United States Geological Survey Open-File Report 96-499

Aftermath of Hurricane Fran in North Carolina–Preliminary Data on Flooding and Water Quality

September 1996

By Jerad D. Bales and
Carolyn J. Oblinger Childress

North Carolina

Storm Track of Hurricane Fran

Floods resulting from Hurricane Fran, which passed through North Carolina on September 5-6, 1996, were some of the most severe and widespread in the State in recent memory. The U.S. Geological Survey (USGS) is responsible for the collection and interpretation of water-resources information, including flood data, for the Nation. As such, the USGS, in cooperation with the North Carolina Department of Environment, Health, and Natural Resources, the U.S. Army Corps of Engineers, and numerous other State and local agencies, is continuing to document the effects of Hurricane Fran on the water resources of North Carolina. The purpose of this report is to present preliminary, selected information on the flooding and associated water-quality conditions which followed Hurricane Fran in North Carolina.

Conditions prior to the hurricane

August 1996 rainfall amounts were above average throughout much of central North Carolina. August rainfall was 1.34 inches above average at Greensboro; 3.08 inches above average at Burlington, and 2.10 inches above average at Fayetteville. Moreover, July rainfall was above average at many reporting stations in the eastern part of the State. Immediately prior to the hurricane on September 1-4, most stations east of Greensboro reported significant rainfall, including Greensboro (5.61 inches), Burlington (0.90 inch), Siler City (3.25 inches), Fayetteville (1.94 inches), New Bern (3.76 inches), and Wilmington (2.55 inches). Consequently, soils in these areas were at or near saturation and had limited capacity for storing the rainfall that fell during the passage of Hurricane Fran.

Because of this excessive rainfall, flows at most gaging stations across north central and parts of eastern North Carolina were already well above average prior to the hurricane. Flows in the Neuse River Basin upstream from Falls dam on September 4 were as much as 10 times greater than the long-term August mean flow. Likewise, flows in the upper Cape Fear River Basin were almost twice the long-term August mean flow on September 4. However, in the northern and central Coastal Plain (for example, the Tar River at Tarboro, Contentnea Creek at Hookerton, and the Trent River near Trenton), flows prior to the hurricane were lower than normal.

Flooding from the Neuse River in Kinston, North Carolina. *photo by D.A. Harned*

Flooding of Crabtree Creek, Raleigh, N.C. *photo by Gary Allen of the News & Observer Publishing Co. in Raleigh*

For additional information, contact:

District Chief, U.S. Geological Survey, 3916 Sunset Ridge Rd, Raleigh, N.C. 27607
Phone: (919) 571-4000
or
access the North Carolina District Home Page on the World Wide Web at
http://wwwnc.usgs.gov/

Rainfall amounts during Hurricane Fran

Rainfall varied widely during the passage of Fran (fig. 1), but the heaviest amounts were reported inland, near and north of Raleigh, in the upper Tar, Neuse, and Cape Fear River Basins. One of the highest reported rainfall amounts for September 5-6 was at the Raleigh-Durham Airport, with a total of 8.8 inches. Rains which followed the hurricane, but were not associated with the storm, exacerbated flooding, and rainfall totals for September 3-12 exceeded one foot in several locations.

Floods resulting from Hurricane Fran

In this century, widespread and severe river flooding in central and eastern North Carolina occurred in September 1928 (lower Cape Fear and Lumber River Basins); August 1940 (Roanoke River Basin); and September 1945 (Cape Fear, Neuse, Lumber, and lower Pee Dee River Basins).

