EVALUATION OF WATER RESOURCES
IN
KIOWA AND BIJOU CREEK BASINS, COLORADO

Prepared for

Colorado Water Conservation Board

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado

May 1966

CER66HD-RAL19

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By H. R. Duke and R. A. Longenbaugh

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ABSTRACT

This report describes the water resources of the Kiowa and Bijou Creek drainages in northeastern Colorado. These intermittent tributaries to the South Platte River drain some 2130 square miles lying within six counties.

The area has a semi-arid climate with an average annual precipitation slightly over 15 inches, most of which falls during the summer months. Since the streams within the study area flow only during storm periods and since there is no water imported into the area, the principle source of water for irrigation is from ground water.

It was estimated that the alluvial aquifer contained 2,373,000 acre-feet of water in 1965, and that it receives 55,800 acre-feet of water annually through natural recharge of precipitation. The Fox Hills sandstone formation was considered to be the only bedrock aquifer capable of supplying moderate quantities of water to wells within the study area. This formation contains an estimated 2,000,000 acre-feet of recoverable water within the area, and could be an important future water source.

The first significant pumping in the area begain in the 1930's, and the annual withdrawal has increased to a maximum of 130,000 acre-feet from about 700 wells for the year 1964. This development has caused ground water level declines as great as 45 feet in some areas.

Based upon present management practices, it is anticipated that water levels will continue to decline in the study area, with resultant decreases in the amount of water pumped. Within fifty years, it is expected that the aquifer will be depleted to the point that only recharge water is available for pumping. By this time,

however, technology will likely develop such methods as artificial recharge and weather modification to feasibly increase the useable water resources of the area.

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INTRODUCTION

Purpose of the Investigation

The purpose of the investigation which this report describes was to evaluate the total water resources of the Kiowa and Bijou Creek drainages in Northeastern Colorado. Both ground and surface water supplies were considered. Specific geologic and hydrologic data were evaluated to provide the Colorado Ground Water Commission with information allowing them to consider the area as a "Designated Ground Water Basin" as described in the Colorado Ground Water Management Act, revised in 1965.

The Kiowa and Bijou Creek drainages were chosen for investigation because previous studies had compiled a large amount of data that could be used. In addition it was recognized that the ground water development in part of the study area has resulted in ground water level declines, and thus, could be classified as a critical ground water area. Because of the available data, the nature of the two drainages, and the extensive ground water development, the Kiowa and Bijou drainages were selected as the first area in Colorado to be considered as a "Designated Ground Water Basin." Data provided by this investigation were introduced as evidence during hearings that were held to consider the area as a "Designated Basin."

Location and Extent of Study Area

The area covered in this investigation lies in the eastern portion of the Denver Basin of Northeastern Colorado. This area includes the entire watershed of the Kiowa and Bijou Creeks and their tributaries above the town of Wiggins, Colorado, as shown in Figure 1. The two creeks are intermittent tributaries to the South Platte River; their confluence with the South Platte being near Wiggins and Fort Morgan, Colorado, respectively.

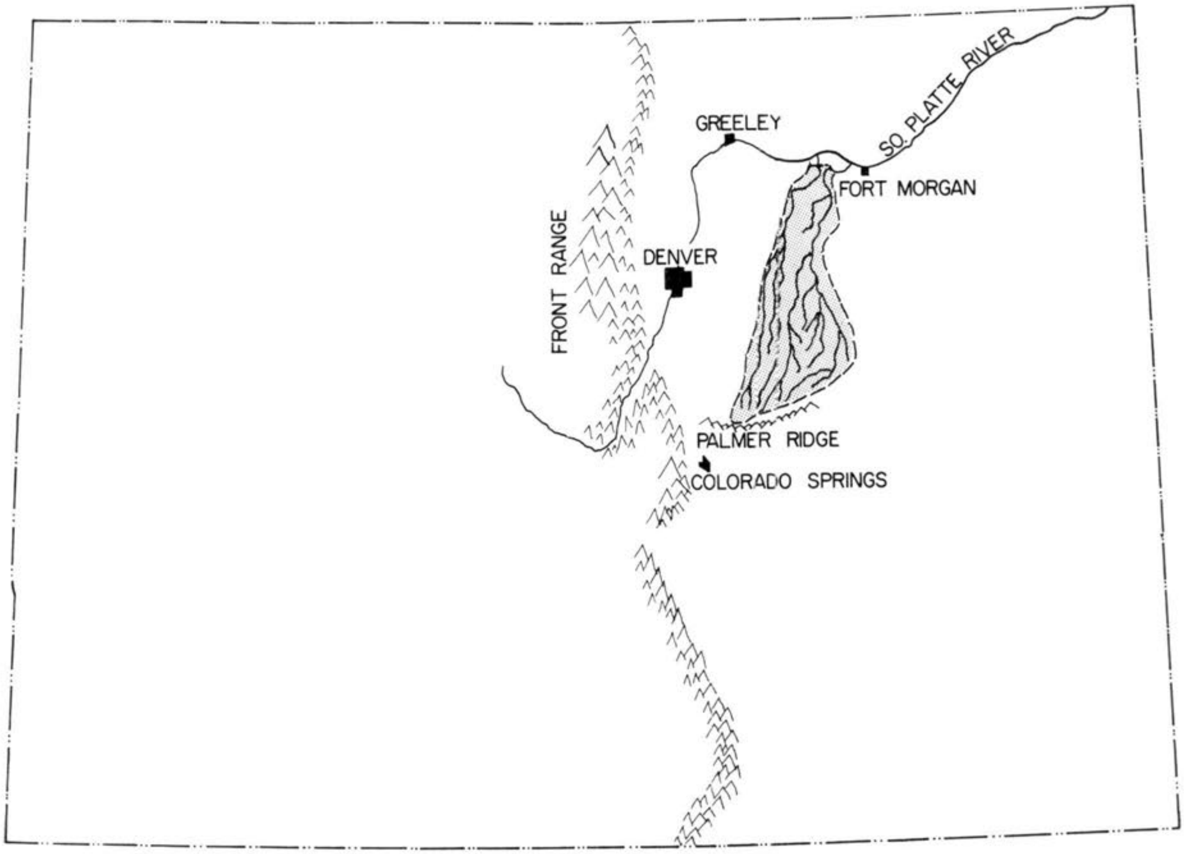

Figure 1. Location of Kiowa-Bijou basin in Colorado.

Together, the two creeks drain an area of 2130 square miles, extending from the South Platte River southward some 110 miles to the headwaters in the Black Forest region near Eastonville, Colorado.

This drainage includes portions of Adams, Arapahoe, Elbert, El Paso, Morgan and Weld Counties.

Items Considered for Evaluation

This investigation was concerned with the evaluation of the total water resources of the basins, including both surface and ground water. The factors evaluated for use by the Colorado Ground Water Commission include the names, descriptions, and boundaries of the various geologic formations underlying the area; an estimate of the volume of water stored in each formation; an estimate of the natural recharge to each of these formations; estimates of historic volumes of water pumped from the basin; the estimated projected pumping for the succeeding fifty years at ten-year intervals; and a list of ground water users of fifteen years or more.

Previous Investigations

Previous intensive investigations in this area were conducted in the late 1940's by the U. S. Geological Survey and reported in Water Supply Paper 1378 in 1957(1)*. These investigations were primarily concerned with the aquifers near the South Platte River itself, but extended southward into this study area approximately twenty miles.

William E. Code studied the ground water in the Bijou Valley within Morgan County during the late 1950's(8). This work was conducted as a Colorado Agricultural Experiment Station project designed to evaluate the ground water use at that time including analysis of the economic impact of ground water use on a community dependent upon

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* Refers to reference numbers in the bibliography.

ground water for its irrigation supply. Considerable historic data were collected during Code's study.

After the passage of Colorado's Ground Water Laws of 1957, consideration was given to the formation of a Bijou "Critical District". At that time data were compiled for the Bijou, Kiowa, and Prospect Valley areas, covering roughly the same area included in WSP 1378.

In 1960, Colorado State University initiated an investigation of that portion of the Kiowa Creek drainage extending from Bennett, Colorado northward some twenty-two miles to Colorado State Highway 52. This investigation(9) was an attempt to evaluate the natural recharge occurring within the Kiowa Creek basin. Later studies in the same area defined the geologic and hydrologic characteristics of this portion of the basin.

Ground water level measurements have been made in parts of the Kiowa-Bijou Basin since the early 1930's(12, 13, 14). These data show the water table dropping in much of the study area, indicating ground water withdrawals are exceeding recharge rates. Power data collected as a part of the water table fluctuation study conducted by the Colorado Agriculture Experiment Station were used to compute the historic amount of pumping that occurred.

Investigation Procedure

Colorado State University entered into a contract with the Colorado Water Conservation Board to evaluate the total water resources of the Kiowa and Bijou Creek drainages on June 1, 1965. Data from previous investigations was utilized as much as possible but some field work was essential. Field work included personal visitation to all irrigation and municipal wells in the study area to locate each well, determine the depth to water, depth to bedrock, and visit with the farmer or owner concerning the well discharge, the yearly days of operation, and the type of crops grown. Power data were collected from the Morgan County and Intermountain Rural Electric Associations. Pump efficiency tests were also conducted.

Office work included delineation of the study area and preparation of bedrock contour, water table contour, saturated thickness, and well location maps for the study area. Computations of the quantity of ground water in storage, historic pumping, natural recharge, and surface water supplies were made. An estimate of ground water withdrawals for the next fifty years was prepared. Basic data have not been included in this report, but summaries, tabulations, and graphs are included when applicable.

Colorado State University was asked to prepare and present the preliminary data at educational meetings prior to the Colorado Ground Water Commission Hearing in Fort Morgan on November 4, 1965. Both authors testified under oath before the Commission on November 4 and December 2, 1965 concerning the water resources of the Kiowa-Bijou Basins as determined by this investigation. This report has been prepared since the Commission hearings and includes all data presented at that time plus additional information developed in the evaluation of the total water resources.

Acknowledgments

The authors wish to express their appreciation to the Colorado Water Conservation Board, its Director, Mr. Felix Sparks, and his staff. Acknowledgment is also given to the Colorado Ground Water Commission, the staff of the Office of the State Engineer, and personnel from the U. S. Geological Survey Water Resources Division for data, suggestions, and criticism of the investigations and report. Data from previous investigations and some funds to prepare this report were provided by the Colorado Agricultural Experiment Station.

Many private individuals were very cooperative in providing the necessary data. These included every farmer in the area and the local well drillers who supplied well logs and observations from years of personal experience. Morgan County Rural Electric Association and Intermountain Rural Electric Association supplied power delivery data necessary for calculating the annual volume of water pumped. Carter Oil Company and Sinclair Oil and Refining Company furnished geologic logs of seismic shot-holes drilled for them in the area. The firm of Woodward, Clyde, Sherard and Associates provided information from their files.

Much of the analysis of data and preparation of maps was done with the assistance of Colorado State University graduate students Larry Land, Nazeer Ahmed, A. V. Sundaram, and Jack Chitwood. Melvin Oliver and Stanley Goodwine, undergraduate students, assisted in field investigations and analysis of electric power data.

DESCRIPTION OF STUDY AREA

Topography and Drainage

Topography

The study area lies in northeastern Colorado on the east side of the Denver Basin. Kiowa and Bijou Creeks, which drain the study area, originate in the timbered Black Forest region, some twenty-five miles northeast of Colorado Springs at an altitude of about 7,400 feet. The upper reaches of this area are characterized by wooded hills cut by steep, rather short tributaries. The topographic gradient in the upper forty miles of both drainages is about 40 feet permile along the main stream. Downstream, the topography gradually flattens to a gradient of about 15 feet per mile at the confluence with the South Platte River Valley.

Bijou Creek enters the South Platte River at an altitude of about 4,300 feet, giving a total relief of 3,100 feet over the study area.

In the upper regions of the area, the watershed boundaries are sharp and well defined, with a steep lateral gradient toward the streams. Near the lower end of the area, this sharp definition disappears and is replaced by a gently sloping divide covered by dune sand in many areas. In this lower portion, the lateral gradient is very small in areas lying between the major tributaries. It is in this region that most of the irrigated acreage is located.

Drainages and Drainage Patterns

Kiowa Creek enters the South Platte River midway between the communities of Orchard and Goodrich. From its headwaters, Kiowa Creek flows generally in a north-northeasterly direction toward the South Platte River. The present location of Kiowa Creek is often near the west boundary of the drainage. Major tributaries include Rock Creek which enters from the east about 5 miles southwest of Wiggins, Mule Creek entering from the east at a point 10 miles southwest of Wiggins, and Comanche Creek with its tributary Wolf Creek which joins Kiowa some 16 miles upstream from Wiggins.

Kiowa Creek is an intermittent surface stream, flowing water during spring snow melt or following summer thunderstorm activity. There are a few reaches on Kiowa Creek and some of its tributaries which are perennial in nature, however these reaches are very short, and no perennial stream leaves the study area. The perennial reaches usually occur in areas where the bedrock outcrops near the surface of the streambed, and the water thus forced to the surface quickly percolates back to the water table below such outcrop areas.

Kiowa Creek and its tributaries are apparently of subsequent origin, the stream courses being approximately parallel. This pattern of stream formation would indicate that the formation of these streams was directed by the upturned edges of the underlying sediments of the formations comprising the Denver Basin.

Bijou Creek turns eastward north of the study area, and has its confluence with the South Platte River near Log Lane Village about three miles northwest of Fort Morgan. The Bijou headwaters lie immediately east of Kiowa Creek. The Bijou drainage is parallel to Kiowa Creek and located some four to twelve miles east of Kiowa Creek.

Bijou Creek is also an intermittent stream, which can flow violently after storm periods. The drainage pattern of Bijou Creek and its tributaries is dendritic, with the West, Middle, and East Bijou Creeks originating near the headwaters of the basin. This type drainage pattern indicates stream development upon rocks of uniform resistance and implies a notable lack of geologic structural control.

Antelope Creek joins Bijou Creek from the west about four miles south of Wiggins. Muddy Creek and Big Muddy Creek (Deer Trail Creek) enter Bijou Creek from the east about eleven miles south of Wiggins. Ten miles south of Hoyt, the main stem of Bijou Creek forks to form West and East Bijou Creeks. The confluence of the Middle with the East Bijou is located east of Byers.

The study area is bordered on the west by the drainages of Lost Creek (Prospect Valley) and Boxelder Creek, on the south by Big Sandy Creek, and on the east by the Badger Creek drainage. Of the 2130 square miles drainage area in the study region, Kiowa Creek drains 740 square miles and Bijou Creek and its tributaries the remaining 1390 square miles.

Determination of Topographic Relief

Topographic maps prepared by the U. S. Geological Survey and the U. S. Army Map Service were used to determine drainage areas and boundaries. It was also necessary to use elevations from these maps as reference points in preparing bedrock contour and water table contour maps. In some areas it was possible to use land surface elevations obtained from petroleum exploration seismic shot-hole logs to supplement the map data.

Except for the extreme eastern portion of the Bijou Creek Basin, seven and one-half minute quadrangle maps from the U. S. Geological Survey were available for the lower 45 miles of the study area. Fifteen minute quadrangle maps were available for the extreme southwestern part of the Kiowa Creek Basin. Outside these areas it was necessary to use the U. S. Army Map Service maps having only 100 foot contour intervals. Bedrock and water table contour maps prepared in this investigation are drawn with dashed lines indicating the limited reliability of the maps where sufficient topographic data were not available.

Topographic Comparison of the Kiowa and Bijou Drainages

The general surface gradient in the study area is toward the northeast with a general west to east slope on any east-west cross section. In the upper regions Bijou Creek lies about 600 feet below and east of Kiowa Creek. Near the north end of the study area this topographic difference has decreased to about 30 feet.

The creek beds range in width from a few feet in the upper reaches of the tributaries to about a quarter mile in Bijou Creek near the town of Hoyt.

The Bijou drainage reaches a maximum width of about 23 miles in Adams and Arapahoe Counties, and has a relatively flat flood plain extending as much as 5 miles wide. The Kiowa drainage is narrower with a maximum width of about 12 miles, and the flood plain seldom exceeds two miles in width.

Bijou Creek has steeper watershed slopes near its headwaters than Kiowa Creek. Both streams feature well defined drainage patterns, but it is quite evident that much of the upper Bijou watershed has very steep slopes with active erosion surfaces. Kiowa Creek also has steep slopes but much of its watershed area supports a good grass cover and active erosion surfaces are not as extensive, therefore erosion occurs less frequently. Both streams would be classified as youthful, featuring both headward cuts and erosion of valley walls along the main stem and the tributaries.

Boundaries

Study Area Boundary

The west, south, and east sides of the study area were chosen to correspond to the topographic or watershed boundary of the two combined drainages. An evaluation of the total water resources of any area would not be logical, or possible, without including the entire drainage area. This is especially true in an area such as the Kiowa-Bijou Drainages, where there is no importation of surface water. Replenishment of the water resources in the area depends solely upon precipitation falling on the watershed.

The topographic boundary includes all the saturated alluvial material deposited by Kiowa and Bijou Creeks and their tributaries, except for a small area along the western edge of the Kiowa drainage in Township 2 South. A small area of shallow saturated thickness extends into the Lost Creek drainage at this point.

In the northern part of the study area the alluvium of the Kiowa and Bijou Creeks and those drainages adjacent to them merges with the alluvium of the South Platte River Valley. For this reason, and because the topographic boundary in this region is poorly defined, it was felt that streamlines, across which no flow occurs, would logically define the water originating within the study area.

Streamlines were constructed using water table contour maps prepared for the Kiowa-Bijou Drainages and adjacent areas near the

South Platte River. The topographic boundary was extended northward until it intersected the point where the saturated alluvium within the Kiowa or Bijou Drainages becomes hydraulically connected with the saturated alluvium of adjacent drainages. From this point northward the study area boundary was defined as the streamline, which would represent a line of no flow from one drainage to the other.

The northern boundary of the study area was selected at a joint staff meeting of Colorado Water Conservation Board, Colorado Ground Water Commission, and Colorado State University personnel. The group recognized that the South Platte River has an alluvial filled channel and water table gradient associated with it. Figure 2 is a north-south cross section of the South Platte Valley taken two miles east of Wiggins. This cross section illustrates the relationship between the existing river location, the deep alluvial filled bedrock channel beneath the South Platte, the Bijou Canal, and the bedrock extending southward into the study area.

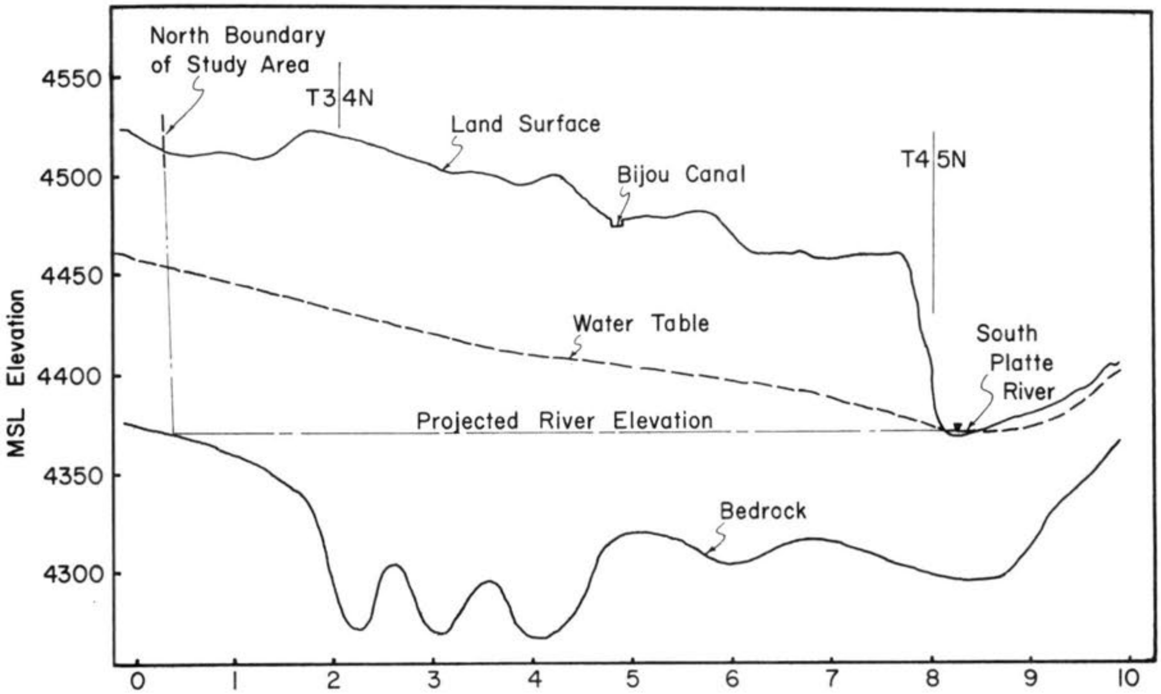

Figure 2. North-south cross section of South Platte River Valley two miles east of Wiggins, Colorado.

The group decided to select the north boundary of the study area so that it would coincide with the north boundary of the proposed "Designated Ground Water Basin" under consideration by the Ground Water Commission. This boundary was selected as the locus of points representing the intersection of a horizontal line projected from the water surface elevation of the South Platte River southward to the underlying bedrock bounding the alluvial material of Kiowa and Bijou Creeks. Figure 2 shows how the river elevation was projected horizontally southward.

It was felt this method of selecting the boundary could be supported on an engineering basis. A well located south of this boundary and penetrating the entire depth of the alluvial material would have its bottom above the river elevation. Thus, it would not be able to draw water directly from the river.

The weakness of this logic is that wells within the basin certainly intercept water moving toward the river, some of which could eventually appear as surface flow in the river. It should be noted, however, that the volume of water intercepted by the wells in the proposed basin does not represent a decrease of corresponding magnitude in the river flow. If this water were not intercepted (i.e., no pumping in the Kiowa and Bijou area) much of the underground flow toward the South Platte would likely be lost to evapotranspiration from a higher water table.

Two other northern boundaries considered were the uppermost canal on the south side of the South Platte River (i.e., the Bijou Canal) and the River itself. U. S. Geological Survey Water Supply Paper 1378(1) contains a map portraying the bedrock elevation where the alluvium of Kiowa and Bijou Creeks intermingles with the alluvium in the South Platte channel. If either the river or the Bijou Canal had been selected as a north boundary the deepest part of the South Platte bedrock channel would have been within the study area as shown in Figure 2. To evaluate only waters originating in the Kiowa-Bijou drainages required elimination of any area containing water originating from the South Platte such as the deep bedrock channel.

