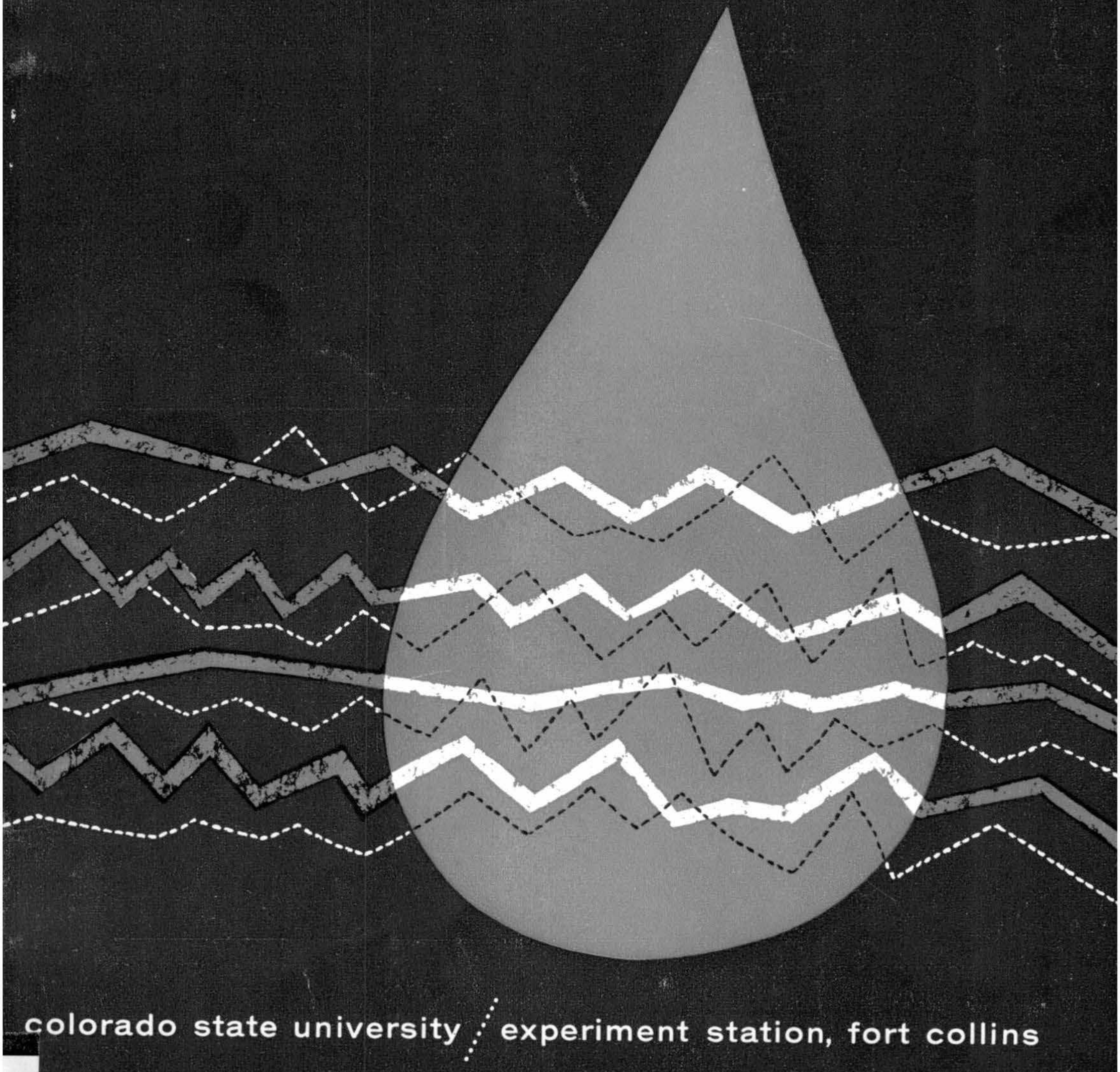
WATER TABLE FLUCTUATIONS

BULLETIN 500-S

in eastern colorado



colorado state university / experiment station, fort collins

Contents

A large part of the work in gathering data for this publication was done in cooperation with the Western Soil and Water Management Research Branch, Agricultural Research Service, U. S. Department of Agriculture.

FORT COLLINS, COLORADO AUGUST 1958

4M—8-58

WATER TABLE FLUCTUATIONS

in Eastern Colorado

W. E. CODE[1]

In 1929 a program was initiated by the Colorado Agricultural Experiment Station to determine changes in the water table in certain areas in Colorado where pumping for irrigation was important. Representative wells were chosen in these areas where it was possible to measure to the water surface with a steel tape. Other wells were added to the network as pumping expanded into new areas. In addition to the steel tape measurements, continuous records are being obtained by means of recording instruments on four wells in the South Platte basin.

Experiment Station Ground Water Investigations

A ground-water use survey was made by the Experiment Station in the South Platte Valley in 1940 and 1941. In this report[2] water-table fluctuations were shown for a large number of observation wells previous to 1942. Also shown are growth charts and tables on power demand translated into acre feet. In 1942 and 1943 a detailed study was made of the ground-water supply of Prospect Valley[3]. This report contains hydro-

[1] Irrigation Engineer, Experiment Station, Colorado State University.

[2] Code, W. E. *Use of Ground Water for Irrigation in the South Platte Valley of Colorado.* Bul. 483, Colorado State University, 1943.

[3] Code, W. E. *Ground Water Supply of Prospect Valley, Colorado.* Tech. Bul. 34, Colorado State University, 1945.

graphs of water table conditions for that area through 1944. A reconnaissance type ground-water survey was made in 1945 in Big Sandy Valley[4].

Investigations by the U. S. Geological Survey

A cooperative agreement between the Ground Water Branch of the U. S. Geological Survey and the state of Colorado was entered into in 1945. Reports on Big Sandy Valley in Elbert and El Paso counties[5] and on Baca County[6] have been published. Reports on Huerfano, Kit Carson counties and the Grand Junction artesian area have been completed but not published. Several other small area studies have been made.

In cooperation with the state and the U. S. Bureau of Reclamation, the Geological Survey has conducted investigations at various times in the San Luis Valley. As part of the Missouri Basin program, surveys have been made in the High Plains area drained by the Republican River and Frenchman Creek. This program also included a study of the South Platte Valley below Hardin in 1949. A printed report on this area is expected in 1958.

As a result of the work being done by the Survey, certain parts of the information here presented have been furnished by that agency. This is particularly true of measurements made in the South Platte Valley below Hardin since 1947.

Ground-Water Hydrology

Hydrologists divide ground water recoverable by means of wells into two types according to occurrence—confined and unconfined. Often these terms are referred to as artesian and water-table conditions. Confined water, as the term signifies, is water under pressure moving through an aquifer, often sandstone which is bounded both above and below by dense rocks such as shale, lava or clay. The source of supply at the outcrop may be many miles from the point of use. Unconfined water is characterized by a water table which is the level at which water stands in a well drilled into the formation. The source of such water may be very close at hand. The data and discussion in this bulletin deal only with unconfined water.

[4] Code, W. E. *Report on Ground Water for Irrigation in Big Sandy Valley, Colorado.* Miscellaneous Series Paper 282, Colorado State University, 1945 (mimeograph).

[5] McLaughlin, T. G. *Geology and Ground-Water Resources of Parts of Lincoln, Elbert and El Paso Counties With Special References to Big Sandy Valley.* Bul. 1, 1946, Colorado Water Conservation Board.

[6] McLaughlin, T. G. *Geology and Ground-Water Resources of Baca County.* Bul. 2, 1954, Colorado Water Conservation Board.

There are two definite characters of unconfined ground water depending on the position of the water table with respect to a stream bed. When the water table is below the stream bed—the common arid climate condition—it is known as influent and when above the stream bed the ground water is referred to as effluent. The effluent type is characteristic of a humid climate and of an irrigated area where lost irrigation water appears as stream flow.

Conditions in an Arid Climate

The position of the water table in a desert or low rainfall region when not disturbed by man is the result of thousands of years of weather conditions. It is in essential equilibrium varying only seasonally or cyclically with minor precipitation changes.

When water is withdrawn for industrial, municipal or agricultural uses, the natural equilibrium is upset and the most frequent result is a lowering of the water table. Under some conditions a new equilibrium at a lower elevation may become established. This may come about by the salvaging of ground water through the water table dropping below the root zone of vegetation and elimination of evaporation from swamps and ponds. Or, the lowering of the water table may create a greater reservoir capacity for the absorption of losses from stream flow.

Except in rare instances of a closed basin, ground water is in motion horizontally. To be flowing, the water table must have a slope. The direction of the slope is generally with the surface of the land. Locally, however, it may deviate from this pattern because of a change in geology or a change in the character of the aquifer.

Direction of flow is discovered by means of field surveys. The elevation of the water table is determined at numerous places in wells and a map constructed on which water-table contours are plotted. The direction of flow is down the steepest slope at any point or at right angles to the contours. It may be found that the contours are much closer together in some places than in others. This may be due to a reduction in area of the aquifer or lower permeability.

Permeability is a term used in ground water hydrology that pertains to the ability of the materials to convey water. Clays have a very low value of permeability, fine sands a greater value, while fairly uniform gravel has a very high value of permeability.

The replenishment of ground water in a pumped area is composed of water moving in from adjacent areas, losses from stream flow, downward movement of moisture lost in irrigation, and precipitation on the area.

It is not unusual for those not acquainted with ground water hydraulics to consider that where ground water is flowing in a well defined valley, the principal supply to a pumped area is coming to it from upstream. This is only partially true. Because water moves very slowly under ground[7], it reacts to pumping very much as a surface reservoir — not as a stream. Water is being drawn from storage and the water table lowers. If a new plane of equilibrium is reached through the salvage of ground water, further lowering will cease. If this is not the case, then water will continue to be drawn from storage and the water table will continue to drop. Water coming in from upstream, ordinarily much less in quantity than usually conceived[8], will be offset by an equal amount escaping down stream. A source of replenishment close at hand must then be looked for.

Ground - water replenishment occurs in several ways. The most important source of new water to an area occurs within its borders from stream flow seepage losses. Initially a considerable amount of ground water will come in from adjacent areas but this will gradually diminish in volume with time. Well water lost from irrigation to the water table can be considered only as circulated water. Direct contributions from precipitation usually are very small. They are almost non-existent in an arid climate except in very sandy soils. Rains seldom wet the soil down more than five feet and this moisture can easily be used up by the vegetative cover. In the High Plains area, recharge from precipitation has been estimated at less than one-half inch annually and in the sand hills at about 1 inch. Since equilibrium is dependent on these conditions any ground water removed by wells is usually being taken from storage. A lowering of the water table will then occur as has been demonstrated many times in the arid west. The rate of lowering will be dependent upon the concentration of wells. In some places where wells are far apart, the effect will be so small as not to have an important effect.

A source of replenishment, so far not mentioned, is that of water spreading or sinking water artificially. A considerable success has been attained in southern California for many years in sinking flood waters in the coarse gravels at the mouths of canons. In the High Plains in Texas an effort is being made to sink water in wells drilled for that purpose in land-locked depressions.

In Colorado the only place where surplus water is being deliberately sunk is in Prospect Valley east of Hudson. Here, water is run into a very leaky,

---

[7] These velocities have been measured by C. S. Slichter and others and have been found to be usually less than ½ mile per year.

[8] For instance, calculations based on a commonly found permeability factor of 1,000 gallons per day per square foot, a valley aquifer 2 miles wide and having a saturated thickness of 50 feet and a water table slope of 20 feet to the mile, would convey a flow of about 1,400 gallons per minute. This could be diverted easily by just 2 irrigation wells.

abandoned reservoir with excellent results. Excessive storm waters are about the only waters not already appropriated that could be used in Colorado for this purpose. A serious difficulty that exists on most of our streams is that such water contains much mud in suspension and, in consequence, receiving areas would soon become sealed. Further, in the cases involving large streams, diversion costs ordinarily would be very high. The detention of storm waters in small tributary channels may have possibilities in sinking water locally and prolonging stream flow.

Conditions in a Humid Climate

In a humid climate, streams are perennial in nature. To be so, the low or base flow is furnished by ground water feeding into the stream. These are gaining streams in contrast to those in an arid climate that lose in volume. The water table must therefore be higher than the stream bed to provide escape conditions. Since generally in such a climate, the ground water is replenished by water moving downward through the soil from precipitation, the water table fluctuates seasonally with precipitation.

It is well known that the water table rises whenever irrigation from streams is a new factor in an area. The losses from canals, reservoirs and in the irrigation of crops bring about an imbalance from natural conditions. These then are replenishment factors. Frequently, as in the case in Colorado, the water table builds up higher than the stream beds and a condition arises closely resembling that of a humid climate. The term **return flow** is the one commonly used in connection with the escape of these excess waters back to a stream. In contrast with humid climate conditions, the water table fluctuates with the irrigation season, being highest at the end of the season.

