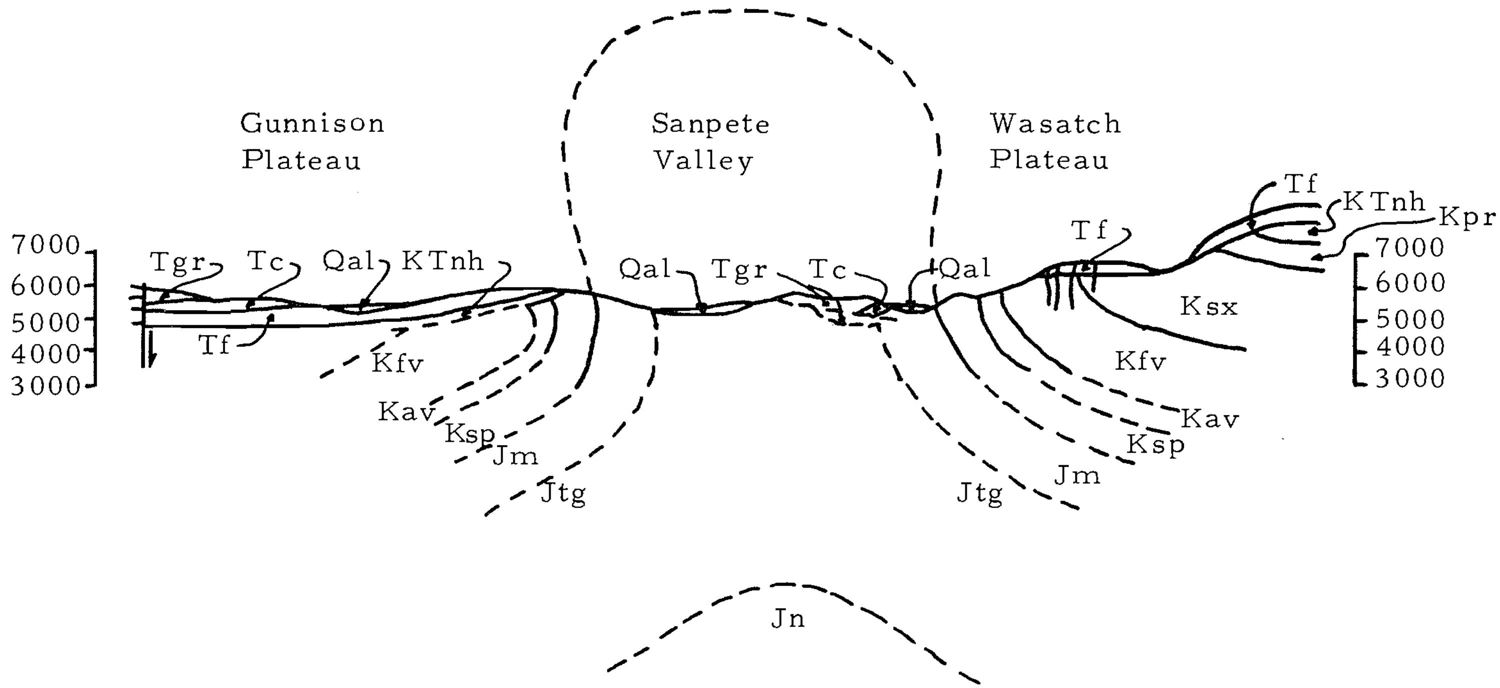


Figure 11. Hydrographs showing relation of water levels in three wells in the Sanpete Valley to cumulative departure from the 1931-1960 normal annual precipitation at Manti



Qal	Alluvium	Kpr	Price River	Jm	Morrison
Tgr	Green River	Ksx	Six Mile Canyon	Jtg	Twist Gulch
Tc	Colton	Kfv	Funk Valley	Jn	Navajo
Tf	Flagstaff	Kav	Allen Valley		
KTnh	North Horn	Ksp	Sanpete		

Figure 12. Structural section of Sanpete Valley (Spieker, 1949)

Appendix B

Tables

Table 14. Twin Creek annual runoff

Year	Annual Runoff (ac.-ft.)
49	(4,850)
50	(3,600)
51	(3,540)
52	(7,180)
53	(4,680)
54	(4,450)
55	4,700
56	4,980
57	8,780
58	7,680
59	4,250
60	4,800
61	4,070
62	7,740
63	5,610
64	6,400
65	8,260
66	5,510

$\overline{X}$ = 5,620

S = 1,680

( ) = estimated

Discrete Points: 3,540, 4,588, 5,636, 6,684, 7,732, 8,780

Table 15. Pleasant Creek annual runoff

Year	Annual Runoff (ac.-ft.)
49	(13,600)
50	(10,150)
51	(9,950)
52	(20,200)
53	(13,180)
54	(12,580)
55	11,210
56	10,020
57	16,030
58	16,230
59	8,830
60	10,330
61	7,900
62	15,450
63	10,000
64	11,740
65	15,390

$\bar{X}$ = 12,500

S = 3,400

( ) = estimated

Discrete Points: 7,900, 10,360, 12,820, 15,280, 17,740, 20,200

Table 16. Ephraim Creek annual runoff

Year	Annual Runoff (ac.-ft.)
49	18,217
50	13,592
51	13,343
52	27,054
53	17,621
54	16,780
55	14,586
56	12,417
57	25,466
58	-
59	8,796
60	13,738
61	10,936
62	28,397
63	12,204

$\overline{X}$ = 16,670

S = 6,260

Discrete Points: 8,796
12,716
16,636
20,556
24,476
28,396

Table 17. Big Springs annual stream flow

Year	Annual Stream flow
49	(6, 100)
50	(4, 550)
51	(4, 460)
52	(9, 050)
53	(5, 900)
54	(5, 630)
55	4, 260
56	5, 548
57	7, 446
58	8, 760
59	5, 329
60	4, 453
61	3, 431
62	6, 205
63	(4, 450)
64	(5, 850)
65	(7, 600)
66	(5, 320)

$\overline{X} = 5,800$

S = 1, 570

( ) = estimated

Discrete Points: 3, 431, 4, 555, 5, 679, 6, 803, 7, 927, 9, 050

Table 18. Summary of available climatic data

Station	Index No.	Division	Lat.	Long.	Elevation (Ft)	Observed Time Years: Temp.	Prec.	Evap.	Special	Type Gage	Recorded By
Beaver Dams	0534	04	39 08	111 34	8,000	-	-	-	S	-	USWB
Buck Flat	1012	04	39 08	111 27	9,500	-	-	-	S	-	SCS
Ephraim Alpine Meadows	2565	04	39 18	111 27	9,850	-	-	-	S	-	USFS
E. HDQS, GBRC	2573	04	39 19	111 29	8,850	-	-	-	S	-	USFS
E. Major's Flat	2574	04	39 20	111 32	6,900	-	-	-	S	R	USFS
E. Oaks	2576	04	39 20	111 31	7,400	-	-	-	S	R	USFS
E. Sorensen Field	2578	04	39 21	111 36	5,750	17	18	-	-	R,NR	USFS
Gooseberry Reservoir	3301	05	39 41	111 19	8,700	-	-	-	S	-	SCS
Mammoth Ranger Station	5352	05	39 42	111 18	8,600	-	-	-	S	-	USWB
Manti (X)	5402	04	39 15	111 38	5,585	67	67	-	-	NR	USWB
Moroni	5837	04	39 32	111 35	5,525	49	54	-	-	NR	USWB
Mount Baldy RS	5906	04	39 08	111 31	9,500	-	-	-	S	-	USWB
Pleasant Creek PH	6915	04	39 32	111 22	6,900	4	12	-	-	NR	USWB
Gunnison	3514	04	39 02	111 49	5,145	11	11	5	-	NR	USWB
Major's Flat	—	—	(NW1/4 S18, T17S, R4E)		7,100	-	-	-	-	-	—
Oaks Climatic Sta.	—	—	(NE1/4 S18, T17S, R4E)		7,655	-	-	-	-	-	—
Oak-Sage Runoff Plot	—	—	(NW1/4 S17, T17S, R4E)		7,900	-	-	-	-	-	—
Bluebell Bridge	—	—	(SE1/4 S21, T17S, R4E)		8,990	-	-	-	-	-	—
Meadows	—	—	(NE1/4 S34, T17S, R4E)		9,860	-	-	-	-	-	—
Alpine Cattle Pasture	—	—	(NW1/4 S35, T17S, R4E)		9,900	-	-	-	-	-	—

Table 18. Continued

Station	Index No.	Division	Lat.	Long.	Elevation (Ft)	Observed Time Years: Temp.	Prec.	Evap.	Special	Type Gage	Recorded By
Alpine Philadelphia Flat	—	—	(NE1/4 S34, T17S, R4E)		9,940	-	-	-	-	-	—
Area A	—	—	(SW1/4 S26, T17S, R4E)		10,010	-	-	-	-	-	—
Area B	—	—	(SW1/4 S26, T17S, R4E)		10,160	-	-	-	-	-	—
Left Fork No. 1	—	—	(SW1/4 S23, T17S, R4E)		10,120	-	-	-	-	-	—
Left Fork No. 2	—	—	(SE1/4 S22, T17S, R4E)		10,000	-	-	-	-	-	—
Left Fork No. 3	—	—	(SE1/4 S15, T17S, R4E)		10,400	-	-	-	-	-	—

Key:

R: Recording Gage
NR: Nonrecording Gage
S: Storage Precipitation Gage. Measurements made at irregular intervals.
(X): Station moved 1' south and 1' east October, 1959.
( ): Legal Description.