Plates 1, 2, and 3 show the study area boundaries in detail. These boundaries are necessarily very irregular, since they were determined from topographic or bedrock features.

Legal Description of Boundaries

The Ground Water Commission was required to provide a legal description of the proposed "Designated Ground Water Basin". To facilitate this legal description and make the boundaries more readily discernable to landowners, the previously described boundary was approximated by coinciding with section lines. Plates 1, 2, and 3 show the legal boundary as selected by the Ground Water Commission and the Colorado Water Conservation Board. A legal description of the proposed "Designated Basin" as prepared for publication in local newspapers appears in Appendix A.

The legal boundary necessarily includes small portions lying outside the watershed and excludes small portions of land lying within the area. These differences never include an entire section of land, however, and it is not likely that a particular person would be included or excluded from the basin who would not otherwise be so.

Climate

The Kiowa-Bijou study area is typical of the semi-arid plains regions. Precipitation is adequate to support grasses and small grains in most years. Seasonal variation of rainfall is a major factor in the productivity of any dryland crop grown in the area. Irrigation has been developed to stabilize yields and support such crops as sugar beets, alfalfa, and corn which could not be grown otherwise.

The average annual rainfall in the study area varies from about 13 inches in the north end to nearly 18 inches in the Black Forest region near the headwaters of the two creeks. For this investigation, the historic data for ten stations in the area were analyzed. The average annual precipitation and the length of record used for each station are shown in Table I.

Table I. Mean annual precipitation at selected stations.

Station	Ave. ppt.	Yrs. of Record
Kiowa	18.00	15
Parker	13.27	33
Limon	14.82	33
Wiggins	14.35	9
Byers	14.31	33
Greenland (8SE)	16.80	25
Simla	13.68	17
Deertrail	14.94	24
Hoyt	13.80	24
Ayer Ranch	17.25	21

The location of these precipitation stations with respect to the study area is shown in Figure 3. Some of the stations lie outside the Kiowa-Bijou drainages, but were selected because of their length of record and similarity of location to short term stations within the area.

Figure 4 shows the average annual distribution of precipitation within the study area. Most of the precipitation occurs during the period from April 15 to August 31. Storms in April and May are often general in nature and may cover the entire watershed. Violent thunderstorms with destructive hail often occur in the months of June, July and August. Rain associated with these thunderstorms is largely responsible for the precipitation during those months. This

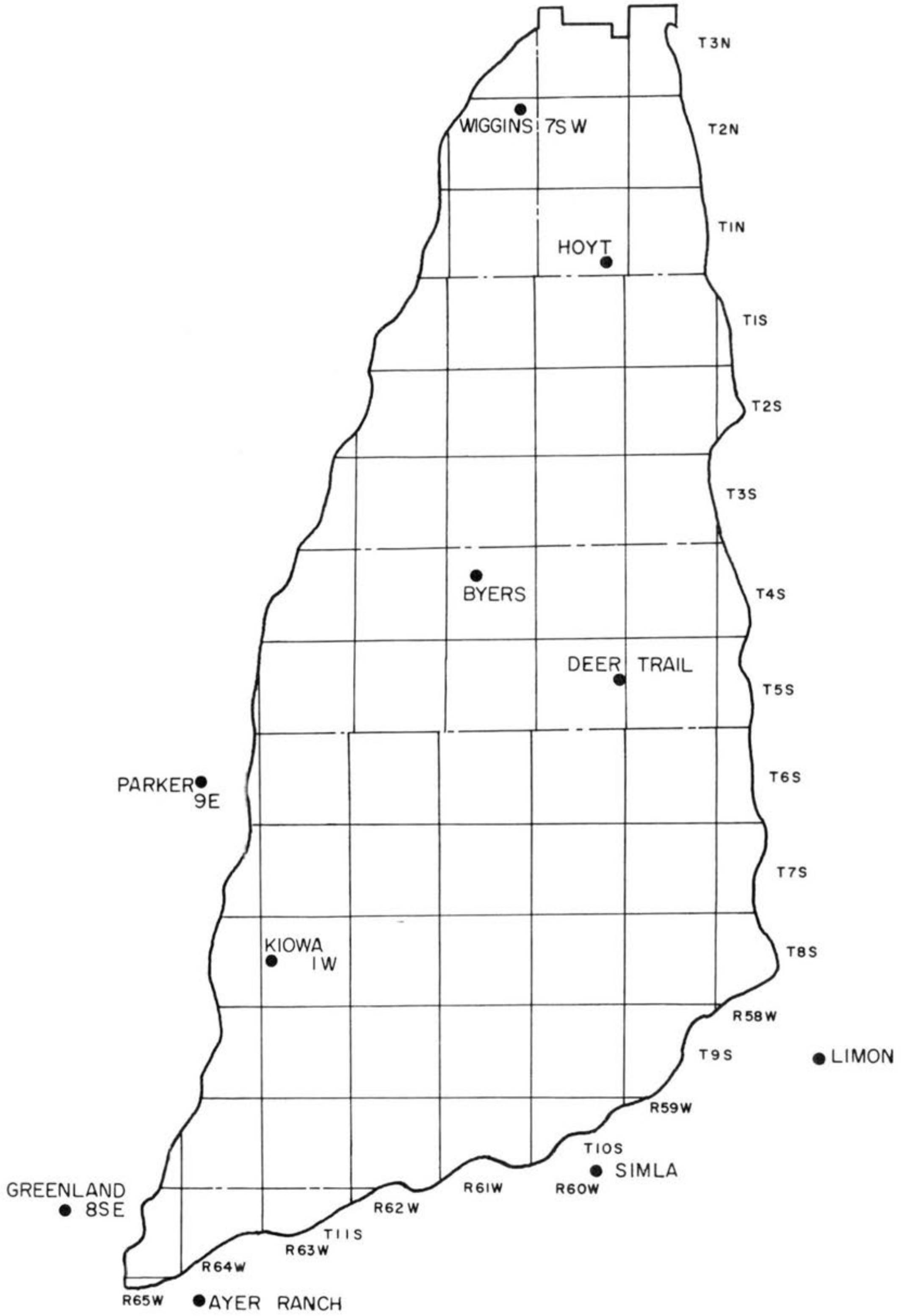

Figure 3. Location of precipitation stations used in the study.

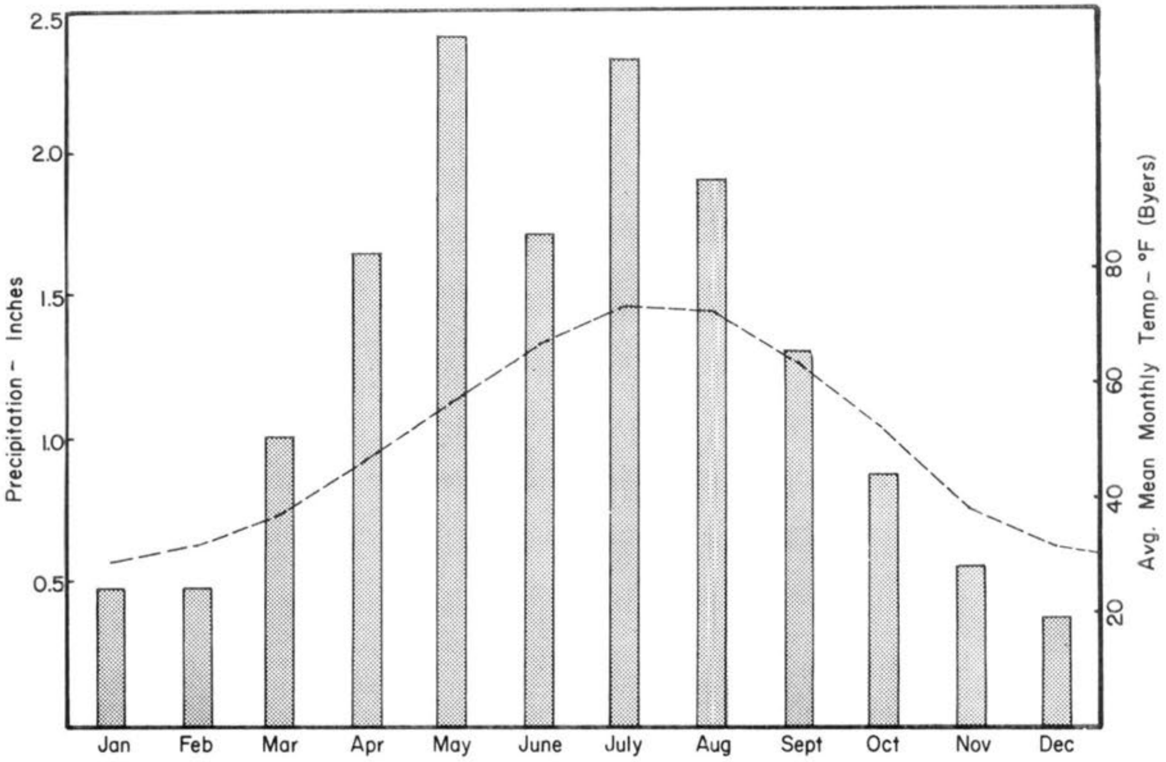

Figure 4. Average monthly precipitation and temperature in the study area.

precipitation may be of high intensity, but covers a limited area of the watershed.

Statistical analyses of the monthly precipitation records for each station listed in Table I indicated no significant difference in the annual distribution of precipitation between stations or the two watersheds. The probability of obtaining precipitation in excess of or less than the mean values had the same frequency between individual stations and between the Kiowa and Bijou watersheds.

The analyses revealed the extreme variability which may be experienced in monthly precipitation. The month of September had the greatest deviation from the mean monthly precipitation. Only about 38 percent of the time will precipitation equal or exceed the mean value for September. This indicates that the study area could expect more dry than wet Septembers and more than likely the month would be either very dry or very wet.

Records show that some months have been completely dry. Usually a large part of the precipitation falls in large infrequent storms. Analyses indicate that for no month is there a 50 percent chance of obtaining normal mean monthly rainfall. The months of February through April and September through December show the least probability of obtaining normal rainfall. During May through August the probability of receiving at least normal rainfall is about 46 percent. This is as expected, since a large portion of the annual rainfall occurs during the summer months.

Figure 5 shows a similar probability analysis of mean annual precipitation. It is noted that this curve indicates the chances are almost 100 percent of receiving at least 40 percent of mean annual precipitation in a given year, and the probability almost zero for receiving greater than twice the normal precipitation.

The probability curve of mean annual precipitation, Figure 5, is much steeper than the monthly curves. This indicates that the probability of a succession of very wet months or very dry months is much lower than that for a particular month to be wetter or drier than normal. It can be seen from Figure 5 that the probability of having an annual precipitation 120 percent or more of normal is only about 22 percent and that 23 percent of the time the rainfall might be less than 80 percent of the mean annual.

The average normal monthly temperature ranges from 24°F to 74°F at Fort Morgan and from 29°F to 74°F at Byers. Maximum daily temperatures may exceed 100°F on a few days during July or August. The region has an average frost free period of approximately 140 days annually. Figure 4 shows the average mean monthly temperature for Byers.

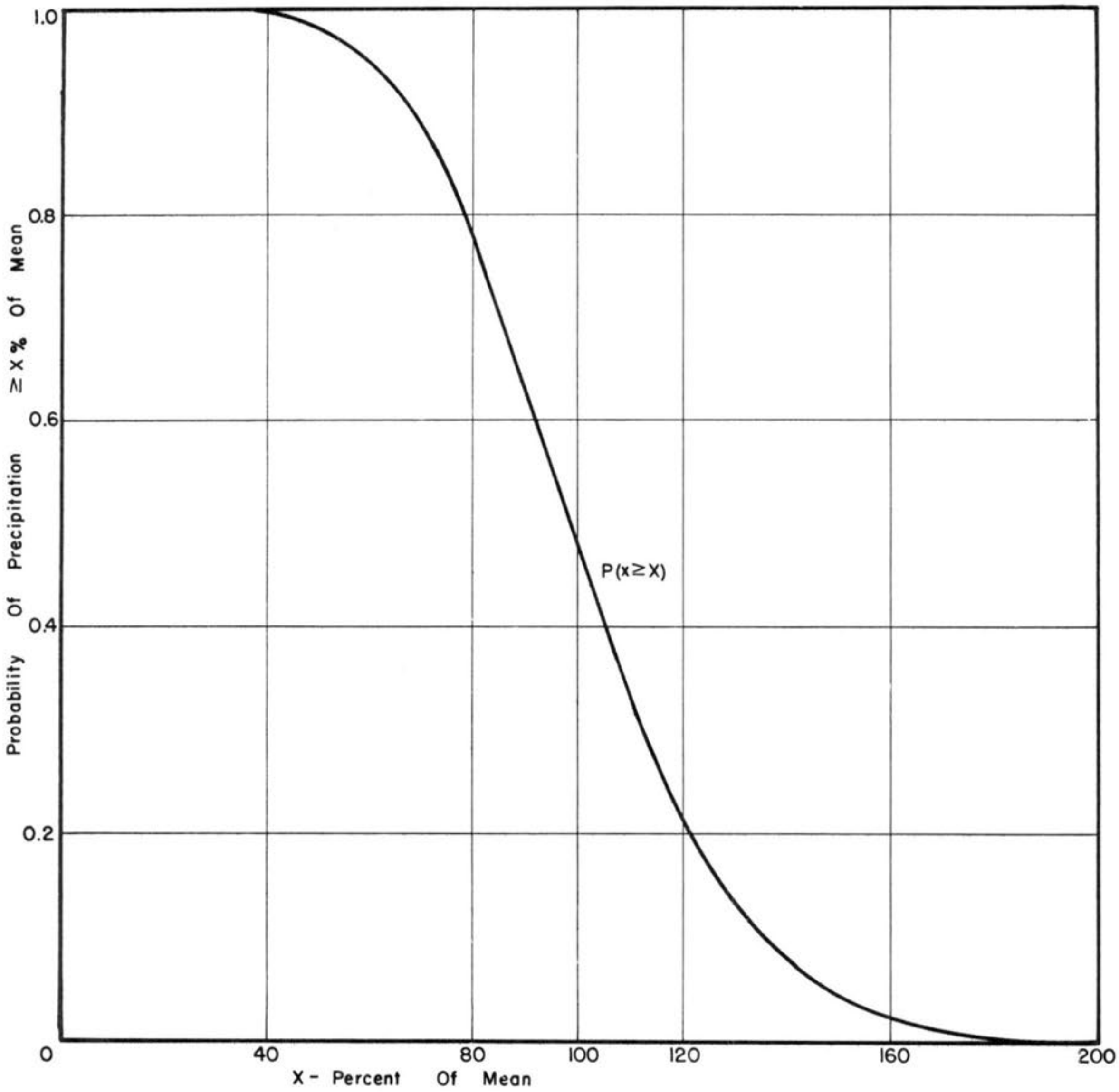

Figure 5. Probability of annual precipitation occurrence.

Land Use

Present Land Use

The upper reaches of both drainages, being of relatively steep relief, are covered with range grasses and scattered to heavily wooded areas. The economy of such areas is primarily ranching, with cultivation being limited to small flat or rolling areas, generally closely adjacent to the streams.

In the downstream areas there is intensive cultivation. Where the flood plain is underlain by saturated alluvium, highly productive irrigated crops are raised. Along the divide areas where there is no saturated alluvium, cultivation is limited mostly to dryland crops of small grains. In areas where the water level has receded greatly, some previously irrigated land has reverted to dryland farming.

The topographic divide areas in the lower end of the region are primarily of dune sand, and until recent years, supported virtually no productive vegetation. Sprinkler irrigation with groundwater has placed some of this land under cultivation.

History of Land Development Due to Irrigation

Irrigation with surface flows - The surface waters of Kiowa and Bijou Creeks and a majority of their tributaries have been heavily appropriated. The priority dates of surface decrees date as early as 1866 (Oakes No. 1 Ditch on Kiowa Creek - 20 cfs). As nearly as can be discerned, a total of 36 direct flow and 4 reservoir decrees have been issued on Kiowa Creek and its tributaries, and on the Bijou 37 surface flow and 39 reservoir decrees. A list of the decrees, dates, amounts, and location is given in Appendix B. Figure 6 shows that these decrees are distributed throughout the entire watersheds of both drainages.

Many of these surface water decrees were issued provisional to construction of the diversion system and use of the water. It is not known how many of these decrees were validated by use. Only a very few of the surface diversion systems are known to exist today. Those that do exist are primarily used for supplemental irrigation of hay crops and for recharge. Most of these provide water only during

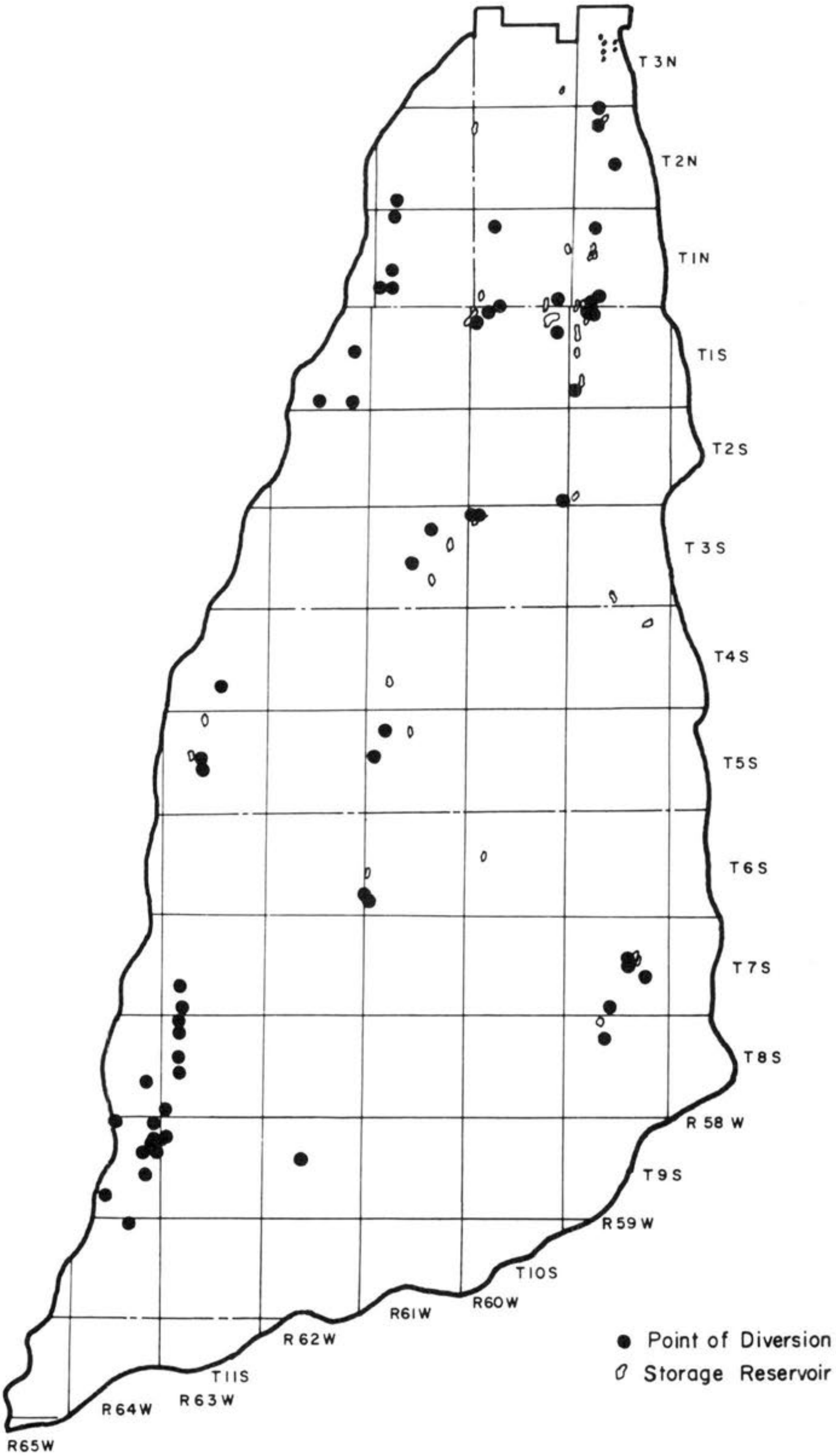

Figure 6. Location of surface water decrees issued in study area.

periods of stream flow following snow melt or summer thunderstorm activity.

The Nile Reservoir and Canal System, a large irrigation project, was designed and constructed to divert water from Bijou Creek. The system never became fully operational and largely failed for lack of a dependable water supply. According to local residents, the remains of most surface diversion systems were destroyed by the floods of 1935, and were never reconstructed because of their inability to provide a reliable source of water.

Irrigation with surface water usually developed on lands immediately adjacent to the streams. Some of the areas that were originally irrigated with surface water are now supplied with ground water by pumps from the underlying saturated alluvium. Adequate records on the amount of water diverted during early surface irrigation periods are lacking and even today data are not collected on stream flows and quantities diverted from Kiowa and Bijou Creeks.

Irrigation with ground water - Some of the oldest wells in Colorado are in the Bijou Drainage. Data on the land area irrigated by wells or by surface flows are not available and can only be estimated. The historic acreage irrigated from wells would be directly related to the number of wells which is reported later in the report. This relationship would also be a function of the yield from the well.

Crops Grown in the Area

Dryland farming is practiced over a large part of the study area and includes small grains, sorghums grown for feed, and alfalfa where the groundwater level is near the surface. Wheat is the predominant small grain and is usually grown utilizing the summer fallow farming practice. Dry land wheat yields have been recorded as high as 75 bushels per acre under ideal conditions but the average yield within the study area is probably nearer 30 bushels per acre.

Table II lists the irrigated crops grown in the area and their total water requirements. Most of the irrigated land lies on the Kiowa and Bijou flood plains. Alfalfa, sugar beets and corn constitute the principle irrigated crops.

Table II. Irrigated crops grown in the study area.

	Total Inches Water Required*
Wheat	15
Barley	15
Corn for Grain	20
Corn for Ensilage	22
Sugar Beets	27
Alfalfa	27
Irrigated Pasture	24
Beans	14
Grain Sorghum	21

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* Requirements computed using Blaney-Criddle Technique and compared with available data from Colorado State University Experiment Station.