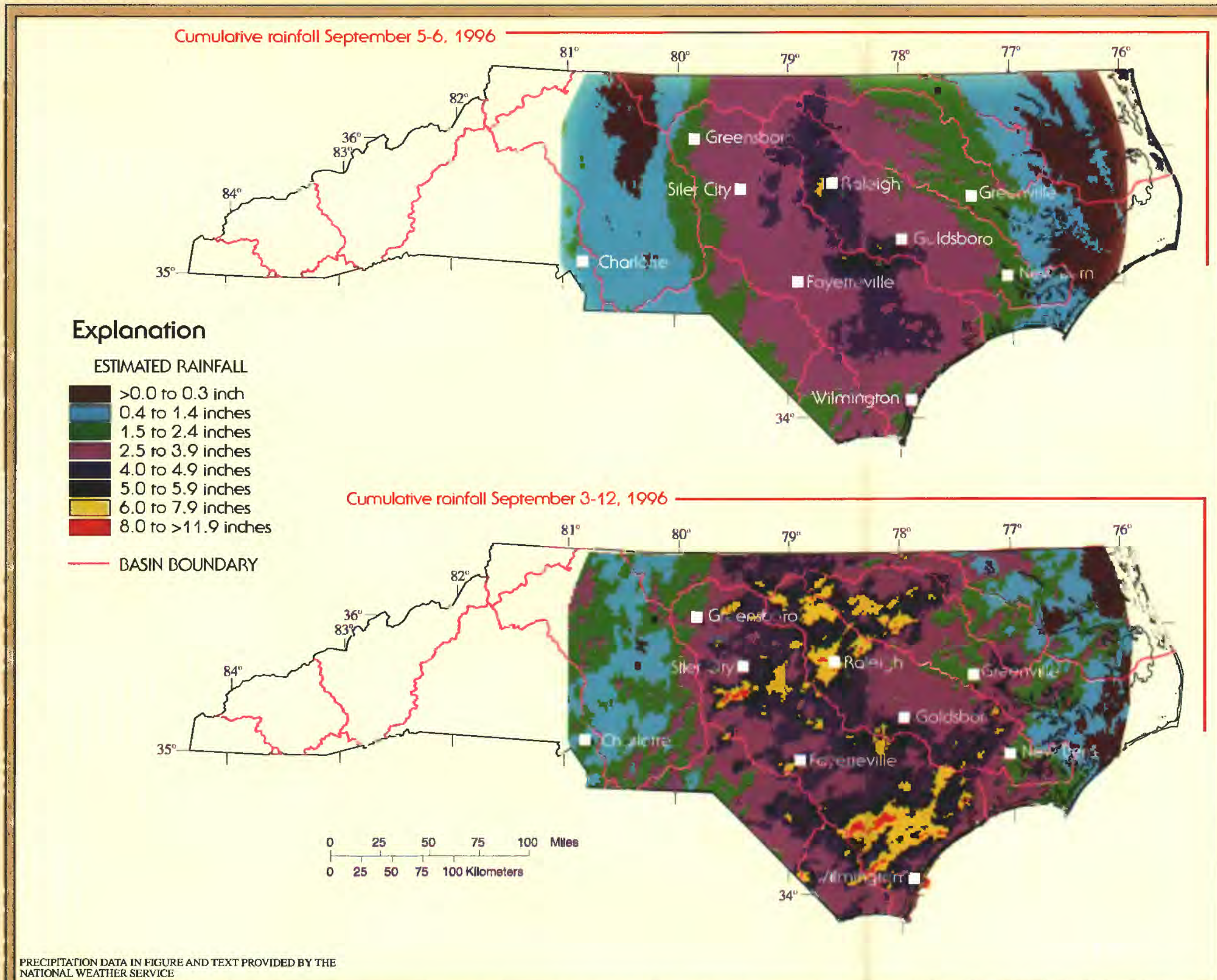


FIGURE 1.–Cumulative rainfall within central and eastern North Carolina for September 5-6 and 3-12, 1996.

Severe, but more localized flooding occurred in the Waccamaw River Basin (fig. 2) in September 1955. All of these floods were the result of rainfall from hurricanes.

Unregulated peak flows resulting from Hurricane Fran surpassed many of the records established during earlier floods this century (table 1). Peaks of record were established for, about 40 sites following the hurricane. Flooding was most severe in the Tar, Neuse, upper Cape Fear, and Waccamaw River Basins.

Tar River Basin

Peak flows in the Tar River near Tar River (site 1) and at Louisburg (site 2) exceeded the 500-year recurrence interval. Peak flows in the Tar River around Rocky Mount had recurrence intervals of between 10 and 25 years, and the peak flow at Tarboro (site 3) had a recurrence interval of between 5 and 10 years (table 1).

The highest flow recorded at a gaging station in the basin was at the upstream-most site, near Tar River, where the drainage area is only 8 percent of the total drainage at Tarboro (site 3, table 1). High rainfall amounts and intensities in the western part of the basin (fig. 1) and a relatively small channel which constricted the flow resulted in the high peak. Further downstream where rainfall was lower, the channel broadens, allowing storage of water in the flood plain. All along the Tar River, water levels rose more than 20 feet above pre-hurricane levels (table 1).

Neuse River Basin

The Neuse River Basin experienced some of the most severe and prolonged flooding from Hurricane Fran and subsequent rainfall. Peak flows were particularly high upstream from Falls dam in the Eno, Flat, and Little Rivers (table 1). The Hurricane Fran peak flow in the Flat River at Bahama (site 7) was almost twice as large as the previous peak of record, which was established in 1938.

Downstream from Falls dam, in Middle Creek near Clayton (site 13), where flows have been measured since 1939, flow peaked at a value about 50 percent greater than the previous peak of record, which exceeded the 500-year recurrence interval. The peak flow in Crabtree Creek (site 9) at Raleigh was more than three times the previously measured peak since the gaging station has been in operation. However, a single measurement of 13,500 ft^3/s (cubic feet per second) was made at site 9 on June 29, 1973. The peak flow in the Little River near Princeton (site 14) had a recurrence interval of between 25 and 50 years (table 1).

