ANALYSIS OF VARIABLES AFFECTING THE FLUCTUATION OF THE WATER TABLE IN THE BIG BLUE RIVER VALLEY BELOW TUTTLE CREEK RESERVOIR

by

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INTRODUCTION

Purpose of the Investigation

The Kansas River valley has been studied from Kansas City to the junction of the Smoky Hill and Republican Rivers. The purpose of this investigation was to conduct a study of ground-water recharge in the Big Blue River Valley below Tuttle Creek Reservoir by observing the fluctuations of the water table in response to precipitation, river stage, and reservoir elevation. It was hoped that through this study the effect of the reservoir upon the water table in the valley below the dam could be established.

Research was conducted from the spring of 1965 to May 1966 through the aid of an assistantship granted by the Kansas State Agricultural Experiment Station.

Area of the Investigation

The area studied is in the Big Blue River valley from Tuttle Creek Dam southeast to the Kansas River, a distance of five miles. Investigations were conducted in the Big Blue River alluvium located in the western part of Pottawatomie County and in the eastern part of Riley County. Eleven square miles were mapped and investigated.

Previous Investigations

One of the first reports on the Big Blue River drainage basin in Kansas was made by Haworth (1913). During the summer of his studies Haworth noted that water flowed continuously in the Big Blue River, but at a minimum. The source of this flow was primarily from bank and ground-water discharge into the stream.

Moore (1940) concluded that well water is recharged from local subsurface drainage into the Kansas River valley. He found that well water differed chemically from normal river water underflow and the water table sloped from the sides of the valley toward the river.

Knapp and others (1940) studied ground-water recharge in Soldier Creek basin in eastern Kansas, where annual recharge was estimated to amount to 0.50 inch. Lohman (1941) reported recharge to the ground-water reservoir from precipitation in the Kansas River valley amounts to as much as ten percent of the annual precipitation. Based on Lohman's estimate the average annual recharge for this area would amount to about 3.2 inches; however, rates of recharge would depend upon the intensity and duration of rainfall. The Kansas River dam at Lawrence causes water to flow into alluvium most of the year.

According to Davis and Carlson (1952), who described the geology and ground-water resources of the Kansas River valley between Lawrence and Topeka, calculations of recharge on a regional basis are not reliable when applied to a small area of study, because the rate of infiltration varies so much, depending upon local geology. The rate of infiltration to the zone of saturation from precipitation in the Kansas River valley is dependent on the clay content of surficial material. The principal area of recharge by precipitation is reported by Davis and Carlson to be the flood plain, with little recharge occurring in old channel scars and on the "backswamp" deposits of the Newman Terrace. They also stated that after periods of high water, when the river supplies water to the alluvium, most of the water will act temporarily as bank storage before draining back into the river. Thus it never actually recharges the ground-water reservoir. An interesting result of their study was that as much as twenty percent of the recharge in the valley between Menoken and Topeka is from the river.

Beck (1959) related recharge to changes in river stage in the area from Topeka to Wamego. He concluded that ground water was discharging into the Kansas River, since the water table sloped toward the river. In the same year, Smith (1959) extended this investigation from Wamego to Manhattan where he described the geology and ground-water resources of the Big Blue and Kansas River valleys in an unpublished Master's thesis at Kansas State University.

Smith's work was conducted before the U.S. Army Corps of Engineers completed construction of the Tuttle Creek Reservoir on the Big Blue River. Water was first impounded on March 7, 1962, at an elevation of 1013.14 feet. Conservation pool level is set at 1075.00 feet.

Methods of Investigation

Field Procedures

Data were collected periodically during the year beginning April 1965 from fifteen wells located in the Big Blue River valley. Frequent measurements of depth to the water table were recorded after periods of heavy rainfall or when outflow from Tuttle Creek Reservoir changed drastically. In addition, data on daily river stage, reservoir elevation, and daily precipitation were obtained at the U.S. Corps of Engineers building at the base of the dam (Appendix I).

Elevation of the measuring point was established at each well by plane table and alidade. The Casement Bridge river gage check bar and bench mark Y111 were referred to for known elevations.

Field equipment consisted of a Fischer M-scope water-level indicator and a steel tape calibrated in tenths of a foot. Data were recorded for each well on U.S.G.S. Water Resources Division's Water Level Measurements Form 9-194.

The field map was modified from a base map used by Smith (1959) and adapted from the seven and one-half minute Tuttle Creek Quadrangle topographic map published by the United States Geological Survey in 1964.

Locations of measured wells, depths to water, and water-table contours are shown on Plates I and II.

Data Analysis

A linear model was established for statistical analysis using precipitation, river stage, and reservoir elevation as independent variables to predict water table elevation, the dependent variable. A set of variables consisting of available data was used because it was believed this would predict water table elevations better than a single variable.

Under the guidance of Dr. Leslie F. Marcus, data from 20 observations gathered over a year's time were used for a class problem in Topics in Statistics 799 and later treated more extensively by the author. A program was written for the IBM 1410 computer to facilitate computations. Much work remains to be done in fitting proper variables of hydrologic data to a statistical model to establish an equation which will be the most accurate in predicting a certain phenomenon. Multiple and partial correlation analysis were conducted to measure the adequacy of the (x) variable in predicting another quantity (y). Graphs were constructed to show the degree of fit of the predicted values of water-table elevation to the measured elevations (Figs. 3 and 4).

Well-numbering System

Wells are numbered according to the order in which they were inventoried and are categorized by county.

Locations of wells in Table 8 are designated by the General Land Office System of land description. The components of the systems are: township, range, section, 160-acre tract within the section, and 40-acre tract within the quarter section.

GEOGRAPHY AND GEOLOGY

The section of the Big Blue River between Tuttle Creek Dam and the Kansas River is a part of the Osage Plains division of the Central Lowlands physiographic province according to Fenneman (1938), and Moore (1940).

The Flint Hills escarpment bifurcates in Pottawatomie County as a result of the distortion of strata by the Nemaha Range (Eardley, 1951). One branch of the escarpment parallels the Big Blue River on the west. The valley walls are formed by moderately-eroded resistant Permian limestone and shale escarpments dipping to the west. The Big Blue River valley which averages 1.5 miles wide, is narrower than the Kansas River valley and has a steeper gradient and a smaller flood plain (Jewett, 1941). The former channel of the Big Blue River, preceding the 1903 flood, marks the eastern border of Riley County, and it joins the Kansas River a mile east of Manhattan. Bedrock of limestone is exposed in the channel of the Big Blue River just below Rocky Ford Dam, north of Manhattan. A shifting of the channel from the eastern side of the valley to its present location uncovered the bedrock which has been eroded and subsequently covered with alluvium in older sections of the stream bed.

River alluvium, deposited by the Big Blue River during alternating cycles of cutting and filling, lies unconformably on Permian bedrock. Such a period of deposition occurred during the early Wisconsin Stage of the Pleistocene Epoch when extensive deposits covered the Kansas and Big Blue River valleys. Later entrenchment of these major rivers produced a well-developed terrace a few feet above the present flood plain. This alluvial deposit was named the Newman Terrace by Davis and Carlson (1952), from the town of Newman, Kansas, where a large segment of the terrace is still well-preserved for almost one mile north and two miles east. The Newman terrace material grades from a medium gray silly clay soil to a gray fine sandy loam at the surface to a light gray to tan fine sand and gravel at its base. The gravel- and sand-sized particles are composed of quartz, feldspar, and granite fragments. Limestone fragments form a minor fraction of the Newman deposits and the scarcity of chert fragments affords a means of differentiating these terrace deposits from others (Moulthrop, 1963).

River-bar gravel found in the Big Blue River is composed of abundant glacial quartzite and flint which is derived from glacial deposits within the drainage basin. The gypsum fraction of the gravel has a source area near Blue Rapids (Smith, 1959).

Since the erection of Tuttle Creek Dam in 1959, the bed load of the Big Blue River derived from upstream sources is now effectively removed from the river below the dam. The reservoir acts as a depositional basin as the velocity of the river slows to a near standstill behind the dam. Since the bed load is negligible, it may be assumed that there is a smaller amount of silt as well as sand and gravel being deposited within the river channel. Recharge to and discharge from the ground-water reservoir is likely to respond more rapidly to river stage than in the Kansas River, which transports more fine material available for deposition within the river channel. In the future it will be interesting to observe the effect the smaller bed load has upon the river channel of the Big Blue River.

CLIMATE

The Big Blue River valley lies in the humid continental climatic belt and is marked by regional extremes of precipitation and temperature. The United States Weather Bureau records give a range of annual precipitation from 17 to 60 inches for Manhattan and a range of temperature from -32°F. to 115°F. Normally more than 67 percent of the annual precipitation falls from May through September. During 1965, 40.12 inches of precipitation fell, a departure of +8.12 inches from normal. Fig. 1 shows normal monthly precipitation at the Tuttle Creek Dam station.

The total precipitation to June 30, 1966, is 7.10 inches, and the deficit of precipitation for the same period is 8.51 inches. Rainfall for 1965 from January to July totaled three times as much the amount recorded for the comparable period of 1966. An early indication of a dry year has proved valid for the first half of 1966.

The average growing season extends from April 20 to October 9. The average temperature for 1965 was 53.3°F., with a departure of -0.4°F., from normal.

GROUND WATER HYDROLOGY

Principles of Occurence and Movement

The following discussion is a brief summary of the principles of ground-water hydrology adapted from Todd (1959). For more complete information of the origin and occurrence of ground water the reader is referred to Meinzer (1923), or to a bibliography published by the U.S. Geological Survey in 1947.

The occurrence of water beneath the earth's surface is called subsurface water, and may be divided into zones of saturation and aeration. In the zone of saturation all interstices of the permeable rock are filled with water under hydrostatic pressure. Subsurface water in the zone of saturation is called ground water, while the upper surface of the zone of saturation is called the ground-water table, or simply the water table. Subsurface water occurring in the zone of aeration above the water table is held in place by surface tension and moves by capillary action. The interstices within the zone of aeration are partially occupied by water and partially by air. Only excess water, termed gravitational water, percolates downward to join the water table under the force of gravity. Generally a single zone of aeration overlies a single zone of saturation and extends upward to the ground surface.

Water added to the zone of saturation moves down gradient at right angles to the water-table contours towards an area of discharge.

The Water Table

The water table usually coincides with the free surface of lakes and rivers. When not confined by overlying impermeable strata, a water table follows the contours of the land with the same general shape and slope in a modified form. The surface configuration of the water table is determined, in general, by the balance between recharge to and discharge from the ground-water reservoir. The configuration of the water table in the Big Blue River valley is shown by the water-table contours in Plates I and II. All points on the water talbe along the same contour are of equal altitude.

In Sec. 31, T.9 S.,R.8 E., and Sec. 6, T.10 S., R.8 E., water is encountered approximately eight feet higher than the elevation of the main water talbe (Plates I and II). The body of water is not continuous, but probably perched on shale or clay lenses within the alluvium. Perched water tables, however, cannot be shown accurately on the water-table contour map.

The shape and slope of the water table, which determine the rate and direction of the movement of ground water, are controlled by several factors. Irregularities in shape and slope of the water talbe in the Big Blue River valley may be caused by (1) the configuration of the underlying Permian floor; (2) discharge into and recharge from streams; (3) recharge of the ground-water reservoir by intermittent streams; (4) unequal additions of water to the ground-water reservoir at different places; (5) local variations in the permeability of the deposits; and (6) local depressions on the water table caused by the pumping of water from wells.

The shape of the bedrock floor formed by underlying Permian rocks controls to some degree the direction of movement of the ground water in the area. In Sec. 19 and 30, R.8 E., T.9 S. on Plates I and II, the old entrenched channel of the Big Blue River looped to the east on the old flood plain. It has since filled in with alluvium which probably has a greater permeability than the surrounding alluvium. This is evident in the higher ground-water elevations recorded in well RL-3 than in well RL-4, the latter of which is located near Rocky Ford Dam. Recharge from the river pond may partially account for the higher readings in well RL-3 (Plate II). The Big Blue River is influent (recharges the ground-water reservoir) above Rocky Ford Dam, while below the Dam it is effluent (receives ground-water discharge). A steep gradient of the water talbe is thereby created in the vicinity.

The configuration and direction of movement of ground water are influenced by the discharge of water into the Big Blue River. A flexure of the contour lines pointing upstream indicates that ground water is moving from the valley sides toward the river, as well as down the valley (Plates I and II).

The beds of intermittent streams lie above the water table and are dry much of the time. After a rain, seepage from runoff percolates through the stream bed and may recharge the ground-water reservoir. Many intermittent streams drain the local valley highlands.

An influent stream trending in an east-west direction and located along the boundary between Sec. 31, T. 9 S., R. 8 E., and Sec. 6, T. 10. S., R. 8 E., has formed a perched water table

(Plates I and II). In this way, unequal additions of water to the ground-water reservoir create irregularities in the shape of the water table. Other things being equal, the slope of the water table, in general, varies inversely with the permeability of the aquifer, i.e., the higher the permeability, the flatter the water table.

Fluctuations of the Water Table

The water table responds to varying conditions of recharge and discharge by rising or falling. It fluctuates with annual variations in rainfall, being both lower and flatter after dry spells than after rainy periods.

The water table changes in elevation more than does the water surface of a reservoir by the addition or depletion of a given quantity of water. If the sand and gravel of a water-bearing formation have an average specific yield of about 25 percent, the addition of one foot of water to the aquifer will raise the water table in that material about four feet (McLaughlin, 1943). In spite of this fact, the amount of water from precipitation directly recharging the ground-water reservoir is so minute that water table fluctuations during a day are very small.

Fluctuations of the water table were recorded at intervals from March 1965 until May 1966 by measuring depth to water in observation wells in the Big Blue River valley below Tuttle Creek Reservoir (see table 9, p. 59).