Geology

General Geology of Northeastern Colorado

The Denver Basin of eastern Colorado is a large, north-south elongated, asymmetrical syncline. The west side of the structure lies in the foothills of the Front Range of the Rocky Mountains where the formations dip steeply to the east toward the synclinal axis which passes north-south through the city of Denver. Eastward from the axis, the formations rise gently for sixty to seventy miles. Figure 7 shows the relationship of the study area to the Denver Basin.

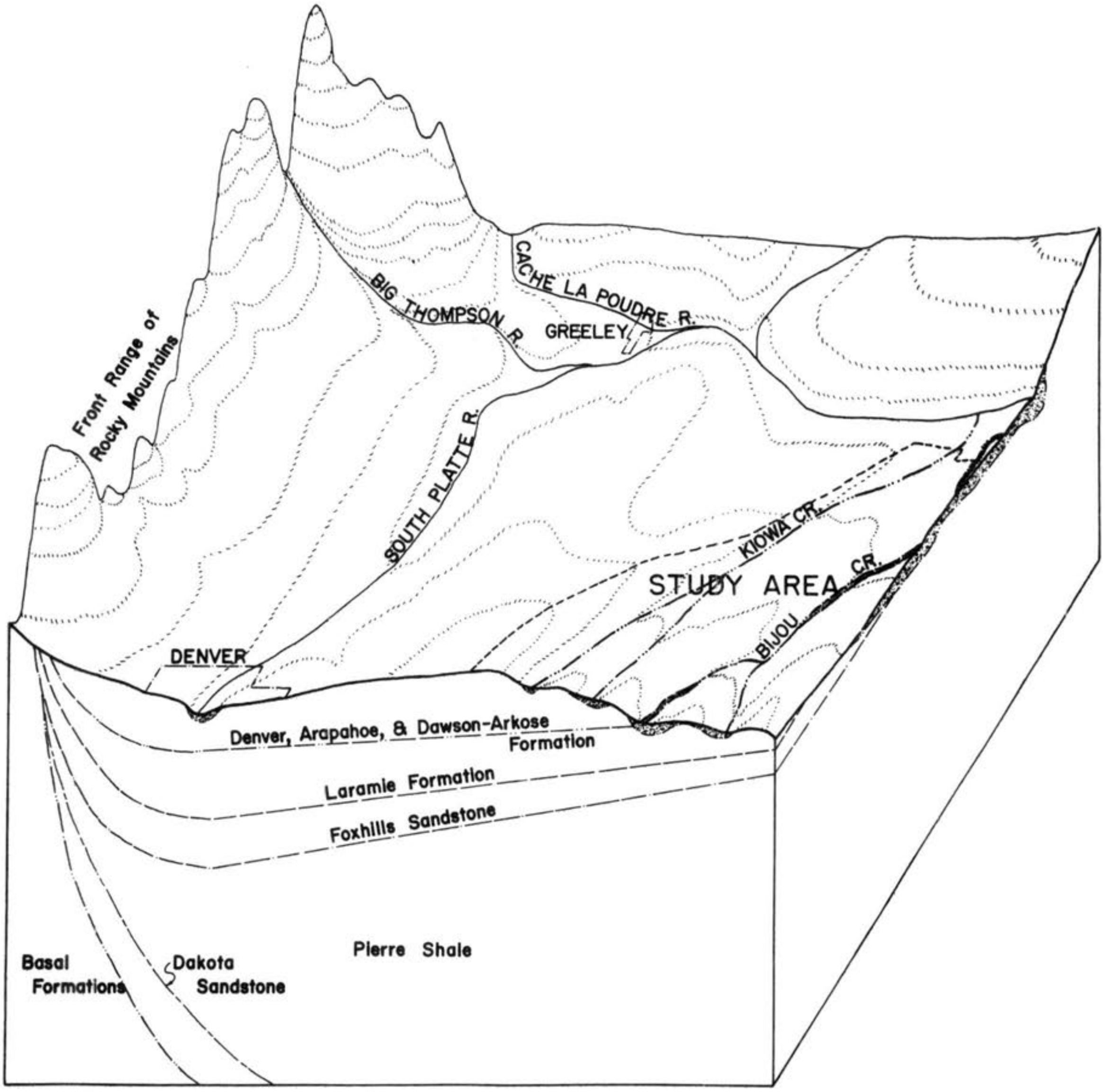

Figure 7. Relation of study area to Denver Basin.

The formations within the Denver Basin are composed mostly of sedimentary materials, ranging in age from Paleozoic to Recent. Immediately to the east of the Bijou Creek drainage, the erosional surface of the Cretaceous formations slopes to the east and is overlain by the Ogallala formation of Tertiary Age.

Geologic Formations Within the Study Area and Their Waterbearing Properties

A brief discussion of the physical characteristics of each of the sedimentary formations overlying the basal formation in the study area follows. These descriptions, for the most part, are taken from U. S. Geological Survey Water Supply Paper 1378(1).

Dakota sandstone - Characteristics of the Dakota sandstone formation beneath the study area have not been studied in detail. This formation lies extremely deep to be used as a source of large quantities of water, probably from 2000 to 6000 feet beneath the surface. The water stored in the Dakota formation in this area is believed to be brackish and unsuitable for use without treatment. For these reasons no consideration was given the Dakota sandstone formation as a source of water in the study area.

Pierre shale - The Pierre shale consists of bluish-black marine shale and silt, containing lenses of sand and sandy shale in the upper portion. The uppermost portion of the formation consists of several feet of yellowish-brown shale, which was often logged on the seismic data used as "yellow clay".

This formation underlies the entire study area and contacts the alluvium only in the extreme northeastern portion of the Bijou drainage. The thickness of the Pierre shale in the study area probably ranges from 2,000 to 6,000 feet.

The Pierre shale is considered a poor source of water. In some areas, the sand lenses may produce as much as 10 gpm for stock or domestic wells, but larger quantities of water should not be expected.

Fox Hills sandstone - The Fox Hills sandstone consists of medium grained buff to yellowish-brown poorly consolidated sandstone. It underlies the entire study area except for the north and east portions and where it has been eroded away by Kiowa and Bijou Creeks. The formation ranges in thickness from a feather edge in the north and east regions to over 200 feet along the southwestern boundary of the study area.

The Fox Hills sandstone lies conformably upon the Pierre shale, and is overlain in the south and west portions of the area by the Laramie formation. The formation dips westward within the study area at about 6 feet per mile.

Near Deertrail, Colorado, wells are reported to obtain several hundred gallons per minute from the Fox Hills formation. Many of these wells, however, penetrate the saturated alluvium and it is believed they draw most of their water from this formation. Since the Fox Hills formation is poorly cemented, it is difficult to determine from irrigation well logs the contact between the alluvium and the Fox Hills.

Because of its ability to supply moderate quantities of water to wells, and the relatively shallow depth to this formation, the Fox Hills sandstone was considered to be a possible source of water for future development.

Laramie formation - The Laramie formation consists of gray to yellowish-brown sand, dark clay and shale, and coal beds. The Laramie formation underlies the southwestern three quarters of the study area, and ranges in thickness from zero in the north and east to probably 300 feet in the southwest.

There are no wells in the study area known to draw significant quantities of water from the Laramie formation. According to McLaughlin, most of the water-bearing beds are in the lower part of the formation. For this reason, most wells which draw water from the Laramie formation also penetrate the Fox Hills sandstone and are commonly referred to as "Fox Hills wells". In this investigation, the water of the lower Laramie formation was not considered separately from that of the Fox Hills sandstone.

Arapahoe and Dawson-Arkose formations - The easternmost edge of the Arapahoe and Dawson-Arkose formations extends into the study area. Although these formations contain a significant amount of water in areas west of the study area, no large capacity wells in the study area are known to draw water from these formations. It is believed that these formations do not contain a significant amount of water within the study area, therefore they were not considered in this investigation.

Castlerock conglomerate - Isolated areas of this formation are present on the surface in the upper regions of the area, especially in the Kiowa Drainage. The formation is easily eroded, and has been completely cut by Kiowa Creek and a number of its tributaries. The Castlerock conglomerate was not considered a significant waterbearing formation.

Alluvium - The alluvium of the Kiowa-Bijou Creek drainages consists mostly of sand and gravel, with numerous clay lenses of varying thickness and areal extent occurring throughout the depth of the formation. These clay lenses are especially apparent in the Bijou Creek drainage, making the aquifer quite heterogeneous and anisotropic.

The thickness of the alluvium ranges from less than a foot in the upper reaches and the sides of the valleys to nearly 200 feet near the north boundary of the study area.

The bedrock contour map (Plate 1) shows the configuration of the surface underlying the alluvium. The approximate thickness of alluvium may be determined by subtracting the elevation of this bedrock from the land surface elevation, except in the areas where dune sand is present.

The alluvium contains almost all of the presently developed supply of ground water in the study area. The extent of the saturated portion of the alluvium is shown on Plate 2.

A more complete discussion of the waterbearing characteristics of the alluvium is presented in a succeeding section of this report.

Relationship of Geology to the Study Area Boundary

With the exception of the alluvial formation and the surface topography developed upon outcropping bedrock, the topographic boundary of the area as described has only coincidental relation to the lower geologic formations. However, the east side of the study area approximates the eastern edge of the Fox Hills sandstone.

Though this basin boundary has no physical significance with respect to underlying formations, no substantial reason could be established for placing the boundary elsewhere. The lower formations have an areal extent many times that of the study area, which makes inclusion of these entire aquifers in this investigation unfeasible.

The permeability of the bedrock aquifers is very low, thus the ground water movement is very slow. The hydraulic gradient in these formations indicates a northeasterly direction of ground water movement away from the outcrops that are recharged near the Front Range and along Palmer Ridge near the headwaters of the study area. (See Figure 1 or Figure 7). Because of the low permeabilities and direction of flow, it is quite unlikely that development in the Fox Hills formation or lower formations within the study area would have significant effects upon lands outside the basin.

Effect of Geology Upon Surface Runoff and Recharge

Records of surface runoff from sub-watersheds are not available but the nature of existing stream channels and observation of stream flows indicates that Bijou Creek often has large floods that originate in its headwaters. These flows carry large sediment loads including a high proportion of gray clay. A large part of the upper Bijou watershed features steep topographic relief cut into the Laramie formation. This formation is an impermeable shale that resists infiltration of precipitation, causing high surface runoff. In addition, the weathered shale erodes easily and supplies the large quantity of gray clay which typifies Bijou flood flows. The suspended clay quickly seals permeable sands and gravels and thus reduces natural recharge of flood flows in the stream beds. The net effect is that floods originating in the headwaters of the Bijou often flow all the way to the South Platte River.

The Kiowa watershed also features steep slopes in its headwaters but the runoff intensities do not seem to be as high as on the Bijou. This could be due to a better vegetative cover on the Kiowa watershed and greater infiltration of precipitation. The Arapahoe and Dawson-Arkose formations, which outcrop and dominate the upper Kiowa watershed, are more permeable than the Laramie formation in the Bijou. Erosion in the Kiowa watershed does not produce the fine clays typical of the Bijou. Thus, high natural recharge rates are maintained in the alluvial channel of Kiowa Creek. Seldom does flood flow from Kiowa Creek ever reach the South Platte River.

It is definitely felt that the Laramie formation in the Bijou watershed causes high surface runoff, heavy sediment loads, and produces fine clays that restrict the natural recharge from the stream. In contrast, the Kiowa watershed produces some high flood flows but the sediment load is less and natural recharge from the stream is very high.

Additional research to evaluate the effect of geology upon flood flows and recharge in the study area is needed.

Ground Water Storage

For purposes of this investigation, only those formations judged to be capable of yielding a sufficient quantity of water for irrigation, industrial, and municipal wells were considered in evaluating the amount of water in storage. Only the water which could be removed by gravity drainage was considered. It is realized that some water will be retained in any formation dewatered by gravity drainage. The depth at which ground water occurs throughout most of the area is greater than the depth to which crop roots will penetrate. Therefore this retained water is irrecoverable and of no significance as a part of the water resources of the area.

The following presentation indicates the relative importance of the significant aquifers in the study area, and describe the methods used for evaluating the recoverable volume of water in storage as of 1965.

Alluvium

The alluvium consists of unconsolidated, poorly sorted sands and gravels that have been stream deposited in the eroded bedrock channels. For the most part, these alluvial channels coincide with the existing location of the surface streams. In some locations, old bedrock channels were completely filled with alluvial material and are not associated with a present surface stream.

Importance - In the Kiowa-Bijou Creeks drainage, the alluvium, where exists, overlies all other waterbearing formations. Being of relatively shallow depth and high permeability, the alluvium yields as much as 1500 gallons per minute to irrigation wells. Well yields depend upon local aquifer properties and saturated thickness.

The alluvium is by far the most important aquifer in the area. A few small capacity wells near Deer Trail and municipal wells at

Byers and Strasburg obtain water from the Fox Hills sandstone. Even in the wells near Deer Trail it is quite probable that the major portion of the production is provided by overlying alluvial material. Domestic and stock supplies are also obtained by many of the residents from the saturated alluvium.

Quantity of water in storage - To determine the quantity of recoverable water stored in the alluvium it was necessary to prepare a bedrock contour map (Plate 1), a water table contour map, and a saturated thickness map. Both the water table contour and saturated thickness maps appear on Plate 2.

Bedrock is defined as a consolidated rock formation having a relatively low permeability, and would thus restrict downward movement of water from the alluvial material. The elevation of the top of the bedrock formation (bottom of alluvial material) was contoured. This map is hereafter referred to as the "bedrock contour map".

Three sources of information were utilized to draw the bedrock contour map. The most extensive and probably most reliable source was drilling logs for seismograph shot-holes drilled in exploration for oil(32, 33). Records from extensive seismograph exploration resulted in thorough coverage of the study area from the Elbert-Arapahoe County line northward. The logs showed the depth to each change in formation. Bedrock elevation was obtained by subtracting the thickness of the alluvial material from the land surface elevation. Land surface elevations were taken from altimeter data, often available for each shot-hole, or from 7 1/2 minute quadrangle maps. Topographic maps of the 7 1/2 minute series were available only north of the Elbert-Arapahoe County line. Some shot-hole data south of this line could not be used because of inadequate land surface elevations available.

Irrigation well logs and measured depths of irrigation wells were used to supplement the seismograph data. In the study area irrigation wells are generally shallow, and it was assumed they penetrated the entire alluvial formation. Comparison of some well logs and well depths revealed that this assumption is usually valid.

Aerial photographs were also used to define the limits of the alluvial material. The use of stereoscopic pairs of photographs made it relatively easy to define the edges of the flood plains. Since this technique was used only in the upper watershed where the bedrock is exposed by the steep topographic relief, it was assumed that the edge of the flood plain approximated the edge of the saturated alluvium.

Outside the flood plains in the upper watersheds little or no alluvium exists. In these areas, the accuracy of the bedrock elevation is relatively unimportant, and was plotted simply as the topographic surface taken from the 1:250,000 scale U. S. Army Map Service maps.

The second step in evaluating the quantity of water in storage was construction of a water table contour map. In April 1965, water levels were measured in 92 irrigation wells in Adams, Weld, and Morgan Counties within the study area. From June 15 through August 15, 1965, water levels were measured in an additional 200 wells. Since the early summer of 1965 was very wet, few of these wells pumped a significant amount during the period of measurement. Careful attention was given to those that had pumped recently, and little weight was given them in drawing the water table contour maps. Water table elevations were computed by subtracting the depth to water from the elevation of the measuring point. Topographic maps were used to estimate the elevation of the measuring points.

To construct the water table contour map it was necessary to interpolate between data points and extrapolate beyond these points. During the analysis, consideration was given to well development as it would be expected to effect water table levels, and to areas of expected high recharge (i.e., sand dune areas). Water table contours were drawn at 20-foot intervals as shown in Plate 2.

In the upper end of the area where detailed topographic maps were not available, the saturated thickness in a well was determined by subtracting depth to water from the depth of the well. The resulting saturated thickness was added to the previously determined bedrock elevation to obtain the water table elevation. Though this method might give misleading values of local water table elevation, it assured the best estimate available of the saturated thickness, the item of most concern.

Examination of the water table contour map reveals several interesting features. In the lower Kiowa Creek basin ground water mounds are present indicating a considerable amount of recharge has occurred. Sufficient data is not as yet available to determine whether this recharge might have occurred as a result of large surface flows in Kiowa Creek during June 1965. Trough areas indicate regions of extremely high pumping.

A map of saturated thickness was constructed by the method of graphically subtracting bedrock elevations from water table elevations. The saturated thickness map is shown as a part of Plate 2.

The saturated thickness map was used to calculate the volume of saturated alluvium. The area covered by each 20-foot zone of saturation was determined with a planimeter and tabulated by townships. The double-end-area method was used for calculation of saturated volumes within each 20-foot zone. This method assumes a linear change in saturated thickness from one zone to the next, an assumption not unreasonable when a large area is considered.

The average drainable porosity for the entire area was estimated to be 20 percent. The U. S. Geological Survey(1), in an aquifer test near the lower end of the area, calculated a storage coefficient of 17 percent. Based upon the expected increase of grain size in the alluvium with distance upstream and the delayed yield of an aquifer, this estimated drainable porosity is believed to be in good judgment. It should be emphasized that no actual samples were taken for determination of porosity and, due to the non-homogeneous, non-isotropic nature of the aquifers, the value of such samples would be questionable. As previously discussed, all computations were based only upon drainable porosity, since that water retained in the formation is of no significance as a water resource.

The total volume of recoverable water stored in each township was calculated by an equation of the form:

$$V = \sum_i S_y \frac{A_i + A_{i+1}}{2} d_i , \tag{1}$$

where

V = volume of recoverable water in acre-feet

S_y = specific yield (drainable porosity--estimated to be 20 percent)

$\frac{A_i + A_{i+1}}{2}$ = average area of zone in acres

d_i = thickness of zone.

The total volume of water recoverable from the alluvium in the study area was calculated to be 2,373,000 acre-feet. Table III shows the distribution of this stored water with distance upstream for each of the two basins.

It is not intended that the limit of saturated alluvium as shown on Plate 2 be used as an absolute guide for location of new wells. The limits were drawn for the express purpose of providing a means for calculating the volume of water in storage. The accuracy in location of these saturated limits depends not only upon the amount of data available, but also upon the local bedrock slope. Since such errors tend to be compensating, it is believed that inaccuracies in calculating the volume in storage will be insignificant.

Table III. Volume of water in storage within the alluvium (acre-feet).

Township	Kiowa Drainage	Bijou Drainage	Total
3N	207,000	157,000	364,000
2N	100,000	139,000	239,000
1N	34,400	193,000	227,400
1S	42,200	319,000	361,200
2S	66,500	420,000	486,500
3S	101,000	190,000	292,000
4S	80,600	105,000	185,600
5S	35,300	63,200	98,500
6S	25,600	28,800	54,400
7S	18,800	23,500	42,300
8S	6,000	9,500	15,500
9S	4,300	1,000	5,300
10S	1,300	--	1,300
Totals:	723,000	1,650,000	2,373,000

Water Stored in Other Formations

The Fox Hills sandstone formation is the only bedrock aquifer within the study area capable of providing water to moderate capacity wells. Other formations provide sufficient water for domestic and stock wells but are considered to be of minor significance in the water resources of the Kiowa and Bijou Basins. The Fox Hills formation has only a few wells withdrawing water from it now and is thus available for future development.

Figure 8, the geologic contact map was utilized in computing the volume of water stored in the Fox Hills sandstone. East-west cross sections of the bedrock topography were drawn at each township

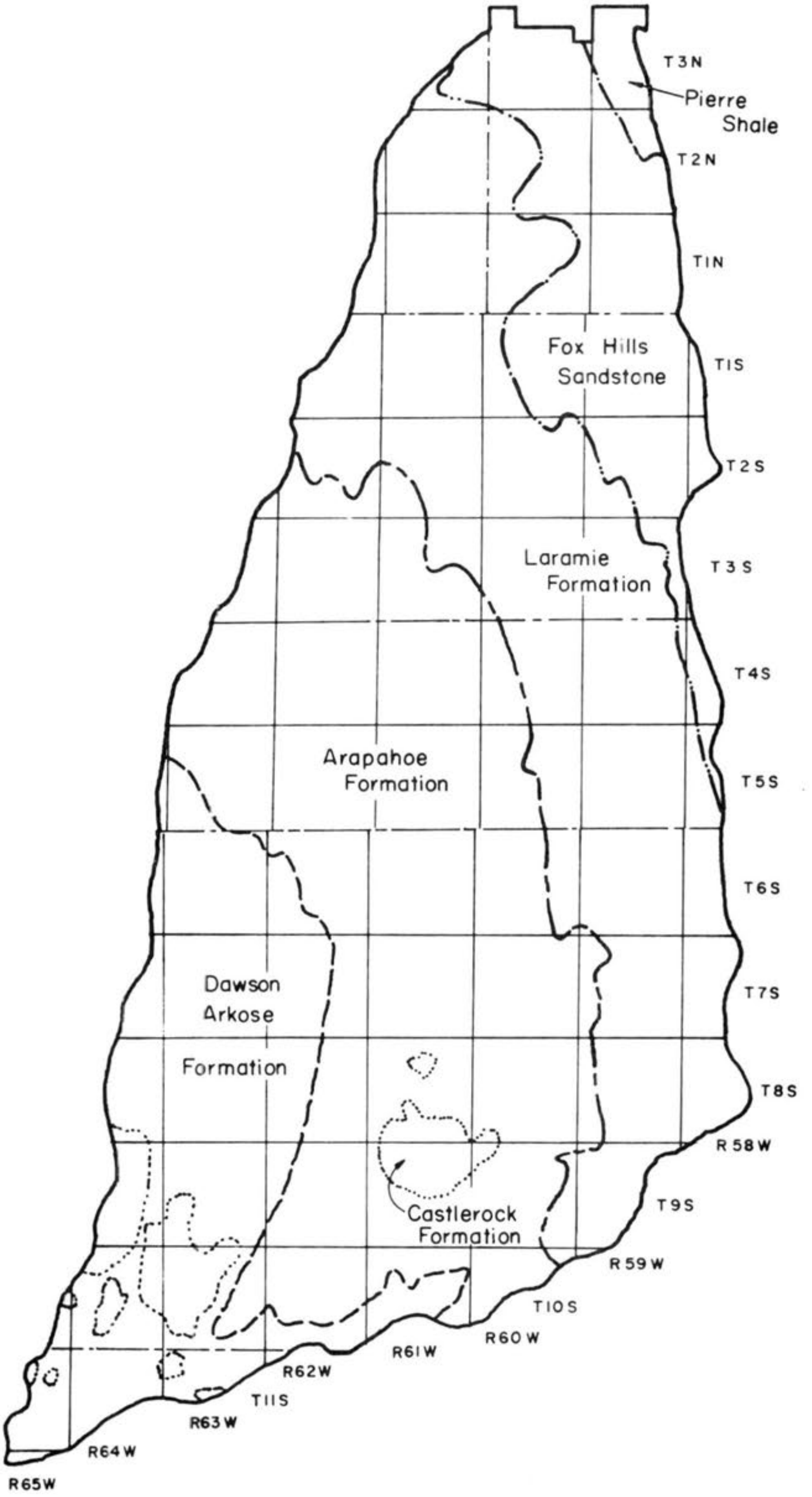

Figure 8. Geologic contact map.

line. From Figure 8, the Fox Hills sandstone - Pierre shale and Fox Hills - Laramie formation contacts were plotted on these geologic cross sections. Using a dip of 6 feet per mile westward as given by the U. S. Geological Survey for these formations, the geologic contacts were projected westward to approximately define the top and bottom of the Fox Hills sandstone formation. From these cross sections, the cross-sectional area of the formation was determined by planimeter. The double-end-area method was used to calculate the total volume of Fox Hills sandstone underlying the study area.

