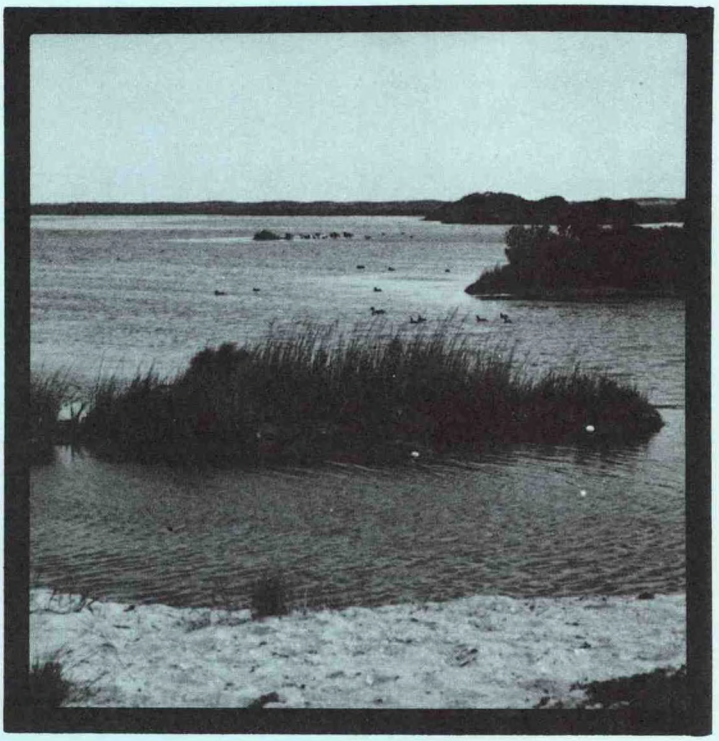
# Marine Environmental Assessment

## CHESAPEAKE BAY

## SEPTEMBER-NOVEMBER 1985



**U.S. DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
National Environmental Satellite, Data, and Information Service
Assessment and Information Services Center

**CLIMATE IMPACT ASSESSMENT**
**UNITED STATES**

The AISC/Marine Environmental Assessment Division (MEAD), Marine Assessment Branch (MAB), produces periodic assessments of weather impacts on economic sectors of marine environmental activity. The Chesapeake Bay region served as a prototype for assessment development. From September 1981 through March 1982, MAB issued monthly assessments of Chesapeake Bay in the economic sectors of fisheries, recreation, and transportation. We now issue quarterly assessments in order to extend the service to other marine areas within existing resource limitations. Each year we publish an Annual Summary giving a longer-term perspective of the impacts for the calendar year.

Please send any comments or subscription queries to the Chief, Marine Assessment Branch, Marine Environmental Assessment Division, NOAA/NESDIS/AISC, E/AI32, 3300 Whitehaven Street, NW, Washington, DC 20235, or call (202) 634-7379.

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February 1986

# Marine Environmental Assessment

## CHESAPEAKE BAY

### SEPTEMBER-NOVEMBER 1985



by Michael J. Dowgiallo
Martin C. Predoehl
Sylvia Z. Green
Isobel C. Sheifer
Robert E. Dennis
Richard P. Stumpf

Marine Assessment Branch
Marine Environmental Assessment Division

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**U.S. DEPARTMENT OF COMMERCE**
**Malcolm Baldrige, Secretary**

**National Oceanic and Atmospheric Administration**
Anthony J. Calio, Administrator

National Environmental Satellite, Data, and Information Service
William P. Bishop, Acting Assistant Administrator

Assessment and Information Services Center
Joan C. Hock, Director

CONTENTS



Figures



Tables

CONTENTS (continued)

# CHESAPEAKE BAY MARINE ASSESSMENT

The marine ecosystem exhibits many complex interrelationships which are difficult to measure. Climatic events do not often produce an obvious immediate response in the marine environment. The extended intervals that frequently exist between a climate event and the observed impact present a problem different from that addressed by the land-oriented assessments that the Assessment and Information Services Center (AISC) produces. This difference necessitates relating changes in climatic variables to marine environmental changes on a quarterly basis. For Chesapeake Bay, June through August covers the warm, relatively stable summer months; September through November covers the dynamic fall period of decreasing temperatures and water column turnover and vertical mixing; December through February covers the cold winter period; and March through May covers the dynamic spring period of increasing temperatures and nutrient enrichment.

The AISC effort in Chesapeake Bay is a first step toward providing operational marine assessments for major water bodies within and adjacent to the United States.

Table 1.--Environmental impact summary, Chesapeake Bay, September - November 1985.

| EVENT | IMPACT SECTOR: Fisheries | | | | | | | | Recreation | | | | Life + Property | | | | | | | Transportation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Finfish harvest activities (general) | Shellfish harvest activities (general) | Oyster population | Oyster quality | Normal species distribution | Blue crab harvest | | | Park usage | Boating activity | Safety | | Lives | Homes | Businesses | Boats, docks | Public property (Bulkheads, piers) | Beach stability | | Port operations | Cost to shippers |
| High winds - Sept. | - | - | | | | | | | | | - | | | | | | | | | - | - |
| Above-normal water temp.-Oct.,Nov. | | | | - | | + | | | | | | | | | | | | | | | |
| High streamflow - Nov. | - | - | | | | | | | | | - | | | | | | | | | | |
| Reduced salinities - Nov. | | | | | | | | | | | | | | | | | | | | | |
| Flooding - Nov. | | | | | | | | | | | | | - | - | - | - | - | - | | | |
| High winds - Nov. | - | - | | | | | | | | | - | | | | | | | | | - | - |

+ Favorable

- Unfavorable

No identifiable effect, data unavailable, or not applicable

## 1. Highlights - General Events and Impacts

The Bay area experienced extensive flood damage from a storm on November 4, the most devastating since Tropical Storm Agnes in 1972. Tidal flooding and easterly winds associated with the storm damaged piers and bulkheads, and produced much erosion in Maryland. Property damage in Maryland, Virginia, West Virginia and the District of Columbia exceeded $1.3 billion with at least 60 storm-related deaths.

The damage to oyster beds that Agnes produced in June 1972 did not occur in November 1985 due to the shorter duration of the flooding. No major changes in species distributions or mortalities of other commercial species were detected following the November 1985 flooding. High winds and waves prevented watermen from working for several days during the early November storm, and during Hurricane Gloria in late September.

Virginia crabbers reported unusually large landings of trawl-caught crabs in November during a period of above-normal water temperatures. The warm water temperatures also affected oyster quality as seen in low yields of oyster meats shucked at packing houses in Virginia.

The storms in September and November minimally affected seasonal recreation trends, because of their short duration. Recreational facilities, however, sustained extensive damage from the November storm. Flooding caused over $500,000 in damage to state-owned boat ramps in Virginia.

Shipping companies incurred increased costs due to productive time lost because of excessive winds at the Port of Baltimore. Crane down-time because of excessive winds may have cost shippers more than $128,000. Most of the shutdown time in the fall 1985 quarter was due to the storms in late September and early November.

## 2. Weather and Oceanography

### 2.1 Weather

Warmer-than-normal weather marked the period from September through November in the Chesapeake Bay area. A heat wave and long spells of dry weather in September were followed by abundant rainfall near the coast from Hurricane Gloria near the end of the month. The Bay watershed to the west remained dry in September while dryness in October was mostly in the northern areas. Areas of the upper James and Potomac rivers were devastated by sudden and severe flooding from a storm of tropical origin in early November. Winds around this storm produced the highest tidal flooding in the Chesapeake Bay region since 1933.

September:

Rains from Hurricane Gloria offset the extreme dryness of the rest of September. Fair weather and near-normal temperatures characterized most of the month, although the first third set a record in some parts of the area because of prolonged temperatures above 90°F.

Hot and dry weather prevailed in the Bay region from the beginning of the month until around the 9th and 10th. A cold front then pushed southward through the region bringing showers and thundershowers with amounts varying from a few tenths of an inch to more than two inches at Washington. Temperatures were their lowest for the month from the 13th to the 16th as the cool air moved southward. Wilkes-Barre and Baltimore set low temperature records for the 13th and 15th, respectively. The cool temperatures moderated, and fair, dry weather continued until the 23rd when Tropical Storm Henri appeared off the coast of Virginia. This storm was met the following day by a cold front, resulting in showers in the lower Bay area. Heavy rains fell mainly along coastal areas as Hurricane Gloria moved northward on the 26th and 27th. Good weather immediately followed the storm and continued through the end of the month.

Precipitation during September was very low among the Bay area stations until Hurricane Gloria brought monthly totals to above-normal for all but two of the stations, Williamsport and Chantilly (Figure 1 and Table 2). However, dryness persisted in the western watershed throughout September. Precipitation for the month ranged from 28 percent below normal at Williamsport to 133 percent above normal at Wilkes-Barre (Table 2). Seven of the stations had rainfalls in excess of 6 inches, most of which came from Hurricane Gloria. Wilkes-Barre received a record 6.52 inches in 24 hours from Gloria, marking its wettest September on record. Baltimore received 6.04 inches of rain from Gloria, second only to 7.82 inches from Hurricane Diane in August 1955. The period preceding Hurricane Gloria in September set a record for low precipitation for all Bay area stations.