When ground water is drawn upon as a supplemental supply in an already irrigated community, several things may happen. When the draft is moderate, the usual highs to which the water table might rise during the irrigation season are reduced. If the incoming surface supply is decidedly short, the rise may not occur at all and a lower than usual water table will occur the following spring. Should there be a succession of years of short water supply, there may be a definite declining tendency during such a period.

In general in Colorado, downward trends of the water table in pumping areas receiving surface supplies have been of a temporary nature. However, there are several small areas which have suffered a considerable lowering over 6- and 8-year periods.

Ground-Water Hydraulics

Because we are dealing with a commodity that we cannot see in action and many influencing factors of a variable nature are hidden from view, evaluation of quantities must be considered as reasonable approximation only in connection with ground-water surveys. Geologists, engineers and mathematicians have developed the science of ground-water hydraulics greatly in the last 40 years. Many tools have been provided that have reduced much of the guesswork of the 19th century.

Work in laboratories and in the field have helped immeasurably to understand how ground water reacts to certain natural or artificial influences. Without going into details, some idea will be given the reader of a few methods used by ground water men in solving problems. It should be mentioned, of course, that the accuracy in evaluating factors is quite dependent on the thoroughness of investigations. Thus, in many instances, the availability of funds for the work could very well influence the results.

The factor of permeability has been mentioned previously. More specifically, as used by the U. S. Geological Survey, it has been given the numerical value of the number of gallons per day passing through a square foot of formation under a 100 percent gradient. For field use, its equivalent value, the number of gallons per day passing at right angles through a section of formation one mile long and one foot wide under a gradient of one foot per mile, is used. The temperature in either expression is to be adjusted to 60° Fahrenheit.

Permeability may be found in the laboratory by passing water through a sample of the formation. This method is subject to considerable error in that the sample as taken from a well is a mixture of material and when put into a cylinder for testing the particle arrangement is nothing like that in nature. Further, the sample is but a minute part of a very large volume on which information is wanted.

A much better evaluation can be made in the field by a well test. A well test provides a permeability evaluation over a considerable volume of materials. It also tests the formation in a horizontal direction, which is the natural condition of flow. In this, a well is pumped continuously at constant discharge for from 3 to perhaps 7 days. During the test, the drawdown within the cone of influence (see Figure 1) is measured in 2 or more observation wells. By a somewhat involved but mathematically correct procedure, a value of permeability is obtained from the data.

If a well test is continued long enough, another factor—storage coefficient — can be obtained.

The storage coefficient is the ratio of the amount of water that will drain out of a sample of formation by gravity to the volume of the sample. Its value seldom exceeds 0.3 (30 percent).

Fortified with a knowledge of these factors and knowing the geologic character of the formations through logs of existing wells or from exploration holes, other items can be evaluated. One important item is that of the total amount of water moving underground down a valley or past any cross-section. The only additional information needed in this is the slope of the water table. Another item—one determined from the storage coefficient—is the total amount of water in storage under a given surface area. Now with the help of these pieces of information, even though subject to error, and a record of water table fluctuations, the hydrologist has a fair picture of the underground conditions and some idea of what the future might hold.

There are still some unknowns that may or may not be anticipated in the evaluation of a ground water supply for development. We do not know, for instance, just how a ground water basin will react to pumping, especially by water coming in from the boundaries when the water table is lowered. Another unknown is the amount of water that is lost in ditches and

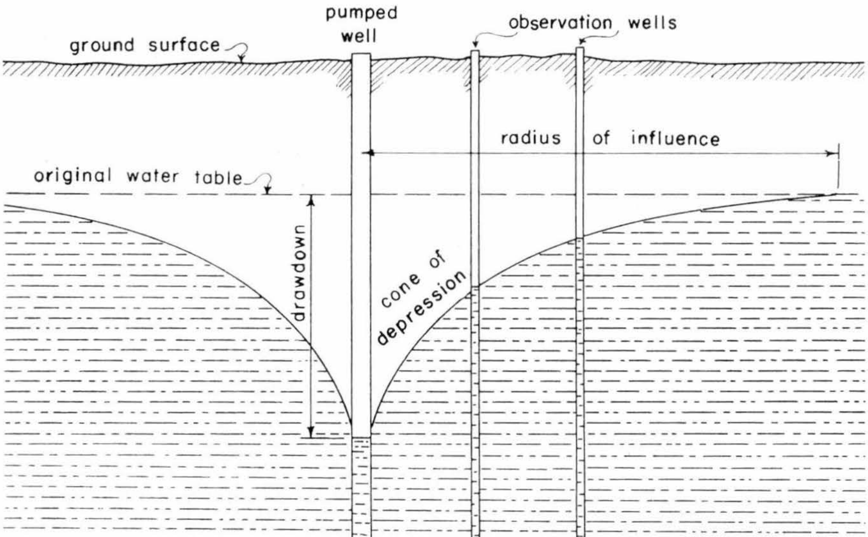


Figure 1. Idealized position of the water table surrounding a well being pumped. The shape is determined from measurements in the observation wells.

that escaping beyond the plant roots in irrigating. Predictions, therefore, cannot be made with high accuracy. It is unfortunate that at present proof must come about by observing the effects of pumping on the water table. Observation wells with long records are necessary to establish the facts. It may take a number of years before an idea can be formed as to the adequacy of a supply. It is, therefore, very desirable that a basin be developed slowly so that there will be time to obtain measurements of the effects of current withdrawals.

Water Table Fluctuations

The patterns of movements in the water table have great significance to ground-water hydrologists. They reflect the many external influences that may be present. To one familiar with the subject, these patterns have definite meanings. One would expect, for instance, that the water table near a stream would fluctuate very little because of the stabilizing effect of the stream. At greater distances and where surface water is being applied, the annual fluctuations could be expected to be greater.

The normal pattern of water table fluctuation in an area served by canals is that of a low point occurring before irrigation starts. This is caused by a gradual draining out of ground water to the river. Very quickly after water comes into the canals, the water table starts to rise and reaches its maximum at about the end of the irrigating season. The extent of rise will depend on the extent of the surface water supply and the amount of pumping. The volume of pumped water may be so great in a season of short water supply that there would be no seasonal rise. A succession of years of subnormal precipitation would result in a downward trend in the water table. Conversely, above normal water tables can occur. That these changes can take place in a short space of time can be observed in a study of the graphs for such areas. On Plate 3 is shown the water supply from the Cache la Poudre River. The rapid change in water table elevation in response to water supply is obvious. The annual pumping draft has a fair relationship to the amount of electric power used. The relationship from year to year cannot be considered accurate because of the steady conversion from engines to electric power in the earlier years.

The amount of power used in the South Platte Valley and for the state is shown in Figure 2 and Table 1. One should examine both the character of the surface water supply and the extent of pumping in order to account for the water table changes that occur.

In areas where ground water

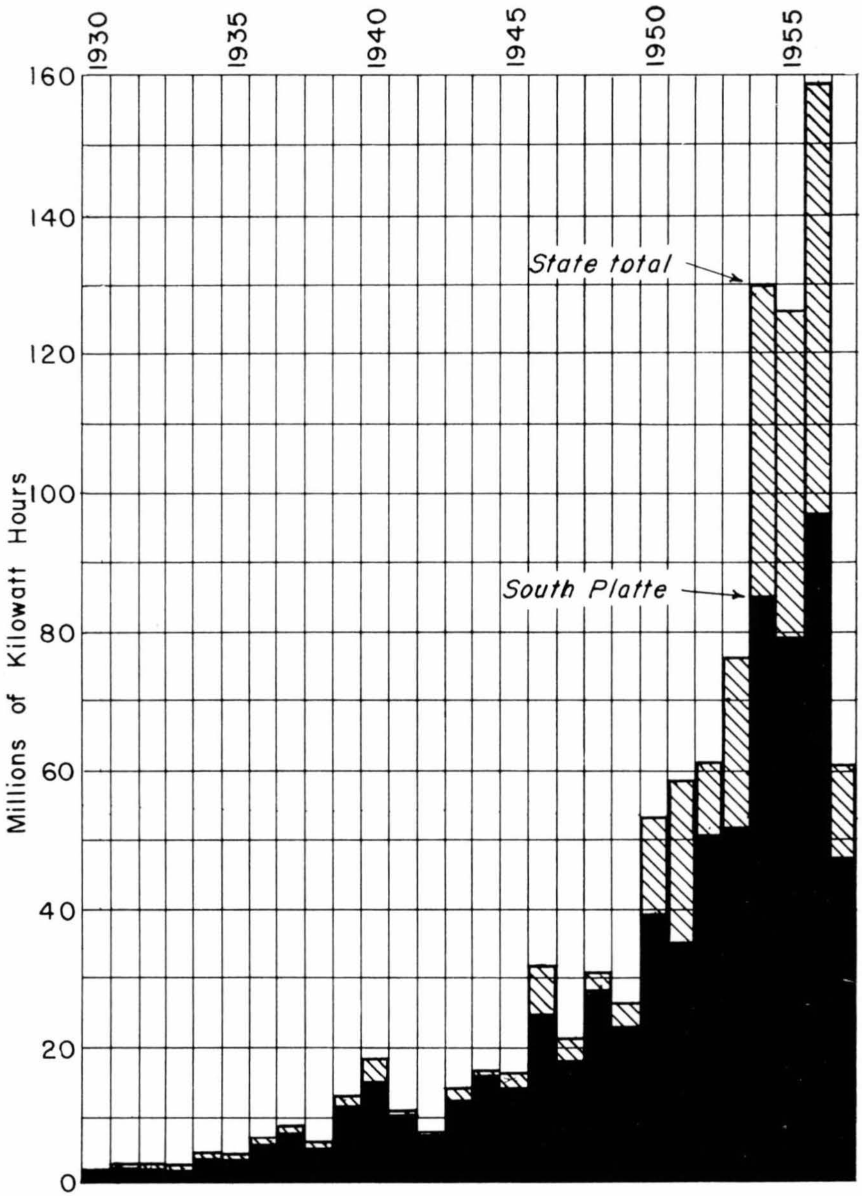


Figure 2. This graph shows the amount of electricity used by irrigation wells in the South Platte Valley and in Colorado as a whole.

Table 1. Use of Electric Power for Pumping Ground Water in Colorado.[1]

Year	Kilowatt Hours		Year	Kilowatt Hours	
	South Platte	State[2]		South Platte	State[2]
1930	1,700,000	2,200,000	1944	16,300,000	16,900,000
1931	2,100,000	2,730,000	1945	14,200,000	16,200,000
1932	2,100,000	2,660,000	1946	25,100,000	32,100,000
1933	1,730,000	2,350,000	1947	18,000,000	21,800,000
1934	3,810,000	4,500,000	1948	28,500,000	31,000,000
1935	3,560,000	4,280,000	1949	23,400,000	26,700,000
1936	5,650,000	6,270,000	1950	39,700,000	53,400,000
1937	7,820,000	8,970,000	1951	35,600,000	58,700,000
1938	5,210,000	6,000,000	1952	50,900,000	61,100,000
1939	11,600,000	13,200,000	1953	52,200,000	76,500,000
1940	15,200,000	18,600,000	1954	85,400,000	130,000,000
1941	10,500,000	11,000,000	1955	79,000,000	126,000,000
1942	7,650,000	7,980,000	1956	96,900,000	159,000,000
1943	12,400,000	14,200,000	1957	47,400,000	61,000,000

[1] From data supplied by utilities operating in the state which increased in number from 5 in 1930 to 15 in 1957. Figures are rounded to indicate probable accuracy.

[2] The total for the state is estimated in part through 1953.

is the sole source of supply a different pattern of water table fluctuation is to be found. Here the high point will be in the spring and lowest in the fall. This spring elevation is usually higher than that of the preceding fall. The reason for this is not entirely because a replenishment has taken place, but rather because of the readjustment that occurs during the winter. During the pumping season, a depression in the water table is created around a well which requires time to fill up and adjust itself to surrounding conditions. In an over-developed area, one where water is continually being removed from storage, each successive spring elevation will be lower than the preceding one. In view of this, the spring measurements ordinarily provide a better guide to the real change that has taken place.

The Water Table Fluctuations Program

On pages that follow are shown in hydrograph form the fluctuations of the water table in some 255 wells. It will be observed that there have been included records of considerable duration that are no longer current. A number of current records have not been included because of the very short period represented.

Ordinarily, measurements were made in the spring and fall or before and after the irrigation season. In the graphs, these points are connected with a solid line. Dotted lines are used to connect points not consecutive in time in the regular program. The measurements to the water table as shown are from the ground surface. Actually they are made from a definite point at the well opening which is referenced to the ground surface. The scale used is uniform throughout — 5 feet between lines.