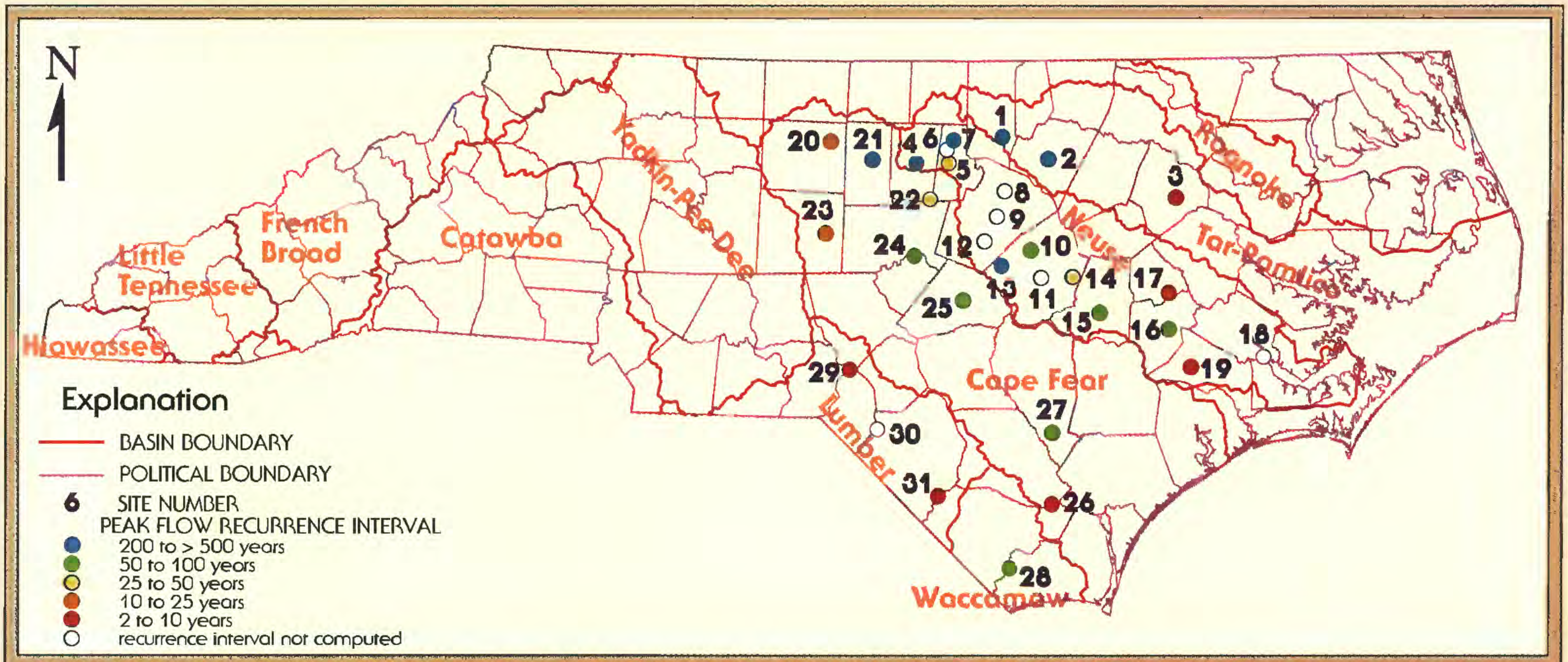


FIGURE 2.–Site locations and recurrence intervals of Hurricane Fran peak flows within North Carolina.

The peak flow resulting from Hurricane Fran in the Neuse River near Clayton (site 10) was 17 percent less than the peak of record which occurred in 1945, before flow in the Neuse River was regulated by Falls dam. The peak flow near Clayton occurred on September 7, when releases from Falls dam were between 300 and 500 ft³/s, or about 2 percent of the peak flow at site 10.

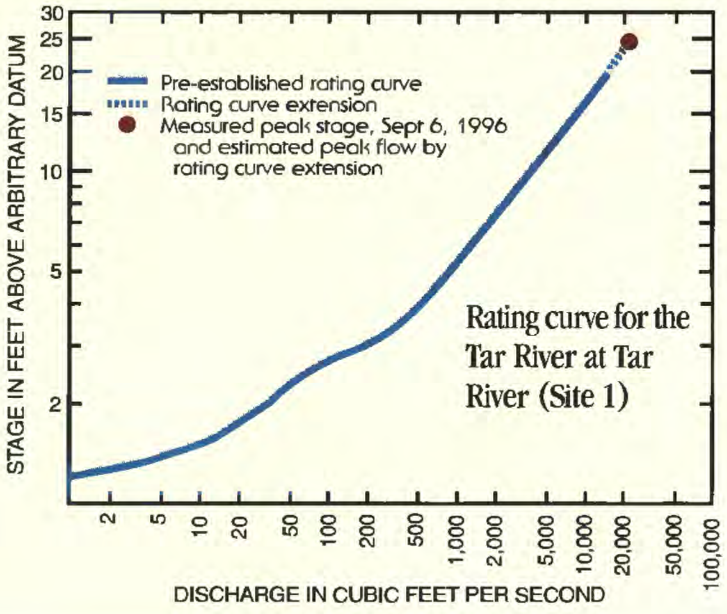
Flooding at Goldsboro and downstream was worsened because of the continued rainfall in the basin after the passage of the hurricane (fig. 1).The Peak flows that occured near Goldsboro (site 15) and at Kinston (site 16), although high, would be expected to occur (or be exceeded) once every 10 to 25 years without Falls dam. With Falls dam, the recurrence intervals of the peak flows near Goldsboro and at Kinston were between 50 and 100 years. The stage near Goldsboro rose to more than 12 feet above flood stage, and the peak stage at Kinston was more than 9 feet above flood stage.

Determination of Peak Flows

River stage and flow (or discharge) are measured at locations called stream-gaging stations. Stage is generally measured continuously and reported to an accuracy of 0.01 foot. Stage information is transmitted by satellite radio to USGS computers, or is stored on site and retrieved periodically by USGS staff.

Flow is more difficult to measure accurately and continuously than is stage. Discharge for a gaging station is typically determined from a pre-established stage-discharge relation, or rating curve. Individual discharge measurements are made at the gaging station using standard procedures, ideally during a time when the river stage is not changing. A series of these measurements made over a range of flow conditions defines the rating curve, which is used to convert continuous measurements of stage to a continuous record of flow. Channel changes, resulting from scour, deposition, or other processes, alter the stage-discharge relation, so that discharge measurements must be made routinely to ensure that the rating curve remains accurate.

