BARATARIA BASIN: HYDROLOGIC AND CLIMATOLOGIC PROCESSES

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BARATARIA BASIN:
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Abstract

To assess the role of forcing functions or respondents in the operation of natural systems within the Barataria Basin Management Unit assessment included: descriptive physical aspects of tides and water levels, based on continuous recording gauging records; descriptive aspects of salinity, based on a variety of recorded data; a synoptic climatic system, based on daily synoptic weather maps and three-hourly observational data at New Orleans; and wave climate. A systematic description of long-term and short-term patterns of water levels, tides, salinity, temperature, and wave climate provide information on the historic and present physical aspects of Barataria Basin. Eight synoptic weather types provide the framework for analysis of the basin's weather by relating local climatic conditions to large-scale circulation patterns. A water budget is also utilized to estimate rates of evapotranspiration and generation of surplus precipitation. Relationships between pairs of parameters drawn from tides, water levels, and salinity at various resolutions are described. Relationships between climatic conditions associated with each synoptic weather type and changes in tidally filtered water levels, salinity, and freshwater surpluses are shown. Also included is the seasonability of waves that front the basin.

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Part 1. Introduction

The hydrologic and climatologic characterization of the Barataria Basin provides background information on important parameters of these categories in the Louisiana coastal zone. Salinity and wave characteristics are included as fundamental parts. In addition to providing an inventory of significant parameter information, procedures will be investigated for integrating and synthesizing their interactions and responses. Companion reports on the basin provide information on the geologic and biologic characterization, and a statewide report on coastal currents completes baseline information required for general understanding of how the natural basin functions. An additional companion statewide report on oil and gas production activities provides information, restricted to this category, on human use of the area. Impacts associated with this use activity that are known are included in the report.

In Parts 1 and 2 of this study background information will be investigated concerning what is known about the hydrologic aspects of the basin. This includes collection of baseline information on: datum determination in establishment of reference points for measuring water level changes; meteorological driving forces; behavior of tides and water levels in respect to the shallow bar-mouth estuaries fronting the basin; and marsh levels in reference to water levels.

Tidal data will be collected and utilized from both published reports and from analysis of raw data. The primary focus from the data concerns determining characteristics and variability for the following tidal conditions (dependent upon availability, resolution, and distribution of information): Long-term changes will provide insights into historical trends for evaluating annual, seasonal, and spatial variations, and behavior of tidal flood and ebb flow within the basin geometry.

Water-level data that are available will be collected and analyzed for determination of surface slopes within the basin and characteristics of annual water level behavior. These determinations will provide a framework of information for assessing seasonal variations and monthly and annual pulses in reference to the datum. The long-term sea level rise trends will be brought into focus.

Salinity, water temperature, and precipitation data will be collected from published information and as raw data. Analysis of salinity data will include procedures for assessing long-term trends, weekly, monthly, and annual averages.

Temperature data will be analyzed for determination of long-term trends and for weekly averages.

Precipitation long-term trends will be determined along with monthly totals and monthly total averages and annual total precipitation.

Previously determined synoptic weather types will be utilized for determination of possible gross scale relationships between climate patterns and macro-environments. This section includes a discussion of weather types with property summaries, water surplus calculations, and characterization for the year 1971.

Analysis of environmental responses to the synoptic weather types will be attempted. This includes the hydrologic parameters of salinity and water levels.

A summary discussion that integrates the findings in the hydrology and climatology studies is included at the end of the main body of this report.

Part 5, wave action, constitutes a separate report that is included at the end of the hydrology-climatology parts to provide summary information on wave characteristics that affect Barataria Basin's Gulf front.

Pertinent Background Studies

"Water level" is used to indicate the mean elevation of the water when averaged over a period of time sufficiently long to eliminate high frequency oscillations caused by surface gravity waves. The expression water level is also referred to as the still water level to indicate the elevation of the water if all gravity waves were at rest (U.S. Coastal Engineering Research Center [CERC] 1973). This parameter with its various averages is the focal point of this section.

If a tide gauge is accurately leveled into a stable benchmark, then by using the standard datum level that has been fixed to the land, a level can be determined that corresponds to the average level of the sea--"sea level." Determination of the datum is the most critical step. Once this has been performed, sea level can be determined by averaging a time series of tidal heights. Mean sea level is defined as the average height of the surface of the sea for all stages of tide over a 19-year-period, usually determined from hourly height readings (CERC 1973).

It has been customary to determine monthly and annual mean sea levels to 0.001 ft or 1 mm according to the units employed, but this can give a false impression of accuracy. If the gauge record can be read to an accuracy of 0.05 ft, random errors in reading the charts will give standard deviations for monthly and annual means of about 0.0019 and 0.0005 ft respectively. Larger errors easily can be introduced, however, through inadequate maintenance and calibration of the gauge. Unless the most careful attention is paid to the maintenance of tide gauges and the reduction of their records, monthly and annual means can only be considered accurate to about 0.01 ft and 0.003 ft respectively (Rossiter 1962).

Mean Low Gulf (MLG) is a second datum that is commonly used along the Gulf of Mexico. This is defined as 0.78 ft below mean sea level.

Datum stability is a major concern. Apparent sea level rose at several locations along the Louisiana and Texas coasts during the years 1959-70. Rates ranged from 0.002 ft/year at Port Isabel, Tex., to a maximum of 0.14 ft/year at South Pass, La. (Swanson and Thurlow 1973). Much of this rate is, presumably, because of subsidence. However, studies along the East Coast of the United States show that sea level trends are parallel to and presumably related to climatological changes (Donn and Shaw 1963). Hicks (1972) has investigated the features of a series of water level records for the U.S. East Coast and the Gulf of Mexico from 1939 to the 1970s. The most prominent features he found were annual variability and apparent secular (long term) trends. He attributes annual variability to changes in meteorological and oceanographic parameters, namely, wind, atmospheric pressure, river discharge, currents, salinity and water temperature. Apparent secular trends could be caused by glacial melt, isostasy, tectonic activity, etc. Although many phenomena induce variations in sea level, not all are equally effective. Locally, one process may dominate all others. Of all the factors governing variations in sea level, errors in geodetic leveling are perhaps the least considered, though they are extremely important. In leveling surveys, errors propagate at least at the one-half power of the distance surveyed (NOAA 1974). The importance of this error has recently been pointed out by Sturges (1974).

The dominant process in controlling water levels, particularly in the lower reaches of the basin, is expected to be the astronomical tides (Appendix B). Henderschott and Munk (1970) offer an excellent review of the theory governing the response of the oceans to the gravitational forcing of the celestial bodies that has been understood for many years. The astronomical tides are generally classified according to their period as diurnal, semidiurnal, and long period. The diurnal tides are dominant in the Gulf of Mexico but influenced by the semidiurnal. Long-period tides that will influence our study region include, among others, fortnightly tides and the 18.6-year tide.

Although the deep-ocean astronomical tides are moderately well understood, the modifications they undergo in shallow water are hardly understood at all. These shallow-water effects on tidal dynamics cause discrepancies in the tides observed at neighboring stations. Therefore, care must be exerted in selecting stations that are truly representative for further analysis (Montgomery 1938).

Meteorological driving, wind and pressure, are probably the next most important processes controlling water levels. In some regions, it is the process that causes the greatest changes. The two meteorological factors which have the greatest effect are atmospheric pressure and wind stress.

Sea level tends to respond atmospheric pressure as an inverse barometer (Patullo et al. 1955) with a theoretical response of 1.01 cm/mb. That is, when atmospheric pressure increases/decreases by 1 mb, sea level drops/rises by 1.01 cm. In reality, there is a finite lag time necessary for the adjustment to take place, and so, some tide records do not show the complete barometric response. Furthermore, wind stress accompanying pressure systems may swamp the effects of the pressure changes. Hamon (1966) suggests that a greater than barometric response may be because moving pressure systems generate continental shelf waves.

In shallow waters such as we are dealing with in the Louisiana coastal area, the effects of wind stress will usually overpower the effects of the accompanying pressure system. When water level changes because of a pressure system, it is independent of depth; when water level changes because of wind stress, it is inversely proportional to depth (Groen and Groves 1963). In our area of interest the most spectacular sea level variations from wind stress are the storm surges accompanying tropical storms and hurricanes (Goudeau and Conner 1968). Lesser winds, though, are also important. Chew (1964) suggests that the annual cycle of local winds causes the annual variations in sea level along the Louisiana coast, a point we will be discussing in a following section. But Sturges (personal communication) suggests rather that these variations are from fluctuations of the wind field over the entire Gulf of Mexico, which cause variations in the mean circulation pattern of the Gulf, and that it is the fluctuation of this circulation that in turn is related to the observed sea level changes at the coast.

Wind systems also drive the surface waves on the ocean. As these waves run into shallow water and break, they may cause "set up," a change in sea level at the coast (Longuet-Higgins 1963).

When a strong atmospheric system crosses an enclosed or semienclosed body of water, seiches may be set in motion. Seiches are oscillations of the water at the natural period of the basin, and they are equivalent to the ringing of an electronic filter when a signal is impulsively applied. Natural periods of a basin can be computed by numerous techniques. For the simplest basins, Merian's formula (Sverdrup et al. 1942) can be applied. Seiches may grow to large amplitudes if the forcing is resonant with the natural period of the basin.

Coastal sea level may be affected by the net addition or deletion of mass or by the replacement of a constant mass of water with water of a different density. In the latter case, the low density water occupies more volume to constitute a given mass and thus sea level stands higher. Precipitation and river runoff both add net water to the coastal zone and, by adding fresh water, tend to lower the average density of the coastal waters. Meade and Emery (1971) estimate that river runoff accounts for 21 percent of the water level variation along the U.S. Gulf Coast. Evaporation tends to remove water from the coastal zone and increase the salinity, consequently increasing the density of the remaining water. Both effects tend to lower water level. On the other hand, though, thermal heating of the water causes expansion and an increase in sea level (Patullo et al. 1955).

Glacial eustasy is a process that causes long-term trends in sea level by the release or storage of water in glaciers. It has been estimated that the trend for the Gulf of Mexico is a rise of 0.18 cm(0.071 in) per year (Meade and Emery 1971), but this number is derived from only 38 years of data, which is probably too short a series to be meaningful. Probably more important to the Louisiana coast is the effect of subsidence because of the consolidation and compaction of recent deltaic sediments. Estimates of subsidence rates have been as high as 0.142 ft per year (Morgan 1973) at some locations. Even if this is excessive or localized, the rates for the Louisiana coast are far greater than estimated rates because of eustatic changes or rise in sea level. There is difficulty in separating the effects of eustasy and subsidence, so the above-mentioned rates should be considered only gross estimates. Furthermore, since the records from which they are estimated are extremely short on any geological time scale, the estimates may be erroneous. For instance, we may be seeing the effects of long-term weather changes instead of subsidence or eustasy.

The tides entering Barataria Bay are diurnal (Appendix B) with a range that varies up to about 3 ft and, on an annual basis, averages about 1.03 ft. Wiseman and others (1974) reported that tidal currents off the Barataria Bay-Caminada Bay complex are characterized by clockwise rotation. Tidal currents near the bottom are weaker than surface or mid-depth currents, and, in addition, tidal currents are strongly affected by local complex density gradients.

A representative tidal excursion (the distance a water particle is displaced during a tidal period solely by tidal currents) for the offshore area is approximately 1.62 nautical miles. This excursion increases to 3.8 nautical miles - 3.4 nautical miles in the region close to Southwest Pass of the Mississippi River. Harmonic analysis of Harper's (1974) data in the nearshore zone indicated strong diurnal components with currents ranging from 0.09 to .192 knot. However, the tidal currents become more significant in Barataria Pass and Caminada Pass. The current for Barataria Pass at maximum ebb was 1.16 knots and for maximum flood was 0.89 knot. The mean current was 0.011 knot. For Caminada Pass he reports two sets of values, one for the outer pass and one for the inner pass. The outer pass is characterized by equal maximum flood and ebb currents while the inner pass is characterized by maximum flood currents of 1.2 knots and maximum ebb currents of 1.7 knots.

Marmer (1948) reported currents for Barataria Pass at maximum flood as being 1.26 knots and maximum ebb as 0.82 knot. At all but one station in the area, ebb currents dominated in both strength and duration. Quatre Bayou Pass was the only pass that exhibited flood domination in strength and duration. Marmer computed a tidal excursion of 7.8 nautical miles in the Barataria Bay region.

Kjerfve (1972, 1973) studied the circulation and salinity distribution in Caminada Bay and investigated the dynamics of the water slope for the same area. He was able to calculate renewal times (time necessary to exchange a specified percentage of the volume of a basin with new water) for the Airplane Lake, Lake Palourde, and Lake Laurier system. His estimates are based on the inclusion and exclusion of wind stress.

Table 1.1. Renewal times in Barataria Basin Management Unit.

Renewal Time	50%	99%
	—diurnal cycles—	
including wind stress	12	80
excluding wind stress	96	640

His study of water slope dynamics indicates the presence of two tidal waves entering Caminada Bay, one from Barataria Pass and one from Caminada Pass. He reported a free oscillation period of 2.2 hours longitudinally and 0.9 hours transversely in Caminada Bay, and a 5.1 hour oscillation for the longitudinal direction of Barataria and Caminada Bay combined. His work emphasized that this estuarine system is quite sensitive to changes in wind direction; northeast winds increase water level, with water levels lagging winds by about 24 hours.

Preliminary investigations into complex wind/water-level relationships in Barataria Bay were carried out by Schneider (unpublished manuscript). She reports winds at Port Sulphur leading water levels at Grand Isle by about 13-15 hours and at Barataria by about 18 hours. Her report of tide levels at Grand Isle leading tide levels at Barataria by 15.5 hours seems erroneous. The lead should be 8.5 hours.

SALINITY

Salinity studies in coastal areas are common because of the variability and distribution of salinity and its effects upon biota and flow regimes. Studies of salinity permit flushing time estimation, yield circulation patterns, and give insight into the effects of meteorological events on water bodies. The conservative nature of salinity makes it an ideal parameter to study in order to characterize mixing in coastal areas.

Salinity can be reported as one of three different but closely related parameters: salinity, chlorinity, or conductance. These are easily interconvertible within certain limits of precision. These parameters are defined in Appendix C.

Meade (1966) showed that salinity was useful in monitoring the effects of winds on estuarine waters. His work in the Connecticut River estuary indicates that isohalines migrate as much as 1-1.5 nautical miles depending on strength and direction of wind.

Gagliano et al. (1970) reported salinity statistics for coastal Louisiana, but without interpreting the data analysis that they obtained from the U.S. Army Corps of Engineers, New Orleans District, and Louisiana Wildlife and Fisheries Commission. They also (1973) described salinity regimes in Louisiana estuaries from available data. Variability of isohaline position is well documented in the Atlas that accompanies that report.

The Louisiana Wildlife and Fisheries Commission has been monitoring salinity in Louisiana coastal waters for a considerable length of time. Barrett (1971) reports that salinities are seasonally variable, fluctuating primarily with seasonal changes in tide, rainfall, river discharge, and evaporation rates. Rainfall was found to be most influential in the upper estuaries. Salt wedges and salinity stratification were found to be absent in most of coastal Louisiana's estuaries.

Eggler et al. (1961) determined that the total salinity of the water in a Terrebonne Parish marsh is not the primary limiting factor in the bionics of the bay. Within the marsh there may be considerable spread in the conductivity versus chlorinity relationship because of variable ionic composition. Average errors for single day estimation of chlorinity from conductance were on the order of 10 to 15 percent.

Ho (1971) studied salinity in John the Fool Bayou water over a limited period during the year and found values varied from 3 ppt in March to 12 ppt in May. The highest salinity occurred during the period April through June. In Airplane Lake and Lake Palourde the opposite appeared to be true; salinity was lowest in May, April, and June, and high during the other months. The range there was 16 ppt to 28 ppt. Salinity fluctuations were attributed to changes in rainfall and direction of freshwater/saltwater interchange.

Ho and Barrett (1975) studied the relationships between salinity and nutrients in Barataria Bay, Caminada Bay, and the offshore waters to delineate the effects of the Mississippi River discharge on Barataria Bay water. Barataria Bay and Caminada Bay stations are characterized by lower nutrient levels than the diluted waters of the offshore stations. The differences between salinities and other chemical constituents indicate that Mississippi River influence on the bays was limited to their lower regions during the study period. Sources of freshwater and associated nutrients introduced into the bays were largely runoff waters from upper marshes via connecting waterways, bayous, and canals.

Chabreck (1970, 1972) studied water salinity and soil salinity, characterizing the entire Louisiana coast according to salinity and vegetation type. Water salinities averaged 18 ppt in the saline vegetative type marsh, 3 ppt in the intermediate vegetative type marsh, and 1 ppt in the fresh vegetative type marsh. The ranges of salinities, however, were not consistent between sections of the same type of marsh. Free soil water (interstitial water) salinity correlated closely with vegetative types in some areas of study. Generally the free soil water is more saline than surface water on the marsh or water in adjacent bayous and lakes.

Joanen (1964) determined that there was a relationship between surface water salinity in a marsh and soil salinity. In all but the saline type marsh, soil salinity was similar to free soil water salinity. In the saline marsh of the Chenier Plain, water salinity was double soil salinity and in the inactive delta salt marsh, water salinities were 70 percent greater than soil salinities.

There is little agreement concerning the effects of salinity on marsh communities. Reed (1947) concluded that salinity was responsible for species distribution in a marsh in North Carolina. His conclusions are not supported by Chapman (1940), Adams (1963), and Lagna (1975). These researchers found no consistent differences in salinities within different plant communities. Salinity has also been reported as having an influence on the height of Spartina alterniflora (Taylor 1938). There have been no studies on duration and frequency of inundation by salinity pulses on marsh productivity.

Gosselink et al. (1975) studied stress physiology on marsh vegetation and found that high salinity is a stress factor for several reasons: it has a pronounced osmotic effect, and it alters absorption of nutrients and minerals, and the high concentration of one ionic species may cause differential absorption of another species. Marsh vegetation tolerates salinity rather than requires it; thus, they may not be true halophytes but facultative halophytes.

To date there has been no extensive work in Louisiana's estuaries that delineates the relationship between water level regimes and salinity regimes.

Data Collection and Assimilation

Data accumulation was broken down into four basic tasks:

1) Location of data-acquiring organizations via literature search.
2) Survey of monitoring station locations.
3) Investigations into record duration sampling frequency and data format.
4) Analysis of data reliability.

Physical parameters that were investigated were water level, salinity, temperature, wind speed and direction, barometric pressure, precipitation, water surplus, and climatological categorization.

Several other parameters were considered, but they were deemed unsuitable for the analysis being performed or were not first-order contributors to the functioning processes of the basin. These parameters include dissolved oxygen, organic carbon, and organic nitrogen content.

Organizations that served as sources of physical data for this study are: The Corps of Engineers (COE), Louisiana Wildlife and Fisheries Commission (LWFC), National Oceanographic and Atmospheric Administration (NOAA), United States Coast and Geodetic Survey (USC&GS), Freeport Sulfur Corp., Shell Development Corp., Louisiana State University Office of Sea Grant Development (LSU-SG), and Louisiana Offshore Oil Port, (LOOP), Inc.

Long-term synoptic records were, in general, sought and the 1968-74 period was particularly appropriate.

Sampling consistency of the data was a problem. The records obtained ranged from continuous strip chart records to arbitrary weekly or monthly samples. Reported averages had to be researched to the original records. Ideally, a sampling period of six hours is necessary to resolve semidiurnal (twelve-hour) events. Most of the data records used in water level analysis were continuous strip chart records, thus this sampling interval was attainable. In cases where only daily or weekly data were available all other data were manipulated at that time increment.

A third consideration was data format. Much of the data required reorganization prior to use. Some data were received as computer printouts, magnetic tapes (digital), strip chart records, punched paper tapes, and electrostatic recordings; some were in less familiar forms. All data were initially cataloged and some were reduced to three-hourly samples. In all cases, reduced data were punched onto IBM cards or stored on magnetic tape (Appendix A).

All data indicated are available through the Coastal Information Program, Louisiana State University Center for Wetland Resources. The format is that which is listed. Cited sources may have more data than that listed in Table A.1, Appendix A. This table lists only data that were evaluated and used during this study and are available. A computer filing system is now being established to allow rapid scanning and access to the entire data base established during the project.

STATION LOCATIONS

The locations of the water level stations in Barataria Bay are plotted on a chart (Fig. 1.1) and listed with the surrounding environment in Table 1.2. The complex interaction of stream flow and tidal influx is readily apparent. At the head of this closed basin, the Bayou Chevreuil station water levels are dominated by fresh water fluctuations (no tidal influence), while the water level at the foot of the basin, Bayou Rigaud, is dominated by influxes from the Gulf of Mexico. These two stations represent end members in a spectrum of forcing regimes from predominantly stream-influenced conditions to predominantly tidal influences.

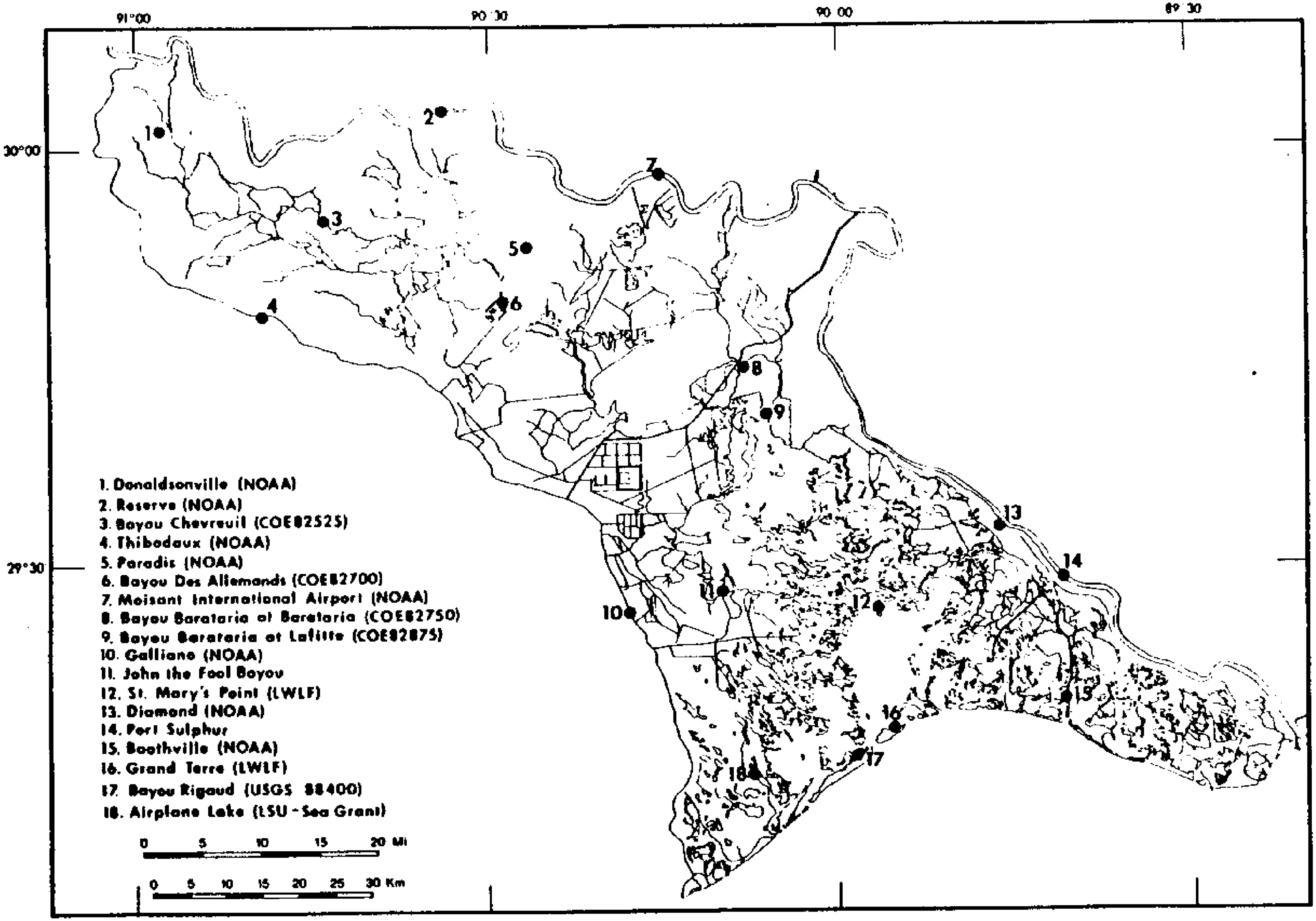

Fig. 1.1. Location of data stations in Barataria Bay Management Unit.

Table 1.2. Identification of Water Level Data Stations in Barataria Basin Management Unit.

Station Name	Location	Surrounding Environment
Humble Oil "A"	29° 10' N 89° 54' W	Gulf of Mexico
Bayou Rigaud	29° 15' 5" N 89° 58' 0" W	Saline Marsh
Grand Terre	29° 16' 28" N 89° 56' 32" W	Saline Marsh
Airplane Lake	29° 13' 20" N 90° 06' 45" W	Saline Marsh
St. Mary's Point	29° 25' 30" N 89° 56' 19" W	Saline Marsh
John the Fool Bayou	29° 28' 26" N 90° 09' 14" W	Saline/Intermediate Marsh
Bayou Barataria at Lafitte	29° 40' 06" N 90° 06' 36" W	Intermediate Marsh
Bayou Barataria at Barataria	29° 44' 29" N 90° 07' 56" W	Intermediate/Fresh Marsh
Bayou Des Allemands	29° 49' 26" N 90° 28' 56" W	Fresh Marsh
Bayou Chevreuil	29° 54' 42" N 90° 43' 48" W	Forest Swamp

Descriptive Hydrological Aspects

Tides

Tidal forcing is a primary flushing mechanism in estuaries, and the study of tidal forcing is essential to understanding the characteristics of tides in the Barataria Basin Management Unit. This section describes tides in the study area. Technical terms are defined in Appendix B.

LONG-TERM TIDE CHANGES

The range of both diurnal and semidiurnal tides exhibits gradual change over a period of 18.6 years. This long-term variability can be attributed to the change in the inclination of the moon's orbit relative to the earth's equator. At maximum inclination there is maximum diurnal tide range and minimum semidiurnal tide range. Conversely, when the inclination is at a minimum, diurnal tide range is at a minimum and semidiurnal tide range is at a maximum. The percentage of change in the yearly range between the two extremes, however, is not equal; diurnal tides show a greater percentage change in yearly range (Marmer 1954).

Twenty years of NOAA data from Bayou Rigaud were analyzed to determine the mean annual tide range from 1951 to 1971 (Fig. 1.2). The minimum mean range of 0.88 ft occurred in 1960 while the maximum mean range of 1.21 ft occurred in 1969. This 0.33 ft change represents a 31.4 percent overall deviation. Marmer (1954) reported a 22 percent deviation for Pensacola, Fla.; however, the harmonic constituent ratio (see Appendix A) for Pensacola (9.56) is less than the harmonic constituent ratio for Bayou Rigaud (10.67). Thus the 9.4 percent difference may be attributable to the difference in this ratio. The larger the ratio, the greater the diurnal component's influence. Since the 18.6-year cycle has a greater effect on the range of the diurnal tide, Bayou Rigaud should experience a greater percentage of change in range than Pensacola.

This trend is not as apparent at other stations further inland from Bayou Rigaud. There is not as much data available, and the astronomical tide is not as important at these inland stations.

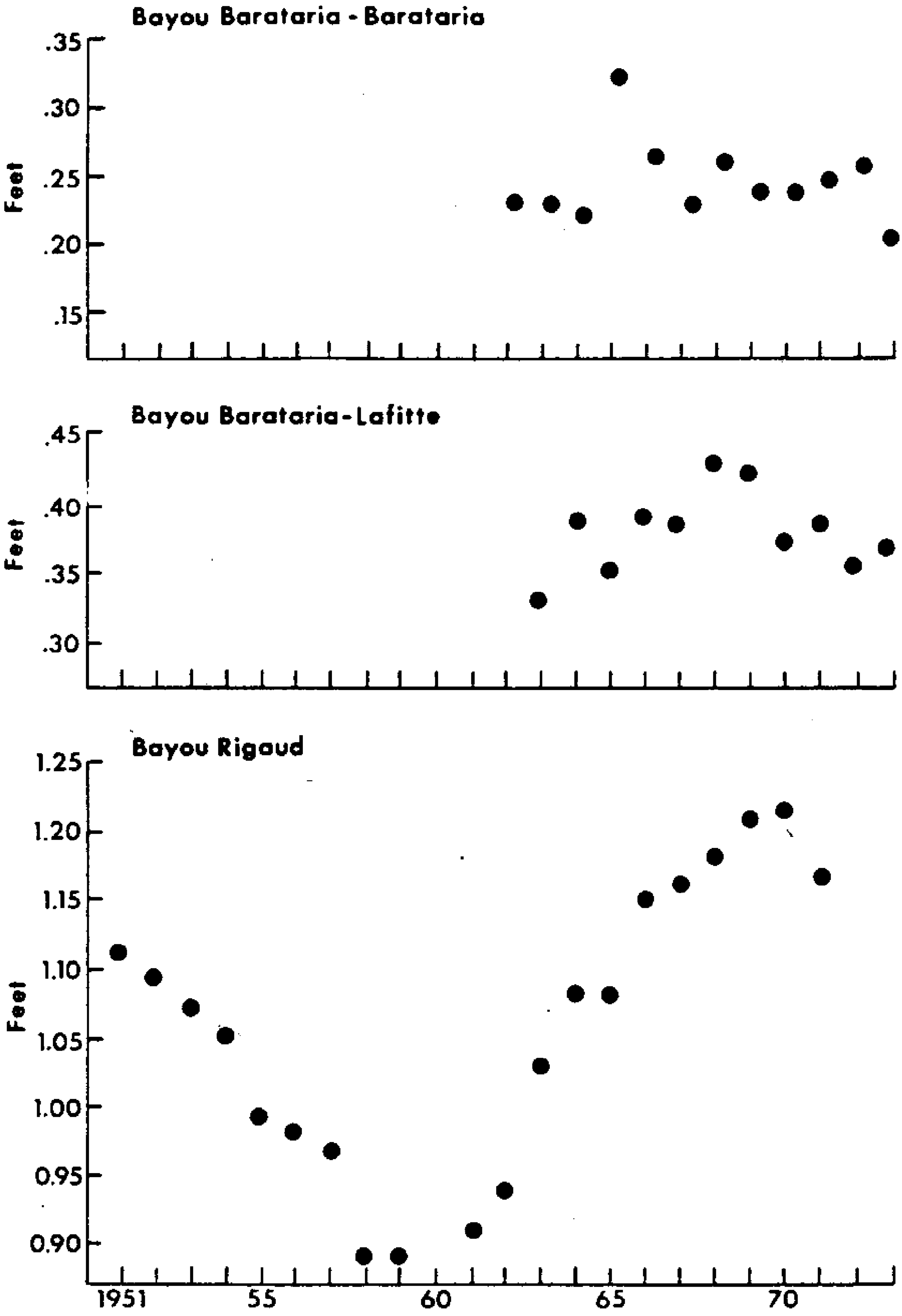

Fig. 1.2. Variation in yearly range of tide in Barataria Bay Management Unit.

Table 1.3. Graphic moments of tide range histograms in Barataria Basin Management Unit.

STATION	SKEWNESS	KURTOSIS
Bayou Rigaud	-.133 slightly low skewed	.81 platykurtic
Lafitte	.166 slightly high skewed	1.024 mesokurtic

Range histograms were constructed for the tide-influenced stations of Bayou Rigaud and Bayou Barataria at Lafitte. Some tides can be observed at Bayou Barataria at Barataria, but the range is generally small and in many cases indistinguishable as discrete tidal cycles.

The tide range was determined by taking the difference between a tide crest (the maximum elevation of a rising tide) and the subsequent trough (the minimum elevation of a falling tide). This difference is the tide range for that day (since tides are diurnal in Barataria Bay), and the process was repeated for the year (Figure 1.3).

These histograms were constructed with a class interval of 0.1 ft. The designation of each class is located at the lower end of the class increment. Graphic moments, skewness (a measure of the asymmetry of the histogram), and kurtosis (a measure of the peakedness of the histogram) of the tide-range histograms were also computed for these two stations. They are presented in Table 1.3. The tide-range histogram from data taken at Bayou Rigaud is very flattened, perhaps even bimodal in character, and the histogram is slightly skewed toward the lower values. The tide-range histogram of Bayou Barataria at Lafitte is mesokurtic (not peaked, not flattened) and slightly skewed to the higher values.

These differences in the graphic moments emphasize the differences in the tide regime at the two stations. Bayou Rigaud admits a tide that has been damped and deformed by a shallow, broad continental shelf. Bayou Barataria admits a tide damped and deformed by the same features, plus an additional thirty miles of shallow energy-adsorptive shoal water. In general, a tidal wave with an amplitude of less than 0.5 ft at Bayou Rigaud would be nearly

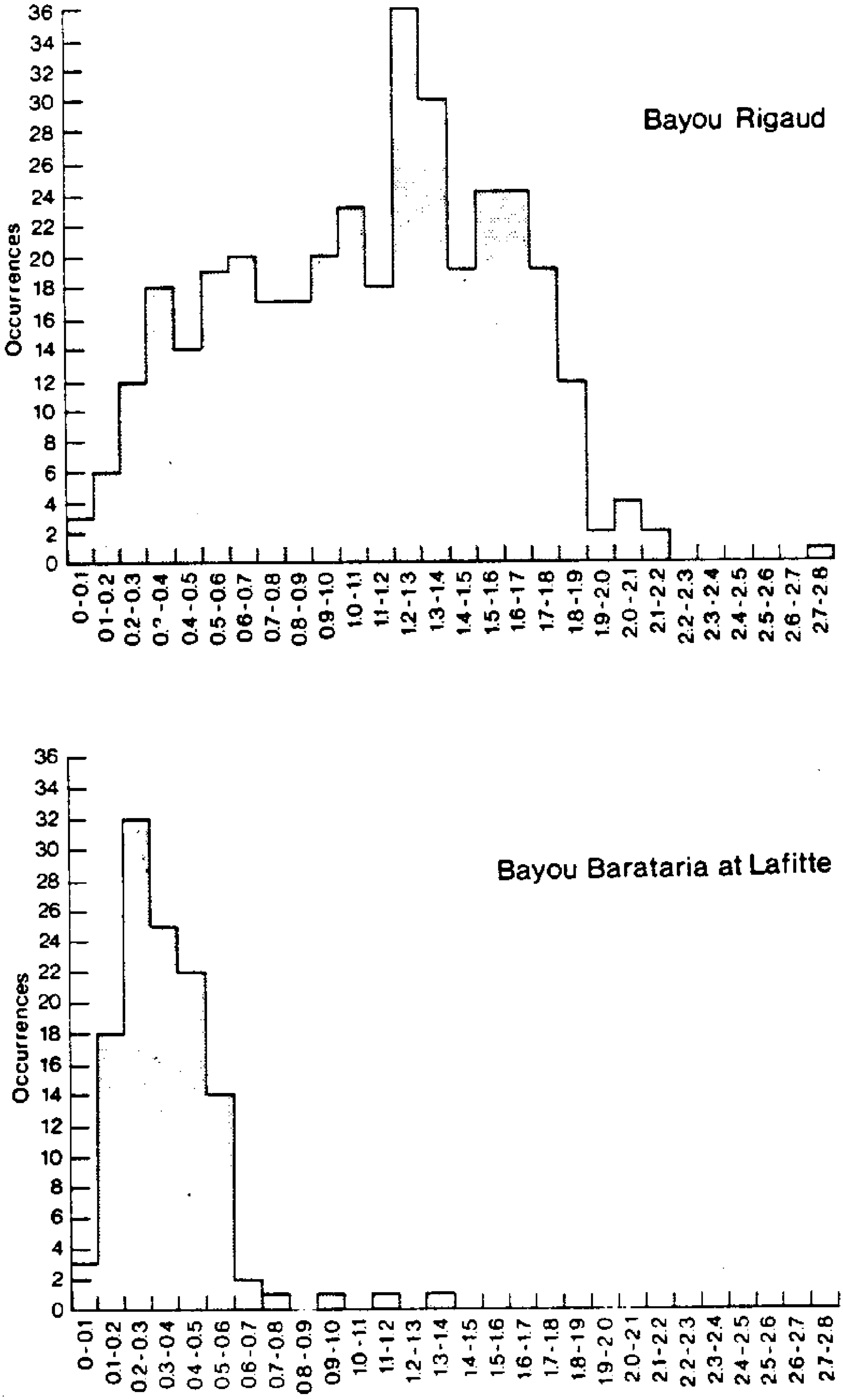

Fig. 1.3. Histograms of tide range at Bayou Rigaud and Bayou Barataria at Lafitte, 1971.

damped out by the time it reached Bayou Barataria at Lafitte and would be completely damped out before it arrived at Bayou Barataria at Barataria.

TIDE RANGE VARIATIONS

The range histogram of Figure 1.3 shows a great deal of variation in tide range for Bayou Rigaud despite the NOAA (1974) mean tide range report of 1.0 ft. The range at Bayou Rigaud is caused by tidal forcing, and varies at the normal tidal periods. A 25-year-average of the mean monthly range at Bayou Rigaud (1948-71) is plotted in Figure 1.4. The annual mean is 1.05 ft, and the monthly variation about that mean is shown. The plot exhibits semiannual periodicity. Minimums occur from March to April and from September to October, which coincide with the spring and autumn equinoxes. The maximums appear in June and December to coincide with summer and winter solstices. This variation in the range of the diurnal tide is a response to the annual variation in the declination of the sun. It should be noted that during the spring and autumn minimums, the mean <u>range</u> of the tide at Bayou Rigaud was 0.99 ft and 0.95 ft respectively. Substantially higher ranges during the summer and winter maximums were 1.14 ft and 1.15 ft, respectively. Although the 25-year mean monthly range was never below 0.95 ft, this does not imply that the range for any given month was never below this value. These changes in range have an effect on the hydrodynamic characteristics of this area. Ten-year mean monthly tide ranges were computed for Bayou Barataria at Lafitte and Bayou Barataria at Barataria (Fig. 1.4). The mean monthly variation in tide range at these two inland stations does not parallel mean monthly tide range at Bayou Rigaud. In March and April when tide range at Bayou Rigaud is at a minimum, the tide range at the two inland stations is at a maximum. In June, when the tide range at Bayou Rigaud is at a maximum, the tide range of the two inland stations show a weak maximum. In general the tide range at the inland stations parallels tide range at Bayou Rigaud for the rest of the annual cycle.

The primary maximum of the two inland stations represents the effect of the tide entering Barataria Bay during stands of relatively high water. The tide is less attenuated during this time. In June, although the tide range is high, absolute water levels are low resulting in greater attenuation of the tide range at the inland stations. Thus the

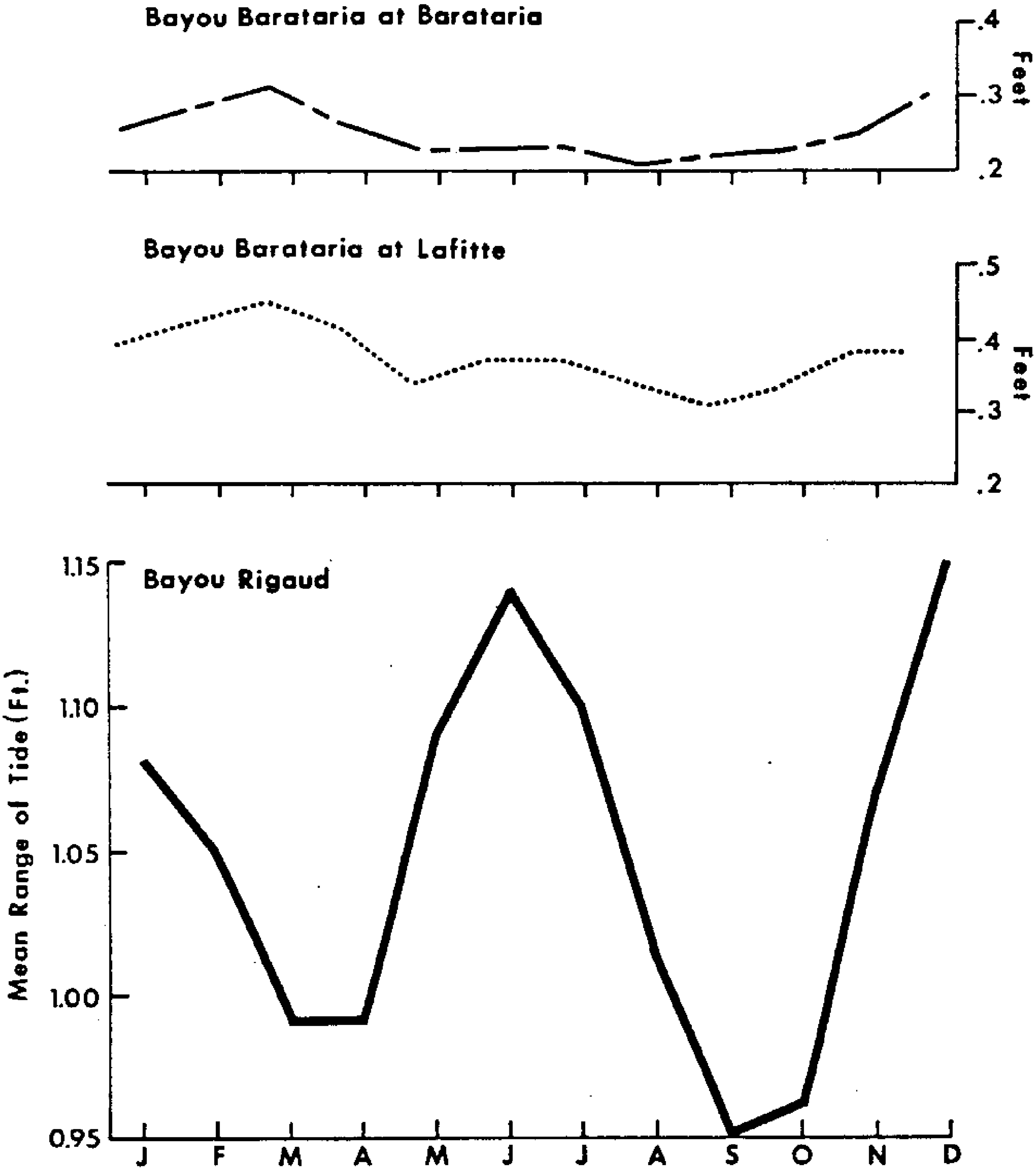

Fig. 1.4. Mean monthly tide range at stations in Barataria Bay Management Unit.

range at the inland stations is less than the range during the spring months. In September, tide range again is at a minimum, but this is the time of high absolute water levels. This tide range attenuation is about the same as during spring. The tide range at Bayou Rigaud at this time is at its lowest point, about 0.04 ft below the spring minimum. The tide range at Bayou Barataria has a corresponding decrease relative to its spring value. Bayou Barataria at Barataria, a station of low tidal energy, is characterized by a 0.03 ft change in tide range.

Both times of high-tide range at Bayou Rigaud coincide with both times of extremely low water levels. Thus despite a large tide range, there is greater attenuation because of the shallow water, which causes energy losses to friction.

The range of the tide also varies on a two-week cycle related to the declination of the moon. When the moon is over the Tropic of Cancer or Capricorn the largest tide ranges result. When the moon is over the equator, tide range is at a minimum. This tidal phenomenon is relatively well understood. The fluctuations of sea level may be considered as a sum of sinusoidal fluctuations with different periods, phases, and amplitudes (see Appendix B). The dominant tidal components in the region immediately west of the Mississippi River delta are the K_1 and O_1 with the M_2 and possibly the S_2 components being of secondary importance. The two diurnal components arise from the variation in declination of the moon as it moves on its orbit. When these two components constructively interfere, tropic tides occur with amplitudes of greater than 1 ft. When they destructively interfere, equatorial tides occur with amplitudes on the order of 3 in or less. During equatorial tides, the influence of the M_2 component is most pronounced (Wiseman et al. 1974).