Hydrographs of wells RL-14, RL-15, and RL-12, and corresponding river elevations are compared to monthly precipitation recorded at Tuttle Creek Weather Station in Fig. 1. It is interesting to note the influence that river stage, as well as precipitation, has upon the hydrographs.

During November 13-19, 1965, outflow from Tuttle Creek Dam averaged 60 c.f.s., when the gates were closed for repairs. For eighteen days prior to this period, outflow was 1,000 c.f.s., while after the gates were opened on November 20 outflow amounted to 4,000 c.f.s. The effect of the sudden changes of outflow is illustrated by the river stage graph in Fig. 1 and is reflected in the three hydrographs. Wells RL-14 and RL-15 are approximately of equal distance from the river, but RL-15 is located within a large meander loop of the Big Blue River. Of these two wells, the hydrograph of RL-14 more closely resembles that of RL-12, which is moderately well-correlated to river stage.

River stage does not correlate to precipitation as well as might be expected because of the regulated outflow from Tuttle Creek Dam. Precipitation which exerts a strong control on reservoir elevation also indirectly influences river stage, although it is regulated by man. It appears, then, that the three variables, river stage, reservoir elevations, and precipitation influence the fluctuations of the ground-water table. Fig. 2 compares and contrasts the relationship between these three variables that will be used later in the investigations to predict ground-water elevations in observation wells.

Thick deposits of Pleistocene and Recent Alluvium, which underly the terraces and the flood plain in the Big Blue River

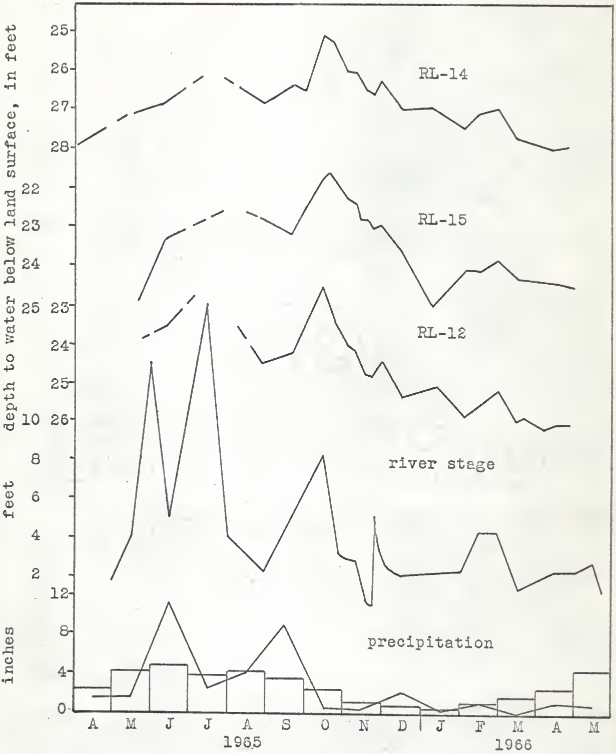


Fig. 1.--Hydrographs of Wells RL-12, 14, and 15, compared to monthly precipitation and river stage.

valley, are good ground-water reservoirs which may contain large quantities of water in storage. This is important because the storage water can be drawn upon during years of low precipitation. A decline of the water table during a year of below-normal precipitation does not necessarily indicate an excessive withdrawal of water from the ground-water reservoir. In dry years, when the amount of recharge to the ground-water reservoir by precipitation is decreased, the amount of water withdrawn by transpiration, evaporation, and pumping often is increased, and the water table falls. During wet years, on the other hand, the recharge from precipitation is increased, water withdrawals generally are decreased, and the water table rises accordingly, perhaps to, or above, its previous high.

The influence of geologic factors on fluctuations of the water table cannot be overlooked. The geologic factors are primarily those of structure and those that effect permeability. The hydrologic properties of the alluvial aquifer in the Big Blue River valley are controlled by variations in permeability rather than structure.

Precipitation. Ground water in the Big Blue River valley is derived from precipitation that falls within the drainage basin. After a moderate rainfall the water table is recharged from two sources: direct infiltration, and bank storage from a stream swollen by surface runoff. Part of the precipitation runs off the surface and becomes streamflow, a part percolates into the ground by infiltration, but is returned to the air through transpiration

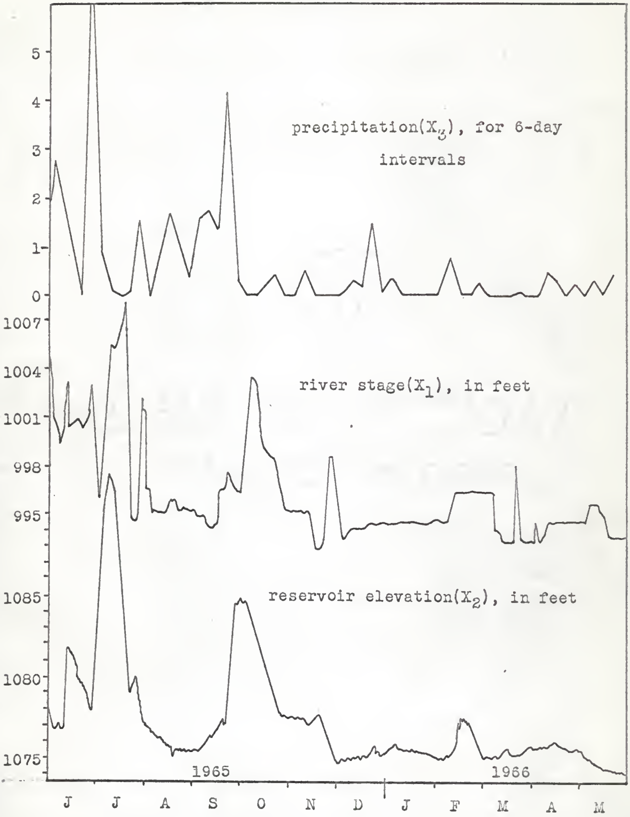


Fig. 2.--Precipitation, river stage, and reservoir elevation.

by plants, and a small remainder percolates downward through the soil and underlying strata until it reaches the water table and recharges the ground-water reservoir.

The effect of rain upon the water table is greatly minimized and sometimes obliterated in the growing season, when rain water is largely dissipated by evaporation and transpiration. The highest level of the water table during the period of research from May 1965, to June 1966, was reached after the growing season in mid-October. The lowest level was reached during April just prior to the growing season when little precipitation was recorded for at least four months. A lag is present due to the time required for precipitation to recharge the water table. The large amount of rainfall recorded for September 1965 recharged the ground-water reservoir during October of the same year and accounts for the highest stage of the water table.

Streamflow. Runoff is defined as the water remaining from precipitation after losses from evaporation, transpiration, and seepage into the ground-water reservoir. Two aspects of runoff often carefully studied for hydrologic purposes are surface runoff and ground-water outflow.

The collection of runoff data requires installation and maintenance of gaging stations that record data of stream flow which is based on a continuous record of stages. Evaluation of these records in terms of stream discharge enables an operator to form a discharge rating curve. When an accurate rating curve is established, a rating table can be computed and applied to daily gage readings to establish the approximate discharge. A rating table is useful only as long as the relationship between stage and discharge remains constant.

Stage is defined as the height of the water surface at a given point along the river above any arbitrary datum, or gage zero. Stage is usually expressed in hundredths of feet and the zero point is selected at or slightly below the lowest low-water elevation known or anticipated at the time the gage was established. The actual elevation of the gage zero should always be determined with reference to suitable permanent benchmarks in the vicinity so that it can be reestablished if damaged by floods, and to permit the determination of relative water-surface elevations along the stream.

In the area under study, stream flow of the Big Blue River is controlled by the outflow from the gates of Tuttle Creek Dam and is regulated in an effort to maintain conservation pool level at 1075 feet while simultaneously supplying an adequate supply of water for navigation downstream. Outflow from each of the growing number of reservoirs in Kansas is regulated as part of a system controlled by the U.S. Army Corps of Engineers at Kansas City, Missouri.

Daily stream flow data from the Rocky Ford, Casement, and Highway U.S. 24 river gage stations on the Big Blue River are listed in the Appendix I, dating from March 1965 through May 1966. In addition, daily outflow (expressed in cubic feet per second) released from Tuttle Creek Reservoir, reservoir elevation, and precipitation is included.

Runoff from the drainage basin of the Big Blue River valley flows into the reservoir above the dam. This leaves only ten miles of uninterrupted drainage between the dam and the Kansas River. The usual swelling of a river after a moderate rainfall does not occur in the Big Blue River below Tuttle Creek Dam, and, therefore, an unusual situation exists.

Reservoir Elevation. A significant correlation between reservoir elevation and water-table elevations (Figs. 1 and 2) illustrates the dominating role that precipitation plays in ground-water recharge, even though stream flow is artificially controlled.

The elevation of the water body at Tuttle Creek Reservoir fluctuates in response to precipitation falling in areas upstream and upon the reservoir itself, and to the rate water is discharged through the gates. The rate of discharge into the Big Blue River is generally not increased until after the reservoir elevation has risen significantly; thus, a time lag results in the correlation between river stage and precipitation in Fig. 2.

Recharge

Recharge is defined as the addition of water to the zone of saturation. Recharge to the ground-water reservoir in the lower Big Blue River valley may occur in several ways: by direct infiltration from precipitation, by seepage of water from streams, and by subsurface inflow of water from adjacent areas.

Infiltration from Precipitation. Precipitation falling upon the ground surface may become either surface runoff or infiltration, depending upon whether or not the rain intensity exceeds the infiltration capacity. In the winter and spring when the ground is unfrozen and vegetation is dead or dormant, precipitation reaches the water table and replenishes the aquifer after the soil-moisture demand has been satisfied. Water reaching the water table begins to move to areas of low elevation, where the natural discharge of the aquifer supports streamflow.

Normally 67 percent of the annual rainfall is received from May through August, when the climate is characterized by high temperatures and plant growth is abundant. Much of the precipitation, therefore, is lost through evapo-transpiration.

Water that is not lost by evapo-transpiration, or runoff percolates downward into the soil zone. The soil will absorb moisture until the amount of water it contains is greater than can be held against the pull of gravity, and not until then will water move downward to the zone of saturation. This downward movement may be prevented by plant transpiration which, during the growing season, may deplete the soil moisture as rapidly as it can be replenished by precipitation. At the end of the growing season the moisture in the soil may be exhausted; water that enters the soil zone during the fall and winter tends to replenish the soil moisture. Under these conditions, the ground-water reservoir is recharged until the oncoming growing season again increases the rate of evapo-transpiration.

The infiltration capacity is the maximum rate at which a soil at any one time is capable of absorbing water. During periods in which the rainfall rate exceeds the infiltration capacity rain enters the soil at capacity rates (Wisler and Brater, 1959).

Vegetation retards runoff particularly during the growing season. Modern methods of terracing and contouring of farm land tend to reduce runoff and, therefore, may increase the rate of recharge to the soil and to the ground-water reservoir.

Numerous factors affect the infiltration rate. Infiltration depends upon the chemical-physical state of the sediments, and the chemical-hydraulic characteristics of the water in those sediments, both of which may vary with time. The infiltration rate is affected by the intensity, rate, and time of precipitation, depth to ground water, sediment (soil) texture and structure, condition of sediment surface and topography, vegetative cover, effects of freezing, inwash of fine material, compaction due to rain, man, and animals, distribution of soil moisture, chemical and physical nature of the water, percentage of entrapped air in the sediments, and atmospheric pressure.

The infiltration rate of a clean sandy soil is affected very little by rain compaction, while the surface of exposed clays can be worked into a nearly impermeable state in this manner. Vegetative cover protects the land from compaction by rain and thereby increases infiltration capacity. Crops such as corn, however, do not provide protection from rain compaction, and furnish only a negligible cover of organic matter. The soil of the Menoken

Terrace, which covers much of the floor of the Big Blue River valley, grades from a silty clay to a sandy loam, may cause infiltration rates to be relatively low. The infiltration rate is greatly affected by the permeability of the sediments. Thus, the critical zone controlling the rate of infiltration is the least permeable zone.

Lewis (1937) and Musgrave and Free (1937) pointed out that with an increase in the initial moisture content in tested samples, the infiltration rate accordingly decreases. This is probably caused by the retention of water in the smallest interstices from the initial supply, thereby reducing the rate of water percolation. In fine-textured materials, the swelling of clay accounts for part of the reduced infiltration rate.

The alluvium and terrace deposits along the Big Blue River valley are conducive to recharge because of the sandy nature of the deposits, the low relief, and the shallow depth to water. The annual recharge by infiltration of precipitation in this area is not known, but it probably is a small percentage of the total precipitation. The work of Lohman (1941, p. 45), however, may serve as a guide to the amount of annual recharge in the Big Blue River area. Lohman calculated that as much as ten percent of the annual precipitation contributed to ground-water recharge at Lawrence in the Kansas River valley. If this work is applicable to the Manhattan area recharge would average about three inches per year.

Seepage of Water from Streams. The scouring action of the Big Blue River tends to maintain a permeable outcrop area where the alluvial aquifer is in contact with the river. Stream water then will enter the aquifer, if the water level in the stream rises above the water in the aquifer. This phenomenon is recognized as bank storage. Water stored in the alluvium in this manner drains readily when the river level falls.

When a well is near the area of recharge, almost all changes in river level may be reproduced on a smaller scale as changes in ground-water level in wells. The fluctuations between river stage and ground-water level have a different magnitude, and there is a slight lag in the raising and lowering of water levels in well RL-14 (Fig. 1), from the fluctuations of the Big Blue River. It is obvious that there is a direct relation between river stage and ground-water level in wells near the river channel.

Subsurface Inflow of Water from Adjacent Areas. One of the objectives of this investigation was to determine the influence of Tuttle Creek Reservoir upon the ground-water reservoir in the Big Blue River valley below the dam. After a careful study, it can be concluded that there is recharge to the ground-water reservoir below the river pond area, but no appreciable recharge south of the east-west trending portion of the Big Blue River channel where the Casement Bridge river gage is located (Plates I, II, and III).