Temperatures among the 11 stations in Figure 1 averaged 1.0°F above normal for the month, ranging from 2.2°F above normal at Harrisburg to 0.1°F below normal at Royal Oak (Table 2). The Pensylvania stations showed the largest positive anomalies for the month while those in the middle Bay area were nearest to normal. During the period from the 4th through the 10th daily maximum temperatures reached 90°F or more, setting records at a number of stations. At

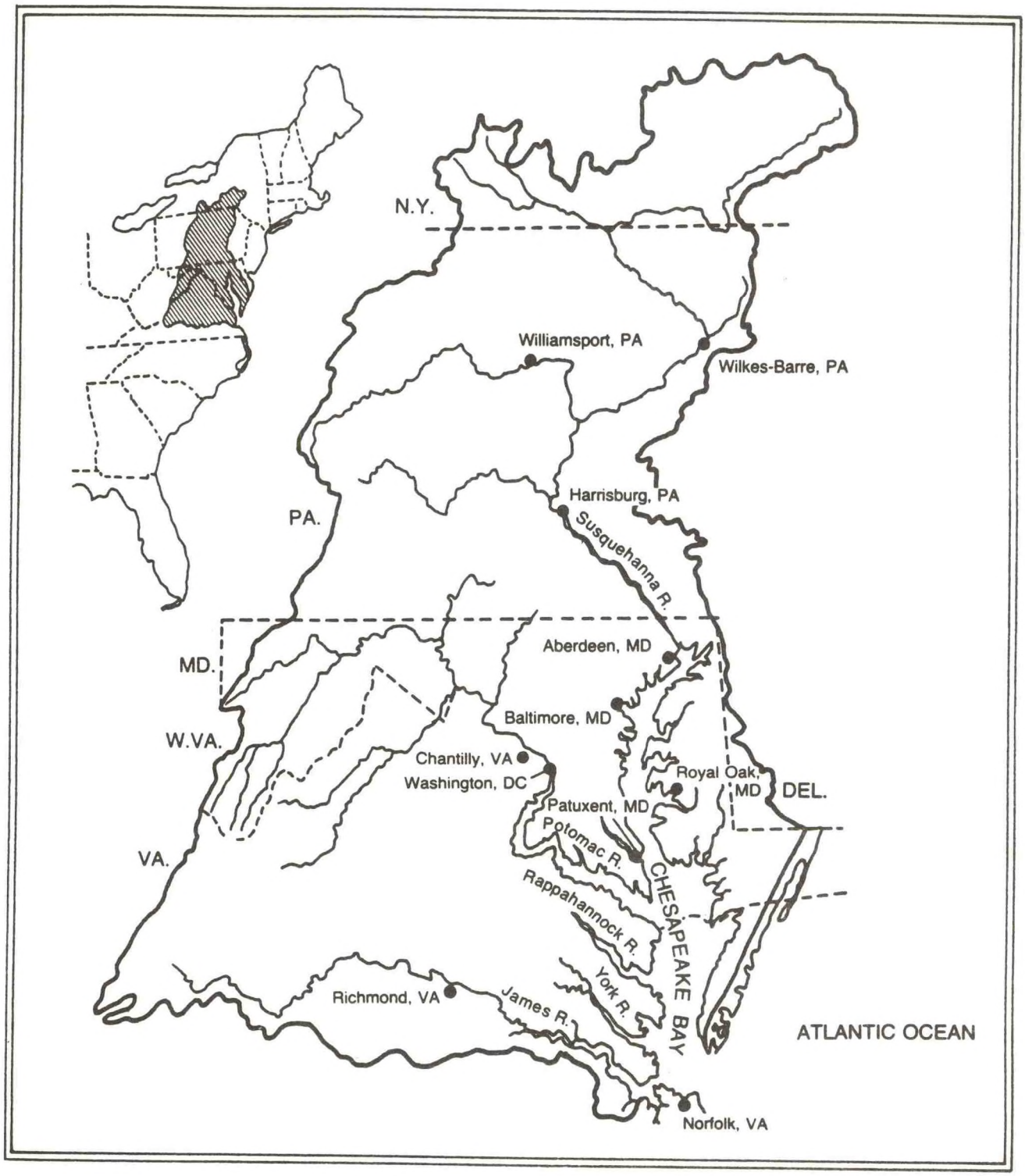



Figure 1. Selected meteorological stations, Chesapeake Bay watershed (Modified EPA map).

Table 2.--Total precipitation, mean air temperatures, and departures from normal for 11 stations, Chesapeake Bay watershed, September - November 1985.

| Station | Total Precipitation (inches) and Departure from Normal Observed/*Anomaly (% of normal) | | | Air Temperature and Departure from Normal Observed/*Anomaly (Deg. F) | | |
|---|---|---|---|---|---|---|
| | September | October | November | September | October | November |
| Williamsport, PA | 2.58/-28% | 1.83/-43% | 5.98/+65% | 65.3/+1.4 | 52.9/+0.6 | 45.1/+3.7 |
| Wilkes-Barre, PA | 7.83/+133% | 1.92/-31% | 4.47/+50% | 64.0/+1.2 | 52.7/+1.0 | 44.5/+3.6 |
| Harrisburg, PA | 3.76/+4% | 1.35/-51% | 6.13/+89% | 69.1/+2.2 | 57.2/+2.2 | 47.9/+4.0 |
| Aberdeen, MD | 6.35/+92% | 3.17/+14% | 3.91/+10% | 70.4/+2.0 | 61.0/+3.0 | 53.0/+6.7 |
| Baltimore, MD | 6.22/+80% | 2.48/-20% | 4.71/+51% | 69.4/+0.5 | 58.8/+1.9 | 52.4/+6.1 |
| Washington, DC | 6.67/+107% | 3.85/+33% | 4.47/+59% | 71.9/+0.8 | 61.2/+1.9 | 54.3/+5.6 |
| Chantilly, VA | 2.96/-9% | 4.06/+35% | 5.27/+76% | 67.5/+0.1 | 58.4/+3.1 | 52.6/+7.8 |
| Royal Oak, MD | 7.74/+108% | 2.05/-41% | 5.11/+37% | 70.2/-0.1 | 62.4/+3.1 | 55.4/+6.5 |
| Patuxent, MD | 6.16/+92% | 4.07/+43% | 5.69/+85% | 71.8/+0.8 | 62.9/+2.6 | 55.7/+6.7 |
| Richmond, VA | 4.97/+41% | 5.09/+36% | 6.99/+112% | 70.8/+0.6 | 62.6/+4.0 | 56.6/+7.7 |
| Norfolk, VA | 6.36/+46% | 3.92/+15% | 5.71/+98% | 73.4/+1.2 | 65.9/+4.6 | 60.3/+8.4 |
| Average | 5.60/+60% | 3.07/-1% | 5.31/+66% | 69.4/+1.0 | 59.6/+2.5 | 52.5/+6.1 |

*Anomaly = departure from 30-year average for each month.

Royal Oak it was the longest such period on record. Stations and their record temperatures and the dates of occurrence are as follows:

New record high temperatures for September

| Station | Temperatures (Date) |
|---|---|
| Harrisburg | 97°F (7th) |
| Washington | 95°F (4th) |
| Patuxent | 96°F (4th, 8th, 9th) |
| Norfolk | 96°F Tied (4th), 97°F (5th), 95°F (9th) |

New record low temperatures for September

| Station | Temperatures (Date) |
|---|---|
| Wilkes-Barre | 37°F (13th) |
| Baltimore | 43°F (15th) |
| Richmond | 44°F (16th) |

Winds from Hurricane Gloria had a sustained speed of 92 mph with a peak gust of 104 mph at South Island off the Chesapeake Bay Bridge-Tunnel. Gusts from Gloria reached 55 mph at Patuxent and 45 mph at Royal Oak and Baltimore. Patuxent reported gusts of 27 mph on the 13th and 26 mph on the 9th, and gusts ranged from 20 to 24 mph on seven other occasions in September. Royal Oak reported gusts of 20 mph on the 8th and 9th and a gust of 25 mph on the 13th.

October:

Two wet periods, the first from the 1st to the 5th of October and the second from the 20th to the 25th, combined to bring near-normal rainfall to the Bay region. Fair weather prevailed most of the time, and temperatures averaged above normal.

Cold fronts on the 1st and the 4th brought rain of 1 to 2 inches from Washington to Richmond. Another cold front pushed through the area on the 10th and was followed by cold fronts on the 14th and 16th. Stations to the north and west of Washington received one half inch or more of precipitation from these fronts. A low pressure system developed on a front which moved into the area late on the 19th, bringing heavy rains to much of the region. Cold fronts followed on the 24th and 27th. A few showers accompanied a cold front on the 30th, which was pushing eastward into the circulation of the decaying Hurricane Juan now covering the region from the Chesapeake Bay southward.

Precipitation in October averaged near normal around the region, ranging from 43 percent above normal at Patuxent to 50 percent below normal at Harrisburg (Table 2).

Temperatures averaged 2.5°F warmer than normal, ranging from 4.6°F above normal at Norfolk to 0.6°F above normal at Williamsport (Table 2). Stations around the south end of the Bay showed increased positive departures from those in September, while those farther north showed smaller positive and even negative trends. Stations had their warmest temperatures of the month around the middle of the month. Royal Oak tied a record of 84°F on the 15th, and Patuxent, Richmond, and Norfolk set new records of 87, 90, and 89°F on that date. Coldest temperatures of the month occurred on the 29th or 30th at all but Norfolk, which reached a low of 44°F on the 27th. Washington reached its low of 43°F on both the 26th and 30th.

Winds gusted to 28 mph on the 15th and to 25 mph on the 5th and 31st at Royal Oak. Winds gusted to 26 mph on the 21st and 31st at Patuxent. Gusts ranged from 20 to 24 mph on 9 other occasions at Patuxent and on 5 other occasions at Royal Oak during the month.

