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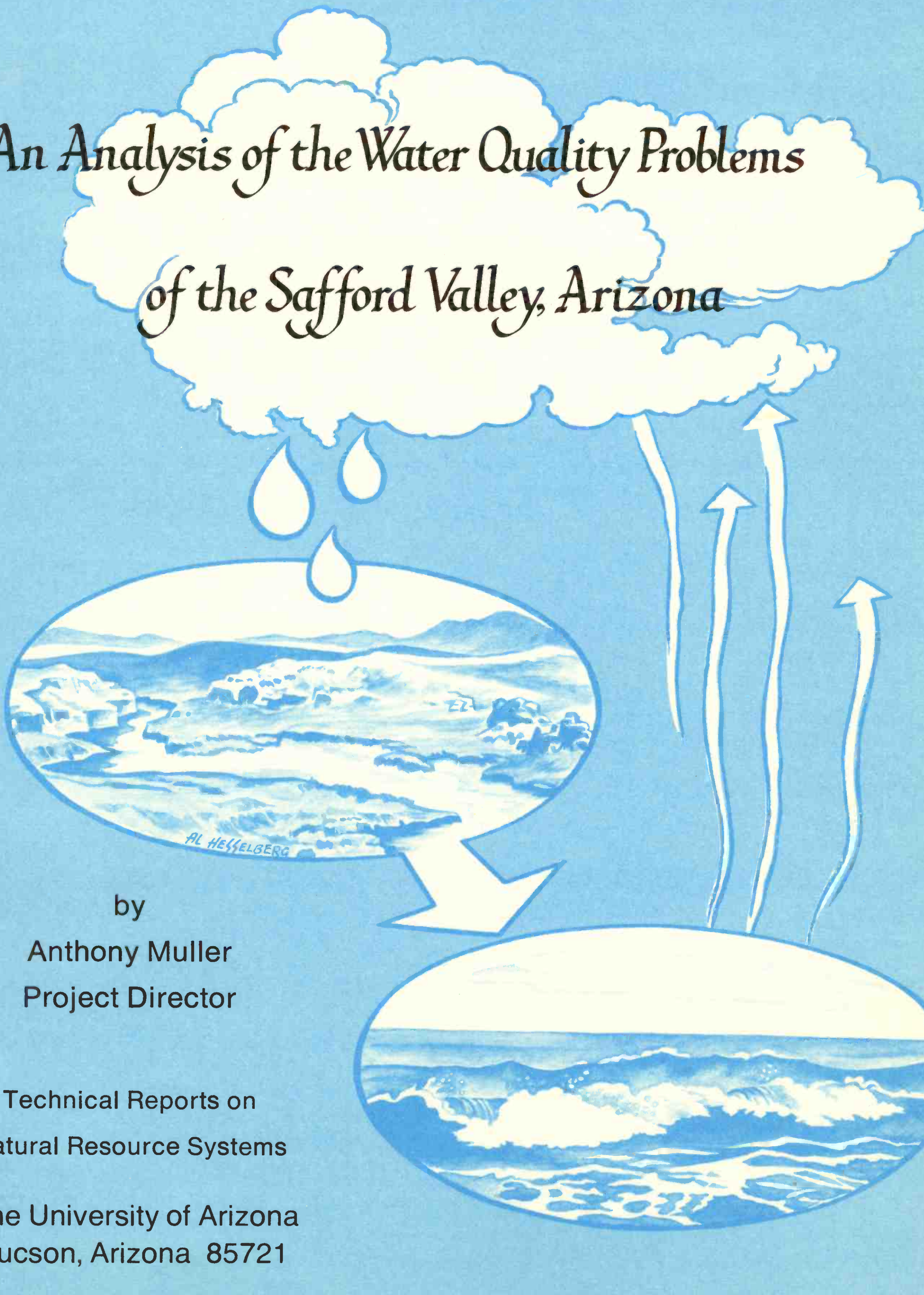
An Analysis of the Water Quality Problems of the Safford Valley, Arizona



by

Anthony Muller

Project Director

Technical Reports on

Natural Resource Systems

The University of Arizona

Tucson, Arizona 85721

AN ANALYSIS OF THE WATER QUALITY PROBLEMS OF THE SAFFORD VALLEY, ARIZONA

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Reports on Natural Resource Systems
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PREFACE

This report constitutes the substance of a paper entitled "An Interdisciplinary Analysis of the Water Quality Problems of the Safford Valley, Arizona," which was the final report to a Student-Oriented Studies Program investigation of the National Science Foundation, and the research herein was funded under Research Grant GY-9571 of that institution.

The National Science Foundation report contains an additional section on a sociologic analysis of the problems covered in this paper. This section was omitted to conform the paper to the intent of this Technical Report Series of the Department of Hydrology and Water Resources. The remaining particpants represent an interdisciplinary team which investigated the water quality problems in the region. The Project Director is currently completing a Bachelor of Science in the Department of Hydrology and Water Resources; Leslie Bond, the team hydrologist, is a graduate student in that department. John Battaile, the team economist, has received an undergraduate degree in economics and is currently enrolled at the University of Arizona Law School. The systems engineer on the project, Philip Lamson, is an honors student in the Department of Systems and Industrial Engineering and is completing his Bachelor of Science degree.

This report series constitutes an effort to communicate to practitioners and researchers, as well as those directly influenced by the problems discussed herein, the complete research results of this study, including economic foundations and detailed development that cannot be reproduced in professional journals. These reports are not intended to serve as a substitute for the review and referee process exerted by the scientific and professional community in these journals. The authors, of course, are solely responsible for the validity of the statements contained herein.

ACKNOWLEDGMENTS

The participants in this research project wish to acknowledge all those who contributed to the study with both information and advice. All of those offering assistance to the participants cannot each be acknowledged here but are thanked as sincerely as those who are listed individually below:

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Associate Professor of Systems and Industrial Engineering
Systems Engineering Advisor

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Professor of Agricultural Economics
Economics Advisor

Margaret Kukuck, Guy Leonard and Linda Zimbler are thanked for their efforts and participation in the National Science Foundation study upon which this report is based.

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Water Resources Research Center is sincerely thanked for the funds from their Office of Water Resources Research Allotment Grant from the Department of the Interior which aided in the publication of this paper.

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ABSTRACT

A marked change in ground water quality in the Safford Valley of Graham County, Arizona, averaging approximately +0.129 x 10^3 mhos electrical conductivity per year and +35 parts per million chloride per year, has been documented between 1940 and 1972 with data from ten long-term sample wells. A chloride change map constructed between these two years shows a general increase of 200 to 400 ppm chloride. The 1972 iso-chemical maps show areas of up to 1600 ppm chloride and 8.0 x 10^3 mhos electrical conductivity, which is extremely saline and considered threshold level for agricultural waters.

The Safford Valley, a structural trough with approximately east-west orientation, averages 12 miles in width and 30 miles in length in the study area. Botnded by typical basin and range province mountains on the northeast and southwest, the valley contains a perennial stream flowing toward the west. A bi-aquifer system constitutes the ground water reservoir of the area with a deep, artesian aquifer of several thousand feet thickness overlaid by a water table aquifer averaging 400 feet in thickness and with the water table rarely over fifty feet from the surface on the eastern end of the valley, deepening to over 5000 feet at the western end. This bedrock-alluvium interface is the lower vertical constraint for the artesian system, thus the thickness of this aquifer increases downstream (to the west). The basin fill consists of a basal conglomerate overlaid by lacustrine evaporite beds, the aquifer cap beds, and recent alluvial material. The artesian aquifer is shown to be up to ten times as saline as the water table aquifer, and appears to increase in temperature and salinity in a downstream direction (corresponding to increasing thicknesses of lacustrine beds included in the extent of this aquifer).

The decrement in the water quality of the surficial aquifer seems to be attributable to four major mechanisms. An increase in salinity may be expected from leakage of saline water from the artesian aquifer. Suck leakage would be stimulated by pumping-caused reduction of confining pressure, and by the puncture of the cap beds by deep wells. Water reaching the aquifer from natural recharge may contribute salts to the system. Such recharging water, if passed through soluble beds, could contribute to the salt content of the aquifer. Lateral movement of water through similar deposits may be a contribution, and the concentration and infiltration of agricultural water could also add to aquifer salinity. Ground water applied to the land surface is concentrated by evaporation and dissolves salts in the unsaturated zone as it re-enters the water table aquifer.

Iso-salinity and salinity-change maps show the quality situation of the water table aquifer to be broken up into three major sections. From the eastern limit of the study area to Safford, the quality is relatively high and stable. From Safford to Pima there appears a uniform increase of low magnitude but continued decrement. Beyond Pima the area exhibits extremely irregular salinity conditions with marked increases and high salinity gradients. The salinity pattern corresponds to the extent of the underlying artesian aquifer but may be influenced to an unknown extent by the down-gradient transport of salts.

The 1972 iso-chemical maps show chevrons of high quality water protruding into the aquifer at points corresponding to the locations of washes. Such wash bottoms are the principal zones of recharge in arid regions. Recharge from the Gila River is of extremely high quality relative to the salinity of the aquifer. There appear no configurations of iso-chemical lines which are attributable to internal movement through saline deposits. The hydraulic gradient of the water table aquifer is relatively constant and follows the gradient of the land surface.

Concentration of irrigation water by evaporation and subsequent leaching while in conveyance to the water table seems to increase the salinity of this percolating water by approximately three-fold. The magnitude of this increase at any one point in space and time is a function of the volume of water applied to the land surface, the amount of evaporation, the initial chemical composition of the water, the chemical characteristics of the unsaturated zone through which it penetrates, and the transmission properties of the aquifer. The salinity increase seems significant but the extent of the contribution to the salinity of the aquifer is dependent on the amount of infiltration to the aquifer. This amount is currently undetermined, but is probably a sizable volume -- especially from pre-irrigation applications.

A sociologic investigation based on responses from a detailed questionnaire-interview program of 41 farmers (25 percent of the farming population), indicated that there is an awareness of the high salinity of ground water being used for irrigation but relatively little concern about the rate of increase of that salinity. The farmers seem reluctant to leave the area and are willing to take somewhat greater economic losses than expected. Since the farmers of the area are principally Mormon, there may be a tie to this historically Mormon region which is stronger than usual.

The economic analysis of the Safford Valley based on the modeling of a "Representative Farm" analog indicates that cotton will remain economical to produce on the basis of the projected salinity trends and ceteris paribus conditions, for a significant time beyond limits of prediction. The analysis indicates that the optimum salt-

resistant crops for the area are being cultivated, and that of these, alfalfa, the least tolerant, will cease to be productive in large areas of the valley by 1990. The entire valley will not be able to economically produce alfalfa by 2040, but will remain in production since it is a necessary crop for cotton and the cotton profits should be sufficient to cover the alfalfa losses.

Pumping is the only element in the operation of the social, physical and economic systems by which salinity change could be influenced significantly. The area east of Safford is the optimal pumping region while that west of Pima is the worst. The employment of surface water should be maximized, and salt-oriented field methods should be employed. Although agriculture does not seem in danger in predictable time, these practices would increase yield (or slow the decrease) and postpone the day when farming will no longer by profitable in the Safford Valley of Graham County, Arizona.

INTRODUCTION

PURPOSE OF INVESTIGATION

The preliminary purpose of the study is to determine if a water quality problem actually exists in the Safford Valley. Prior to this investigation it had not been determined whether the quality of the ground water in the area is deteriorating, or whether some localized quality changes in the valley have been overinterpreted by the farmers. If a change in water quality has been identified, it is the purpose of the inquiry to determine the magnitude and pattern of such a change.

It is further the purpose of this investigation to propose a theoretical physical mechanism by which the water of the effected aquifer is changing quality and to test this theoretical mechanism with actual physical data. This theoretical mechanism, or group of mechanisms, which influence the water quality, is then to be made into a physical model of the hydrologic system in the valley.

This physical model, with statistical analyses of historical data, is to be used to project future changes in ground water quality. These projected changes are to be used in the determination of the future agricultural and economic conditions in the valley.

It is a purpose of this investigation to analyze the economic system in the area and to produce an economic model of the valley based on this analysis. Production functions, projecting the percentage yield of crops with respect to soil water salinity, are to be the predictive mechanism by which the effect of the changes of irrigation water quality on the economic system of the valley are to be monitored. The combination of the economic and physical models should then be able to predict the time in which the crops currently grown in the valley will become unfeasible for profitable cultivation. Alternative economic and agricultural methods are to be proposed, and tested, in an attempt to optimize the efficiency of the local agriculture in light of the deteriorating water quality. Such alternatives are to be in the form of tolerant crop selection, irrigation and pumping practices, and land management.

The projection of future water demands of the Safford Valley, for both agriculture and municipal uses, is another purpose of the study. The feasibility of the growth or change in water demand is to be investigated in terms of the available sources of water for use. Alternatives to management practices that deteriorate the quality of the aquifer, such as waste disposal and salt well drainage, are to be explored.

It is the final purpose of the study to produce a causal-relationship flow model, in a general form, which will analogize the interrelationships of the physical, economic and social systems (51) in an area suffering from deterioration of water quality. Since the model will be both general, and in the form of a flow diagram, it should be applicable to other areas and to situations where chemical pollutants, not natural salts, are the principal concern. The elements in this model are to be quantified to the extent possible in the scope of this study, and variables with insufficient data are to be identified and described for additional study.

An additional intention of the study is to make the data, interpretations, and recommendations of the project available to those influenced by the water quality problem in the valley so that it may play a part in their considerations as to choices of land and water management techniques which are to be utilized in the area.

SETTING OF INVESTIGATION

PHYSICAL SETTING

The Safford Valley lies in 2,963,000-acre Graham County, in the southeastern part of Arizona. For the purposes of this paper the Safford Valley is defined to be that section of land lying along the Gila River which is included in the Safford and Thatcher, Arizona, fifteen minute quadrangle maps of the United States Department of the Interior, Geologic Survey (67, 68). The location of this research area is indicated in the Index section of the Index and Topographic Map which follows, and may be identified by the intersection of the thirty-third parallel of latitude and the one hundred and tenth meridian of longitude (44).

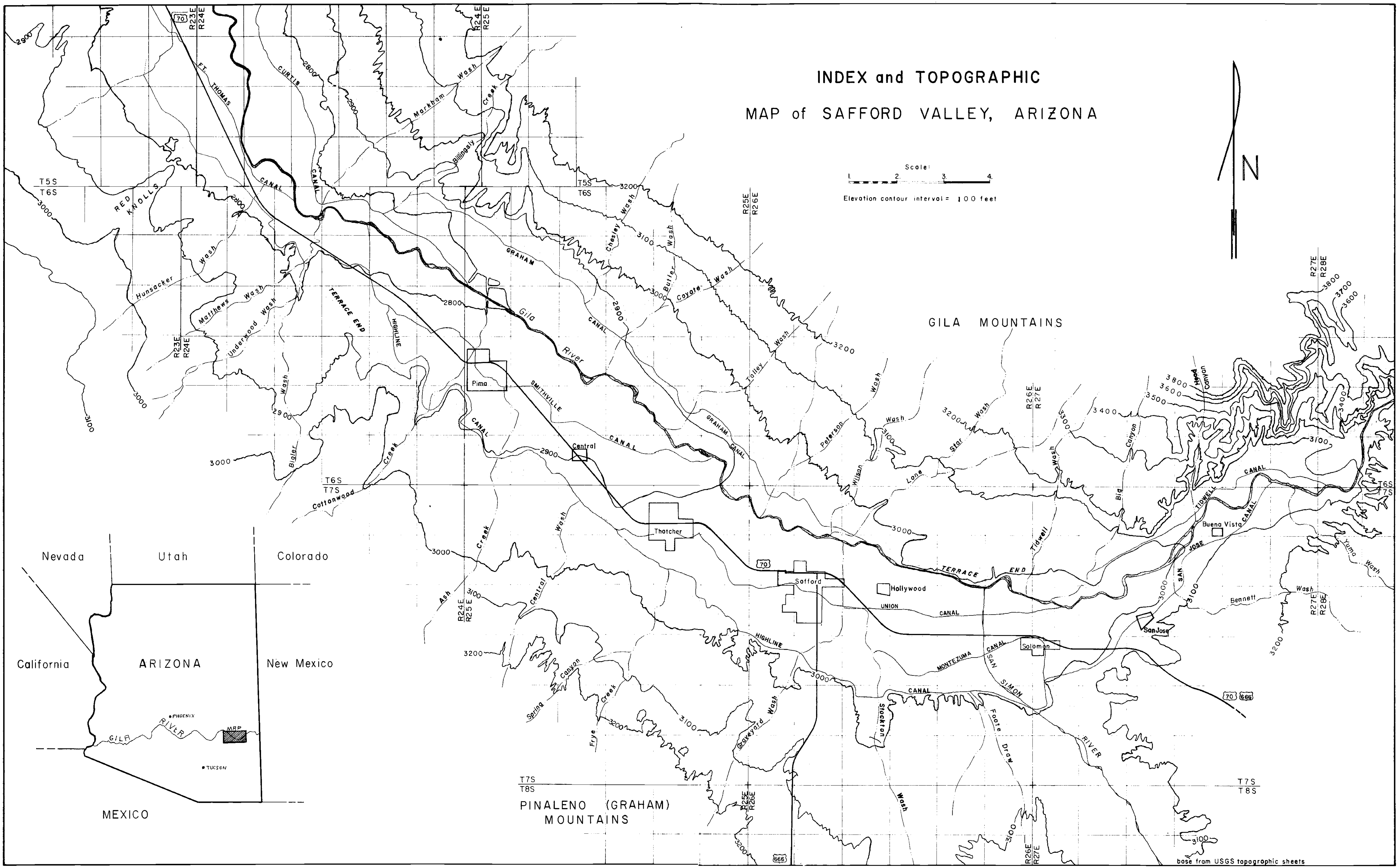
The Safford Valley is an intermontane trough, averaging 15 miles in width, and trending approximately N 45° W for 25 miles on the western limb while trending approximately N 60° E for 8 miles on the minor eastern limb. The valley is bounded by the Pinaleno (Graham) Mountains on the southwest and by the Gila Mountains on the north and northeast. Elevations in the valley range from 2700 to about 3900 feet above sea level, but the elevation of Mount Graham in the Pinaleno Range is 10,713 feet. Elevations in the Gila Mountains range from 3900 to 6000 feet (30).

The Gila River is the largest and the sole perennial stream in the Safford Valley, though it is dry or nearly dry (from diversion) near the month of June. The river courses through the entire 32 miles of the valley, meandering well over 40 miles in this distance. All the remaining natural drainageways flow only after rainstorms or from snowmelt in spring. The elevation of the river as it enters the Safford Valley is approximately 3100 feet above sea level and the elevation as it leaves is 2700 feet. The principal tributary of the Gila River is the San Simon Creek, which enters the study area from the south and joins the Gila River near the town of Solomon (30).

The over-all pattern of the Gila River as it flows from New Mexico to the Colorado River on the California border is that of a well-developed meandering stream. The river leaves the Dundan-Virden Valley, the first on its course to the Colorado, before it enters the Safford Valley. After leaving this valley it continues for another 30 miles and flows into San Carlos Reservoir behind Coolidge Dam on the western boundary of Graham County (44).

Drainageways entering the Gila River along this section are the primary contributors of the several thousand feet of valley fill material underlying the valley. Such drainageways are Stockton Wash, Graveyard Wash, Frye Creek, Matthews Wash and Goodwin Wash, which enter the river from the Pinaleno or southern side. Lone Star, Watson, Peck and Markham Washes enter from the northern side. In general, the drainageways from the south are more frequent, larger, and more competent than those on the north (30, 67, 68).

The Safford Valley trough, as other valleys that lie roughly parallel to it in the Mexican Highland section of the Basin and Range province in southeastern Arizona, is underlain by thick detrital deposits. It is commonly accepted by geologists that the origin of such valleys, and the mountains between which they lie, originated by block faulting. The Pinaleno Mountains are made up primarily of pre-Cambrian Pinal schists while the Gila Mountains are mostly late Tertiary extrusive igneous rocks. The valley fill material is primarily lacustrine and fluvial Quaternary sediment. The sediments along the side of the valley are cut by deep washes and truncated by erosion forming the terraces that are the most obvious physical features to a visitor to the valley (30).



INDEX and TOPOGRAPHIC
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 100 feet
N
GILA MOUNTAINS
PINALENO (GRAHAM) MOUNTAINS
Gila River
Pima
Central
Thatcher
Safford
Hollywood
Solomon
San Jose
Buena Vista
GRAHAM CANAL
SMITHVILLE CANAL
HIGHLINE CANAL
UNION CANAL
MONTEZUMA CANAL
TIDWELL CANAL
SAN JOSE CANAL
FT. THOMAS CANAL
CURTIS CANAL
TERRACE END
RED KNOLLS
SAN SIMON RIVER
Nevada
Utah
Colorado
California
ARIZONA
New Mexico
MEXICO
PHOENIX
TUCSON
GILA RIVER
MAP
base from USGS topographic sheets

CLIMATIC SETTING

The area of the Safford Valley lying in the lowlands along the Gila River, and south along San Simon Creek, has a warm, desert climate. The remainder of the research area, which is the upper terraces and foothills of both the Pinaleno and Gila Mountains, has a warm, semidesert climate. The difference in the two climatic types in the Safford Valley is not significant, with those areas having semidesert climate receiving slightly more precipitation and having slightly lower temperatures. Most of the Safford Valley is under the influence of the desert type.

The summers are warm, with temperatures well into the hundreds occurring regularly. The temperature decreases as elevation increases along the sides of the valley. The maximum temperature at these higher elevations during the summer averages 5 degrees lower, and the minimum temperature in winter averages 5 to 10 degrees lower than in the valley bottom (56).

Precipitation in the Safford Valley, as gaged at the Safford Experimental Farm Weather Station, averages less than 9 inches each year but during summer thunderstorms more than 2 inches have been recorded in a 24-hour period. These storms generally are accompanied by strong winds and occasionally hail. During the winter, snow is commonly found at the summit of the Pinaleno Mountains, but on the average less than 2 inches falls on the valley floor annually. Precipitation at higher elevations is nearly the same as that recorded at Safford Station, or between 11 and 12 inches annually (30, 56).

In general, there are two periods of precipitation per year in the Safford Valley. A secondary maximum of precipitation begins in November or December and extends through March, and the primary maximum begins in July and extends through September. April, May and June usually are dry, at least until the summer rains begin. On the average, about 20 percent more precipitation occurs during the period from May to October than from November to April. The precipitation in the winter comes from moist air flowing from the Pacific Ocean, and that in the summer, from moisture sources in the Gulf of Mexico. Relative humidity data are not available for extended periods of record from the Safford Station, but generally the frequent irrigations together with rainstorms increase the humidity in the summer (56).

Prevailing winds usually blow from the southeast in the summer and from the northwest in the winter. These winds are moisture laden and provide a source for the periods of summer and winter precipitation. Fairly mild, steady winds blow for several successive days in spring. These winds sometimes start in March and continue into April or on into May. The moisture laden winds from the southeast produce summer rains of lesser magnitude than would be expected as compared with similar valleys in southern Arizona. The Pinaleno, and similar mountains, lying to the south and southeast of the Safford Valley intercept some of the moisture that would otherwise reach the valley. This orographic interception of this moisture from the Pacific Ocean makes the Safford Valley somewhat dryer than other comparable valleys (30).

HISTORICAL PERSPECTIVE (51)

The Gila River has been in existence since geologic times. It was named by the Yuma Indians, to whom the word meant salty water (11). The Apache Indians and the Mexicans each had their towns along the banks of the Gila, but Mormons established the first permanent agricultural communities on the Gila in the Safford Valley.

Mormons first came to Arizona with the Mormon Battalion, assembled in 1836, during the Mexican War. The Mormon Battalion was the result of an agreement between the Mormons, who had been persecuted in Illinois and Missouri, and President Polk, who wanted colonists for California (11). Brigham Young, the Mormon prophet, saw in the Battalion a chance to realize the State of the Desert -- "a Mormon commonwealth to stretch from the Gila River in the south to the northern boundary of Idaho in the north, and between the Sierra Nevada Mountains in the west to the Rockies in the east." (76) Although the route of the Battalion through Arizona crossed only one point of future Mormon settlement, it established the Mormons in the West (36).

From 1858 to 1877, Jacob Hamblin led missionary parties from Utah into northern Arizona to convert the Hopi and Moqui Indians. This missionary scouting was followed by settlement, but unsatisfactory living conditions and Indian troubles along the Little Colorado aroused the desire in the settlers to move south where the Battalion had found fertile valleys. This led to the establishment of Safford in 1875 (36). Smithville, later renamed Pima, was founded about five years later. In 1881, Thatcher and Curtis, now called Eden, were established. The valley, at that time, was fairly level and covered with mesquite. The Gila River, lined with cottonwood and willow trees, meandered through marshes and swamps (10); wild game was plentiful and the soil was fertile; the climate was sunny and warm with a long growing season. The area seemed a paradise (76).

Mormon agricultural communities, unlike frontier communities, were founded on well-developed ideals. There were no drinking places or disorderly resorts. Mormons were generally farmers and the Church itself seemed to have the idea that its members shall live by, upon and through the products of the soil. Mutual cooperation and organization were strongly held beliefs (52). The fact that Mormons were a persecuted sect at the time helped to bind them in their goal. Their goal, and task, was to make the desert bloom, to help create the State of the Desert. Irrigating with water from the Gila River was the method by which they sought to accomplish this (49).

Between 1879 and 1883 Mormons had settled and cleared 8,900 acres of land, built forty miles of new irrigation canals, and cultivated 3,000 acres (76). Cereals were the chief crop since they required the least amount of water (22). The Mormons found a market for their produce in the mining camps, military posts, and cattle ranches of the Gentiles. From 1882 to 1883 the population in the Safford Valley doubled, as a result of immigration from Utah. This immigration was caused by a new wave of persecution against polygamists, stimulated by the Edmunds Tucker Law passed by Congress. The period from 1883 to 1890 was a time of expansion with an increase in land values, the building of several new canals, and an increase in tillable land to be 35,000 acres. By this time, most religious persecution had stopped and Mormons were in control of the farm land in the Safford Valley (9).

River conditions have changed over the years. The Gila River, once a relatively narrow stream with occasional lagoons, now had underbrush growing along the banks which gave flood waters full sweep of the area, washing away the more fertile low-lying river lands. As more land was put under cultivation, a regular summer deficiency of water occurred. This water scarcity problem has developed since 1888. Cries for more equitable distirbution of water between canals were ignored, but plans to build a reservoir and another canal were made. In a drought, ground water was the only water available (76).

Today most of the cities in the valley are no longer predominantly Mormon. Farming and cattle ranching dominate the economy; and the principal crops grown are long and short staple cotton, grain sorghum, barley, alfalfa, pecans and vegetables (48). Mining and tourism are becoming increasingly important in the area, with water quality and quantity still remaining a problem.

CULTURAL AND ECONOMIC SETTING

The population of the Safford Valley has increased by just under 2000 people between 1960 and 1970, to a current level of 13, 584 (66). These inhabitants of the valley are primarily located in the municipalities of Safford, Thatcher, Pima, Solomon and Central. The city of Safford, being the largest of these towns, was founded in 1875 and incorporated in 1901. It is the County Seat of Graham County, which was established in 1881 (54). The 16,578 inhabitants (66) of the county are concentrated in this area with secondary concentrations in the San Simon Valley along San Simon Creek, and on the San Carlos Indian Reservation. Many of the smaller towns are becoming abandoned as transportation improves and centralization occurs.

Agriculture provides the mainstay of the Safford Valley economy, accounting for more than 45 percent of the export employment (54). If all agriculture dependent activities are included, this percentage would be approximately 63 percent. The work force of the Safford Valley consists of 4864 individuals of 16 years of age or older (66). The second principal source of employment for working force is local, state, and federal government centered at the County Seat. The following table gives a breakdown of the total (not export) employment in the valley in 1970, which is not expected to have changed more than one percent per year.

TABLE 1

1970 Annual Average Employment (54)

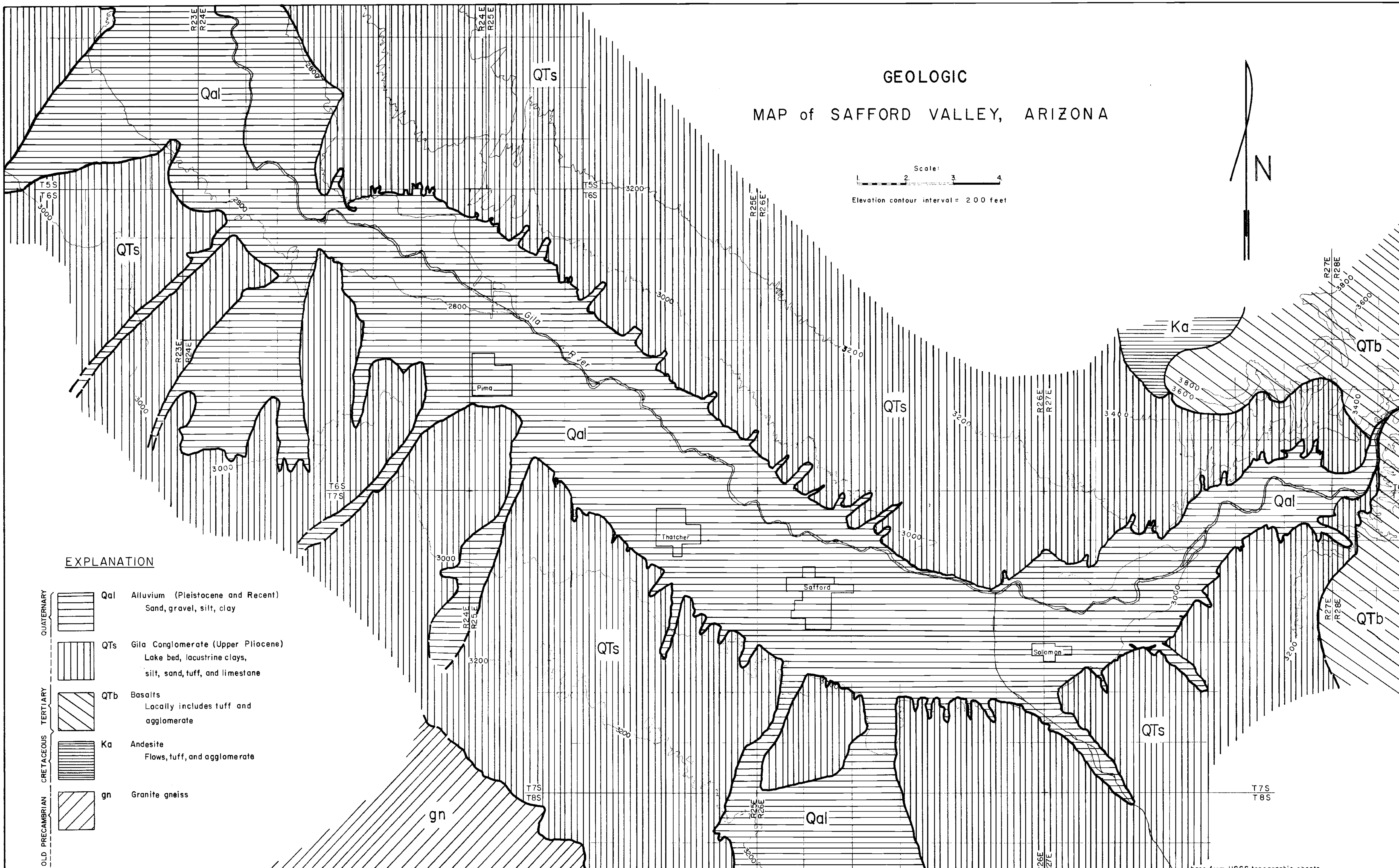
Economic Sector	Number of Workers	Percent of Total
Manufacturing	175	4.0
Mining and Quarrying	120	2.8
Contract Construction	75	1.7
Transportation, Communication and Public Utility	100	2.2
Wholesale/Retail Trade	775	17.5
Finance, Insurance and Real Estate	75	1.7
Services	600	13.6
Government	1,200	27.1
Other	400	9.0
Agriculture	900	20.3

Table 1 and the 5.6 percent unemployment account for the entire labor force of the valley. The 1970 census indicates that 248 members of the working force are farmers or farm managers (66). These members own or operate the entire farming industry of the valley. There are 163 farms of a minimum of 10 cultivated acres (50). Cotton and sorghum are the principal agricultural commodities produced by these farms, with barley and alfalfa as secondary crops. Cotton gins and sugar beets processing are the principal agriculture dependent industries.

Other industries in the valley are the small companies producing camping equipment, mobile homes and fiber glass. These industries produce an annual income of approximately $23,600,000 with $10,000,000 coming from the agricultural factor (53). Cotton is the main contributor to this sum. Upland cotton acreage reached a peak of 17,000 acres in 1951 and American-Egyptian cotton reached that acreage in 1963. Cotton is grown under an acreage allotment plan established by the U. S. Department of Agriculture. A few farmers and ranchers produce beef cattle which are grazed primarily on the unirrigated lands above the valley floor. A meat processing plant operates in Safford and packs some of the locally produced beef products (30).

Transportation in the Safford Valley is sufficient for local requirements. U. S. Highway 70 crosses the study area in a southeast-northwest direction, and U. S. Highway 666 intersects it from the south at Safford (67). A branch line of the Southern Pacific Railroad passes through the area. To the northeast of Safford there is an airport with two lighted, paved runways of 4800 feet and the control has UNICOM facilities (54). Only the roads in the municipalities are paved, in general, but the county roads which are unpaved are extremely well maintained. Most locations in the study area were easily reached by the field teams in this study.

Eastern Arizona College at Thatcher offers pre-occupational and vocational courses to prepare individuals for immediate employment in addition to a pre-professional curriculum designed to provide the first two years of a longer educational program (54). The local public elementary school has a faculty of 34 and an enrollment of 1,422 while the local public high school has a faculty of 54 and an enrollment of 800 students (55). Tourism in the Safford Valley has become a profitable industry in the last few years. The valley has ample lodging facilities. The good bass, bluegill and trout fishing with the deer, bear, javelina, turkey, quail and dove hunting attract the sportsman. Mount Graham and the hot mineral baths are available to the less active traveler (55).


GEOLOGIC
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
N
EXPLANATION
QUATERNARY
Qal Alluvium (Pleistocene and Recent)
Sand, gravel, silt, clay
QTs Gila Conglomerate (Upper Pliocene)
Lake bed, lacustrine clays,
silt, sand, tuff, and limestone
TERTIARY
QTb Basalts
Locally includes tuff and
agglomerate
CRETACEOUS
Ka Andesite
Flows, tuff, and agglomerate
OLD PRECAMBRIAN
gn Granite gneiss
Qal
QTs
QTb
Ka
gn
Gila River
Pima
Thatcher
Safford
Solomon
R23E R24E
R24E R25E
R25E R26E
R26E R27E
R27E R28E
T5S T6S
T6S T7S
T7S T8S
2800
3000
3200
3400
3600
3800
base from USGS topographic sheets

PHYSICAL SYSTEM

The Safford Basin, as the Safford Valley is termed in most geologic studies of the region, is an elongated structural trough. It is bounded by the Gila and Peloncillo Mountains to the northeast and east, and by the Turnbull, Santa Teresa and Pinaleno Mountains to the southwest. The valley is oriented northwest-southeast, with a minor limb oriented northeast-southwest, and is the repository for sediments principally derived from the surrounding mountains with some sediments brought into the valley by the Gila River and San Simon Creek drainages. The Gila River is the principal drainage and sediment transport mechanism of the basin. The Gila River has a gradient of approximately 10 feet to the mile on the average, as compared to the San Simon Creek which drops about 20 feet in elevation per mile. The topographic configuration of these and other principal features of the area are shown on the Index and Topographic Map of the Valley in the accompanying text (44).

The physical elements of the hydrologic environment in the Safford Valley deal principally with a double aquifer system. A deep artesian aquifer system occupies the lowest reaches of the valley, to bedrock, and extends to a cap stratum located relatively near the surface. A shallow water table aquifer rests upon this cap stratum. The shallow aquifer is in hydraulic contact with the Gila River. and because of its relatively good quality, is used as a source of irrigation water. The shallow aquifer system, often called the irrigation aquifer, is the system which is being examined. The water quality of this system is currently within tolerable limits for agriculture, as opposed to the quality of the artesian aquifer water. This artesian water is generally extremely saline and often exhibits geothermal characteristics. The confining layer between the two aquifer systems has frequently been punctured by wells, both operating and abandoned. The water from such wells is used in the mineral and hot bath industry of the Safford Valley.

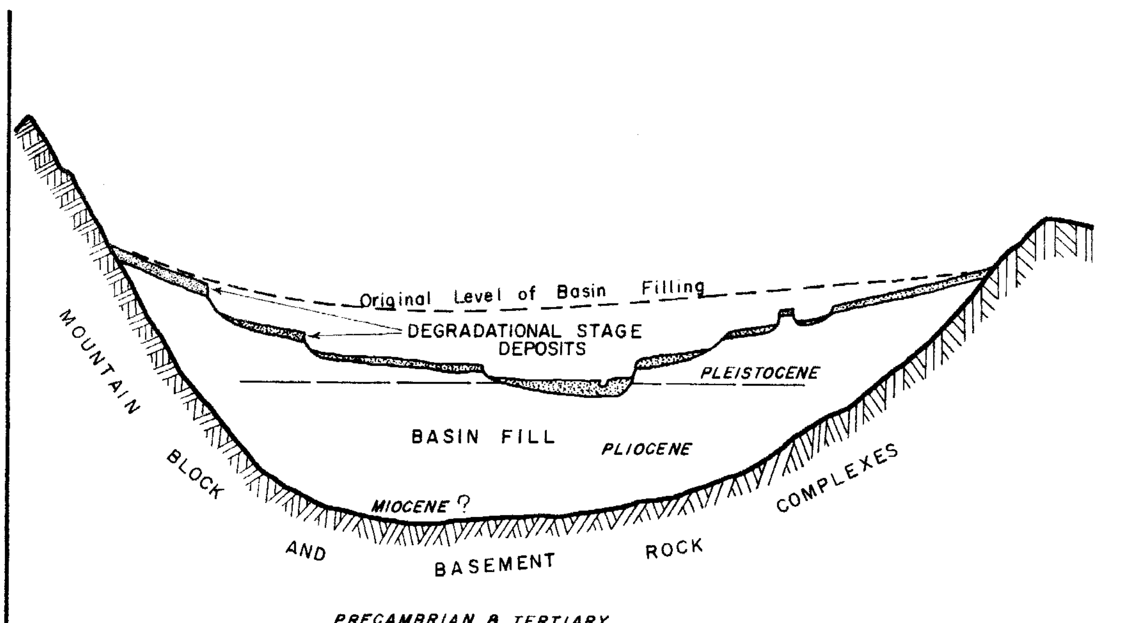
GEOLOGIC HISTORY OF THE SAFFORD VALLEY

There have been three principal stages of geologic development of the Safford Basin which are proposed by Harbour (37) as significant time-stratigraphic units into which the deposits in the basin could be categorized. The initial stage is termed "mountain blocks and basement rocks," the second "aggradational stage basin fill," and the third "degradational stage deposits."

Mountain blocks and basement rocks were emplaced prior to the structural closure of the Safford Basin. This unit is comprised primarily of Precambrian igneous, metamorphic and sedimentary rocks, Paleozoic sediments, and Cretaceous-Tertiary volcanic rocks on the southwestern side of the basin, and Tertiary and Cretaceous volcanics on the northeastern side.

The aggradational stage basin fill consists of rocks deposited within the basin after structural closure in the Tertiary, but prior to the subsequent opening near Coolidge Dam. Coolidge Dam is located approximately 30 miles downstream from the northernmost end of the west limb of the valley lying in the study area. During this aggradational stage, sediments derived from the surrounding mountains were deposited within the hydrologically closed basin (37). The sediment from the Pinaleno and Santa Teresa Mountains is high in quartz and feldspars, as those mountains are principally of granitic gneiss, schist and granite. The sediment from the Gila and Peloncillo Mountains, which are formed principally from lava flows and ash beds, is of basaltic, andesitic and rhyolitic derivation. There are only a few granitic intrusive rocks along the base of the Gila Mountains (30). The degradational stage began when the Mescal Mountains were cut structurally through drainage when the Gila River began. The relationships of the deposits of the three stages discussed are illustrated in Figure 1. The earlier basin fill deposits were subjected to erosion during periodic lowering of the basin base level to its present elevation. The topographic relief of the Safford Valley today is primarily composed of remnants of basin fill deposits, still subject to erosion. The principal relief featurs involved are the truncated terrace remnants.

During the period of hydrologic closure from late Tertiary to the Pleistocene, the Safford Basin was the site of an extensive lake which perhaps in part arose as a result of climatic fluctuations. Indeed, it is this interval of closure and the lake deposits themselves which are the most significant of the geologic periods of the valley. These lacustrine deposits exhibit their significance in their effects on and control of the present ground water hydrology of the Safford Basin.



Simplified Relationships of three Local Stages of Rock Units in the Safford Valley (after Harbour)
Figure 1

DESCRIPTIVE GEOLOGY

IGNEOUS AND METAMORPHIC ROCKS

The Pinaleno Mountains and the cores of the Santa Teresa and Turnbull Mountains, according to Knechtel (44), are composed mainly of pre-Cambrian Pinal schist and the associated igneous rocks. Cambrian quartzite, early Tertiary quartz monsonite, and middle or late Tertiary volcanic rocks crop out on the northeast side of these mountain ranges but are there commonly overlapped and concealed by the Gila conglomerate originating from the Gila River and San Simon Creek.

The Peloncillo and Gila Mountains, which border the basin on the northeast, are made up primarily of intrusive and extrusive igneous rocks, a large part of which are probably of Tertiary age, although some of the lava flows may be Quaternary (44). Some of these flows crop out near the point of entry of the Gila River into the Saffford Valley. The old sandstones upon which these flows rest exhibit the features of extensive contact metamorphism.

Surficial cap layers, which are the upper boundary for the sediments discussed on the following pages, are composed of coarse gravels, pebbles and boulders. In Sec. 27, R25E, T7S, for example, there are boulders 2 feet in diameter which occur in the conglomerate that caps a small mesa type exposure (44). The boulders, which are clearly of igneous and metamorphic origin although extremely well worn and rounded, do not all originate from the neighboring mountains. Some of these boulders can be tied to Pinaleno Mountains by minerologic identification, though many of them do not have a source area readily apparent in the valley. These igneous rocks seem to have been transported by the Gila River when the base level was in correspondence with the elevation of these terrace tops.

The igneous and metamorphic rocks of the region are only superficially mentioned since the materials of principal interest in a study of ground water quality are the sediments deposited in the valley or basin, which comprise the aquifer material.

SEDIMENTS AND SEDIMENTARY ROCKS

Basin Fill Deposits (51)

The aggradational stage basin fill deposits of the Safford Valley are of primary interest to the hydrogeologist working in the study area. These sediments are responsible for the quality of the ground water of the valley, and they provide the physical components of artesian aquifer systems.

The basin fill of the Safford Valley deposits have been divided stratigraphically into two principal units by previous investigators. W. L. Van Horn proposed that they be divided along the Pleistocene-Pliocene boundary into the Solomonsville Pliocene beds and the Solomonsville Pleistocene beds (72). J. Harbour agreed with the major division but used the names Upper Basin Fill and Lower Basin Fill (37). In this text, the terminology devised by Harbour shall be employed. Both workers locate the Pleistocene-Pliocene boundary in the stratigraphic section by paleontological interpretation of fossil remains.

The Lower Basin Fill is the more significant portion of the basin fill deposits. The Upper Basin Fill sediments are exposed in isolated hills, having for the most part been eroded from the central part of the valley. Erosion progressed into the upper beds of the Lower Basin Fill in the valley center.

The Lower Basin Fill has two main divisions which are texturally distinguishable. The lower division is a generally coarse-grained clastic sequence, while the upper division consists of a fine-grained lacustrine sequence. The Upper Basin Fill is a sequence of coarse alluvium and mudflow deposits with minor interbedded floodplain and lake deposits (72).

An assignment of facies can be made with regard to lithologic homogeneity, texture, composition and structural relationship. Both the Upper and Lower Basin Fill are divided into four facies; there are two facies which are common to each (72). This breakdown is tabularized below.

TABLE 2 (72)

Facies Assignments

Strata	Facies
Upper Basin Fill	Tuffaceous lacustrine facies, Piedmont facies, Orange silt and conglomerate facies, Camel track tuff marker bed
Common Facies	Calcareous facies, Red facies
Lower Basin Fill	Delta facies, Green clay facies, Evaporite facies, Basal conglomerate facies

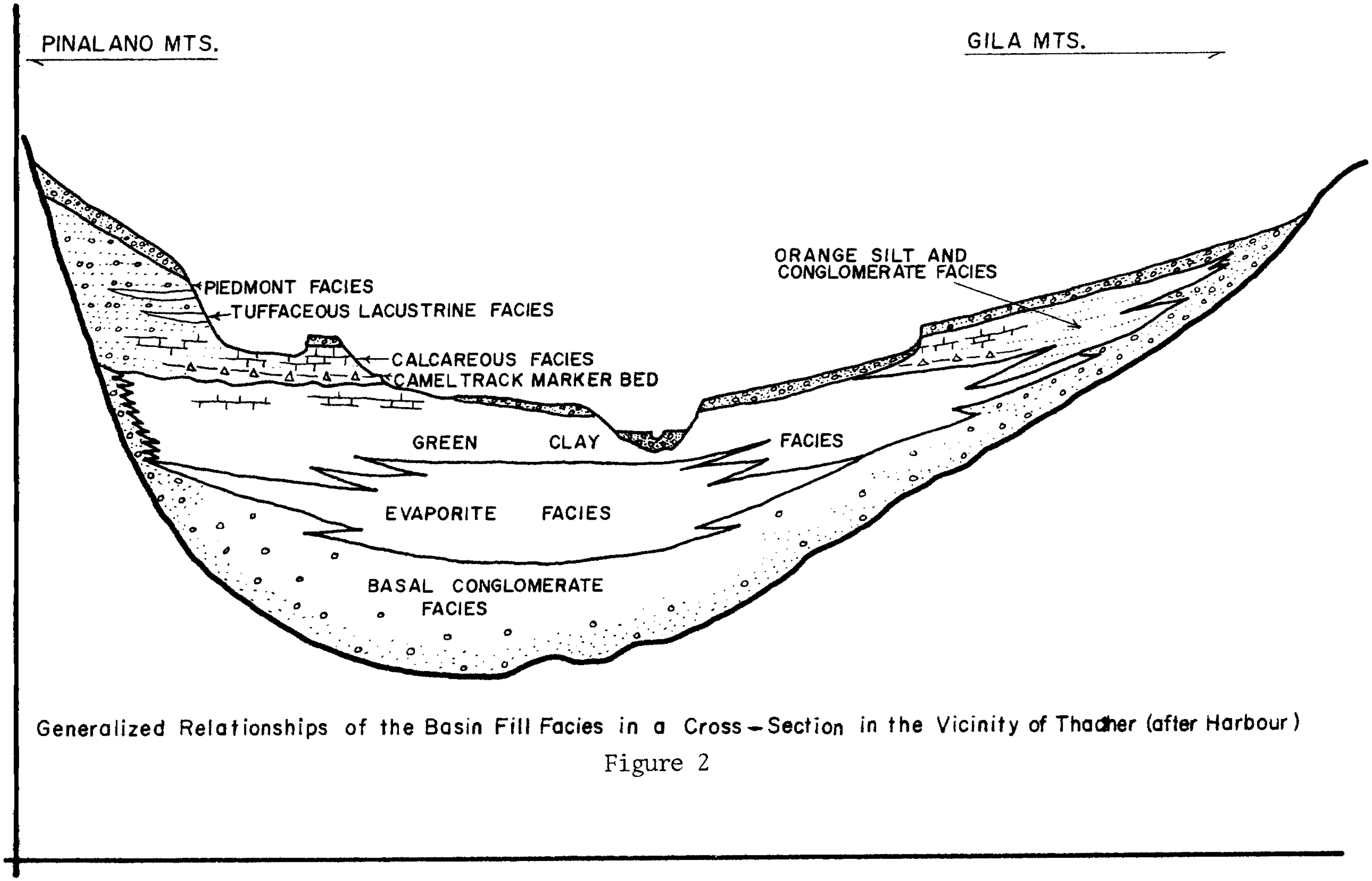
The structural relationship of these facies is illustrated by Figure 2, Generalized Relationships of the Basin Fill Facies in a Cross-Section in the Vicinity of Thatcher; and the age relationship is shown by Figure 1, Simplified Relationships of the Three Local Stages of Rock Units in the Safford Valley.

Lower Basin Fill (51)

Basal Conglomerate Facies. Outcrops of conglomeratic material near mountain fronts around the Safford Valley were first postulated to belong to the lowest portion of the valley fill by G. K. Gilbert in 1875 (31). Knechtel, in his 1938 paper (44) discussed all basin fill under the term "Gila Conglomerate" and makes no distinction between overlying fine-grained lacustrine beds or underlying coarse material. He states.

> These [lacustrine] prevailingly fine-grained materials grade laterally into fanglomerates . . . which extend in belts along the sides of younger orange silt and conglomerate facies high on the valley sides, resting on bed rock. Artesian water from the basal conglomerate facies, lower near the valley center, suggests that the facies is contiguous to the marginal fanglomerates. (44)

This relationship is demonstrated in Figure 3.

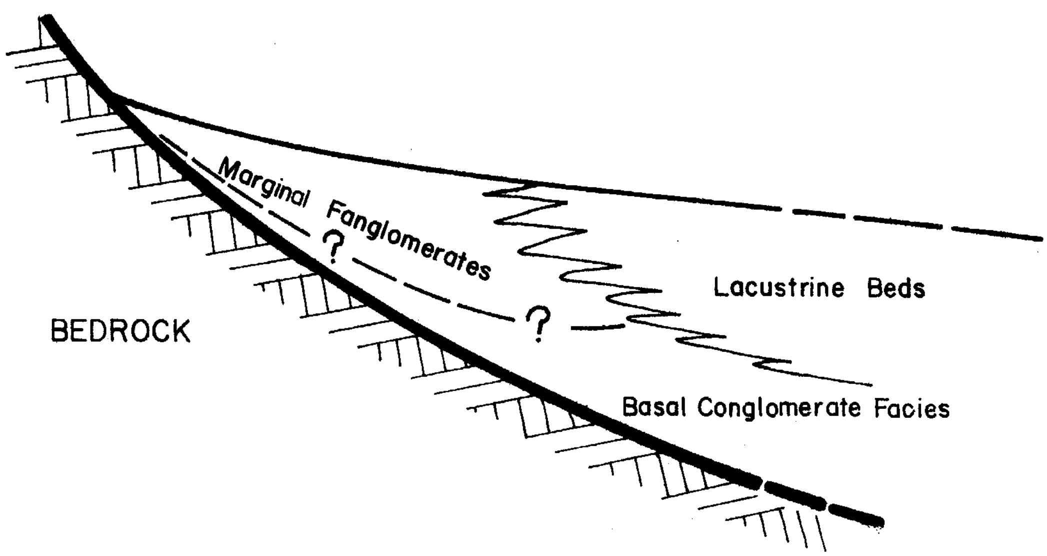


Generalized Relationships of the Basin Fill Facies in a Cross-Section in the Vicinity of Thatcher (after Harbour)

Figure 2

Figure 3

VALLEY MARGIN RELATIONSHIPS



<u>Valley Margin Relationships</u> Basal Conglomerate Facies underlying Marginal Fanglomerates, with undefined interface, and Lacustrine Beds of the inter-valley, with an interfingered interface.

Extensive interbedding of the basal conglomerate facies and lacustrine beds is indicated by the alternation of fine-grained and coarse-grained clastic strata which are uncorrelatable, by the production of artesian water at varying elevations in the same well, and by the presence of fanglomerate beds along the sides of the valley. The belts of fanglomerate exposures are several miles wide in some locations but are absent in others (44). Knechtel's discussion is very general in tone and should be read with consideration.

The marginal fanglomerates are important in that they comprise the recharge area for the basal conglomerate facies. The exact nature of their relationship is unknown. Outcrops of material thought to represent the basal conglomerate facies are found associated with fanglomerate material of the much finer bed of artesian aquifer in uncorrelatable beds and elevations throughout the basin.

A series of Kennecott Copper Company water wells drilled into the bed rock complex. from near the Gila Mountains toward the valley bottom penetrate coarse conglomerate materials before reaching that complex. The thickness of the coarse unit increases toward the valley center and is interpreted as the northeastern extension of the basal conglomerate facies (37).

The deepest well in the valley, the Mary S. Mack well, penetrates the basal conglomerate facies at an elevation of 1350 feet, the facies top being determined by a change in lithology and the absence of the evaporite minerals. A log of this well showing the lithology and facies assignments of the strata appear in Figure 4.

The Southern Pacific Well near Safford was abandoned at an elevation of 1100 feet while still drilling in evaporite impregnated shale. This well log appears in Figure 5. This apparent disparity is explained by Harbour as evidence of lowering of the basement rocks in the Safford area (37).

Evaporite Facies. The evaporite facies is located along the center of the Safford Basin, and is defined by well logs since no surface outcrops occur. Beds of halite (NaCl), gypsum ($CaSO_4:2H_2O$) and limestone resulting from the evaporation of saline lake waters have been reported, as have clay and shale beds impregnated with those evaporite beds (44). The most probable explanation of the occurrence of evaporite minerals within the valley is that over a long period of climatic fluctuation from humid conditions to semi-arid or arid conditions the level of the saline table dropped. This caused concentrations of dissolved salts to rise. and precipitation of evaporite minerals occurred. The salts are presumed to have been derived from the entire upper drainage of the Gila River, and to have been transported by that river into this hydrologically closed basin.

The Southern Pacific well near Safford penetrated a sequence of yellow and brown clay with gypsum streaks at 2,120 feet above sea level, and was abandoned at the 1,100 foot level in salty clay. The more western and more marginal Mary S. Mack well intersected a 500-foot shale sequence with a gypsiferous shale bed at 2,270 feet, which is possibly the evaporite equivalent in the red facies at that location (37). The one gypsiferous shale noted by Knechtel at 2,665 feet above sea level is elevationally correlative with the evaporite sequence cut by the Southern Pacific well near Safford. Relatively pure gypsum beds are found to the east of the Southern Pacific well near Tanque, but at a higher elevation. The data suggests that the lake center was in the Safford area where the thickest sequence of these beds was found (37), which coincided with the elevational extent of the basal conglomerate section and the possibility of basement lowering at that location. The stratigraphic conelations between these wells, and other deep logged wells in critical locations appear in Figure 6. The facies assignments indicated by Harbour and by the researchers appear with the interpretation of stratigraphic continuity along the length of the Gila River in the study area.

Green Clay Facies. The upper beds of the green clay facies are exposed on both sides of the Gila River from Ashurst to Safford. The thickest outcrops of this facies are located along the first terrace northeast of the Gila River, south of the Safford Municipal Airport. The over-all aspect of the outcrops is that of a texturally uniform, laminated, and poorly indurated light grey claystone with clear and conformable contacts. Presence of thicker units in the sequence provides lithologic relief, but is uncorrelatable.

Subsurface interpretation with the green clay facies is hampered by the variety of terms with which it is described. References to "blue clay," "clay," and "lake beds," are common in many logs (44). Harbour reports 610' of green clay in the Southern Pacific well near Safford which ends with 400' of yellow clay, the bottom of which is 2200' above sea level (37). Four measured sections in Figure 7 were sampled and analyzed during the Hydrology Field Camp. Measured Section IV from Big Canyon shows the top of the green clay at 3299' above sea level, indicating the total thickness of the facies in the Safford area was about 1600 feet, 400 feet of which was eroded from the center of the basin.

Measured Sections I and II show an abundance of red silty material with some light grey clay, showing a grading toward the west of the green clay facies into the red facies. The texture of the material in Sections I and II is coarser than that of Sections III and IV.