Three lines of evidence are presented to support the above conclusion: (1) the pressure relief wells located at the base of Tuttle Creek Dam; (2) the river pond; (3) the elevation of the water table below the river pond.

There are forty-three pressure relief wells arranged below and parallel to the axis of the dam, yielding water at a combined total of about 40 cubic feet per second. The pressure relief wells lower the piezometric surface sufficiently to reduce surface seepage and minimize soil creep. The piezometric surface is an imaginary surface coinciding with the hydrostatic pressure level of the water in the reservoir. If the piezometric surface lies above the ground surface, a well penetrating the aquifer will flow freely. It is suspected that a quantity of subsurface inflow seeps into the river pond, despite the two rows of pressure relief wells.

Excavation of construction material for the dam reached a depth of about 40 feet below ground level at the site of the river pond, and subsequent deposition of silt and clay have formed a relatively impermeable floor in the present pond, thereby appreciably reducing any recharge to the ground-water reservoir down-valley. When the river pond has been drained by opening Rocky Ford Dam, water has been observed welling up in the form of springs from the floor of the excavation (Personal communication, E. L. Dodson, U.S. Army Corps of Engineers). Most hydrostatic pressure not accounted for by the pressure relief wells is either released in the river pond, which cuts through the alluvial aquifer, or flows beneath the river pond thereby recharging ground-water levels in the area between the pond and the casement bridge over the Big Blue River.

The Rocky Ford Dam maintains a local high water table to the north, and pools water upstream at an elevation higher than that of the dam (1011.3 feet), including the river pond.

Discharge

Ground-water discharge is defined as the removal of water from the zone of saturation. In the Big Blue River valley, ground water is discharged by evaporation and transpiration, seepage into streams, and by wells.

Moore (1940) reported that a considerable part of the annual rainfall in Kansas, possibly more than 85 percent, is returned to the air by evaporation and transpiration from plants. Alfalfa probably has the most extensive deep-penetrating root system of any plant in the Big Blue River valley, and may penetrate the ground as much as thirty feet. This type of water-loving vegetation, including salt cedar, willow, and cottonwood, have root systems deep enough to reach the capillary fringe or water table. They have been named phreatophytes, from the Greek root-words meaning a "well plant". Most of the water discharged by transpiration and evaporation is lost from the soil zone within the zone of aeration.

The Big Blue River received water by seepage from the ground-water reservoir during most of this investigation. The contour maps in Plates I and II illustrate this fact by featuring a water table that slopes toward the river. It is felt that substantial quantities of ground-water discharge into the Big Blue River below the river pond area, and thus recharge from Tuttle Creek Reservoir is negligible south of the Casement Bridge portion of the Big Blue River.

Streamflow records account for about 3.5 inches per year of the average annual 33 inches of rainfall in Kansas. The recharging of underground reservoirs is partly offset by discharge into surface flow, computed at 0.5 inch per year (Moore, 1940). Sayre (1950) concluded that about 40 percent of the flow of surface streams in the United States is derived from ground-water discharge.

Water discharged from wells in the Big Blue River valley is utilized for domestic, irrigation, and stock purposes. The demand for water in the last sixteen years has rapidly risen with the increased use of large quantities of water for irrigation of crops during July and August. At lease nine irrigation wells are located within one-half mile of the Big Blue River in the area of study, excluding the Manhattan municipal wells, which have an average maximum pumping rate of about 1,000 gallons per minute. When pumping twenty-four hours a day during July and August, discharge by the irrigation wells exceeds recharge.

During the past century, the use of water has increased tremendously. In 1900 the use of water was less than 100 gallons a day per capita, but in 1950 the daily per capita rate of water use was more than 1,000 gallons (Fischel, p. 429).

Configuration

Maximum conditions of the water table from April 1965 through May 1966 were attributed to the unusually large amount of precipitation received during September 1965 (Fig. 1). As a result, maximum water-table elevations were recorded during October 1965, as shown on Plate I. After that time, the water table dropped three to four feet in most wells, until minimum conditions were recorded on April 18, 1966, (Plate II). This date was used because complete data were available at the time of analysis. It is assumed that if the present trend of precipitation continues, minimum conditions of the water table for 1966 will occur near the end of the growing season, in early September. Data for these two extremes of the water table are in Tables 1 and 2.

Smith (1959) constructed a contour map of the water table which included the Big Blue River valley. Most of his measurements were recorded on or near June 15, 1959, which is a relatively wet time of year. Smith reported the water level in some wells was as much as ten feet higher when measured in 1959 than in the summers of 1955 through 1957. He concluded the water table in the Big Blue River valley, as measured in observation wells during June 1957, was the highest since 1951.

A residual contour map on Plate III was formed by subtracting the June 1959 elevations from the June 6, 1965, water table elevations obtained by measuring depth to water. For the purpose of comparison, precipitation amounted to 8.30 inches six weeks prior to July 15, 1959, and 5.00 inches six weeks prior to June 6, 1965.

Although an area of large negative residuals in Plate III is located above a perched water table, the true water table was measured, since the wells which were inventoried penetrated the perched water table. The area is recharged by seepage from a drainage ditch. The large residuals are explained by the fact that only 1.83 inches of precipitation fell during May 1965, while 8.30 inches were recorded for May 1959. It is interesting to note the present water table is lower in the central portion of the valley and higher toward the sides of the valley. The northern negative residual area is probably a result of increased usage of water at Rocky Ford Trailer Park. Two weeks prior to June 15, 1959, only a trace of rainfall was recorded, whereas 2.93 inches were recorded for the same time interval prior to June 6, 1965.

The northern positive residual area immediately south of the river pond area is approximately 4.4 feet higher than it was prior to the pooling of Tuttle Creek Reservoir. Subsurface seepage from the reservoir and river pond which recharges the aquifer, is eventually discharged into the Big Blue River channel in the vicinity of the Casement Bridge river gage.

The position of the positive residuals near the sides, and negative residuals in the center of the valley can be explained by the time lag required for adjustment of the water table to variations in amounts of precipitation received. The groundwater reservoir in the center of the valley had not been significantly recharged when measurements were made on June 6, 1965, as it had been on June 15, 1959.

Table 1. Maximum stage of the water table

Maximum Conditions	Data	Remarks
Date: October 12, 1965		
River Stage (in feet)		
3 weeks prior	966.6 (2000 cfs)	rising
1-week period prior	1003.0 (10,000 cfs)	falling
October 12, 1965	1000.30 (6000 cfs)	falling
Reservoir Elevation (in feet)		
September 1, 1965	1075.35	rising
September 30, 1965	1084.81	falling
October 12, 1965	1081.40	falling
Precipitation (in inches)		
September total	9.77	high
October 1-12	0.00	low

EXPLANATION OF PLATE I

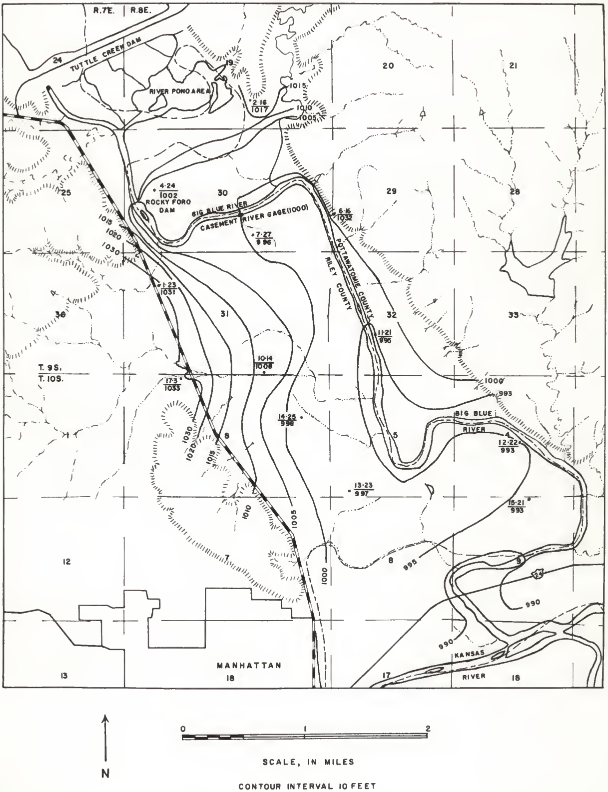
Contour map of the maximum conditions of the water table occurring on October 12, 1965, in the Big Blue River valley.

$$\frac{1\text{-}23}{1031} =$$

1-23 Well number - depth to water table below land surface

1031 elevation of water table

PLATE I



R.7E.
R.8E.
TUTTLE CREEK DAM
RIVER POND AREA
ROCKY FORD DAM
BIG BLUE RIVER
CASEMENT RIVER GAGE(1000)
POTTAWATOMIE COUNTY
RILEY COUNTY
T. 9S.
T. 10S.
BIG BLUE RIVER
KANSAS RIVER
MANHATTAN
2·16 / 1017
4·24 / 1002
6·16 / 1032
7·27 / 996
1·23 / 1031
11·21 / 995
10·14 / 1008
17·3 / 1033
14·25 / 998
12·22 / 993
13·23 / 997
15·21 / 993
1015
1010
1005
1020
1030
1000
995
993
990
24
19
20
21
25
30
29
28
36
31
32
33
1
6
5
4
12
7
8
9
13
18
17
16
0
1
2
SCALE, IN MILES
N
CONTOUR INTERVAL 10 FEET

Table 2. Minimum stage of the water table

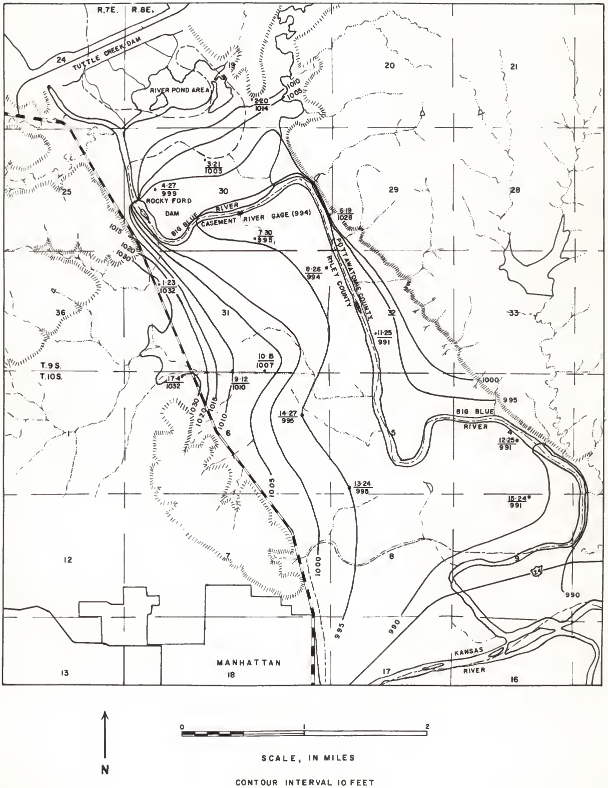
Minimum Conditions	Data	Remarks
Date: April 18, 1966		
River Stage (in feet)		
3 weeks prior	993.3 (300 cfs)	stable
1-week period prior	994.2 (600 cfs)	stable
April 18, 1966	994.2 (600 cfs)	stable
Reservoir Elevation (in feet)		
March 1, 1966	1075.40	stable
March 30, 1966	1075.60	stable
April 18, 1966	1075.71	falling
Precipitation (in inches)		
March	00.03	very low
April 1-18	00.81	normal

EXPLANATION OF PLATE II

Contour map of minimum conditions of the water table occurring on April 18, 1966, in the Big Blue River valley.

$\dfrac{\text{1-23}}{\text{1031}}$ = Well number - depth to water table below land surface / elevation of water table

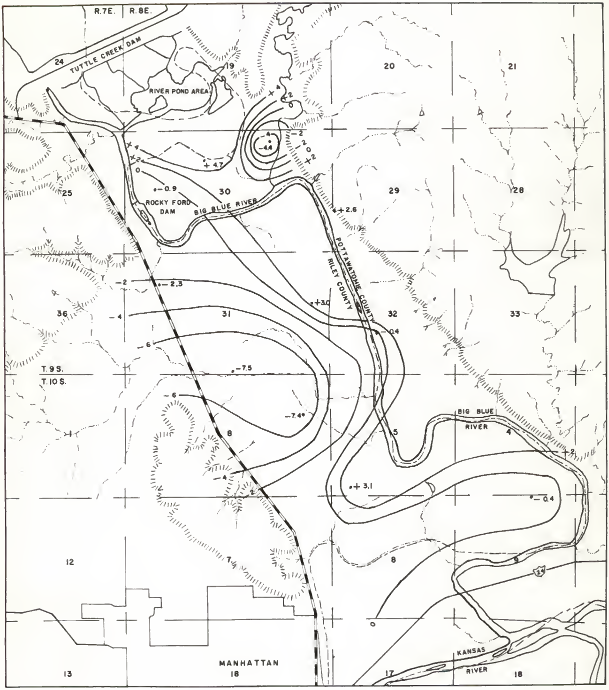
PLATE II


R.7E.
R.8E.
TUTTLE CREEK DAM
RIVER POND AREA
ROCKY FORD DAM
BIG BLUE RIVER
CASEMENT RIVER GAGE (994)
POTTAWATOMIE COUNTY
RILEY COUNTY
T.9S.
T.10S.
MANHATTAN
KANSAS RIVER
CONTOUR INTERVAL 10 FEET
SCALE, IN MILES

EXPLANATION OF PLATE III

Residual contour map comparing June 15, 1959, water-table elevations to those of June 6, 1965. A negative residual indicates a lower 1965 reading.