November:

November was cloudy, warm, and wet. It was the warmest November on record at Norfolk, Richmond, and Royal Oak and the second-warmest at Baltimore. The storm of the 4th and 5th, which brought the devastating floods to the mountainous areas of Virginia and West Virginia, also brought the highest tidal flooding since 1933 to portions of the Chesapeake Bay.

Easterly flow covered the Chesapeake Bay area during the first several days in November as the low-pressure center which had been Hurricane Juan moved northward, spreading rain over much of the Bay drainage basin. A second low pressure system moved in from the south and intensified late on the 4th, bringing very heavy rains -- 6 inches or more in 24 hours -- to stations in the mountains of Virginia and West Virginia, where the James, Potomac, and other rivers have their origins. Flooding along rivers and streams in West Virginia exceeded any on record.

The Bay area sustained extensive flood damage from the storm of the 4th which followed Hurricane Juan. It was the most devastating since Tropical Storm Agnes in 1972. The effects of the flooding are discussed in Section 4 at the end of this report.

Cold fronts crossed through the area on the 7th and 11th, producing little precipitation. Warming continued -- to record temperatures -- until a cold front on the 14th caused temperatures to fall. Warming resumed from the 17th to the 19th while a stationary frontal zone remained in the area. A cold front on the 20th brought more than 2 inches of rain to Richmond and Norfolk over the 21st and 22nd.

The area was again in a stationary frontal zone from the 25th to the end of the month. Rains of from one to two inches occurred over the 29th and 30th throughout the area.

Precipitation averaged 5.31 inches (66 percent above normal) among the 11 stations in Figure 1 during November. Monthly totals ranged from 3.91 inches (10 percent above normal) at Aberdeen to 6.99 inches (112 percent above normal) at Richmond (Table 2). Seven of the 11 stations had more than 5 inches of rain (Table 2).

Although extremely heavy rains fell in the mountains of Virginia and West Virginia in early November, most of the monthly precipitation for the stations nearer to the Bay was recorded during the second half of the month. Royal Oak received 0.81 inches during the first half of November out of a monthly total of 5.11 inches, and Patuxent received 0.93 inches during the first half out of a monthly total of 5.69 inches. Some of the heaviest rainfalls during the month in these areas fell on the 22nd, 23rd, and the 30th.

Temperatures during the month averaged 6.0°F above normal, ranging from 3.6°F above normal at Wilkes-Barre to 8.4°F above normal at Norfolk (Table 2). The greater positive anomalies were seen farther south in the area. Highest monthly temperatures were reached around the 14th or the 20th, and a number of record values were set. Monthly lows were reached from the 21st to the 25th with the majority occurring on the 24th. Stations and their record high temperatures and the dates of occurrence are as follows:

New record high temperatures for November

| Station | Temperatures (Date) | Remarks |
|---|---|---|
| Norfolk | 79°F (11th), 80°F (20th, 28th) | Warmest November |
| Richmond | 80°F (14th, Record tied) | Warmest November |
| Patuxent | 78°F (14th), 76°F (20th), 71°F (27th) | |
| Royal Oak | 73°F (11th, 19th), 74°F (20th) | Warmest November |
| Baltimore | 75°F (11th), 77°F (20th), 69°F (22nd) | |

A peak gust of 67 mph during the storm of November 4th was reported in the Norfolk area. Gusts reached 45 mph at Patuxent and 40 mph at Royal Oak on the 4th. Patuxent reported gusts of 29 mph on the 3rd and 30 mph on the 8th in addition to 11 occasions of gusts from 20 to 24 mph. At Royal Oak gusts reached 30 mph on the 3rd, 29 mph on the 15th, 27 mph on the 1st and 22nd, 23 mph on the 2nd, and 22 mph on the 10th.

## 2.2 Streamflow

Bay streamflow was below normal in September and October, though heavy upstream rainstorms early in November produced record-high streamflow in that month (Figure 2). Streamflow was below normal in all months of 1985 except August and November, marking 1985 as a dry year. The 1985 cumulative streamflow anomaly for January through November was a deficit of 2.6 trillion gallons, though the heavy streamflow in November brought the cumulative anomaly closer to normal (Figure 3). Heavy upstream rainfall in early November associated with Tropical Storm Juan and another storm system produced widespread flooding in Bay tributaries (See Section 2.1, Weather). November river flows reached heights in some areas comparable to the devastating floods following Tropical Storm Agnes in 1972, though the November 1985 flooding was of shorter duration. The November 1985 flow of 164,000 cubic feet per second set a new record for that month, surpassing the previous record of 131,800 cfs set in November 1972.

Precipitation in the region averaged 60 percent above normal among the 11 stations in Figure 1 in September, though streamflow remained below normal. The average precipitation anomaly in November (+66 percent) was very close to the September anomaly (+60 percent). However, record high streamflow in November resulted from the heavy upstream rainfall in early November combined with several other rainfall periods in November. Rainfall in September was associated almost entirely with Hurricane Gloria over a short period at the end of September. Most of the rainfall from Gloria fell over a smaller area nearer to the Bay proper which did not greatly add to the total freshwater inflow for September.

Floodwaters crested on November 7 in the upper Potomac River. Turbidity produced by the high sediment loads of the floodwaters is clearly visible in satellite imagery of the Bay area (Figure 4). In the November 7 image of Figure 4, turbidity fronts can be seen in the Potomac, Rappahannock, and James rivers. Sediment discharge from the Potomac River basin above Washington was approximately 1,134,000 tons, compared to the normal November figure of only 7,550 tons. The November 8 image shows downstream progress of these fronts, noticeably in the Potomac and James rivers. The turbid water in the Rappahannock River covers a greater area in the November 8 image, but with slight downstream progress.

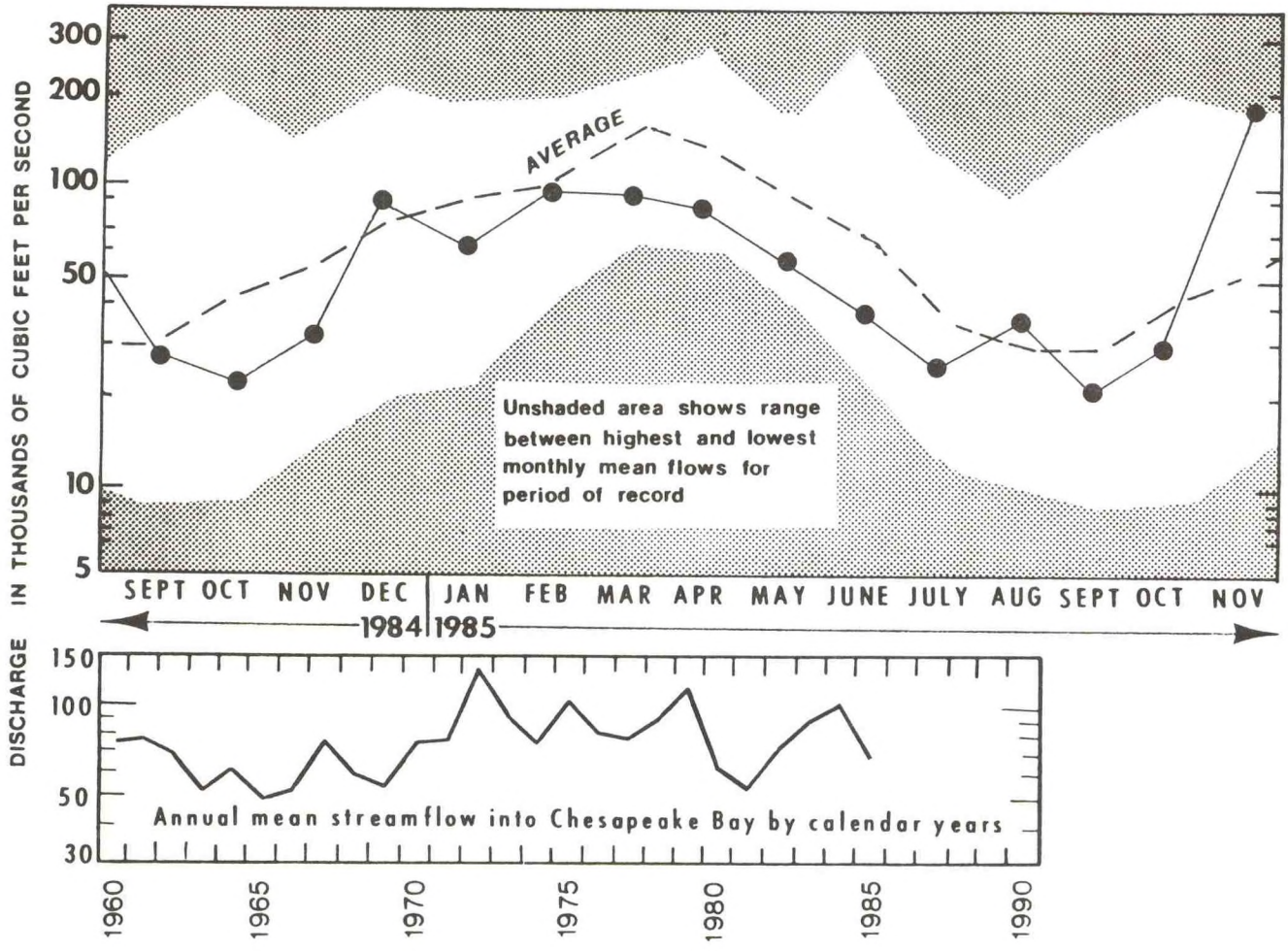



Figure 2.-- Monthly streamflow into Chesapeake Bay, September-November 1985 and annual mean flow 1960-1984. Bay streamflow was below normal in September and October. The record high streamflow in November reflects the large amount of freshwater which entered the Bay system following upstream rainstorms in eary November. Data from U.S. Geological Survey.