SPATIAL VARIATIONS IN TIDE RANGE

To investigate the relationship between tide ranges at consecutive stations, the tide range at Bayou Barataria at Lafitte was plotted as a function of range at Bayou Rigaud (Fig. 1.5). Most of the points represent multiple occurrences. A strong positive correlation between the ranges at the two stations is indicated. There is a larger spread in range at Bayou Rigaud than at Bayou Barataria at Lafitte. A similar figure (Fig. 1.6) was constructed for Bayou Barataria at Barataria and Bayou Barataria at Lafitte. Data shows that the range at Bayou Barataria at Lafitte are spread more

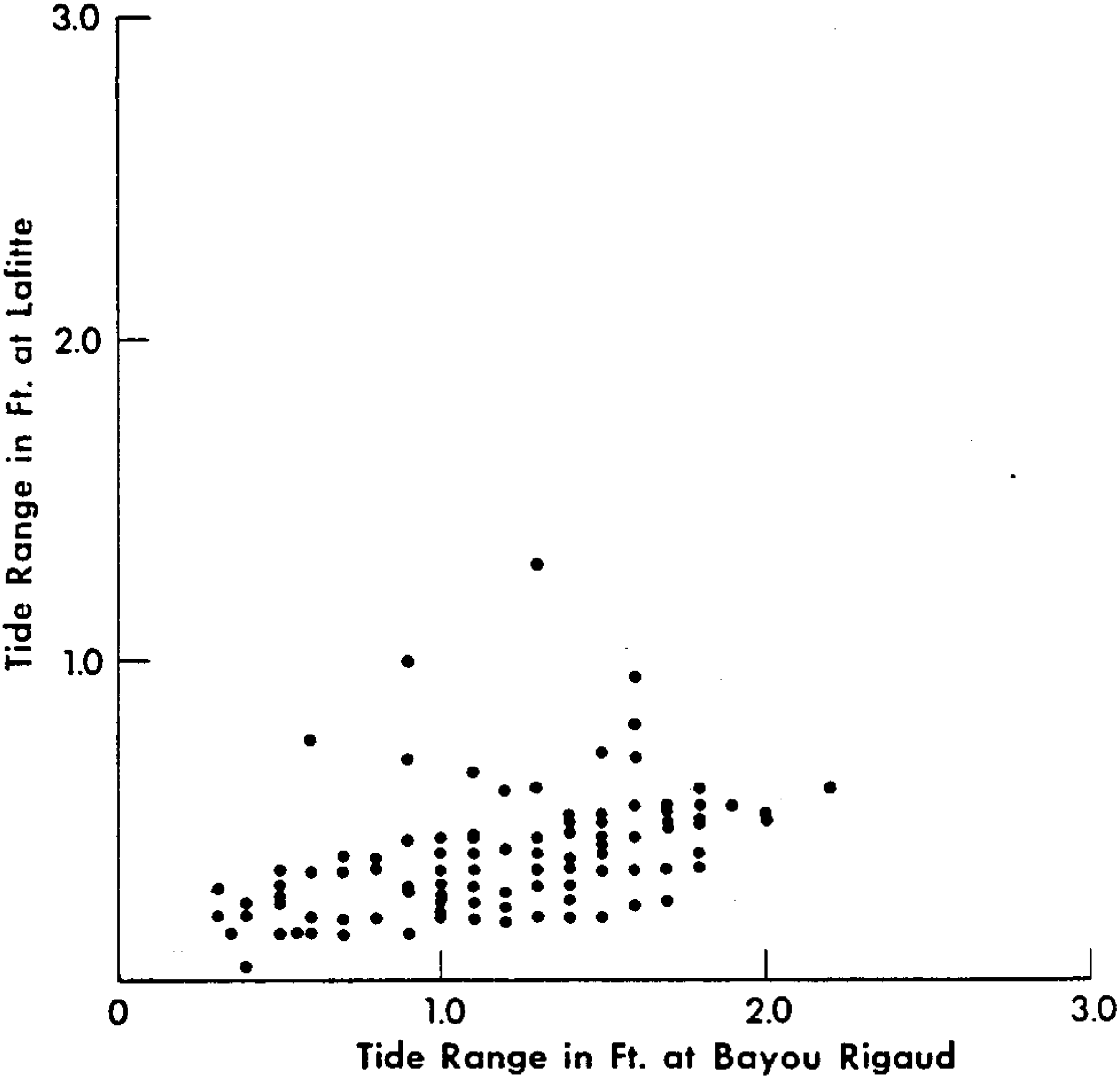

Fig. 1.5. Tide range at Bayou Barataria at Lafitte as a function of tide range at Bayou Rigaud, 1971.

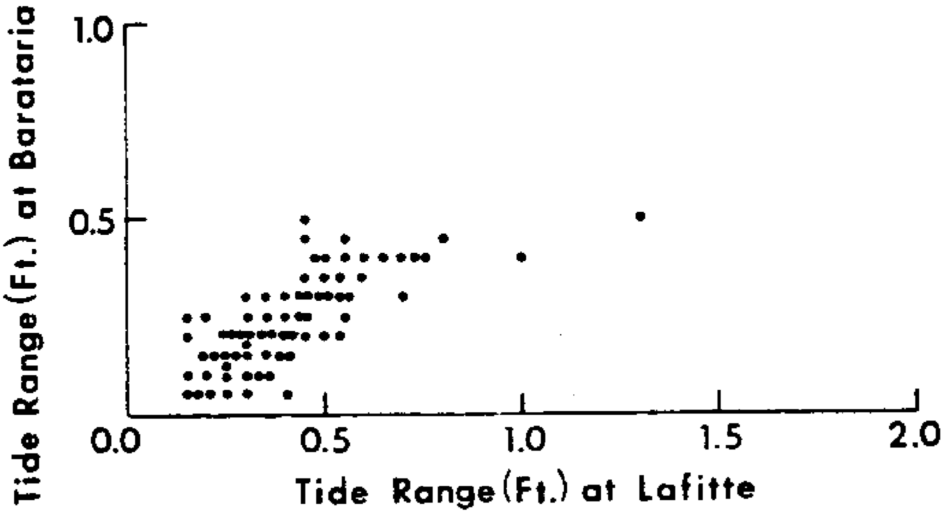

Fig. 1.6. Tide range at Bayou Barataria at Barataria as a function of tide range at Bayou Barataria at Lafitte, 1971.

than at Bayou Barataria at Barataria. This was expected since the Lafitte station lies more seaward than the Barataria station.

In general, when tide range at Bayou Rigaud is high, inland stations would also register higher ranges. This tidal forcing is the major influence at the Gulf end of the basin. As the distance increases inland it becomes less important. There is an obvious diminishing of mean range as one moves from Bayou Rigaud towards Bayou Barataria at Barataria. Inland of Bayou Barataria at Barataria tidal influence is nearly zero. Figure 1.7 exhibits a ysnoptic picture of tidal influence within Barataria Basin, showing that tidal influence diminished as distance inland increases and that there is no organized tide at either Bayou des Allemands or Bayou Chevreuil. A co-range chart was constructed to facilitate showing this attenuation (Fig. 1.8). Co-range lines join locations of equal range. The co-range lines were constructed from tide data for 1971 from the stations in Barataria Basin. Two assumptions were made: (1) there is one tidal wave entering Barataria Bay through Barataria Pass; (2) there is a linear attenuation of range between consecutive stations. Neither of these assumptions is completely valid, however, this will not affect general trends. It should be noted that these data are means for 1971 only and are intended to show general trends rather than absolute values. They should be used with the full understanding of the assumptions.

These data indicate that a progressive tide enters Barataria Bay through Barataria Pass (In reality a progressive tide enters at different times through each of the other passes, but evaluation of the influence of each of these is beyond the scope of this study.). As distance from the Gulf increases in the up basin direction, the tide range is attenuated and generally cannot be seen at Bayou des Allemands.

Attenuation coefficients were computed for mean tide ranges between consecutive stations in Barataria Bay (Table 1.4). In addition attenuation coefficients were related back to Bayou Rigaud (Table 1.4).

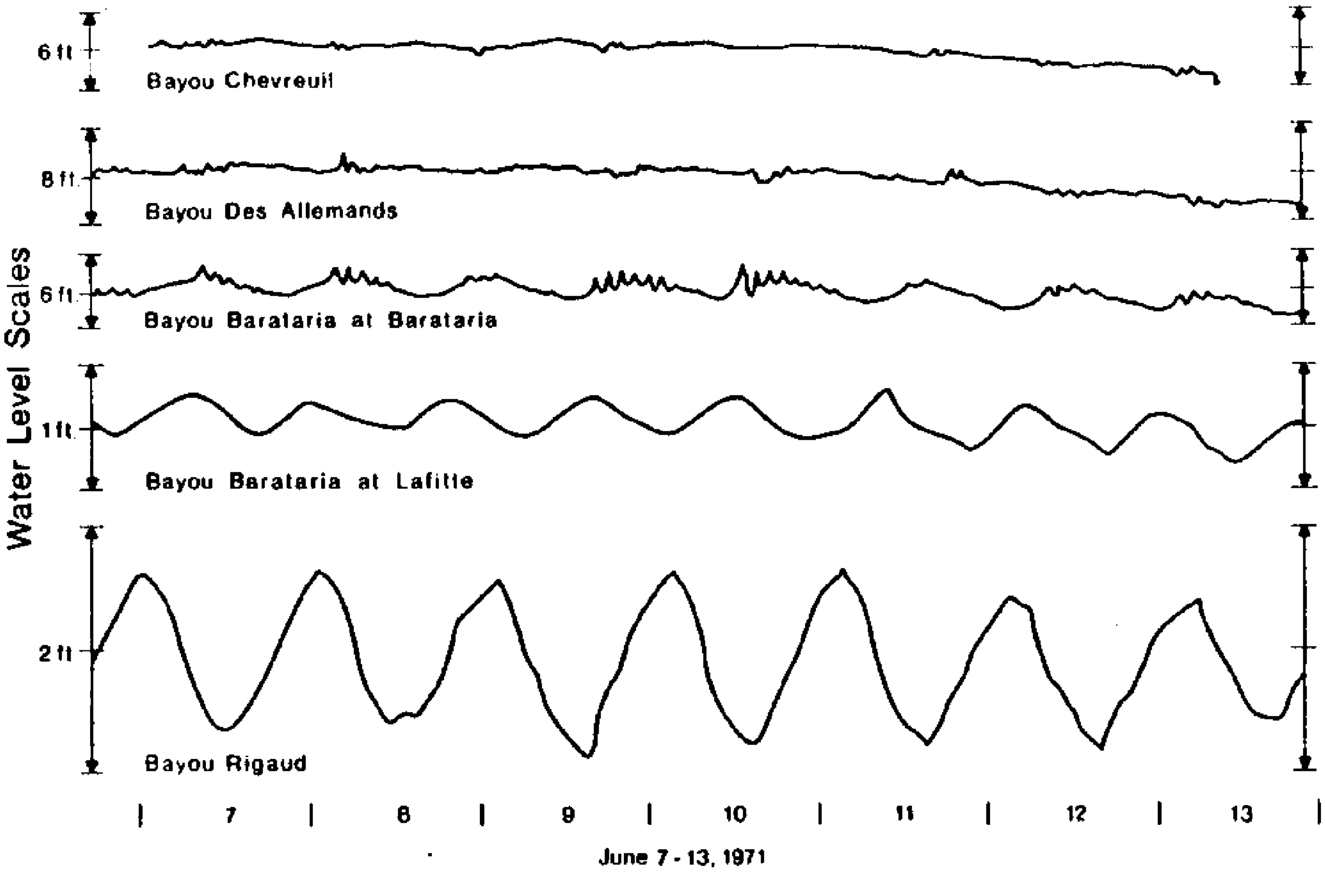

Fig. 1.7. Synoptic water levels and tides for five Barataria Bay Management Unit water level stations, 7 June 1971 to 13 June 1971.

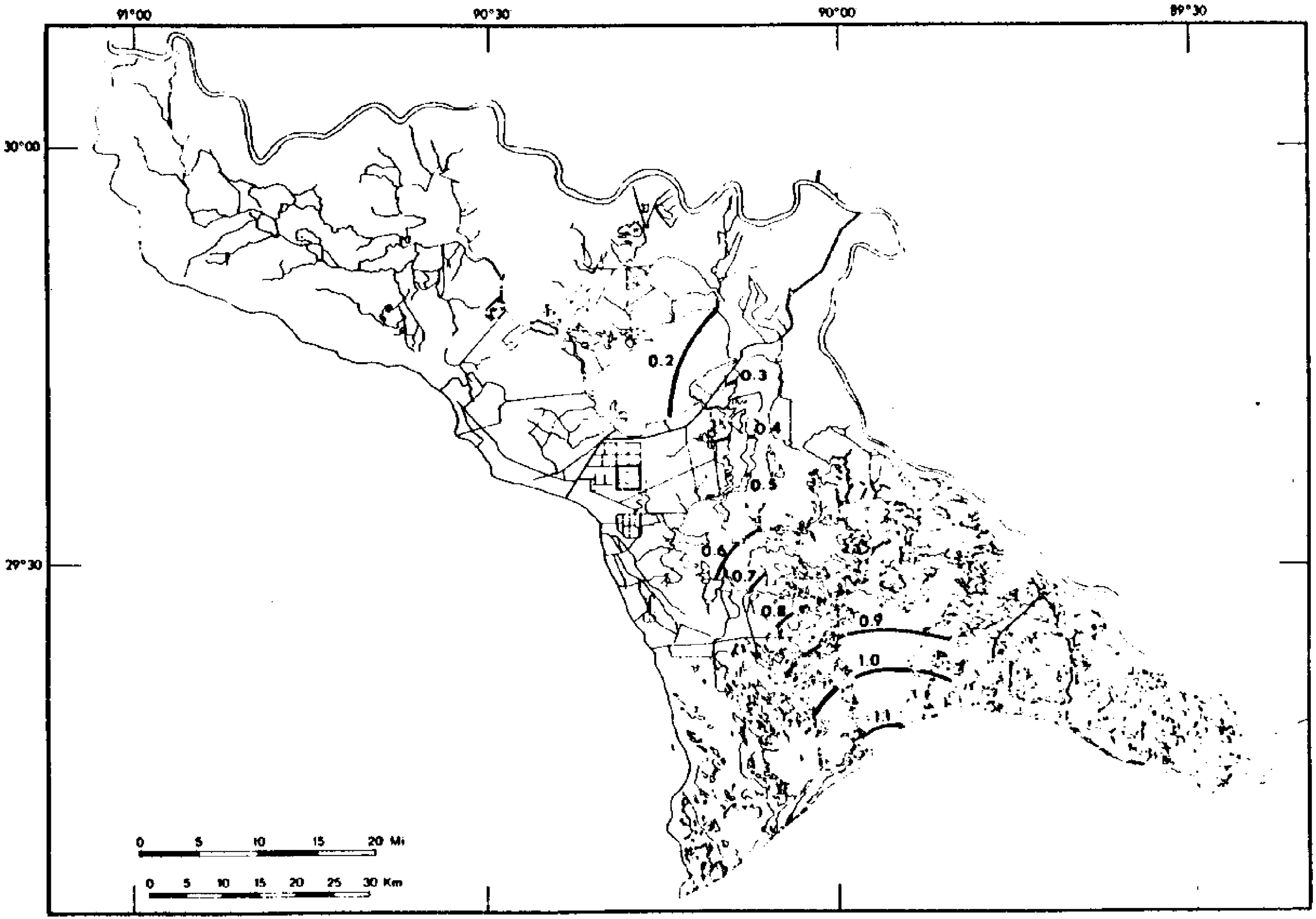

Fig. 1.8. Co-range lines for Barataria Bay Management Unit, 1971.

The high attenuation of the tidal range is indicative of the energy absorbing properties of the shallow marsh-bay environment. This attenuation also is indicative of the poor flushing characteristics of the tide in the upper reaches of Barataria Bay where the total water level change from tide action is rarely greater than 0.5 ft and is more likely to be between 0.2 ft and 0.3 ft under normal conditions. In times of storms meteorological tides can amplify these ranges.

TIDAL LAG TIME

The progression of the tide investigated using tidal lags between consecutive stations. The time of arrival at each station was determined from the original strip chart. This could not be done in all cases because, at times, water level fluctuations from other factors mased the bulge created by the tide (Table 1.5).

From these were computed the mean observed lag time between stations as well as the mean observed lag time between Bayou Rigaud and each station within the basin.

A visual display of the behavior of the tidal influences as well as a convenient way of comparing the actual records with predicted tidal influences was needed. To accomplish this co-tide charts were constructed. Co-tide lines connect points where high tide occurs simultaneously. Two plots of co-tide lines were constructed, one from predicted times of high water at the coast and the long wave phase velocity, and the other from actual mean lag times.

Table 1.4. Attenuation Coefficients of Tide Range in Barataria Basin Management Unit.

Station Name	Mean Tide Range (feet)	Attenuation* %	Total Attenuation** %
Bayou Rigaud	1.17	0.0	0.0
Bayou Barataria at Lafitte	0.38	67.5	67.5
Bayou Barataria at Barataria	0.23	39.5	80.4

*Re: previous station
**Re: Bayou Rigaud

Table 1.5. Lag Times of Tides in the Barataria Basin Management Unit.

Station Name	No. Data Points	Lag Time* (hrs)	Lag Time** (hrs)
Bayou Rigaud	---	0.0	0.0
Bayou Barataria at Lafitte	136	6.06	6.06
Bayou Barataria at Barataria	274	2.74	8.8

*Re: previous station
**Re: Bayou Rigaud

The predicted co-tide line chart (Fig. 1.9) was prepared as follows: The speed of the tidal wave was computed from the standard shallow water wave propagation equation

$$C = \sqrt{gh} \qquad (1)$$

where

C = speed of the shallow water wave form
g = gravity
h = water depth

g and h being readily available; T was computed then,

$$C \times d = T \qquad (2)$$

where

d = distance and
T = lag time.

This is considered a valid way to determine how long it would take a tide to progress up a basin in the absence of friction.

Figure 1.10 shows actual co-tide lines starting at Bayou Rigaud as the (0) reference and progressing up the basin. Observed co-tide lines (Fig. 1.11) are plotted at one hour intervals while the predicted co-tide lines are plotted at half hour increments. Predicted values only poorly describe the observations. This discrepancy between theory and reality emphasizes that Barataria Basin does not meet all the idealized conditions of the theoretical shallow water wave equation, and that other mechanisms are

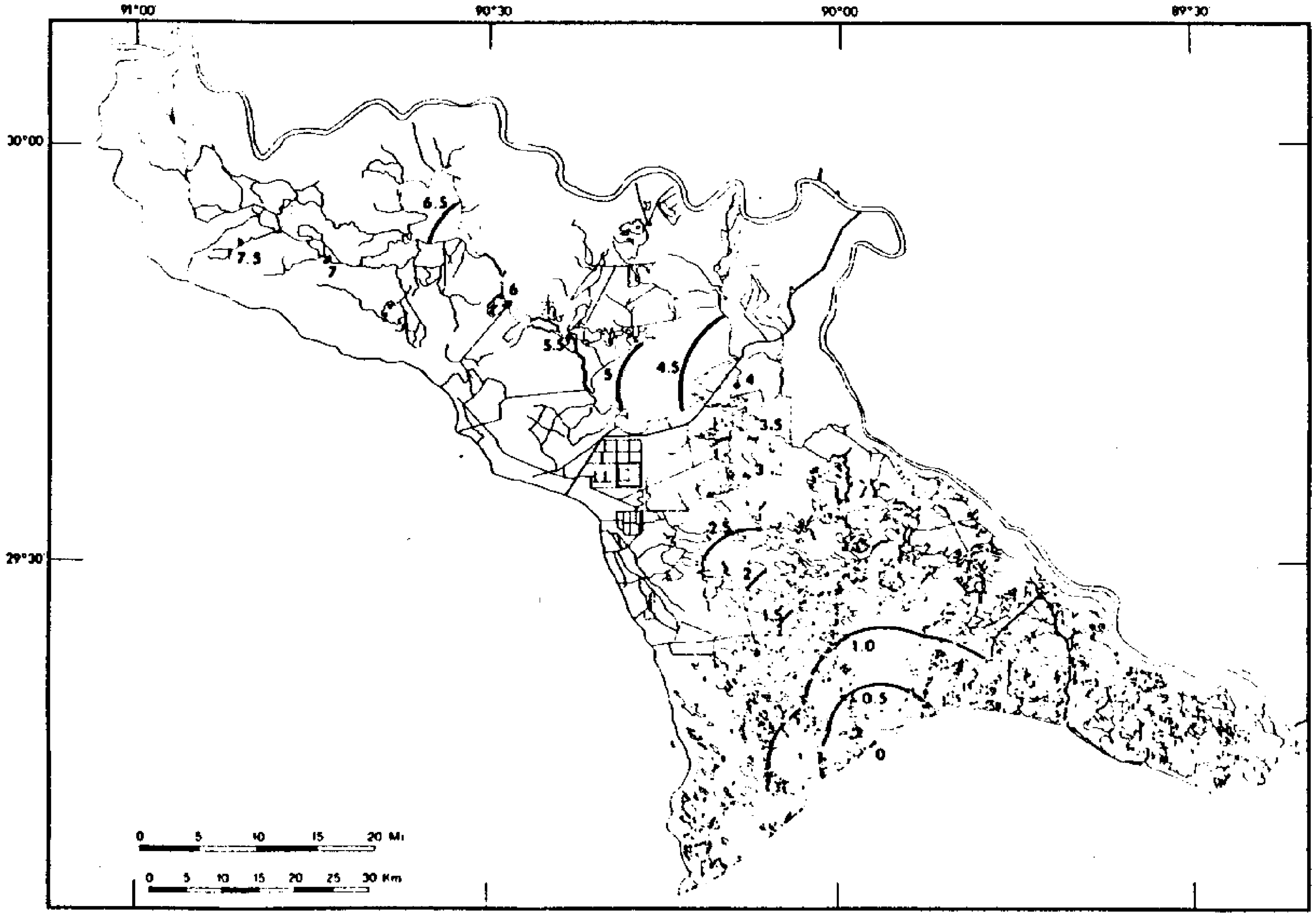

Fig. 1.9. Predicted co-tide chart for Barataria Bay Management Unit.

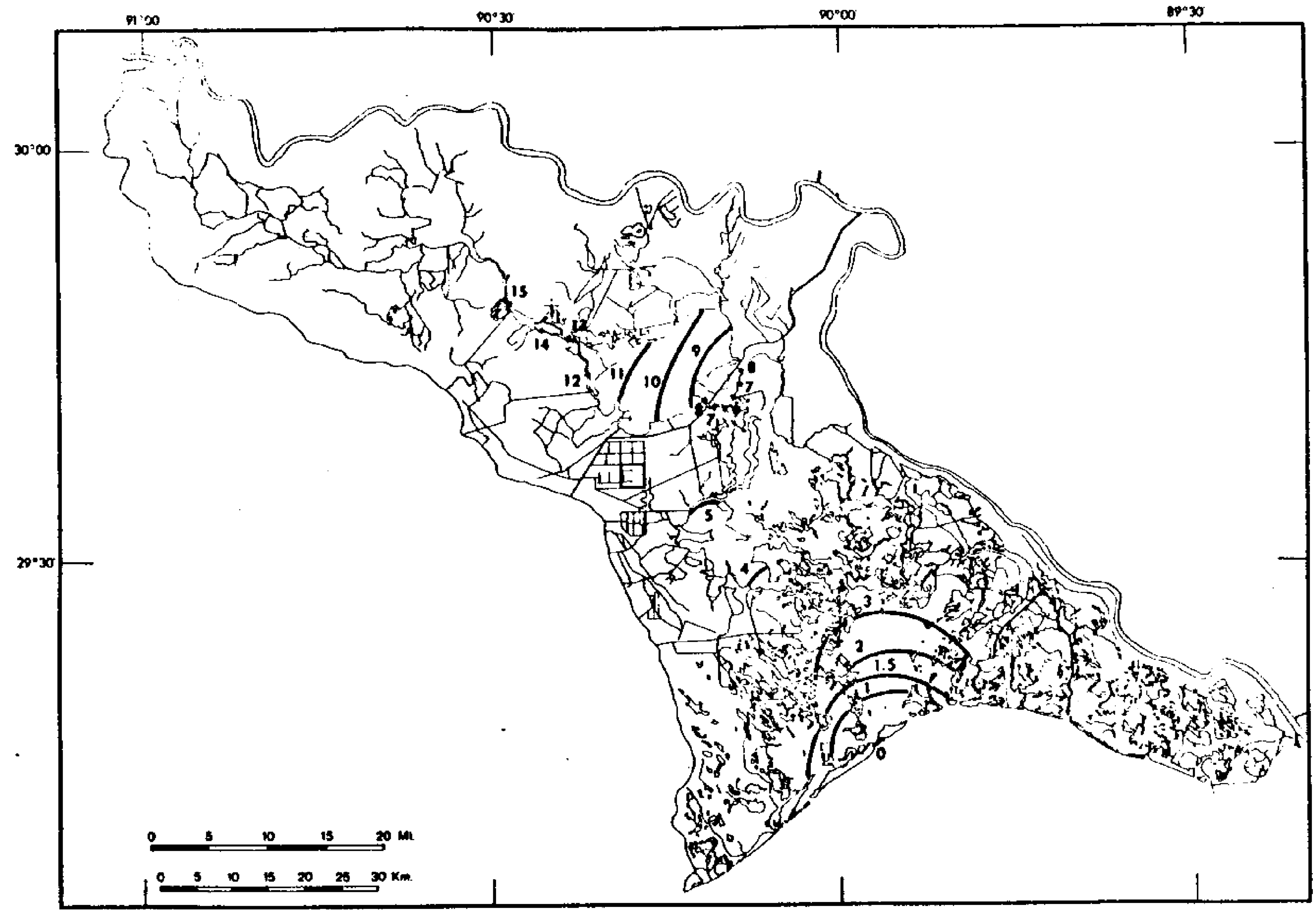

Fig. 1.10. Observed co-tide chart for Barataria Bay Management Unit.

influencing the physics of the basin. The most important factor that is not accounted for is the energy absorption of the marsh environment. The interactions with shallow waters, fine-grained sediments, and irregular marsh islands slows the tide down to approximately one-third of its normal speed. Energy dissipation robs the tide of its flushing powers and reduces it to a gentle small-scale oscillation.

In the upper reaches of Barataria Bay there is a gentle diurnal oscillation that is not caused by tidal forcing from the Gulf of Mexico. Although it is not well studied, it appears to be a sea breeze driven oscillation. At Des Allemands this change amounts to about 0.14 ft and at Bayou Chevreuil during the summer months this change is about 0.05 ft (Butler 1975).

WATER LEVELS

Isolating the water exchange mechanisms is of primary importance to an understanding of the functioning of the study area. One mechanism for forcing water motion in an estuary is through barotropic pressure gradients, i.e., the stream profile from the head of the basin and the slope of the sea surface at the seaward end of the basin. Water level datums based on COE published data (1975) and USC&GS unpublished data were used for correcting data to MSL at Bayou Rigaud, Bayou Barataria at Lafitte, Bayou Barataria at Barataria, Bayou Des Allemands, and Bayou Chevreuil gaging stations and also to determine these slopes. Annual mean water levels were obtained by two different methods. The first method was the averaging of three hourly readings at all stations in Barataria Bay for the calendar year 1971. Another estimate was obtained taking means of published daily (0800) readings for the entire year for each station (COE 1965, 1968, 1969, 1970, 1971, 1972, 1973). The two data sets for 1971 were compared using a Student-t statistical test commonly used to detect differences in population means. The F value was low, indicating that the two methods of averaging tend to produce the same result. The absolute difference between the two sets of means was 0.01 ft, which was an order of magnitude less than the resolution of the three hourly readings. Means derived from the 0800 readings were used in the sea surface slope computations. The difference in mean water level was obtained between each two consecutive stations progressing from the head of the basin. The distance between stations, using stream length, was measured, and the water slope between the stations was computed. Values computed for 1971 are listed in Table 1.6.

Table 1.6. Barataria Bay, Surface Water Slope, 1971.

Interval	Difference in MWL (ft)	Shortest Water Path (miles)	Slope (ft/mi)
Bayou Stations			
Chevreuil to Des Allemands	+0.19	19.0	+0.010
Des Allemands to Barataria at Barataria	-0.13	25.5	-0.005
Barataria at Barataria to Barataria at Lafitte	-0.05	6.5	-0.008
Barataria at Lafitte to Rigaud	-0.35	21.0	-0.011

Difficulty in interpreting these individual slopes was due to inconsistency in slope direction. From Des Allemands the slope is negative in both the seaward direction and landward direction. Because this seems to be physically unrealistic, a best fit linear regression was performed on each set of yearly means. They are presented in Table 1.7.

Table 1.7. Surface Water Slope, Barataria Basin, 1965-72.

Year	slope ft/mile	r^2	Confidence Level
1965	.0062	.58	.88
1968	.0066	.59	.88
1969	.0054	.57	.87
1970	.0039	.38	.74
1971	.0033	.31	.66
1972	.0037	.82	.97

These best fit slopes were obtained for the years 1965 and 1968 inclusive through 1972. These are plotted in Figure 1.11 to show that there is a similarity of water slope among the years, and that the slope is not a function of absolute water level. The slopes themselves are very low and a test was performed to verify that they are significantly different from zero slope. In spite of the fact that the r^2 values were low, these slopes are significant at the listed confidence intervals. These very low slopes indicate that stream action is not dominant in Barataria Basin. Stream flow in this basin is generated by water surpluses, since there is no other source for headwaters. These surpluses, in turn, are generated by excess precipitation. It has been established that there are modest currents from Bayou Chevreuil into Lac Des Allemands of about 0.27 knot much of the year, but that in midsummer during periods of low water these currents become oscillatory with a diurnal period (Butler 1975). There seems to be a discrepancy between actual water slope and computed water slopes. But Barataria Bay is a dynamic area: sediments are unstable and subject to varying degrees of subsidence. Survey work in this area is difficult because of high water content and subsequent instability of frequently inundated sediments. And so the COE estimate of survey leveling precision of ±0.25 ft is reasonable. In view of the above, it seems impossible at present to determine the importance of flow caused by a fresh water pressure head.

Figure 1.12 was constructed to demonstrate how this information could be displayed if the datums were reliable. This figure, however, should not be used for any other purpose.

Three water level statistics were used to help describe the study area: monthly means for the 1968-73 period, histograms of water levels, and associated moments. Tidal statistics are available only from stations showing considerable tidal influence. Histograms of water level frequency and tide range frequency were computed for the year 1971. Where appropriate, values were computed relative to mean sea level using COE published correction factors.

Monthly mean water levels were computed to show seasonal trends in water height within the Barataria Management Unit. These means were computed by two methods: (1) by averaging three-hourly readings during the month; (2) by averaging daily 0800 readings for the month. A t-test was used to compare the two data sets each month; and since the results indicated that there was not a significant difference between the two sets each month, the 0800 daily readings were used to compute the monthly mean water levels.

Figure 1.13 is an annual series of mean monthly water levels at the four inland stations in Barataria Bay starting in 1968 and continuing through 1973. There is considerable variation among the graphs there, but there are also similarities worth noting.

For any given year all four stations exhibit the same behavior: each year shows two maximums and two minimums, one maximum in the spring and the other in early fall. Despite this regularity, there is no consistency concerning which is the primary maximum. Some years the spring peak is minimal: e.g., 1971 was a year of dry spring and wet fall; 1968 and 1969 were years of dry falls and dry springs. The year 1970 had low water surpluses for both spring and fall, however, this is not immediately evident because an apparent increase in water levels throughout the basin is an important effect. Another year (1973) had very high surpluses in the spring and stream action appears to have had a very important role in controlling water motions in the upper reaches of Barataria Basin. The only other year in which stream action appears to have a high contribution was in the spring of 1969 when water levels at Bayou Chevreuil were high enough to be of significance.

The seasonal cycles of water levels are important for several reasons. The spring peak represents excess precipitation runoff. During the next three months (approximately 90 diurnal tidal cycles), this water is flushed out of Barataria Bay. This is essentially a flushing of the freshwater input. After the minimum there is a three-month period of reverse flushing. Water is being slowly pumped back into Barataria Bay from the Gulf of Mexico. This in turn is flushed out in about three months time. There are unusual events that intensify the

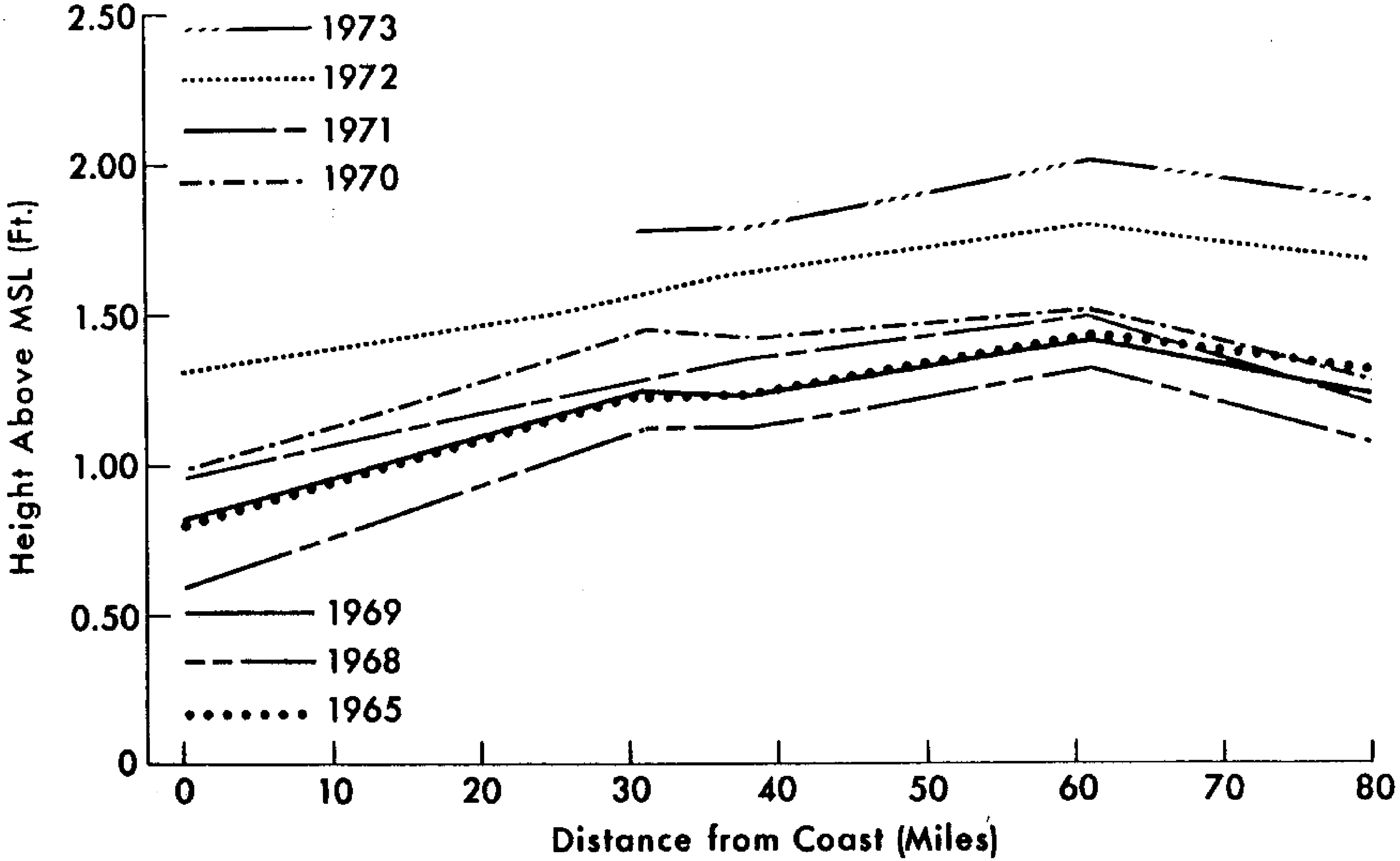

Fig. 1.11. Surface water slope, Barataria Bay.

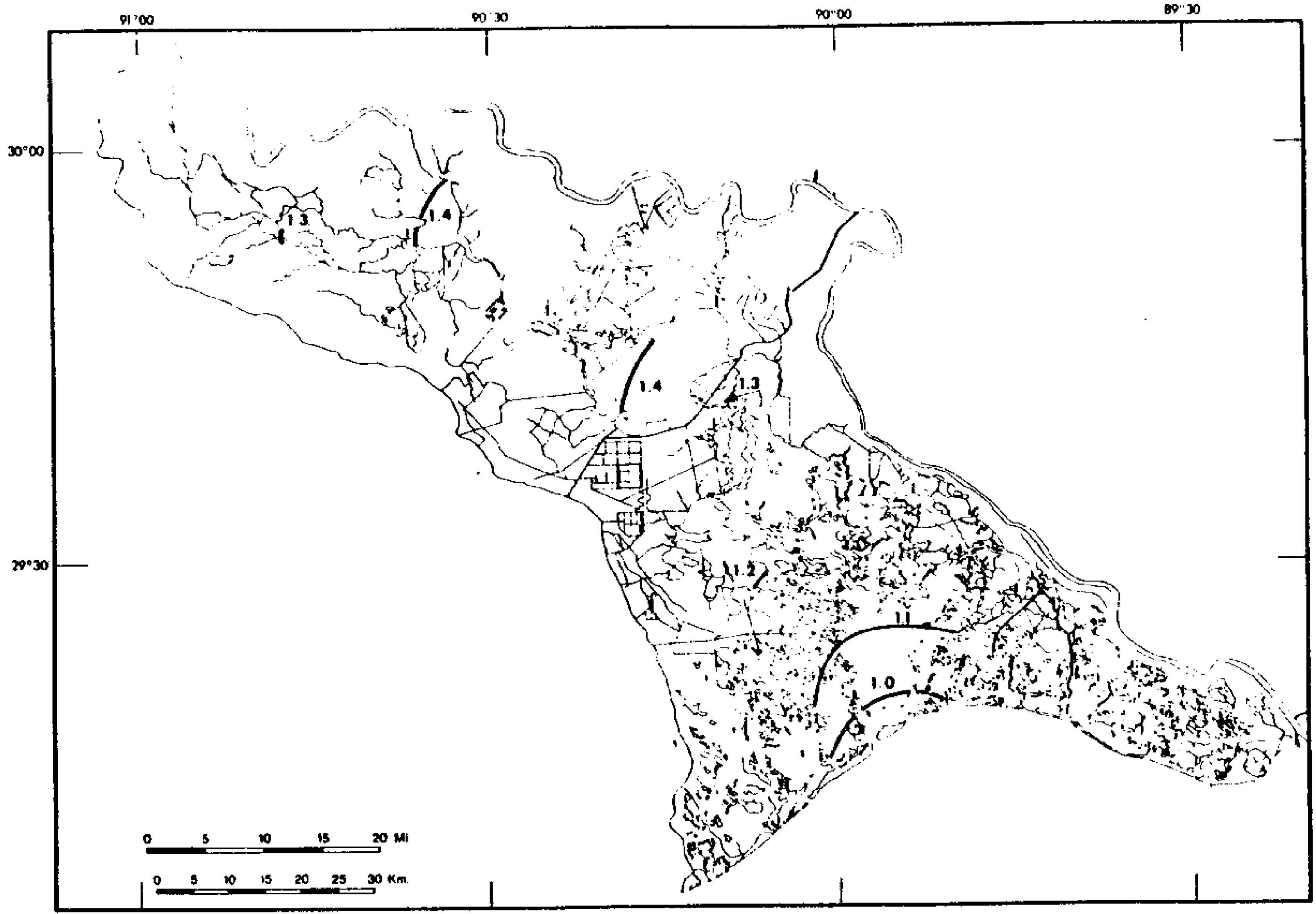

Fig. 1.12. Co-mean water level chart, Barataria Bay.

spring freshet and unusual events that create an autumnal freshet. An example year of an intense spring freshet is 1973, and 1971 is an example year of an intense autumn freshet.

The most outstanding feature of this semiannual cycle is the apparent slowness with which high water levels are drained from the basin. There may be factors that have not been considered here, e.g., global water budget, that greatly contribute to this situation. In addition Sturges (1976) indicates that wind stress over the Gulf of Mexico produces a current that strongly affects water levels in coastal areas along the northern Gulf of Mexico. During the summer and winter months, wind stress produces an eastward-flowing current which lowers water levels along the coast; the reduction in wind stress during the fall and spring months, in addition to thermal effects in the fall, produces higher stands of water.

Because much water level variability is due to astronomical effects and can be predicted, the predicted mean monthly water levels were subtracted from observed mean monthly water levels at Bayou Rigaud for the years 1968 inclusive through 1971 (Figure 1.14). January and December had the lowest water levels, and September had the highest. There is no indication of the semiannual cycle that appears characteristic of the Barataria Region. The July minimum in the predicted water levels is missing, but it is present in all observed water level records. Theoretically, if water levels for a given year were exactly as predicted, the actual minus the astronomical (or residual) would equal zero. Any deviation from this indicates a surplus or deficit in water. In only one case, 1968, was there a deficit or a negative monthly residual. In almost every other case these were positive. In all but one year there is a spring surplus and a fall surplus. There is no consistency as to the time of occurrence. Each year during this period was a wet year, which accounts for the relative excess of water.

Computer-drawn histograms of water levels were constructed for stations in Barataria Basin from three-hourly readings for the year 1971. All data were adjusted to mean sea level using the COE published correction factors. Water level histograms are shown in Figure 1.15. All histograms were constructed with a class interval of 0.1 ft. The designation of each class is located at the lower end of the class increment.

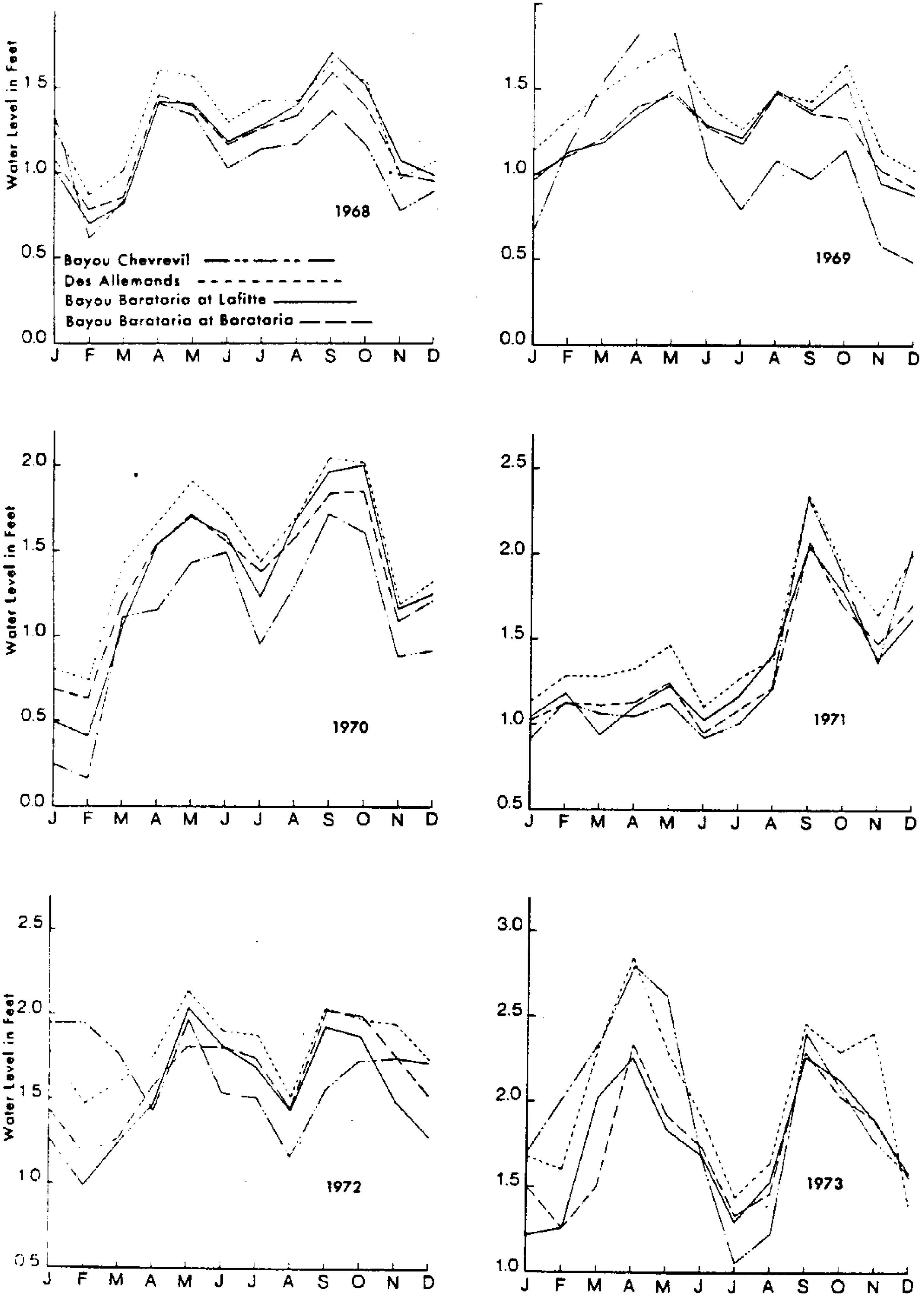

Fig. 1.13. Mean monthly water levels at Barataria Bay stations for 1968-73.