Figure 4

LOG OF THE MARY S. MACK WELL

(after Harbour paper)

DEPTH	FACIES ASSIGNMENT	THICKNESS	DESCRIPTION
3	INNER-VALLEY FILL	3	Sandy loam
20	INNER-VALLEY FILL	17	Sand
180	INNER-VALLEY FILL	160	Gravel; water
			Unconformity
300	RED FACIES	120	Red sandstone
460	RED FACIES	160	Red sandy shale
500	RED FACIES	40	Brown shale
510	RED FACIES	10	Black shale
560	RED FACIES	50	Brown shale
656	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	96	Gray shale
684	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	28	Red sandstone
740	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	56	Blue shale
835	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	95	Gray shale
852	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	17	Gypsum and shale
870	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	18	Blue shale
950	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	80	Hard shale
960	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	10	Gray shale
1020	Calcareous zone within Red Facies; probably equivalent to Evaporite Facies	60	Blue shale
1270	RED FACIES	250	Brown shale
1300	RED FACIES	30	Gravel
1390	RED FACIES	90	Brown shale
1392	RED FACIES	2	Limy shale
1450	RED FACIES	58	Red shale
1451	BASAL CONGLOMERATE FACIES	1	Sand
1470	BASAL CONGLOMERATE FACIES	19	Gravel
1542	BASAL CONGLOMERATE FACIES	72	Red sandstone
1580	BASAL CONGLOMERATE FACIES	38	Red shale
1625	BASAL CONGLOMERATE FACIES	45	Red sand
1630	BASAL CONGLOMERATE FACIES	5	Gravel
1645	BASAL CONGLOMERATE FACIES	15	Red sand
1720	BASAL CONGLOMERATE FACIES	75	Sand; water
1730	BASAL CONGLOMERATE FACIES	10	Gravel
1748	BASAL CONGLOMERATE FACIES	18	Red sand
1788	BASAL CONGLOMERATE FACIES	40	Sandy shale
1803	BASAL CONGLOMERATE FACIES	15	Gravel
1820	BASAL CONGLOMERATE FACIES	17	Red shale
1830	BASAL CONGLOMERATE FACIES	10	Red gravel
1880	BASAL CONGLOMERATE FACIES	50	Red sand
1885	BASAL CONGLOMERATE FACIES	5	Red shale
1897	BASAL CONGLOMERATE FACIES	12	Gravel
1947	BASAL CONGLOMERATE FACIES	50	Hard red sand
1949	BASAL CONGLOMERATE FACIES	2	Limy shale; sand
1952	BASAL CONGLOMERATE FACIES	3	Limy shale
2143	BASAL CONGLOMERATE FACIES	191	Red sand
2220	BASAL CONGLOMERATE FACIES	77	Sand; water
2250	BASAL CONGLOMERATE FACIES	30	Red sand
2305	BASAL CONGLOMERATE FACIES	55	Red shale
2318	BASAL CONGLOMERATE FACIES	13	Sand; water
2399	BASAL CONGLOMERATE FACIES	81	Red sand
2475	BASAL CONGLOMERATE FACIES	76	Red shale
2480	BASAL CONGLOMERATE FACIES	5	Gravel
2498	BASAL CONGLOMERATE FACIES	18	Limy shale
2520	BASAL CONGLOMERATE FACIES	22	Gravel
2575	BASAL CONGLOMERATE FACIES	55	Red shale
2660	BASAL CONGLOMERATE FACIES	85	Red sand
2250	BASAL CONGLOMERATE FACIES	30	Red shale
2702	BASAL CONGLOMERATE FACIES	12	Broken sand; lime
2770	BASAL CONGLOMERATE FACIES	68	Sandy shale
2800	BASAL CONGLOMERATE FACIES	30	Red sandstone
2840	BASAL CONGLOMERATE FACIES	40	Red shale
2850	BASAL CONGLOMERATE FACIES	10	Pink shale
2851	BASAL CONGLOMERATE FACIES	1	Pink sandstone
3005	BASAL CONGLOMERATE FACIES	155	Red sandstone
3094	BASAL CONGLOMERATE FACIES	89	Red shale
3101	BASAL CONGLOMERATE FACIES	7	Hard lime
3140	BASAL CONGLOMERATE FACIES	39	Sand
3210	BASAL CONGLOMERATE FACIES	70	Red sand; water
3212	BASAL CONGLOMERATE FACIES	2	Gray lime
3247	BASAL CONGLOMERATE FACIES	35	Red sand
3250	BASAL CONGLOMERATE FACIES	3	Gray lime
3254	BASAL CONGLOMERATE FACIES	4	Gray sand
3258	BASAL CONGLOMERATE FACIES	4	Gray lime
3273	BASAL CONGLOMERATE FACIES	15	Gray sand
3287	BASAL CONGLOMERATE FACIES	14	Sandy lime
3530	BASAL CONGLOMERATE FACIES	243	Red sandstone
3540	BASAL CONGLOMERATE FACIES	10	Red sandy shale
3720	BASAL CONGLOMERATE FACIES	180	Red sandstone
3734	BASAL CONGLOMERATE FACIES	14	Red sandy shale
3738	BASAL CONGLOMERATE FACIES	4	Gypsum
3767	BASAL CONGLOMERATE FACIES	29+?	Red sandstone

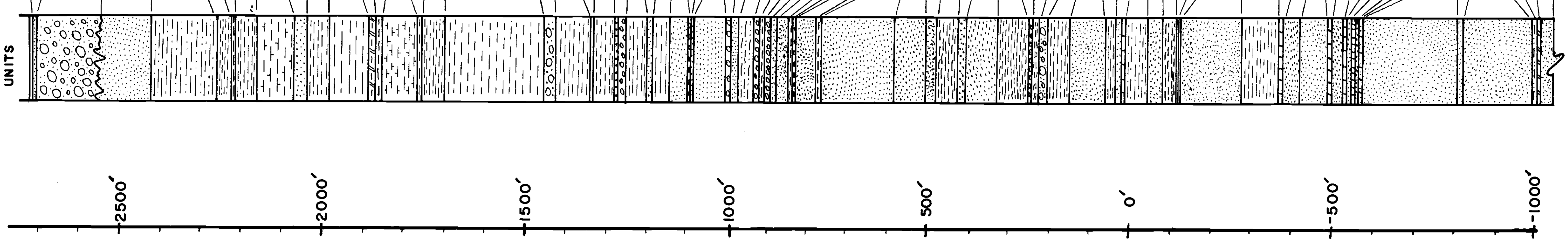


Figure 5

SOUTHERN PACIFIC R. R. WELL LOG

Log after Harbour Description of Unit	Thickness (feet)	Depths (feet)	Elevation (feet)	Assignment of Facies
				(top = 2920 feet)
Soil	8	8	2912	
Gravel and Boulders	82	90	2830	INNER-VALLEY FILL
Blue clay	100	190	2730	GREEN CLAY FACIES
Yellow clay	70	260	2660	
Blue clay	40	300	2620	
?				? ?
Yellow stratified clay	400	700	2220	
Yellow clay with streaks of gypsum	100	800	2120	EVAPORITE FACIES
Yellow clay with strata of hard rock	95	895	2025	
Yellow and brown clay with salt	105	1000	1920	
Salty clay	820	1820	1100	

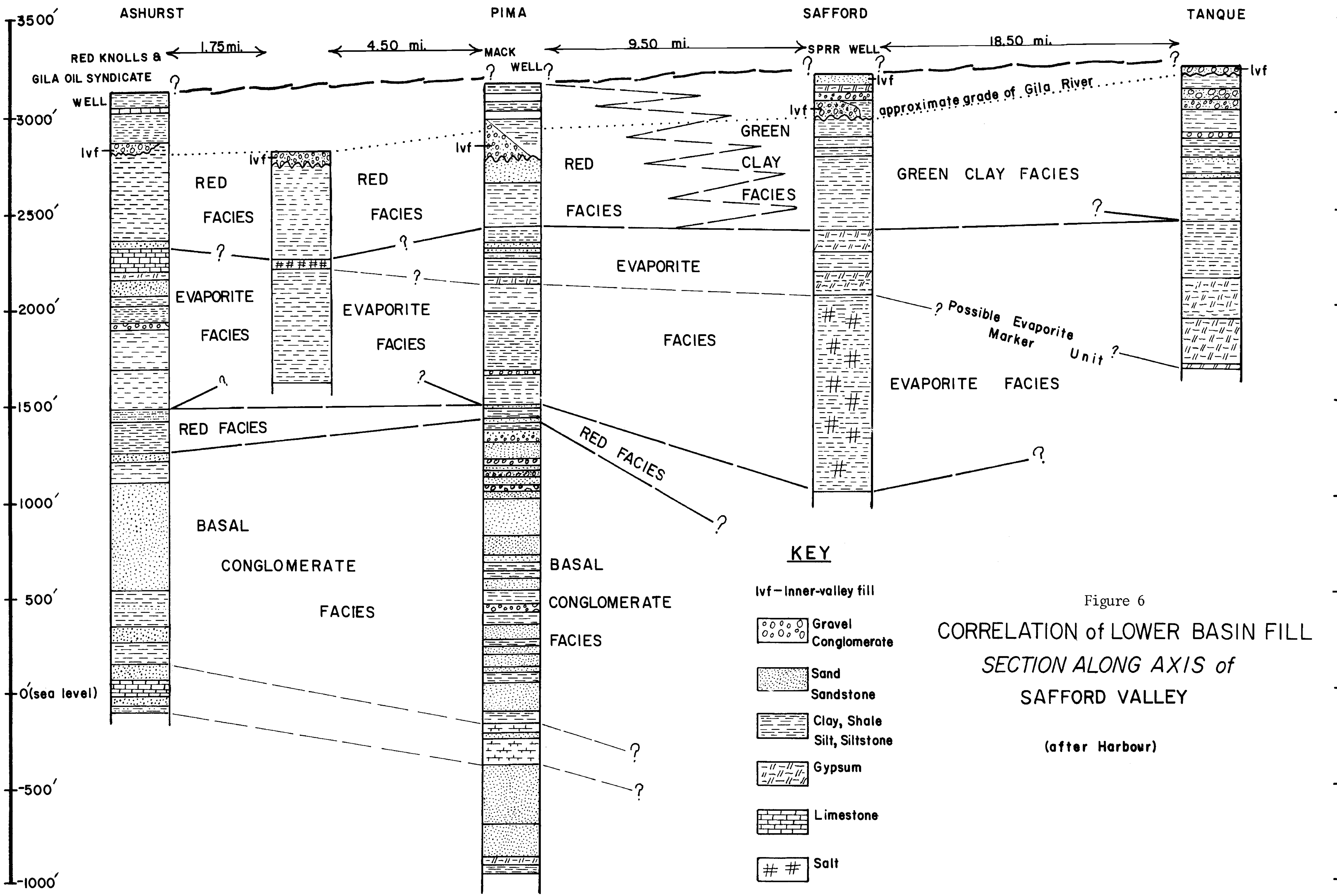


Figure 6

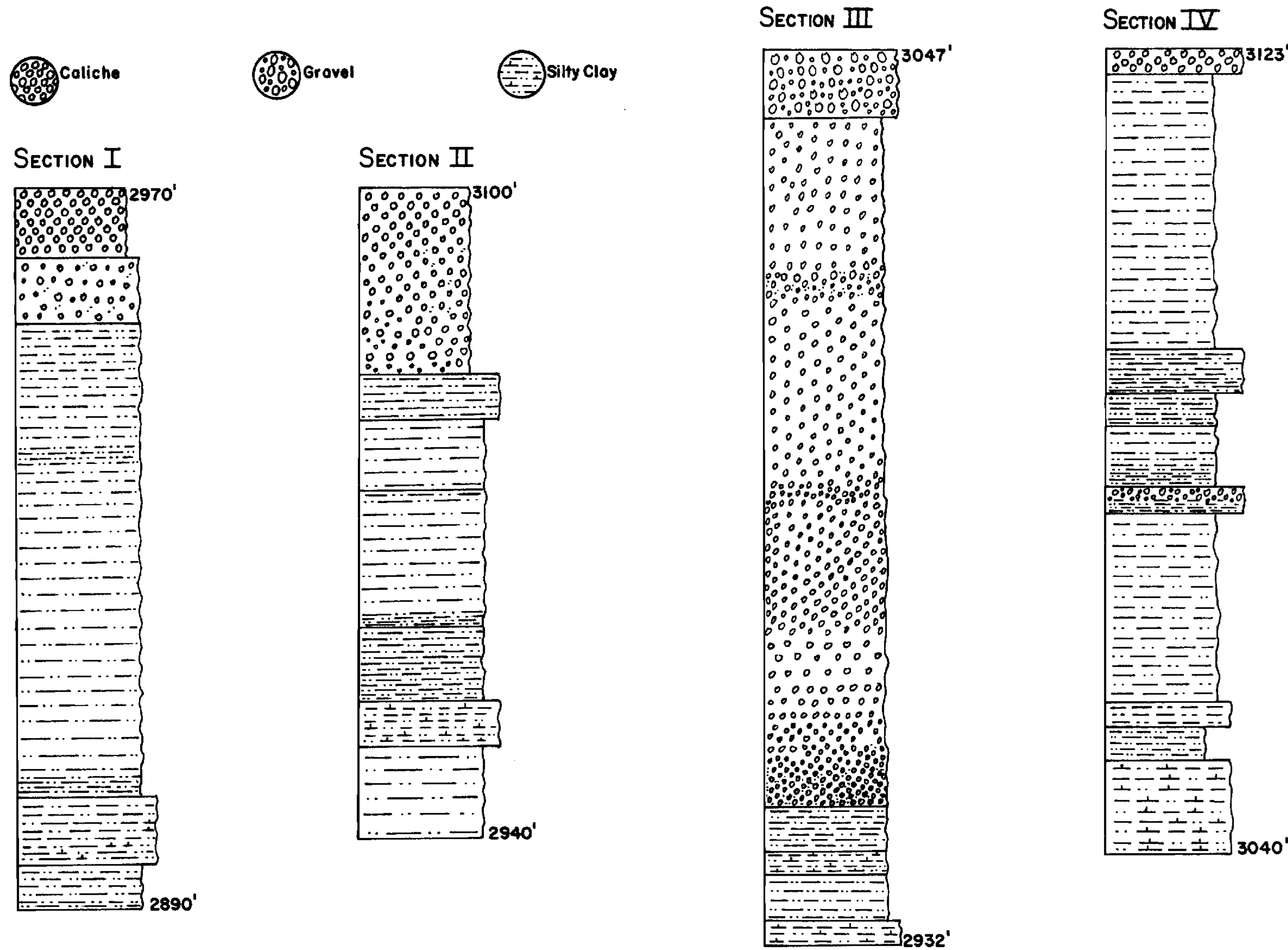
CORRELATION of LOWER BASIN FILL

SECTION ALONG AXIS of

SAFFORD VALLEY

(after Harbour)

Figure 7
MEASURED SECTIONS



Frequent occurrences are noted of evaporite minerals -- gypsum. salt and carbonate -- in the measured sections of the green clay facies. Lack of petrographic analysis of the lower beds of the facies cut by drilled wells prevents extrapolation of this observation into the subsurface sections.

The green clay facies is overlain unconformably by the piedmont facies in most areas, on both sides of the central basin. In some areas where no cap rock is available, green hummocks or mounds are observed.

Thickset total sections of the green clay facies occur in the Safford area, and support the conjecture that the lake center was there. The beds of the facies are essentially horizontal, but dip slightly toward the northwest. Harbour places the Pleistocene-Pliocene boundary at the top of the green clay facies (37).

Red Facies. The texturally uniform clays of the green clay facies grade laterally westward into the coarser beds of the red facies. The red facies occur in both upper and lower basin fill, but the upper beds have been well eroded from the base. Sedimentary units consist of varying proportions of reddish brosn sands, silts and clays. In outcrops, the red facies is mainly buried under its own eroded debris, and a shovel is required to expose it. The sediments are thinly bedded, poorly cemented and often bedded indistinctly.

In both the Mack well and the Gila Oil Syndicate well (shown in Figure 6, indicating the correlations of the Lower Basin Fill), the base of the red facies is chosen at the top of the highest conglomeratic bed of the basal conglomerate facies. The red facies section of both wells are similar, but differ in that a calcareous section in the Gila well, correlated to that of the Mack well, contains no evaporite minerals (37).

Hydrogeological Analysis of the Lower Basin Fill

Sediments of the Lower Basin Fill facies were deposited in lightly saline waters of a Pleistocene-Pliocene lake. Saline water of that lake remains in the basal conglomeratic facies. The overlying fine-grained sequences of the evaporite, green clay and red facies act as aquitards, imposing confining conditions on the permeable beds of the conglomerate facies. The evaporite and green clay facies contribute some salts to the ground waters of the basin. Water flowing through the quaternary alluvium water table aquifer is exposed to evaporite minerals of the green clay facies on which the alluvium rests. Intertonguing of the basal facies and overlying evaporite and green clay facies brings water of the lower aquifer into contact with evaporite salts. This comprises the source areas for the salts dissolved in the artesian aquifer. The contact between the irrigation aquifer and the soluble evaporites and the contact between the two aquifers are the principal considerations in the development of the ground waters of the area. Such development should take into consideration the extent of such contacts in natural conditions and the alteration of this extent by foreign conditions caused by pumping. Pumping, by imposing a hydraulic gradient artificial to the location, may set up flow lines in the aquifer which cause such contacts to increase in frequency.

Soil Survey

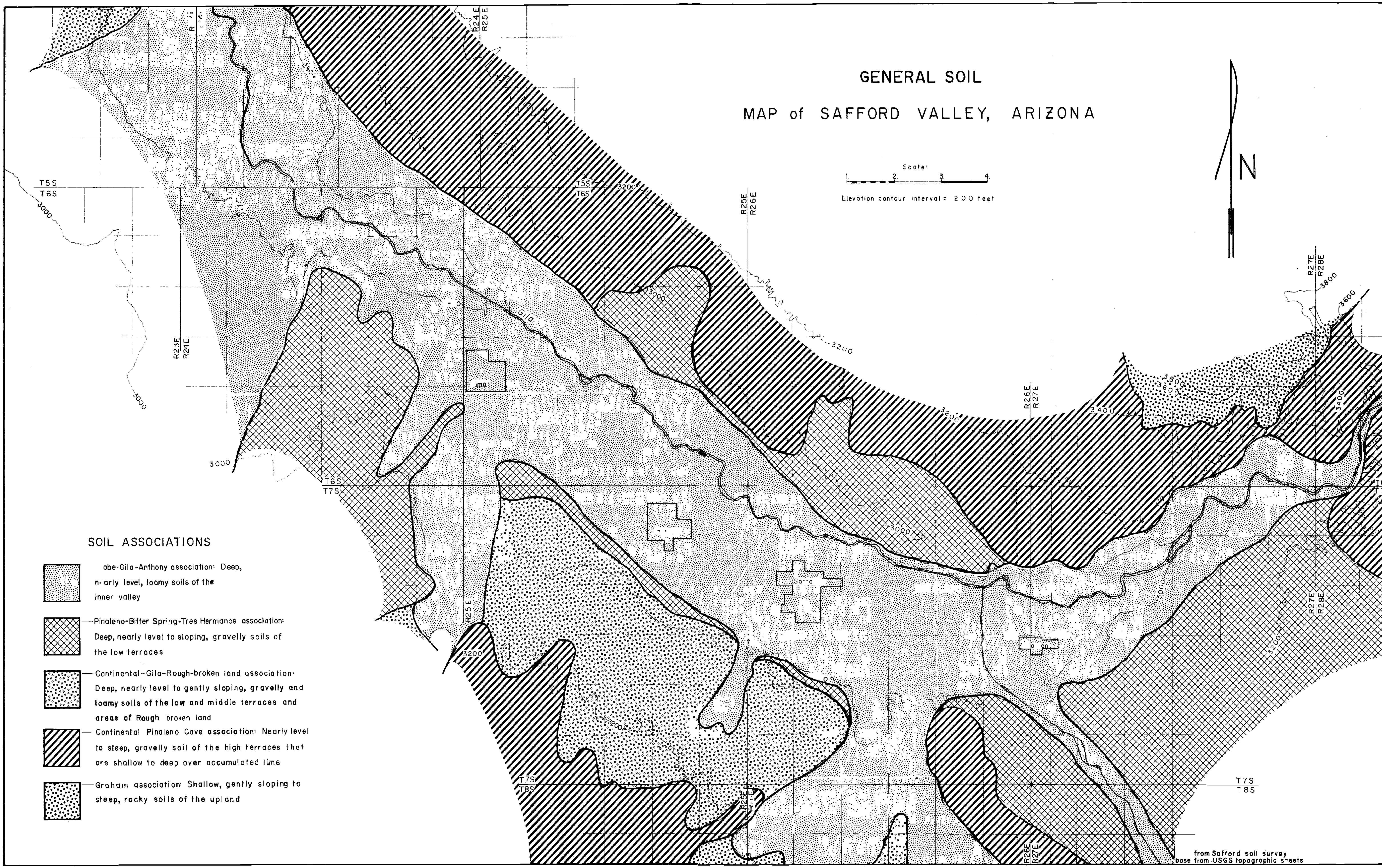
The General Soil Map shows the soil associations in the region of this study. A soil association is a landscape that has distinctive proportional patterns of soil (32). It normally consists of one or more major soils and is named for these constituents. The soils of one association may occur in another, but in a different pattern (30, 32). References are the General Soils Map and the Topographic Map in this volume. Additional detailed information on the following associations is available from the Safford Area Soil Survey of the Department of Agricultural Soil Conservation Services.

Grable-Gila-Anthony Association

This association consists of soils on flood plains and alluvial fans along the Gila River, San Simon Creek and their tributaries of the inner valley. Slopes range from 0 to 2 percent. Elevations range from 2600 to 3100 feet above sea level, and the average annual rainfall is about 9 inches. In unirrigated areas the vegetation is mesquite, saltbrush, saltcedar, creosotebush, and annual weed and grasses. This association makes up approximately 43 percent of the Safford Valley.

Grable soils make up about 25 percent of this association; Gila soils, 23 percent; Anthony soils, 22 percent; and fragmented soils, the remaining 30 percent.

The Grable and Gila soils are deep, are well drained, and have good available water holding capacity. The Grable soils commonly have a dark-colored clay loam surface layer and loamy underlying material. The Gila soils commonly have a light-colored sandy loam surface layer and loamy underlying material. The Anthony soils are deep, are well drained, and have fair available moisture holding capacity. These soils commonly have a light-colored sandy loam surface layer and sandy loam underlying material.



GENERAL SOIL
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
N
SOIL ASSOCIATIONS
abe-Gila-Anthony association: Deep, n-arly level, loamy soils of the inner valley
Pinaleno-Bitter Spring-Tres Hermanos association: Deep, nearly level to sloping, gravelly soils of the low terraces
Continental-Gila-Rough-broken land association: Deep, nearly level to gently sloping, gravelly and loamy soils of the low and middle terraces and areas of Rough broken land
Continental Pinaleno Cave association: Nearly level to steep, gravelly soil of the high terraces that are shallow to deep over accumulated lime
Graham association: Shallow, gently sloping to steep, rocky soils of the upland
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
3000
3200
3400
3600
3800
Gila
from Safford soil survey
base from USGS topographic s-eets

The soils of this association are used mainly for irrigated crops; chiefly cotton, alfalfa, sorghum, small grains, and pasture grasses. Most of these soils have few limitations to use. The coarser-textured soils require irrigation more frequently than the finer ones (30).

Pinaleno-Bitter Springs-Tres Hermanos Association

This association consists of smooth, nearly level soils on low terraces and sloping soils on rounded ridges of the low terraces. These terraces are above the inner valley, and in a few places large washes have cut into them.

This association extends from the eastern end of the area indicated in the General Soils Map, along both sides of the Gila River to the vicinity of Pima. Except for steep escarpments, slopes range from 0 to 5 percent. Elevations range from 2700 to 3200 feet above sea level, and the average rainfall is about 9 inches. Only a small acreage is irrigated, and the unirrigated vegetation is similar to the previous association with the addition of cholla and a reduced amount of the small shrubs. This association makes up approximately 11 percent of the Safford Valley.

The pinaleno soils make up about 50 percent of this association; Bitter Springs soils, 20 percent; Tres Hermanos soils, 15 percent; and minor soils and land types, 15 percent.

The pinaleno soils are on the top edges of low terraces and are deep and well-drained. They typically have a brown gravelly loam surface layer and a reddish-brown very gravelly loam or clay loam subsoil. At a depth of 2 to 3 feet is a layer of weakly cemented accumulated lime. The available moisture-holding capacity is low to fair.

The Bitter Springs soils are on the less sloping parts of the low terraces. They are deep, well-drained, and calcareous. They typically have a thin, gravelly sandy loam surface layer and a gravelly loam or sandy loam subsoil. The available moisture-holding capacity is similar to the Pinaleno soils.

The Tres Hermanos soils occupy the tops of terraces and side slopes on low knolls. They are deep, well-drained, and calcareous, with a typical pink gravelly sandy loam surface layer and a brown sandy clay loam subsoil. In some places, the Tres Hermanos soils are saline and have little or no vegetation.

The soils in this associations are used mainly for desert range. Cattle and wildlife graze the sparse vegetation, but only in a few places can the animals obtain drinking water. Most of the grazing is provided by annuals that grow early in the spring and during rainy periods in summer (30).

Continental-Gila-Rough Broken Land Association

This association consists of soils on broad terraces and alluvial fans along the south side of the inner valley from Stockton Wash to just below Pima. Low ridges are on the terraces and washes have cut deep canyons with steep-sided slopes. Slopes range from 0 to 60 percent. Elevations range from 2700 to 3300 feet, and the average annual rainfall is 9 inches. The vegetation is creosotebush, snakeweed, saltbrush, mesquite, cactus, ocotillo, some tobosa, and annual weeds and grasses. This associations makes up about 15 percent of the Safford Valley.

Continental soils make up about 35 percent of this association; Gila soils, 25 percent, rough broken land, 20 percent; and minor soils and land types, 20 percent. Gravelly alluvium also occurs in a small acreage.

The Continental soils are on the tops of the terraces and are generally about 29 inches deep over a weakly to strongly cemented layer of accumulated lime. They commonly have a reddish-brown gravelly sandy loam surface layer and a gravelly clay loam or a cobbly clay subsoil above this lime. The available moisture-holding capacity is low.

The Gila soils have previously been described in the explanation of the first association of this series.

Rough broken land consists of exposed valley fill on the steep, eroded sides of terraces and canyons. This valley fill ranges from gravelly sand to clay, but in many places is silty. In some places, gravel is exposed and many areas are saline. The available moisture-holding capacity ranges from very low to good, depending on texture.

Soils of this associaiton are used for grazing, wildlife, and water supply. None of the land is irrigated. Because of the low annual rainfall, these soils provide little forage for cattle or wildlife except early in the spring and late in the summer when annual plants grow after rains (30).

Continental-Pinaleno-Cave Association

This association consists of nearly level to steep soils on high terraces. Slopes range from 3 to 5 percent but in some places are more than 30 percent. The terraces are dissected and drained by washes that flow into the Gila River. Elevations range from 2800 to 4800 feet, and average annual rainfall is 11 inches. The vegetation is mostly creosotebush, whitethorn, catclaw, and mesquite, but annual grasses and weeds grow after rainy periods. On the higher parts of the terraces there are areas in curly mesquite, tobosa, snakeweed, wolfberry, and many annual plants but only a small smount of creosotebush. This association makes up about 29 percent of the Safford Valley.

Continental soils make up about 30 percent of this association; Pinaleno soils, 25 percent; cave soils, 18 percent; and the remaining 27 percent is made up of minor soils and land types.

The Continental and Pinaleno soils have been discussed in this paper in conjunction with previously described soil associations.

The Cave soils may be found on the rounded ridges and edges of terraces and on remnants of dissected terraces. These soils are well-drained and are light brown to pinkish gray. They have a gravelly sandy loam surface layer and gravelly loam underlying material. These soils are less than 20 inches deep over strongly cemented layers of lime and are calcareous throughout. The available moisture-holding capacity above these cemented layers is very low.

The soils of this association are used for grazing, wildlife, and water supply. Grazing is fair on the areas of Continental and Pinaleno soils that have little brush, being better near the mountains than near the river. Drinking water is available for cattle most of the year. Deer, rabbits, and small game birds generally live near the drainageways (30).

Graham Association

This association consists of gently sloping to steeply sloping soils on long, narrow, rounded ridgetops and the sides of deep canyons on the eastern part of the Gila Mountains. Slopes range from 2 to 40 percent. Elevations range from 3600 to 4500 feet, and the average annual rainfall is approximately 11 inches. The vegetation is primarily tobosa, side-oats grama, three-awn, paloverde, ocotillo, snakeweed, and cactus, but Mormon tea, hauhillo, and a few junipers grow on the north-facing slopes. This association makes up about 2 percent of the Safford Valley.

Graham soils make up about 60 percent of the association. The remaining 40 percent consists of bare rock, very shallow soils, on steep mountaintops and side slopes, and areas of talus.

The Graham soils are mainly on the sides and tops of mountains. These soils are shallow, well-drained, and dark reddish brown. They commonly have a very cobbly clay loam surface layer and a gravelly clay subsoil. Graham soils are formed from weathered basalt and are 12 to 20 inches deep to bedrock. The available moisture-holding capacity above the bedrock is very low. Rock crops out along the ridge tops and on steep side slopes.

The soils in this association are used for desert range, wildlife and water supply. The grasses provide good grazing for cattle, and drinking water is available most of the year from ponds built on the bottom of canyons. Much of the runoff from precipitation flows into sandy drainageways with high infiltration capacities and recharges the groundwater (30).

Soil-Water Relationships

Irrigation water can be used to remove excess soluble salts from soils by leaching. If the soils are flooded, the water will dissolve the salt and carry it beyond the depth penetrated by roots. Approximately 50 percent of the soluble salts can be leached out of a soil by applying 6 inches of water for each foot of soil depth. If 12 inches of water is applied, about 80 percent of salt can be removed. More water is required if flooding is not used. Removing salts from all irrigated soils in the Safford Valley should be fairly simple, but removal is less simple from the Continental and Pinaleno soils.

Irrigation water can be used to remove sodium and excess soluble salts from saline-alkali soils by leaching. In many soils, leaching with saline water gives best results because the saline water flocculates the soil material and makes it more permeable (30). If the saline water contains more than 50 percent calcium, the calcium replaces sodium in the soil. After several successive leachings with saline water, the saline-alkali soils are suitable for farming. The permeability will also be retained. Removal of sodium will improve if the content of salt in the water is reduced in each successive leaching. In some soils, gypsum or some other soil amendment may be needed to supply calcium to replace the sodium that is removed. This need for a soil amendment and the kind and amount is unique to each situation (30).

STRUCTURAL CHARACTERISTICS OF THE AQUIFER SYSTEMS

ARTESIAN AQUIFER CHARACTERISTICS

Recharge of the Artesian Aquifer

Recharge of the artesian aquifer consists primarily of water infiltrating or flowing onto the marginal alluvial deposits, orange silt, and conglomerate deposits which overlie and grade into the basal conglomerate facies. Water flows onto these deposits as runoff resulting from storms over the surrounding mountains. Precipitation onto small drainage areas collects and percolates toward the valley center, crossing the porous and permeable deposits marginal to the mountain fronts. Some of the larger channels which drain the Gila Mountains, to the northeast of the basin, have been backfilled with coarse sediments. Recharge into these sediments flows through them and into the basal conglomerate by way of the coarse marginal deposits.

The July 1969 and Jule 1972 Water Table Maps show regions which are apparent recharge areas to the irrigation aquifer. These zones are in association with drainageways from both mountain ranges in the area. Water from these drainages to the irrigation aquifer must pass over the exposed margins of the basal conglomerate facies, as shown by the valley cross-sections. Water enters the facies under gravitational forces.

The sediments in the Safford Valley are saturated to the level of the lowest parts (44). This is to say, the extent of the lower aquifer system is to the basement complex interface, as determined by the gravity study. New supplies of water, during periods of high precipitation pour into the valley and percolate into the gravelly parts of the stream-built slopes. The water beneath the slopes has accumulated until it stands above the level of the central flats of the valley, and consequently migrates toward the low areas, where it may reappear in the form of springs and evaporate. In the upper parts of the slopes the valley fill consists largely of gravel, but farther down in the valley the gravel gives way to alternating beds of clay, sand, and evaporites (as indicated in the valley cross-sections). Beneath the center of the valley these beds are nearly level, but beneath the slopes they curve upward (44). The gravel and sand are porous and therefore allow the percolation of water. but the clay is so impermeable that it can be considered water-tight. The water which sinks into the gravel in the upper parts of the slopes and tunnels toward the central axis becomes confined below the layers of clay, and the water which accumulates back of it places it under pressure. This pressure may become so great that when the clay layers are punctured by drilling the confined water will escape into the surficial. The water from this aquifer, usually of poorer quality than that of the irrigation aquifer, may escape in natural flaws in the clay confining beds. Pumping, releasing confining pressure of the surface beds, may stimulate such escape.

Gravity Survey

A gravity survey was conducted by the students of the Hydrology Summer Field Camp from July 6 to 12, 1972, using a Worden "Educator" gravimeter loaned by the Geophysics Laboratory of the University of Arizona. This data (80) with the data of the prior year (79) and supplemental data from the Geologic Survey (21) were used in this aspect of the investigation.

Principals and Applications of Gravity Methods

Newton's law of gravity and Newton's second law of motion (with the density-mass-volume relationship) yield the expressions:

$$g = G \frac{DV}{r^2} \qquad [1]$$

Gravitational acceleration g is directly proportional to the density D and the volume V of the mass (earth materials beneath the gravimeter) and inversely proportional to the square of the distance from the attractive body. Modern gravimeters, such as the Worden, do not measure absolute values of gravity but differences in gravity from a standard or base station, such as the Safford Airport which was used in this study. In this way local differences in gravity may be determined, as are local differences in density and thus local differences in structure (60).

In the base of this survey the structure sought is the interface between the igneous bedrock and the alluvial fill of the valley. The location and configuration of this basement complex is indicated by the reduced gravity observations expressed as gravity anomalies. This interface is believed to be the lower limit of the artesian aquifer system in the valley; although the gravity determinations are not able to determine the actual presence of water, but only the presence of those structures that may control water (such as the interface).

Reduction of Gravity Data

For gravity data to be the most useful, the values of observed gravity should be corrected for station elevation, latitude, and influence of nearby topography.

The elevation correction contains two parts -- the free air correction, and the Bouguer correction. Equation [1] indicates that gravity is inversely proportional to the distance from a datum. The free air correction reduces all data to a datum, sea level as a convention, to make all data points comparable in elevation and leaving gravitational differences caused only by the physical characteristics of the observation station. The free air correction for a sea level datum is -0.09406 mgal/ft. A gal is the unit in which the acceleration of gravity is represented in gravity studies and is equivalent to one cm per second per second. The Bouguer reduction compensates for the rock between the station and the datum which increases the value of gravity by an amount proportional to both the altitude of the station from the datum and the density of the rock between the station and the datum. Essentially, the Bouguer reduction removes the gravitational effect of a flat, infinite slab of rock of the thickness equal to the elevation of the station above the sea level datum with a given density. This density is determined by convention to be 2.67 gm/cm^3, which is the average crustal density for the earth. The Bouguer corection using this density is +0.034 mgal/ft. The combined term or elevation correction is -0.060 mgal/ft using the above indicated assumptions while the expression for the general case is:

$$g_0 = g + H\ (0.09406 - 0.01273D)\ \text{mgal} \qquad [2]$$

The corrected gravity g_0 is a function of the observed gravity g, elevation H and the density of the rock beneath the station D.

The observed gravity is also a function of latitude since the earth is not a perfect sphere (7). The compensation for the ellipsoidal (or geoidal) shape of the earth is available from tables for hundredths of minutes of latitude. With the latitude correction the data is reduced to a sphere at sea level, leaving all gravity anomalies due to regional and local features (60).

In the case of the Safford Valley gravity survey no topographic correction was made since it was felt that the influence of topography in the region was homogeneous and not sufficent to change hydrologic interpretations of the results. Geodetic studies would require such a correction in this area.

Geologic Interpretation of Gravity Data

The reduced data, now representing anomalous gravity conditions, is presented in the Bouguer Gravity Anomaly Map. A selected 214 stations are plotted and contoured. The contours, although in milligals, may be interpreted as representing the alluvium-basement interface in configuration, if not in magnitude. The values are all negative, indicating that the gravity in the area is less than the value for a theoretically homogeneous and spherical earth (as it is in all continental areas). The smaller the value, the deeper the bedrock.

The Bouguer Gravity Anomaly Map indicates a long narrow trough trending N 45° W along the southwestern side of the valley and parallel to it. The contours on the southern side of the trough are generally more closely spaced than on the northern side. This would indicate that the basement on the southern side slopes more steeply than on the northern. This trough may be interpreted to be the contact between the Pinaleno and Gila basement complexes. This interpretation is supported by the surficial slopes of these complexes; the slope of the Pinaleno Mountains is comparably steep and the slope of the Gila Mountains is similarly gradual, as indicated in topographic maps of the area.

The west limb of the valley has this trough as the dominant feature, and is gradually sloping and relatively shallow in the remainder of the limb to the north of the trough. There is a small mound of approximately four square miles in surface area to the north of the trough which could indicate the absence of the artesian aquifer system at this point.

The east limb of the valley is underlain by bedrock at a much shallower depth. As the Gila River enters the valley at the gorge on the eastern side it lies directly on bedrock, when then slopes gradually; downward to the west. There is a small low on the north side of this limb, covering approximately six square miles.

To determine the actual configuration and depth to the basement complex in the valley a computer model (74) was used to construct cross-sectional profiles along the lines indicated on the Bouguer Gravity Anomaly Map. The model, written by Robert West of the Geophysics Laboratory at the University of Arizona, calculates elevation of bedrock from sea level (Z1) in alluvial fill basins. The model was used for a two phase valley, with one density for the alluvium and one for the bedrock. The difference between the densities of the bedrock and the alluvium (D1) was taken to be -0.30 gm/cm^3, a typical value for basin and range province valleys. The program requires an additional reduction in the removal of regional anomalies, with the values 0.21, 0.16 and 0.40 mgal/mile calculated to be the regional trends for the A, B and C profiles, respectively. This correction leaves only local features apparent in the data. The program is iterative in approximating the interface location and five iterations were considered sufficient to determine the location of bedrock with sufficient accuracy for this study. The residual gravity value RESID is also an indication of the extent of convergence of the iterative calculations, and a value of 0.50 was recommended by the author of the program for this variable. The location of the interface indicated by the program for stations with RESID values greater than 0.50 should not be considered as accurate to more than 10 percent. In the program on the following pages, ZT is the elevation from sea level of the station located XP feet northward along the profile from the first station.

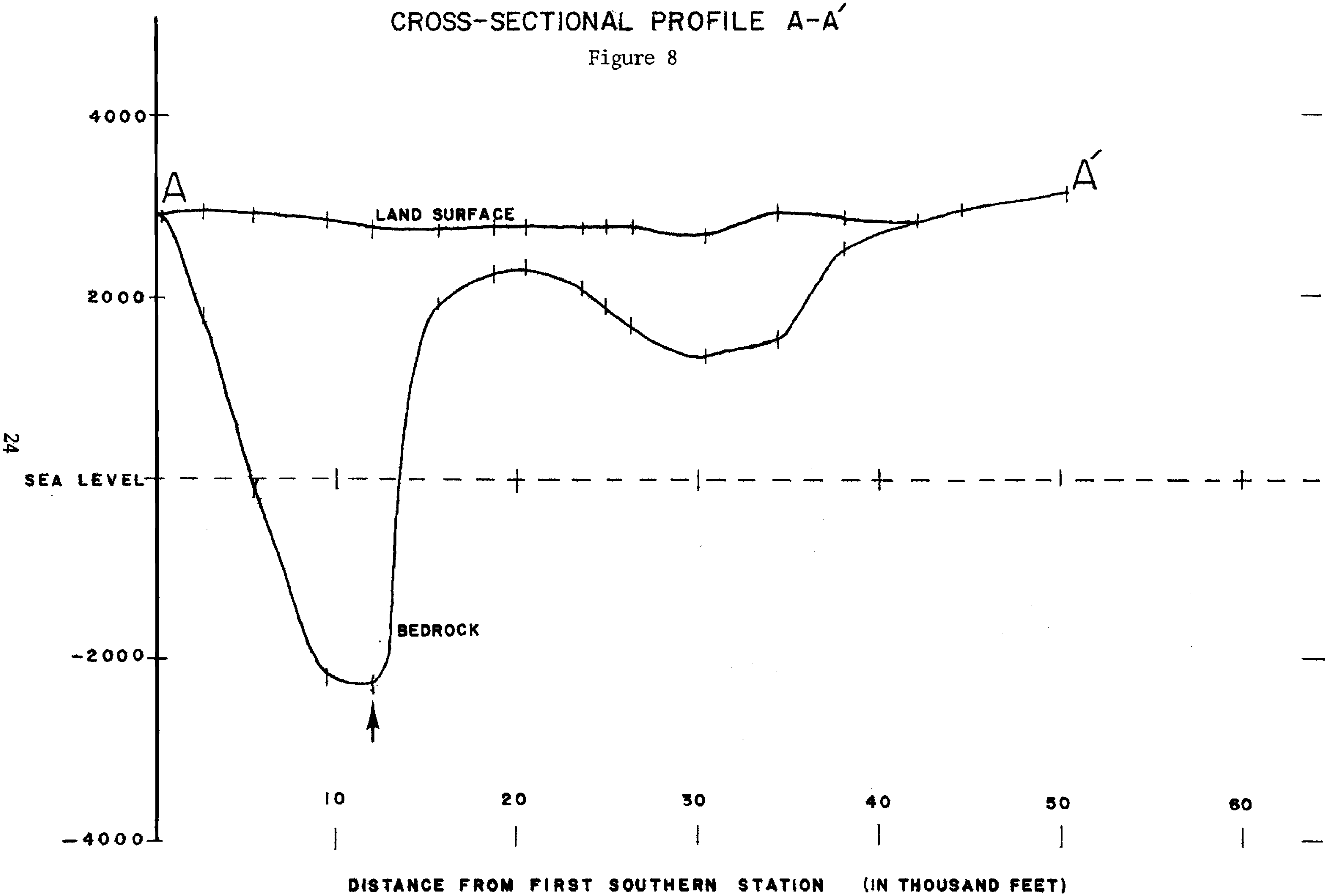
Profile A-A'. The A-A' profile trends N 37° E and passes through the northern end of the west limb of the valley. The line has 16 stations and is 50,100 feet in length. The RESID values of this cross-section are all acceptable. The line intersects the prominent trough on the southern end and then a small mound at approximately the center of the cross-section. Both these features are reflected in the profile (Figure 8). The mound is a local feature and should not be considered pervasive. The deepest point along this section is 5219 feet below the land surface. The previous iterations show the values increasing, so this depth can be considered a minimum. The configuration of the trough, and possibly the rather steep drop on the northern side could be indicative of fault scarps paralleling the valley along its sides. A much more detailed gravity survey is required to determine the presence of faults at these locations.

Profile B-B'. The B-B' profile trends N 37° E, parallel to the A-A' profile, and passes through the town of Thatcher. The line has 19 stations and is 63,750 feet in length. The fifth point from the southern end is the only point with a RESID value greater than 0.50 and the Z1 value is believed to be high, as indicated from the trend of the prior iterations (not presented in the paper). The profile (Figure 9) indicates this station to be the deepest point along this section, being a minimum of 5235 feet below the surface (or at least 2005 feet below sea level). This depth is extremely similar to the depth found in profile A-A'. The trough is readily apparent, as are the previously mentioned slopes of the basement complexes on either side. The interface on the southern side seems to be smooth while that on the northern seems to have fluctuations up to 1600 feet in 6000 feet horizontal distance.

Profile C-C'. The C-C' profile trends N 37° W and passes through the east limb of the valley. The line has 10 stations and is 31,600 feet in length. The seventh and eighth points from the southern end have residual gravity (RESID) values above 0.50. The trend of the previous iterations (not presented in this paper) indicate the seventh point to be approximately 600 feet low and the eighth point to be about 900 feet high. The profile (Figure 10) reflects the gravity low through which it passes in the northern third of the cross-section. This low is though to be caused by a region of lower density rock since it is in a geologically inhomogeneous area and since known points of bedrock are nearby. A body of andesite, above the datum, which may be underlying this area (see Geologic Map), with density of 2.23 to 2.41 gm/cm^3 (60) would account for approximately 3.27 mgals or 900 feet addition to all points below the datum (60, 74). This version of the profile, as shown in the figure, indicates a shallow and fairly smooth interface.

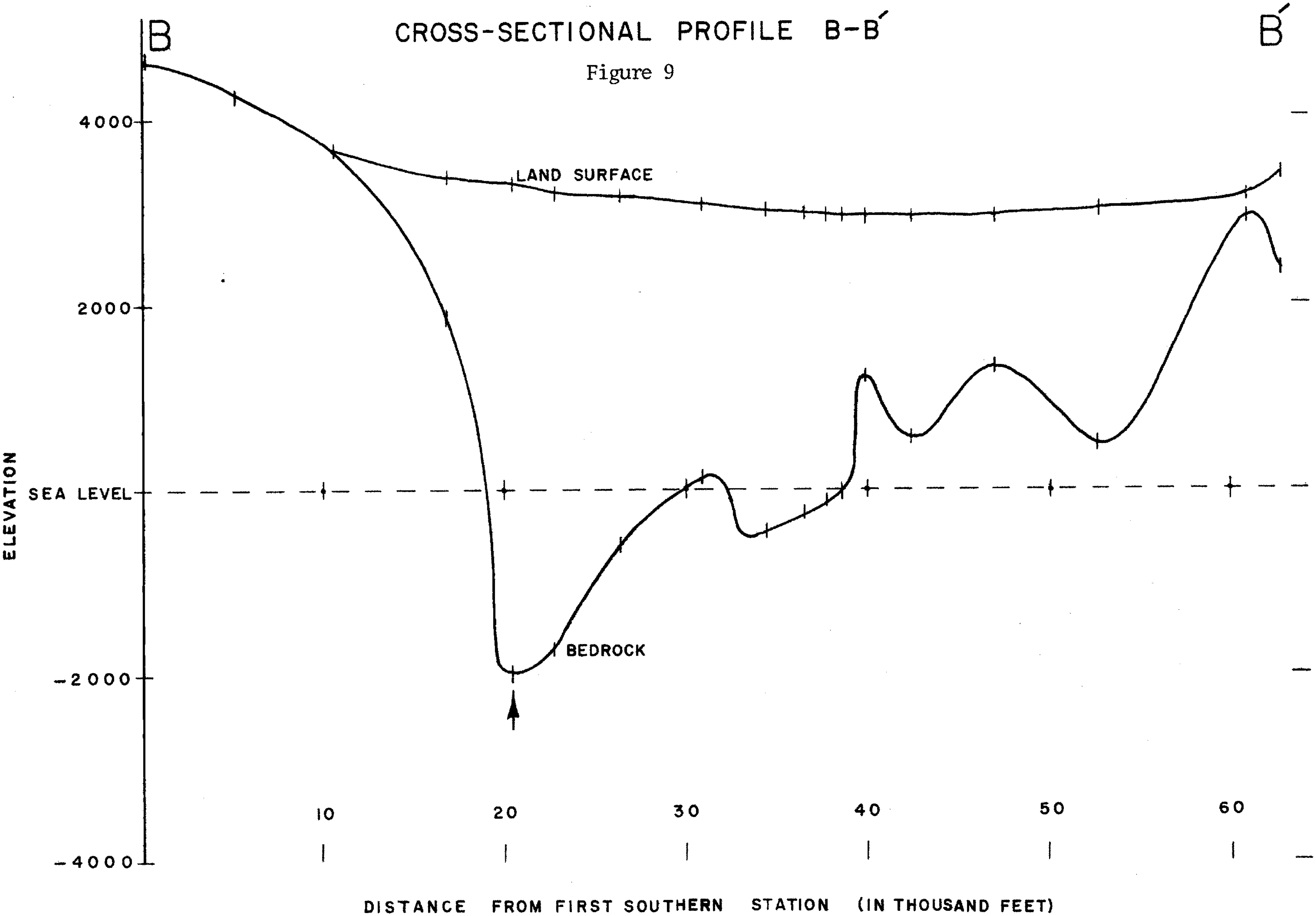
CROSS-SECTIONAL PROFILE A-A′

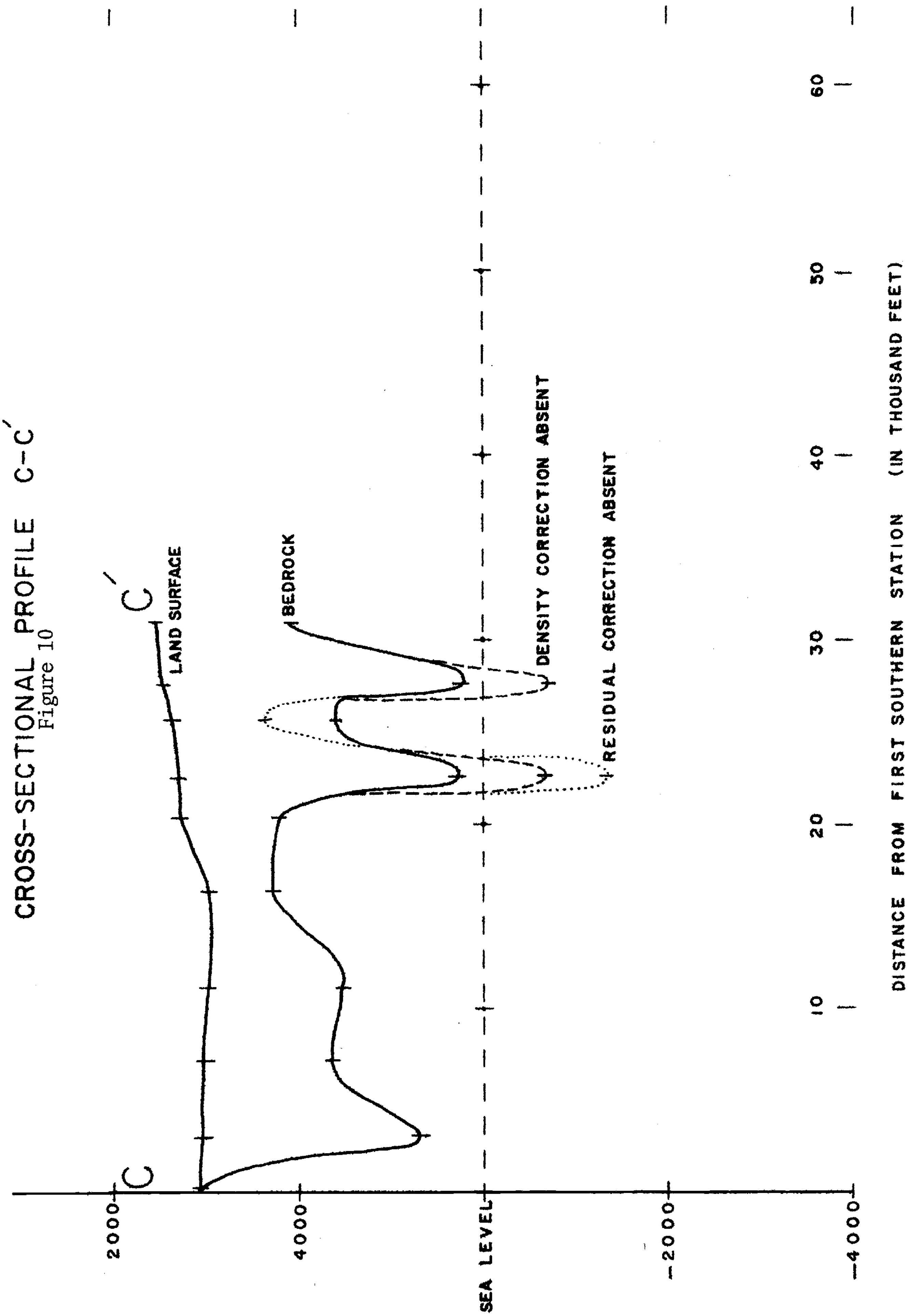
Figure 8



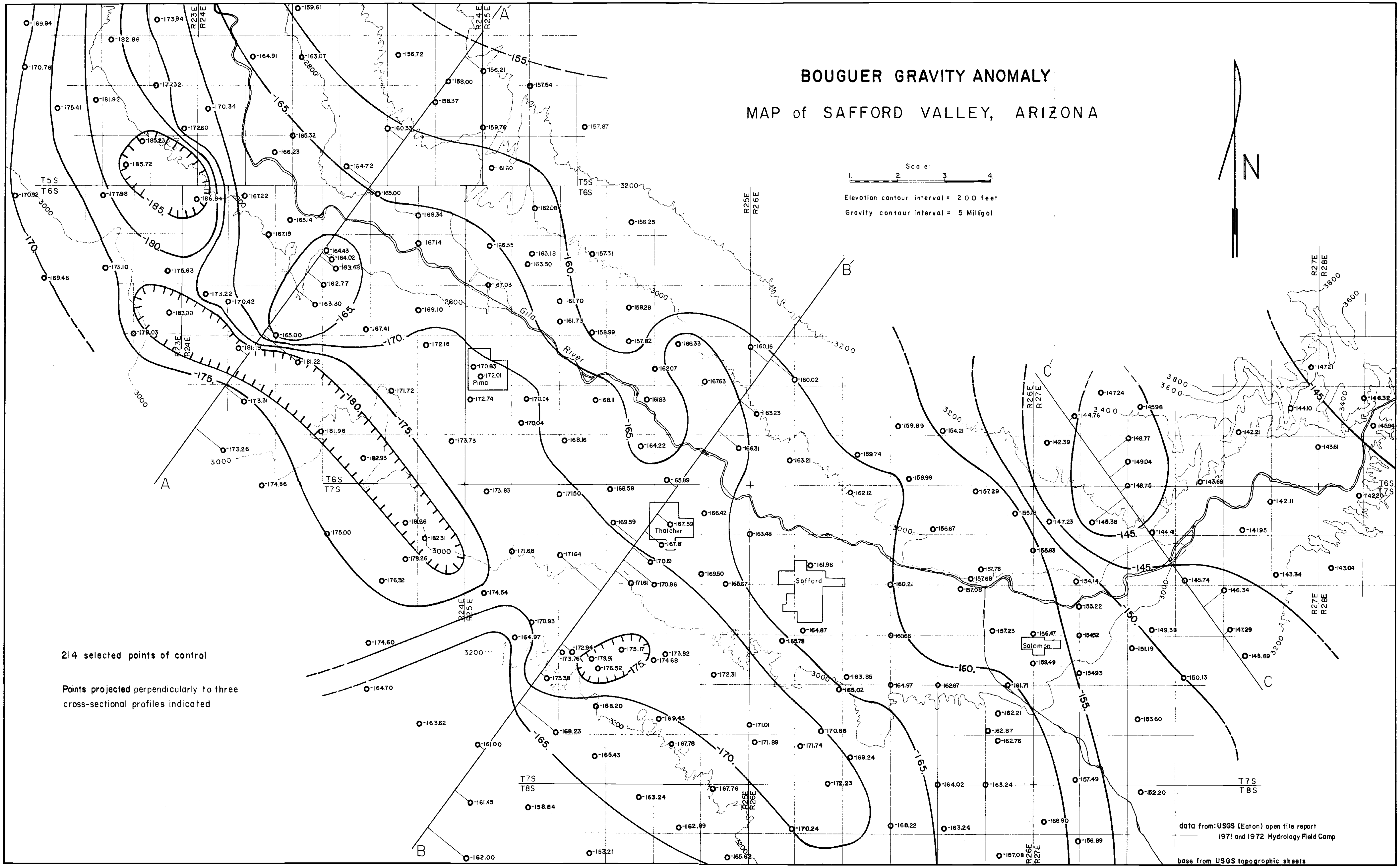
CROSS-SECTIONAL PROFILE B-B′

Figure 9





CROSS-SECTIONAL PROFILE C–C′
Figure 10


BOUGUER GRAVITY ANOMALY
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1. 2. 3. 4.
Elevation contour interval = 200 feet
Gravity contour interval = 5 Milligal
N
214 selected points of control
Points projected perpendicularly to three cross-sectional profiles indicated
data from: USGS (Eaton) open file report
1971 and 1972 Hydrology Field Camp
base from USGS topographic sheets
Gila River
Pima
Thatcher
Safford
Solomon
A
A'
B
B'
C
C'
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E

