PRECONSTRUCTION AND SIMULATED POSTCONSTRUCTION GROUND-WATER LEVELS AT URBAN CENTERS IN THE RED RIVER NAVIGATION PROJECT AREA, LOUISIANA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4154

Prepared in cooperation with the

U.S. ARMY CORPS OF ENGINEERS

New Orleans District

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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GEOLOGICAL SURVEY

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GEOLOGICAL SURVEY

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Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

PRECONSTRUCTION AND SIMULATED POSTCONSTRUCTION GROUND-WATER LEVELS AT URBAN CENTERS IN THE RED RIVER NAVIGATION PROJECT AREA, LOUISIANA

By James E. Rogers

ABSTRACT

Construction of locks and dams along the Red River as part of the Red River Navigation Project will cause new, higher minimum stages for the river for each of the navigation pools. The rise of water levels caused by the dams will be greatest at the dam sites and will be progressively less upstream in each pool. The higher river levels will cause water levels in the Red River alluvial aquifer, which is hydraulically connected to the Red River, to rise. The greatest rise in water levels will occur adjacent to the locks and dams--as much as 23 feet at Lock and Dam 5--where the change in stage on the river is greatest. The change in water level in the alluvial aquifer will be progressively less upstream from each dam and progressively less with distance from the stream.

The alluvial valley area studied is about 2,000 square miles. Urban areas in the Red River Valley, which are the focus of this study, are the developed areas of Bossier City, Shreveport (in part), Coushatta, Campti, Clarence, Natchitoches (in part), Colfax, Boyce, and Alexandria.

The changes in average water level in the alluvial aquifer at urban areas in the valley were simulated by mathematical modeling of the stream-aquifer flow system. Average water levels are projected to be as much as 8 to 12 feet higher in the aquifer near the river in the Shreveport-Bossier City-Barksdale Air Force Base area. At the edge of the flood plain, water levels will be 1 to 5 feet higher. At Coushatta, water levels will be 5 to 9 feet higher. Water levels at Campti will be as much as 15 to 19 feet higher near the river and 10 to 13 feet higher 1/2 mile from the river. At Clarence, which is about 1 mile from the river, water levels will rise about 4 feet; and at Natchitoches, which is several miles from the river, water levels in the alluvium will rise 1 to 2 feet. Water levels at Colfax will rise 8 to 10 feet near the river and 4 to 6 feet 1 mile from the river. At Boyce, water levels will rise 4 to 6 feet. In the Alexandria-England Air Force Base area, water levels will rise 6 to 7 feet near the river and 1 to 2 feet on the side of the area more distant from the river.

The saturated zone in the silt and clay that overlies and confines the aquifer is where the principal impact of higher water levels on the urban areas will occur. As water levels in the aquifer rise, the upper surface of the saturated zone in the silt and clay above the aquifer will rise. Hydrographs of the potentiometric level in the aquifer and of the

piezometric level in the overlying deposits illustrate the mutual response at a site to stress, such as change in river stage, on the flow system.

After construction of locks and dams, the response will be similar but at a higher elevation. The Red River will recharge the alluvial aquifer in about 1 percent of the project area, especially near Lock and Dam 3 and 4. Subsequently this water will be discharged into one of the tributary streams, such as the Cane River or Bayou Pierre, and return to the Red River downstream.

In low-lying areas near the river, particularly in the Shreveport-Bossier City area and in the southeastern part of Alexandria, ground-water levels will be at or near land surface after construction. The size of the areas now affected by shallower ground-water levels probably will increase.

INTRODUCTION

The U.S. Army Corps of Engineers considered a number of alternate plans before beginning construction of a series of locks and dams on the Red River in Louisiana as part of the Red River Navigation Project. The navigation system built from any of the proposed plans will have a succession of pools that will cause higher stages in the stream during medium- and low-flow periods. As a result, water levels in the alluvial deposits (aquifer and overlying confining bed) that underlie the valley also will rise in most of the valley.

Higher water levels in the alluvium may have either beneficial or adverse impacts on agriculture and may have adverse impacts on structures. An earlier study evaluated potential water-level changes in the alluvium to determine the impact of projected changes on agriculture. During the earlier project, one of several proposed plans, the B-3 modified plan, appeared to be the probable configuration of the navigation system that would be approved for construction. Using proposed stage changes in the river based on this plan, the effects on ground-water levels in the alluvium in rural areas were studied by the U.S. Geological Survey, (Ludwig, 1979a and b; Ludwig and Reed, 1979; Ludwig and Terry, 1979a and b). Data from the study were used by the Soil Conservation Service (1977) to evaluate the impact of water-level changes in the alluvium on crops and other vegetation.

After completion of the rural studies, the Corps of Engineers decided that a similar evaluation for urban areas was desirable because the rural studies did not take into consideration the effects of paved streets, parking lots, and buildings on infiltration of rainfall or modification of evapotranspiration. The U.S. Geological Survey participated in several phases of the urban study, and this report presents the results of that participation. Most urban areas are near the Red River; and additional observation points were needed to document, more precisely, water-level changes that will occur in the urban areas. Because the urban study was made later, it benefited from a longer available record for some of the observation wells in and near urban areas.

The purpose of this study was to determine the effects of the proposed navigation system (plan B-3, modified) on ground water in the Red River alluvium. Of particular interest were water levels in the alluvium at urban and suburban areas after construction of the system. The following procedures were used to determine these effects:

1. Analyze the ground-water system and determine average water levels as an indicator of preconstruction, steady-state conditions.
2. Synthesize long-term-average water levels for sites having short periods of record to provide data points within urban areas compatible with those in rural areas.
3. Determine, by means of digital modeling of the aquifer-stream system, the change in ground-water levels in response to proposed changes in stage of the Red River.
4. Superpose water-level changes, determined by modeling, on preconstruction average water levels (steady-state conditions) to predict a postconstruction average potentiometric (water-level) surface (steady-state conditions).
5. Determine the relation between the average potentiometric surface of the Red River alluvial aquifer and the piezometric level of the overlying confining beds.

The hydrologic information collected for this report also served as a foundation on which a consultant for the Corps of Engineers, D'Appolonia Consulting Engineers, Inc., built part of its hydrologic analysis. Because both the D'Appolonia report (1980) and this report present hydrologic information on some of the same areas but in a different manner, some comments on the differences are in order. This report presents results for urban areas in the Red River Valley using the lock and dam configuration of the B-3 modified plan, whereas the D'Appolonia report presents results for both rural and urban areas using the lock and dam configurations of the B-3 modified plan and the B-1 plan. The results and conclusions in this report are based on steady-state (average conditions) analysis of the hydrologic data, utilizing a digital model of ground-water flow to predict changes in the potentiometric level of the alluvial aquifer (the sand and gravel parts of the alluvium). The D'Appolonia report is based on a model of transient conditions to predict water-level changes (piezometric level) in the silt and clay beds overlying the alluvial aquifer. The contour maps in the two reports represent different parts of the flow system in the alluvium--this report shows water-level contours of the potentiometric surface of the alluvial aquifer and the D'Appolonia report shows by water-level contours the upper surface of the zone of saturation in the silt and clay overlying the alluvial aquifer. This report also presents information on the water level in the silt and clay deposits but only at selected observation points by means of hydrographs. No attempt is made to contour the area based on data from these hydrographs.

Further explanation of methods, techniques, and interpretations of the U.S. Geological Survey are given in the remainder of this report.

Location

The Red River Navigation Project extends from the confluence of the Red and Black Rivers in central Louisiana to Shreveport in northwestern Louisiana (fig. 1). The alluvial valley area included is about 2,000 mi^2. Urban areas in the Red River Valley, which are the focus of this study, are the developed areas of Bossier City, Shreveport (in part), Coushatta, Campti, Clarence, Natchitoches (in part), Colfax, Boyce, and Alexandria. In addition, the developed areas at Barksdale Air Force Base adjacent to Bossier City and England Air Force Base adjacent to Alexandria were included as urban areas with the respective cities. Suburban areas near each community are included with adjacent urban areas. Urban centers in the Lock and Dam 2 area are Alexandria, England Air Force Base, and Boyce. Colfax, Clarence, and Natchitoches are in the Lock and Dam 3 area. Campti and Coushatta are in the Lock and Dam 4 area; and Shreveport, Bossier City, and Barksdale Air Force Base are in the Lock and Dam 5 area. The position of the urban areas relative to the various locks and dams is shown in figure 1.

None of the urban areas are in the Lock and Dam 1 area; thus, the urban study included only areas in Lock and Dam 2, 3, 4, and 5. The location of these locks and dams and the respective proposed pool stages (B-3, modified plan) are as follows:

Lock and Dam No.	River mile (1967)	Realined mile[1]	Proposed pool stage (ft)
2	87	75	58
3	137	111	87
4	[2]192	[2]157	115
5	243	198	145

[1] River mile above mouth of river after realinement of channel for navigation project.

[2] These mileages represent a change in location for Lock and Dam 4 from that used in earlier studies.

Climate

The Red River Valley in the project area has a humid, subtropical climate. Rainfall ranges from an annual average of about 58 in. at Alexandria to about 48 in. at Shreveport. Rainfall may be high any month of the year, but the wetter months generally occur in winter and early spring. The drier months generally occur in late summer and early fall. In addition to seasonal variations, rainfall is variable from year to year. Annual extremes at Alexandria between 1951 and 1978 were 36.16 in.

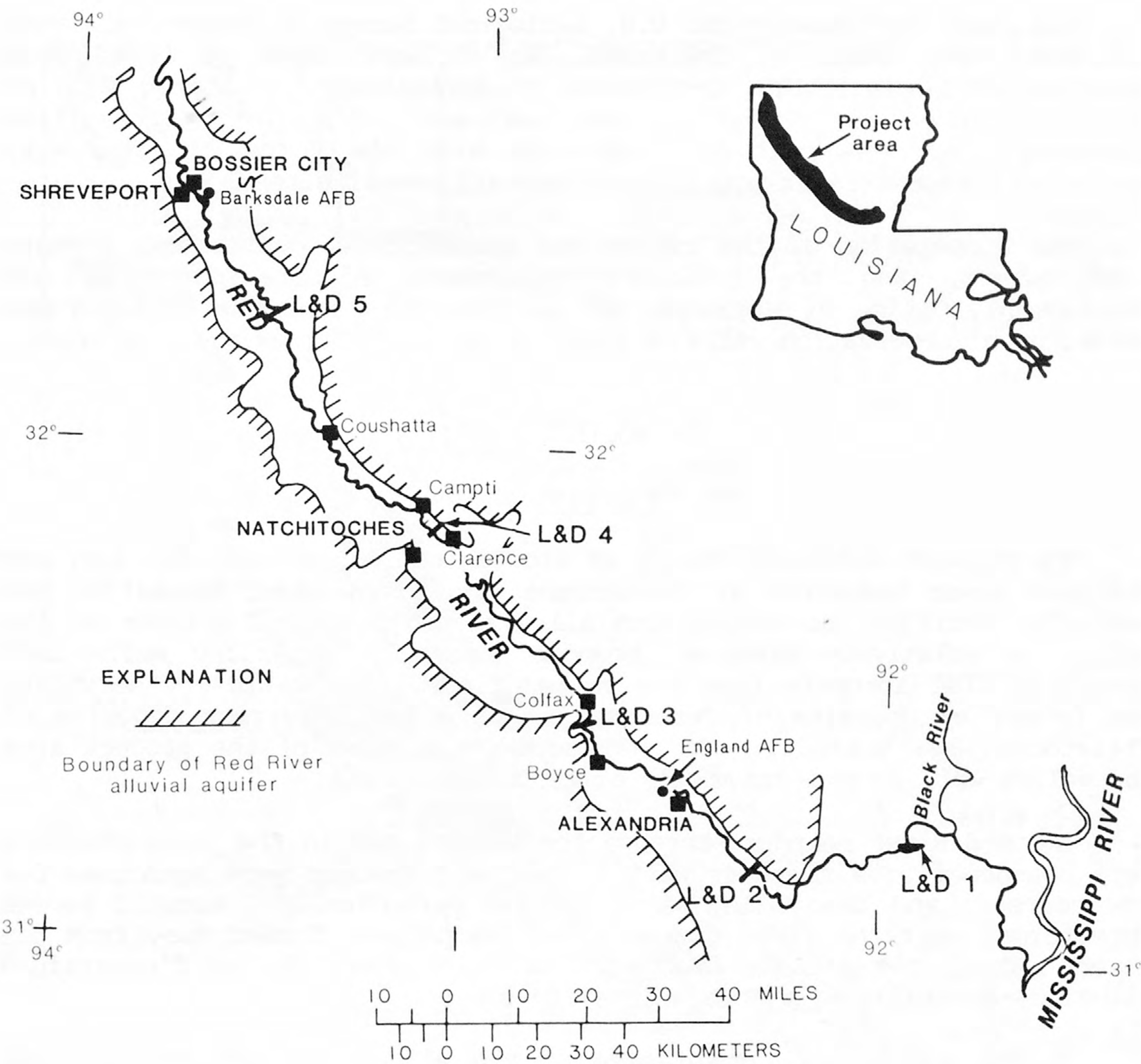

Figure 1.--Location of report area.