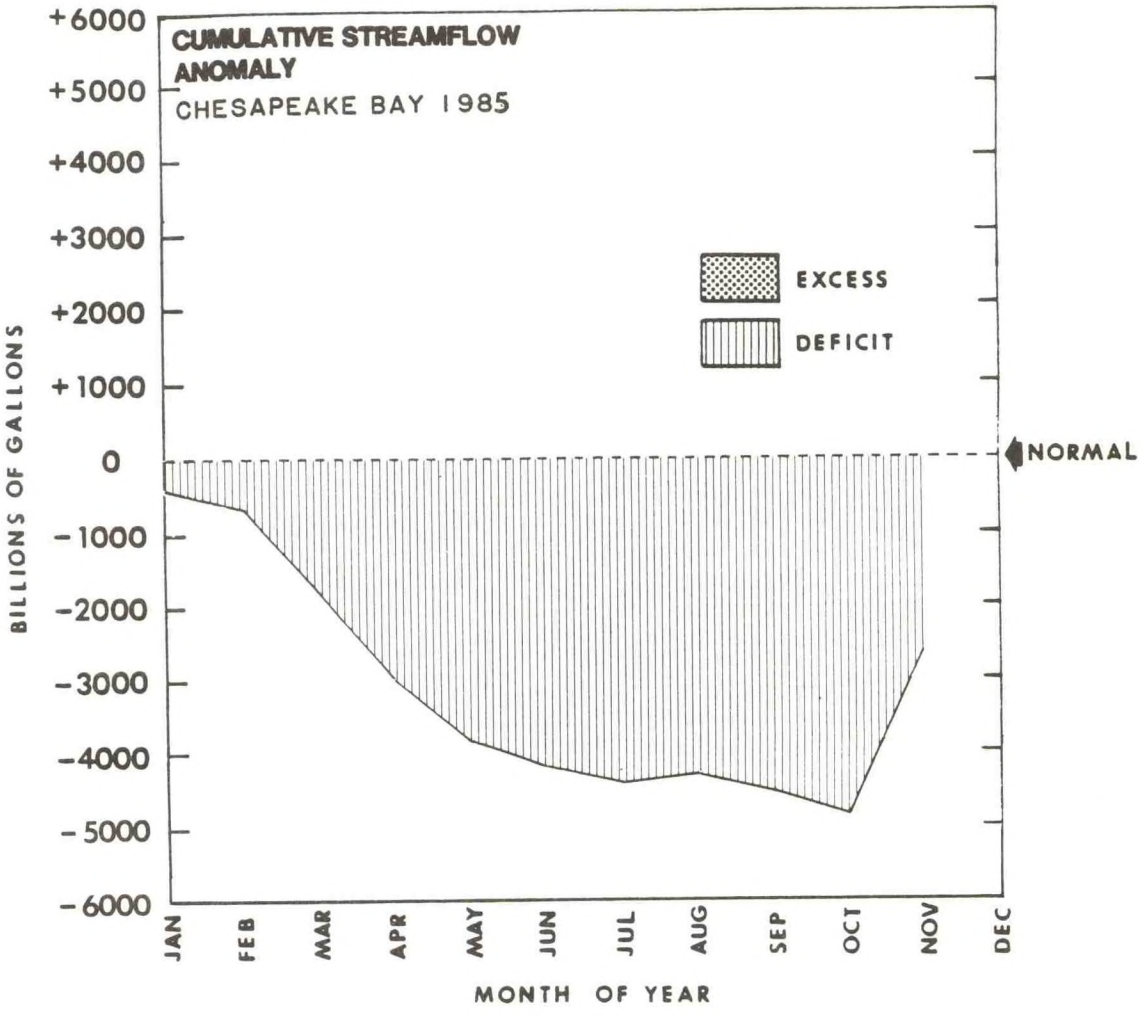



Figure 3.-- Cumulative monthly streamflow anomaly, Chesapeake Bay, 1985. The cumulative anomaly (monthly sum of negative and positive departures from normal by calendar year) for January through November 1985 was a deficit of 2.6 trillion gallons. The large deficit was sharply reduced following high streamflow in November. Data from U.S. Geological Survey.

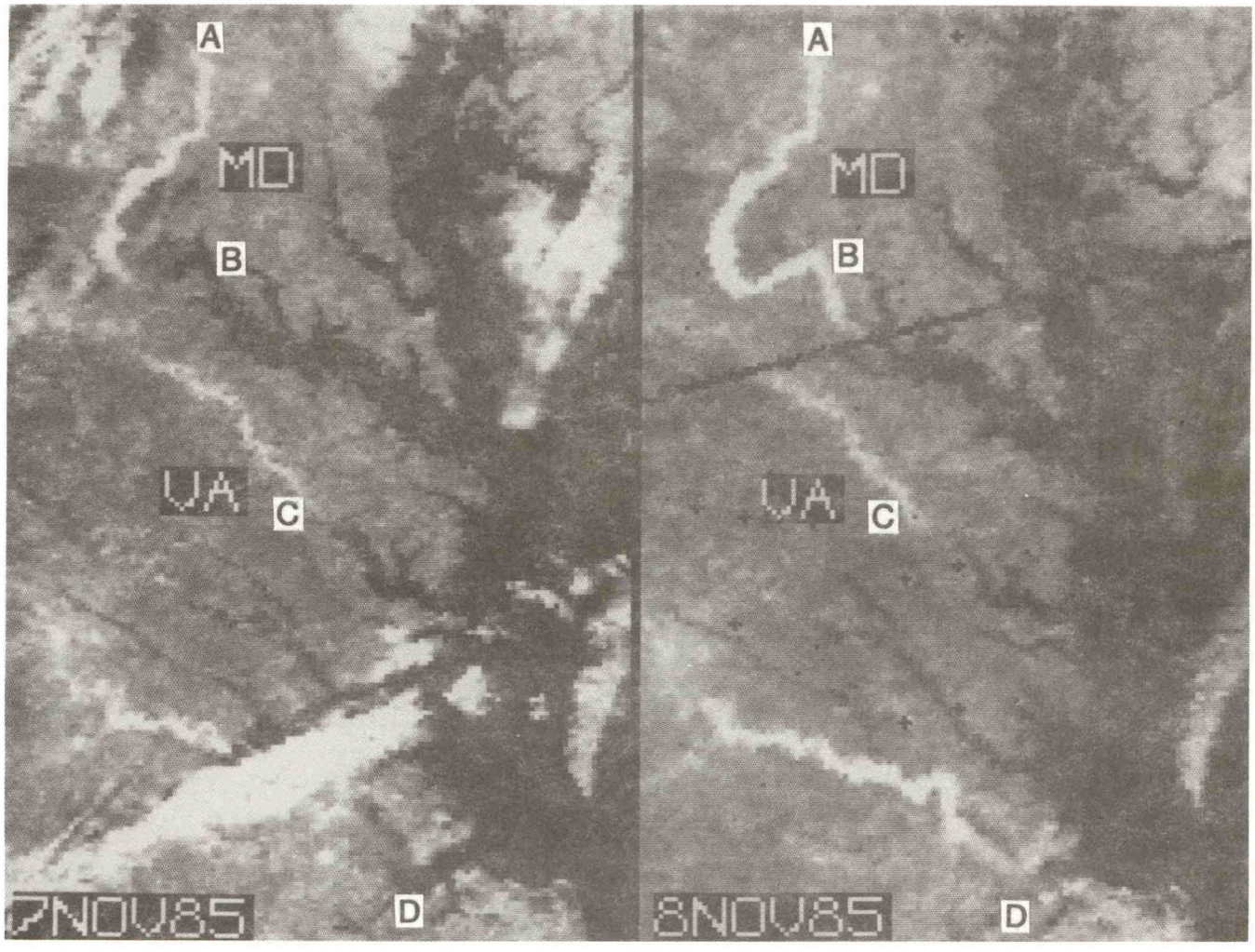



Figure 4.-- Satellite images of Chesapeake Bay showing turbidity in its tributaries produced by high streamflow conditions in November 1985. The November 7 image shows the location of the turbidity front in the flooded Potomac River at about 15 miles upstream of the 301 Bridge near reference point B. The November 8 image shows the downstream progress of the front at approximately 20 miles below the 301 Bridge. The downstream progress of turbidity fronts can also be seen in the Rappahannock River near C in the images and in the James River near D.