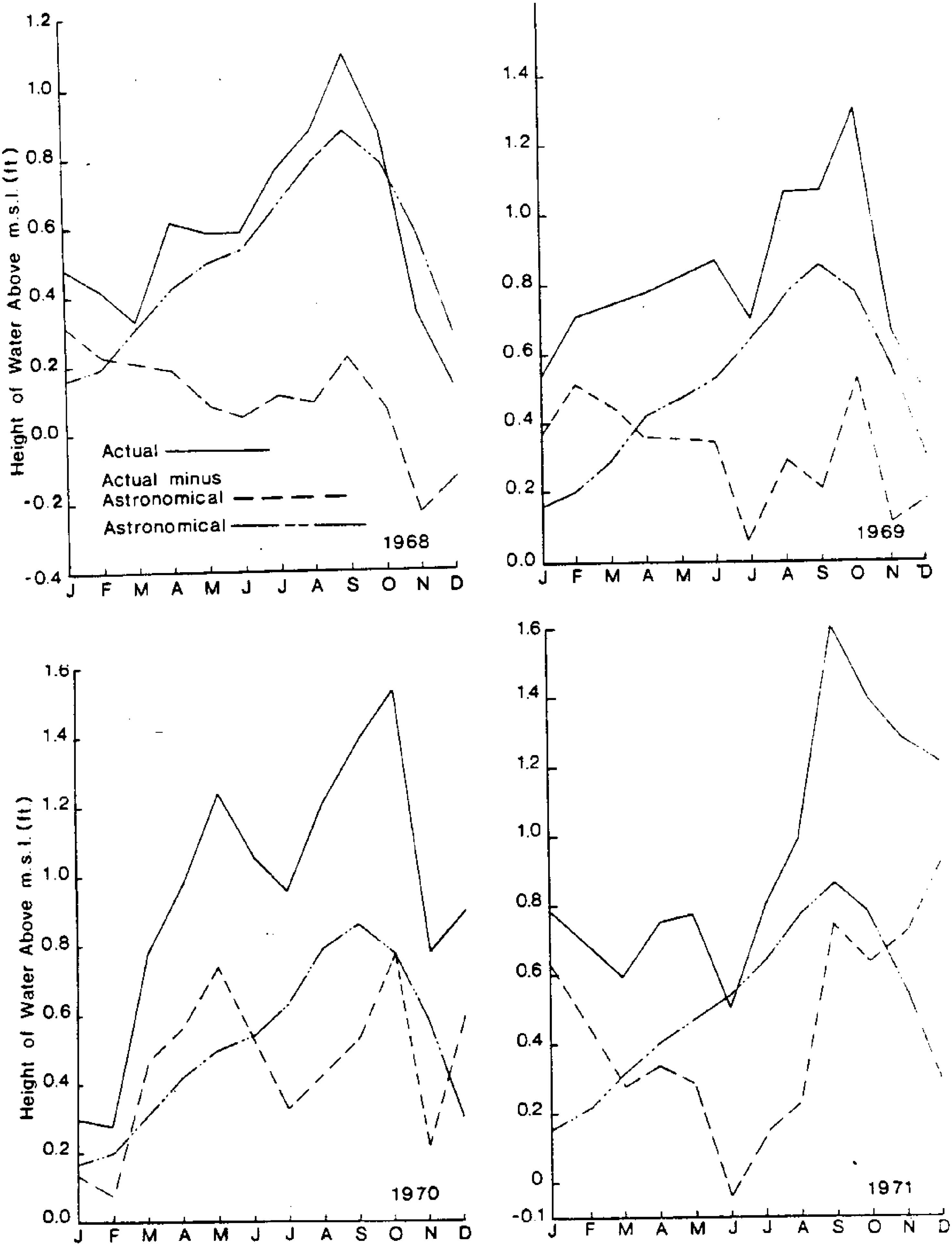

Fig. 1.14. Mean monthly water levels, predicted water levels, and residual water levels for 1968-71.

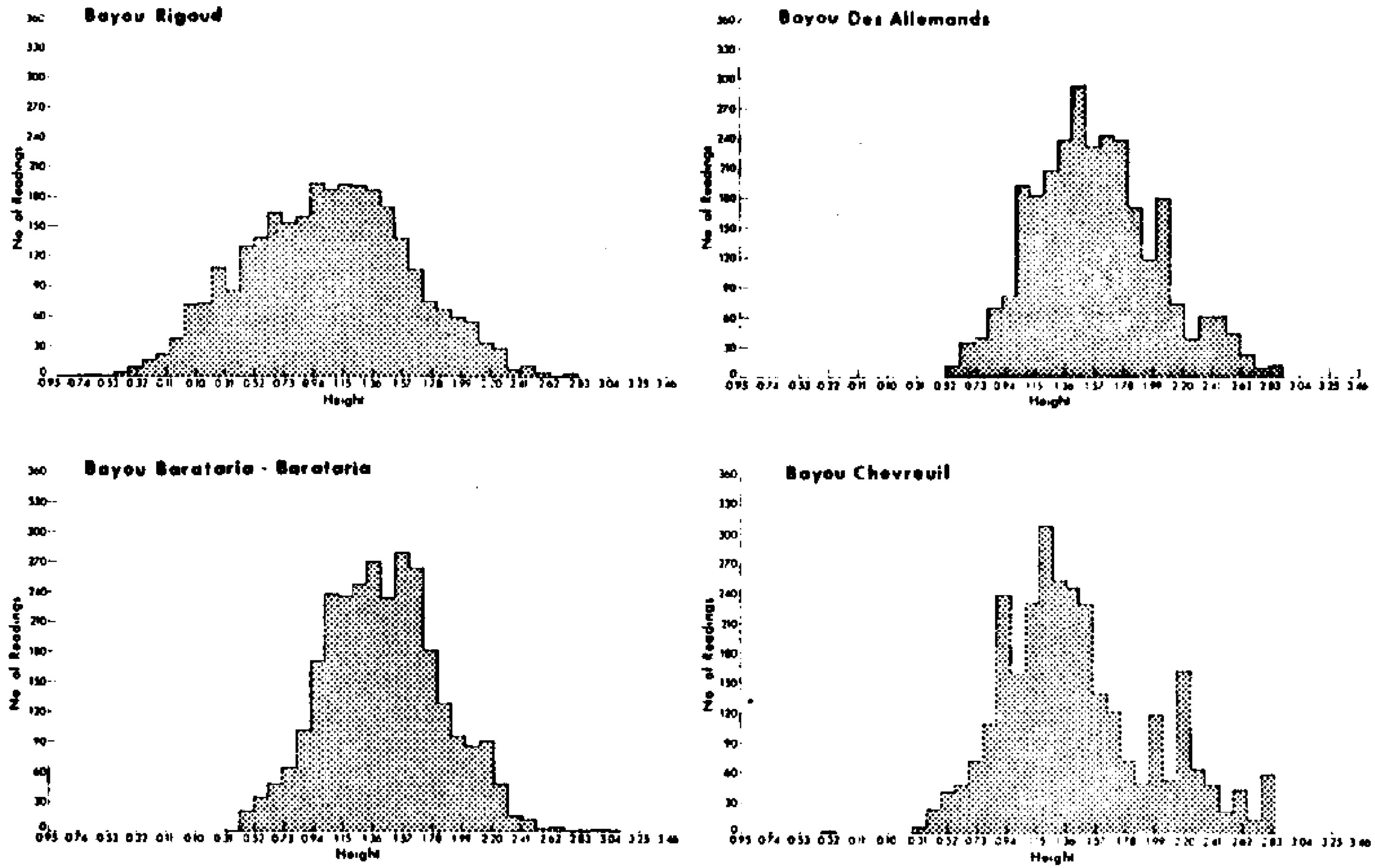

Fig. 1.15. Histograms of water height at stations in Barataria Bay, 1971.

The water level histograms are similar, but there is a slight difference between the Bayou Chevreuil histogram and the histograms from lower Barataria Basin. Table 1.8 presents the graphic moments, skewness, and kurtosis. There is no significant skewness to any of the water level histograms with the exception of the Bayou Chevreuil histogram. This histogram is skewed to the higher values. There is a slight trend in skewness as distance inland from the coast is increased. Each successive station is a slight bit more skewed toward the larger values. However, there is no dramatic change in this parameter even at the most extreme inland station. The Bayou Chevreuil water level histogram is only slightly skewed to the higher values. This progression of skewness could be expected in an area that is at one end tidal with diurnal fluctuations, and that is at the other end predominantly stream controlled with higher values occurring several times a year during the freshet.

Table 1.8. Graphic Moments of Water Level Histograms.

STATION	SKEWNESS	KURTOSIS
Bayou Rigaud	.0213 nearly symmetrical	0.98 mesokurtic
Lafitte	.027 nearly symmetrical	.92 mesokurtic
Barataria	0.072 nearly symmetrical	0.92 mesokurtic
Des Allemands	0.082 nearly symmetrical	1.06 mesokurtic
Bayou Chevreuil	0.239 slightly high skewed	1.08 mesokurtic

The kurtosis of the five histograms is also given in Table 1.8. There is no apparent trend, and all histograms are mesokurtic. They do not exhibit bimodal characteristics nor are they excessively peaked.

EXTREME WATER LEVELS

The highest and lowest water levels for each month were studied by comparing monthly extremes to mean water level at each station in Barataria Bay (Tables 1.9 and 1.10) for the year of 1971. The high extremes os high waters are generally found at all stations during the month of September except at Bayou Rigaud, with high water extending through October, November, and with December water levels being highest at Bayou Rigaud. It should be noted that although water level is high in September throughout the Bay, two Gulf Tropical disturbances influenced the Louisiana coast during September 1971. The low extremes of high water levels (Table 1.9) are found in June at all stations in Barataria Basin. June is a time of low absolute water levels.

Table 1.9. Difference between annual mean water and monthly extreme high water level, 1971.

	Bayou Rigaud	Bayou Barataria at Lafitte	Bayou Barataria at Barataria	Bayou Des Allemands	Bayou Chevreuil
Jan.	1.68	0.90	0.67	0.27	0.23
Feb.	1.68	0.80	0.77	0.42	0.33
Mar.	1.48	0.70	0.97	0.24	0.23
Apr.	1.38	0.65	0.67	0.42	0.23
May	1.78	0.70	0.87	0.52	0.51
June	1.28**	0.30**	0.17**	0.07**	0.11**
July	1.58	0.50	0.27	0.22	0.13
Aug.	1.58	0.50	0.37	0.32	0.48
Sept.	2.28	1.10*	1.77*	1.37*	1.53*
Oct.	1.98	0.90	0.82	0.90	1.13
Nov.	2.08	0.70	0.67	0.60	0.53
Dec.	2.58*	0.80	0.87	0.92	0.93

*Highest
**Lowest

Table 1.10. Difference between annual mean water and monthly extreme low water level, 1971.

	Bayou Rigaud	Bayou Barataria at Lafitte	Bayou Barataria at Barataria	Bayou Des Allemands	Bayou Chevreuil
Jan.	0.62	1.15	1.03**	0.93	0.95
Feb.	0.92	.55	0.88	0.68	0.57
Mar.	1.32**	1.05	0.93	0.90	0.90
Apr.	0.62	1.25**	0.93	1.03**	1.08**
May	0.62	.70	0.78	0.56	0.62
June	1.12	.80	0.78	0.58	0.87
July	0.72	.55	0.58	0.48	0.92
Aug.	0.42	.30	0.63	0.53	0.52
Sept.	-0.28*	-0.38*	-0.47*	-0.12*	-0.48*
Oct.	-0.18	0.15	-0.13	-0.10	-0.18
Nov.	0.32	0.35	0.38	0.15	0.27
Dec.	0.32	0.40	0.38	-0.02	-0.43

*Highest
**Lowest

The low extreme water levels did not behave as regularly as the high extremes. Extreme lows occurred during March at Bayou Rigaud, however, the low extreme water levels occurred in January at Bayou Barataria at Barataria and in April at the other stations. The highest lows occur during September and in both September and October the lowest monthly values are larger than the local annual mean water level. Lowest extreme lows occur in the spring and are caused by strong frontal passages with associated northerly winds.

The number of times per month that water levels surpassed MHW and total hours when water levels were in excess of local mean high water for 1971 were prepared (Table 1.11 and 1.12). At Bayou Rigaud the frequency is quite high as compared to other stations in Barataria Bay. In spite of this the total hours per month for Bayou Rigaud is considerably smaller than other stations in Barataria Bay. The months with high monthly frequencies of water level events exceeding mean high water for Bayou Rigaud are September through December.

Table 1.11. Monthly Frequency of Water Levels in Excess of Local MHW for 1971.

	Bayou Rigaud	Bayou Barataria @ Lafitte	Bayou Barataria @ Barataria
Jan.	9	1	1
Feb.	7	7	8
Mar.	2	6	5
Apr.	12	8	3
May	7	5	9
June	4	2	3
July	7	3	8
Aug.	17	8	14
Sept.	28	3	1
Oct.	26	13	5
Nov.	23	10	12
Dec.	20	13	6

---

*Note that all references to mean high water are for 1971 and are referenced to MSL each station. In

Table 1.12. Monthly Total Hours of Water Levels in Excess of Local MHW, 1971.

	Bayou Rigaud	Bayou Barataria @ Lafitte	Bayou Barataria @ Barataria
Jan.	27	30	30
Feb.	35	123	136
Mar.	8	78	153
Apr.	35	156	306
May	123	78	246
June	8	12	12
July	24	36	90
Aug.	69	72	198
Sept.	243	549	720
Oct.	176	423	739
Nov.	141	216	309
Dec.	121	291	669

At this time there is approximately one event per day. The fall and winter months are also times of higher event frequencies for Bayou Barataria at Lafitte. That is not the case for Bayou Barataria at Barataria. At Bayou Barataria at Barataria mean high water is 0.1 ft above mean sea level. August and November at Bayou Barataria at Lafitte and at Barataria have high frequencies of events, but these values are not as high as the frequencies of events at Bayou Rigaud. The total hours per month of water levels in excess of mean high water (Table 1.12) coupled with frequency of occurrence of water level events above mean high water gives insight into process differences between the stations. When frequencies of water level events in excess of mean high water at Bayou Rigaud are low, total hours per month of water levels in excess of mean high water at Bayou Rigaud are low. When frequencies of events are high, total hours are usually high. In general the ratio of total hours to frequency of events on a monthly basis ranges from 3 to 18 hours/event with a mean of 6 hours/event for Bayou Rigaud. At Bayou Barataria at Lafitte this ratio changes from 6 to 183 hours/events with a mean value of 30 hours/

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the case of Bayou Rigaud mean high water is 0.6 ft above mean sea level. At Bayou Barataria at Lafitte, mean high water is 0.2 ft above mean sea level.

events. Finally, at Bayou Barataria at Barataria, this ratio ranges from 11 to 720 hours/event with a mean of 126 hours/event. Thus, proceeding from inland toward the Gulf the effects of normal tidal processes become progressively more obvious as being the controlling factor of water levels. In the most inland areas, local rainfall and runoff control water levels. The tidal effect is slight.

SEASONAL AND ANNUAL FLUCTUATIONS IN WATER LEVELS

The frequency of occurrence and total time water levels occur in excess of mean water level was compiled for each station for the year 1971 (Figs. 1.16 and 1.17). Frequency and total time was computed for each 0.1 ft increment above mean sea level. Conner and others (1976) employed this information to estimate effects of impoundment on water exchange. While there have been quite a few estimates of the height of the marsh above some datum, to date there has been no extensive study with this objective in mind. An arbitrary level has been suggested as local mean high water and for the sake of convenience has been used here to illustrate how Tables 1.13 and 1.14 were constructed.

Since each station is related back to local mean sea level and mean high water is 0.6 ft above mean sea level at Bayou Rigaud, an intersection with the curve indicates that there were 128 discrete periods of inundation above this level and 12.05 percent of the entire year was the total time of inundation. Tables 1.11 and 1.12 show when the inundation occurred.

Table 1.13. Frequency of water levels exceeding local MHW, 1971.

	Bayou Rigaud	Bayou Barataria @ Lafitte	Bayou Barataria @ Barataria
MHW	128	79	75
+0.1	104	61	66
0.2	87	47	55
0.3	71	40	40
0.4	47	25	22
0.5	29	19	21
0.6	18	8	24

Table 1.13. Continued.

0.7	14	3	12
0.8	6	1	3
0.9	4	1	2
1.0	3	1	2
1.1	1	1	2
1.2	1	1	1
1.3	1	1	1
1.4	0	0	1
1.5	0	0	1
1.6	0	0	0

Table 1.14. Percentage of time water levels exceed local MHW for 1971.

	Bayou Rigaud	Bayou Barataria @ Lafitte	Bayou Barataria @ Barataria
Local MHW	12.05	23.66	41.33
+0.1	9.45	17.43	31.78
+0.2	7.12	12.26	22.80
+0.3	5.07	8.52	16.61
+0.4	3.18	4.83	12.22
+0.5	2.02	2.32	8.97
+0.6	1.02	1.09	6.06
+0.7	0.075	0.44	2.97
+0.8	0.030	0.23	1.13
+0.9	0.017	0.13	0.4
+1.1	0.003	0.10	0.3
+1.3	0	0.03	0.13
+1.4	0	0	0.1
+1.5	0	0	0.03
+1.6	0	0	0

Long-Term Water Level Changes

Sea level is defined as the average of hourly water levels for a 19-year-period. However, this value changes depending on which 19-year-period is used. In a dynamic area, annual changes in mean

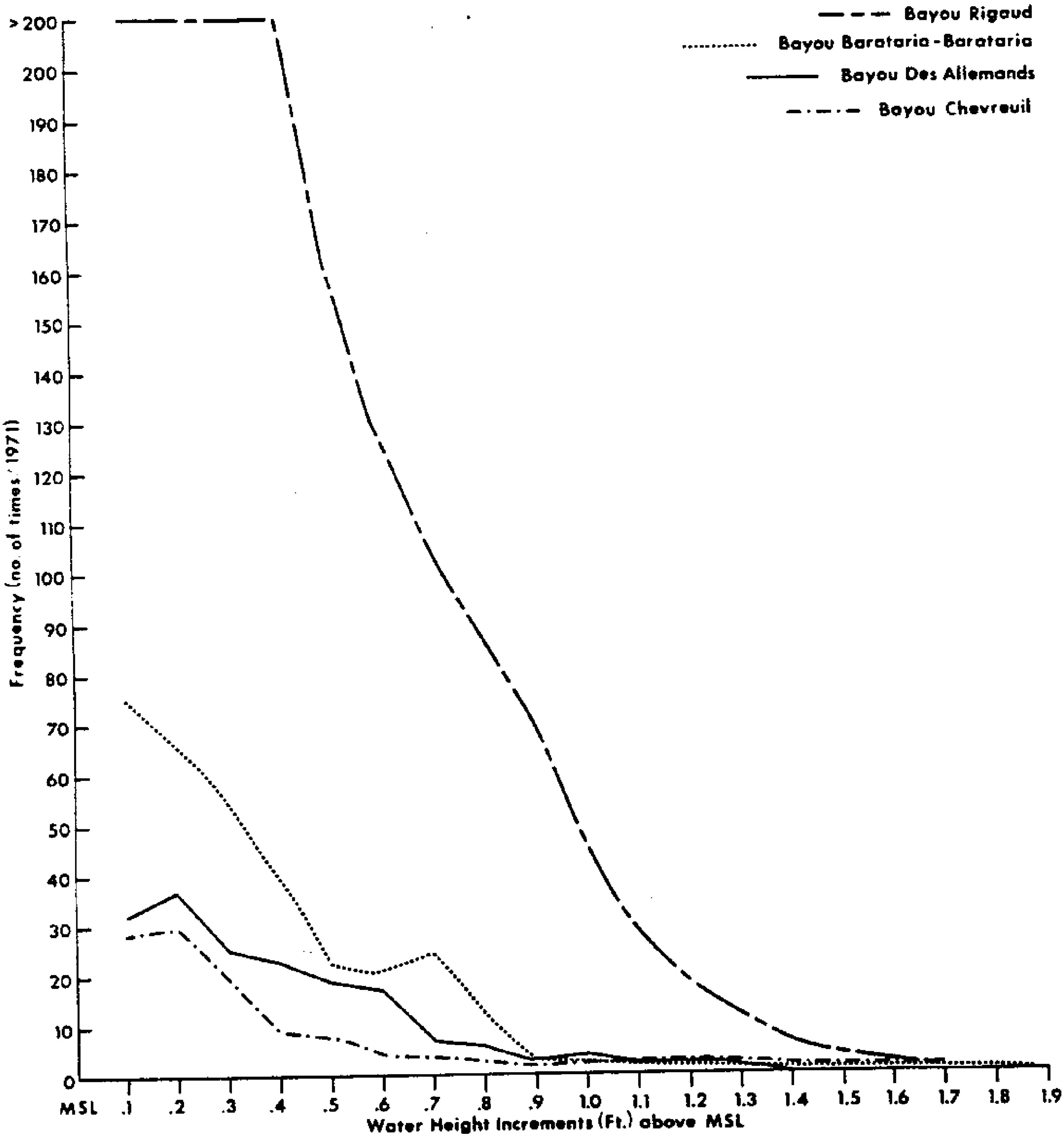

Fig. 1.16. Frequency of discrete oscillations above specified heights relative to local mean sea level, 1971.

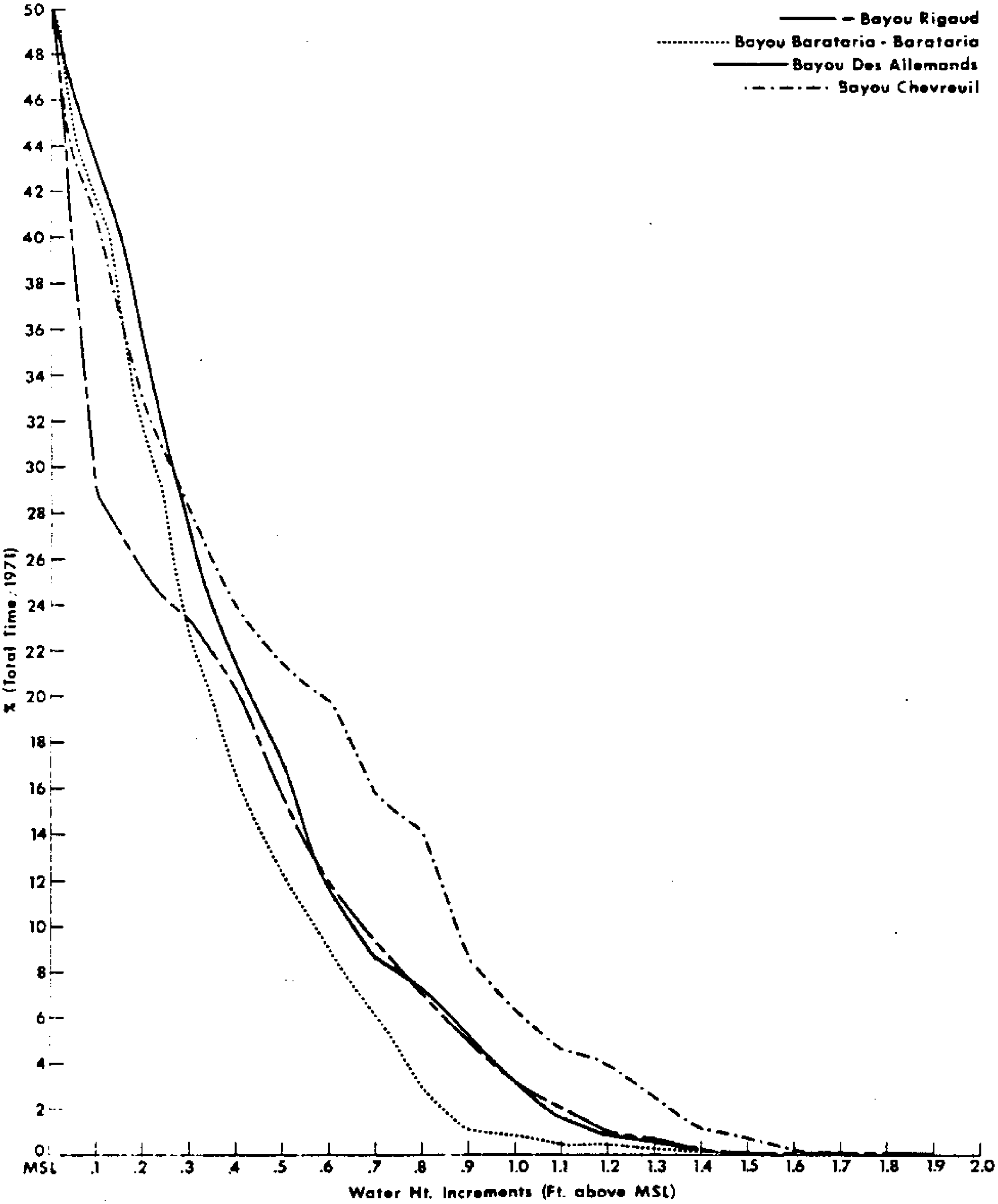

Fig. 1.17. Total time in percentage of a year of discrete oscillations above specified heights relative to local mean sea level, 1971.

water levels are of importance, especially if there are water level trends that could possibly affect geological, chemical, and biological aspects of the environment, as well as other physical processes. Geological processes produced by sea level increase might include inlet widening, coastal retreat, sedimentation changes, marsh deterioration, and in turn, salinity intrusion (Adams et al. 1976). These changes in turn can affect the type and abundance of estuarine organisms, therefore influencing the entire distribution of life throughout coastal waters. This especially affects endemic residential species such as clams, oysters, marsh grasses, cypress trees, and other vegetation (Van Sickle et al. 1976).

Mean annual sea levels for Barataria Basin Management Unit are presented in Fig. 1.18. Although there is great deal of variation, there is an increasing water level trend at all stations for the entire period of record at above the 0.95 confidence level. The correlation coefficients are not high; however, the slopes from linear regressions for all stations are similar even with unequal periods of record (Table 1.15).

Table 1.15. Annual water level increases in Barataria Bay.

Station	Period of Record	r^2	slope (ft/yr)
Bayou Rigaud	1947 - 1971	0.61	0.028
Bayou Barataria @ Lafitte	1962 - 1973	0.71	0.043
Bayou Barataria @ Barataria	1962 - 1973	0.69	0.049
Bayou Des Allemands	1965 - 1973	0.54	0.058
Bayou Chevreuil	1965 - 1973	0.35	0.052

Correlation coefficients were computed between pairs of stations in an attempt to determine whether causes of apparent sea level rise were similar. If all stations exhibited parallel trends, one could assume that the causes of sea level rise affected all

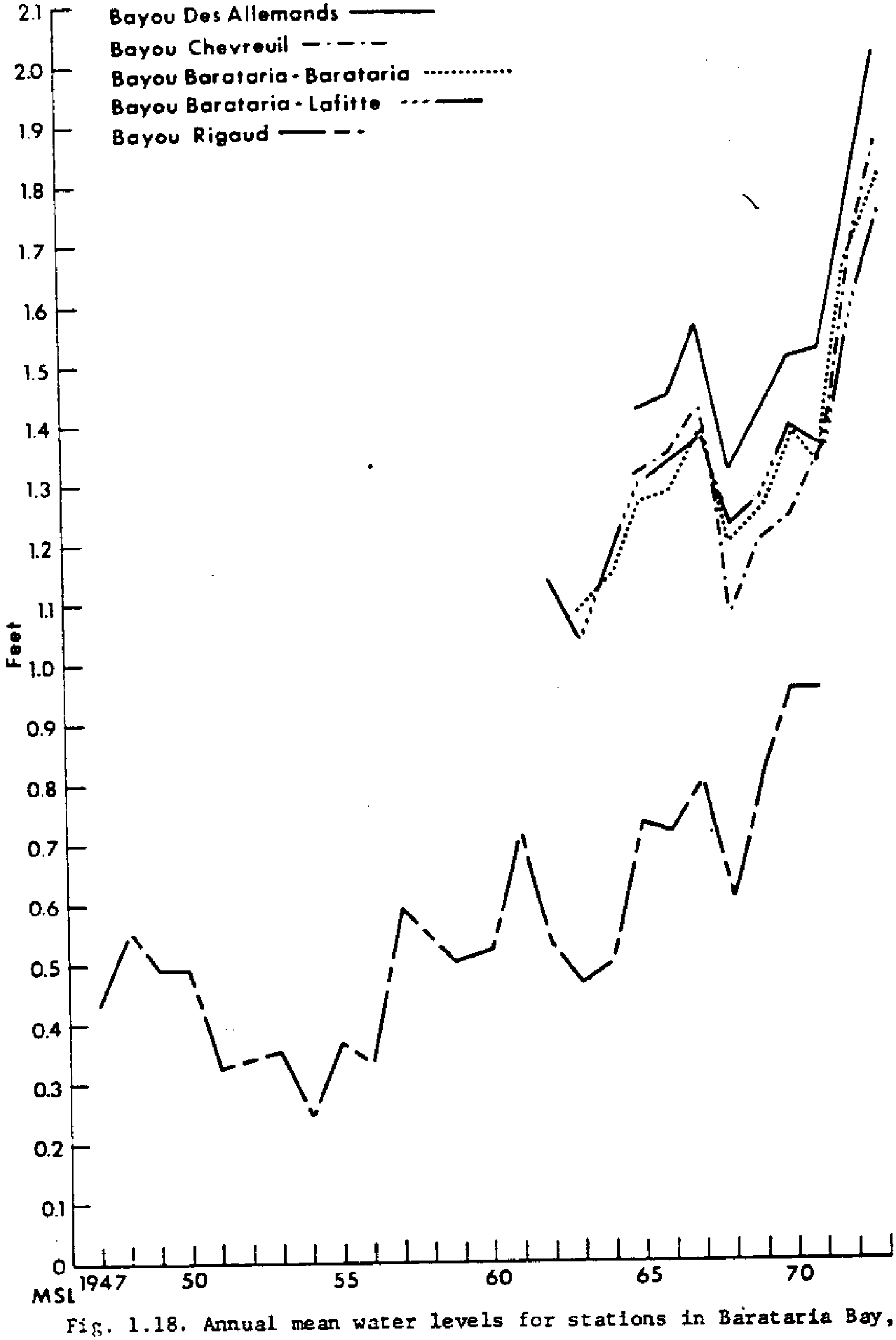

Fig. 1.18. Annual mean water levels for stations in Barataria Bay, 1947-1971.

stations within Barataria regardless of location. This, however, is not the case. There was a general parallelism between sea level changes during years with concurrent records but were far from perfect, suggesting that more than one long term process is active or the response at different stations is non-linear (Table 1.16).

Table 1.16. Annual Water Level Correlation, Barataria Bay.

Station Pairs sea level comparison	r^2
Bayou Rigaud - Bayou Barataria @ Lafitte	0.80
Bayou Rigaud - Bayou Barataria @ Barataria	0.68
Bayou Rigaud - Bayou Des Allemands	0.48
Bayou Rigaud - Bayou Chevreuil	0.02

When the correlation is made from each station to Bayou Rigaud there is a definite decrease in correlation with distance increasing from Bayou Rigaud in an up-basin direction. Thus, the forcing at the Bayou Rigaud station has a lesser effect at each successive station up the basin. The same procedure was also performed using Bayou Chevreuil as the independent variable (Table 1.17).

Table 1.17. Annual Water Level Correlations in Barataria Bay

Station Pairs sea level comparison	r^2
Bayou Chevreuil - Bayou Des Allemands	.94
Bayou Chevreuil - Bayou Barataria @ Barataria	.92
Bayou Chevreuil - Bayou Barataria @ Lafitte	.88
Bayou Chevreuil - Bayou Rigaud	.02

Water level changes at Bayou Chevreuil, Bayou Des Allemands, Bayou Barataria at Barataria appear similar, however, Bayou Barataria at Barataria still reflects some lower basin trends. This may be indicative of differential subsidence. Adams et al. (1976) report various land loss/gain figures as being locally controlled. Although these station areas were not studied, the same conditions probably hold as for the areas that were studied, that is, land loss/gain is a function of local conditions.

The apparent parallel rise in sea level at the inland stations could also be because of precipitation. There is not enough data to confirm or refute this possibility absolutely. The inland-most stations have been in operation since 1951, but the data for 1951 through 1963 are unavailable at this time. The 1963-present data were readily available. This period of time was a particularly wet one. On the basis of this limited amount of data, a correlation coefficient was obtained between the annual Bayou Chevreuil water level and New Orleans Precipitation records. The r^2 was 0.72. New Orleans weather data was the closest record and even with the distance involved this possible cause is not beyond reason. With the inclusion of more data from a period of normal and dry years, this can be studied further because precipitation seems an unlikely candidate for a 0.8 ft rise over the period of record.

Part 2. Salinity and Temperature - Descriptive

Introduction

Salinity and temperature vary, to a large extent, as the result of water exchange; they are indicative of the distributions and habitats of various biological species; and they are generally the most abundant data sets available. For Barataria Basin all known significant data sets were located and documented. The data were carefully evaluated and incorporated into the displays and analyses when deemed meaningful. These data collection techniques are reviewed in Appendix C.

Salinity and temperature data were obtained from four stations in Barataria Basin: (1) Grand Terre, (2) St. Mary's Point, (3) Bayou Barataria at Lafitte, and (4) Bayou Barataria at Barataria. The location of these stations is shown in Figure 2.1. The frequency of sampling was continuous at Grand Terre and Bayou Barataria at Barataria, daily at Bayou Barataria at Lafitte, and weekly at St. Mary's Point. The period of record for each station is included in a detailed description of the instruments employed and treatment of the data in Appendix C.

Long-term Trends — Salinity

Long-term salinity trends were qualitatively analyzed by graphically examining averages of 14 to 19 years of data at three stations within the Basin. Week-to-week changes were examined by plotting averaged weekly means from Grand Terre (1961-74), averaged weekly readings from St. Mary's Point (1961-74), and averaged weekly means from Bayou Barataria at Lafitte (1961-74). The methods for obtaining these means are described in Appendix C. Month-to-month changes were examined by plotting averaged monthly means for these three stations for the same time period (1961-74). Plots were constructed of annual averages of salinity at Grand Terre (1961-74), St. Mary's Point (1956-74), and Bayou Barataria at Lafitte (1956-74). Each of these will be presented and described separately to show long-term trends. The 1971 records are superimposed on the long-term weekly plots to illustrate year-to-year variability from the long-term averages.

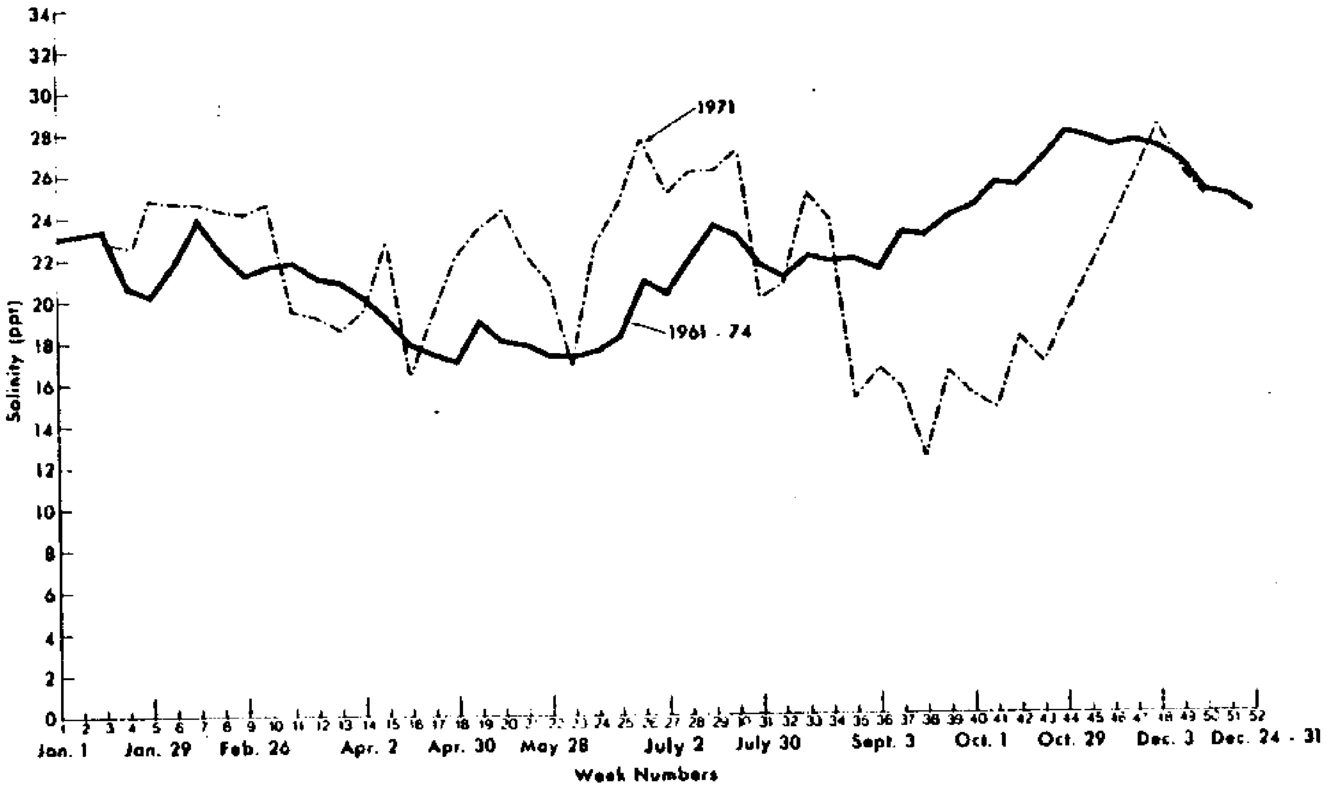

Fig. 2.1. Averaged weekly means of salinity at Grand Terre (long-term plus 1971).

WEEKLY AVERAGES

Grand Terre

Salinity has been recorded on a continuous basis at Grand Terre by the Louisiana Wildlife and Fisheries Commission since 1961. The average weekly salinities for the 52 weeks of the year were estimated by LWFC from 14 years of data (1961-74), as described in Appendix C, p. 000. These values were plotted to show the mean annual cycle (see Fig. 2.1). The 1971 weekly values were also plotted to show that year's deviation from the 14-year mean.

It can be seen that the highest long-term mean values occur in late fall, around the end of October (44th week); the lowest occur in April and May (18th to 23d week). The drop from the end of October to May is relatively uniform, whereas the overall rise between May and October appears to contain a local high/low cycle in July and early September. The 1971 record reflects the high degree of deviation from the long-term trends possible during any given year. Significant highs are exhibited in May (20th week), June (26th week), and December (48th week). The other major feature is a pronounced low during September (38th week), which extends throughout September and October and then increases toward the December high. The discrepancies are large, many, and obvious.

St. Mary's Point

Salinity data have been collected in the vicinity of St. Mary's Point during various periods since 1945. The frequency of sampling, method of measurement, and the agency collecting the samples have varied during this time (see Appendix C. However, we obtained all the data from the Louisiana Wildlife and Fisheries Commission. The period of 1961-74 was chosen for averaging and graphical display in order to make the period of record represented in the long-term means consistent at all stations. The values obtained by the averaging method described in Appendix C were plotted to show the long-term means (see Fig. 2.2). The 1971 weekly readings are also plotted to show that particular year's deviation from the average. It can be seen that the highest long-term mean values occur in the late fall, around the end of October (44th week), while the lowest values occur in the late winter, around the end of January (5th week). The pattern of fluctuation between these extreme points

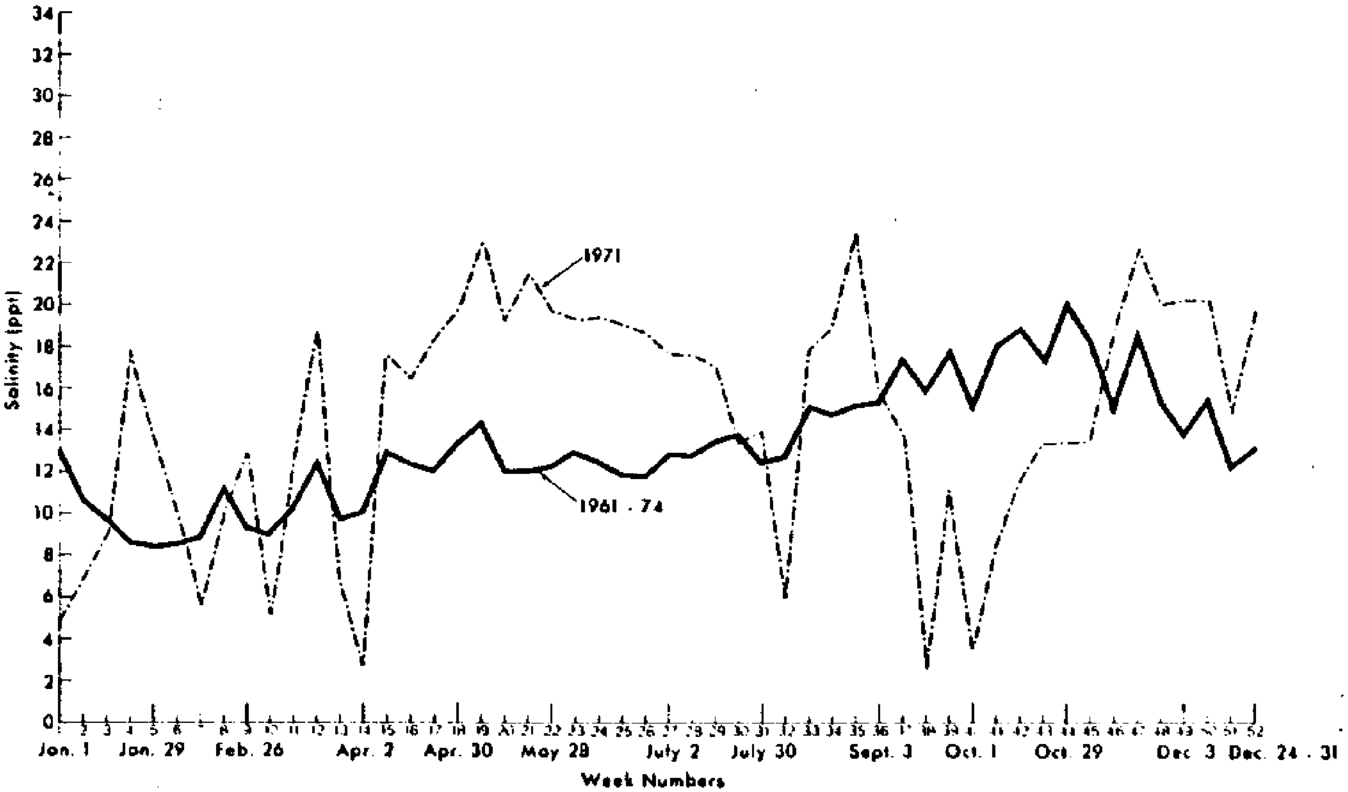

Fig. 2.2 Averaged weekly readings of salinity at St. Mary's Point (long-term plus 1971.

is quite similar to that described above at Grand Terre. This general pattern is not reflected in the superimposed 1971 record, which shows a particularly high salinity in the spring—around the first of May— and a particularly low salinity in the fall, around the first of October. The general variability is extremely high. The range of data extends from 2.5 ppt to 23.5 ppt in 1971 while the long-term averaged data only range from 8.4 ppt to 20.0 ppt while exhibiting a smooth gradual change with time. The extreme range of 1971 occurs within a 3-week period, and the variability during January, February, and March is very evident. It is expected that much of the variation experienced is because only weekly readings were available at St. Mary's Point. Thus, since only one sample per week was taken, this could easily have been taken at a time that was not truly representative of the salinity during the entire week. There is a more consistent period during April, May, June, and some of July, which suggests that when the local variation is less, the weekly sampling interval more nearly gathers representative values.

Bayou Barataria at Lafitte

Salinity data have been collected at Bayou Barataria at Lafitte on a daily basis by the U.S. Army Corps of Engineers since 1955. Long-term mean weekly salinities (1961-74) are plotted in Figure 2.3. The method for determining these values is described in Appendix C. Weekly averages for 1971 were calculated from daily readings and superimposed on the long-term mean plot to illustrate the yearly variability. It can be seen that the highest value occurs in the late fall, around the end of October (44th week) while the lowest values occur in the late winter, around the end of February (8th week). The general trends seen at Grand Terre and St. Mary's Point are less evident in the Lafitte record because the absolute salinities are less, which graphically suppresses visual variations. The 1971 data follow the long-term mean early in the year but deviate with high May salinities (18th to 23d week) and the extremely low values all during the fall months of September, October, November, and December (36th to 52d week). The overall variability appears much lower than at Grand Terre and St. Mary's Point, but this is because of the lower absolute levels at Lafitte. The percentage variability of the yearly record is approximately the same at all three stations.