in 1963 and 79.27 in. in 1961. At Shreveport the extremes were 30.03 in. in 1963 and 67.23 in. in 1957. The variation at each site is more than 100 percent. The project area near Shreveport is somewhat drier and warmer in the summer than near Alexandria.

Rainfall infiltrates the alluvium and recharges the alluvial aquifer throughout the area in Louisiana. Recharge is greatest in the winter and early spring. Later in the year evapotranspiration intercepts most of the potential recharge from rainfall.

Acknowledgments

The study was done by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers, New Orleans District. The Soil Conservation Service, U.S. Department of Agriculture, collected much of the water-level data used in the analyses. D'Appolonia Consulting Engineers, Inc., as part of their work with the Corps of Engineers, installed piezometers at most urban observation-well sites.

The cooperation of the cities and communities, businesses, private land owners, and the Louisiana Department of Transportation and Development, Office of Highways, all of whom permitted the drilling and servicing of observation wells on their property, is greatly appreciated.

THE AQUIFER SYSTEM

Description

The present Red River Valley is eroded into deposits of Tertiary age and into river sediments of Pleistocene age. Subsequent deposition has partially refilled the valley with alluvial sediments. The floor of the valley is relatively flat and bounded laterally by valley walls that generally rise abruptly from the valley floor. The walls of the valley are formed by deposits of Tertiary age or alluvial-terrace deposits of Pleistocene age (fig. 2). In the southernmost part of the project area the valley wall is made up mostly of terrace deposits.

The Red River meanders through the valley; and in the past, meanders were abandoned, new meanders were formed, old courses were abandoned for new courses, and the valley was inundated periodically. Natural levees were formed near the river courses; backswamps were formed away from the river. Thus, the present floor of the valley consists of fine-grained alluvium--generally silt, clay, or silty clay.

In the subsurface, grain size of the alluvium typically increases with depth and grades from fine sand, to coarse sand, to coarse sand and gravel at the base. On the basis of grain size, the alluvium is divided into two parts: (1) the fine-grained upper deposits, which are made up of silt, clay or fine sand, and (2) the coarse-grained lower deposits, which are made up of coarse sand or gravel. The lower deposits form the alluvial aquifer; the upper, less permeable deposits constitute the confining layer.

The Red River Valley is variable in width and the alluvial aquifer has similar variations in lateral extent. The thickness of the alluvium, the lower part that comprises the aquifer and the upper part that comprises the confining bed, also varies from place to place. In general, the alluvium thickens from Shreveport in the Lock and Dam 5 area to Alexandria in the Lock and Dam 2 area. In places, changes in the relative thickness of the aquifer compared to the confining bed may be minor; in other places, changes may be large and abrupt. For example,

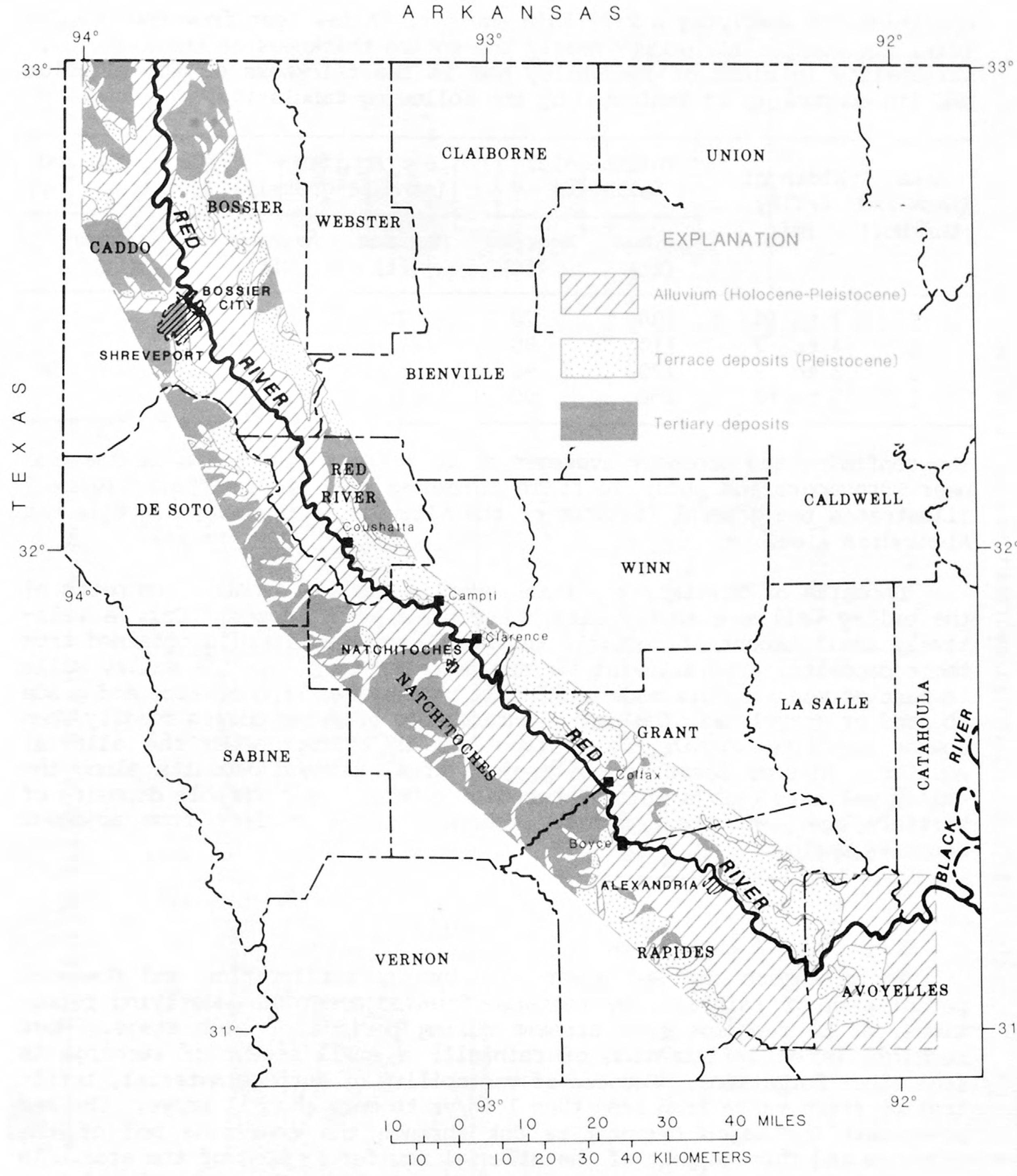

Figure 2.--Generalized geologic map, Red River Valley, Louisiana.

abandoned meanders filled with fine-grained material produce a very thick confining bed overlying a very thin aquifer. A few feet from the meander scar, the aquifer may occupy nearly the entire thickness of the alluvium. Variability in width of the valley and in the thickness of the alluvium and its components is indicated by the following tabulation:

Area (Lock and Dam No.)	Width of valley (mi)	Thickness of alluvium		Aquifer (sand or gravel)		Confining bed (silt or clay)
		Maximum (ft)	Average (ft)	Maximum (ft)	Average (ft)	Maximum (ft)
5	7 to 10	100	70	70	50	60
4	4 to 7	110	80	75	40	60
3	3 to 9	120	90	60	45	85
2	5 to 10	150	90	110	50	115

The confining bed probably averages about 20 ft in thickness in the area near Shreveport and about 40 ft in thickness near Alexandria. Figure 3 illustrates the general features of the alluvium in the subsurface in the Alexandria area.

Deposits of Tertiary age that underlie the valley and form parts of the valley wall are mostly clay but contain sand lenses. Only a relatively small amount of recharge to the alluvial aquifer is obtained from these deposits. The alluvial-terrace deposits that form the valley walls in part of the area are made up of silt or clay near the surface and grade to sand or gravel near the base. Interchange of water occurs readily when coarse deposits within the terrace are in contact with the alluvial aquifer. In some parts of the project area, terrace deposits along the valley wall are only a thin veneer over older, less permeable deposits of Tertiary age. At these sites, recharge to the aquifer from adjacent deposits is low.

Hydrology

Water enters the Red River alluvium by infiltration and downward percolation of rainfall, by recharge from adjacent or underlying formations, or by recharge from streams during periods of high stage. Most recharge is by infiltration of rainfall; a small amount of recharge is from other formations. Because of variability of surface material, infiltration rates range from less than 1 in/yr to more than 11 in/yr. The Red River and its major tributaries cut through the confining bed of the alluvium and through part of the alluvial aquifer in most of the area. In places, the river cuts through all of the aquifer. As a result, interchange of water occurs between the alluvial aquifer and these streams. Although local recharge to the aquifer from streams occurs during high stages, when stream stages are lower, water discharges from the aquifer to the stream. Virtually all inflow is discharged to the streams or by evapotranspiration. The interchange of water between the aquifer and the