Table 19. Summary of available stream gaging data

	Gaging Station	Period of Record	Recorded by
1.	Pleasant Creek near Mount Pleasant	1955-Present	USGS
2.	Twin Creek near Mount Pleasant	1955-Present	USGS
3.	Spring City Tunnel near Spring City	1950-62(3)	USGS
4.	Fairview Ditch near Fairview	1952-62(3)	USGS
5.	San Pitch River near Fairview	1954-57(1)	USBR
6.	San Pitch River near Mount Pleasant	1954-57(1)	USBR
7.	San Pitch River near Moroni	1954-57(1)	USBR
8.	San Pitch River at Moroni	1954-57(1)	USBR
9.	San Pitch River near Chester	1954-57(1)	USBR
10.	Ephraim Creek near Ephraim	1941-Present	USGS
11.	Ephraim Tunnel near Ephraim	1950-62(3)	USGS
12.	Twelve Mile Creek near Mayfield	1960-Present	USGS
13.	Sevier River near Gunnison	1912-Present	USGS
14.	Candland Ditch near Mount Pleasant	1950-58(2)	USGS
15.	Coal Fork Ditch near Mount Pleasant	1950-58(2)	USGS
16.	Twin Creek Tunnel near Mount Pleasant	1950-58(2)	USGS
17.	Black Canyon Ditch near Spring City	1950-58(2)	USGS

Table 19. Continued

	Gaging Station	Period of Record	Recorded by
18.	Cedar Creek Tunnel near Spring City	1950-58(2)	USGS
19.	Reeder Ditch near Spring City	1950-58(2)	USGS
20.	John Austin Ditch near Ephraim	1950-58(2)	USGS
21.	Madsen Ditch near Ephraim	1950-58(2)	USGS
22.	Larsen Tunnel near Ephraim	1950-58(2)	USGS
23.	Horseshoe Tunnel near Ephraim	1950-58(2)	USGS
24.	Bluebell Bridge	———	USFS
25.	Alpine Cattle Pasture	———	USFS
26.	Area A	———	USFS
27.	Area B	———	USFS
28.	Left Fork No. 1	———	USFS

Key:

(1)No records are available for winter months, November through February.

(2)Low flow transmountain diversions; average less than 1,100 acre feet.

(3)High flow transmountain diversions from Colorado River basin. Average flow is greater than 1,100 acre feet.

Table 20. Irrigation and canal companies (Ag. Exp. Sta., E.C. 331)

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
Bagnall Ditch Co. Chester, Utah	San Pitch River	-	-	-	824.00
Big Ditch Association Mt. Pleasant, Utah	-	-	-	-	-
Birch Creek Irr. Co. Fairview, Utah	Birch Creek	-	-	1,100	-
Brady Ditch Co. Fairview, Utah	San Pitch River	-	-	365	806.30
Cedar Creek High Water Irrigation Co. Mt. Pleasant, Utah	-	-	-	-	-
Cedar Creek Tunnel Irr. Co., Mt. Pleasant, Utah	-	6-12-44	600 shares at 5.00	-	-
Cedar Creek Irr. Co. Spring City, Utah	Cedar Creek	5-13-05	15,000	600	-
Chester Irrigation Co. Chester, Utah	Oak & Canal Creeks flowing wells Reservoirs No. 1, 2, 3, 4, 5	4-22-27	25,900 at 50.00	1,000	-
Coal Fork Irrigation Co. Mt. Pleasant, Utah	-	-	-	-	-

Table 20. Continued

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
Company Owned Well Co. Manti, Utah	-	-	-	-	-
Cottonwood-Gooseberry Irr. Co. Fairview, Utah	Cottonwood Cr. Gooseberry Reservoir	6-18-48	40,000 at 5.00	1,500	-
Crooked Creek Irr. Co. Fairview, Utah	-	-	-	-	-
Ditch 7 & 8 Pumping Co. Ephraim, Utah	-	12-17-35	4,200 at 12.00	-	-
Dry Creek Irrigation Co. Fairview, Utah	Dry Creek	-	-	300	-
East Milburn Irr. Co. Fairview, Utah	San Pitch River	-	-	250	599.30
Ephraim Irrigation Co. Ephraim, Utah	Ephraim Cotton-wood Creek	2-28-20	250,000	6,000	-
Ephraim Willow Creek Ephraim, Utah	Ephraim Willow Creek	2-20-20	60,000	1,000	-
Excell Irrigation Co. Ephraim, Utah	-	10-16-63	-	-	-
Fairview Birch Creek Irrigation Company Fairview, Utah	-	5-14-14	20,000	-	-

Table 20. Continued

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
Fairview Cottonwood Irr. Co., Fairview, Utah	Cottonwood Creek	-	-	750	-
Fountain Green Irr. Co. Fountain Green, Utah	Birch & Pole Canyon Creeks, Springs, Wells, Cedar Reservoir	2-14-56	34,870	1,050	-
Freedom Irr. & Water-works Co., Freedom, Utah	Current & Maple Canyon Creeks	6-6 - 99	5,012	160	-
Grave Yard Ditch	San Pitch River	-	-	-	474.30
Horseshoe Irrigation Co. Spring City, Utah	Oak & Canal Canyon Creeks	12-2 - 24	250,000 at 10.00	9,000	-
Indianola Irr. Company Indianola (Fairview), Utah	Thistle, Clear Rock Creeks	-	-	2,180	-
Larsen Irrigation Co. Fairview, Utah	-	8-27-17	100,000	-	-
Larsen Irr. Ditch Co. Fairview, Utah	-	-	-	-	-
Lone Pine Ditch Co. Fairview, Utah	-	-	-	-	-
Long Ditch Irr. Co. Milburn, Utah	Springs	-	-	600	-

Table 20. Continued

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
M & M Irr. Company Moroni, Utah	San Pitch River	3-27-37	-	3,200	2,713.38
Manti Irrigation Co. Manti, Utah	Manti Creek, Conrad Res., Mt. Lake	1-19-39	120,254	5,700	-
Manti Irr. & Res. Co. Manti, Utah	Funks Lake Reservoir	3-16-99	12,500	1,200	-
Manti Willow Creek Irr. Co., Manti, Utah	-	-	-	-	-
Mayfield Irrigation Co. Mayfield, Utah	-	8-29-16	160,000	-	-
McArthur Frandsen Ditch Co., Mt. Pleasant, Utah	San Pitch River	10-14-53	-	525	1,483.60
Meadow Irrigation Co. Fairview, Utah	Seepage from high water table	4-20-28	750 at 5.00	90	-
Meadow Ditch & Irr. Co. Milburn, Utah	San Pitch River	-	-	270	397.90
Milburn Irrigation Co. Milburn (Fairview), Utah	South Fork of San Pitch River	-	-	300	-
Miner-Turpin Ditch Co. Fairview, Utah	Spring Creek Springs	-	-	90	411.84