Location of Observation Wells

A very large part of the observation wells are in the older irrigated areas receiving surface waters through canals. Ground water in these areas is used to supplement the basic supply. Most of the tributary valleys are underlain with sands and gravels containing ground water in economically recoverable quantities. These valleys are narrow, contain a normally dry stream bed and for the most part do not receive water from a canal system. The irrigation wells and therefore the observation wells are confined to these valleys. For the purpose of portraying natural conditions, graphs of a few wells outside the pumping and irrigated areas are shown.

In general the graphs are arranged in downstream order of the main drainage. At proper points, the groups along the tributaries are inserted. Where wells in the tributaries merge with those along the main stem, an arbitrary boundary is chosen.

Identification of Wells

The system of well identification used by the Ground Water Branch of the U. S. Geological Survey consisting of a series of letters and numbers has been adopted in this bulletin. It may appear complicated, but a little study on the part of the reader will make it possible to quickly locate a well. One should, of course, be conversant with land location nomenclature.

Since the material in this bulletin covers the eastern part of the state only, initial letter designations apply only to regions north and south of the base line. This line follows the 40th parallel, which is about 12 miles north of Denver. The area north of the base line is designated by the B symbol and that to the south the C symbol. The first number is the range north or south of the base line, the second the township west of the sixth principal meridian. The third number is the section number and the letters following designate the quarter-quarter section in the manner shown in Figure 3. Thus, a well with the designation of B 7-65-12cd would be in the southeast quarter of the

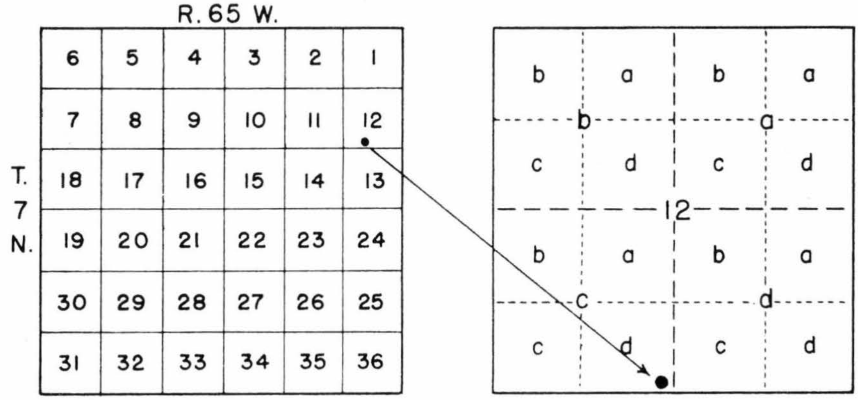


Figure 3. Method employed in describing the location of a well by means of numbers and letters. The designation of the location shown is B 7-65-12cd.

south-west quarter (shown) of section 12, T. 7 N., R. 65 W. In some instances the 40-acre tract is further broken down by a third letter into a 10-acre tract or, if there is more than one well involved in the area, number 1, 2 or 3 may follow the letters.

Comments on Graphs of Records

The graphs shown on Plates 1 to 17 are arranged in downstream order in most instances. In the case of the South Platte, the order is interrupted where a tributary comes in to insert the records of wells in that valley.

South Platte Valley Main Stem

All the observation wells in the main valley are in areas served by canals. The wells are, therefore, used to supplement surface supplies. Some of the wells are close to the river while others may be at a distance of several miles. Those close to the river will show a small annual fluctuation and no persistent trend. Wells B-4-66-17bcc and B-4-60-9abl are typical for such a location. The stabilizing effect of the river is evident. Farther back from the river, the seasonal fluctuations are greater as indicated by B-2-66-20bc. This well shows that conditions have remained in equilibrium for a long time.

Farther downstream in the Gilcrest area, there is a concentration of pumping and large losses from canals. The annual fluctuation here is commonly 8 feet. Two periods of subnormal stream flow, one in 1940 and the other in 1954-56, were attended by abnormal pumping drafts and the effect is clearly indicated in well B-4-66-14abl and others in the vicinity.

The wells near Fort Morgan

have been grouped in this category although some are as much as 8 miles south of the river and above canals. Terrace sands and gravels extend some distance back in this vicinity. Most of the records start at a low point in about 1940. The water table rose over a 2- or 3-year period, remained somewhat constant through 1952, then took a decided dip during the following 4 years.

Previous to 1940 the water table had been at a dangerously high level in places south of Fort Morgan and a few ponds appeared. Pumping started here in volume about 1936 and this combined with less than normal surface supplies caused some lowering during the latter part of the 1930 decade.

Well B-3-57-6dc1 is in the basement of the city hall and is equipped with an automatic recorder.

Cache la Poudre Valley—The principal concentration of wells is in the Box Elder Creek valley north and east of Fort Collins. The water table near Wellington has been subject to fluctuations of considerable magnitude. The lands in this area are under a canal that has suffered from short water supplies for some time. In consequence, there have been many wells drilled in the past 20 years and the draft has exceeded replenishment much of the time. However, during 1942 to 1944 and 1957 the water supply was good and a sharp recovery took place. Well B 9-68-33bdc is at the west edge of Wellington.

Farther south where other canals cross the valley, the variations in the water table become less and less. As previously mentioned, the water table fluctuations reflect the water supply situation. Comparisons with the hydrograph of stream flow at the foot of Plate 3 show the relationship quite markedly. From Fort Collins east, the water table is quite stable.

Lone Tree Valley—This valley is irrigated from canals heading in the Cache la Poudre. Graphs of the fluctuations in the water table are shown in Plates 4, 5, and 6. The wells for which the first 5 graphs are shown are above canals. Of these only well B 8-65-8bbb is being used. The considerable variation in B-8-66-1bab is thought to be caused by flood flows in Lone Tree Creek.

In general the fluctuations can be correlated with the magnitude of the surface water supply. When that supply is low, then there is a greater demand on ground water. Changes in the water table have been greatest in the west side of the valley, particularly in the Eaton - Lucerne area. They have been least along the east side of the valley.

The graph of well B 7-65-18-cdb needs some explanation. This well was drilled, not for a supplemental water supply at the time, but to relieve a high water table condition in the immediate vicinity. This objective was accomplished quickly but the need of supplemental water led to the drilling of two other wells nearby. Their combined draft lowered the water table considerably as can be seen.

Crow Creek—Graphs of only a small group of wells east of Gill are available. The tail end of only one canal reaches into the valley. The water table has been lowered significantly in a part of this area.

Box Elder Valley—Graphs of water table fluctuations in Box Elder Valley together with a very few of short duration in Bee Be Draw are shown on Plates 7 and 8. All the wells in Box Elder Valley in Adams County are above canals, hence they produce the entire irrigation water supply in that county.

Observation wells were established in the Adams County reach of the valley coincident with the beginning of ground-water development. It will be seen that up to about 1948 there were but minor fluctuations in the water table. Replenishment due to floods in Box Elder Creek are evident. Electric power became available in 1943 which encouraged a greater use of the wells. This fact and expansion of the irrigated area caused a greater draft on ground water, resulting in a continued decline since 1949, as shown by well C 2-65-35dbb.

That part of the valley in southern Weld County is supplied with water from the Henrylyn Irrigation District. Pumping began here in about 1924. A rising tendency is to be noted until 1949. A very serious decline developed after that as shown by well B 1-65-24cdc, which was partly recovered in 1957.

The few observation wells in BeeBe Draw and the shortness of the records do not permit much comment. These do indicate a substantial lowering of the water table in places northwest of Hudson in the last several years.

Prospect Valley—Prospect Valley has had an interesting history. This area is also served by canals in the Henrylyn Irrigation District. Because of a severe water shortage, explorations were begun in 1932 to locate a ground-water supply. In this there was considerable success and by 1940 there were 67 pumping plants in operation in a rather small area. The water table began to recede immediately, reaching a low point in 1941. In 1942 a reversal took place and except for the year 1946 the rise was continuous until 1950 when again a decline set in, much more serious than the initial one (see Plate 8). Well B 1-63-28abb shows the effect of losses from a reservoir at the south end of the area. Well B 2-63-32aa is below a reservoir on the west edge of the area farther north. It also shows the effect of reservoir losses but to a lesser degree. There being no pumped wells nearby, the graph is much smoother than the others. A general recovery of 5 or more feet occurred in 1957 when the surface supply was very good. A more detailed study of this valley is reported on in 1945[9].

Kiowa Valley — Irrigation wells are scattered throughout the length of this valley in Adams and Weld counties. At its lower end, however, in Morgan County, they are quite concentrated. All water used in irrigation is derived from wells. The few observation wells covering the area in Adams County and southern Weld County show a downward tendency as indicated by well C 1-62-34cd. Any replenishment of consequence to ground water in this valley must come from floods in Kiowa Creek.

Records of longer duration are available at the lower end near Wiggins. Near Wiggins the alluvial fans of Kiowa and Bijou Creeks merge with no distinguishing topographic features to permit separation. In this area irrigation well development started in 1934 and is nearly fully developed now. The water table here has receded about 1 or 1½ feet annually without interruption in the past 10 years or so as shown by well B 3-60-22 ccc.

Bijou Valley—Bijou Valley is the largest of the south tributaries of the South Platte. The creek is subject to tremendous floods (100,000 cubic feet per second) which are the principal source of ground-water replenishment. Ground-water development began here in 1935 and grew rapidly in the following 15 years when it about reached its present stage in Morgan County. Development still continues in Adams County. It does not appear that there will be new lands brought under irrigation in Morgan County and in the northern part of Adams County because of the receding water table in these parts.

By 1948 it became obvious that the rate of ground-water extraction was in excess of replacement. The rate of water table lowering increased sharply after that date as shown on Plate 10 and has shown no symptoms of slackening. The total lowering has been greater in the southern part of Morgan County and northern Adams County. The rate near, and north of Wiggins, although of significance, is less.

With the exception of the year 1957, sizable flood flows in the Bijou have been fewer in number than usual since 1935. The extent of losses through the area from flood flows is unknown but replenishment from that source does exist. The well hydrographs do not yield significant information on this factor.

Beaver Valley — The highest canal cuts into Beaver Valley about 2 miles south of Brush. Above this canal, irrigation is by means of wells. Recharge is

[9] Code, W. E. *Ground Water Supply of Prospect Valley, Colorado.* Technical Bulletin 34, Colorado State University, 1945.

principally from losses from flood flows in Beaver Creek. Some of the irrigation wells were drilled as early as 1910, but active increase in the number did not start until about 1936. As late as 1946, the rate of groundwater use did not appear to produce any significant trends in the water table (see Plate 12). Beginning then, a steady decline has developed, becoming greatest in the heavily pumped area in the vicinity of Gary as shown by well B 1-56-1dc.

Pawnee Valley — Pumping is not very heavy in this small area which is under canals. No trends developed until the drought period of 1954-56 which caused a dip of about 5 feet.

Arkansas Valley Drainage

There is very little groundwater development for irrigation west of the junction of Fountain Creek with the Arkansas River at Pueblo. Observation wells are located only in Fountain Valley near Fountain; in Big Sandy Valley near Simla; and along the main stem of the Arkansas. Hydrographs covering these areas are on Plates 15, 16 and 17.

Fountain Valley—In Fountain and Jimmy Camp valleys there are at least 120 pumping plants. Four observation wells only represent water-table conditions in Fountain Valley and these are in the vicinity of the town of Fountain. The wide swing in well 15-66-14abd reflects the pumping from nearby wells installed in 1954. Well C 16-65-16bb definitely reflects surface supply in Fountain Creek.

Arkansas Valley Main Stem—Irrigation wells throughout the valley supplement supplies from river diversions. Much agricultural land lies in the socalled first bottoms which are but a few feet above the river channel. Sands and gravels occur under terraces at higher elevations on both sides of the river but these terraces are discontinuous. The top of the underlying shales is often higher than the first bottoms, giving rise to a water table with fluctuations of a different character than those in the bottoms.

Without doubt, the river has a stabilizing influence on the water table under the bottom lands. This is demonstrated in the graphs of wells C 20-63-33aa, C 21-61-23bbb, C 21-61-23db and C 21-61-24d. There is reason to suspect that the gradual rise in the water table has been due to a rise in the river bed caused by silt deposits.

Water tables under the terraces reflect the combined effects of supplies through the canals and the extent of pumping. The effect of the drought years of 1940-1941 and 1953-1956 are marked. This is shown in the graphs of such wells as C 21-63-8 ca near Vineland, C 22-59-18 ccc near Fowler, and C 22-58-21 bd near Manzanola. All wells responded significantly to the excellent surface supplies in 1957.

A group of wells extending

from east of LaJunta to the state line has been added recently but the records are of too short duration to be included.

Big Sandy Valley — Measurements on five observation wells in El Paso and Elbert counties are being made by the U. S. Geological Survey. The graphs reveal a slight downward tendency which probably reflects creek flow conditions. The sandy character of the creek bed affords excellent conditions for the absorption of flood flows. Storm water flows in this reach of the creek are numerous but have to be of considerable magnitude (possibly 1,000 cfs at Simla) to reach to the mouth near Lamar. Because of the proximity of bed rock or other conditions reducing the flow area in the sands, water is forced to the surface to produce a small permanent flow in places. Between such places there are potential storage reservoirs for the absorption of flows. Lowering of the water table temporarily along the creek by pumping increases the capacity of these reservoirs. A water table lowering here therefore need not be looked upon with alarm.