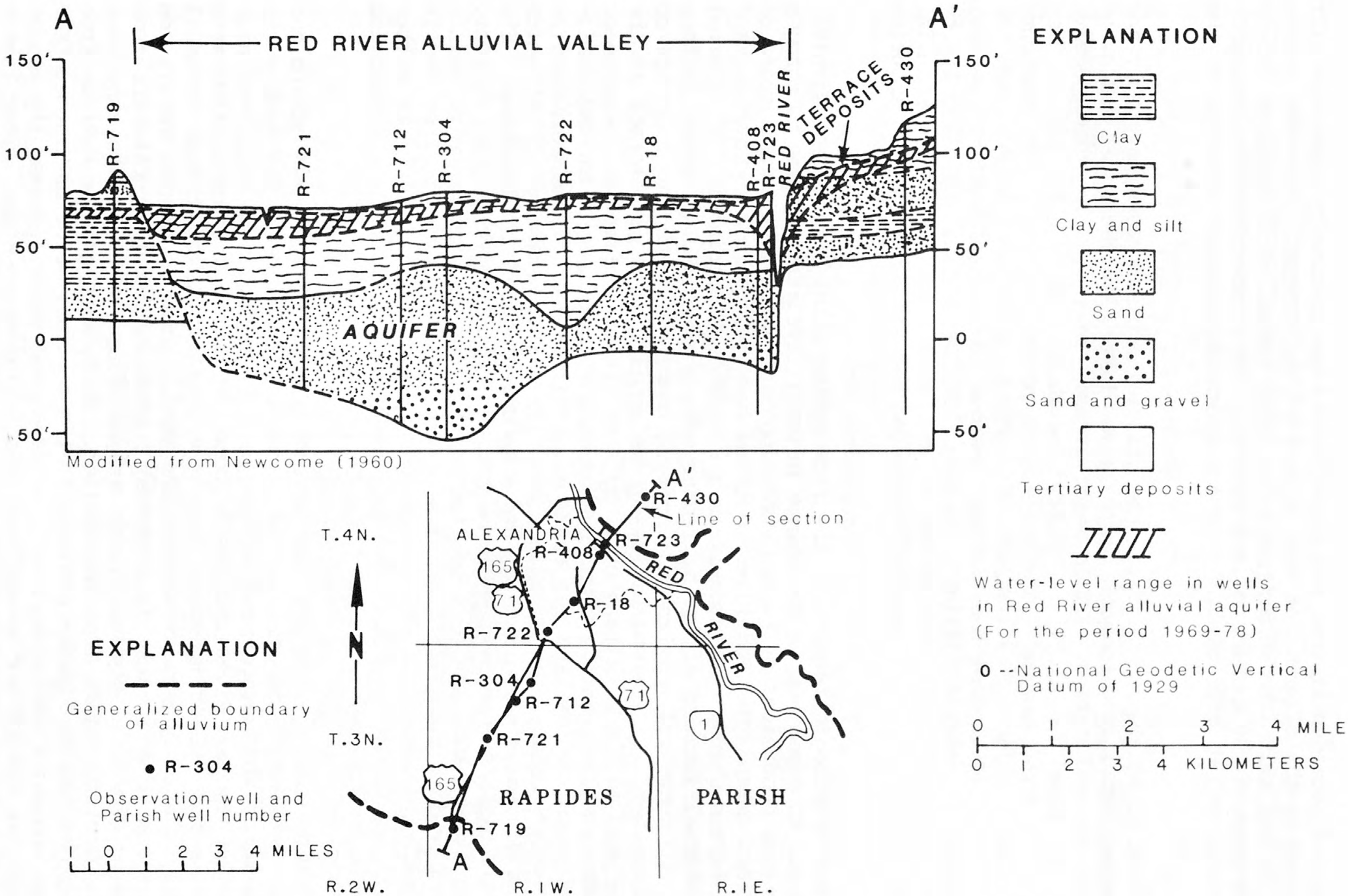

Figure 3.--Geologic section, Red River Valley.

streams is retarded at some places and from time to time by layers of silt deposited by the stream. At high stages of the streams, increased energy tends to put silt into suspension or to erode banks, which improves interchange between the stream and the aquifer. Good interconnection probably is maintained at most stages in areas where the current impinges on the river bank.

Most water that infiltrates the alluvial aquifer moves laterally and downvalley until it discharges into the Red River, the principal drain, or one of its tributaries. Other major streams in the valley that receive discharge from the alluvial aquifer are Bayou Pierre, Red Chute, Cane River, and Bayou Rapides. The general shape of the water-level contours in the valley (fig. 4) illustrate the lateral and downvalley movement of water. The position of the contours changes continuously but the general configuration remains similar. In some low, swampy areas, discharge by evapotranspiration is great enough so that water moves from the alluvial aquifer through the fine-grained confining bed into the root zone during most of the year.

The hydrologic feature of the flow system with the greatest significance for this project is the change in water level in response to changes in natural conditions or to new conditions imposed by the construction of locks and dams. The Red River alluvium has a dynamic flow system, and water levels change continuously as a result of a combination of internal and external factors affecting recharge or discharge. Internal factors are: (1) vertical conductivity of the upper part of the alluvium or confining bed, (2) transmissivity of the aquifer, and (3) storage in the aquifer and in the confining bed. External factors affecting recharge or discharge, and ultimately affecting water levels, are: (1) the availability of precipitation and the resultant infiltration; (2) evapotranspiration, which reduces infiltration; and (3) stream stage or level which retards discharge at high stage and enhances discharge at low stage. The internal factors change very little from season to season or year to year. On the other hand, the external factors can have a wide range of values and can produce significant changes in water level in the aquifer and in the confining layer. Factors that are difficult to classify as either internal or external are the physical dimensions and hydrologic boundaries of the alluvium and the included aquifer.

Ground-water levels are high in the late winter and early spring and usually decline to annual lows in September or October. The high water levels occur when evapotranspiration is low, rainfall is high, and high stages on the Red River and its tributaries retard or stop outflow from or cause some water movement into the aquifer. Even though rainfall remains relatively high throughout the year, increased evapotranspiration in the summer and early fall prevents most infiltrating rainfall from exceeding root-zone depths. Lower stages of the river at the same time permit greater outflow from the aquifer. Thus, with greater outflow from the aquifer and negligible recharge to the aquifer, water is removed from storage and water levels decline. Extremely wet years increase the amount of water in storage and extend the time during which higher water levels occur. In dry years, less water is in storage and water levels are lower.

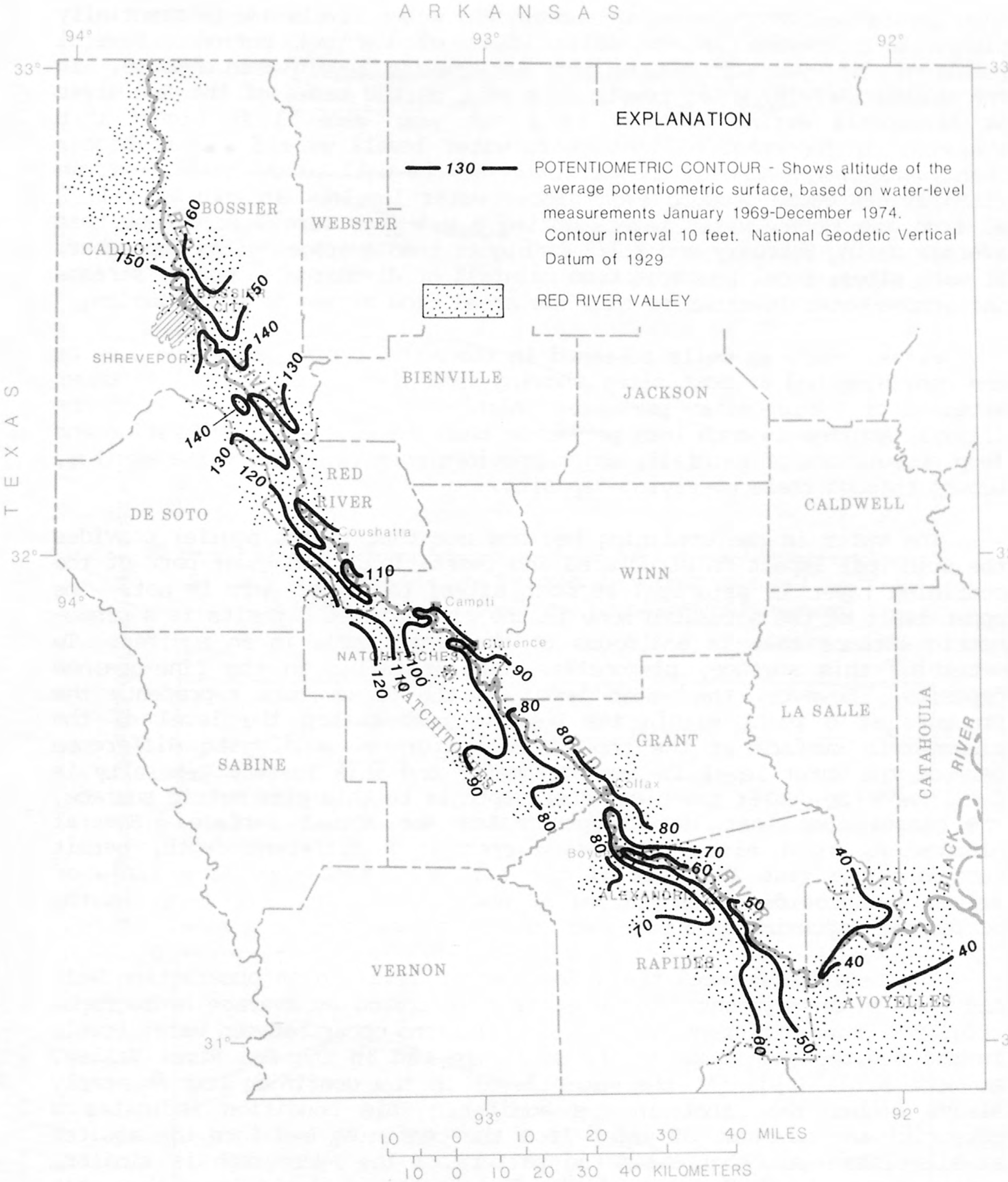

Figure 4.--Average potentiometric surface of the Red River alluvial aquifer, Red River Valley, Louisiana.

When several wet years occur in succession, water levels are substantially higher than average in the latter part of the wet period. Several relatively dry years result in much lower water levels than average. In the period 1969-78, water levels in a well on the banks of the Red River at Alexandria during February of a wet year were 11 ft higher than average. In September of that year, water levels were 6 1/2 ft higher than average. Because of the proximity of the well to the river, extreme flood events could produce even higher water levels. In another well 3 mi from the river, water levels during a wet year were 3 ft higher than average during February and 2 1/2 ft higher than average during September. At many sites, local recharge from rainfall or discharge to nearby streams influences water levels more than the areal flow system of the alluvium.

Water levels in wells screened in the aquifer rise above the base of the confining bed at most sites showing that the aquifer system is under artesian or semiartesian pressure. Although the confining layer of the alluvial aquifer is much less permeable than the aquifer, infiltration and deep percolation of rainfall, which provides most recharge to the aquifer, occurs through these overlying deposits.

The water in the confining bed and not that in the aquifer provides the principal impact on structures and vegetation. The lower part of the confining layer is saturated at most sites; the upper part is not. The upper limit of the saturated zone in the fine-grained deposits is a piezometric surface that is analogous to the water table in an aquifer. To determine this surface, piezometers were installed in the fine-grained deposits. However, the water level in the piezometers represents the pressure at a point within the deposit rather than the level of the piezometric surface at the top of the saturated zone. The difference between the water level in the piezometer and this surface generally is small, and the nearer the piezometer depth is to this piezometric surface, the closer the water level approximates the actual surface. Several piezometers at a site, each being open at a different depth, permit recording the rise and fall of the saturated zone through a range of values and provide an indication of how closely the water level in the piezometer approximates a point on the top of the saturated zone.

The relation between the average water level in an observation well and that in an adjacent piezometer is illustrated by average hydrographs (fig. 5). Four different patterns or relations occur between water levels in the aquifer and those in the confining bed in the Red River Valley. At some sites (fig. 5A) the water level in the confining bed is nearly always higher than that in the aquifer. This condition indicates a potential for movement of water from the confining bed into the aquifer at all times. At other sites the pattern of the hydrograph is similar, but the water level in the confining bed is nearly always lower than that in the aquifer, which indicates a potential for movement from the aquifer into the confining bed at all times. At these latter sites discharge from the confining bed is mostly by evapotranspiration.