The technique described above indicated that there was about 194,000,000 acre-feet of the Fox Hills formation within the study area boundary. This value, of course, is subject to the errors included in the calculations. When additional wells are drilled into the formation the data can be used to check or refine the computed value.

The Fox Hills sandstone is a fine grained, somewhat consolidated formation varying in the degree of cementation. It was estimated that the average drainable porosity (storage coefficient) of this aquifer was only about one percent. Multiplying the total volume of the formation by the drainable porosity indicates that there are approximately 2,000,000 acre-feet of water now in storage within the study area that could be withdrawn from the Fox Hills formation.

Recharge to the Basin

Alluvium

In 1960, Colorado State University initiated an investigation of natural recharge on that portion of Kiowa Creek extending from Bennett, Colorado northward 25 miles to Colorado State Highway 52. Stream gauging sites were instrumented and extensive precipitation and observation well networks were established. Results from this four year study indicated that approximately 1/2 inch, or 3.3 percent, of the precipitation falling on the upper watershed was recharged within the study reach. Initial estimates of the natural recharge, using the data from the Kiowa Creek investigation, indicated the average annual recharge would be 20,000 acre-feet in the Kiowa drainage 37,000 acre-feet in the Bijou drainage for a total of 57,000 acre-feet in the study area.

Detailed analyses of available rainfall, streamflow, and water level records have substantiated this estimate. The analyses included an evaluation of natural recharge in the upper watershed represented by ground water underflow across the Adams-Arapahoe county line and the average annual pumping above that line, and the natural recharge from streams and direct percolation of precipitation occurring north of the county line.

Historic ground water level records indicate that there has been little change in water levels in the southern portion of Adams County in recent years. If one can assume that there are insignificant losses to evapotranspiration from the water table in the upper basin, then the natural recharge in the upper basin is represented by the underflow plus that amount of the pumped water which is consumptively used.

Streamflows of Kiowa Creek were measured near Bennett from 1960 through 1964. Measurements at this station include the total flow from the watershed above this point because ground water flows are forced to the surface by the bedrock which is near the surface of the stream. During the five-year period the average annual flow at Bennett was approximately 2,000 acre-feet. Even during peak periods of runoff, no water reached the South Platte River from Kiowa Creek. All of it was recharged within the study area. It is estimated that Kiowa Creek will deliver an average of 2000 acre-feet of water annually for recharge north of the Adams-Arapahoe County line. This estimate is probably conservative and does not reflect flood flows such as those that occurred in 1935 and again in 1965.

Surface flows in Wolf and Comanche Creeks were not measured, but were minimal during the 1960-64 period. Normal surface flows of both Wolf and Comanche Creeks are naturally recharged and do not leave the study area. For this study the surface flows and their natural recharge contribution were considered insignificant for both Wolf and Comanche Creeks north of the Adams-Arapahoe County line.

Since the only gauging station on Bijou Creek was located near the lower end of the study area, and since Bijou Creek frequently discharges surface flow from the area during storm periods, analyses similar to those for Kiowa Creek could not be made for the Bijou drainage. Based upon the relative permeabilities of the two streams, and upon their bed widths, it was estimated that Bijou Creek recharged 500 acre-feet annually in each 6 mile reach below the Adams-Arapahoe County line.

Considering the previous study on the upper Kiowa drainage, and the fact that the lower regions of both drainages are flatter, resulting in less runoff, it was estimated that five percent of the precipitation falling directly upon the lower portion of the area is recharged.

Table IV summarizes the estimated annual recharge rates discussed above. Note the study area is broken into five reaches with respective recharge values.

Table IV. Summary of estimated annual natural recharge to the alluvium.

Reach	From Underflow (ac-ft)		From Streamflow (ac-ft)		From Precipitation (ac-ft)	
	Kiowa	Bijou	Kiowa	Bijou	Kiowa	Bijou
Above Adams-Arapahoe County Line	8,650	8,700	(Included in Underflow)		(Pumped) 3,100	4,600
T2-3S (12 mi)	---	---	2,000	1,000	2,950	8,600
T1N-1S (12 mi)	---	---	All surface flow assumed to percolate in first 12 mile reach	1,000	4,150	4,600
T2N (6 mi)	---	---		500	1,500	1,300
T3N (6 mi)	---	---		500	1,750	900
		Totals			24,100	31,700
		Total for Study Area			55,800	

Other Formations

Recharge to the Fox Hills sandstone is probably very small. The natural gradient of water in the formation is toward the northeast from Palmer Ridge and the Front Range. It is not known how much the development of deep wells in the Denver Basin has effected this gradient, but it is estimated that the rate of natural recharge to the Fox Hills in the study area is less than 5000 acre-feet per year.

Since the formation is overlain by the less permeable Laramie formation throughout most of the basin, most of this recharge occurs in the northeastern portion of the basin, where saturated alluvium contacts the Fox Hills formation.

Ground Water Outflow From Study Area

General Description

Similar to other South Platte River tributaries, the alluvial material of the Kiowa and Bijou drainages merges with the alluvium of the South Platte near the tributaries' confluence with the river. Although the lithology of the alluvial materials is somewhat different, the tributary and river alluvial materials are hydraulically connected and thus function as a single alluvial aquifer. For the most part, the area where the alluvial materials are connected lies north of the northern boundary of the study area. No attempt was made in this investigation to study the lithological differences between the South Platte and the Kiowa or Bijou alluvium.

From a strict definition, the underground water of the Kiowa and Bijou drainages is tributary to the South Platte River. The velocity at which this water flows, however, is extremely small compared to water in a similar surface stream. It is estimated that a drop of water entering the ground water of the Kiowa Creek drainage near Strasburg, Colorado would (assuming it were not lost to evapotranspiration) reach the South Platte River valley in 120 years. A similar drop of water entering the Bijou Creek aquifer west of Deer Trail, Colorado would take 380 years to reach the South Platte River valley. This difference in travel time for similar distances (42 and 50 miles respectively) is attributed to a lower permeability and smaller hydraulic gradient in the Bijou aquifer than in the Kiowa aquifer.

A pressure wave created by recharge or sudden discharge of a large quantity of water will travel much faster than an individual water particle, much as waves on an open body of water can travel faster than the water itself. Previous studies by Colorado State University showed that the pressure wave created by recharge in Kiowa Creek traveled downstream at the rate of about 3.5 miles per year; roughly ten times the velocity of an individual particle. This illustrates the difference in time experienced in the aquifers between feeling the effects of a recharge or discharge and the actual delivery of a particular drop of water.

In the upper reaches of the study area, the underground flow is very nearly parallel to the direction of the surface drainage, i.e., generally north-northeast. At the lower end of the area, however, this outflow from the study area merges with the underflow of the South Platte River valley and begins to turn toward the east. To define the final disposition of the Kiowa-Bijou underflow would be conjecture. However, it is probable that a portion is pumped by wells in the South Platte River valley itself, some is used by crops or phreatophytes where this water nears the surface, and eventually, somewhere downstream from its confluence with the South Platte valley, a portion of this water may flow into the river.

Underflow Calculation

The estimated underflow from the Kiowa and Bijou Creek basins across the imaginary lines shown in Figure 9 was calculated for the year 1935, before substantial pumping developed in the area; for 1965, the time of this investigation; and for 2015, fifty years into the future.

It is realized that the lines across which underflow was determined will not exactly represent the underflow leaving the north end of the area. These lines were chosen to lie as nearly perpendicular to the direction of flow as possible in such a lateral position that, with

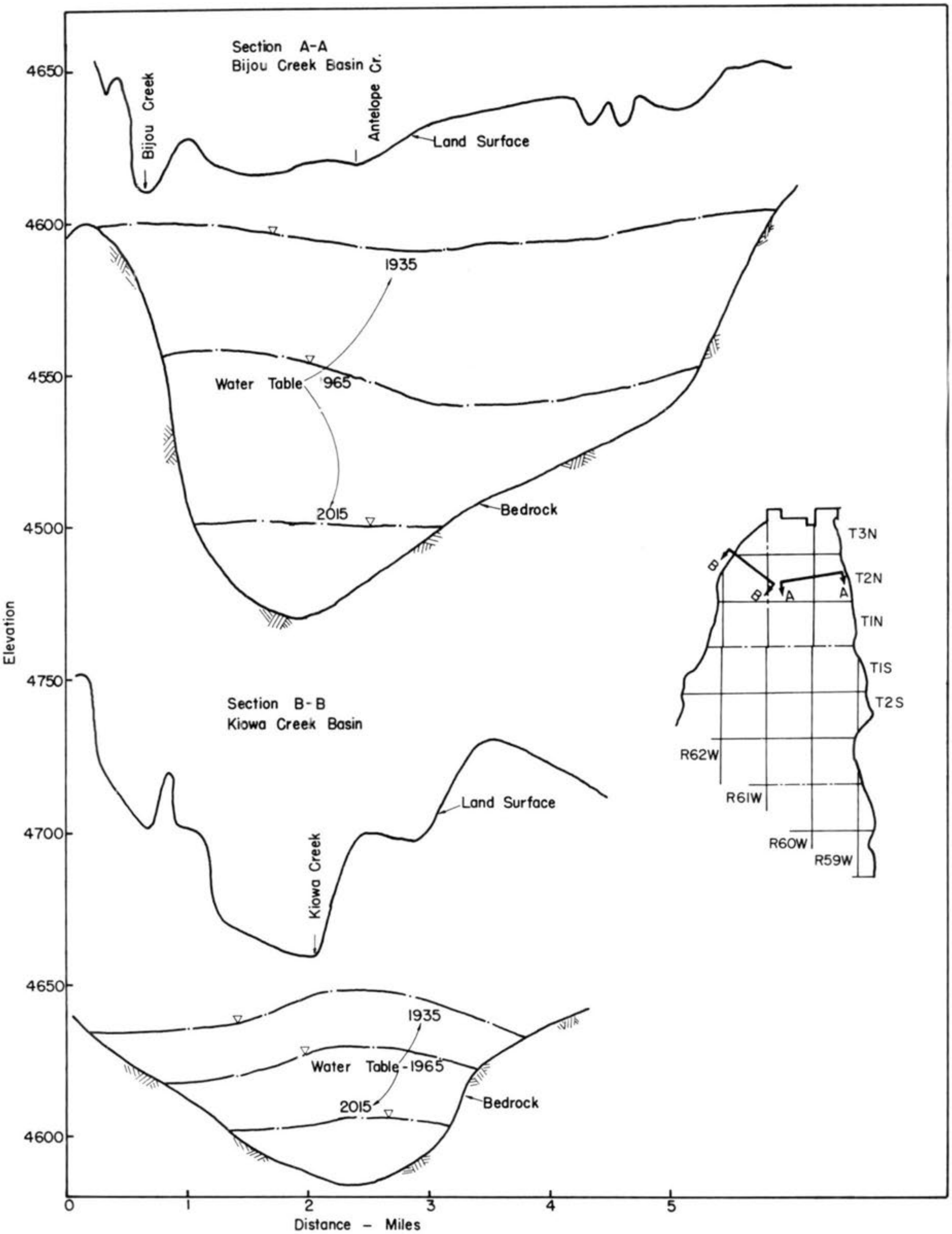

Figure 9. Cross sections used to compute underflow and their location within the study area.

the water levels estimated for 1935, the ground waters within the Kiowa and Bijou drainages would not yet have merged with each other or with the underground water of adjacent areas. Since the exact water table configuration of the surrounding area in 1935 is unknown, it would be very difficult to estimate the underflow in an area which might have been influenced by adjoining aquifers.

In order to calculate the underflow in 1935, water table elevations were estimated from existing long term well hydrographs. The hydraulic gradient was estimated from these adjusted elevations, and permeability values were taken from the U. S. Geological Survey WSP 1378(1). Darcy's law was used to compute the outflow and has the form

$$Q = KAi$$

where:

Q = Outflow expressed as gallons per day

K = Permeability expressed in gallons per day per square foot

A = Area expressed as foot-miles

i = Gradient expressed as feet per mile.

The water table contour map (Plate 2) was used to determine gradients and cross-sectional areas for the 1965 calculation. The estimate for 50 years hence was based upon an estimated decline of 25 feet in the Kiowa drainage and 50 feet in the Bijou drainage. Figure 9 shows the cross sections and relative ground water levels used in these calculations. Table V lists the parameters used in the calculations and the calculated results.

Comparison of the depletion of underground flow to the South Platte River Valley with the amount of pumping which occurred in the study area reveals the significance of this pumping. From 1935 to 1965, pumping has resulted in an accumulated decrease of underflow amounting to approximately 100,000 acre-feet. During this same period, the volume of water pumped in the study area has been about 13 times this reduction in underflow.

Table V. Summary of underflow computations from Kiowa and Bijou Creek into the South Platte alluvium.

	1935		1965		2015	
	Kiowa	Bijou	Kiowa	Bijou	Kiowa	Bijou
Permeability gpd/ft^2	2000	1040	2000	1040	2000	1040
Gradient ft/mi	20	17	20	15	15	10
Area, ft-mi	129	430	72.4	195	25.0	39.0
Discharge, Ac-ft/yr	5760	8540	3210	3430	844	478
Total Discharge Ac-ft/yr	14,300		6640		1322	

Prior to the time irrigation began in the area, it is reasonable to assume that the water levels in the aquifers were relatively stable. If this was so, then the discharge from the area (underflow plus evapotranspiration) would have been equivalent to the natural recharge. Assuming that the natural recharge at that time was equivalent to the present estimated recharge of 55,800 acre-feet per year, and taking the 1935 computed outflow of 14,300 acre-feet, the difference of 41,500 acre-feet represents the amount of water lost to evapotranspiration from high water tables. Lowering of the water table has probably resulted in the salvage of most of this water.

USE OF WATER IN THE BASIN

Surface Water Resources

Precipitation and Surface Flows

Since there is no importation of surface water into the Kiowa-Bijou watersheds, the only source of surface water is the precipitation which falls within the watersheds. The average annual precipitation of 15.17 inches within the area amounts to about 1,720,000 acre-feet of water annually. Most of the mean annual precipitation falls in small storms of short duration, causing little surface runoff.

Adjusted short term stream gaging records for Bijou Creek near Wiggins, Colorado show a mean estimated annual runoff of about 6000 acre-feet. This estimate is based upon an average annual runoff of 6700 acre-feet for the years 1950 through 1956. That Bijou Creek has significant, regular surface flow is evidenced by the nature of the streambed itself. The streambed is relatively wide and free of vegetation throughout the length of the main channel.

On the other hand, Kiowa Creek seldom discharges any surface flow from the study area. Near Bennett, Colorado, the bed of Kiowa Creek is some 300 feet wide, while it narrows to about 10 feet near Wiggins. Though surface flows sometimes pass the gaging station at Bennett, only the largest storms result in surface flow reaching the South Platte River. Thus, normal flows passing Bennett are recharged to the ground water before leaving the study area.

That Bijou Creek discharges surface water when Kiowa Creek does not can be explained by the physical characteristics of the two watersheds. The alluvium underlying Bijou Creek contains many interspersed lenses of relatively impermeable clay which reduce the infiltration rate considerably. Kiowa Creek, on the other hand, has a more permeable, homogeneous aquifer that allows infiltration of most flood flows. The specific capacities of wells in the Kiowa Creek aquifer are generally about twice that of similar wells in the Bijou aquifer, indicating the higher permeability.

Another factor contributing to larger flows in Bijou Creek is the fact that the waters of Bijou Creek normally carry a very heavy sediment load. U. S. Geological Survey samples have shown as much as 15 percent by weight of silt and clay in the water of Bijou Creek. This fine sediment tends to seal the creek bed and reduce infiltration. Kiowa Creek, on the other hand, carries much less fine sediment than Bijou Creek. This is due in part to the geologic nature of the drainages. Waters originating in areas underlain by coarse materials carry less sediment and maintain higher recharge rates than those originating from areas underlain by shale and other fine grained, easily erodible materials.

Based strictly upon conjecture, it is assumed that the Upper Basin Improvement Project on Kiowa Creek helps to reduce peak flows and contributes to a greater recharge rate in Kiowa Creek than in Bijou Creek where no detention structures are present. Data to evaluate the effect of the detention structures on the total recharge are not available.

Surface Water Diversions

As described in a previous section, the surface flows of the Kiowa-Bijou Creek drainages are heavily appropriated. However, these surface flows, except for short reaches in the upper Kiowa Creek drainage, are of very short duration and occur infrequently. Existing storage reservoirs in the study area use only a small portion of the flood waters for irrigation.

Measuring devices to record stream flows and the quantity of water diverted from flood flows or from the perennially flowing reaches of the streams are not maintained. Records of flows and diversions are not recorded and the Kiowa and Bijou surface waters are essentially unadministered. When Kiowa and Bijou flood flows occur that actually reach the South Platte River, these flows are usually not needed to satisfy South Platte surface decrees.

Flood flows are detained and spread over a large area to enhance recharge in at least one location in the basin. Near the Homestead Grange Hall, about 1/2 mile south of Colorado Highway 52 on Kiowa Creek, an extensive system of dikes detains and spreads the flood flows over a large section of the broad, flat flood plain. Benefits from this practice include increased recharge and direct irrigation of hay crops grown on the spreading area. Similar practices applied at other selected sites could utilize more of the flood flows to a better advantage.

Ground Water Resources

Development of Pump Irrigation

Code(8) reports that the first attempts to obtain irrigation wells in the Bijou Valley were in Adams County. He found several abandoned wells in 1930 in this area, some of which may have dated back as early as 1910.

Field inventories during the summer of 1965 and investigations of well registration records revealed that no wells in present use were drilled prior to 1935.

From the beginning of pump irrigation of significant proportions in 1935, development progressed rather slowly. In 1939, electric power was made available in the lower region of the study area by Morgan County REA. By 1940, Code reported 28 operating irrigation wells in the Bijou Valley in Morgan County.

Records indicate that during the war years of 1942-1946, the number of wells in the study area more than doubled. Mr. Baer, a long term resident of the area, verified this fact during his testimony before the Ground Water Commission on December 2, 1965. He stated that this increase in the number of wells was forced by the country's need for war time food production, and was hampered only by the difficulty encountered in obtaining the necessary pumps and motors.

The steady increase in number of wells in the area has continued to the present time. Sharp increases were noted during the drought periods of the mid-1950's and early 1960's. At the time of the field inventories in 1965, there were 700 wells that could be located in the study area, 37 of which had been abandoned. Without a doubt there were numerous other wells drilled, operated, and abandoned prior to 1957 when registration of wells was required.

Figure 10 shows the rate of development of irrigation wells in the study area from 1935 to 1965. The wells drilled prior to 1957 represent only those which were registered at that time, or are in existence today. Therefore, the number of wells shown in Figure 10 may be somewhat low for the years preceding 1957.

The location and reported discharge of irrigation wells inventoried during 1965 are shown on Plate 3. It should be noted that the discharge indicated on Plate 3 is a reported value, as discharge was measured for only 39 wells in the study area. It has been observed that the general tendency is to over-estimate the reported discharge and in many areas the well discharge drops off during late summer due to declining water levels.

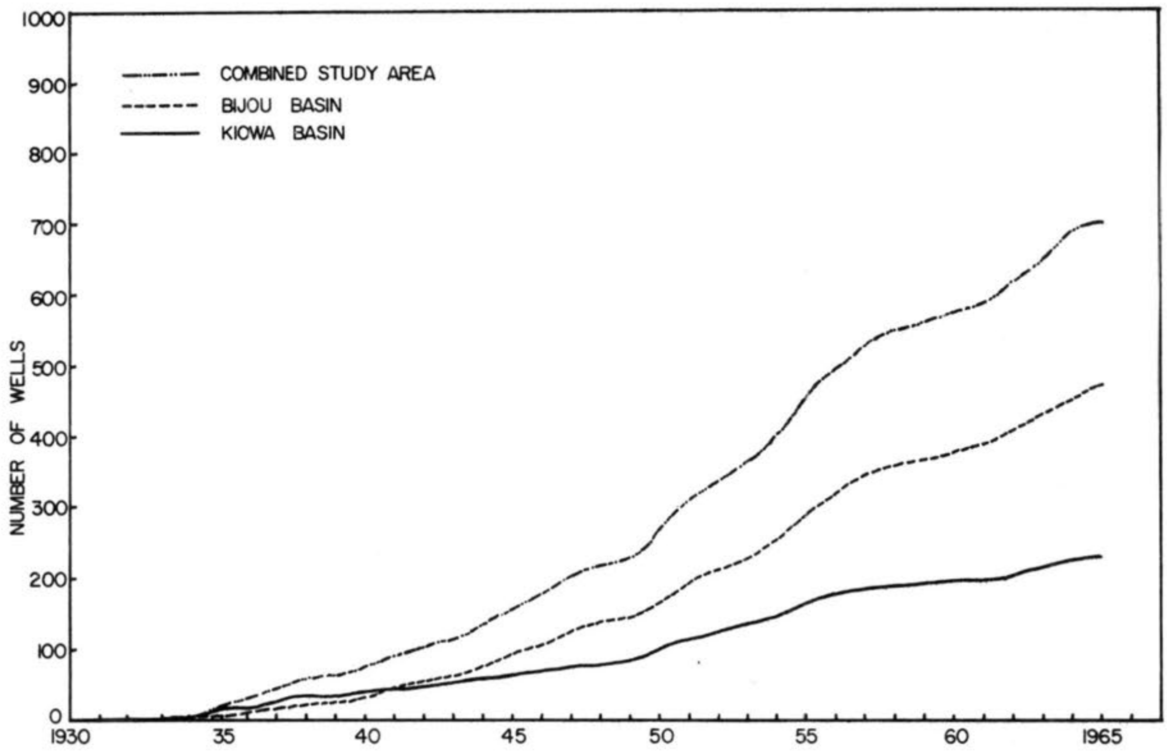

Figure 10. Cumulative development of large capacity wells.