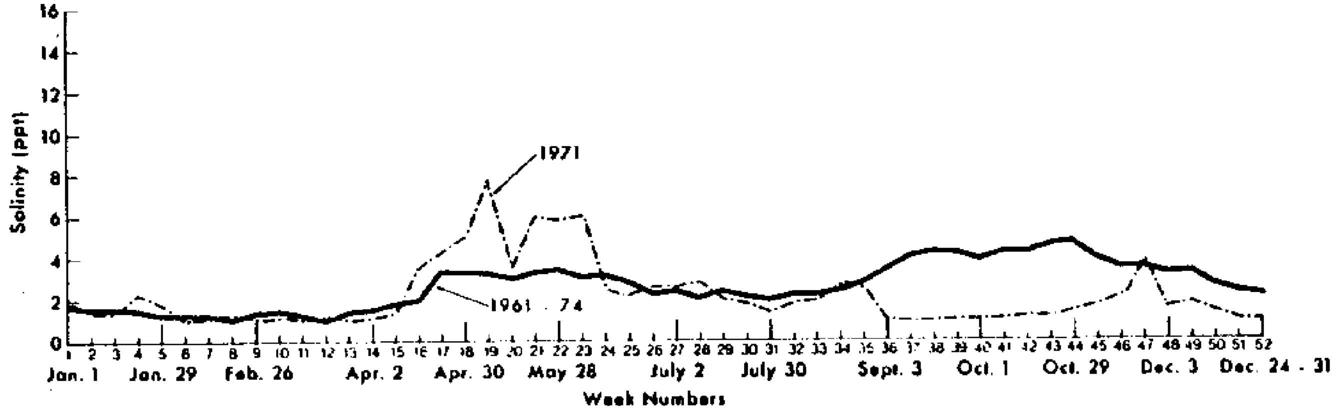

Fig. 2.3. Averaged weekly means of salinity at Bayou Barataria at Lafitte (long-term plus 1971).

LENGTH OF AVERAGED RECORD

The choice of the time period 1961-74 was dictated primarily by the availability of useful data rather than by scientific criteria related to the physical environment. However, since daily values of chlorinity for Bayou Barataria at Lafitte were available back to 1956, we were able to calculate the weekly averages of salinity for this entire period (see App. C, Table C.4). A simple analysis was therefore made to determine the effect of the inclusion of these other five years on the overall weekly means. Two curves were drawn, one including 1961-74 data and the other including 1956-74 data (see Fig. 2.4). The net effect was a lowering of the absolute salinities plotted, i.e. a downward displacement of the curve. The separation between the two curves increased as the absolute salinities increased. Trends remained almost identical with no appreciable discrepancies between the two records. While the average salinities between 1956 and 1960 were significantly lower than during later years at Lafitte, the inclusion of these additional data do not alter the trends already evident. It can therefore be concluded that the 1961-74 records suffice for the purpose of visually examining trends in the weekly averaged salinity data.

SUMMARY

While the long-term mean salinities represented by the 1961-74 data vary significantly between the three stations (22.2, 13.3, and 2.7 ppt at Grand Terre, St. Mary's Point, and Bayou Barataria at Lafitte, respectively), the patterns for these stations are similar. Relative highs and lows vary somewhat in specific time of occurrence, but the spring low/fall high sequence appears consistently.

It can be seen that the 1971 record does not accurately reflect the long-term trends established by the 1961-74 data. Correlation coefficients between these two data sets of 0.384 at Grand Terre, 0.014 at St. Mary's Point, and 0.035 at Bayou Barataria at Lafitte support this observation.

MONTHLY AVERAGES

The long-term salinity trends were also evaluated on a monthly basis. Averaged monthly means (1961-74) at Grand Terre, St. Mary's Point, and Bayou Barataria at Lafitte were plotted on a common graph for easy comparison (see Fig. 2.5). The highest value at Grand Terre occurred in November; the lowest occurred in May. At St. Mary's Point, the

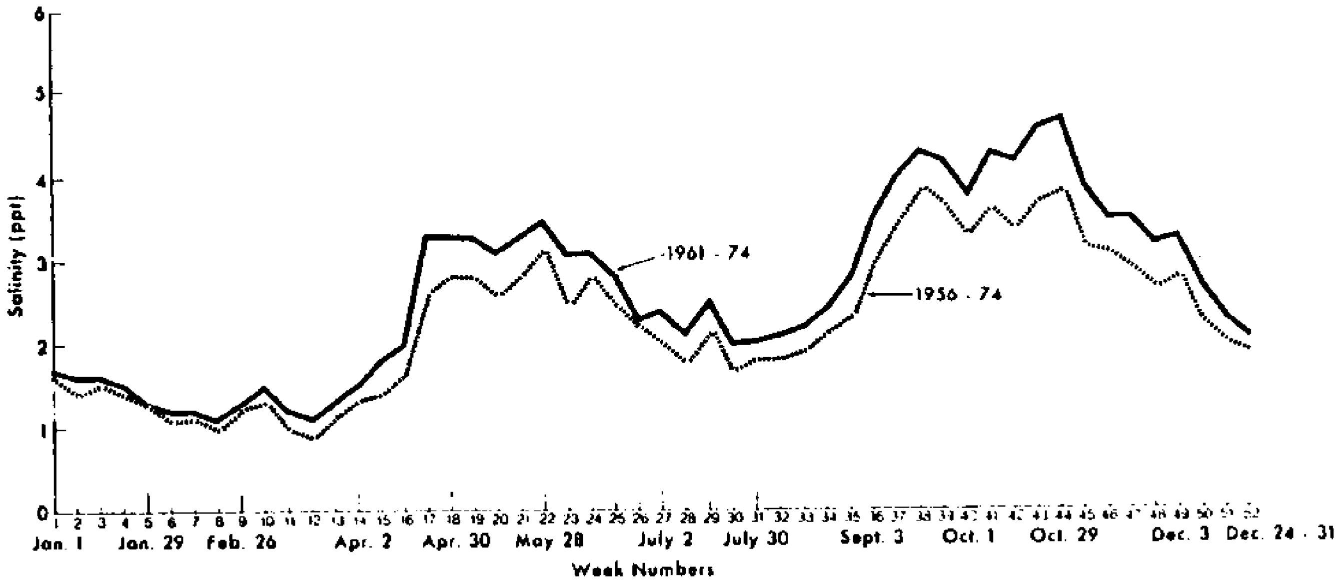

Fig. 2.4. Averaged weekly means of salinity at Bayou Barataria at Lafitte (long-term comparisons).

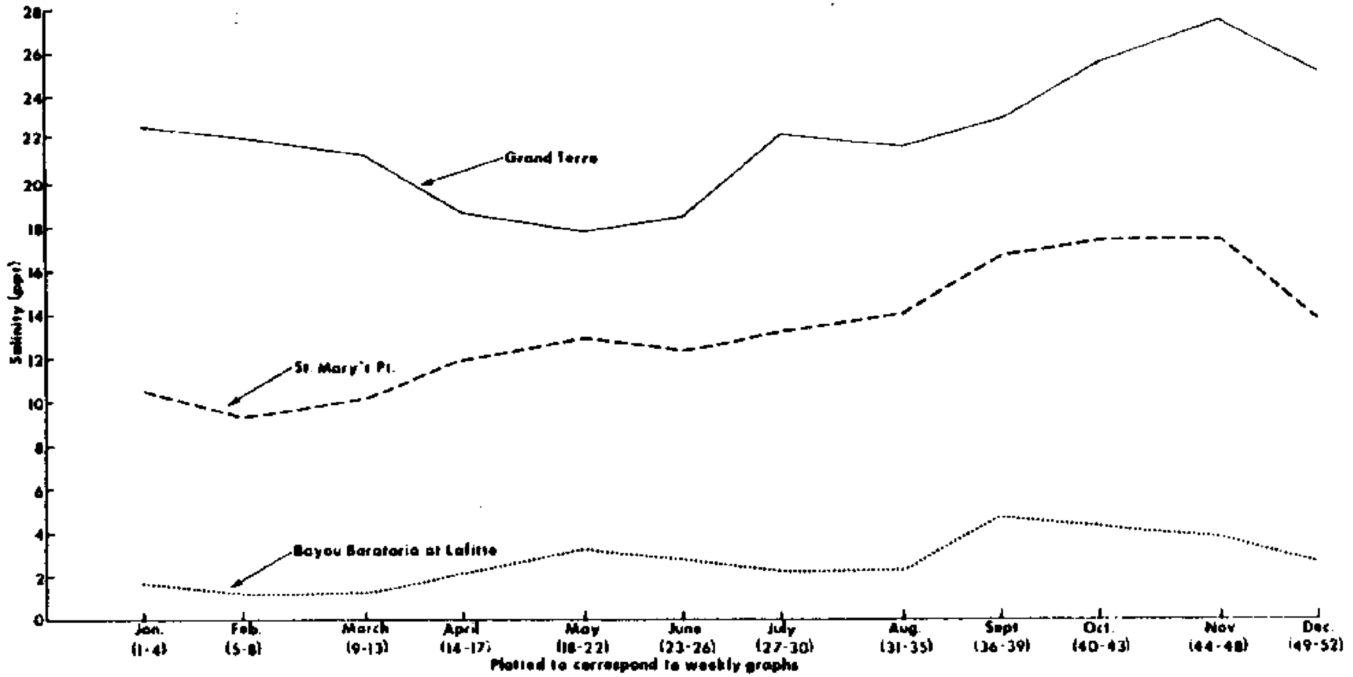

Fig. 2.5. Long-term averaged monthly means of salinity, 1961-74.

highest value occurred in October and November; the lowest value occurred in February. The highest value at Bayou Barataria at Lafitte occurred in September; the lowest value occurred in February. The curves are smoother than when the data were plotted on a weekly basis, the same fall high/spring low trends are well defined. But the spring low at Grand Terre lags that in the upper basin by three months.

Means for each month of each year were also plotted on a common graph (1961-74 at Grand Terre, 1960-74 at St. Mary's Point, and 1960-74 at Bayou Barataria at Lafitte). This was performed by computer because of the large amount of data handled; curves were drawn directly by the computer-controlled Varian plotter. As anticipated, a high degree of variability over the entire period of record was observed.

In order to establish whether or not there was any correlation between the salinities at these three stations, correlation coefficients were computed for monthly mean salinities between (1) Grand Terre and St. Mary's Point and (2) between St. Mary's Point and Bayou Barataria at Lafitte (see Table 2.1). These figures show a very low correlation between data sets 1 and 2.

These calculations support the conclusions drawn from the long-term weekly averages, that even though a spring low/fall high appears consistently at all three stations, the specific times of occurrence and the duration of these high and low periods vary somewhat from station to station.

Table 2.1. Correlation Coefficients between Monthly Mean Salinities

Year	Grand Terre - SMP	SMP - Lafitte
1960	*	.75
1961	*	.57
1962	.48	.79
1963	.09	.64
1964	.31	.65
1965	.25	.32
1966	.81	.36
1967	.14	.57
1968	.19	.22
1969	.65	.81
1970	.02	.03
1971	.17	.46

Table 2.1. Continued.

1972	.62	.83
1973	.41	.24
1974	.82	.63
ENTIRE RECORD	.38	.53

ANNUAL AVERAGES

The final compilation of salinity records to show long-term trends was the calculation and presentation of yearly averages. Records from Grand Terre (1961-74), St. Mary's Point (1956-74), and Bayou Barataria at Lafitte (1956-74) were used to obtain the data for the three curves shown in Figure 2.6. It should be noted that data gaps at St. Mary's Point in 1965 and 1966 resulted in the calculation of incorrect yearly values for 1965 and 1966 based upon the sparce data available. Values plotted in Figure 2.6 for St. Mary's Point represent interpolated data for the years 1965 and 1966. The curves presented in Figure 2.6 substantiate the conclusion mentioned above that the salinities were particularly low during the 1956 to 1960 period. Starting with the abrupt rise between 1961 and 1962, the three records follow each other very closely. The highest salinity common to all stations was in 1963, while the lowest was in 1961. It is interesting to note that the lowest year was followed directly by two of the highest years of the period. This in turn was followed by an abrupt decrease to another low salinity year. This pattern does not repeat itself within the time frame studied. The high salinity year of 1972 appears dramatically on all three records. The return to low salinity values in 1973 eliminates the tendency to draw any conclusion from these curves that a steady long-term significant increase is occurring.

However, the observation that for the period 1961-74 the salinity of every long-term averaged weekly mean for Bayou Barataria at Lafitte was higher than the corresponding values for the period 1956-74 prompted an investigation into the significance of this occurrence. As previously discussed, the period 1956-60 had been arbitrarily included in these long-term averages. In searching for some possible explanation and a more logical breaking point, we looked into the difference in salinity before and after the dredging of the Barataria

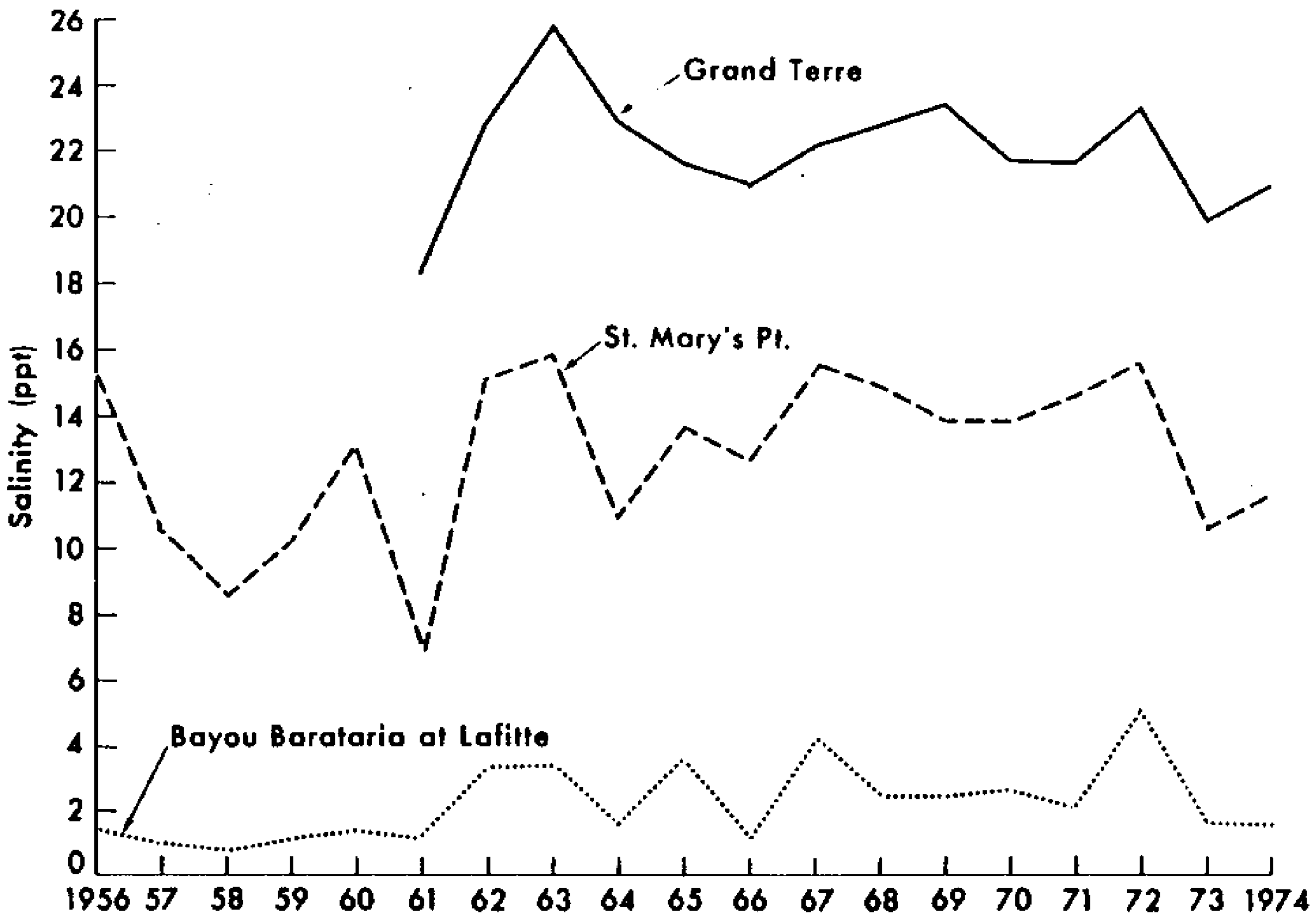

Fig. 2.6. Annual averages of salinity at Grand Terre, St. Mary's Point, and Bayou Barataria at Lafitte. Values for 1965 and 1966 at St. Mary's Point are interpolations because of the following data gaps: weeks 37–49 in 1965 and weeks 1-23 in 1966.

Waterway, which began around the middle of 1962. A t-test was run on the annual averages of salinity for two different data sets: (1-A) 1956-62 versus (1-B) 1963-74 and (2-A) 1956-61 versus (2-B) 1962-74.

The t-value obtained from comparing part A versus part B of data set 1 was 2.30, with 17 degrees of freedom. This indicates a significant probability (at the 95 percent level) that the increase in salinity from the period 1956-62 to the period 1963-74 would not have been by chance alone. The t-value obtained from comparing part A versus part B of data set 2 was 3.25, with 17 degrees of freedom. This also indicates a significant probability (at the 95 percent level) that the increase in salinity from the period 1956-61 to the period 1962-74 would not have been by chance alone.

It should be emphasized that a number of factors may be involved in this increase in salinity at Lafitte; and because of this, no one factor can be isolated as the cause. Land loss by natural processes in lower Barataria Basin may well be one factor involved in this increase with other possible factors including rainfall, Mississippi River discharge, and storm surges, as well as man-induced changes other than the dredging of the Barataria Waterway. One other possibility may be a correlation with the 18.6-year tide range cycle. Unfortunately, the period of record for salinity is insufficient to establish this possible correlation. The time periods before and after the dredging of the Barataria Waterway were chosen simply because the occurrence of this event at this time was well documented.

Long-term Trends — Water Temperature

WEEKLY AVERAGES

Temperature data were examined for three stations. Weekly averages were obtained from data reduced from the continuous chart recordings at Grand Terre (1958-75); weekly readings were obtained from the records at St. Mary's Point (1968-75); and daily readings were used to obtain weekly averages for Bayou Barataria at Lafitte (1970-73). All data were collected in degrees centigrade or converted from fahrenheit to centigrade for consistency. Both scales are indicated on the following plots. Weekly averages or readings for 1971 are superimposed on the composite plots to compare yearly variability to the long-term averages.

Grand Terre

The 17-year averaged weekly means obtained from the Grand Terre continuous records and the 1971 weekly averages are plotted in Figure 2.7. The averaged data are extremely smooth because of the long record length. There is a gradual seasonal rise starting at a winter low of 12.4°C in January (2d week), peaking at 30°C the first week of August (32d week), and dropping abruptly through October and November back to the winter low. A 15-week summer plateau (± 1.0°C) was maintained from the end of May (23d week) to the middle of September (38th week). The 1971 record varies considerably around the long-term curve but follows its trend. The largest discrepancy in 1971 was a warm 3-week period in December, where the 1971 temperature rose an average of 5.6°C above the averaged weekly means.

St. Mary's Point

The averages of 7 years of weekly temperature readings from St. Mary's Point and the 1971 weekly readings are plotted in Figure 2.8. The averaged data are not as smooth as those at Grand Terre because of the smaller number of samples averaged. Gradual seasonal warming from a winter low of 11.4°C in January (2d week), to a peak of 30.3°C near the end of July (30th week), and subsequent cooling in October and November are observed. A 16-week summer plateau (± 1.0°C) was maintained from the end of May (23d week) to the middle of September (39th week). The 1971 record varies considerably around the long-term curve but follows its trend closely. The longest discrepancy in 1971 was a slightly warmer 3-week period in December, where the 1971 temperature rose an average of 5.8°C above the averaged weekly means. The overall variability is considerably greater at this station than at Grand Terre, which is undoubtedly accounted for by the fact that the weekly averages used at Grand Terre have inherent smoothing because they are averages, while the weekly readings at St. Mary's Point have no smoothing at all. This can be seen by comparing Figures 2.7 and 2.8. The variability present in both curves is fairly consistent throughout the whole year.

Bayou Barataria at Lafitte

The 4-year averages of weekly means obtained from the Lafitte daily records and the 1971 weekly averages are plotted in Figure 2.9. It can be seen that the averaged data at this station are less

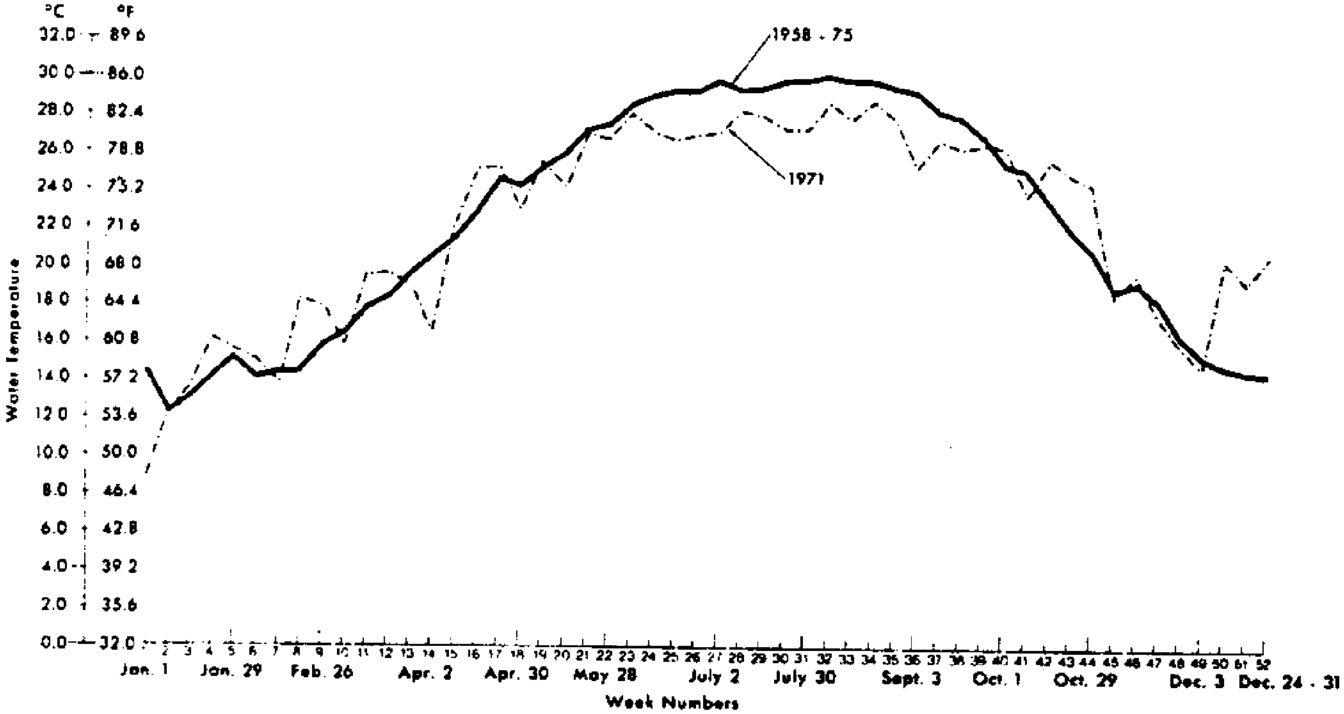

Fig. 2.7. Averaged weekly means of water temperature at Grand Terre (long-term plus 1971).

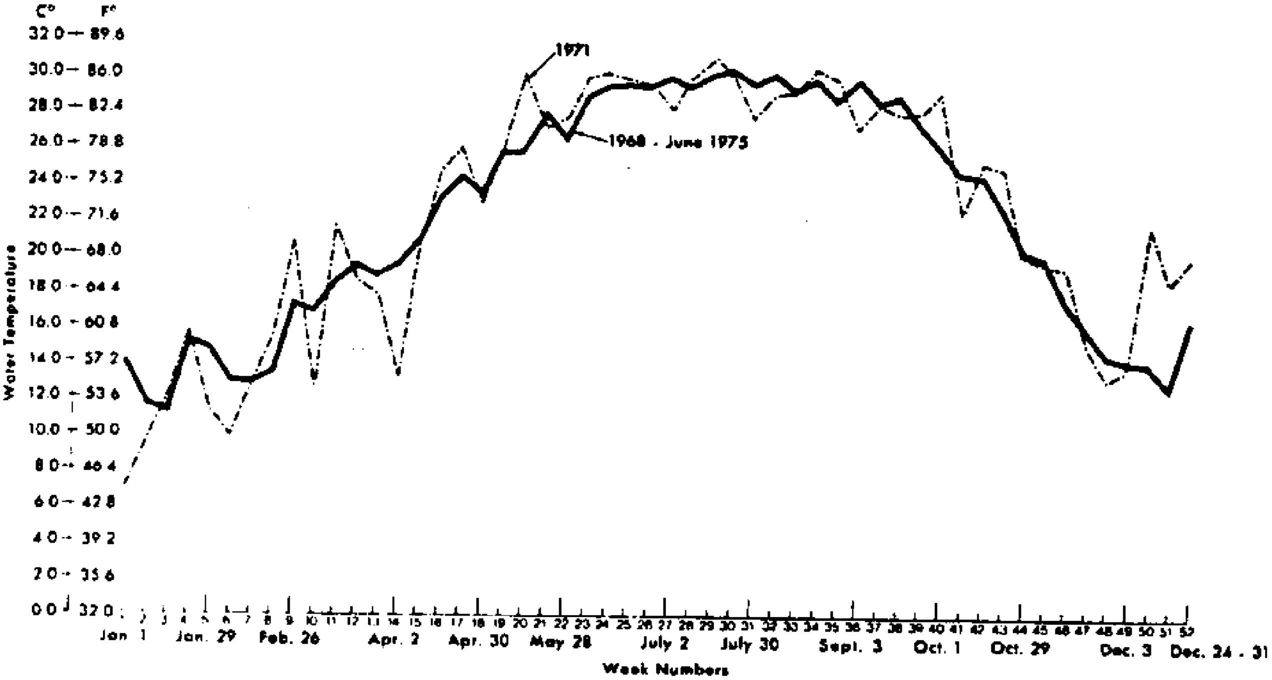

Fig. 2.8. Averaged weekly readings of water temperature at St. Mary's Point (long-term plus 1971).

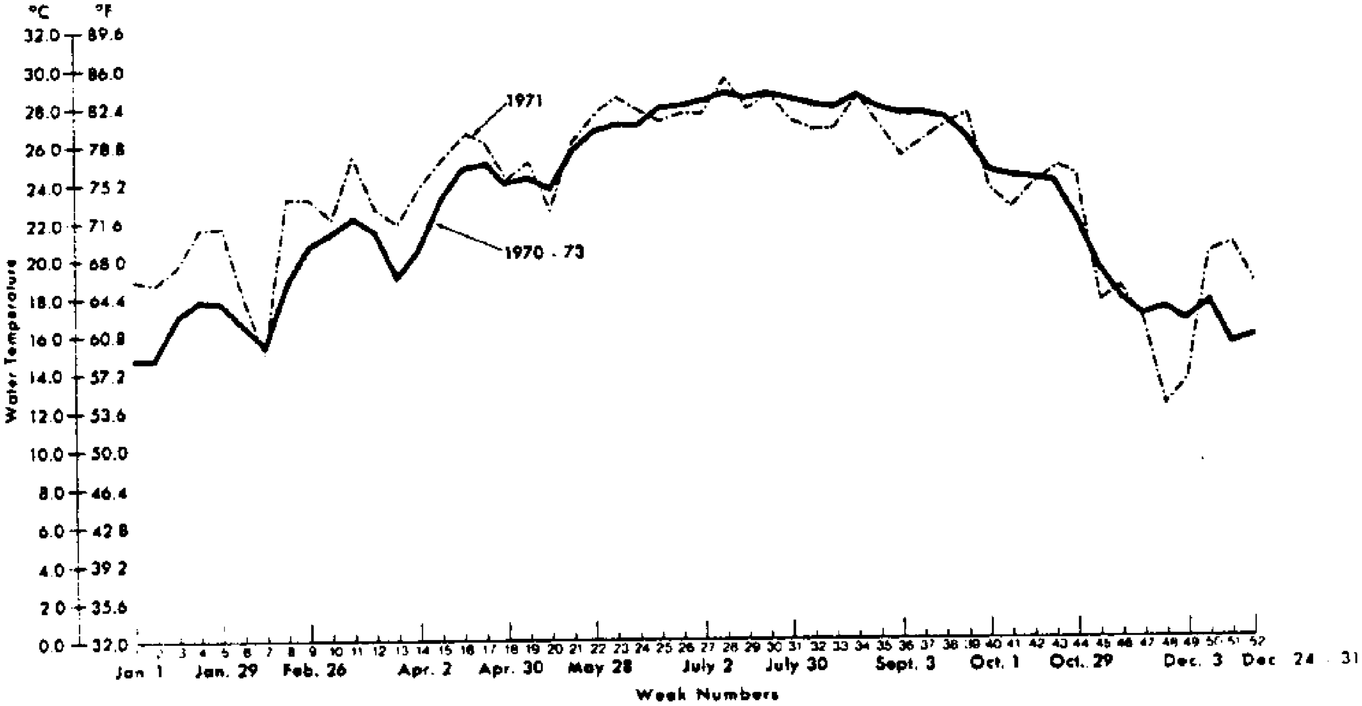

Fig. 2.9. Averaged weekly means of water temperature at Bayou Barataria at Lafitte (long-term plus 1971).

smooth than that at either of the other two locations. A similar seasonal warming from 14.7°C in January (2d week) to 28.6°C near the end of July (30th week), and back to the winter low is observed. A 17-week summer plateau (± 1.0°C) was maintained from the end of May (22d week) to the middle of September (39th week). The 1971 record varies considerably around the long-term curve but again follows its trend closely. The warmer trend in December is not as prominent, rising only an average of 3.8°C above the averaged weekly means. The overall variability of the weekly means is considerable at Lafitte mainly because of the short record (only 4 years). The 1971 variability is approximately the same as at the other stations where weekly means are available and is fairly consistent throughout the year.

SUMMARY

The long-term mean water temperatures represented by the available data are very similar at all three stations: 22.3°C at Grand Terre (1958-75); 21.8°C at St. Mary's Point (1968-75); and 22.8°C at Bayou Barataria at Lafitte (1970-73). These three stations also demonstrate similar trends. They are consistent even to individual weeks. In each case the annual water temperature curve is strongly asymmetrical with the warming trend 30-38 weeks in length and the cooling trend about 14 weeks.

Although the temperature records from all three stations exhibit the same general trends, there are differences that, although subtle, are significant. Grand Terre records show less of a change than St. Mary's Point, a later time arrival of maximum temperature, and a shorter period of the high temperature plateau. These three differences are thought to be related to thermal inertia (resistance to thermal change) brought about by the proximity of Grand Terre to the Gulf of Mexico. Temperature changes are moderated by the presence of such a large body of water. St. Mary's Point, on the other hand, is in a shallow estuarine area, which responds quickly to thermal inputs.

There would be a higher resistance to salinity change at Grand Terre if salinity were not drastically affected by Mississippi River discharge in the area offshore from Grand Terre.

Poor predictability of any given year from the long-term means is shown by a high degree of variation between the long-term means and 1971, although temperature data are considerably less variable than those of salinity.

Comparison of the long-term averaged weekly salinity means and long-term weekly temperature means at Grand Terre show that the forces that drive temperature changes act independently of the forces that drive salinity changes. During the spring, temperature is rising while salinity is falling. From late May through August salinity is rising and temperature is either steady or rising. In September and October, temperature is falling and salinity is rising. In November and December salinity has peaked and is falling.

Long-term Trends — Precipitation

Gulf waters enter the basin through tidal inlets. Freshwater input to Barataria Basin is provided. primarily from precipitation, agricultural runoff and some through the Algiers lock or New Orleans into the Intracoastal Waterway. An order of magnitude estimate of precipitation over the Basin was gained by investigating the long-term precipitation data collected and reported by the National Climatic

Center (NOAA), from New Orleans International Airport. These data were plotted in three different formats to show long-term trends:

- Monthly total precipitation for 1960-74 (New Orleans)
- Monthly total averaged precipitation for 1961-74 and 1971 (New Orleans)
- Annual total precipitation for 1956-74 (New Orleans)

MONTHLY TOTAL PRECIPITATION FOR 1960-74 (NEW ORLEANS)

Data were used directly from the listed precipitation in the Local Climatological Data—Annual Summary with Comparative Data—1974, New Orleans, La., as published by the National Climatic Center in Ashville, N.C. These monthly total precipitations were plotted each month from 1960 to 1974 (see Fig. 2.10). The most prominent feature of the plot is the complete lack of a pattern from month to month. A month with particularly high precipitation may be preceded or followed by a month with relatively low precipitation. Conversely, a month with particularly high precipitation may be preceded or followed by another month with relatively high precipitation. The years with several high monthly totals were 1961, 1966, and 1973. Although these years do not necessarily contain the highest rainfall of the 14-year record, they do seem to be indicative of exceptionally wet years. On the other hand, this criterion is not the only indication of exceptionally wet years.

Also, a record rainfall may occur during a particular month of a year that does not have an exceptionally high total. A good example of this is September 1971, during which there was a total rainfall of 16.74 inches, even though the entire year of 1971 did not have an exceptionally high total. Most (15.43 in) of the September 1971 rainfall occurred during two Gulf tropical disturbances.

A very poor correlation was found between monthly total precipitation at New Orleans (1960-74) and monthly average salinities at Grand Terre (1961-74), St. Mary's Point (1960-74), and Bayou Barataria at Lafitte (1960-74). Correlation coefficients of 0.021, 0.024, and 0.044 between precipitation at New Orleans and salinity at Grand Terre, St. Mary's Point, and Bayou Barataria at Lafitte, respectively, demonstrate that these two parameters do not correlate with each other on a monthly basis. As discussed below in Part 4, many factors other than precipitation alone control salinity fluctuations.

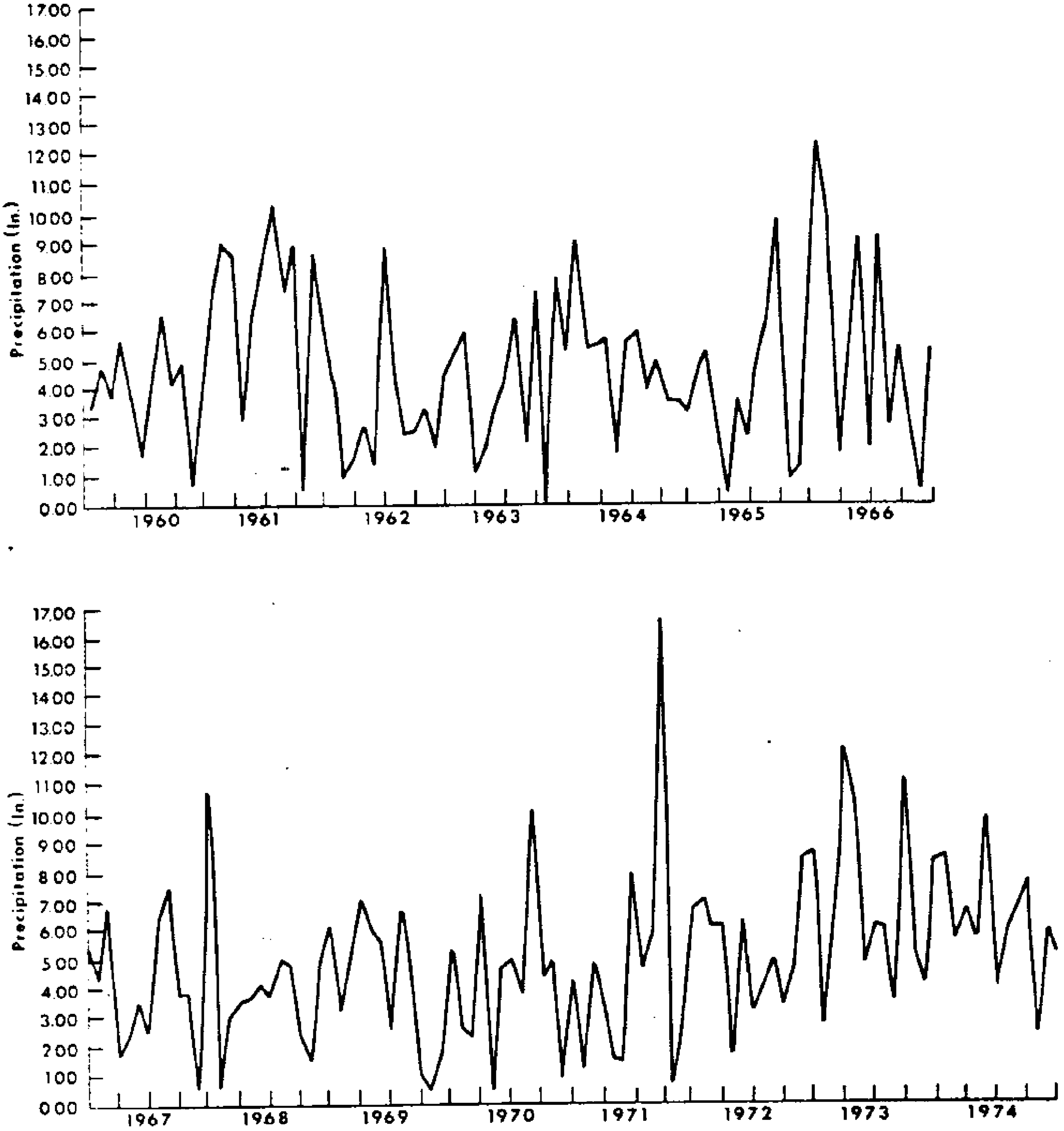

Fig. 2.10. Monthly total precipitation in New Orleans (1960-74).

MONTHLY TOTAL AVERAGED PRECIPITATION FOR 1961-74 AND 1971 (NEW ORLEANS)

The monthly total precipitation, as described above, was averaged over the 1961-74 time period to seek seasonal trends. The averaged totals were plotted (Fig. 2.11), and the 1971 totals were superimposed for comparison. The averaged curve is drastically smoothed, making it very difficult to recognize any significant monthly variation. A slight low (1.34 in below the 1961-74 annual average) is evident in April; highs are seen during July, September, and December, with an extreme low in October.

Even though there is not a great deal of visually apparent difference between seasons on a long-term averaged basis, calculated values show that the lowest 3-month average is for the period October to December (4.15 in), which is 15 percent (0.74 in) below the 1961-74 monthly average for the entire year (4.89 in). This fall-low precipitation corresponds with the fall-high salinities observed at all three stations in the long-term averaged data. For this 3-month period (Oct. - Dec.), the salinity at Grand Terre (26.0 ppt) is 17 percent (3.8 ppt) above the annual average (22.2 ppt); the salinity at St. Mary's Point (16.2 ppt) is 22 percent (2.9 ppt) above the annual average (13.3 ppt); and at Bayou Barataria at Lafitte the salinity (3.5 ppt) is 30 percent (0.8 ppt) above the annual average (2.7 ppt). The data failed to support a similar correlation between the highest 3-month value of long-term average precipitation, which occurred during the period July to September (5.93 in), and the lowest 3-month values of long-term average salinity. The lowest average salinity at Grand Terre was for the period April to June (18.3 ppt); at St. Mary's Point the lowest was for the period January to March (10.0 ppt); and at Bayou Barataria at Lafitte the lowest was for the period January to March (1.4 ppt). The latter may be due to the secondary precipitation peak in January through March, but the former is related to Mississippi River outflow.

As illustrated in Figure 2.11, rainfall during the year 1971 as opposed to the long-term averages exhibited exceptionally low values during April and May and an exceptionally high value in September. This unusual monthly pattern probably explains the lack in September.

ANNUAL TOTAL PRECIPITATION FOR 1956-74 (NEW ORLEANS)

The data as referred to above was again plotted to show the annual total precipitation per year for the 1956-74 period (see Fig. 2.12). It differentiates between wet and dry years; 1961 and 1973 were exceptionally wet years while 1962 and 1968 were particularly dry years. Other extremes can be seen in the curve, but no obvious trend or cyclic pattern is present. The variability from year to year is very large and provides no assistance in characterizing the system dynamics as the result of repeatable processes.

SUMMARY

These precipitation data from New Orleans provide an insight into another source of water input to the Barataria Basin. A more detailed analysis of water surplus is presented in Part 3. These records are included here to show the general trends and severe limitations of these data when studying the dynamics of an environmental system.

Salinity Variability

The variability of the salinity data prompted a detailed analysis of the standard statistical properties of the salinity for the long-term period, 1956-74. Annual averages and the means for each corresponding week based on this 19-year data record were obtained. The standard Statistical Analysis System (SAS) analysis package was implemented, and a plot was constructed showing the long-term weekly mean of salinity at Bayou Barataria at Lafitte, the calculated standard deviation, and the coefficient of variation (see Fig. 2.13). The analysis shows a close correspondence between the three parameters. Salinity peaks can be seen during weeks 10, 15, 18, 22, 29, 38, 43, and 49. The standard deviation follows the high salinity values but not perfectly. The correlation coefficient is 0.69 for the annual cycle. The correlation between these two parameters is 0.85 for the first 26 weeks but is 0.61 for the last 26 weeks. Thus the pattern of salinity variation increasing with an increase in mean salinity is more likely to be found during the spring than during the summer and fall months. The relation between the coefficient of variation and either of the other two parameters is not so clear.

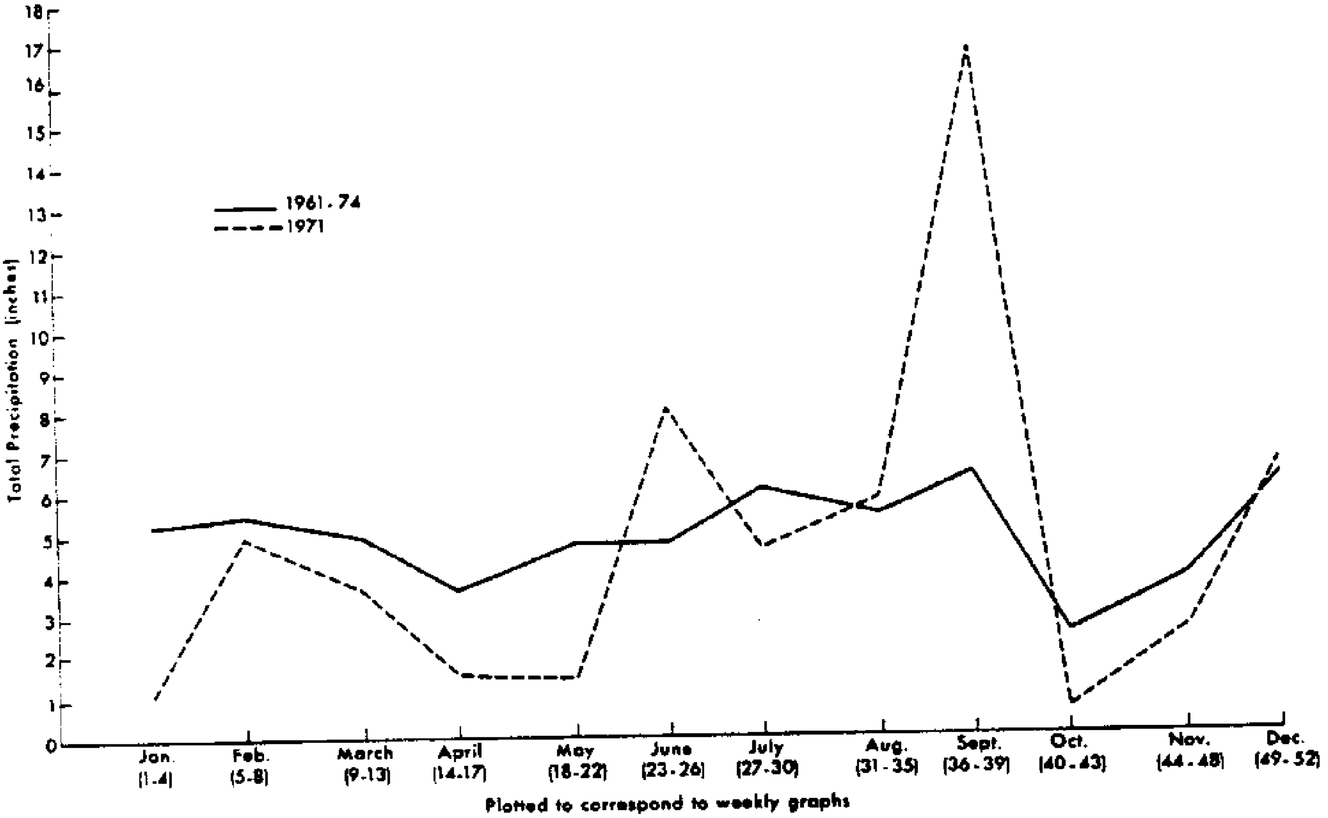

Fig. 2.11. Monthly total averaged precipitation at New Orleans (1961-74 and 1971).