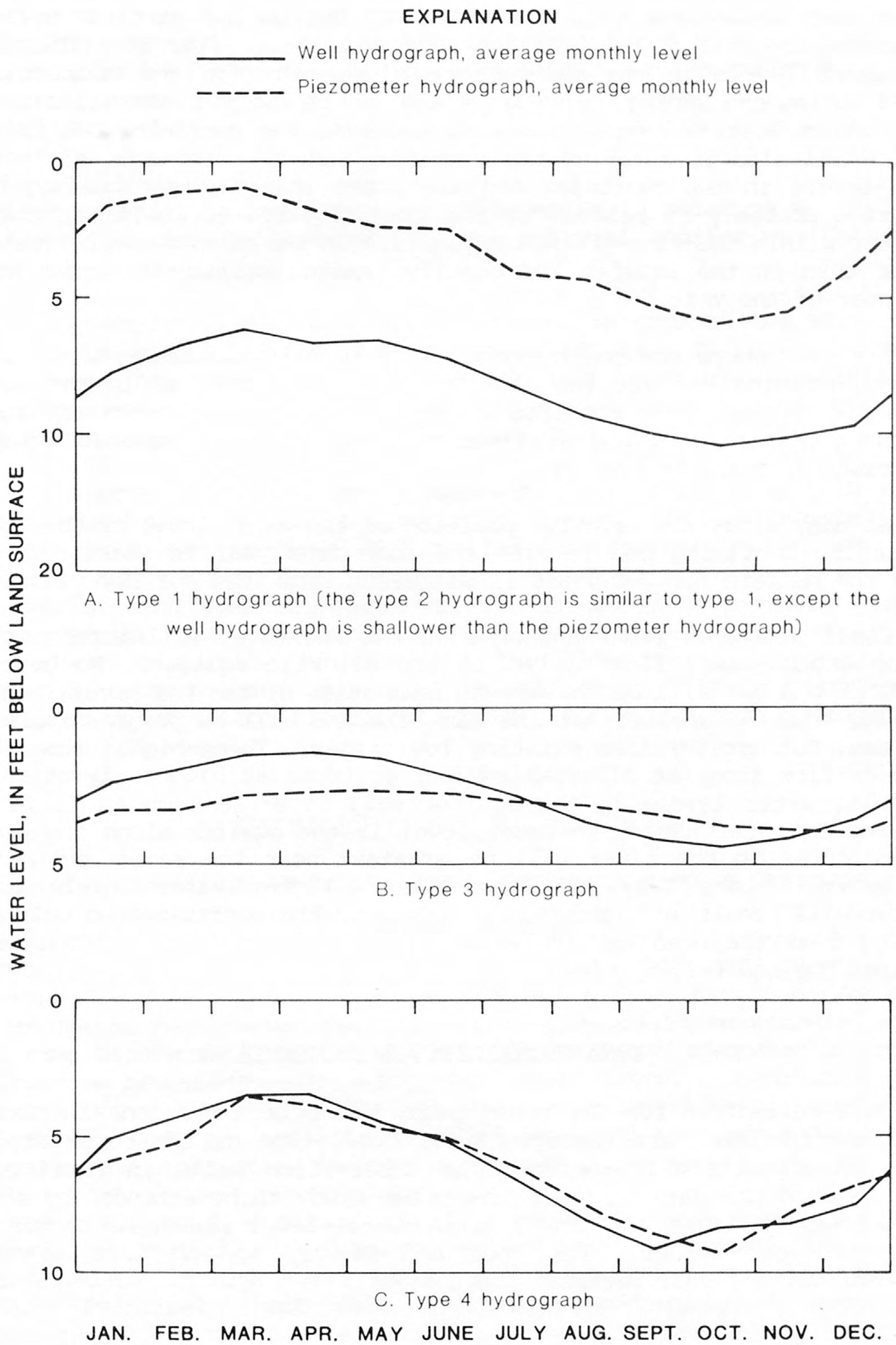

Figure 5.--Relation between water levels in the aquifer and in the confining layer.

At some sites near urban areas, water levels in the aquifer are higher than water levels in the confining bed during part of the year, but during the rest of the year the reverse is true (fig. 5B). The period when water levels in the aquifer are higher than in the confining bed occurs during the spring. Spring is also a time of high precipitation and low evapotranspiration--thus water is entering the confining bed from the surface and also is entering the confining bed from the aquifer; yet the water levels in the confining bed are lower than in the aquifer. This condition probably is related to the time required for physical transfer of water within the fine-grained deposits. In the summer water levels are higher than in the aquifer and usually remain that way for most of the remainder of the year.

At sites where the confining bed is very silty or sandy, water levels in the confining bed are the same or nearly the same as in the aquifer (fig. 5C). Under these conditions water moves freely between the aquifer and the confining bed, and at times recharge-discharge relations may not be obvious from the hydrograph.

At many sites the relative position of the water level of the aquifer and of the confining bed remains the same from year to year. At other sites the pattern for wet years is different from that for dry years.

Construction of locks and dams on the Red River will impose changes on the ground-water flow system in the alluvial aquifer. Pools behind each lock and dam will be the new minimum stage of the Red River. Changes in stage will be greatest at the dam site and will be progressively less upstream, but greater than existing low stages. These higher stages will cause outflow from the alluvial aquifer to occur at higher elevations; as a result, water levels in the aquifer will rise--as much as 23 ft near Lock and Dam 5. Changes in water level in the aquifer along any profile perpendicular to the river will be greatest near the river and will be progressively less away from the river. Higher water levels in the aquifer will result in higher water levels in the confining bed. In about 1 percent of the area the increased river stage will cause the river to recharge the aquifer.

DATA COLLECTION AND SYNTHESIS

Data collection for the urban study was a continuation, in part, of that done for the rural study. After completion of the rural study in 1975, measurements were continued at observation wells in rural areas, which allowed the data base for the urban study to be extended by several years. For the Lock and Dam 2 area, water-level measurements extended over a 10-year period. For Lock and Dam 3, 4, and 5, measurements extended over a 7-year period.

About 90 additional observation wells were installed in urban areas to better define the shape of the potentiometric surface of the alluvial aquifer and to provide data for use in modeling the aquifer system. At the site of each of the urban wells, piezometers were installed to determine the piezometric level at various depths within the fine-grained deposits overlying the alluvial aquifer. The water levels in these piezometers represent, approximately, the upper limit of saturation in the fine-grained deposits. The position of the top of the zone of saturated material in the fine-grained deposits in relation to the water level in adjacent wells screened in the alluvial aquifer was determined by comparing hydrographs.

Pore-pressure transducers were installed in some of the very clayey intervals to determine the effectiveness of the shallow piezometers installed at the same site. The piezometers recorded essentially the same variations in water level as those determined using the pore-pressure transducers.

To represent steady-state ground-water conditions for this study, water levels for a 7 to 10 year period of record (through December 1978) were averaged. For the 90 wells installed for the urban study, the period of record was only about 1 1/2 years. Correlation of water levels in these wells with those of nearby wells that have long periods of record and that exhibit similar seasonal variations permitted synthesis of long-term records comparable to those of the older wells. Averages were correlated rather than individual measurements. These correlations resulted in about 90 additional data points for determining average water levels in urban areas.

SIMULATION OF THE AQUIFER SYSTEM

Before the urban study was made, studies using a nonsteady-state model and a steady-state model of ground-water flow had been made for rural (agricultural) areas in the Red River Valley. Proper calibration of the nonsteady-state model required a data base of several years duration. Because construction had started on the lock and dam system and new wells constructed for the urban study could be measured only a short time before analysis was needed, time was not adequate to properly calibrate a nonsteady-state model for urban areas. Therefore, as the area of study was the same, the steady-state model (GWFlow) used in the rural study (Bedinger and others, 1973) was used to project water-level changes in the urban areas for the postconstruction period.

The same grid spacings, grid orientation, grid locations, and boundaries were used. Development, calibration, and sensitivity of the model as used in the rural study are discussed in Ludwig and Terry (1980). Principal input data for the two-dimensional model are: transmissivity of the aquifer, the hydrologic boundaries, the ratio of change in evapotranspiration to change in aquifer head ($\Delta ET/\Delta H$), change in stream stages, and thickness and hydraulic conductivity of the streambed material.

Only two modifications were made to model input for the urban study. In part of the Lock and Dam 2 area, transmissivity values were modified because additional data were available. Transmissivity was not changed in the other lock and dam areas. Simulations using the old transmissivity configuration and the new transmissivity configuration showed that water-level change was very insensitive to small changes in transmissivity. In the urban areas, estimates were made of the amount of area covered by houses, buildings, paved streets, and paved parking lots to determine how much the area where rainfall could infiltrate the soil had been reduced. To reflect the land area covered by these impermeable structures, values of $\Delta ET/\Delta H$ were reduced at urban nodes. Modeling based on various reductions in $\Delta ET/\Delta H$ (table 1) shows that the effect on water levels of changing $\Delta ET/\Delta H$ in the urban areas is not great. The percentage reduction in $\Delta ET/\Delta H$ made at urban nodes at each urban area is given in table 2.

To estimate the change in head in the aquifer resulting from a change in river stage, an initial stress was applied only to the stream nodes; other nodes were left unstressed (Ludwig and Terry, 1980, p. 21). In the model simulations, the stress applied at stream nodes was the change in average stream stage from preconstruction to postconstruction conditions. The resulting change in head simulated at each node in the aquifer was then added to the head at that node obtained from a contour map of the preconstruction average potentiometric surface. The specified head for each node, so obtained, is the average head of the postconstruction potentiometric surface at that node and was used to develop the postconstruction potentiometric maps. Thus, the average water-levels for the preconstruction period are not used directly in the model, but are critical for predicting average water levels in the postconstruction period.

WATER-LEVEL CONDITIONS, URBAN AREAS

All of the urban areas studied for this project, except the Natchitoches area, are adjacent to the Red River. However, some of the areas are partially outside the valley on deposits of Tertiary age or on terrace deposits of Pleistocene age. These areas include Shreveport, Coushatta, Campti, and Natchitoches. The other urban areas are entirely within the valley.

Water levels in wells in the alluvial aquifer, which is hydraulically connected to the Red River, have the greatest range in fluctuation near the river because of the great changes in stage of the river seasonally. During extended dry periods when river stage is low, water levels in wells in the aquifer near the river may be more than 30 ft below the land surface. During extended periods when the river is at flood stage, water levels may be above land surface in wells screened in the alluvial aquifer near the river. At sites more distant from the river, seasonal variations in water level generally are much less. In some places water levels fluctuate as little as 1 ft seasonally.