Table 20. Continued

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
Mower Ditch Co. Fairview, Utah	San Pitch River	-	-	175	463.10
Mt. Pleasant Birch Creek Irrigation Company Mt. Pleasant, Utah	Birch Creek	1-11-27	8,000 at 20.00	1,400	-
Moroni Irrigation Co. Moroni, Utah	San Pitch River	6-1-37	78,125 at 25.00	2,800	6,059.22
Mountain Tunnel Irr. Co. Mt. Pleasant, Utah	-	9-6-09	16,800	-	-
New Fayette Irrigation Co. Fayette, Utah	-	4-1-54	5,651 at 10.00	-	-
North Creek Irrigation Co. Mt. Pleasant, Utah	North Creek	4-18-91	9,500 at 10.00	2,000	-
North Dry Creek Fairview, Utah	-	-	-	-	-
North San Pitch Water Co. Fairview, Utah	-	-	-	-	-
North Six Mile Creek Irr. Co., Manti, Utah	Six Mile Creek	4-8-89	-	1,350	-
Olsen-Seeley Ditch Co. Ephraim, Utah	-	-	-	-	306.00

Table 20. Continued

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
Pleasant Creek Highland Irrigation Company Mt. Pleasant, Utah	Pleasant Creek	12-13-10	20,000	1,890	-
Pleasant Creek Irr. Co. Mt. Pleasant, Utah	Pleasant Creek	4-18-91	30,000 at 10.00	2,210	-
Rock Dam Irrigation Co. Moroni, Utah	San Pitch River	4-18-16	3,500	1,500	2,572.00
Sanpete Oak Creek Irr. Co. Fairview, Utah	Oak Creek	6-3 -11	14,895	660	-
San Pitch City Ditch Co. Fairview, Utah	San Pitch River	10 - 1 -54	-	300	639.50
San Pitch Well Co. Ephraim, Utah	-	-	-	-	-
Sheep Ditch Co. Fairview, Utah	San Pitch River	7-14-45	-	350	362.50
Silver Creek Irr. Co. Wales, Utah	Silver River	-	-	600	-
Silver Creek Reservoir Co., Wales, Utah	Silver Creek Silver Creek Reservoir	6-17-20	-	600	-
Spring Branch Fairview, Utah	-	-	-	-	-

Table 20. Continued

Name and Address	Source of Water	Incorporation Date	Capital Stock	Acres Irrigated	Acre Feet Delivered Year 1963
Spring Canyon Irrigation Co., Fairview, Utah	-	11-25-11	5,250	-	-
State Highway Well Assn. Fountain Green, Utah	-	-	-	-	-
Twin Creeks Irr. Co. Mt. Pleasant, Utah	Cedar & Twin Creeks	4-18-91	19,000 at 10.00	1,800	-
Wales Irrigation Co. Wales, Utah	New Canyon & Peter Canyon Creek	2-5 -16	2,170	400	-
West Milburn Irr. Co. Fairview, Utah	San Pitch River	-	-	-	397.70
West Point Irr. Co. Wales, Utah	San Pitch River	-	-	6,000	995.00

Table 21. Summary of snow courses

Number	Name	Section	Town-ship	Range	Elevation	Data	Period of Record
IIKI3P	Beaver Dams	27	19S	3E	8,000	SC, SPC	1951-Present
IIKIIP	G. B. R. C. Headquarters	21	17S	4E	8,700	SC, SPC	1930-Present
IIKIO	G. B. R. C. Meadows	26 & 27	17S	4E	10,000	SC	1930-Present
IIK3MP	Mammoth R. S. Cottonwood Creek	13	13S	5E	8,800	SC, SMS, SPC	1928, 1930-Present
IIK34	Middle Fork	16	18S	4E	9,600	SC	1956-Present
IIKI2P	Mt. Baldy R. S.	19	19S	4E	9,500	SC, SPC	1951-Present
IIK36	Rees' Flat	24	15S	2E	7,300	SC	1956-Present
IIK35	Thistle Flat	24	18S	4E	8,500	SC	1956-Present
IIK4P	Gooseberry Reservoir	25	13S	5E	8,700	SC, SPC	1930-Present
IIKS	Huntington-Horseshoe	12	14S	5E	9,800	SC	1930-Present

Key:

SC: Snow Course

SPC: Storage Precipitation Gage

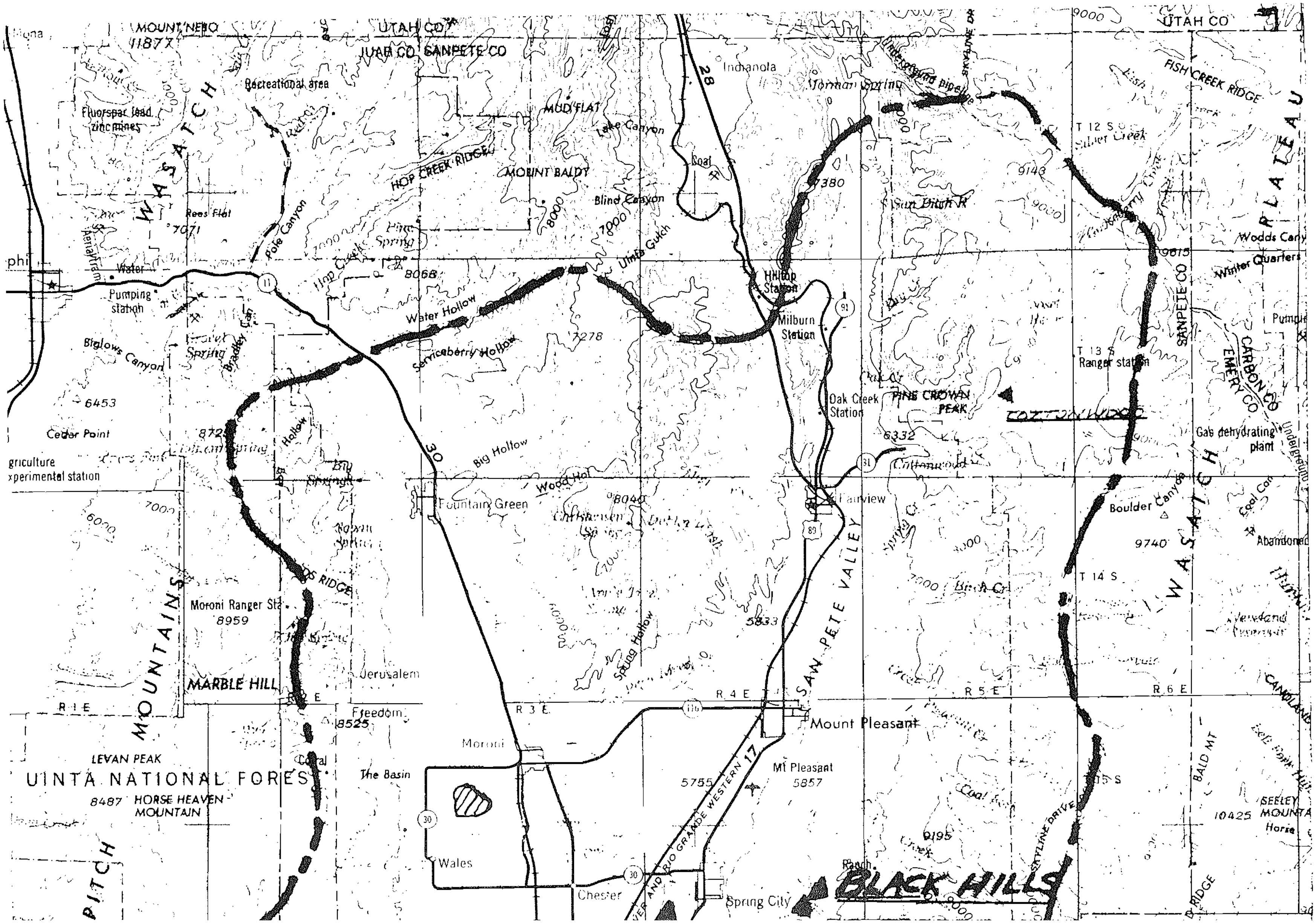
SMS: Soil Moisture Station

Table 22. Wells in Sanpete County (State of Utah, 1958)