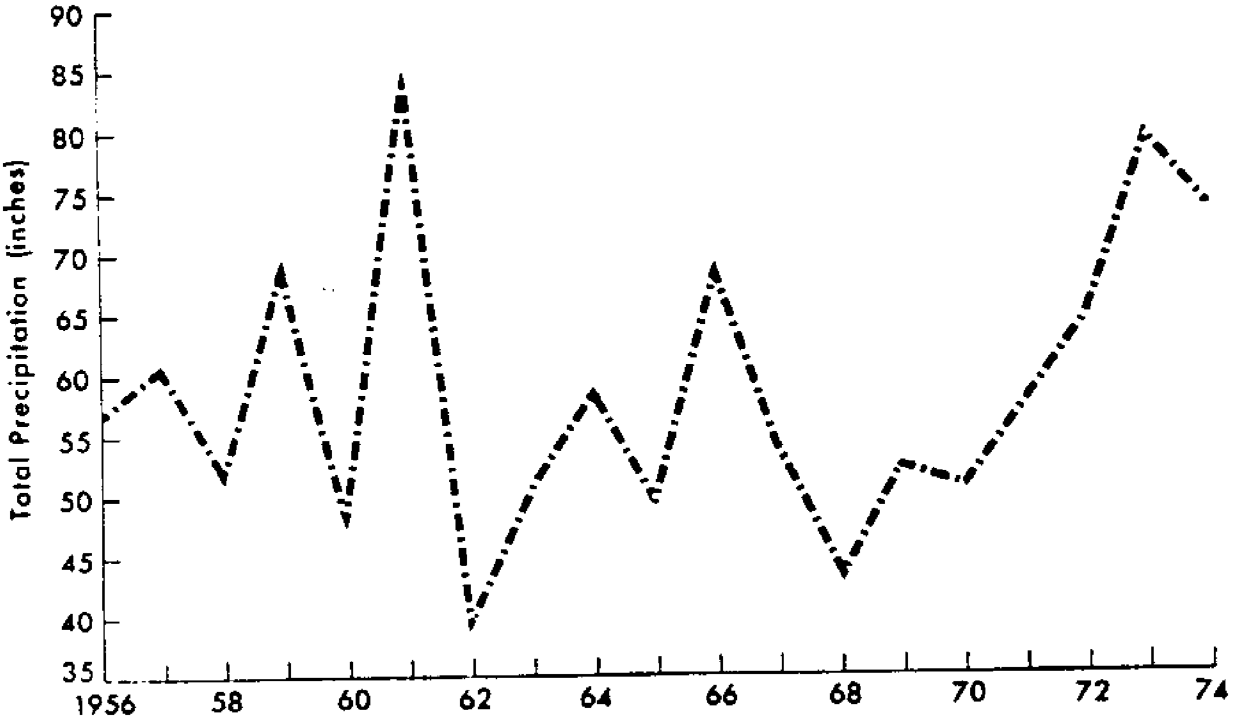

Fig. 2.12. Annual total precipitation at New Orleans (1956-74).

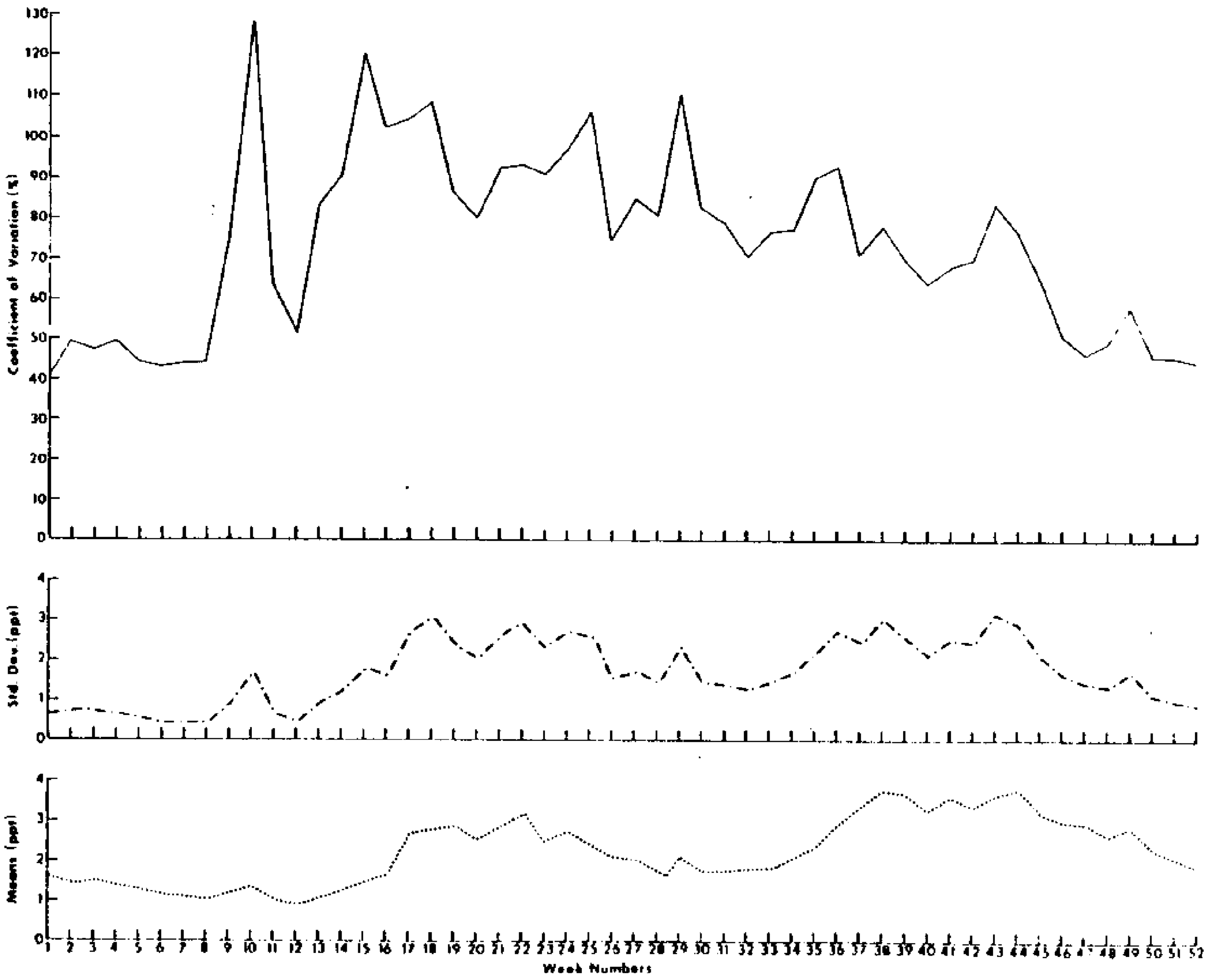

Fig. 2.13. Long-term weekly salinity statistics at Bayou Barataria at Lafitte (1956-74): long-term weekly means; standard deviation; and coefficient of variation.

Part 3. Synoptic Weather Types as Indexes of Forcing Functions for Environmental Systems

INTRODUCTION

Physical parameters (air temperature, relative humidity, wind, etc.) derived from meteorological observations make up what is generally thought of as weather, and, in the longer term, climate. Since weather events exert such a strong influence over environmental processes and responses, an understanding of frequencies and extremes of weather properties in a region can provide valuable insight into the functions of that region as a natural system. Analysis of these weather properties and consequent environmental interactions forms the basis of climatological interpretation.

Conventional climatological analysis often relies on statistical generalizations of means, extremes, and frequencies of meteorological data for long time periods. It is now recognized that these elementary climatic data are inadequate in much bioclimatological work (Barry and Perry 1973, p. 427); year-to-year variation of global circulation regimes precludes precise specification of a region's climate and environmental interactions in these terms.

Climatic data need to be organized so their variations can be related directly to variations in selected environmental parameters, thereby providing a means of assessing climate's contribution in causing a natural system to function. For this purpose it is useful to group climatic data into synoptic classes rather than treating the whole frequency distribution together. Organizing regional climate into a synoptic framework combines selected parameters into weather types and characterizes selected weather properties associated with each type.

The daily weather can be organized on the basis of atmospheric circulation into relatively few types, which provide an environmental baseline inventory. This synoptic approach is from a local perspective, and the subcontinental atmospheric circulations are categorized in terms of weather.

WEATHER TYPES

From the perspective of New Orleans, a first-order weather station of the National Weather Service, the synoptic weather situation at 0600 hours CST on the daily weather map of the National Weather Service has been classified into one of eight all-inclusive types for each day from 1971 through 1974 (Muller 1976). Brief comments about each synoptic type follow:

Pacific High.--Pacific High circulation usually brings mild and relatively dry air following a cold front across southern Louisiana. Most often the center of the surface high is over the eastern Pacific Ocean or west of the Rocky Mountains.

Continental High.--The Continental High anticyclone center is usually east of the Rocky Mountains, and the associated surface air flow is from Canadian or Arctic regions. This weather type is restricted to fair weather associated with the core of the anticyclone.

Frontal Overrunning.--The frontal overrunning synoptic type occurs frequently when the polar front is more or less stationary along the Gulf Coast or over the northern Gulf. Frequently waves develop along the front over the western Gulf and then sweep northeastward bringing heavy clouds and precipitation to southern Louisiana. Generally either polar or Arctic air is associated with this weather type.

Coastal Return.--When the crest of an anticyclone ridge drifts to the east of Louisiana, surface winds over New Orleans veer from northeast to east to southeast. During winter and spring the surface air usually represents continental polar air modified by short passages over the Atlantic and Gulf during clockwise circulation near the Gulf Coast. During summer and autumn, in contrast, the coastal return also includes the Bermuda High situation, when a ridge of tropical air extends westward from the Atlantic over the southeastern states, and the air flow over New Orleans is again from easterly components.

Gulf Return.--When the anticyclonic ridge drifts further eastward, the isobar configuration usually results in a strong return flow of maritime tropical air from the Caribbean and Gulf on the western margin of the ridge. A similar flow occurs when developing low pressure over the Texas panhandle begins to sweep northeastward. In both of these situations, the coastal return flow of modified continental air is gradually replaced by moist tropical air as surface winds continue to veer from the east to southeast to south.

Frontal Gulf Return.--When the return flow is affected by convergence or lifting along an approaching front, the resultant weather deserves special designation as a separate weather type. Arbitrarily, frontal Gulf return includes periods when a cold front from the west or north is located within a zone extending out about 300 miles from New Orleans. This type also includes periods after a northeastward-moving warm front has crossed over New Orleans, but only until the front has progressed 100 or more miles to the northeast. Hence, frontal Gulf return is restricted to warm-sector periods when fronts are affecting the weather over New Orleans, and Gulf return includes the same air flow with distant fronts.

Gulf Tropical Disturbances.--During summer and fall, southern Louisiana is occasionally influenced by tropical systems that usually drift from east to west across the northern Gulf. These disturbances range from relatively weak easterly waves to rare but severe hurricanes such as Camille in 1969. Gulf tropical disturbances are associated with instability through deep moist layers, and copius precipitation is often produced.

Gulf High.—Especially during summer there are periods when the western extension of the Bermuda High is displaced southward over the Gulf of Mexico, and the weak local circulation is from the southwest. This flow consists usually of maritime tropical air, but occasionally somewhat drier continental tropical air from western Texas will reach New Orleans. Infrequently during winter and spring a flat high pressure cell over the Gulf will also draw warm, dry air from Texas or Mexico over Louisiana.

Cataloging the weather into types involves the formulation of synoptic weather type calendars based on occurrence and duration of each weather type. The procedure involves studying daily surface weather maps and classifying the weather at New Orleans into one of the eight types. Each month is then structured into a calendar by fitting the observational data, published for every third hour, to the weather map analysis of synoptic types.

PROPERTY SUMMARIES

The calendars and monthly summaries of meteorological properties by synoptic weather types provide a climatic baseline from which inferences about environmental interactions may be drawn. Table 3.1 summarizes the properties of weather types for four Januaries (1971-74) and illustrates the contrasts among weather types. At 0600 hours in January, for example, Table 3.1 shows the orderly sequence of mean temperature in degrees fahrenheit running from CH as the coldest to FGR as the warmest.

TABLE 3.1

Mean Properties Synoptic Weather Types
New Orleans January 1971-1974

0600 CST	PH	CH	FOR	CR	GR	FGR	GTD	GH
No. Cases	8	17	37	8	30	18	0	5
Air Temperature	49	38	47	48	62	67	-	49
Dew Point Temperature	47	31	41	45	60	64	-	45
Relative Humidity	92	78	81	89	93	91	-	65
Wind Direction	34	04	01	12	14	17	-	35
Wind Speed	4	7	10	4	6	8	-	4
Cloud Cover	4	1	9	7	9	9	-	4

1500 CST	PH	CH	FOR	CR	GR	FGR	GTD	GH
No. Cases	8	19	33	9	30	20	0	5
Air Temperature	66	54	53	61	73	73	-	66
Dew Point Temperature	48	32	45	48	62	65	-	41
Relative Humidity	53	45	76	64	70	76	-	48
Wind Direction	32	36	01	07	16	19	-	30
Wind Speed	8	9	10	9	11	9	-	8
Cloud Cover	2	1	10	6	7	10	-	4

Both the dewpoint temperature and relative humidity follow a relatively similar progression. There is also a logical progression of mean wind directions given in azimuths from 01 through 36 to represent 10° through 360°. Mean wind speeds are in knots, and the stronger winds associated with frontal activity are obvious in the table. Cloud cover is relatively high, except for the CH type.

Precipitation and evaporation are closely related to the weather types. Table 3.2 shows which weather types produce precipitation. It is important to note that 45 percent and 17 percent of the total precipitation during the four-year period was associated with the FGR and FOR types respectively: hence frontal activity accounted for about two-thirds of the rainfall. These two weather types were present only 27 percent of the time.

Reference to Table 3.1 illustrates that rates of evaporation change with each weather type. When it is cloudy and the air is moist (as in FGR), evaporation will be much less than when it is clear and the air is drier (as in CH). Solar energy input and vapor pressure gradient are conducive to evaporation in the latter case.

WATER SURPLUS CALCULATIONS

Rainfall, which can be measured directly (if not accurately), is not the best indicator of environmental stress within a natural system. The difference in incoming precipitation and potential evapotranspiration (energy demand on the environment for water) is a much better indicator. A water-budget framework in conjunction with the synoptic weather types provides useful estimates of moisture transport and exchange and of water surplus generation within a basin.

Freshwater input into a basin can be estimated by use of a daily climatic water budget developed by Thornthwaite (1948). Figure 3.1 can be used to discuss the basic water budget components summed on a monthly basis as they apply to Baton Rouge for the period 1960 through 1967 (Muller and Larimore 1975). Potential evapotranspiration (PE) is represented by the upper continuous curve. Potential evapotranspiration may be defined as the maximum amount of evapotranspiration that would take place with a continuous vegetation cover and no shortage of soil moisture to the vegetation over a large area. Potential evapotranspiration is based on energy supplied principally by solar radiation. Thornthwaite based his estimates of PE upon mean

TABLE 3.2

Mean Monthly Precipitation by Synoptic Weather Types
New Orleans 1971-1974
In Inches

	J	F	M	A	M	J	J	A	S	O	N	D	YR	%
PH	0	0.1	0	0.2	0	0	0	0	0	0	0	0	0.3	
CH	0	0.1	0	0	0	0.4	0.3	0	0	0	0	0	0.8	1
FOR	1.5	1.5	1.6	1.2	0.2	0.1	0.4	0.1	0.6	0.5	2.6	1.5	11.8	17
CR	0	0	0	0	0	0	0.2	1.1	0.4	0.2	0	0	1.9	3
GR	0.8	0.2	0.1	0.5	0.4	1.9	2.0	1.1	0.1	0.8	0.1	0	8.0	12
FGR	2.5	3.8	5.4	2.9	4.2	0.4	0.1	0.7	1.0	1.6	2.5	5.5	30.6	45
GTD	0	0	0	0	0.8	0	0.2	0.7	7.5	0	0	0	9.2	13
GH	0	0	0	0	0	2.4	1.9	1.4	0.1	0	0	0	5.8	8
All Types	4.8	5.7	7.1	4.8	5.6	5.2	5.1	5.1	9.7	3.1	5.2	7.0	68.4	

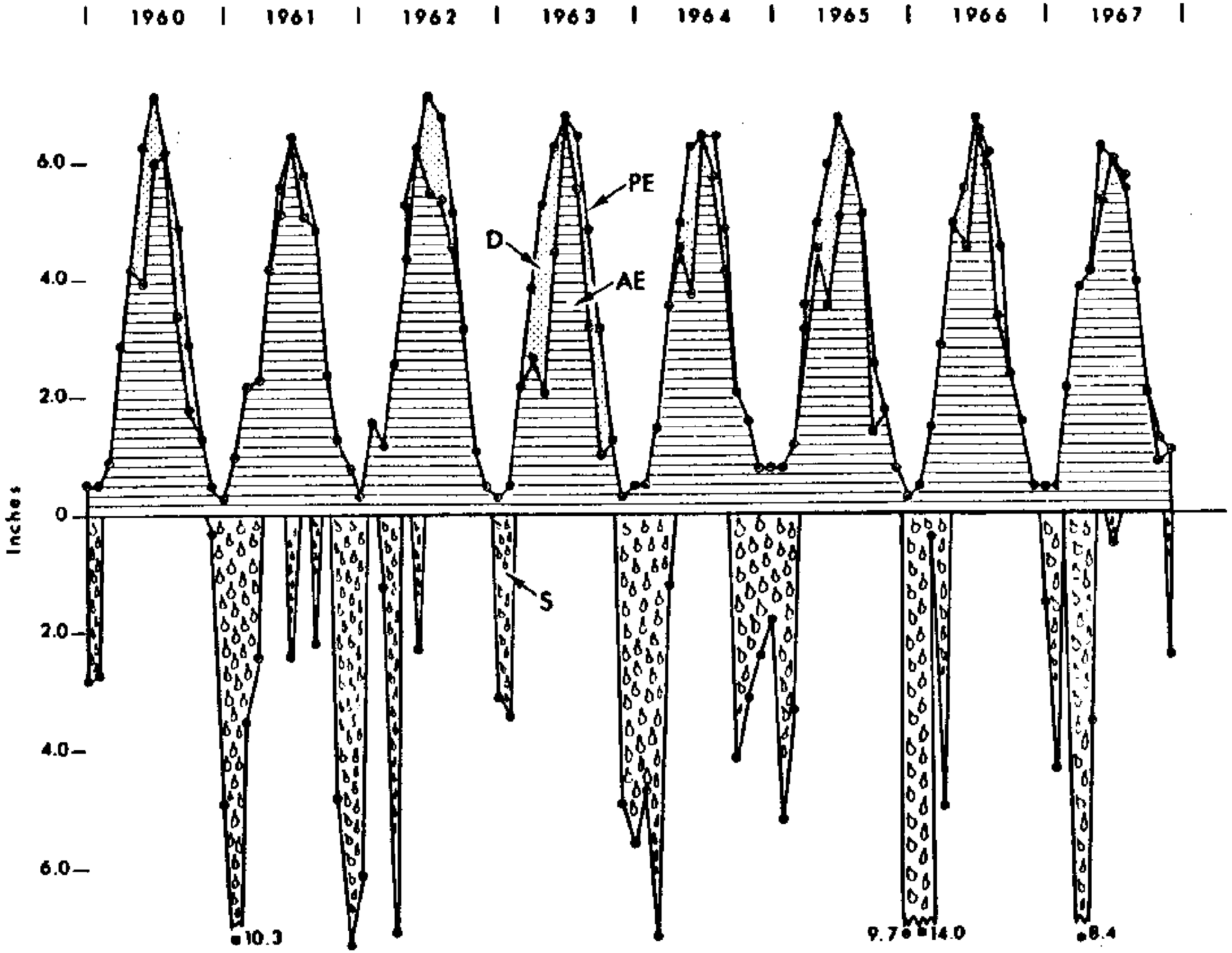

Fig. 3.1. Monthly course of computed water balance budget factors, potential evapotranspiration (PE), actual evaporation (AE), deficit (D), and surplus (S) at Baton Rouge, La. 1960-67.

monthly temperatures and day-length factors. In a daily water budget, mean daily temperatures are utilized instead.

The horizontally ruled areas in Figure 3.1 represent actual evapotranspiration (AE). Since declining soil moisture inhibits actual evapotranspiration, AE is often less than PE. This is especially true in the summer and autumn in Baton Rouge. When AE is less than PE, a deficit (D) occurs and plants begin to suffer from the decreased soil moisture and lower transpiration rates.

Of more immediate concern in this study is the surplus (S). Surplus is the "excess precipitation" after accounting for losses to evapotranspiration and soil-moisture storage. Surplus is moisture available for streamflow or groundwater recharge. Figure 3.1 illustrates that surpluses are greatest in winter and early spring when precipitation is high and PE is low.

Figure 3.2 illustrates how surplus is calculated for vegetated surfaces. Precipitation (P) that falls on the vegetative surface is subjected to PE. If P-PE is negative or zero, all of the precipitation is evaporated and no moisture is left for surplus. If P-PE is positive, some moisture infiltrates into the soil and the remaining moisture becomes surplus (groundwater recharge, streamflow, etc.). The amount of positive P-PE entering the soil can be no greater than soil moisture storage deficiency prior to precipitation.

A computer program of the Thornthwaite daily climatic water budget prepared by Yoshioka (1971) was modified for application to Barataria Basin. The four primary modifications were: (1) potential evapotranspiration, (2) soil moisture storage, (3) precipitation intensity, and (4) marsh and open-water surplus. Indirect evidence from streamflow data and evaporation pans suggests that the Thornthwaite PE estimates for Louisiana are a little low in winter and a little high in summer, with overall annual estimates probably less than 10 percent below "real-world" PE (Muller and Larimore 1975). As a result, 12 monthly coefficients were inserted to convert Thornthwaite PE to the equivalent of pan evaporation.

A two-layer soil moisture storage replaced a single-layer storage in the original Thornthwaite model. This, together with a precipitation intensity factor, allows for moisture exchanges to operate easily within the upper soil moisture zone and for a more gradual exchange to occur with depth.

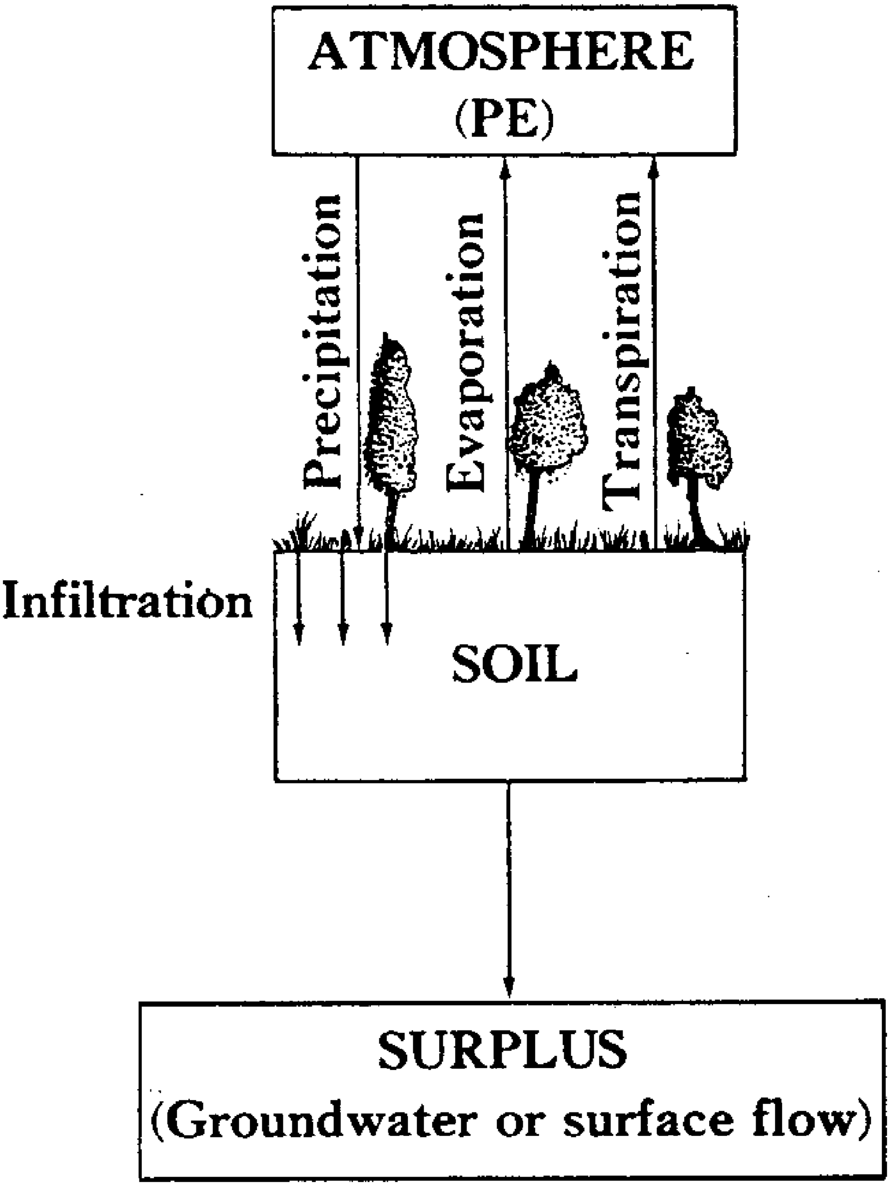

Fig. 3.2. Surplus calculation for well-drained surfaces.

Open-water and marsh areas were treated differently than well-drained vegetated areas (Muller 1975). Since water is nearly always near the surface in the marsh and always at the surface in the open-water areas, no soil moisture storage factor was used. Surplus (S) then becomes the positive P-PE term (Fig. 3.3; see Fig. 3.2 for comparison with well-drained areas).

Water surplus for Barataria Basin is computed as follows:

1) land surface: $S_L = (P_L - PE_L) - \Delta ST_L$, where S_L is the surplus over a well-drained, vegetated surface (land); P_L is the precipitation over land; PE is the potential evapotranspiration over land; $(P_L - PE_L)$ is positive; and ΔST_L is the change in soil moisture storage.

2) open water surface: $Sw = Pw - PEw$, where Sw is the surplus over open-water or marsh areas; Pw is the precipitation over open-water; PEw is the potential evapotranspiration over open-water; and $(Pw - PEw)$ is positive.

3) basin surplus: $S = C_L S_L + CwSw$, where S is the basin surplus, and C_L and Cw are fractions of the basin area occupied by land and open water, respectively.

Table 3.3 illustrates the two weighting techniques that were applied to the climatic stations and the different land (or water) surfaces. Column 4 lists the coefficients, as previously discussed, given each station during the analysis while columns 5 and 6 show those given to surfaces based upon percentage of marsh. It can be seen in Figure 3.4 that sub-basin I approximates the drainage area of Bayou Chevreuil at Chegby, and sub-basins I through V sum to the drainage area of Bayou Des Allemands at Des Allemands. Sub-basins I through VI represent the area of Barataria Basin above Lafitte, and sub-basins I through VII equal the entire area of Barataria Basin.

The climate of Barataria Basin has been organized in terms of the eight synoptic weather types to establish the relationships between climate, surplus precipitation, water levels, and salinity. All the weather events and associated properties that occurred in the basin during 1971 have been put into one of the eight types. Though other processes such as oceanographic forcing functions are recognized as important within the system, synoptic organization allows a closer look at climatological aspects of energy transfers,

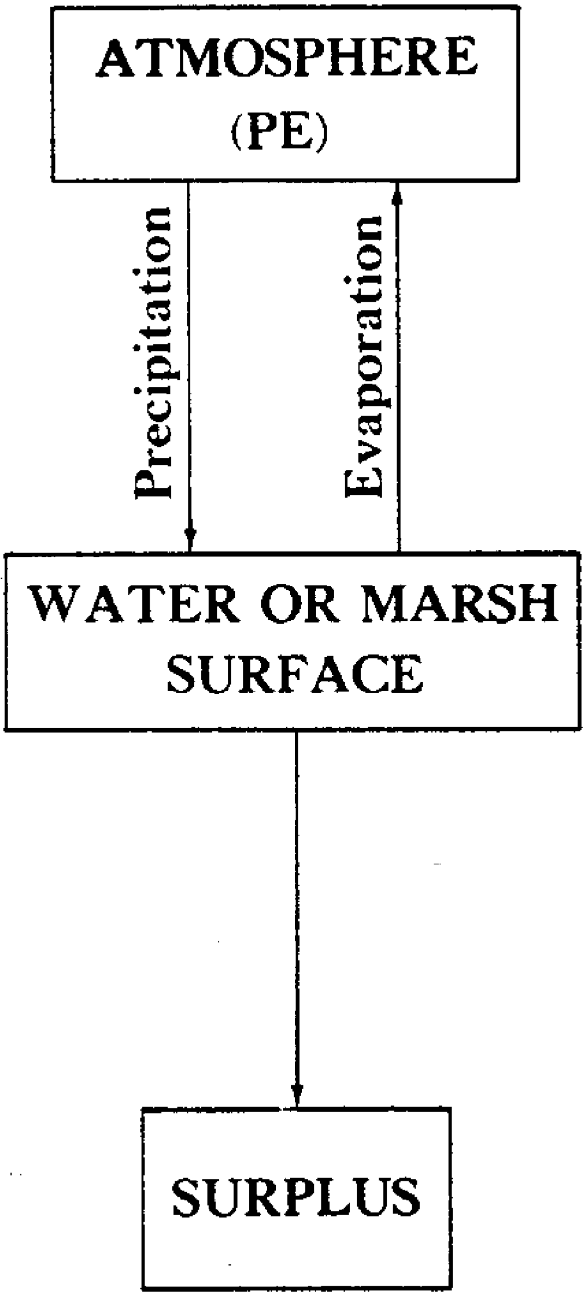

Fig. 3.3. Surplus calculation for open water and marsh surfaces.

TABLE 3.3

Climatic Stations, Station Weights, and Marsh *vs* Non-Marsh Areas for Sub-Basins of Barataria Basin

SUB-BASIN Col 1	AREA (mi^2) Col 2	CLIMATIC STATION Col 3	STATION WEIGHT Col 4	% NON-MARSH Col 5	% MARSH Col 6
I	268.3	Donaldsonville	60	38	62
		Reserve	10		
		Schriever	30		
II	113.0	Paradis	20	27	73
		Schriever	80		
III	39.0	Paradis	100	02	98
IV	157.7	N.O. Audubon	10	33	67
		Paradis	30		
		Reserve	60		
V	29.4	N.O. Audubon	40	0	100
		Paradis	40		
		Schriever	20		
VI	394.2	Paradis	50	13	87
		N.O. Audubon	50		
VII	1013.7	Galliano	40	0	100
		Diamond	60		
	2015.3				

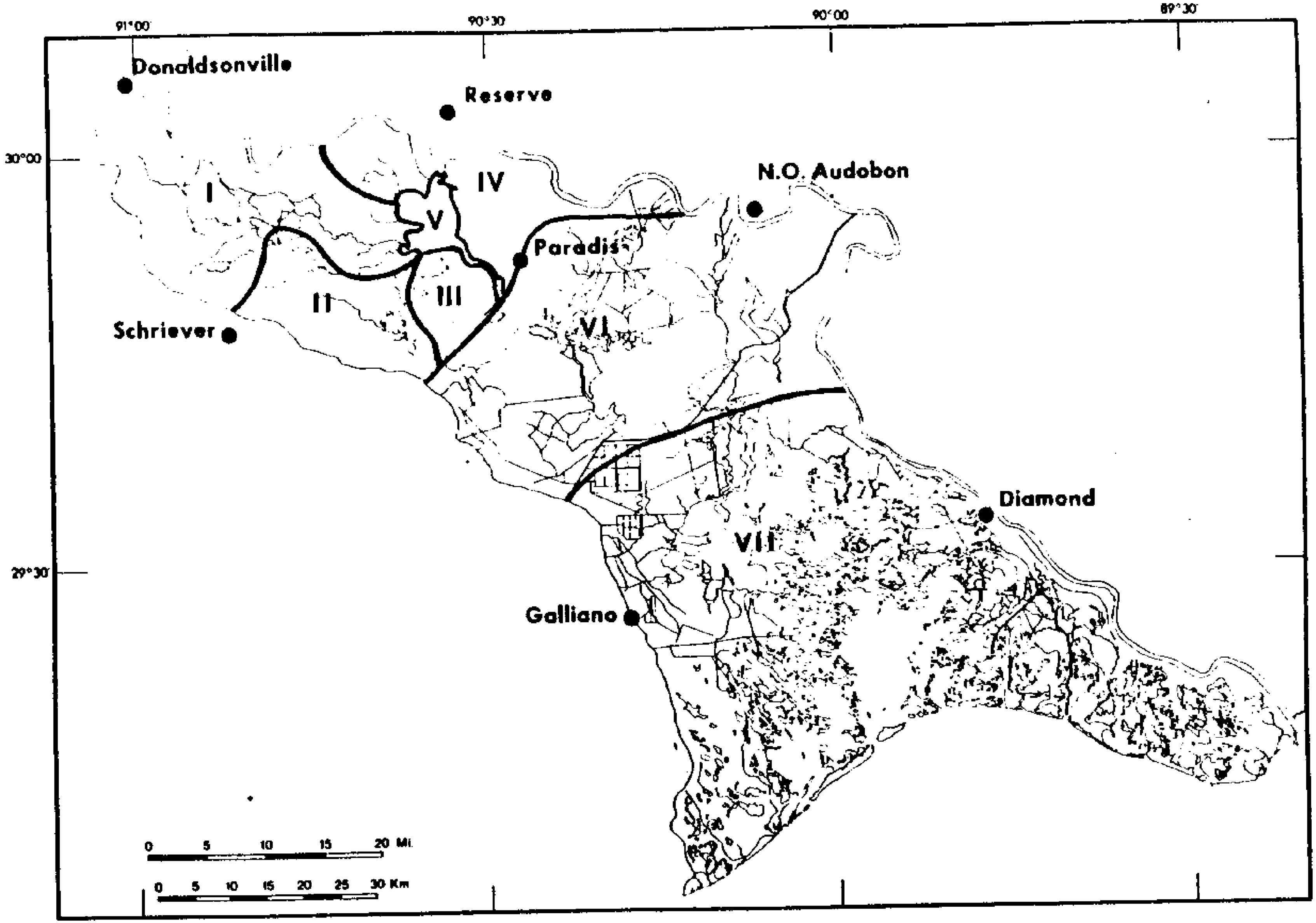

Fig. 3.4. Location of climate stations and subbasins.

atmospheric moisture content and transport, and environment-atmospheric moisture exchange.

The synoptic climatological baseline has been produced with New Orleans data, but the same sequences and weather type duration and properties are assumed over the entire basin. A time lag factor is acknowledged, but lack of synoptic climatological data over the basin necessitates utilization of the New Orleans baseline for assessment of climatic driving functions within Barataria Basin.

CHARACTERIZATION OF 1971

A characterization of 1971 in terms of the weather types is presented here to illustrate the usefulness of synoptic climatology in the Barataria Basin study. Table 3.4 shows the percent of time each weather type occurred. Weather conditions associated with each type were present the actual amount of time shown in the table. For instance, CH type was present 21 percent of 1971, GR 17 percent, and GTD only 6 percent. The continental polar (cP) index is an indicator of the occurrence of drier, cooler continental air over the basin (33 percent of the year), whereas the maritime tropical (mT) index indicates the amount of time moist, warm air was present (49 percent of the year). More important than the annual totals, though, are the percent of time the synoptic weather types were present in each month and their seasonal progression of occurrence. Storminess, as indicated by the storminess index, diminishes in the summer, pointing out the seasonal retreat of frontal activity from the region.

Mean properties of each weather type have been formulated for January, April, July, and October, providing an assessment of the impact of weather through the year when related to occurrence and duration of each synoptic weather type (Tables 3.5, 3.6, 3.7, 3.8). A comparison of Table 3.5 with Table 3.1 shows how January 1971 weather compared to the four-year average January weather. Annual regimes of mean weather type properties for CH and GR (the most dominant weather types in terms of duration) are shown in Tables 3.9 and 3.10. The 0600 CST means represent minimum values, whereas 1500 CST means represent maximum values for each of the parameters.

Table 3.11 shows the percent of time precipitation occurred within each weather type, given in terms of percent rainy hours (defined as any hour

TABLE 3.4

SYNOPTIC WEATHER TYPES

Percent of Hours

New Orleans, 1971

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Pacific High	4	13	15	5	7	0	0	0	0	15	5	6	6
Continental High	18	21	21	22	30	3	4	27	22	26	42	17	21
Frontal Overrunning	21	16	15	14	14	0	8	6	7	3	15	27	12
Coastal Return	12	15	11	10	5	5	0	8	17	40	22	2	12
Gulf Return	29	11	16	20	17	38	37	8	8	8	8	9	17
Frontal Gulf Return	14	24	23	29	27	0	6	0	4	6	8	38	15
Gulf Tropical Disturbance	0	0	0	0	0	0	13	11	43	0	0	0	6
Gulf High	2	0	0	0	0	55	32	40	0	2	0	0	11
Frontal Index (FOR & FGR)	35	40	38	43	41	0	14	6	11	9	23	65	27
cP Index (FOR & CH)	39	37	36	36	44	3	12	33	29	29	27	44	33
mT Index (GR, FGR,GH,GTD)	45	35	39	49	44	93	88	59	55	16	16	47	49
Storminess Index (FOR,FGR,GTD)	35	40	38	43	41	0	27	17	54	9	23	65	33

TABLE 3.5 Mean Properties of Synoptic Weather Types, New Orleans, January 1971.

<u>0600 CST</u>	PH	CH	FOR	CR	GR	FGR	GTD	GH
No. Cases	2	5	7	4	8	4	0	1
Air Temperature	42	40	41	43	62	65	-	54
Dew Point Temperature	38	32	33	41	60	63	-	53
Relative Humidity	86	73	76	92	92	93	-	96
Wind Direction	06	03	36	14	15	22	-	0
Wind Speed	3	8	10	3	6	7	-	0
Cloud Cover	6	1	9	7	9	10	-	10
<u>1500 CST</u>								
No. Cases	1	8	6	2	10	3	0	1
Air Temperature	54	57	51	57	72	75	-	64
Dew Point Temperature	40	33	38	49	59	63	-	61
Relative Humidity	59	42	67	76	66	65	-	90
Wind Direction	21	01	34	07	17	22	-	29
Wind Speed	3	9	11	9	10	10	-	5
Cloud Cover	4	1	10	4	7	7	-	10

TABLE 3.6 Mean Properties of Synoptic Weather Types, New Orleans, April 1971.

	PH	CH	FOR	CR	GR	FGR	GTD	GH
0600 CST								
No. Cases	1	7	5	2	6	9	0	0
Air Temperature	61	44	57	44	64	72	-	-
Dew Point Temperature	53	38	52	41	60	67	-	-
Relative Humidity	75	80	83	91	87	86	-	-
Wind Direction	01	35	32	05	11	19	-	-
Wind Speed	5	6	8	2	5	6	-	-
Cloud Cover	0	0	10	5	8	9	-	-
1500 CST								
No. Cases	2	6	4	4	5	9	0	0
Air Temperature	81	68	75	75	78	82	-	-
Dew Point Temperature	62	36	57	46	63	67	-	-
Relative Humidity	53	32	55	37	62	62	-	-
Wind Direction	37	33	04	12	16	20	-	-
Wind Speed	9	10	10	10	9	9	-	-
Cloud Cover	3	2	9	3	6	8	-	-

TABLE 3.7 Mean Properties of Synoptic Weather Types, New Orleans, July 1971

	PH	CH	FOR	CR	GR	FGR	GTD	GH
0600 CST								
No. Cases	0	1	2	0	11	2	4	11
Air Temperature	-	72	73	-	76	75	77	75
Dew Point Temperature	-	70	70	-	72	71	73	71
Relative Humidity	-	93	89	-	87	89	88	89
Wind Direction	-	0	28	-	09	30	06	25
Wind Speed	-	0	3	-	4	2	5	4
Cloud Cover	-	10	10	-	6	9	4	5
1500 CST								
No. Cases	0	1	3	0	11	2	4	10
Air Temperature	-	89	82	-	84	80	82	89
Dew Point Temperature	-	70	74	-	74	71	72	73
Relative Humidity	-	54	77	-	88	75	71	61
Wind Direction	-	03	31	-	16	30	11	29
Wind Speed	-	5	7	-	7	5	10	6
Cloud Cover	-	2	9	-	8	10	6	7

TABLE 3.8 Mean Properties of Synoptic Weather Types, New Orleans, October 1971

	PH	CH	FOR	CR	GR	FGR	GTD	GH
0600 CST								
No. Cases	5	8	1	13	1	2	0	1
Air Temperature	60	59	73	65	68	72	-	63
Dew Point Temperature	58	55	71	63	67	69	-	61
Relative Humidity	94	89	93	92	97	90	-	93
Wind Direction	30	02	35	05	0	0	-	0
Wind Speed	3	5	4	4	0	0	-	0
Cloud Cover	0	1	3	4	1	6	-	5
1500 CST								
No. Cases	5	8	1	12	3	2	0	0
Air Temperature	69	78	81	80	85	85	-	-
Dew Point Temperature	60	55	71	65	71	72	-	-
Relative Humidity	77	46	72	59	63	65	-	-
Wind Direction	31	36	36	06	12	07	-	-
Wind Speed	4	6	6	7	8	7	-	-
Cloud Cover	0	3	10	4	5	7	-	-

TABLE 3.9 Annual Regime Mean Weather Type Properties, New Orleans, 1971
Continental High

	No. Cases	Ta	Td	RH	Wind Dir.	Wind Speed	Cloud Cover	Fog
<u>0600 CST</u>								
Jan	5	40	32	73	03	8	1	0
Feb	7	38	32	82	04	6	1	0
Mar	7	41	31	69	33	8	1	0
Apr	7	44	38	80	35	6	0	0
May	10	61	55	81	04	6	2	0
Jun	1	72	69	90	0	0	4	0
Jul	1	72	70	93	0	0	10	1
Aug	9	73	70	89	35	3	1	0
Sep	7	69	66	90	01	4	2	0
Oct	8	59	55	89	02	5	1	0
Nov	13	50	44	81	02	8	2	0
Dec	6	55	50	86	04	6	2	1
<u>1500 CST</u>								
Jan	8	57	33	42	01	9	1	0
Feb	5	52	32	45	34	11	0	0
Mar	7	56	29	37	33	10	1	0
Apr	6	68	36	32	33	10	2	0
May	10	82	57	43	34	6	3	0
Jun	1	86	70	59	20	6	8	0
Jul	1	89	70	54	03	5	2	0
Aug	8	90	70	53	01	6	3	0
Sep	6	85	65	52	36	7	3	0
Oct	8	78	55	46	36	6	3	0
Nov	11	66	43	44	01	8	1	0
Dec	5	65	51	63	04	6	5	0

TABLE 3.10 Annual Regime Mean Weather Type Properties, New Orleans, 1971
Gulf Return

	No. Cases	Ta	Td	RH	Wind Dir.	Wind Speed	Cloud Cover	Fog
0600 CST								
Jan	8	62	60	92	15	6	9	2
Feb	3	53	52	96	09	4	2	0
Mar	5	62	58	88	13	8	8	0
Apr	6	64	60	87	11	5	8	1
May	6	69	64	84	10	8	6	0
Jun	11	72	68	89	14	3	5	0
Jul	11	76	72	87	09	4	6	0
Aug	3	73	70	91	08	3	3	0
Sep	2	78	74	88	12	5	6	0
Oct	1	68	67	97	0	0	1	0
Nov	2	67	65	93	10	4	5	0
Dec	2	62	62	99	13	4	5	1
1500 CST								
Jan	10	72	59	66	17	10	7	0
Feb	3	73	56	56	12	12	4	0
Mar	6	72	58	63	16	11	9	0
Apr	5	78	63	62	16	9	6	0
May	5	84	63	50	16	14	4	0
Jun	12	83	69	65	19	9	8	1
Jul	11	84	74	88	16	7	8	0
Aug	2	85	71	63	15	9	8	0
Sep	3	85	72	67	12	7	8	0
Oct	3	85	71	63	12	8	5	0
Nov	2	81	70	70	13	10	6	0
Dec	3	77	66	68	16	12	4	0

TABLE 3.11 Percent Rainy Hours By Synoptic Weather Types, New Orleans, 1971

	J	F	M	A	M	J	J	A	S	O	N	D	Year
PH	0	0	0	0	0	-	-	-	-	0	0	0	0
CH	0	1	0	0	0	0	11	0	0	0	0	0	0
FOR	9	8	3	0	3	-	23	18	4	0	14	15	9
CR	0	0	0	0	0	0	-	8	0	4	3	0	2
GR	3	1	3	3	0	5	8	2	3	0	6	1	4
FGR	5	15	11	0	4	-	4	-	19	0	5	9	7
GTD	-	-	-	-	-	-	8	17	27	-	-	-	22
GH	0	-	-	-	-	8	3	6	-	0	-	-	6

TABLE 3.12 Monthly Precipitation by Synoptic Weather Types, New Orleans, 1971 in Inches

	J	F	M	A	M	J	J	A	S	O	N	D	YR	%
PH	0	0	0	0	0	-	-	-	-	0	0	0	0	0
CH	0	0	0	0	0	0	.1	0	0	0	0	0	.1	0
FOR	.4	1.0	.5	0	.5	-	.7	.3	0	0	1.7	3.2	8.3	15
CR	0	0	0	0	0	0	-	.8	0	.6	.2	0	1.6	3
GR	.4	0	.3	1.5	0	3.9	2.4	.1	.1	0	.1	0	8.8	15
FGR	.3	3.9	2.9	0	.9	-	0	-	1.2	0	.7	3.4	13.3	23
GTD	-	-	-	-	-	-	.7	1.3	15.5	-	-	-	17.5	30
GH	0	-	-	-	-	4.1	.6	3.2	-	0	-	-	7.9	14
TOTAL	1.1	4.9	3.7	1.5	1.3	8.0	4.5	5.7	16.8	.6	2.7	6.6	57.5	100

during which at least 0.01" of precipitation was recorded). Precipitation measured in 1971 is summed by synoptic weather types in Table 3.12. The direct relation of synoptic weather type occurrence to precipitation is easily seen by reference to Figure 3.5. Three weather types (FOR, FGR, GTD) account for 68 percent of the total precipitation, yet they were present only 33 percent of the hours in the year. The intensity of rainfall associated with GTD is evident when it is considered that it occurred only 6 percent of the total hours in 1971, 22 percent of which were rainy hours, yet the weather type produced 30 percent of year's precipitation. A comparison of Table 3.12 and 3.2 shows how the precipitation regime in 1971 compares with the four-year annual average.