The rating curve is considered accurate only over the range for which discharge measurements have been made. Discharge measurements generally are not available for the full range of flows at gaging stations which have been in operation for only a few years. Even at gaging stations which have been in continuous operation for 30 years or more, discharge measurements for extremely high flows, such as those that occurred following Hurricane Fran, are difficult to obtain because (1) these events are rare, (2) peak flows may persist for only a short time making measurement difficult, and (3) measurement sites often are inaccessible during extremely high flows.



Estimates of peak flows, which are outside the range of the established rating curve, may be made by an extrapolation of the rating curve to the peak stage. Many of the peak flows reported in table 1 and used in the loading calculations (table 2) were estimated in this manner. At some gaging stations having large rating curve extensions, indirect methods of discharge determination based on channel properties and hydraulic principles may be used to obtain an independent estimate of the peak flow. These indirect methods generally require accurate determination of channel morphology through surveying and application of computer programs, and may require several months to complete for all of the affected gaging stations. Consequently, continuing evaluation of Hurricane Fran flood records may result in some slight revision of the peak flows presented in this report.

Cape Fear River Basin

Flooding in the Cape Fear River Basin (fig.2) was most severe in the northern part of the basin, where rainfall during the hurricane was heaviest (fig. 1). The peak flow in the Haw River at Haw River (site 21) exceeded the previous peak flow, and had a recurrence interval of between 200 and 500 years. Extremely high flows also occurred in small streams in Orange and Durham Counties, but downstream flooding in the Cape Fear River from these streams and the Haw River was reduced because of storage in Jordan Lake.
The peak flow in the Cape Fear River at Lillington (site 25) was the highest recorded since Jordan Lake was completed in 1981, and was about 40 percent higher than the previous peak since then. High flows in the Cape Fear River were primarily the result of contributions from the Deep River, which joins the Cape Fear River between Jordan dam and Lillington. The peak flow in the Deep River at Moncure (site 24) had a recurrence interval of between 50 and 100 years, and was very nearly equal to the peak flow at Lillington (site 25). However, the Hurricane Fran peak flow at site 24 was only 60 percent of the peak of record, which occurred in 1945.

Table 1: Hurricane Fran flood information for selected streamflow gaging stations in North Carolina

[mi², square mile; ft³/s, cubic feet per second; R., River; nr., near; ni, flood stage not identified; >, greater than; ---, recurrence interval not computed because of insufficient record; unreg, flow unregulated by upstream reservoirs; na, not applicable; reg, flow regulated by upstream reservoir releases; C., Creek; nd, data not available; Crsrds, Crossroads]

				Hurricane Fran peak river stages (1996)			Previous peak flow of record		Hurricane Fran peak flow	
Site no. (fig. 2)	Station name (USGS station number)	Period of record	Drainage area (mi²)	Date of peak stage	Feet above flood stage[a]	Feet[b] above 9-1-96 stage	Date	Flow (ft³/s)	Flow (ft³/s)	Recurrence interval
	Tar River Basin									
1	Tar R. nr. Tar River (02081500)	1939-96	167	9-6-96	ni	22	4-27-78	14,200	22.500	>500
2	Tar R. at Louisburg (02081747)	1963-96	427	9-7-96	5.2	21	4-28-78	13,100	20,000	>500
3	Tar R. at Tarboro (02083500)	1931-96	2,183	9-15-96	7.6	23	8-20-40	37,200	21,800	5-10
	Neuse River Basin									
4	Eno R. at Hillsborough (02085000)	1927-71,1985-96 1985-96	66	9-6-96	ni	20	9-18-45	11,000	10,200	200-500
5	Eno R. nr. Durham (02085070)	1963-96	141	9-6-96	ni	22	4-26-78	9,620	14,000	25
6	Little R. nr. Orange Factory (0208521324)	1987-96	78.2	9-6-96	ni	11	3-4-93	7,380	16,500	---
7	Flat R. at Bahama (02085500)	1925-96	149	9-6-96	ni	16	7-26-38	20.000	37,000	>500
8	Neuse R. nr. Falls (02087183)	1970-83 (unreg)	771	na	ni	na	9-45	23,300	7,500	---
	......do..........	1983-96 (reg)	.....do.....	9-16-96	ni	7	3-8-93	7,850	7,500	---
9	Crabtree C. at U.S.1at Raleigh (02087324)	1990-96	121	9-6-96	ni	nd	6-29-73	13,500	>11,000	---
10	Neuse R. nr. Clayton (02087500)	1927-83 (unreg)	1,150	na	ni	na	9-19-45	22,900	19,500	25-50
	.....do..........	1983-96 (reg)	.....do.....	9-7-96	ni	19	8-28-95	10,800	19,500	50-100
12	Swift C.nr. McCullars Crsrds. (0208758850)	1987-96	35.8	9-6-96	ni	nd	2-17-95	1,240	7,200	---
13	Middle C. nr. Clayton (02088000)	1939-96	83.5	9-6-96	ni	13	2-3-73	8,510	13,000	>500
14	Little R. nr. Princeton (02088500)	1930-96	232	9-8-96	ni	nd	10-6-64	7,150	4,900	25-50
15	Neuse R. nr. Goldsboro (02089000)	1930-83 (unreg)	2,399	na	ni	na	9-27-45	30,700	26,000	10-25
	.....do..........	1983-96 (reg)	.....do.....	9-12-96	12.2	21	3-6-87	18,000	26,000	50-100
16	Neuse R. at Kinston (02089500)	1930-83 (unreg)	2,692	na	ni	na	10-3-64	26,000	24,000	10
	.....do..........	1983-96 (reg)	.....do.....	9-17-96	9.1	nd	3-9-87	18,600	24,000	50
17	Contentnea C. at Hookerton (02091500)	1928-96	733	9-8-96	ni	nd	10-8-64	17,200	4,800	2-5
19	Trent R. nr. Trenton (02092500)	1951-96	168	9-6-96	ni	nd	9-21-55	9,100	3,200	5-10
	Cape Fear River Basin									
20	Reedy Fork nr. Gibsonville (02094500)	1928-68 (unreg)	131	na	ni	na	9-25-47	11,600	6,320	10-25
	.....do..........	1969-96 (reg)	.....do.....	9-6-96	ni	nd	6-21-72	5,660	6,320	10-25
21	Haw R. at Haw River (02096500)	1928-96	606	9-6-96	14.8	31	9-18-45	37,000	43,500	200-500
22	Morgan C. nr. Chapel Hill (02097517)	1982-96	41	9-6-96	ni	nd	3-4-93	2,780	4,200	25-50
23	Deep R. at Ramseur (02100500)	1922-96	349	9-6-96	ni	25	9-18-45	43,000	24,000	10-25
24	Deep R. at Moncure (02102000)	1930-96	1,434	9-6-96	-7.1	11	9-18-45	80,300	48,300	50-100
25	Cape Fear R. at Lillington (02102500)	1923-81 (unreg)	3,464	na	ni	na	9-19-45	150,000	52,800	2-5
	.....do..........	1981-96 (reg)	.....do.....	9-6-96	ni	17	4-6-93	37,500	52,800	50-100
26	Cape Fear R. at Lock 1 nr. Kelly (02105769)	1969-81 (unreg)	5,255	na	ni	na	3-3-79	57,000	33,000	---
	.....do..........	1981-96 (reg)	.....do.....	9-9-96	-1.6	7	3-6-87	44,500	33,000	5
27	Black R. nr. Tomahawk (02106500)	1951-96	676	9-10-96	ni	17	9-17-84	17,500	13,500	50-100
	Waccamaw and Lumber River Basins									
28	Waccamaw R. at Freeland (02109500)	1939-96	680	9-12-96	ni	8	9-25-55	10,200	12,500	100
29	Drowning C. at Hoffman (02133500)	1939-96	183	9-7-96	ni	nd	9-18-45	10,900	1,850	2-5
30	Lumber R. nr. Maxton (02133624)	1980-85,1987-96	365	9-10-96	ni	nd	2-21-95	2,390	2,800	---
31	Lumber R. at Boardman (02134500)	1929-96	1,228	9-15-96	ni	nd	9-24-45	13,400	7,920	5-10