Well Coordinate Number	Date of Collection	Specific Conductance (Micromhos at 25°C.)	Chemical Analysis in parts per million															Percent Sodium	Analysis By
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	(Na + K)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total Dissolved Solids	Total Hardness as $CaCO_3$		
(C-17-1)	11/23/53	1,460	36	0.02	56	54	160		4.6	232	81	318	0.3	1.4	821	362	49	GS
(C-19-1)25cd-2	5/1955	3,540	31	0.08	211	174	392		15	514	1,020	403	0.2	68	2,640	1,240	40	GS
(D-13-2)35	2/26/41		4.0	0.00	62	16		12		274	7.7	13	0.0	0.0				PH
(D-14-2)13aa	5/1955	478	20	0.02	60	21	11		0.3	268	11	20	0.2	2.4	277	236	9	GS
(D-14-3)33bcc-1	5/1955	1,210	46	0.11	124	61	22		3.0	344	112	124	0.0	42	710	560	8	GS
(D-14-4)1abc-1	7/25/52		19	0.05	62	29		25		352	16	7.9	0.4	11	344	273		PH
(D-15-2)2	5/7/41		2.7	0.00	54	22		7.8		262	11	12	0.2	0.0	277	225		PH
(D-15-2)25c	5/7/41		3.8	0.00	81	30		23		360	43	26	0.4	0.0	420	324		PH
(D-15-3)9acb-1	9/21/55		14		105	22		20		335	43	48	0.2	8.2	387	236		PH
(D-15-3)25	11/2/51	796	23		60	53	36		2.6	394	61	49	0.2	0.3	479	368	17	GS
(D-15-4)	8/20/52		12	0.60	38	43		18		345	21	0.0	0.0	5.7	336	271		PH
(D-16-3)4aaa-1	11/2/51	1,240	58	0.02	98	51	99		10	402	188	113	0.0	6.1	821	454	32	GS
(D-16-3)4aaa-1	5/1955	1,100	60	0.08	80	53	100		8.7	360	181	110	0.2	5.7	765	418	34	GS
(D-16-3)4aaa-2	11/2/51	1,230	62							414	198	102	0.0	5.7				GS
(D-16-3)31	8/27/51	536			58	48		7.6		350	32	27				342	5	GS
(D-16-3)31	11/2/51	656	16	0.05	58	48	16		1.6	348	35	19	0.1	29	394	342	9	GS
(D-17-2)1cba-1	11/2/51	517	20	0.09	39	37	20		1.6	268	42	20	0.1	0.3	312	250	15	GS
(D-17-2)1cba-2	11/2/51	769	26	0.06	49	47	53		1.6	340	81	48	0.3	0.6	474	316	27	GS
(D-17-2)15dac-1	11/2/51	832	21		58	55	50		2.0	365	113	40	0.1	2.4	520	370	23	GS
(D-17-3)6dba-1	5/1955	832	17	0.04	73	59	15		1.9	420	40	25	0.1	43	456	424	7	GS
(D-17-3)30dbd-1	5/1955	596	39	0.05	41	45	21		2.2	272	81	17	0.6	0.9	370	288	14	GS
(D-18-2)13	2/6/41		5.6	0.05	26	15		129		421	86	55	0.7	3.0	635			PH
(D-19-1)	9/8/50		9.2	0.00	25	27		101		303	81	41	0.3	0.7	438	174		PH
(D-19-1)29	9/11/50		19	0.00	40	60		128		442	127	87	0.4	31	730	344		PH
(D-19-2)	3/10/50		17	0.80	80	56		87		466	102	85	0.1	13.2	704	433		PH
(D-19-2)2b	5/7/41		8.3		43	29		16		262	22	20	0.2	0.0	280	228		PH
(D-19-2)8	5/7/55		2.1	0.10	103	19		229		521	155	148	0.8	41	896	336		PH
(D-19-2)9	11/2/51	1,310	28		54	55	164		3.2	481	143	108	0.4	42	834	360	49	GS
(D-20-1)25a	5/1955		30	0.17	43	43		121		378	60	119		9.4	609	284		GS

Appendix C

Plates


MOUNT NEBO
11877
UTAH CO
JUAB CO SANPETE CO
Indianola
Recreational area
Fluorspar lead zinc mines
W A S A T C H
MUD FLAT
Lake Canyon
HOP CREEK RIDGE
MOUNT BALDY
Blind Canyon
Coal
7380
Rees Flat
7071
Pole Canyon
Uinta Gulch
Water
Pumping station
8068
Water Hollow
Hilltop Station
Milburn Station
Bigelows Canyon
Serviceberry Hollow
7278
6453
Cedar Point
Agriculture experimental station
Big Hollow
Oak Creek Station
PINE CROWN PEAK
6332
Cottonwood
Fountain Green
Wood Hol
8040
Fairview
SAN PETE VALLEY
Moroni Ranger Sta
8959
MARBLE HILL
Jerusalem
5833
R 1 E
R 3 E
R 4 E
R 5 E
R 6 E
Freedom
8525
Mount Pleasant
Moroni
LEVAN PEAK
UINTA NATIONAL FOREST
The Basin
Mt Pleasant
5857
5755
8487 HORSE HEAVEN MOUNTAIN
Wales
Chester
Spring City
BLACK HILLS
Ranch
9195
P I T C H
M O U N T A I N S
FISH CREEK RIDGE
T 12 S
Silver Creek
9148
9615
Wodds Cany
Winter Quarters
SANPETE CO
CARBON CO
EMERY CO
T 13 S
Ranger station
Gas dehydrating plant
Boulder Canyon
9740
Abandoned
T 14 S
W A S A T C H
P L A T E A U
CANDLAND
BALD MT
SEELEY MOUNTA
10425
SKYLINE DRIVE
Underground pipeline
RIDGE