The properties and temporal sequence of synoptic weather types suggest environmental responses. In the case of the particular objective, for instance, variations in precipitation and wind direction (and speed) affect water level and salinity. Occurrence of precipitation-producing weather types over the basin governs generation of surplus water and runoff; a direct relationship with basin hydrology exists. Other environmental impacts may not be so obvious.

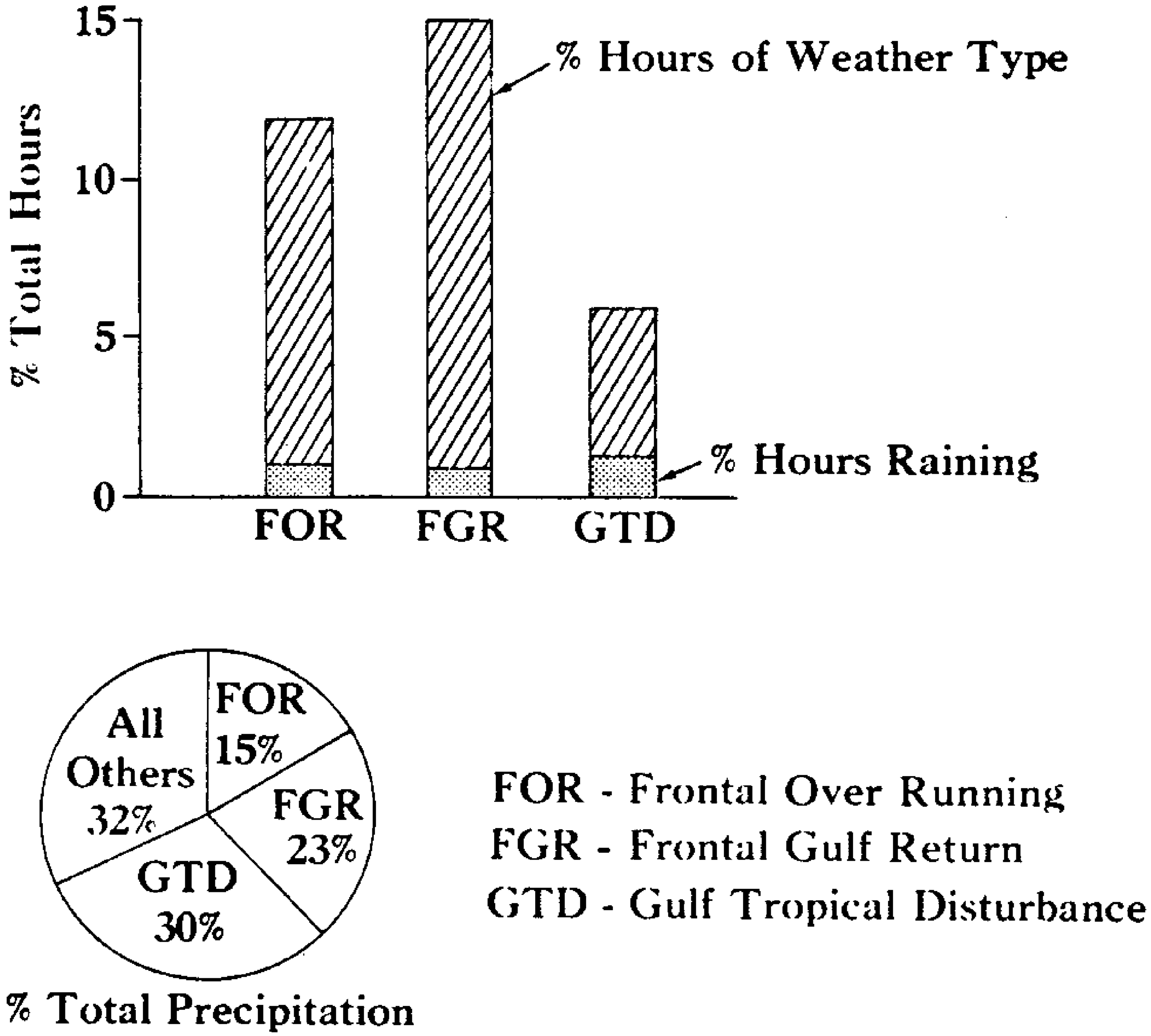

Fig. 3.5. Relationship between synoptic weather types and total annual precipitation, 1971.

Part 4. Analyses of Environmental Responses

Analyses of Relationships Between Synoptic Weather Types and Environmental Parameters

INTRODUCTION

Solar radiation is often thought of as the ultimate driving force for most environmental systems, either directly, as sunlight and photosynthesis, or indirectly, through the atmospheric circulation and associated weather. Some very important environmental parameters can also be treated as responses to meteorological inputs. Water levels in marshes and estuaries are affected by wind direction and speed, the fetch and duration of the wind, atmospheric pressure, rainfall and evapotranspiration, and, of course, astronomical tides. Wind direction tends to be especially significant because northerly winds drive Gulf waters away from the coast, lowering water levels across the coastal wetlands; and southerly winds drive Gulf waters up against the coastline, raising water levels across the wetlands. Salinity levels are similarly affected, especially by wind and precipitation-evaporation ratios.

Although rigorous relationships between wind speed and stress on water surfaces are known, the lack of standard meteorological data across the coastal wetland inhibits application of these relationships to environmental management objectives. There is a need for more comprehensive relationships between weather and environmental parameters that can be applied over broad areas of the coastal wetland for resource management. The synoptic weather types, discussed in the previous section, can be utilized for this resource objective. Specifically, the sequences of weather through time, in terms of the synoptic weather type calendars for Moisant Airport, New Orleans, can be compared to water level and salinity changes in Barataria Basin, in order to ascertain the degree of response between weather and environmental parameters.

SYNOPTIC WEATHER TYPES AND WATER LEVEL AND SALINITY CHANGES AT 4-HOUR INTERVALS

Figure 4.1 shows changes of water levels at Bayou Rigaud and salinity at Grand Terre at 4-hour intervals for October 1971, a period selected as reasonably representative of a broad range of synoptic weather types and environmental responses. The time series shows both measured water levels and adjusted (or filtered) water levels with the semidiurnal and diurnal tidal forcing function eliminated by a 39-hour Doodsen filter (Groves 1949); this assumes that the variability of filtered water levels is a response to only meteorological inputs. The synoptic weather types at New Orleans are also displayed as an environmental baseline, which supposedly forces water level and salinity changes in the basin. The graphs also show the generation of surplus precipitation by daily precipitation from a number of climatological stations around the margins of the basin minus evapotranspiration from the water-balance model; surpluses should increase water levels and decrease salinity theoretically. Table 4.1 shows selected mean properties of synoptic weather types at New Orleans averaged over the 4-year period between 1971 and 1974.

Table 4.1. Selected Mean Properties of Synoptic Weather Types at New Orleans*

	Wind Direction/ Speed		Cloud Cover		% Mean Annual Precipitation
	Jan	July	Jan	July	
Gulf High (GH)	33/6	26/6	4	6	8
Pacific High (PH)	33/6	--	3	-	0
Continental High (CH)	02/8	02/6	1	6	1
Frontal Overrunning (FOR)	01/10	31/7	10	10	17
Coastal Return (CR)	10/7	09/9	7	6	3
Gulf Return (GR)	15/9	15/6	8	7	12
Frontal Gulf Return (FGR)	18/9	24/5	10	9	45
Gulf Tropical Disturbance (GTD)	--	10/7	-	6	13

*Wind direction in ten degrees of azimuth from 01 (10°=NNE) through 18 (180°=south) to 36 (360°=north). Wind speed in knots. Cloud cover on a scale of 0 (clear) through 10 (cloudy).

Figure 4.1 also shows an overall temporal relationship between the sequence of synoptic weather types and filtered water levels and salinity. Filtered water levels tended to drop during the extended periods of the Continental High (CH) and Pacific High (PH) types, when Table 4.1 indicates westerly to northerly winds can be expected. Filtered water levels increased, on the other hand, during the two extended periods of the Coastal Return type (CR), when easterly winds are expected to increase water levels. During much of the early portion of October, filtered water levels did not respond so closely to the sequence of synoptic weather types, although there are examples such as 6 and 8 October when water levels responded as anticipated by means of the synoptic weather type calendar. During the early part of the month, the types may have changed too rapidly to result in significant responses.

There are several reasons for the association between synoptic weather types and environmental responses, such as water levels, being imperfect. One is the geographical distance between the location of the synoptic weather type calendar at New Orleans and Bayou Rigaud/Grand Terre, located near the lower end of Barataria Basin, adjacent to the Gulf, almost 60 miles to the south. Stationary weather fronts often persist for several days over this region, with the Frontal Overrunning (FOR) or Continental High (CH) types to the north at New Orleans, and the Frontal Gulf Return type (FGR) to the south along the coast. In this situation, water levels normally continue to increase in lower Barataria Bay, but the baseline data at New Orleans indicate water-level decreases should be espected. During October 1971, these stationary fronts did not persist over the basin, but a few adjustments to the synoptic baseline data had to be made several times over the entire year 1971 to be representative of lower Barataria Basin conditions. These adjustments were based on synoptic weather maps.

The synoptic types are inclusive of all situations, so there are also a number of marginal or very weak situations when winds were weak or ineffective in changing water levels significantly. Similarly, wind directions in these marginal situations did not always remain consistent with the means shown in Table 4.1.

Figure 4.1 also shows the time series of salinity data at Grand Terre. Similarly, salinity levels tended to decrease during the extended periods of the Continental (CH) and Pacific High (PH) types

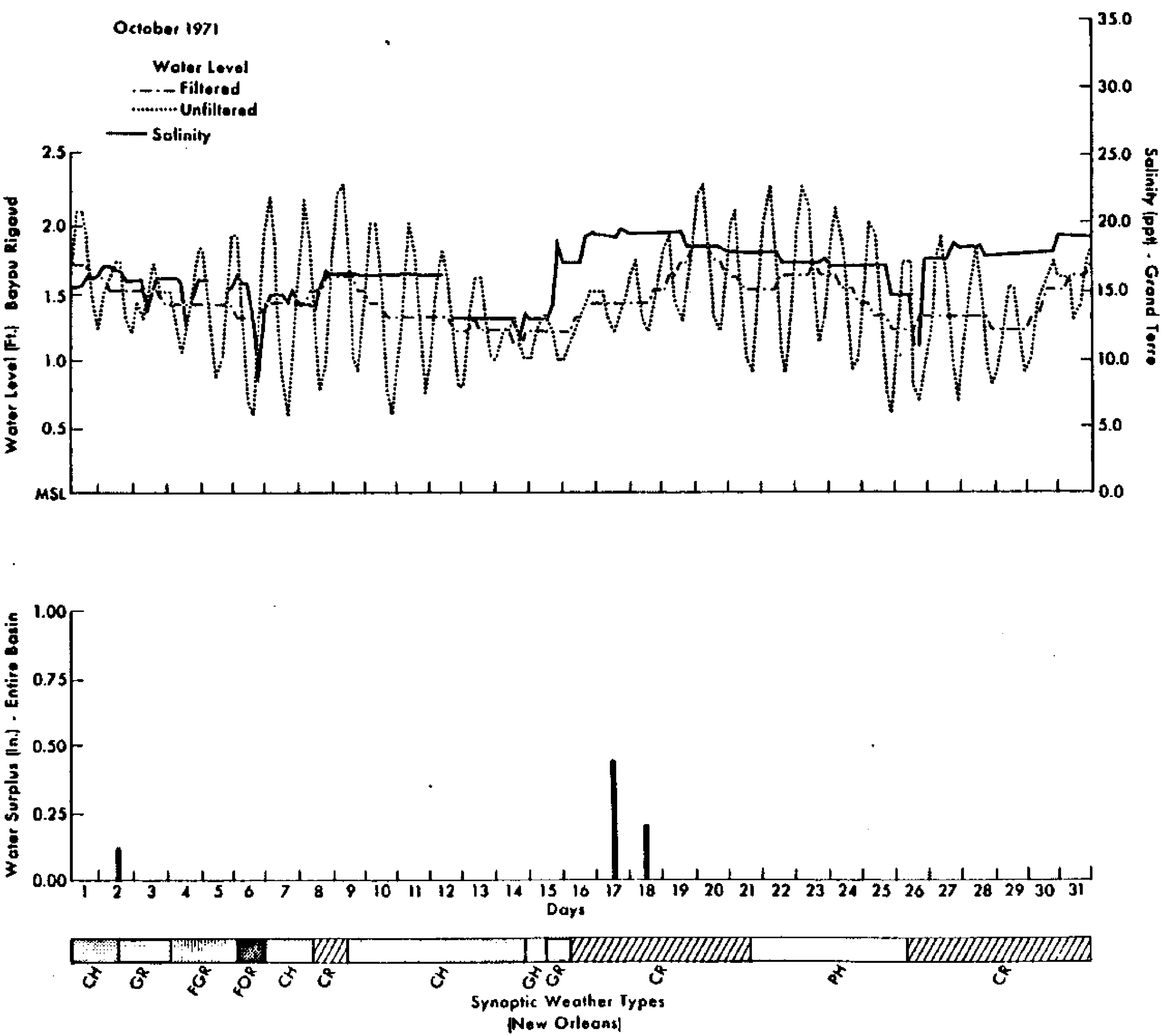

Fig. 4.1. Water level/salinity variations, water surplus, and synoptic weather types plotted in four-hour intervals for October 1971.

and to increase during the two extended periods of the Coastal Return type (CR). During the early part of the month there are short-term changes of salinity that cannot possibly be explained by the synoptic weather type calendar.

SYNOPTIC WEATHER TYPES AND WATER LEVEL AND SALINITY CHANGES ON A DAILY BASIS

Figure 4.2 shows filtered water levels and salinity plotted on a 24-hour basis at 8 a.m. during October 1971; the synoptic weather type calendar for New Orleans and surpluses for the entire Barataria Basin are also shown. This figure shows that the same general relationships between changes in filtered water levels and salinity and the synoptic weather type calendar (seen in Fig. 4.1) are preserved, and the further analysis of these relationships was carried out using changes of water level and salinity on a 24-hour basis. The synoptic weather type calendars and the regimes of filtered water levels and salinities for wetland sites are not commonly available for inspection or study. Therefore, monthly time-series graphs of the weather types and associated filtered water level and salinity data on a daily basis for 1971 for Bayou Rigaud/Grand Terre are included as Figure Appendix D. Inspection of these figures also shows that water level and salinity changes tended to follow the calendars of the synoptic weather types at New Orleans.

ANALYSES OF RELATIONSHIPS BETWEEN SYNOPTIC WEATHER TYPES, WATER LEVELS, AND SALINITY

The synoptic weather types have been grouped into combinations that are thought to produce similar responses of water levels and salinity over the Barataria Basin. The table below lists the synoptic weather type combinations that are utilized in these analyses:

Combination 1	CR, GR, or FGR changing to FOR, PH, CH, OR GH (cold front)
Combination 2	PH and GH
Combination 3	CH and FOR
Combination 4	GH, PH, CH, or FOR changing to CR
Combination 5	CR
Combination 6	GR and FGR
Combination 7	GH, PH, CH, FOR, or CR changing to GR or FGR (warm front)
Combination 8	GTD

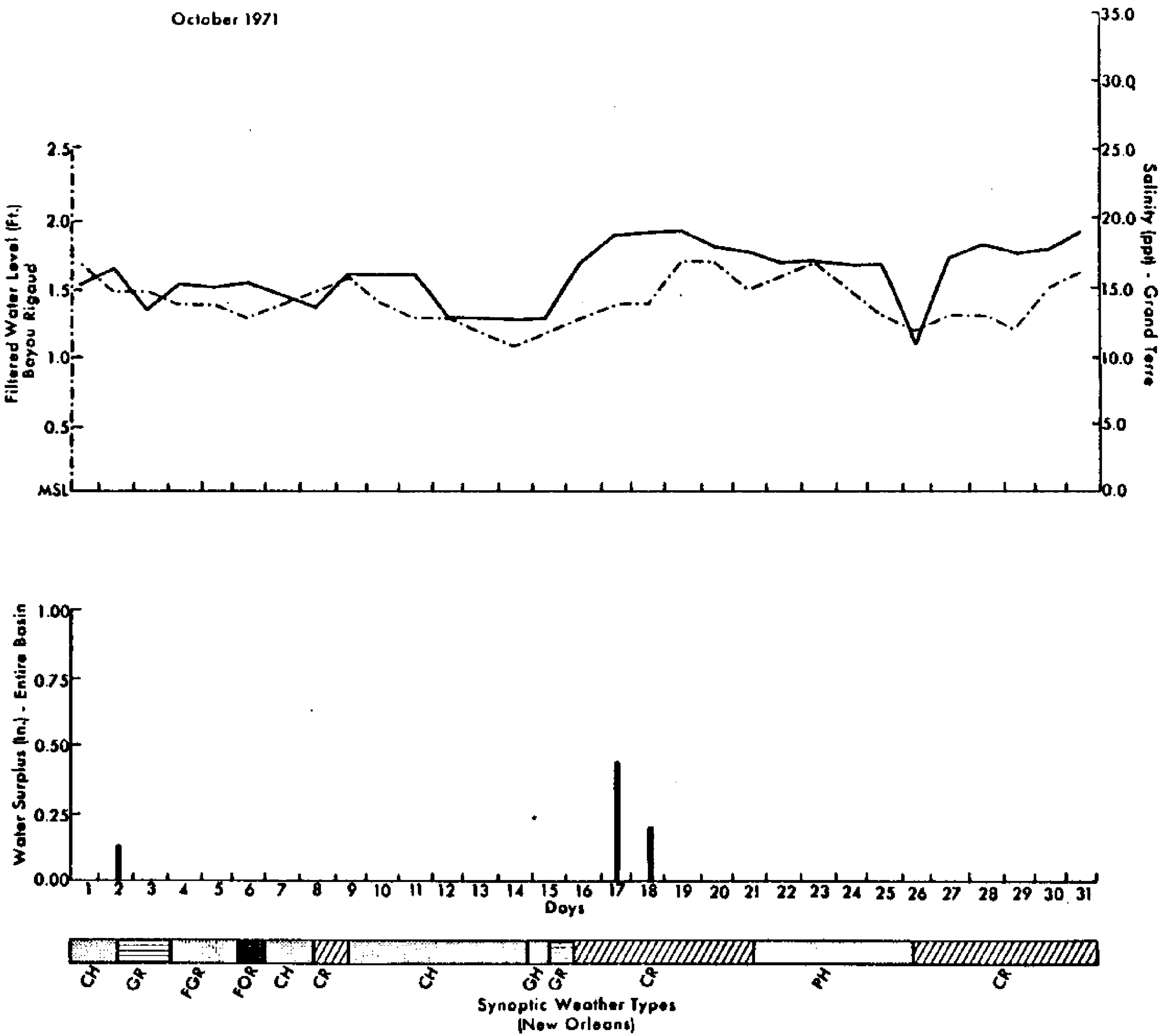

Fig. 4.2. Water level/salinity variations, water surplus, and synoptic weather types for October 1971.

Combination 1, representing a colf front passage, should be expected to decrease water levels and salinity, as should combinations 2 and 3 since they are associated with west to northeast winds. Combination 4 is associated with winds shifting gradually from northwest to east or southeast, so water levels and salinities should increase. Combinations 5 and 6 tend to produce rising water levels and salinities since they are associated with winds from east through south-southwest. Combination 7 represents a sequence of weather type changes through the 24-hour period that can best be described as passage of a warm front over the basin; it should be understood that it is only necessary for one or more of the five synoptic weather types to occur before passage of the warm front. Both water levels and salinity should tend to increase during combination 7. There are no preferred wind directions associated with combination 8 because tropical disturbances can approach the basin from all directions except northwest through northeast.

The analysis of relationships between the synoptic weather types and environmental response was performed by summing daily changes in water levels and salinity (0800-0800) that occurred during each of the weather type combinations. Water level data measured at Bayou Rigaud in the lower basin and Bayou Chevreuil in the upper basin were analyzed. Salinity data measured at Grand Terre were analyzed.

Water level data used in the analysis of Bayou Rigaud had tidal effects filtered out by use of a 39-hour Doodsen filter, leaving water level variations that resulted from only climatological forcing functions. Days having a 24-hour change in water level of less than 0.2 ft were omitted from the analysis. Some 112 days were used, and days with surplus (excess precipitation) were separated from days with no surplus.

The relationships established at Bayou Rigaud are displayed in Figure 4.3. For example, filtered water levels rose a total of 3.1 ft and fell a total of 0.6 ft over the year during days that were classified as combination 6 with no surplus. Hence the predicted responses were not observed in every case, but expected relationships are firmly established. For example on days with no surplus, typically fair weather days, combinations 2 and 3 drove water levels down, and 5 and 6 drove water levels up. Warm front passages (7) and cold front passages (1) demonstrated no departures from the expected relationships. Ratios of increments up to increments down are shown in the figure.

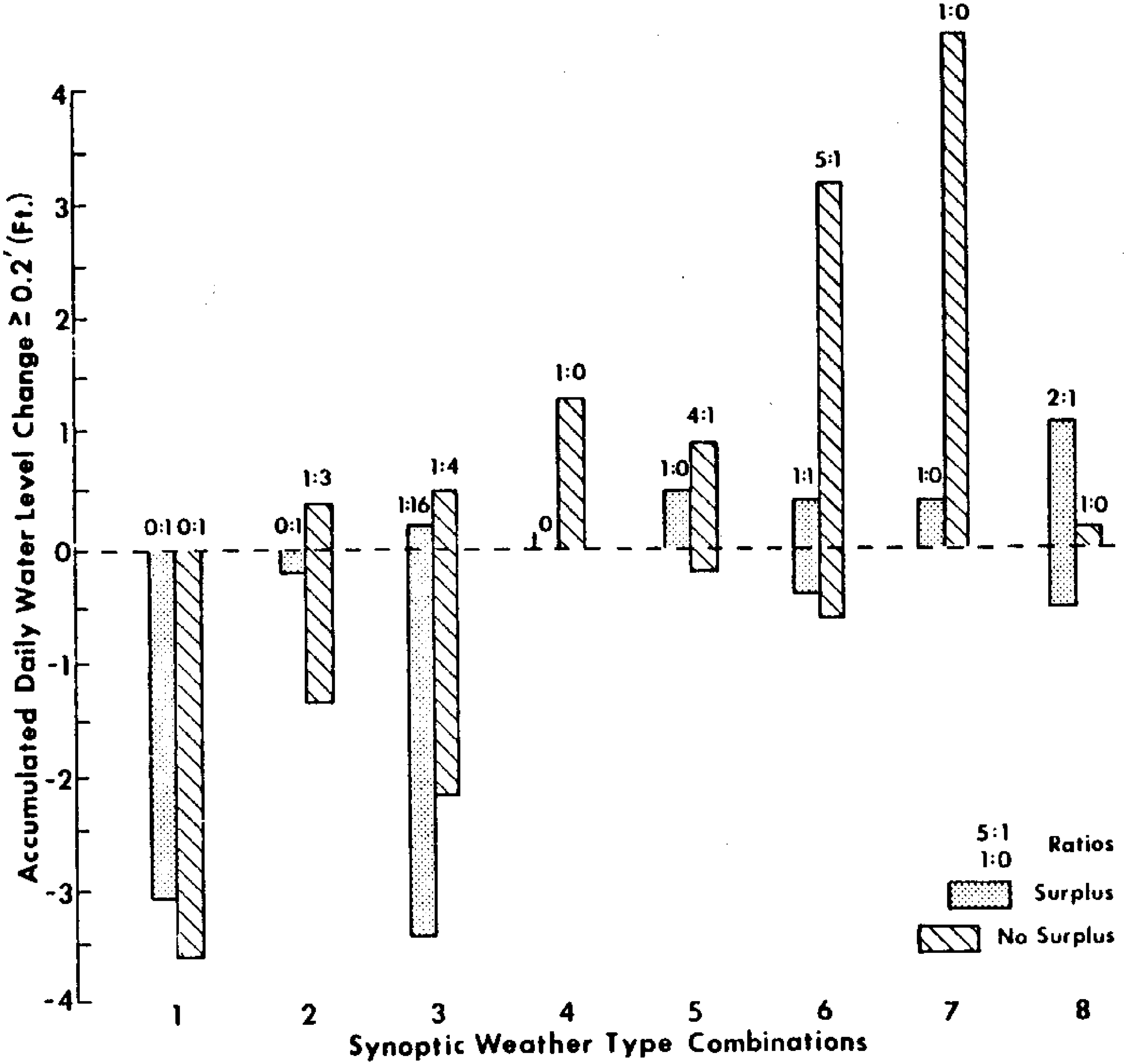

Fig. 4.3. Response of water level at Bayou Rigaud to synoptic weather type combinations during 1971.

Results for Bayou Chevreuil are shown in Figure 4.4. On nonsurplus days there, the same strong relationships between weather types and water level response were observed. Actual measured water level data were used there since tidal influence in this part of the basin is nonexistent. Every day of the year was used in the analysis.

The effect of surplus on the relationships is seen in both Figures 4.3 and 4.4. It was expected that decreases in water levels would be lessened by surplus precipitation and that water levels increasing as a result of the weather types would be augmented by surpluses.

At Bayou Chevreuil this relationship is strongly established. For example, combination 2 causes decreases in water levels on nonsurplus days 19 times greater than increases, whereas on days with a surplus, decreases are only 2 times greater than increases. Combination 3 causes water level decreases 5 times greater than increases on nonsurplus days, but only 2 times greater on surplus days. The ratios for combination 6 are 4 to 1 increases on nonsurplus days and 7 to 1 increases on surplus days.

At Bayou Rigaud the relationships associated with surplus days are not as firm. Ratios for combination 3 are 4 to 1 decreases on nonsurplus days and 16 to 1 decreases on surplus days. Combination 6 shows 5 to 1 increases on nonsurplus days but only 1 to 1 increases on surplus days. It is reasonable to expect that surpluses would have a significant effect on water levels in the upper basin but little or no effect on water levels in the lower basin adjacent to the Gulf.

The analysis of salinity did not produce such strong evidence for the expected relationships (Figure 4.5). Only days with 1 ppt change or greater were used, a total of 124 days for the year. Expected trends on nonsurplus days are confirmed only for combinations 1, 4, 5, and 7. The frontal passage combinations show the strongest relationships, with warm front passages increasing salinities at a ratio of 6 to 1 and cold front passages decreasing salinities at a ratio of 1 to 0 on days with no surplus.

Availability of surplus increases the occurrence of the expected relationship, especially in the frontal passage categories. Warm fronts with surplus increase salinities at a diminished ratio of 5 to 1, and cold fronts with surplus decrease salinities at an augmented ratio of 15 to 1.

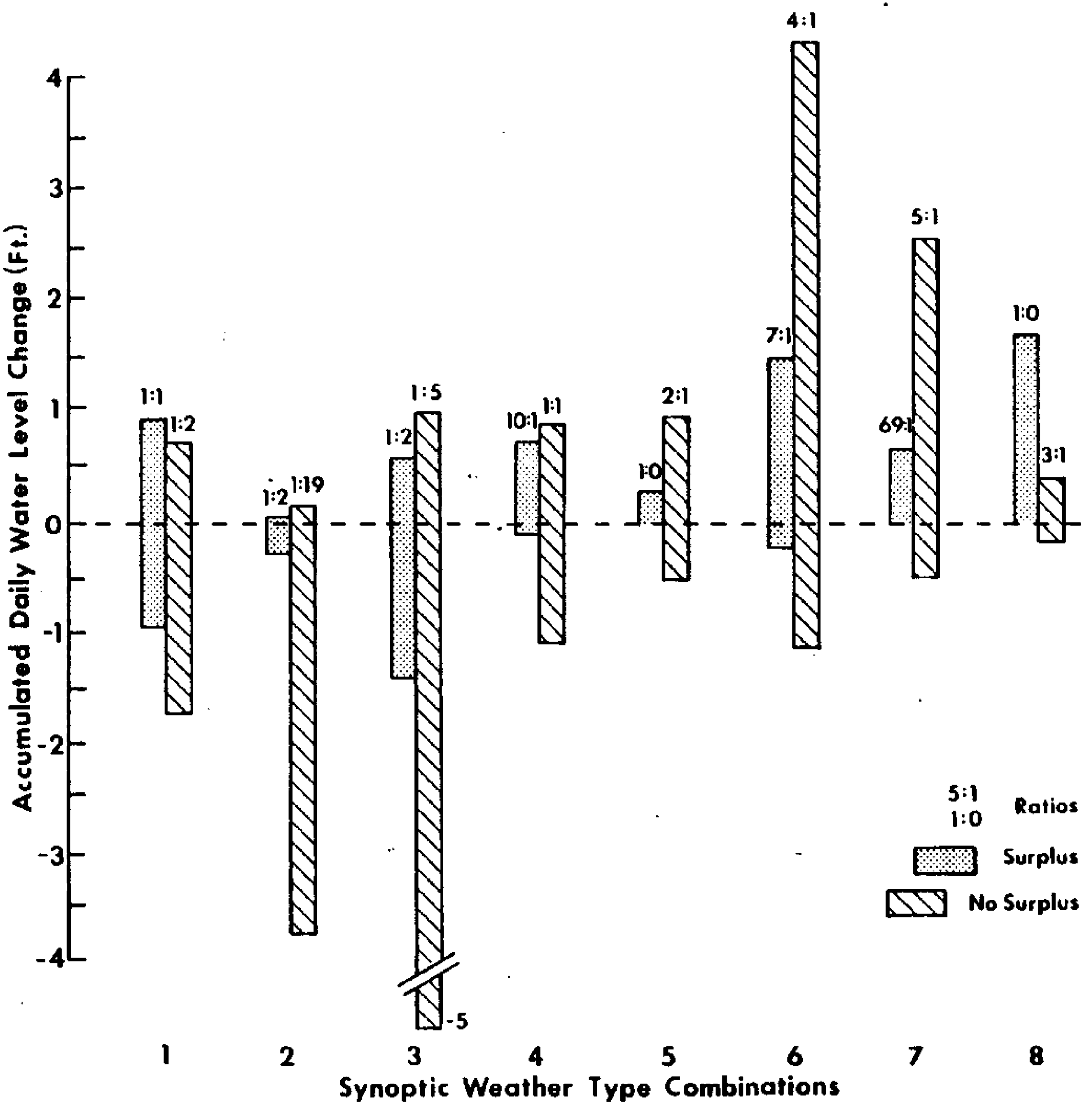

Fig. 4.4. Response of water level at Bayou Chevreuil near Chegby to synoptic weather types at New Orleans, 1971.

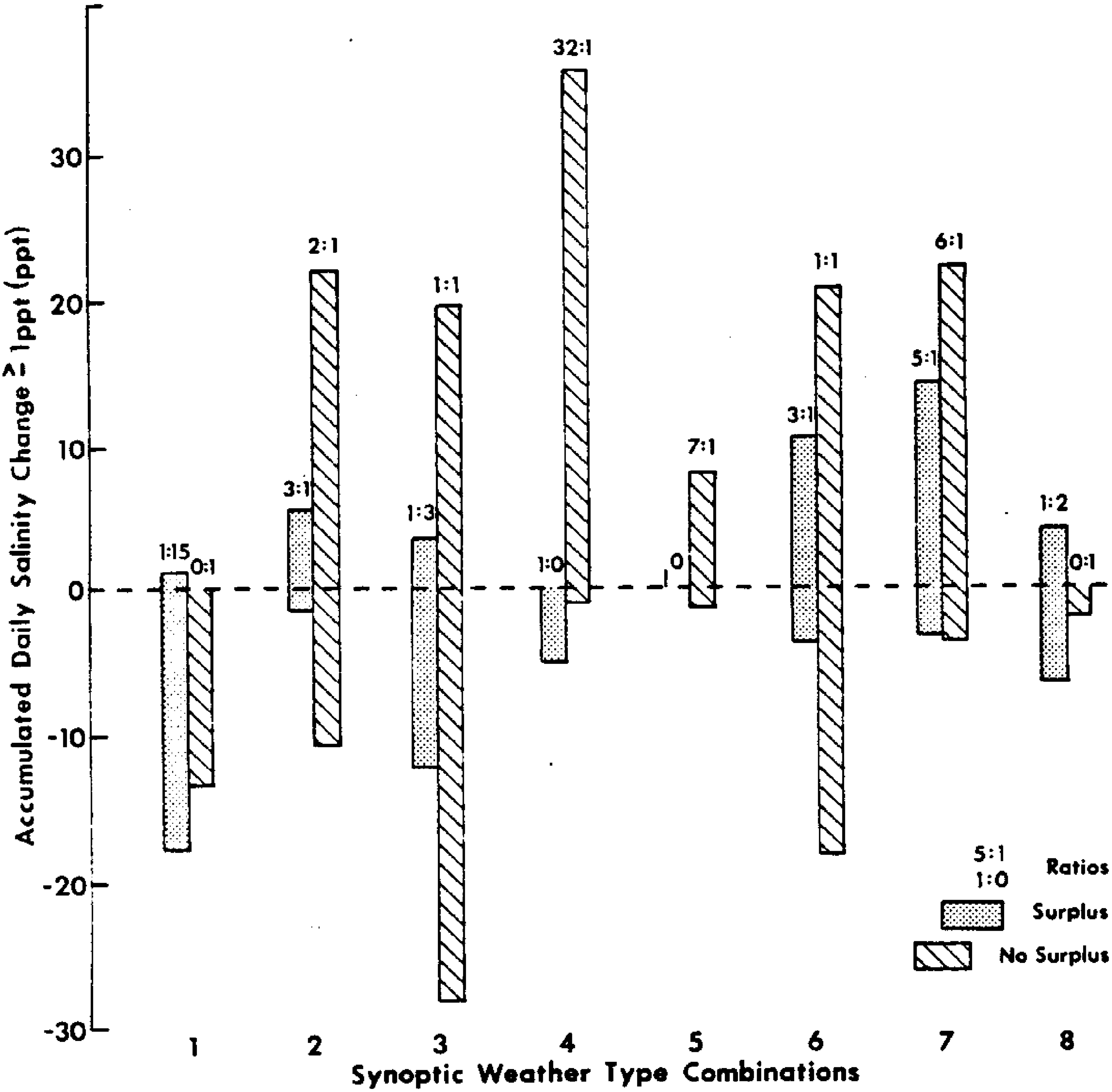

Fig. 4.5. Response of salinity at Grand Terre to synoptic weather types, 1971.

This analysis of relationships among combinations of synoptic weather types, water levels, and salinity illustrates that water levels respond strongly to meteorological inputs associated with the synoptic weather types. For the single salinity station at Grand Terre, the relationships between salinity regimes and synoptic weather types are less well established. Other environmental inputs such as Mississippi River discharge may not be well indexed by the combinations of synoptic weather types utilized for this analysis. It is likely that salinity regimes are more closely related to the weather types in the middle regions of the basin.

Part 5. Wave Action Offshore of Barataria Basin

Wave action is always an important consideration in defining a coastal environment because waves are generally the main source of energy for mixing water masses and transporting sediments. Wave action is the combination of waves of various heights, periods, and directions occurring at any one time at a given place. The day-to-day changes in these values can be thought of as wave weather. The average or statistical occurrences of various wave values, determined over several years of observation, is wave climate. Wave weather, like its meteorological counterpart, is much less predictable than wave climate. What will be presented here is a brief review of wave climate in a region offshore of Barataria Basin.

There is considerable experience with wave action in the northern Gulf owing to the high concentration of exploration and production of oil in the delta area. This experience takes the form of raw data, analyzed data, wave weather prediction models, wave climate, data, and monitoring programs. These activities, however, are conducted by industry or consulting firms and the results are not generally available to the public. Thus the actual information that can be openly reviewed is only a small part of what is in existence.

The wave action in Barataria Basin and offshore results from the effect of wind in the water surface. Wind systems (weather systems)—e.g., fronts, squalls, and hurricanes--produce characteristic sets or combinations of waves. These waves can be described in two ways. First, the waves resulting from each weather system can be given as they change their height, period, and direction over time. The second technique is to give the percentage of occurrence of waves in a certain range of heights, or periods occurring, during, say, a month, from whatever wind system. Both methods have relative advantages, the statistics being important for total effects (i.e., engineering fatigue, erosion of beaches), while the wind system approach is good for prediction of wave weather or the temporal or sequential change in wave action.

Although there are several wind systems of importance in the northern Gulf, including squalls, sea breeze, fronts, high-pressure cells, gradient winds, hurricanes, and tropical storms, only the winds associated with winter frontal passages or hurricanes produce the really sustained or large

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waves occurring offshore. Squalls and the sea breeze can be the cause of a significant chop within Barataria Bay for short periods of time.

The seasonal occurrence of the various wind systems produce a wave climate offshore of Barataria Basin that also shows a large seasonal variability. The occurrence of large waves is an indicator of this seasonal trend. Figure 5.1 exhibits the percentage of time during each month that waves over 8 ft in height of all periods occur. During the winter period the percentage is maximum at about 30 percent, which generally decreases during the spring, reaching a low of about 2 percent during July. There is a sharp rise in percentage in September and then a gradual increase to the January maximum.

This seasonability also produces significant change in the distribution of wave heights and their direction during the year. Figure 5.2 shows the percentage occurrence of waves in 7 ft height ranges for April, July, September, and December. Most of the wave heights during the 3 months of September, December, and April occur in the range of 4-6 ft, while in July the range most frequently occurring is 2-4 ft. During December the wave heights above 15 ft occur some 3 percent as frequently as during September, even though waves during December in the ranges 8-10 and 10-15 ft are more frequent. The direction of the approach of the waves toward Barataria Bay also shows seasonal changes. Figure 3 shows the frequency of occurrence of waves in three directions classes centered at southwest, south, and southeast. Generally waves predominate from the southeast during September, December, and April and from the southwest during July. The period of the waves is generally associated with wave heights, so that the smallest waves have the shortest period, as shown in Table 5.1.

The most extreme wave action occurring in the northern Gulf is because of hurricane winds. These wind systems occur generally through the summer and early fall months at an annual frequency of about one per year. The wave field of a single hurricane can contain more energy than is expended in total for the rest of the year. An example of this is the great hurricane Camille of 17 August 1969. The hurricane was considered to be a 1 in 100-year hurricane having peak winds over 200 mph. The maximum observed wave heights were 74 ft. The extent of hurricane-induced waves across coastal

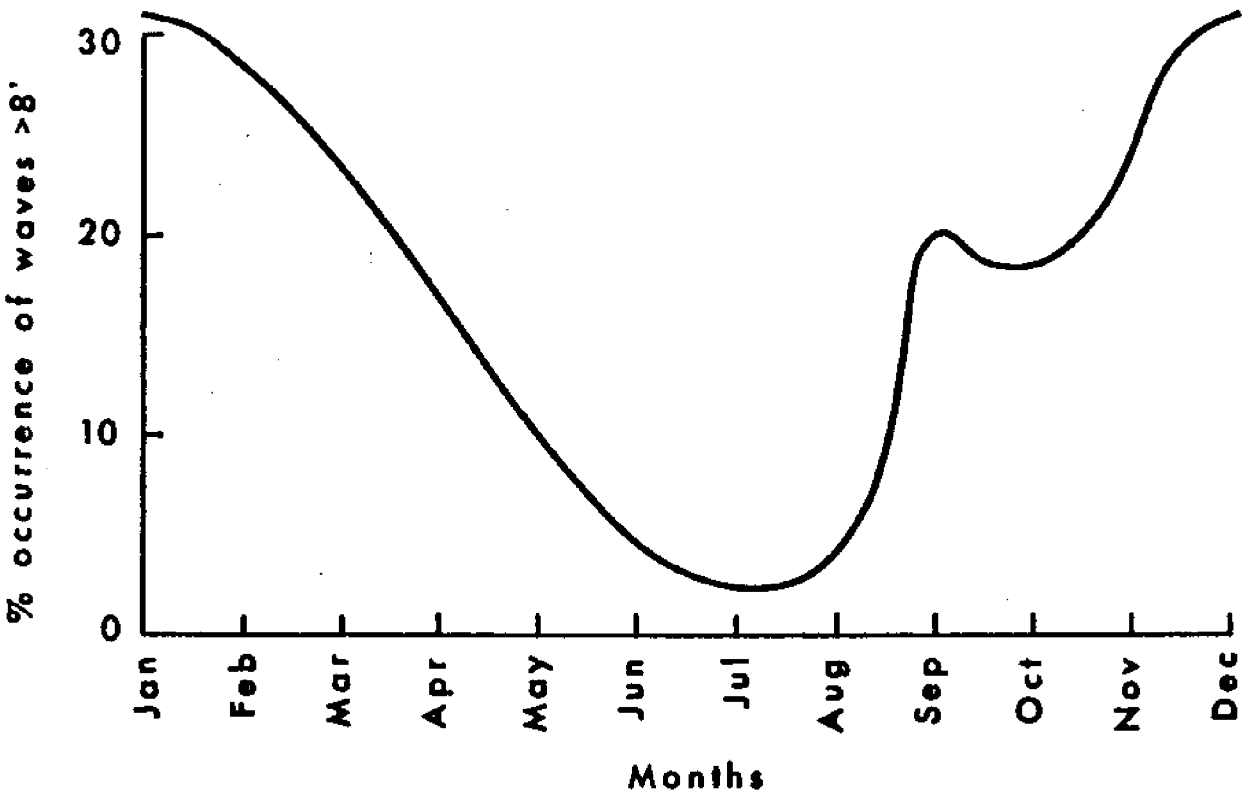

Fig. 5.1. Percentage of occurrence of waves having a height greater than 8 ft for a typical year.

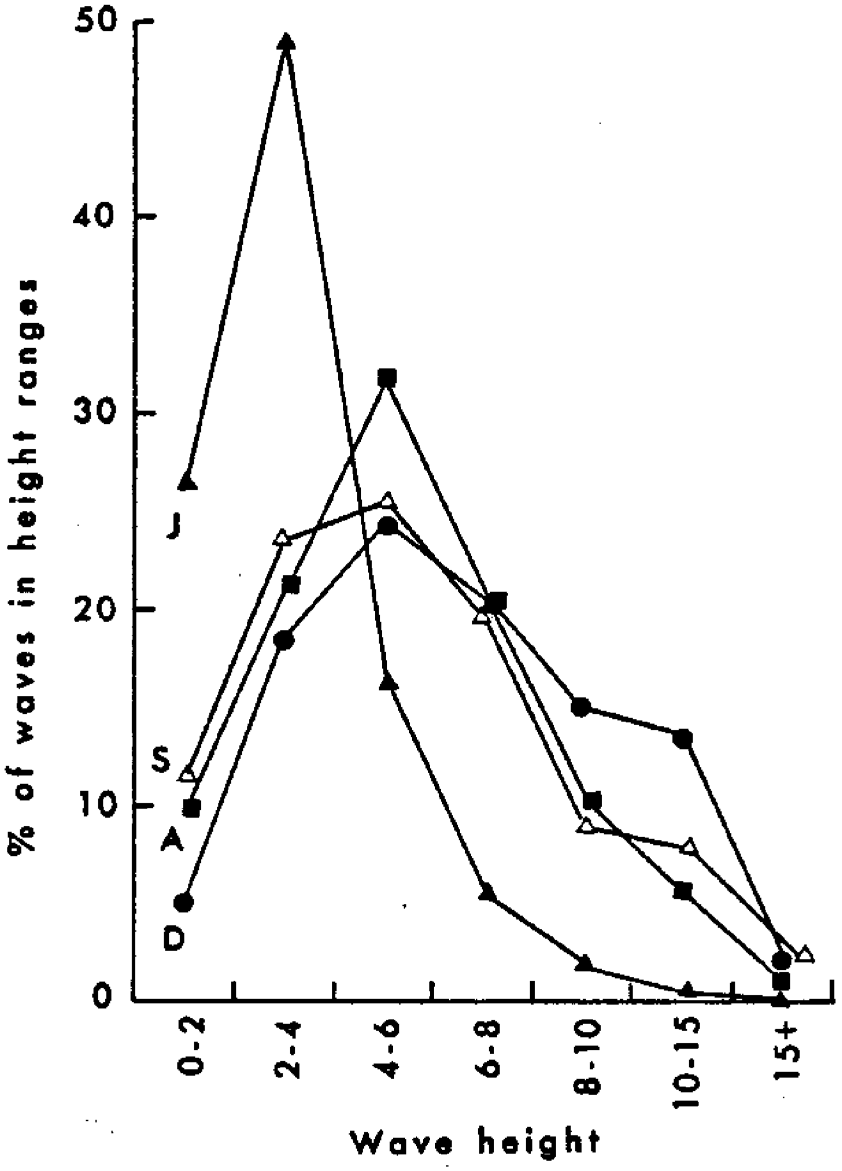

Fig. 5.2. Percentage of waves having heights within selected ranges for four months of the typical year; December (D), April (A), July (J), and September (S).