TWO DIMENSIONAL GRAVITY MODEL PROGRAM LISTING—

WITH OUTPUT FOR FIFTH ITERATION IN ALL PROFILE CALCULATIONS

```
              PROGRAM ITMODEL(INPUT,OUTPUT,TAPE1=INPUT)
        C UNIVERSITY OF ARIZONA, DEPT. OF GEOS., LAB OF GEOPHYSICS ITERATIVE TWO
        C DIMENSIONAL GRAVITY MODEL PROGRAM. WRITTEN IN FOR THE UCC CDC 6400
        C COMPUTER SYSTEM IN FORTRAN IV. THIS PROGRAM CALCULATES A MODEL FOR
        C GRAVTY DATA TAKEN OVER AN ALLUVIAL FILLED VALLEY WHEN THE TWO DIMEN.
        C ASSUMPTION HOLDS. THE MODEL IS BASED UPON THE GRAVITY EFFECT OF A TWO
        C DIMENSIONAL RECTANGULAR STRIP. WRITTEN BY R.E. WEST, MAY, 1971.
        C EACH STRIP CAN BE DIVIDED INTO AS MANY AS 4 PARTS WHICH HAVE Z COORDI.
        C AND DENSITIES FROM TOP TO BOTTOM ZT,Z1,Z2,Z3, AND ZB: D1,D2,D3, AND D4
        C THIS ALLOWS VERTICAL DENSITY VARIATION. HORIZONTAL DENSITY VARIATION
        C IS OBTAINED BY VARYING STRIP DENSITIES.XE(N) IS THE COORDI. OF THE,
        C STRIP EDGES AND XP(N) GIVES THE COORDI. OF STRIP CENTERS. GRES(N) IS
        C THE OBSERVED RESIDUAL ANOMALY AT XP(N), GCALC(N) IS THE CALCULATED
        C GRAVITY EFFECT AT XP(N), AND RESID(N)=GCALC(N)-GRES(N). ITYPE SPECIFIES
        C THE STRIP TYPE (SEE PROGRAM WRITE UP). THE RESIDUAL ANOMALY GRES(N)
        C =GO(N)-GR(N) WHERE GO(N) IS THE BOUGUER ANOMALY AT XP(N) AND GR(N) IS
        C THE REGIONAL CORRECTION AT XP(N).
000003        COMMON     XE(101),ZT(101),Z1(101),Z2(101),Z3(101),ZB(101),D1(101),
             XD2(101),D3(101),D4(101),GO(101),GR(101),ALPHA(7),XP(101),GRES(101)
             X,RESID(101),LINEC,LINELIM,I1,ITYPE(101),GCALC(101),RESLIM,LOOPLIM,
             XNLOOP
        C INITIALIZE ARRAYS TO ZERO
000003        DO  1N2=1,101
000005        XE(N2)=0.0
000006        ZT(N2)=0.0 $ GRES(N2)=0.0
000010        Z1(N2)=0.0 $ RESID(N2)=0.0
000012        Z2(N2)=0.0 $ XP(N2)=0.0
000014        Z3(N2)=0.0 $ ITYPE(N2)=0
000016        ZB(N2)=0.0 $ GCALC(N2)=0.0
000020        D1(N2)=0.0
000021        D2(N2)=0.0
000022        D3(N2)=0.0
000023        D4(N2)=0.0
000024        GO(N2)=0.0
000025        GR(N2)=0.0
000026      1 CONTINUE
        C INITIALIZE COUNTERS
000030        I1=0
000030        NLOOP=0
000031        LINEC=0
000032        LINELIM=48
000034        READ 1000,ALPHA,RESLIM,LOOPLIM
        C ALPHA=PROFILE DESIGNATION, RESLIM=RESIDUAL LIMIT IN MGAL,LOOPL1=MAX NO
        C ITERATIONS. INPUTDATA UNITS-XET-ZBT (FT). D1T-D4T (GM/CM**3), GOT-GRT
        C (MGAL). Z AXIS POSITIVE UP.
        C PRINT HEADING
000045        PRINT 4000,ALPHA,RESLIM,LOOPLIM
        C READ IN DATA AND STORE IN ARRAYS.
000057      5 READ 2000,XET,ZTT,Z1T,Z2T,Z3T,ZBT,D1T,D2T,D3T,D4T,GOT,GRT,ITYPET
000115        IF(EOF,1)4,3
000120      3 I1=I1+1
000122        XE(I1)=XET
000124        ZT(I1)=ZTT
000125        Z1(I1)=Z1T
000127        Z2(I1)=Z2T
000130        Z3(I1)=Z3T
000132        ZB(I1)=ZBT
```

```
000133          D1(I1)=-.3
000135          D2(I1)=D2T
000136          D3(I1)=D3T
000140          D4(I1)=D4T
000141          GO(I1)=GOT
000143          XX1=I1
000143          GR(I1)=GO(1) +(.210)*(XX1-1.)
000150          ITYPE(I1)=ITYPET
000152          GO TO 5
000152        4 I1=I1-1
       C THE LAST CARD CONTAINS ONLY XET OF THE LAST RECTANGLE EDGE. I1 IS THE
       C NO. OF COMPOSITE RECTANGES IF STRIPS.
       C CALCULATE STRIP CENTER POINTS XP(I) AND STORE
000154          DO  6N3=1,I1
000155          N4=N3+1
000156          XP(N3)=( XE(N4)- XE(N3))/2.0 +  XE(N3)
000163        6 CONTINUE
       C CALCULATE RESIDUAL ANOMALIES AND STORE GRES(N)
000166          DO  7N5=1,I1
000167          GRES(N5)=GO(N5)-GR(N5)
000171        7 CONTINUE
       C CALCULATE RESIDUALS RESID(N) AND STORE DATA.
000174        8 DO  9N6=1,I1
000176          RESID(N6)=GCALC(N6)-GRES(N6)
000200        9 CONTINUE
       C CHECK EACH RESID(N) TO SEE IF IT IS LESS THAN RESLIM
000203          NRES=0
000204          DO  10N7=1,I1
000205          XTEMP=RESID(N7) $ TEMP1=ABS(XTEMP)
000210          IF(TEMP1.LT.RESLIM)10,11
000216       11 NRES=NRES+1
000220       10 CONTINUE
000223          IF(NRES .EQ.0)13,16
000227       13 PRINT 3000,RESLIM,NLOOP
000237          LINEC=LINEC+2
000241          IF(LINEC.GE.LINELIM)14,15
000246       14 PRINT 4000,ALPHA,RESLIM,LOOPLIM
000260          LINEC=0
000261       15 CALL PRINTIT
000262          STOP
       C CHECK TO SEE IF NLOOP EQUAL TO LOOPLIM
000264       16 IF(NLOOP.GE.LOOPLIM)17,20
000271       17 PRINT 5000,RESLIM,LOOPLIM
000301          LINEC=LINEC+2
000303          IF(LINEC.GE.LINELIM)18,19
000310       18 PRINT 4000,ALPHA,RESLIM,LOOPLIM
000322          LINEC=0
000323       19 CALL PRINTIT
000324          STOP
       C PRINT RESULTS FOR EACH ITERATION.
000326       20 IF(NLOOP.EQ.0)99,100
000332      100 PRINT 6000,NLOOP
000340          LINEC=LINEC+1
000342          IF(LINEC.GE.LINELIM)101,102
000347      101 PRINT 4000,ALPHA,RESLIM,LOOPLIM
000361          LINEC=0
000362      102 CALL PRINTIT
       C ADJUST MODEL. VALUE  OF ZT,Z1,Z2,Z3,OR Z4  IS ADJUSTED DEPENDING UPON
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```
        C VALUE OF ITYPE (SEE PROGRAM WRITE UP).
000363     99 N8=0
000364     21 N8=N8+1
000366        IF(N8.GT.I1)GO TO 26
000371        NTYPE=ITYPE(N8)
000372        GO TO(21,22,21,23,21,24,21,25,21),NTYPE
000406     22 Z1(N8)=Z1(N8)+RESID(N8)/(.01277382*D1(N8))
000413        IF(Z1(N8).GE.ZT(N8))Z1(N8)=ZT(N8)
000417        GO TO 21
000420     23 Z2(N8)=Z2(N8)+RESID(N8)/(.01277382*D2(N8))
000425        IF(Z2(N8).GE.Z1(N8))Z2(N8)=Z1(N8)
000431        GO TO 21
000432     24 Z3(N8)=Z3(N8)+RESID(N8)/(.01277382*D3(N8))
000437        IF(Z3(N8).GE.Z2(N8))Z3(N8)=Z2(N8)
000443        GO TO 21
000444     25 ZB(N8)=ZB(N8)+RESID(N8)/(.01277382*D4(N8))
000451        IF(ZB(N8).GE.Z3(N8))ZB(N8)=Z3(N8)
000455        GO TO 21
        C CALCULATE GRAVITY EFFECT OF ADJUSTED MODEL AT EACH XP(N). VALUES OF XA,
        C XB,ZA,AND ZC THAT ARE CALCULATED DEPEND UPON THE VALUE OF ITYPE
        C (SEE PROGRAM WRITE UP).
000456     26 DO  27J=1,I1
000460        GSUM=0.0
000461        DO  28K=1,I1
000463        IF(ITYPE(K).EQ.1)28,29
000470     29 XA=XP(J)-XE(K)
000473        XB=XP(J)-XE(K+1)
000475        ZA=ZT(J)-ZT(K)
000477        ZC=ZT(J)-Z1(K)
000501        DEN1=D1(K)
000502        GSUM=GSUM+GI(DEN1,XA,XB,ZA,ZC)
000510        IF(ITYPE(K).EQ.2.OR.ITYPE(K).EQ.3)28,30
000520     30 ZA=ZC
000521        ZC=ZT(J)-Z2(K)
000524        DEN2=D2(K)
000525        GSUM=GSUM+GI(DEN2,XA,XB,ZA,ZC)
000533        IF(ITYPE(K).EQ.4.OR.ITYPE(K).EQ.5)28,31
000543     31 ZA=ZC
000544        ZC=ZT(J)-Z3(K)
000547        DEN3=D3(K)
000550        GSUM=GSUM+GI(DEN3,XA,XB,ZA,ZC)
000556        IF(ITYPE(K).EQ.6.OR.ITYPE(K).EQ.7)28,32
000566     32 ZA=ZC
000567        ZC=ZT(J)-ZB(K)
000572        DEN4=D4(K)
000573        GSUM=GSUM+GI(DEN4,XA,XB,ZA,ZC)
000601     28 CONTINUE
000604        GCALC(J)=GSUM
000606     27 CONTINUE
000610        NLOOP=NLOOP+1
000611        GO TO 8
000612   1000 FORMAT(7A10,F4.2,I4)
000612   2000 FORMAT(F10.0,5F6.0,4F5.2,2F7.3,I2)
000612   3000 FORMAT(27X,*NORMAL CONVERGENCE - ALL RESIDUALS ARE LESS THAN*,1X,
             XF4.2,*MGAL. *,I4,*ITERATIONS REQUIRED*,/)
000612   4000 FORMAT(1H1//50X,*---TWO DIMENSIONAL GRAVITY MODEL---*,/10X,7A10,5X
             X,*RESLIM=*,F4.2,*MGAL    LOOPLIM=*,I4,*ITERATIONS*//)
000612   5000 FORMAT(15X, *MODEL DOES NOT CONVERGE - AT LEAST ONE RESIDUAL WAS
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              XGREATER THAN *,F4.2,*MGAL WHEN *,I4,*ITERATIONS WERE COMPLETED.*./
              X)
000612   6000 FORMAT(53X,*RESULTS FOR ITERATION NO.*,I4,/)
000612        END


              SUBROUTINE PRINTIT
        C THIS SUBROUTINE PRINTS OUT ALL RESULTS WHEN IT IS CALLED
000002        COMMON    XE(101),ZT(101),Z1(101),Z2(101),Z3(101),ZB(101),D1(101),
             XD2(101),D3(101),D4(101),GO(101),GR(101),ALPHA(7),XP(101),GRES(101)
             X,RESID(101),LINEC,LINELIM,I1,ITYPE(101),GCALC(101),RESLIM,LOOPLIM,
             XNLOOP
000002        N1=0
000003        N2=0
000004      1 N1=N1+1
000006        N2=N1+1
000007        PRINT 1000,XP(N1),XE(N1),XE(N2),ZT(N1),Z1(N1),Z2(N1),Z3(N1),ZB(N1)
             X,D1(N1),D2(N1),D3(N1),D4(N1),GCALC(N1),GRES(N1),RESID(N1),ITYPE(N1
             X)
000072        LINEC=LINEC+5
000074        IF (LINEC.GE.LINELIM)2,3
000101      2 PRINT 2000,ALPHA,RESLIM,LOOPLIM
000113        LINEC=0
000114      3 IF(N1.GE.I1)4,5
000121      4 RETURN
000122      5 GO TO 1
000123   1000 FORMAT(10X,*XP=*,F11.3,5X,*XE1=*,F11.3,5X,*XE2=*,F11.3,/10X,*ZT=*,
             XF7.0,5X,*Z1=*,F7.0,5X,*Z2=*,F7.0,5X,*Z3=*,F7.0,5X,*ZB=*,F7.0,/10X,
             X*D1=*,F6.2,5X,*D2=*,F6.2, 5X,*D3=*,F6.2,5X,*D4=*,F6.2,/10X,*GCALC=
             X*,F8.3,5X,*GRES=*,F8.3,5X,*RESID=*,F8.3,5X,*ITYPE=*,I2,/)
000123   2000 FORMAT(1H1//50X,*---TWO DIMENSIONAL GRAVITY MODEL---*,/10X,7A10,5X
             X,*RESLIM=*,F4.2,*MGAL    LOOPLIM=*,I4,*ITERATIONS*//)
000123        END


              FUNCTION GI(D,X1,X2,Z1,Z2)
        C THIS FUNCTION CALCULATES GI THE GRAVITY EFFECT OF AN INDIVIDUAL
        C RECTANGULAR STRIP. X1 AND X2 ARE THE HORIZONTAL DISTANCES OF THE
        C OBSERVER FROM THE EDGES OF THE RECTANGLE. AND Z1 AND Z2 ARE THE
        C VERTICAL DISTANCES OF THE OBSERVER FROM THE UPPER AND LOWER EDGES
        C RESPECTIVELY. D IS THE DENSITY CONSRAST.
000010        A1=Z2*Z2+X1*X1
000012        A2=Z1*Z1+X1*X1
000014        A3=(A1/A2)**0.5
000020        A4=ALOG(A3)*X1
000026        B1=Z2*Z2+X2*X2
000030        B2=Z1*Z1+X2*X2
000032        B3=(B1/B2)**0.5
000037        B4=ALOG(B3)*X2
000045        C1=Z2*(ATAN2(X1,Z2)-ATAN2(X2,Z2))
000051        D1=Z1*(ATAN2(X1,Z1)-ATAN2(X2,Z1))
000075        GI=.004066032*D*(A4-B4+C1-D1)
000103        RETURN
000104        END
```

```
                                        ---TWO DIMENSIONAL GRAVITY MODEL---
TWO DIMENSIONAL GRAVITY MODEL OF THE SAFFORD VALLEY...PROFILE A-A'          RESLIM= .50MGAL    LOOPLIM=   5ITERATIONS

    MODEL DOES NOT CONVERGE - AT LEAST ONE RESIDUAL WAS  GREATER THAN  .50MGAL WHEN    5ITERATIONS WERE COMPLETED.

XP=      0.000      XE1=  -2840.000      XE2=   2840.000
ZT=    2970      Z1=    2970       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -9.853      GRES=    0.000     RESID=  -9.853     ITYPE= 2

XP=   5320.000      XE1=   2840.000      XE2=   7800.000
ZT=    2920      Z1=     -70       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -11.468      GRES=   -.269     RESID= -11.199     ITYPE= 2

XP=   9700.000      XE1=   7800.000      XE2=  11600.000
ZT=    2900      Z1=   -2184       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -12.491      GRES=  -8.368     RESID=  -4.123     ITYPE= 2

XP=  12250.000      XE1=  11600.000      XE2=  12900.000
ZT=    2870      Z1=   -2249       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -10.447      GRES=  -8.617     RESID=  -1.830     ITYPE= 2

XP=  14350.000      XE1=  12900.000      XE2=  15800.000
ZT=    2660      Z1=    1927       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -6.179      GRES=   7.384     RESID= -13.563     ITYPE= 2

XP=  17700.000      XE1=  15800.000      XE2=  19600.000
ZT=    2810      Z1=    2313       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -3.559      GRES=   8.865     RESID= -12.424     ITYPE= 2

XP=  20900.000      XE1=  19600.000      XE2=  22200.000
ZT=    2800      Z1=    2394       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -2.659      GRES=   9.176     RESID= -11.835     ITYPE= 2

XP=  22700.000      XE1=  22200.000      XE2=  23200.000
ZT=    2800      Z1=    2100       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -3.330      GRES=   8.047     RESID= -11.377     ITYPE= 2

XP=  23450.000      XE1=  23200.000      XE2=  23700.000
ZT=    2800      Z1=    1951       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -3.686      GRES=   7.478     RESID= -11.164     ITYPE= 2

XP=  25950.000      XE1=  23700.000      XE2=  28200.000
ZT=    2800      Z1=    1790       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.30      D3= -0.00      D4= -0.00
GCALC=  -4.124      GRES=   6.859     RESID= -10.983     ITYPE= 2
```

```
                                    ---TWO DIMENSIONAL GRAVITY MODEL---
TWO DIMENSIONAL GRAVITY MODEL OF THE SAFFORD VALLEY...PROFILE A-A'          RESLIM= .50MGAL    LOOPLIM=    5ITERATIONS

XP=  30300.000      XE1=  28200.000      XE2=  32400.000
ZT=   2770      Z1=   1584      Z2=      -0     Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -4.441      GRES=   6.070      RESID= -10.511      ITYPE= 2

XP=  33900.000      XE1=  32400.000      XE2=  35400.000
ZT=   2785      Z1=   1600      Z2=      -0     Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -4.120      GRES=   6.131      RESID= -10.251      ITYPE= 2

XP=  38250.000      XE1=  35400.000      XE2=  41100.000
ZT=   2960      Z1=   2688      Z2=      -0     Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -1.464      GRES=  10.302      RESID= -11.766      ITYPE= 2

XP=  43100.000      XE1=  41100.000      XE2=  45100.000
ZT=   3020      Z1=   3020      Z2=      -0     Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=   -.236      GRES=  12.043      RESID= -12.279      ITYPE= 2

XP=  46850.000      XE1=  45100.000      XE2=  48600.000
ZT=   3040      Z1=   3040      Z2=      -0     Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=   -.158      GRES=  12.194      RESID= -12.352      ITYPE= 2

XP=  50100.000      XE1=  48600.000      XE2=  51600.000
ZT=   3170      Z1=   3170      Z2=      -0     Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=   -.136      GRES=  13.765      RESID= -13.901      ITYPE= 2
```

```
---TWO DIMENSIONAL GRAVITY MODEL---
TWO DIMENSIONAL GRAVITY MODEL OF THE SAFFORD VALLEY...PROFILE B-B'          RESLIM= .50MGAL   LOOPLIM=   5ITERATIONS

     MODEL DOES NOT CONVERGE - AT LEAST ONE RESIDUAL WAS  GREATER THAN  .50MGAL WHEN    5ITERATIONS WERE COMPLETED.

XP=       0.000     XE1=  -2480.000     XE2=   2480.000
ZT=   4640     Z1=   4640      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00     D3= -0.00     D4= -0.00
GCALC=    -.522     GRES=   0.000     RESID=    -.522     ITYPE= 2

XP=   4985.000     XE1=   2480.000     XE2=   7490.000
ZT=   4240     Z1=   4240      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00     D3= -0.00     D4= -0.00
GCALC=    -.721     GRES=    .331     RESID=   -1.052     ITYPE= 2

XP=  10560.000     XE1=   7490.000     XE2=  13630.000
ZT=   3600     Z1=   3600      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00     D3= -0.00     D4= -0.00
GCALC=   -1.208     GRES=    .562     RESID=   -1.770     ITYPE= 2

XP=  16900.000     XE1=  13630.000     XE2=  20170.000
ZT=   3320     Z1=   1966      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00     D3= -0.00     D4= -0.00
GCALC=   -7.037     GRES=   -6.887     RESID=    -.150     ITYPE= 2
```

Profile B-B'

Continued On Next Page

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                                  ---TWO DIMENSIONAL GRAVITY MODEL---
TWO DIMENSIONAL GRAVITY MODEL OF THE SAFFORD VALLEY...PROFILE B-B'        RESLIM= .50MGAL   LOOPLIM=   5ITERATIONS

XP=  20800.000     XE1=  20170.000      XE2=  21430.000
ZT=   3230      Z1=   -2005      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -10.989     GRES= -12.256     RESID=    1.267     ITYPE= 2          <--

XP=  22915.000     XE1=  21430.000      XE2=  24400.000
ZT=   3130      Z1=   -1655      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -12.476     GRES= -12.855     RESID=     .379     ITYPE= 2

XP=  26400.000     XE1=  24400.000      XE2=  28400.000
ZT=   3120      Z1=    -486      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -12.490     GRES= -12.254     RESID=    -.236     ITYPE= 2

XP=  30800.000     XE1=  28400.000      XE2=  33200.000
ZT=   3050      Z1=     186      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -11.366     GRES= -11.173     RESID=    -.193     ITYPE= 2

XP=  34350.000     XE1=  33200.000      XE2=  35500.000
ZT=   3000      Z1=    -498      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -11.172     GRES= -11.362     RESID=     .190     ITYPE= 2

XP=  36350.000     XE1=  35500.000      XE2=  37200.000
ZT=   2980      Z1=    -255      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -10.792     GRES= -10.831     RESID=     .039     ITYPE= 2

XP=  37700.000     XE1=  37200.000      XE2=  38200.000
ZT=   2960      Z1=    -186      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC= -10.203     GRES= -10.380     RESID=     .177     ITYPE= 2

XP=  38600.000     XE1=  38200.000      XE2=  39000.000
ZT=   2940      Z1=    -147      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -9.629     GRES=  -9.999     RESID=     .370     ITYPE= 2

XP=  40050.000     XE1=  39000.000      XE2=  41100.000
ZT=   2920      Z1=    1200      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -8.771     GRES=  -8.438     RESID=    -.333     ITYPE= 2

XP=  42450.000     XE1=  41100.000      XE2=  43800.000
ZT=   2920      Z1=     541      Z2=      -0      Z3=      -0      ZB=      -0
D1=  -.30      D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -8.273     GRES=  -8.437     RESID=     .164     ITYPE= 2
```

---TWO DIMENSIONAL GRAVITY MODEL---

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TWO DIMENSIONAL GRAVITY MODEL OF THE SAFFORD VALLEY...PROFILE B-B'          RESLIM= .50MGAL   LOOPLIM=   5ITERATIONS

XP=  46850.000      XE1=  43800.000      XE2=  49900.000
ZT=   2915      Z1=   1290       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -6.975      GRES=  -6.956      RESID=    -.019     ITYPE= 2

XP=  52700.000      XE1=  49900.000      XE2=  55500.000
ZT=   2870      Z1=    529       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -7.586      GRES=  -7.595      RESID=     .009     ITYPE= 2

XP=  57050.000      XE1=  55500.000      XE2=  58600.000
ZT=   3080      Z1=   2124       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -4.787      GRES=  -4.734      RESID=    -.053     ITYPE= 2

XP=  61000.000      XE1=  58600.000      XE2=  63400.000
ZT=   3200      Z1=   2933       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -1.856      GRES=  -1.883      RESID=     .027     ITYPE= 2

XP= -63750.000      XE1=  63400.000      XE2=  64100.000
ZT=   3210      Z1=   2140       Z2=       -0       Z3=      -0      ZB=      -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -2.419      GRES=  -1.962      RESID=    -.457     ITYPE= 2
```

```
                              ---TWO DIMENSIONAL GRAVITY MODEL---
TWO DIMENSIONAL GRAVITY MODEL OF THE SAFFORD VALLEY...PROFILE C-C'          RESLIM= .50MGAL    LOOPLIM=    5ITERATIONS

     MODEL DOES NOT CONVERGE - AT LEAST ONE RESIDUAL WAS  GREATER THAN  .50MGAL WHEN     5ITERATIONS WERE COMPLETED.

XP=      0.000      XE1=  -1582.000      XE2=   1582.000
ZT=   3170      Z1=   3170      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -1.387      GRES=   0.000      RESID=  -1.387      ITYPE= 2

XP=   3301.000      XE1=   1582.000      XE2=   5020.000
ZT=   3140      Z1=    711      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -6.691      GRES=  -6.619      RESID=   -.072      ITYPE= 2

XP=   6810.000      XE1=   5020.000      XE2=   8600.000
ZT=   3100      Z1=   1631      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -5.968      GRES=  -5.888      RESID=   -.080      ITYPE= 2

XP=  11150.000      XE1=   8600.000      XE2=  13700.000
ZT=   3010      Z1=   1501      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -5.502      GRES=  -5.507      RESID=    .005      ITYPE= 2

XP=  16450.000      XE1=  13700.000      XE2=  19200.000
ZT=   3200      Z1=   2282      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -4.442      GRES=  -4.396      RESID=   -.046      ITYPE= 2

XP=  20550.000      XE1=  19200.000      XE2=  21900.000
ZT=   3220      Z1=   2188      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -5.870      GRES=  -5.585      RESID=   -.285      ITYPE= 2

XP=  22650.000      XE1=  21900.000      XE2=  23400.000
ZT=   3220      Z1=  -1328      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -7.385      GRES=  -9.174      RESID=   1.789      ITYPE= 2          <--

XP=  24660.000      XE1=  23400.000      XE2=  25920.000
ZT=   3270      Z1=   2354      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -7.281      GRES=  -6.683      RESID=   -.598      ITYPE= 2          <--

XP=  27610.000      XE1=  25920.000      XE2=  29300.000
ZT=   3290      Z1=   -729      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -9.071      GRES=  -9.632      RESID=    .561      ITYPE= 2

XP=  31600.000      XE1=  29300.000      XE2=  33900.000
ZT=   3370      Z1=   2049      Z2=     -0      Z3=     -0      ZB=     -0
D1=  -.30     D2= -0.00      D3= -0.00      D4= -0.00
GCALC=  -6.148      GRES=  -5.841      RESID=   -.307      ITYPE= 2
```

IRRIGATION AQUIFER CHARACTERISTICS

Central Basin Degradational Stage Deposits

Hydrologically significant layers of silt, sands, and gravels were deposited in the central and lowest part of the Safford Basin during the degradational stage of basin development. These sediments rest on the green clay facies and provide a water table aquifer which is tapped by the wells of the agricultural industry of the basin.

Well logs (44) indicate an average aquifer thickness of 50 feet throughout the valley. The sediments slope toward the northwest, as does the valley floor. In cross-section the deposits appear to lie in a trough cut into the green clay facies, and to slope gently at the surface toward the Gila River.

The central valley degradational stage deposits are composed to alluvial material derived from the upper basin fill and the upriver drainage area of the Gila River. The deposits are thickest in the valley center and thin toward the sides. Virtually every well drilled in the valley center notes the coarse texture of the deposits; terms such as "coarse sand" and "gravel" are frequent.

As an aquifer, the degradational stage deposits are ideal. Specific yield of the aquifer is calculated to be in the average range of 10 to 15 percent. In dry years, over 100,000 acre-feet of water is produced from the aquifer. Recharge to the aquifer is mainly from the channel of the Gila River, with some contributions from agricultural tailwater, deep infiltration, and basin interflow.

Recharge of Irrigation Aquifer

The porous sediments which lie upon the clay and shale confining layers of the artesian aquifer system make up the water table, or irrigation, aquifer of the valley. This lower boundary of this aquifer is usually between 200 and 300 feet from the land surface, although great variability is found throughout the valley. The confining layer is generally more shallow near Sanchez Gorge, where the Gila River enters the Safford Valley, and generally deeper downstream along the river.

Recharge of the irrigation aquifer is accomplished by infiltration from the Gila River. This type of recharge from stream or river bottoms is common in desert regions. Some recharge also occurs from groundwater flow under the short ephemeral channels which drain into the Gila River. Deep seepage from irrigation is also a recharge consideration, although the extent of such recharge is not known.

CHEMICAL CHARACTERISTICS OF THE AQUIFER SYSTEMS IN THE SAFFORD VALLEY

GENERAL DISCUSSION OF WATER CHEMISTRY

Factors in Ion Uptake by Water

In general, the three factors which determine the ionic content of water are: availability of soluble material; time of coincidence of water with this soluble material; and temperature of the system during and after coincidence. The availability and type of soluble ions varies greatly, both on a macroscopic and microscopic level. Solution of ions is a logarithmic function over time, that is, the uptake of ions over time (from a specific source) decreases with time as equilibrium is approached. The temperature of the system largely controls both the rate of solution and the equilibrium concentration of ions. As temperature increases, both the rate of solution and the capacity of the water to hold the ions in solution increase, making these terms directly proportional. In a confined (artesian) aquifer system, pressure will have a pronounced effect upon water chemistry, principally on the concentration of dissolves gasses in the water. Further discussion of the effects of pressure will be neglected since our primary interest is in the unconfined aquifer (5).

The chemical equilibrium attained by constituents in ground water also depends on the partial pressure of atmospheric constitutents, hydrogen and hydroxyl ion concentrations (pH), redox potential (Eh), and the relative concentration of the other constituents in solution in that water (12). The concentrations are dependent on the thermodynamic equilibrium constants of the specific chemical equations placing each constituent into solution. The thermodynamic equilibrium constant in turn is a function of the activity of the specific ion and the Gibbs Free Energy (F) of the equation.

General Sources of Dissolved Matter in Water

The chemical constituents of both ground water and surface water depend on the history of the geologic formations the waters pass through and exist in, as well as the chemical composition of the rocks. In volcanic rocks, for instance, the ions usually associated with the rock itself are calcium, magnesium, bicarbonate and fluoride. However, if the material has been subjected to a marine environment, high concentrations of sodium and chloride may be present. Water from igneous rocks will typically have low concentrations of these constituents due to the presence of hydrochloric and sulfuric acids, as found in volcanic rocks, for example.

Water from metamorphic and phetonic rocks is usually of good quality, except where salts may be concentrated by evaporation. Some metamorphic rocks such as marble and dolomite may contribute significantly to water hardness.

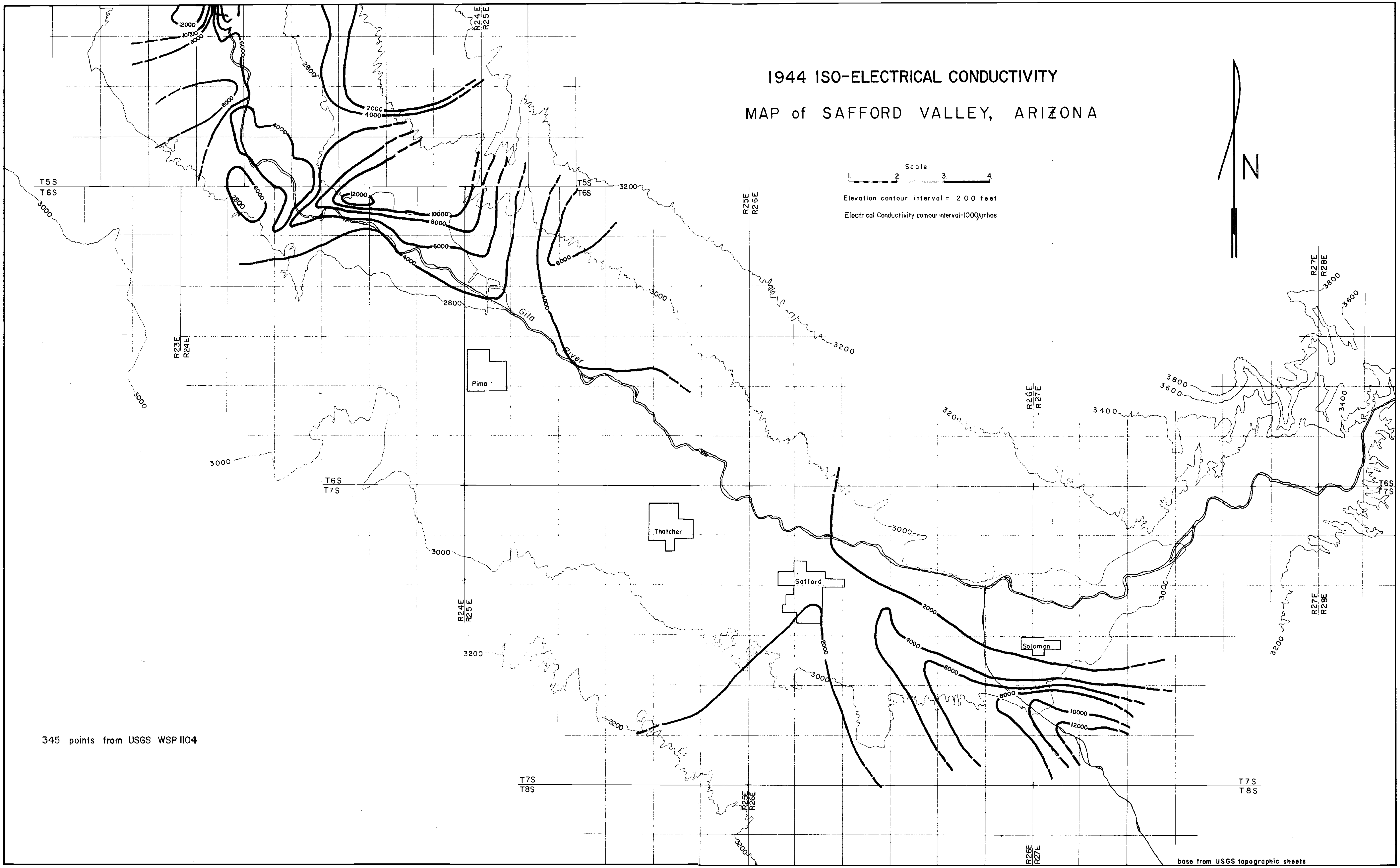
Ground water in sedimentary rocks may contain large components of sodium and chloride, but these concentrations are usually a function of depth. Older and deeper sedimentary rocks may contain a brine which runs as high as 350,000 ppm total dissolved solids (about ten times the concentration of sea water), while surficial sandstones may have at little as 100 ppm total dissolved solids.

Ground water quality in nonindurated sediments may vary greatly since the ionic constituency is controlled principally by the parent material and the geomorphology of the area. In highly developed river valleys, an additional control may be provided by the quality of the river water which provides recharge to the ground water aquifer system. In general, river valleys will have good quality water, since the recharge source is usually the local infiltration of precipitation.

Large valleys of tectonic origin will vary most widely in water chemistry. If good valley drainage has existed during the morphology of the valley, the water quality may be quite good; however, if there have been alternating openings and closures of the valley drainage (as in the case of the Safford Valley) due to tectonic activity, beds of evaporites such as gypsums may exist either extensively or locally (12).

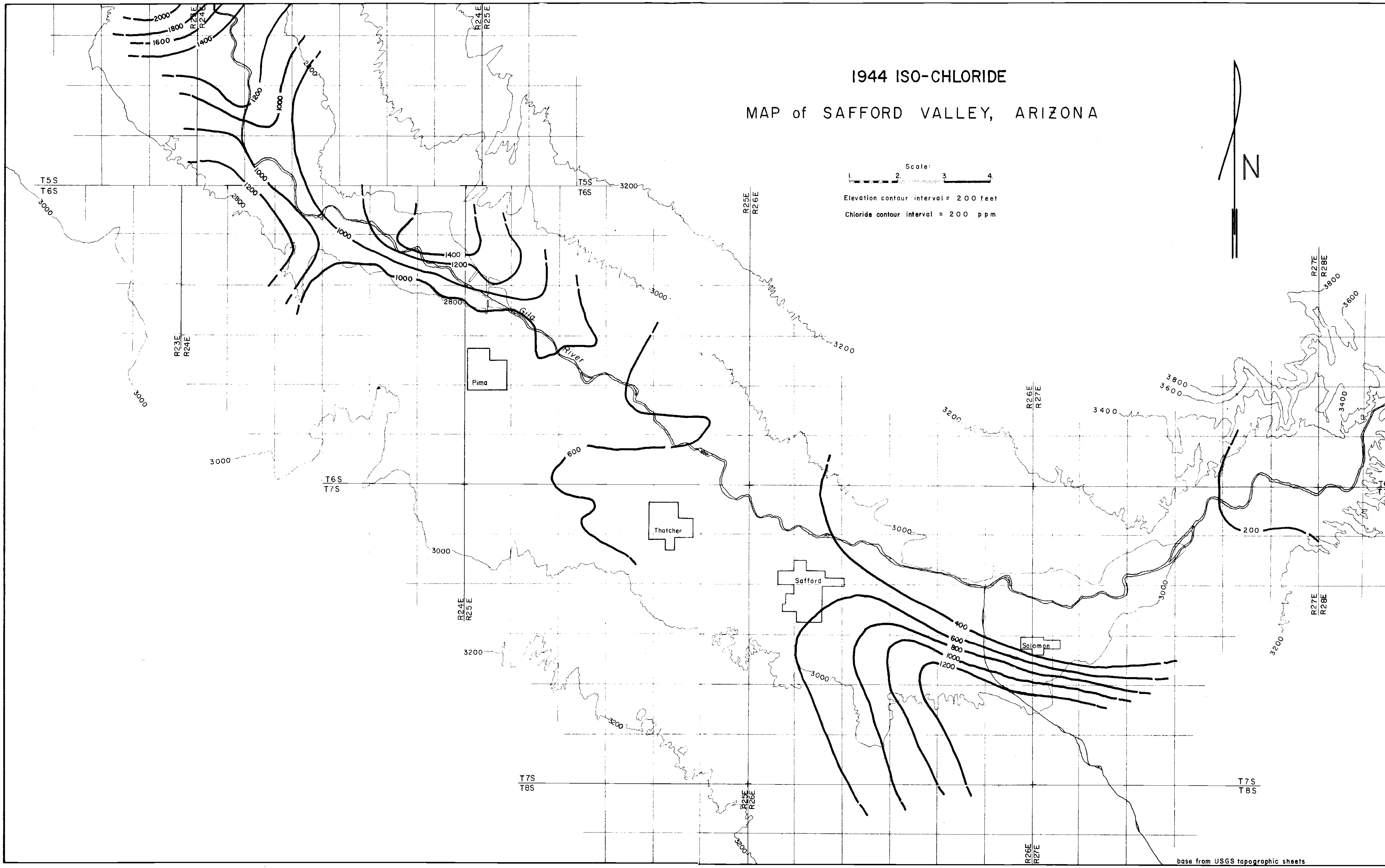
Sampling Techniques -- Water Quality

The 1972 water quality samples were collected by the students of the University of Arizona Hydrology Summer Field Camp (Hydrology 214S) from July 10 to July 14, 1972 (80). At most of the sampling locations, two samples were taken simultaneously; one for analysis at the field camp laboratory and another for analysis at the Soil and Water Testing Laboratory of the Agricultural Experiment Station at the University of Arizona. It should be noted that the students were learning the U. S. Geologic Survey water-well location system during this project, and some errors may have been made in location of sampling points.



1944 ISO-ELECTRICAL CONDUCTIVITY
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
Electrical Conductivity contour interval=1000 μmhos
N
345 points from USGS WSP 1104
base from USGS topographic sheets
Pima
Thatcher
Safford
Solomon
Gila River
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
2000
4000
6000
8000
10000
12000
2800
3000
3200
3400
3600
3800

1944 ISO-CHLORIDE MAP of SAFFORD VALLEY, ARIZONA



The sampled wells were located primarily from a well data file provided by Dr. J. J. Wright, the Field Camp Director. This file has been compiled by previous students in Hydrology 214-S, and is revised and supplemented each year. The students were divided into teams of three and assigned specific areas to sample, both for water quality (on pumping wells) and water table level (on non-pumping wells). As far as we know, all quality samples were collected from pumping wells, that is, no static samples were taken, and no artesian wells or springs were sampled. The students were encouraged to attain thorough coverage of their areas without sampling more than four wells per section. The exception to this was a well field in the extreme upper end of the east limb of the valley, which proved interesting from the standpoint of temperature and quality correlation. This area is discussed below in the section on the Larson Well-Field Anomaly.

The field camp analysis was performed within twenty-four hours after the samples were collected, while the lab analysis was performed at the Soil and Water Testing Laboratory from two to four weeks after collection. During the collection, transportation and storage, the samples were protected to all extents possible from heat and light. Mr. Ed Carpenter, Director of the Agricultural Experiment Station Laboratory, stated that for the purposes of our investigation, changes in the chemical constituents as a result of time and temperature variation could be considered negligible.

The actual sampling of the pumping wells was accomplished by filling one-pint polyethylene sample bottles from the well discharge pipes. The bottles and caps were first rinsed in the well water, then the bottles were filled about 90 percent full, capped and labeled with the well location and discharge temperature.

The data published by Hem (38) were collected during the period 1940-1944 by a variety of methods. Due to the nature of groundwater investigation, all sources were utilized. Hem states that the preferred sampling technique was to collect samples from pumping wells in order to avoid surface contaminants and possible changes in water chemistry due to static water being in contact with the well casing. In order to get a more thorough coverage of the study area data were included which were collected by other means. These include bailing, sampling from hand-pumped wells, sampling from seeps, and sampling irrigation drains.

Water Sample Analysis Techniques

1940 to 1944 Sample Analysis Methods

Hem (38) describes the technique for determining specific conductance (electrical conductivity) and states that analytical procedures were those used commonly by the Geological Survey.

The apparatus used by the Geological Survey for the determination of electrical conductivity is essentially the same as the solubridge in general use today. The analysis is performed by running an alternating current to platinum electrodes, nulling the current by means of a Wheatstone Bridge, and determining the resistance of a standard thickness of sample. The resistance thus determined is inverted and reported as "micromhos" (μmhos).

The procedure for determination of chloride involves titration with a silver nitrate solution and a potassium chromate indicator. No precision data are available on these techniques.

A Hack Chemical Company Portable Water Engineer's Laboratory model DR-EL, was used in the field camp analysis. The Hack kit includes precise quantities of reagents in plastic "pillows" which greatly reduces measurement errors. However, a number of these reagents have registered trade names (tm. reg.) and the actual chemistry of the analysis is not available to the users. Therefore, a comparison of techniques is not possible for all of the analyses.

The accuracies reported for the various analyses result partly from the students' failure to dilute the more highly mineralized samples and partly from the use of pipettes with 0.1 ml accuracy. These errors do not include errors arising from differences in titration techniques.

1. Electrical conductivity was measured by an Industrial Instruments solubridge. This instrument is nulled as described above and is read directly in mhos. The instrument is easy to use, but the logarithmic scale is limited to an accuracy of $\pm$ 10 percent throughout the range.
2. Chloride determination was accomplished by titration of the sample with a mercuric nitrate solution and a diphenylcarbazone indicator/buffer. Under ideal conditions, the accuracy of this technique is $\pm$ 25 ppm.
3. Calcium hardness determination is a titrametric procedure using two of the unknown reagents mentioned above. A small amount of potassium hydroxide is added to the sample, along with "CalVer II" (tm. reg.). This mixture is then titrated with "TitraVer" (tm. reg.). The accuracy is limited to $\pm$ 50 ppm.
4. Total hardness is determined by adding a small amount of "Hardness I" (tm. reg.) to the sample, along with "ManVer II" (tm. reg.), and titrating with "TitraVer" (tm. reg.). The accuracy is limited to $\pm$ 50 ppm.

5. The pH was measured with a pH meter which was later determined to be operating improperly.
6. Fluoride was determined by adding SPADNS Fluoride Reagent to the sample and comparing it to a 0.5, 1.0, 1.5, or 2.0 ppm fluoride standard. Accuracy was ± 0.25 ppm, and indeterminant beyond 2.0 ppm fluoride.
7. Sulfate was determined by adding SulfaVer to the sample and using the colorimeter provided in the Hack DR-EL kit.

Soil and Water Laboratory Techniques

The following test procedures outline the steps used by the Soil and Water Testing Laboratory of the University of Arizona Agricultural Experiment Station to analyze the water samples of this study.

1. Electrical conductivity was determined by use of an Industrial Instruments Model RC 16B2 solubridge and reported as EC x 10^3. Accuracy is estimated to ± .1 x 10^3 μmhos.
2. Chloride determination was identical to the USGS standard method described above. Accuracy is estimated to be ± 5 percent above 50 ppm.
3. Calcium hardness was determined by adding potassium hydroxide and a calcein indicator to the sample and titrating with disodium dihydrogen 1,2 cyclohexane-diaminetetraoacetate (CDTA).
4. Total hardness (calcium and magnesium) was determined by adding Calmagite and titrating with CDTA. If the titration failed to work properly, it was assumed that no magnesium was present, so a new sample was used with the Calgamite, methyl red indicator, and a small amount of magnesium EDTA. Accuracy for both calcium and total hardness was estimated to be + 5 percent above 40 ppm.
5. The pH was determined by a Beckman Zeromatic (Model 96) pH meter and accuracy is estimated to be ± .2 pH.
6. Fluoride was determined by use of a Heath Model EUW 301 millivolt meter and Orion Fluoride and Reference electrodes. The voltmeter was calibrated using 0.2, 0.4, 0.6, 0.8, 1.0 and 2.0 ppm standard fluoride solutions. Accuracy is estimated to be ± 5 percent above 0.2 ppm.
7. Sulfate determination was made by titration with Thorin. The titration reagents were barium chloride and a hydrochloric acid-sodium hydroxide buffer. Since calcium and magnesium also react with Thorin, they were first removed with Ambulite IR-120, a cation exchange resin.
8. Sodium was determined by use of a Perkin-Elmer 303 Atomic Absorption Spectrophotometer. Accuracy is estimated to be ± five percent.

All accuracy estimates were provided by Mr. Edward Carpenter of the University of Arizona Soil and Water Testing Laboratory.

1969 to 1972 Sample Analysis Techniques

The field lab analysis was performed by students of Hydrology 214-S during field camp. For this reason, there may be discrepancies in the results, since as many as twenty students may have been involved in the analysis of a single chemical constituent during the course. This may lead to relatively large errors, particularly in the analyses which involve titration.

Field-Laboratory Chemical Analysis Data Comparison

Data on the chemical characteristics of the irrigation aquifer from the Hydrology Summer Field Camps of prior years were obtained by the same field methods described. Analyses for total hardness, calcium hardness, alkalinity, chloride, fluoride and sulfate were made. Measurements were also made for electrical conductivity and pH. The students involved in the current Hydrology Summer Field Camp question the accuracy of these measurements, seeing the actual methods in operation.

The analyses obtained from field methods of the current Field Camp are not used in this study because of the duplicate samples which were analyzed by the laboratory of the University of Arizona Agricultural Experiment Station. These analyses are both more comprehensive and more accurate. The only other series of comprehensive samples and laboratory analyses were made by Hem (38) in the early part of the nineteen forties. Occasional samples have been taken by the Agriculture Experiment Station and by the Geologic Survey, but these give only scattered point information on conditions of the aquifer. More thorough samplings have been made by the Field Camps of this year and of three years prior. These samplings usually ranged from 60 to 80 samples (74), this year being the first to include 120 points.

Since the same field methods were used on Field Camp samples of all years, it was felt that the dependability of the analyses should be checked. The dependability of samples is assumed to be constant through the years, as is the method of analysis. The dependability of the analyses of prior years may then be estimated by determining the dependability of the current field analyses as related to the laboratory analyses of the same samples. Electrical conductivity, chloride, sulfate, pH and fluoride are the only characteristics the two analyses have in common for comparison. The hardness and alkalinity measurements of field analyses are not compatible in definition to those measurements made by the University laboratory. Total hardness of the field analyses is defined as the sum of the free ionic constituents of magnesium, calcium and iron in parts per million. Alkalinity is the equivalent amount of reactive calcium in parts per million required by the sample.

Linear correlations between the corresponding measurements of the field and laboratory analyses were conducted on the 120 samples of the Field Camp data of 1972. Table 3 represents the compilation of these correlations. Both a linear correlation coefficient and a covariance of the sample ordered pairs were calculated.

The linear correlation coefficient indicates the dependability of the field electrical conductivity, chloride and sulfate measurements to be acceptable. The pH and fluoride measurements are similarly indicated to be unacceptable.

The mean values of the electrical conductivity and chloride measurements indicate that not only is there a high linear correlation between the data sets but that there is also congruity between the distributions of the data points. This is shown by the proximity of the means, relative to the magnitude of the actual values, that such congruity exists. There is a significant difference in the mean values of the sulfate calculations, approximately 25 percent of the actual means. Although there is a high correlation between the sulfate data sets, this difference shows systematic error difference between the data sets. A factor of 0.777 is required to make the field data colinear with and comparable to the laboratory analyses.

The pH values are shown to be random, with no correlation to each other as indicated by the linear correlation coefficient. This may be explained by two principal ways. The Beckman pH meter used for the field analyses was susceptible to significant drift between calibrations, and the samples transported to the laboratory in Tucson may have been subject to shifts in equilibrium. If significant changes in partial pressure of carbon dioxide had occurred at the surface of the water sample, a new equilibrium between $CO_{2(g)}$, carbonate, bicarbonate, hydroxide ion, and hydrogen ion (pH) would be reached.

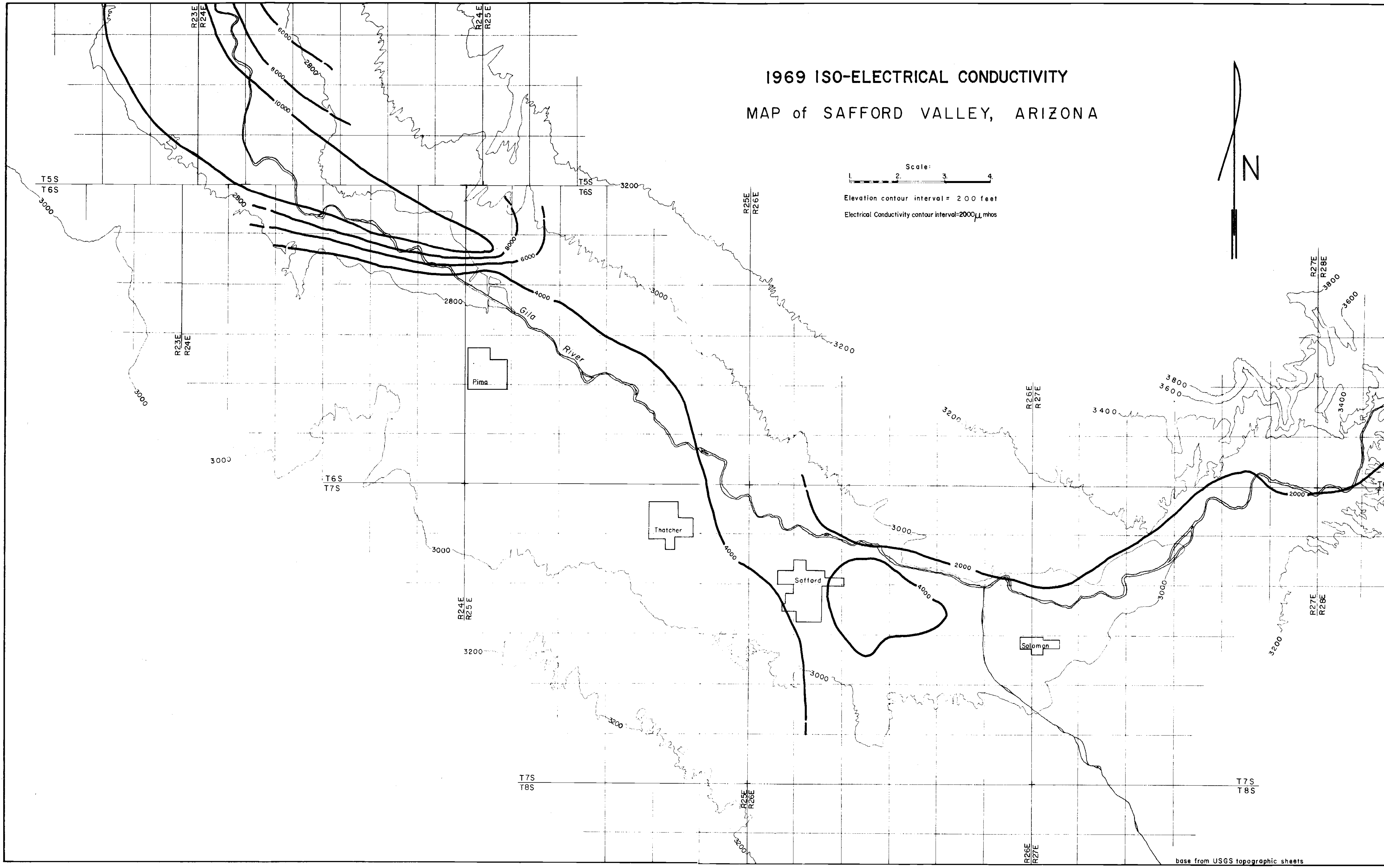
Fluoride was analyzed in the field by a colorimetric test. The color comparison vials contained samples for 1.00 and 2.00 parts per million fluoride. The student making the analysis must estimate the intermediate values of fluoride, and must estimate the colors of concentrations higher than 2.00 ppm. Such higher values were common, as indicated by the standard deviation of the laboratory values (.7), and the mean of the same set (1.6 ppm). Because of this great amount of human interpretation, and human error, the fluoride measurements of the field analyses are confirmed to be unacceptable in dependability.

Electrical conductivity, chloride and sulfate (if the appropriate multiplicative factor is used) measurements by the Hydrology Field Camp methods may be used with considerations of high dependability. These measurements are comparable to their laboratory analysis counterparts.

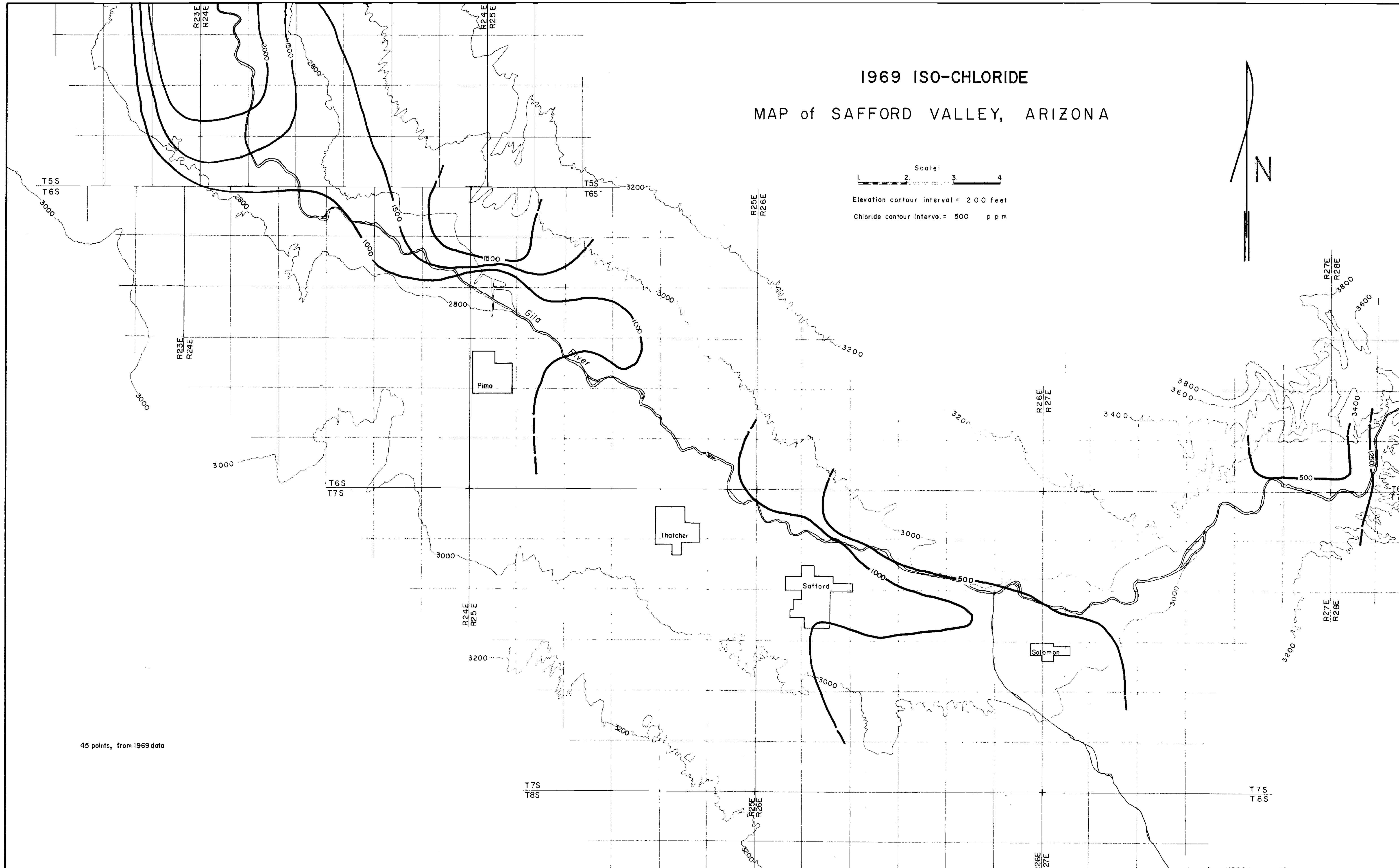
Table 3

FIELD CHEMICAL ANALYSIS DEPENDABILITY TEST
LINEAR CORRELATIONS CALCULATED BETWEEN FIELD AND LABORATORY ANALYSES
FOR 120 OBSERVATIONS

	EC*10**3 FIELD (X)	EC*10**3 LAB (Y)	CHLORIDE FIELD (X)	CHLORIDE LAB (Y)	SULFATE FIELD (X)	SULFATE LAB (Y)	PH FIELD (X)	PH LAB (Y)	FLOURIDE FIELD (X)	FLOURIDE LAB (Y)
SUM OF VALUES	393.7	367.5	85928.0	88427.0	49778.0	38574.0	924.0	868.4	294.5	186.6
SUM OF SQUARED VALUES	1727.3	1770.7	94657052.0	97703069.0	31928260.0	15316976.0	7127.8	6148.6	1126.7	380.7
MEAN OF VALUES	3.3	3.1	716.1	736.9	414.8	321.5	7.7	7.2	2.5	1.6
SIGMA OF VALUES	1.9	2.3	525.4	520.7	306.5	155.9	.3	.3	1.8	.7
SUM OF X*Y VALUES	1616.23		90919012.00		20172090.00		6609.32		542.65	
MEAN OF X*Y VALUES	13.47		757658.43		168100.75		55.08		4.52	
COVARIANCE OF X AND Y	3.42		229994.87		34757.93		-.00		.71	
LINEAR CORRELATION COEFFICIENT	.7742 ←		.8496 ←		.7271 ←		-.0121		.4432	
DEPENDABILITY	ACCEPTABLE		ACCEPTABLE		ACCEPTABLE		UNACCEPTABLE		UNACCEPTABLE	



1969 ISO-ELECTRICAL CONDUCTIVITY
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1. 2. 3. 4.
Elevation contour interval = 200 feet
Electrical Conductivity contour interval=2000 μ mhos
N
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
base from USGS topographic sheets


1969 ISO-CHLORIDE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
Chloride contour interval = 500 ppm
N
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
2000
1500
1000
500
2800
3000
3200
3400
3600
3800
45 points, from 1969 data
base from USGS topographic sheets

CHEMISTRY OF THE ARTESIAN AQUIFER SYSTEM IN THE SAFFORD VALLEY

A system of artesian aquifers exists, apparently, throughout the Safford Basin. The aquifer system is contained within the Tertiary and Pleistocene valley fill, and there are probably numerous poorly connected water-bearing strata in this fill (37, 38).