Table 1.--Effects of reducing $\Delta ET/\Delta H$ at selected urban nodes

No reduction in $\Delta ET/\Delta H$ (rural model)	$\Delta ET/\Delta H$ reduced (percent)					
	20	30	40	50	60	70
	Steady-state model head-change projections (feet)					
	Lock and Dam 2					
3.1	----	----	----	3.5	3.7	3.7
.6	----	----	----	.9	1.0	.9
6.1	----	----	----	6.9	6.5	6.6
3.9	----	----	----	4.1	4.2	4.2
4.7	----	4.7	4.7	4.8	---	---
	Lock and Dam 3					
4.0	4.0	4.0	4.0	---	---	---
1.2	1.2	1.2	1.2	---	---	---
5.8	6.0	6.1	6.2	---	---	---
4.0	4.1	4.2	4.3	---	---	---
7.0	7.1	7.2	7.3	---	---	---
	Lock and Dam 4					
8.0	8.1	8.2	8.2	---	---	---
9.2	9.2	9.2	9.2	---	---	---
10.7	10.9	11.0	11.0	---	---	---
10.3	10.4	10.4	10.5	---	---	---
15.9	16.0	16.0	16.0	---	---	---
	Lock and Dam 5					
4.1	----	----	----	4.7	4.8	5.0
1.7	----	----	----	2.0	2.0	2.1
3.7	----	----	----	3.9	4.0	4.0
6.0	----	----	----	6.6	6.6	6.8
4.9	----	----	----	5.5	5.5	5.7

Table 2.--Reduction of $\Delta ET/\Delta H$ for urban simulation

Urban area	Reduction of rural $\Delta ET/\Delta H$ value (percent)
Lock and Dam 2	
Alexandria	50
England Air Force Base	30
Boyce	30
Lock and Dam 3	
Clarence	30
Natchitoches	30
Colfax	30
Lock and Dam 4	
Coushatta	30
Campti	30
Lock and Dam 5	
Bossier City	50
Barksdale Air Force Base	30
Shreveport	50

At urban sites not entirely within the valley, the effects of extreme changes in stage of the Red River on water levels in the alluvial aquifer may differ from the effects on water levels in adjacent aquifers. Adjacent deposits of Tertiary age are mostly clay, and the water level in sand beds of Tertiary age generally have only a limited response to stage changes of the Red River. Water levels in the terrace deposits of Pleistocene age are more responsive to changes in river stage. However, at many sites water levels in the terrace deposits are higher than water levels in the alluvial aquifer, and large changes in stage of the Red River are required to produce relatively small changes in water level in the terrace deposits.

Water levels in the fine-grained deposits overlying the alluvial aquifer respond to changes in water level in the aquifer. When water levels in wells screened in the alluvial aquifer are at or near land surface, water levels in the fine-grained deposits at most sites also tend to be near land surface. The relation between the saturated surface in the confining bed and the potentiometric surface of the alluvial aquifer is discussed in the previous section, "Hydrology".

After construction of navigation pools on the Red River, water levels will be higher in the alluvial aquifer during low-flow periods, and thus, average water levels will be higher. During floods, however, water levels in the aquifer will be nearly the same as during similar events in the preconstruction period. The average water level of the aquifer will be representative of new steady-state conditions in the flow system. The changes between preconstruction and postconstruction levels for urban areas are summarized in figure 6, which shows the predicted water-level rise along lines perpendicular to the river. One value is for the side of the urban area nearest the river, the other, for the side farthest from the river. These values indicate the postconstruction rise in water level and not depth to water below land surface. For example, at Bossier City, the average water-level rise at the river is 8.4 ft; at a distance of 3 mi from the river the average rise is 2.2 ft.

Hydrographs for selected sites in each urban area in the following sections illustrate water-level changes in the fine-grained deposits overlying the aquifer and in wells in the alluvial aquifer. Average monthly water levels for both the aquifer and the confining bed have been plotted. In addition, average water levels (preconstruction) for the base period (7 to 10 years) for each unit are shown as are the average values based on model predictions (postconstruction). Displacement of the hydrographs (aquifer and confining bed) upward by the difference between the preconstruction and postconstruction average water level (ΔH) will approximate the hydrograph relation in the postconstruction period. When the displacement upward is small, the approximation is very close. When the displacement of the water levels is large, some deviation in shape of the hydrographs can be expected. For example, as water levels rise evaporation increases, which tends to reduce the water-level rise and modify the shape of the hydrograph slightly. Where the hydrograph in the postconstruction position indicates that water levels in the fine-grained deposits are substantially above land surface, potential recharge is being rejected. The saturated zone, obviously, extends no higher than land surface, but the potentiometric surface within the fine-grained material may. Shallower piezometers at the site would have a potentiometric level nearer land surface. Very shallow piezometers (less than a foot deep) probably would have a potentiometric surface at land surface.

In the following sections water levels in wells in the alluvial aquifer during the preconstruction period and during the postconstruction period are illustrated areally by an average potentiometric map for each period for each urban area. A comparison of the map pairs of an urban area indicates the average change in water level.

Shreveport-Bossier City-Barksdale Air Force Base

A large part of Shreveport is on the outcrop of deposits of Tertiary age and terrace deposits of Pleistocene age. An area on the west bank north of the downtown area and an area near the Red River downstream from the downtown area are on alluvial deposits of the river. Bossier City and Barksdale Air Force Base, on the east bank of the river, are on alluvium of the Red River.

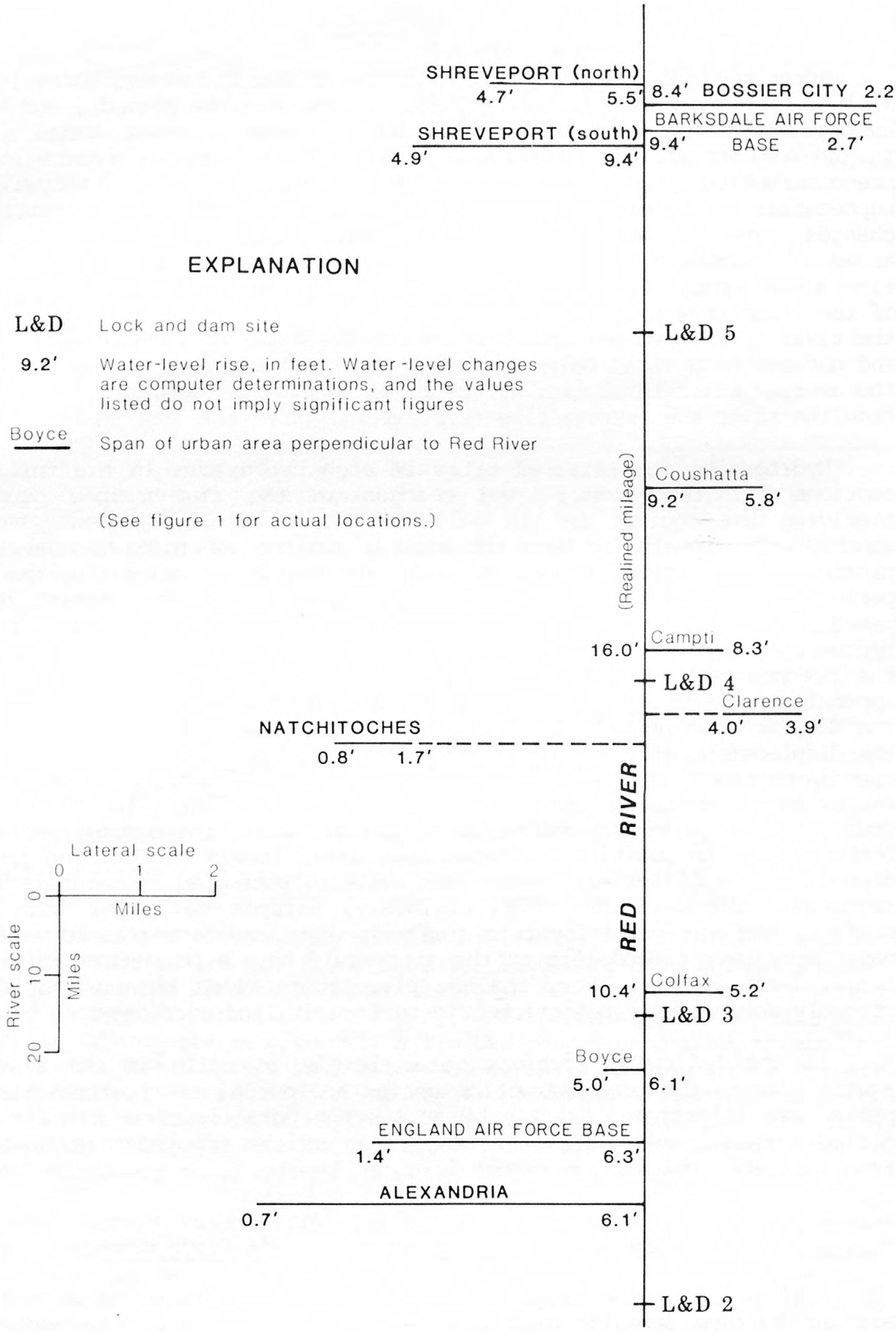

Figure 6.--Average water-level changes along profiles perpendicular to the Red River at urban areas (plan B-3, modified).

Most water-level changes within the terrace deposits in the postconstruction period will be negligible. The terrace deposits generally occur several miles from the river and changes in water level in the alluvium at the contact between the terrace and alluvium are small. The magnitude of average water-level change in the Red River alluvium, as determined by steady-state modeling, is greatest near the river and is minimal several miles from the river. On the Shreveport side of the river, the alluvium generally extends less than 3 mi from the stream. Average water-level changes range from 8 to 12 ft near the river and from 1 to 5 ft near the edge of the flood plain. Near the river, average water levels are 15 to 30 ft below land surface now and are projected to be 6 to 24 ft below land surface at most sites in the postconstruction period. Even though average water levels for wells near the river may be substantially below land surface, during high river stage, water levels in these wells may be near or slightly above land surface. In some low-lying areas in old river meanders, average water levels are near land surface now and may be above land surface in the postconstruction period.

On the Bossier City-Barksdale Air Force Base side of the river, average water levels in the postconstruction period will be 5 to 9 ft higher in the area near the river. In areas more than 3 mi from the river, the average change in water level is projected to be 1 to 2 ft.

A comparison of the contours showing the average water level before construction (pl. 1) and after construction (pl. 2) illustrates the projected change in the configuration of the average water-level surface for the aquifer and in the confining bed. The seasonal variation in water levels on the Bossier City side of the river is illustrated by the hydrograph (fig. 7) of wells Bo-284, Bo-284b, and Bo-285; and variations on the Shreveport side of the river are indicated by the hydrograph (fig. 8) of wells Cd-471 and Cd-471a. All of the wells cited are 1 3/4 to 3 mi from the river. The fine-grained deposits (confining bed) overlying the alluvial aquifer are coarser in the southern part of the Shreveport-Bossier City-Barksdale Air Force Base area than farther downstream. Vertical movement of water occurs readily in these coarser deposits; thus, at many sites water levels in the fine-grained deposits are nearly the same as levels in wells in the alluvial aquifer. However, sites on the north side of Shreveport and on the north and east sides of Bossier City are swampy areas where the confining bed contains thick clays. Water levels in the confining bed in these areas do not coincide with the potentiometric surface of the aquifer but respond as illustrated in well Bo-284b in figure 7.

Coushatta

Although Coushatta is adjacent to the Red River, the community is at the edge of the valley and is mostly on terrace deposits of Pleistocene age. About 1/4 mi^2 of Coushatta adjacent to the river is built on the alluvium.