Water Table Fluctuations

As early as 1934, Mr. W. E. Code of Colorado State University began monitoring water levels in a few wells in the Bijou Valley. In 1936 he began to extend this network into the Kiowa Creek drainage. These early records were invaluable to this study for estimation of historic water levels and historic pumping.

The observation well network has been expanded over the years and now includes 50 wells in the Kiowa and 54 wells in the Bijou drainages. The water level in each of these wells has been measured twice annually, during the off-irrigation season, since their establishment as observation wells.

Figure 11 shows ground water level hydrographs for typical wells in the alluvium within the study area. These hydrographs are quite typical of irrigation wells in areas not having supplemental or imported surface water for irrigation. That is, the measured water level is always lower in the fall (if unusual recharge does not occur during the summer months) than in the spring. The lower static water table in the fall represents the residual drawdown from the summer pumping. This cone of depression fills from fall to spring and the water levels rise as long as the well is inoperative. In an area irrigated by stream diversion, the water levels are usually higher in the fall and return to about the same level each spring. This reflects deep percolation losses during the irrigation season causing the higher water table even though the wells may have been pumped.

Wells B2-60-13dd* and B2-60-26dd depict water level declines in the north end of the study area and show declines of 45 and 40 feet, respectively, in about 30 years of record. Well B2-60-13dd, in particular, typifies the increasing fluctuation of water levels from spring to fall as the saturated thickness in the aquifer decreases.

Well C1-62-34cd is located about one mile east of Kiowa Creek and shows the effect of ground water recharge by Kiowa Creek. Note the rise in water table from 1958 to 1963 that corresponds with a 5-year period of above average streamflow in Kiowa Creek. Another observation well, C2-62-20dbc, not shown on the hydrographs, had a water level rise of at least 12 feet during 1960 associated with the spring snow melt runoff. This observation well, equipped with an automatic recorder from 1960 to 1964, showed almost an instantaneous response

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* Represents well location based upon the U. S. Bureau of Land Management system of land subdivision.

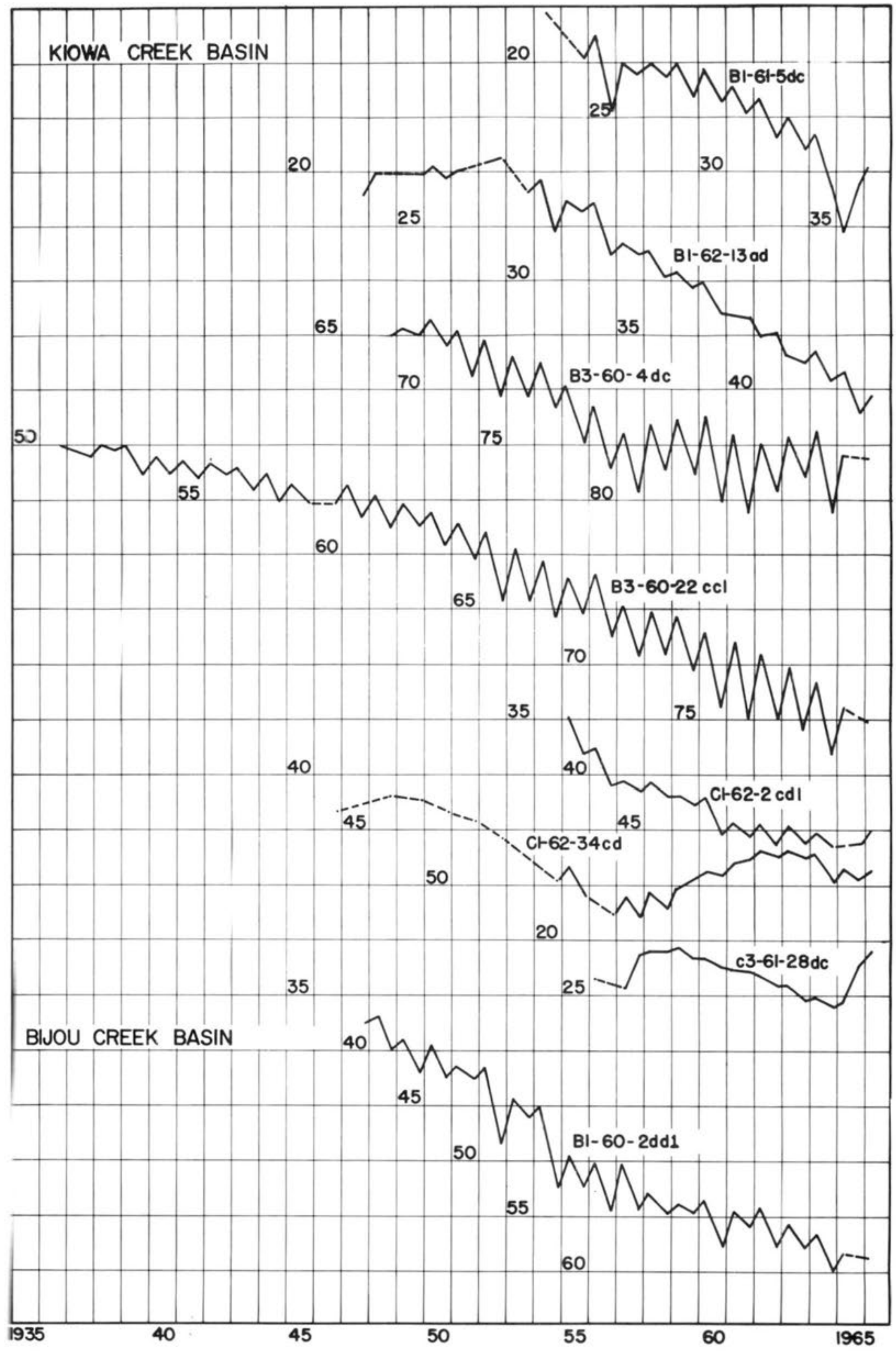

Figure 11. Typical water level hydrographs in study area.

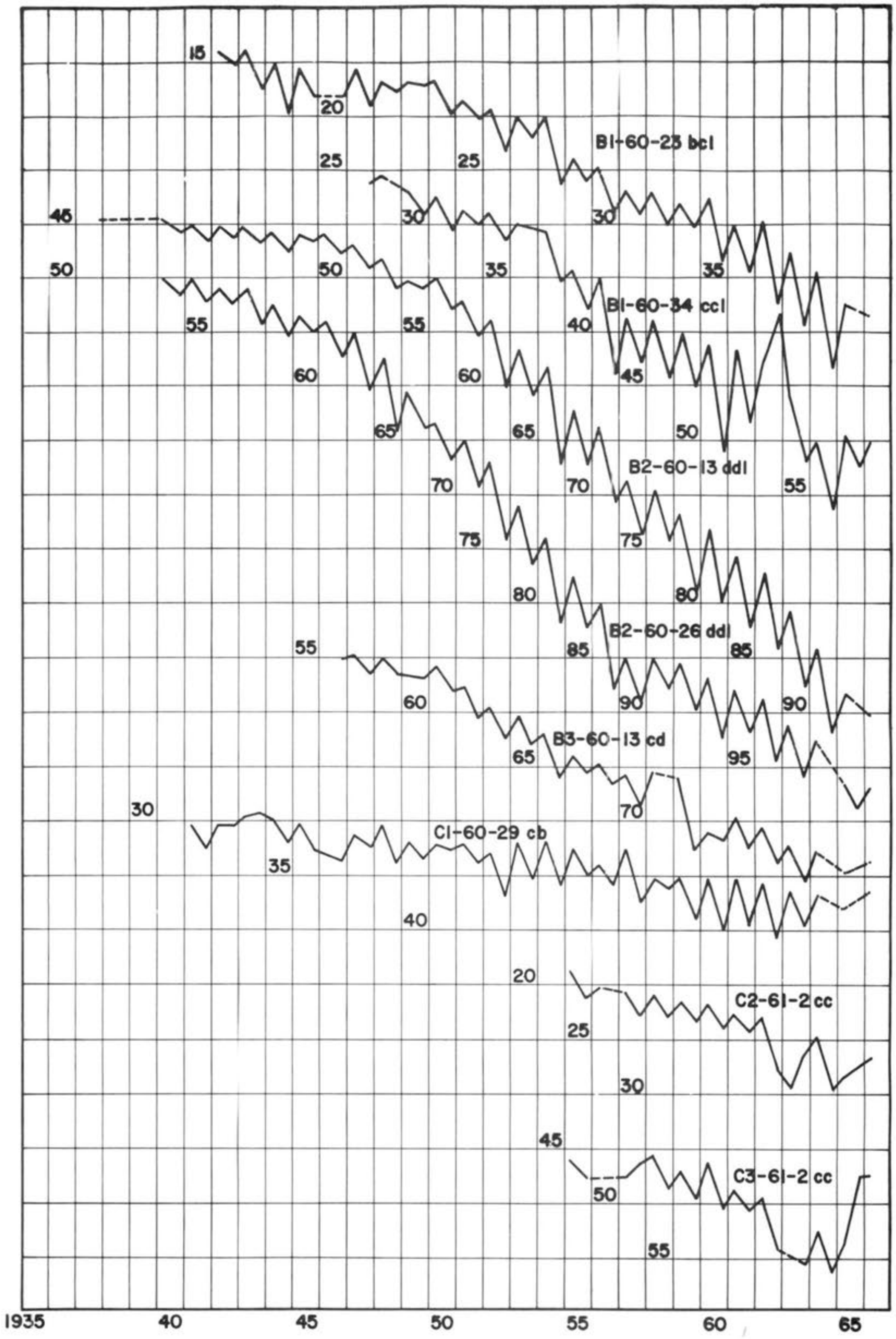

Figure 11. Continued.

to any flow in Kiowa Creek. The magnitude of the water level rise was a function of the length of time of flow.

Calculation of Historic Pumping

Source of data - For a number of years, Colorado State University has collected and compiled gross power deliveries to irrigation pumping plants from each electric power supplier in Colorado. These data were used in preliminary computations of pumping in the study area.

Records of Morgan County REA and Intermountain REA power deliveries for individual wells were placed on microfilm and used to refine the computed values of historic pumping. In the final computation of pumping in the area, these records were individually analyzed. Historic water levels as measured by Colorado State University and the U. S. Geological Survey were utilized to help estimate pumping lifts. Data concerning efficiency of pumping plants in the area were obtained from another study conducted by Colorado State University personnel in the study area during the summer of 1965.

Necessary assumptions - Due to the large number of wells within the study area, it would be virtually impossible to determine the operating characteristics of each well within a reasonable time period. For this reason, it was necessary to make some simplifying assumptions concerning the operation of these wells.

The parameters to be used in computing the amount of water pumped include power consumption, pumping lift, and pumping plant efficiency. In order to determine pumping lifts, the static water level was first estimated for those wells not measured during the field inventory. Surface elevations were established for all wells in areas where available topographic maps allowed a reasonably accurate determination. Static water levels were estimated by subtracting the water table elevation (Plate 2) from this surface elevation. In areas where topographic maps were not available, depth-to-water contour maps were constructed to aid in estimation of static depths. Water levels for previous years were estimated by adjusting the current water level to correspond with historic water level changes observed in nearby observation wells.

Because the production of almost all wells in the area has decreased since the pumps were installed, it was assumed that all pumps were presently being operated at the maximum capacity of the aquifer to yield water. The drawdown was assumed to be within 10 feet of the bedrock. Dividing the reported yield by the drawdown (i.e., saturated thickness minus 10 feet) for wells in which the water level was measured gave an average specific capacity (gallons per minute per foot of drawdown) for each drainage. Based upon this analysis the specific capacity in the Bijou drainage was estimated to be 18 gpm/ft and that in the Kiowa drainage 35 gpm/ft.

Efficiency tests conducted on 39 pumping plants in the area were analyzed for relationship between pump capacity and efficiency. The reported capacities of the wells within the study area were divided into five groups, and each group assigned an average efficiency. Those groups and their respective efficiencies are presented in Table VI.

Programming and calculation - Because of the large volume of data to be processed (some 40,000 documents were placed on microfilm), an electronic computer was utilized for computation of volumes of water pumped. Data from the microfilm were placed on IBM 1231 Optical Page Reader sheets and a program was prepared that allowed direct computation from the hand marked sheets without laborious punching of data cards. The IBM 1401 computer at Colorado State University was used for the analyses.

The general method of operation of the program was as follows: After storing all data for a well in memory, the computer

Table VI. Average pumping plant efficiency.

Capacity	Efficiency
0-249 gpm	20%
250-499 gpm	37%
500-749 gpm	50%
750-999 gpm	57%
1000 gpm and over	60%

selected an average efficiency for the plant based upon Table VI and the reported capacity. From the watershed designation, an average specific capacity was chosen, and the drawdown calculated by dividing this specific capacity into the reported capacity of the well. The lift was then determined by summing this drawdown and the static water level read in as data. The monthly volume pumped was calculated utilizing the monthly power deliveries, calculated pumping lift, and selected efficiency.

Output from the computer included a printout of the hookup number, location, names of drainage and county, the capacity of the well, static water level, drawdown, total lift, efficiency, monthly volumes pumped, and total annual volume pumped for each well. Output on punch cards for further analysis included two decks of cards. One deck included the same information as was printed, the other was the raw power data as obtained from the microfilm. A sample of the printed output is included in Appendix C.

Significance of non-electric wells - All machine computation was limited to electrically powered wells. The field inventories revealed a total of 27 wells powered by internal combustion engines. Since it is very difficult to determine the power consumption of these plants, the total volume pumped by these combustion plants was calculated by multiplying the reported capacity by the average hours of annual use reported by the farmer. The total estimated volume pumped by these non-electric plants was 5000 acre-feet for 1964.

Annual pumping volumes - Preliminary estimates of pumping volumes were made prior to the time an analysis of individual power records could be completed. These estimates were based solely upon the power deliveries of Morgan County REA and an estimated average efficiency and average depth to water in the area. The drawdown was estimated to be 15 feet in all wells, and the average efficiency 50 percent. Table VII gives the results of this preliminary estimate to two significant figures.

Table VII. Preliminary estimates of pumping.

Year	Acre-Feet	Year	Acre-Feet
1938	1,400	1952	130,000
1939	5,400	1953	110,000
1940	14,000	1954	210,000
1941	13,000	1955	190,000
1942	12,000	1956	270,000
1943	21,000	1957	110,000
1944	32,000	1958	140,000
1945	29,000	1959	170,000
1946	44,000	1960	210,000
1947	37,000	1961	140,000
1948	54,000	1962	180,000
1949	44,000	1963	270,000
1950	73,000	1964	290,000
1951	71,000		

The computer analysis of individual volumes pumped showed the total volume to be considerably less than the preliminary estimate, especially in recent years. This discrepancy is primarily attributable to misjudgment as to the number of wells operating in the study area. Individual analysis showed only 630 wells operated during 1964, whereas the preliminary estimate assumed 800 operating wells. It was also found that the wells in the southern portion of the area generally were of much lower capacity, therefore lower efficiency, and pumped less water during 1964 than was estimated by a direct proportion of power delivered by Morgan County REA.

Another major factor in this discrepancy was that the computed drawdowns in individual wells were, in most instances, considerably greater than the assumed 15 feet in the preliminary estimate.

The total yearly volumes of water pumped based upon the individual well analyses are given in Table VIII. These values are considered to be conservative in that the computed lifts from the computer analyses may have exceeded the actual lift. It was felt that the analyses for individual wells gave the best estimate available, however.

The monthly distribution of pumping for 1964 is illustrated in Figure 12. As might be expected, the months July through September showed the greatest amount of pumping. Perhaps the relatively small amount of pumping during the spring months might suggest water would be available for early maturing crops which could be grown to better utilize limited supplies of water.

The distribution of pumping within the study area is shown in Figure 13 for the year 1964. This figure displays the approximate percentage of the total volume pumped in the study area that was withdrawn from each township within each of the two areas. About 60 percent of the pumping in 1964 occurred in Morgan and Weld Counties (i.e., T1N-T3N). Over 90 percent of the pumping was below the Adams-Arapahoe County line.

Table VIII. Estimated total annual pumping within study area.

Year	Kiowa Basin (ac-ft)	Bijou Basin (ac-ft)	Total (ac-ft)
1938	360	440	800
1939	1,340	1,660	3,000
1940	3,560	4,440	8,000
1941	3,100	3,900	7,000
1942	3,060	3,940	7,000
1943	5,220	6,780	12,000
1944	7,800	10,200	18,000
1945	7,250	9,750	17,000
1946	10,600	14,400	25,000
1947	9,200	12,800	22,000
1948	11,700	16,600	28,300
1949	9,200	12,200	22,400
1950	15,600	22,700	38,300
1951	14,900	22,300	37,200
1952	21,600	32,900	54,500
1953	19,100	29,400	48,500
1954	34,000	53,000	87,000
1955	29,400	46,600	76,000
1956	37,700	61,000	98,700
1957	20,100	33,300	53,400
1958	24,300	40,700	65,000
1959	27,900	47,500	75,400
1960	33,000	57,200	90,200
1961	25,000	44,100	69,100
1962	34,500	62,000	96,500
1963	41,500	75,500	117,000
1964	45,600	84,400	130,000

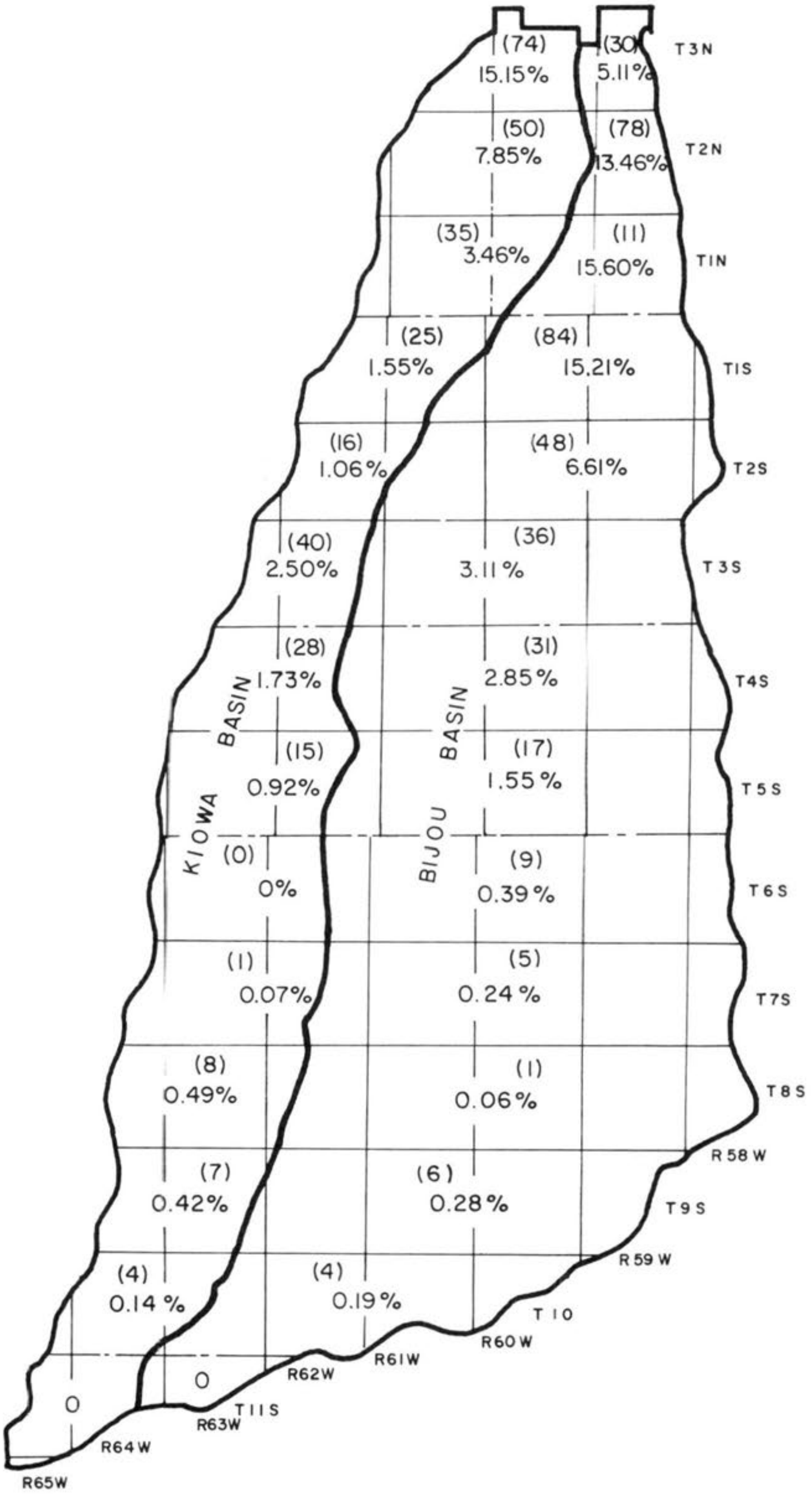

Figure 13. Distribution of wells and total pumping within study area-1964.

Future Use of Ground Water

Based upon the great technological strides of the past fifty years, it is extremely difficult to estimate what advances in water utilization may occur in the succeeding fifty years. The ideas presented in this section are based upon presently forseeable developments.

Management Practices

The maximum utilization of present water resources in the study area rests upon sound judgment of the water users in the area. Many present management practices waste water now available, but corrective measures for prevention of all waste may not be economically or physically feasible at present. As water resources become more scarce, measures to reduce waste will be implemented.