PLATE III



SCALE, IN MILES

CONTOUR INTERVAL 10 FEET

STATISTICAL TREATMENT OF HYDROLOGICAL DATA

It is reasonable to assume that more than one factor exerts an influence on fluctuations of the water table. In such a case the experimenter may use a set of variables X_1, $X_2, \ldots, X_k$ which he feels will predict another quantity Y with better results than would a single variable X. At this point the following questions arise: How many variables influence the system? Are these variables interrelated? For a given set of variables, which are the most important in controlling the phenomenon under study? Do the more important variables remain influential under all environmental conditions, or does their relative importance vary from one location, or one time, to another?

Fluctuations of the water table are caused by changes in the relative amounts of recharge to and discharge from an aquifer. Generally speaking, recharge and discharge are ultimately controled by the amount of precipitation received in a region over a given period of time.

Multiple linear regression was used as a method of analysis since it is usually impossible in natural systems to isolate variables which are truly independent; that is, which are in themselves neither interrelated nor mutually related to some other variable. If real independent variables existed, or if one could be isolated and held constant as other variables were alternately varied while their effects on the dependent noted, simpler methods of analysis could be used (Holmes and Goodell, 1964). Since this situation seldom occurs, multiple regression makes it possible to test for the cumulative correlations and partial correlation of all the measured "independent" variables against an established dependent variable.

The problem selected for analysis involves fluctuations of the water table expressed as a function of independent variables related to precipitation. Stated in functional notation, this relationship is

$$Y = f(X_1, X_2, X_3) \tag{1}$$

where the dependent variable (Y) is the elevation of the water table, and river stage (X_1), reservoir elevation (X_2), and precipitation (X_3) are the independent variables.

Applications of the above expression when used in a statistical model are of considerable interest in studying the availability and future development of water resources and in pure hydrological research.

Explanation of the Model. Data were subjected to statistical analysis consisting of multiple linear regression, which utilized the following model

$$Y = \mu_Y + e \tag{2}$$

$$\mu_Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \tag{3}$$

The B_i are unknown parameters of the independent variables described above and e is an error term. Data consisted of 20 observations of each of the four variables: elevation of the water table at observation wells and corresponding values for river stage, reservoir elevation, and precipitation. The model assumed for these data is

$$Y_i = B_0 + B_1X_{i1} + B_2X_{i2} + B_3X_{i3} \qquad (4)$$

It was assumed that X_1, X_2, and X_3 were measured without error and the e_i are uncorrelated random variables with mean zero.

The ground-water reservoir is not usually in a state of equilibrium due to the fluctuating variables which control recharge to and discharge from the ground-water body. It was found necessary to compensate for a lag in time between fluctuations of the three (X) variables and response of the water table to these variations. For this reason, data recorded prior to the measurement of well elevation were used for the three (X) variables. Data of representative wells RL-12 and RL-15 are presented in Tables 3 and 4 for conditions where a set of X variables approaches a state of equilibrium with the ground-water reservoir. The data were selected by means of the multiple regression process which measures the degree of adequacy a set of X variables predicts the Y variable. The following discussion is a brief outline of the linear multiple regression process. Detailed examples of the multiple regression technique are presented by Krumbein and Graybill (1965), Krumbein (1959, and Miller and Kahn (1962).

On the basis of observed data of Y, X_1, X_2, and X_3, values are estimated for B_0, B_1, B_2, and B_3 (denoting the estimates by $\hat{B}_0$, $\hat{B}_1$, $\hat{B}_2$, and $\hat{B}_3$, and D(Y) by $_Y$); the prediction equation is

$$\mu_Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \qquad (5)$$

If observed values for X_1, X_2, and X_3 from another set of data for which the model in Eq. (4) is assumed to be adequate, then μ_Y is the predicted water-table elevation in that well. To find the prediction equation (5), the estimators B_0, B_1, B_2, and B_3 must be obtained. This process is accomplished by computing the corrected sum of the squares and cross products of X_{i1}, X_{i2}, and X_{i3} each and with Y_i from the data in Tables 3 and 4.

A set of normal equations consisting of the corrected sum of squares and cross products as coefficients of the $\hat{B}_i$ are written in matrix form. A matrix is a rectangular array of pq elements in p rows and q columns. The system of linear equations represented by matrices yields, when solved by the Abbreviated Doolittle method, the desired $\hat{B}_i$ values of the prediction equation.

Discussion of Results. Fluctuations of well elevations for RL-12(Y) were best explained by data (see Table 3) recorded for X_1 and X_2 one week prior to and accumulative X_3 for a five week period prior to the measurement of well elevations (Y_1).

Data for RL-15 in Table 4 fit the model best when values of X_1 and X_2 were considered three weeks prior to and accumulative X_3 for a five week period prior to the date of well-elevation (Y_2) measurements.

RL-12 is approximately 0,10 mile and RL-15 0.43 mile from the Big Blue River. The time lag required for the water table to respond to changes in variables X_1 and X_2 is noticeable as distance from the river increases. Reservoir elevation (X_2) correlates to well elevation best as shown by the large

Table 3. River stage, reservoir elevation, precipitation, and water-table elevation of well RL-12

Date	River stage X_1, feet	Reservoir elevation X_2, feet	Precipitation X_3, inches	Well-water elevation Y_1, feet
06/06/65	1004.02	1079.17	4.06	993.60
09/01/65	993.86	1075.33	3.63	999.26
09/21/65	993.04	1077.02	8.53	992.80
10/12/65	1001.88	1084.90	7.70	994.60
10/19/65	998.93	1081.40	5.66	994.20
10/26/65	997.35	1079.23	4.52	993.70
11/04/65	993.82	1077.53	0.91	993.10
11/11/65	993.80	1077.30	0.64	992.80
11/16/65	993.79	1077.10	1.22	992.40
11/18/65	993.79	1076.98	1.22	992.32
11/23/65	991.56	1077.37	1.01	992.42
11/30/65	996.13	1077.30	0.58	992.65
12/15/65	992.85	1075.06	1.04	991.80
01/12/66	993.02	1075.50	2.39	992.03
02/03/66	993.04	1075.20	0.49	991.30
02/15/66	993.23	1075.00	1.00	991.55
03/01/66	995.12	1076.40	1.10	991.95
03/15/66	992.10	1075.20	1.15	991.10
04/18/66	993.07	1075.80	0.84	990.95
04/26/66	993.07	1075.66	0.87	990.95

Table 4. River stage, reservoir elevation, precipitation, and water-table elevation of well RL-15

Date	River stage X_1, feet	Reservoir elevation X_2, feet	Precipitation X_3, inches	Well-water elevation Y_2, feet
06/06/65	995.49	1076.08	4.06	991.60
09/01/65	994.66	1076.20	4.54	992.20
09/21/65	993.77	1075.38	7.53	991.80
10/12/65	996.66	1079.64	5.64	993.30
10/19/65	995.92	1084.65	5.66	993.40
10/26/65	1002.62	1084.80	4.52	993.15
11/04/65	998.15	1080.70	0.91	992.75
11/11/65	998.01	1078.60	0.64	992.55
11/16/65	994.60	1077.60	1.22	992.25
11/18/65	994.50	1077.55	1.22	992.25
11/23/65	994.54	1077.34	1.01	992.05
11/30/65	994.53	1077.10	0.58	992.10
12/15/65	997.95	1076.80	0.94	991.40
01/12/66	993.74	1075.18	2.39	989.95
02/03/66	993.78	1075.48	0.49	990.85
02/15/66	993.78	1075.26	1.00	990.90
03/01/66	993.77	1076.13	1.10	991.10
03/15/66	995.86	1076.40	1.15	990.72
04/18/66	992.94	1075.50	0.84	990.60
04/26/66	992.93	1075.70	0.87	990.50

regression coefficient and high confidence level of the Student's t test (Table 5). It is concluded that river elevation (X_1) and precipitation (X_3) are not much more effective in predicting water-table elevation than is the variable X_2 alone.

The $\hat{B}_i$ coefficients, multiple correlation coefficient ($\hat{R}^2$), and prediction equation of Table 5 were obtained through the aid of a 1410 IBM computer program utilizing the multiple regression analysis of a linear model. The four basic steps performed by a computer in running a program are: (1) read in the directions; (2) feed in the data; (3) compute the quantities; (4) write out the results. The copy of the 1410 Fortran program is in the Appendix.

The estimate of B_2 for RL-14 (Table 5) is 0.27 feet, which means that the average rate of change of water-table elevation per unit change in reservoir elevation is estimated to be 0.27 feet per feet.

The standard errors of B_i were calculated by taking the square root of the estimated variance times the corresponding B_i element of the inverse of the sums of square matrix, obtained by the Abbreviated Doolittle method (Krumbein and Graybill, p. 281-282). Variance is the square of the standard deviation (6) of a population. The estimated variance for RL-12 was 0.24 and 0.37 for RL-15. The standard errors serve as a measure of how much the regression coefficients may vary from the true population coefficients as a result of repeated sampling. The smaller the standard error allowed for a regression coefficient, the greater is the confidence that it represents a true parameter.

Table 5. Regression of water-table elevations on the variables river stage, reservoir elevation, and precipitation

Well RL-12 (Y_1)

Variable	Regression Coefficient	Standard error	Student's t
River stage (X_1)	0.05	0.06	0.82
Reservoir elevation (X_2)	0.27	0.08	3.25**
Precipitation (X_3)	0.09	0.05	1.80*
Constant (B_0)	665.45		

Prediction equation: $\hat{\mu}_Y = 665.45 + 0.05X_1 + 0.27X_2 + 0.09X_3$ (6)

R^2	0.812

Well RL-15 (Y_2)

River stage (X_1)	0.02	0.09	0.22
Reservoir elevation (X_2)	0.24	0.08	3.00**
Precipitation (X_3)	0.09	0.07	1.29
Constant (B_0)	705.90		

Prediction equation: $\hat{\mu}_Y = 705.90 + 0.02X_1 + 0.24X_2 + 0.09X_3$ (7)

R^2	0.684

** 99.5% confidence interval of t distribution

* 95% confidence interval of t distribution

Values of the Student's t test in Table 5 are derived by dividing the regression coefficients·by their corresponding standard eerors. These values are compared with a table of t values to test for the significance of the regression coefficients at particular confidence levels. Reservoir elevation (X_2) is significant at the 99.5 percent level for both wells and precipitation (X_3) of well RL-14 is significant at the 95 percent probability level.

Tables 6 and 7 list the observed, fitted (predicted) values and the deviations of the fitted data from the observed well elevations for RL-14 and RL-15 respectively. The fitted data were derived from the prediction equations of Table 5. These data are represented graphically in Figures 3 and 4.

The prediction equation formed for the data of representative well RL-12 should apply to wells located within 0.25 mile of the Big Blue River. Thus water table elevations may be predicted by substituting proper data for X_1, X_2, and X_3 in Eq. (6). Ground-water elevations in wells located from about 0.25 to 0.60 mile from the Big Blue River are obtained from Eq. (7), the prediction equation of representative well RL-15.

A measure of the adequacy of the X variables in predicting water-table elevation (μ_Y) is indicated by the multiple regression coefficient (R^2). Only 68.40 percent of the variation of water-table fluctuations are accounted for by the prediction equation representing RL-15, whereas 81.20 percent is explained by the equation for RL-12. This can be attributed to (1) the fact that well RL-15 is 0.43 mile and RL-12 is 0.10 mile from the river; (2) a higher order (non-linear) relationship between

Table 6. Fitted data of RL-12 for well elevations

Observed value	Fitted value	Deviation
991.60	991.56	.04
992.20	991.62	.58
991.80	991.67	.13
993.30	992.60	.70
993.40	993.81	-.41
993.15	993.89	-.74
992.75	992.46	.29
992.55	991.92	.63
992.25	991.65	.60
992.25	991.64	.61
992.05	991.57	.48
992.10	991.47	.63
991.40	991.51	-.11
989.95	991.15	-1.20
990.85	991.05	-.20
990.90	991.04	-.14
991.10	991.26	-.16
990.72	991.38	-.66
990.60	991.07	-.47
990.50	991.12	-.62

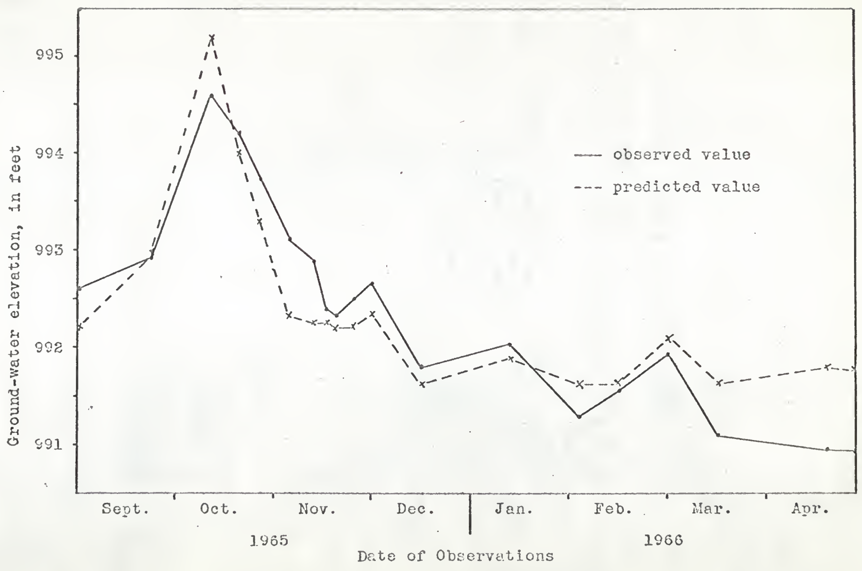


Fig. 3.--Comparison of predicted and observed values of water elevations for Well RL-12.