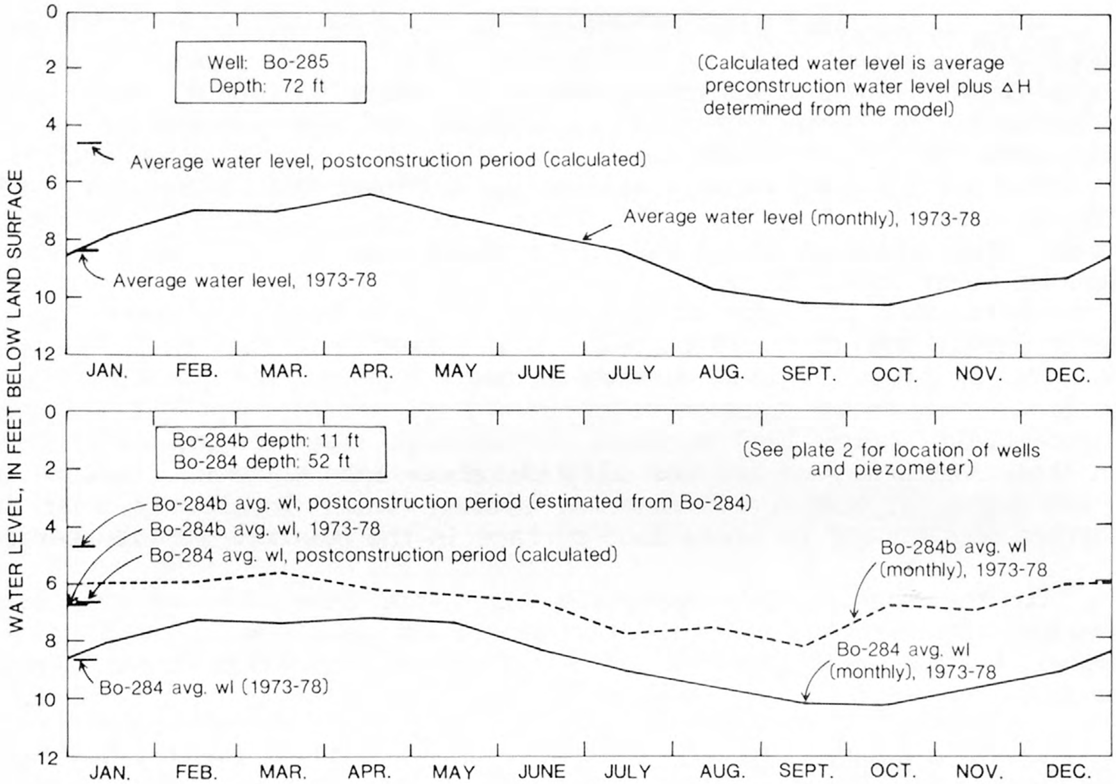

Figure 7.--Average water levels at wells Bo-284 and Bo-285 and piezometer Bo-284b.

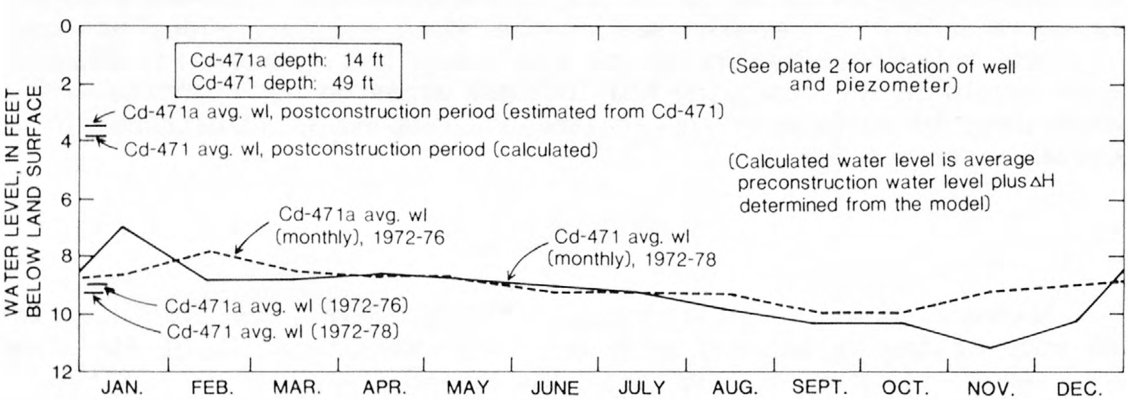

Figure 8.--Average water levels at well Cd-471 and piezometer Cd-471a.

Water levels in the terrace deposits at Coushatta are 15 to 30 ft or more below land surface. At several observation well sites, water levels in the wells are lower than the depth of the adjacent piezometer (generally about 15 ft in depth); these piezometers in the confining bed were dry throughout the period of record. At observation wells near the Red River, water-level fluctuations for the short period of record are 6 to 8 ft. For the same period of record, water levels in the observation wells more distant from the river are 1 to 3 ft.

After the lock and dam system is built, the average water-level rise near the river is projected to be approximately 5 to 9 ft. The nearby terrace deposits will have a similar rise in water level because good interconnection exists and because ground-water discharge will be affected by the higher pool stage. Average water levels in the terrace deposits under these conditions will be 14 to 21 ft below land surface. Because only the Red River alluvium is simulated by the flow model, no attempt was made to project water-level changes in terrace deposits away from the river. For the alluvial aquifer near Coushatta, plates 3 and 4 illustrate average water levels in the area during preconstruction and postconstruction periods, respectively.

One long-term observation well, R-212, is screened in the Red River alluvial aquifer near Coushatta. The hydrographs of well R-212 and piezometer R-212c (fig. 9) illustrate the average monthly response of the alluvial aquifer and the confining bed for the period of record. A similar response, but at a higher elevation, is projected for the post-construction period.

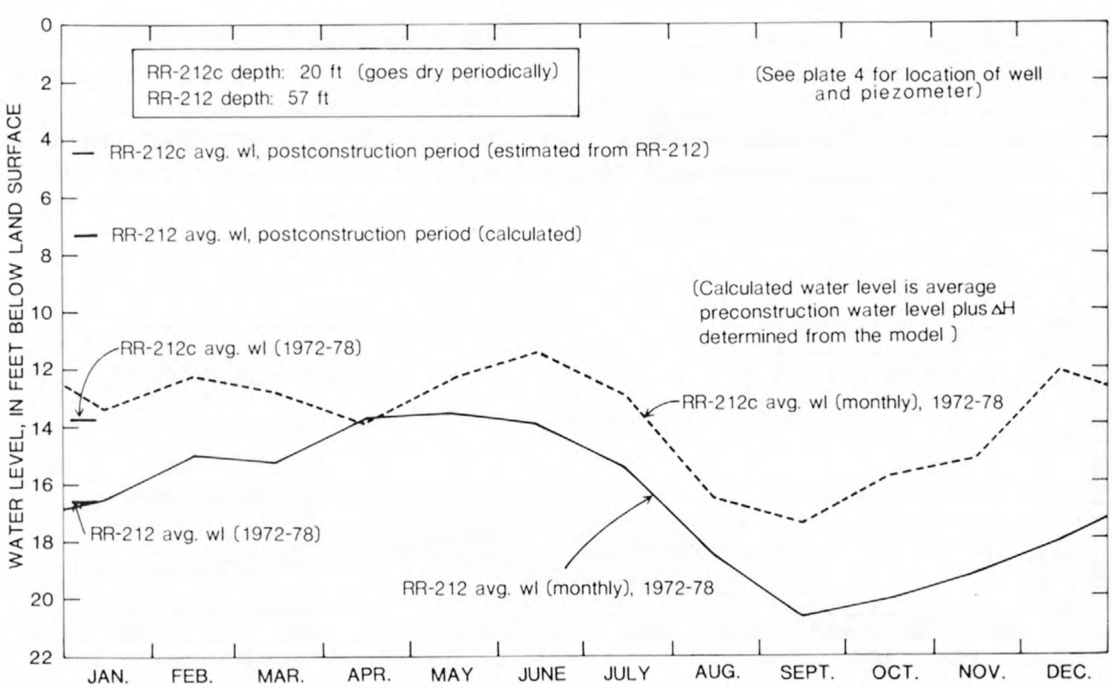

Figure 9.--Average water levels at well RR-212 and piezometer RR-212c.

Campti

Campti is adjacent to the Red River but is built on terrace deposits of Pleistocene age that form the valley wall. The town is several miles upstream from one of the sites proposed for Lock and Dam 4. For a lock and dam at this proposed site, model simulation of the aquifer indicates that average water levels in the alluvial aquifer will rise 15 to 19 ft near the river and 10 to 13 ft 1/2 mi away. Water levels in the terrace deposits under present conditions are about 20 to 30 ft below land surface--a level about 22 ft higher than water levels in the adjacent alluvium. A large increase in water level in the alluvium in the postconstruction period may cause only a small increase in water level in the terrace deposits. Plates 5 and 6 illustrate average water levels in the alluvial aquifer in the preconstruction and postconstruction periods, respectively. The area underlain by terrace deposits is not contoured. The average monthly water level at Campti for the period of record is illustrated by the hydrograph of well Na-304 (fig. 10), screened in the terrace deposits. None of the observation wells near the community were screened in the Red River alluvium.

On the west side of the Red River in the Campti area, potentiometric contours for the postconstruction period indicate that water from the Red River will recharge the alluvial aquifer. Subsequently this water would be discharged into Bayou Pierre. Recharge of the alluvium by the Red River under steady-state conditions occurs in about 1 percent of the valley. It occurs at this site because Bayou Pierre empties into the Red River below Lock and Dam 4, and as a result, average water levels in the bayou are lower than those in the nearby reach of the Red River above Lock and Dam 4.

Piezometers at each well site at Campti are dry part of the time. This condition coincides with the time that water levels in the terrace aquifer are below the depth (17-31 ft) of the piezometers. When water levels in the aquifer are higher, then the piezometers contain water and water levels in the piezometers respond similarly to water levels in the adjacent well.

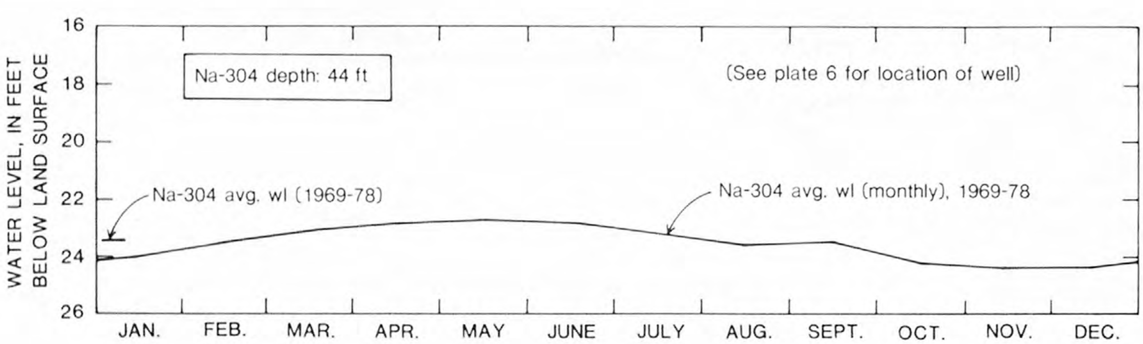

Figure 10.--Average water levels at well Na-304 screened in terrace deposits, Campti area, La.

In the alluvial aquifer near Campti, the potential exists for water levels in wells in the aquifer and levels in the confining bed to occur very near land surface when stages are high on the Red River, which can occur under both preconstruction and postconstruction conditions.

Clarence and Natchitoches

All of Clarence and the part of Natchitoches east of Cane River Lake are built on the alluvium of the Red River. Most of Natchitoches is built on deposits of Tertiary age or on terrace deposits of Pleistocene age.