Crops - The type of crops grown in the area have a considerable influence upon the average annual volume of water pumped (See Table II for a list of water requirements). As an example, alfalfa hay, and sugarbeets consume more water than corn. Grain crops such as wheat, barley, and sorghum consume even less water. No attempt is made in this report to determine the relative economic value of water applied to these various crops. Future agronomic research will undoubtedly develop crop varieties and irrigation practices allowing sustained yields with less water than presently used.

As the individual farmer's water resources become more limited, reduced yields of wells may force more diversification of crop types. Rather than pump a limited supply of water for a relatively short period to inadequately irrigate one major crop, this same supply could be pumped for a longer period of time at a lower rate and adequately irrigate three or four major crops requiring their maximum amount of water at different times of the year. A cropping system combining, for example, small grains, early season crops such as potatoes, and late summer crops such as sugar beets could extend the irrigation season almost continuously from late winter through early September. Although this practice will not reduce the annual volume of water pumped, it will help to prolong the economic life of a limited supply of water.

High water tables and phreatophytes - Very few places in the study area have, in recent years, had sufficiently high water tables to result in significant evaporation directly from the water table. There is probably little that can be done in the area to recover water from this source of waste at present. This factor might, however, become significant in the future for areas adjacent to recharge projects if such projects are initiated.

Although phreatophytes are not a large problem in the study area, there are a significant number of large cottonwood trees, especially adjacent to Bijou Creek. These trees are capable of extending their roots to considerable depth in order to draw water directly from the water table. A moderate infestation of these phreatophytes will use two or three times as much water as most agricultural crops grown on the same area.

Studies are presently underway in many parts of the Southwest to develop feasible means of destroying phreatophytes as a method of salvaging water otherwise lost to nonbeneficial use. Similar studies should be initiated to determine what benefits could be obtained by removal of some cottonwoods from the study area.

Irrigation practices - Interviews with local farmers while conducting field inventories showed that the average pumping season in the Kiowa-Bijou area is 119 days. During approximately 20 days of the 140-day growing season the pumps are not used. Some farmers reported use as high as 210 days per year, indicating that diversified cropping is practical in the area. In the future, these longer pumping seasons will likely become more common as a means of obtaining the maximum net income from increasingly smaller water supplies.

In this investigation, it was estimated that the average irrigation efficiency in the study area was 70 percent. Thus, 30 percent of the water pumped for irrigation percolates below the root zone and returns to the water table. Although this deep percolation in itself does not represent a loss of the water resource, it does increase the cost of water made available for consumptive use. Probably the major sources of deep percolation loss in this area are the use of open, unlined ditches for field delivery and irrigation runs much too long for the soil type present. Undoubtedly, as water becomes more scarce in the basin, more efficient irrigation practices will be utilized to maintain the economic feasibility of pump irrigation.

Effect of falling water tables - As shown in Plate 3, a total of 37 registered wells have been abandoned in the Kiowa-Bijou watershed. Although the reason for abandonment is not known, the location of most of the abandoned wells in or outside the fringe area of saturated alluvium suggests that water level declines have been the major cause of abandonment. As water levels continue to decline, more wells will certainly be abandoned.

It should be pointed out that the abandoned wells shown on Plate 3 include only those which were registered under the 1957 law. It was impossible to determine the number of wells abandoned prior to that time, although there were probably a considerable number which were not located during the field inventories.

Based upon the present water levels, a drop of 20 feet in water level would represent depletion of about 1,200,000 acre-feet of stored ground water. Such a decline would leave about 120 wells now in operation outside the saturated alluvium. A considerable number of additional wells would probably be left with too little saturated thickness to operate economically.

At present rates of decline this 20-foot decline will occur in six to ten years in some portions of the study area. Other portions, especially in Kiowa Creek where considerable recharge occurs, may never experience 20-foot declines.

As water levels decline, the production of wells in the area can naturally be expected to decline correspondingly. Lower water levels mean not only greater pumping lifts, but also smaller attainable gradients and less area through which flow can occur. For purposes of projecting pumping, it was assumed that well yields would decrease in proportion to the square of water level declines.

Due to the shape of the cone of depression surrounding a pumped well, an infinite number of wells would be required to withdraw all the drainable water from the formation. Of course, this sort of spacing will never be realized, but will be approached if the aquifer is to be utilized to its fullest. As well production declines, economy of pump operation will dictate replacement of large pumps by smaller ones. To supplement loss of production from existing wells it will be necessary to drill new wells between the existing ones. By combining the lower production of individual wells and the larger number of wells it may be possible to maintain the existing production for a longer period. Many small wells properly placed and pumped at moderate rates could intercept the water that is recharged.

Prediction of Future Pumping

A number of factors were considered in estimating future pumping in the area. Since it is difficult to guess what steps the local people might take to conserve their water, the effect of a possible water management district was not considered. Although it is realized that the majority of the wells will decrease in production each year, and some will be abandoned, it is expected that the addition of replacement wells and supplemental wells will enable the area to maintain present average volumes of pumping for several years in the future. After additional wells have reached a maximum practical density, and as the pumping season approaches the growing season in length, continually decreasing well production will result in decreasing annual pumping volumes.

To calculate future pumping volumes, it was estimated that 30 percent of the water pumped to the surface returns to the water table through deep percolation beyond the root zone. As water becomes more scarce and better management practices are utilized, this percentage will undoubtedly decrease. It was assumed that only 20 percent would return by the end of 50 years. Based upon these estimates, and neglecting the changes in underflow from the study area, the present depletion of ground water storage is 70 percent of the annual pumping volume, less the 55,800 acre-feet of natural recharge.

Predicted pumping volumes, by ten year intervals, are presented in Table IX, and include adjustments for declining water tables, return flows, and the natural recharge.

Table IX. Predicted future pumping.

Year	Estimated Annual Pumping (acre-feet)
1975	97,000
1985	87,000
1995	80,000
2005	77,000
2015	75,000

As previously stated, these figures are based upon presently available technological achievements. The investigators hope that this prediction is rather pessimistic, and that further research will develop a practical means of increasing the life of the Kiowa-Bijou alluvial aquifer.

Possibility for Artificial Recharge

Since the Kiowa-Bijou area has no imported water, and since over appropriation of the South Platte River makes such importation unlikely, the investigators feel that artificial recharge of flood waters will be the key to increasing the life span of the Kiowa-Bijou aquifer. Previous studies in Colorado and elsewhere have indicated that artificial recharge of flood waters may be possible and feasible in ephemeral streams such as Kiowa and Bijou Creeks.

Kiowa watershed

Flow records for only five years (1960-64) at Bennett on Kiowa Creek indicate an average flow of a little over 2000 acre-feet passed this point. This water was naturally recharged to the aquifer since no flow reached the South Platte River. Thus, it appears that benefits from artificial recharge of Kiowa Creek flood flows would be recognized only when extremely high flows occur that would allow some water to reach the river or in the relocation of recharge so as to relieve pump overdrafts in a particular area. By recharging water in the upper part of the aquifer it is possible to reduce surface evaporation of the stream flow and allow maximum reuse of irrigation deep percolation losses. A recycling by pumping of deep percolation losses has the effect of increasing the water supply, but may create some water quality problems due to concentration of salts.

The study to evaluate the natural recharge on Kiowa Creek conducted by Colorado State University (9, 10, 11) indicated that in Townships one and two south the infiltration of flood flows into the alluvium was very high and there was also a large volume of unsaturated alluvial material to receive the recharged water. This same area in the Kiowa watershed would be very suitable for construction and operation of artificial recharge facilities. Small low cost earth dams to impound and spread flood flows allowing them to infiltrate and recharge the alluvium could be used.

Bijou watershed

Seven years of stream flow records (1950-56) are available on Bijou Creek near Wiggins. These records show that flood flows in the Bijou frequently reach the South Platte River. This indicates that water is available for artificial recharge.

A flood frequency analysis of the seven years record was made and the results are shown in Figure 14. The short period of record limits the reliability of the analyses. Additional flow records to verify or change the frequency analysis are needed. If the recurrence intervals plotted on Figure 14 are too small then the expected discharge for a particular return period would be somewhat less than indicated.

A flood frequency analysis would be very useful in designing and constructing artificial recharge facilities. Figure 14 indicates that there is a flow of 3000 acre-feet available for recharge once every two years, or a flow of 44,000 acre-feet once each ten years. The size of the recharge facilities and their respective spillways could thus be designed for a particular recurrence interval.

Artificial recharge structures in the Bijou watershed should be placed north of the Adams-Arapahoe county line because of the limited unsaturated alluvium south of this line. Care must also be taken to not locate the facilities where impermeable clay layers would prevent percolation of the water to the water table. Much of the Bijou valley is underlain by these clay lenses and test drilling in the proposed site is recommended to select an area free of fine sediments.

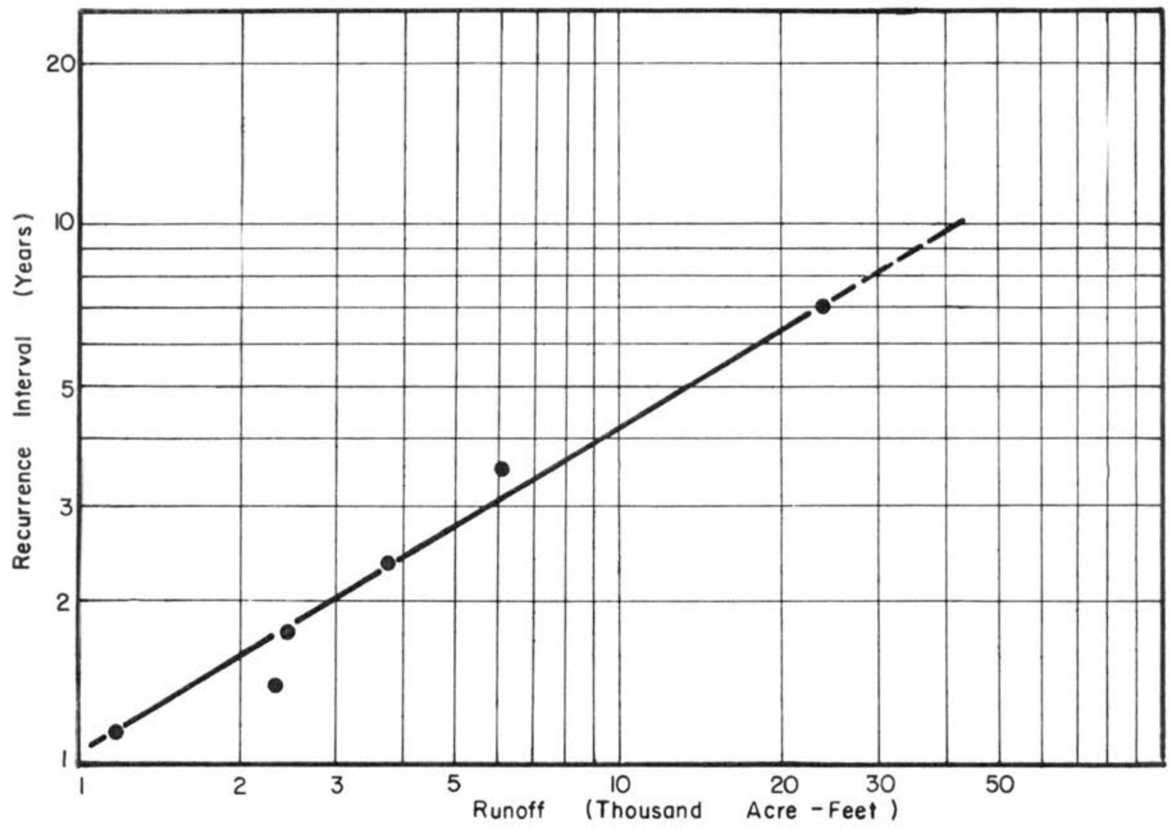

Figure 14. Expected runoff for Bijou Creek near Wiggins, Colorado.

Maintenance, including removal of fine sediment deposits, will be required to prevent reduction in the infiltration capacity.

Ground Water Users of 15 Years

A listing of wells registered with the State Engineer which were drilled during or prior to 1950 is presented in Appendix D*.

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* Listing was provided by personnel of the State Engineer's Office.

It should be noted that this listing does not include those wells which the owner failed to register under the Well Registration Law of 1957.

The average annual volume of water pumped by these wells was computed by multiplying 70 percent of the reported discharge by the hours of operation and converting this quantity to acre-feet. Field inventories in 1965 showed that an average discharge of 70 percent of that initially reported was fairly representative, considering that well yields have declined and reported yields were normally quite optimistic. Reports from farmers also showed that on the average they pumped from the wells over a 119 day period. Analyses of power records and corresponding volumes pumped for individual wells showed that the pumps were operated an average of 10 hours per day for each of the 119 days.

In 1950 there were 238 wells in the study area and the total volume pumped was 38,300 acre-feet or an average of 160 acre-feet per well.

SUMMARY AND CONCLUSIONS

The purpose of the study was to evaluate the total water resources, both surface and ground water, in the 2130 square mile study area composed of the Kiowa and Bijou Creek watersheds. This area is tributary to the South Platte River and features intermittent stream flow following spring snow melt or summer thunderstorm activity. Perennial streamflow into or out of the study area does not exist.

The study area is underlain by sedimentary rocks and features alluvial filled stream channels. The principle aquifers consist of the saturated alluvium, which is now used extensively as an irrigation supply, and the Fox Hills sandstone which is relatively undeveloped but could supply moderate amounts of water to wells.

Other formations such as the Laramie, Pierre shale, Arapahoe, and the Dawson-Arkose yield small quantities of water for domestic and stock purposes within the study area but were not considered in detail within this report. The Dakota sandstone was not considered because water from this aquifer within the study area is brackish and the formation occurs at a great depth below the surface.

The average annual precipitation varies from about 13 inches near Wiggins to 18 inches near the headwaters for an average of 15.17 inches over the entire watershed. This amounts to about 1,720,000 acre feet of water annually. Most of the precipitation occurs from April 15 to the end of August. Although much of the precipitation is associated with localized storms, a statistical analysis of rainfall revealed no significant difference in the annual distribution of precipitation between stations or the watersheds.

The only replenishment source of water is that which falls as precipitation on the watershed. This was the principle reason for selecting study area boundaries that include the entire watershed and not just the saturated alluvium. The area underlain by saturated alluvium includes only 27 percent of the total study area.

There are 116 surface water decrees on record in the State Engineer's Office within the study area. Irrigation projects associated with most of these have been abandoned due to inadequate or unreliable water supplies. Those that remain are largely used for supplemental irrigation of hay or for recharge. The amount of land irrigated or the quantity of water diverted within the study area is not known because adequate records are not kept. It is felt the amount of land irrigated by surface flows is minimal compared to that irrigated from ground water.

It was estimated that the volume of water stored in the alluvial fill material in 1965 that could be removed was 2,373,000 acre-feet. A similar estimate for the quantity of water available from the Fox

Hills formation within the study area was approximately 2,000,000 acre-feet. These two values represent a large quantity of water in storage that has accumulated over many years. Analyses of natural recharge rates indicate that about 55,800 acre-feet of water is annually recharged to the alluvium. This water falls as precipitation on the watershed and no water is imported into the study area from outside sources. The annual recharge to the Fox Hills sandstone is estimated to be less than 5,000 acre-feet.

Wells were first drilled in the study area in the early 1930's and slowly increased in number till the late 1940's. In the summer of 1965 there were 700 wells in the area and analyses indicate that approximately 130,000 acre-feet of water were pumped in 1964. The quantity of water pumped of course, has increased as the number of wells increased. Historic water level measurements illustrate a decline in the water table in a large part of the study area. This indicates that water withdrawal rates have exceeded recharge rates. Water level decline of as much as 45 feet over the last 30 years has occurred in some parts of the study area. Some land previously irrigated has reverted back to dryland farming as a result of water table declines.

Analyses of future pump withdrawals depend upon many unforeseen parameters. It was estimated that the amount that could be pumped from the alluvial aquifer would decrease to about 75,000 acre-feet annually by the year 2015 as the existing water in storage is removed.

Only by restricting pumping or increasing the recharge will it be possible to prolong the life of the aquifer. Restricted pumping and changes in the water use could be promoted by a local area management district. This same district could support and operate artificial recharge facilities to increase the recharge. It appears that little water is now available from Kiowa Creek for artificial recharge but the flows from Bijou Creek that reach the South Platte

River could be utilized if suitable facilities could be designed and constructed. The only other solution would be to import water into the area from an outside source.

Estimated values for the various items presented in this report are based upon analyses of existing data and are considered to be the best estimates available at this time. As additional data becomes available these estimates should be re-evaluated and changes made where applicable.

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APPENDICES

APPENDIX A

LEGAL DESCRIPTION OF THE STUDY AREA

The following legal description of the proposed "Designated Ground Water Basin" was prepared by the staff of the Colorado Water Conservation Board. The description is referenced to the Sixth Principal Meridian.

"The lands to be included in the proposed designated ground water basin are located in parts of Morgan, Weld, Adams, Arapahoe, Elbert, and El Paso Counties, State of Colorado and are described as follows:

T.3N., R.61W., Sections 13, 14, 22 thru 27 (incl.), 34, 35, and 36. -- T.3N., R.60W., All sections except 1, 2, 3, 4, and 12. -- T.3N., R.59W., Sections 4 thru 9 (incl.), 16 thru 20 (incl.), and 29 thru 32 (incl.) -- T.2N., R.62W., Sections 24, 25, and 36. -- T.2N., R.61W., All sections except 5, 6, 7, and 8. -- T.2N., R.60W., All sections. -- T.2N., R.59W., Sections 5 thru 9 (incl.), 16 thru 21 (incl.), and 28 thru 34 (incl.). -- T.1N., R.62W., Sections 1, 12, 13, 23 thru 26 (incl.), 35 and 36. -- T.1N., R.61W., All sections. -- T.1N., R.60W., All sections. -- T.1N., R.59W., Sections 3 thru 11 (incl.), 14 thru 23 (incl.), and 26 thru 35 (incl.). -- T.1S., R.62W., Sections 1, 2, 3, 10 thru 15 (incl.), 21 thru 28 (incl.), and 33 thru 36 (incl.).- T.1S., R.61W., All sections. --T.1S., R.60W., All sections. --T.1S., R.59W., All sections. -- T.1S., R.58W., Sections 19, 30, and 31. -- T.2S., R.63W., Section 36 only. T.2S., R.62W., All sections except 6, 7, and 18. -- T.2S., R.61W., All sections. -- T.2S., R.60W., All sections. -- T.2S., R.59W., All sections. -- T.2S., R.58W., Sections 6, 7, 17 thru 20 (incl.), and 30. --T.3S., R.63W., Sections 1, 2, 11 thru 14 (incl.), 23 thru 27 (incl.), and 34, 35, and 36. -- T.3S., R.62W., All sections. -- T.3S., R.61W, All sections. -- T.3S., R.60W., All sections. -- T.3S., R.59W., All sections except 1 and 12. -- T.4S., R.63W., Sections 1, 2, 3, 9 thru 16 (incl.), 20 thru 36 (incl.). -- T.4S., R.62W., All sections. -- T.4S., R.61W., All sections. -- T.4S., R.60W., All sections. -- T.4S., R.59W., All sections. -- T.4S., R.58W., Sections 6, 7, 17 thru 20 (incl.), and 28 thru 33 (incl.). -- T.5S., R.64W., Sections 1, 12, 13, 24, 25, and 36. -- T.5S., R.63W., All sections. -- T.5S., R.62W., All sections. -- T.5S., R.61W., All sections. -- T.5S., R.60W., All sections. -- T.5S., R.59W., All sections. -- T.5S., R.59W., Sections 4 thru 9 (incl.). 16 thru 21 (incl.), and 28 thru 32 (incl.). -- T.6S., R.64W., Sections 1, 12, 13, 24, 25, and 36. -- T.6S., R.63W., All sections. - T.6S., R.62W., All sections. -- T.6S., R.61W., All sections. -- T.6S., R.60W., All sections. -- T.6S., R.59W., All sections. -- T.6S., R.58W., Sections 5 thru 8 (incl.), 17 thru 20 (incl.), and 28 thru 33 (incl.). -- T.7S., R.64W., Sections 1, 12, 13, 23 thru 27 (incl.), and 34 thru 36 (incl.). -- T.7S., R.63W., All sections. -- T.7S., R.62W., All sections. -- T.7S., R.61W., All sections.- T.7S., R.60W., All sections. -- T.7S., R.59W., All sections. -- T.7S., R.58W., Sections 3 thru 10(incl.), 16 thru 21 (incl.), and 28 thru 33 (incl.). -- T.8S., R.64W., Sections 1 thru 4 (incl.), 9 thru 16 (incl.), 21 thru 28 (incl.), and 33 thru 36 (incl.). -- T.8S., R.63W., All sections. -- T.8S., R.62W., All sections. -- T.8S., R.61 W., All sections. -- T.8S., R.60W., All sections. -- T.8S., R.59W., All sections. -- T.8S., R.58W., Sections 4 thru 9 (incl.), 15 thru 22 (incl.), and 27 thru 31 (incl.). -- T.9S., R.64W., Sections 1 thru 4 (incl.), 10 thru 15 (incl.), 21 thru 28 (incl.), and 33 thru 36 (incl.). -- T.9S., R.63W., All sections. - T.9S., R.62W., All sections. -- T.9S., R.61W., All sections. -- T.9S., R.60W., All sections. -- T.9S., R.59W., Sections 2 thru 10 (incl.), 15 thru 22 (incl.), and 28 thru 32 (incl.), -- T.10S., R.65W., Sections 25 and 36. -- T.10S., R.64W., Sections 1 thru 4 (incl.), 8 thru 17 (incl.), and 19 thru 36 (incl.). -- T.10S., R.63W., All sections. -- T.10S., R.62W., All sections. -- T.10S., R.61W., Sections 1 thru 20 (incl.), and 22, 23, 24, 30, and 31. --T.10S., R.60W., Sections 1 thru 10 (incl.), and 17 thru 19 (incl.). -- T.11S., R.65W., Sections 1, 2, 11 thru 14 (incl.), 22 thru 27 (incl.), 34, 35, and 36. -- T.11S., R.64W., Sections 1 thru 22 (incl.), 29, and 30. -- T.11S., R.63W., Sections 1 thru 10 (incl.), and 16 thru 18 (incl.)."