Other Water Table Records

The U. S. Geological Survey has a network of observation wells established in the High Plains drainage in Phillips, Washington, Yuma, Kit Carson and Baca Counties. These are short time records and are available at the Denver office. For the most part they show no significant trends. However, near Cope in Washington County, and in places in Baca County, where there is a concentration of irrigation wells, a decline in the water table has been noted.

Plate 1

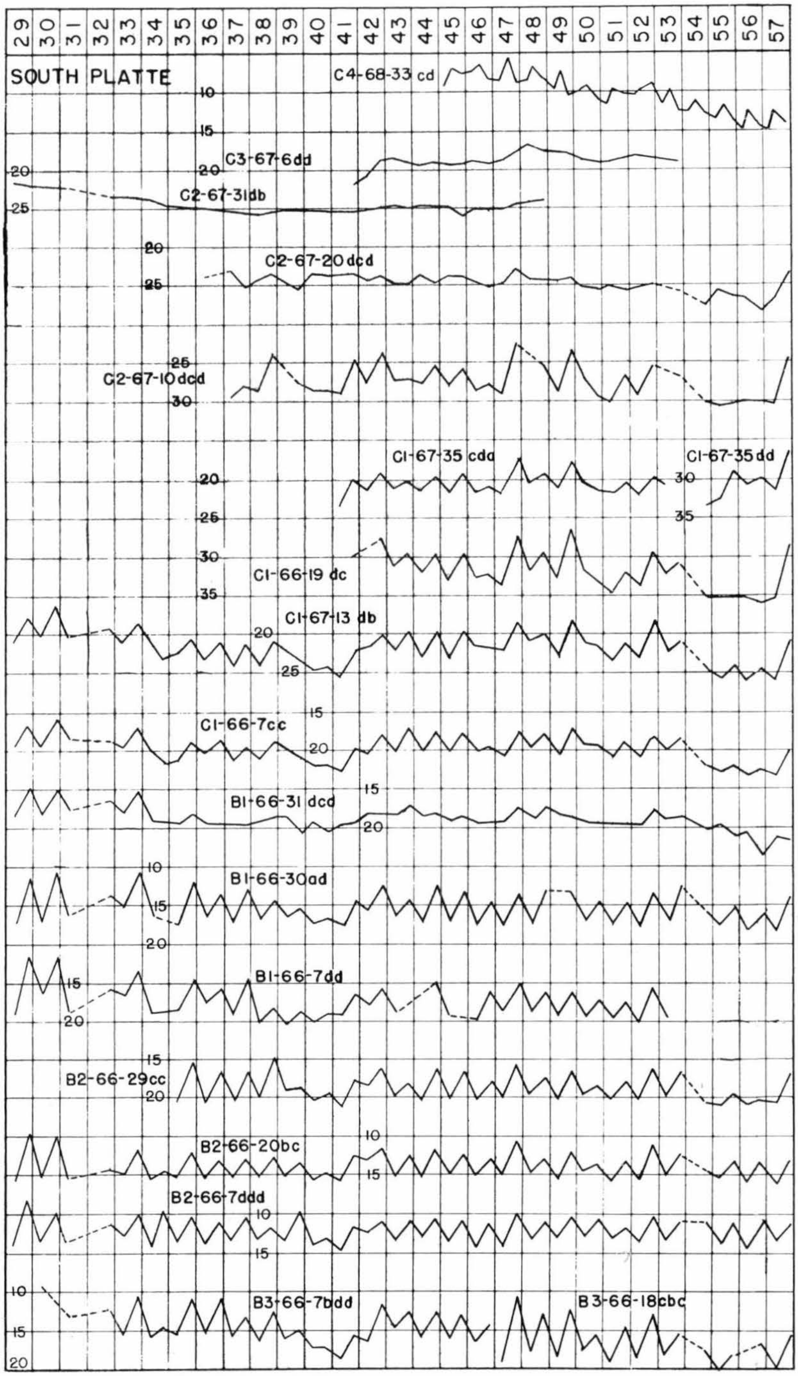

29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
SOUTH PLATTE
C4-68-33 cd
C3-67-6dd
C2-67-31db
C2-67-20dcd
C2-67-10dcd
C1-67-35 cdd
C1-67-35dd
C1-66-19 dc
C1-67-13 db
C1-66-7cc
B1-66-31 dcd
B1-66-30ad
B1-66-7dd
B2-66-29cc
B2-66-20bc
B2-66-7ddd
B3-66-7bdd
B3-66-18cbc

Plate 2

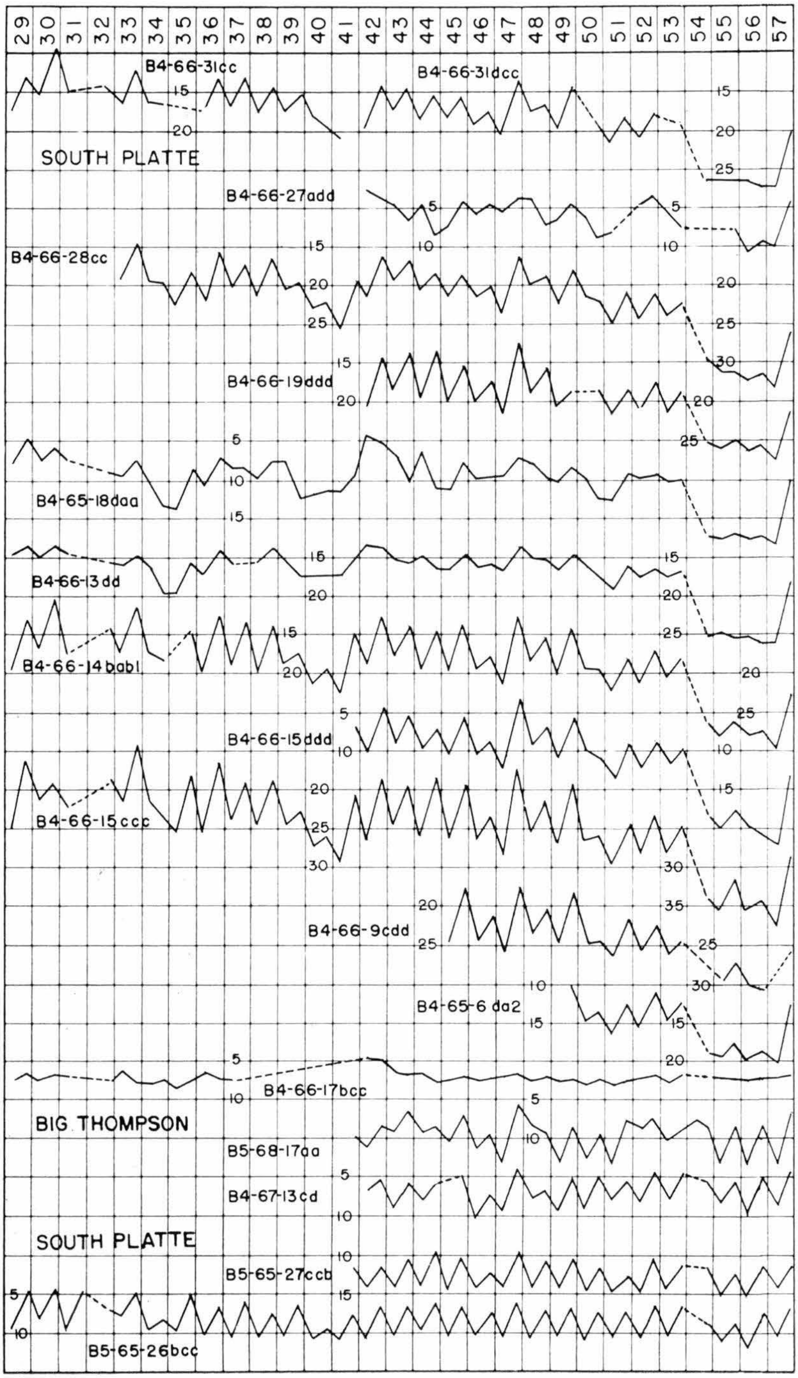

29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
B4-66-31cc
B4-66-31dcc
SOUTH PLATTE
B4-66-27add
B4-66-28cc
B4-66-19ddd
B4-65-18daa
B4-66-13dd
B4-66-14babl
B4-66-15ddd
B4-66-15ccc
B4-66-9cdd
B4-65-6 da2
B4-66-17bcc
BIG THOMPSON
B5-68-17aa
B4-67-13cd
SOUTH PLATTE
B5-65-27ccb
B5-65-26bcc

Plate 3

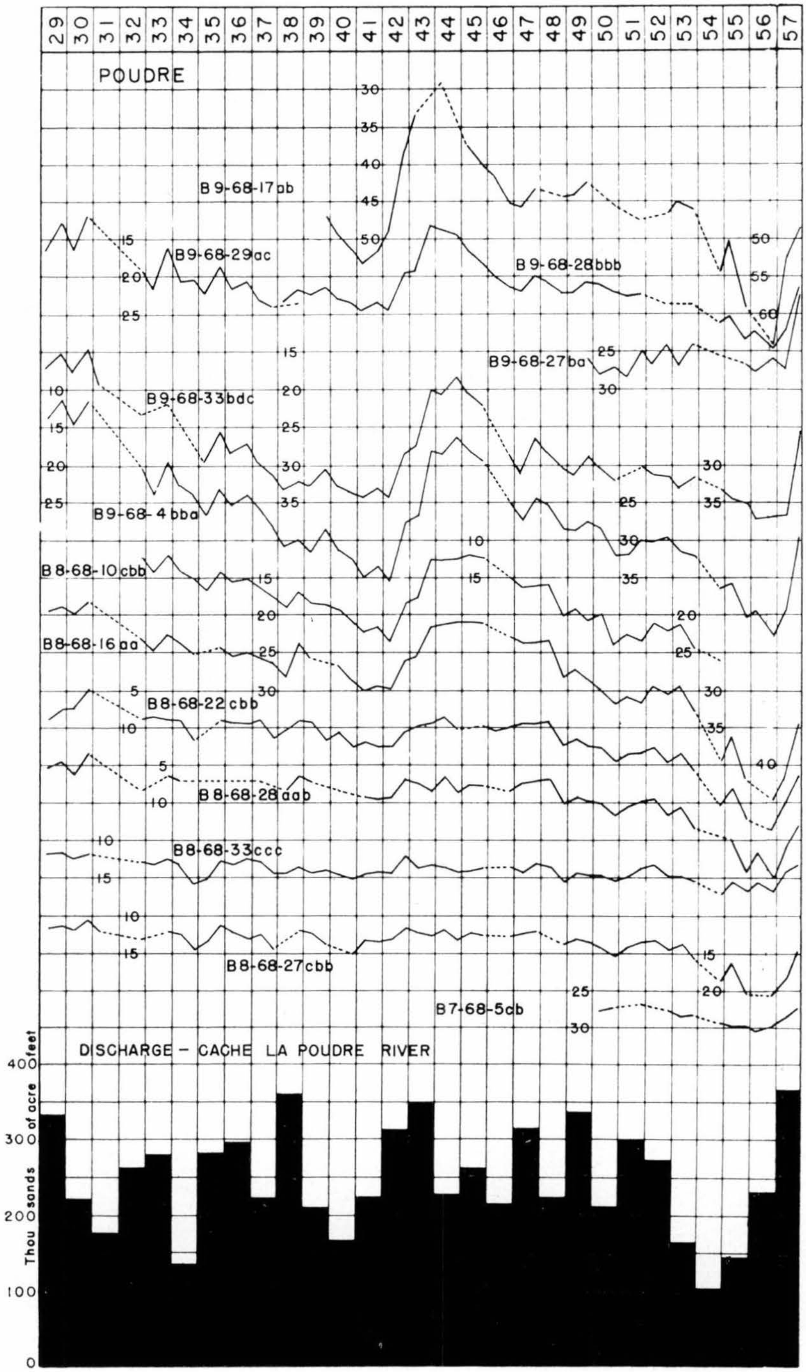

POUDRE
B9-68-17ab
B9-68-29ac
B9-68-28bbb
B9-68-27ba
B9-68-33bdc
B9-68-4bba
B8-68-10cbb
B8-68-16aa
B8-68-22cbb
B8-68-28aab
B8-68-33ccc
B8-68-27cbb
B7-68-5cb
DISCHARGE - CACHE LA POUDRE RIVER
Thousands of acre feet