Table 7. Fitted data of RL-15 for well elevations

Observed value	Fitted value	Deviation
993.60	993.51	.09
992.60	992.22	.38
992.80	992.83	-.03
994.60	995.29	-.69
994.20	994.03	.17
993.70	993.27	.43
993.10	992.33	.77
992.80	992.24	.56
992.40	992.24	.16
992.32	992.21	.11
992.42	992.20	.22
992.65	992.34	.31
991.80	991.63	.17
992.03	991.88	.15
991.30	991.63	-.33
991.55	991.63	-.08
991.95	992.10	-.15
991.10	991.64	-.54
990.95	991.82	-.87
990.95	991.79	-.84

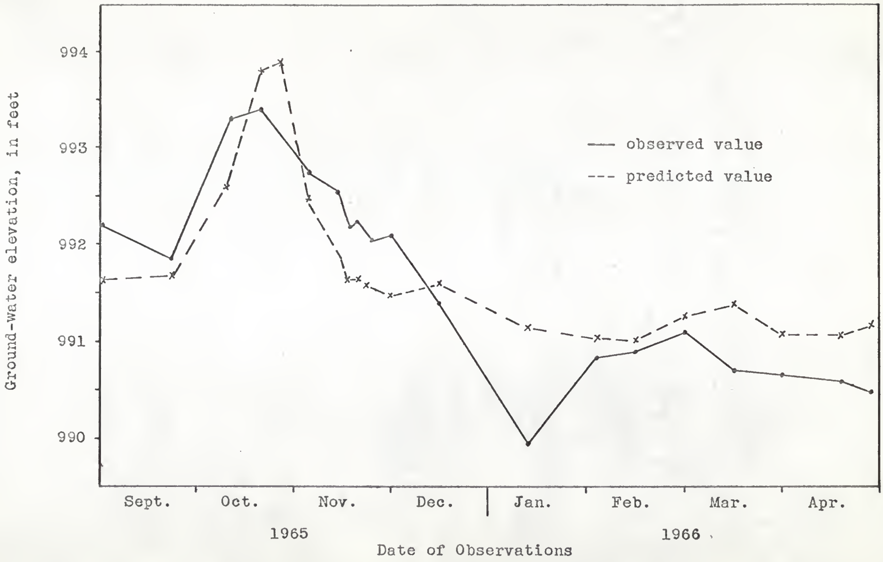


Fig. 4--Comparison of predicted and observed values of water elevations for Well RL-15.

water-table fluctuations and independent variables; (3) factors not measured; (4) to experimental errors, or errors in procedure.

By means of analysis of partial correlation and the use of multiple correlation (R^2), the magnitude of the contribution of each X variable to the variation in Y can be estimated.

The matrices of the simple correlation coefficients below were obtained from the data of Tables 3 and 4 by matrix methods adapted for machine use (as illustrated in Krumbein and Graybill, p. 264-270).

Correlation Matrix for RL-12 (Y_1) Run #13

$$\begin{array}{cccc} X_1 & X_2 & X_3 & Y_1 \\ \end{array}$$
$$\begin{bmatrix} 1.0000 & .7930 & .5017 & .7569 \\ .7930 & 1.0000 & .5855 & .8780 \\ .5017 & .5855 & 1.0000 & .6635 \\ .7569 & .8780 & .6635 & 1.0000 \end{bmatrix}$$

Correlation Matrix for RL-15 Run #19

$$\begin{array}{cccc} X_1 & X_2 & X_3 & Y_2 \\ \end{array}$$
$$\begin{bmatrix} 1.0000 & .7545 & .1901 & .6163 \\ .7545 & 1.0000 & .3520 & .8060 \\ .1901 & .3520 & 1.0000 & .4533 \\ .6163 & .8060 & .4533 & 1.0000 \end{bmatrix}$$

The $\hat{R}^2$ measures the effectiveness of two or more X variables simultaneously as a predictor of Y. The computed value of $\hat{R}^2$, for the data in Table 3 is 0.8120, and the quantity $100\hat{R}^2 = 81.20$ represents the percentage of the total corrected sums of squares accounted for by X_1, X_2, and X_3 acting together. Therefore, approximately 19 percent of the variability of Y is not accounted for, and the prediction equation (6) is, in this case, quite good.

By computing the partial correlation coefficients $r_{Y3.2}$ and $r_{Y1.23}$, it can be estimated how much better X_1, X_2, and X_3 together are as predictors than X_2 alone. The two factors to the left of the dot in the subscript $r_{Y3.2}$ are the factors whose correlation is measured, in this case Y and X_3, and those to the right of the dot indicate those that are held fixed. This in effect first holds X_2 statistically constant and examines the effect of X_3 in the presence of X_2. The same applies to $r_{Y1.23}$ (Krumbein and Graybill, pp. 295-299).

The value of $r_{Y3.2}$ is 3.40. The meaning of this coefficient can be seen by considering $r_{Y2} = 0.8780$, which means that X_2 acting alone accounts for $100r_{Y2}^2$ or 77.08 percent of the total corrected sum of squares of Y. In other words, when X_2 alone is considered, the unexplained variation is 22.92 percent. The quantity $100r_{Y3.2}^2 = 11.56$ percent means that X_3 in the presence of X_2 accounts for 2.67 percent of the total corrected sum of squares of Y. On the same basis, X_3 in the presence of X_1 and X_2 accounts for 1.45 percent of the unexplained variation. The sum of these percentages, $77.08 + 2.67 + 1.45 = 81.20$, is the same value obtained by using R^2 as a measure of the effectiveness of the three X variables taken together for RL-12.

It was surprising to find that reservoir elevation (X_2) most accurately predicted well elevation (Y). Many applications of this study can be extended for future work in determining the factors affecting water-table fluctuations below a reservoir.

Table 8. Records of wells in Big Blue River Valley

Well No.	Location	Owner or Tenant	Type of Well[1]	Measuring Point: Description	Measuring Point: Distance above land surface (feet)	Measuring Point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	Date of Measurement
	T.9S.,R.8E							
RL-1	SWNW Sec 31	Standard Sch.	D	Pump base	0.50	1054.40	23.00	9-21-65
RL-2	SWNE Sec 19	R. McCoy	N	Casing top	0.60	1034.10	21.00	6-06-65
RL-3	SENW Sec 30	G. Borg	I	Pump base	0.70	1024.10	20.10	2-15-66
RL-4	NWSW Sec 30	G. Borg	N	Basement floor	-7.00	1019.20	18.90	6-06-65
RL-5	NWNE Sec 30	V. Borg	D	Casing top	-4.70	1021.00	18.00	3-01-66
PT-6	NESE Sec 30	G. & V. Borg	N	Cement Platform	0.00	1047.00	19.50	6-06-65
RL-7	SWSE Sec 31	Gooche's farm	I	Outlet Orifice	0.60	1025.50	28.00	6-06-65
RL-8	NENE Sec 31	Gooche's farm	I	pump base	0.60	1020.10	24.20	11-04-65
RL-9	SWSE Sec 31	C. Drumm	D	concrete pit top	0.65	1024.00	18.90	5-03-65
RL-10	SWSE Sec 31	Luke's Rod & Gun	D,C	Brick pit top	0.00	1022.30	15.20	5-03-65

Table 8. Records of wells in Big Blue River Valley (continued)

Well No.	Location	Owner or Tenant	Type of Well[1]	Measuring Point: Description	Measuring Point: Distance above land surface (feet)	Measuring Point: Height above mean sea level (feet)	Depth to water level below measuring point (feet)	date of Measurement
PT-11	NESW Sec 32	J. Scandlin	N	casing top	0.60	1017.00	23.60	11-04-65
	T.10S.,R.8E							
RL-12	NWSE Sec 4	P. Irvine	I	pump base	0.80	1017.10	23.50	6-06-65
RL-13	SWSW Sec 5	G. Kiel	N	concrete pit top	0.00	1019.30	25.30	5-08-65
RL-14	SENE Sec 6	B. Brooks	I	pump base	1.50	1023.00	26.90	6-06-65
RL-15	NWSE Sec 9	Moyer	I	pump base	0.30	1015.00	23.40	6-06-65
RL-16	NWNW Sec 9	R. Nixon	N	basement floor	-7.00	1001.00	19.70	5-08-65

[1]Type of well: C, commercial; I, irrigation; D, domestic; N, none (observation).

Table 9. Depth to ground-water table in feet and tenths measured in observation wells*

Date	Well Number										
	1.	2.	4.	6.	7.	8.	10.	11.	12.	13.	14.	15.
6/6	24.0	21.0	18.9	19.5	28.0	----	----	----	23.5	----	26.9	23.4
9/1	----	17.8	17.9	21.0	29.4	----	----	----	24.5	----	26.8	22.8
9/21	23.0	18.1	18.3	13.9	29.0	----	----	----	24.3	----	26.8	23.2
10/2	23.0	12.9	18.4	13.5	28.6	----	13.8	23.1	----	23.4	26.5	22.5
10/12	23.1	17.0	17.4	15.5	27.2	----	----	21.6	22.5	22.7	25.1	21.7
10/19	23.1	18.0	17.1	15.9	27.3	----	----	22.1	22.9	22.5	25.3	21.6
10/26	23.1	18.9	17.2	16.5	28.0	----	----	22.7	23.4	22.6	25.7	21.9
11/4	23.3	19.7	17.6	17.0	28.7	24.2	15.1	23.6	24.0	22.8	26.1	22.3
11/11	23.2	20.1	17.9	17.1	29.0	24.4	14.8	23.6	24.3	22.6	26.2	22.5
11/16	23.2	20.3	18.2	17.3	29.6	24.7	14.8	24.2	24.7	22.8	26.6	22.8
11/18	----	20.4	18.2	----	29.7	24.8	----	----	24.8	22.8	26.6	22.8
11/24	23.2	20.6	18.5	17.5	29.2	24.5	14.9	23.8	24.7	22.7	26.5	23.0
11/30	23.3	20.8	18.4	17.7	29.2	24.7	----	23.5	24.5	22.9	26.4	22.9
12/15	23.3	21.0	18.9	18.3	29.7	25.2	15.0	----	25.3	23.2	27.1	23.6
1/12	23.0	19.3	19.5	15.9	29.9	25.1	----	25.1	25.1	23.1	27.1	25.1
2/3	23.0	19.9	19.9	16.4	30.1	25.9	14.9	24.9	25.8	23.3	27.5	24.2
2/15	22.9	20.1	19.9	16.7	28.8	25.7	----	24.7	25.6	23.3	27.2	24.1
3/1	23.0	20.6	19.5	17.1	29.5	25.4	15.0	24.4	25.2	23.5	27.1	23.9
3/15	23.1	20.8	19.9	17.9	30.4	26.1	15.1	25.4	26.0	23.7	27.8	24.3
4/18	23.2	20.8	20.2	18.8	30.7	26.4	15.0	25.6	26.2	23.9	28.0	24.4
4/26	23.2	20.9	20.1	----	30.6	----	15.0	----	26.2	24.0	28.0	24.5

* From measuring point (see Table 8)

CONCLUSIONS

Ground-water levels in the Big Blue River valley below Tuttle Creek Reservoir are ultimately maintained by recharge into the alluvial aquifer from factors controlled by precipitation. It was found that quantities of precipitation received correlate significantly to fluctuations of reservoir elevation and river stage. Recharge is mainly from the valley sides and the Tuttle Creek Reservoir river pond area as illustrated by water-table contours flexing upstream and crossing the valley south of the river pond. However, river stage influences the amount of recharge to and discharge from the ground-water reservoir. River stage is in turn controlled by reservoir elevation, which usually dictates the amount of outflow from the reservoir by a direct relationship. Precipitation does not influence river stage as it would normally because runoff from the valley drainage basin is controlled by Tuttle Creek Reservoir. The reservoir stabilizes river flow by releasing storm water at a conservative rate, nearly eliminating high water after heavy rainfall.

Fluctuations of the water table were analyzed by a multiple regression technique applied to a linear model. The theory of regression develops a relationship between a set of variables X_1, $X_2, \ldots X_k$, and the mean value of another variable Y, observable with them.

$$Y = f(X_1 \ldots, X_k)$$

is the regression equation of Y on $X_1, \ldots, X_k$. This method of analysis has applications in a number of geological situations where empirical relations are sought between some dependent variable and a selected set of independent variables that are believed to control the event under study. The analytical results may be used to guide future experimentation or to provide a basis for predicting values of the dependent variable associated with given values of the independent variables.

Although an effort has been made to form some generalizations about water-table fluctuations, this investigation was intended to begin work on a general study of recharge in the major Kansas river valleys and to present a method of analysis for subsequent work. It is evident that generalizations about fluctuations of the water table based on field studies must take into consideration the physical meaning of the variables included in the study, the reliability of the measurements made, and the statistical meaning of the random sample as a representation of the population.