[a] Flood stage identified by the National Weather Service.

[b] Values rounded to the nearest foot.

The flood peak in the Black River (site 27) occurred on September 10 and had a recurrence interval of between 50 and 100 years. This flooding was likely due, however, to the combined rains of Hurricane Fran (fig. 1) and the heavier rains which fell 3 days after the hurricane.

Waccamaw and Lumber River Basins

The peak flow in the Waccamaw River at Freeland (site 28) on September 12 was about 20 percent higher than the previous peak, which occurred as a result of Hurricane Diane in 1955. The peak flow at site 28 had a recurrence interval of about 100 years, but the recurrence interval of the peak flow at nearby site 31 (Lumber River at Boardman) was less than 10 years. As in the Black River Basin, it is likely that flooding in the Waccamaw River Basin was more a result of rainfall after Hurricane Fran than during the storm (fig. 1). In fact, some of the largest rainfall amounts over the Waccamaw River Basin appear to have occurred after

Bobby Ragland making discharge measurement on the Waccamaw River, North Carolina.

photo by: Bob High, of the Whiteville News.

Recurrence Interval

Statistical techniques, through a process called frequency analysis, are used to estimate the probability of the occurrence of a flow having a given magnitude at a gaging station. The recurrence interval (or sometimes called the return period) of a peak flow is based on the probability that the flow will be equalled or exceeded in any given year. For example, there is a 1 in 100 chance that a flow of 35,500 ft³/s or greater will occur during any year at the Haw River at Haw River (site 21, fig. 2). Thus, a peak flow of 35,500 ft³/s at site 21 is said to have a 100-year recurrence interval. This is not to say that a peak flow of 35,500 ft³/s will not occur more than once during a 100-year period at site 21, but rather there is only a 1 in 100 chance that a flow of this magnitude or greater will occur in any year.

Ten or more years of measured annual peak flows at a gaging station are required to perform a frequency analysis for the station. More confidence can be placed in a frequency analysis based on, for example, 30 years of record at the station than an analysis based on 10 years of record. Recurrence intervals at a gaging station change if there is a significant change in the flow regime at the station caused by an impoundment or major diversion of flow. For example, the 50-year flood at the Neuse River near Clayton (site 10, fig. 2) before the construction of Falls Dam was 21,400 ft³/s, whereas the 50-year flood at site 10 for post-impoundment conditions is 19,000 ft³/s

In table 1, recurrence intervals for unregulated and regulated conditions are given for sites that are downstream from reservoirs. As an example of how this information is to be interpreted, a flow of 24,000 ft³/s or greater was expected to occur at Kinston, on average, once every 10 years before Falls dam was built. With Falls dam in place, a flow of 24,000 ft³/s or greater is expected to occur at Kinston once every 50 years.