The reasons for believing that these recharge areas are located as described earlier in this paper is that water from the artesian aquifer in and near the recharge areas is of better quality than artesian water found further toward the center of the basin. This was observed in the case of the Pinaleno recharge area by Hem (38), as a result of extensive sampling and research of published material. Examination of the Larson well-field anomaly, located generally between Sanchez and Buena Vista on the south side of the Gila River, indicates that there is a large source of good quality geothermal water somewhere above that point.

Most water from the artesian aquifer is obtained from wells which have been drilled into the Tertiary and Pleistocene valley-fill formations. The deepest of these is the Mack well (Figure 4) drilled for oil exploration to a depth of 3767 feet. Other flowing wells within our area of investigation are located primarily on the upper terraces below the Pinaleno Mountains, although one highly mineralized geothermal well provides water for a health spa due north of Thatcher on the south side of the river.

There are numerous springs associated with the artesian aquifer which occur as an apparent result of faulting. These occur from the general area of Big Spring Wash all the way to the San Carlos Indian Reservation some twenty miles to the northwest of the study area. Hem states that in general the springs with lower flows have lower temperature, but that the water chemistry for all of these springs is very similar. Water from most of these springs contains from 3,000 to 4,000 ppm of total dissolved solids. The constituents predominantly involved are sodium and chloride, with high fluoride and borate concentrations (38).

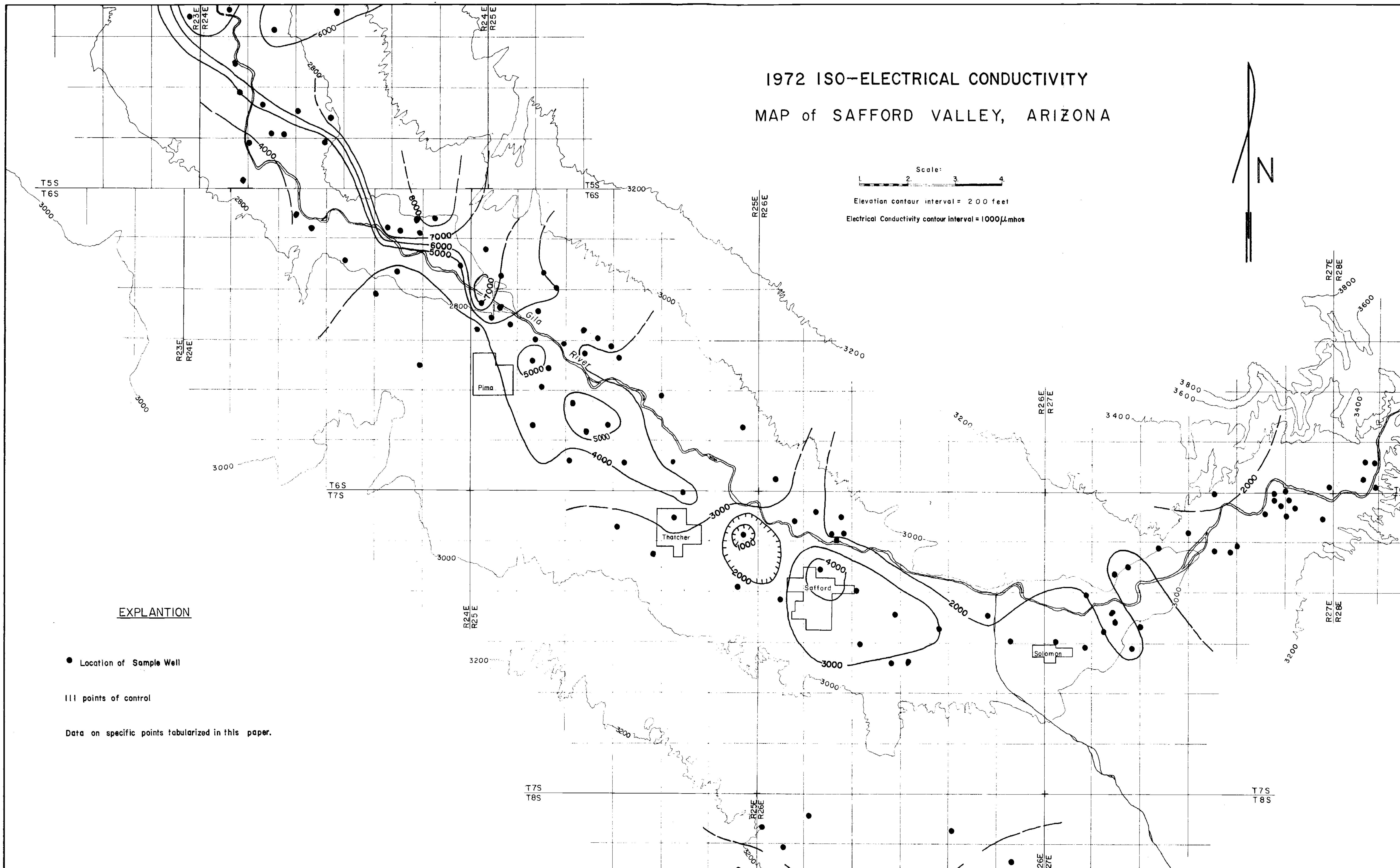
Concentrations of the chemical constituents in the water were not determined in this study for the reasons previously indicated. During the course of Field Camp, during the first weeks of the study, the participants involved visited several hot springs and artesian wells around the valley. Chemical analysis of two of these artesian aquifer discharge points had old chemical analyses posted near the point of issue. The accuracy of these analyses is not known, but is believed to be sufficient to give an indication of the artesian aquifer quality. Table 4 gives the values of these posted chemistries.

TABLE 4

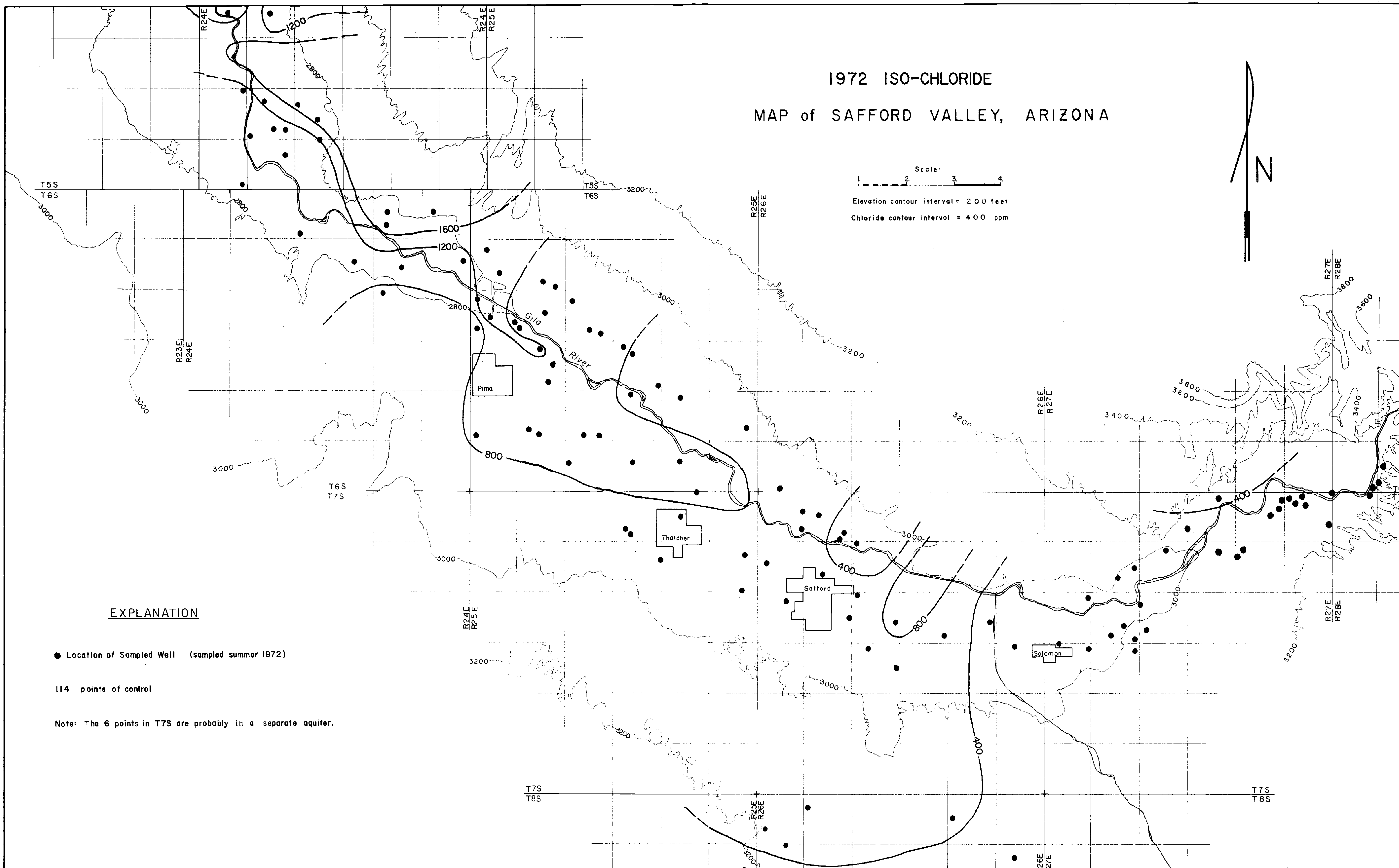
Artesian Aquifer Chemical Analyses (80)
(Concentrations in parts per million)

	Thatcher Well	Indian Hot Springs Seep
Location	R25E T7S 2 NE1/4 NE1/4	R24E T5S 17 NE1/4 SE1/4
Total Soluble Salts	5110	4060
EC x 10^3	8.5	≈7.7
Ca	56	78
Mg	3	10
Na	1861	1048
Cl	2440	1420
SO_4	650	405
CO_3	0	0
HCO_3	98	100
F	6.5	4.1
NO_3	3.0	--
SAR	66.0	--
Temperature	125°F	119°F

Further analyses of the artesian aquifer water is available from Hem (38) and is extremely more accurate than the analyses of Table 4, although it is much less recent. The water of this aquifer seems to be comparable to the analyses of the table. This conclusion is based on the highly saline taste and the strong odor of the water issuing from the artesian aquifer.


1972 ISO-ELECTRICAL CONDUCTIVITY
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1. 2. 3. 4.
Elevation contour interval = 200 feet
Electrical Conductivity contour interval = 1000 μmhos
N
EXPLANTION
Location of Sample Well
111 points of control
Data on specific points tabularized in this paper.
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
8000
7000
6000
5000
4000
3000
2000
1000
2800
3000
3200
3400
3600
3800
base from USGS topographic sheets

1972 ISO-CHLORIDE MAP of SAFFORD VALLEY, ARIZONA



EXPLANATION

● Location of Sampled Well (sampled summer 1972)

114 points of control

Note: The 6 points in T7S are probably in a separate aquifer.

CHEMISTRY OF THE IRRIGATION AQUIFER SYSTEM

Discussion of Groundwater

The aquifer from which most of the irrigation water used in the Safford Basin is drawn is composed of recent alluvium, with some small, discontinuous layers of evaporites. All of the strata in this upper aquifer are either of varying thickness or discontinuous, giving rise to a number of hydrologic characteristics which are difficult to specify in terms of quantity or precise location. Hem (38) states, for instance, that water from a single well has been known to vary in total dissolved solids by as much as 50 percent in a few months. During our investigation at Hydrology Summer Field Camp in 1972, there were found instances of wells located within a sixteenth section varying by almost an order of magnitude in water quality equivalent to Hem's findings in the data reported in USGS Water Supply Paper 1104. While much of this variance may be a result of sampling from different depths, it serves as an indication of rather extreme local heterogeneity.

As stated above, it is believed that all samples collected at Hydrology Summer Field Camp were from the upper, or irrigation aquifer. Therefore, the hydrology of this aquifer will be described using this data. The water table maps may have some errors due to the students' inability to determine precisely the elevation of the well head. Also, since the data was collected during the summer irrigation season, many of the most dramatic features are the direct result of heavy pumpage.

From the July 1972 Water Table Map, it is apparent that the predominant feature in the water surface is the downstream gradient. At the time this map was constructed, all of the water in the Gila River was being diverted at the Solomonsville diversion dam, so little effect of recharge from the river is evident. For a further explanation of the effect of pumpage on the groundwater contours, see Figure 11.

Aside from the effects of the downstream gradient and pumping interference, there are several apparent sources of recharge to the irrigation aquifer. From the Water Table Maps, these areas are: Lone Star Wash, and the wash to the northwest of Lone Star Wash (Sec. 31, 32, 33, R26E, T6S and Sec. 4, 5, and 6, R26E, T7S); the washes between Big Spring Wash and Markham Wash (Sec. 33, 34, R24E, T5S; Sec. 1, R24E T6S; and Sec. 6, R25E, T6S); and several washes on the south side of the basin, including particularly Ash Creek (Sec. 30, 31, and 32, R25E, T6S), and Frye Creek (Sec. 11, 12, and 13, R25E, T7S).

From an examination of the water quality maps, it is obvious that in general, the quality of groundwater increases as you go away from the center of the valley, and decreases as you go downstream. This indicates that the only major source of high quality groundwater for the basin is the river itself. This is in agreement with the geologic study of the basin which was done at Hydrology 214-S: soluble salts of sodium and calcium were found throughout the upper terraces, and any water which percolated through these beds would be lowered in quality. Also, as pumpage continues or increases in the center of the basin, the water table gradient induced will continue to bring lower quality water to the center of the basin. This effect will be further discussed below.

Specific sources of low quality water in the irrigation aquifer may be associated with the highly mineralized water of the artesian aquifer system below. For instance, in the area of Cactus Flat (Sec. 6, 7, R26E, T8S), there are several highly mineralized wells located in close proximity to the artesian wells used by the health spas. Also, in the area north and northwest of Pima, there are areas of extremely poor water, but these are located in the general area of the fault zone mentioned above.

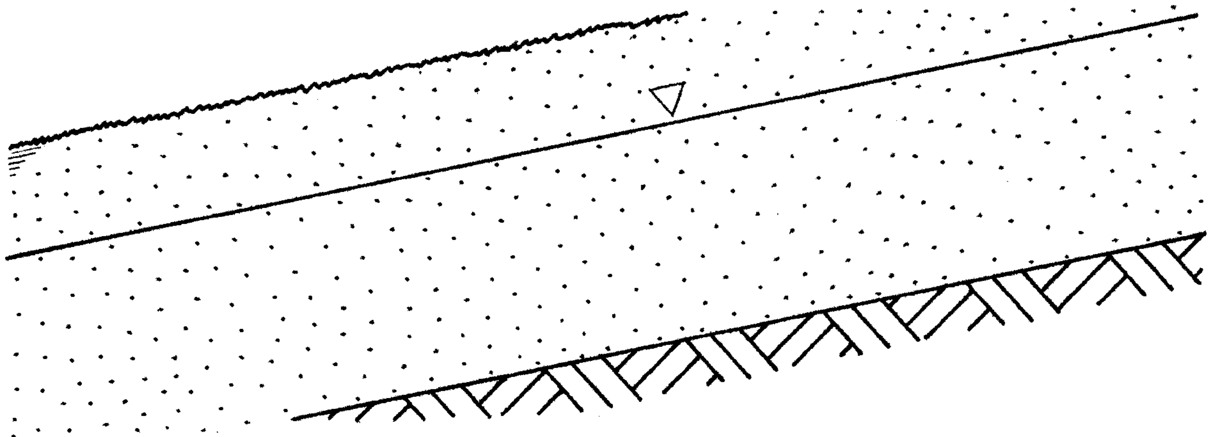
In addition, there are numerous examples of extremely localized conditions of changing water quality. Dr. Fred Turner, Director of the University of Arizona Experimental Farm at Safford (Sec. 22, R26E, T7S) stated that Water quality in the farm wells is slowly improving, and Mr. M. N. Larson says that when the Yuma Wash watershed (Sec. 1, R27E, T7S and Sec. 7 and 8, R28E, T7S) receives rainfall, the quality of his water (Sec. 1, R27E, T7S) improves. As indicated elsewhere in this report, however, the farmers often feel their water quality is worsening.

Water Quality Changes

Long-Term Sampling Identification

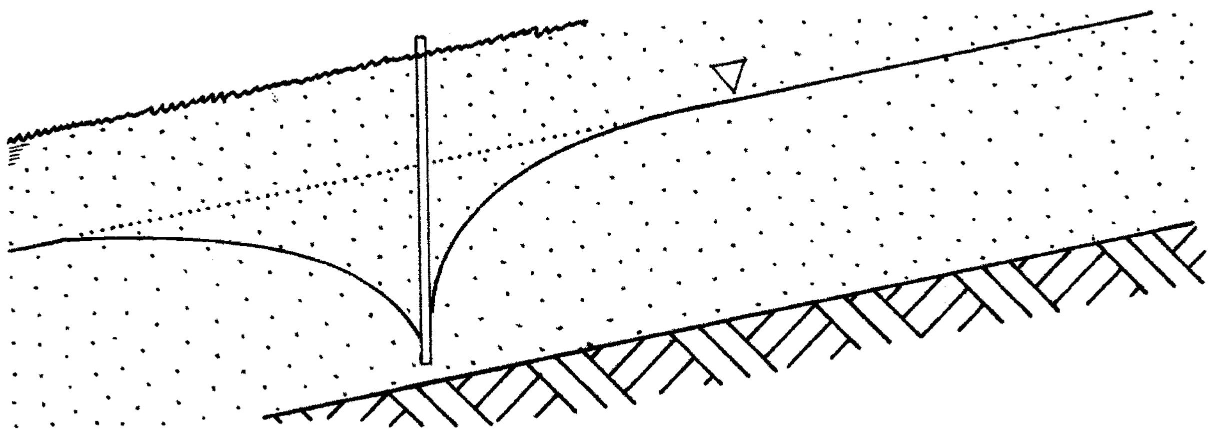
To receive an accurate idea of the changes in water quality of an aquifer, a long-term sampling program must be established, sampling designated control wells for a significant period of record. Water samples must be taken from the same wells, since there should be spatial control in such time-based measurements. Differences in water quality between wells only a few feet apart may be 50 percent or more. The well depth, local geology, and well characteristics may be the factors causing such differences.

Because of the limited time for this project, it was not possible to set up a long-term sampling program as described. A long-term historical record was constructed from literature as a substitute for such a program. Wells

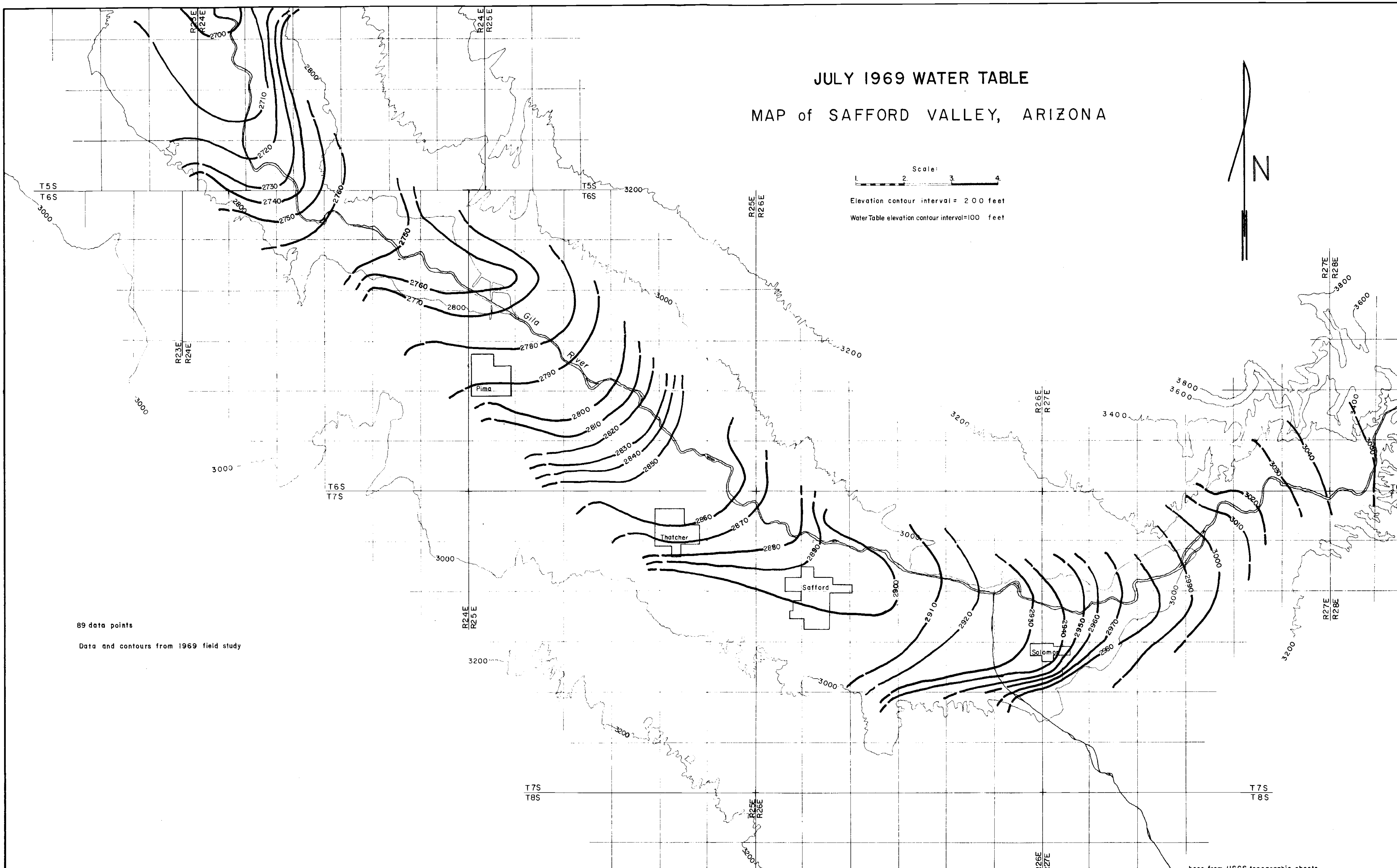


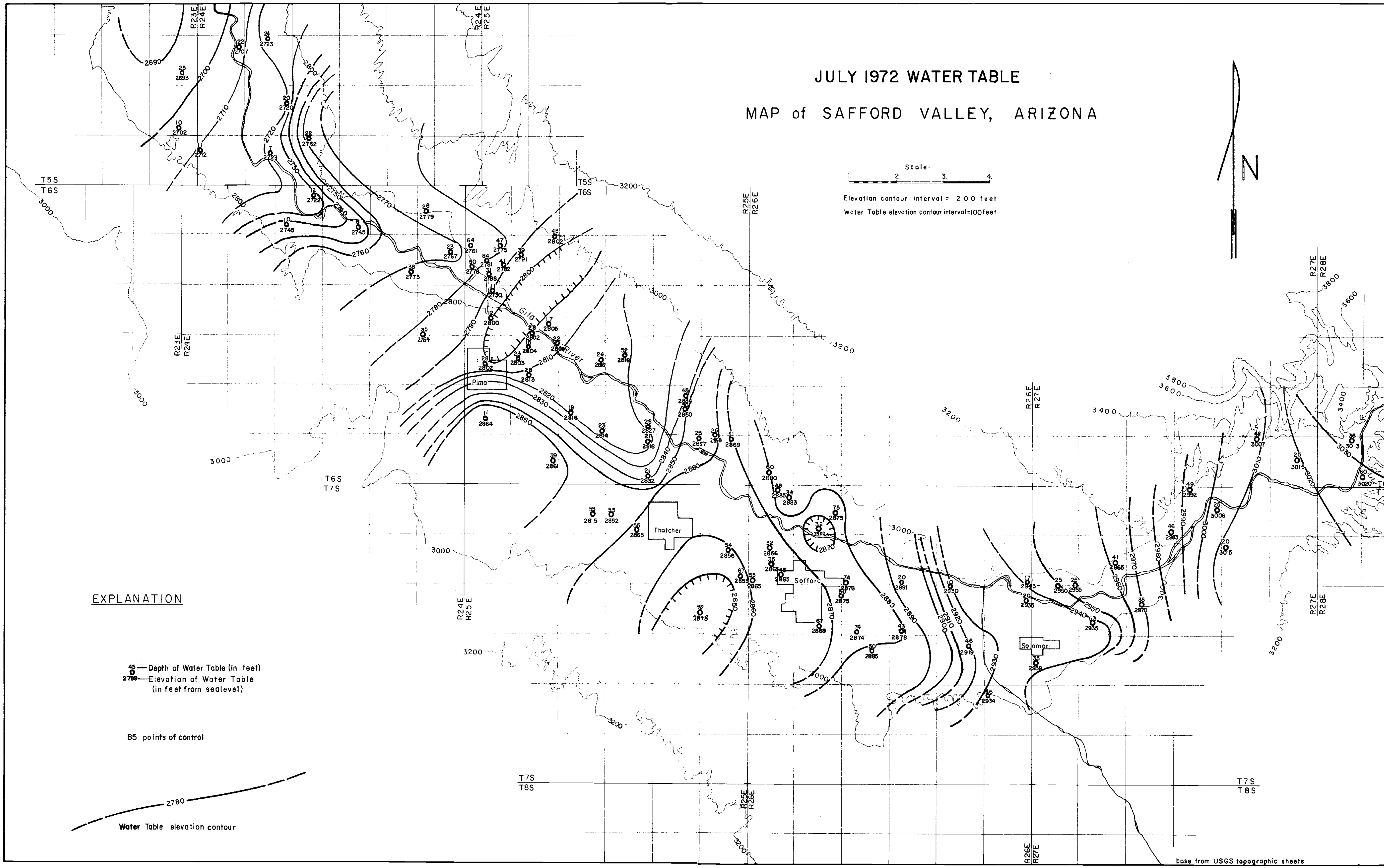
A 1 Cross-section of "typical" water table situation in a sloping and unconfined aquifer system, with the water table parallel to the land surface and to the vertical confining layer.

Figure 11
Water Table Configurations



A 2 Cross-section of aquifer in A 2 being pumped by one penetrating well. Dotted line indicates original water table. Note relative slopes of the two sides of the cone of depression around the pumping well.


JULY 1969 WATER TABLE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
Elevation contour interval = 200 feet
Water Table elevation contour interval = 100 feet
N
89 data points
Data and contours from 1969 field study
base from USGS topographic sheets
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
2700
2710
2720
2730
2740
2750
2760
2770
2780
2790
2800
2810
2820
2830
2840
2850
2860
2870
2880
2890
2900
2910
2920
2930
2940
2950
2960
2970
2980
2990
3000
3010
3020
3030
3040
3200
3400
3600
3800


JULY 1972 WATER TABLE
MAP of SAFFORD VALLEY, ARIZONA
N
Scale:
1. 2. 3. 4.
Elevation contour interval = 200 feet
Water Table elevation contour interval=100feet
EXPLANATION
45 — Depth of Water Table (in feet)
2789 — Elevation of Water Table (in feet from sealevel)
85 points of control
2780
Water Table elevation contour
Pima
Thatcher
Safford
Solomon
Gila River
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
base from USGS topographic sheets

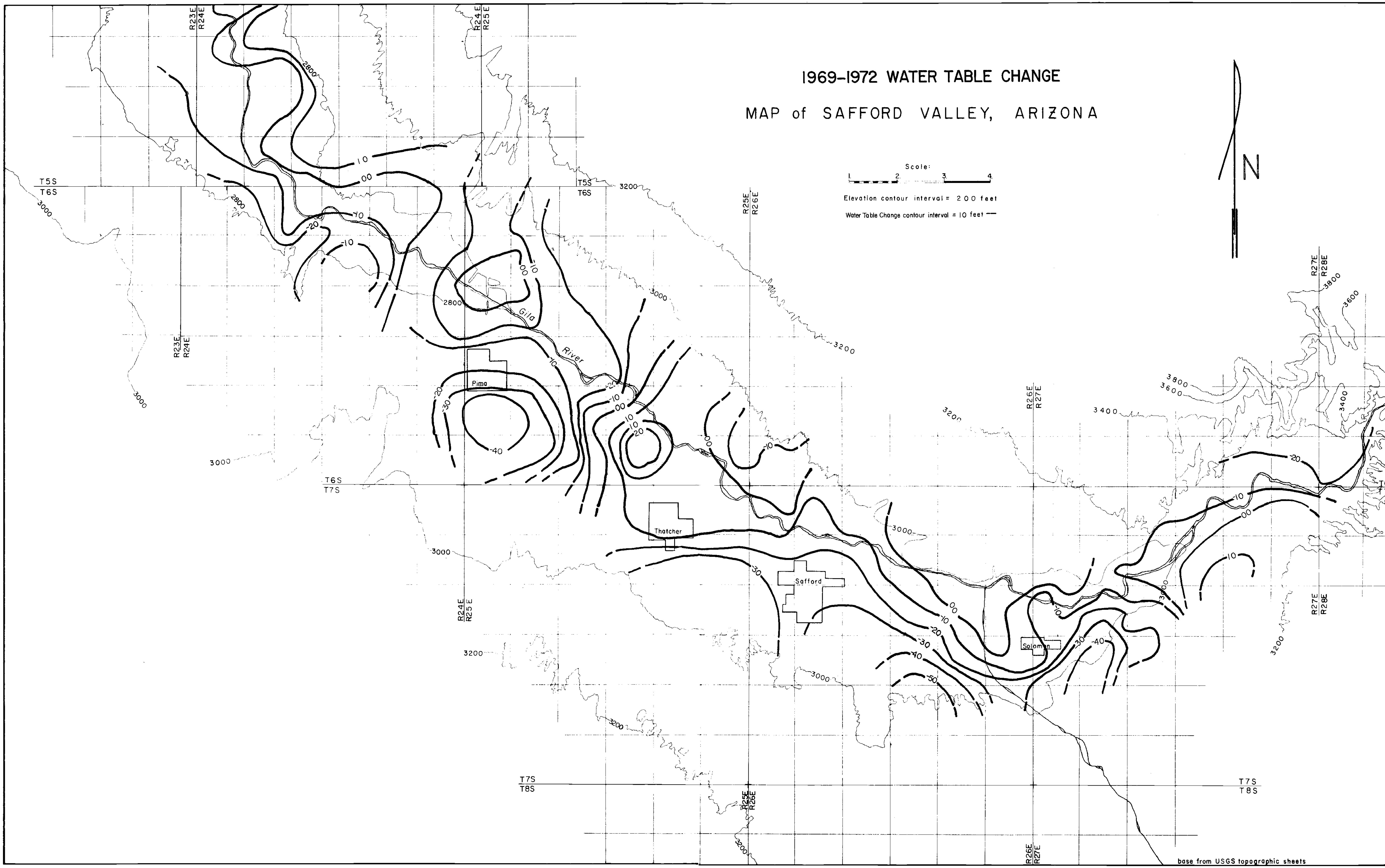
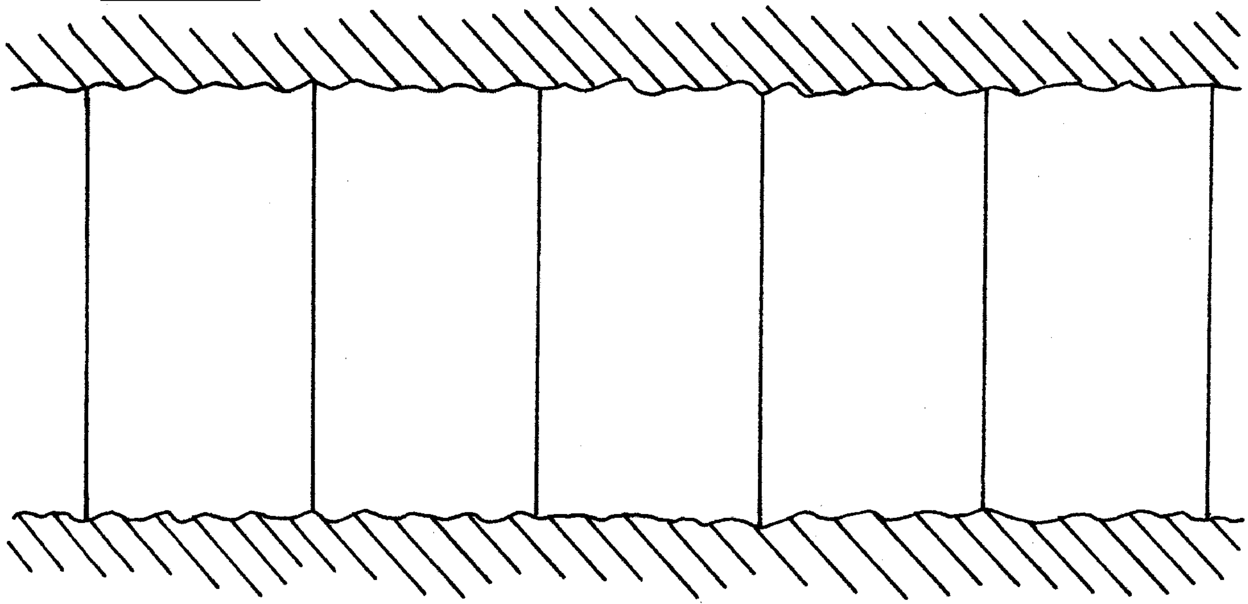
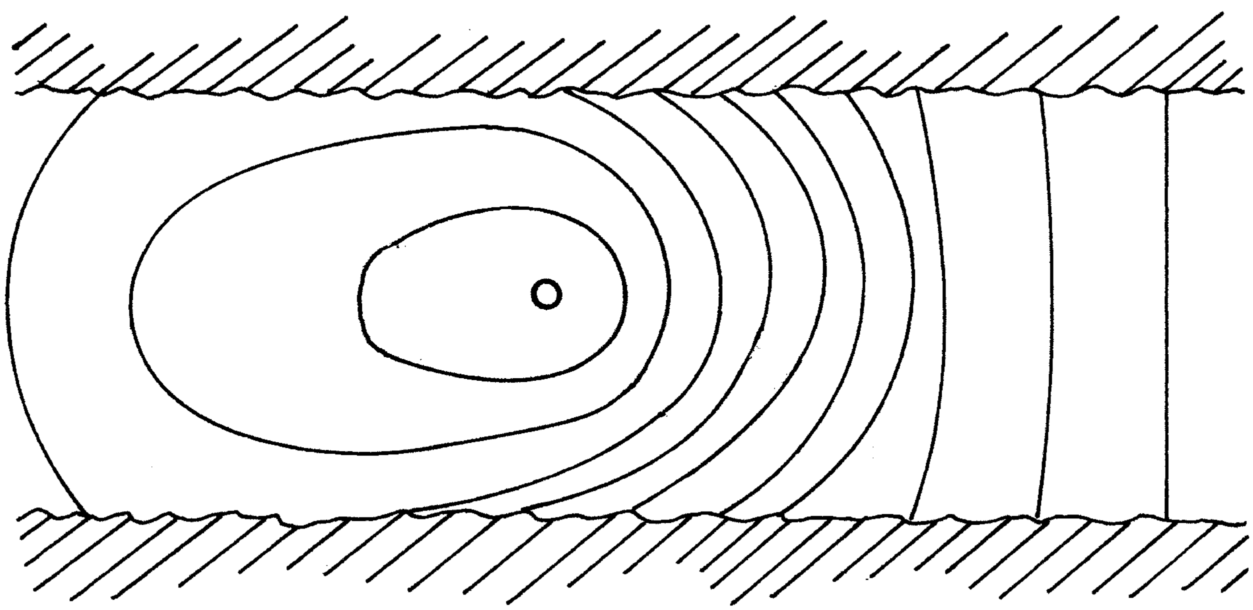

1969-1972 WATER TABLE CHANGE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
Water Table Change contour interval = 10 feet
N
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
base from USGS topographic sheets

Figure 11--Continued



B 1 Map view of water table with equi-potential contours for situation indicated in A 1. Note continuous and plainar water table surface sloping perpendicular to the constraining layer.

Figure 11--Continued



B 2 Map view of water table with equi-potential contours for situation indicated in A 2. Note grouping of contours on upstream side of the cone of depression, and excentric ellips configuration.

were identified in which two or more samples have been taken. These wells were not only identified by location but by owner name, since well fields and clusters caused identification problems. These wells were then sought and sampled by the field teams. Only those wells with sample periods greater than five years were considered. Ten such wells were found in the Safford Valley study area.

The water sample analyses from literature were found to be incomplete. Many of the constituents identified by the current laboratory analyses were not determined. Electrical conductivity and chloride were determined in all the long-term sample wells. These being the constituents of primary importance, comparisons of the measurements were made with time.

The ten wells with sufficient historical record for consideration in a long-term sampling comparison are well distributed along the Gila River in the study area. The well locations are found on the Long-Term Sample Well Location Map. The well locations, electrical conductivity, time of sampling, and source are presented in Table 5 for these wells.

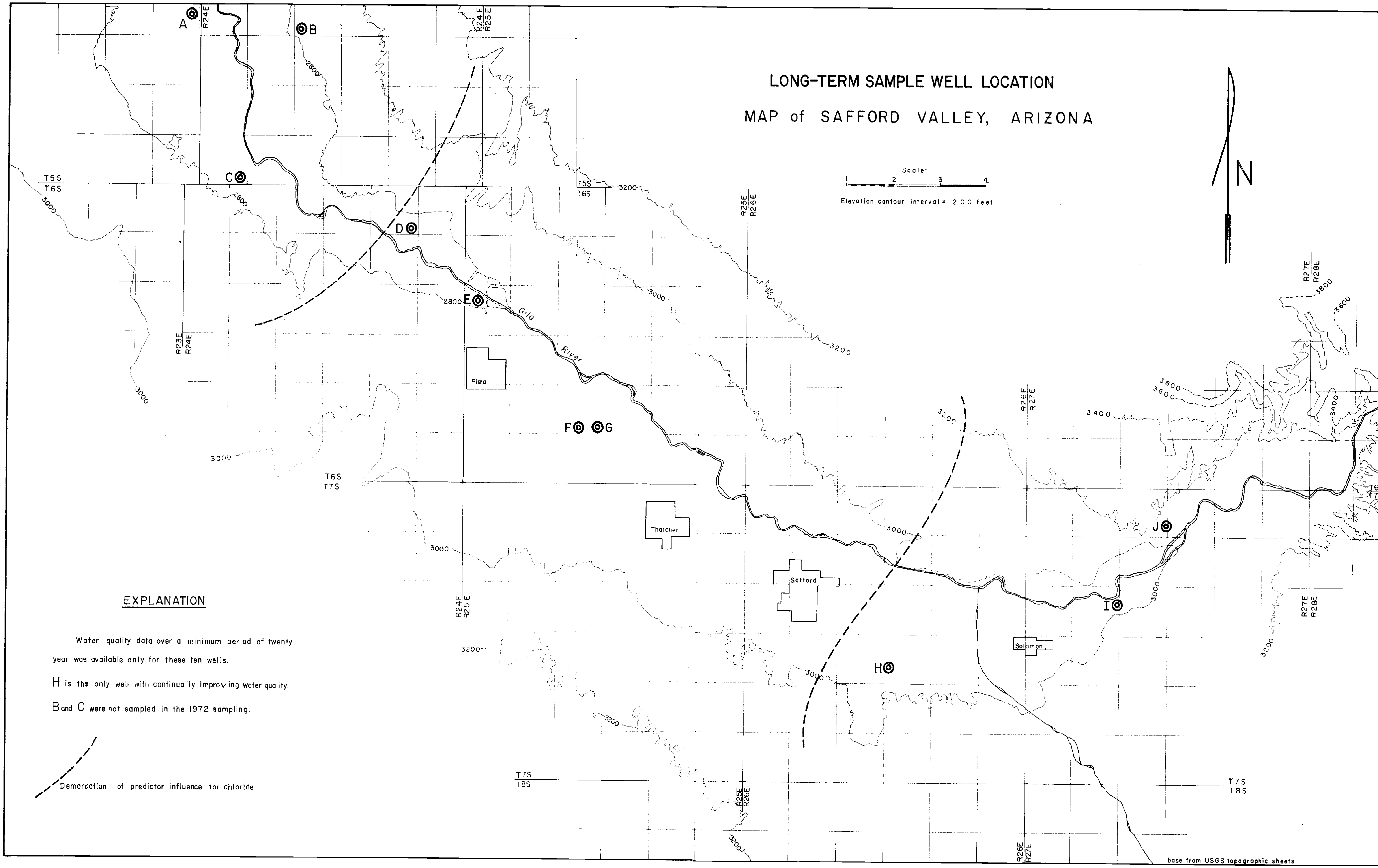
TABLE 5

Long-Term Sample Well Chemical Comparison

Designation	Location	Owner	Sampling Date	Data Source	Electrical Conductivity ($ECx10^3$)	Chloride (ppm)
A	5 23 13 ad	F. Moody	4/44	(38)	2.5	475
			6/54	(59)	6.9	2258
			7/72	(80)	7.6	2200
B	4 23 27 dd	H. Uhli	6/40	(38)	5.4	1388
			2/54	(58)	7.6	2680
C	4 24 31 dd	E. Palmer	8/41	(38)	2.2	1520
			3/60	(59)	8.0	2224
D	6 24 02 dd	L. Hancock	7/41	(38)	9.4	1800
			5/51	(58)	7.3	1544
			7/72	(80)	7.5	1580
E	6 25 18 ca	Dodge-Nevada Canal Co.	6/40	(38)	1.2	328
			4/43	(38)	1.6	388
			3/44	(38)	2.2	488
			11/59	(58)	4.9	1230
			7/72	(80)	7.0	1400
F	6 25 28 dd	Smithville Canal Co.	3/44	(38)	2.6	480
			11/59	(58)	5.3	1359
			7/72	(80)	5.8	1504
G	6 25 28 dc	E. Hoopes	5/41	(38)	2.6	485
			9/58	(59)	5.4	1346
			7/72	(80)	5.7	1515
H	7 26 22 cb	A. Montereth	5/41	(38)	2.0	918
			9/58	(59)	4.2	400
			7/72	(80)	2.2	350
I	7 27 17 db	S. Claridge	7/40	(38)	1.4	232
			3/61	(59)	2.2	334
			7/66	(9)	2.4	400
			7/72	(80)	2.8	440
J	7 27 03 cb	P. Allred	4/43	(38)	1.2	200
			6/59	(58)	1.6	290
			7/72	(80)	1.9	320

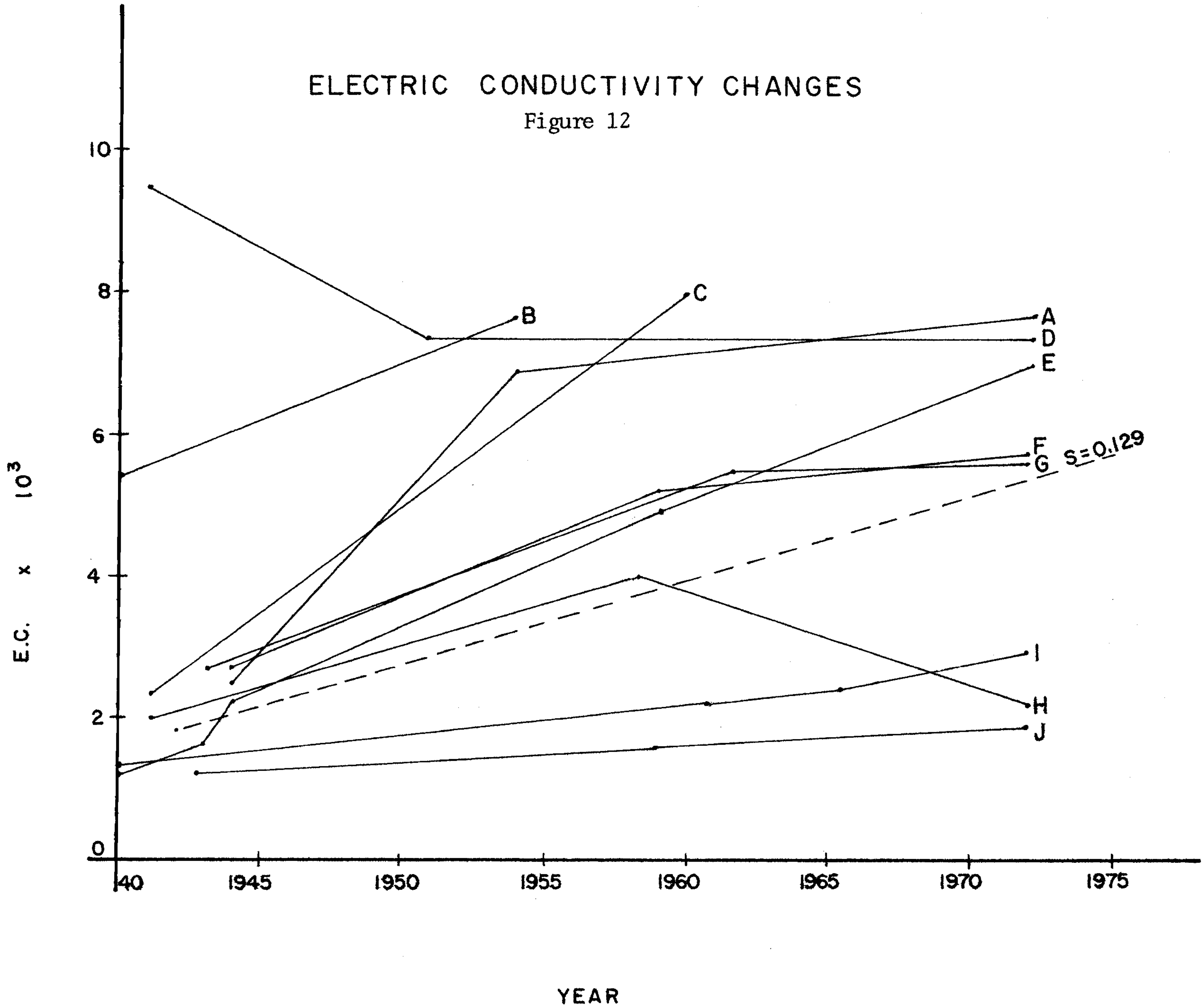
The graphic presentation of the data in Table 5 may be found in Figures 12 and 13. The solids lines represented by the letter designations indicate the corresponding salinity curve from the table.

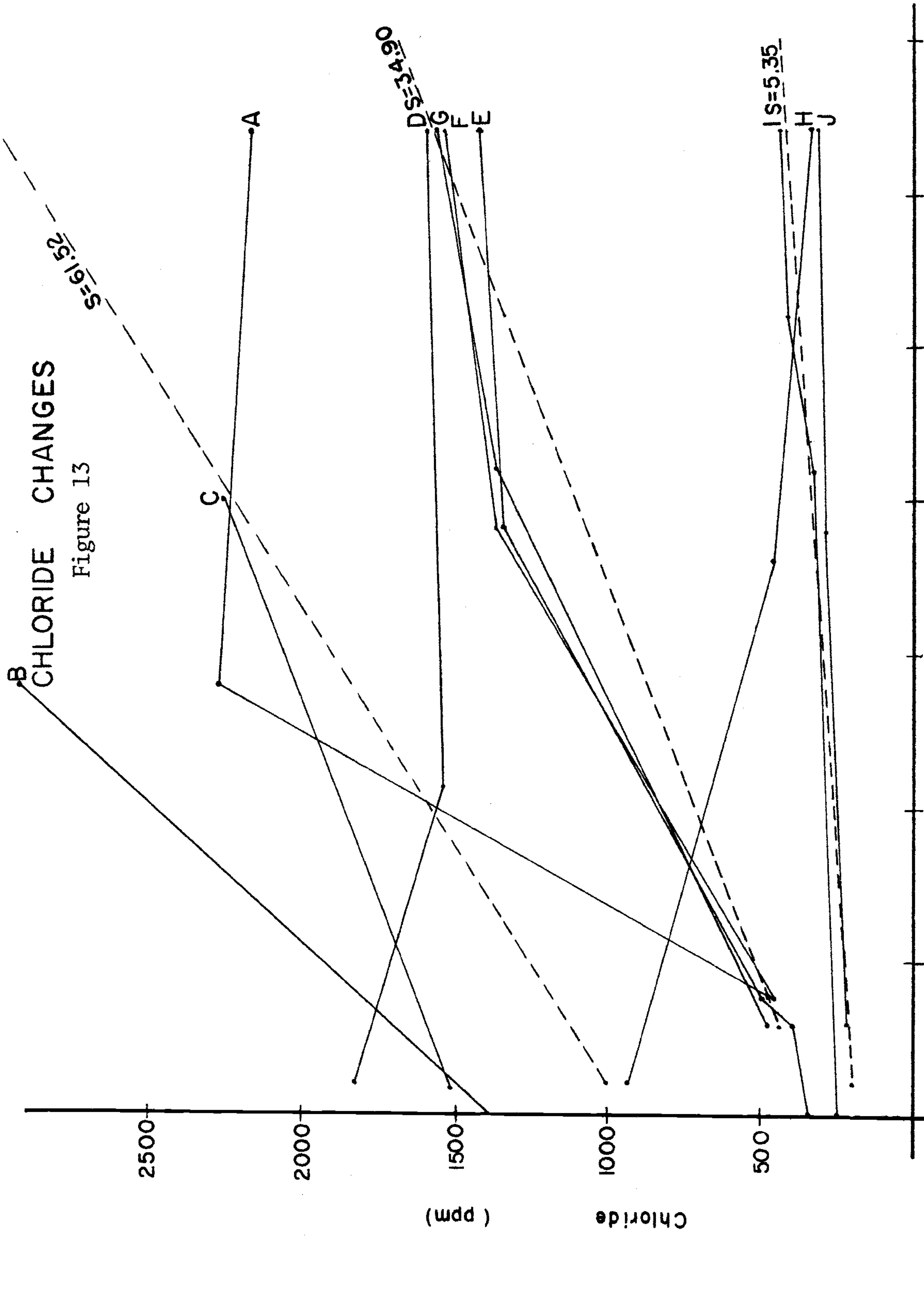
Figure 12 represents the changes in electrical conductivity over a thirty-two year period for the ten control wells. Two of the twenty-one segments in this figure indicate a decrease in the electrical conductivity of the sample well, and no line in the figure indicates continual improvement over the period of record. The two


LONG-TERM SAMPLE WELL LOCATION
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1. 2. 3. 4.
Elevation contour interval = 200 feet
N
EXPLANATION
Water quality data over a minimum period of twenty year was available only for these ten wells.
H is the only well with continually improving water quality.
B and C were not sampled in the 1972 sampling.
Demarcation of predictor influence for chloride
A
B
C
D
E
F
G
H
I
J
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
2800
3000
3200
3400
3600
3800
base from USGS topographic sheets

ELECTRIC CONDUCTIVITY CHANGES

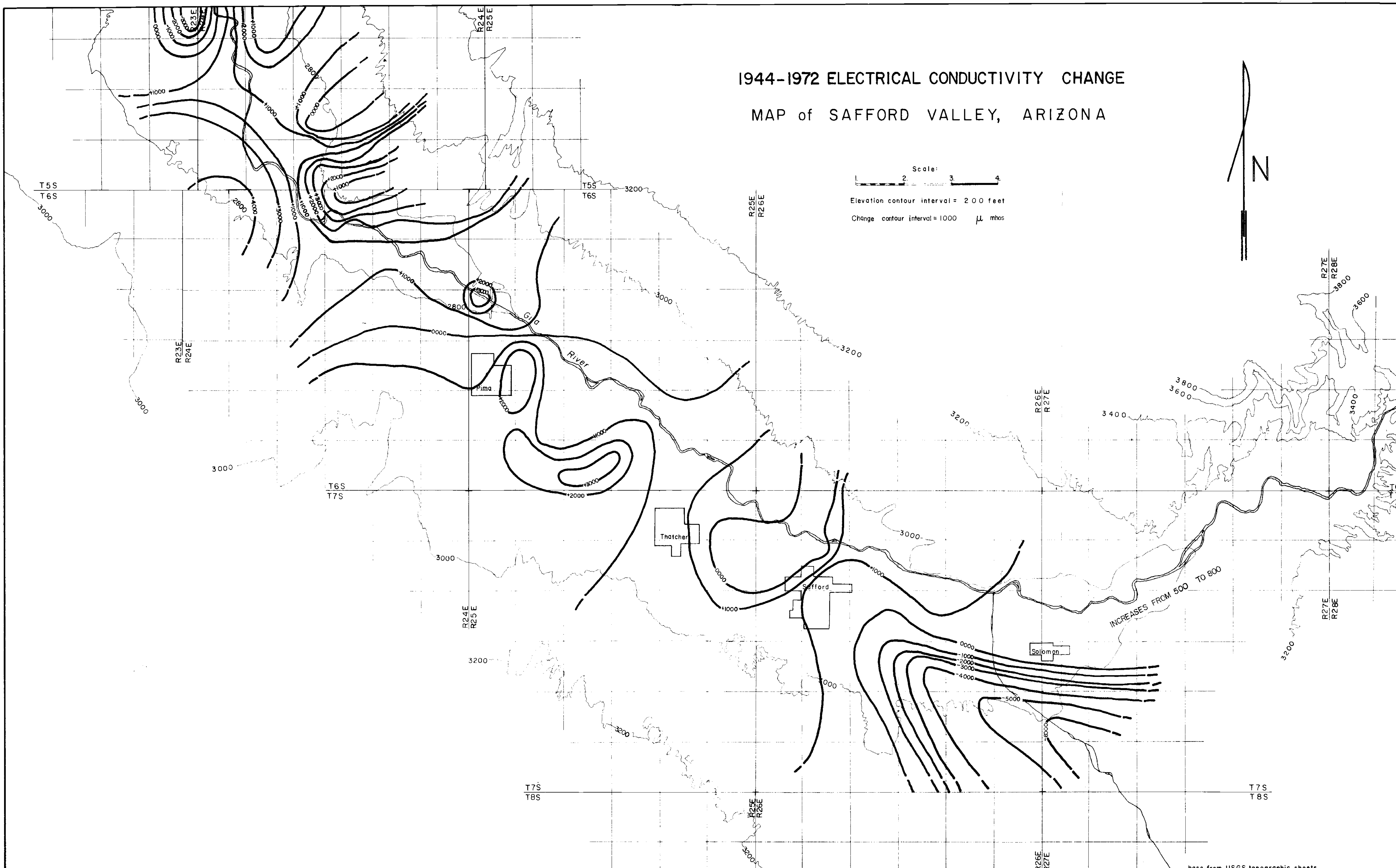
Figure 12

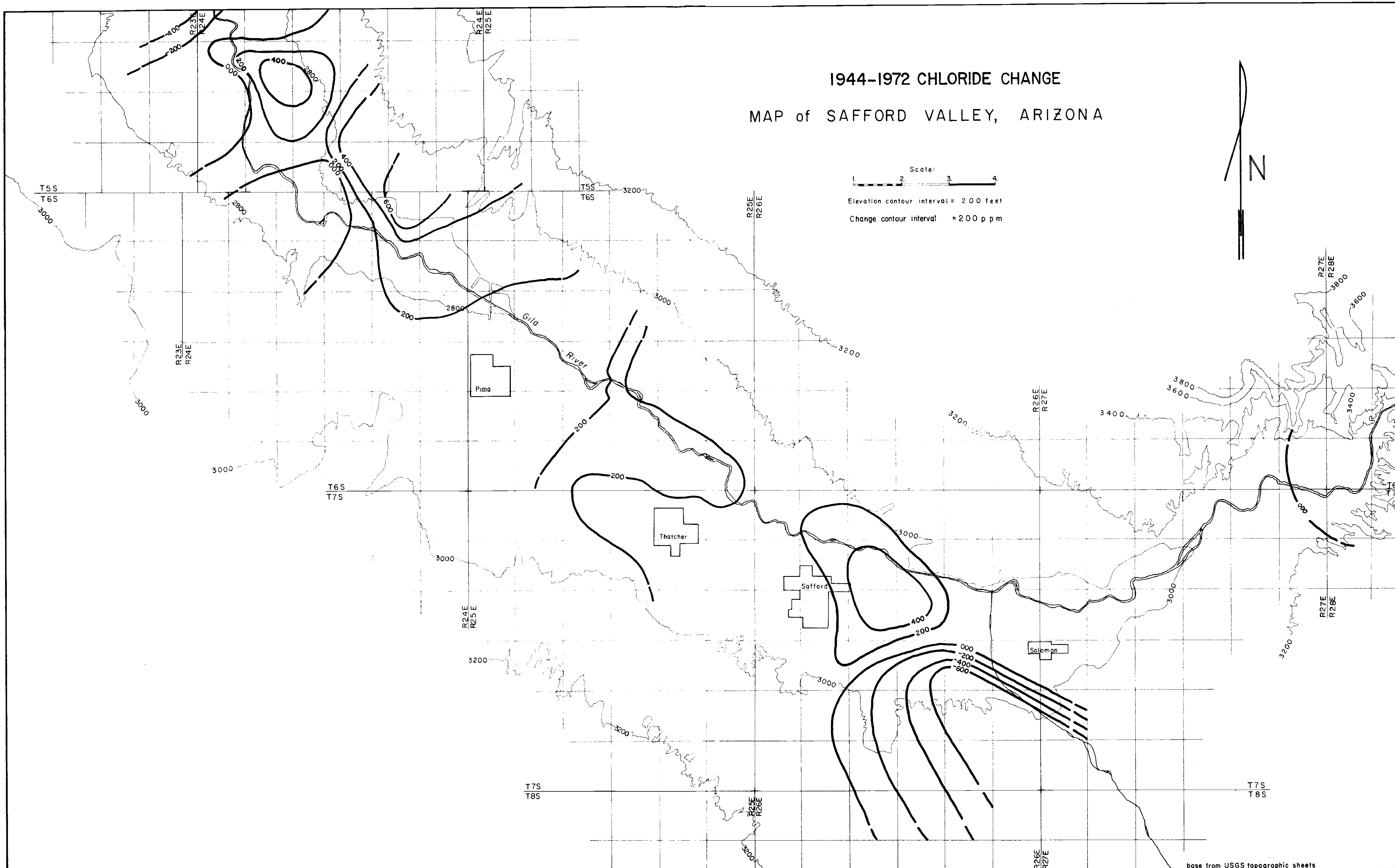




CHLORIDE CHANGES

Figure 13


1944-1972 ELECTRICAL CONDUCTIVITY CHANGE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
Elevation contour interval = 200 feet
Change contour interval = 1000 μ mhos
N
Gila River
Pima
Thatcher
Safford
Solomon
INCREASES FROM 500 TO 800
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
base from USGS topographic sheets


1944-1972 CHLORIDE CHANGE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
Change contour interval = 200 ppm
N
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
base from USGS topographic sheets

decreasing electrical conductivity segments comprise 23.66 years of the 273.38 years of cumulative record, and are defined by two of the thirty-one points in the figure. Both of these lines, D and H, have increasing segments. On the basis of these indications, the points defining these anomalous segments are taken to be measurement errors, or at best, points unrepresentative of the regional trend in electrical conductivity. The measurement error interpretation is not supported by the comparable decreases in the chloride measurements as indicated in Figure 13. The electrical conductivity and chloride measurements offer a control to each other in this case.