Plate 4

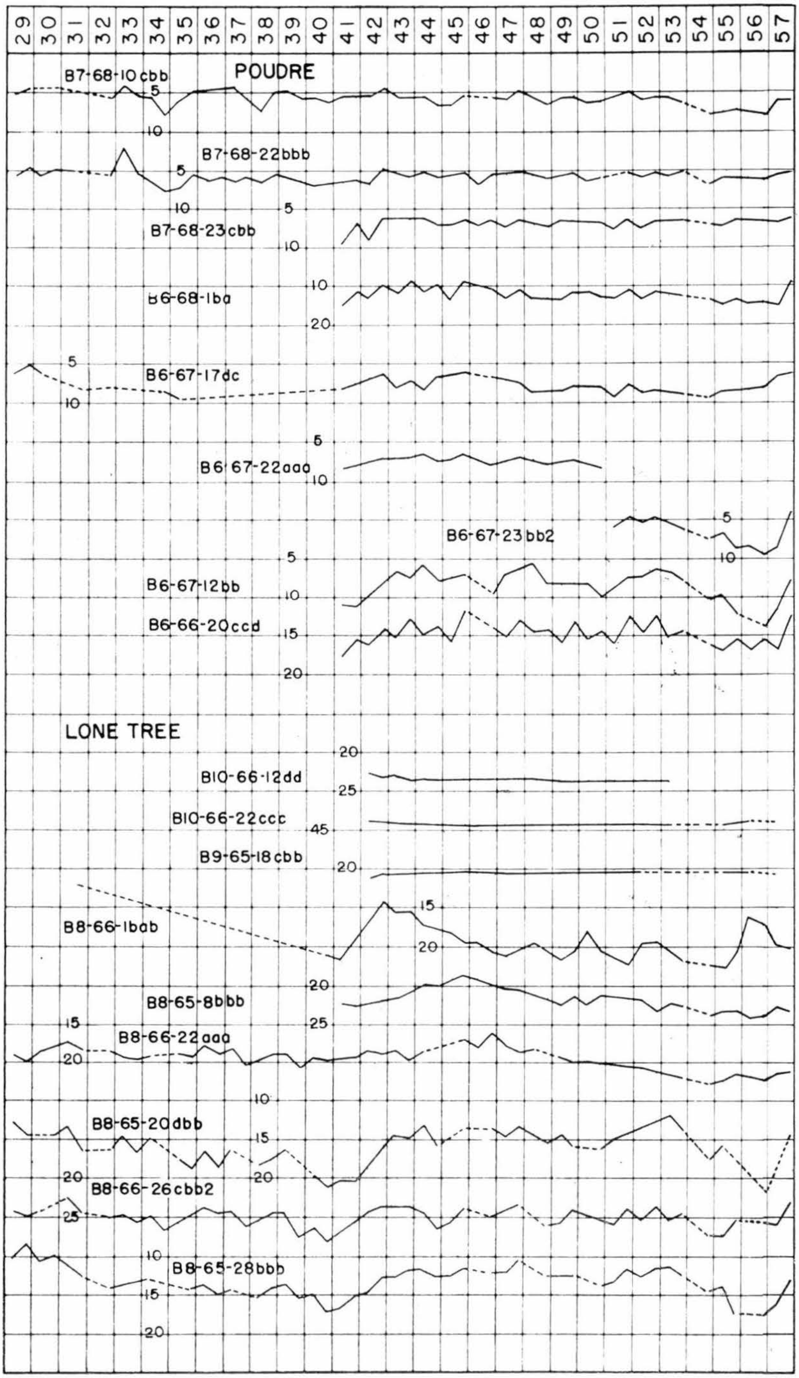
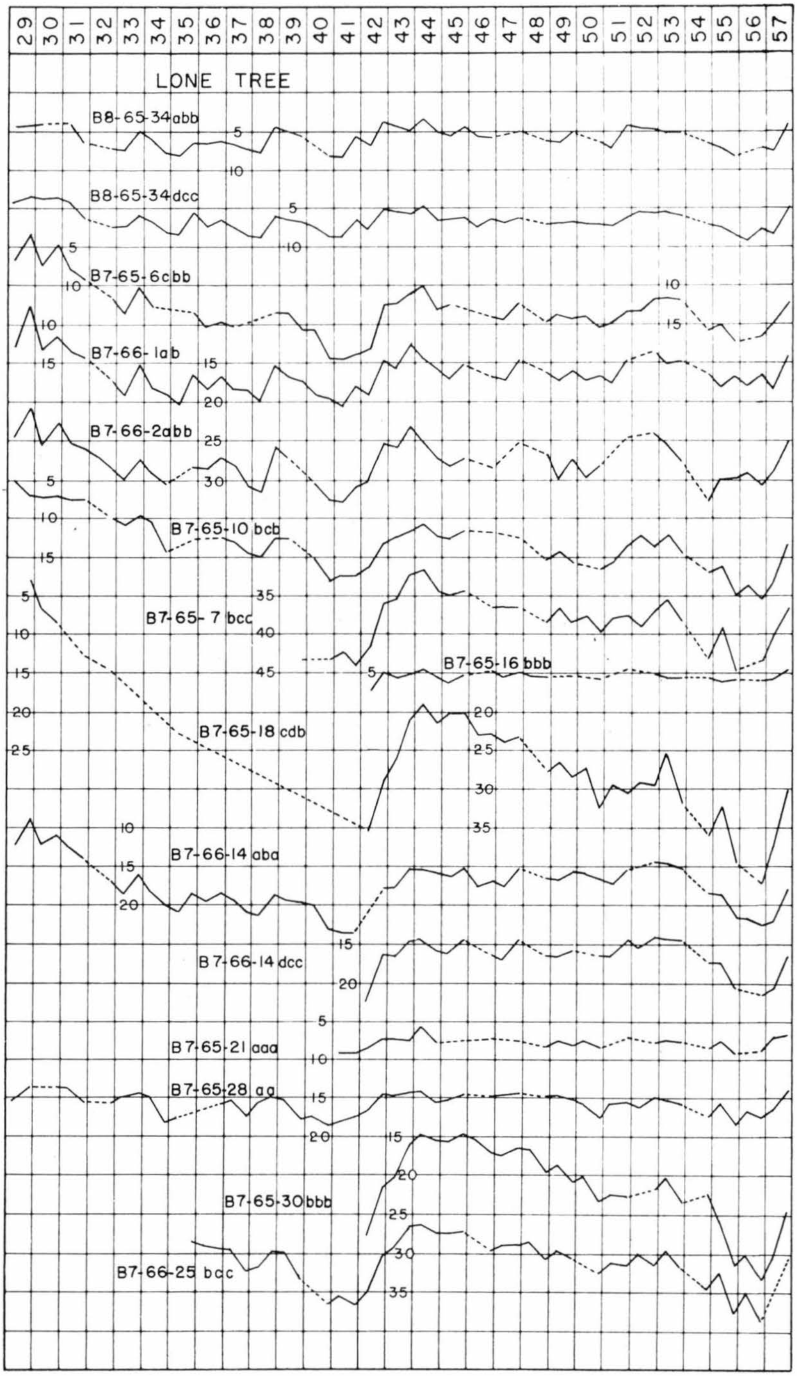

29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
POUDRE
B7-68-10cbb
B7-68-22bbb
B7-68-23cbb
B6-68-1ba
B6-67-17dc
B6-67-22aaa
B6-67-23bb2
B6-67-12bb
B6-66-20ccd
LONE TREE
B10-66-12dd
B10-66-22ccc
B9-65-18cbb
B8-66-1bab
B8-65-8bbb
B8-66-22aaa
B8-65-20dbb
B8-66-26cbb2
B8-65-28bbb

Plate 5



29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
LONE TREE
B8-65-34abb
B8-65-34dcc
B7-65-6cbb
B7-66-1ab
B7-66-2abb
B7-65-10 bcb
B7-65- 7 bcc
B7-65-16 bbb
B7-65-18 cdb
B7-66-14 aba
B7-66-14 dcc
B7-65-21 aaa
B7-65-28 aa
B7-65-30bbb
B7-66-25 bcc