Clarence and Natchitoches are near the upper end of the proposed pool behind Lock and Dam 3 (plan B-3, modified). As a result, changes in average water level predicted for the postconstruction period are small. At Clarence, model predictions of average water-level changes are about 4 ft; at Natchitoches, about 1 to 2 ft. Average water levels in the preconstruction and postconstruction period are illustrated on plates 7 and 8, respectively. The hydrograph of well Na-290 (fig. 11) at Natchitoches illustrates monthly average water levels in wells in the alluvial aquifer for the period of record. The hydrograph of well Na-308 (fig. 12) illustrates similar conditons at Clarence. The response of the saturated zone in the confining bed is illustrated in figure 11 by the hydrograph of an adjacent piezometer (Na-290d) completed in the fine-grained deposits. There was no piezometer adjacent to well Na-308 at Clarence. At two other well sites in Clarence, adjacent piezometers (both with short periods of record) consistently had water levels higher than those in the nearby well in the aquifer.

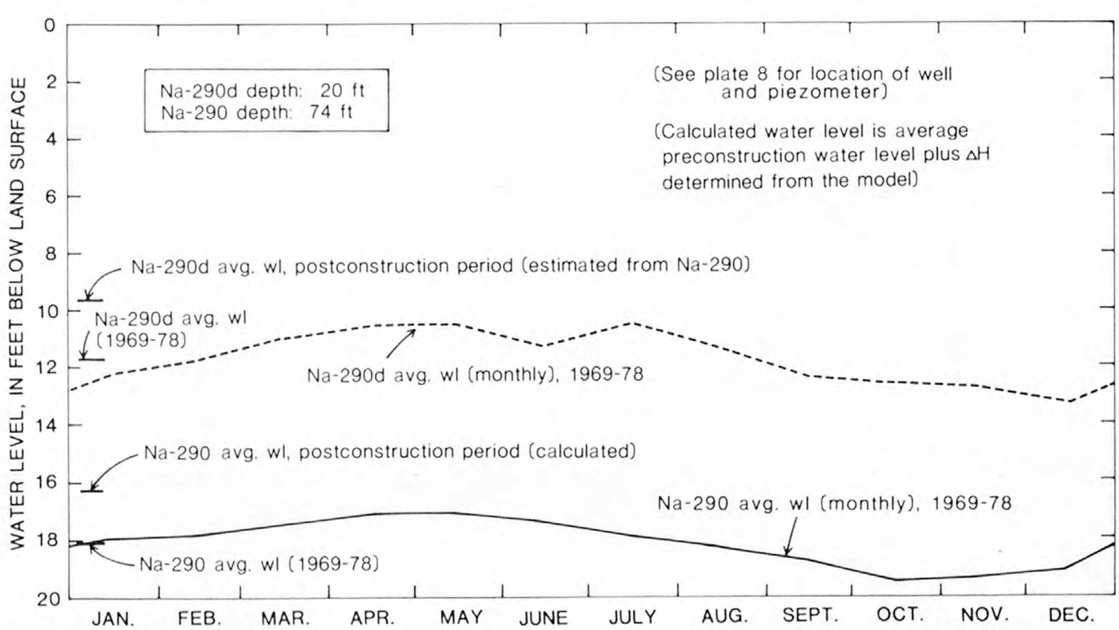

Figure 11.--Average water levels at well Na-290 and piezometer Na-290d.

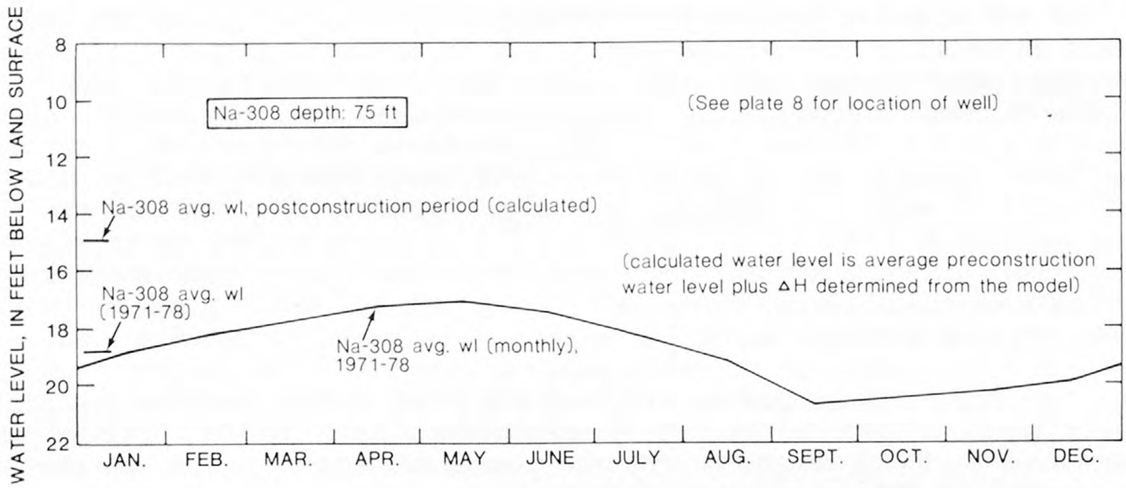

Figure 12.--Average water levels at well Na-308.

Colfax

All of Colfax is built on alluvium of the Red River. The community is a short distance upstream from the site proposed for Lock and Dam 3 (plan B-3, modified). Average water levels in wells in the alluvial aquifer in the postconstruction period are projected to rise about 8 to 10 ft near the river and about 4 to 6 ft a mile from the river. Projected water levels in the alluvial aquifer near the river at Colfax are lower than the pool stage for plan B-3, modified. These lower levels may result because the Cane River Diversion Canal (which discharges into the next lower pool) maintains lower levels in the alluvial aquifer to the west of the Red River and because of potential underflow downstream under the lock and dam. Possibly, water-level rise near the river may be greater than projected. The 1/2 mi grid spacing makes precise simulation at the river difficult. Plates 9 and 10 illustrate average water levels in the preconstruction and postconstruction periods, respectively. The hydrograph of well G-349 (fig. 13), east of Colfax, illustrates the monthly average water levels in the alluvial aquifer for the period of record. Water levels would fluctuate similarly but have higher values in the postconstruction period.

The alluvial aquifer is artesian or semiartesian in most of the area at Colfax. The saturated zone in the confining bed responds to changes in the potentiometric surface of the aquifer. At well G-349 (fig. 13) the water level in the adjacent piezometer (G-349e) screened in the overlying confining bed is 1 to 6 ft above the water level in the aquifer, depending on the time of year. The hydrograph of the piezometer near well G-349 (fig. 13) differs from typical hydrographs, principally because of the short period of record (4 years) that was used for the average values.

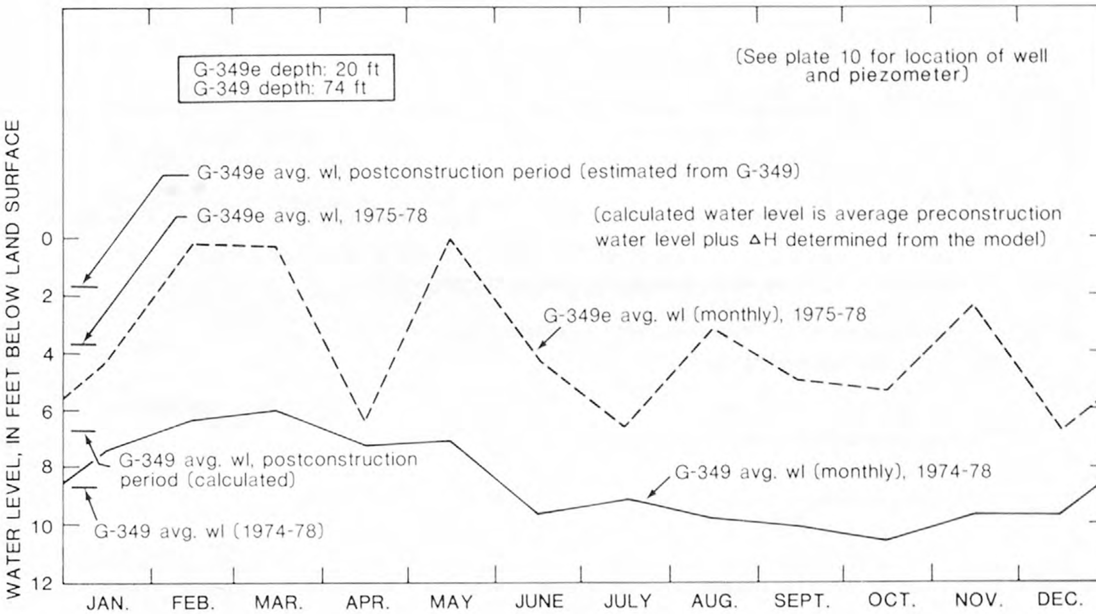

Figure 13.--Average water levels at well G-349 and piezometer G-349e.

On the west side of the river, potentiometric contours for the post-construction period indicate that water from the Red River will recharge the alluvial aquifer and subsequently be discharged into the Cane River. This condition results because Cane River discharges through the Cane River Diversion Canal into the Red River below Lock and Dam 3. Thus, lower average water levels are maintained in the stream than in the nearby reach of the Red River above Lock and Dam 3.

Boyce

Boyce is built on the Red River alluvium near the river. The community is a few miles from the upper end of the proposed pool for Lock and Dam 2. Thus, water-level change in the river from the preconstruction to the postconstruction period will be relatively small. Average water levels in the alluvial aquifer for the preconstruction period and post-construction period are illustrated on plates 11 and 12, respectively. In the preconstruction period, average water levels are 7 to 16 ft below land surface. Average water levels are projected to rise 5 to 6 ft in the postconstruction period.

The only nearby observation well with a long period of record is R-970, located about 1/2 mi south of Boyce. The hydrograph of this well (fig. 14) illustrates the average monthly water level and the seasonal fluctuation in wells in the alluvial aquifer. Average water levels in the adjacent piezometer (R-970b) in the confining bed (fig. 14) are about 2 ft higher than water levels in wells in the aquifer during most of the year. On the average, water levels in the fine-grained deposits probably will be at or near land surface at this site during the first 5 months of the year during the postconstruction period.

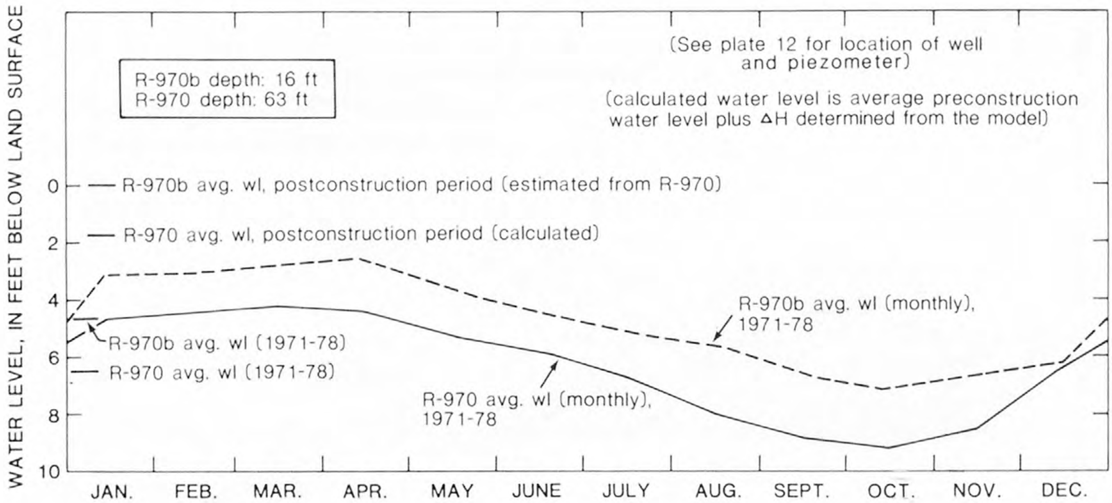

Figure 14.--Average water levels at well R-970 and piezometer R-970b.