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APPENDIX I

Daily Records of River Stage, Reservoir Elevation, and Precipitation from April 1965 to June 1966 for Big Blue River Valley below Tuttle Creek Reservoir

MARCH 1965

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	1.3	3.83	6.24	1500	1028.73	1.19
2	1.3	3.71	6.99	1500	1082.59	T
3	1.3	3.73	6.57	1500	1084.79	T
4	1.3	3.75	6.55	1500	1085.42	T
5	1.3	3.75	6.21	1500	1085.76	T
6	1.0	3.76	6.01	1500	1085.95	T
7	1.0	3.75	5.77	1500	1086.12	T
8	1.0	3.76	5.59	1500	1016.26	
9	1.0	3.75	5.36	1500	1086.38	
10	1.0	3.75	5.25	1500	1086.59	
11	1.6	4.98	5.77	2500	1086.67	
12	3.6	9.68	7.98	7500	1086.28	
13	2.8	7.56	6.94	5000	1086.40	
14	2.8	7.56	6.94	5000	1086.50	0.12
15	2.8	7.55	6.93	5000	1086.49	
16	2.8	7.52	6.89	5000	1086.32	
17	2.8	7.53	6.95	5000	1086.61	1.15
18	3.6	9.58	7.98	7500	1085.90	T
19	5.0	13.40	10.32	12000	1085.50	
20	4.3	11.58	9.2	10000	1084.60	
21	4.3	11.53	9.14	10000	1083.70	
22	4.3	11.51	9.12	10000	1083.00	
23	3.8	9.47	7.96	8000	1082.50	0.02
24	3.8	9.47	7.91	8000	1081.80	T
25	4.5	12.04	9.37	10000	1080.80	T
26	4.9	13.06	10.01	12000	1079.60	T
27	4.4	11.88	9.26	11000	1078.40	
28	3.7	9.86	8.07	8000	1077.70	
29	3.4	9.13	7.63	7000	1076.90	T
30	2.4	6.52	6.22	4000	1076.70	
31	2.0	5.74	5.74	3000	1076.50	

[1] Zero point elevation in feet
Rockyford: 1011.30
Casement: 991.86
Highway No. 24: 985.96

[2] Monthly records for local stations:
Tuttle Creek: 2.48
Agronomy Farm: 2.06
Manhattan No. 2: 2.50
Trace $\leq$ 0.05 inch

APRIL 1965

(outline for Appendix I)

Date	River Gages: Rockyford	River Gages: Casement Bridge	River Gages: Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	1.0	4.31	5.03	2000	1076.40	
2	1.1	4.28	5.01	2000	1076.32	0.05
3	1.1	4.42	4.99	2000	1076.33	T
4	1.2	4.20	5.01	2000	1076.31	T
5	1.1	4.20	5.00	2000	1076.26	T
6	1.1	4.12	4.99	2000	1076.31	0.08
7	1.1	4.12	5.04	2000	1076.29	
8	1.1	4.40	5.13	2000	1076.32	
9	1.1	4.29	5.04	2000	1076.49	
10	1.1	4.29	4.99	2000	1076.73	
11	1.1	4.36	4.96	2000	1076.84	
12	1.1	4.34	4.93	2000	1077.05	
13	1.1	4.34	4.97	2000	1076.91	
14	1.1	4.32	5.01	3000	1076.94	0.15
15	1.1	4.39	5.71	3000	1076.70	0.20
16	1.8	5.55	5.66	3000	1076.60	
17	1.8	5.54	5.64	3000	1076.13	
18	1.8	5.53	5.63	3000	1075.94	
19	1.8	5.52	5.59	3000	1075.80	
20	2.0	5.52	5.55	3000	1075.72	
21	1.8	5.51	5.52	3000	1075.50	
22	0.4	2.80	4.20	1000	1075.47	
23	0.5	1.77	3.62	500	1075.54	
24	0.5	1.87	3.63	500	1075.62	T
25	0.3	1.91	3.77	500	1075.72	0.82
26	0.5	1.83	3.69	500	1075.65	
27	0.5	1.88	3.68	500	1075.70	
28	0.5	1.84	3.67	500	1075.75	
29	0.5	1.85	3.66	500	1075.75	
30	0.5	1.84	3.62	500	1075.75	

[2]Monthly records for local stations:
Tuttle Creek: 1.89
Agronomy Farm: 1.48
Manhattan No. 2: 1.64

MAY 1965

(outline for Appendix I)

Date	River Gages: Rockyford	River Gages: Casement Bridge	River Gages: Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	0.5	1.85	3.59	500	1075.70	
2	0.5	1.86	3.59	500	1075.70	
3	0.5	1.93	3.66	500	1075.80	
4	0.5	1.93	3.68	500	1075.80	
5	0.7	2.33	3.43	700	1075.85	0.50
6	0.7	3.14	4.13	1000	1075.86	
7	0.5	2.83	4.11	1000	1075.82	
8	0.5	1.95	3.66	500	1075.87	
9	0.5	1.94	3.67	500	1075.97	0.23
10	0.5	1.91	3.60	500	1076.00	
11	0.5	1.92	3.61	500	1076.14	T
12	0.5	1.92	3.73	500	1076.24	
13	1.4	3.64	4.73	1500	1076.26	
14	1.5	4.00	4.89	2000	1076.23	0.45
15	1.5	4.00	4.82	2000	1076.15	0.03
16	1.4	3.99	4.77	2000	1076.08	
17	1.5	3.99	4.74	2000	1075.95	
18	1.1	2.90	4.17	1000	1075.99	
19	1.1	2.89	4.12	1000	1075.99	0.07
20	1.1	2.89	4.08	1000	1075.97	
21	1.1	2.90	4.06	1000	1075.98	
22	1.1	2.90	4.07	1000	1075.97	
23	1.1	2.89	4.07	1000	1075.97	
24	1.1	2.90	4.06	1000	1075.90	
25	1.1	2.80	4.05	1000	1076.34	0.31
26	1.1	2.92	4.03	1000	1077.75	0.24
27	2.0	5.33	5.32	3000	1079.17	
28	2.0	5.37	5.49	3000	1080.29	
29	5.0	13.33	10.08	12000	1079.62	
30	5.1	13.26	10.23	12000	1079.17	
31	5.1	13.26	10.23	12000	1078.10	

[2]Monthly records for local stations:
Tuttle Creek: 1.83
Agronomy Farm: 1.93
Manhattan No. 2: 2.39

JUNE 1965

(outline for Appendix I)

Date	River Gages: Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip- itation[2]
1	5.1	13.23	10.49	1200	1077.80	1.17
2	5.1	10.31	13.14	12000	1076.34	
3	3.9	10.38	8.86	8000	1076.20	
4	3.4	8.80	8.37	6000	1076.10	
5	3.2	8.42	7.91	6000	1076.50	1.06
6	3.2	8.39	7.49	6000	1076.70	0.15
7	3.2	8.39	7.83	6000	1076.50	
8	3.2	8.39	8.16	6000	1076.40	0.57
9	3.2	8.40	9.19	6000	1076.00	0.03
10	0.6	2.41	7.80	500	1076.20	1.06
11	0.6	5.58	11.46	500	1076.97	
12	0.6	2.79	8.25	500	1078.14	0.85
13	1.8	5.05	8.64	2500	1079.00	
14	1.8	4.99	8.26	2500	1080.15	0.55
15	1.8	5.01	8.43	2500	1081.00	
16	2.4	6.55	8.23	4000	1081.70	
17	3.2	8.43	8.61	6000	1082.10	
18	3.2	8.43	8.74	6000	1081.65	
19	3.2	8.43	8.80	6000	1081.60	
20	3.2	8.41	8.46	6000	1081.58	
21	3.2	8.38	8.16	6000	1081.40	T
22	3.2	8.35	8.02	6000	1081.00	
23	3.2	8.33	7.90	6000	1079.70	
24	3.2	8.32	7.88	6000	1079.60	
25	3.2	8.29	7.90	6000	1078.87	0.03
26	3.2	8.32	8.02	6000	1078.60	0.80
27	3.2	8.57	11.51	6000	1078.10	1.35
28	3.2	11.07	15.24	6000	1080.20	3.80
29	0.7	6.56	12.45	500	1081.60	
30	0.6	6.46	12.31	500	1083.22	0.45

[2]Monthly records for local stations:

Tuttle Creek: 11.87
Agronomy Farm: 11.62
Manhattan No. 2: 12.01

JULY 1965

(outline for Appendix I)

Date	River Gages: Rockyford	River Gages: Casement Bridge	River Gages: Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	0.6	4.78	10.69	500	1085.80	
2		6.68	10.72	6000	1087.97	T
3	0.6	4.43	10.70	500	1090.90	
4	0.6	3.19	8.75	500	1092.80	0.05
5	0.6	2.46	7.27	500	1093.90	
6	3.2	8.62	10.03	6000	1094.30	0.94
7	3.2	8.57	10.82	6000	1094.40	
8	4.4	12.31	13.37	10000	1094.00	
9	4.5	13.47	13.37	12000	1093.30	0.09
10	4.9	13.33	12.80	12000	1092.00	T
11	5.0	13.24	12.27	12000	1091.80	T
12	4.9	13.18	11.94	12000	1090.20	T
13	4.9	13.11	11.70	12000	1089.40	
14	5.7	15.22	12.62	15000	1088.00	
15	5.7	15.14	12.44	15000	1086.70	
16	6.2	16.56	13.20	17500	1085.00	
17	6.1	16.45	13.25	17500	1083.00	T
18	6.1	16.34	12.97	17500	1081.70	
19	6.1	16.21	12.74	17500	1080.00	T
20	3.4	9.5	9.3	7000	1079.40	0.09
21	0.6	2.77	6.66	500	1079.86	
22	0.6	2.71	6.11	500	1080.00	
23	0.6	2.68	5.99	500	1080.20	
24	0.6	2.67	6.32	500	1080.40	
25	1.9	5.79	7.66	3000	1080.30	
26	3.0	7.83	8.33	5000	1080.00	
27	3.7	9.61	9.13	7000	1079.50	1.02
28	3.7	9.59	9.03	7000	1078.60	0.50
29	3.7	9.56	8.95	7000	1078.00	
30	3.7	9.53	8.84	7000	1077.30	
31	1.6	4.73	6.78	2000	1077.00	

[2]Monthly records for local stations:
Tuttle Creek: 2.69
Agronomy Farm: 3.66
Manhattan No. 2: 3.27

AUGUST 1965

(outline for Appendix I)

	River Gages[1]					
Date	Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precipitation[2]
1	1.6	4.67	6.76	2000	1076.90	
2	1.6	4.63	6.76	2000	1076.80	
3	1.6	4.57	6.66	2000	1076.60	
4	1.6	4.54	6.53	2000	1076.60	
5	1.0	3.28	5.97	2000	1076.50	
6	1.0	3.25	5.89	1000	1076.39	T
7	1.0	3.24	5.80	1000	1076.39	0.90
8	1.0	3.18	5.61	1000	1076.40	
9	1.0	3.17	5.47	1000	1076.30	
10	1.0	3.16	5.37	1000	1076.20	
11	1.0	3.16	5.26	1000	1076.20	
12	1.0	3.13	5.14	1000	1076.20	
13	1.0	3.14	5.08	1000	1076.00	
14	1.3	3.82	5.34	1500	1075.88	
15	1.3	3.83	5.31	1500	1075.80	
16	1.3	3.82	5.28	1500	1075.60	T
17	1.3	3.82	5.26	1500	1075.50	0.11
18	1.3	3.87	5.33	1500	1075.60	1.62
19	1.0	3.11	4.90	1000	1075.00	0.09
20	1.0	3.11	4.92	1000	1075.42	T
21	1.0	3.11	4.95	1000	1075.39	0.03
22	1.0	3.10	4.93	1000	1075.40	T
23	1.0	3.10	5.07	1000	1075.38	0.02
24	1.0	3.23	5.52	1000	1075.38	0.90
25	1.0	3.10	5.35	1000	1075.33	
26	0.6	2.28	4.97	500	1075.36	
27	0.6	2.27	5.05	500	1075.39	
28	0.6	2.26	4.90	500	1075.38	
29	0.6	2.27	4.82	500	1035.20	0.07
30	0.6	2.27	4.70	500	1075.38	0.10
31	0.6	2.27	4.63	500	1075.38	0.20

[2] Monthly records for local stations:
Tuttle Creek: 4.04
Agronomy Farm: 2.95
Manhattan No. 2: 2.95

SEPTEMBER 1965

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	0.6	2.28	4.69	500	1075.35	0.09
2	0.6	2.27	4.63	500	1075.32	
3	0.9	2.95	4.91	1000	1075.22	
4	0.9	3.05	5.05	1000	1075.31	1.43
5	0.9	2.98	4.81	1000	1075.44	
6	0.9	2.97	4.78	1000	1075.59	0.08
7	0.9	2.97	4.87	1000	1075.67	
8	0.9	2.97	5.16	1000	1075.66	
9	0.6	2.26	4.86	500	1075.75	
10	0.7	2.41	5.27	500	1076.20	1.77
11	0.7	2.27	4.98	500	1076.41	
12	0.7	2.27	5.31	500	1076.52	
13	0.7	2.29	5.29	500	1076.82	0.45
14	0.7	2.28	5.28	500	1077.02	T
15	1.0	2.96	4.91	1000	1077.16	
16	1.6	4.30	5.33	2000	1077.11	
17	1.6	4.31	5.25	2000	1077.11	T
18	1.6	4.32	5.38	2000	1077.07	0.88
19	1.6	4.36	5.97	2000	1077.08	0.46
20	1.6	4.35	5.90	2000	1077.15	0.23
21		5.16	9.50	2000	1079.64	3.55
22	0.8	4.81	10.62	500	1082.74	
23	1.5	4.38	9.91	1000	1084.15	
24	1.5	4.85	9.11	2000	1084.29	
25	1.5	4.47	7.83	2000	1084.47	
26	1.5	4.46	7.64	2000	1084.63	
27	1.5	4.43	7.27	2000	1084.59	0.03
28	1.5	4.42	7.06	2000	1084.65	0.03
29	1.5	4.40	6.61	2000	1084.68	
30	1.5	4.37	6.25	2000	1084.81	0.27

[2]Monthly records for local stations:
Agronomy Farm: 8.47
Manhattan No. 2: 8.39
Tuttle Creek: 9.27