Plate 6

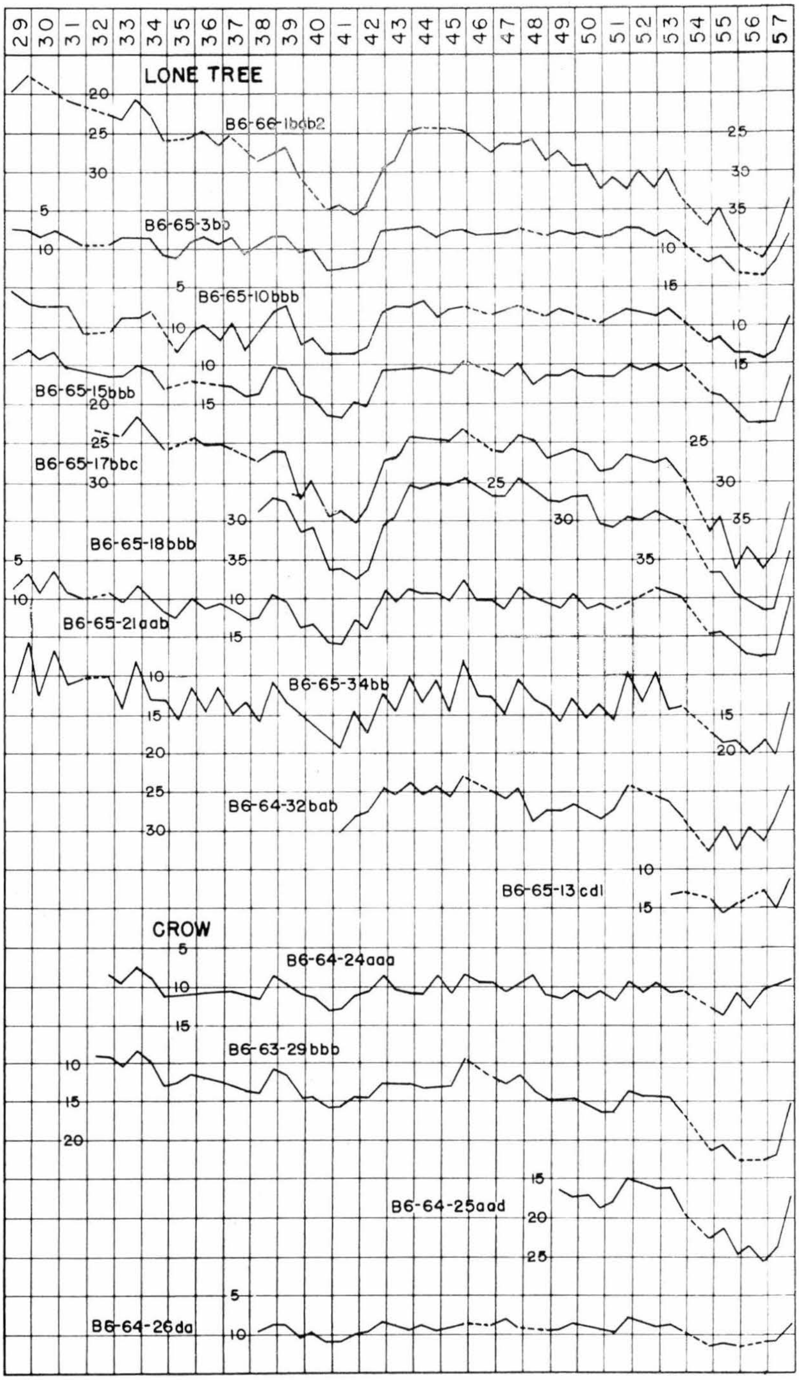
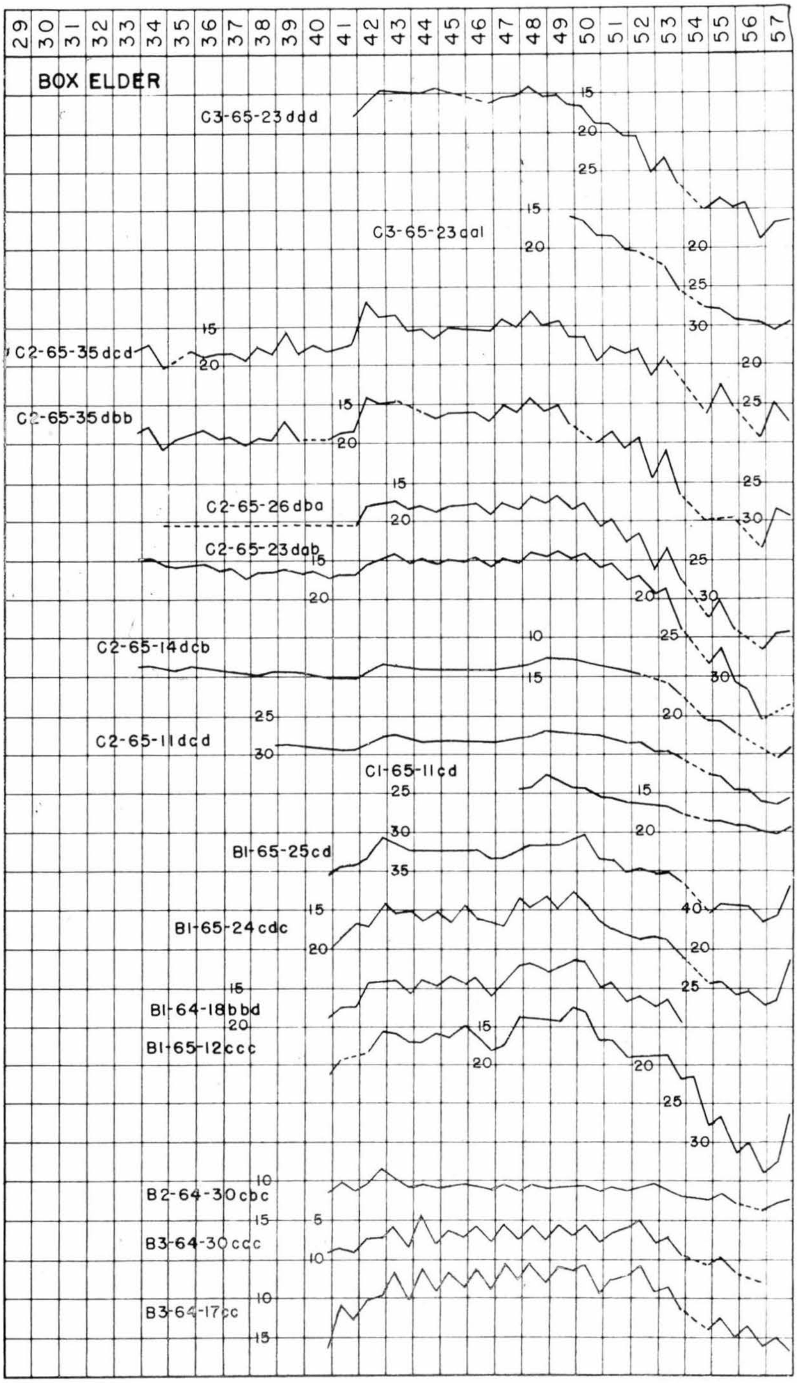
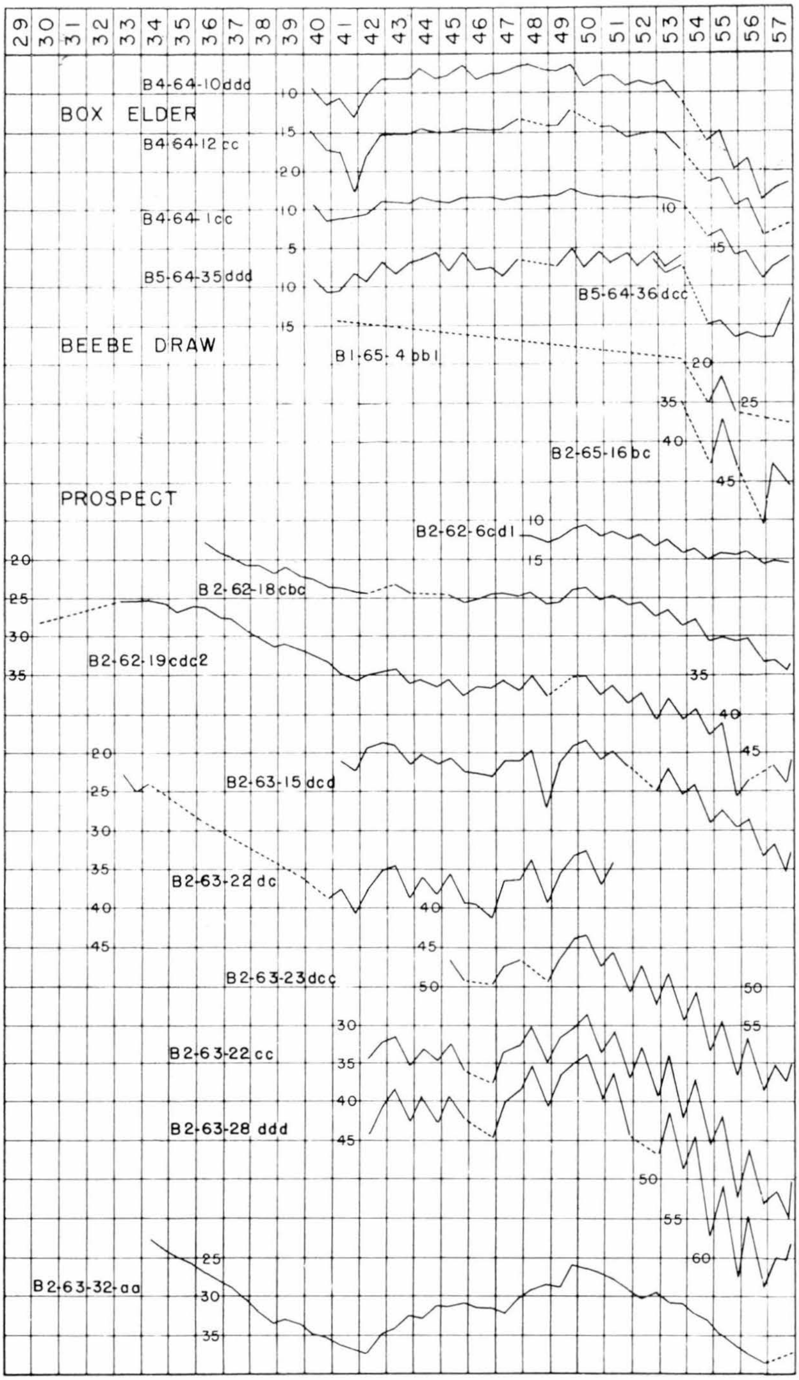

29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
LONE TREE
B6-66-1bdb2
B6-65-3bb
B6-65-10bbb
B6-65-15bbb
B6-65-17bbc
B6-65-18bbb
B6-65-21aab
B6-65-34bb
B6-64-32bab
B6-65-13cdl
CROW
B6-64-24aaa
B6-63-29bbb
B6-64-25aad
B6-64-26da

Plate 7



29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
BOX ELDER
C3-65-23ddd
C3-65-23dal
C2-65-35dcd
C2-65-35dbb
C2-65-26dba
C2-65-23dab
C2-65-14dcb
C2-65-11dcd
C1-65-11cd
B1-65-25cd
B1-65-24cdc
B1-64-18bbd
B1-65-12ccc
B2-64-30cbc
B3-64-30ccc
B3-64-17cc

Plate 8



29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
BOX ELDER
B4-64-10ddd
B4-64-12cc
B4-64-1cc
B5-64-35ddd
B5-64-36dcc
BEEBE DRAW
B1-65-4bbl
B2-65-16bc
PROSPECT
B2-62-6cdl
B2-62-18cbc
B2-62-19cdc2
B2-63-15dcd
B2-63-22dc
B2-63-23dcc
B2-63-22cc
B2-63-28ddd
B2-63-32-aa

Plate 9

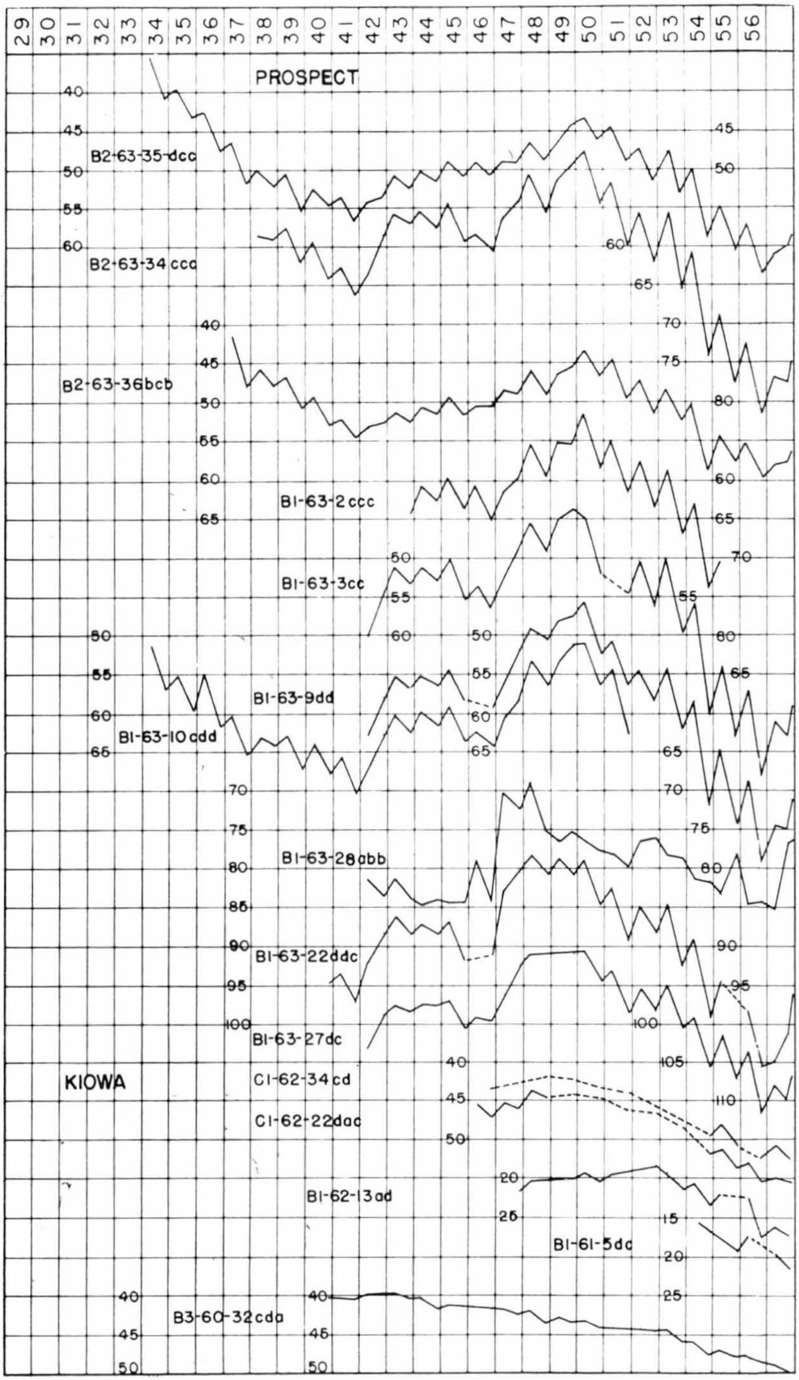
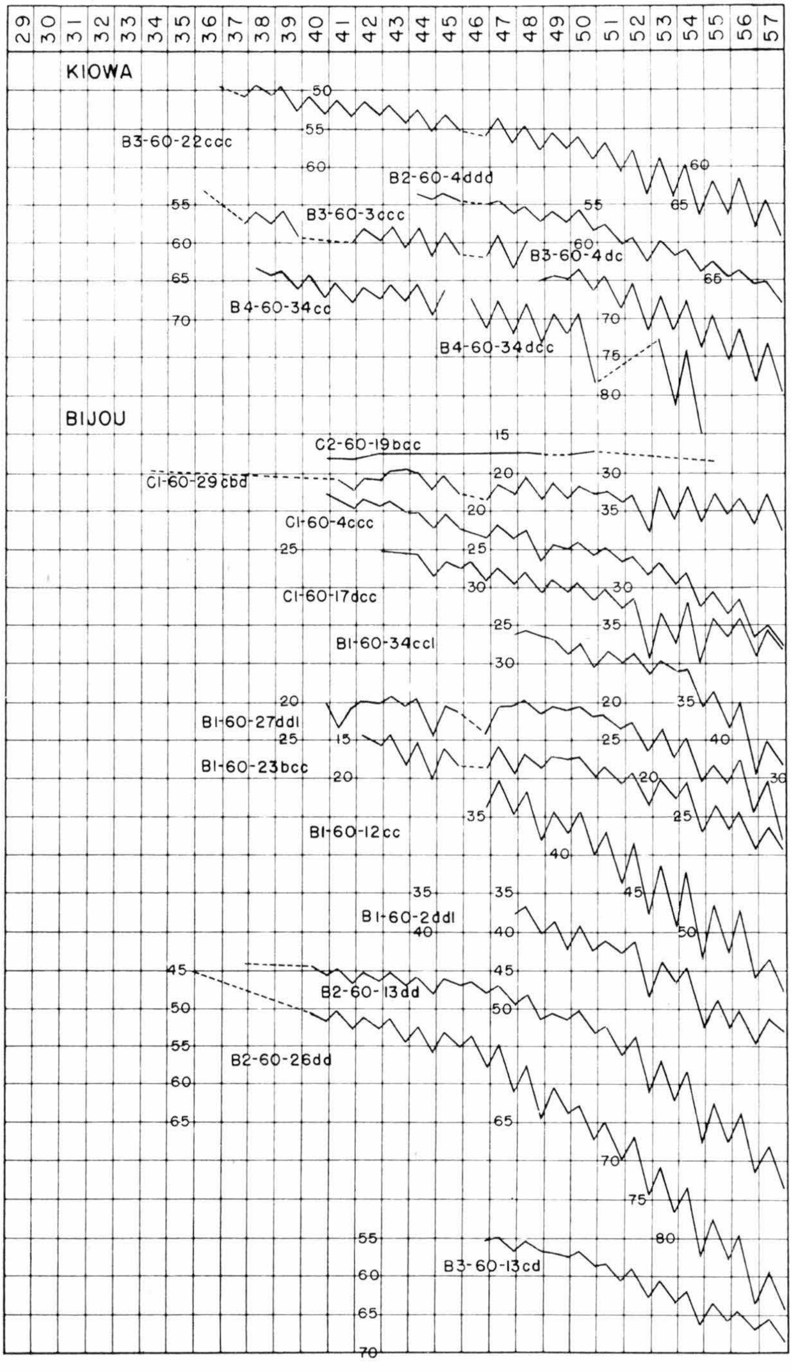