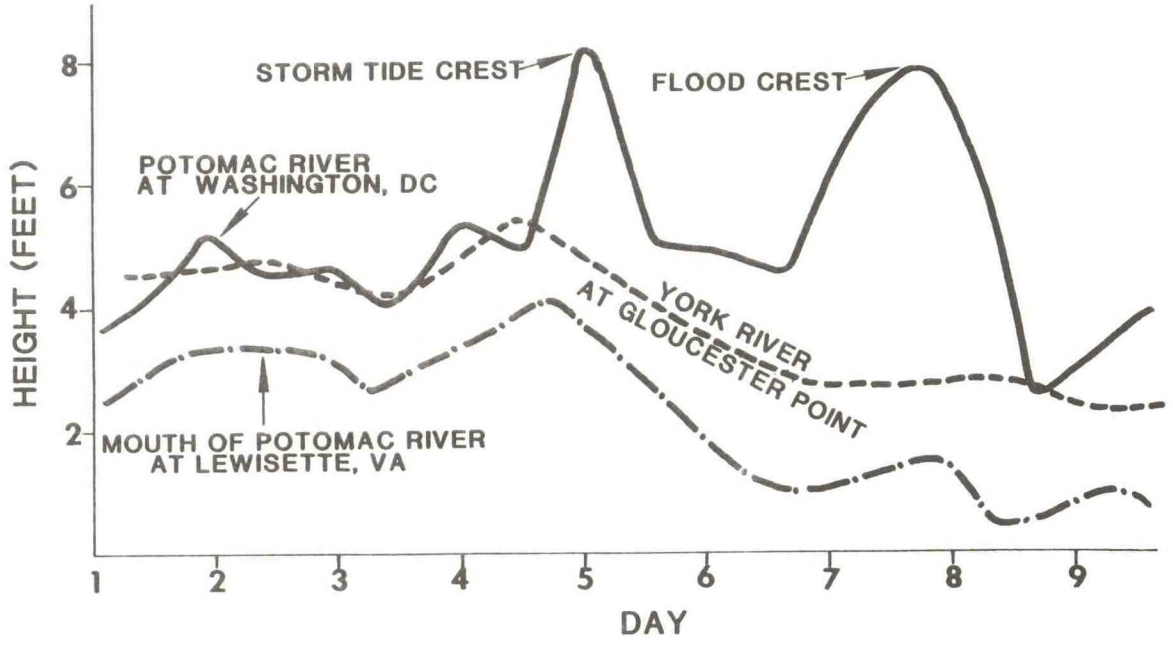
## 2.3 Bay water levels

During the first several days in November the low pressure system which had been Hurricane Juan and which was now moving through the southeastern United States set up a circulation covering most of this part of the country. This circulation was strengthened by a high pressure area over southeast Canada. During the last several days in October and early in November the winds off the Chesapeake Bay mouth blew from the northeast. Later these winds became more easterly. Bay water levels mounted and crested on November 2 inside the mouth of the Bay around noontime. Hampton Roads and Chesapeake Bay Bridge-Tunnel water-level gauging stations reported highest water levels of the month at this time.

On November 4 a new storm developed over the Carolinas and Virginia, reaching full strength late in the day. In addition to the large amount of rainfall produced in the mountains of Virginia and West Virginia, it also generated strong southerly winds. Much of the accumulated water in the mouth of the Bay was pushed northward, flooding river channels and inlets to the Bay, particularly in the western shore areas from the combination of high tides and storm surge. The illustration below shows the crest at Gloucester Point on the York River, and at Lewisette, VA near the mouth of the Potomac River, and at Washington, DC late on the 4th or early on the 5th. The flooding was severe along the western shore of the Bay in Anne Arundel County, MD where people were forced to flee in some areas from the rising water. Flooding damaged boats, piers, bulkheads and shorelines.

As flood waters from the storm moved downstream in the Potomac River they crested again at Washington, DC on the 7th. This crest as shown in the illustration is slightly lower than that of near midnight on the 4th, but is much broader.

**PROFILES OF NOVEMBER TIDAL CRESTS ABOVE MEAN LOW WATER**



## 2.4 Oceanography

Monthly average salinities around the Bay were slightly above normal in September and October and anomalies decreased in November following unusual rainfall (Table 3 and Figure 5). Water temperatures began the quarter slightly below normal in the upper Bay and slightly above normal in the lower Bay. Water temperatures remained above normal during the rest of the quarter.

### Salinity:

Despite apparently normal monthly averages at stations around the Bay, daily salinity values were highly variable during the quarter, especially in the lower Bay. Baltimore, Annapolis, and Solomons all remained above normal in salinity until late in the quarter when runoff from the Susquehanna basin depressed values below normal the last few days of November.

Kiptopeke and Chesapeake Bay Bridge-Tunnel each began the quarter with above-normal salinities. Four times during the period high runoff from the Potomac caused salinity to drop to normal at the Bay Bridge-Tunnel and below normal at Kiptopeke. Finally, the large runoff following the unusual rainfall conditions associated with remnants of Tropical Storm Juan in early November brought salinities at these stations nearly 3 parts per thousand (ppt) below normal for the remainder of the quarter. The late November surge in runoff further depressed salinity values to nearly 4 ppt below normal at the very end of November.

Due to runoff from strong storms in the region, surface salinities in major rivers (Potomac, James, York, Rappahannock) along the Bay fell to very low readings at times during November. The fresh water boundary (0.0 ppt) in the Potomac reached Maryland Point November 19, and Ragged Point had a salinity reading of 8.6 ppt that date, a decrease of 9 ppt from observations a month earlier. Bottom salinities were not as strongly affected.

In the James River, however, the salt intrusion, normally extending 70 kilometers upstream, was reduced to only 40 km on November 18. Surface values at the mouth of the rivers followed the flood waters which crested at Hampton Roads on November 9. The sampling of November 19 reflects a recovery stage of the salt distribution, but still clearly shows salinity at the mouth of the James, York, and Rappahannock rivers depressed by 6 ppt, 3 ppt, and 2 ppt, respectively, from a month earlier.

### Temperature:

Surface water temperatures were slightly below normal at Baltimore and Solomons in September while all other stations were slightly above normal. In October water temperatures began to return to normal in the upper Bay. Solomons, Kiptopeke, and Bay Bridge-Tunnel showed between 2 to 6°F above-normal water temperature for October and November. Kiptopeke increased by 3°F in November while Bay Bridge-Tunnel increased by 2°F.

Table 3.--Bay surface salinities and surface water temperatures, September - November 1985.

| Station | Surface Salinity and Departure from Normal Observed/Anomaly* (ppt) | | | Surface Water Temperature and Departure from Normal Observed/Anomaly* (Deg. F) | | |
|---|---|---|---|---|---|---|
| | September | October | November | September | October | November |
| Baltimore, MD | 13.3/+3.6 | 12.4/+1.6 | 11.4/+0.3 | 74.6/-0.6 | 66.2/+0.5 | 57.0/+3.0 |
| Annapolis, MD | N/A | 14.4/+1.3 | 13.1/-0.5 | N/A | 65.4/+0.5 | 56.8/+3.9 |
| Solomons, MD | 16.7/+1.9 | 17.9/+1.9 | 17.7/+1.1 | 75.6/-0.1 | 68.5/+2.8 | 60.2/+5.5 |
| Kiptopeke, VA | 29.0/+1.3 | 27.9/+0.2 | 26.8/-0.3 | 76.9/+3.1 | 68.0/+3.4 | 60.3/+6.5 |
| Bay Bridge-Tunnel, VA | 26.4/+2.3 | 25.8/+1.7 | 21.8/-1.5 | 76.1/+0.7 | 70.5/+4.7 | 61.9/+6.7 |

*Anomaly = departure from long-term monthly averages. All salinity data are provisional. Salinities are based on water densities normalized to 15°C. N/A = not available.