OCTOBER 1965

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1		6.51	7.22	4000	1084.31	
2	2.5	6.51	7.14	4000	1084.63	
3	3.3	8.49	8.06	6000	1084.45	
4	3.8	10.24	9.00	8000	1083.75	
5		11.12	9.58	10000	1084.60	
6	4.2	11.13	9.64	10000	1085.00	
7	4.2	11.11	9.45	10000	1084.70	
8	4.2	11.09	9.36	10000	1084.00	
9	4.2	11.00	9.28	10000	1083.30	
10	4.2	10.96	9.23	10000	1082.60	
11	4.2	10.94	9.19	10000	1081.80	
12	3.1	8.17	7.79	6000	1081.40	
13	2.6	6.62	7.08	4000	1081.10	
14	2.6	6.65	7.16	4000	1080.70	0.21
15	2.6	6.62	7.04	4000	1080.50	
16	2.6	6.60	7.02	4000	1080.30	T
17	2.6	6.60	7.01	4000	1079.94	
18	2.6	6.58	6.96	4000	1079.50	
19	2.6	6.59	6.91	4000	1079.23	0.43
20	2.6	6.55	6.81	4000	1078.90	
21	2.6	6.51	6.72	4000	1078.60	
22	2.6	6.51	6.65	4000	1078.20	
23	1.6	4.48	5.75	2000	1078.00	
24	1.6	4.46	5.70	2000	1077.83	
25	1.6	4.46	5.69	2000	1077.68	
26	1.0	3.10	5.30	1000	1077.60	
27	1.0	3.08	5.48	1000	1077.56	
28	1.0	3.06	5.56	1000	1077.55	
29	1.0	3.06	5.75	1000	1077.50	
30	1.0	3.05	5.85	1000	1077.48	
31	1.0	3.05	5.88	1000	1077.47	

[2]Monthly records for local stations:
Agronomy Farm: 1.11
Manhattan No. 2: 1.36
Tuttle Creek Dam: 0.64

NOVEMBER 1965

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	1.0	3.06	5.90	1000	1077.40	
2	1.0	3.04	5.80	1000	1077.34	
3	1.0	3.04	5.83	1000	1077.79	
4	1.0	3.04	5.82	1000	1077.30	
5	1.0	3.04	5.84	1000	1077.23	
6	1.0	3.04	5.86	1000	1077.20	T
7	1.0	3.03	5.88	1000	1077.17	
8	1.0	3.03	5.94	1000	1077.15	
9	1.0	3.03	5.96	1000	1077.10	
10	1.0	3.03	5.90	1000	1077.0	
11	1.0	3.03	5.74	1000	1076.98	T
12	1.0	3.03	5.60	1000	1076.99	0.58
13	0.05	0.89	4.88	70	1077.04	
14	0.05	0.85	4.80	70	1077.14	
15	0.05	0.83	4.77	70	1077.20	
16	0.05	0.85	4.72	45.4	1077.37	
17	0.05	0.73	4.60	45.4	1077.39	
18	-.10	0.69	4.55	45.4	1077.39	
19	-.10	0.68	4.51	45.4	1077.47	
20	0.20	0.96	4.52	200	1077.54	
21	0.20	1.08	4.60	1000	1077.60	
22	0.10	2.99	5.14	2000	1077.57	
23	2.0	5.37	6.09	3000	1077.30	
24	2.5	6.45	6.57	4000	1076.80	
25	2.5	6.43	6.54	4000	1076.50	
26	2.5	6.42	6.52	4000	1076.19	
27	2.5	6.52	6.55	4000	1075.69	T
28	2.5	6.52	6.53	4000	1075.35	
29	2.5	6.50	6.50	4000	1074.92	
30	1.0	3.00	5.07	1000	1074.76	

[2]Monthly records for local stations:
- Agronomy Farm: 0.28
- Manhattan No. 2: 0.29
- Tuttle Creek Dam: 0.58

DECEMBER 1965

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	0.3	1.43	4.54	200	1074.80	
2	0.3	1.49	4.48	200	1074.89	0.08
3	0.3	1.48	4.46	200	1074.95	
4	0.3	1.39	4.45	200	1074.97	
5	0.3	1.39	4.43	200	1075.04	
6	0.5	2.08	4.64	500	1075.00	
7	0.5	2.08	4.63	500	1075.00	
8	0.5	2.09	4.61	500	1075.06	
9	0.5	2.09	4.60	500	1075.00	
10	0.5	2.09	4.56	500	1075.08	T
11	0.5	2.09	4.60	500	1075.10	0.28
12	0.5	2.08	4.54	500	1075.20	
13	0.5	2.06	4.53	500	1075.16	
14	0.5	2.06	4.52	500	1075.21	T
15	0.5	2.06	4.51	500	1075.23	0.06
16	0.6	2.22	4.56	600	1075.22	0.08
17	0.6	2.22	4.54	600	1075.20	
18	0.6	2.23	4.55	600	1075.20	T
19	0.6	2.23	4.53	600	1075.19	
20	0.6	2.23	4.52	600	1075.20	
21	0.6	2.23	4.51	600	1075.18	
22	0.6	2.24	4.51	600	1075.18	
23	0.6	2.26	4.52	600	1075.10	
24	0.6	2.31	4.67	600	1075.49	1.50
25	0.6	2.27	4.80	600	1075.30	0.08
26	0.6	2.26	4.84	600	1075.27	
27	0.6	2.26	4.77	600	1075.42	
28	0.6	2.26	4.66	600	1075.30	
29	0.6	2.26	4.59	600	1075.35	
30	0.6	2.26	4.56	600	1075.35	
31	0.6	2.26	4.61	600	1075.45	

[2]Monthly records for local stations:
Agronomy Farm: 2.17
Manhattan No. 2: 2.23
Tuttle Creek Dam: 2.08

JANUARY 1966

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	0.6	2.27	4.62	600	1075.4	
2	0.6	2.27	4.71	600	1075.48	0.39
3	0.6	2.26	4.64	600	1075.43	
4	0.6	2.26	4.60	600	1075.42	
5	0.6	2.26	4.60	600	1075.50	
6	0.7	2.27	4.59	600	1075.54	
7	0.7	2.28	4.57	600	1075.57	
8	0.7	2.28	4.58	600	1075.46	
9	0.7	2.28	4.49	600	1075.46	
10	0.7	2.28	4.49	600	1075.46	
11	0.7	2.28	4.51	600	1075.42	
12	0.7	2.28	4.51	600	1075.47	T
13	0.7	2.28	4.51	600	1075.48	0.05
14	0.7	2.28	4.50	600	1075.46	
15	0.7	2.28	4.49	600	1075.47	
16	0.7	2.28	4.49	600	1075.54	
17	0.7	2.27	4.48	600	1075.49	T
18	0.7	2.27	4.44	600	1075.43	
19	0.7	2.27	4.46	600	1075.39	
20	0.7	2.27	4.39	600	1075.38	
21	0.7	2.27	4.31	600	1075.39	T
22	0.7	2.27	4.20	600	1075.37	
23	0.7	2.27	4.21	600	1075.30	
24	0.7	2.27	4.24	600	1075.27	T
25	0.7	2.28	4.22	600	1075.26	0.03
26	0.7	2.28	4.25	600	1075.23	0.01
27	0.7	2.28	4.26	600	1075.20	
28	0.7	2.28	4.48	600	1075.19	
29	0.7	2.29	4.22	600	1075.19	
30	0.7	2.85	4.69	600	1075.13	
31	0.7	2.53	3.04	600	1075.13	

[2]Monthly records for local stations:

Agronomy Farm: 0.71
Manhattan No. 2: 0.40
Tuttle Creek Dam: 0.48

FEBRUARY 1966

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	0.7	2.47	5.02	600	1075.12	T
2	0.7	2.40	4.98	600	1075.10	T
3	0.7	2.30	4.95	600	1075.10	T
4	0.7	2.29	4.88	600	1075.12	
5	0.7	2.29	4.73	600	1075.08	
6	0.7	2.27	4.67	600	1075.12	
7	0.7	2.27	4.64	600	1075.13	
8	0.7	2.27	4.53	600	1075.00	T
9	0.7	2.32	4.60	600	1075.00	0.80
10	0.7	2.32	4.59	600	1075.00	
11	1.6	4.33	5.52	2000	1075.20	
12	1.6	4.34	5.66	2000	1075.50	
13	1.6	4.35	5.93	2000	1076.10	T
14	1.6	4.35	6.00	2000	1076.50	T
15	1.6	4.35	5.95	2000	1076.80	
16	1.6	4.34	5.95	2000	1076.10	
17	1.6	4.34	5.76	2000	1077.10	
18	1.6	4.34	5.66	2000	1077.00	
19	1.6	4.34	5.58	2000	1077.00	
20	1.6	4.34	5.57	2000	1076.70	
21	1.6	4.36	5.58	2000	1076.50	T
22	1.6	4.36	5.44	2000	1076.40	T
23	1.6	4.36	5.31	2000	1076.30	
24	1.6	4.36	5.34	2000	1076.00	
25	1.6	4.35	5.41	2000	1075.90	
26	1.6	4.35	5.47	2000	1075.80	
27	1.6	4.35	5.60	2000	1075.65	0.25
28	1.6	4.35	5.68	2000	1075.50	T

[2]Monthly records for local stations:
Agronomy Farm: 0.70
Manhattan No. 2: 0.67
Tuttle Creek Dam: 1.05

MARCH 1966

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1	1.6	4.33	5.76	2000	1075.4	
2	1.6	4.36	5.81	2000	1075.2	
3	1.6	4.32	5.80	2000	1075.1	T
4	0.6	1.99	4.88	500	1075.1	T
5		1.35	4.55	200	1075.2	T
6		1.59	4.45	200	1075.2	
7		1.36	4.39	200	1075.1	
8		1.34	4.46	200	1075.2	
9		1.34	4.51	200	1075.1	
10		1.34	4.51	200	1075.2	
11		1.34	4.51	200	1075.3	
12		1.36	4.49	200	1075.4	
13		1.35	4.50	200	1075.4	
14		1.35	4.50	200	1075.5	
15		1.35	4.51	200	1075.5	
16	0.3	1.35	4.49	200	1075.6	
17	2.4	6.27	6.48	4000	1075.2	
18	0.9	2.76	4.98	1000	1075.1	
19	0.4	1.46	4.47	300	1075.2	
20	0.4	1.45	4.46	300	1075.2	
21	0.4	1.45	4.46	300	1075.2	
22	0.4	1.45	4.46	300	1075.3	
23	0.4	1.39	4.41	300	1075.4	0.03
24		1.41	4.40	300	1075.4	
25		1.42	4.38	300	1075.4	
26		1.43	4.34	300	1075.4	
27		1.44	4.39	300	1075.4	
28		1.44	4.25	300	1075.5	
29		1.44	4.22	300	1075.5	
30	0.4	1.44	4.21	300	1075.5	
31	0.4	1.45	4.20	300	1075.6	

[2]Monthly records for local stations:
Agronomy Farm: 0.04
Manhattan No. 2: 0.06
Tuttle Creek Dam: 0.03

APRIL 1966

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1		2.65	4.73	300	1075.60	
2	-1.2	0.50	3.93	300	1075.60	
3	0.3	1.15	3.92	300	1075.70	
4	0.4	1.42	4.17	300	1075.70	
5		1.43	4.14	300	1075.70	
6		1.43	3.96	300	1075.75	
7	0.4	1.43	4.07	300	1075.78	
8	0.4	1.46	4.19	300	1075.80	
9	0.8	2.26	4.31	700	1075.80	
10	0.8	2.28	4.40	700	1075.70	
11	0.8	2.31	4.47	700	1075.80	0.49
12	0.8	2.31	6.42	600	1075.80	T
13		2.35	5.71	600	1075.80	0.32
14		2.33	5.03	600	1075.78	
15		2.32	4.98	600	1075.70	
16	0.7	2.32	4.87	600	1075.67	
17		2.31	4.74	600	1075.70	
18		2.31	4.68	600	1075.71	
19		2.31	4.64	600	1075.66	T
20		2.32	4.58	600	1075.78	
21		2.32	4.56	600	1075.61	
22		2.32	4.54	600	1075.59	
23		2.32	4.54	600	1075.60	0.03
24		2.32	4.52	600	1075.56	
25		2.32	4.52	600	1075.54	
26		2.32	4.51	600	1075.52	
27	0.7	2.33	4.51	600	1075.50	
28		2.33	4.48	600	1075.50	0.04
29		2.33	4.49	600	1075.48	
30		2.34	4.47	600	1075.52	0.10

[2]Monthly records for local stations:
Agronomy Farm: 1.83
Manhattan No. 2: 2.03
Tuttle Creek Dam: 1.07

April 1st: Rocky Ford flood gate was opened about 9:30 PM 31 March 1966 (by authorized person). Gate closed 11:30 AM, 1 April 1966.