The trend of the segments in Figure 12 was visually found to be relatively uniform, with no clusters of lines of similar trend. This is more readily apparent in similar figures of different scale. The mean trend of the segments was determined by the following formula:

$$S = \frac{\sum_{n=A}^{J} \Delta EC_n}{\sum_{n=A}^{J} \Delta t_n} \qquad [3]$$

In this equation, n is the index from A to J, Δt is the time the given slope is in effect, and ΔEC is the change in electrical conductivity over that given time.

The slope of each segment is weighted by the time that slope is in effect on that specific well. The weighted slope was taken for all segments but those of lines D and H, which were thought unrepresentative. The weighted slope was found to be 0.129, which indicates that on the average the electrical conductivity of a well in the Safford Valley increases by 0.129 millimhos per year. This value is to be used as a predictor for water quality changes. It should be noted that the dashed line in Figure 12 has the slope of the predictor, but the location of the line in the figure is arbitrary since the point of origin for the line (which is the initial electrical conductivity) was chosen arbitrarily.

Figure 13 represents the changes in chloride content of the same set of wells over the same period as Figure 12. Lines D and H have increasing segments in the Chloride Change diagram as they do in the Electrical Conductivity Change diagram. An additional decreasing segment is found in the last part of the A line. These segments are all taken as unrepresentative of the surrounding region.

The chloride change lines in Figure 13 have clusters with similar trends. The H and J lines comprise such a trend, with the latter section of the I line as a possible contribution. The second set of lines with similar trends include D, E, F and G. The A, B and C lines comprise a third loose cluster. The clusters have regional tendencies, HIJ being on the east limb of the valley, DEFG being in the central and lower west limb, and ABC being in the far west limb on the northern limit of the study area.

Weighted mean slopes were calculated for the three clusters described. Equation [3] was used, with a substitution of ΔCl (change in chloride over a given segment) for the ΔEC term. The slopes and corresponding exclusions are indicated in Table 6.

TABLE 6

Regional Weighted Mean Chloride Change Slopes
(in ppm chloride increase per year)

Cluster	Exclusions	Slope
ABC	no exclusions	61.52
DEFG	last segment of D	34.90
HIJ	first segment of H	5.35

The weighted main slopes calculated for chloride change indicate that as one follows the river from the entry into the valley on the east side the magnitude of the chloride change increases. An examination of the location of the sample wells from the Long-Term Sample Well Location Map will show the relative magnitude of the changes of the individual lines. A similar observation may be made about the changes indicated in Figure 12 for the electrical conductivity changes.

Special note should be made of the decreasing chloride concentrations indicated by Figure 13 at well H. The decreasing quality is corroborated by the water quality change maps, by records of the University of Arizona Agricultural Experiment Station which is located in the same area, and by information obtained from the sociologic questionnaire. For this reason, although the data from this point is excluded from calculations as being unrepresentative of the valley, it should still not be discarded. The point is a good long-term indicator of the local feature in that section of the valley.

Water Quality Change Maps

The only comprehensive study of the water quality of the area other than the one conducted by this research group was conducted by Hem (38) approximately thirty years ago. The water quality maps of these two studies have been presented. Water quality change maps were constructed from these two state maps by overlay transposition methods. Only electrical conductivity and chloride, the principal constituents of interest, were measured with sufficient density to be used in comparisons.

The 1944-1972 Electrical Conductivity Change Map represents the changes during that time period in 1000 μmhos. A prominent feature on this map is the chevron of improving water at the southern part of the bend in the valley. The axis of the fold defined by the contour lines follows the San Simon Creek drainage. There is an analogous chevron of poor quality water as an apparent feature in the 1944 Electrical Conductivity Map. This feature is absent from the 1972 Electrical Conductivity Map. The 1944-1972 Electrical Conductivity Change Map shows the disappearance of this salt water importation feature with the negative change chevron in the area surrounding the creek. The University of Arizona Agricultural Experiment Station Farm, Safford Branch, is located at T7S, R26E Section 22 bb. The farm is located within the chevron of improving quality, and confirmation of water quality improvement is made by analyses of the water from the principal irrigation well of the farm. This well has been regularly sampled, and the water analyzed since the acquisition of the Safford Farm in 1945 (65).

The east limb of the valley, that area to the northeast of the chevron, has changes in electrical conductivity of only small magnitude. All the observed changes were positive, and between 500 and 800 μmhos. No contours are found in this region in the Electrical Conductivity Map. A smaller contour interval would indicate relatively inhomogeneous increase patterns in the electrical conductivity, with a general increasing trend as toward the chevron.

There is a gentle fluctuation of between +1000 and 0000 μmhos between the end of the chevron until just north of Pima along the Gila River. There are two anomalous areas of +2000 and +3000 μmhos. These are both closed mounds between Safford and Pima. The area involved with this generally featureless characteristic is approximately 10 miles long, parallel to the Gila River, and the width of the underlying aquifer system, transverse to it.

The remainder of the valley to the north and northwest of Pima is relatively stable to slightly increasing tendencies along the river, with fingers of high increases indicated stemming from the terraces. There is a region of improving water quality (as shown by the reductions in electrical conductivity) just on the northern limit of the study area. This region has electrical conductivity decreases by as much as 3000 μmhos.

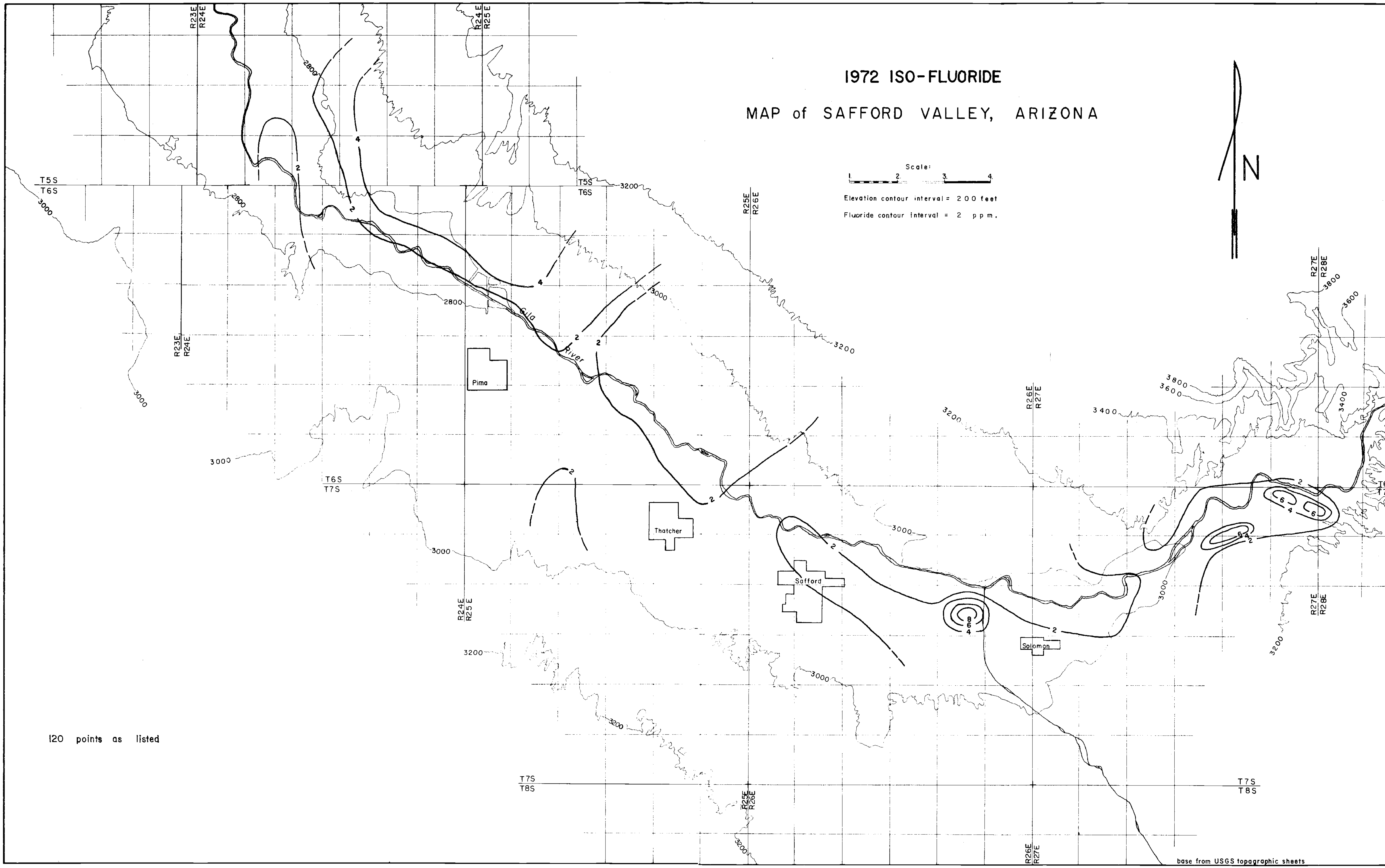
The 1944-1972 Chloride Change Map has the same principal features as described for the 1944-1972 Electrical Conductivity Change Map. The chevron of improving water is similarly associated with the San Simon Creek drainage. It should be noted that the contours on the northern side of the chevron are more closely spaced than on the south. This in quality is more violent on the side facing the Gila River than on the side away from it.

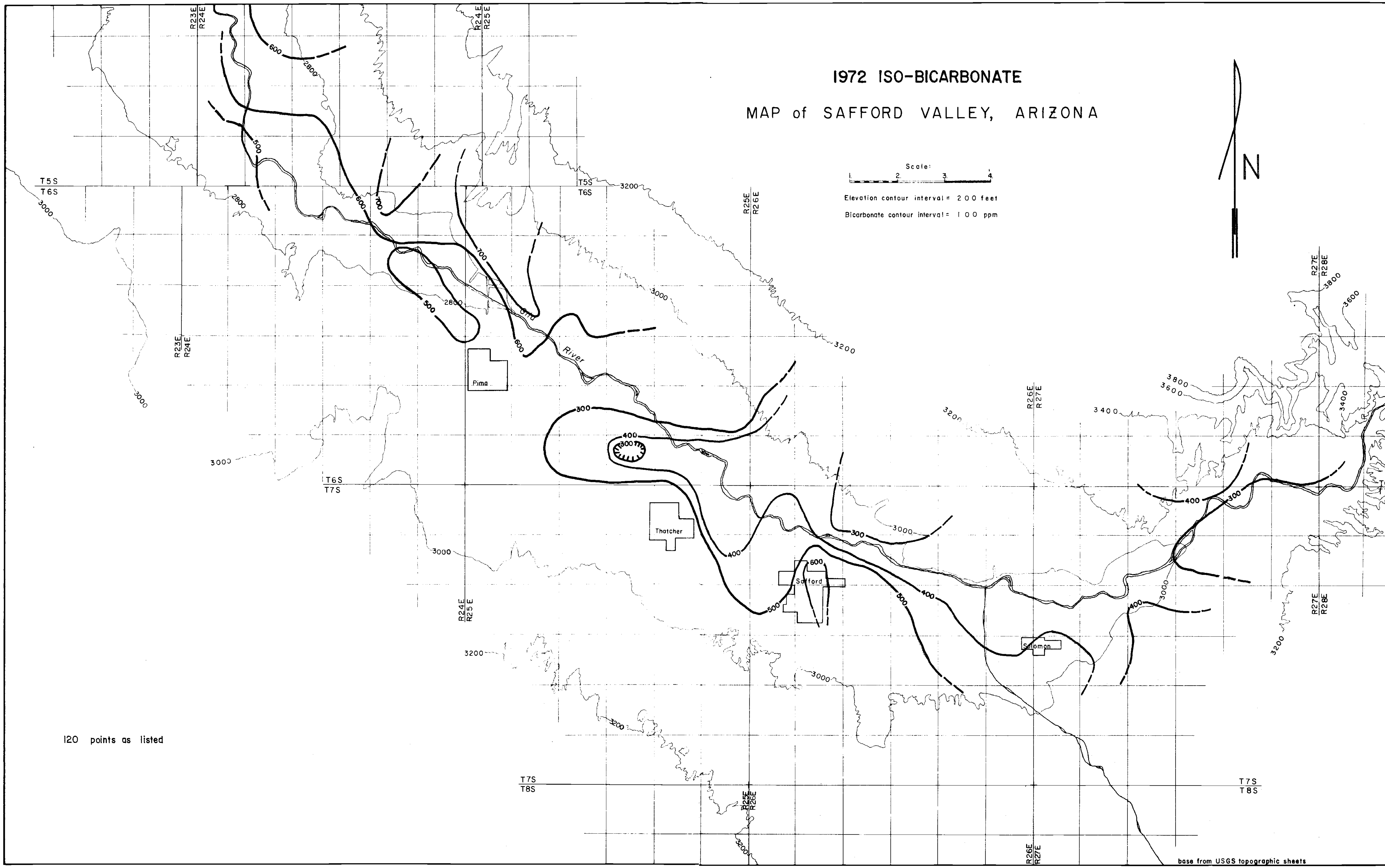
The area between Safford and Pima is a relatively homogeneous region with widely spaced contours in the neighborhood of +2000 ppm chloride. There is one small closed mound to the east of Safford with an increase of +400 ppm chloride. The irregularities to the north and northwest of Pima that are apparent in the Electrical Conductivity are reflected in the Chloride Change Map also. The relatively stable region around the river and the region of increasing salinity (decreasing chloride) on the norther limit of the study area are also apparent on the Chloride Change Map.

The relationship between the three definite regions indicated in the water quality change maps and the clusters of long-term sampling trend lines should not be overlooked. The ABC cluster is a very irregular group of lines with both increasing and decreasing segments and little close groupings. The same description applies to the quality features of the region of inhomogeneous change to the north and northeast of Pima. The DEFG cluster is very tightly grouped with uniform increases along the entire area. The D line, the most inconsistent of the four, is the one closest to the inhomogeneous region downstream. The HIJ cluster is the most gently increasing area, with strong grouping. This corresponds to the area of least increase on the east limb of the Safford Valley. In addition, the H

1972 ISO-FLUORIDE

MAP of SAFFORD VALLEY, ARIZONA




1972 ISO-BICARBONATE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
Bicarbonate contour interval = 100 ppm
N
Pima
Thatcher
Safford
Solomon
Gila River
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
120 points as listed
base from USGS topographic sheets

line of Figure 13 continually decreases. The chloride value of the H well is decreasing at a slower rate as time increases from the 1941 value, until the slope of the last segment is very similar to the I and J values. This corresponds to the disappearance of the anomalous chevron and the formation of equilibrium with the adjacent waters, since the 1972 Iso-chloride Map shows no anomalous feature at the location of the chevron, indicating that the chevron is now at or near equilibrium. The change of slope of the H line corresponds to this change in chloride content in the area.

The changes in electrical conductivity and in chloride indicated in the previous sections identify the existence and extent of the water quality problem in the Safford Valley. The problem seems to be most extensive in the northern section of the west limb of the valley. The area least affected is the relatively small and shallow east limb of the valley.

Proposed Mechanisms Causing Water Quality Changes

Figure 14 graphically represents the flow patterns of both water and salt existing in any area of the Safford Valley. The diagram is divided into areas representing the unsaturated zone, the saturated zone of the irrigation aquifer, and the saturated zone of the artesian aquifer. The unsaturated zone surface and material are further divided into field and non-field areas, as designated.

Infiltration reaching the irrigation aquifer from water applied to fields is designated by I_f. I_f is made up of pumping water P and non-pumping water such as precipitation and surface water diversion, N. This value must be reduced by evapotranspirations from the field (ET) to estimate the quantity of the I_f water. Infiltration from non-field areas is simply N less evaporation, E. The quality of these infiltration waters is dependent on the chemical characteristics of the material through which they pass in the unsaturated zone.

Lateral water moving into and in the irrigation aquifer, designated by S_i in the figure, indicates both quantity and quality of this water which is limited in volume by the transmissivity of the aquifer material, and in chemistry by the chemical properties of the same material. The hydraulic gradient set up by pumping may change the amount and configuration of flow paths of this constituent.

Leakage of the artesian aquifer, A_l, is controlled by the permeability of the constraining aquitard, the pressure of the irrigation aquifer above the aquitard, and the characteristics of the artesian aquifer. Pumping of the irrigation aquifer affects the volume of leakage water. Artesian aquifer recharge and discharge are indicated by A_r and A_o, respectively.

Pumping (P) and lateral seepage out of the system (S_o) are the outputs indicated in the figure from the irrigation aquifer. Pumping is the only variable in the system as defined which is influenced by man. The purpose of the investigation is to determine the changes in quality of this water and to propose mechanisms for these changes. Figure 14 indicates that I_f, I_o, S_i and A_l are the only contributors in both quantity and quality to the water pumped. These sources are discussed in the following sections.

Leakage from the Artesian Aquifer

It is presumed by Hem (38) that in certain areas of the Safford Basin, there is leakage from the lower aquifer into the upper aquifer as a result of a difference in head. If this mechanism does indeed exist, it may be supposed that in local areas of heavy pumpage, this head differential would be increased, at least periodically over the years, and that leakage would be more likely to occur in these regions.

Infiltration of Irrigation Waters

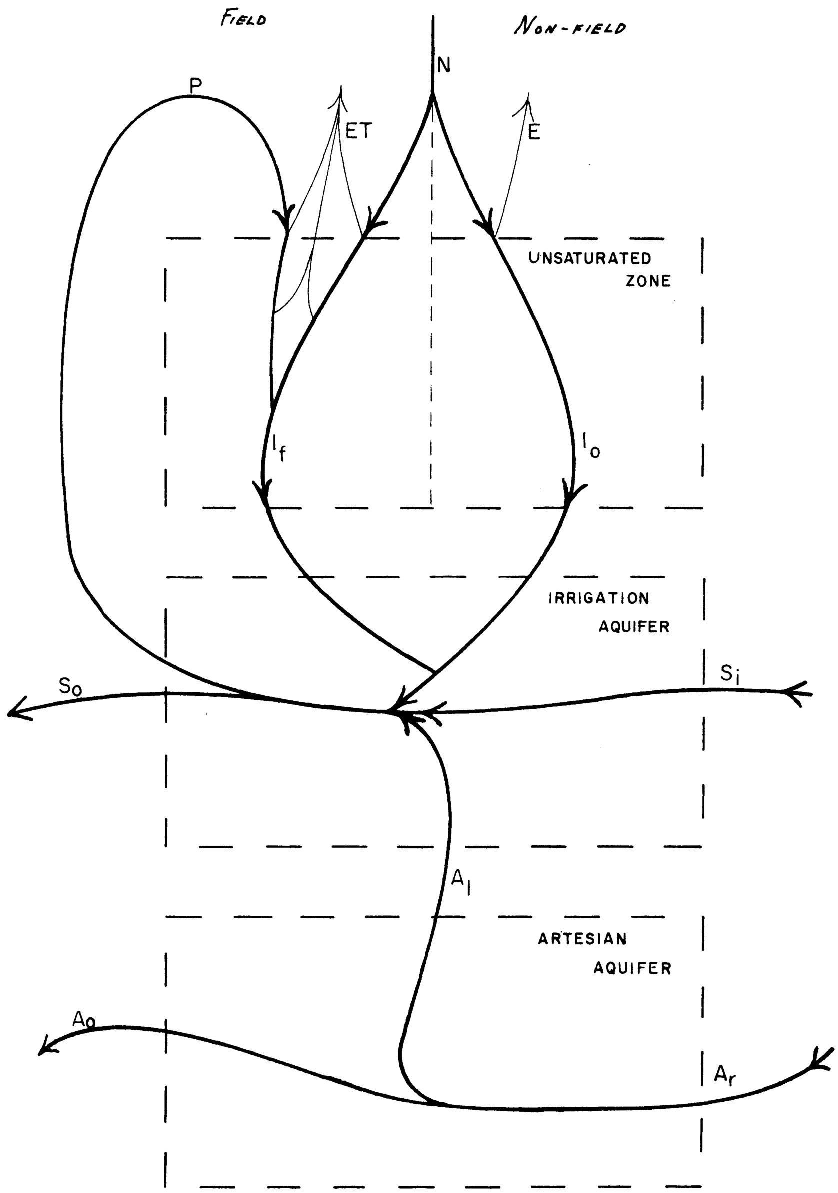
The chemical concentrations in irrigation water generally increases for two reasons. First, the water tends to leach soluble salts out of the soils through which they pass; and second, much of the water is evaporated or taken up by plants, leaving the chemicals in a much smaller volume of water. If this water reaches the water table, there would be a marked increase in dissolved matter in the water. This system is further modeled in the section discussing the quality of recharge water from irrigation.

Lateral Movement through Structures Containing Soluble Salts

In a basin such as the Safford Valley, it may be expected that a certain amount of water moving from the edges of the basin toward the center will pass through saline beds, dissolving some of the salt as it goes. This process might explain some of the highly variable wells, since locally heavy pumping could change the local lines of flow considerably. Since this irrigation aquifer has been rather heavily pumped for many years, it is also possible that a generally steeper slope has been imposed on the water table in a cross-valley direction, increasing the arrival rate of highly saline water from the terraces and decreasing the dilution effects of the river water.

Natural Recharge Salt Contributions

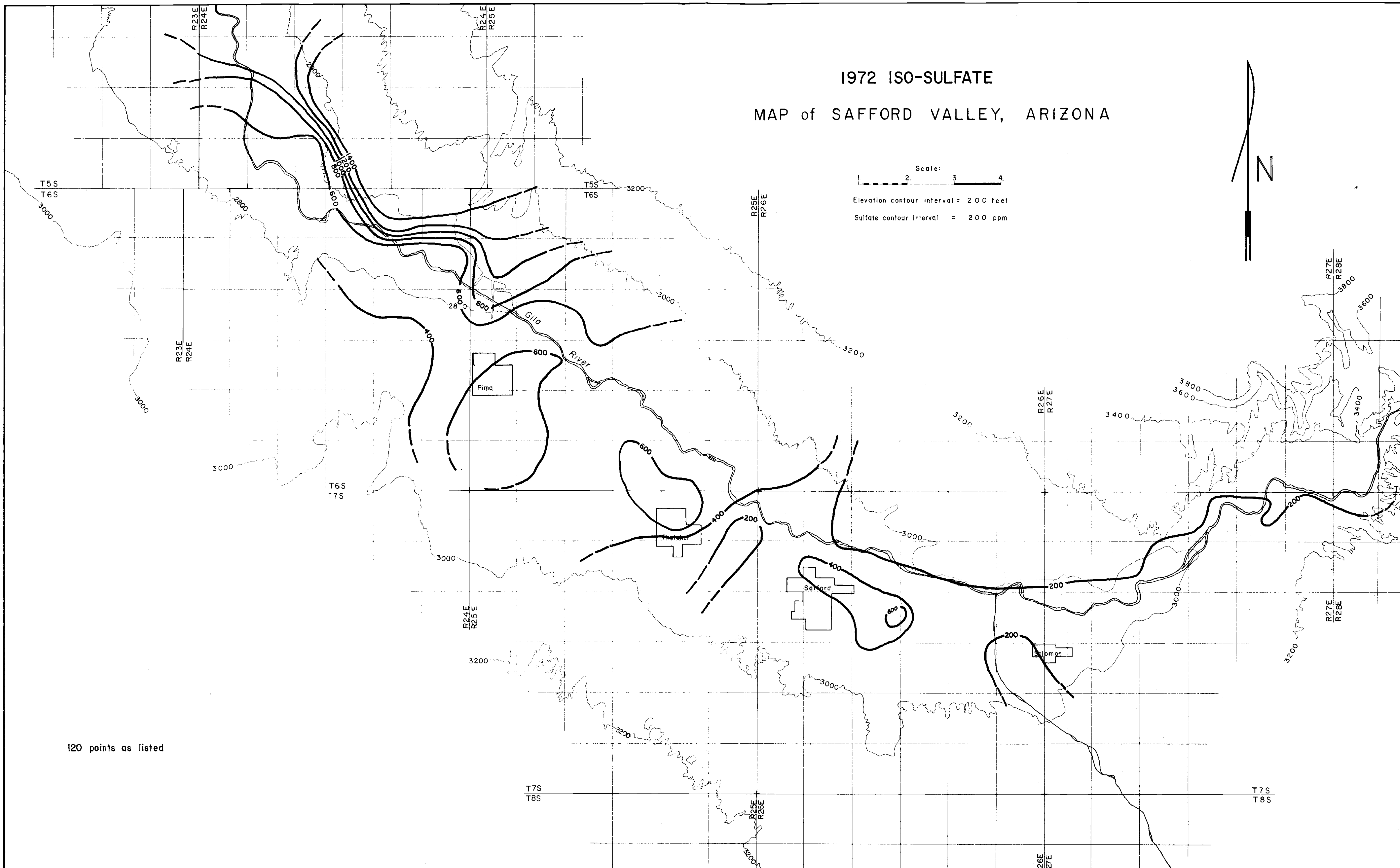
Another potential source of salinity in groundwater is influx of saline water from drainages either within or outside of the basin. In the case of the Safford Basin, water from these sources seems to be of higher, rather than lower quality, with the exception of the area around Indian Hot Springs and associated drainages. This water quality is reflected by the contours of good quality water which are apparent at the mouths of tributary washes as they enter the area of influence of the irrigation aquifer (see the water quality and topographic maps).

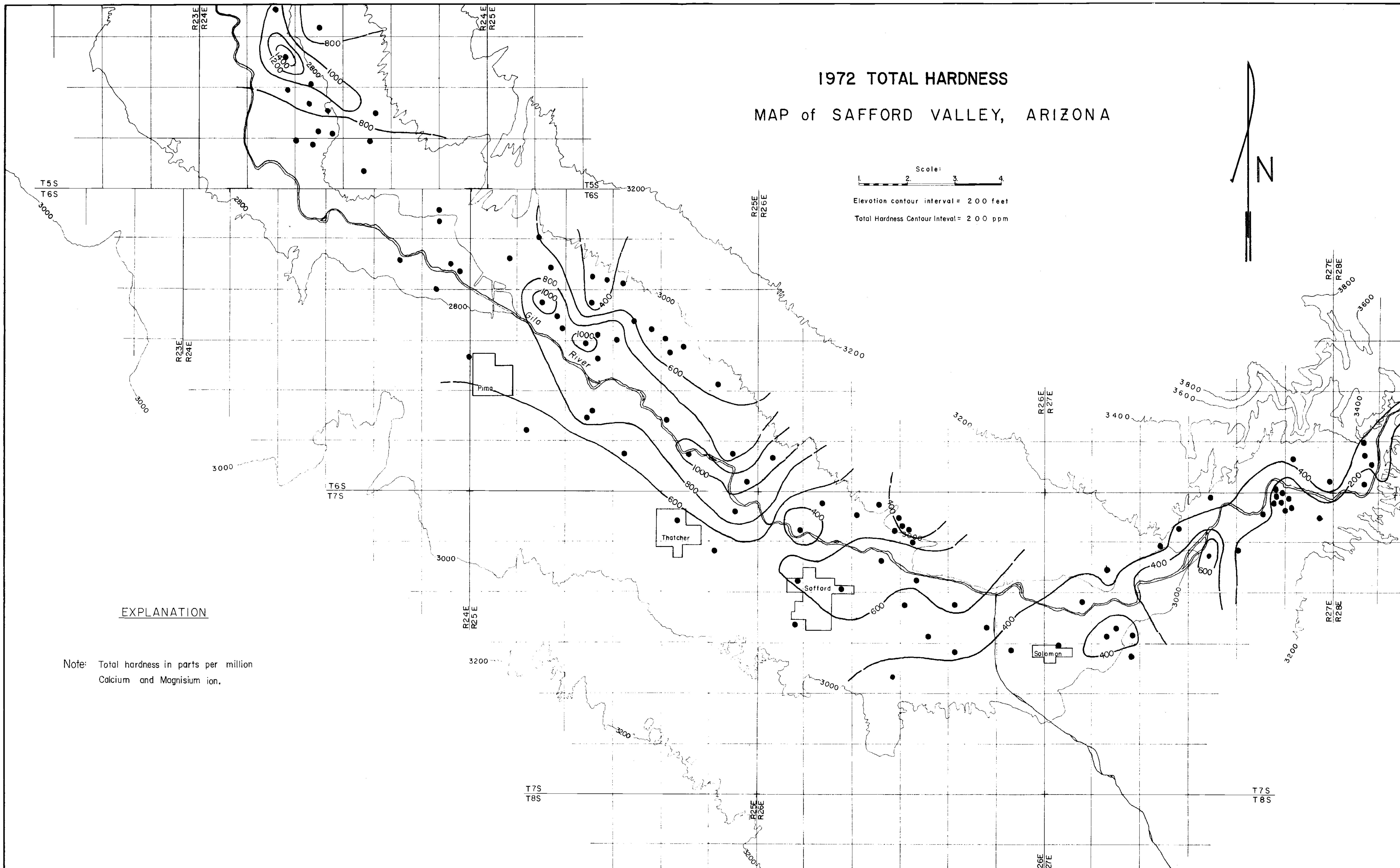


FLOW of WATER and SALTS in the PHYSICAL SYSTEM MODEL

Figure 14

1972 ISO-SULFATE MAP of SAFFORD VALLEY, ARIZONA




1972 TOTAL HARDNESS
MAP of SAFFORD VALLEY, ARIZONA
Scale:
Elevation contour interval = 200 feet
Total Hardness Contour Inteval = 200 ppm
N
EXPLANATION
Note: Total hardness in parts per million Calcium and Magnisium ion.
Pima
Thatcher
Safford
Solomon
Gila River
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
base from USGS topographic sheets

The Larson Well-Field Anomaly

In the extreme eastern end of the Safford basin is a series of wells on land belonging to Mr. Moroni Larson of Solomonsville (see Figure 15). As noted, this set of wells is very peculiar with regard to temperature variations.

In a conversation held in the field on July 11, 1972, Mr. Larson stated that he owned the land on which all of the wells are located. He further stated that when the wells were drilled all of them were hot and that the wells on the east side of the road gradually cooled after pumping. He also said that a number of the hot wells, specifically No. 8 in Figure 15, had artesian flow during the winter when pumping for irrigation stopped, and well No. 8 flowed sixty miner's inches (1 miner's inch = 0.025 cfs in Arizona) or around 675 gpm.

A statistical analysis of certain chemical contents vs. temperature was performed on these ten wells, with no conclusive results. The analysis consisted of correlation between chloride content and temperature, and sulfate and temperature. The correlation coefficient for chloride vs. temperature was 0.19, while the correlation between sulfate and temperature was 0.55. The method of calculation was

$$\rho_{XY} = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{(n - 1)\, \sigma_X \sigma_Y} \qquad [4]$$

where (X_i, Y_i) is a data pair, $\bar{X}$ and $\bar{Y}$ are average or mean values for the data sets, n is the number of data pairs, and σ_X and σ_Y are the standard deviations of the data sets.

The results are inconclusive because the chloride correlation is extremely low, while the higher sulfate correlation is expected due to the dependence of solubility of sulfate on temperature. It was hoped that this method of analysis would indicate different sources of water for the hot wells.

After numerous discussions with faculty members and graduate students in the Department of Hydrology and Water Resources at the University of Arizona, a mechanism was postulated which may explain the various aspects of this anomaly.

Since the Gila River flows over bare and shallowly buried basalt in the reach just above the San Jose Diversion Dam, where it enters the valley, it is proposed that a fault zone upstream provides the heat which is measured in wells 6 through 10. A local fault system under the alluvium could easily escape detection.

The transport mechanism is hypothesized to be an ancestral river channel of the Gila River (see Figures 16 and 17). Since the basin has filled with sediments over geologic time, it is reasonable to assume that the ancestral channel was steeper, and in that event, it is likely that the fill would be composed of relatively coarse basaltic materials. If this channel was covered at a later time with finer materials, it would develop artesian pressure due to its higher transmissivity. Furthermore, if this channel exists, it may be a primary source of recharge for the artesian aquifer which lies beneath the clay facies (see Figure 16). The fact that all of the wells were hot at the time they were drilled would result from leakage from the hot channel water into the surrounding aquifer under undisturbed conditions. If, as Mr. Larson believes, the colder wells are recharged from the Yuma Wash watershed, and all of the wells are pumped every year, this isothermal conditions could not be expected to persist.

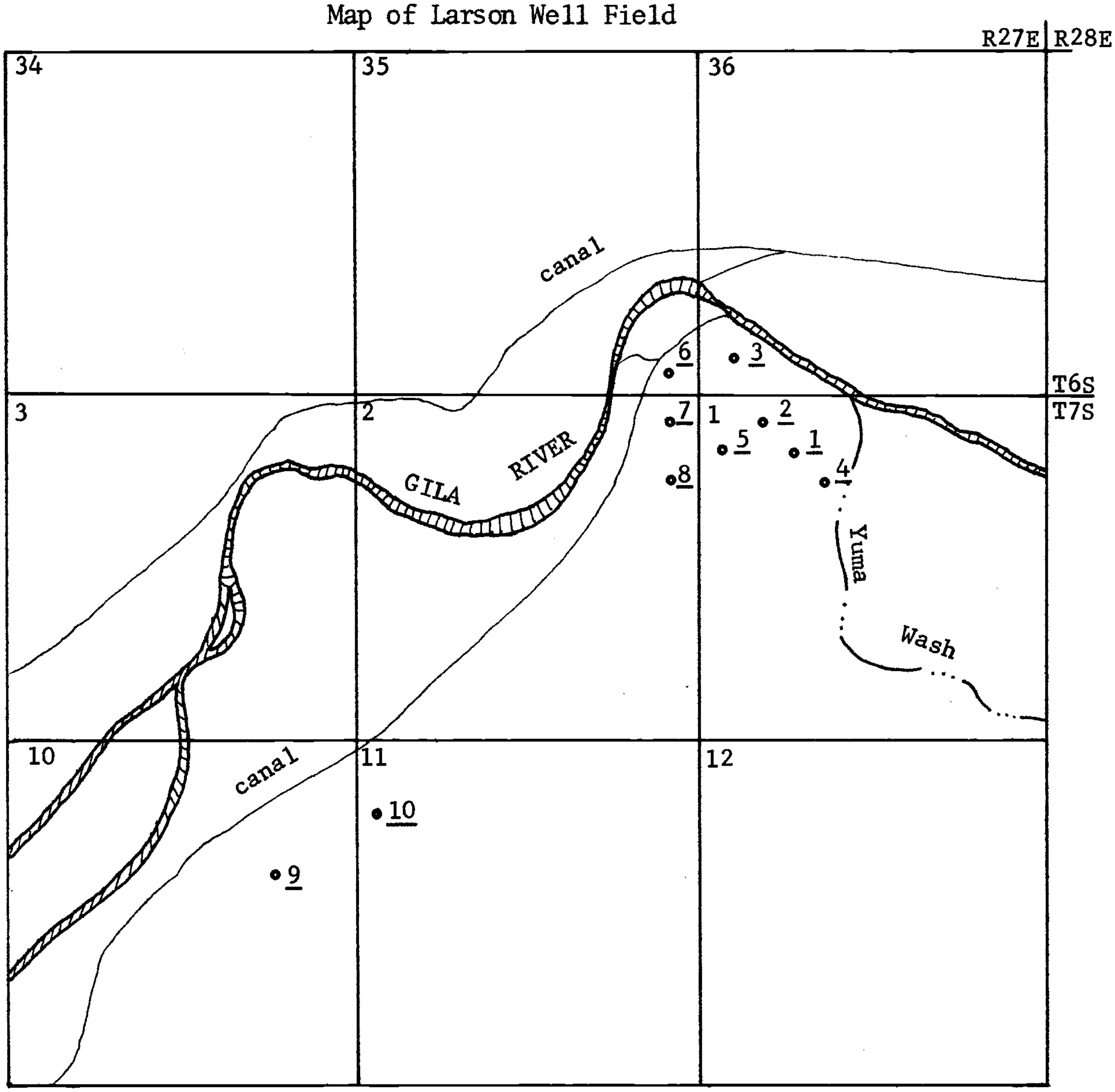
A further investigation of this anomaly might well lead to a better understanding of the hydrology of the upper Safford Basin and quantification of some of the boundary conditions for the basin. One method for this investigation might be the geothermetric technique described by Supkow (63). Dr. Supkow indicated that this area appeared to be ideal for geothermal analysis since the temperature differences in the two systems are large, and the alluvium is relatively shallow in this area.

The San Simon Creek Anomaly

A dominant feature in the water quality maps, both electrical conductivity and chloride, of 1944 is the chevron of very saline water which has the San Simon Creek as its major fold axis. The actual surface configuration of the San Simon Creek turns from this fold line, as seen in the maps, to a north-south orientation. This is an artificial alteration of the shape of this drainageway. The ancestral San Simon is thought to have flowed along the chevron. The ancestral, highly permeable, stream channel of coarse gravel offers a good media by which to transmit the salty water of the creek into the water table aquifer system proper.

The chevron does not appear in the 1969 maps of water quality, or those of 1972. The area of the chevron is shown to have recovered to an equilibrium state of salinity by the 1944-1972 Electrical Conductivity Change and Chloride Change Maps.

Figure 15
Map of Larson Well Field



Wells discussed in connection with Larson Well Field Anomaly. Wells 1 through 8 are on the Larson Property. The wells are numbered with ranking of temperature, with well 1 being the coldest.

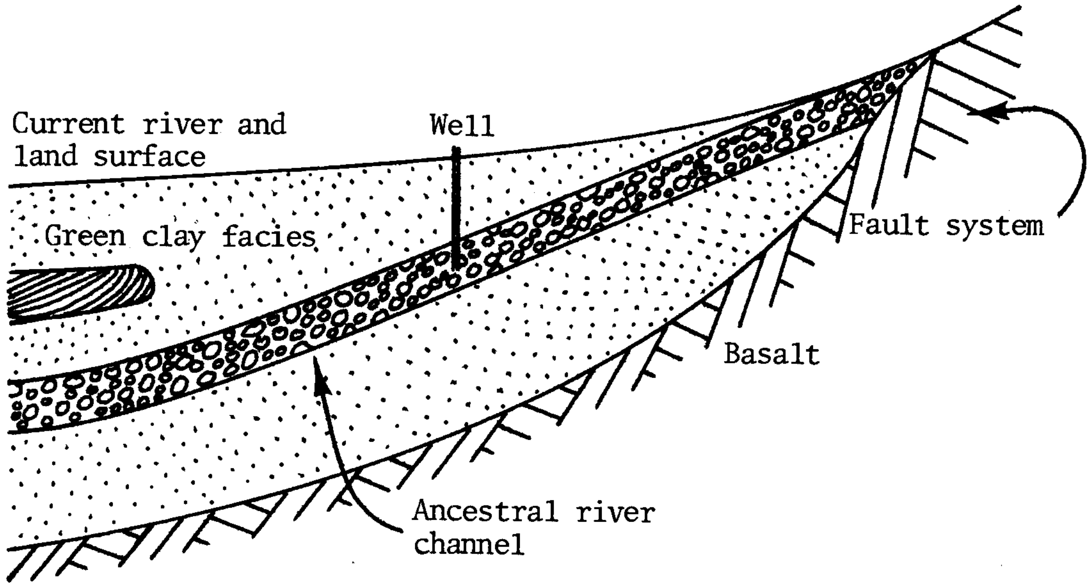


Figure 16. Cross-section View of Larson Anomaly.

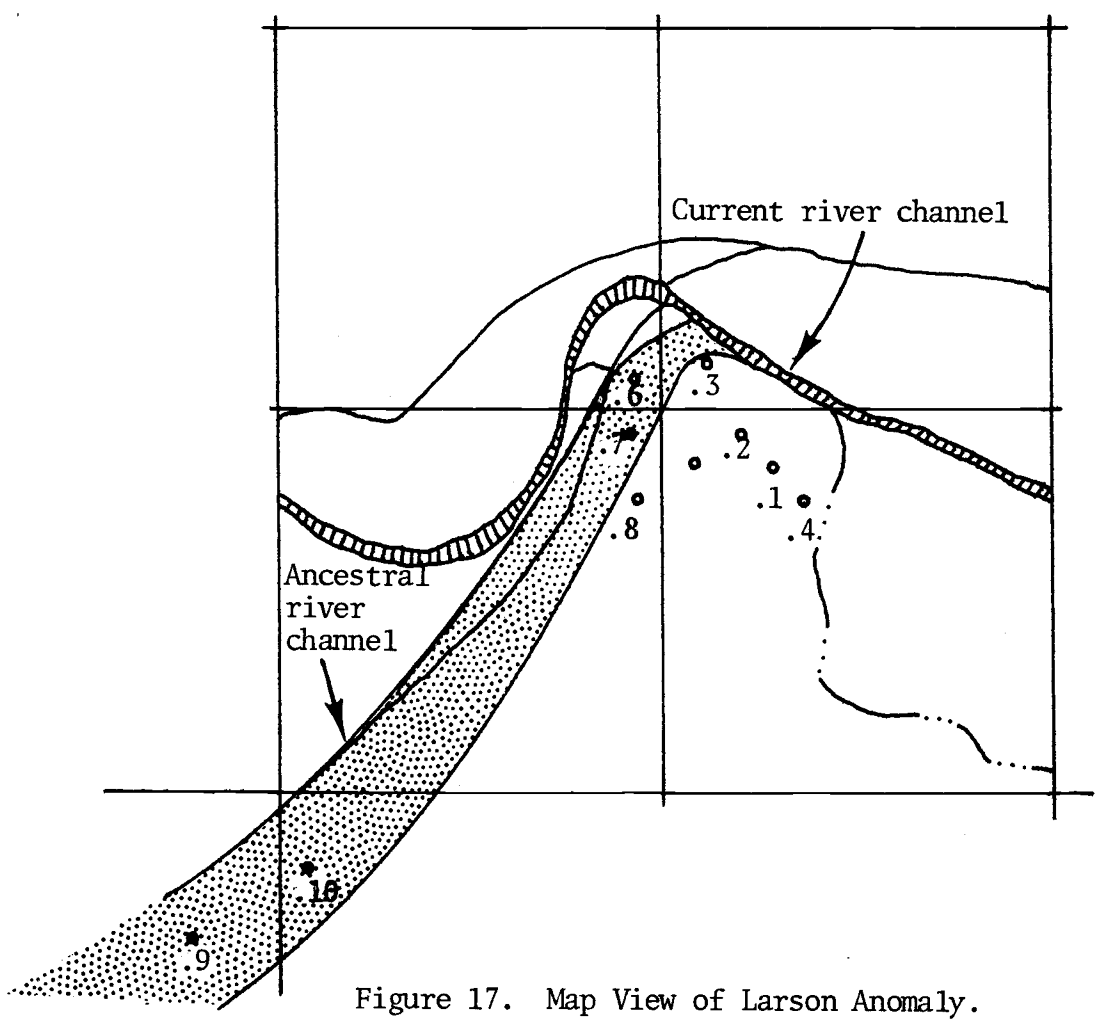


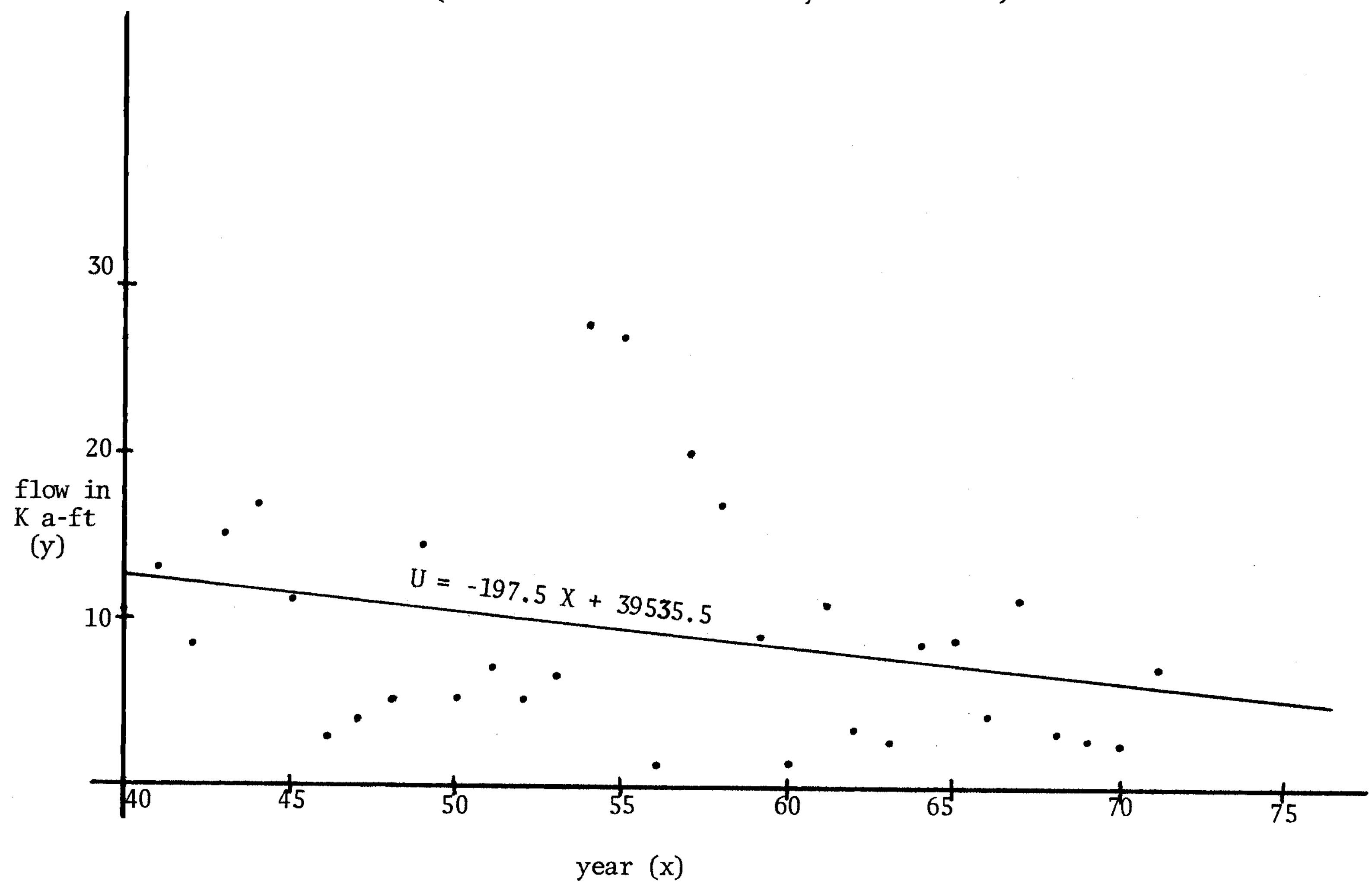
Figure 17. Map View of Larson Anomaly.

The mechanism by which this salt reduction is accomplished is not known, although a good hypothesis exists. The disappearance of this saline chevron is the dominant improvement feature in the valley. The University of Arizona Safford Experimental Farm lies within the influence of this improving water, as does one of the farms samples in the sociologic survey. Both report continual, long-range improvements in water quality of wells in the irrigation aquifer. It should be noted that, although the 1944-1972 Electrical Conductivity Map shows areas of improvement in water of wells in the irrigation aquifer, the only two improvements which have come to the attention of the participants through report of the well owners are those noted here.

It is proposed that the water of the San Simon Creek, which is extremely saline (62), is transmitted in subsurface flow through a relatively permeably ancestral stream channel. The decrease in salinity is attributed to the decrease in volume of flow in the San Simon. This decrease is documented in Figure 18 by the plot of stream flow per calendar year in San Simon Creek (in thousand acre-feet) for a period of record from 1944 to 1971, and the least squares optimum linear best fit line. The decreasing slope of this line supports the hypothesis for the mechanism. Note that a least square line for the last ten years would have a much steeper negative slope.

Figure 18

Annual Discharge of San Simon Creek
(as it enters Safford Valley near Solomon).



COMPUTER SIMULATION MODELING

MODELING OF PHYSICAL AQUIFER CHARACTERISTICS

In very general terms, there are two basic ways of modeling an aquifer system: the electrical analog model, based on the correspondence between the flow of electricity in a network and the flow of water in a porous medium; and the digital simulation model based on the mathematics of flow systems.

Electrical Analog Modeling

The electrical analog model is the older method of aquifer simulation and is still a useful tool in some limited situations. The basis for analog modeling is the relationship between electronic components and physical parameters of aquifer systems. For example, permeability in an aquifer may be logically compared to conductance (the inverse of resistance) in an electrical system, and storage in a physical system may be compared to capacitance. Similarly, a pressure difference, or head (a difference in hydraulic potential) is analogous to a voltage difference (a difference in electrical potential) in an electrical system.

The simplest analog model compares Ohm's law with Darcy's Law as follows. Ohm's Law is written:

$$I = V/R \qquad [5]$$

where I is amperage, V is voltage and R is resistance; and Darcy's Law is written:

$$Q = PIA \qquad [6]$$

where Q is the flow rate, P is permeability, I is the head difference and A is the cross-sectional area in consideration.

In the derivation of R in Equation [5], the cross-sectional area is included, so a direct comparison of resistance and permeability times area may be made. As mentioned above, voltage potential and head potential have similar mathematical properties. Now, by setting resistance and voltage in a system to correspond to permeability times area and head, we can have the electrical system produce an amperage which corresponds to a flow in the aquifer system.

In analog modeling, a grid system is devised which corresponds to the aquifer system. Usually this is done only in two dimensions, since the three-dimensional model becomes cumbersome and difficult to work on. Each node in the grid system corresponds to a physical location in the aquifer, and will have a voltage corresponding to the potential head (water table level) at that point. Between the nodes will be resistors which are scaled to represent the permeability times the unit area represented by the node.

At initial conditions, the voltage may be constant across the network, indicating a level water table throughout the aquifer. Now, if a voltage is added at a point (simulating recharge) or subtracted (simulating discharge), the other nodes may be examined to determine the water table level at other points in the aquifer.

By the addition of capacitors to simulate storativity in the aquifer, the more complex aspects of flow in a porous medium with conservation of mass, the model becomes a more complete mathematical description of the aquifer. A discussion of problems of accuracy and resolution will be included below in the discussion of the digital models used in the aquifer simulation.

The analog model is useful both as a learning instrument and a deterministic tool for decision making. If sufficient data is available for calibration, it will give excellent results. Compared to a computer, the cost is very low, which makes it a viable tool in undeveloped and underdeveloped areas. However, where computers are available, a digital approach is generally used due to the relative ease of changing parameters on computer cards as opposed to changing electronic components in the analog model. Also, as the modelling process continues in a specific basin, it may be desired to increase the resolution of the model. In digital simulation, this involves adding data cards, while in analog modelling, it would generally mean starting again.

Digital Modeling

The most widely used method for computer simulation of aquifer systems if the finite difference model as defined by Prickett and Lonnquist (55). The mathematics for this method are derived from the conservation of mass equation for non-steady, two-dimensional flow in an artesian, non-homogeneous, isotropic aquifer. This equation is

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right) = S\frac{\partial h}{\partial t} + Q \qquad [7]$$

where T is aquifer transmissivity, h is head, t is time, S is aquifer storage coefficient, Q is net groundwater withdrawal rate per area, and x and y are rectangular coordinates.

The general theory, as described by Prickett and Lonnquist is that as water is removed (or added) at a node in the grid, the effect of this change is felt in time at the node around it. This effect is a function of the transmissivity and storativity of the aquifer between the nodes. A great deal of work has been done in calibration, sensitivity testing, and streamlining of the program and data handling techniques for this method of modeling (29).

Prickett and Lonnquist describe a model of this type, giving an actual program listing and mathematical derivations of all formulae and modifications. This program is fairly complete for most aquifer situations since it includes boundary conditions, variable pumping rates, leaky aquifer conditions, induced infiltration (influent seepage from surface water sources), groundwater evapotranspiration, water table conditions and a discussion of three-dimensional simulation.

In the Safford Basin, there are numerous wells which may be sampled for water table level and water quality, but few accurate well-logs are available, and no cores from which transmissivity may be calculated are available. Pumping rates are also difficult to ascertain, since even the farmers usually have only a general idea of how much water they pump. Some data may be collected by pump tests, but pump tests are difficult to run since they require coordination with pumping needs of the well owner. Even if adequate aquifer data could be obtained for the irrigated portion of the basin, the boundary conditions would be virtually impossible to determine with confidence.

Added to this are the problems of recharge, evapotranspiration by phreatophytes, and leakage from the artesian aquifer. In general, values for these factors are obtained by water budgets and other empirical methods, and are usually calculated on a macro scale and presumed constant over the total area.

To cope with this lack of data, an empirical approach to calibration of the model is used. An average value for transmissivity and storativity are assigned to all nodes, and boundary conditions, recharge, and evapotranspiration are estimated by the investigator. Historical values for pumpage (where available) are then used for the available record, and the water table levels calculated are compared with historic values. Transmissivity and storativity are then modified by the investigator until the computer results agree to the needed precision with the historic record. During this process, the boundary conditions and recharge values may also be modified. Of course, any new data which becomes available during the investigation is also incorporated. At this point, if the simulation is satisfactory to the investigator and his sponsors, the model may be used as a predictive tool.