Water-quality conditions during the flooding

Water samples were collected and physical water-quality constituents (dissolved oxygen, pH, temperature, and specific conductance) were measured at 5 sites on the Neuse River, and at one site each on the Eno, Tar, and Cape Fear Rivers and Contentnea Creek (table 2; fig 2). Sampling occurred from 1 to 12 days after Hurricane Fran. Water samples were analyzed for nutrients, 5-day biochemical-oxygen demand (BOD_5), total organic carbon, and major anions and cations. Preliminary results on dissolved oxygen, BOD_5, total nitrogen, and total phosphorus concentrations are presented and, where data are available, compared to previous measurements at each site.

Dissolved Oxygen

The minimum acceptable instantaneous dissolved-oxygen concentration is 4 milligrams per liter (mg/L) (N.C. Department of Environment, Health, and Natural Resources, 1996) for the protection of aquatic life and wildlife and for recreational and agricultural uses. A graph of dissolved-oxygen concentrations versus miles below Falls dam shows the dissolved-oxygen profile for the Neuse River during two periods after Hurricane Fran (fig. 3).

For the period September 10 to 13, dissolved-oxygen concentrations steadily declined along the length of the Neuse River from Falls (site 8; 7.7 mg/L) to Goldsboro (site 15; 0.4 mg/L). Concentrations were 1.2 mg/L or less from Goldsboro to Kinston (site 16) and New Bern (site 18). On September 17, 1996, the dissolved-oxygen profile had changed very little. Dissolved-oxygen concentration in the Neuse River at Smithfield (site 11) was 4.4 mg/L and was 1 mg/L or less from Goldsboro to New Bern. Based on medians of long-term year-round data collected by the USGS, dissolved-oxygen concentrations typically are 8.7 mg/L near Falls, 8.0 mg/L at Smithfield, and 8.3 mg/L at Kinston. The median dissolved-oxygen concentration at New Bern for August 1996 was 6.5 mg/L.

Very low dissolved-oxygen concentrations also were measured in Contentnea Creek at Hookerton (1.0 mg/L on September 10 and 0.3 mg/L on September 12), Tar River at Tarboro (3.3 mg/L on September 11), and Cape Fear River at Lock 1 near Kelly (2.5 mg/L on September 13). Dissolved-oxygen concentration in the Eno River at Hillsborough, in the headwaters of the Neuse River Basin, measured 7.5 mg/L on September 6.

Biochemical Oxygen Demand (BOD_5)

BOD_5 is a measure of the amount of oxygen required to biochemically degrade organic material and to oxidize reduced forms of nitrogen (ammonia and nitrite). High inputs of oxygen-demanding organic material from natural sources, resuspension of bottom sediments, and wastewater system

Table 2. Single-day and mean annual nitrogen, phosphorus, and BOD_5 loads for selected water-quality stations [ft³/s, cubic feet per second; BOD_5, biochemical oxygen demand; tons/yr, tons per year; ---, data not available]

Site no. (fig. 2)	Station name (USGS station number)	Date	Mean daily discharge (ft³/s)	Single day estimated load (tons)			Mean annual load (tons/yr)	
				Nitrogen	Phosphorus	BOD_5	Nitrogen	Phosphorus
	Tar River Basin							
3	Tar River at Tarboro (02083500)	9-11-96	9,850	23	2.9	66	[a]2,200	[a]270
	Neuse River Basin							
4	Eno River at Hillsborough (02085000)	9-6-96	[b]8,300	21	2.9	---	[c]76	[c]4
8	Neuse River near Falls (02087183)	9-13-96	5,250	11	---	27	[d]450	[d]32
10	Neuse River near Clayton (02087500)	9-13-96	8,140	19	4.2	42	---	---
11	Neuse River at Smithfield (02087570)	9-10-96	[e]6,250	8.7	2.7	35	[c]1,600	[c]170
		9-13-96	[e]8,540	20	4.8	44	...do...	...do...
15	Neuse River near Goldsboro (02089000)	9-10-96	18,800	34	10	410	---	---
		9-12-96	23,500	76	---	360	...do...	...do...
16	Neuse River at Kinston (02089500)	9-10-96	7,440	12	4	88	[a]3,400	[a]350
		9-16-96	23,300		—	465	...do...	...do...
17	Contentnea Creek at Hookerton (02091500)	9-10-96	2,870	5.9	2.9	53	[a]1,200	[a]160
		9-12-96	4,160	23	0.9	95	...do...	...do...
18	Neuse River at New Bern (02092162)	9-11-96	---	---	---	---	---	---
	Cape Fear River Basin							
26	Cape Fear River at Lock 1 near Kelly (02105769)	9-13-96	44,600	124		265	---	---

a Period of computation is 1980-92 (Harned and others, 1995).
b Instantaneous discharge.
c Period of computation is 1989-92.
d Period of computation is 1989-94 (Childress and Treece, 1996).
e Calculated from the gage at site 10.