PROSPECT
B2-63-35 dcc
B2-63-34 ccc
B2-63-36bcb
B1-63-2 ccc
B1-63-3cc
B1-63-9dd
B1-63-10 cdd
B1-63-28abb
B1-63-22ddc
B1-63-27dc
KIOWA
C1-62-34cd
C1-62-22dac
B1-62-13ad
B1-61-5dc
B3-60-32cda

Plate 10



29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
KIOWA
B3-60-22ccc
B2-60-4ddd
B3-60-3ccc
B3-60-4dc
B4-60-34cc
B4-60-34dcc
BIJOU
C2-60-19bcc
C1-60-29cbd
C1-60-4ccc
C1-60-17dcc
B1-60-34ccl
B1-60-27ddl
B1-60-23bcc
B1-60-12cc
B1-60-2ddl
B2-60-13dd
B2-60-26dd
B3-60-13cd

Plate 11

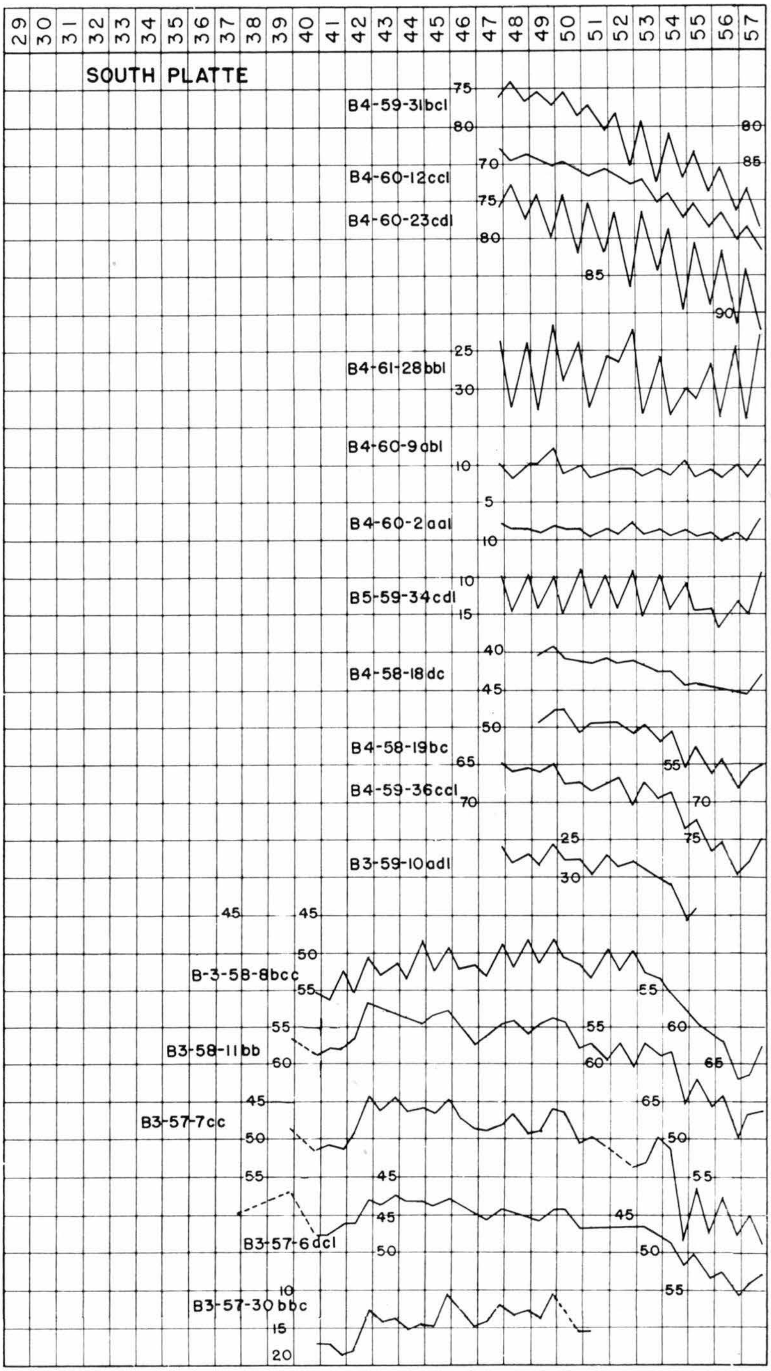
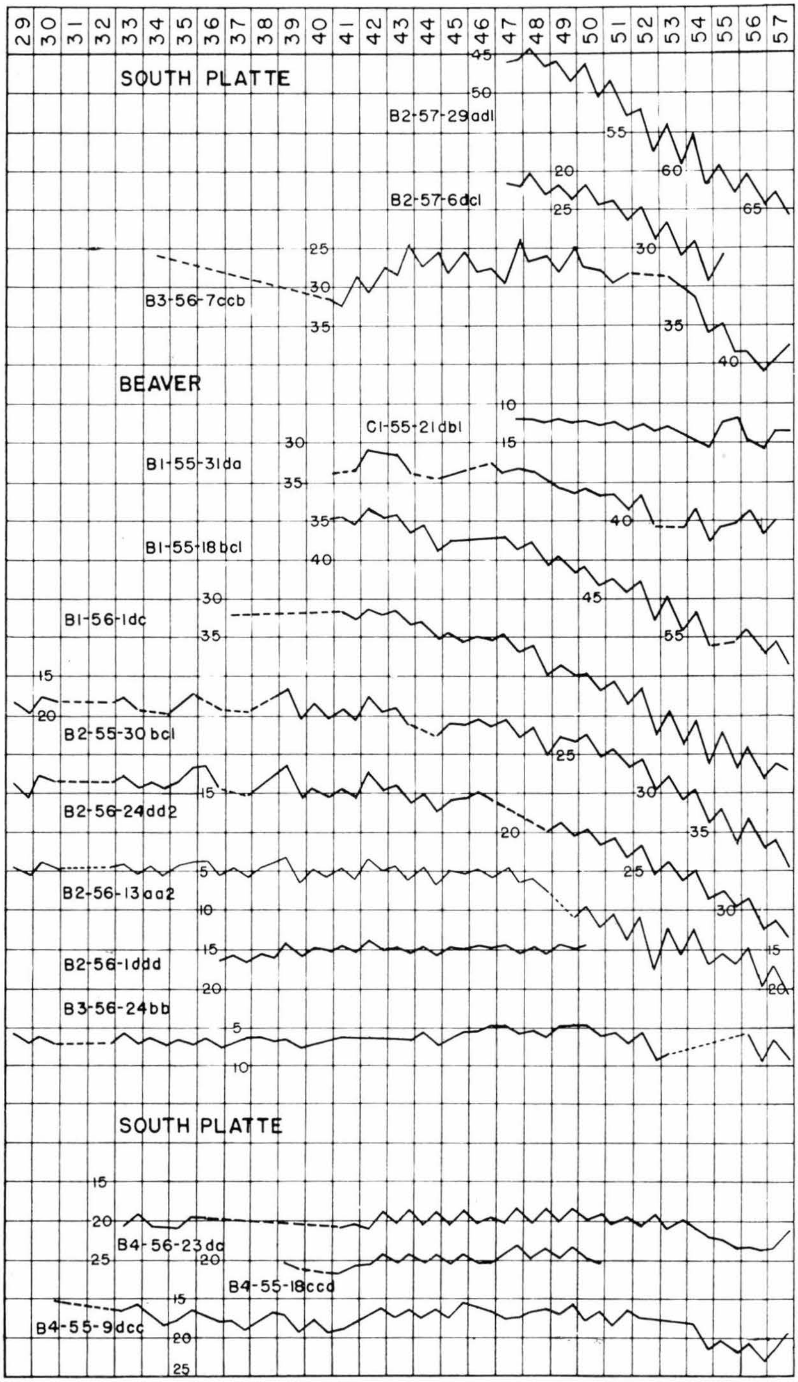

29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
SOUTH PLATTE
B4-59-31bcl
B4-60-12ccl
B4-60-23cdl
B4-61-28bbl
B4-60-9abl
B4-60-2aal
B5-59-34cdl
B4-58-18dc
B4-58-19bc
B4-59-36ccl
B3-59-10adl
B-3-58-8bcc
B3-58-11bb
B3-57-7cc
B3-57-6dcl
B3-57-30bbc

Plate 12



29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
SOUTH PLATTE
B2-57-29adl
B2-57-6dcl
B3-56-7ccb
BEAVER
C1-55-21dbl
B1-55-31da
B1-55-18bcl
B1-56-1dc
B2-55-30bcl
B2-56-24dd2
B2-56-13aa2
B2-56-1ddd
B3-56-24bb
SOUTH PLATTE
B4-56-23da
B4-55-18ccd
B4-55-9dcc