Alexandria and England Air Force Base

Alexandria and England Air Force Base are built on the alluvium of the Red River. The area encompassed by these two developed areas is larger than any other urban area within the Red River Valley in Louisiana. The population potentially affected by changes in water level in the alluvium is also greater here than at other urban areas.

These developed areas are about midway between the proposed Lock and Dam 2 and the upper end of the pool formed by construction of the lock and dam. Average water levels in wells in the Red River alluvial aquifer are projected to rise 6 to 7 ft near the river at Alexandria and England Air Force Base. On the side of the developed areas away from the river, average water levels are projected to rise 1 ft at Alexandria and 1 to 2 1/2 ft at the air base. The lower value at Alexandria occurs because the city extends farther from the river than the air base. The average preconstruction and postconstruction water-level surface of the alluvial aquifer is illustrated on plates 13 and 14, respectively. Because of the size of the area and because conditions vary areally, four hydrographs (figs. 15 and 16) are presented to show various conditions. In some of the low areas of Alexandria, water levels in wells screened in the alluvial aquifer are above land surface in the winter and early spring of most years. These conditions will persist in the postconstruction period--water levels will be somewhat higher and the area with water levels above land surface will be somewhat larger.

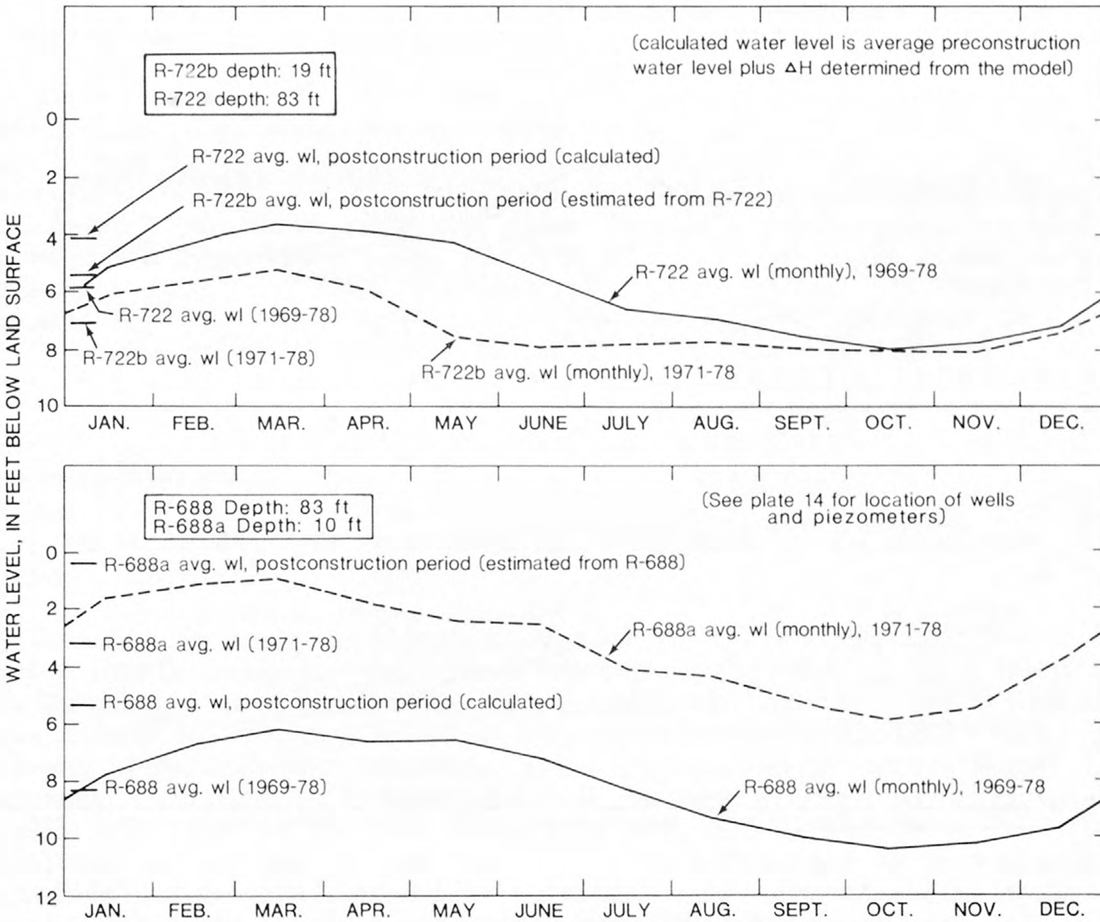

Figure 15.--Average water levels at well R-688, piezometer R-688a, well R-722, and piezometer R-722b.

The average monthly level and the seasonal variation of the surface of the saturated zone in the fine-grained deposits (confining bed) overlying the alluvial aquifer are illustrated by hydrographs of piezometers plotted in figures 15 and 16 with the adjacent well. At sites in or near low swampy areas, water levels in the piezometers are at or slightly above land surface in late winter and early spring of most years. In the postconstruction period, the length of time that this condition persists probably will be longer. At the same time, higher sites on natural levees may have water levels several feet below land surface.

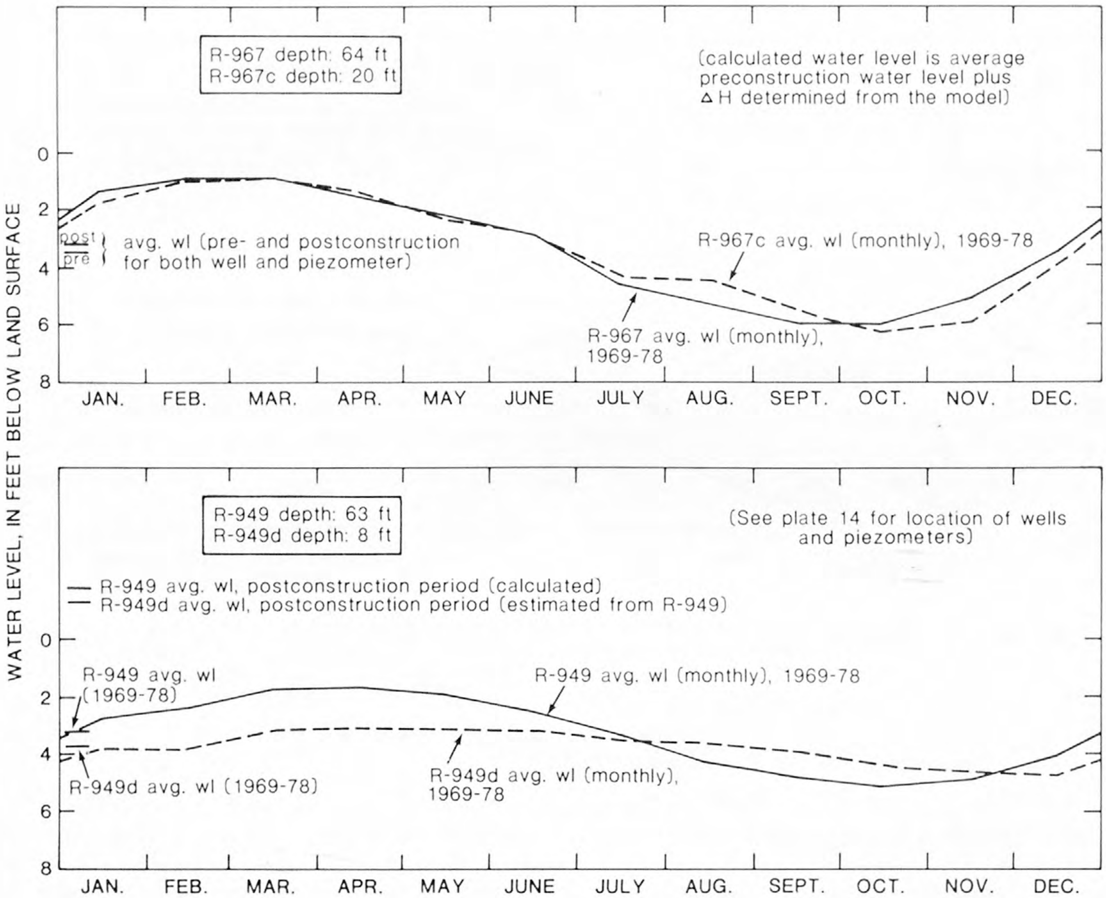

Figure 16.--Average water levels at well R-967, piezometer R-967c, well R-949, and piezometer R-949d.

SUMMARY AND CONCLUSIONS

The Red River Navigation Project extends from the confluence of the Red and Black Rivers in central Louisiana to Shreveport in northwestern Louisiana (fig. 1). The alluvial valley area included is about 2,000 mi^2. Urban areas in the Red River Valley, which are the focus of this study, are the developed areas of Bossier City, Shreveport (in part), Coushatta, Campti, Clarence, Natchitoches (in part), Colfax, Boyce, and Alexandria.

Construction of locks and dams along the Red River in Louisiana will modify the ground-water flow system in the Red River alluvial aquifer. Higher minimum stages on the river caused by pooling of water behind the dams will cause higher water levels--as much as 23 ft higher at Lock and Dam 5--within the aquifer. Upstream from each dam and farther from the river, water-level rise will be progressively less. In addition, flow paths will be modified--principally in the vicinity of the locks and dams. In about 1 percent of the area, especially near Lock and Dam 3 and 4, water from the river will recharge the alluvial aquifer. This water subsequently will return to the Red River via the Cane River and Bayou Pierre, respectively.

The stream-aquifer flow system for one possible arrangement of locks and dams (plan B-3, modified) was modeled to permit prediction of average water levels in urban areas in the postconstruction period. For this plan, average water levels in the alluvial aquifer are predicted to rise as much as 8 to 12 ft near the river in the Shreveport-Bossier City-Barksdale Air Force Base area. At the edge of the flood plain, water levels will rise 1 to 5 ft. At Coushatta, water levels will rise 5 to 9 ft. Near the river at Campti water levels will rise 15 to 19 ft; 1/2 mile from the river the rise will be 10 to 13 ft. At Clarence, water levels will rise about 4 ft; at Natchitoches, about 1 to 2 ft. Water levels at Colfax will rise 8 to 10 ft near the river and 4 to 6 ft 1 mi from the river. Water-level rise will be 4 to 6 ft at Boyce. In the Alexandria-England Air Force Base area, water levels will rise 6 to 7 ft near the river; 1 ft at Alexandria on the side of the city away from the river; and 1 to 2 1/2 ft at England Air Force Base on the side away from the river.

The rise in the potentiometric surface of the aquifer (as indicated by water levels in wells) will cause the top of the zone of saturation in the overlying fine-grained sediments (confining bed) to rise. Because the data base was not sufficiently long to calibrate a model to simulate transient flow in the aquifer, water levels were approximated by steady-state conditions. Hydrographs illustrate average monthly levels and show the relation between the top of the zone of saturation and the potentiometric surface of the aquifer. Preconstruction data show that the top of the zone of saturation can be about equal to or as much as several feet above or below the potentiometric surface of the aquifer. Postconstruction relations were simulated by transposing the hydrographs upward by the amount of projected change in average water level in the postconstruction period. The amount of transposition ranged from 0 near the edge of the flood plain in some areas to 20 ft or more near some locks and dams. Where transposition of the hydrographs indicates that water levels in the fine-grained material are above land surface, rejected recharge and runoff or ponding of water may occur.

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