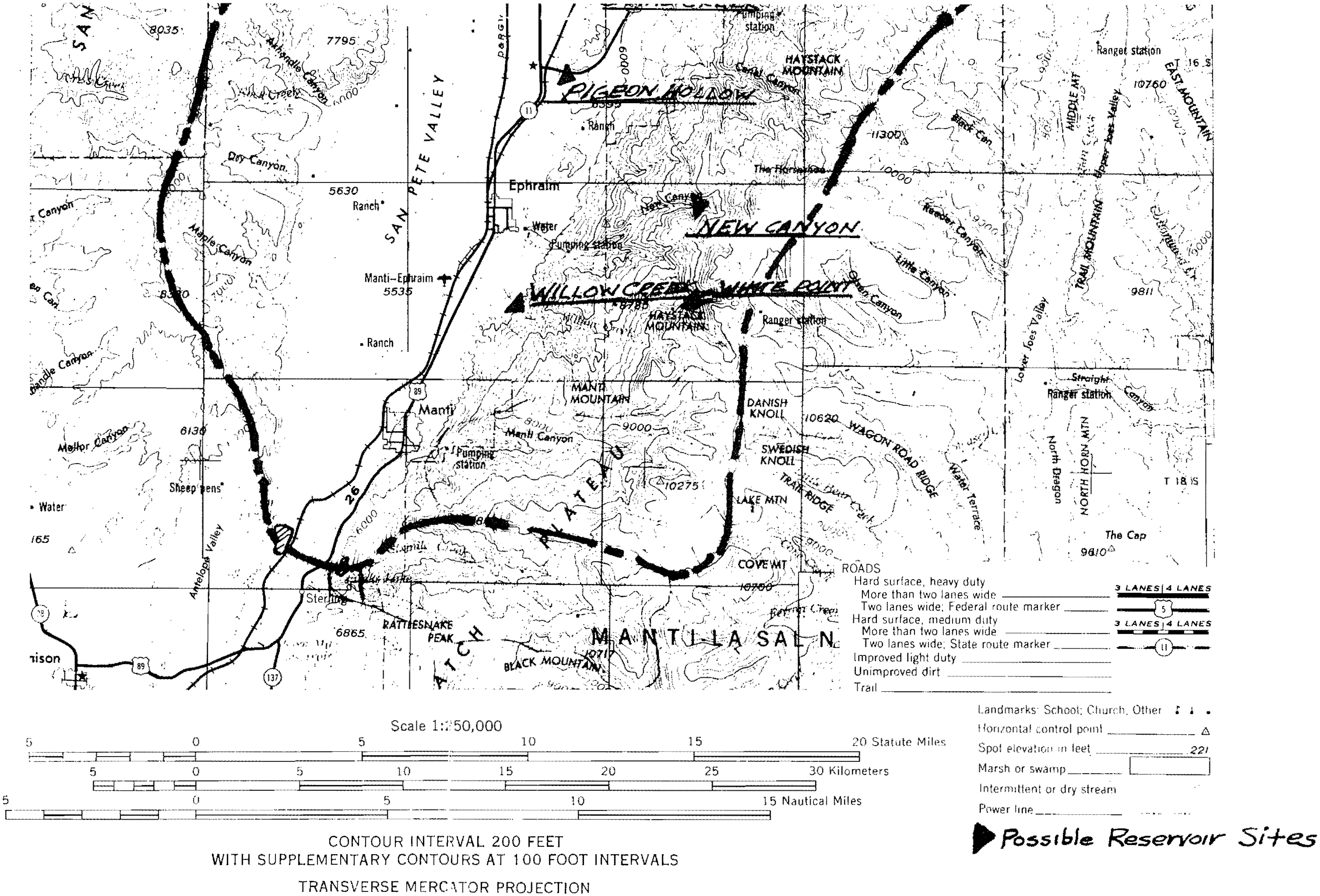
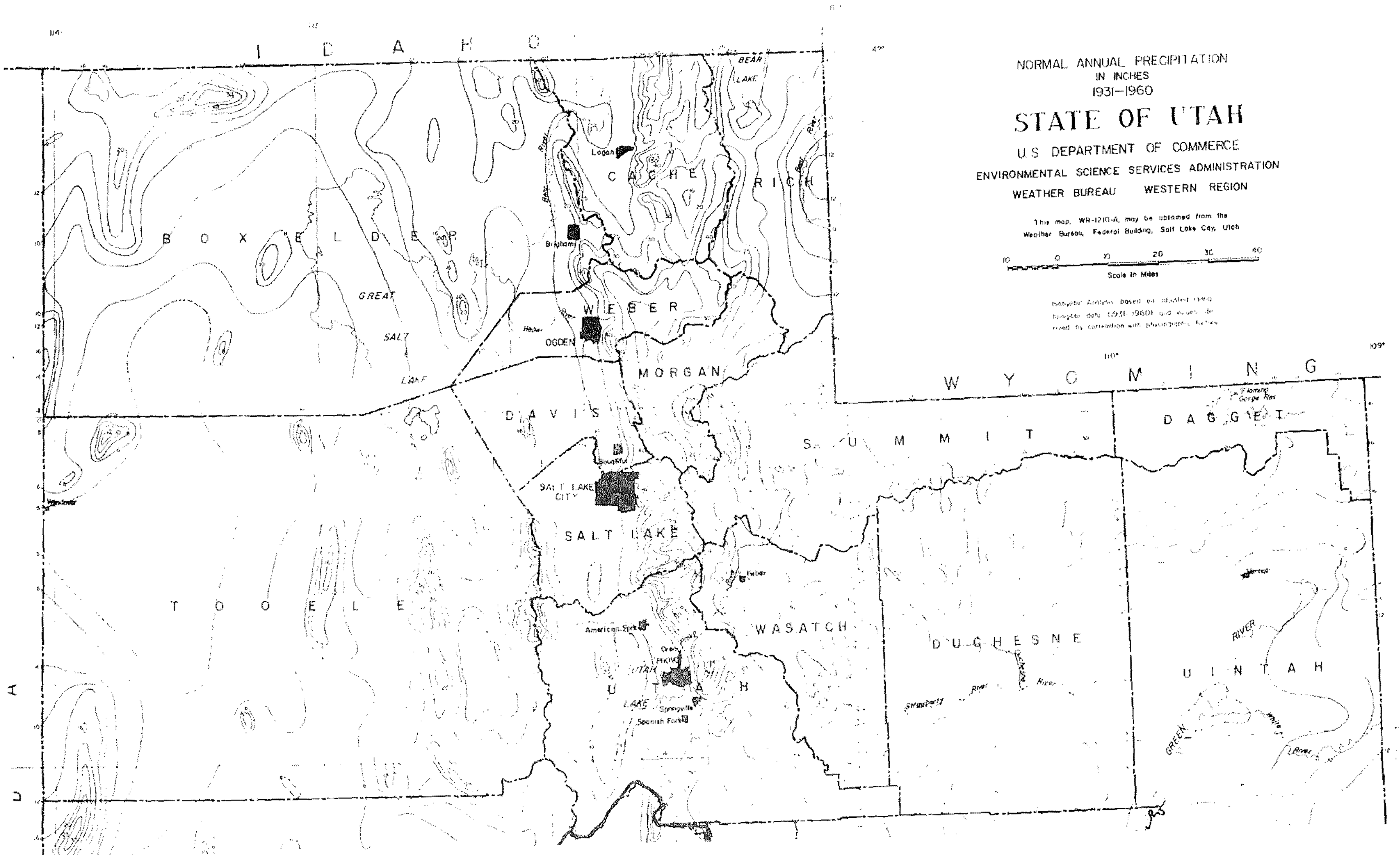
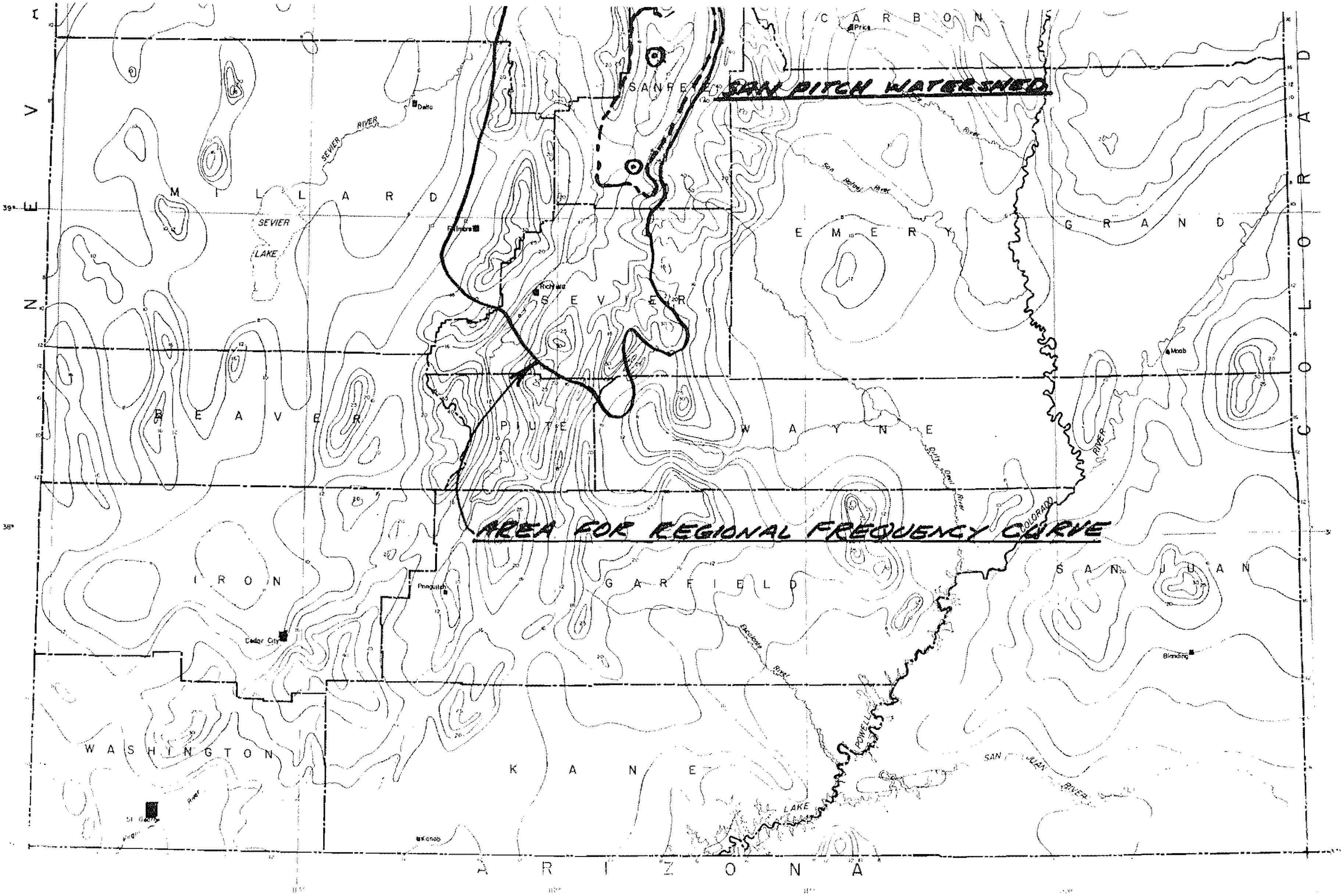