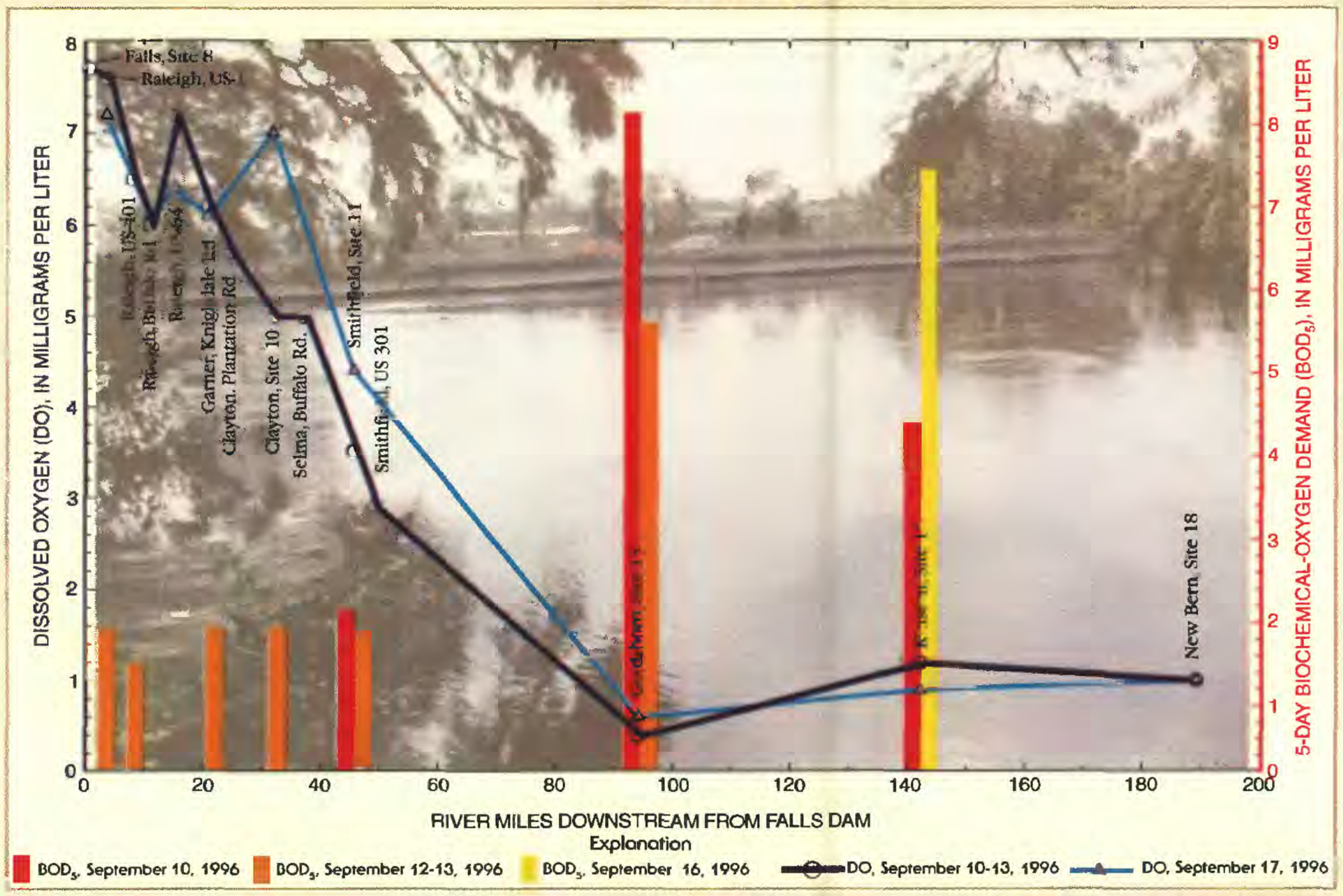


FIGURE 3.–Dissolved-oxygen concentration and biochemical oxygen demand in Neuse River. Background photograph is the Neuse River at Kinston on September 16 looking towards the NC 11 bridge.

overflows are typical causes of instream oxygen depletion during flooding.

During September 10-13, concentrations of BOD_5 in the Neuse River were less than 2.1 mg/L from Falls dam to Smithfield (fig. 3). Concentrations increased markedly between Smithfield and Goldsboro where concentrations were 8.1 mg/L on September 10 and 5.6 mg/L on September 12. At Kinston BOD_5 concentrations were 4.4 and 7.4 mg/L on September 10 and 16. BOD_5 concentrations were also elevated in Contentnea Creek (6.9 and 8.5 mg/L). By comparison, for the period 1990-95, median BOD_5 concentration was 1.8 mg./L for the Neuse River near Falls and less than 1.2 mg/L at Clayton, Smithfield, Goldsboro, and Kinston (North Carolina Division of Water Quality STORET database). The median for Contentnea Creek at Hookerton for the same period was 1.2 mg/L.

Nitrogen, Phosphorus, and BOD_5 Loads

Control of nitrogen and phosphorus inputs to Coastal water systems has been an important effort of State regulators. Flood waters have the potential to transport large loads of nutrients to nutrient-sensitive estuaries and sounds. However, following Hurricane Fran, concentrations of nitrogen and phosphorus were generally small relative to the long-term record. During September 10-13, nitrogen concentrations in the Neuse River at Smithfield and at Kinston were about 0.5 mg/L, less than the long-term fifth percentile concentration. Phosphorus concentrations were about 0.2 mg/L, near the long-term median concentrations at Smithfield and at Kinston.

Large quantities of streamflow were associated with Hurricane Fran (in the rivers sampled, peak streamflow ranged from 2- to 500-year recurrences). Therefore even these moderate concentrations of nutrients produced significant loads. Loads of nitrogen, phosphorus, and BOD_5, reported in tons per day, were calculated for days when samples were collected following the hurricane (table 2). These single-day loads of nitrogen and phosphorus also were compared to mean annual loads at sites where previous records were available. Single-day nitrogen loads typically were less than 2 percent of mean annual loads, whereas single-day phosphorus loads typically were from 1 to 3 percent of mean annual load.