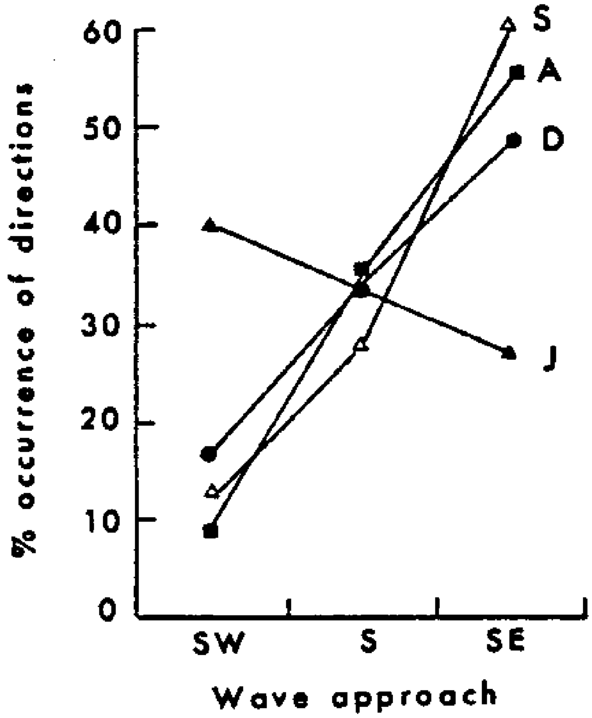

Fig. 5.3. Percentage of waves having a a direction of propagation from three directions: SW, S, and SE for the months of December (D), April (A), July (J), and September (S).

Louisiana is indicated in Figure 5.4 the maximum waves are indicated at 80 ft, and the wave height is greater than 20 ft all across Louisiana. Wave periods during the hurricane averaged about 10 seconds; however, waves as long as 16 seconds were observed.

The intensity of wave action to be expected over the future is difficult to predict. Experts in the field have predicted different values for what the 20-year and 50-year storms should be. However, taking an average of these predictions, we can make general estimates as to future extremes in wave action. Figure 5.5 shows maximum height and water level rise expected in about 100 ft of water offshore of Barataria Basin over return periods between 2 and 200 years. It indicates that even every 2 years maximum wave heights of 35 ft and water level rises of 2 ft can be expected.

Table 5.1 Wave height/period relationship.

Wave Height (ft.)	Wave period (sec.)
0-2	0-4
2-4	4-5
4-6	5-7
6-8	7-8
8-10-0	8-10
10-15	9-10
15+	9-12

The effect of the offshore wave action on Barataria Basin coastline is a function of the shallow water wave processes occurring near the shoreline. These processes distribute and modify incoming waves including primarily wave refraction and attenuation. Shoreline wave heights can vary by a factor of 2 or more even for a uniform offshore wave field because of nearshore wave processes. Some of these processes critically depend upon the bathymetry of nearshore waters; modifications to this region can result in larger scale changes in the coastal wave action affecting Barataria Basin.

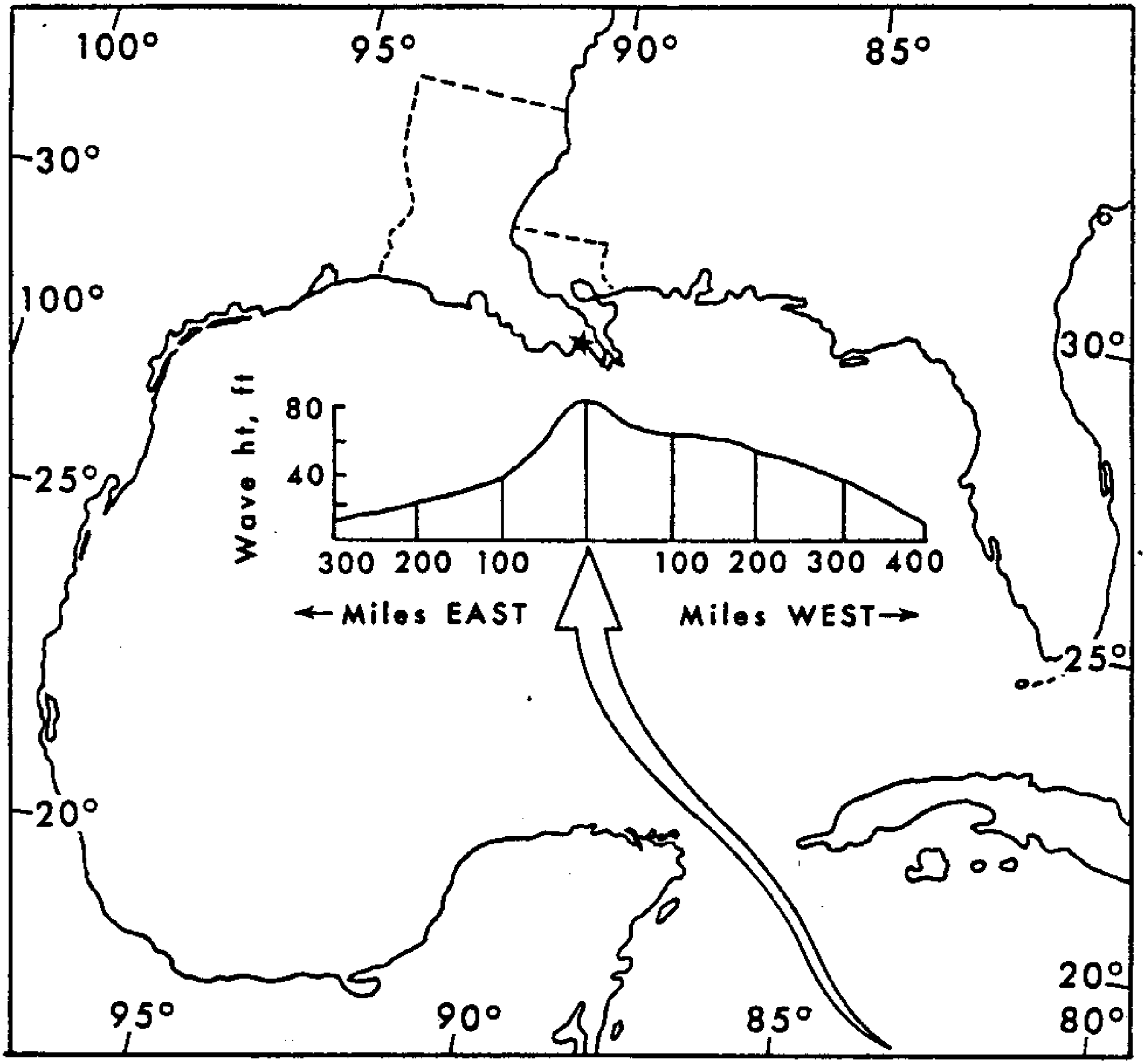

Fig. 5.4. Distribution of wave heights along the Gulf Coast resulting from a 100-year hurricane.

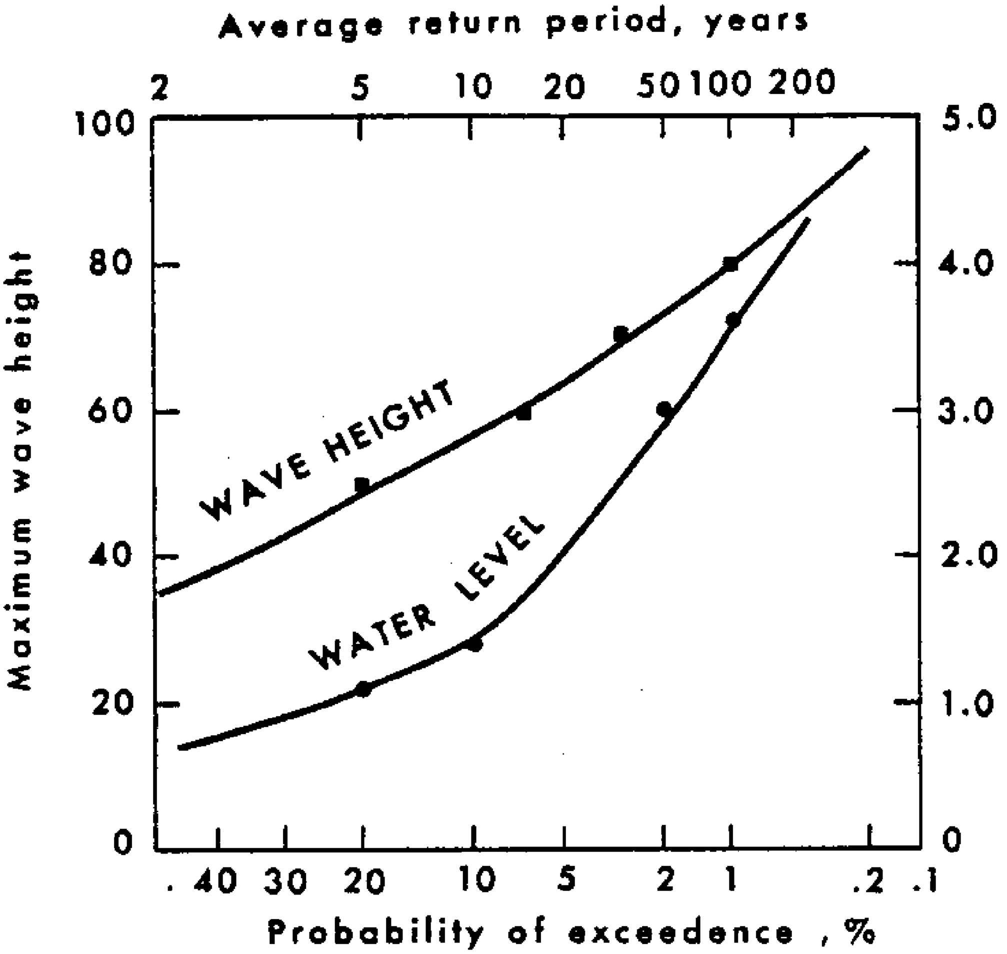

Fig. 5.5. The maximum wave height and water level rise offshore of Barataria Bay (100 ft water depth) occurring for various return periods.

Summary

The foregoing discussion and the subsequent appendixes comprise the pilot study of hydrology and climatology physical processes and interactions active within Barataria Basin. This work consisted of data collection, reduction, and manipulation. In the course of the present work, numerous aspects of the temporal and spatial behavior of various physical parameters of the basin were determined. Some results are new while others represent pertinent information culled from many pre-existing sources. This information is summarized below, in a qualitative fashion, without distinction as to whether the results are novel or previously known. Quantitative discussions may be sought in the main text and appendixes. The following information is predominantly concerned with long-term, annual, and seasonal trends.

1) The tides within the basin are predominantly diurnal, with the tidal range varying in a fortnightly period and decreasing as distance from the coast increases. The tide is 67 percent attenuated by the time it arrives at Bayou Barataria at Lafitte (6.06 hours after arrival at Bayou Rigaud); 2.74 hours later the tide arrives 80.4 percent attenuated at Bayou Barataria at Barataria six miles north of Lafitte. The arrival and recognition of the tide is dependent upon absolute water levels: low absolute water levels cause attenuation of the tide form.

   Tides are critical in successful transport of pelagic larvae forms of commercial shrimp from offshore spawning to inshore nursery grounds. Strong tidal influx promotes good shrimp larvae recruitment from offshore spawning grounds to inshore nursery grounds. This occurs in February through April for Brown shrimp and corresponds with the period when tide range is highest in the inland parts of the basin. This same pattern is repeated during the critical period for white shrimp emigrationsduring the months of June through September but less intensely.

2) Water level has risen since 1954 with an apparent increase in rate occurring around 1960. Much of this apparent rise, though, may be because of subsidence of the tide gauge site. Both water level and tide range vary with an 18.6-year-period, and they exhibit a significant semi-

annual periodicity. Water levels are highest in September with a secondary maximum in the spring, while tidal range has maxima in June and December and minima in March and September. High water levels in February through April are normally associated with successful Brown shrimp years with the condition that salinity and temperature are also high. This is believed to increase the areal extent of the nursery grounds by flooding the marsh. Shorter variations in level and range also occur in response to astronomical forcing and weather patterns.

An example of biological response to meteorological forcing is the recruitment of Brown shrimp to the estuaries in February through April. A system that lowers water levels in estuary (strong north winds) followed by a system that brings a return of water from the Gulf (strong southerly winds) is believed to be responsible for successful recruitment. This series of systems occurs in a typical Louisiana spring. Heavy rainfalls during this time lower salinity and limit the available nursery ground, thus inhibiting successful growth of Brown shrimp.

Annual mean water level slopes change are 3 to 5 x 10^{-3} ft/mile and are independent of absolute water level. Extreme high waters occur in September; extreme low waters occur during January, February, March, and April. The highest frequency of water level oscillations above MHW occur in September inclusive through December. This is also the time of highest total hours of water levels in excess of MHW.

3) While precipitation records show no noticeable long-term trends, there is a measurable drop in precipitation from high July/August/September values to low August/September values. It is also apparent that precipitation is associated primarily with the Frontal Overrunning, Gulf Return, Frontal Gulf Return, and Gulf Tropical Disturbance climatic types. Relative to their duration of occurrence, Gulf Tropical Disturbances account for a disproportionate amount of precipitation. Surplus water, associated with maximum precipitation and minimum evaporation (i.e. Frontal Overrunning, Frontal Gulf

Return, and Gulf Tropical Disturbance climatic types) is a maximum in late winter and spring and a minimum in autumn.

The high water surpluses and low salinity from January to April are associated with low Brown shrimp catches in May and June.

4) The salinity regime at Lafitte appears to have undergone a change around 1962, but no other long-term record exists for comparison. The Barataria Waterway was constructed at about this time, but there is no documentation to specifically tie the change to the waterway. There is also a trend at St. Mary's Point toward increasing salinities, but quantification remains problematic. Oyster-lease distribution has moved northward well into Little Lake during the past two decades. On a seasonal basis, Grand Terre salinities have a maximum in October-November and a May minimum, while further up the basin the minimum occurs in February-March. Salinities decrease significantly landward even though the Barataria Basin catchment area is severely restricted. High temperature and salinities in the upper estuary provide an extended nursery ground for Brown shrimp in spring.
5) Water temperature increases from a mid-January low to a plateau of warm temperatures from May thru mid-September, and the rate of this temperature increase is critical for growth of Brown shrimp. The drastic temperature changes associated with cold fronts October through December are triggering factors for the emigration of White shrimp from inshore to offshore fisheries.
6) The synoptic weather types occur for durations of a few hours to half a month. Weather types characterized by southerly winds (Coastal Return, Gulf Return, and Frontal Gulf Return) occur primarily in summer, while northerly wind types (Pacific High, Continental High, and Frontal Gulf Return) occur primarily in winter. The Gulf High type, with northerly winds, though, also occurs mostly in summer. Gulf tropical disturbances are most frequent in July, August, and September.
7) Wave attack along the Barataria Basin coast and pulses of water associated with tides and storms in and out of the basin provide the mechanisms for coastal erosion and land loss within the basin. Water pulses that exceed MHW occurred 128 times during 1971. On an average of once

every three days raised water occurs above MHW. The seasonal high-water period that extends from September through December coincides with part of the high wave season. Low water levels for the months of September and October are actually higher than the annual mean value. Although seasonal coastal erosion and land loss has not been documented, the variable wave and water level conditions are suspect in being periods when destructive processes are active.

Appendix A. Value of the Data

An important objective of the study of the hydrological and climatological processes of Barataria Basin was to be able to compare absolute water levels at each measurement station and to correlate these levels with some marsh level datum. This was seriously hampered by the imprecise vertical calibration of instruments' gauge zero with respect to any established first order benchmark. General procedure has been to calibrate gauge zero through a network of temporary benchmarks (TBM) and a first order permanent benchmark (PBM) to Mean Sea Level (MSL). Errors inherent within this procedure are compounded by the use of different sea level datums (1918, 1929, and 1939) for different measurement stations. All vertical controls were originally surveyed from United States Coast and Geodetic Service (USC&GS) first-order benchmarks, assuring an accuracy of ± 0.1 ft. The zeroing of the U.S. Army Corps of Engineers (COE) gauging stations was accomplished by surveying to temporary benchmarks, which were in turn surveyed into USC&GS permanent benchmarks, but only using third-order standards. Communications with the New Orleans District COE survey section indicate that the vertical control of these water level gauges is within 3 in. Although this presents definite shortcomings when relative water levels are compared, it is the best data available.

Bayou Rigaud. The latest survey data for Bayou Rigaud is unavailable because of loss of the permanent benchmark in 1973. An unacceptable survey was conducted by the USC&GS just prior to the disappearance of the benchmark. The gauge at Bayou Rigaud will be resurveyed into an alternate first-order benchmark in the near future. The present reference of the gauge to MSL was established by a survey in 1947, to 1929 sea level.

Bayou Barataria at Lafitte. The gauge at Lafitte was surveyed to MSL using 1939 datum using third-order levels.

Bayou Barataria at Barataira. There is no detailed information available concerning the surveying of the gauge at Barataria. A published correction constant is used, but a more accurate tie-in to MSL cannot be accomplished without an extensive effort on the part of the COE to locate the original survey records.

Bayou Des Allemands. The gauge at Bayou Des Allemands was surveyed to MSL using 1918 datum by the USC&GS using first-order levels.

Bayou Chevreuil. The gauge at Bayou Chevreuil was surveyed to MSL using 1929 datum by the USC&GS using third-order levels. The original Bayou Chevreuil station benchmark was destroyed, and the gauge was resurveyed, resulting in a 1.2 ft discrepancy from the ogirinal survey. The origin of the error is not clear because COE water level publications indicate a -0.6 ft correction while the gauge worksheets erroneously report a + 0.6 ft correction. The result is that a -0.6 ft factor corrects the readings to a 1929 third-order MSL.

Table A.7 summarizes the previous discussion and shows the station, the correction factor to MSL, the year last surveyed, and the level of survey accuracy for each water level station within the pilot study area.

Other factors that effect data reliability are instrumentation and record continuity. Water-level instruments such as the Bristol gas purged pressure gauge (Model 1G3X628-15) used at the USCG station at Grand Isle are typical of those used to convert water level information to analog strip chart recordings. These instruments require periodic maintenance, paper changing and calibration. It is evident from the actual records that the calibrations drift so that the specified 0.01 ft resolution is attainable only under ideal conditions, and the accuracy should not be reported any closer than 0.01 ft.

Record gaps occur from damaged equipment, equipment failure, paper outage, etc., presenting a serious problem when time series analysis is performed.

Time intervals with maximum synoptic data were selected for detailed analysis. Short data gaps can be filled by linear interpolation, but longer gaps represent unretrievable data and make the surrounding record of questionable value. Many major gaps occur from storm damage, which is unfortunate since storms are times of high interest. Data gaps cannot be satisfactorily reconstructed because of the large excursions of the parameter values during these extreme events. The year 1971 was an excellent data year as there were very few gaps and record continuity was maintained through hurricanes Edith and Fern (September 1971).

Table A.1. Barataria Bay Pilot Study Data Handling

C = Catalogued = identified, located, and existence verified
R = Reduced = interpreted and listed at three hours intervals
P = Punched = punched on IBM cards and/or shared on magnetic tape

WATER LEVEL

Sta. Ident. (Number)	Name	Year and Staus																	
		1968			1969			1970			1971			1972			1973		
		C	R	P	C	R	P	C	R	P	C	R	P	C	R	P	C	R	P
USC&GS (88400)	Bayou Rigaud	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X[1]
LWFC	Grand Terre	X			X			X			X	X	X	X			X		
LSU Sea Grant	Airplane Lake				X[2]			X	X	X	X	X	X	X			X		
LSU Sea Grant	John the Fool Bayou							X[2]			X	X	X	X					
COE (82875)	Bayou Barataria at Lafitte										X	X	X	X	X	X[2]			
COE (82750)	Bayou Barataria at Barataria							X	X	X	X	X	X	X	X	X[2]	X	X	X
COE (82700)	Bayou Des Allemands	X			X			X	X	X[2]	X	X	X	X	X	X[2]	X		
COE (82525)	Bayou Chevreuil	X			X			X	X	X[2]	X	X	X	X	X	X[2]	X		
COE (82350)	Bayou Lafourche										X	X							
Humble Oil	Humble Oil Platform "A"	X	X		X	X		X	X[1]										

[1] January only

[2] Substantial data missing

Table A.2. Salinity.

Sta. Ident. (Number)	Name	Year and Status														
		1956-1961			1962-1970			1971			1972-1974			1975		
		C	R	P	C	R	P	C	R	P	C	R	P	C	R	P
LWFC (3015)	Grand Terre				X[2]			X	X	X	X[2]			X[2]		
LWFC (3017)	St. Mary's Point	X[1]			X[4]			X	X	X[4]	X[4]			X[4]		
COE (82875)	Bayou Barataria at Lafitte	X[1]			X[1]			X	X	X[1]	X[1]			X[1]		
COE (82750)	Bayou Barataria at Barataria	X[3]			X[3]			X	X	X	X					

[1] Daily readings [2] Weekly averages [3] Spotty [4] Weekly readings

Table A.3. Temperature.

Sta. Ident. (Number)	Name	Year and Status														
		1956-1961			1962-1970			1971			1972-1974			1975		
		C	R	P	C	R	P	C	R	P	C	R	P	C	R	P
LWFC (3015)	Grand Terre	X[2]			X[2]			X	X	X[2]	X[2]			X[2]		
LWFC (3017)	St. Mary's Point				X[3]			X	X	X[3]	X[3]			X[3]		
COE (82875)	Bayou Barataria at Lafitte				X[1]			X	X	X[1]	X[1]					
COE (82750)	Bayou Barataria at Barataria				X[4]			X[4]								

[1] Daily readings [2] Weekly averages [3] Weekly readings [4] Monthly readings

Table A.4. Wind Speed and Direction

Sta. Ident. (Number)	Name	Year and Status																	
		1969-1970			1971			1972			1973			1974			1975		
		C	P	R	C	P	R	C	P	R	C	P	R	C	P	R	C	P	R
	Boothville																		
Freeport Sulfur	Por Port Sulfur	X			X	X	X	X			X								

Table A.5. Meteorological - Synoptic Weather Types[1]

S Sta. Ident. (Number)	Name	Year and Status																	
		1970			1971			1972			1973			1974			1975		
		C	R	P	C	R	P	C	R	P	C	R	P	C	R	P	C	R	P
	New Orleans Moisant Int. Airport	X			X	X		X	X		X	X		X	X		X	X[2]	
	Boothville							X			X			X	X				
	Grand Isle										X			X	X				

[1] Data compiled to produce weather types consist of Air Temperature, Dew Point Temperature, Relative Humidity, Cloud Cover, Precipitation, Wind Speed and Wind Direction.

[2] Data available through June 1975.

Table A.6. Meteorological - Hydroclimatological[1]

Sta. Ident. (Number)	Name	Year and Status					
		1888-1950	1950-1969	1970	1971	1972	1973-1975
		C R P	C R P	C R P[4]	C R P[4]	C R P	C R P
	Donaldsonville		X	X X X	X X X	X	X X X
	Reserve		X	X X X	X X X	X	X X X
	New Orleans[2] Moissant	X	X	X X X	X X X	X	X X X
	Paradis		X	X X X	X X X	X	X X X
	Schriever		X	X X X	X X X	X	X X X
	Houma		X	X X X	X X X	X	X X X
	Thibodaux						X X X[3]
	Diamond		X[5]	X X X	X X X	X	X X X
	Galiano			X X X	X X X	X	X X X
	Grand Isle		X[6]	X X X	X X X	X	X X X

---

[1] Temperature and precipitation at all stations unless otherwise indicated.

[2] First order station - all meteorological parameter

[3] Some 1974 to Jan. 75.

[4] All data stored on special tape.

[5] Data available from 1960 to present.

[6] Data available from 1969 to present.

Table A-7

Barataria Bay Water Level Gauge Calibration Data

Station Name	Corr factor	Corr to	Last Survey	Order of Survey[1]	MSL Datum
Bayou Rigaud	-5.63	MSL	1947	----	1929
Grand Terre	0.0	MSL	1967	first	1939
Airplane Lake	-14.19	MSL	--	----	--
Bayou Barataria at Lafitte	0.0	MSL	1939	third	1939
Bayou Barataria at Barataria	-0.78	MSL	1941	third	
Bayou Des Allemands	0.0	MSL	1918	first	1918
Bayou Chevreuil	-0.6	MSL	1929	third	1929

[1] There are three levels of vertical control.

First Order = 4 mm $\sqrt{K}$ = .0131 ft $\sqrt{M}$: Class I & II

Second Order = 6 mm $\sqrt{K}$ = .0197 ft $\sqrt{M}$: Class I
8 mm $\sqrt{K}$ = .0263 ft $\sqrt{M}$: Class II

Third Order = 12 mm $\sqrt{K}$ = .0395 ft $\sqrt{M}$: Class I & II

where K = distance of run in kilometers
M = distance of run in miles

Appendix B. Tides

Tide is defined as the periodic rising and falling of water level that results from effects of gravitational attraction of the moon, sun, and other astronomical bodies acting upon a rotating earth. Although the accompanying horizontal movements of the water resulting from the same cause are also sometimes called the tide, it is preferable to designate the latter as tidal currents, reserving the same tide for vertical movements (CERC 1973).

A tidal day is defined as the time of the rotation of the earth with respect to the moon or the interval between two successive upper transits of the moon over a specific meridian, 24.84 solar hours (24 hours and 50 minutes) (CERC 1973). A tidal period is the interval of time between two consecutive occurrences of the same phase of the tide (CERC 1973).

Within each tidal period there is one high water and one low water. High water is the maximum elevation reached by each rising tide (CERC 1973) and is frequently called the crest. Low water is the minimum height reached by each falling tide (CERC 1973) and is frequently called the trough. The height of the tide is generally measured from some arbitrary datum that has been accurately leveled to some benchmark. Thus over a 19-year period the average height of the high waters and the average height of the low waters can be determined. These by definition are mean high water (MHW) and mean low water (MLW). If the type of tide is either semidiurnal or mixed, all high waters and all low waters are used in the averaging procedure. If the type of the tide is diurnal only, the higher high waters are included in the averaging procedure. There is no rationale for fixing what the higher high waters are.

The range of the tide is the difference in height between a crest and the following trough. The mean range is the 19-year average of all ranges.

The mean tide level is half the difference between mean high water and mean low water (CERC 1973). It should be noted that this level is not always equivalent to mean sea level.

There are other terms used in the study of tides that describe hypothetical situations. Such terms are co-tide, co-range, and co-height charts. These types of charts are effectively used to show temporal or vertical distributions of the tide over a large area. For example, co-tidal lines are indications of a coincidence in the time of high tide. Thus the lines join places at which high water occurs simultaneously (Russell 1968, Doodson and Warburg 1941).

In a similar manner co-range lines join places that have equal ranges, and co-height charts join places that have equal water heights relative to a common datum.

The tide-producing forces can be computed with great accuracy, but the response of the oceans to these forces is extremely complicated and determinations of response for predictive purposes have been avoided. What has been done is to assume that the tide is the sum of a series of harmonic oscillations or partial tides having the period of the tide-producing forces. In addition, annual and semiannual terms that are not related to astronomical forces but that are the result of prevailing winds or changes in sea level from heating and cooling must be added at each locality. These terms are called the meteorological tides. In areas where the tidal wave form is deformed by friction, particularly in shallow bays, it may be necessary to introduce harmonics of the forcing frequencies to adequately describe the tide. Each of these terms is weighed proportionally to its empirical, rather than theoretical, importance in each particular locality.

The most important tide-producing forces are those of nearly semidiurnal and nearly diurnal period. These drive semidiurnal, diurnal, and mixed tides. A semidiurnal tide is one that has two high waters and two low waters in a tidal day with comparatively little diurnal inequality (CERC 1973). A diurnal tide is one that has one high water and one low water in a tidal day (CERC 1973). A mixed tide is one in which the presence of a diurnal wave is conspicuous by the large inequality in either the high or low water heights with two high waters and two low waters usually occurring each tidal day. In strictness, all tides are mixed, but the name is usually applied without definite limits to the tide intermediate to those predominantly semidiurnal and those predominantly diurnal (CERC 1973).

There are two main semidiurnal tide producing forces; one with a period of 12.42 hours and one with a period of 12.0 hours. The interaction of these two components produces a temporal variation in tidal amplitude. The semidiurnal tide will be great when these two partial tides coincide and small when they counteract each other. The larger of these tides is called spring tides and the smaller is called neap tides. In localities that have dominant semidiurnal components, spring and neap tides come at intervals of about 14 days.

There is also a fortnightly variation of the diurnal tide. This is because the distribution of the moon's tide-producing force over the earth varies with the declination of the moon. The tides that display the greatest diurnal range are called tropic tides since they occur when the moon is at its maximum angle relative to the equator, over the Tropic of Cancer or Capricorn. The tides that display the smallest range are called equitorial because the moon's angle relative to the equator is at a minimum.

Tide predictions published by NOAA give the false impression that tidal effects in coastal regions are well understood. This impression is especially false concerning tides in the Gulf of Mexico.

The tide in the Gulf of Mexico is diurnal and mixed; the semidiurnal tide is conspicuously absent. The type of tide present at a location can be described from a ratio of harmonic constants. The harmonic constants are:

Name	Designation	Period
Principal lunar semidiurnal	M_2	12.42 hr
Principal solar semidiurnal	S_2	12.00 hr
Luni solar diurnal	K_1	23.93 hr
Lunar diurnal	O_1	25.82 hr

The ratio of these components is

$$\frac{(K_1 + O_1)}{(M_2 + S_2)}$$

and the designations are

Designation	$(K_1 + O_1)/(M_2 \pm S_2)$ ratio
Semidiurnal	0 - 0.25
Mixed Semidiurnal	0.25 - 1.50
Mixed Diurnal	1.50 - 3.00
Diurnal	> 3.00

The ratio's of harmonic constants for Louisiana's stations are:

Station	$\frac{(K_1 + O_1)}{(M_2 + S_2)}$
New Orleans, Lake Pontchartrain	9.00
Pass Manchac	15.00
New Orleans, Miss. River	12.75
Port Eads, Miss. River	7.80
Bayou Rigaud	10.67
Weeks Bay	2.95
Eugene Island	2.43
Calcasieu Light	1.26

There is no place in the Gulf that has a ratio below 0.5, so in the Gulf of Mexico the semidiurnal type is not represented. To date, there are several hypotheses that explain the diurnal nature of the tides in the Gulf of Mexico, e.g. Harris (1907), Grace (1932, 1933), Marmer (1954), but none are conclusive. Platzman (1972) estimated the free period of oscillation of the Gulf of Mexico to be 21.2 hours which lends support to the traditional opinion that the tidal regime is affected by basin resonance.

Appendix C. Salinity and Temperature

The formal definition of salinity is "the weight in grammes of the dissolved inorganic matter in 1 kg of sea water, after all bromide and iodide have been replaced by the equivalent amount of chloride, and all carbonate converted to oxide" (Cox 1965). Until about 1900 this slow and difficult method was used with good reproducibility. Because of its difficulty, however, other methods of determining salinity came under scrutiny--among them, conductance, density, and chloride content. The Stockholm Convention of 1899 found a close correlation between the chloride content of seawater and the salinity. This new parameter called chlorinity (Cl) was defined as the "halide concentration in parts per mille by weight, measured by reaction with silver nitrate, and computed on the assumption that all the halide is chloride" (Cox 1965).

The Convention then put forth the mathematical expression:

$$S \text{ ppt} = 1.805\text{Cl ppt} + 0.030$$

This relation has been used almost exclusively for years, but with advancing technology and more stringent demands on accuracy this relationship has been challenged and the form

$$S \text{ ppt} = 1.80655\text{Cl ppt}$$

has been suggested (Cox et al. 1967, p. 213). Usually salinity is then rounded to two decimal places.

The elimination of the 0.030 constant, which was inserted to allow for the diluting effect of fresh water from Baltic rivers, does not appreciably affect salinities within the range of 30 to 40 ppt. Near the land-sea interface of estuarine waters, where salinities are below this range, the great variability between samples minimizes errors introduced by simplification of the above relationship. It should also be borne in mind that the ion composition of estuarine waters may be very different from that of pure oceanic seawater. Sea-land boundary waters typically contain a higher proportion of carbonate and sulfate to chloride with an accompanying increase in the proportion of calcium to sodium (Collier 1970, p. 67).

During the past 25 years the direct chemical methods have been replaced in many instances by the measurement of related parameters. An example is the measurement of electrical conductivity followed by the mathematical conversion to salinity. These techniques provide a simple, rapid, inexpensive measurement process while allowing continuous in situ salinity records to be obtained. Much care, however, must be taken in the interpretation of such records because not only is conductivity sensitive to temperature variations, but in estuarine areas, ionic composition, which influences the electrical conductivity of the water sample, may vary from that of seawater, for which the salinity-conductivity relation was determined. Conversion has been achieved using tabulated conversion factors (U.S. Naval Oceanographic Office 1966). It should be emphasized that combination of data measured by different methods and reliance values measured by different methods and reliance on spatially and temporally separated data must be carefully approached. Such problems are difficult to avoid in many cases because of the limited data base, but care must be taken in interpreting the data. Salinity measurements taken within the Barataria Basin range from the weekly gathering of water samples for later chemical titration to the chart recording of continuous in situ measurements using a modern induction salinometer.

One important factor in the overall usefulness of salinity and temperature data is their compatibility with other data sets. The general criterion imposed upon Barataria Basin data was that three-hour sampling be maintained for adequate resolution of tidal forcing. This has been followed wherever possible. There are, however, many areas where data were not collected that frequently. Most of the salinity data at St. Mary's Point, for instance, was collected on a weekly basis; thus, the specification of a 3-hour sampling period was not possible. When continuous recordings were available, however, values were read off at intervals of 3 hours. It is, thus, important to note that the temporal resolution is dictated almost entirely by the availability of data rather than by scientific criteria. Equally as important, the spatial resolution of the data is restricted; the Barataria Basin is well monitored relative to other parts of the Louisiana Coastal Zone but still leaves large gaps in the "optimally" conceived data network. The stations chosen for investigation, in seaward to landward order, were Grand Terre, St. Mary's Point, Bayou Barataria at Lafitte, and Bayou Barataria at Barataria. The following is a detailed description of these four stations, including locations, data obtained, instrumentation, and treatment of the data.

MEASUREMENT STATIONS

Grand Terre

The most seaward station investigated, Grand Terre, is located at a boat slip on the north side of Grand Terre, which is at the south end of Barataria Bay (see Fig. 1.1). This station is designated by the Louisiana Wildlife and Fisheries Commission (LWFC) as Area III, Station 15 (3015), and it has a latitude of 29° 16' 28" and a longitude of 89° 56' 32" (Barrett 1971, p. 42). Conductivity has been measured on a continuous basis by the LWFC Division of Oysters, Water Bottoms, and Seafoods at this station since 1961. The first instrument used was a Beckman RQ conductivity recorder, which was installed 16 May 1961. This instrument recorded conductivity on 10-in diameter charts in micromhos/cm at 25°C. Hourly values were read from these charts by LWFC and converted to salinity in parts per thousand (ppt) with the use of a table prepared from a conversion graph provided by Beckman Instruments, Inc. The accuracy given in the specifications for this instrument is ± 2% of the conductivity reading. From August 1967 to July 1975 a Beckman RSQ electrodeless induction salinometer, which is equipped with automatic temperature compensation, was used for measuring conductivity. Conductivity is internally converted to salinity in ppt and, again, recorded on 10-in diameter charts. The specifications for this instrument give the accuracy as ± 0.5 ppt salinity. The total depth of water at this point is approximately 3 ft; the sensor of the salinometer is located approximately 1 ft above the bottom.

For the entire year, 1971, we received copies of the original disc recordings of salinity in ppt, reduced data at various intervals, manipulated it a number of ways, and stored it in various forms. For the period May 1961 to March 1975 we obtained computer printouts from LWFC of daily and weekly maximum, minimum, and mean salinities of all years combined plus monthly, seasonal, and annual maximum, minimum, and mean salinities of all years combined. These means for all years combined were calculated by averaging the mean salinities for corresponding intervals (weeks, months, seasons, or years) throughout these 14 years. The method used by LWFC was to code the number of hours per day that the salinity was within a given range to the nearest ppt and then compute a weighted average to the nearest 0.1 ppt. We also obtained a printout of 1971 with the total number of hours per day at each salinity reading and a printout of 1974 with the same information plus the daily mean averaged to 0.1 ppt and the weekly, monthly, and seasonal averages.

In order to test the validity of the averaging technique, we made daily calculations of the values from 14 August 1971 to 2 November 1971 by two methods: (1) by the method described above and (2) by estimating the salinity to the nearest 0.1 ppt at hourly intervals on the continuous discs and averaging these values to the nearest 0.1 ppt. Results obtained from the two methods agreed to a surprising degree. The maximum difference was 0.6 ppt, which occurred only once. In most cases the results were within one or two tenths of a ppt of each other (well within instrumental accuracy). Once the reliability of the first method was ascertained, it was the method chosen to calculate weekly averages for 1971 (see Table C.1). This table also includes the 1961-74 averages.

Salinity data at hourly intervals were coded and punched to the nearest 0.1 ppt from continuous discs for the period 14 August 1971 to 17 November 1971 and at 3-hour intervals to the nearest 0.5 ppt from 19 January 1971 to 14 December 1971. For this period of time, 8:00 a.m. values were also read from these charts to the nearest 0.1 ppt and tabulated (see Table C.2).

Table C.1. Weekly Average Salinity at Grand Terre

Week No.	Salinity (ppt) 1961-74	1971	Week No.	Salinity (ppt) 1961-74	1971
1	23.1	*	27	20.3	25.2
2	23.2	*	28	21.9	26.0

Table C.1. Continued.

3	23.4	22.9	29	23.5	26.1
4	20.6	22.7	30	23.0	27.1
5	20.2	24.9	31	21.7	20.0
6	21.9	24.7	32	21.0	20.7
7	23.9	24.7	33	22.0	25.0
8	22.3	24.4	34	21.8	23.8
9	21.2	24.2	35	21.9	15.2
10	21.7	24.7	36	21.4	16.5
11	21.8	19.5	37	23.2	15.7
12	21.1	19.2	38	23.0	12.3
13	20.9	18.6	39	23.9	16.5
14	20.1	19.4	40	24.4	15.3
15	19.1	22.8	41	25.5	14.7
16	17.9	16.5	42	25.4	18.0
17	17.4	19.2	43	26.6	16.9
18	17.0	22.1	44	27.9	19.1
19	19.0	23.4	45	27.7	*
20	18.0	24.3	46	27.2	*
21	17.8	22.1	47	27.5	*
22	17.3	20.9	48	27.1	28.1
23	17.3	16.9	49	26.5	26.2
24	17.6	22.6	50	25.0	24.7
25	18.2	24.6	51	24.8	*
26	20.8	27.7	52	24.1	*

* = no data.

Table C.2. Daily 8:00 a.m. Salinity (ppt) at Grand Terre, 1971.

Date	Salinity
Jan. 1, 1971	--
2	--
3	--
4	--
5	--
6	--
7	--
8	--
9	--
10	--
11	--
12	--
13	--
14	--
15	--
16	--
17	--
18	--
19	20.5
20	20.2
21	24.0
22	26.0
23	25.5
24	25.0
25	21.2
26	20.5
27	20.5
28	22.0
29	22.5
30	24.3
31	26.8
Feb. 1	25.2
2	24.0
3	26.0
4	26.5
5	26.3
6	26.2
7	26.0
8	26.0
9	24.5
10	19.6
11	25.2
Feb. 12	27.0
13	25.5
14	20.8
15	20.0
16	22.0
17	21.0
18	24.7
19	24.5
20	24.0
21	23.2
22	22.0
23	21.5
24	25.5
25	27.0
26	26.5
27	23.5
28	23.0
Mar. 1	24.0
2	25.0
3	22.5
4	--
5	26.5
6	26.5
7	24.3
8	21.0
9	25.0
10	25.5
11	24.8
12	23.5
13	21.2
14	19.0
15	15.5
16	--
17	--
18	--
19	--
20	--
21	--
22	--
23	21.5
24	16.4
25	19.0
Mar. 26	19.0
27	18.2
28	19.2
29	19.1
30	--
31	17.5
Apr. 1	18.5
2	18.0
3	17.0
4	20.7
5	20.5
6	--
7	20.5
8	16.5
9	26.5
10	25.0
11	24.3
12	23.5
13	26.5
14	--
15	--
16	--
17	--
18	--
19	--
20	17.5
21	16.5
22	17.0
23	18.0
24	17.2
25	18.0
26	--
27	20.5
28	20.0
29	21.0
30	22.0
May 1	20.6
2	17.5
3	--
4	23.5
5	24.5

Date	Sal.
May 6	24.7
7	24.8
8	24.5
9	24.2
10	--
11	23.0
12	23.0
13	20.7
14	24.0
15	23.7
16	23.8
17	25.2
18	25.6
19	25.8
20	23.0
21	22.5
22	22.7
23	22.5
24	22.6
25	22.5
26	20.8
27	20.8
28	20.6
29	20.5
30	20.3
31	20.3
June 1	--
2	22.3
3	19.6
4	18.2
5	16.0
6	16.0
7	16.5
8	17.5
9	17.5
10	17.5
11	18.2
12	18.5
13	18.3
14	19.8
15	22.8
16	24.8
17	30.8
18	30.0
19	26.0
20	23.0
21	22.0
22	21.5
23	22.2
June 24	24.3
25	27.2
26	26.8
27	31.0
28	31.0
29	30.0
30	25.0
July 1	22.0
2	21.2
3	21.8
4	25.0
5	26.2
6	26.5
7	30.5
8	29.0
9	27.0
10	27.0
11	26.0
12	25.9
13	25.8
14	25.0
15	--
16	26.0
17	27.0
18	26.5
19	26.5
20	28.0
21	--
22	24.0
23	27.0
24	28.0
25	28.0
26	27.5
27	27.0
28	25.5
29	25.3
30	—
31	—
Aug. 1	—
2	--
3	19.2
4	20.3
5	19.5
6	18.0
7	17.5
8	17.5
9	22.5
10	22.6
Aug. 11	22.3
12	19.0
13	26.0
14	29.6
15	26.4
16	25.6
17	24.0
18	25.0
19	25.5
20	25.6
21	25.0
22	23.5
23	22.4
24	—
25	—
26	—
27	—
28	—
29	—
30	—
31	—
Sept. 1	18.6
2	18.0
3	16.8*
4	16.1
5	15.7
6	15.4
7	18.9
8	18.4
9	16.1*
10	16.5
11	16.5
12	—
13	—
14	—
15	14.4
16	13.0
17	7.2
18	8.3
19	11.8*
20	10.7*
21	8.2*
22	15.0
23	15.8
24	15.5
25	17.0
26	17.5
27	17.3
28	16.8*
29	15.6
30	15.7

Date	Sal.
Oct. 1	15.5
2	16.7
3	13.6
4	15.5
5	15.2*
6	15.5
7	14.7
8	13.8
9	16.3
10	16.2
11	16.2
12	13.0*
13	13.0
14	12.9
15	13.0
16	17.0
17	19.0
18	19.2
19	19.3
20	18.1
21	17.8
22	17.0
23	17.0
24	16.8
25	16.8
26	10.8
27	17.2
28	18.2
29	17.6
30	17.7
31	19.0
Nov. 1	19.0
2	21.0
3	—
4	—
5	—
6	—
7	—
8	—
9	—
10	—
11	—
12	—
13	—
14	—
15	—
16	—
17	—
18	—
Nov. 19	—
20	—
21	—
22	—
23	—
24	—
25	—
26	—
27	—
28	—
29	—
30	28.0
Dec. 1	27.0
2	26.8
3	27.2
4	21.0
5	22.5
6	24.8
7	26.0
8	25.5
9	28.0
10	28.0
11	24.0
12	24.2
13	23.0
14	23.8

— no data
* interpolated

Air and water temperatures have been measured and recorded continuously by LWFC at Grand Terre since January 1958 with a Taylor temperature recorder (mercury-filled capillary system). The model originally used is unknown; around 1963 a Taylor 76JM was installed. The specifications for this instrument give the temperature range as -10°C to 50°C and the accuracy as ± 0.5°C. It is calibrated every week against a scientific glass thermometer and readjusted when necessary to assure readings to within 0.5 degrees. Weekly maximum, minimum, and mean values of water temperature (°C) for all these years combined (through September 1975) were obtained from the Division of Oysters, Water Bottoms, and Seafoods. Monthly and annual maximum, minimum, and mean values for each year plus all years combined were also obtained. Temperature data at this station were treated and reported in the same manner by LWFC as were salinity data, i.e., the number of hours per day that the temperature was within a given range was coded to the nearest degree and then averaged to the nearest 0.1 degree. Therefore, any single reading was reported to the nearest degree, and any mean was reported to the nearest 0.1 degree.