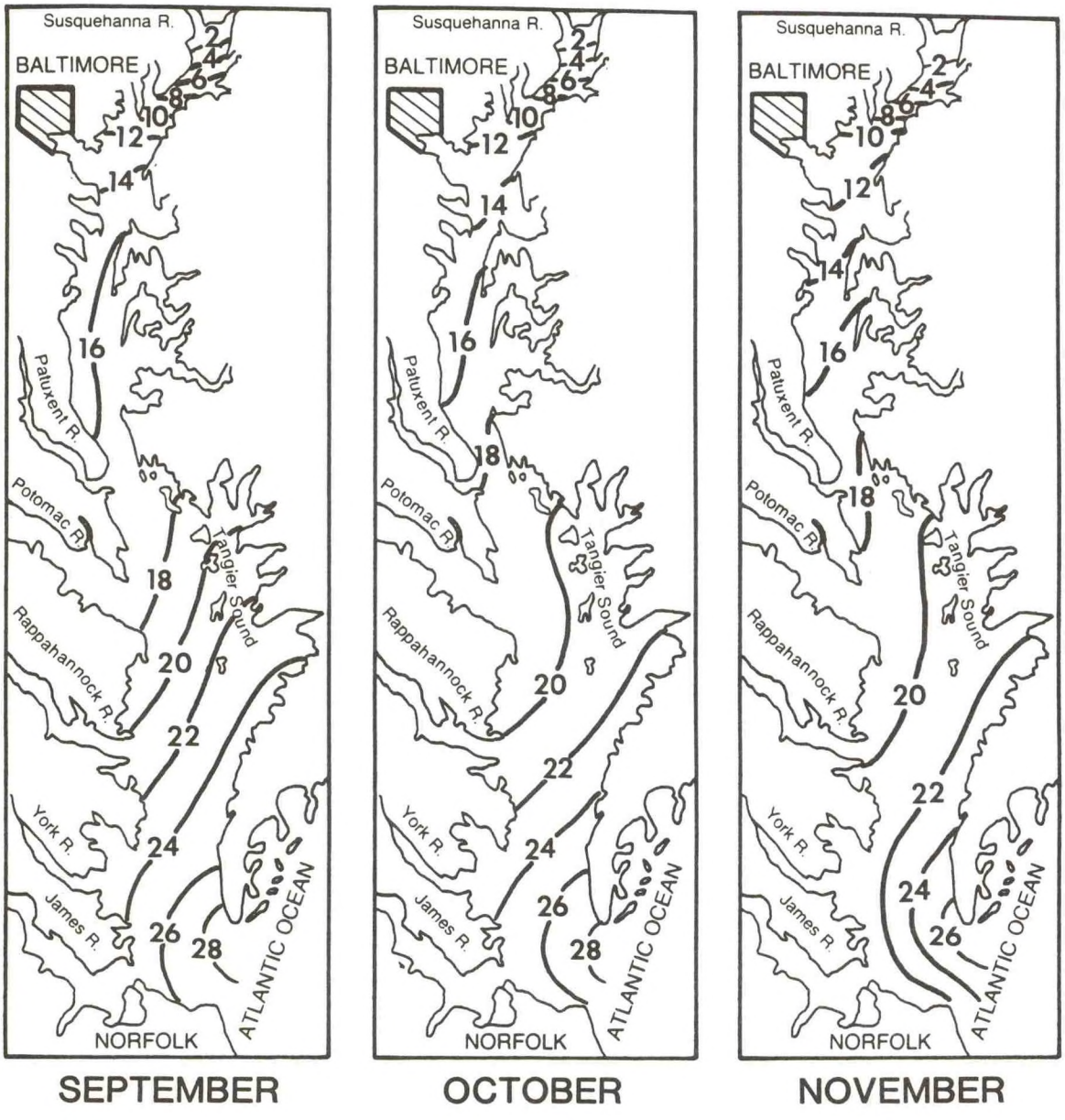



Figure 5.-- Mean surface salinity distribution, Chesapeake Bay, September-November 1985. Isohalines (parts per thousand) are linearly interpolated from designated station data. Salinities remained above normal in September and October as they had throughout the summer quarter. Heavy rains and greatly increased streamflow in early November caused a Bay-wide reduction in salinities. Data from National Ocean Service, NOAA. Data from cruises and other sampling stations are used to supplement NOS station data.

## 3. Impacts of Climate/Weather on Bay Fisheries, Recreation, and Transportation

### 3.1 Fisheries

Crabbers in Virginia reported unusually large landings of trawl-caught crabs in November during a period of above-normal water temperatures. The warm water temperatures also affected oyster quality as seen in low yields of oyster meats shucked at packing houses in Virginia. Flood conditions in early November caused extensive property damage in the Bay watershed, though no major effects on commercially important Bay species were detected. A good Bay-wide spatset was reported, especially in areas of Maryland, where very high spat counts were reported.

Blue crabs:

Maryland blue crab landings exceeded 1984 quantities through September in 1985 but were lower in October and November 1985 than in those months in 1984 (Table 4). However, the total commercial blue crab catch in Maryland for 1985 is expected to be the highest of the last five years, according to preliminary estimates.

Watermen in Virginia reported unusually large trawl catches of blue crabs in November. The large trawl catches of crabs coincided with a period of above-normal water temperatures. Crabs become inactive as water temperatures cool in late fall, though in 1985 more crabs may have remained active longer, contributing to the larger trawl catches. The increase in landings resulted in lower prices in the blue crab market in Virginia. Watermen in Virginia lost some crab pots during high winds and waves associated with the early November storms.

Researchers at Old Domininion University found patches of extremely high densities of first stage blue crab larvae in offshore coastal waters in late August. Fewer later stage larvae were present in late summer than are normally found in the study, which may indicate that spawning and development was delayed in summer 1985. Preliminary results of a Virginia Institute of Marine Science (VIMS) study at one site in the lower Bay showed that crab megalopae and first stage juveniles were found in lesser numbers than during the comparable period in September of the previous two years. VIMS trawl sampling in October in the York, Rappahannock, and James rivers in Virginia showed an average number of juveniles of the 1985 year class, concentrated mostly in the middle portions of the rivers. Further trawl sampling of juveniles in spring and early summer will provide more information on the success of the 1985 year class.

Blue crabs of the 1984 year class (crabs spawned in 1984) were present in high numbers in summer 1985. The survival of the 1984 year class and recruitment of crabs spawned in 1985 will determine the size of the total harvest during the 1986 season.

Oysters:

Virginia and Maryland monitoring agencies observed no large scale mortalities of adult or seed oysters following the extensive flooding in early November (see Section 2.1, Weather). Oysters close up and stop feeding and are able to

Table 4.--Maryland and Virginia blue crab landings, September - November 1984-85.

| | | Maryland | | Virginia | |
|---|---|---|---|---|---|
| | | Pounds | Dollars | Pounds | Dollars |
| September | 1984 | 8,899,733 | $2,025,010 | 5,201,872 | $ 988,805 |
| | 1985 | 9,295,782 | $2,116,332 | 3,509,658 | $ 656,758 |
| | 1984-85 % change | +4% | +5% | -33% | -34% |
| October | 1984 | 6,328,261 | $1,275,610 | 5,102,480 | $ 840,276 |
| | 1985 | 5,267,879 | $1,000,726 | 3,645,668 | $1,037,173 |
| | 1984-85 % change | -17% | -22% | -29% | +23% |
| November | 1984 | 2,113,199 | $ 570,316 | 2,389,282 | $ 389,892 |
| | 1985 | 2,091,073 | $ 528,854 | 2,311,727 | $ 390,694 |
| | 1984-85 % change | -1% | -7% | -3% | 0% |

Data from Maryland Department of Natural Resources and Virginia Marine Resources Commission. Landings for Potomac River proper are not included. All 1985 landings are preliminary.

N/A = Not available.

survive short periods of extreme drops in salinity. Though flood levels in some Bay tributaries were comparable to those reached during Tropical Storm Agnes in June 1972, the damage to oyster beds that Agnes produced did not occur in November 1985 due to the short duration of the flooding. Water temperatures were higher in June during Agnes and salinities were lower which produced extensive oyster mortalities. Oysters were able to tolerate lower salinities better in the lower water temperatures of November. Portions of the James River were closed to the harvesting of oysters by the State of Virginia following the November 4 flooding due to sewage contamination from overflow conditions at treatment plants in the Hampton Roads sanitation district.

The middle and upper Bay experienced very good oyster spatset in 1985, as seen in the Maryland Department of Natural Resources (DNR) fall survey of natural oyster bars from the upper Bay down through Pocomoke Sound. Spat sets were widespread with very high counts, compared to the very low spatset reported in 1984. The survey of 55 key oyster bars in Maryland showed an average of 133 spat per bushel compared to the near-zero average count in 1984. Spat counts ranged to as high as three to four thousand per bushel in areas such as Broad Creek at the lower Choptank River. The survey also showed no recent oyster mortality, indicaing that the overall adult oyster population is healthy and strong. The combination of the good Bay-wide spatset with the absence of oyster mortality indicates that the overall oyster stock is beginning an upswing from the poor reproduction and gradually declining resource of the past few years, according to the Maryland DNR.

Maryland and Virginia watermen experienced difficulty selling oysters early in the oyster season during a period of low prices and reduced market demand. Prices were much lower in fall 1985 compared to fall 1984, notably in Maryland in October (Table 5). Oysters brought in from states other than Maryland and Virginia competed with sales of Bay oysters, contributing to the lower prices. Out-of-state oysters included oysters from Louisiana packing houses and from the west coast.

Poor oyster quality contributed to the low prices watermen received for oysters in October. Seasonal cooling of water temperatures in late fall brings on an increase in oyster meat quality as oysters store glycogen (put on fat). Warmer-than-normal water temperatures in late fall 1985 apparently delayed the normal seasonal improvement in oyster quality, as was seen in poor shucking rates in packing houses in Virginia. Shucking rates of 3.5 to 4.5 pints per bushel were reported from oysters taken from the Rappahannock River and other Chesapeake Bay tributaries in Virginia. Shucking rates of between 6.8 to 7.2 pints per bushel are normally considered good for these areas. Shucking rates were higher at the end of November as oyster quality showed improvement with cooling water temperatures.

Table 5.--Maryland and Virginia oyster landings, September - November 1984-85.

| | Maryland | | Virginia | |
|---|---|---|---|---|
| | Bushels | Dollars | Bushels | Dollars |
| September 1984 | 94,312 | $1,279,218 | --- | --- |
| 1985 | 126,039 | $1,215,838 | --- | --- |
| 1984-85 % change | +34% | -5% | --- | --- |
| October 1984 | 260,053 | $4,010,715 | 49,508 | $633,219 |
| 1985 | 252,792 | $2,353,371 | 28,526 | $257,634 |
| 1984-85 % change | -3% | -41% | -42% | -59% |
| November 1984 | 232,624 | $3,608,862 | 73,498 | $940,549 |
| 1985 | 170,281 | $1,924,895 | 80,905 | $831,523 |
| 1984-85 % change | -27% | -47% | +10% | -12% |

Data from Maryland Department of Natural Resources and Virginia Marine Resources Commission. All 1985 landings are preliminary. Potomac River landings are not included. Virginia public oyster-ground harvest begins in October.

## 3.2 Recreation

Marine recreational activity during the fall 1985 quarter around Chesapeake Bay was affected during Hurricane Gloria near the end of September and the storm in early November which resulted in severe flooding in the Bay area (see Section 2.1 Weather).

The National Weather Service marine advisories and warnings for Chesapeake Bay are listed in Table 6. The effects of hurricane Gloria are seen in September from the multiple advisories and warnings on September 26, 27, and 28. On September 26 a small craft advisory was issued for the entire Bay and Tidal Potomac River. Later that day a gale warning was also issued for the entire Bay and Tidal Potomac River with the small craft advisory remaining in effect. A hurricane warning was issued that evening for the entire Bay and remained in effect until the next day. The hurricane warning on the 27th of September was later downgraded to a gale warning and by that evening a small craft advisory was in effect for the remainder of the day. During the storms that affected the Bay from the 1st to the 5th of November, 4 gale warnings and 7 small craft advisories were issued. A larger number of gale warnings and small craft advisories were issued in the fall 1985 compared to 1984.