It should be readily apparent that the calibration is largely dependent upon the resolution of the model; that is, the distance between nodes. In homogeneous aquifers, fairly large grids may be viable, but in areas where distinct aquifer changes occur in close proximity, calibration may not be possible with large distances between the nodes. For example, in the Safford Basin, the aquifer varies in depth as you go across the valley. Since transmissivity is a function of aquifer thickness, an internodal distance of one-half mile may be required to obtain any real simulation of a local condition.

MODELING OF CHEMICAL AQUIFER CHARACTERISTICS

Predicting Quality of Recharge Water from Irrigation

Modeling Objectives

One of the proposed mechanisms to which the changes in water quality of the irrigation aquifer can be attributed is the input of saline recharge water originating from irrigation applications. The modeling of this mechanism may be accomplished by a program series developed by Dr. Gordon Dutt, and others, of the University of Arizona Department of Agricultural Chemistry and Soils for the Bureau of Reclamation of the Department of the Interior. By the application of this modeling technique to the irrigation water infiltration mechanism, it is sought to predict the concentrations of the chemical constituents reaching the irrigation aquifer.

From the predictions, profiles indicating chemical concentrations with depth are to be constructed and used to determine the water quality of the infiltration input at any given water table level in the valley. These predicted concentrations are to indicate the relative significance of this proposed mechanism of contamination respective to the other salinity inputs. The applications of this program may be made to model natural recharge situations as proposed in an alternative mechanism suggested, but the lack of data prohibits this application in this investigation (15).

Although a principle purpose of this study is to model the systems operating in the Safford Valley, with both digital representations and flow causal relationships, the infiltration water contamination mechanisms is the only one which may be simulated by current digital computer modeling techniques available.

Modeling Theory

The features of the model utilized in this investigation are limited to the contributions of salts made by the initial irrigation waters and the soil matrices through which they percolate. The interaction between the soil solutions transmitted toward the irrigation aquifer and the soil media are considered. The processes considered are irrigation water application and movement, evapotranspiration, changes in solute concentration of soil-water due to ion exchange and ionic disassociations, and the solubilities of $CaCO_3$ (lime) and $CaSO_4{:}2H_2O$ (gypsum). The model features considering nitrogen transformations (including hydrolysis of urea-N) immobilization-mineralization of ammonia-N or organic-N, immobilization of nitrate-N, and nitrogen uptake by crops are not utilized (20).

The prediction of percolating soil solutions with soil minerals is based on chemical thermodynamic relationships. The soil mineral surfaces are charged negatively due to imperfections in crystal structure. To preserve electrical neutrality in the solution-solute system, positively charges ions are attracted to these surfaces. If a solution contains such ions, referred to as exchangeable ions, comes into contact with such minerals making up an exchange resin, the ions with a greater affinity of tension to the surface are in solution, they replace those in contact with the mineral. Since this exchange is reversible, the concentrations in immediate contact with the soil materials attain chemical equilibrium concentrations (16).

Each ion pair has a unique relationship, which can be expressed by a thermodynamic equilibrium equation, relating the concentrations of the initial soil-water to the equilibrium concentrations by the chemical thermodynamic equilibrium constant of the exchange reaction. This constant (K) is a function of the mean activity coefficients of the constituents involved and the relative ionic strengths (μ). For each chemical and each exchange reaction, there is an associated change in Gibb's Free Energy, F, of the system. The total free energy change is equal to the summation of the free energy changes of the individual ion pair reactions. The F term is independent of the path of the reaction and if the reactions are reversible with pressure and temperature held constant, the initial and final reactions are also independent of the path of the reaction. This enables a determination of the concentrations of the equilibrium solutions by any path (18).

The equilibrium concentrations of the soil-water change as they drain toward the irrigation aquifer. The applied irrigation water of initial chemical concentrations infiltrates through the unsaturated zone segments of distinct chemical characteristics defined as chemical horizons used as data. The water achieves chemical equilibrium with each strata as it passes through that strata by the force of gravity. The water, then, is in a dynamic equilibrium with the soil media through which it passes. If relative cross-sectional chemical homogeneity exists underlying all irrigated areas of the valley, the concentrations of the percolating water at a given level in the profile may be taken to be the concentrating of the recharge water if the water table is at that specific level.

An additional factor influencing the amount of salts reaching the aquifer is the concentration of initial salts in the water applied to the field. Evaporation from this ponded water increases the concentrations of the solutes by reduction of the solvent volume. In the Safford area, evaporated losses from irrigation water during the period of ponding comprise a significant percentage of the total water applied.

Model Operation

The model analysis of the unsaturated zone is divided into three sections, the first section consisting of the first 21 segments from the surface, the second of the next 23, and the third section consisting of the last 22 segments. The purpose of this breakdown is to adapt the program model, usually used for shallow soil sections, to the 95 feet of unsaturated zone examined in this investigation. This is accomplished by applying the program to each section inputing the results of the preceding section.

The input to the first application of the program model is the values of the chemical concentrations of the water applied to the field for pre-irrigation. Pre-irrigation is the only water input considered since the volume of the periodic irrigation during the growing season is not considered to be sufficient to contribute recharge to the irrigation aquifer (65). The 18 inches (45.72 cm) of water applied on the average for pre-irrigation (35) is believed to have a significant contribution to the volume of recharge water. The actual significance of this volume is not determined in this investigation, but may be found by the application of the Unsaturated Flow Model which is usually used in correspondence to this chemical model, but which was unavailable to this study (20).

The initial moisture conditions of the unsaturated zone were considered to be approximately field capacity, or half the saturation percentage, as indicated in Table 7. The water applied to the field surface was taken to have a ponding period of approximately 28 hours (39). This would mean that the entire volume of water applied is removed from the surface by evaporation and infiltration during that period. Evaporation is taken to be approximately one inch during the ponding period (41). These figures assume average soil characteristics, and average diurnal temperature fluctuations during the pre-irrigation season. These moisture conditions, seepage rates, infiltration rates, and soil-moisture storage volumes are calculated for the unsaturated zone soil segments previously described and are loaded onto an input tape to be used by the main program. This information is stored in the form of retained moisture volume, moisture inflow, and moisture outflow values for each segment under consideration and each time step in the analysis.

The concentrations of the chemical constituents NO_3^-, Ca^{++}, Na^+, Mg^{++}, HCO_3^-, Cl^-, CO_3^- and SO_4^- are inputed to the program in card form. The values chosen for these input variables were indicated to be average values for pumped water from the chemical analyses made by the study and calculated in Table 3. The second and third applications of the program use the predicted concentrations by the prior section analyses. The chemical concentrations of the soil segments for the same ions as in the irrigation water analyses were inputed to the program with the exchange capacity, gypsum content, bulk density, soil organic matter coefficient, and carbon-nitrogen ratio for each segment (19). These values appear in Table 7 as measured by the Agricultural Experiment Laboratory.

The full capability of the program model was not required since options for fertilizer contamination, organic contamination, repeated irrigation applications, plant root distribution, plant nitrogen uptake, and irrigation water additives were not needed. There are no plants in the field during pre-irrigation, and the periodic irrigations were neglected as described above.

The water infiltrated during each time period is considered to move as a unit volume, or slug, through the entire set of soil horizons in a time independent manner which allows chemical equilibrium to be reached. The slug is considered to be of constant width and equivalent to that of the initial ponded water. The temperature throughout each segment is also considered to be fixed with a value of 25 degrees Centigrade.

With the conditions stated above, the program was executed with the three sets of data from the three sections of the unsaturated zone. The results of these analyses appear in Table 9 and interpretations follow.

The assumptions of average quality infiltration water, as indicated by the Appendix and by Table 3, were used. The water quality values used appear in Table 8.

TABLE 7

Soil Chemistry Analysis Results

Field No.	1	2	3	4	5	6	7	8	9	10
Depth range of sample (ft)	1-12	12-30	30-48	48-49	50-52	52-56	56-58	56-60	60-63	63-69
Lab No.	3640	3641	3642	3643	3644	3645	3646	3647	3648	3649
Soluble Salts (ppm)	406	322	434	357	378	371	308	448	385	525
EC x 10^3 for 1:2 extract	.58	.46	.62	.51	.54	.53	.44	.64	.55	.75
Calcium (ppm)	17	15	25	17	18	19	12	26	20	22
Magnesium (ppm)	4	5	6	7	6	9	5	7	8	10
Sodium (ppm)	88	71	87	77	80	80	70	98	95	137
Chloride (ppm)	150	120	150	104	120	120	104	140	200	225
Sulfate (ppm)	70	60	75	95	80	75	70	90	70	100
Carbonate (ppm)	0	0	0	0	0	0	0	0	0	0
Bicarbonate (ppm)	122	122	134	166	134	134	98	151	183	183
Nitrate (ppm)	37.5	15.0	107.5	17.5	20.0	7.5	15.0	130.0	7.5	17.5
pH on 1:2 extract	8.7	8.6	8.25	8.25	8.3	8.6	8.8	8.1	8.5	8.6
Saturation Percentage	29	32	34	58	44	31	31	33	49	78
CEC	7.3	8.1	14.1	23.5	16.8	13.5	9.5	12.5	16.5	17.2
Field No.	11	12	13	14	15	16	17	18	19	20
Depth range of sample (ft)	69-72	72-74	74-75	75-79	79-84	84-85	85-89	89-90	90-92	92-95
Lab No.	3650	3651	3652	3653	3654	3655	3656	3657	3658	3659
Soluble Salts (ppm)	784	1085	616	588	1568	1925	1680	2555	1484	574
EC x 10^3 for 1:2 extract	1.12	1.55	.88	.84	2.24	2.75	2.40	3.65	2.12	.82
Calcium (ppm)	23	9	8	7	11	10	10	10	6	7
Magnesium (ppm)	13	7	4	5	5	8	5	8	8	3
Sodium (ppm)	207	336	208	189	491	600	520	850	475	192
Chloride (ppm)	350	465	275	250	640	725	700	1000	625	180
Sulfate (ppm)	130	130	100	95	165	195	155	235	145	80
Carbonate (ppm)	0	0	0	0	0	0	0	0	0	0
Bicarbonate (ppm)	183	244	232	244	279	305	244	305	244	193
Nitrate (ppm)	15.0	17.5	15.0	15.0	12.5	15.0	12.5	20.0	10.0	10.0
pH on 1:2 extract	8.4	8.8	8.5	8.5	8.85	8.9	8.85	8.95	8.85	8.7
Saturation Percentage	84	146	107	111	150	127	115	183	117	42
CEC	20.5	23.6	20.1	27.0	26.3	5.1	24.9	28.2	21.7	26.1

TABLE 8

Average Irrigation Water Chemistry

Constituent	Concentration
EC x 10^3	3.1 millimhos
Ca^{++}	100 ppm
Mg^{++}	35 ppm
Na^{+}	450 ppm
Cl^{-}	736 ppm
$SO_4^{=}$	321 ppm
$CO_3^{=}$	0 ppm
HCO_3^{-}	250 ppm
NO_3^{-}	12 ppm
Fl^{-}	1.6 ppm
pH	7.2

Model Results

Tables 9, 10 and 11 present the predicted ionic concentrations for the first, second and third sections of model, respectively. The concentrations appear in units of micrograms of constituent per soil segment. The soil segment volumes appear in terms of cubic centimeters of water in the segment in the last column of the tables. The following relationship indicates

$$\frac{\mu \text{ gm salt}}{\text{CC } H_2O} \approx \frac{\mu \text{ gm salt}}{\text{gm } H_2O} = \frac{10^{-6} \text{ gm salt}}{\text{gm } H_2O} \equiv 1 \text{ ppm} \qquad [8]$$

Figure 19 shows a chemical profile of chloride ion as predicted by the chemical model. The chloride concentrations in parts per million as calculated with Equation [8], are plotted against depth in this figure. The initial concentration of chloride in irrigation water is 736 ppm from Table 8. At 95 feet, the extent of available modeling impact data, the chloride concentration has risen to 2209 ppm, or approximately three times the initial value. The three prominent spikes in the profile at 6, 36 and 80 feet represent sharp increases in salinity associated with highly saline evaporitic lacustrine beds.

The profile in Figure 19 may be used to predict the quality of percolating water as it reaches the water table, if the assumption is made that the chemistries of the unsaturated zone samples used in the model are not unrepresentative of the unsaturated zone pervasive in the valley. If such an assumption is made, the depth to the water table (from the July 1972 Water Table Map) may be used to find the corresponding chloride concentration from Figure 19.

The concentrations of salt in this percolating water seem to be sufficient to label this as significant, although further analysis is required to show what volume of water with this predicted quality actually reaches the aquifer.

Additional Chemical Aquifer Models

With some modifications, calibration of the finite difference model to the Tucson Basin in Arizona has been investigated by J. Gates and others of the University of Arizona (29). Further study of this aquifer system is continuing with emphasis on water quality.

Since the partial differential equation used in the finite difference model (Equation [7]) approaches the dispersion equation if the distance elements approach zero, it was decided to use the existing model with a mass balance for dissolved solids included. In this approach, the total amount of an element which reaches a node in a time interval is mixed completely with the total water arriving at the node at that time and leaves the node in proportion to the amount of water leaving the node. Several of the complications of aquifer chemistry will be

TABLE 9

Segment 1: Predicted Water Quality

PREDICTED AMOUNTS(UG/SEGMENT OF SOIL)--(SEGVOL=CC WATER/SEG SOIL)

SEG	NH3	NO3	UREA	ORN	CA	NA	MG	HCO3	CL	CO3	SO4	ENH4	SEGVOL
2	.000	433.416	0.000	0.000	1988.159	8759.933	491.782	8367.092	14619.999	0.000	3461.002	.000	10.607
3	.000	697.454	0.000	0.000	2098.735	10110.755	509.096	11474.690	17020.251	0.000	3823.275	.000	10.607
4	.000	874.971	0.000	0.000	2127.581	11[illegible]18.940	515.713	13563.453	18633.988	0.000	3937.297	.000	10.607
5	.000	3034.424	0.000	0.000	6198.326	35490.513	1508.399	45678.008	50177.416	0.000	11089.294	.000	10.607
6	0.000	1239.195	0.000	0.000	2293.54	12882.316	555.565	17849.088	21944.986	0.000	4531.078	.000	10.607
7	0.000	1239.195	0.000	0.000	2293.54	12882.316	555.565	17849.088	21944.986	0.000	4531.078	.000	10.607
8	0.000	1239.195	0.000	0.000	2293.54	12882.316	555.565	17849.088	21944.986	0.000	4531.078	.000	10.607
9	0.000	1239.195	0.000	0.000	2293.54	12882.316	555.565	17849.088	21944.986	0.000	4531.078	.000	10.607
10	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
11	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
12	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
13	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
14	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
15	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
16	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
17	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
18	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
19	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
20	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704
21	.000	491.581	0.000	0.000	2038.781	10393.304	709.028	17849.088	17535.237	0.000	3893.954	.000	11.704

TABLE 10

Segment 2: Predicted Water Quality

PREDICTED AMOUNTS(UG/SEGMENT OF SOIL)--(SEGVOL=CC WATER/$EG SOIL)

SEG	NH3	NO3	UREA	ORN	CA	NA	MG	HCO3	CL	CO3	SO4	ENH4	SEGVOL
2	0.000	1256.595	0.000	0.000	3212.562	13104.542	805.256	21794. 51	22263.366	0.000	7188.719	.000	12.450
3	0.000	2005.962	0.000	0.000	3246.692	12976.615	801.064	21086.244	22159.039	0.000	8050.455	.000	12.450
4	.000	2509.777	0.000	0.000	3171.487	12890.607	782.381	20610.372	22088.898	0.000	8331.790	.000	12.450
5	.000	8692.937	0.000	0.000	8744.713	39162.543	2167.060	61921.488	67266.055	0.000	23414.469	.000	12.450
6	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
7	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
8	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
9	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
10	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
11	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
12	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
13	0.000	3543.483	0.000	0.000	3198.538	12714.139	788.665	19633.997	21944.986	0.000	9520.160	.000	12.450
14	0.000	495.678	0.000	0.000	2284.624	11503.269	904.415	21151.169	16808.925	0.000	10598.210	.000	16.220
15	0.000	495.678	0.000	0.000	2284.624	11503.269	904.415	21151.169	16808.925	0.000	10598.210	.000	16.220
16	0.000	495.678	0.000	0.000	2284.624	11503.269	904.415	21151.169	16808.925	0.000	10598.210	.000	16.220
17	0.000	495.678	0.000	0.000	2284.624	11503.269	904.415	21151.169	16808.925	0.000	10598.210	.000	16.220
18	0.000	495.678	0.000	0.000	2284.624	11503.269	904.415	21151.169	16808.925	0.000	10598.210	.000	16.220
19	0.000	1679.579	0.000	0.000	2465.537	12848.681	913.295	21061.924	21633.709	0.000	9970.412	.000	13.780
20	0.000	1679.579	0.000	0.000	2465.537	12848.681	913.295	21061.924	21633.709	0.000	9970.412	.000	13.780
21	0.000	1679.579	0.000	0.000	2465.537	12848.681	913.295	21061.924	21633.709	0.000	9970.412	.000	13.780
22	0.000	1679.579	0.000	0.000	2465.537	12848.681	913.295	21061.924	21633.709	0.000	9970.412	.000	13.780
23	0.000	1679.579	0.000	0.000	2465.537	12848.681	913.295	21061.924	21633.709	0.000	9970.412	.000	13.780

TABLE 11

Segment 3: Predicted Water Quality

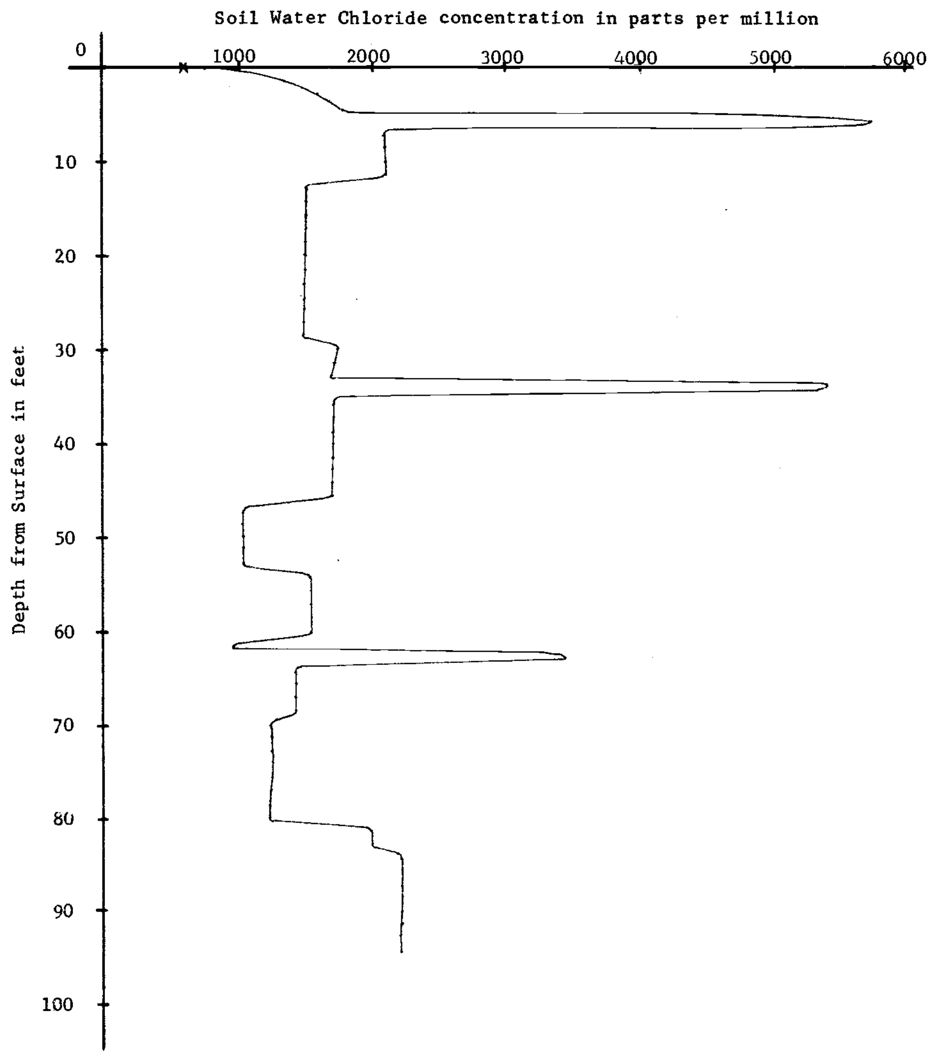
PREDICTED AMOUNTS(UG/SEGMENT OF SOIL)--(SEGVOL=CC WATER/SEG SOIL)

SEG	NH3	NO3	UREA	ORN	CA	NA	MG	HCO3	CL	CO3	SO4	ENH4	SEGVOL
2	0.000	453.079	0.000	0.000	2656.333	17644.553	1365.545	24164.287	29556.638	0.000	12867.662	.000	29.600
3	0.000	1466.252	0.000	0.000	7468.237	61428.817	3896.005	76352.897	102665.376	0.000	37954.124	.000	29.600
4	0.000	535.643	0.000	0.000	2902.160	25226.467	1508.387	26773.632	42022.313	0.000	15309.051	.000	29.600
5	0.000	535.643	0.000	0.000	2902.160	25226.467	1508.387	26773.632	42022.313	0.000	15309.051	.000	29.600
6	0.000	535.643	0.000	0.000	2902.160	25226.467	1508.387	26773.632	42022.313	0.000	15309.051	.000	29.600
7	0.000	535.643	0.000	0.000	2902.160	25226.467	1508.387	26773.632	42022.313	0.000	15309.051	.000	29.600
8	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
9	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
10	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
11	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
12	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
13	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
14	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
15	0.000	495.678	0.000	0.000	1151.866	33635.290	697.790	36590.630	59661.308	0.000	16717.781	.000	47.100
16	0.000	450.616	0.000	0.000	1136.651	77361.166	863.283	34805.722	94420.505	0.000	23289.572	.000	47.100
17	0.000	450.616	0.000	0.000	1136.651	77361.166	863.283	34805.722	94420.505	0.000	23289.572	.000	47.100
18	0.000	450.616	0.000	0.000	1135.496	77361.166	862.567	34805.722	94420.505	0.000	23283.976	.000	42.730
19	0.000	450.616	0.000	0.000	1135.496	77361.166	862.567	34805.722	94420.505	0.000	23283.976	.000	42.730
20	0.000	450.616	0.000	0.000	1135.496	77361.166	862.567	34805.722	94420.505	0.000	23283.976	.000	42.730
21	0.000	450.616	0.000	0.000	1135.496	77361.166	862.567	34805.722	94420.505	0.000	23283.976	.000	42.730
22	0.000	450.616	0.000	0.000	1135.496	77361.166	862.567	34805.722	94420.505	0.000	23283.976	.000	42.730

incorporated into the model at a later date, including reactions between components during the mixing process. Of primary interest in this investigation are heavy metals and nitrogen.

Figure 19

Predicted Chloride Cross-sectional Profile for Soil Water Solution
(from percolating water model)



E C O N O M I C   S Y S T E M

ECONOMIC ENVIRONMENT OF THE SAFFORD VALLEY

PURPOSES OF MODELING THE ECONOMIC SYSTEM

In the simplest sense, this investigation is concerned with the interaction between two existing systems of differing sorts: a natural, physical system and a human social system. The natural, physical system -- which will be (at least conceptually) isolated from the more extensive physical system of which it is a part -- is the complex of hydrologic phenomena occurring in the Safford Valley area. The human social system comprises the residents of the Safford Valley and their interactions.

Obviously, many possible interactions may be envisioned as taking place between any group of human beings and its physical environment. In an actual situation such as that existing in the Safford Valley, though, the nature of this interaction may be taken as given; it has been determined over the years by time and chance, the varied motives of men and women, such physical considerations as those of climate and soil type, and countless other factors. The people of the Safford Valley use nearly all of their water in irrigated agriculture, rather than as tourist attraction or input in the manufacture of some industrial product such as steel or textiles. Further, irrigated agriculture is the valley's most important economic activity. Substantiating statistical information appears in the introduction of this paper. It should be reiterated at this point that agriculture is pre-eminently an economic activity; that is, a purposive activity carried out by a human agent to achieve an economic goal, the consumption of goods and services. In practical terms, a Safford Valley farmer grows and sells his cotton, sorghum and alfalfa to make as much money as he can, ultimately permitting him to maximize his consumption of goods and services. Admittedly, this is a rather simplistic and stylized view of human motives, but it should not seem intuitively implausible when considered in the context of economic activity. It further permits the development of economics as a predictive model of human behavior, capable of determining the end economic result of some hydrologic change (such as an increase in groundwater salinity) which affects crop output in a specified fashion. Such an economic result can not only be seen as the direct social effect of a cause which happens in the physical environment, but as the means through which other, secondary, social effects are brought about. This reasoning, in which the causal nexus between the physical and social systems is seen as economic in nature, led to the inclusion in the project of an economic model cell which functions as the means by which "hydrologic cause leads to social effect."

FOCUS OF ECONOMIC INVESTIGATION

The economic model cell focuses exclusively on the valley's irrigated agriculture; no consideration is given to either industrial or municipal uses of water. This includes both the modeling that follows and the system analogy proposed by the Inter-System Flow Model.

The justification of such a procedure is simply that, in the Safford Valley, these omitted uses are of minimal economic importance relative to the use of water in agriculture. Several considerations underlie this judgment, the most important of which are the inescapable facts of, first, the overriding economic importance to the valley of its irrigated agriculture, and second, the fact that most of the valley's water supply is used in agriculture. The case for the first point can be found above, in "Purposes of Modeling." The latter point deserves some elaboration. Available data on water use in the Safford Valley do not present a complete picture of the situation. Gila River water, for instance, is carefully apportioned and accounted for (35). On the other hand, no information has come to light which directly reports the amount of pumped water used. For present purposes, it seems satisfactory to note that over 90 percent (81) of all water used in Arizona is employed in irrigated agriculture and that this proportion must certainly be higher in the case of a sparsely populated, heavily agricultural area such as the Safford Valley.

Of substantial import here is that returns per unit of water used are generally much higher in non-agricultural sectors than in agriculture. An example is given by Young and Martin (47):

> Recently . . . a large meat processing company decided to build a livestock slaughter facility in Tolleson. Their water demands seem large -- 2 to 2.25 million gallons a day or about six to seven acre-feet. However, in a year this plant would use no more water than would, for example 600 acres of sorghum. Six hundred acres of sorghum generate about $58,000 per year of gross income and about 9,000 man-hours . . . of employment. The work force contemplated for the processing plant is about 225 employees, or some 65 times as large as the sorghum crop. The relative volume of income generated by the proposed plant would probably be even larger since wages in such employment are greater than in farming.

They also state: "The various non-agricultural sectors generate incomes ranging from 20 to nearly one thousand times as large per acre-foot of water as even high value intensive agricultural sectors." (47) The point is that productivity per unit of water is so great as to, in effect, guarantee a water supply for these uses; a manufacturer or municipality faced with a salinity problem would probably find importation of acceptable water economically feasible. On the other hand, agricultural users, faced with low productivity per unit of water (as well as much greater demand, in absolute terms) presumably would be much less likely to import water. Finally, no substantial industrial use of water exists in the Safford Valley at present. These, in sum, are the kinds of considerations which led to a wholly agriculture-centered model.

A brief overview of this model will be given here, to facilitate the reader's understanding of the discussion which follows. On the advice of the project advisor in agricultural economics, Dr. William Marin, a format was chosen in which the aggregate of the valley's agriculture is encapsulated into one "representative farm." Data on crop budgets and cropping patterns provide a detailed description of this farm's operation. This information establishes the "initial conditions" for operation of the farm model. At this point the hydrologic model cell is used to generate a change (presumably in the direction of increased salinity) in water quality. The effect of this change on crop yields (and thereby on farm profits) can then be computed, using a table of production functions relating crop yields to root-zone soil salinity.

The farmer confronted with such a situation has three broad responses. He may simply accept a reduced yield, and hence a lower net return; or he may use excess water to leach built-up salt deposits out of the root zone. Finally, he may change his cropping patterns in a number of ways, generally in the direction of emphasizing the most salt-tolerant and/or most profitable crops. Of course, any combination of these courses of action may be selected. A principal objective of the model is to determine valley farmers' response to the salinity problem; this aspect will be examined below in detail.

Farmer response will also be considered in the context of the valley as a community. This matter will not be treated in the formal model itself, but will be discussed on an intuitive basis in the perspective of Arizona agriculture and trends in agriculture generally.

ECONOMIC THEORY AND ITS APPLICATIONS TO THIS STUDY

As previously stated, economic theory provides a conceptual framework for design and operation of the economic model cell. This section has the broad objective of presenting those parts of economic analysis relevant to the problem at hand. Additionally, some remarks on methodology will be offered, in which the virtues and limitations of the experimental procedure will be examined, and any caveats set forth.

It should be noted here that economic theory is, in itself, a sort of model; the type of reasoning used to derive economic theory is similar to that used in all phases of the present study. The following sentences from Ferguson's popular text, Microeconomic Theory, (24) are offered not only as descriptive of the theorizing process in economics but as a sketch of the modeling theory in general:

> The economist, having begun with a portion of the real world, proceeds, through the use of completely theoretical means, to arrive at conclusions about the real world. His first step entails abstraction from the real world into a simplified logical model. His second step requires the use of logical argument to arrive at an abstract conclusion. His final step consists of a return to the real world by means of an interpretation that yields conclusions in terms of the concrete, sensible world of physical reality. (24)

It should further be mentioned that, to the extent economic theory is herein employed, it involves only what has been called "standard firm analysis." While the techniques used in the present study are applied to the operation of a representative Safford Valley farm, they are equally applicable to the operation of some "representative" industrial firm facing the sort of market discussed in this section.

THE REPRESENTATIVE FARM

The starting point of this analysis is a construct referred to as "the representative farm." It is meant to be a microcosm of the total of farming operations in the Safford Valley. Information on size and cropping patterns has been provided by sociologists (51) and the aerial survey of the crop distribution (as indicated in the Land Usage Map): data on costs and returns are from Wildermuth, Martin and Riech, Costs and Returns Data for Representative General Crop Farms in Arizona (26). Combining these two sets of information yields the initial (pre-operative) conditions of the model, a detailed picture of the economic aspects of farm operation in the valley.

At this stage, the data for the representative farm amount to a series of budgets, one for each crop grown; the relative proportions of each crop which comprise the total output of the farms surveyed; and water demand figures, stated in terms of both quantity and quality. Figures for quantity of water demanded are again taken from Wildermuth, Martin and Riech (75), while the project hydrologists have specified an initial water quality level with electrical conductivity of 4×10^3 mhos, from base year 1972. Thus, the representative farm's water demand is in terms such as, "X acre-feet of water equal in quality to that of 1972." This information will be presented below in detail, as comprising the initial conditions for operation of the farm model.

Any experimental procedure represents a compromise between competing needs; in this case, the method of attack chosen seemed appropriate to the problem and yet feasible given the time and money allotted to the project. More complex experimental procedures were considered, such as the use of linear programming techniques to compute water demand and farmer response (26). The use of the these methods, though, seemed to violate a fundamental economic criterion in that their marginal cost in terms of time and complexity was much greater than their marginal benefit in terms of increased or more certain knowledge. A problem of this sort has a very high degree of built-in uncertainty (see below, the section discussing the limits of ceteris paribus conditions) and it was concluded that further methodological complexity would generate no real payoff in terms of real-world implications.

THE FARM AS AN OPTIMIZING UNIT

Budgeting techniques will be used to predict the behavior of the farm when confronted with a change in water quality. The only assumption necessary is that the farm be a profit maximizer -- that is, that the purpose of its operation be to maximize net return.[1] In the context of this analysis, the farm will continue to operate as long as returns from production exceed variable costs. It is conceivable that such net returns may not cover fixed costs and that the individual farmer may operate at a loss, or choose to sell his farm; but these are complex questions which will be avoided in operation of the model per se, since they involve unspecified (and probably unspeficiable) variables such as the individual farmer's opportunity cost as well as time-lagged concepts as expectations.

Rather, the model itself will be used in a "short-run" sense; this means that such factors as farm size and technology are taken as given. The "long-run" -- in which these factors may change -- will not be treated in the formal model, as it is incapable of handling such changes. These considerations will, however, be dealt with in the conclusion.

The important concept here is that the assumption of profit maximization gives rise to a determinate resource allocation on the part of the farmer, referred to herein as "equilibrium." Once this state is reached, the maximizing farmer will not deviate from it and indeed will return to it after temporary disturbances.[2] Any permanent change in product prices, resource costs, or the physical relations of production (production function) will result in an adjustment to a new, though not necessarily different, equilibrium.

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[1]This assumption is not found to be universally true in the Safford Valley. The sociologic survey conducted for the basic research on this paper (51) has shown that not all farmers in the region operate their farms for the sole purpose as a maximizer of net returns. Nineteen of forty-one farmers sampled have received an education of more than twelve years. Six of these have completed college, and of these, three have received higher degrees. At least these three, which include a retired judge and dentist, do not operate their farms for a solely profit maximizing purpose. Such "philanthropic" farmers are not unusual in the area. Although they do not contribute a large portion of the economy of the area, they do offer cases where the principal assumption to the optimizing unit economic model. Farmers of this type are willing to operate at a lower rate of net return than the optimizing farmer. The philanthropic farmer may even be willing to take a larger and more prolonged loss than his economically competitive counterpart. This non-optimizing behavior by some of the farmers in the community makes the valley "more salt tolerant" than it would be otherwise.

[2]The philanthropic farmer will follow the behavior of the maximizing farmer in all such fluctuation and will return to equilibrium level in the same manner while both farmers are in non-marginal profit returning conditions. Deviations in behavior of these two operation methods occurs only when returns approach or surpass the marginal level. The philanthropic farmer seeks his own equilibrium in such situations.

MARKET STRUCTURE

The markets in which agricultural products are traded are generally considered the closest real-world approximation to the economist's analytic construct of "the perfectly competitive market." A rigorous exposition of the theory of perfect competition is beyond the scope of this study and will not be embarked upon here; rather, the relevant aspects of this theoretical concept will be discussed in the context of the present study.

A first requisite for the existence of a perfectly competitive market is that the product bought and sold be homogeneous. This condition, in fact, seems to be met with respect to agricultural markets. Such crops as "spring lettuce," "long staple cotton," and "grain sorghum" are traded in commodity markets as undifferentiated products, in which one lot is substantially indistinguishable from any other.

A second condition for the existence of a perfectly competitive market is that no individual produces have a market share large enough to influence market price. This has often been referred to as the "requirement of atomism," and results in a situation in which the individual farmer (or firm) is a price taker; he may decide to sell any or all or none of his output, but should he choose to sell, it can only be accomplished at the prevailing price level. This leads to the individual producer's demand schedule shown in Figure 20, which is a straight, horizontal line.

This does not negate the law of demand; consumers will still demand more of an agricultural quantity at a relatively low price than at a relatively high one. Conversely, years of low yields in agriculture (and consequently supply effects) are years in which agricultural prices are relatively high. Industry-wide prices are set by ordinary forces of supply and demand, and, indeed, the demand curve for a product of a perfectly-competitive industry shows the expected inverse relationship between price level and quantity demand.

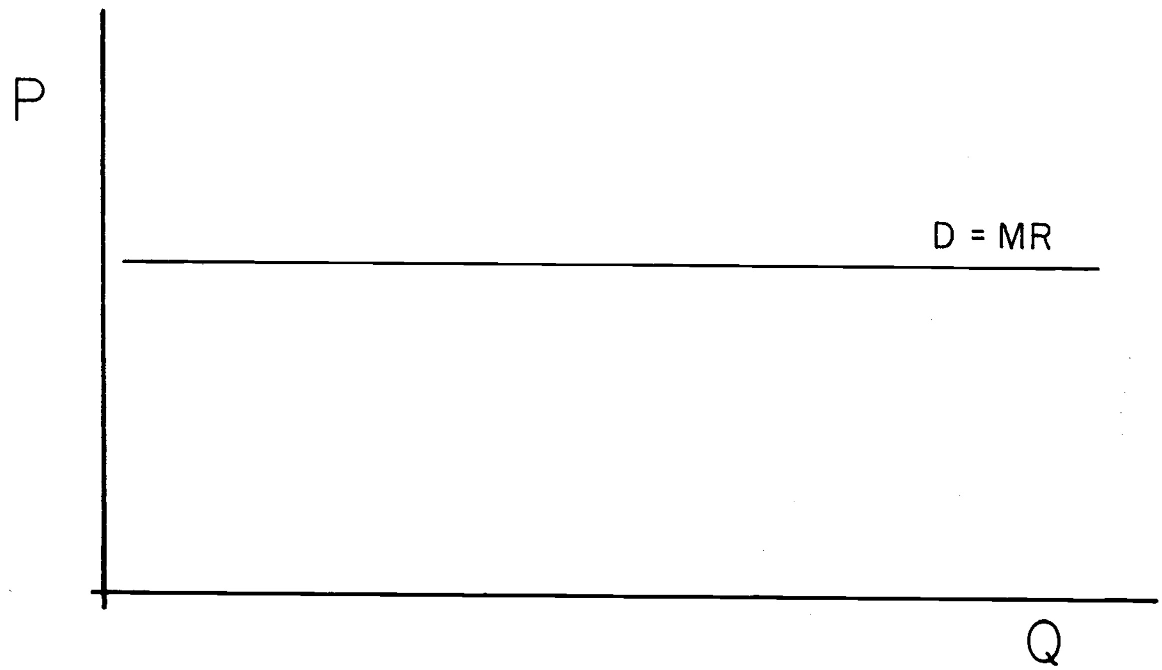
This effect sometimes results from forces other than that of the free market. An example is the market for cotton, in which the government sets a support price level.

Thus, the agricultural producer, given a production function (expressing the physical "state of the art" of the production process), a set of input and product prices, and a specified farm size, has only to choose the combination of crops that maximizes return over variable cost. In a theoretical sense, then, he becomes an analogy of a computer, adjusting his output mathematically in response to price changes. To recapitulate: farm product prices are determined by impersonal forces of supply and demand; the individual farmer has no control over price.

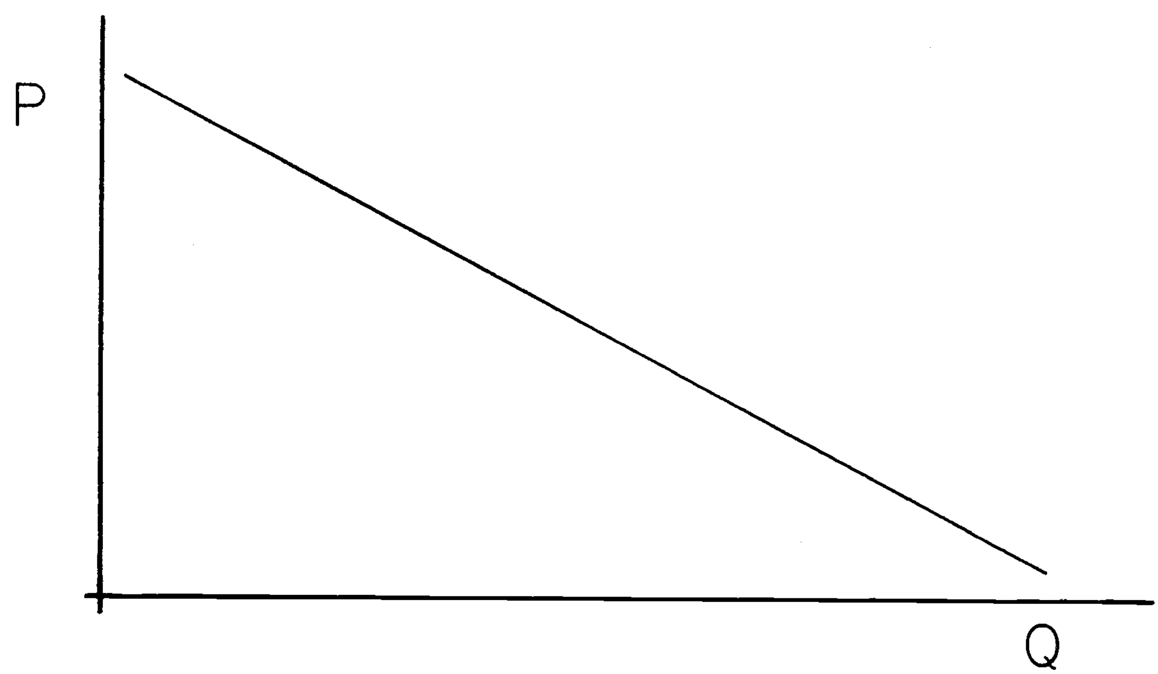
DEMAND SCHEDULES

Figure 20

DEMAND SCHEDULE FOR THE INDIVIDUAL FIRM UNDER CONDITIONS OF PERFECT COMPETITION



DEMAND SCHEDULE FOR THE INDUSTRY UNDER CONDITIONS OF PERFECT COMPETITION



THE EFFECT OF A RESOURCE CONSTRAINT

The analytical techniques used in the economic model cell is that of "ceteris paribus," loosely translated as "everything else held constant." The "everything else" refers, in this case, to all factors other than water quality (treated as the independent variable in the economic model cell) and crop yield (treated as the dependent variable). All other variables, in effect, become parameters or state variables.

The specific techniques is as follows: the starting point is the representative farm in a situation of equilibrium. Product prices and resource costs have been specified. Also, it should be noted that the production function, or physical relationships governing the production process, is taken as given: "a production function is a schedule (or table, or mathematical equation) showing the maximum amount of output that can be produced from any specified set of inputs, given the existing technology 'state of the art.' In short, the production function is a catalogue of output possibilities." (75) In effect, the tables in Costs and Returns Data for Representative General Farms in Arizona (75) provide production functions, though not in the precise form stated above. The data in the tables are drawn from surveys of farmers who, presumably, are profit maximizers; on this basis it may be assumed that each input listed in the table is being used at its optimum rate. This is the point at which the marginal product per unit of input equals its marginal cost. Stating the same point differently, the optimum rate of factor use is at the point where the marginal product is equal to the factor/product price ratio, or $dY/dX = Px/Py$, where x is factor and y is product. This can be clarified by example: since five acre-feet of water rather than six are applied per acre of cotton (see Table 14), it may be deduced that the value of the product derived from the use of the sixth acre-foot would be less than the cost of that sixth acre-foot.

While these tables do not provide any complete "catalogue of output possibilities," they do show the most efficient combination of inputs (i.e., that producing the greatest output) for a given set of product and factor prices. This information is useful in the present context because these prices can be held constant; the effect of a given change in salinity is assumed to be on the production function alone.

Production functions have been developed in which the independent variable is electrical conductivity of the root-zone soil saturation extract and crop yield the dependent variable. USDA Handbook 60 provides formulas which relate quality of applied irrigation water to electrical conductivity of the soil saturation extract (71). This procedure is discussed in detail in the section dealing with physical aspects of the model. This procedure, in sum, permits a direct chain of inference leading from a given change in water quality to a change in crop yields. On the basis of this latter change, it will be possible to determine end economic effects. This procedure will be carried out in its quantitative dimension in the section on modeling, at which time the question of farmer response will be explored.

NOTES ON METHODOLOGY: THE LIMITS OF CETERIS PARIBUS

No exposition of an experimental technique can be considered complete without an examination of the virtues and defects of the methodology involved. In this case, a central assumption of the model procedure is that of ceteris paribus. This term is descriptive of a procedure, frequently employed in economic analysis, in which a problem involving many variables -- among which the relationships may or may not be specified -- is dealt with by freezing, or holding constant, all except a single one which is termed the independent variable. In this way, a conceptual link may be established between, for example, a given monetary policy variable and Gross National Product. In the present project, a change in salinity of applied water is isolated as the independent variable and net farm income is the dependent variable. This has been done on straightforward, intuitive grounds; obviously the investigation of the economic effects of a salinity problem depends on some connection between these two variables. It should be mentioned, though, that this connection could have been made using a very different sort of procedure, but one which also relies heavily on a ceteris paribus type technique. Referred to here is the extremely useful tool of correlation analysis, in which each variable is tested, ceteris paribus, for correlation with a previously determined dependent variable.

An issue which must be faced is the question of the experiment's validity in real-world terms. This question is often discussed in terms of whether model assumptions are "realistic" or not. At the same time, there is a view that this criterion is meaningless, and that the evaluation of a model should depend on the success or failure of its predictions (26). Obviously any predictions generated by the present model are not likely to be subject to review in the very near future. Without resolving this controversy, the issue of the validity of the ceteris paribus assumption will be considered here.

Does it make sense to consider the effect of salinity on net farm income while holding all other variables constant, such as those of farm management, input and product prices, technology, government programs, climatic conditions, and the likelihood of nuclear war, constant? The point of including the latter two variables is simply to demonstrate that the real-world situation is subject to a great many influences, most of which cannot be evaluated but are, in a sense, "held constant." These are treated by simply ignoring them, though their effects will be incorporated into the real result by which the "success" or "failure" of the model is tested. The justification for ignoring such factors as these is simply that there is no plausible way to build them in. Other variables, though -- such as the examples given above of changes in farm management, price inflation and technological progress -- may be expected to bear on the real-world situation. Farm management practices, indeed, may be expected to change as a corollary of the salinity increase. Why not build them in? The answer is, simply, that there's no way to gage the magnitude of the effects of many of these variables, though the direction of the effects is often intuitively clear. In such cases, these variables are subject to verbal and logical analysis and the test of common sense, but no quantitative determination will be made of their effects.

In any analysis of this sort, short-run predictions are clearly superior to longer-range ones simply by virtue of the lesser degree of inherent uncertainty involved. Technological change, for example, is much more likely to be apparent over a forty-year span than one of five years. Farm management practices often change slowly, but more rapidly than does technology. Farmers faced with a salinity problem may level their land and change their cultivation practices; covered ditches may be used to transport irrigation water. Such measures introduce uncertainty into the model, yet the direction of this effect can be considered in analysis of model results. Besides, such measures impose a direct cost on the farmer; for this reason, net effects of the change in farm management may not be great.

Finally, all data used in the present study have been obtained by statistical means and therefore manifest the strengths and weaknesses peculiar to such procedures, and incorporate those assumptions.

MODELING

INITIAL CONDITIONS: THE REPRESENTATIVE FARM

A size of 320 acres was chosen for the representative farm, on the basis of an informal review of the sociological survey (51) rather than by any formal statistical procedure. Detailed information on fixed costs of Graham County general crop farms was only available for three farm sizes, of 160, 320 and 800 acres, so it was considered advisable to select one of these alternatives (as well as permissible, since a wide variation in size was observed). Originally it was thought that smaller farms, being the least efficient and therefore the most marginal, would be the first to feel the financial effects of any increased salinity, and this reasoning supported choosing the smallest indicated (160-acre) farm size for the representative farm. Mitigating against this choice, though, was that larger farms account for a much greater proportion of total output and thus are of greater economic importance. An additional matter coming out of the survey is of interest here: that the smallest farms generally grow only cotton and one or two other crops, while farms above 250 acres generally produce all the valley's main crops -- cotton, alfalfa, sorghum, and barley. The farmer gains in efficiency and ease of cultivation when he plants relatively few crops, but he is also more vulnerable to adversities that may affect only a given crop, such as disease or unfavorable market conditions. Economies of scale seem to be substantial enough to permit large farmers to produce a larger variety of crops. This has the effect of decreasing risk over the short run (the normally accepted _raison d'etre_ of diversification) and therefore probably reduces the variance of long-term fluctuation in gross income. These kinds of consideration tended to support the choice of the 320-acre size; it was felt that the farm should be at least large enough to plausibly produce all the crops normally grown in the valley.

Average cropping pattern of the farms surveyed was as follows: 50 percent cotton, 23 percent barley, 14 percent alfalfa, and 13 percent sorghum. In terms of the 320-acre representative farm, this works out to 160 acres of cotton, 73 acres of barley, 45 acres of alfalfa and 42 acres of sorghum. A complete financial picture of the farm is given in Table 13. Again, all data on costs and returns in this section, as well as the table format, are from Wildermuth, Martin and Riech, _Costs and Returns Data for Representative General Crop Farms in Arizona_ (75). Table 12 with footnotes, provides a detailed breakdown of fixed costs. Table 14 in included as an example of the actual crop budgets relied upon. This type of information was supplied for the four main crops grown in the Safford Valley. As can be seen in Table 13, returns to land and management are determined by subtracting total fixed costs (less the interest on the land investment) from returns above variable cost. In the case in point, this comes to $21,880. Returns to management alone are $3,960; this latter figure is obtained by subtracting interest that could have been earned -- at 7 percent -- on the land investment of $256,000 from returns to land and management.

TABLE 12

Annual Fixed Costs for a Representative 320-Acre General Crop Farm in Graham County, Arizona (75).

Resource[a]	Average Value[b] of Investment	Costs per Year: Depreciation[c]	Interest[d]	Taxes[e], Insurance[f] and Miscellaneous
	(dollars)	(dollars)	(dollars)	(dollars)
Automotive	3,000	267	210	72
Power Equipment	13,267	1,561	929	98
Land Preparation Equipment	2,506	346	175	19
Planting and Cultivating Equipment	3,410	426	239	25
Harvesting Equipment	18,906	2,902	1,323	140
Land[g], Buildings and Irrigation Equipment	256,000	1,572[h]	17,920	2,204
Miscellaneous Equipment	295	30	21	2
Other Miscellaneous Fixed Costs[i]				450
TOTALS	297,384	7,104	20,817	3,010
TOTAL ANNUAL FIXED COSTS[j]				30,931

a. Typical equipment inventory for 160-, 320- and 800-acre farms. Equipment investment is estimated from actual farm survey. Source: Billy M. Comer, "Aspects of Resource Combinations and Enterprises Selection on Eastern Arizona Farms." Unpublished M.S. Thesis, The University of Arizona, 1967. Value is determined using 1966 new prices.

b. Average investment = $\frac{\text{New Cost + Salvage Value}}{2}$

c. Annual depreciation is calculated using the straight line method.

Annual depreciation = $\frac{\text{New Cost - Salvage Value}}{\text{Years Life}}$

d. Annual interest on investment is estimated by charging the assumed market rate of interest (seven percent) against the average investment.

e. Full cash value for tax purposes is assumed to $550 per acre. The assessed value is 18 percent of full cash value. The property tax rate is assumed to $6.78 per $100 of assessed valuation. Tax rates will vary with school districts. The personal property tax is based on a tax rate of $9 per $100 of assessed valuation. The assessed valuation is estimated to be six percent of the average value of the equipment.

f. The cost of insurance on buildings is based on $1 per $100 average valuation. The average valuation is one-half of the total investment in buildings. The cost of insurance on equipment is based on $.20 per $100 average valuation.

g. Land value is based on sales data and estimated to be $800 per acre including buildings and irrigation equipment.

h. Depreciation on irrigation equipment and buildings.

i. The estimated personal liability insurance is based on the type and amount of machinery and number of employees.

j. Total annual fixed cost is the sum of interest on average investment, depreciation, taxes, insurance and miscellaneous fixed charges.

TABLE 13

Calculation of Returns to Land and Management for the Representative (320-acre) Safford Valley Farm (75).

Returns above Variable Cost for the Whole Farm

Crop	Percent of Total Acreage	Acres	Per Acre Returns above Variable Cost	Total Returns above Variable Cost
			(dollars)	(dollars)
Alfalfa	14	45	64.37	2,897
Barley	23	73	38.65	2,821
Cotton	50	160	173.41	27,745
Sorghum	13	42	33.90	1,428
Total Returns above Variable Cost				34,891
Fixed Costs:			(dollars)	
Depreciation			7,104	
Taxes, Insurance and Miscellaneous			3,010	
Interest on Investment (excluding land)			2,897	
Total Fixed Costs for the Whole Farm			13,011	
Returns to Land and Management ($34,891 - $13,011)				$21,880

TABLE 14

Per Acre Variable Costs and Returns for Producing Cotton (Solid Plant) on a Representative General Crop Farm in Graham County, Arizona (75).

	Yield[a]	Price[b]	Gross Returns
Lint	870 lbs.	24.77¢/lb.	$215.19
Seed	1479 lbs.	2.5 ¢/lb.	36.97
Government Payment[c]			84.40
Total Gross Returns			$336.86

Item	Cost: Item	Cost: Total	
Land Preparation and Plant			
Land[d]	$ 4.48		
Fuel and Repairs	4.13		
Seed	3.30		
Total		11.97	
Growing Costs			
Labor[d]	$12.67		
Capital, including Chemical Treatments	40.50		
Total		53.15	
Variable Costs of Overhead[e]		23.23	
Harvest Costs		62.72	
Total Variable Costs (Excluding Water)			$151.08

	Cost-Return Summary
Water Cost (five acre-feet)[f]	$ 12.37
Total Variable Costs (Excluding Water)	151.08
Total Variable Costs	$163.45
Returns Above Total Variable Costs	$173.41

a. Five-year (1964-1968) county average yield as compiled by the Arizona Crop & Livestock Reporting Service with adjustments made for tare weight and solid planting basis.

b. Weighted 1968 average price for Graham County as determined by grade, staple length and micronaire discount. Computed from USDA Market News Service Reports.

c. The government payment is determined by multiplying the support payment of 14.73 cents per pound times 65 percent of projected yield. The projected yield for Graham County is 882 pounds per acre. Under the 1969 Cotton Program, a farmer does not receive any government payment for cotton produced on acreage in excess of 65 percent of his total allotment.

d. Tractor drivers at $1.60 per hour.
Irrigation labor at $1.40 per hour.

e. Includes: pickup variable costs, non-calendar labor, hail insurance and other cash overhead variable costs.

Interest on preharvest costs for six months at seven percent interest.

f. Average cost of surface water in Graham County is estimated to be $2.48 per acre-foot. The actual costs incurred by an individual grower may be higher or lower depending on the efficiency of the irrigation distribution system and management practices.

FARMER RESPONSE

Alternatives

Several courses of action are available to the irrigator confronted with an increase in the salinity of his water supply. A broad survey of these procedures will first be presented, with a view toward conveying the variety of responses possible to this sort of problem. These alternatives will then be discussed in the context of the salt problem in the Safford Valley, with emphasis on the way physical and institutional factors affect the farmer's response. Finally, an attempt will be made to determine possible economic effects of the salinity problem based on probably farmer response.

If additional water is available and no soil problems exist, the farmer can simply increase the quantity of applied leaching water. Should soil conditions not permit this, the alternatives are to adjust the soil conditions or replace salt-sensitive crops with salt-tolerant ones. A final option is to take no action, resulting in a decreased crop yield.

If additional water is not available, the farmer may reduce total cropped acreage, enabling him to increase per acre amount of applied water. In cutting back his acreage, he may (a) remove the least profitable crops to use this water on more profitable crops, (b) remove the least salt-tolerant crops or (c) reduce cropped acreage proportionately, thus keeping the initial enterprise combination. Of course, the option still exists to take no action and simply accept the yield decrement.

Methods exist for calculating the effect of each of these responses upon the individual farmer. The original plan for the economic model involved determining the cost of each alternative method, and the subsequent selection of the lowest-cost alternative. Then, the economic outcome for the individual farmer would have been computed on the basis of the alternative selected. As work on the problem progressed, however, it became apparent that local conditions unique to the Safford Valley rendered many of the above alternatives inviable. These facts led to the adoption of the "yield decrement" approach to calculating the salinity problem's economic effects on the individual farmer; final results have been obtained through the use of this method. At this point it would seem appropriate to discuss the considerations leading to that judgment.

It should be noted that the term "yield decrement" refers to two different, though related, concepts. First, it refers to the farmer response itself; for reasons to be mentioned below, Safford Valley farmers are placed in the position of "having to accept the yield decrement." Second, the term may be used to refer to the budgeting process (or formula) used to calculate the economic effect of accepting or not accepting the yield decrement.

Several local conditions in the Safford Valley combine to render alternatives involving leaching generally inapplicable to the problem at hand. Good quality water from the Gila River is not always available; during the last two years, for instance, drought conditions have prevailed and no river water at all could be had. Second, the Gila Compact (35) governing allocation of river water restricts its use for purposes of leaching. Indeed, leaching per se is prohibited as being a "non-beneficial" use of scarce river water. A practice called "pre-irrigation" is permitted, however, in which river water is applied, when available, to fields before planting. This may be done only once a year, as preparation for the soil. Finally, in years when river water can be had, the allotment of water rights is such that not all users in the valley are guaranteed availability of water.

There remains the possibility of leaching with groundwater. In the case in point, however, this works out poorly due to the twin obstacles of soil impermeability and the salinity problem itself. As groundwater becomes higher in concentration of total dissolved solids, its use for leaching becomes still less feasible. When salinity of the applied water approaches the present mean root zone level for any crop, no amount of water of the same quality can dilute it to offset the concentrating effect caused by consumptive use.