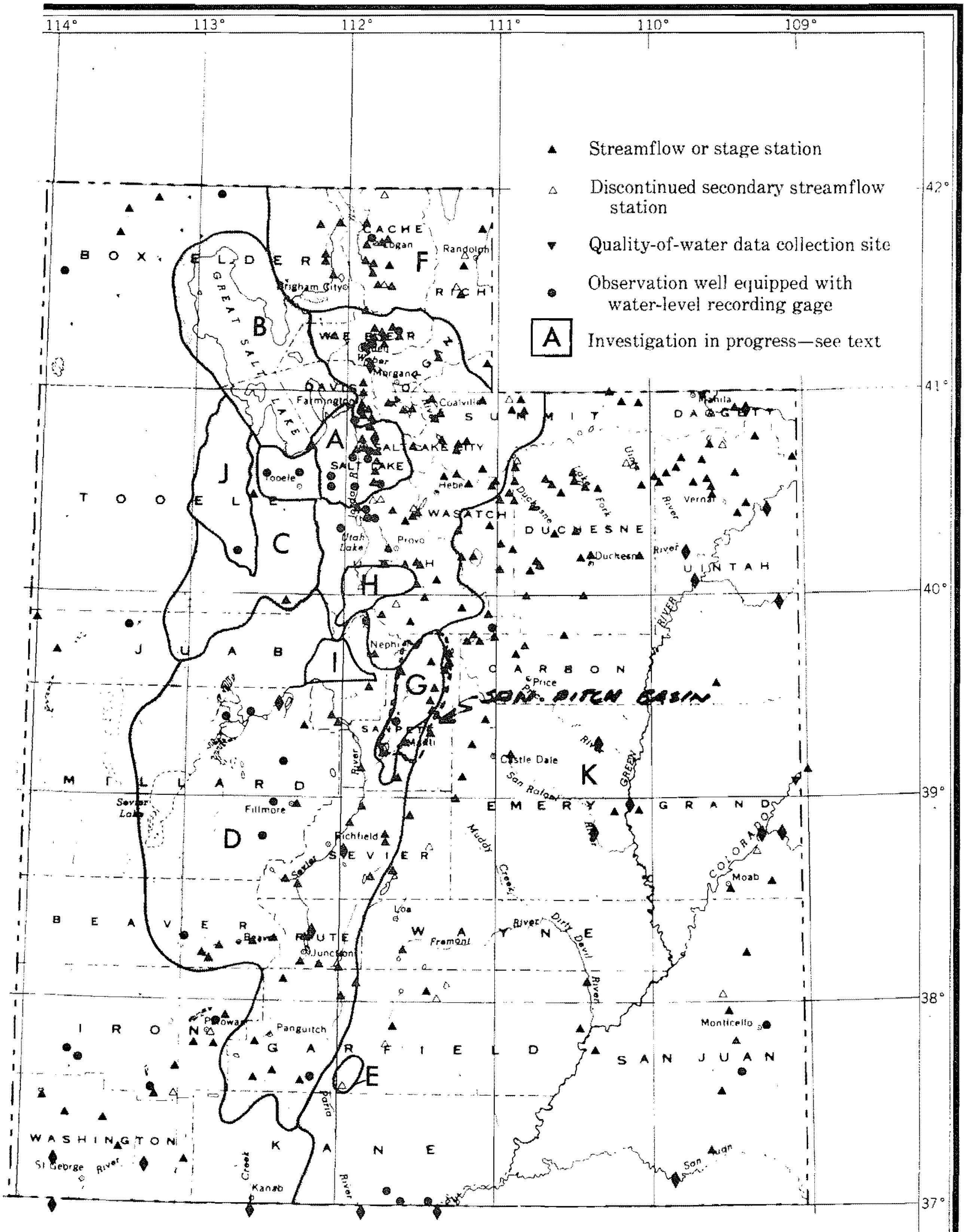
Plate I. Topographical and area map of San Pitch River Basin showing potential reservoir sites


NORMAL ANNUAL PRECIPITATION
IN INCHES
1931–1960
STATE OF UTAH
U.S DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU WESTERN REGION
This map, WR-1210-A, may be obtained from the Weather Bureau, Federal Building, Salt Lake City, Utah
Scale in Miles
10 0 10 20 30 40
IDAHO
WYOMING
BOX ELDER
CACHE
RICH
WEBER
MORGAN
DAVIS
SUMMIT
DAGGETT
SALT LAKE
TOOELE
WASATCH
DUCHESNE
UINTAH
UTAH
GREAT SALT LAKE
UTAH LAKE
BEAR LAKE
Logan
Brigham
OGDEN
Bountiful
SALT LAKE CITY
Heber
American Fork
Orem
Provo
Springville
Spanish Fork
Wendover
GREEN RIVER