Table 7 shows U.S. Coast Guard Search and Rescue (SAR) cases. During the 1985 quarter the total SAR cases at all Groups showed increases over the 1984 quarter. SAR statistics for Group Baltimore and Group Norfolk in the fall 1985 quarter include all requests for assistance, whether or not the Coast Guard responded. The higher number of cases reported in fall 1985 compared to fall 1984 reflects this change, though cases reported during the storm events of late September and early November also contributed to the higher overall caseloads. The storms appear to have had the most effect on the increases seen in the SAR caseload at Group Baltimore. Group Eastern Shore SAR caseload increased slightly in September and November with a few storm-related cases. Cases handled by Group Norfolk during the two storms included boats blown away from piers, boats sinking, and disabled boats.

Maryland Department of Natural Resources accident statistics for recreational boating are listed in Table 8. Boating accidents in Maryland increased during the 1985 quarter over the same period in 1984. Flooding and strong winds in November caused extensive property damage.

Attendance and revenue for selected Maryland and Virginia state parks are listed in Table 9. Sandy Point showed a decrease in fall 1985 attendance and revenue when compared to the 1984 quarter. The storms passed Sandy Point quickly having minimal effect on attendance and park facilities. Some flooding occurred at Point Lookout in late September from hurricane Gloria. Attendance was slightly reduced with less campers visiting the park during the month.

All Virginia Parks showed an increase in attendance throughout the 1985 quarter when compared to the 1984 quarter, except at Seashore where attendance decreased due to the hazard preparations before the storms. The storms showed no effect on attendance at Chippokes, as attendance was higher compared to the 1984 quarter. Westmoreland experienced minor flooding, erosion, and groyne wash outs following the storm in late September. However, monthly attendance at Westmoreland in September showed an increase over September 1984. Many people came to Westmoreland to observe storm damage, contributing to the increase in September 1985 attendance.

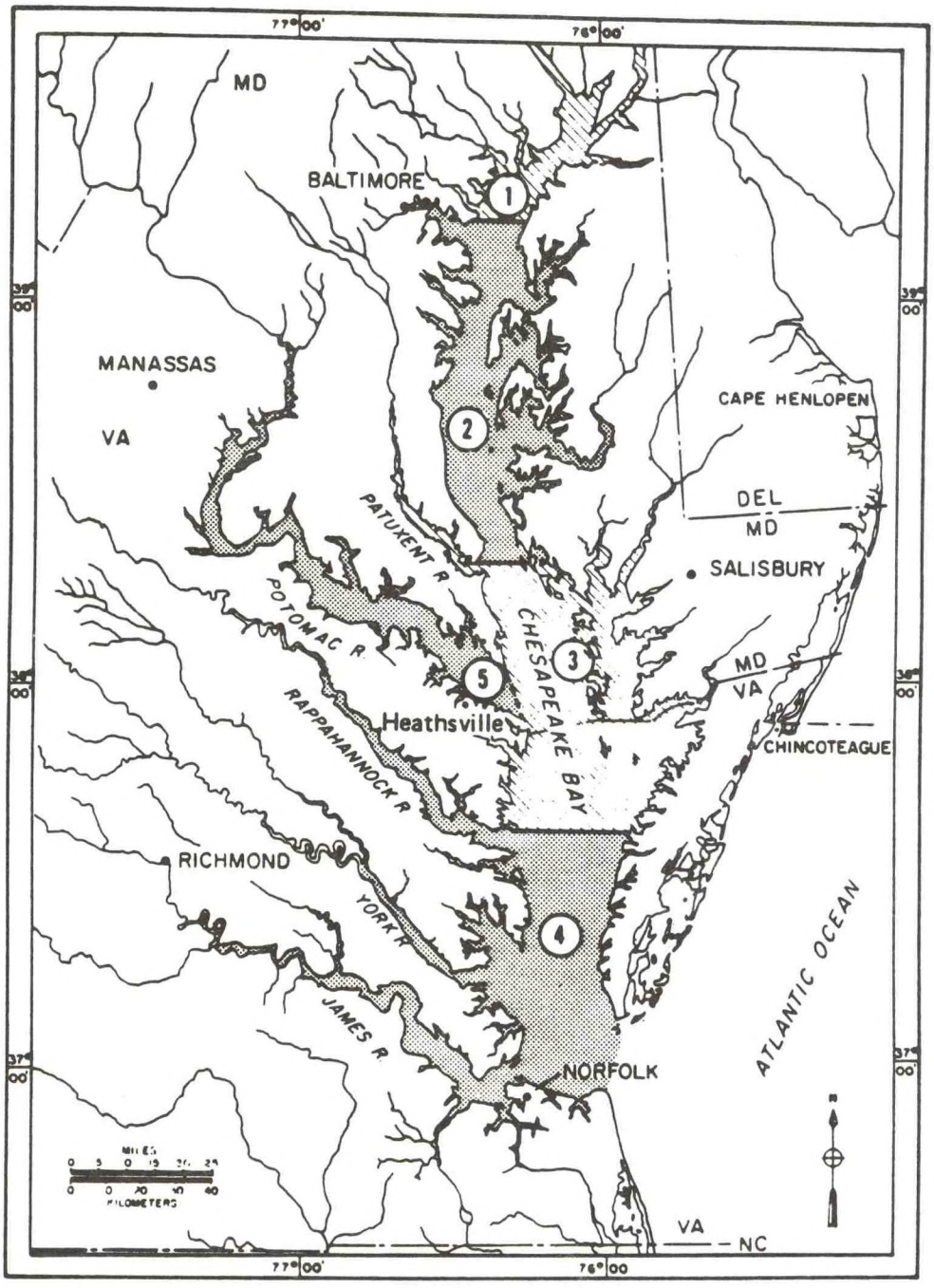



Figure 6.-- National Weather Service (NWS) forecast areas for Chesapeake Bay.

**Key to forecast areas:**

1 = Head of Bay to Baltimore Harbor
2 = Baltimore Harbor to Patuxent River
3 = Patuxent River to Windmill Point
4 = Windmill Point to Mouth of Bay
5 = Tidal Potomac River

Table 6.--Marine advisories/warnings, Chesapeake Bay, September - November 1985 (National Weather Service data). For definition of areas see Figure 6.

| Date | Condition Report[1] | Location[2] |
|---|---|---|
| September 11 | A | Entire Bay and Tidal Potomac River |
| 11 | A | Head of Bay to Windmill Point and Tidal Potomac River |
| 13 | A | Head of Bay to Windmill Point and Tidal Potomac River |
| 14 | A | Entire Bay and Tidal Potomac River |
| 23 | A | Mouth of Bay |
| 23 | A | Head of Bay to Windmill Point and Tidal Potomac River |
| 23 | A | Mouth of Bay |
| 26 | A | Entire Bay and Tidal Potomac River |
| 26 | B | Entire Bay and Tidal Potomac River |
| 26 | D | Entire Bay |
| 27 | D | Entire Bay |
| 27 | B | Tidal Potomac River |
| 27 | A | Entire Bay and Tidal Potomac River |
| 28 | A | Entire Bay |
| October 5 | A | Entire Bay and Tidal Potomac River |
| 20 | A | Mouth of Bay |
| 21 | A | Patuxent River to Windmill Point |
| 22 | A | Patuxent River to Mouth of Bay |
| 28 | A | Entire Bay and Tidal Potomac River |
| 28 | A | Head of Bay to Windmill Point and Tidal Potomac River |
| 30 | A | Mouth of Bay |
| 31 | A | Mouth of Bay to Windmill Point and Tidal Potomac River |
| November 1 | A | Patuxent River to Mouth of Bay and Tidal Potomac River |
| 2 | B | Mouth of Bay |
| 2 | A | Baltimore Harbor to Patuxent River |
| 2 | A | Mouth of Bay |
| 3 | A | Mouth of Bay |

[1] Key to Condition Reports:

A = Small Craft Advisory (Wind 25-34 knots)
B = Gale Warning (Wind 34-47 knots)
C = Storm (Wind 47-64 knots)
D = Special Marine Warning (Unusual weather phenomena)

[2] Windmill Point = North side of Rappahannock River

Table 6.--(Continued). Marine advisories/warnings, Chesapeake Bay, September - November 1985 (National Weather Service data). For definition of areas see Figure 6.

| Date | | Condition Report[1] | Location[2] |
|---|---|---|---|
| November | 3 | A | Head of Bay to Windmill Point and Tidal Potomac River |
| | 4 | B | Mouth of Bay |
| | 4 | B | Baltimore Harbor to Mouth of Bay |
| | 4 | B | Head of Bay |
| | 4 | A | Patuxent River to Mouth of Bay |
| | 5 | A | Head of Bay to Patuxent River |
| | 5 | A | Entire Bay and Tidal Potomac River |
| | 9 | A | Entire Bay and Tidal Potomac River |
| | 10 | A | Entire Bay and Tidal Potomac River |
| | 14 | A | Entire Bay and Tidal Potomac River |
| | 15 | A | Entire Bay and Tidal Potomac River |
| | 16 | A | Entire Bay and Tidal Potomac River |
| | 20 | A | Entire Bay and Tidal Potomac River |
| | 21 | A | Mouth of Bay |
| | 22 | B | Mouth of Bay |
| | 22 | A | Head of Bay to Windmill Point and Tidal Potomac River |
| | 22 | B | Mouth of Bay |
| | 23 | A | Mouth of Bay |
| | 28 | A | Mouth of Bay |
| | 30 | A | Mouth of Bay |