It was felt that these conditions rendered alternatives involving leaching unrealistic. Clearly, in such a situation calculation of the costs of such methods would serve no purpose. There still remained the problem of dealing with pre-irrigation to the extent that it is used. This difficulty was handled by, in effect, building this practice into the hydrologic model. Base year EC figures are predicted upon pre-irrigation, as are predictions generated for future years.

A second possible series of responses involves changes in cropping patterns. The farmer has the option of shifting in the direction of salt-tolerant crops, or phasing out marginally profitable crops and using the water thus gained to leach acreage devoted to more profitable crops. The fact is, though, that the crops already grown in the Safford Valley, with the exception of alfalfa, are among the most salt-tolerant known. The most important of these -- providing nearly 80 percent of the representative farm's net over variable costs -- is cotton. Output is restricted by government regulation; for obvious reasons, valley farmers grow as much cotton as their allotments permit. Any shift away from cotton is unlikely; apart from its profitability, only bermuda grass, barley and oats are more salt-tolerant. Sorghum as well is relatively salt-tolerant. Alfalfa, though, will become unprofitable as salinity increases (and yields consequently decrease) long before either barley, cotton or sorghum. The yield-decrement procedure is quite capable of determining salinity levels at which, for example, alfalfa will be replaced with a more salt-tolerant crop and what crop (or crops) these will be.

The Method of Choice

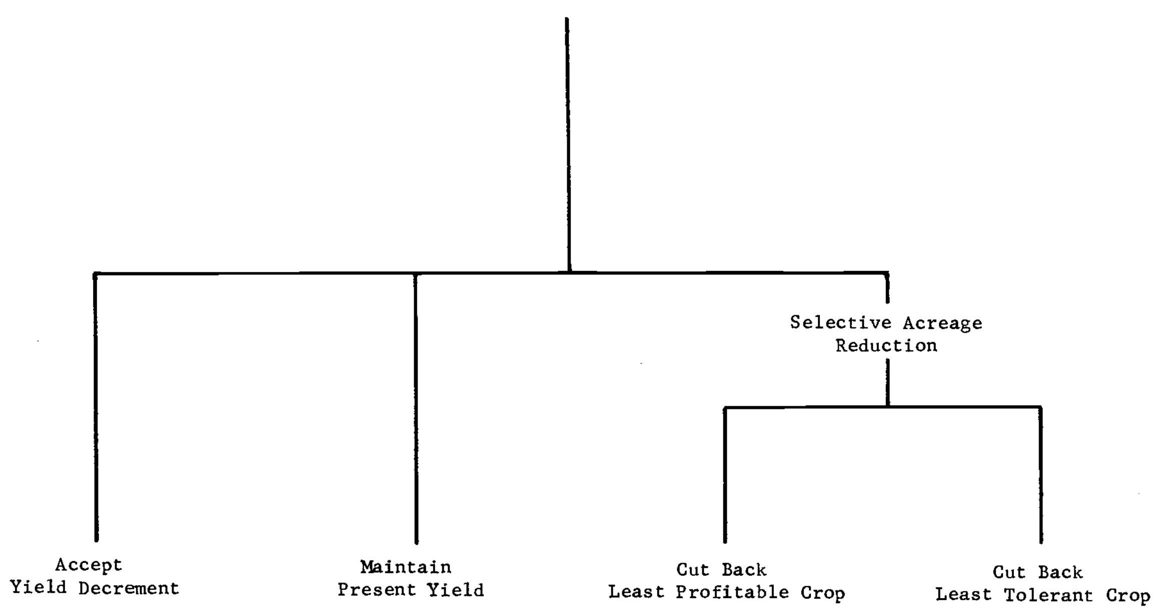
In this section, "yield decrement" methods refer to the process used in computing the economic effect of reduced yields and thereby of applied water salinity. Again, this calculation is made on a ceteris paribus basis. Farm management practices (and hence variable costs) are assumed not to change. Both price levels and technology are also assumed held constant. The only effect of increasing salinity is to reduce crop yields, so gross returns decrease while costs are held constant; in this fashion, the farmer's net returns are reduced. As the gross return from a given crop approaches its variable cost of production, net returns of course approach zero.

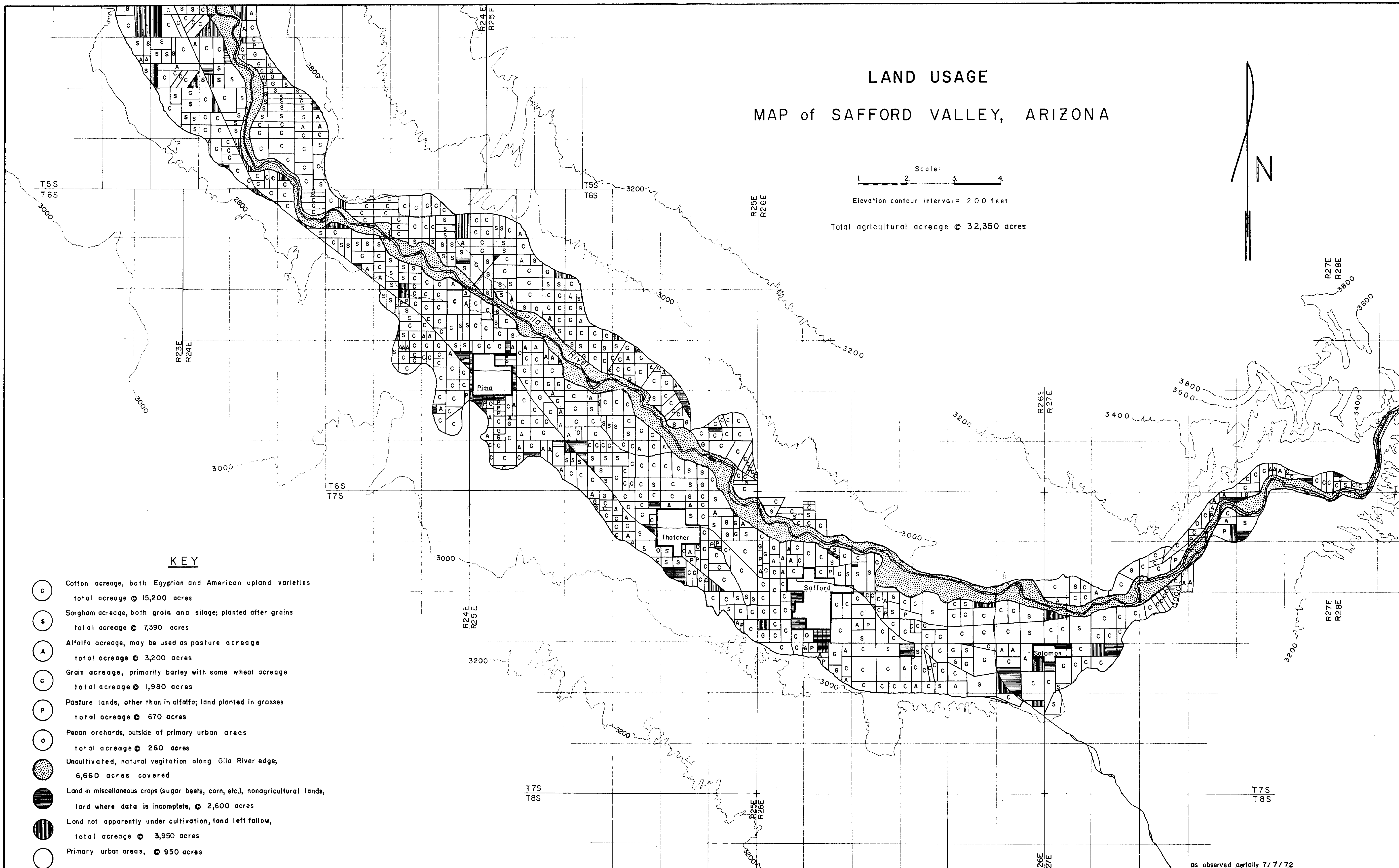
The actual choice made among the alternatives relies not solely on an economic basis, but on one influenced by the individual characteristics of the farmer making that choice. This choice influence is further described in the sections dealing with the Inter-System Flow Model.

Figure 21

QUALITY

DEGRADATION




LAND USAGE
MAP of SAFFORD VALLEY, ARIZONA
Scale:
1 2 3 4
Elevation contour interval = 200 feet
Total agricultural acreage © 32,350 acres
N
Gila River
Pima
Thatcher
Safford
Solomon
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
KEY
Cotton acreage, both Egyptian and American upland varieties
total acreage © 15,200 acres
Sorghum acreage, both grain and silage; planted after grains
total acreage © 7,390 acres
Alfalfa acreage, may be used as pasture acreage
total acreage © 3,200 acres
Grain acreage, primarily barley with some wheat acreage
total acreage © 1,980 acres
Pasture lands, other than in alfalfa; land planted in grasses
total acreage © 670 acres
Pecan orchards, outside of primary urban areas
total acreage © 260 acres
Uncultivated, natural vegitation along Gila River edge;
6,660 acres covered
Land in miscellaneous crops (sugar beets, corn, etc.), nonagricultural lands,
land where data is incomplete, © 2,600 acres
Land not apparently under cultivation, land left fallow,
total acreage © 3,950 acres
Primary urban areas, © 950 acres
as observed aerially 7/7/72
base from USGS topographic sheets

INFERENCES

EFFECT ON FARMERS

Economic Conditions

The yield-decrement approach can be applied to the economics of the representative farm from a number of angles, all of which focus on the production functions given in Figure 22. This work, which may be described as the "heart" of the model, was carried out at the Department of Agriculture Salinity Laboratory in Riverside, California (71). On the one hand, the hydrologic model can be used to generate a value in terms of root-zone electrical conductivity (EC) and findings made on the basis of that figure: What happens when root-zone EC reaches a specific level? What crops will be grown? Will the farmer continue to do business? A second approach -- and the one selected for use here -- is to assume a continuing increase in salinity and inquire at what points certain crops will become unprofitable, when resources might pass to larger and more efficient units, and the like. The result of this approach is a series of thresholds, as it were; since there is clearly no reason to present the entire chronology of this forecasted increase in salinity, only certain of these "threshold" points will be discussed in detail. Particular attention will be devoted, of course, to the economic meaning of these points. Finally, an attempt will be made at placing these predictions in real-world perspective.

It will be recalled that a base year of 1972 was chosen, at which time EC of a soil-saturation extract was assumed to be 4 millimhos/cm. At this point it becomes necessary to look at the production functions to determine if this level of root-zone salinity has any associated yield decrement. As can be ascertained from Figure 22, yields of cotton, barley, and sorghum remain substantially unaffected by a root-zone EC of 4 mmhos. Yields of alfalfa, though, have suffered considerably from salinity. It will be assumed that the 85 percent yield associated with the base-year EC of 4 mmhos is, in fact, the yield on which per acre gross returns of $146 are based. Net returns at this yield are $64, or 44 percent; thus alfalfa will yield no net return whatever when yield falls below 56 percent, ceteris paribus. Since base yield (on which gross returns information is based) is only 85 percent, this works out to 56 percent of 85 percent, or about 48 percent. As can be seen in Figure 22, alfalfa yields will approach this point as EC approaches 8 mmhos.

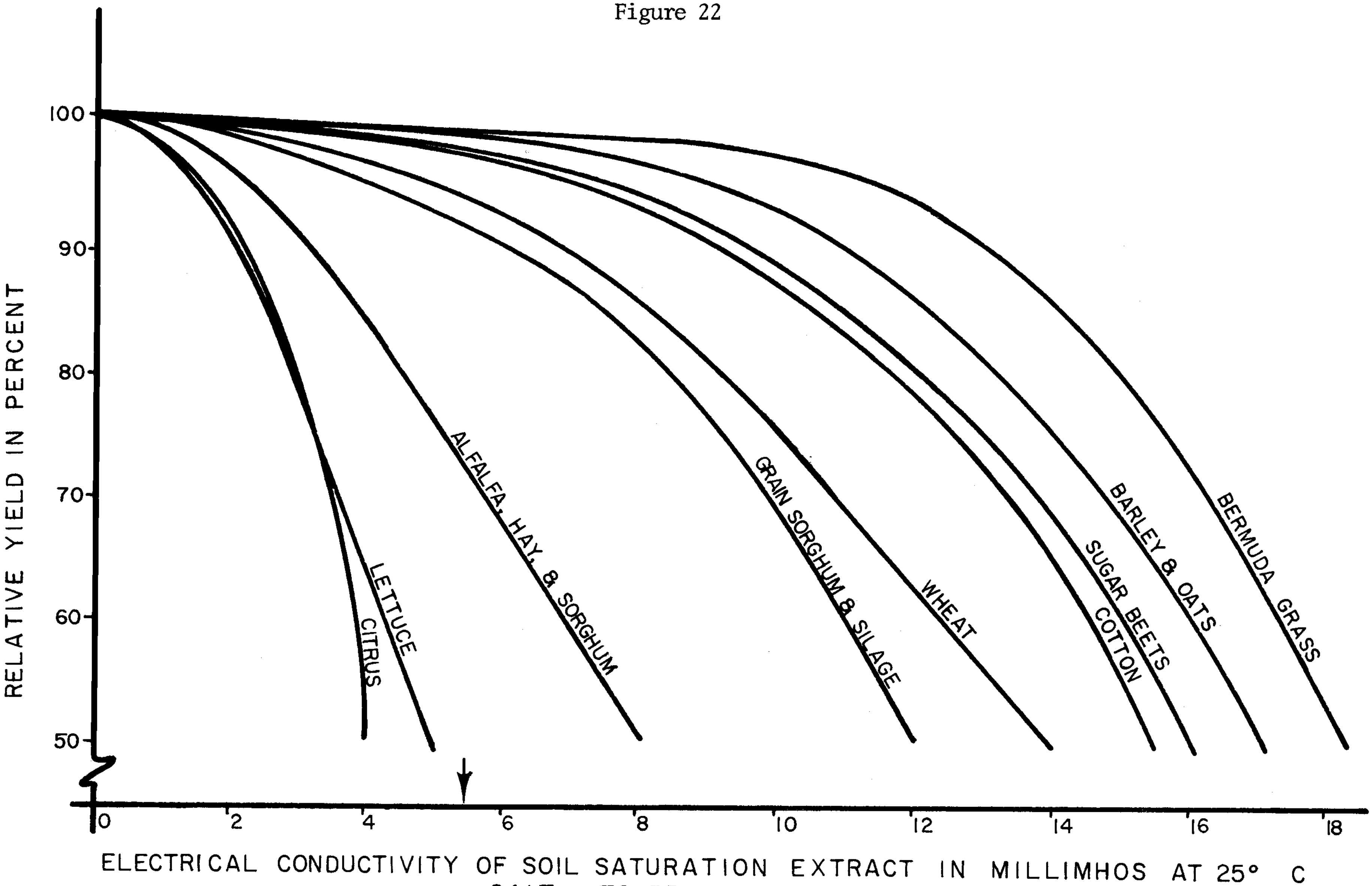
This point, though, is of no economic meaning, since the acreage used for alfalfa will be used to produce another crop as soon as net returns per acre from alfalfa fall below net returns from that other crop. In this case, the replacement crop will be barley since it is both more profitable and more salt-tolerant than sorghum. (Cotton is, of course, far and away the most profitable crop grown in the valley as well as one of the most tolerant. Acreage used for cotton production, though, is restricted, and it has been assumed that the representative farm already has exhausted its allotment. For this reason, it is not likely that alfalfa would be replaced with cotton. In fact, if valley farmers could grow and sell as much cotton as they desired at current prices, it is unlikely that any other crop would be grown at all.)

Barley returns about $39 per acre (these are figures from Table 13 rounded off to the nearest dollar), so it may be assumed that alfalfa will be replaced with barley when returns from alfalfa production fall below this value. This is in fact an over-simplification, since farmers may grow alfalfa for other reasons than simple costs-and-returns considerations alone. For example, the federal cotton program has required farmers to set aside a certain percentage of acreage as a "conserving base," which must be kept in non-depleting use. Alfalfa is the only non-depleting crop widely grown in Arizona, and for that reason may provide a return on acreage substantially above that generated in any other available non-depleting use. To what extent this factor would, in fact, affect farmer response cannot be determined. Its effect would be in the direction, though, of raising the EC level at which alfalfa would be phased out.

Variable costs of producing alfalfa are given as $82; returns over this are $64. Gross return, as previously mentioned, is $82 plus $64, or $146. Holding inputs (and hence variable costs) constant, net return reaches 39 (the euqal of that provided by barley) when gross return is $121. This takes place at 82 percent of base year yield of 85 percent, or 70 percent. Returning to the production functions in Figure 22 shows that alfalfa reaches a 70 percent yield at an EC of 5.5 mmhos. At this EC level cotton and barley remain virtually unaffected, while yields of sorghum have fallen 4 percent to 96 percent. Gross returns from sorghum are $101/acre, so the effect of a 4 percent drop in yield is to reduce this to $97. Since costs are assumed constant at $67. the result is to decrease net over variable cost by $4 or 12 percent, from $34 to $30.

Economic effects on the whole farm may be determined on the basis of the above calculations. What are the effects, ceteris paribus, of a deterioration in quality of applied water sufficient to raise root-zone EC from 4 mmhos

Figure 22



SALT TOLERANCES

to above 5.5 mmhos? 45 acres have been converted from alfalfa to barley, at net loss of $25 per acre of $1125. This time of conversion, when alfalfa becomes unproductive, is plotted on the Projected Alfalfa Production Termination Map. The calculations involved have been described in the physical constraint section. In addition, net return on 42 acres of sorghum has fallen by $4 per acre, or a total of $168. Thus, the total effect on the farmer is a net loss of $1293, or about 6 percent of base-year returns to land and management. The new enterprise combination is 160 acres of cotton, 118 acres of barley and 42 acres of sorghum.

Clearly, as root-zone EC continues to increase, net returns continue to drop. For instance, at an EC value of 8 mmhos, only barley is unaffected; sorghum yields have fallen to 83 percent, and cotton to 95 percent. The effect of this change is to decrease base-year returns to land and management by a total of $4577, or 21 percent. This represents a further loss of $3284 beyond losses incurred at EC of 5.5 mmhos, and is principally due to the decrease in cotton yields.

These budgeting techniques are also useful in determining specific economic effects on the representative farm, beyond simply tracing the results of a continuing increase in salinity. What, for instance, happens to farm income when root-zone salinity is so high as to cut returns from cotton in half? At what level may this result be expected? This indicates a level of 75 percent yield, at which point gross returns amount to $250/acre, of which $163 is variable cost and $87 net. This takes place when EC reaches 14 mmhos. Its effect on the entire operation is as follows: barley yields 80 percent of base yield, about $20 per acre over variable costs. Sorghum has long since ceased providing any net return at all, so presumably only cotton and barley are grown. Cotton allotment is held constant at 160 acres, yielding $13,920 in net income, while barley yields a total net of $3200. Net over fixed costs (returns to land and management) are $4,109.

How bad must conditions become for the representative farm to go out of business? No specific answer is possible here, since this depends upon the opportunity cost of farming to the individual farmer of continuing to farm. Certainly an individual who would find the operation of a 320-acre farm satisfying at a rate of return of $21,880 per year might choose to sell his farm and find other employment rather than see his income fall to $4,109. When he might do so, however, cannot be determined. The operation might well be taken over by an individual not dependent for his livelihood on farming, to whom the opportunity cost of farming is lower. It might also be taken over by a larger operation; economies of scale might permit continuing profitable operation after the less efficient small farmer has been forced out of business. This pattern, in fact, has often been observed in American agriculture -- the decline of small farming units and the rise of large "agribusiness" operations. Obviously, if salinity is allowed to increase without limit, a point must be reached at which agriculture will disappear in the Safford Valley; but the likelihood of this happening in the foreseeable future is not great.

Physical Constraints

Although this is in the Economic System description section, this discussion deals with the methods involved in the construction of the Projected Alfalfa Production Termination Map. The termination dates of alfalfa production are calculated here since, as indicated in the previous discussion, the productivity of cotton is not in question in the far foreseeable future.

The production termination date of alfalfa corresponds to the soil root-zone extract electrical conductivity of 5.5 mmhos. This level is predicted by the economic model, as the electrical conductivity which is indicated by the production functions to correspond with a yield decrement to 70 percent of capacity. This 70 percent yield is indicated to be the level at which the production of alfalfa becomes no longer economically feasible. The current soil root-zone extract electrical conductivity (of a one-to-one solution) is approximately 4 mmhos (2, 64, 80) -- see Table 7. The change in electrical conductivity requried to reach this production termination level is 1.5 mmhos (5.5 minus 4.0).

Using a form of the soil salinity prediction equation of the U.S. Department of Agriculture, the water quality required to make that change is determined. The equation

$$EC_{iw} = \frac{D_{iw}}{D_s} \frac{(d_s)}{(d_w)} \frac{(SP)}{100} \Delta EC_e \qquad [9]$$

yields EC_{iw}, the electrical conductivity of the irrigation water required to make a change of ΔEC_e in the electrical conductivity of the soil root-zone electrical conductivity, as a function of bulk density of the soil, d_s; the bulk density of water, d_w; the depth of irrigation water applied during the growing season, D_{iw}; the depth of soil influenced by this water, D_s; and the saturation percentage of the soil.

The value of ΔEC_e has been determined to be 1.5 mmhos. The bulk density of a typical agricultural soil of the Safford Valley, as indicated by the soil survey, is approximately 1.6 mmhos (recommended by the Soil Analysis Laboratory of the University of Arizona). The bulk density of water is taken to be the standard value of 1 gm/cc. The depth of irrigation water required to cultivate a crop of alfalfa in the Safford Valley, D_{iw}. was determined by the Blaney-Criddle Method. The basic Blaney-Criddle formula is

$$U = KF \qquad [10]$$

where U is the consumptive use of that crop (amount of irrigation water required), K is the crop coefficient, and F is the sum of monthly consumptive use factors.

$$F = \Sigma \frac{tp}{100} = \Sigma f \qquad [11]$$

Here, t is the mean monthly temperature in degrees Fahrenheit, and p is the monthly percentage of daylight hours of the year. Constants for the calculations were obtained from Erie (22) and the consumptive use results appear in Table 15.

TABLE 15

Consumptive Use for Crops in the Safford Valley (in inches of water).

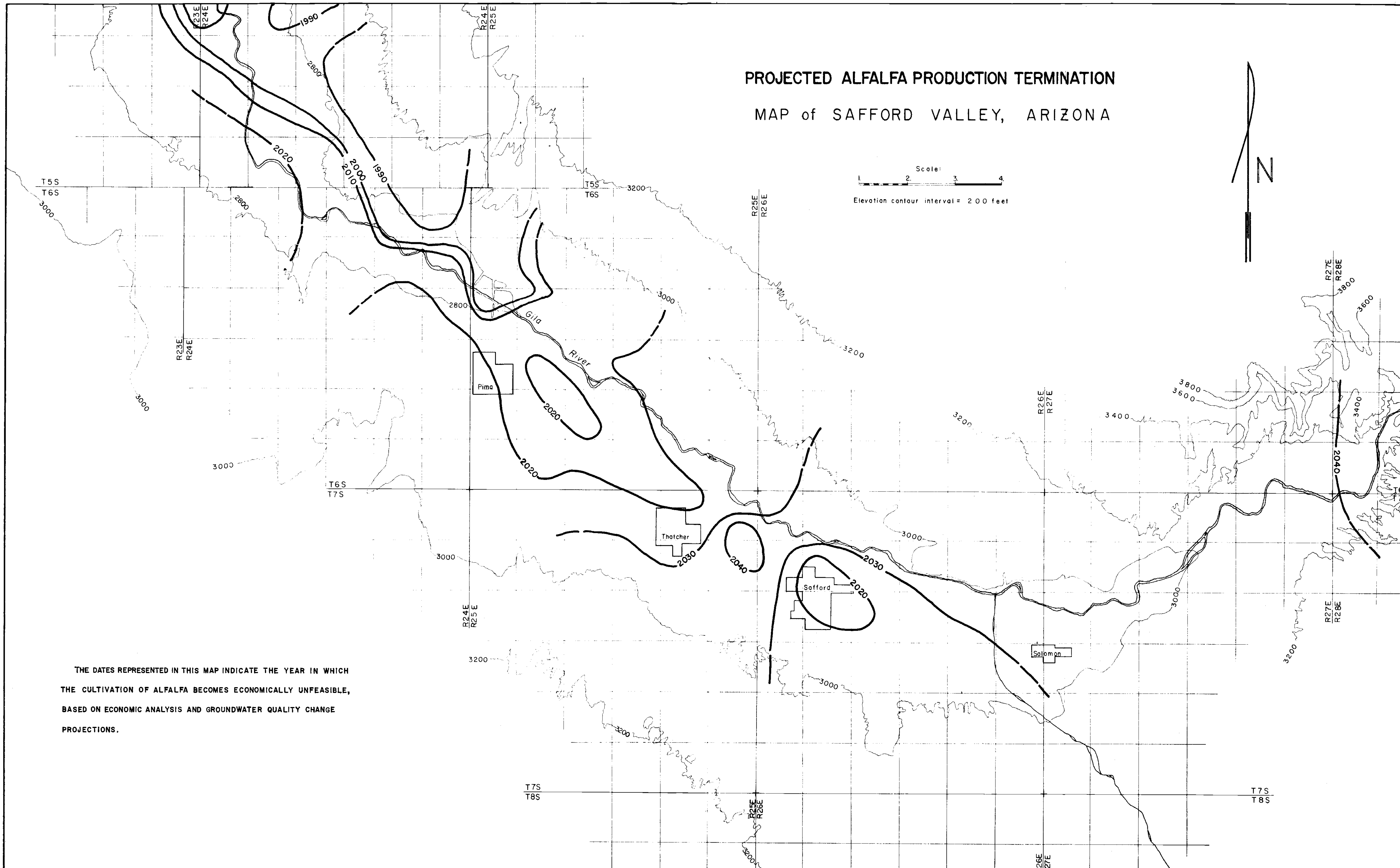
Month	t (°F)	p* (33°N)	f	Alfalfa K=1.20	Cotton K=0.79	Sorghum K=0.90	Wheat K=0.99
J	45.0	7.18	3.23	--	--	--	0.694
F	48.5	6.96	3.38	1.555	--	--	1.216
M	54.5	8.36	4.56	5.518	--	--	4.172
A	63.0	8.76	5.52	6.955	0.497	0.828	10.046
M	71.0	9.65	6.85	9.316	1.850	7.240	5.925
J	80.0	9.62	7.70	10.472	5.005	12,320	--
J	85.0	9.80	8.33	10.246	9.996	6.664	--
A	82.0	9.30	7.63	8.393	10.682	5.875	--
S	71.0	8.34	5.92	7.874	6.571	8.406	--
O	66.0	7.93	5.23	5.178	3.295	4.079	--
N	52.0	7.18	3.73	2.984	0.485	1.865	--
D	45.5	7.02	3.19	--	--	0.255	--
Total Growing Season Consumptive Use				68.49	38.38	47.53	22.04

*Erie, French and Harris (22).

The D_{iw} value for a growing season of alfalfa was 68.49 inches of water, with an additional 18 inches applied for pre-irrigation (64). The D_s value is equal to the depth of soil in which the irrigation water salts are deposited, or the depth of primary wetting. This depth, for the soil type and for the field samples, is estimated at 48 inches (39, 57). The saturation percentage of the average soil used was in the range of 24 to 32 percent, with 28 percent chosen to be the value of the SP value (64) -- see Table 7. Equation [9] yields a value of 9.8 milimhos for EC_{iw} in irrigation well water used.

The physical model yielded a water quality decrement of 0.129 millmhos per year. At this rate, the following equation yields the number of years required to reach the EC_{iw} level of 9.8 mmhos.

$$n = \frac{EC_{iw} - EC_{72}}{0.129 \text{ mmhos}} \qquad [12]$$


PROJECTED ALFALFA PRODUCTION TERMINATION
MAP of SAFFORD VALLEY, ARIZONA
Scale:
Elevation contour interval = 200 feet
N
THE DATES REPRESENTED IN THIS MAP INDICATE THE YEAR IN WHICH THE CULTIVATION OF ALFALFA BECOMES ECONOMICALLY UNFEASIBLE, BASED ON ECONOMIC ANALYSIS AND GROUNDWATER QUALITY CHANGE PROJECTIONS.
Gila River
Pima
Thatcher
Safford
Solomon
1990
2000
2010
2020
2030
2040
T5S
T6S
T7S
T8S
R23E
R24E
R25E
R26E
R27E
R28E
2800
3000
3200
3400
3600
3800
base from USGS topographic sheets

In this equation, EC_{72} is the current 1972 water quality as determined by the irrigation aquifer sampling, and n is the actual number of years from 1972 left for the economically productive cultivation of alfalfa.

These n values, for a series of EC_{72} terms, were calculated and plotted on the Projected Alfalfa Production Termination Map (after n was added to 1972, to yield the actual production termination date). The map indicates with year contours the data at which the area within the labelled contour will reach the 70 percent production level, and thus, when alfalfa will no longer be profitable. It should be noted that a great many assumptions (as has been indicated) have been made, the most important of which is that of ceteris paribus conditions. A further use of the map is the general water quality decrement as it applies to other crops and to their specific production functions.

INFERENCES FOR THE COMMUNITY

There are a number of direct inferences which can be made on the basis of the results of the representative farm model. Again, it should be emphasized that uncertainty is greater in the case of long-range prediction. It seems reasonable to expect, for instance, that should root-zone EC levels rise to near 5.5 mhos, serious pressure will be exerted upon the continued profitability of alfalfa. Various techniques are available for attentuating the effects of salinity, but these also impose an economic cost; thus, their use will be subject to the optimizing constraint, and no more money can be expected to be spend on employment of these techniques than will be returned by them.

A result such as the prediction that cotton returns will be halved when EC levels reach 14 mhos is obviously more questionable. This hydrologic phenomenon is unlikely to take place very soon, if indeed it ever takes place, and should it take place, other changes might have occurred in government programs, technology, and the like, the effects of which cannot be predicted.

What are the implications for the Safford Valley of a continuing increase in salinity? In general, they tend to accentuate rather than go against the grain of the prevailing trend in United States agriculture away from small family farms and in the direction of large, efficient operations. The data used in the model do not fully reflect existing size/efficiency advantages enjoyed by larger farms. Fixed costs per acre run about 11 percent higher for the 160-acre size farm than for the 800-acre farm. The data used in per acre variable costs figures are averages gleaned from a survey of farms of varied size, and hence do not reflect the substantial edge large-scale farms have in terms of professional management, superior equipment, and the like, all of which have their effect on the variable cost side.

It may be expected that as net returns decrease due to the continuing deterioration in water quality, the value of agricultural land will decrease. Farming will, in effect, become a more marginal undertaking in the Safford Valley. The nature of agricultural markets is such that market price would not normally be affected by supply considerations obtaining in a small area such as the Safford Valley, so it is not likely that price increases will result from the decreased quantity supplied locally.

At this point it is well to remember the initial assumptions of the model. Farm management, product prices and resource costs, government programs, and technology, to name just a few factors conceivably bearing upon the situation in the Safford Valley, are all assumed to remain constant. All, in fact, are likely to change. The format of the model assumes instantaneous adjustment; actually, adjustments take place over time. Finally, data in the model are considered applicable to a "typical" Safford Valley farm. In the real world, though, there exist substantial variations among farms. For these reasons, the predictions generated by the model may not be accurate with respect to real-world events.

INTER-SYSTEM FLOW MODEL

The causal relationship flow model presented in Figure 23 was developed to determine the interdependence of the social, economic and physical systems active in the Safford Valley. The model is comprised of three sections representing the three systems involved. The variables that make up these systems are dissimilar in characteristics. The variables represented by circles in Figure 23 are termed external variables and are those which are not influenced by actions or conditions derived from the valley. The variables represented by squares are termed state variables and are characteristics inherent to the valley and not caused by any other variable defined in the model. The variables represented by rectangles are termed functional variables or functional relations and have a relationship with the constituent variables that are inputs to the rectangle.

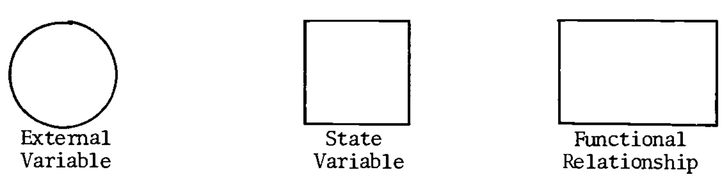
The relationships defined by these functional variables may be causal or summational. The extent to which these functions are defined is not uniform. The functions in the sociologic segment of the model are defined only in a qualified manner, since the quantification of human variables is both inexact and beyond the scope of this project. Other functions, such as some in the economic segment, are simple arithmetic relationships. Optimization functions are also present in this segment. The physical segment of the model contains some functions that are defined by entire digital computer programs, such as the prediction of the quality of infiltration water.

Those variables that are not quantified should be further investigated. This flow model may then be converted into a digital model, with the addition of an iterative mechanism to allow for time differentiations.

TABLE 16

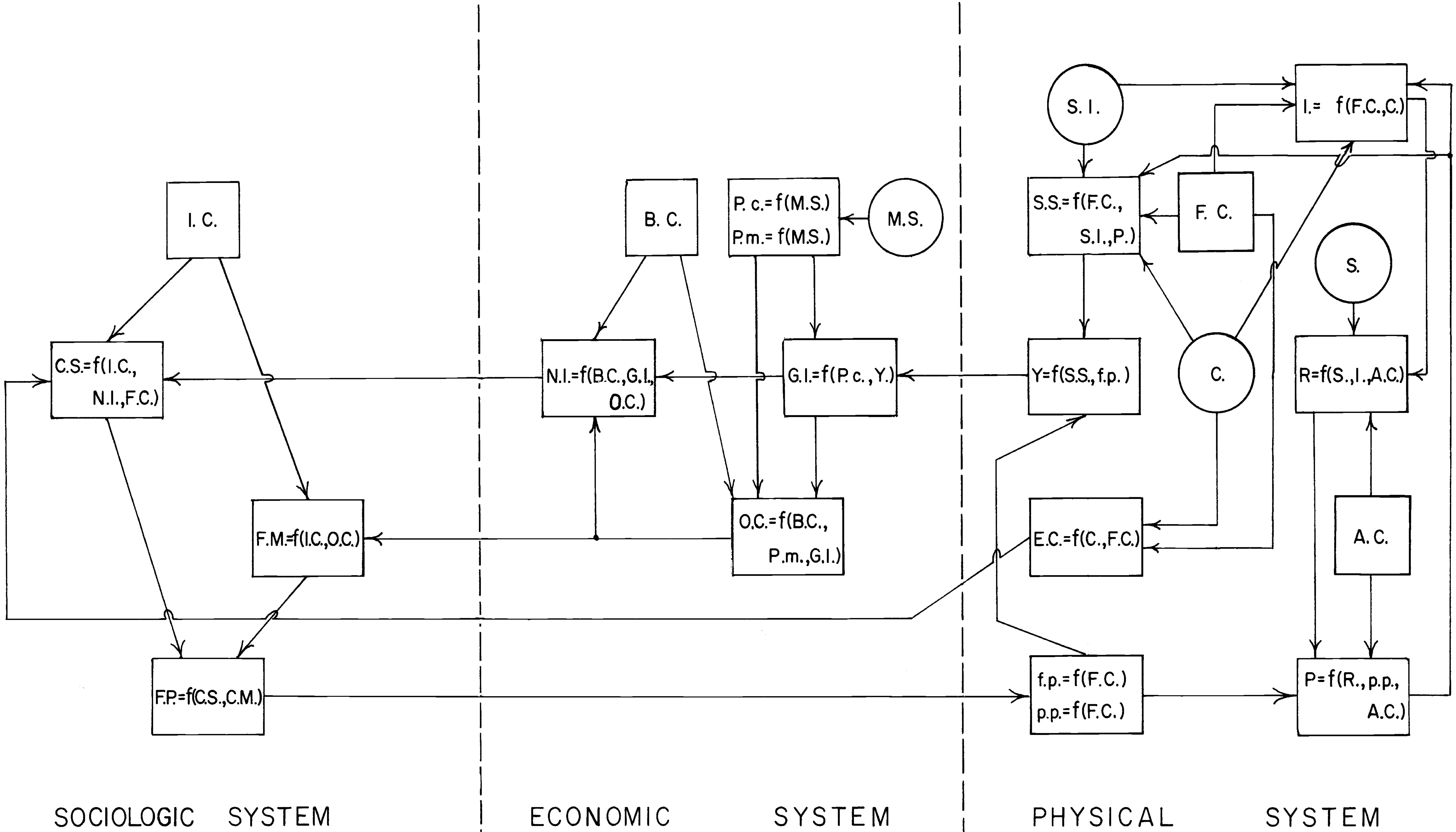
Inter-System Flow Model: Variable Notation

Sociologic System	
I.C.	Individual Characteristics
C.S.	Crop Selection
F.M.	Optimum Farming Method
F.P.	Farming Practices
Economic System	
B.C.	Best Operational Cost of Farm
M.S.	Market Status
P.C.	Market Price of Crop
P.M.	Market Price of Farming Methods
N.I.	Net Income
G.I.	Gross Income
O.C.	Cost of Optimum Farming Method
Y.	Crop Yield
Physical System	
S.I.	Surface water Inflow
S.S.	Soil Water Salinity
F.C.	Physical Field Characteristics
I.	Infiltration
S.	Lateral Groundwater Seepage
R.	Recharge
C.	Climatic Variables
E.C.	Observable Environmental Characteristics
A.C.	Aquifer Characteristics
P.	Pumpage
F.P.	Field Practices
P.P.	Pumping Practices



INTER-SYSTEM FLOW MODEL

Figure 23



MODEL COMPONENTS

PHYSICAL SYSTEM

Infiltration Variable

Field Characteristics

The Field Characteristics variable (F.C.) is a state variable comprised of physical conditions that are intrinsic to the cultivated areas of a farm, including fields and pasture lands. Important terms in this variable are the soil type and condition, as described in the Soil Survey included in this paper. Soil compaction, the principal element of soil condition, is an important feature of the F.C. variable. A prime agency of soil compaction in land use is the application of farming machinery. Track-type tractors exert the least pressure of farm equipment, as recorded by Gray (34), with horses being second and wheeled vehicles exerting the most. Wheeled tractors are the principal farm machines used in the Safford Valley for the maintenance of cotton fields. Such tractors are recorded to cause measurable compaction in soils such as the Grable-Gila-Anthony association at a depth of 9 inches after 10 to 20 passes. Machine compaction results in a reduction of pore space and increasing the soil bulk density, thus reducing permeability (34).

The infiltration capacity of the soil (f_p) is a field characteristic determined by the extent of this compaction. The amount of clays and the extent to which they swell upon application of water, and reduce infiltration, is also involved in this variable. Land leveling, an agricultural practice used in some parts of the valley, is a contributing factor to these conditions.

Chemical characteristics of the field, as well as the physical ones just described are components of the F.C. variable. The salt concentration and distribution in the soil is a consideration. The distribution of salts in the soil matrix is dependent on the furrow shape employed. The ridge planting method, which is the most commonly employed furrow configuration used in the Safford Valley, is the least beneficial to crops (25). Double row methods are preferable to the standard ridge planting method in terms of salt management. This method has occasionally been observed in the valley by the field teams, but is far from common. The optimum furrow shape is the sloping bed method (25) which concentrates the salts the furthest from the root structure of the plants. The distribution of salts in these various furrow configurations is indicated in Figure 24.

Climatic Variables

The Climatic Variables term (C.) includes all measurable climatic influences in the valley. The amount of water that is applied on the fields from precipitation, as well as the time distribution and quality, is included. Rain water quality is not as constant since the summer thunderstorms in this area are electrical and produce electron dependent compounds in the water. Temperature is included in the variable as an influence on evaporation as is water vapor pressure, or relative humidity. Solar radiation quantities, as used in the Blaney-Criddle Evapotranspiration estimates, are considered an element of the C. variable.

Because of the independent nature of this variable, it is considered an external influence and therefore, an external variable. Climate is not dependent on activities of the farmers, other than the possible increase of relative humidity during irrigation season. Weather modification is not considered in the variable because of questionable results.

Water Inputs

The external variable S.I. represents surface water inflow. Both quantity and quality are included in the definition of the S.I. term. The quantity of surface water diverted from the Gila River and applied to irrigated fields is a function of the flow in the river at that given time and the allocations of surface water made by the Gila River Water Commissioner. Both the river flow and the allocations are not dependent on local influences and therefore are functionally external.

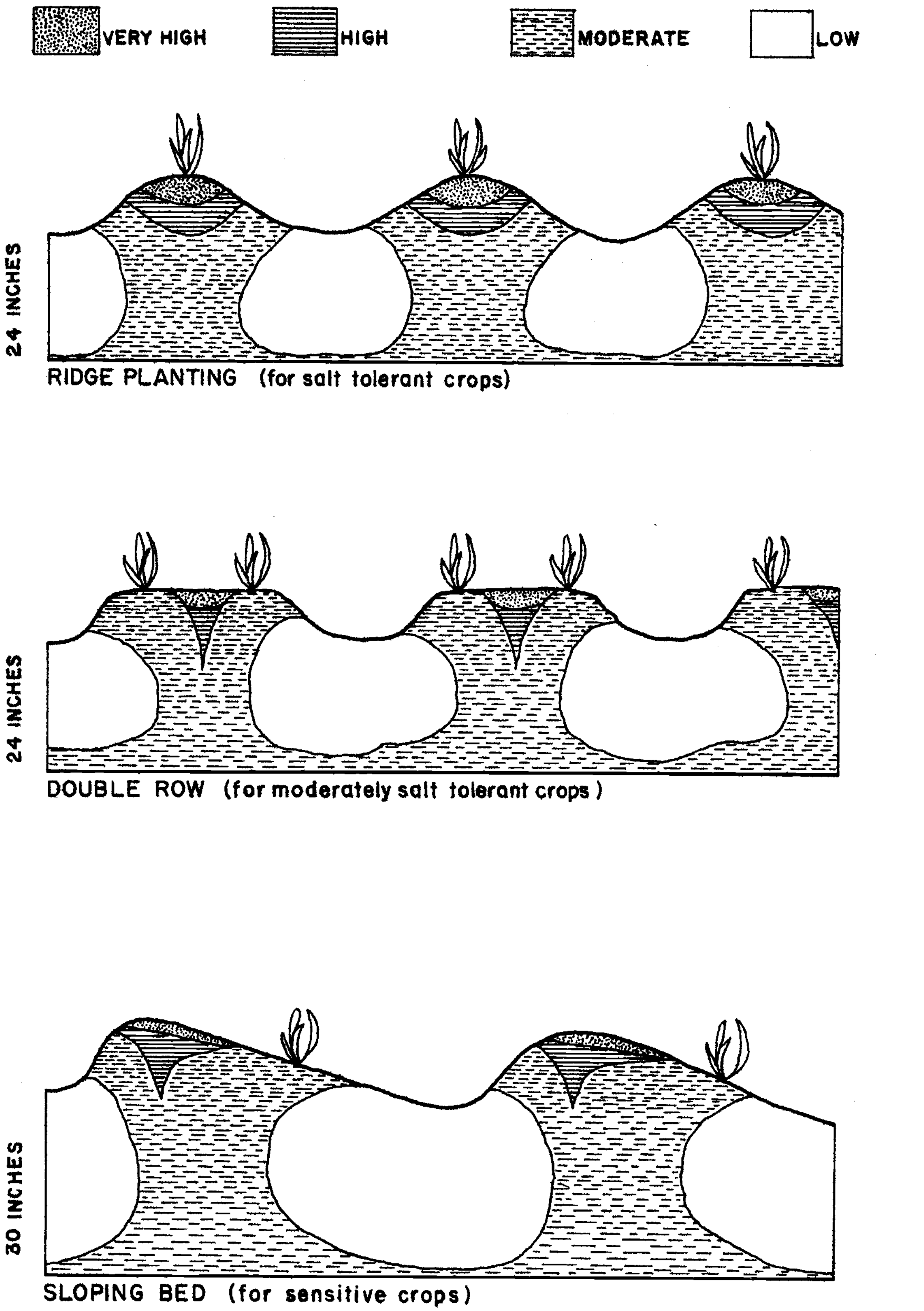
The Pumping variable (P.) indicates the quantity and quality of the water pumped by the farmer as well as the time of year the pumping occurs and the location of the well pumping. The P. variable is functional and defined in detail later in this paper.

Functional Determination of Infiltration Variable

Infiltration is the passage of water through the surface of the soil into the soil matrix. A distinction is made between infiltration and percolation, the movement of water within the soil. This will be considered under the

CROSS SECTIONS OF COMMON TYPES OF BEDS ILLUSTRATING SOIL DEPOSITS OF SOLUBLE SALTS FOLLOWING A SEASON OF FURROW IRRIGATION

Figure 24



recharge variable, discussed later in this section. It should be noted that the phenomena are closely related, since infiltration cannot continue unimpeded unless percolation removes unfiltered water from the surface soil.

The maximum rate at which water can enter the soil at a particular point under a given set of conditions is defined as f_p, or infiltration capacity. The actual infiltration rate, f_i, equals the infiltration capacity only when the supply rate, i_s, equals or exceeds f_p. The supply rate in rainfall may be less than f_p since it is defined as applied water less rate of retention, but in irrigation there is always sufficient water to meet this condition. Theoretical concepts presume that actual infiltration rates equal the supply rate when $i_s \leq f_p$ and are otherwise at the capacity rate. The value of f_p is at a maximum f_o at the beginning of an application and approaches a low, constant rate, f_c, as the soil profile becomes saturated (45). The limiting value is controlled by the subsoil permeability, a constituent of the F.C. variable. The infiltration capacity curves are approximated by the form

$$f_p = f_c + (f_o - f_c)\, e^{-kt} \qquad [13]$$

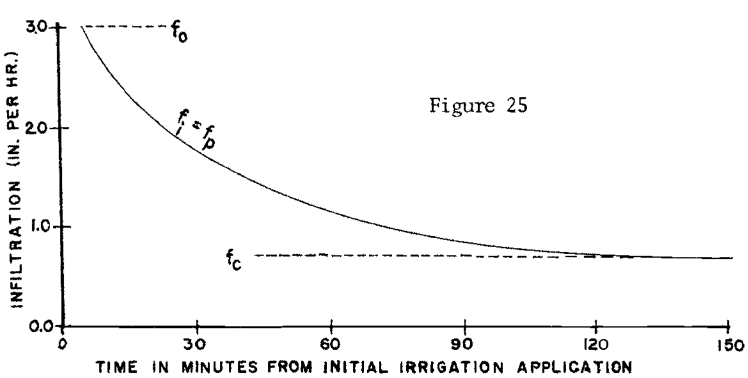
where k is an empirical constant from F.C., e is the Napierian logarithmic base, and t is time from the beginning of application. The k constants are further described by Horton (40).

Crude infiltrometer tests on the Gable soils of the Safford Valley by Aba-Husayn (80) indicate that the infiltration rate is as indicated in Figure 25. The values on the infiltration axis of the graph are approximate since the infiltrometer used was improvised in the field. The general shape of the curve and the relative rates can be assumed correct.

The amount of water applied to the surface of the field, Q, is equal to the infiltrated water, I, plus the water lost as runoff or tailing water, T, plus the water lost to evapotranspiration, ET. This yields the water balance equation as follows:

$$Q = I + T + ET \qquad [14]$$

The estimation of ET by the Blaney-Criddle method has appeared earlier in this paper. It can be assumed that the quality of the water in Q is equal to the quality in T. The water lost in ET can be assumed to have negligible salt content. The water that infiltrates thus contains the salt remaining from the ET water. The amount of water applied during irrigation is designed to provide moisture to the root zone of the crop, and not to percolate significantly further, since this would be wasted for agricultural uses. The water in the root zone is then used by the plants or is evaporated through the soil pore spaces, leaving the salt from the I and ET contributions in the soil. These salts in the root zone of the soil affect the root production yield of the crops as described in the explanation of the Yield variable (Y.), which follows.



APPROXIMATE GABLE SOIL INFILTRATION RATE

Recharge Variable

Lateral Ground Water Seepage

Lateral ground water seepage in the valley is expressed by the S. variable, and includes both inflow and outflow of water. The variable is limited to the upper, or irrigation aquifer, since the artesian aquifer is believed to be a system distinct from outside the study area.

Since the Gila River enters the Safford Valley on bedrock, there is no lateral ground water seepage entering the irrigation aquifer. At this point of entry there is the normal saturated flow which is transported through the fill alluvium which extends for a few feet beneath the river bottom. Similar saturated flow occurs at the San Simon Creek entrance to the valley. In this case, however, there is aquifer material of some extent which also has water seeping laterally into the irrigation aquifer. The seepage from this source is believed to be limited because of the low flow quantities in San Simon Creek and because of the local geology defining the aquifer. There are no other points in the valley where the local geology could allow lateral ground water seepage into the upper aquifer.

The only outflow by seepage from this aquifer can occur at the northwestern corner of the research area where the Gila River leaves the Safford Valley. The gradient of the water table, as indicated in the 1972 Water Table Map, shows that flow lines in the irrigation aquifer carry ground water out of the system. The magnitude of this outflow is not estimated as significant, but constant.

The S. variable represents the net lateral ground water seepage in the Safford Valley. The value can be considered negligible, as is often the case in water balances of this kind where the actual amount of later seepage is unmeasurable. The variable is considered an external variable, although the amount of pumping may influence the amount of flow by changing the hydraulic gradient near the entry and exit points previously described.

Aquifer Characteristics

The Aquifer Characteristics variable, A.C., is a state variable, only marginally dependent on the actions of the farmers of the valley. The variable includes the porosity, permeability, transmissivity, specific yield, specific retention, sorting, and aquifer structure. The location and extent of soluble minerals which may contribute salts to the ground water are also included. The depth of the aquifer from the surface and the horizontal extent of the aquifer are terms of the A.C. variable.

These characteristics can be altered by subsidence, excess pumping, clay swelling and compaction. These factors do not seem to be present in the Safford Valley, after the geologic and hydrologic investigations (80).

Functional Determination of Recharge Variables

The recharge areas of the irrigation aquifer have been described in the Physical System section of this paper. Channel bottoms are generally considered the most likely areas for irrigation aquifer recharge. The relatively small amount of recharge in desert regions such as Safford is reflected in the great depths to water in upland areas and the exceptionally flat hydraulic gradients that are commonly encountered. Under virgin conditions the gradient may be so small that important hydrologic barriers cannot be identified. Ground water development increases the amount of water moving through the surface and steepens all surrounding gradients (12).

The recharge to this aquifer is dependent on the lateral seepage variable, the water that enters the aquifer from field seepage and river seepage. The water contributed from these sources, as controlled by the A.C. variable characteristics, produces the net natural recharge of the irrigation aquifer. The quality of this recharge water is determined by the program presented as a cause of the changes in the aquifer water quality.

Under the natural conditions the variable R. is zero. The aquifer is at capacity and the amount in is thus equal to the amount out in a given period. When pumping is introduced, an additional output is introduced. The value of R. then becomes positive, since more water enters the system naturally than is removed naturally.

Pumping Variable

The Pumping Variable, P., is a functional variable dependent on Recharge, pumping practices, and Aquifer Characteristics (as have previously been defined). P. includes both quality and quantity of the water pumped. The quantity of water pumped is dependent on the amount of water sought (P.P.) and the amount of water available, which is a function of the A.C. and R. variables. The quality of the water pumped is dependent on the location of the well, the amount of water pumped (both from P.P.), and the physical conditions of the water and aquifer associated with the well (from A.C. and R.).

The P. variable is of extreme importance in the influence it has on soil salinity, as described further in this section. The principal problem in the Safford Valley, as indicated by this study, is the quality of water that is pumped from the irrigation aquifer. A decrease in the amount of water required from pumping, or an improvement of the irrigation aquifer water quality would be ideal solutions to the problem. These solutions do not seem to be possible in light of the economic and physical situations which exist in the area. A secondary solution would be to maintain the water quality of this aquifer at the current rate, or to at least slow the rate of deterioration of the quality, since only the P.P. variable, of those affecting P., can be directly influenced by management practices. Of the others, A.C. is a state variable and R. can be influenced only in a remote and ineffective manner.

The importance of the Pumping variable is further shown in the following two sections on soil salinity and on crop yield. Modes of affecting P. have been discussed in earlier sections.

Soil Salinity Variable

The Soil Salinity variable is a function of the quality of the water applied and the local Field Characteristics (F.C.). The water applied may be derived from precipitation (C.), from well water (P.), or from Surface Water Inflow (S.I.). The Surface Water variable includes all water diverted from the Gila River which is used for irrigation. This value is a state variable since the stage of the river during the irrigation season is not predictable and not dependent on Safford Valley variables.

The quality of the three sources of water is known as well as the amount applied. The following equation, from the U. S. Department of Agriculture (2), relates these qualities to soil salinity:

$$\frac{D_{iw}}{D_s} = \frac{(d_s)}{(d_w)} \frac{(SP)}{(100)} \frac{\Delta EC_e}{EC_{iw}} \qquad [15]$$

D_{iw} is the equivalent depth of water applied, D_s is the depth of soil influenced, d_s and d_w are the densities of the soil and water respectively, SP is the saturation percentage of the soil, EC_{iw} is the electrical conductivity of the water applied which is used as an indicator of the total soluble salts in the water, and ΔEC_e is the change (increase) in the soil salinity in terms of electrical conductivity of the saturated extract of the soil. All but the electrical conductivity terms are constants. The D_{iw} and D_s terms are constant for each crop studied. D_{iw} is determined by the consumptive use of the crop during the irrigation season.

By changing the EC_{iw} values, the equation yields ΔEC_e values. These values may be used to determine the marginal limit of productivity of crops as indicated in the description of the economic system. The variable being the principal input to the determination of the Yield variable represents the physical conditions of the field after the operations of infiltration and recharge.

Crop Yield Variable

Crop Yield (Y.) is a function of field characteristics and of farm practices. The Field Characteristics (F.C.) have been selectively included in the Soil Salinity variable. The configuration of salt concentrations in the soil is described in the discussion of the Infiltration variable and illustrated in Figure 24. This configuration is input to the Crop Yield function indirectly, through the S.S. variable as shown in Figure 23.

The actual functional relationship by which salt affects plant growth is somewhat complex. It is a matter of observation that the presence of salt in the soil of the plant root zone in concentrations much in excess of those required for normal plant functions frequently results in some decrement in growth and yield of most varieties of crops, including cotton and sorghum. The following discussion will be limited to the effects of substrate salinity on the physiologic responses of cultivated plants. The agronomic aspect of the problem is treated by Bernstein (6).

Several proposed mechanisms exist for salinity affecting plant responses. These include a reduced water availability in the substrate, that is a "physiological drought" in the sense that effects of salinity on the hydraulic potential of the substrate may be similar to the effects of low soil water content, and an excessive ion accumulation in the plant tissues, possibly combined with a reduced uptake of essential mineral elements (57). The concentration of soluble salt constituents in the soil water may reach osmotically significant proportions. At this point, unique to each plant type, the osmotic pressure of the soil solution becomes greater than that of the tissue in the roots of the crop. This may occur to the extent of preventing the introduction of water into the roots of the plant because of the osmotic back pressure, or may actually cause water to migrate out of the tissue of the roots into the soil in an attempt to bring the two solutions to the same concentration. This second case would reduce the water content of the entire plant, since osmotic equilibria would be maintained in the plant structure. It should be noted that since the cells of the root system do not have ideal semi-permeable membranes, there is also a migration of the soluble salts into the cell structure of the plant. In such a manner the presence of electrolytes in the root medium, in these "osmotic concentrations" (57), generally results in a much enhanced concentration of electrolytes in the plant, with adverse effects on the ion balance within cells and tissue. Special consideration of chloride and sodium ions should be made in such cases.

The presence of enhanced quantities of electrolytes in plant cells is likely to have direct effects on protein hydration, because of the effect of the ions on the character of the hydration shell surrounding the protein molecule. This in turn is likely to affect protoplasmic viscosity and volume relationships (57). Changes in enzyme activity and suppressed RNA and DNA accumulation have also been reported by Slatyer (57), particularly when ions such as Na^+ and Cl^- are involved.

Since the actual physiologic function has only been defined in a qualified and theoretical manner, the actual relationship between soil salinity and plant yield is commonly determined by another method. The production functions presented in the description of the economic system represent these relationships for the crops significant to the valley by curves indicating percentage of maximum yield as a function of soil salinity. These curves are derived empirically and their applicability for areas other than the original setting of the experiments has been questioned. The production functions used in this paper are thought to be sufficiently accurate for application in the Safford Valley.

Price Variables

The Market Status variable, M.S., being the only external variable of the economic system introduces the conditions of the macroeconomic environment on the economic system of the Safford Valley. The elements involved in this term include the market price of land, labor and capital, as dictated by that environment. The Market Price of Crops (P.C.) and the Market Price of Farming Methods (P.M.) are components of this M.S. term.