Plate 13

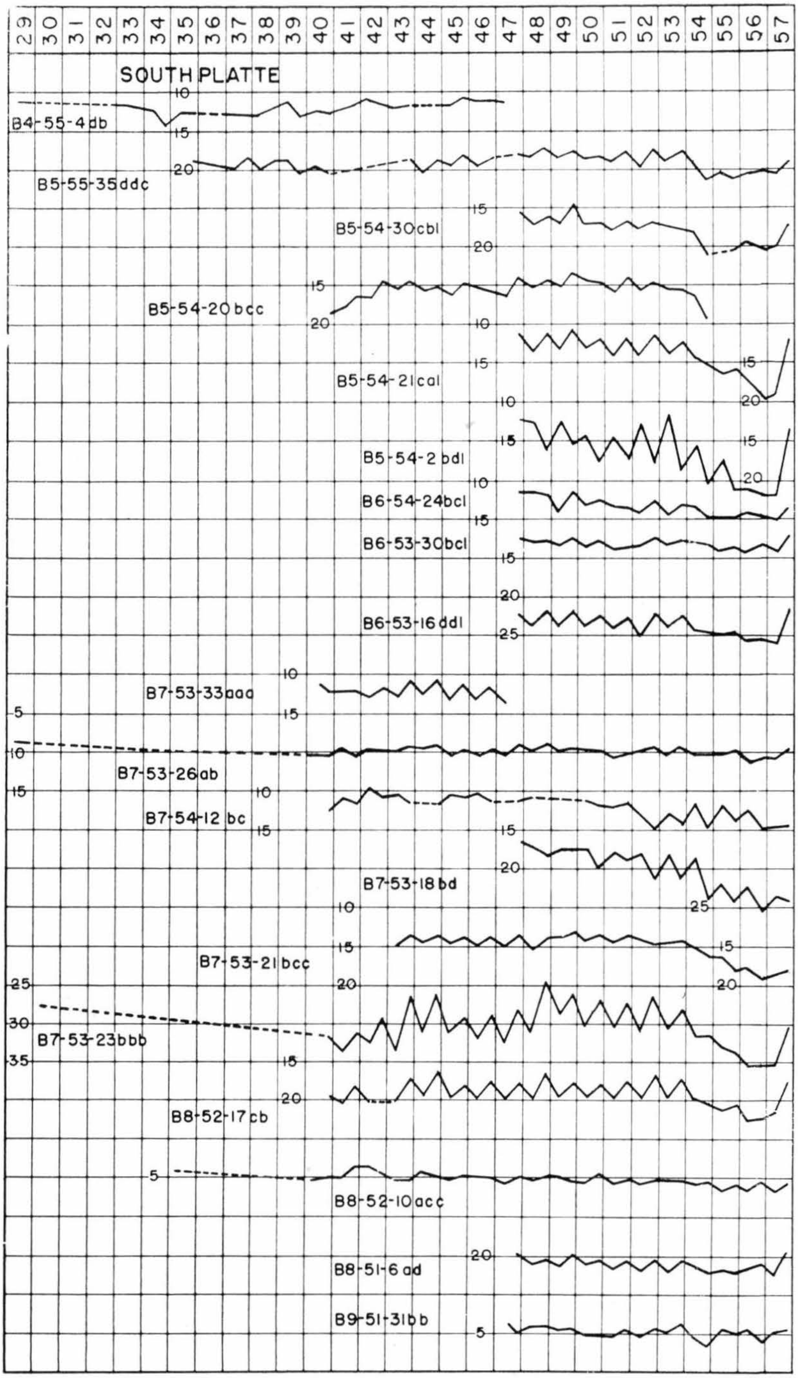
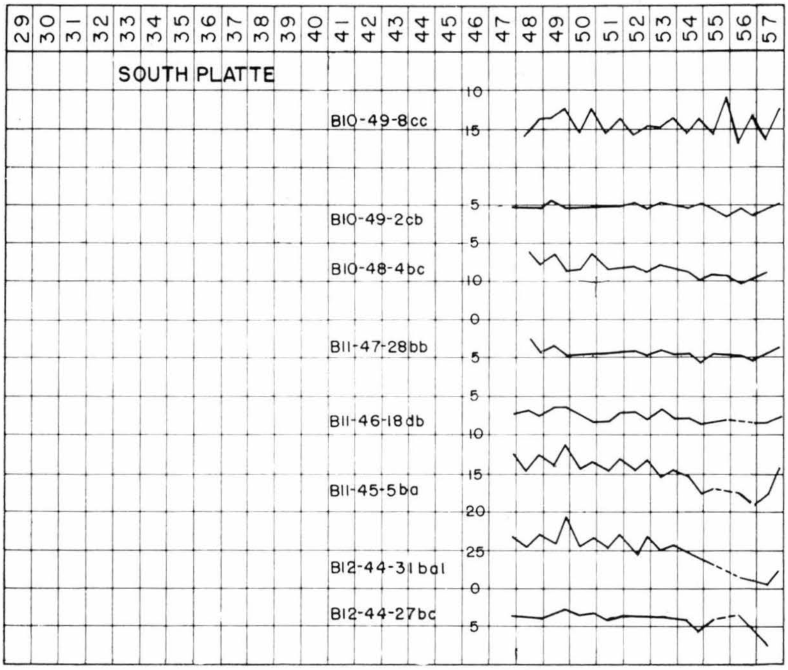
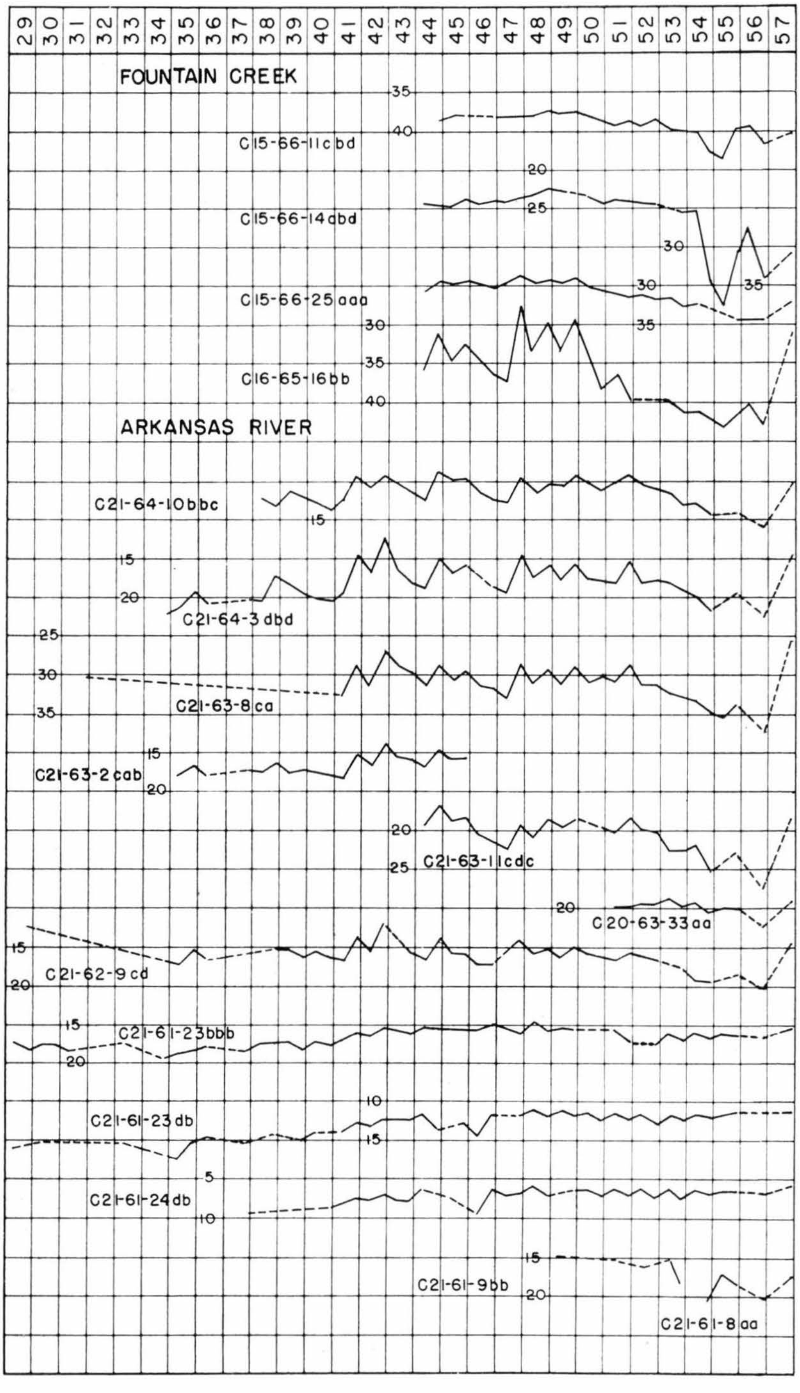

29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
SOUTH PLATTE
B4-55-4db
B5-55-35ddc
B5-54-30cbl
B5-54-20bcc
B5-54-21cal
B5-54-2bdl
B6-54-24bcl
B6-53-30bcl
B6-53-16ddl
B7-53-33aaa
B7-53-26ab
B7-54-12bc
B7-53-18bd
B7-53-21bcc
B7-53-23bbb
B8-52-17cb
B8-52-10acc
B8-51-6ad
B9-51-31bb

Plate 14



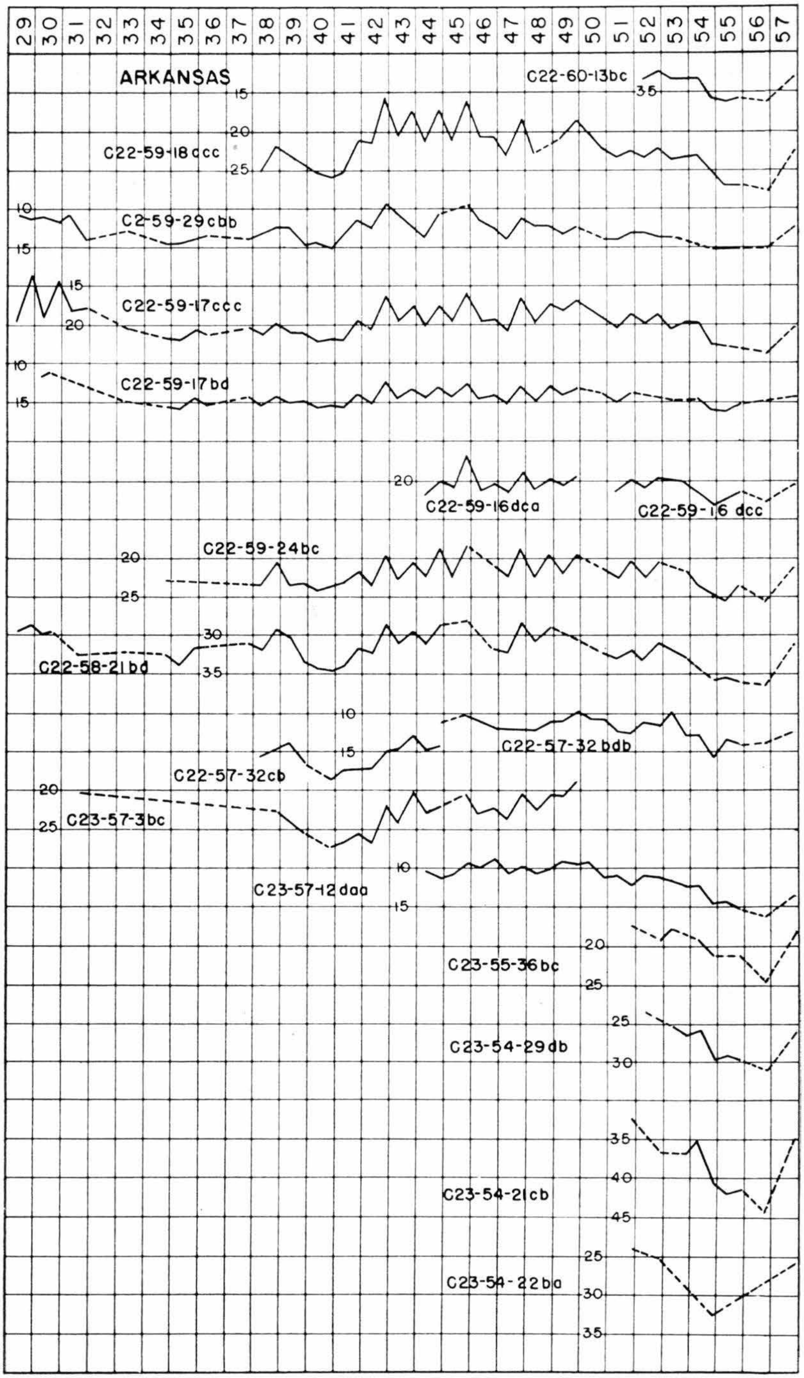
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
SOUTH PLATTE
B10-49-8cc
B10-49-2cb
B10-48-4bc
B11-47-28bb
B11-46-18db
B11-45-5ba
B12-44-31bal
B12-44-27bc
10
15
5
5
10
0
5
5
10
15
20
25
0
5

Plate 15



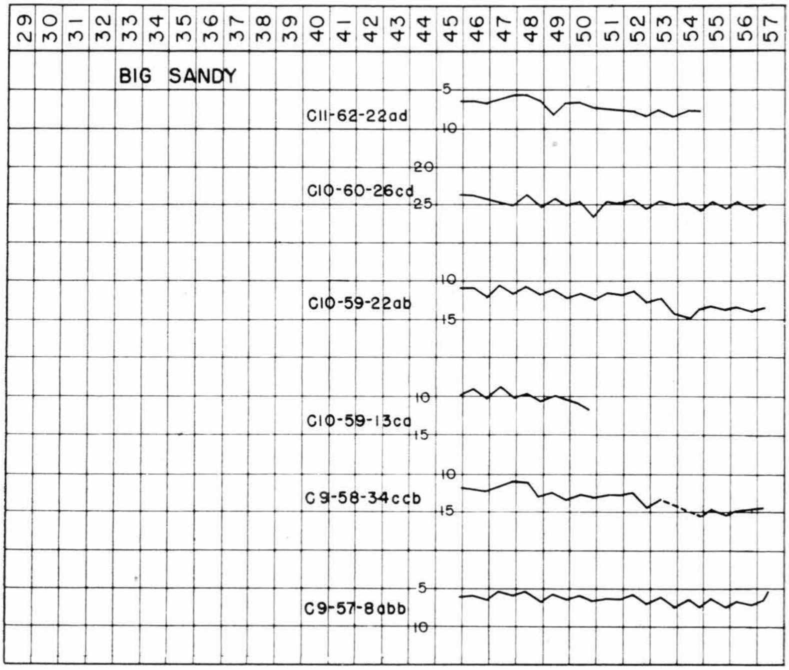
29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
FOUNTAIN CREEK
C15-66-11cbd
C15-66-14dbd
C15-66-25aaa
C16-65-16bb
ARKANSAS RIVER
C21-64-10bbc
C21-64-3dbd
C21-63-8ca
C21-63-2cab
C21-63-11cdc
C20-63-33aa
C21-62-9cd
C21-61-23bbb
C21-61-23db
C21-61-24db
C21-61-9bb
C21-61-8aa

Plate 16



29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
ARKANSAS
C22-60-13bc
C22-59-18dcc
C2-59-29cbb
C22-59-17ccc
C22-59-17bd
C22-59-16dca
C22-59-16dcc
C22-59-24bc
C22-58-21bd
C22-57-32bdb
C22-57-32cb
C23-57-3bc
C23-57-12daa
C23-55-36bc
C23-54-29db
C23-54-21cb
C23-54-22ba

Plate 17



29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57
BIG SANDY
C11-62-22ad
5
10
C10-60-26cd
20
25
C10-59-22ab
10
15
C10-59-13ca
10
15
C9-58-34ccb
10
15
C9-57-8abb
5
10