New Bern Water-Quality Monitor

The USGS monitors water quality, including dissolved oxygen and salinity, near the water surface and near the stream bed of the Neuse River estuary near New Bern (site 18, fig. 2). Salinity differences between salt water from Pamlico Sound and the Neuse River generally cause the river to stratify at New Bern, as was the condition during August (fig. 4). Under stratified conditions, dissolved oxygen is depleted near the river bed compared to surface waters (median 6.5 mg/L in August). Salinity record beginning late on September 4, when the water level in the estuary began to rise, indicates the mixing effect of winds from Hurricane Fran. The salinity of bottom waters decreased when mixed with fresh river water near the surface (a similar effect occurred on July 12 from Hurricane Bertha). As Hurricane Fran passed, on September 5, salinity sharply increased indicating the effects of the storm surge followed by a sharp decrease from the influx of freshwater runoff from the Neuse River.

Storm-induced mixing also resulted in a short-term increase of dissolved-oxygen concentration in surface and bottom waters and loss of stratification. This was followed by a decline in dissolved oxygen at both surface and bottom. As of September 20, almost 2 weeks after Hurricane Fran, the Neuse River had not restratified at New Bern–salinity was 0.04 parts per thousand, and dissolved oxygen was less than 2 mg/L.

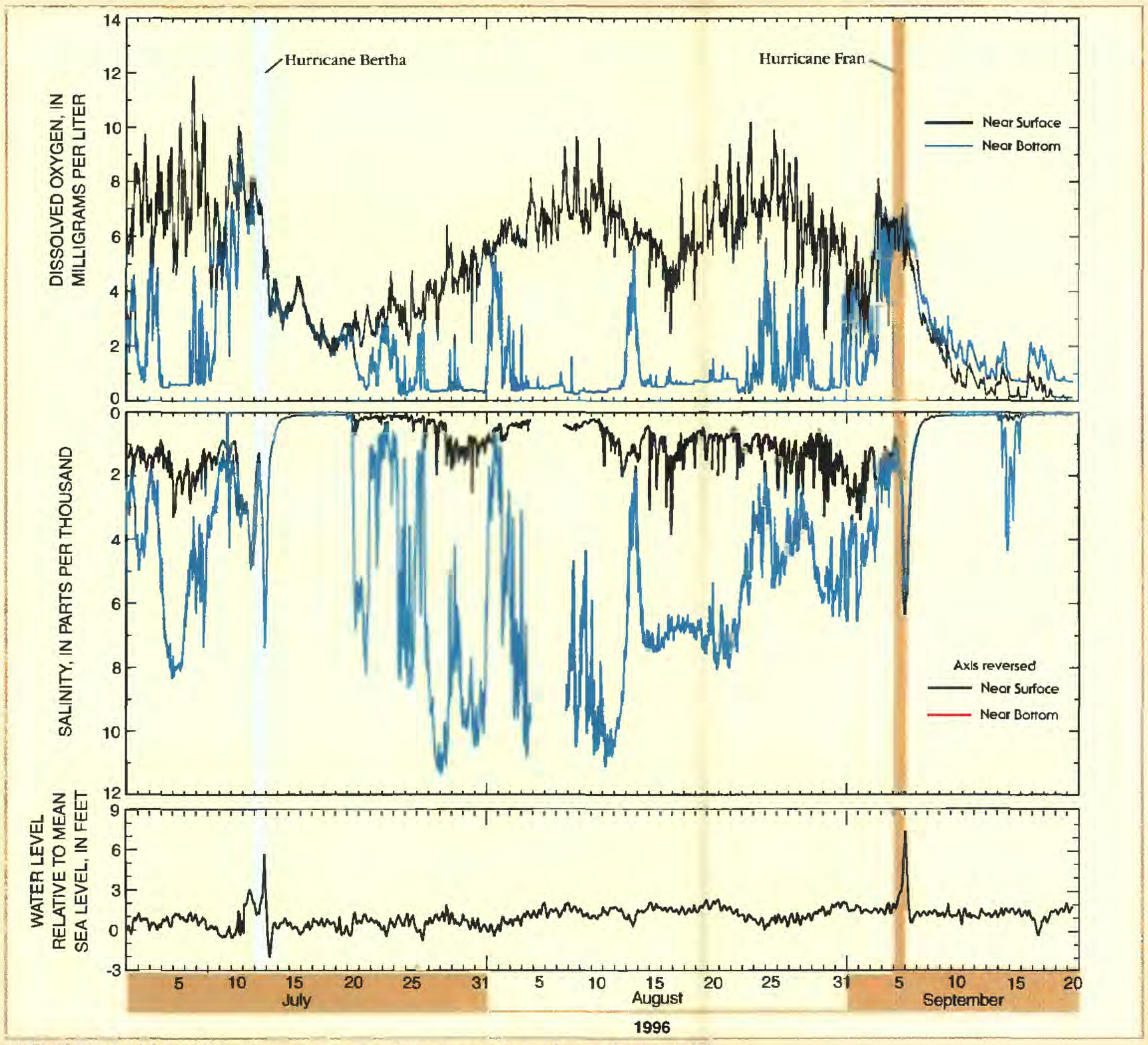


FIGURE 4.–New Bern water-quality monitor data (site 18)

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Produced by: USGS, Raleigh, North Carolina J.Caras-Illustrator