⊙ Climatological Station

Plate II. Precipitation isohyetal map of Utah



HYDROLOGIC DATA NETWORK AND INVESTIGATIONS IN PROGRESS IN UTAH AS OF AUGUST 1965

50 0 50 100 MILES

Plate III. Hydrologic data network in Utah

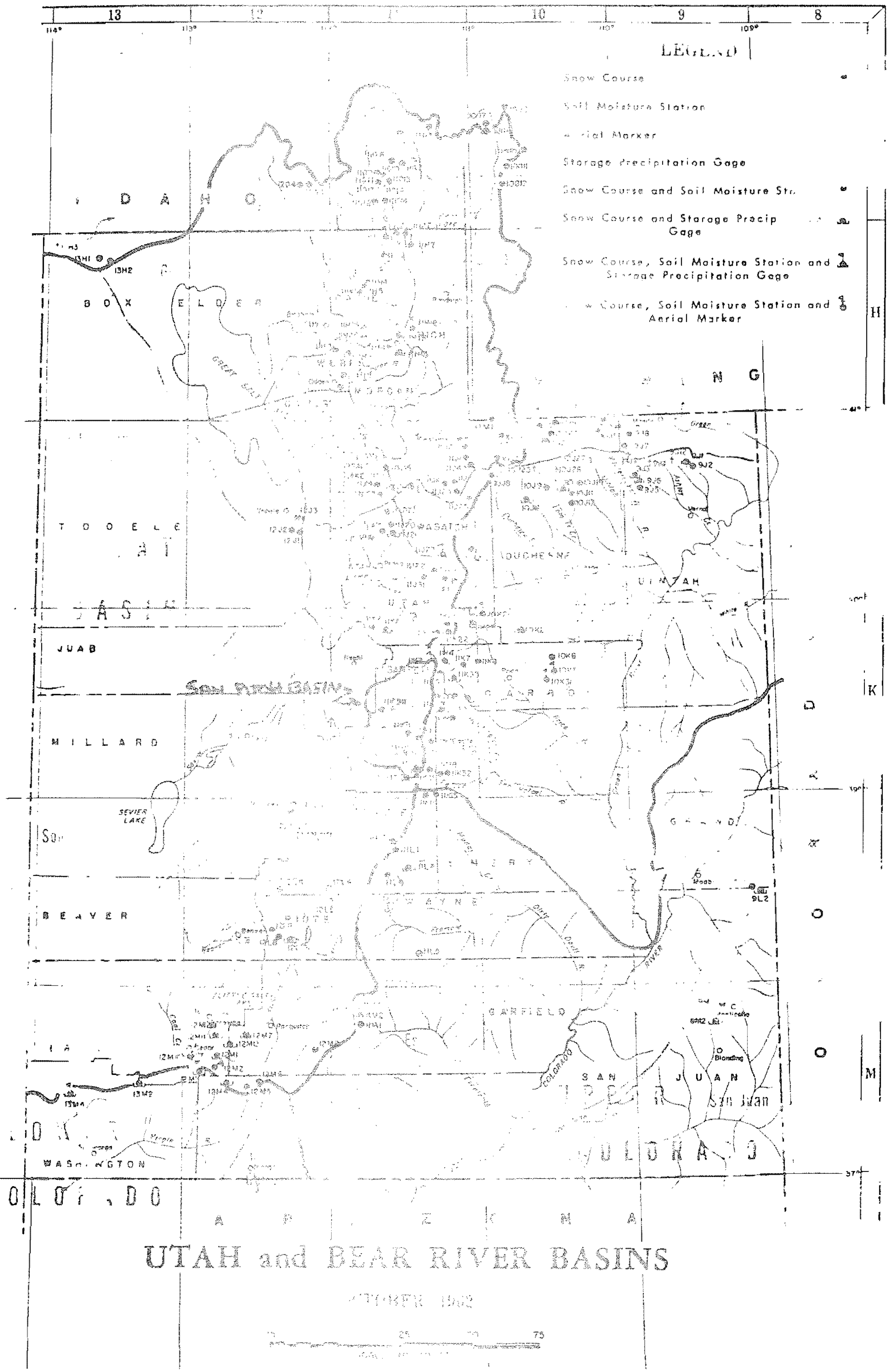
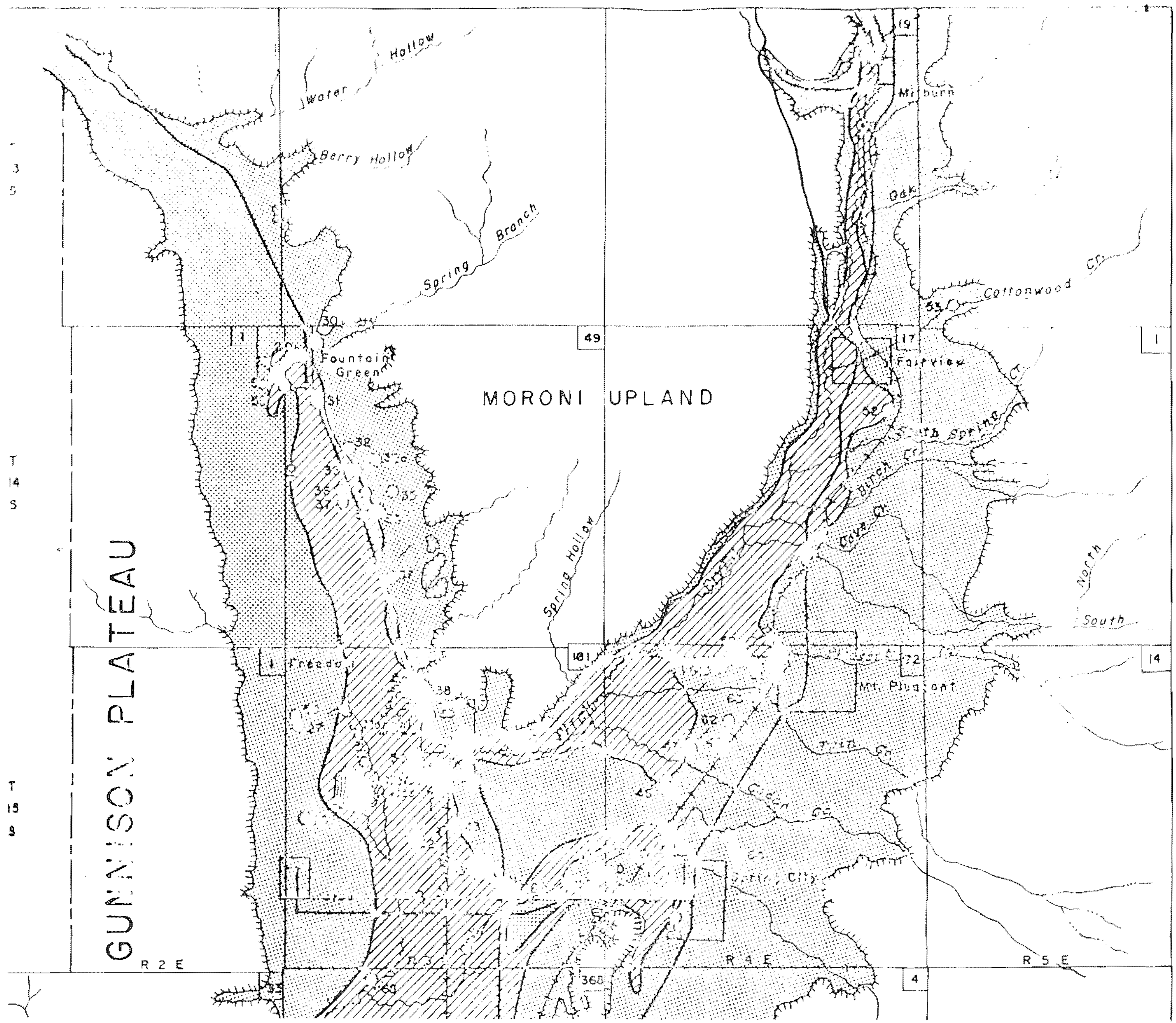


Plate IV. Map of snow course and precipitation stations in Utah



MORONI UPLAND
GUNNISON PLATEAU
Fountain Green
Fairview
Milburn
Mt. Pleasant
Spring City
Freedom
Water Hollow
Berry Hollow
Spring Branch
Spring Hollow
Oak
Cottonwood Cr.
South Spring
Birch Cr.
Cove Cr.
North
South
R 2 E
R 4 E
R 5 E
T 14 S
T 15 S
49
181
368