The P.C. variable is a dynamic term, fluctuating annually with the demand for that specific crop. All crops cultivated in the valley are included in the term. The P.M. variable fluctuates similarly with the availability of field labor and capital farming materials. Both terms are somewhat influenced by activities occurring in the valley, for example, the P.C. variable is influenced by the amount of crop produced in the area with respect to the total amount of crop produced. This influence is considered negligible since both the extent and effect cannot be quantified.

Gross Income Variable

As was mentioned earlier, the most important and only input to the economic sector of the inter-system flow model is the Yield variable, Y., which is an output of the physical system. The Y. variable and the P.C. variable are the terms on which the Gross Income of the Farmer (G.I.) are dependent. The G.I. term includes only income derived from agricultural practices of the farmer, neglecting external sources of income. By this definition of G.I., it is apparent that in this simplified conceptualization of income, the G.I. variable is equal to the product of the yields of each crop produced and the corresponding price of these crops, or more simply,

$$G.I. = (Y.)\ (P.C.) \qquad [16]$$

It is seen that G.I. is solely a function of the yields and the current prices on the market of the crops grown.

The G.I. variable reflects the fluctuations in crop productivity, caused by factors such as soil salinity. These fluctuations are realized in changes in the term through its dependence on the Y. variable.

Cost of Optimum Farming Method Variable

An important segment of the system is the Cost of Optimum Farming Method function, denoted in Figure 23 by O.C. The purpose of this variable is to determine the cost to the farmer of the optimum field method. This optimum cost varies as a function of the G.I. term, the Base Operational Cost of the Farm (B.C.), and the P.M. variable. The B.C. variable indicates the expenditures involved in the operation of a standard, representative farm. The characteristics of such a representative farm in terms of economic parameters have been described under the Modeling section of the Economic System, earlier in this paper.

G.I. is necessary for the optimization process of autonomously weighing the probable expenditures for a particular method to the expected return and the available income. It should be noted that this function is independent of external influences and is automatically determined in the economic system of the model. The farmer cannot influence the selection of the best farming method at this point; however, O.C. is an input to the sociologic system in which the farmer is able to intervene as is described in the explanation of the sociologic system. It should be noted here that the costs indicated by the O.C. variable are not included in the B.C. term since the B.C. term includes only inalterable expenditures.

Net Income Variable

The final function of the economic system is the Net Income (N.I.) of the farmer which is derived from his agricultural activities. The omission of external sources of income is also applied in the case of this term. The terms contributing to the N.I. variable are B.C., O.C. and G.I. The Net Income would be equal to the gross income minus the sum of the optimum and base costs, or equivalently:

$$N.I. = G.I. - (O.C. + B.C.) \qquad [17]$$

The significance of the N.I. function is due to its role as a crucial input to the sociologic system in the decision-making process. It should be noted that the determination of N.I. assumes that the optimum farming method indicated by the O.C. term has been implemented by the farmer. Such implementation is most often the case, since by the utilization of the optimum method the farmer maximizes his profits. If the method indicated by O.C. is not employed the N.I. would still be effective since the Crop Selection variable to which it is input in the sociologic system required the maximum N.I., as always reflected in the term.

The interpretation of the N.I. variable is an indication of the marginality of the farming operation, if optimally managed. This term then can be used as an economic indicator of the influences of water quality changes on the efficiency of the farm.

Crop Selection Variable

Individual Characteristics

The Individual Characteristics state variable (I.C.) is an all-encompassing term. Within this variable there are all the terms which distinguish an individual from another in personality. An alternative name for the term could be "previous experience," but even more is involved. Age, formal education, religious training, childhood environment, and all types of experiences are contributing factors.

When an indivudal makes a decision he interprets information from the outside world that is pertinent to the decision. This information is then weighed by the individual in terms of his standards and his previous experiences. These experiences are those pertinent to the subject and in conscious recall as well as those that are no longer in memory and remain to the individual just as judgements and preconceptions. The decision, selection or choice is then different among different people in the same situation because of these factors.

If two people could experience exactly the same stimuli from birth, there would still be differences in such similar state decisions. Heredity affects the perception of the first stimuli or experiences that the individual encounters as a child. Such differences in perception effected by heredity can be physiologic, such as optical or tactile, or can be mental, such as the ability or willingness to learn.

The derivation, isolation and identification of such differences are well beyond the scope of this project, if at all possible. Because of the extreme complexity involved in the causal determination of this variable, it is taken to be a state variable. For the purpose of this study, the variable is limited to the experiences of a farmer in the Safford Valley dealing with previous crop yield, factors affecting productivity, fluctuations in the price he receives for his crop, his knowledge of farming methods and his general optimism and ability to accept new information. The limitation of the variable to farmers (or farm managers) is made because of the applications of the term. The variable is only to influence the determination of variables dealing with agricultural and management practices of farmers.

Functional Determination of Crop Selection

The factors involved in the determination of Crop Selection as described in this model are Net Income (N.I.), observable environmental characteristics (E.C.), and Individual Characteristics. As described previously, N.I. is the net income derived from the sale of farm crops grown by the valley on an individual basis, and E.C. are the characteristics of the environment which are observable to the farmer, such as climatic trends and field conditions.

This model of the sociologic factors active in the valley, the farmer as a specific, operates under the assumption that these are the sole inputs which make up crop selection. The N.I. variable indicates to the farmer if the current crop is profitable, and if so, to what extent. The E.C. variable indicates to the farmer if conditions are conducive to reproduce the circumstances that produced the crop returning the N.I. income. These factors are considered in light of the I.C. term previously described.

If the farmer knows tolerance levels of crops to salt (I.C.) and the salt conditions of the surface water and wells with which he irrigated (E.C.), he may determine if a change of crop to one more tolerant is necessary. If such a change is indicated, he may select the one shown to be optimum in terms of return and tolerance. If I.C. does not indicate the farmer has enough information to make these decisions then the status quo conditions are maintained.

The relative tolerance of crops to soil-water salinity has been indicated previously in this paper. It has been determined that the most tolerant crops that can be grown in the valley are being grown. In this case the option of not growing any crops must be considered in the possibilities of the C.S. variable. If the farm is operating on such a margin that the E.C. and N.I. variables are interpreted by the farmer and I.C. to indicate that it would not be profitable to remain in operation, the C.S. variable would reflect this by showing that "no crop" was the crop selection chosen.

The probability of this C.S. choice is very small because of the gradual changes of the water quality and because of the effective leaching methods employed by the local farmers. The frequency of such leachings may have to be increased, but the point where it will no longer be effective is not in sight.

Farming Methods Variable

The Farming Methods variable is a function of variables that have all been previously defined. The Farming Methods variable (F.M.) is a function of Individual Characteristics (I.C.) and Cost of Optimum Farming Method (O.C.).

The O.C. variable is defined by the optimization function in the economic system of the model. The O.C. selection is purely economic and is not influenced by the sociologic I.C. variable. The choice is left to the farmer to use this optimum method or not.

The principal methods involved are in watering practices. Irrigation by flooding is the method currently employed in the Safford Valley. Sprinkler irrigation and drip irrigation are the only alternative methods that are considered herein.

Sprinkler irrigation methods on cotton have been examined at the Safford Branch Experimental Station of the University of Arizona Experimental Farm (8). The study compared sprinkler with flood irrigation methods in diurnal variation and direct correlation experiments. The sodium concentration of washings from cotton leaves indicated a higher value from samples irrigated by sprinkling. The following table shows that this increased concentration is not harmful to the crop yield. Cotton sprinkled at night gives consistently higher yields than flood irrigation techniques, and uses considerably less water. This decrease water consumption by the plant is the significant advantage of this method. Since the infiltration and concentration of irrigation water play a role in the decreasing water quality, the effect of decreasing the amount of the saline water applications to crops is to slow the deterioration of water quality that is contributed by this source. The principal setback of this method is the initial cost of sprinkling mechanism and piping.

TABLE 17

Cotton Yields from Sprinkler and Flood Irrigation (17)
(in pounds of seed cotton for fifty feet of irrigated row)

	Irrigation Method		
	Sprinkler		Flood
Treatment and Variety	Day	Night	(Furrow)
BEDDED FIELD			
Short Staple Cotton 1517D	8.8	13.2	13.0
Long Staple Cotton S2	1.7	4.9	4.0
FLAT FIELD			
Short Staple Cotton 1517D	8.3	11.8	10.2
Long Staple Cotton S2	1.2	2.5	(no data)

The second alternative to flood irrigation is the use of drip emitter methods. Drip irrigation involves the placing of an emitter valve at the base of each plant or group of plants and piping connecting the emitters to the water source. There is no requirement for a pump to supply the piping system since the principal source of irrigation water is well water and therefore has a pump already in the system (23). The effectiveness of drip irrigation on annual crops is still questionable. Orchards and similar long-term cultivations are well suited to the use of drip irrigation since the plants have a fixed stem and one installation of the watering network is sufficient. The initial cost of labor for installation and equipment occurs only once with orchard applications, but a crop such as cotton requires the annual installation and removal of the irrigation system hardware. This would make the method of questionable value as an F.M. alternative in the Safford Valley.

There are other factors involved in F.M. such as fertilizer application, furrow shape, and frequency of irrigation. These factors are not believed to significantly influence the variables which F.M. influences.

Farm Practices Variable

The Farm Practices variable (F.P.) is a function of two variables described previously. C.S. and F.M. are the components of this term. The method in which the components make up F.P. is not a functional relationship but simply a composite of the two values. Farming Practices include the crops chosen. the method of land tilling, the furrow type, the method of irrigation, the fertilizer application method, the amount of diversion water used for irrigation, the number of wells and the extent of their usage, and the extent of field leveling. Many of these factors originate from the Farming Methods variable constituents which were not described in detail in the last section.

The purpose of this variable is to express, in one term, all the items in which the human influence of the farmer can be exhibited. Farming Practices include all the factors in which the farmer can affect the agricultural environment of the valley.

The F.P. variable may be broken down into two groups of farmer influences. Field practices (F.P.) and pumping practices (P.P.) are the functional constituents of this sociologic variable. Field Practices include all farmer-determined operations on his fields, irrigation ditches, and pasture land. Pumping practices include how long wells pump, when they are in operation, where they are located, into what aquifer they extend and how the well is maintained. These factors, in the form of F.P., are the variables that form the sole output of the sociologic system and the sole input to the physical system.

Irrigation Methods Employed. All cropland in the Safford Valley is irrigated. Identifying the irrigation methods employed by farmers is relevant. More efficient methods of irrigation would help to relieve the water quality situation. Optimal methods of determining when and how long to irrigate may make better use of the existing water. The irrigation system in the valley consists of cooperatively owned canals and ditches. Each canal company operates its own wells and sells this water to farmers according to water appropriations. The canal company's canals are used to transport water from the company's wells to the farmer's ditches. The farmer uses his ditches to transport his own pump water or the canal water to his fields. The principal means of irrigating a field crop such as alfalfa or barley is by flooding (1). Flooding methods require the land surface and part of the crop to be covered with water. The water may be applied to the field from irrigation ditches by pumping, by outlets in the ditches, or by siphons (tubes which draw the water from the irrigation ditch to the field or row) (13). A crop like cotton or sorghum is irrigated by means of an outlet or siphon (14). An outlet, in this case, distributes water to four or five rows and requires planted rows to begin some distance from the outlet to avoid damaging the crop. Siphon tubes are the best of the two methods since water and land waste is reduced. Other methods which may be employed are the sprinkler and the trickle system. Although they are more efficient, they are also more costly. These methods are further discussed in subsequent sections of the paper. To decide when to irrigate and how long to irrigate, farmers examine plant and soil signs. Wilting, color of the leaves, leaf temperature, growth rate, and the stage of plant development are factors in making the decision when to irrigate. Soil signs are read with the aid of soil probes, or augers, and tensiometers. A soil probe takes a sample of the soil and shows the moisture of the soil at root level. A tensiometer, a porous cup put in the ground to measure water tension is another indicator of the moistness of the soil. Both may be used to decide when and how long to irrigate (36).

Water Conservation. In this arid region, conservation of water was thought to be an important variable reflecting the farmer's conception of water scarcity. The more methods a farmer employs to conserve water, the more concern he is showing about the scarcity. The primary methods to conserve water are the construction of cement-lined irrigation ditches, and the leveling of farm land to a desired grade. By reducing the seepage of water into the soil around the dirt ditch, cement ditches increase the amount of water which actually reaches the fields. The cement also discourages growth of vegetation which uses some of the precious water. Leveled land ensures even water distribution. If there are high and low spots in a field, some plants get too little water and some get too much. Uneven water distribution uses up more water than necessary. Although cementing ditches and leveling land are expensive, there is a government program which helps the farmer with part of the expense. One other method to conserve water is to interrow irrigate, the application of water to every other row of plants. This method can only be used at the less critical stages of plant development since a shortage of water during critical growing periods damages the plant and reduces yields.

Leaching-Preirrigation Practices. The Safford Valley is known for saline pump water. The Gila River, another source for irrigation water, is less saline than pump water and canal water; however, in periods of drought the river does not flow. Farmers, then, are forced to use their salty pump water consistently on their fields. Although canal water is used also, in a drought it is almost as saline as pump water, since the canal companies pump ground water into their canals during such periods. Use of saline water builds up salts in the soil, reducing yields, and finally rendering the land useless for crop production. Under these conditons leaching or pre-irrigation is an important farm practice reflecting the farmer's knowledge of farming conditions in the valley (42). Leaching is the application of a heavy irrigation to move salts downward below the root zone of the crop (28). Usually leaching precedes planting but may be done after, on certain field crops. It is a permanent agricultural practice on irrigated lands but is especially applicable in the Safford Valley since most of the water used is more saline than what is usable for irrigation (64). The good quality leaching water dissolves the salts in the soil and transports them below the root zone. Under the terms of the Gila Compact, it is illegal to use river water for leaching, as further explained in following sections (35). Pre-irrigation is used to moisten the soil in preparation for the yound plants. River water may be used for pre-irrigation. If river water is employed, pre-irrigation accomplishes leaching; thus, most farmers use the term pre-irrigation for both practices.

MODEL OPERATION

SYSTEM INPUT/OUTPUT RELATIONSHIPS

The farmer, a component of the sociologic system, is influenced by the physical system through the physical variable, F.C., the observable environmental conditions of his farm. The farmer's interpretation of these conditions influences his expectation of his field productivities. The entire influence of the physical system on the sociologic system is transmitted by this variable, and the decisions made by the farmer based on physical inputs are dependent on this variable according to the functional relationship previously described.

Conversely, the entire influence of the sociologic system on the physical system is reflected by the variable F.P., the farming practices locally employed. The sole method in which the farmer can alter the physical state of his agricultural environment is by application of this variable. Weather modification is not considered in this paper due to the limited and questionable results of this procedure to date. The effect of the variable F.P., the only output from the sociologic system on the physical system is governed by the functional relationship described in the previous section.

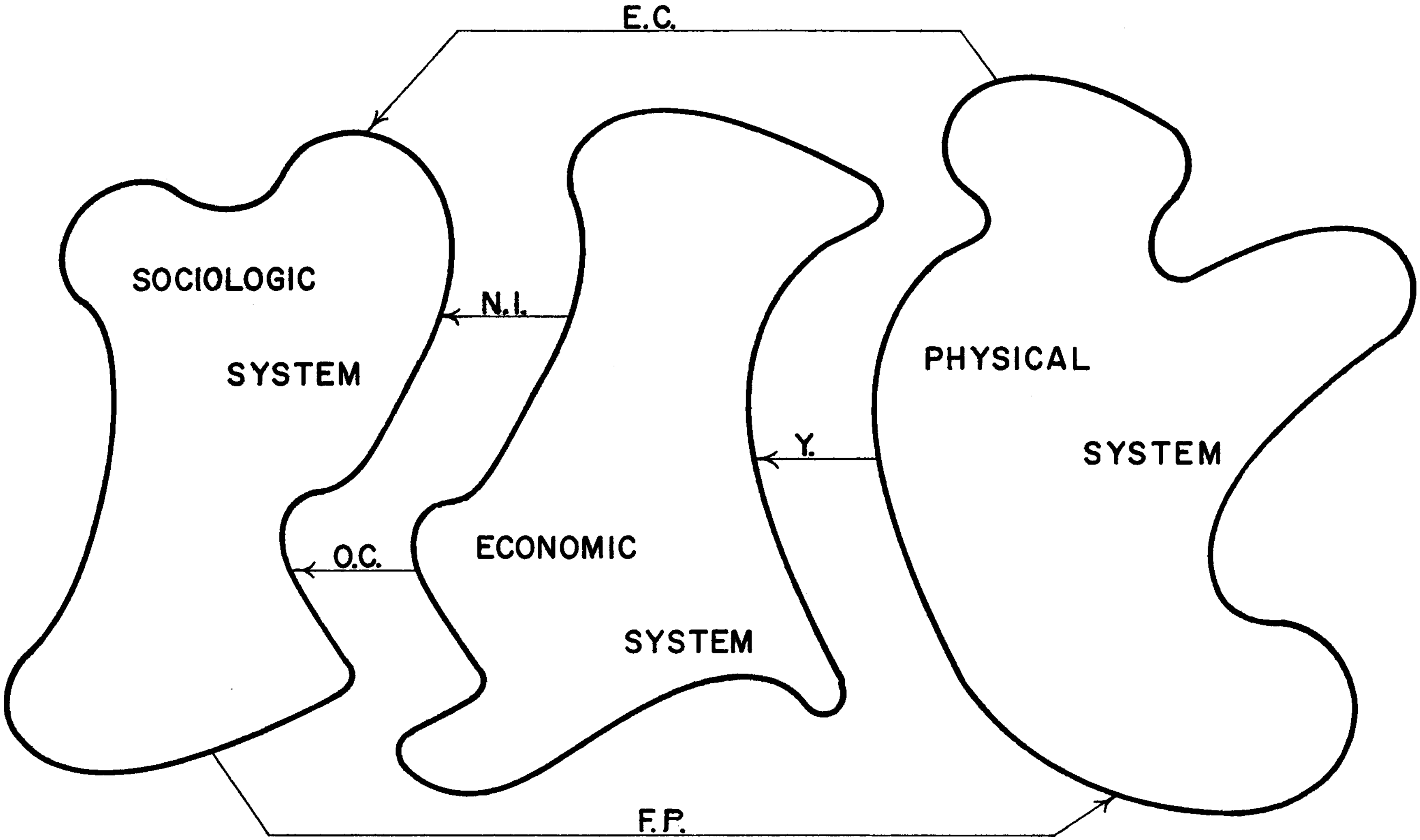
Crop yield, Y., is the only physical variable with influence on the economic systme. Being the only input into the economic system from any other section of the model, the economic system can be internally altered only by the manipulation of this variable. All the other independent terms of the economic system are either externally determined or are fixed state variables. Because of this situation the economic system is the most autonomous component of the model. It should be noted that the entire output of this system is solely influencing the sociologic variables (46).

The elements from the economic system directly influencing the variables of the sociologic system are N.I., the net income of the individual farmer, and O.C., the cost of the optimal farming method. These variables provide information enabling the farmer to make decisions regarding crop selection and farming practices. With these inputs, the sociologic system becomes the only component of the model to have inputs from both the remaining systems. This makes the sociologic system the most dependent, and at the same time the most responsive component of the three.

The actual interrelationships between the systems comprising the Inter-System Flow Model are most readily apparent in the examination of the flow situation of each individual variable and the constraints these variables place upon each other, as shown in the following section.

Figure 26

SYSTEM INPUT/OUTPUT RELATIONSHIPS—



SYSTEM FLOW RELATIONSHIPS

The simplest entry point to this Inter-System Flow Model is at the transition from the physical system to the economic system through the Y. variable. The crop considered in this case will be cotton. In 1969 an estimated 36,000 bales of Upland and American-Egyptian cotton were produced in Graham County, or approximately 334 bales per quarter section of cultivated land (4). At 500 pounds per bale this would give a farmer cultivating that amount of cotton a yield of 167,000 pounds. The price of cotton (P.C.) in 1969 was 23 cents per pound (4) so the farmer has an income of $38,400 gross (G.I.)

The farming method found optimum in that year was flood irrigation using ridge planted furrows. The main expenditures in this method are for labor and water. The labor for trimming, hoeing, hoe-trimming, weeding, blocking and thinning for a farm of that size per growing season is approximately $13,200 (4). Let us assume this farmer used one-third pumped water and two-thirds river (diversion) water for the five acre-feet per acre the cotton required in that season. The approximate cost of water, including canal and pump maintenance. should be appxorimately $3100 (62) for our hypothetical farmer, and his O.C. value is about $16,300 for flood irrigation.

If we assume a $10,000 base operational cost (B.C.) of the farm for that year his total agriculturally-oriented expenditures would be $26,300 and using Equation [17], his N.I. value will be $12,100. This value is only his agricultural net income, not including external sources of income, assuming this optimum irrigation method, and not including expenditures unrelated to the production of his agricultural profit.

The net income (N.I.) of the farmer influences his Crop Selection variable (C.S.). The farmer takes into consideration his previous experiences as defined in I.C., the characteristics of his fields and of the climate (E.C.), and his net income (N.I.) as an indicator of the success he has had in farming. In the case of the hypothetical 1969 farmer just discussed, he will probably select to maintain the crop and acreage of the previous year. In cases where the N.I. variable is sufficiently small or the expectation of the E.C. variable is sufficiently poor, he may choose to cultivate no crop in the following year.

Perhaps this is not as difficult as the last situation discussed. In this case, an alteration in the Farming methods may be indicated by the constituents I.C. and O.C. For example, if the price of cotton is extremely high and if the field conditions indicate the potential of severe salt burn to his crops the farmer may make a C.S. selection to remain in business and only change his farming methods. In this case the O.C. value may indicate that sprinkler irrigation is the optimum method for the watering of cotton, even though the capital investment is high. The optimization function of the economic model has determined that this method is most conducive to a high return because of the high crop price.

The crop selection and the optimum farming method make up the F.P. variable which lists the factors in which actions by the farmer can influence the physical system. In the case in point, the compaction of the field soil by the equipment placing sprinklers is included, as an example. The terms involved in the F.P. variable may be grouped under pumping practices (P.P.) and field practices (F.P.).

The pumping practice term involves the amount and time distribution of withdrawals from the farmer's wells. In this manner the P.P. variable influences the Pumping variable, P. For example, assuming ceteris paribus conditions on the other variables influencing P. (such as R. and A.C.), if the farmer pumps his wells a great deal during a short period of time he sets up a sharp hydraulic gradient toward the well. These conditions transport water from different locations than would a P.P. value of low and even pumping. The quality of this water may be similarly different, as dictated by the Recharge (R.) and Aquifer Characteristics (A.C.) terms. If these variables are such that the water transported during severe pumping came from a more distant point than from even pumping conditions, the water may be more saline. Such a high salinity may be due to the water being drawn through a salt-bearing stratum in the aquifer (A.C.) by the increased gradient, or due to highly saline recharge (R.) to the aquifer being transported to the well by the same gradient.

Such a recharge conditions may arise in a case where the irrigation water concentration mechanism for the salinization of the irrigation aquifer is predominant. In such a case, the parameters I. and S. combine at the point in question to form water of this poor quality. Either of the terms in this situation may be zero, letting the entire contribution to the quality factor of P. be made by the other term. The combination of the infiltration and seepage water with the constraints of the aquifer characteristics is a point function, and may not be computed for areas unless assumptions of regional homogeneity are made. Changes in the point function value which are dependent on human activities are caused by direct influences of the P.P. variable and by indirect influences of the F.C. variable exhibited through the effects of irrigation water quality and quantity.

The Pumping variable, as determined by these influences, contributes water to the field as do the Surface Water Inflow variable (S.I.) and precipitation contribution to the Climatic (C.) variable. The quantity of each of these water inputs to the field may be varied from field to field and from year to year. If low rains have produced a low stage in the Gila River and its canals during the months of flood irrigation the primary constituent of the water reaching the field will be from the pumped water, which is the most saline of the three (8). If, on the other hand, precipitation has been significant during the period before irrigation season, the principal inputs of water in both quantity and quality will be the best and second-best quality water. Precipitation and diversion water make this contribution (56, 62).

The quality of the water applied to the field is transformed into soil salinity terms in the method described in the S.S. variable discussion. The soil salinity is proportional to the quality of the water applied. The soil salinity is also proportional to the percentage of optimum yield that may be expected from the crop if the optimum water is applied, as indicated by the production function of that specific crop. In this way, the water applied becomes proportional (or inversely proportional in this case) to the yield of the crop.

With the last step of inputing the Yield variable Y. into the Gross Income variable of the economic system, the cycle has once been completed. The flow relations indicated show the effect of the alteration of any one variable on the remaining model components. The model in this state may be used to predict changes of parameters in a qualified manner, in terms of their input effects. A further quantification of the model functional variables, where possible, may yield an over-all digital model of the system.

S U M M A R Y   A N D   C O N C L U S I O N S

The Safford Valley was found to be a structural trough with a generally east-west orientation. The basement complex is at the surface on the upstream, or eastern, limb of the valley and extends at its deepest point to over 5000 feet below the surface on the downstream limb. The material filling this trough may be broken down into three facies groups. The Lower Basin Fill is the primary contribution to this material. A basal conglomerate is overlain by an extensive evaporite facies, which is subsequently overlain by a green clay facies and some delta deposits. The Gila River intercepts the Lower Basin Fill in the bottom of the valley. Transitional deposits comprised of calcareous and red facies cover the Lower Basin Fill away from the river. The Upper Basin Fill, of which only remnants seem to be apparent, terminates the series with tuffaceous lacustrine, piedmont and conglomerate facies. In plane view, the lower positions of the valley along the river seem to be Pleistocene and Holocene alluvial deposits, such as sand, gravel, silt and clay. The upper positions of the valley which comprise the terraces seem to consist of Upper Pliocene Gila Congomerate, lake beds, lacustrine clays, silts, sand, tuff and limestone.

The Safford Valley is hydrogeologically divided into two aquifer systems. The artesian aquifer system occupies the lower extent of the basin fill and is believed to extend to the bedrock-fill interface in lower extent. The upper boundary of the system is apparently, or is in, the green clay facies of the lower basin fill. Since the basement complex deepens in the downstream direction, and since the green clay facies and red facies into which it grades in the western limb are relatively level, the vertical extent of this aquifer similarly increases in that direction. A surficial water table aquifer occupies the Quarternary alluvial material in the overlying stratigraphy of the upper surface. The water table of this aquifer seems to conform with the configuration of the land surface under static or non-pumping conditions.

The water of the artesian aquifer is in general extremely saline, with electrical conductivity in the neighborhood of 8 millimhos. Extreme variability in salinity among samples from this aquifer has been observed. The water also exhibits thermal properties and may be above 100°F in many locations. Measurements in the one hundred and twenty degree Farenheit range are not unusual. The material which makes up this aquifer was deposited in the lightly saline water of a Pleistocene-Pliocene lake. The water of this lake is believed to still occupy the basal conglomerate facies. The artesian conditions are imposed by the confining forces of the green clay and evaporite facies which also contribute to the salinity of the aquifer. The intertonguing of the basal and evaporite facies brings water into contact with the remnant evaporitic salts of the lake.

The salinity of the water table aquifer averages in the neighborhood of 4 millimhos, and thus, is currently in the acceptable range for agriculture, its principal use. The source of salts to this water is a more difficult question than the artesian aquifer source, and has a four input model proposed. One input of both water and salt into the water table aquifer is natural recharge. Such recharge, primarily from wash-bottom sources during precipitation periods and influence from perennial streams, is shown to have a lower salinity than the state (original) concentrations of the chemical constituents in the aquifer. This source would then improve aquifer salinity, as brought out by chevrons of high quality water at such wash locations in iso-chemical maps. A second input is that water which infiltrates from irrigated areas. This would mean pumped irrigation water (ground water) plus surface water irrigation, plus precipitation, less evapotranspiration. A thermodynamic chemical equilibrium was applied to this mechanism, using well cuttings as aquifer samples. It was found that if the applied water to the field had 735 ppm chloride (which was found to be average in irrigation water), the chloride content would be 2100 ppm by the time it reached the aquifer. This constitutes a three-fold increase in the salinity, as indicated by chloride, of the aquifer. The third input is a source of salts within the aquifer itself, that is, lateral movement of water in the aquifer through soluble beds. The relative scarcity of evaporitic beds in this zone of fill coupled with low hydraulic gradients as a force to move water through such beds limits the significance of this contribution. The final, and most important, contribution of salts to the system is leakage from the artesian aquifer. This leakage occurs through natural imperfections in the cap beds as well as punctures of the confining layer made by deep wells. The pressure of the artesian aquifer encourages such leakage of salts and water into the overlying aquifer. The contact between the water table aquifer and the artesian aquifer is a principal consideration in the development of the ground water resources of the valley. Such development should take into consideration the extent of these contacts under natural conditions as well as alienation of this extent by foreign conditions caused by pumping. Pumping by imposing a hydraulic gradient artificial to the location may set up flow lines in the two aquifers which encourage the occurence of such contacts, or leaks. The volume of water entering the system in this manner is felt to be significant, although estimates are difficult.

At any point in the water table aquifer system these four contributions are believed to make up the salinity increase, although the extent of each mechanism varies from point to point. This increase in salinity has been found to be approximately +0.13 millimhos and +35 ppm chloride per year on the average, between 1940 and 1972. The rates do not seem to be uniform throughout the valley. Iso-chemical maps indicate the change may be divided into three major sections. From the Gila River's entry point into the valley until Safford there seems to be a uniform, relatively stable salinity condition with the highest quality water in the valley. From Safford to Pima there is a uniform, low magnitude increase in salinity. From Pima to the downstream limit of the valley the area exhibits extremely irregular salinity change conditions. Thus, progressing in the downstream direction the aquifer becomes more saline, more rapidly deteriorating, and deteriorating in a less uniform fashion. Although downgradient movement of salts may be a contributing factor, the correspondence to the increasing artesian aquifer is not considered coincidental. The salinity of the artesian aquifer generally increases in this direction, leakage points are more common, and there may be more head difference between the aquifers. It is therefore recommended the first area mentioned be that primarily pumped, and the last not pumped at all. Although this recommendation is obviously impossible to implement, canal companies can use wells in the stable region in preference to elsewhere, and further development may be planned with this consideration.

Production functions show productivity of the principal commercial crops in the valley (alfalfa, hay, sorghum, cotton, barley) all to be above 90% relative yield (except alfalfa) with the current root zone soil salinity in the neighborhood of 4 millimhos for the growing season. Of these crops, alfalfa is the least tolerant to salt. Economic analysis on a ceteris paribus basis, on a representative farm, indicates that alfalfa will no longer be economically feasible to produce at the 70% relative yield level. This is not to say that no return on the crop may be expected at that level, since this occurs at 48% relative yield, but that the next productive-tolerant variety (barley in this case) will replace alfalfa as the cultivated crop. This 70% relative yield value for alfalfa production is indicated by the production function to correspond to a root zone soil salinity of 5.5 millimhos. An analysis of water quality data from irrigation wells that have repeatedly been sampled since 1940, and which thus yield 32 years of record, was performed for chloride and electrical conductivity measurements. Electrical conductivity yielded an increase of 0.13 millimhos per year for a weighted mean slope. Note that this is not a line of best fit for the data. Chloride measurements clustered themselves into three definite groups, which correspond to the above-mentioned areas. The area to Safford showed a general increase of +5.35 ppm chloride per year with one well in the "San Simon Anomaly" area that exhibited an improvement in water quality. The Safford to Pima area showed a tight cluster of +34.90 ppm chloride per year. The final area downstream of Pima showed a very loose cluster of only three wells with a weighted mean annual increase of +61.52 ppm chloride per year. These analyses both support the pumping area recommendations and yield a basis by which to project future changes in the ground water quality. The electrical conductivity increase rate, when applied to the 1972 electrical conductivity map will yield projected values for any given year. If, on the other hand, a level of electrical conductivity may be fixed, and by using the rate of change projection and the 1972 base year data for that point, the year in which the specified level is reached will be computed. The Department of Agriculture's equation to relate root zone soil salinity to salinity of irrigation water was applied to the 5.5 millimhos root zone soil electrical conductivity. The irrigation water value obtained, 9.8 millimhos irrigation water electrical conductivity, was used as the limit for analysis in determining the year such a level would be reached, by the method just described. It was found that the three regions of salinity appeared here also. The area first to reach this level was that beyond Pima. A contour map of the replacement date of alfalfa indicates over 3,000 acres of land unable to use local water for alfalfa production by 1990. The entire region will be unable to support alfalfa by 2010. The Safford to Pima region will rather uniformally reach this level circa 2020, while the remaining region will achieve the level in 2040.

Cotton is the primary agricultural product of the region, with an estimated 15,200 acres in production, or nearly half of the 32,350 acres of agricultural land. Cotton is at the same time the most tolerant crop with the exception of barley. The maximum acreage of cotton is currently being produced since an allotment system limits the crop acreage. Of the $173 per acre profit on cotton in the area, $84 per acre is a government subsidy payment. Because of this payment the replacement and no profit levels of the crop are pushed well out of the time range within which this study will make projections. It is safe to say that under ceteris paribus conditions the economic cultivation of cotton is under no danger for a significant time into the predictable future. Further, since cotton is the principal economic element in agricultural profits, the agriculturally-based economy, under these same conditions, is sound.

Sociologic analysis showed that in general the local farmers, based on 41 field interviews, which constitutes 25 percent of the farms with 20 or more acres under cultivation, showed cognizance, yet little concern of the water quality situation influencing their land. Many did not use salt control techniques such as furrow sloping or efficient irrigation methods.

An inter-system flow model was constructed in an attempt to synthesize the sociologic, economic and physical systems which operate in the valley. Systems elements were broken down into state variables (internal characteristics of the system), external variables (characteristics of the outside world with influence on the system), and functional relationships (working system components). The interconnections of the three subsystems mentioned were isolated to be crop yield (physical to economics), net income and operational costs (economic to sociologic), farming practices (sociologic to physical) and observable field characteristics (physical to sociologic). The only factor which is affected by farmer behavior that can affect salinity is pumping practices, an element of farming practices. This, in turn, is primarily dependent on "individual characteristics," which is a catch-all element for all learned and experienced behavior of the farmer. Thus, education on salt control farming methods and on the actual local salinity situation is the method by which salinity control measures may be realized.

In general, the obvious primary recommendation is to employ all the high quality river water allowable by the Gila Compact. This is currently being done. Second, the pumping regime proposed should be both currently phased in and considered in further development of ground water resources in the valley. Third, salt control farming methods should be encouraged by farmer information programs and further investigation methods such as night sprinkler irrigation. Fourth, although currently sugar beets have disease problems in the region, continued research at the Safford Farm branch of the Agriculture Experiment Station should be encouraged for the possibility of future re-introduction of sugar beets as an economic and extremely salt-tolerant crop. Fifth, well drilling practices should be encouraged which would avoid puncture of the artesian aquifer confining layer and wells that do intercept this layer should be plugged in a manner such that the flow of saline water is both not allowed to contaminate the irrigation aquifer and is not allowed to flow into the local water sources. It should be noted that these recommendations emphasize the ceteris paribus nature of the investigation and conclusions. Factors such as the introduction of extensive copper mining or fluctuation of market status of the crops concerned has not been considered. Under these conditions, the valley has a long and productive agricultural life for the future, and with the recommendations employed may have even higher yields and an even longer period of productivity. Good planning should be the fundamental consideration of the region's inhabitants.

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APPENDIX

TABULARIZATION OF 1972 WATER QUALITY DATA

The following tables list the complete chemical analyses for the water samples collected during the field work at Hydrology Summer Field Camp.

The Field Number entry in the table identifies the sample location by the standard Geologic Survey location method. The first digit indicates the township number south of the Arizona base line. The second two digits are the range number west of the Gila and Salt River Meridian. The last two digits indicate the section number of the sample location. The letters indicated after the numbers locate the sample down to the sixty-fourth of a section by the standard Geological Survey method. All the Safford Valley is located in the Arizona D quadrant of the state.

The sample analyzed by the University of Arizona Agricultural Experiment Station for total soluble salts, electrical conductivity, calcium, magnesium, sodium, chloride, sulfate, carbonate, bicarbonate, fluoride, nitrate and pH. Electrical conductivity is expressed in millimhos, and soluble salts are in terms of total parts per million.

The SAR (Sodium Absorption Ratio) (58) of the water sample was calculated by the expression:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} \quad [18]$$

In Equation [18] the term Na^{+} is defined as the amount of sodium in the sample in terms of milliequivalents per liter, which is proportional to parts per million as follows (17):

$$\frac{Na^{+}\ (ppm)}{22.98} = meq\ Na^{+}/liter \quad [19]$$

The similar relationships for Ca^{++} and Mg^{++} are:

$$\frac{Ca^{++}\ (ppm)}{20.05} = meq\ Ca^{++}/liter \quad [20]$$

and,

$$\frac{Mg^{++}\ (ppm)}{12.15} = meq\ Mg^{++}/liter \quad [21]$$

The water classification was determined as indicated by Dutt (19). In this classification method the salt (C) content and sodium (S), or SAR, are used to determine the water type. The method indicates low to high (1 to 4) values of each of these constituents. The vast majority of the samples fell in the C4 class with S4 as the primary sodium classification. A description of the classes found in these samples follows (17).

<u>C2-S1 Medium Salinity-Low Sodium Water</u>

Waters in this class may be used for irrigation if a moderate amount of leaching is done. Plants with moderate salt tolerance can be grown in most cases without special salinity control practices. Very little danger exists from development of harmful levels of exchangeable sodium. but some sodium-sensitive crops are exceptions.

<u>C3-S1 High Salinity-Low Sodium Water</u>

This water should only be used on soils which can be leached easily. Salinity control must be practiced at all times. Only salt tolerant plants should be grown.

<u>C3-S4 High Salinity-Very High Sodium Water</u>

Because of the high salt content of this water, it should be used only on soils having unrestricted drainage, for use by crops with good salt tolerance. Amendments to the water may not be practical to waters of such very high salinity.

<u>C4-S1 Very High Salinity-Low Sodium Water</u>

This water is considered to be poor quality for irrigation but it may be used if all other conditions are favorable. Of these conditions, drainage is the most significant and must be applied for leaching and only crops of the highest salt tolerance used. There is little danger of exchangeable sodium problems with this water.

C4-S2 Very High Salinity-Medium Sodium Water

The very high salinity of this water permits occasional use and only then under favorable soil and plant conditions. An exchangeable sodium problem might develop in a soil irrigated with this water if the soil is fine-textured or otherwise poorly drained. Only plants of high salt tolerance should be grown if water of this quality must be used.

C4-S3 Ver High Salinity-High Sodium Water

Because of the excessively high salt content of this water it is not recommended for use except under very special conditions. If used at all the soil must be permeable and very well drained. Water must be applied in considerable excess to provide better salt transport to depth. and only the most salt tolerant crops should be used.

C4-S4 Very High Salinity-Very High Sodium Water

This water is undesirable for irrigation with respect to both salinity and alkalinity. If used at all, it should be used very freely to leach the salt from the soil. Calcium from any source, whether dissolved from the soil or applied as an amendment, may improve the water to the point where it may have limited use; thus, calcium amendments may improve conditions where waters belonging in classes C1-S3 and C1-S4 may have provisional use as irrigation water.

Field No.	52203bba	72711bbb	62507baa	52310aab	42328cdc	52433baa	82612bdb	62736ccc	62410bdd	62423add	72621add	62736ccc
Lab No.	3427	3428	3429	3430	3431	3432	3433	3434	3435	3436	3437	3438
Soluble Salts ppm.	256	1077	5011	626	1747	3402	970	956	2890	2318	2011	888
$ECx10^3$	0.33	1.57	6.50	0.96	2.65	4.50	1.53	1.51	4.25	3.40	2.90	1.5
Calcium ppm.	40	4.4	120	100	80	200	27	5.6	124	154	70	4.4
Magnesium ppm.	4.3	0.97	72	17	20.2	70.5	4.3	0.49	80.3	57.2	20.7	0.97
Sodium ppm.	21	365	1460	40	450	840	281	320	660	520	534	290
Chloride ppm.	20	220	1480	34	520	1166	244	246	1010	726	580	244
Sulfate ppm.	62	150	1100	96	330	600	235	105	410	310	230	110
Carbonate ppm.	0.0	10.8	0.0	0.0	0.0	0.0	13.2	0.0	0.0	0.0	13.2	0.0
Bicarbonate ppm.	107	212	708	325	329	488	161	254	556	520	520	210
Fluoride ppm.	0.66	9.50	5.20	.68	.91	1.40	1.10	2.95	1.30	1.62	1.77	4.65
Nitrate ppm.	1.3	4.5	66.6	13	17.25	36	3.75	20.25	48	29.3	41.3	24
WATER CLASSIFICATION	C2-S1	C4-S4	C4-S4	C3-S1	C4-S2	C3-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4
SAR	0.6	24.2	16.±	0.7	9.9	20.±	12.2	24.2	11.3	10.3	14.2	20.
pH	8.5	7.6	7.4	7.6	7.9	8.4	7.7	7.6	7.6	8.7	7.6	7.5

Field No.	72704daa	72617add	72606adc	72704daa	62402bdc	62734dcc	72708add	62406cac	62508ddb	72613cdd	72708dbb	62412adc
Lab No.	3439	3440	3440	3441	3443	3444	3445	3446	3447	3448	3449	3450
Soluble Salts ppm.	1064	2555	1858	1045	5496	1544	1281	5104	3431	1363	1371	3105
$ECx10^3$	1.68	3.5	2.6	1.52	7.75	2.4	2.05	7.05	5.0	2.2	2.2	4.5
Calcium ppm.	101	152	124	103	147	118	109	191	78	92	124	184
Magnesium ppm.	22.9	42.6	37.7	22.4	72.2	37.2	28.5	75.2	36.5	24.3	29.2	53
Sodium ppm.	217	615	375	209	1320	327	205	1340	940	328	280	750
Chloride ppm.	246	750	560	248	1890	410	344	1660	990	360	370	1020
Sulfate ppm.	120	390	260	110	1265	200	190	1100	720	190	200	500
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate ppm.	337	549	422	303	707	415	366	589	634	366	366	586
Fluoride ppm.	1.75	1.3	1.63	1.55	4.85	2.45	2.1	3.3	3.55	2.25	2.1	2.65
Nitrate ppm.	18	55.5	27.75	19.5	90	34.5	36	75	28.5	0.0	0.0	9.0
WATER CLASSIFICATION	C4-S2	C4-S4	C4-S3	C4-S2	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S3	C4-S3	C4-S4
SAR	4.3	11.6	5.9	4.2	30±	6.0	4.2	24±	28±	6.1	5.3	29±
pH	7.6	7.5	7.5	7.6	7.6	7.4	7.6	7.7	7.6	7.6	7.6	7.5

Field No.	72501ddc	72605ddc	72702aca	82605bcc	62805dac	62509ccc	52829add	62831dac	62523ccc	62525dab	72621baa	62411dab
Lab No.	3451	3452	3453	3454	3455	3456	3457	3458	3459	3460	3461	3462
Soluble Salts ppm.	578	1020	1096	2013	2898	3352	4490	817	2425	2412	2294	2671
ECx10³	0.88	1.5	1.68	2.6	0.6	4.88	6.5	1.3	3.5	3.5	3.67	3.7
Calcium ppm.	63	9716	80	171	54	138	280	70	144	148	115	238
Magnesium ppm.	16	22	16.4	47	13	54	84	18	51	48	34	51
Sodium ppm.	71	195	256	400	25	865	1010	167	530	540	575	560
Chloride ppm.	92	260	342	700	18	1020	1600	252	710	710	630	880
Sulfate ppm.	70	120	130	450	20	650	800	70	450	450	400	475
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate ppm.	264	312	264	244	259	610	659	237	537	512	5.37	464
Fluoride ppm.	0.70	1.38	2.05	1.15	0.46	3.95	1.4	1.32	3.25	2.95	1.05	1.0
Nitrate ppm.	1.4	12	5.25	0.0	0.3	10.5	55.5	0.0	.75	1.5	1.5	2.25
WATER CLASSIFICATION	C3-S1	C4-S2	C4-S2	C4-S4	C2-S1	C4-S4	C4-S4	C4-S1	C4-S4	C4-S4	C4-S3	C4-S3
SAR	1.8	4.1	5.9	6.3	0.8	28±	30±	3.8	8.4	11.1	4.7	7.6
pH	7.6	7.5	7.6	7.6	7.8	7.6	7.7	7.6	7.6	7.6	7.5	7.7

Field No.	62401bdc	72716cba	72709abb	72614add	72609ccd	72416bab	62526dcc	62526dcc	72701bba	72605bdd	62518bda	62518bab
Lab No.	3463	3464	3465	3466	3467	3468	3469	3470	3471	3472	3473	3474
Soluble Salts ppm.	5486	1350	1248	1325	2567	1106	3437	3369	786	1642	3870	3870
ECx10³	8.25	2.1	1.8	1.95	3.7	1.75	4.75	4.75	1.25	2.2	5.25	5.25
Calcium ppm.	171	92	114	137	172	111	200	220	4	114	298	277
Magnesium ppm.	81	23	27.4	30.2	41.3	25	67	84	0.24	29	87	87
Sodium ppm.	1290	215	235	257	530	203	785	775	264	240	800	840
Chloride ppm.	1850	350	332	336	780	276	1160	1150	216	430	1300	1348
Sulfate ppm.	1375	240	160	180	500	140	650	550	75	350	700	650
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.4	0.0	0.0	0.0
Bicarbonate ppm.	659	427	356	376	537	337	561	561	200	378	683	587
Fluoride ppm.	4.75	2.85	1.55	8.1	2.55	1.65	2.1	1.4	2.9	1.75	1.32	1.63
Nitrate ppm.	55.5	0.0	21.75	5	0.0	12.75	12	27.75	9.0	0.0	0.82	79.5
WATER CLASSIFICATION	C4-S4	C4-S2	C4-S2	C4-S2	C4-S4	C4-S2	C4-S4	C4-S4	C4-S4	C4-C3	C4-S4	C4-S4
SAR	30±	4.3	4.0	4.3	9.0	3.4	30±	30±	22.2	4.3	30±	40±
pH	7.6	7.7	7.5	7.5	7.6	7.5	7.6	7.6	8.8	7.6	7.6	7.5

Field No.	62518daa	62516cac	62522bcb	62508cad	72616add	62507bda	62520bac	62520bac	72615dad	72710abc	52432aca	52303abb
Lab No.	3475	3476	3477	3478	3479	3480	3481	3482	3483	3484	3485	3486
Soluble Salts ppm.	2633	2785	2489	3508	2926	4794	3014	3829	1925	1106	2934	289
$ECx10^3$	4.75	4.25	3.7	5.0	3.9	7.0	4.35	5.5	3.0	1.8	4.25	.37
Calcium ppm.	221	206	117	85	190	128	100	278	146	16.8	187	41
Magnesium ppm.	67	57	37	32	47	68	32	86	39	3.7	51	5.5
Sodium ppm.	140	590	560	950	630	1280	775	780	400	365	690	19
Chloride ppm.	1030	900	760	1060	820	1500	840	1350	500	256	915	24
Sulfate ppm.	575	500	400	660	460	1050	500	600	350	230	550	80
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.0	0.0
Bicarbonate ppm.	598	525	586	647	537	708	732	659	464	215	512	110
Fluoride ppm.	1.4	2.2	3.75	5.5	3.25	4.45	3.5	1.3	2.6	7.5	2.35	0.6
Nitrate ppm.	0.10	4.5	25.5	68.3	39	55.5	31.5	75	23.3	5.25	27	1.6
WATER CLASSIFICATION	C4-S3	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C2-S1
SAR	1.9	12.0	11.8	30±	28±	30±	20±	30±	6.7±	12.9	13.2	0.2
pH	7.5	7.6	7.7	7.7	7.6	7.6	7.7	7.7	7.5	8.3	7.5	7.4

Field No.	82602ccb	62735ddd	72701bbb	52429bcd	72608caa	62831dba	72719aaa	62518cbd	82512dba	42333dab	52431aac	62631cdd
Lab No.	3487	3488	3489	3490	3491	3492	3493	3494	3495	3496	3497	3498
Soluble Salts ppm.	1696	814	830	3820	3060	785	1452	2512	704	386	2682	2181
$ECx10^3$	2.8	1.43	1.2	5.0	4.25	1.25	2.0	3.5	1.23	1.48	3.6	3.2
Calcium ppm.	23.6	3.6	5.2	243	221	31	110	232	5.2	60	192	199
Magnesium ppm.	2.5	.49	.49	70.5	57	8.6	30	54	.49	8.5	46	49
Sodium ppm.	505	237	283.	880	620	200	290	495	248	31	580	440
Chloride ppm.	700	228	200	1250	940	214	345	785	218	28	850	700
Sulfate ppm.	300	120	90	700	550	100	250	450	150	85	500	400
Carbonate ppm.	0.0	12	14.4	0.0	0.0	0.0	0.0	0.0	9.6	0.0	0.0	12
Bicarbonate ppm.	153	200	2.20	647	610	224	397	451	56	171	488	354
Fluoride ppm.	1.2	7.0	4.3	1.65	2.35	1.85	2.4	1.12	9.0	0.6	1.55	1.65
Nitrate ppm.	5.3	6.0	12.75	27.8	60	6.0	27.8	44.3	6.0	1.6	24.8	25.5
WATER CLASSIFICATION	C4-S4	C4-S4	C4-S2	C4-S4	C4-S4	C4-S2	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4
SAR	26.6	20.8	8.4	24.8	16.9	7.6	17.2	7.0	5.8	0.7	4.3±	2.8±
pH	7.5	8.7	8.4	7.5	7.6	8.6	7.5	7.8	8.0	7.4	7.5	7.5

Field No.	62516dca	52428dbb	72720aaa	72717dba	72717dda	62507dba	72503cbc	72762aaa	62414baa	62831ccb	62831dbd	62530ccd
Lab No.	3499	3500	3501	3502	3503	3504	3505	3506	3507	3508	3509	3510
Soluble Salts ppm.	3087	5525	1383	1169	1265	4226	1975	830	2511	984	763	2680
$ECx10^3$	4.25	7.75	2.0	1.9	1.95	6.0	2.75	1.5	3.5	1.45	1.2	3.7
Calcium ppm.	136	192	68.8	129	120	140	93	6.2	144	118	74	114
Magnesium ppm.	47	86	16.5	29	25.3	61	77	.73	87	29	16	42
Sodium ppm.	785	1460	315	192	283	1010	400	241	515	155	144	625
Chloride ppm.	880	1750	320	236	246	1350	520	194	780	242	212	820
Sulfate ppm.	550	1250	250	170	170	825	300	120	450	120	75	450
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0
Bicarbonate ppm.	634	647	390	386	395	756	549	239	300	298	232	561
Fluoride ppm.	1.65	2.45	3.4	1.8	2.0	4.2	1.27	7.0	1.21	1.2	1.3	1.74
Nitrate ppm.	53.3	137.4	19.5	25.5	23.25	79.5	34.5	13.5	33.8	22.5	9.0	66
WATER CLASSIFICATION	C4-S4	C4-S4	C4-S4	C4-S3	C4-S3	C4-S4	C4-S4	C4-S2	C4-S4	C4-S2	C4-S1	C4-S4
SAR	30±	30±	7.2	3.6	5.3	30±	7.3	6.3	15.3	2.7	3.1	16.3
pH	7.6	7.7	7.7	9.0	7.5	7.7	7.7	8.5	7.5	7.8	7.8	7.6

Field No.	72701bab	52430aad	72719aaa	62831ada	62527bac	72605dcd	72701bac	42326cdd	82607abb	62529cad	72512dcd	62534bdb
Lab No.	3511	3512	3513	3514	3515	3518	3519	3520	3521	3522	3523	3524
Soluble Salts ppm.	623	3387	1467	985	2531	1560	875	6791	1584	3055	2037	3123
ECx10[3]	1.28	5.0	2.15	1.65	3.4	2.2	5.6	10.25	2.75	4.38	2.9	4.5
Calcium ppm.	4.0	230	110	100	120	134	1.35	159	4.4	83	183	276
Magnesium ppm.	.36	63	32	21	50	32	1.5	159	4.4	83	53	96
Sodium ppm.	260	708	289	193	575	285	285	1290	475	650	385	640
Chloride ppm.	232	1120	350	372	720	420	195	3000	510	1060	560	1120
Sulfate ppm.	80	600	250	80	475	300	120	1150	350	475	325	700
Carbonate ppm.	9.6	0.0	0.0	0.0	0.0	0.0	12	0.0	0.0	0.0	0.0	0.0
Bicarbonate ppm.	234	634	403	210	549	366	244	585	207	537	464	207
Fluoride ppm.	2.85	1.95	2.8	1.3	3.2	1.3	4.85	1.9	8.5	1.3	.91	1.45
Nitrate ppm.	9.0	30	30	7.5	39	21.8	10.5	7.5	9.0	63	66	82.6
WATER CLASSIFICATION	C4-S2	C4-S4	C4-S2	C4-S3	C4-S4	C4-S3	C4-S2	C4-S4	C4-S4	C4-S4	C4-S3	C4-S4
SAR	3.8	8.9±	4.6	5.8	25±	5.4	2.9	30±	7.6	30±	5.3	11.6
pH	8.5	7.5	7.6	8.6	7.6	7.5	7.8	7.5	8.1	7.6	7.5	7.5

Field No.	62521aaa	52418acc	72707ddd	62528dad	62533bcc	72717cad	62535bdb	42329acd	42318dca	62928acb	52429cdd	62520aaa
Lab No.	3525	3526	3527	3528	3529	3530	3531	3532	3533	3534	3535	3536
Soluble Salts ppm.	2945	4389	1246	3089	2458	1397	1992	4890	586	5173	3177	2855
$ECx10^3$	4.25	6.0	2.0	1.5	3.75	2.0	3.5	6.5	0.98	6.5	4.5	4.25
Calcium ppm.	140	260	106	232	112	129	199	296	52	454	195	237
Magnesium ppm.	58	86	24	71.5	78	31	55.5	73	9	113	55	55
Sodium ppm.	715	1000	203	637	500	241	543	1390	109	1080	718	580
Chloride ppm.	820	1550	270	1140	820	330	880	1650	116	1800	1020	940
Sulfate ppm.	565	800	250	500	450	250	450	900	100	1390	600	500
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate ppm.	586	634	366	464	451	378	378	512	195	317	561	512
Fluoride ppm.	3.15	1.4	1.85	1.75	1.63	1.74	2.15	0.73	1.27	1.27	2.75	2.15
Nitrate ppm.	57.8	57.8	24.8	42.8	45.8	36	27	68.3	3.75	17.3	28.5	29.3
WATER CLASSIFICATION	C4-S4	C4-S4	C4-S3	C4-S4	C4-S4	C4-S3	C4-S4	C4-S4	C3-S1	C4-S4	C4-S4	C4-S4
SAR	26.0	40±	4.1	14.3	9.4	4.1	7.4	28±	2.8	30±	28±	11.6
pH	7.8	7.6	7.6	7.5	7.6	7.5	7.5	7.6	7.4	7.3	7.5	7.6

Field No.	72604ddd	72718cdc	62535dcc	72606daa	52417cdb	52419acd	72701add	72503cbd	72605dac	42329acd	72502bdd	72710aad
Lab No.	3537	3538	3539	3540	3541	3542	3543	3544	3545	3546	3547	3548
Soluble Salts ppm.	945	1470	3300	1915	3537	5207	1144	2006	980	4720	2419	792
ECx10³	1.65	2.05	4.5	2.8	4.7	6.5	1.8	2.8	1.55	6.25	3.5	1.35
Calcium ppm.	99	107	292	158	164	444	6.2	94	89	300	259	69
Magnesium ppm.	20	29	91	37	65	113	1.34	75	21	71	64	15
Sodium ppm.	178	318	640	390	865	1100	359	415	190	1170	400	163
Chloride ppm.	250	350	1120	535	1160	1950	250	520	260	1640	700	218
Sulfate ppm.	110	225	550	350	700	950	250	325	120	950	400	70
Carbonate ppm.	0.0	0.0	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0
Bicarbonate ppm.	276	415	537	415	537	610	256	537	283	512	537	244
Fluoride ppm.	1.53	2.30	2.0	2.0	1.85	1.3	7.3	1.3	1.55	0.70	0.77	1.0
Nitrate ppm.	10.5	24.0	6.8	27.8	44.3	39	4.5	39	15.75	66	57.8	10.5
WATER CLASSIFICATION	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S4	C4-S2
SAR	3.2	5.7	5.5	6.6	30±	30±	23.7	7.9	4.3	30±	5.4	3.9
pH	7.6	7.7	7.5	7.5	7.7	7.5	8.4	7.6	7.6	7.6	7.5	7.7