MAY 1966

(outline for Appendix I)

Date	River Gages[1] Rockyford	Casement Bridge	Highway No. 24	Gate Setting	Reservoir Setting	Precip-itation[2]
1		2.33	4.48	600	1075.44	T
2		2.33	4.45	600	1075.40	
3		2.33	4.45	600	1075.39	
4		2.32	4.45	600	1075.33	
5		3.02	4.71	1000	1075.30	
6	1.4	3.64	4.97	1500	1075.20	
7		3.64	4.96	1500	1074.98	
8		3.64	4.93	1500	1074.86	
9	1.3	3.61	4.90	1500	1074.72	T
10		3.61	4.90	1500	1074.52	
11		3.63	4.87	1500	1074.38	0.15
12		3.62	4.85	1500	1074.34	0.19
13		2.90	4.54	800	1074.27	
14		2.87	4.52	800	1074.15	
15		2.89	4.50	800	1074.02	
16		2.88	4.49	800	1074.00	
17		3.84	4.93	1500	1073.89	
18		1.30	3.82	200	1073.91	
19		1.26	3.73	200	1073.90	
20		2.10	4.08	500	1073.90	
21		1.36	3.72	200	1073.97	0.47
22		1.29	3.69	200	1073.97	
23		1.29	3.67	200	1074.10	
24		2.63	4.23	750	1073.92	
25		1.42	3.74	200	1073.92	
26		1.39	3.66	200	1073.95	
27		1.38	3.65	200	1073.90	
28	1.1	3.09	4.40	1000	1073.95	
29	0.9	2.57	4.16	700	1073.90	0.09
30		2.57	4.16	700	1073.81	0.27
31		2.58	4.16	700	1073.82	

[2]Monthly records for local stations:
Agronomy Farm: 1.65
Manhattan No. 2: 1.87
Tuttle Creek Dam: 1.17

APPENDIX II

IBM 1410 Computer Program

```
MCN$$      JCB  STAT 799 MULTIPLE REGRESSICN
MCN$$      CCMT 15,10,PAGES,L.F.MARCUS STATISTICS
MCN$$      ASGN MJB,12
MCN$$      ASGN MGC,16
MCN$$      MCDE GC,TEST
MCN$$      EXEQ FCRTRAN,,,,,,,WELL
      DIMENSIONCND(50,10),TMEAN(10),SS(10,10),CCR(10),A(9,9),
     1BETA(9,9),ALPHA(9),RSQ(9),VAR(9),SE(9),SEALPH(9),
     2F(9),SEBETA(9),FIT(50),DEV(50),IPIVCT(9),INDEX(9,2),
     3TITLE(20,8)
    1 FCRMAT(3I3)
    2 FCRMAT(6X,F6.2,4X,F6.2,F3.2,2F5.2)
    3 FCRMAT(1H ,4I5)
    4 FCRMAT(1H ,5F16.8)
    5 FCRMAT(1H ,3F16.8)
    6 FCRMAT(1H ,4F16.8)
    7 FCRMAT(1H ,4F16.8,2I5)
    8 FCRMAT(1H ,I5,3F16.8)
    9 FCRMAT(8A10)
   11 FCRMAT(1H ,8A10)
      READ(1,9)((TITLE(I,J),J=1,8),I=1,20)
      READ(1,1)NN,M,LL
      NDDF=NN-LL-1
      READ(1,2)((D(I,J),J=1,M),I=1,NN)
      DC10 J=1,M
   10 TMEAN(J)=0.0
      DC20 I=1,M
      DC20J=1,M
   20 SS(I,J)=0.0
      DC30I=1,LL
      DC30J=1,LL
   30 BETA(I,J)=0.0
      MLL=M-LL
      DC40I=1,MLL
   40 ALPHA(I)=0.0
      DC50I=1,MLL
   50 RSQ(I)=0.0
      DC60I=1,MLL
      DC60J=1,NN
   60 FIT(J)=0.0
      AN=NN
      AM=M
      AL=LL
      DC120J=1,M
      DC110I=1,NN
  110 TMEAN(J)=D(I,J)+TMEAN(J)
  120 TMEAN(J)=TMEAN(J)/AN
      DC140I=1,M
      DC140J=1,M
      DC140K=1,NN
  140 SS(I,J)=SS(I,J)+(D(K,I)-TMEAN(I))*(D(K,J)-TMEAN(J))
      DC160I=1,LL
      DC160J=1,LL
```

```
160 A(I,J)=SS(I,J)
    N=LL
    DO21J=1,N
 21 IPIVOT(J)=0
    DO551I=1,N
    AMAX=0.0
    DO105J=1,N
    IF(IPIVOT(J).EQ.1)GOTO105
    DO101K=1,N
    IF(IPIVOT(K).EQ.1)GOTO101
    IF(AMAX.GE.ABS(A(J,K)))GOTO101
    IROW=J
    ICOLUM=K
    AMAX=ABS(A(J,K))
101 CONTINUE
105 CONTINUE
    IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
    IF(IROW.EQ.ICOLUM)GOTO261
    DO201L=1,N
    SWAP=A(IROW,L)
    A(IROW,L)=A(ICOLUM,L)
201 A(ICOLUM,L)=SWAP
261 INDEX(I,1)=IROW
    INDEX(I,2)=ICOLUM
    PIVOT=A(ICOLUM,ICOLUM)
    A(ICOLUM,ICOLUM)=1.0
    DO351L=1,N
351 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT
    DO551L1=1,N
    IF(L1.EQ.ICOLUM)GOTO551
    T=A(L1,ICOLUM)
    A(L1,ICOLUM)=0.0
    DO451L=1,N
451 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
551 CONTINUE
    DO710I=1,N
    L=N+1-I
    IF(INDEX(L,1).EQ.INDEX(L,2))GOTO710
    JROW=INDEX(L,1)
    JCOLUM=INDEX(L,2)
    DO705K=1,N
    SWAP=A(K,JROW)
    A(K,JROW)=A(K,JCOLUM)
    A(K,JCOLUM)=SWAP
705 CONTINUE
710 CONTINUE
    DO170I=1,MLL
    IJK=I+LL
    DO170J=1,LL
    DO170K=1,LL
170 BETA(I,J)=A(J,K)*SS(IJK,K)+BETA(I,J)
    DO190I=1,MLL
    IJK=LL+I
```

```
      DO180J=1,LL
  180 ALPHA(I)=BETA(I,J)*TMEAN(J)+ALPHA(I)
  190 ALPHA(I)=TMEAN(IJK)-ALPHA(I)
      DO210I=1,MLL
      IJK=LL+I
      DO200J=1,LL
  200 RSQ(I)=BETA(I,J)*SS(IJK,J)+RSQ(I)
      RSQ(I)=RSQ(I)/SS(IJK,IJK)
      VAR(I)=SS(IJK,IJK)*(1.-RSQ(I))/(AN-AL-1.)
      IF(VAR(I).LE.0.0)GOTO210
      SE(I)=VAR(I)**.5
      SEALPH(I)=(VAR(I)/AN)**.5
  210 F(I)=(RSQ(I)*(AN-AL-1.))/((1.-RSQ(I))*AL)
      WRITE(3,11)((TITLE(I,J),J=1,8),I=1,2)
      WRITE(3,3)NN,M,LL,MLL
      WRITE(3,11)((TITLE(I,J),J=1,8),I=3,4)
      WRITE(3,4)(TMEAN(J),J=1,M)
      WRITE(3,11)((TITLE(I,J),J=1,8),I=5,6)
      DO250I=1,M
  250 WRITE(3,4)(SS(I,J),J=1,M)
      WRITE(3,11)((TITLE(I,J),J=1,8),I=7,8)
      DO260I=1,M
      DO150J=1,M
  150 COR(J)=SS(I,J)/((SS(I,I)*SS(J,J))**.5)
  260 WRITE(3,4)(COR(J),J=1,M)
      WRITE(3,11)((TITLE(I,J),J=1,8),I=9,10)
      DO270I=1,LL
  270 WRITE(3,5)(A(I,J),J=1,LL)
      DO280I=1,MLL
      IJK=LL+I
      WRITE(3,11)(TITLE(I+10,J),J=1,8)
      WRITE(3,6)ALPHA(I),(BETA(I,J),J=1,LL)
      WRITE(3,11)(TITLE(I+11,J),J=1,8)
      DO220J=1,LL
      SEBETA(J)=(A(J,J)*VAR(I))**.5
  220 CONTINUE
      WRITE(3,6)SEALPH(I),(SEBETA(J),J=1,LL)
      WRITE(3,11)(TITLE(I+12,J),J=1,8)
      WRITE(3,7)VAR(I),SE(I),RSQ(I),F(I),LL,NDDF
      WRITE(3,11)(TITLE(I+13,J),J=1,8)
      WRITE(3,11)(TITLE(I+14,J),J=1,8)
      DO280J=1,NN
      FIT(J)=0.
      DO230K=1,LL
  230 FIT(J)=D(J,K)*BETA(I,K)+FIT(J)
      FIT(J)=FIT(J)+ALPHA(I)
      DEV(J)=D(J,IJK)-FIT(J)
  280 WRITE(3,8)J,D(J,IJK),FIT(J),DEV(J)
      STOP
      END
```

REFERENCES

Beck, H. V. (1959): Geology and Ground-water Resources of the Kansas River Valley between Wamego and Topeka Vicinity, Kansas Geol. Survey Bull. 135, pp. 1-88.

Bentall, R. (1963): Methods of Collecting and Interpreting Ground-water Data, U. S. Geol. Survey Water Supply Paper 1544-H, pp. 1-97.

Davis, S. N., and W. A. Carlson (1952): Geology and Ground-water Resources of the Kansas River Valley between Lawrence and Topeka, Kansas Geol. Survey Bull. 96, pt. 5, pp. 201-276.

Eardley, A. J. (1951): Structural Geology of North America, Harper, New York.

Fenneman, N. M. (1938): Physiography of Eastern United States, McGraw-Hill Book Co., New York, 714 p.

Ferris, J. G. (1959): Chapter on Ground Water in Hydrology, edited by C. P. Wisler and E. F. Brater, John Wiley and Sons, New York, pp. 127-191.

Fischel, V. C. (1948): Ground-water Resources of the Kansas City, Kansas Area, Kansas Geol. Survey Bull. 71, pp. 1-109.

Fischel, V. C. (1956): Long-term Trends at Ground-water Levels in the United States, Trans. American Geophys. Union, Vol. 37, pp. 429-435.

Foster, E. E. (1948): Rainfall and Runoff, The Macmillan Co., New York, pp. 1-468.

Haworth, E. (1913): Special Report on Well Waters in Kansas, Kansas Geol. Survey Bull. 1, pp. 1-106.

Holmes, C. W., and H. G. Goodell (1964): The Prediction of Strength in the Sediments of St. Andrew Bay, Florida, J. Sediment. Petrol., Vol. 34, pp. 134-143.

Jewett, J. M. (1941): Geology of Riley and Geary Counties, Kansas Geol. Survey Bull. 39, pp. 1-164.

Johnson, A. I. (1963): A Field Method for Measurement of Infiltration, U. S. Geol. Survey Water Supply Paper 1544-F.

Johnson, C. R., and C. F. Keech (1959): Geology and Ground-water Resources of the Big Blue River Basin above Crete, Nebraska, U. S. Geol. Survey Water Supply Paper 1474.

Kazmann, R. G. (1965): Modern Hydrology, Harper and Row, New York, p. 275.

Knapp, G. S., et al., (1940): A Kansas Water Program: Report of Governor's Water Commission, Kansas, pp. 1-66.

Krumbein, W. C. (1959): The "Sorting Out" of Geological Variables Illustrated by Regression Analysis of Factors Contolling Beach Firmness, J. Sediment. Petrol., Vol. 29, pp. 575-587.

_______, and F. C. Graybill (1965): An Introduction to Statistical Models in Geology, McGraw-Hill Book Co., New York, p. 461.

Linsely, R. K., et al., (1949): Applied Hydrology, McGraw-Hill Book Co., p. 667.

Lewis, M. R. (1937): The Rate of Infiltration of Water in Irrigation-practice, Trans. Amer. Geophys. Union, Vol. 18, pp. 361-368.

Lohman, S. W. (1941): Ground-water Conditions in the Vicinity of Lawrence, Kansas, Kansas Geol. Survey Bull. 38, pt. 2, pp. 17-64.

McLaughlin, T. G. (1943): Geology and Ground-water Resources of Hamilton and Kearny Counties, Kansas, Kansas Geol. Survey Bull. 49, pp. 11-216.

Meinzer, O. E. (1923): Outline of Ground-water Hydrology with Definitions, U. S. Geol. Survey Water Supply Paper 494.

Miller, R. L., and J. S. Kahn (1962): Statistical Analysis in the Geological Sciences, John Wiley and Sons, Inc., New York.

Moore, R. C. (1940): Ground-water Resources of Kansas, Kansas Geol Survey Bull. 27, pp. 1-112.

Moulthrop, J. S. (1963): Pleistocene Geology and Ground Water of Kansas River Valley between Manhattan and Junction City, Kansas, Unpublished Master's thesis, Kansas State Univ., Manhattan, Kansas.

Musgrave, G. W., and G. R. Free (1937): Preliminary Report on a Determination of Comparitive Infiltration Rates on Some Major Soil Types, Am. Geophys. Union Trans., Vol. 18, pp. 345-349.

Rao, C. R. (1952): Advanced Statistical Methods in Biometric Research, John Wiley and Sons, New York

Sayre, A. N. (1950): Ground Water, Sci. Amer., Vol. 183, No. 5, pp. 14-19.

Scott, G. R., et al., (1959): Geology and Construction-material Resources of Pottawatomie County, Kansas, U. S. Geol. Survey Bull. 1060-C, pp. 97-148.

Smith, J. T. (1959): Geology and Ground-water Resources of the Kansas River Valley between Wamego and Manhattan, Kansas, Unpublished Master's thesis, Kansas State Univ., Manhattan, Kansas.

Snedecor, G. W. (1940): Statistical Methods, The Iowa State College Press, Ames, Iowa.

U. S. Weather Bureau, (1965-1966): Climatological Data, Kansas Section, U. S. Dept. of Commerce.

ANALYSIS OF VARIABLES AFFECTING THE FLUCTUATION OF THE WATER TABLE IN THE BIG BLUE RIVER VALLEY BELOW TUTTLE CREEK RESERVOIR

by

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B. S., Marietta College, 1964

AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

A study of hydrology in the Big Blue River valley below Tuttle Creek Reservoir revealed that fluctuations of the water table were controlled to a moderately high degree by three variables: river stage, reservoir elevation, and precipitation. Direct recharge into the alluvium from the reservoir is not as appreciable as might be expected as a result of the system of pressure-relief wells and the depth of the river pond below the dam. Subsurface seepage from the reservoir tends to maintain and slightly raise water-table elevations. The most important effect of the reservoir upon the ground-water resources in the valley below is attributed to the controlled flow in the Big Blue River which stabilizes river stage throughout the year.

Data representing fluctuations of the water table for a year were analyzed by the multiple regression technique utilizing a linear model. An equation consisting of the three variables, river stage, river elevation, and precipitation, was obtained whereby elevations of the water table in other wells may be predicted by substituting data for the three independent variables.

Reservoir elevation correlates well to water-table elevation and, of the three variables, exerts the greatest influence on fluctuations of the ground-water surface.

A time lag between adjustment of the ground-water reservoir to changes in the three variables becomes apparent with distance from the river, and was compensated for by using data up to five weeks old.