[1] Key to Condition Reports:

A = Small Craft Advisory (Wind 25-34 knots)
B = Gale Warning (Wind 34-47 knots)
C = Storm (Wind 47-64 knots)
D = Special Marine Warning (Unusual weather phenomena)

[2] Windmill Point = North side of Rappahannock River

Table 7.--U.S. Coast Guard Search and Rescue (SAR) caseload, September - November 1984 and 1985.

| Month | Number of Search and Rescues | | | | | |
|---|---|---|---|---|---|---|
| | Group Baltimore | | Group Eastern Shore | | Group Norfolk | |
| | 1984 | 1985 | 1984 | 1985 | 1984 | 1985 |
| September | 157 | 269 | 5 | 21 | 140 | 192 |
| October | 142 | 186 | 14 | 9 | 97 | 79 |
| November | 77 | 93 | 7 | 14 | 51 | 52 |
| Totals | 376 | 548 | 26 | 44 | 288 | 323 |

Group Baltimore - most of Upper Bay
Group Eastern Shore - lower central portion of Eastern Shore
Group Norfolk - most of Lower Bay

Table 8.--Maryland marine accident statistics, September - November 1984 and 1985.

| Month | No. of Boating Accidents | | No. of Injuries | | No. of Deaths | | Property Damage | |
|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1984 | 1985 | 1984 | 1985 | 1984 | 1985 |
| September | 32 | 27 | 8 | 12 | 4 | 4 | $153,925 | $66,595 |
| October | 14 | 14 | 0 | 5 | 0 | 0 | $ 39,816 | $79,800 |
| November | 5 | 11 | 0 | 1 | 1 | 0 | $ 21,650 | $67,090 |
| Totals | 51 | 52 | 8 | 18 | 5 | 4 | $215,391 | $213,485 |

Data Source: Maryland Department of Natural Resources Marine Police. All categories are for recreational boating. Includes Potomac River to Virginia shoreline. Data are preliminary.

Table 9.--State parks attendance and revenue, selected Maryland and Virginia facilities, September - November 1985.

| Facility | Month | | | | | |
|---|---|---|---|---|---|---|
| | September | | October | | November | |
| Maryland | Attendance | Revenue | Attendance | Revenue | Attendance | Revenue |
| Sandy Point | 73,798 | $23,268 | 54,143 | $ 1,876 | 13,710 | $ 0 |
| Point Lookout | 34,612 | $14,583 | 25,475 | $ 6,050 | 5,510 | $4,406 |
| Virginia | | | | | | |
| Westmoreland | 12,691 | $ 9,251 | 8,039 | $ 5,254 | 1,477 | $ 798 |
| Chippokes | 4,388 | $ 665 | 3,611 | $ 190 | 2,017 | $ 45 |
| York River | 5,942 | $ 465 | 4,990 | $ 400 | 3,549 | $ 17 |
| Seashore | 66,615 | $34,612 | 33,150 | $16,543 | 16,348 | $2,273 |

Data from Maryland Department of Natural Resources, Forest, Park, and Wildlife Service; and Virginia Department of Conservation and Economic Development, Division of State Parks. Revenue does not always reflect usage levels. Special scheduled activities, seasonal revenue changes, and equipment breakdown influence total revenue amounts.

## 3.3 Transportation

Winds in excess of 40 mph shut down crane operations 7 times at the Port of Baltimore for a total of 32 hours and 10 minutes (Table 10). During the same period in fall 1984, winds shut down crane operations 3 times for a total of 8 hours and 59 minutes.

Table 10.--Number of crane shutdowns and productive time lost due to wind in excess of 40 mph at Port of Baltimore, September - November 1985.

| Date | | Number of Shutdowns | Productive Time Lost (Hours:Minutes) |
|---|---|---|---|
| September | 9 | 1 | 3:05 |
| | 10 | 1 | 1:55 |
| | 26 | 1 | :42 |
| | 27 | 1 | 14:10 |
| October | 15 | 1 | :43 |
| November | 4 | 1 | 10:20 |
| | 5 | 1 | 1:15 |
| Totals | | 7 | 32:10 |

Data from Maryland Port Administration.

Winds associated with Hurricane Gloria in late September and the storm in early November resulted in the longer shutdowns on September 27 and November 4.

Losses incurred by individual container-line shippers from crane down-time includes pay to stevedore crews at $1500 per hour and vessel down time at $2500 per hour. Based on the total down-time, shippers may have experienced costs in excess of $128,000 due to excessive winds in the fall 1985 quarter.

## 4. Impacts of Storms in Early November 1985

The Chesapeake Bay region suffered damages ranging from catastrophic to minor as a result of the rain and winds from the remnants of Hurricane Juan and a low-pressure tropical air system which followed. As early as October 30, rain from Juan was falling in Virginia and West Virginia. Rainfall amounts of an inch a day were recorded in areas of the Bay drainage system through November 2. This saturated the soil and set the stage for major flooding.

On November 2 a warm tropical air system began moving into the Chesapeake Bay region and provided the catalyst for the disaster which followed. Heavy rains occurred on the 3rd and 4th in the West Virginia and Virginia and more rain fell as the storm moved north through the region on the 5th and 6th. Rainfall in excess of 10 inches was recorded over portions of the southern Appalachians during the first five days of November. Montebello, VA reported 18 inches in this period. Milan, WV, located on the South Branch of the Potomac River, reported rainfall of 14 inches between November 1 and 6.

In West Virginia, along many rivers and streams, flooding of 100- to 500-year flood level frequencies occurred. Records were established in the headwaters of the Potomac basin. Flash flooding was widespread in eastern West West Virginia and the panhandle during the severe rainfall of November 4. The Potomac River at Paw-Paw crested at 54 feet, 29 feet above flood stage on November 5. The Potomac River and its branches, tributaries, and forks gathered runoff volume while descending from the mountains and did great damage to forests, mills, towns, roads, businesses, and homes. The towns of Franklin, Petersburg, and Moorefield were particularly hard hit. At Harpers Ferry, flood waters inundated the lowlying historic district. Greatest damages in West Virginia were sustained in the areas closest to the headwaters. Homes and their contents suffered the greatest loss, and towns were completely destroyed leaving thousands homeless. West Virginia preliminary estimates put total damage figures figures at $578 million with 38 people known to have died in the floods.

In Virginia, the Roanoke-Salem area was particularly hard hit with the Roanoke River cresting at 23.35 feet on November 4, well above the previous maximum flood level of 19.61 feet recorded on June 21, 1972 during Tropical Storm Agnes. Damage to the area was severe. Although the Roanoke River does not drain into the Chesapeake Bay, its headwaters originate very close to those of the James River which is part of the Bay system. At Buchanan, which was devastated, the James River reached an historic high of 38.84 feet on November 5. In the Lynchburg area, the James River flood elevation exceeded the previous record stage by about 7 feet. About $8 million in tobacco was lost in one of the many warehouses along the river. At Richmond, the James crested at 30.76 feet on November 7 at the city locks. This was 21 feet above the flood stage. It was the worst flooding since 1972. The water treatment plant in Richmond was kept in operation through the extra efforts of city employees who sandbagged it. The waste treatment plant, however, was knocked out of operation and for a time raw sewage flowed into the river. Strong easterly winds associated with the remnants of Juan forced water into the mouth of the Bay and created tidal flooding in the southern Bay. The low-pressure system that brought heavy rains on the 3rd and 4th had a strong southerly flow which caused tidal flooding in areas adjacent to the Bay. (For additional information on water levels in the

Bay during this period, see section 2.3.) There was extensive damage to piers, docks, and seawalls as well as to beaches, boardwalks, and parks. In Gloucester County, two municipal piers were damaged to the extent of $800,000. Total preliminary damage estimates for Virginia were over $753 million with 22 people known dead.

Maryland had flooding both from storm surge and swollen rivers as a result of the low-pressure warm air system from the south that moved into the area on the 4th and 5th. Damages in Maryland, however, were not as extensive as those in Virginia and West Virginia. Winds blowing up the Bay generated high tides and backed up rivers that enter it. Annapolis and Baltimore had minor flooding. Anne Arundel was the Maryland county most affected by tidal flooding. Homes and businesses were damaged by the waters and a serious component of loss was damage to bulkheads and piers and through erosion. As the winds passed, runoff from the heavy rains swelled rivers causing serious flooding. The Potomac River at Hancock crested on November 6 at 42 feet, 12 feet above flood stage. Maryland's only death from the storm occurred on November 4 when a mudslide near Cumberland washed away tracks and sent a train down the mountainside into the Savage River. Total estamated damages in Maryland were $19 million with $9 million of that being the damage assessed to bulkheads, piers, and erosion.

Elsewhere in the Chesapeake Bay region, severity of damage varied. Pennsylvania had heavy losses from the storms, but most of this occurred out of the Chesapeake waterhshed in the Monongahela and Ohio Rivers. The District of Columbia was the jurisdiction least affected. Georgetown received some minor flooding on November 7, and mud had to be swept from District streets and buildings sandbagged. The District government estimated losses at under $1 million. However, Federally-administered property in the District did not fare as well. The grounds of the Jefferson Memorial and East and West Potomac Parks were inundated. The most serious and costly damage occurred along the C&O Canal and the towpath beside it. In Georgetown, a 30-foot-long gap in the towpath east of Fletcher's Boat House was created by raging water and debris. Damage to the towpath and canal along its 189-mile expanse from Georgetown to Cumberland, MD was estimated at $9.3 million.



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