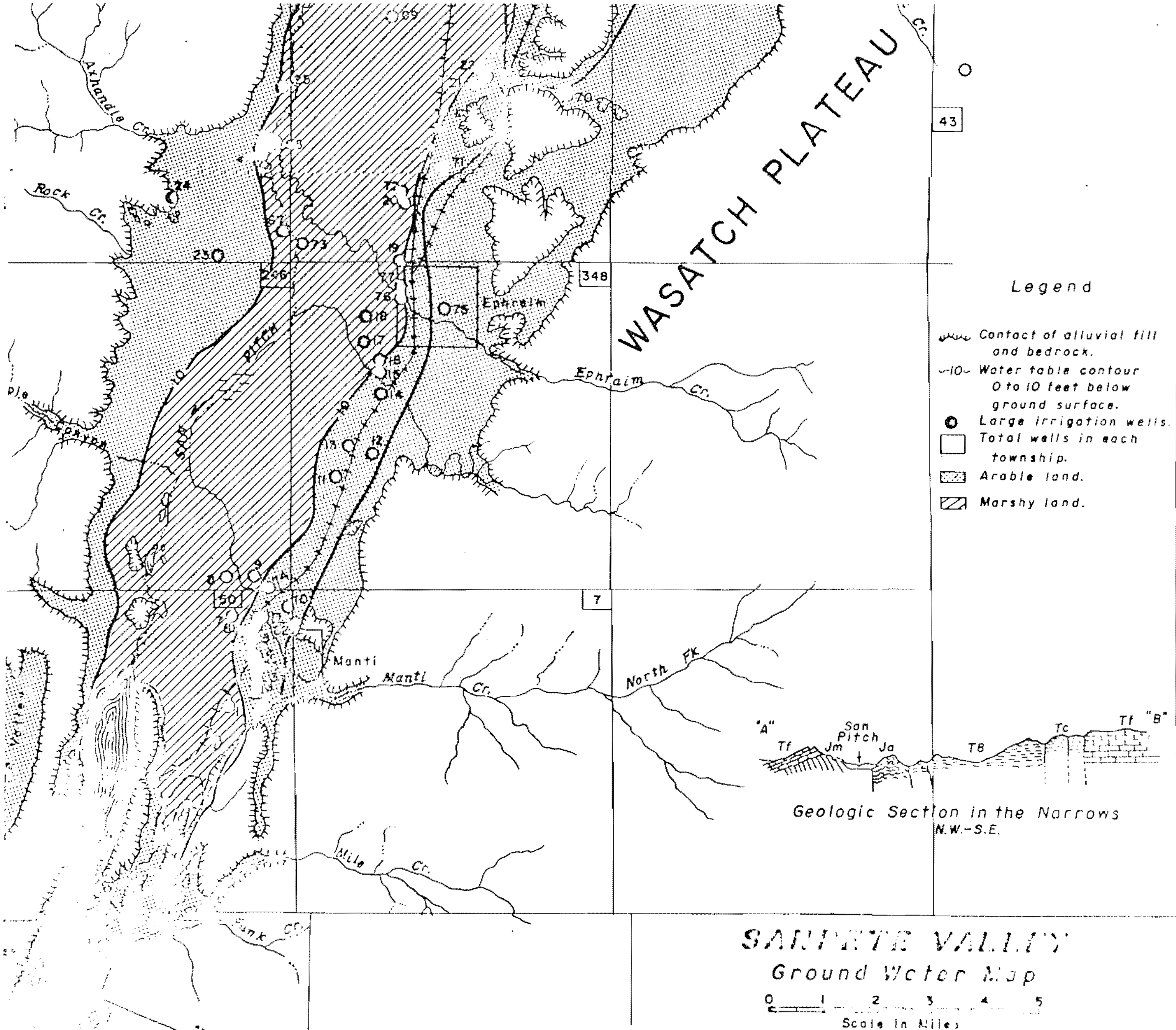


Plate V. Sanpete Valley groundwater map

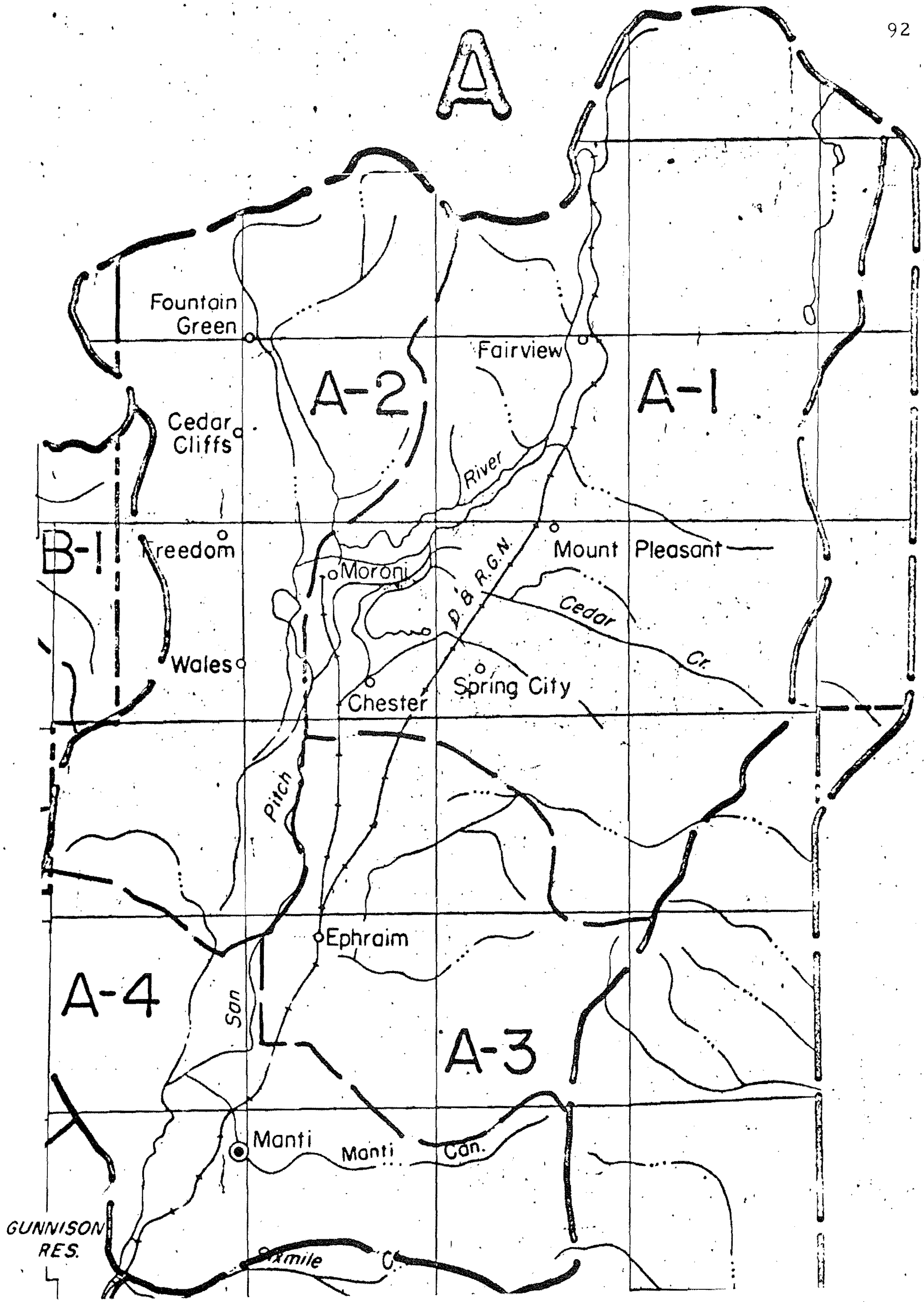


Plate VI. Map of San Pitch River Basin showing irrigation subareas

Appendix D

Correspondence

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Federal Building, Room 4012
125 South State Street
Salt Lake City, Utah 84111

December 21, 1967

Mr. James Ballif
Water Research Laboratory
Utah State University
Logan, Utah

Dear Mr. Ballif:

In answer to your letter requesting information on the hydrology of the San Pitch River above Gunnison Reservoir, we have the following information:

1. Our water budget for the base period 1931-1960 indicates an inflow of 22,860 ac.ft. The tributary inflow into the valley lands above Gunnison Reservoir in the same period was 169,680 ac.ft. Our water budgets also show a consumptive use in the wet areas of 121,250 ac.ft. The consumptive use in the irrigated areas is 110,300 ac.ft. We can assume that this latter use would be natural flow into Gunnison Reservoir if there were no irrigation, and would make a total inflow of 133,160 ac.ft.

2. The downstream water requirements on the San Pitch River in the irrigated area is 34,400 ac.ft. This does not include consumptive use by wet meadows or other phreatophyte areas. Part of this use is supplied for Six Mile and Twelve Mile Creeks and includes the area under both Gunnison and Mayfield Irrigation Companies, as well as small private systems. Present diversion efficiency from the river to the root zone is estimated at 30%.

3. We have estimated the costs on one transmountain diversion in conjunction with the North Sanpete Watershed project. Based on a delivery to farm head gate efficiency of 85% and amortizing at 3½%, the cost per ac.ft. is $14.20. This is probably higher than the existing transmountain diversion cost, but would indicate feasibility of any future developments.

4. We don't have information of the maximum and minimum capacities of transmountain diversions. Our records indicate that the average into A-1 is 4,940 ac.ft. annually and into A-3 is 6,170 ac.ft. annually.

5. We don't have any information on distribution costs of present systems. The Division of Water Resources made extensive studies in this area a number of years ago, and may have the information you need.

6. Studies on well costs in connection with proposed projects in the Mt. Pleasant area indicate an annual extraction cost of $9.87 per ac.ft. This was amortized for 30 years at 3¼%. If you need an itemized breakdown on fixed and recurring costs, we will be glad to supply you with this information.

7. Study of ground water in watershed A-1 indicates that about 20 additional wells can be drilled in this area without effects on existing yields.

Sincerely,

Harold T Brown

Harold T. Brown
Field Party Leader,
Sevier River Basin

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Federal Building, Room 4012
125 South State Street
Salt Lake City, Utah 84111
February 20, 1968

Mr. James D. Ballif
Research Assistant
Utah Water Research Laboratory
Utah State University
Logan, Utah 84321

Dear Mr. Ballif:

Attached is the information you requested in your letter of January 22, 1968.

Sincerely yours,

Harold T. Brown

Harold T. Brown
Field Party Leader

Attachment

	Capacity Acre Feet	Surface Area Acres	Embankment Cubic Yards	Cost
Loggers Fork	1,600	69	139,000	210,000
	720	44	55,000	82,000
Patten	130	6	26,500	47,500
Funks Lake	700	150	15,000	
Willow Creek	450	18	134,000	203,000
	150	12	41,000	62,000
Moroni	8,000	480	450,000	940,000
	3,350	260	185,000	390,000
Jensen	800	36	250,000	375,000
	255	18	55,500	83,000
Johnson	430	21	130,000	195,000
	115	11	45,000	68,000
	250	16	86,000	130,000

VITA

James Douglas Ballif

Candidate for the Degree of

Master of Science

Report: A Conceptual Model of the San Pitch River Basin

Major Field: Civil Engineering

Biographical Information:

Personal Data: Born at Preston, Idaho, May 2, 1943, son of Karl G. and Marion Anderson Ballif; married Sandra Marshall September 4, 1966; one child--Trevor Michel.

Education: Received the Bachelor of Science degree from Utah State University, with a major in Civil Engineering, in 1965.

Professional Societies: Associate member, American Society of Civil Engineers; member, Sigma Tau Honorary Engineering Fraternity.

Professional Experience: 1965-67, Civil Engineer, U. S. Army Corps of Engineers, Los Angeles District; 1967-68, Research Assistant, Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah.