THE INDEPENDENCE DAY FLOOD OF 1994 AND EFFECTS ON WATER LEVELS IN THE UPPER FLORIDAN AQUIFER, ALBANY AREA, GEORGIA

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ABSTRACT

Remnants of Tropical Storm Alberto moved from the Gulf of Mexico into southwestern Georgia on Independence Day weekend, 1994. Rainfall was scattered over the western half of Georgia, eastern Alabama, and the Florida panhandle. The heaviest rainfall occurred in the Flint River watershed, where Americus, Ga., received about 28 in. from July 3-7, with about 21 in. falling in a 24-hour period on July 5-6. Torrential rainfall resulted in record flooding during the period July 4-19. At Albany, the Flint River crested at a stage of 43 ft, which was 23 ft above flood stage, and more than 5 ft higher than the previously known record stage of 37.8 ft, which occurred in January 1925.

Heavy rainfall and extensive flooding caused water levels in the Upper Floridan aquifer to rise to historic record high levels in much of the study area near the Flint River. Water levels in the aquifer responded to flooding conditions at magnitudes and rates controlled by the hydraulic conductivity and pre-flood potentiometric surface of the aquifer, and the distance from the flooded area. Where the hydraulic conductivity of the aquifer is relatively low, the response to rising floodwaters was slow and the recovery period was delayed after the river receded. However, where the hydraulic conductivity of the aquifer is high, response was rapid both to rising floodwaters and to recession of the river.

INTRODUCTION

Rains produced by Tropical Storm Alberto resulted in unprecedented flooding in Georgia during July 1994. Flood waters inundated entire communities as numerous streams reached peak stages and discharges far greater than previously recorded. Many municipal, industrial, and private water systems were rendered unserviceable for days. A total of 55 counties in Georgia, mostly in the southwestern part of the State, were declared as Federal flood-disaster areas by President Clinton.

In the Albany area, the interaction between area streams and the shallow Upper Floridan aquifer is well understood during normal stream and aquifer conditions. Peak stages of streams were unprecedented during the Independence Day Flood of 1994 and the resulting stream and aquifer relations had not been previously observed.

The interpretation of the stream and aquifer relations was confounded, as floodwaters spilled over stream banks. Hundreds of thousands of acres of land were inundated for the first time during contemporary time. In the karst Albany area, where cavernous limestone occurs near land surface, a part of the flood water may have been vertically transmitted into the Upper Floridan aquifer where the protective overburden was breached by previous sinkhole collapse.

This paper presents a peliminary evaluation of stream and aquifer relations in the Albany area prior to, during, and shortly after the occurrence of the Independence Day Flood of 1994.

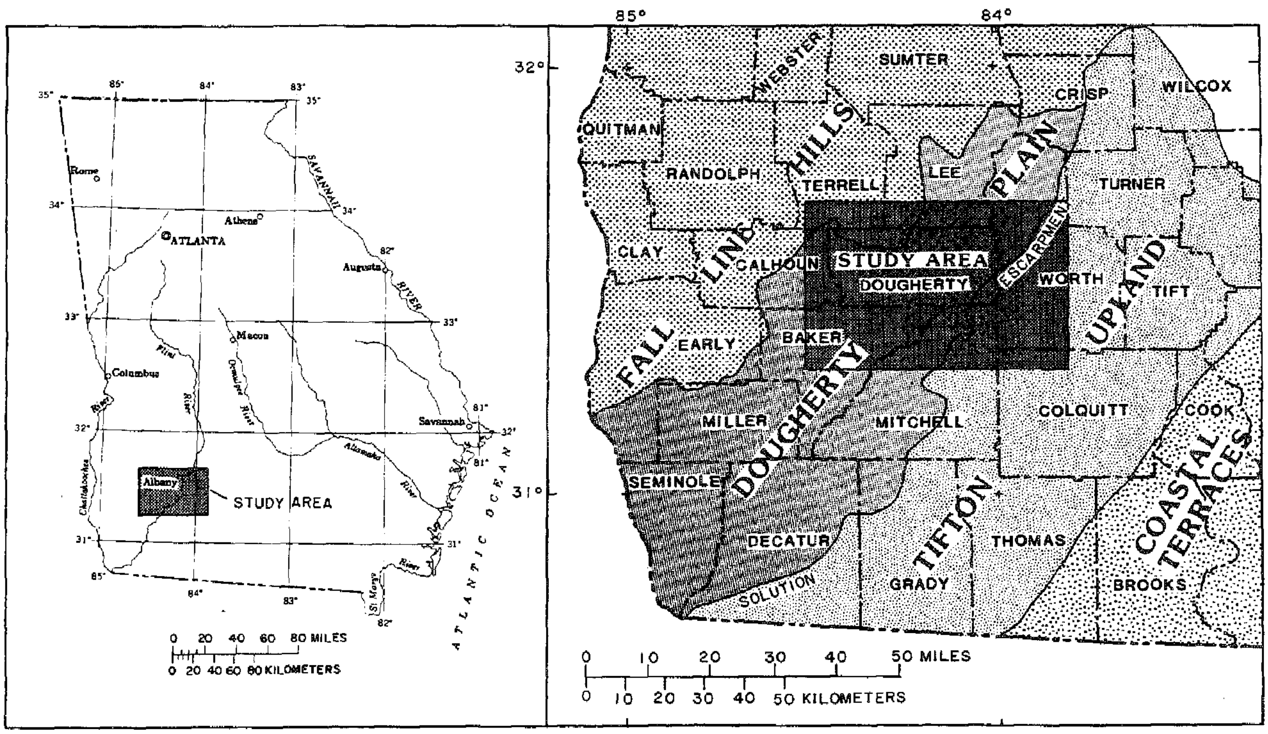

Figure 1. Location of study area and physiographic districts of the southwestern Georgia Coastal Plain.

Description of the Study Area. The study area lies in the Dougherty Plain district (Clark and Zisa, 1976) (fig. 1) of the Coastal Plain of Georgia. The Dougherty Plain is an inner lowland that was formed mainly by the stripping away of sediments (Fenneman, 1938) which left the underlying limestone vulnerable to weathering processes. As a result, the Dougherty Plain is characterized by karst topography and is marked by numerous flat-bottomed or rounded sinkholes (depressions). Many depressions are filled with material of low permeability and some hold water year round.

Active solutioning in parts of the Dougherty Plain has transferred much of the drainage from the surface to underground channels. Only larger streams flow in the terraced valleys (Hicks and others, 1987). Major streams in the area are the Flint River and three tributary streams: Kinchafoonee, Muckalee, and Coolewahee Creeks.

Tropical Storm Alberto. Tropical Storm Alberto grew from a tropical depression which formed off the western coast of Cuba in the Gulf of Mexico on June 30, 1994. During the early morning of July 3, Tropical Storm Alberto first touched land in the Florida panhandle. Once ashore, the storm rapidly lost energy and was downgraded to a tropical depression by mid-afternoon on the same day. Remnants drifted north, to just southwest of Atlanta early on July 5, and became stationary until it dissipated on July 7.

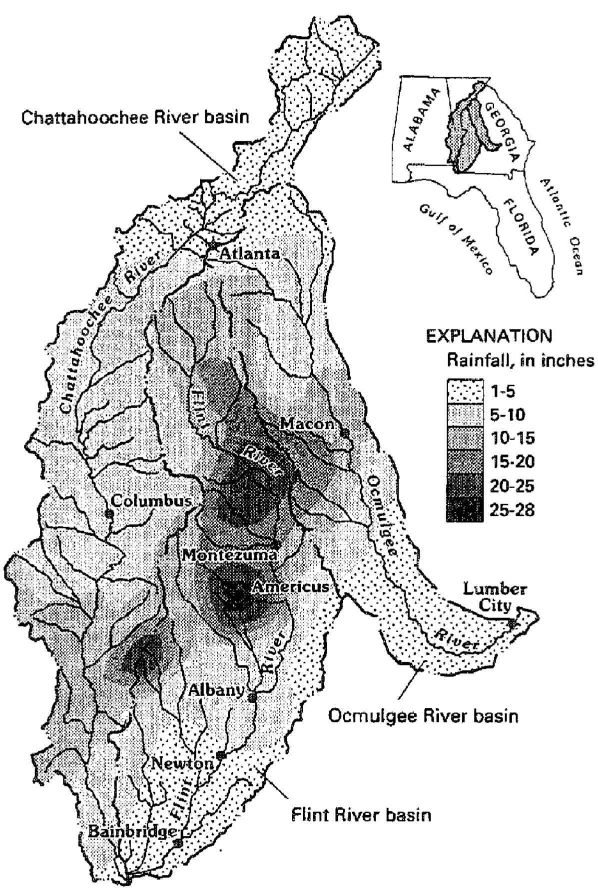

Figure 2. Rainfall distribution resulting from Tropical Storm Alberto, July 3-7, 1994.

Slow movement of the storm and abundant tropical moisture combined to produce historic rainfalls over much of central and western Georgia. Storm rainfall totals of more than 13 in. were common (fig. 2). The Americus, Ga., area received 28 in. of rainfall during the period July 3-7, and more than 21 in. in a 24-hour period on July 5 and 6 (U.S. Department of Commerce, National Weather Service, written commun., 1994). Total rainfall for Americus was about 60 percent of the area's mean annual. The intense rainfall that occurred during July 5 and 6 was nearly 2.5 times greater than the area's estimated 100-year recurrence interval 24-hour rainfall (U.S. Department of Commerce, National Weather Service, written commun., 1994).

RATE AND MAGNITUDE OF FLOODING ON AREA STREAMS

The floods resulting from Tropical Storm Alberto were no less remarkable than the rainfall that produced them. Flash flooding began early on July 5 in the Americus area, about 20 mi north of the study area's northern boundary. Muckalee Creek at Americus peaked on July 6 at a discharge of 33,500 ft^3/sec which is about 4.0 times larger than the 100-year recurrence interval streamflow. About 20 mi to the southwest, Kinchafoonee Creek near Dawson peaked early on July 7 at a discharge 1.4 times greater than the 100-year flood discharge. Flooding in the Americus area was likely compounded by the instantaneous release of significant volumes of water as numerous small lakes drained when the earthen dams failed.

Heavy local rainfall and composite flood flow from the northern part of the Flint River watershed began affecting streamflow in the northern part of the study area early on July 4. The Flint River at Georgia Highway 32 near Oakfield (fig. 6, site A) began rising about mid-day on July 5 (fig. 3), primarily as a result of emergency releases from Lake Blackshear, located a few miles north of the streamflow gaging station at the Georgia Highway 32 bridge. The Flint River crested at this station shortly after midnight on July 10 at about 40 ft (altitude of about 226 ft above mean sea level) and a peak discharge of about 112,000 ft^3/sec.

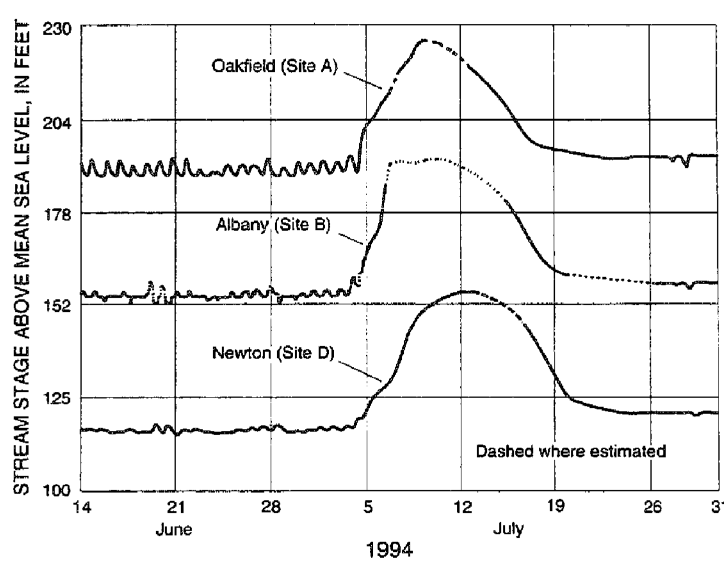

Figure 3. Stream altitudes for Flint River at Oakfield, Albany and Newton, Georgia, June 14-July 31, 1994.

At the Flint River at Albany gaging station (fig. 6, site B), about 14.2 mi south of the Oakfield gage, river levels began rising at about mid-day on July 5 (fig. 3). During the next 48 hours, streamflow of the Flint River at Albany increased at an incredible rate. On the morning of July 5, the stage of the Flint River was at a stage of 7 ft. By early evening on July 7, the stage had risen to nearly 42 ft, 22 ft above flood stage. The stage fluctuated between 42 and 43 ft until the river again began to rise on July 9 and eventually peaked early on July 11 at a record of about 43 ft (altitude of about 193 ft above mean sea level), and more than 5 ft higher than the previous record stage of 37.8 ft, which occurred during January 1925. The peak discharge of about 120,000 ft^3/sec greatly surpassed annual peak discharges for the period of record.

The Flint River at Albany increased in stage and discharge at a much more rapid rate than at the gaging station at Oakfield. Kinchafoonee and Muckalee Creeks converge with the Flint River less than 1 mi north of the Albany gaging station. The large volume of flood flow discharged into the Flint River from these streams produced the rapid rise and early peak discharge at the Albany gaging station (fig. 6, site B). The second rise, and subsequent peak recorded on July 11, resulted from the arrival of the flood flow generated in the northern part of the Flint River basin.

About 29 mi south of Albany, at the Flint River at Newton gaging station (fig. 6, site D), the river began rising during the early afternoon of July 5 (fig. 3). The rate of rise was much less than observed at Albany. The Flint River peaked mid-morning on July 13 at a stage of about 45 ft (altitude of about 155 ft above mean sea level) and a discharge of about 100,000 ft^3/sec.

HYDROGEOLOGY OF THE UPPER FLORIDAN AQUIFER

Only the upper part of the thick sequence of Coastal Plain sediments underlying the study area is pertinent to this study. The upper part consists of, in ascending order, the Lisbon Formation, the Clinchfield Sand, the Ocala Limestone, the Suwannee Limestone, and the undifferentiated overburden.

The Upper Floridan aquifer consists of the Ocala Limestone and the Clinchfield Sand in the northern part of the study area, the Suwannee Limestone and the Ocala Limestone (fig. 4) in the eastern part of the study area, and the Ocala Limestone in the southern part. The Lisbon Formation is thick and dense and acts as the lower confining unit of the Upper Floridan aquifer.

The Upper Floridan aquifer is divided into upper and lower water-bearing zones having different hydraulic properties (Torak and others, 1991). The primary permeability of the Ocala Limestone is generally low; however, the lower part of the formation has well developed permeability along solution-enlarged joints, bedding planes, and fractures which together form the lower water-bearing zone which is the principal water-transmitting part of the Upper Floridan aquifer. The upper part of the Ocala, which forms the upper water-bearing zone, is dense, highly weathered limestone and generally has low permeability. However, in some parts of the study area solutioning along the

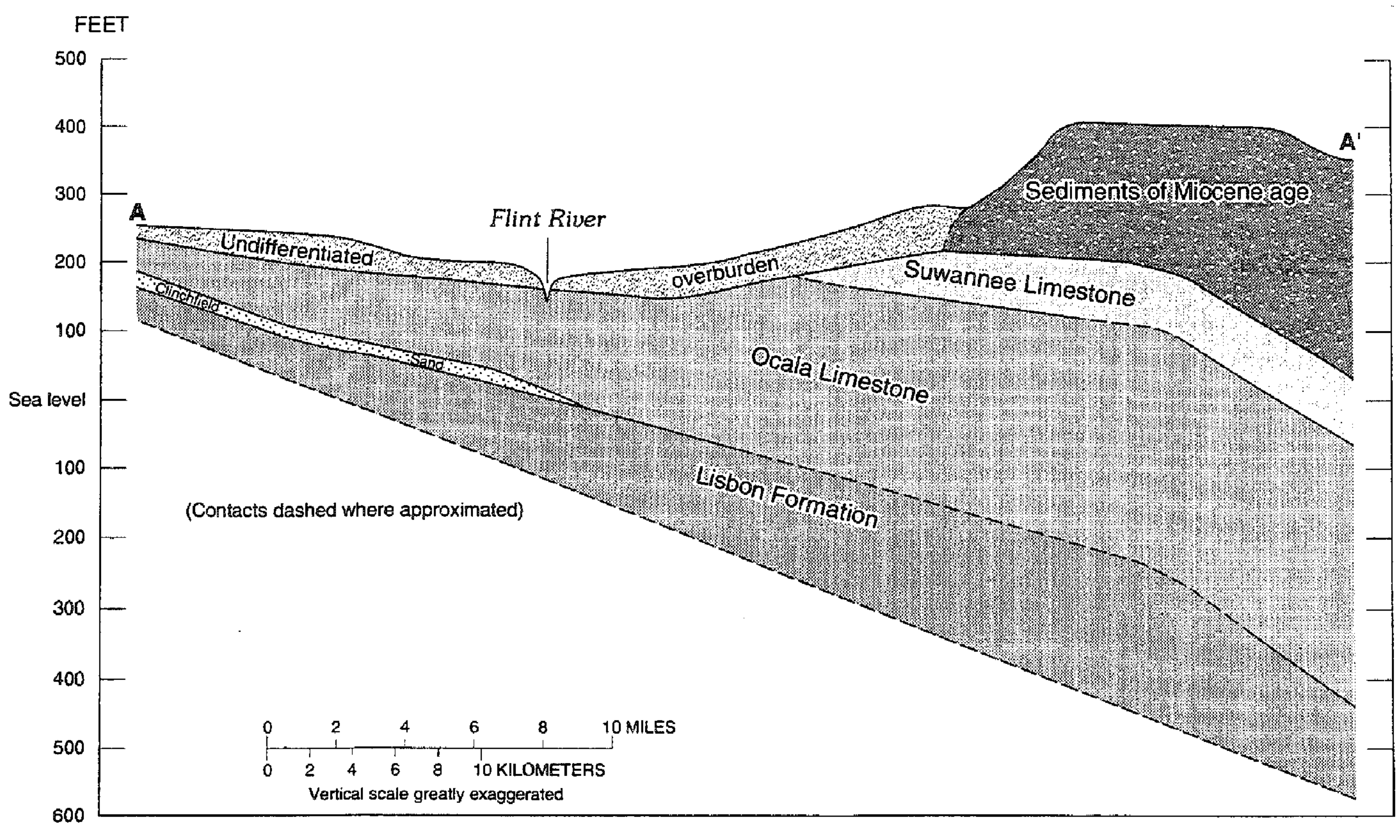

Figure 4. Generalized section A - A′. Line of section is shown on figure 6.

overburden and Ocala contact has created lateral conduits of relatively high permeability. In areas away from streams, where ground-water flow rates are not influenced by changes in stream stage, the solution conduits are usually filled with fine-grained sediments. Near the streams, frequently changing hydraulic gradients in the aquifer have flushed the sediments from the conduits in the part of the study area south of Albany and they form springs that emerge in and near the Flint River. In most areas, the upper water-bearing zone of the Upper Floridan aquifer functions primarily to supply water to the lower water-bearing zone.

Hydraulic conductivity of the Upper Floridan aquifer varies areally throughout the study area. There is a significant difference between the conductivity in the northern part of the study area (generally the area north of the Lee and Dougherty County line) and the remainder of the area. Hydraulic conductivity of the aquifer increases progressively to the south. (See Hicks, and others, 1987; and Torak and others, 1991, for more detailed descriptions.)

Ground-water flow in the Upper Floridan aquifer can be classified generally as either diffuse, where flow is analogous to conditions in a homogeneous aquifer and can be described by using basic Darcian equations; or conduit, where flow occurs in distinct conduits and the surrounding rock has comparatively low porosity and permeability. Ground-water flow in the conduits may be rapid and turbulent.

The undifferentiated overburden consists of alternating layers of sand, silt, and clay. The more permeable part of the overburden may seasonally contain a water-table aquifer, which may interchange water with the Upper Floridan aquifer. In most areas, the lower, clayey part of the undifferentiated overburden confines the underlying Upper Floridan aquifer (Torak and others, 1991).

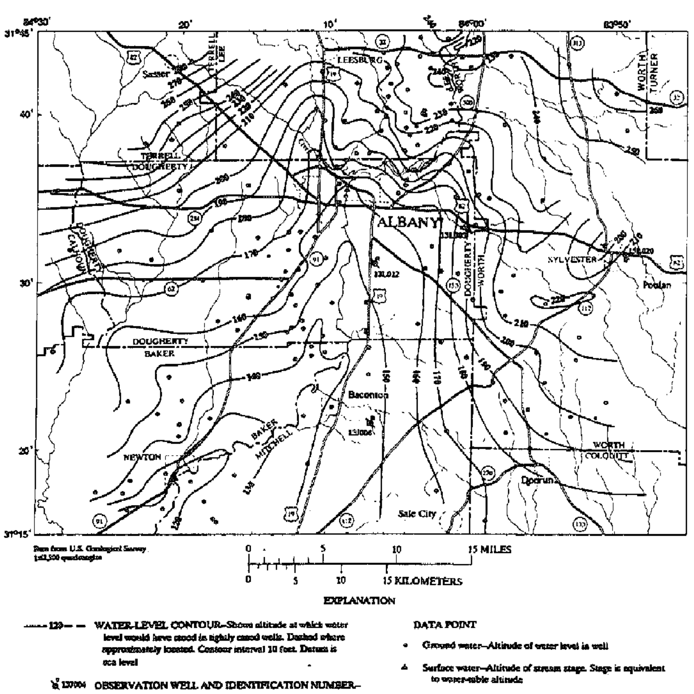

Figure 5. Potentiometric surface of the Upper Floridan aquifer, November 1993.

Water-Level Fluctuations. Water levels in the Upper Floridan aquifer respond positively to recharge and negatively to discharge. The rate and magnitude of water-level fluctuations in response to rainfall is not predictable, varies areally, and may range from very slow to instantaneous. Antecedent moisture conditions and differences in overburden lithology and thickness influence the rate and magnitude of water-level fluctuations in the Upper Floridan aquifer. Ground-water levels also are strongly influenced by fluctuations in stream stage in parts of the study area.

A potentiometric map of the study area was constructed using water-level data collected in November 1993 in base-flow conditions from wells tapping either the upper, the lower, or both water-bearing zones. The map indicates that ground-water gradients were generally toward the Flint River and the direction of regional ground-water flow was toward the south (fig. 5). Normal seasonal changes in recharge and discharge may locally alter the shape of the potentiometric surface, but do not change appreciably the directions of ground-water flow. Ground-water levels are usually at their maximum during late spring, following the winter recharge period, and decline to their minimum in late fall as a result of increased rates of evapotranspiration and pumpage that occur during the summer and early fall. For the most part, the Upper Floridan aquifer is in equilibrium; recharge received from normal annual rainfall approximately equals the combined natural and man-induced discharge (Hicks and others, 1987).

STREAM AND AQUIFER INTERACTION

Ground-water discharge from the Upper Floridan aquifer maintains base flow in the Flint River and its tributaries. Under normal streamflow conditions, discharge from the aquifer is at a maximum during late winter and early spring when the hydraulic-head differential (aquifer head higher than river stage) is the greatest. In late spring when the rate of ground-water withdrawal increases, the aquifer head declines and the volume of ground-water discharge to streams is reduced. The rate of ground-water discharge progressively declines through the summer and reaches a minimum by late fall prior to the initiation of the typically rainy winter months. Base flow was measured in the study area during October 1986 (fig. 6) as a part of a previous investigation (Hicks and others, 1987). These measurements indicated that the Flint River received about 645 ft^3/sec of ground-water discharge in the river reach between Albany and Newton. In this part of the study area, major solution conduits (springs) emerging in or near the Flint River transmit large volumes of water from the Upper Floridan aquifer to the river (Torak and others, 1991).

In the northern part of the study area, ground-water discharge to the streams is limited primarily to seepage from the exposed limestone banks or sheet flow along the areally extensive clay layer observed at the base of the overburden. During the base-flow measurements (Hicks and other, 1987), ground-water discharge to the Flint River or its major tributaries was much less significant in the northern part of the study area (fig. 6).

The rate of flow at the stream and aquifer boundary is controlled by the hydraulic conductivity of the boundary material and the head differential across the boundary. Because the hydraulic conductivity is constant, fluctuations in rate of flow are controlled primarily by changes in the head differential, or hydraulic gradient. Thus, an increase in aquifer

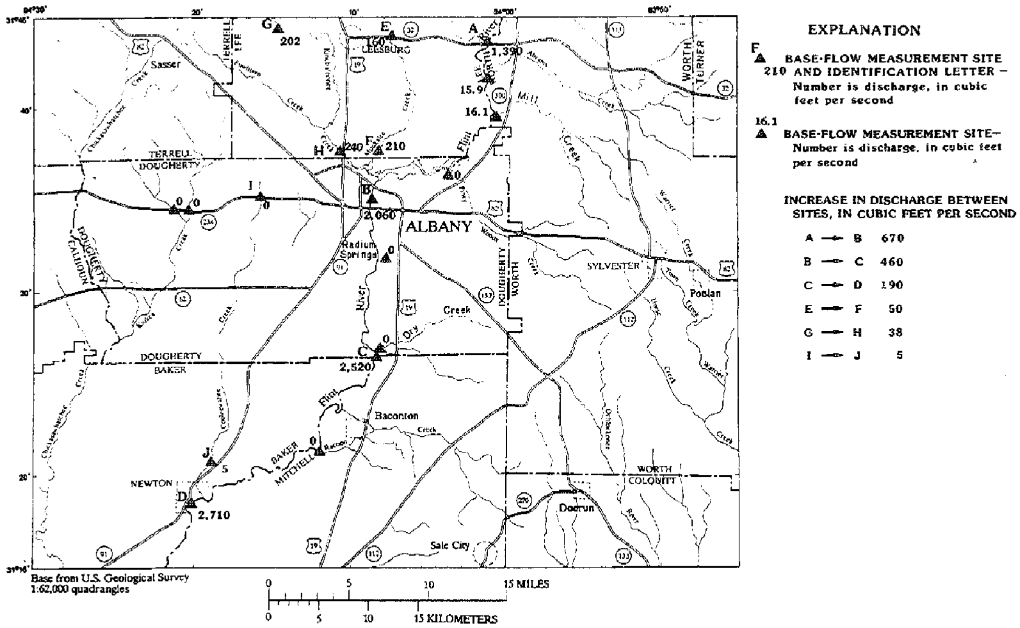

Figure 6. Locations of base-flow measurements, November 27-28, 1984, observation wells, and trace of geologic section A-A′ (shown on figure 4).

head without a corresponding increase in stream stage will result in an increase in ground-water discharge to the stream. Conversely, a rise in stream stage without a corresponding increase in aquifer head will result in a decrease in aquifer discharge. If the river stage exceeds the aquifer head, a flow reversal may occur.

Sudden changes in river stage for short durations of time do not necessarily cause a corresponding water-level change in the aquifer (Torak and others, 1991). A rise in river stage immediately reduces the volume of ground-water discharge to the stream; in effect, the river creates a hydraulic barrier to the aquifer which causes the head to build up in the aquifer. If the river stage continues to rise, the aquifer head will continue to build and will transmit a pressure pulse for a quantifiable distance away from the pressure source (the stream). The distance away from the stream that the pressure pulse is observed is a function of the aquifer hydraulic characteristics, the magnitude of the river stage, and the duration of the flood. Because of the pressure effect, the water-level increase at an observation point away from the river may not be the result of the transfer of river water into the aquifer, but rather an artifact of the change in hydraulic gradient at the stream and aquifer boundary.

EFFECTS OF FLOODING ON WATER LEVELS IN THE UPPER FLORIDAN AQUIFER

The magnitude and rate of ground-water-level change in response to the passing of the Flint River flood peak varied areally. During the flood, the altitude of the potentiometric surface of the Upper Floridan aquifer was primarily controlled by average hydraulic properties of the aquifer, distance from the Flint River, and ambient (pre-flood) altitude of the potentiometric surface of the aquifer.

In the northern part of the study area, the water level in an observation well located 0.4 mi from the Flint River increased only about 9 ft in response to an increase in river stage of nearly 36 ft (figs. 3, 6, and 7). In addition, the rate of ground-water-level change was very slow relative to the rapid rise of the river. In this part of the study area, the hydraulic conductivity of the aquifer is relatively low and the stream and aquifer connection is very poor (Hicks and others, 1987). As a result, a reverse in hydraulic gradient (Flint River to Upper Floridan aquifer) likely did not extend far beyond the river banks.

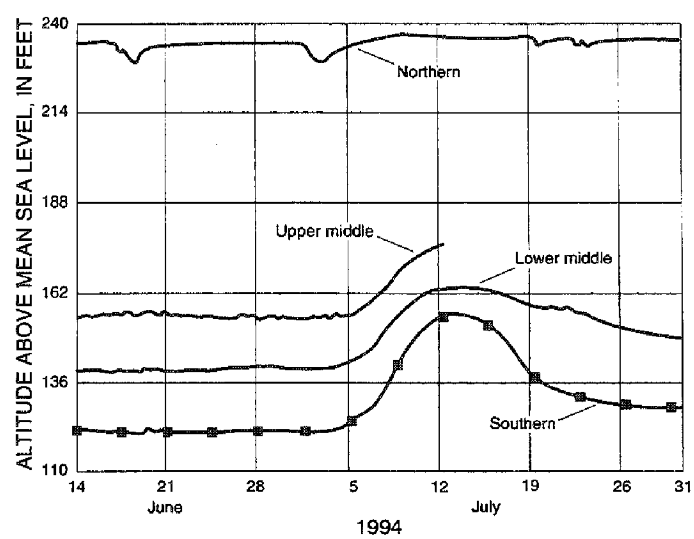

Figure 7. Water-level fluctuations in wells tapping the Upper Floridan aquifer, June 14-July 31, 1994.

Relatively high hydraulic conductivity of the Upper Floridan aquifer and a good stream and aquifer connection south of Albany in the middle part of the study area resulted in rapid and significant ground-water level response to fluctuations in river stage (figs. 3, 6, and 7). In this area, ground-water levels increased at such a high rate that several continuous recorders were disabled as the float-activated tapes came off the recorder pulleys. At an observation well located in the upper part of the middle area 0.4 mi from the river, ground-water levels increased by about 24 ft in response to a river-stage increase of about 38 ft. In the lower part of the middle area, water levels in an observation well about 1.1 mi from the river increased by 26 ft in response to a river stage increase of about 39 ft. A comparison of site-specific ground-water levels and the stage of the Flint River, suggests that there was potential for reversal of the hydraulic gradient. However, the potentiometric map (fig. 5) indicates that the hydraulic gradient of the Upper Floridan aquifer is relatively steep in the upper part of the middle area and less steep in the lower part. As a result, it is likely that hydrostatic pressure in the aquifer prevented widespread lateral movement of river water into the aquifer in the upper part of the middle area, but allowed greater lateral migration in the lower part of the middle area where the hydraulic gradient was less steep.

In the southern part of the study area, ground-water levels in the Upper Floridan aquifer increased by 31 ft at an observation well located 1.2 mi from the Flint River in response to an increase in river stage of 39 ft (figs. 3, 6, and 7). Here, hydraulic conductivity of the Upper Floridan aquifer is very high, there is a very good stream and aquifer connection, and the hydraulic gradient is relatively flat. As a result, it is likely that the flow reversal that developed as the stage of the Flint River peaked caused water from the river to migrate laterally a considerable distance into the aquifer.

As the flood peak passed, ground-water levels began to return to pre-flood levels (figs. 3 and 7). The rate of recovery also is controlled by the same hydraulic factors that control the rate of rise. Thus, ground-water levels in the northern part of the study area recovered slowly. In contrast, in the southern part of the area, ground-water levels recovered as quickly as the flood receded. Flushing of river water from the aquifer was rapid in this part of the study area. For example, a spring near the west bank of the Flint River (not shown on base map) was observed discharging a large volume of apparently clear ground water less than 48 hours after the Flint River crested. During the flood, this spring was more than 39 ft below the surface of the muddy Flint River.

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