APPENDIX B

SURFACE WATER DECREES IN STUDY AREA

DITCH DECREES

Priority No.	Name of Ditch	Source	Decree Date	Decree sec-ft*	Location S	Location T	Location R
		KIOWA CREEK BASIN					
1	Oakes No. 1	Kiowa Creek	4-26-66	2.0	28	9S	64W
2	Wendling	Killin's Spring Run	4-1-68	5.0	20	8S	63W
3	Oakes No. 3	Kiowa Creek	5-1-68	15.0	23	9S	64W
4	Aux No. 1	Kiowa Creek	9-15-75	2.5	14	9S	64W
5	Dietrich No. 1	Kiowa Creek	5-1-78	2.5	1	9S	64W
6	Dietrich No. 2	Kiowa Creek	9-10-79	1.5	12	9S	64W
7	Fred Bachman No. 2	Kiowa Creek	3-20-81	5.5	32	7S	63W
9	Fred Bachman No. 3	Kiowa Creek	7-3-82	1.0	29	7S	63W
10	George A. Wood	Kiowa Creek	4-10-83	3.0	6	9S	64W
11	Dietrich No. 3	Kiowa Creek	4-2-85	1.0	12	9S	64W
12	Ehrler	Kiowa Creek	3-15-86	1.0	5	8S	63W
13	Elbert	Kiowa Creek	2-8-87	1.0	3	10S	64W
14	Aux No. 2	Kiowa Creek	2-12-87	1.0	13	9S	64W
15	Fahrion	Kiowa Creek	9-20-87	1.0	17	8S	63W
29	Alex Brazelton	West Kiowa Creek	1-1-88	1.26			
16	D. C. Bailey	Kiowa Creek	4-3-88	5.5	7	9S	63W
26	Renner No. 1	Kiowa Creek	6-1-88	10.71	27	4S	63W
18	Kruse and Mauldin	Running Creek	2-17-89	1.5	26	8S	64W
4	Comanche	Comanche Creek	12-2-89	4.0	35	1S	62W
19	Marki	Kiowa Creek	5-25-90	1.0	8	8S	63W
9	Gibson No. 2	Kiowa Creek	7-14-92	147.0	21	5S	63W
10	Egelhoff Grove	Kiowa Creek	5-15-93	46.0	16	5S	63W
27	Ell Triangle	Comanche Creek	10-15-95	52.0			
11	Desert Ditch and Extensions	Kiowa Creek	10-23-95	140.0	33	1S	62W
53	Wahl and Epple	Kiowa Creek	10-1-00	115.0	30	1N	61W
54	Rock Bluff	Rock Bluff Creek	10-1-00	50.0	8	1N	60W
55	C. Wahl	Kiowa Creek	10-3-00	180.0	32	2N	61W
14	Living Springs Nos. 1 and 2	Comanche Creek	3-1-03	79.2	14	1S	62W
72	Wahl	Kiowa Creek	12-14-05	23.0	5	1N	61W
16	Desert Ditch and Extensions	Kiowa Creek	4-1-06		33	1S	62W
21	Desert Ditch and Extensions	Kiowa Creek	4-1-07	P	33	1S	62W
28	Washita	Comanche Creek	5-28-07	17.82			
92	Caroline Epple No. 1	Mule Creek	12-17-07	150.0 P	29	1N	61W
93	Caroline Epple No. 2	Mule Creek	12-17-07	150.0 P	20	1N	61W
28	Gleason	Kiowa Creek	6-20-08	5.16	31	8S	63W
33	Carnahan Underflow	Kiowa Creek	2-17-12	1.5	12	9S	64W
		BIJOU CREEK BASIN					
7	Meadow Springs	Meadow Springs Creek	6-1-70	2.0	6	3S	60W
1	Page and Foster	West Bijou Creek	2-10-88	8.0	18	5S	61W
2	Bijou	West Bijou Creek	2-23-88	30.0	8	5S	61W
3	Craven	West Bijou Creek	2-10-89	1.0		5S	61W
17	Bueck	East Bijou Creek	9-15-89	22.0	9	8S	59W
48	Bijou Reservoir Inlet	Bijou Creek	7-5-91	P	5	2N	59W
5	Bramkamp	Deer Trail Creek	2-15-92	5.0	36	2S	60W
6	Moore	Deer Trail Creek	11-6-93	P	30	1S	59W

APPENDIX B (continued)

SURFACE WATER DECREES IN STUDY AREA

DITCH DECREES

Priority			Decree		Location		
No.	Name of Ditch	Source	Date	sec-ft*	S	T	R
		BIJOU CREEK BASIN					
24	East Gulch Ditch	East Gulch	11-14-95	6.8	30	6S	61W
12	Moore Enl.	Deer Trail Creek	11-24-95	127.55	30	1S	59W
22	Maguire	West Bijou Creek	4-10-96	5.3	16	9S	62W
13	Meadow Springs Enl.	Meadow Springs Creek	6-5-97	6.0	6	3S	60W
15	Bailey - Hack	Antelope and Little Antelope Creeks	11-14-04	36.0	5	1S	60W
80	Pipe Line of Bijou Valley Ditch and Reservoir System	Bijou Creek	5-15-06	27.0	35	1N	60W
23	Wassman	East Bijou Creek	5-18-06	14.0	15	7S	59W
80A	Brewer	Deer Trail Creek	6-9-06	22.0 P	21	2N	59W
24	M.H.	Long Gulch	6-20-06	23.5 P	15	7S	59W
17	Moore 2nd Enl.	Deer Trail Creek	7-25-06	P	30	1S	59W
25	M. H. No. 2	East Bijou Creek	9-15-06	50.4	23	7S	59W
26	M. H. No. 3	East Bijou Creek	11-1-06	230.15	33	7S	59W
18	Adams Ditch and Pipeline	Meadow Springs Creek	2-8-07	3.0	6	3S	60W
19	Swanson	West Bijou Creek	2-15-07	17.5	10	3S	61W
20	Clark and James	West Bijou Creek	4-1-07	288.0	21	3S	61W
84	D. T.	Deer Trail Creek	4-23-07	71.72P	32	1N	59W
32	Agate Res. and Ditch	East Bijou Creek	6-1-07	30.0			
29	Conter	Bijou Creek	1-17-08	44.0			
27	East Gulch Ditch and Reservoir Enl.	East Gulch	2-6-08	P	30	6S	61W
22	Upper Nile and Extension	Bijou and Antelope Creeks	6-9-08	P	33-5	1S	60W
95	Barnhouse	Antelope Creek	6-9-08	47.85	7	1S	60W
95A	Lower Nile	Bijou and Antelope Creeks	6-9-08	P	8-21	2N	59W
96	Base Line Reservoir, Outlet	Deer Trail Creek	7-28-08	44.0	32	1N	59W
23	Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	P	11	1S	60W
116	D.T. No. 2	Deer Trail Creek	12-21-09	P	8	1N	59W
24	Outlet No. 1 of Supplemental Reservoir	Deer Trail Creek	4-24-10	P	5	1S	59W
25	Outlet No. 2 of Supplemental Reservoir	Deer Trail Creek	4-24-10	P	5	1S	59W
29	Maguire Enl.	West Bijou Creek	4-3-11	9.7	16	9S	62W
31	Brothe Ditch	Deer Trail Creek	4-1-12	200.0 Max. 2000			

APPENDIX B (continued)

SURFACE WATER DECREES IN STUDY AREA

RESERVOIR DECREES

Priority No.	Name of Reservoir	Source of Supply	Decree			Location		
			Date	(ac-ft)*		S	T	R
		KIOWA CREEK BASIN						
5	Gibson No. 1	Kiowa Creek	11-15-92			16	5S	63W
6	Gibson No. 2	Kiowa Creek	6-15-93			4	5S	63W
12	Rock Creek No. 1	Rock Creek	6-1-07	460	P	31	1N	60W
20	Rock Creek No. 2	Rock Creek	9-5-09	643	P	6-7-12	1S	60W
		BIJOU CREEK BASIN						
1	Bijou	West Bijou Creek	4-27-89	2296		29	4S	61W
1	Bueck	East Bijou Creek	9-15-89	750		4	8S	59W
2	Bijou No. 1	Bijou Creek	7-5-91		P		3N	59W
3	Bijou No. 2	Bijou Creek	7-5-91		P		3N	59W
4	Bijou No. 3	Bijou Creek	7-5-91		P		3N	59W
5	Bijou No. 4	Bijou Creek	7-5-91		P		3N	59W
6	Bijou No. 5	Bijou Creek	7-5-91		P		3N	59W
7	Bijou No. 6	Bijou Creek	7-5-91		P		3N	59W
2	Bramkamp	Deer Trail Creek	2-15-92	193		31	2S	59W
4	Mary Lawless	West Bijou Creek	12-23-93	1713	P	9	5S	61W
7	Moore No. 1	Deer Trail Creek	4-1-94	114		30	1S	59W
8	Hopewell No. 1	West Bijou Creek	9-27-03	1840		27	3S	61W
9	Moore No. 2	Deer Trail Creek	4-1-05	23		18	1S	59W
40A	Brewer "A"	Bijou Creek	6-9-06	65	P	8	2N	59W
2	M.H.	Long Gulch	7-17-06	70	P	15	7S	59W
10	Moore No. 4	Deer Trail Creek	7-25-06	860		6-31	1S-1N	59W
3	M.H. No. 2	East Bijou Creek and Gulches	9-1-06	256	P	15	7S	59W
4	M.H. No. 2 Enl.	East Bijou Creek and Gulches	12-9-06	522	P	15	7S	59W
13	Noonen No. 2	Deer Trail Creek	10-22-07	2662		10-11	4S	59W
47	Base Line	Deer Trail Creek	1-28-08	216	P	5-32	1S-1N	59W
5	East Gulch	East Gulch	2-6-08	18	P	19	6S	61W
13A	Adams	Bijou Creek	6-9-08	11040	P		1S	60W
51	Barnhouse	Antelope Creek	6-9-08			7-18	1S	59W
51A	Macarthy	Bijou and Antelope Creeks	6-9-08	0.2	P		3N	60W
14	Meadow Springs	Meadow Springs Creek	6-15-08	116		6	3S	60W
15	Reservoir "A" of the Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	487	P	1-2-11	1S	60W
16	Reservoir "B" of the Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	714	P	2-35	1S-1N	60W
54	Reservoir "D" of the Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	253	P	13	1N	60W
17	Hopewell No. 2	West Bijou Creek	10-15-08	2700	P	23-14	3S	61W
6	New Kingsbury	Willow Gulch	5-2-09	536	P	17	6S	60W
21	Bramkamp Enl.	Deer Trail Creek	9-27-09	2066	P	31	2S	59W
68A	West Nile	Rock, Bijou, and Antelope Creeks	9-28-09		P		2N	60-61W
69	D.T. No. 1	Deer Trail Creek	12-21-09	138	P	17	1N	59W
69	D.T. No. 2	Deer Trail Creek	12-21-09	112	P	20	1N	59W
69	D.T. No. 3	Deer Trail Creek	12-21-09	125	P	20	1N	59W

APPENDIX B (continued)

SURFACE WATER DECREES IN STUDY AREA

RESERVOIR DECREES

Priority			Decree			Location		
No.	Name of Reservoir	Source of Supply	Date	(ac-ft)*		S	T	R
		KIOWA CREEK BASIN						
5	Gibson No. 1	Kiowa Creek	11-15-92			16	5S	63W
6	Gibson No. 2	Kiowa Creek	6-15-93			4	5S	63W
12	Rock Creek No. 1	Rock Creek	6-1-07	460	P	31	1N	60W
20	Rock Creek No. 2	Rock Creek	9-5-09	643	P	6-7-12	1S	60W
		BIJOU CREEK BASIN						
1	Bijou	West Bijou Creek	4-27-89	2296		29	4S	61W
1	Bueck	East Bijou Creek	9-15-89	750		4	8S	59W
2	Bijou No. 1	Bijou Creek	7-5-91		P		3N	59W
3	Bijou No. 2	Bijou Creek	7-5-91		P		3N	59W
4	Bijou No. 3	Bijou Creek	7-5-91		P		3N	59W
5	Bijou No. 4	Bijou Creek	7-5-91		P		3N	59W
6	Bijou No. 5	Bijou Creek	7-5-91		P		3N	59W
7	Bijou No. 6	Bijou Creek	7-5-91		P		3N	59W
2	Bramkamp	Deer Trail Creek	2-15-92	193		31	2S	59W
4	Mary Lawless	West Bijou Creek	12-23-93	1713	P	9	5S	61W
7	Moore No. 1	Deer Trail Creek	4-1-94	114		30	1S	59W
8	Hopewell No. 1	West Bijou Creek	9-27-03	1840		27	3S	61W
9	Moore No. 2	Deer Trail Creek	4-1-05	23		18	1S	59W
40A	Brewer "A"	Bijou Creek	6-9-06	65	P	8	2N	59W
2	M.H.	Long Gulch	7-17-06	70	P	15	7S	59W
10	Moore No. 4	Deer Trail Creek	7-25-06	860		6-31	1S-1N	59W
3	M.H. No. 2	East Bijou Creek and Gulches	9-1-06	256	P	15	7S	59W
4	M.H. No. 2 Enl.	East Bijou Creek and Gulches	12-9-06	522	P	15	7S	59W
13	Noonen No. 2	Deer Trail Creek	10-22-07	2662		10-11	4S	59W
47	Base Line	Deer Trail Creek	1-28-08	216	P	5-32	1S-1N	59W
5	East Gulch	East Gulch	2-6-08	18	P	19	6S	61W
13A	Adams	Bijou Creek	6-9-08	11040	P		1S	60W
51	Barnhouse	Antelope Creek	6-9-08			7-18	1S	59W
51A	Macarthy	Bijou and Antelope Creeks	6-9-08	0.2	P		3N	60W
14	Meadow Springs	Meadow Springs Creek	6-15-08	116		6	3S	60W
15	Reservoir "A" of the Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	487	P	1-2-11	1S	60W
16	Reservoir "B" of the Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	714	P	2-35	1S-1N	60W
54	Reservoir "D" of the Bijou Valley Ditch and Reservoir System	Bijou Creek	9-1-08	253	P	13	1N	60W
17	Hopewell No. 2	West Bijou Creek	10-15-08	2700	P	23-14	3S	61W
6	New Kingsbury	Willow Gulch	5-2-09	536	P	17	6S	60W
21	Bramkamp Enl.	Deer Trail Creek	9-27-09	2066	P	31	2S	59W
68A	West Nile	Rock, Bijou, and Antelope Creeks	9-28-09		P		2N	60-61W
69	D.T. No. 1	Deer Trail Creek	12-21-09	138	P	17	1N	59W
69	D.T. No. 2	Deer Trail Creek	12-21-09	112	P	20	1N	59W
69	D.T. No. 3	Deer Trail Creek	12-21-09	125	P	20	1N	59W

APPENDIX B (continued)

SURFACE WATER DECREES IN STUDY AREA

RESERVOIR DECREES

Priority			Decree				Location	
No.	Name of Reservoir	Source of Supply	Date	(ac-ft)*		S	T	R
		BIJOU CREEK BASIN						
70	Base Line Enl.	Deer Trail Creek	1-20-10	167	P	5-32	1S-1N	59W
22	Supplemental	Deer Trail Creek	4-24-10	57	P	5-8	1S	59W
23	Noonen No. 2 Enl.	Deer Trail Creek	3-26-12	3445	P	11	4S	59W
24	Noonen Seepage	Deer Trail Creek	5-1-12	176	P	33	3S	59W

* P denotes Provisional Decree

APPENDIX C. SAMPLE OF COMPUTER OUTPUT FOR PUMPING CALCULATION

	LOCATION											MONTHLY VOLUME PUMPED											
HOOKUP NO	TNSH	RNG	SEC	QTR	YEAR	BASIN	COUNTY	EFF	CAPAC	WLEV	DDN	JFM	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT VOL	HEAD
81 6190	N03	61	36	04	1963	KIOWAC	WELD	60	145	50	041	0000	0000	0799	0570	0815	0669	0447	0616	0000	0000	03916	091
81 6191	N03	61	36	26	1963	KIOWAC	WELD	60	180	59	051	0000	0000	0717	0556	0603	0473	0277	0308	0000	0000	02934	110
81 6192	N03	61	36	27	1963	KIOWAC	WELD	57	090	34	025	0000	0000	0000	0000	0000	0907	0653	0542	0000	0000	02102	059
8437861	N03	61	36	52	1963	KIOWAC	WELD	60	160	44	045	0000	0000	0203	0687	0749	0749	0282	0109	0000	0013	02792	089
8437860	N03	61	36	77	1963	KIOWAC	WELD	57	100	45	028	0000	0000	0492	0670	0874	0786	0234	0130	0000	0024	03210	073
8437862	N03	61	36	78	1963	KIOWAC	WELD	60	150	44	042	0000	0000	0232	0390	0750	0728	0025	0050	0000	0070	02245	086
865096101	N02	60	04	28	1963	KIOWAC	MORGAN	37	030	78	008	0000	0000	0429	0261	0253	0162	0185	0130	0000	0001	01421	086
8650961	N02	60	04	26	1963	KIOWAC	MORGAN	37	030	78	008	0000	0000	0468	0277	0271	0174	0188	0115	0000	0000	01493	086
81 544	N02	60	06	51	1963	KIOWAC	MORGAN	37	040	64	011	0000	0000	0745	0424	0600	0479	0304	0065	0000	0201	02818	075
8866181	N02	60	06	77	1963	KIOWAC	MORGAN	57	090	50	025	0000	0000	1002	0670	1374	1105	0461	0069	0000	0102	04783	075
81 543	N02	60	06	78	1963	KIOWAC	MORGAN	57	100	44	028	0000	0000	1821	1567	1349	1096	0572	0000	0000	0000	06405	072
8541081	N02	60	10	52	1963	KIOWAC	MORGAN	20	025	71	007	0000	0000	0309	0323	0265	0191	0111	0010	0000	0000	01209	076
8541082	N02	60	10	53	1963	KIOWAC	MORGAN	37	035	82	010	0000	0000	0134	0109	0099	0069	0044	0009	0000	0000	00464	092
8541083	N02	60	10	54	1963	KIOWAC	MORGAN	37	035	72	010	0000	0000	0376	0256	0226	0156	0106	0023	0000	0000	01143	082
8541089	N02	60	10	55	1963	KIOWAC	MORGAN	20	015	74	004	0000	0000	0000	0072	0070	0047	0020	0007	0000	0000	00216	078
81 3331	N02	60	11	27	1963	KIOWAC	MORGAN	50	060	82	017	0000	0000	0867	0525	0556	0493	0429	0104	0000	0000	02974	099
81 3334	N02	60	11	29	1963	KIOWAC	MORGAN	57	100	80	028	0000	0000	1070	0571	0638	0565	0543	0148	0000	0000	03535	108
8648453	N02	60	12	27	1963	KIOWAC	MORGAN	50	065	68	018	0000	0000	1027	0216	0566	0377	0449	0157	0000	0000	02792	086
8435990	N02	60	13	52	1963	KIOWAC	MORGAN	50	060	86	017	0000	0000	0457	0307	0225	0224	0383	0160	0000	0000	01756	103
8435991	N02	60	13	53	1963	KIOWAC	MORGAN	50	060	90	017	0000	0000	0652	0366	0347	0296	0321	0072	0000	0000	02054	107
8435992	N02	60	13	54	1963	KIOWAC	MORGAN	57	080	93	022	0000	0000	0485	0334	0237	0233	0300	0127	0000	0000	01716	115
8435993	N02	60	13	55	1963	KIOWAC	MORGAN	57	080	89	022	0000	0000	0759	0589	0537	0593	0583	0129	0000	0000	03190	111
81 3332	N02	60	14	27	1963	KIOWAC	MORGAN	37	040	95	011	0000	0000	0391	0220	0214	0140	0160	0049	0000	0000	01174	106
81 3335	N02	60	14	28	1963	KIOWAC	MORGAN	57	080	88	022	0000	0000	1032	0531	0534	0399	0538	0111	0000	0000	03145	110
81 3330	N02	60	35	53	1963	KIOWAC	MORGAN	20	015	75	004	0000	0000	0644	0274	0390	0345	0396	0130	0000	0000	02179	079
8328657	N02	61	02	01	1963	KIOWAC	WELD	57	100	35	028	0030	0000	1238	0751	0972	0924	0969	0326	0000	0029	05239	063
8328658	N02	61	02	51	1963	KIOWAC	WELD	57	100	43	028	0009	0000	1676	1090	1048	0653	0990	0517	0000	0006	05989	071
8328656	N02	61	02	52	1963	KIOWAC	WELD	57	100	46	028	0000	0000	1315	1360	1311	0819	0741	0615	0000	0006	06167	074
8328659	N02	61	02	53	1963	KIOWAC	WELD	57	100	39	028	0000	0000	1355	1303	1136	1170	1027	0563	0000	0007	06561	067
8328660	N02	61	02	54	1963	KIOWAC	WELD	37	050	37	014	0000	0000	0463	0654	0658	0428	0383	0213	0000	0004	02803	051
8328661	N02	61	02	55	1963	KIOWAC	WELD	57	080	64	022	0000	0000	0717	0790	0747	0480	0722	0369	0000	0004	03829	086
8544170	N02	61	10	26	1963	KIOWAC	WELD	57	090	33	025	0000	0000	0442	0066	0697	1279	0700	0212	0000	0000	03396	058

Note: Multiply CAPAC by 10 to obtain reported discharge.
Multiply volumes pumped by 10^{-1} to obtain actual volumes.

APPENDIX D

LIST OF GROUND WATER USERS IN EXCESS OF FIFTEEN YEARS

Register No.	Name	Location QT	QT	S	T	R	Year of First Use	Average Annual Volume (ac-ft)	Use
20958	Habel, Walter G.	SW	NW	26	2S	62W	1912	117	Irr.
00461	Tuxhorn, Ed H.	SW	NW	4	4S	61W	1924	73	Irr.
10464	Nesom, Harry, Jr.	SE	SE	26	1S	60W	1930	117	Irr.
04582	Morse, Alice	SW	SE	32	2N	61W	1932	117	Irr.
06680	Young, Wiltis I.	SE	NE	9	2S	62W	1932	88	Irr.
06646	Nordloh, Chas. B.	SW	SE	22	1S	62W	1932	80	Irr.
12113	Loose, Albert	SE	SE	21	3N	60W	1934	190	Irr.
00931	Wahl, William F.	SW	SE	7	1N	61W	1934	263	Irr.
06225	Rossman, Clarence E.	SE	NE	28	3N	60W	1934	102	Irr.
06178	Parr, Esta D.	SE	SE	9	3N	60W	1934	226	Irr.
20958	Habel, Walter G.	SE	SE	26	2S	62W	1935	128	Irr.
06361	Harshman, Floyd	SW	SE	2	1N	60W	1935	109	Irr.
04422	Holden, B.A.	SW	SW	22	3N	60W	1935	182	Irr.
06972	Schlidt, George	SW	SW	5	1N	61W	1935	365	Irr.
14331	Westoff, Vernon	SE	NW	11	2N	61W	1935	131	Irr.
12114	Loose, Arnold W.	SW	SE	21	3N	60W	1935	102	Irr.
08604	Hanson, Henning	SE	NE	29	3N	60W	1935	117	Irr.
04420	James, Harry	SE	SW	18	3N	60W	1935	161	Irr.
04574	Bradbury, Tom O.	NW	NW	33	4S	61W	1935	88	Irr.
10465	Nesom, Harry, Jr.	SE	SE	26	1S	60W	1935	131	Irr.
10863	Nordloh, John H.	SE	SW	34	1S	62W	1935	29	Irr.
13331	Baughman, John W.	SW	SE	27	1S	62W	1935	175	Irr.
13332	Baughman, John W.	SE	SW	27	1S	62W	1935	292	Irr.
01798	Baer, R. A.	SE	SE	14	2N	60W	1936	73	Irr.
01796	Baer, Robert A.	SE	SE	26	2N	60W	1936	175	Irr.
00768	Reck, Herta, et. al.	SE	SE	33	3N	60W	1936	190	Irr.
01659	Rosener, Carl	SW	SE	7	1N	59W	1936	175	Irr.
12717	Lapp, Jacob, Jr.	SW	NW	14	1N	60W	1936	124	Irr.
06384	Shaklee, Orville	SW	SE	35	1N	62W	1936	88	Irr.
13148	Keifer, Ruth M., Mrs.	SE	SE	10	1S	60W	1936	131	Irr.
10564	Miller, Phillip	SW	SE	7	2N	59W	1936	88	Irr.
13335	Baughman, John W.	SE	SW	3	3S	62W	1936	109	Irr.
13333	Baughman, John W.	SW	SW	31	1S	60W	1936	109	Irr.
13334	Baughman, John W.	SW	SW	31	1S	60W	1936	109	Irr.
10467	Nesom, Harry, Jr.	SE	NW	26	1S	60W	1936	146	Irr.
06644	Nordloh, Chas. B.	SW	SE	22	1S	62W	1936	66	Irr.
10864	Nordloh, John H.	SE	SE	34	1S	62W	1936	88	Irr.
10578	Viets, Frank G.	SW	SW	25	2N	60W	1936	175	Irr.
08732	Sirios, Louis N.	SW	SW	32	2N	61W	1937	161	Irr.
15329	Nichols, Floyd	SW	SW	26	2N	60W	1937	44	Irr.
11385	Loose, Robert	SW	NW	36	3N	61W	1937	204	Irr.
01418	Kennish, Wm., Sr.	SW	NE	22	3N	60W	1937	204	Irr.
10283	Mate, Edna I.	SE	NE	9	3N	60W	1937	204	Irr.
06167	Busch, Louise, W.	SW	SW	10	3N	60W	1937	182	Irr.
06811	Flack, C.H.	NE	SE	22	6S	59W	1937	146	Irr.
06812	Flack, C.H.	SE	SE	22	6S	59W	1937	146	Irr.
10299	Friehauf, Jake	SW	NW	36	2N	60W	1937	161	Irr.
10496	Herbst, Henry W.	NW	SE	29	3N	60W	1937	117	Irr.
05829	Cook, Carl	SE	SW	18	2N	59W	1937	161	Irr.
08316	Rosener, Maurice	SE	SE	17	1N	59W	1937	262	Irr.
00431	Weimer, Adam	SE	NW	22	3N	60W	1937	248	Irr.
13466	Hart, J. A.	SW	NW	34	4S	62W	1937	44	Irr.
05829	Cook, Hilda	SE	SW	18	2N	59W	1937	161	Irr.
05983	Schlagel, John	SE	NW	10	3N	60W	1937	204	Irr.

APPENDIX D (continued)

LIST OF GROUND WATER USERS IN EXCESS OF FIFTEEN YEARS

Register No.	Name	Location QT	QT	S	T	R	Year of First Use	Average Annual Volume (ac-ft)	Use
08774	Seader, George	SE	SE	13	2N	60W	1937	175	Irr.
05904	Shelton, Elbert R.	NE	NE	7	1N	61W	1937	175	Irr.
14996	Bigler, Robert H.	NE	NE	20	3N	60W	1937	365	Irr.
11386	Loose, Robert	NW	SW	36	3N	61W	1938	219	Irr.
08795	Westoff, Vernon	SW	NE	11	2N	61W	1938	146	Irr.
12201	Allmer, Jake A.	SW	NE	14	1N	60W	1938	58	Irr.
10179	Flader Land Company	SW	SW	18	3S	60W	1938	80	Irr.
07323	Bernhardt, Jacob J.	NW	NE	36	3N	61W	1938	292	Irr.
11518	Lohman and Johnson	SW	NW	22	1N	60W	1938	117	Irr.
08309	Epple and Weigele	SW	SW	11	2N	61W	1938	161	Irr.
00435	Weimer, Adam	SE	SW	15	3N	60W	1938	248	Irr.
06251	Baumgartner, Dave	SW	SE	27	1N	60W	1938	175	Irr.
04585	Richardson, William E.	SW	SW	20	2N	59W	1938	131	Irr.
06645	Nordloh, Chas. B.	SE	SW	22	1S	62W	1938	66	Irr.
06647	Nordloh, Chas. B.	NW	SE	22	1S	62W	1938	117	Irr.
00435	Weimer, Esther	SE	SW	15	3N	60W	1938	248	Irr.
08539	Wells, Paul	SW	SW	26	1N	60W	1939	146	Irr.
01253	McConnell, R.K.	SW	SE	1	1N	60W	1939	161	Irr.
10332	Rohn, Henry	SW	NW	13	1N	60W	1940	234	Irr.
10329	Rohn, Jake, Jr.	SW	NW	18	2N	59W	1940	146	Irr.
08625	Hlad, Charles	SW	SE	5	1N	61W	1940	146	Irr.
12115	Loose, Arnold W.	NW	NE	21	3N	60W	1940	197	Irr.
10974	Colorado Hog Co.	SW	NW	23	1N	60W	1940	73	Irr.
06188	Gilliland, R.C.	SE	SW	10	3N	60W	1940	182	Irr.
08201	Wekesser, Alex	SW	SW	11	1N	60W	1940	131	Irr.
12346	Leasure Brothers	SW	SW	25	1S	60W	1940	204	Irr.
11519	Lohman and Johnson	SW	NW	22	1N	60W	1940	117	Irr.
05959	Wathen, L. A.	NW	SW	31	3N	60W	1940	263	Irr.
06100	Augustine, Howard P.	SW	NW	27	1N	60W	1940	66	Irr.
01422	Clough, Albert C.	SW	SW	24	2N	60W	1940	175	Irr.
14614	Feldmann, R.R.	SW	NW	31	1S	59W	1940	51	Irr.
19708	Weibert, Emanuel	SW	SW	4	1S	60W	1941	102	Irr.
12431	Johnson, Aaron	NW	NE	34	1N	60W	1941	44	Irr.
12432	Johnson, Aaron J.	SW	NE	34	1N	60W	1941	88	Irr.
07085	Richardson, Dale	SW	SW	29	2N	59W	1941	124	Irr.
01658	Rosener, Carl	NW	NW	19	1N	59W	1941	187	Irr.
12116	Bigler, Harry W.	SE	SW	21	3N	60W	1941	219	Irr.
10337	Rohn, Katherine	SW	NW	6	1N	59W	1941	117	Irr.
19622	Holmquist, Anna J.	NW	SE	29	4S	61W	1941	82	Irr.
19622	Holmquist, Anna J.	NW	SE	29	4S	61W	1941	44	Irr.
00522	Christensen, Roy	NW	NW	32	8S	63W	1941	88	Irr.
19921	Hepperly, A.K.	SE	SW	25	3N	60W	1941	121	Irr.
06364	Harshman, Floyd	SW	SE	11	1N	60W	1941	124	Irr.
00834	English, Lester A.	SE	SW	20	3N	60W	1941	183	Irr.
11925	Harshman, Lillie	SW	NE	25	3N	60W	1941	183	Irr.
00763	Nix, J. H.	SW	SE	24	3N	60W	1941	117	Irr.
11377	Alkire, Forrest S.	SW	SE	6	2N	60W	1942	160	Irr.
11376	Alkire, Forrest S.	SW	NW	6	2N	60W	1942	175	Irr.
08503	Yeager, Albert	SW	SW	20	1S	60W	1942	80	Irr.
06358	Harshman, Seth	SW	SE	36	2N	60W	1942	102	Irr.
10333	Rohn, Raymond	SE	SW	13	1N	60W	1942	44	Irr.
06959	Sanden, Carl	SE	SW	17	1S	60W	1942	146	Irr.
06048	Linderholm and Son	SW	NE	7	2N	59W	1942	234	Irr.
08243	Meier, John, Jr.	SW	NE	1	2N	60W	1942	161	Irr.

APPENDIX D (continued)

LIST OF GROUND WATER USERS IN EXCESS OF FIFTEEN YEARS

Register No.	Name	Location					Year of First Use	Average Annual Volume (ac-ft)	Use
		QT	QT	S	T	R			
13157	Rosener, Mary E.	SW	SW	11	3N	60W	1942	146	Irr.
19534	Watson, Edgar H.	SE	SE	33	1N	60W	1942	104	Irr.
10592	Musgrave, James T.	SW	SW	2	1S	60W	1942	175	Irr.
08230	Lee, Elmer J., Dr.	SW	SW	13	2N	60W	1942	175	Irr.
01254	McConnell, R.K.	SW	SE	1	1N	60W	1942	117	Irr.
08645	Neb, Dave G.	SW	SE	16	3N	60W	1942	234	Irr.
14998	Howell, Kirk	SW	SW	26	3N	60W	1943	248	Irr.
19708	Weibert, Emanuel	NE	SW	4	1S	60W	1943	131	Irr.
06359	Harshman, Seth	NW	SW	36	2N	60W	1943	117	Irr.
08541	Wells, Paul	SW	NW	34	1N	60W	1943	44	Irr.
07322	Bernhardt, Jacob J.	SW	NE	36	3N	61W	1943	146	Irr.
12365	Roark, C.M.	SW	NE	14	1S	60W	1943	146	Irr.
01663	Ewertz, Joseph	SW	SW	35	2N	60W	1943	146	Irr.
00766	Reck Herta et.al.	SE	SE	4	2N	60W	1943	161	Irr.
06719	Parr, Esta D.	NE	SW	9	3N	60W	1943	204	Irr.
01883	Kerksick, Wm. J.	NW	SW	23	1S	62W	1943	117	Irr.
14615	Feldman, R.R.	SW	NW	31	1S	59W	1943	109	Irr.
00835	English, L. A.	NW	SE	20	3N	60W	1944	219	Irr.
14623	Hogan, Anna B., Mrs.	SW	SW	12	1N	60W	1944	131	Irr.
15467	Templin J. Laten	SW	NW	12	1N	60W	1944	44	Irr.
00684	Herzman, Carl W., et. al.	SW	NW	5	1N	59W	1944	117	Irr.
08249	Kunce, Frank W.	SW	NE	9	1S	60W	1944	204	Irr.
11240	Rogers, G.J.	SW	NE	11	3N	60W	1944	117	Irr.
19535	Watson, Edgar H.	SW	NE	4	1S	60W	1944	117	Irr.
11672	Schmidt, Glen E.	SW	NW	8	1N	61W	1944	263	Irr.
10338	Rohn, Katherine	SE	NW	6	1N	59W	1944	102	Irr.
19167	Claycomb, M.F.	SE	SW	2	3S	61W	1944	175	Irr.
08540	Wells, Paul	SE	SE	27	1N	60W	1944	175	Irr.
01660	Rosener, Carl	SW	NW	7	1N	59W	1944	146	Irr.
08542	Wells, Paul	NW	NW	34	1N	60W	1944	117	Irr.
19163	Musgrave, Loyd	NW	SW	3	1S	60W	1944	175	Irr.
06960	Ehn, Delbert	SE	SW	17	1S	60W	1944	175	Irr.
10334	Rohn, Jake	NW	SE	13	1N	60W	1944	117	Irr.
08244	Meier, John, Jr.	SE	NW	1	2N	60W	1944	204	Irr.
12353	Meisner, Henry	SW	SW	10	2N	60W	1944	117	Irr.
00960	Engelbrecht, Ernest	SE	NE	33	3S	62W	1944	29	Irr.
10378	Weibert, Emanuel	SW	SW	33	1N	60W	1944	175	Irr.
06988	Kammerzell, George	SW	SE	31	2N	59W	1944	234	Irr.
06989	Kammerzell, George	SW	NE	31	2N	59W	1944	234	Irr.
06960	Sanden, Carl	SE	SW	17	1S	60W	1944	175	Irr.
00436	Weimer, Adam	SW	SE	15	3N	60W	1944	248	Irr.
07102	Richardson, Donald C.	SW	SE	30	2N	59W	1945	204	Irr.
10579	Viets, Frank G.	SE	SE	25	2N	60W	1945	248	Irr.
07337	Larsen, C.L.	SE	NE	20	2N	59W	1945	234	Irr.
08250	Kunce, Frank W.	SW	NW	9	1S	60W	1945	175	Irr.
19194	Reck, Mary L.	SW	SE	22	1N	60W	1945	131	Irr.
10330	Rohn Bros.	SW	SW	20	1N	59W	1945	117	Irr.
12704	Michaud, Victor J.	SW	NE	36	5S	62W	1945	73	Irr.
08246	Kunce, Frank	SE	NW	20	1S	60W	1945	146	Irr.
07319	Allen, Howard P.	SE	NE	35	2N	60W	1945	175	Irr.
15107	Greenwalt, Dan	NW	NW	26	2N	60W	1945	36	Irr.
15611	Sides, Clifton C.	SW	SE	5	3N	60W	1945	292	Irr.
10807	Hilbert, W.H.	SW	SE	19	1N	59W	1945	204	Irr.
00599	Willars, Cecil	SW	SW	24	3N	60W	1945	234	Irr.

APPENDIX D (continued)

LIST OF GROUND WATER USERS IN EXCESS OF FIFTEEN YEARS

Register No.	Name	Location					Year of First Use	Average Annual Volume (ac-ft)	Use
		QT	QT	S	T	R			
04586	Richardson, William E.	SW	NW	19	2N	59W	1945	175	Irr.
08399	Reed, Clarence E.	SE	NW	26	2N	60W	1945	146	Irr.
08424	Romero, Eufracio	SE	SW	6	1N	59W	1945	102	Irr.
08711	Lind, Ray	SW	NE	33	1N	60W	1946	175	Irr.
10580	Viets, Frank G.	SW	NE	25	2N	60W	1946	248	Irr.
07193	Richardson, Dale	SE	NW	29	2N	59W	1946	146	Irr.
05954	Dill, Ted	NE	SW	23	2S	60W	1946	219	Irr.
19708	Weibert, Emanuel	SE	SE	4	1S	60W	1946	146	Irr.
15330	Nichols, Floyd	SE	SW	26	2N	60W	1946	73	Irr.
01423	Clough, Albert C.	SW	SW	24	2N	60W	1946	175	Irr.
08605	Hanson, Henning	SE	NE	29	3N	60W	1946	146	Irr.
10491	Weller, Fred C.	SW	SE	1	2N	60W	1946	146	Irr.
08504	Yeager, Herman	SE	SW	20	1S	60W	1946	146	Irr.
11613	Harshman, Merrill D.	SW	NW	27	3N	60W	1946	161	Irr.
01825	Ewertz Brothers	NE	SE	34	2N	60W	1946	44	Irr.
01938	Kammerzell, Henry	SE	SW	13	3N	60W	1946	204	Irr.
06987	Kammerzell, Henry	SW	SW	30	2N	59W	1946	233	Irr.
13467	Hart, J. A.	SW	NW	34	4S	62W	1946	44	Irr.
08397	Causey, Clifford	NE	SW	23	1S	60W	1946	190	Irr.
15612	Sides, Clifton C.	SW	SE	8	3N	60W	1946	292	Irr.
01669	Moore, G.W.	SW	SE	12	2N	60W	1946	197	Irr.
06984	Howell, Kirk	SW	SW	2	2N	61W	1946	233	Irr.
08202	Wekesser, Alex	SE	SW	11	1N	60W	1946	146	Irr.
12358	Judson, Carl J.	SE	NE	36	2N	60W	1947	233	Irr.
10565	Miller, Phillip	SW	NE	18	2N	59W	1947	175	Irr.
05982	Schlagel, John	SW	NE	10	3N	60W	1947	219	Irr.
07190	Lipe, T. E.	NW	NE	30	1N	59W	1947	175	Irr.
12893	Midcap, F.C.	NE	SW	27	2N	60W	1947	58	Irr.
19534	Watson, Edgar H.	SW	SE	33	1N	60W	1947	55	Irr.
14644	White, Clifford M.	SW	NE	26	2N	60W	1947	131	Irr.
06270	Busch, Louise W.	SE	NW	15	3N	60W	1947	146	Irr.
14624	Hogan, Anna B., Mrs.	SE	SW	12	1N	60W	1947	131	Irr.
08247	Kunce and Huffsmith	SW	NW	20	1S	60W	1947	146	Irr.
15468	Templin, J. Laten	SE	NE	11	1N	60W	1947	175	Irr.
19621	Holmquist, Paul	SW	SW	6	2S	60W	1947	71	Irr.
08312	Currier, Asa	NE	SW	35	1S	60W	1947	234	Irr.
08735	Brown, Odis	SW	NW	25	2N	60W	1947	117	Irr.
01826	Ewertz Brothers	SE	NW	34	2N	60W	1947	117	Irr.
15613	Sides, Clifton C.	SW	NE	5	3N	60W	1947	219	Irr.
06000	Lebsock, J.J.	SW	SE	23	3N	60W	1947	175	Irr.
13158	Rosener, Mary E.	NW	SW	11	3N	60W	1947	161	Irr.
06252	Baumgartner, Jake	NW	SE	27	1N	60W	1947	117	Irr.
04587	Richardson, William E.	SE	SW	20	2N	59W	1947	161	Irr.
15614	Sides, Clifton C.	SW	NE	8	3N	60W	1947	219	Irr.
09683	Ford, John	SW	SW	22	2S	60W	1947	161	Irr.
08425	Romero, Eufracio	SW	SW	6	1N	59W	1947	88	Irr.
08251	Kunce, Frank W.	NE	SW	9	1S	60W	1948	263	Irr.
12894	Midcap, Fred H.	NE	SW	27	2N	60W	1948	58	Irr.
12202	Allmer, Jake A.	SE	NE	14	1N	60W	1948	109	Irr.
10566	Miller, Phillip	NW	NE	18	2N	59W	1948	175	Irr.
10335	Rohn, Katherine	NE	SW	13	1N	60W	1948	102	Irr.
10861	Nordloh, John H.	SE	SE	34	1S	62W	1948	44	Irr.
10865	Nordloh, John H., Jr.	SW	SE	34	1S	62W	1948	44	Irr.
01255	McConnell, R.K.	SE	SE	1	1N	60W	1948	117	Irr.

APPENDIX D (continued)

LIST OF GROUND WATER USERS IN EXCESS OF FIFTEEN YEARS

Register No.	Name	Location					Year of First Use	Average Annual Volume (ac-ft)	Use
		QT	QT	S	T	R			
13756	Gartrell, Harry	SW	SW	3	2N	60W	1948	117	Irr.
13134	Hicks, Alta E.	SE	NW	28	3S	61W	1948	51	Irr.
19621	Holmquist, Paul	SE	SW	1	2S	61W	1948	62	Irr.
10753	Kimzey Brothers	SW	NE	31	8S	63W	1948	33	Irr.
06226	Rossman, Clarence E.	SE	NE	28	3N	60W	1948	66	Irr.
01673	Penfold, Jess M.	SW	SW	7	2N	59W	1948	234	Irr.
00155	Crandall, A.E.	SW	NW	33	1N	60W	1948	117	Irr.
06990	Kammerzell, George	SW	SW	31	2N	59W	1948	234	Irr.
14517	Benzel. C.R.	SE	SW	36	3N	60W	1948	190	Irr.
08231	Lee, Elmer J., Dr.	NW	SW	13	2N	60W	1948	175	Irr.
01797	Baer, Robert A.	SE	SE	11	2N	60W	1949	131	Irr.
07321	Bernhardt, Lovie B.	NW	SE	36	3N	61W	1949	153	Irr.
06363	Harshman, Floyd	SE	SE	35	2N	60W	1949	66	Irr.
13135	Hicks, Alta E.	NE	SW	28	3S	61W	1949	51	Irr.
06362	Harshman, Floyd	SW	SE	2	1N	60W	1949	109	Irr.
10497	Herbst, Henry W.	NE	SE	29	3N	60W	1949	175	Irr.
08449	Anderson, Earl	SW	SE	5	1S	60W	1949	88	Irr.
08450	Anderson, Earl	SE	SE	5	1S	60W	1949	58	Irr.
01664	Ewertz, Joseph	SE	SW	35	2N	60W	1949	88	Irr.
08401	Lasswell, Ella R., Mrs.	SE	SE	23	2N	60W	1949	146	Irr.

PLATE I BEDROCK CONTOUR

CIVIL ENGINEERING SECTION
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO
OCTOBER 15, 1965

BEDROCK CONTOUR MAP
KIOWA - BIJOU CREEK BASINS, COLORADO

PLATE 2 SATURATED THICKNESS

CIVIL ENGINEERING SECTION
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO
OCTOBER 15, 1965

MAP OF WATER TABLE CONTOURS & SATURATED THICKNESS – SUMMER 1965
KIOWA – BIJOU CREEK BASINS, COLORADO

PLATE 3 WELL LOCATIONS

CIVIL ENGINEERING SECTION
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO
OCTOBER 15, 1965

LOCATION MAP & REPORTED CAPACITIES FOR IRRIGATION AND MUNICIPAL WELLS

KIOWA – BIJOU CREEK BASINS, COLORADO