As with salinity, for 1971 we received weekly averages of water temperature and copies of the original continuous disc recordings of both air temperature and water temperature. The values for water temperature were coded and put on computer cards to the nearest 0.1 degree at 3-hour intervals from 14 August to 27 November 1971.

St. Mary's Point

The next landward station investigated is currently located at St. Mary's Point, approximately 10 miles NNW of Grand Terre at a latitude of 29° 25' 30" and a longitude of 89° 56' 19" (see Figure 1.1). At the present time salinity and temperature are monitored at this station by LWFC, which designates it as Area III, Station 17 (3017). The total depth of the water at this location is some 6 to 8 ft. Measurements of salinity and water temperature near the surface and near the bottom indicate a high degree of mixing in this area so that either set of values reliably may be used for comparison with values at other locations. Surface readings were chosen because of the extensiveness of this data as opposed to that of bottom sampling. Actually, readings designated as surface values include samples taken at mid-depth.

We obtained salinity measurements made in the vicinity of St. Mary's Point during various periods from 1945 to the present. The frequency of sampling, method of measurement, and agency collecting the samples have varied during this time. However, we obtained all the data from LWFC.

The earliest data collected in this area that we used consisted of only a few samples taken between 13 July 1945 and 23 February 1947 at a location described as Station 14, 500 yards SE of St. Mary's Point in upper Barataria Bay and 800 yards NW of Saturday Island. These salinity data "were determined by titration procedure employing a silver nitrate solution which had been standardized with 'Standard Sea Water' samples obtained from Woods Hole Oceanographic Institution" (Hewatt 1951, p. 14).

The data between 11 April 1947 and 31 August 1949 were obtained from daily sampling at a location designated by Hewatt as Station 47, which is "Slightly n.w. about 1500 ft from the western point of St. Mary's Point. It is over Bozo Zibilich's oyster lease No. 10876" (Hewatt 1951, p. 16). The sampling was performed by a method worthy of the following detailed description given by Hewatt (1951, p. 17):

> During the early spring of 1947, under the direction of Mr. W. B. James and Mr. L. M. Hubby of the Texas Company Geophysical Laboratory, Houston, Texas, a "Salinity Recording Instrument" was developed. The first instrument was mounted on a speed-boat and was employed in a study of the dispersal of bleedwater in the canal system of The Texas Company's Lafitte Oil Field. The resistivity apparatus was found to be very accurate in its early tests at which time it was checked regularly by titration procedure .... On April 11, 1947, a "salinity boat", equipped with a recording apparatus, began making a daily run on the waters of the Barataria Bay area. Beginning on that date an isohaline chart was constructed each day through February 7, 1948, to show the salinity distribution in those waters.

Daily sampling at Station 47 occurred during the course of daily runs made for about 20 months along a north-to-south transect across Barataria Bay. These daily values were recorded and tabulated in salinity to the nearest 0.1 ppt.

No salinity data were received between September 1949 and May 1956. Beginning in June 1956, sampling in this area was conducted by the U.S. Army Corps of

Engineers at Manila Village. The station, originally designated B-2 and later given the number 82903, was located at a latitude of 29° 25' 00" and a longitude of 89° 58' 15". The sounded depth of the water here is given as 5 ft; daily chlorinity of mid-depth samples was determined by the Mohr titration method (U.S. Army Corps of Engineers 1963). The data we obtained from LWFC include these values converted to salinity to the nearest 0.1 ppt during the period June 1956 to December 1961.

The Louisiana Wildlife and Fisheries Commission began sampling at St. Mary's Point (latitude 29° 25' 30"; longitude 89° 56' 19") in January 1962. From this time to April 1966, a Beckman RQ conductivity recorder such as was used at Grand Terre was employed for weekly measurements of conductivity in micromhos/cm, which were converted to salinity with the use of the conversion chart provided by Beckman Instruments, Inc.

This instrument was replaced with a Beckman RS5 in situ induction salinometer in April 1966, which was used for weekly measurements until June 1975. The RS5 measures conductivity and temperature and computes salinity from these measurements. The specifications for this instrument state the accuracy as ± 0.3 ppt salinity when the conversion from conductivity to salinity is done internally.

We obtained computer printouts from the Division of Oysters, Water Bottoms, and Seafoods of the salinity data described above in the vicinity of St. Mary's Point from 1945 to 1975 that give the daily, weekly, monthly, seasonal, and annual averages for each year plus all years combined. Weekly readings to the nearest 0.1 ppt were coded and put on computer cards by date for the period 7 January 1971 to 28 December 1971.

Even though the salinity data we obtained from LWFC date from as early as 1945, most of the data analyzed were those taken since 1961. Daily measurements were made during 1961 but since then only weekly samples have been taken. It should be noted in observing the use of weekly values at St. Mary's Point that weekly averages calculated from daily readings at Manila Village during 1961 are included in the 1961-74 long-term weekly values (see Table C.3). These values were obtained by averaging salinities for corresponding weeks throughout this period. Thus, each data point represents an average of 14 values.

Table C.3. Weekly Average Salinity at St. Mary's Point

Week No.	Salinity (ppt)		Week No.	Salinity (ppt)	
	1961-74	1971*		1961-74	1971*
1	13.0	4.8	27	12.8	17.7
2	10.6	—	28	12.8	17.6
3	9.7	9.1	29	13.5	17.1
4	8.6	17.8	30	13.8	13.5
5	8.4	13.5	31	12.4	13.9
6	8.6	9.9	32	12.7	5.9
7	8.8	5.7	33	15.1	17.8
8	11.2	10.0	34	14.7	18.9
9	9.3	12.9	35	15.2	23.5
10	8.9	5.1	36	15.3	15.8
11	10.3	12.2	37	17.4	13.6
12	12.4	18.6	38	15.8	2.5
13	9.8	6.9	39	17.8	11.1
14	10.1	2.7	40	15.2	3.5
15	12.9	17.5	41	18.0	8.4
16	12.4	16.5	42	18.8	11.6
17	12.0	18.5	43	17.4	13.3
18	13.4	19.7	44	20.0	—
19	14.3	23.0	45	18.3	13.4
20	12.0	19.2	46	15.0	18.7
21	12.0	21.4	47	18.6	22.7
22	12.3	19.6	48	15.3	20.0
23	12.9	19.3	49	13.8	20.2
24	12.5	19.4	50	15.5	20.2
25	11.9	—	51	12.2	14.8
26	11.8	18.6	52	13.1	19.7

*Weekly readings.

Even though it was necessary to use weekly readings at this station, the values were coded, punched, graphed, and plotted according to the actual days on which the measurements were taken in order to achieve as much uniformity as possible for comparison with other data.

Water temperature has been measured weekly at St. Mary's Point by LWFC since 1968 with the Beckman RS5 described above. The specifications for this instrument give the temperature range as 0-40°C ± 0.5°C. A printout was obtained of weekly, monthly, seasonal, and annual averages for each year plus all years combined from 1968 through the first half of 1975. Weekly readings in degrees centigrade to the nearest 0.1 degree were coded and put on computer cards by date for the period 7 January to 28 December 1971.

Bayou Barataria at Lafitte

The next landward station studied is Bayou Barataria at Lafitte, approximately 20 miles inland from St. Mary's Point and approximately 30 miles NNW of Grand Terre, 29° 40' 06" lat. and 90° 06' 36" long. (see Fig. 1.1). This station is maintained by the New Orleans District of the U.S. Army Corps of Engineers and currently is numbered 82875; through 1961 it was designated B-1.

The chloride ion content has been measured daily by the Mohr titration method at this location since October 1955. The depth of the water is approximately 13 ft MLG (Mean Low Gulf). From 1955 to 1961 chlorinity was measured from samples taken at various depths (usually 1, 5, and 7 ft below the surface). Since July 1961 sampling has been mostly at mid-depth (approximately 5 ft below the surface).

We obtained Storage and Retrieval (STORET) printouts from the New Orleans District Corps of Engineers through the facilities of the Environmental Protection Agency (EPA) of daily measurements of chlorinity from October 1955 to December 1974. These computer printouts included monthly and annual averages of mid-depth measurements for each year and all years combined.

Weekly averages of chlorinity were calculated from daily 5 ft values and then converted to salinity by the following equation suggested by Cox et al. (1967, p. 213)

$$S \text{ ppt} = 1.80655 \text{ Cl ppt} \qquad (C.1)$$

These calculations and conversions were performed for each week of each year from 1956 through 1974. Averages were then calculated on a weekly basis for the following groups of years: 1956-1960; 1961-1965; 1966-1970; 1971-1974; 1956-1974; and 1961-1974 (see Table C.4). Long-term values obtained from the 1961-74 data were plotted in Figure 2.3 in order to maintain consistency with other graphs.

Daily mid-depth chlorinity measurements for 1968-73 were converted to salinity with the standard equation, C.1, and then converted to specific conductance at 25°C according to the method suggested by the U.S. Naval Oceanographic Office (1966). In salinity range of 0.00 to 9.99 ppt (salinity rounded to two decimal places) and at a temperature of 25°C, this formula is:

$$\text{Specific Conductance (millimhos/cm)} = [(S \text{ ppt})(0.001658) + 0.0004] \times 1000 \qquad (C.2)$$

The daily salinity values to the nearest 0.1 ppt were coded and put on computer cards for the period 1 January 1971 to 31 December 1971. The salinity exceeded 9.99 ppt only once, with a value of 10.03 ppt. Equation C.2 produced a specific conductance of 17.02 millimhos/cm. A corrected version for a salinity range of 10.00 to 19.99 ppt gave a specific conductance of 17.05 millimhos/cm.

Daily mid-depth measurements of water temperature at Bayou Barataria at Lafitte were received from the New Orleans District Corps of Engineers for the period 11 August 1969 to 31 December 1973. Through 1972 temperature was measured in degrees fahrenheit and recorded to the nearest degree. Measurements were taken in degrees centigrade and recorded to the nearest degree beginning in 1973.

Daily water temperature values in degrees fahrenheit were coded and put on computer cards for the period 1 January 1971 to 31 December 1971. Even though measurements were recorded only to the nearest degree at this station, the values were treated as if they were to the nearest 0.1 degree, and this tenth was assumed to be zero. Weekly averages were calculated from the daily values in degrees fahrenheit for 1970, 1971, and 1972 and then averaged for the entire period of 1970-72. The 1970-72 averages were converted to degrees centigrade by the following standard equation:

$$°C = \frac{5}{9}(°F-32) \qquad (C.3)$$

Weekly averages were calculated for the year 1973 in degrees centigrade. In order to arrive at weekly averages for the entire period 1970-73, the 1970-72 averages to the nearest 0.1 degree in degrees centigrade were multiplied by three, added to the 1973 values, and the totals divided by four. Weekly averages in degrees fahrenheit were also converted to degrees centigrade for the year 1971 (see Table C.5).

Bayou Barataria at Barataria

The farthest inland station investigated was Bayou Barataria at Barataria, approximately 5 miles from Bayou Barataria at Lafitte and approximately 35 miles NNW of Grand Terre, the most seaward

Table C.4. Weekly Average Salinity (ppt) at Bayou Barataria at Lafitte.

Week	YEAR																								
No.	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1961-1974	1956-1974	1956-1960	1961-1965	1966-1970	1971-1974
1	1.31	1.01	0.83	1.45	1.27	1.59	0.69	3.28	1.60	1.94	1.37	1.74	1.76	1.92	2.61	1.95	0.81	2.03	1.03	1.74	1.59	1.17	1.82	1.88	1.45
2	1.26	1.11	0.78	0.96	0.88	1.53	0.59	3.75	1.14	1.85	1.39	1.36	1.66	1.78	2.28	1.69	0.81	1.79	0.92	1.60	1.39	1.00	1.77	1.69	1.25
3	2.06	1.03	0.72	1.46	0.92	1.25	0.61	3.32	1.03	1.65	*	1.23	1.89	2.16	2.38	1.35	0.77	2.07	0.84	1.58	1.49	1.24	1.57	1.92	1.26
4	2.30	1.33	0.57	1.47	0.89	1.22	0.56	2.87	0.81	1.34	*	1.18	1.70	1.64	2.17	2.34	0.68	1.85	0.51	1.45	1.41	1.31	1.36	1.67	1.35
5	1.60	1.62	0.64	1.28	1.02	1.10	0.41	2.77	0.99	1.28	0.92	1.26	1.73	1.66	2.09	1.75	0.65	1.37	0.55	1.32	1.29	1.23	1.29	1.53	1.08
6	1.39	1.23	0.52	0.91	1.02	1.11	0.55	2.49	0.87	1.30	1.07	0.89	1.56	1.65	1.80	1.11	0.58	1.21	0.34	1.20	1.15	1.01	1.26	1.39	0.56
7	1.12	1.20	0.47	0.80	0.81	1.03	0.58	2.29	0.96	1.12	1.27	0.87	1.85	1.70	1.72	1.22	0.61	0.88	0.52	1.19	1.11	0.88	1.20	1.48	0.81
8	1.11	1.12	0.70	0.72	0.79	0.84	0.91	2.09	0.93	0.96	0.75	0.83	1.20	1.42	2.26	1.25	0.63	0.85	0.46	1.10	1.04	0.89	1.15	1.29	0.80
9	1.15	1.00	0.67	0.51	0.79	0.70	1.15	1.94	0.90	4.06	0.52	0.89	1.33	1.37	2.87	1.15	0.52	0.90	0.43	1.34	1.20	0.82	1.75	1.40	0.75
10	1.00	0.59	0.52	0.53	0.69	0.59	0.70	1.90	0.80	7.91	0.50	0.82	1.44	1.42	1.81	1.08	0.42	*	0.50	1.53	1.31	0.73	2.38	1.20	0.67
11	0.82	0.86	0.35	0.57	0.64	0.57	0.86	2.07	0.73	2.97	0.50	1.01	1.68	1.21	1.64	1.14	0.43	1.32	0.44	1.18	1.04	0.65	1.44	1.21	0.83
12	0.79	0.80	0.32	0.51	0.47	0.49	1.19	2.26	0.66	1.05	0.49	1.49	1.33	0.83	1.34	1.15	*	1.11	0.47	1.07	0.93	0.58	1.13	1.10	0.91
13	0.91	0.55	0.39	0.53	0.63	0.43	0.91	2.66	0.62	1.26	0.57	4.02	1.93	0.92	1.35	1.01	0.57	0.85	0.47	1.25	1.09	0.62	1.18	1.76	0.73
14	2.07	0.62	0.41	0.51	0.46	0.39	1.04	3.90	0.76	1.36	0.49	3.74	3.78	0.97	1.39	1.13	0.65	0.76	0.47	1.49	1.31	0.81	1.49	2.07	0.75
15	0.97	0.52	0.45	0.52	0.49	0.36	1.39	2.72	0.60	1.81	0.62	8.30	2.13	1.07	1.49	1.31	1.18	0.73	0.89	1.76	1.45	0.59	1.38	2.72	1.03
16	1.15	0.54	0.38	0.43	0.49	0.36	0.76	5.46	0.61	1.12	1.05	5.21	2.34	0.89	4.01	3.52	1.08	0.61	0.46	1.95	1.60	0.61	1.66	2.70	1.42
17	1.22	0.59	0.11	0.57	0.54	0.42	2.28	4.96	0.71	1.96	3.97	6.53	2.66	0.94	7.98	3.31	9.23	0.75	0.62	3.33	2.59	0.61	2.07	4.42	3.48
18	1.23	0.22	*	0.66	1.98	0.53	2.87	7.27	0.57	1.54	1.67	8.92	1.44	0.94	4.73	5.01	9.99	0.70	0.55	3.34	2.31	0.95	2.56	3.54	4.06
19	1.13	0.55	*	2.04	1.00	0.98	1.34	3.28	0.71	4.16	2.91	7.58	4.17	0.77	6.07	7.81	5.43	0.50	0.33	3.31	2.34	1.10	2.09	4.30	3.52
20	1.24	0.58	*	1.62	0.76	0.54	3.26	4.34	0.39	6.84	1.22	5.66	2.76	0.71	6.05	3.59	3.32	*	1.00	3.05	2.55	1.03	3.07	3.28	2.64
21	1.11	1.94	0.89	2.06	0.76	0.50	4.13	5.40	0.63	10.04	0.71	4.98	1.75	0.82	6.06	6.05	3.04	1.42	1.10	3.33	2.81	1.35	4.14	2.86	2.90
22	3.00	0.88	0.78	5.10	0.79	0.61	11.23	5.51	0.61	5.13	0.75	7.05	1.54	0.91	4.09	5.75	3.36	1.56	0.53	3.47	3.11	2.11	4.62	2.87	2.80
23	1.40	0.52	0.88	0.94	0.99	0.60	4.60	6.29	0.93	5.31	0.81	7.30	1.64	0.96	2.81	6.00	4.42	0.94	0.93	3.10	2.52	0.93	3.55	2.70	3.07
24	5.15	0.74	1.02	0.53	1.76	0.56	3.83	4.42	1.17	6.93	0.69	9.83	1.46	1.07	3.27	2.56	6.46	0.45	0.57	3.09	2.76	1.84	3.38	3.26	2.51
25	1.76	0.78	0.82	0.50	2.29	0.51	3.41	4.71	1.20	5.79	0.60	10.99	1.58	1.12	2.73	2.09	4.12	0.45	0.50	2.94	2.42	1.23	3.12	3.40	1.79
26	1.41	1.64	0.79	0.38	4.55	0.49	2.82	2.51	1.57	5.07	0.69	5.95	1.63	1.52	2.94	2.61	3.29	0.52	0.80	2.32	2.17	1.75	2.40	2.55	1.81

Table C.4. Continued

Week No.	YEAR 1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1961-1974	1956-1974	1956-1960	1961-1965	1966-1970	1971-1974
27	1.23	0.79	0.87	0.32	1.33	0.52	2.93	2.28	1.02	4.84	0.66	6.53	2.47	1.30	3.12	2.64	4.42	0.50	0.67	2.42	2.02	0.91	2.32	2.82	2.06
28	1.07	0.81	0.91	0.34	2.15	0.55	3.10	2.06	0.85	3.49	0.63	5.95	2.42	1.12	2.68	2.81	*	0.53	0.54	2.06	1.78	1.06	2.01	2.56	1.29
29	1.14	0.79	0.80	0.42	1.49	0.47	3.17	2.17	0.88	3.21	0.55	5.54	1.22	1.18	2.81	2.04	9.86	0.73	0.67	2.46	2.06	0.93	1.98	2.26	3.33
30	1.18	0.80	0.81	0.47	1.22	0.54	3.12	2.37	0.83	3.67	0.61	4.98	0.75	1.00	2.32	1.76	4.94	0.94	0.73	2.04	1.74	0.90	2.11	1.93	2.09
31	1.16	0.72	0.59	0.38	3.00	0.42	3.50	2.00	0.74	3.59	0.59	5.11	1.56	1.15	1.96	1.40	3.85	0.73	0.83	1.96	1.75	1.17	2.35	2.07	1.70
32	1.19	1.13	0.67	0.34	2.15	0.46	2.93	2.12	0.78	3.44	0.61	5.03	1.95	1.14	2.89	1.82	3.69	0.82	1.18	2.06	1.81	1.10	1.95	2.32	1.88
33	1.37	0.76	0.64	0.38	1.77	0.49	4.10	2.18	0.77	2.95	0.67	5.07	2.03	1.25	2.24	1.90	4.65	0.97	0.83	2.16	1.87	0.98	2.10	2.25	2.14
34	1.25	0.92	0.68	0.48	3.55	0.56	5.74	2.21	0.78	2.64	0.65	4.85	1.93	1.80	2.15	2.61	5.22	1.18	0.82	2.37	2.11	1.38	2.39	2.28	2.46
35	1.42	1.08	0.55	0.34	1.49	0.57	9.08	2.53	0.67	2.81	0.87	4.13	2.95	2.06	2.13	2.53	5.67	2.18	1.20	2.81	2.33	0.98	3.13	2.43	2.90
36	1.60	1.25	1.13	0.33	1.86	0.59	4.86	3.05	1.23	3.23	0.79	3.46	3.37	1.78	1.84	0.92	8.94	10.29	5.25	3.54	2.94	1.23	2.59	2.25	6.35
37	3.19	1.65	0.76	0.74	2.43	5.25	4.42	3.71	1.16	7.16	1.35	3.75	4.16	1.74	2.05	0.88	10.01	4.27	5.51	3.96	3.38	1.75	4.34	2.61	5.17
38	3.46	1.12	1.19	3.52	1.85	4.05	5.54	6.48	2.48	6.90	1.07	3.98	4.50	3.08	1.61	0.89	13.56	2.84	3.13	4.29	3.75	2.23	5.09	2.85	5.11
39	1.43	0.75	0.69	6.10	2.69	3.58	6.70	5.79	7.51	4.48	0.80	3.80	4.65	2.96	1.60	0.95	9.95	2.77	2.84	4.17	3.69	2.33	5.61	2.76	4.13
40	1.05	0.75	0.59	3.89	2.28	3.12	5.40	3.78	7.45	3.80	0.83	3.75	4.77	4.59	1.98	1.04	7.65	2.17	2.92	3.80	3.25	1.71	4.71	3.18	3.45
41	1.13	0.87	0.64	2.42	2.07	2.84	6.88	4.86	4.11	3.41	1.96	3.64	5.64	8.92	2.78	1.01	8.59	2.67	3.13	4.32	3.56	1.43	4.42	4.59	3.85
42	1.14	0.97	0.92	1.16	2.04	2.15	6.26	5.25	4.86	4.29	1.71	3.59	6.01	5.25	1.76	1.07	9.97	3.09	3.10	4.17	3.43	1.25	4.56	3.66	4.31
43	1.12	1.67	0.68	1.16	1.65	1.99	4.89	5.43	4.27	3.76	1.16	4.34	4.80	9.18	2.91	1.10	13.05	2.23	4.86	4.57	3.70	1.26	4.07	4.48	5.31
44	1.27	0.75	0.84	1.19	1.63	5.06	4.91	4.06	3.88	3.70	1.20	5.48	4.20	9.50	1.78	1.41	9.55	2.27	9.21	4.73	3.78	1.14	4.32	4.43	5.61
45	1.39	0.94	1.02	1.15	1.55	3.08	4.27	5.22	3.35	5.92	1.86	3.66	4.07	6.40	1.80	1.69	8.30	1.56	3.75	3.92	3.21	1.21	4.37	3.56	3.83
46	1.42	3.17	1.51	1.14	1.89	2.82	4.21	2.60	3.26	4.99	3.15	3.46	3.13	4.98	1.83	2.07	7.89	2.46	2.61	3.53	3.08	1.83	3.58	3.31	3.76
47	1.45	1.65	0.95	1.31	2.07	1.85	5.81	2.95	3.10	4.07	2.77	3.98	3.06	4.42	1.71	3.62	5.78	2.45	2.92	3.46	2.94	1.49	3.56	3.19	3.69
48	1.31	1.06	0.99	1.23	1.95	1.71	4.24	2.66	2.90	4.19	1.95	4.01	3.79	5.43	2.48	1.63	4.37	2.82	2.41	3.19	2.69	1.31	3.14	3.53	2.81
49	1.42	0.97	1.11	0.98	3.40	1.68	4.65	2.46	3.08	4.32	4.33	4.16	2.50	7.52	2.46	1.76	3.50	2.32	1.50	3.30	2.85	1.58	3.24	4.19	2.27
50	1.67	0.68	0.90	1.33	2.46	1.37	3.80	2.14	2.46	4.73	2.41	2.40	2.52	4.21	2.83	1.42	3.25	2.24	1.79	2.68	2.35	1.41	2.90	2.87	2.18
51	1.54	1.03	1.03	1.27	1.82	1.11	4.29	2.01	2.22	2.25	2.62	2.79	2.79	3.57	1.58	0.95	3.04	1.65	1.30	2.30	2.05	1.34	2.38	2.67	1.74
52	1.00	0.95	1.49	1.36	2.01	0.85	4.23	1.97	2.13	2.06	2.02	2.22	2.35	3.08	1.86	0.87	2.71	1.44	1.22	2.07	1.89	1.36	2.25	2.31	1.56

* Insufficient data.

Table C.5. Weekly Average Water Temperature at Bayou Barataria at Lafitte

Week No.	YEAR				Aver. °F 1970-72	Aver. °C 1970-72	1973 °C	Aver. °C 1970-73	1971 °C
	1969	1970	1971	1972					
1		64.1	66.0	51.1	60.4	15.8	11.3	14.7	18.9
2		64.6	65.7	58.6	63.0	17.2	7.2	14.7	18.7
3		73.7	67.4	56.6	65.9	18.8	11.6	17.0	19.7
4		75.3	70.9	60.3	68.8	20.4	9.8	17.8	21.6
5		71.1	71.1	55.7	66.0	18.9	14.1	17.7	21.7
6		74.3	64.0	54.0	64.1	17.8	12.7	16.5	17.8
7		73.1	58.9	54.9	62.3	16.8	10.8	15.3	14.9
8		77.0	73.7	57.4	69.4	20.8	12.8	18.8	23.2
9		82.6	73.7	61.5	72.6	22.6	15.0	20.7	23.2
10		81.1	72.0	65.1	72.7	22.6	17.2	21.3	22.2
11		80.3	77.7	67.1	75.0	23.9	16.8	22.1	25.4
12		81.9	72.6	63.1	72.5	22.5	17.9	21.4	22.6
13		66.7	71.4	67.7	68.6	20.3	14.9	19.0	21.9
14		69.6	74.6	71.7	72.0	22.2	14.8	20.4	23.7
15		72.7	77.1	75.7	75.2	24.0	20.5	23.1	25.1
16		78.6	79.7	72.0	76.8	24.9	23.9	24.7	26.5
17		80.7	78.9	75.1	78.2	25.7	22.8	25.0	26.1
18		76.7	75.7	75.1	75.8	24.3	22.5	23.9	24.3
19		79.1	77.1	75.1	77.1	25.1	21.7	24.3	25.1
20		77.6	72.3	74.3	74.7	23.7	23.6	23.7	22.4
21		74.2	78.9	78.0	77.0	25.0	27.8	25.7	26.1
22		75.4	81.4	80.0	78.9	26.1	28.4	26.7	27.4
23		76.4	83.1	80.0	79.8	26.6	28.3	27.0	28.4
24		75.6	82.3	80.9	79.6	26.4	28.7	27.0	27.9
25		80.3	80.9	84.6	81.9	27.7	28.3	27.9	27.2
26		76.4	81.7	84.6	80.9	27.2	30.4	28.0	27.6

Table C.5. Continued.

Week No.	YEAR				Aver. °F 1970-72	Aver. °C 1970-72	1973 °C	Aver. °C 1970-73	1971 °C
	1969	1970	1971	1972					
27		79.7	81.7	84.3	81.9	27.7	30.2	28.3	27.6
28		80.4	84.9	83.4	82.9	28.3	29.9	28.7	29.4
29		80.1	82.3	82.6	81.7	27.6	30.9	28.4	27.9
30		80.7	83.4	84.3	82.8	28.2	29.6	28.6	28.6
31		82.3	81.0	84.9	82.7	28.2	28.9	28.4	27.2
32		80.0	80.3	86.6	82.3	27.9	28.7	28.1	26.8
33	83.4	80.9	80.3	84.3	81.8	27.7	28.3	27.9	26.8
34	83.7	80.7	83.1	88.3	84.0	28.9	27.7	28.6	28.4
35	84.4	81.0	80.6	85.1	82.2	27.9	27.9	27.9	27.0
36	85.7	81.7	77.7	88.3	82.6	28.1	25.9	27.6	25.4
37	80.9	80.3	78.9	85.7	81.6	27.6	27.8	27.6	26.1
38	83.4	80.3	80.6	84.9	81.9	27.7	26.5	27.4	27.0
39	81.0	78.3	81.7	77.4	79.1	26.2	26.9	26.4	27.6
40	83.3	72.3	74.6	78.3	75.1	23.9	26.8	24.6	23.7
41	83.6	69.9	72.6	81.4	74.6	23.7	26.2	24.3	22.6
42	83.0	72.3	74.9	80.6	75.9	24.4	23.2	24.1	23.8
43	76.0	70.7	76.3	81.7	76.2	24.6	22.2	24.0	24.6
44	75.0	60.3	75.7	80.9	72.3	22.4	20.4	21.9	24.3
45	76.3	58.6	64.0	76.0	66.2	19.0	20.2	19.3	17.8
46	71.0	53.9	65.1	72.0	63.7	17.6	18.3	17.8	18.4
47	71.7	52.1	62.0	65.0	59.7	15.4	21.3	16.9	16.7
48	68.9	62.3	54.0	67.7	61.3	16.3	19.7	17.2	12.2
49	69.1	58.6	56.3	72.9	62.6	17.0	15.0	16.5	13.5
50	73.3	60.0	68.3	69.7	66.0	18.9	13.6	17.6	20.2
51	73.4	67.4	69.1	53.4	63.3	17.4	8.9	15.3	20.6
52	70.5	63.3	65.7	55.8	61.6	16.4	13.6	15.7	18.7

$°C = \frac{5}{9}\ (°F-32)$

station investigated (see Fig. 1.1). Bayou Barataria at Barataria is located at 29° 44' 29" lat. and 90° 07' 56" long. This station (no. 82750) is maintained by the New Orleans District Corps of Engineers and originally was designated as B-15. The depth of the water at this location is approximately 13 ft below MLG. Until 1971 chlorinity was measured by the Mohr method of titration of samples taken at various depths. In 1971 a Beckman RQ-2 conductivity recorder, which has the same specifications as the RQ that was used at Grand Terre, was installed with the probe at a depth of 3 ft below MLG (approximately 4 feet below the surface).

Hourly readings, digitized from 10-inch diameter continuous charts, and daily maximum, minimum, and mean values of conductivity were obtained from the Corps of Engineers from 12 April 1971 to 31 December 1973. The hourly conductivity values were coded to the nearest 0.1 millimho and put on computer cards for the period 14 August 1971 to 27 November 1971. Conductivity values at 3-hour intervals were coded to the nearest 0.1 millimho and put on computer cards for the period 12 April 1971 to 31 December 1971. Computer cards for this period were also produced with the values converted to salinity to the nearest 0.1 ppt according to the following equation:

$$\text{S ppt} = \frac{\left[\dfrac{\text{Specific Conductance (millimhos/cm at 25°C)}}{1000}\right] - 0.0004}{0.001658} \qquad \text{(C.4)}$$

This equation, which is valid up to 16.9634 millimhos, is a reversal of the equation suggested by the U.S. Naval Oceanographic Office (1966) for converting salinity to specific conductance.

Chlorinity values of samples taken at various depths and at various time intervals between 9 June 1957 and 20 June 1971 (a total of 374 values) were obtained from the Corps of Engineers; but these data were not reduced because of the lack of uniformity in depth and time interval and because the salinity at this station is so similar to that at Bayou Barataria at Lafitte, where the data were much more uniform and covered a longer period of time.

Monthly water temperatures at various depths from 2 March 1969 to 20 June 1971 were obtained from the Corps of Engineers and catalogued but were not reduced because the sampling was infrequent.

As a matter of convenience to the reader, a list giving the dates included in each week has been provided (see Table C.6). Week 9 always includes February 26 to March 4, whether February has 28 or 29 days in a given year; week number 52 always has 8 days.

Table C.6. Week Numbers and Corresponding Dates.

Week No.		Dates	Week No.		Dates
1	Jan.	1-7	27	July	2-8
2		8-14	28		9-15
3		15-21	29		16-22
4		22-28	30		23-29
5		29-Feb. 4	31		30-Aug. 5
6	Feb.	5-11	32	Aug.	6-12
7		12-18	33		13-19
8		19-25	34		20-26
9		26-Mar. 4	35		27-Sept. 2
10	Mar.	5-11	36	Sept.	3-9
11		12-18	37		10-16
12		19-25	38		17-23
13		26-Apr. 1	39		24-30
14	Apr.	2-8	40	Oct.	1-7
15		9-15	41		8-14
16		16-22	42		15-21
17		23-29	43		22-28
18		30-May 6	44		29-Nov. 4
19	May	7-13	45	Nov.	5-11
20		14-20	46		12-18
21		21-27	47		19-25
22		28-June 3	48		26-Dec. 2
23	June	4-10	49	Dec.	3-9
24		11-17	50		10-16
25		18-24	51		17-23
26		25-July 1	52		24-31

Appendix D. Water Level/Salinity Variations, Water Surplus, and Synoptic Weather Types

A Calendar for 1971

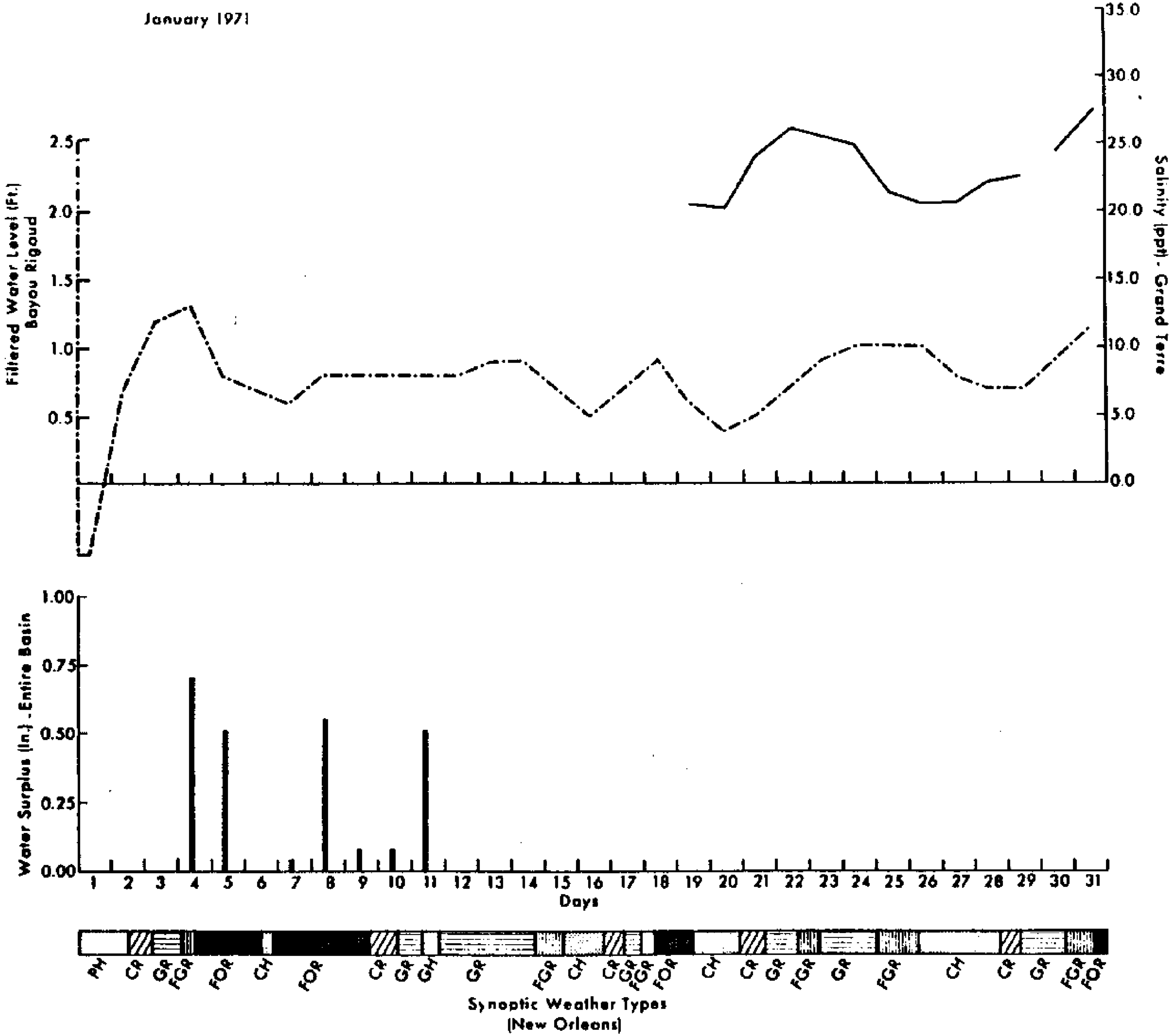

Fig. D.1. Water level/salinity variations, water surplus, and synoptic weather types for January 1971.

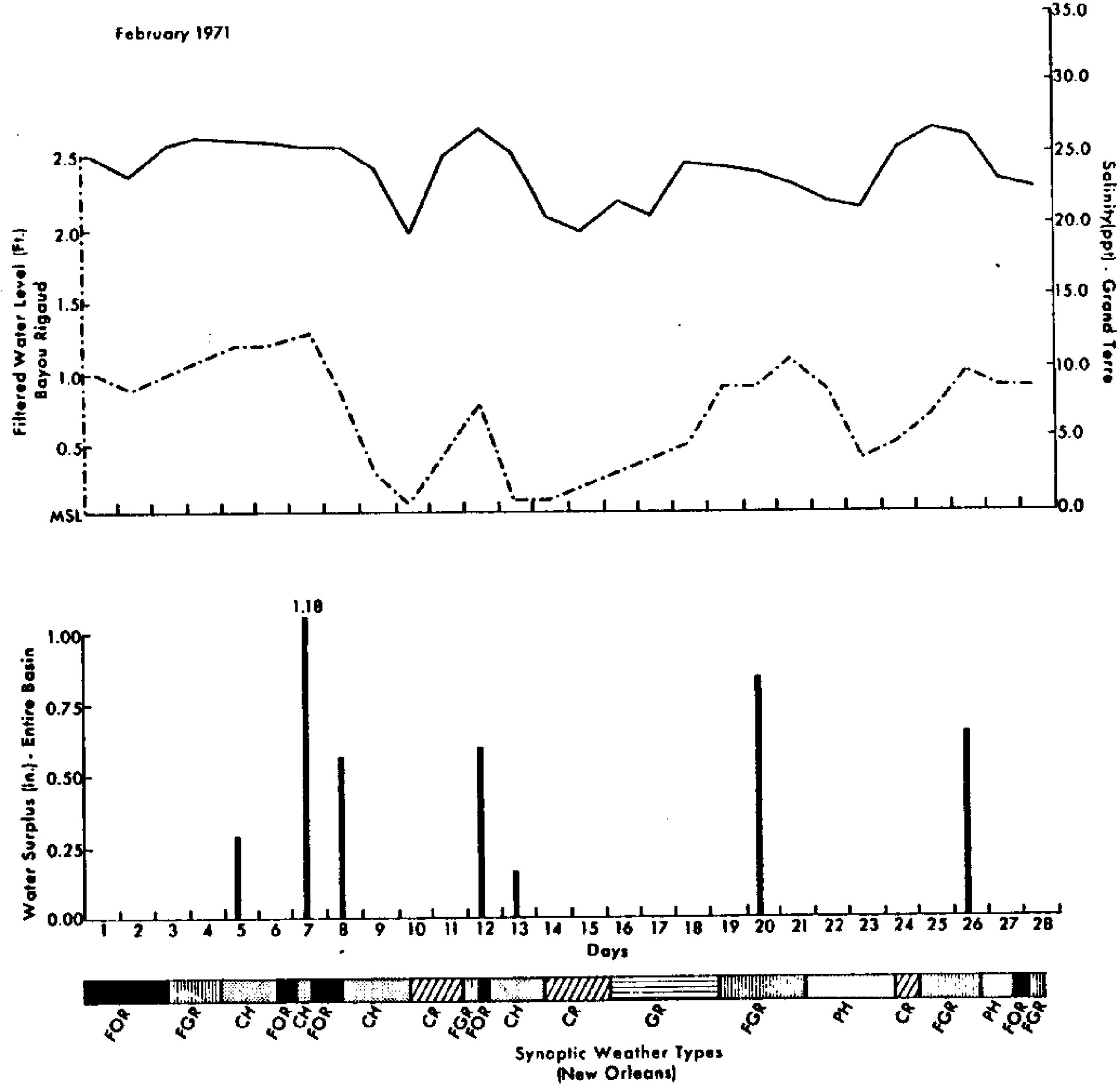

Fig. D.2. Water level/salinity variations, water surplus, and synoptic weather types for February 1971.

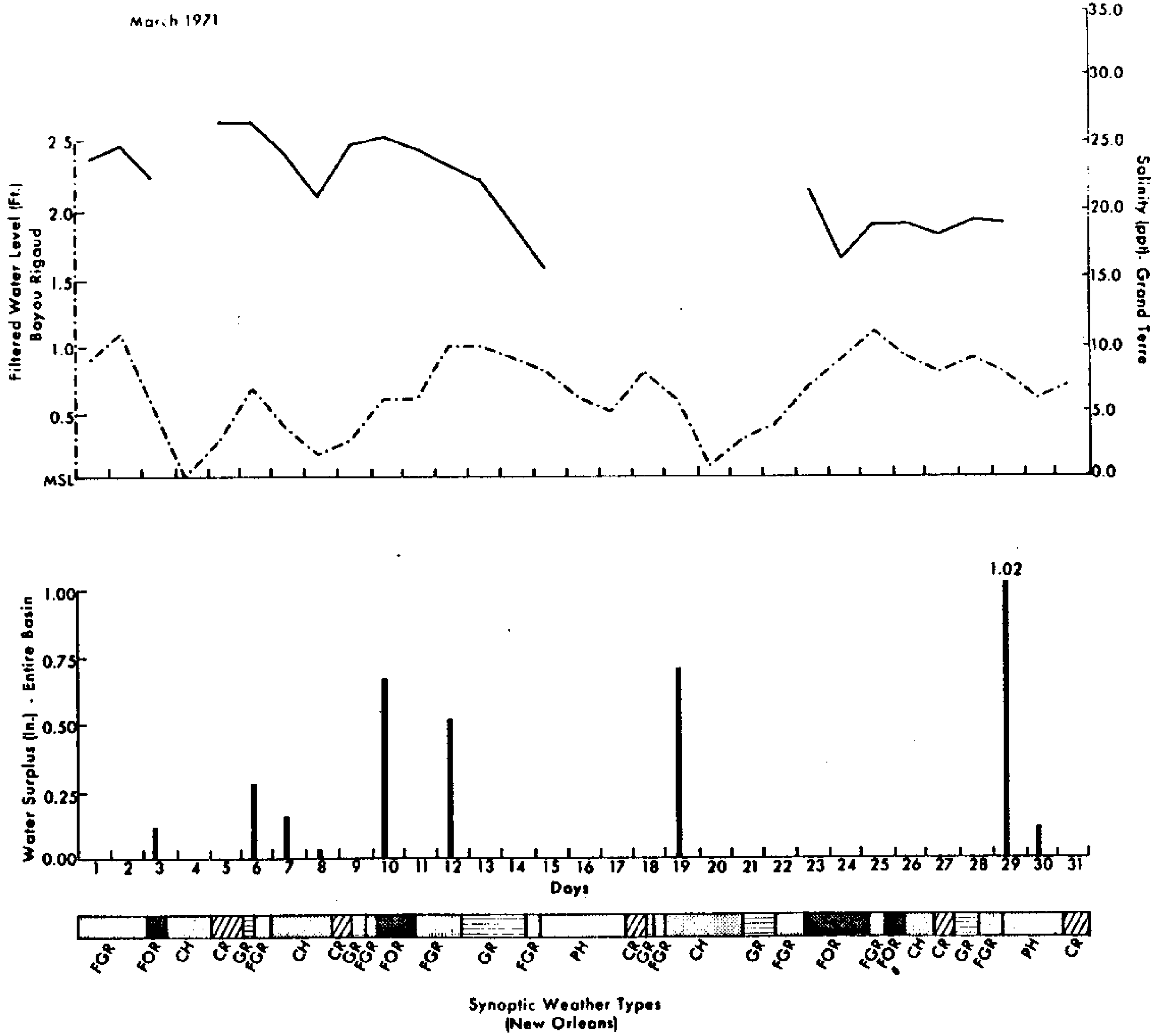

Fig. D.3. Water level/salinity variations, water surplus, and synoptic weather types for March 1971.

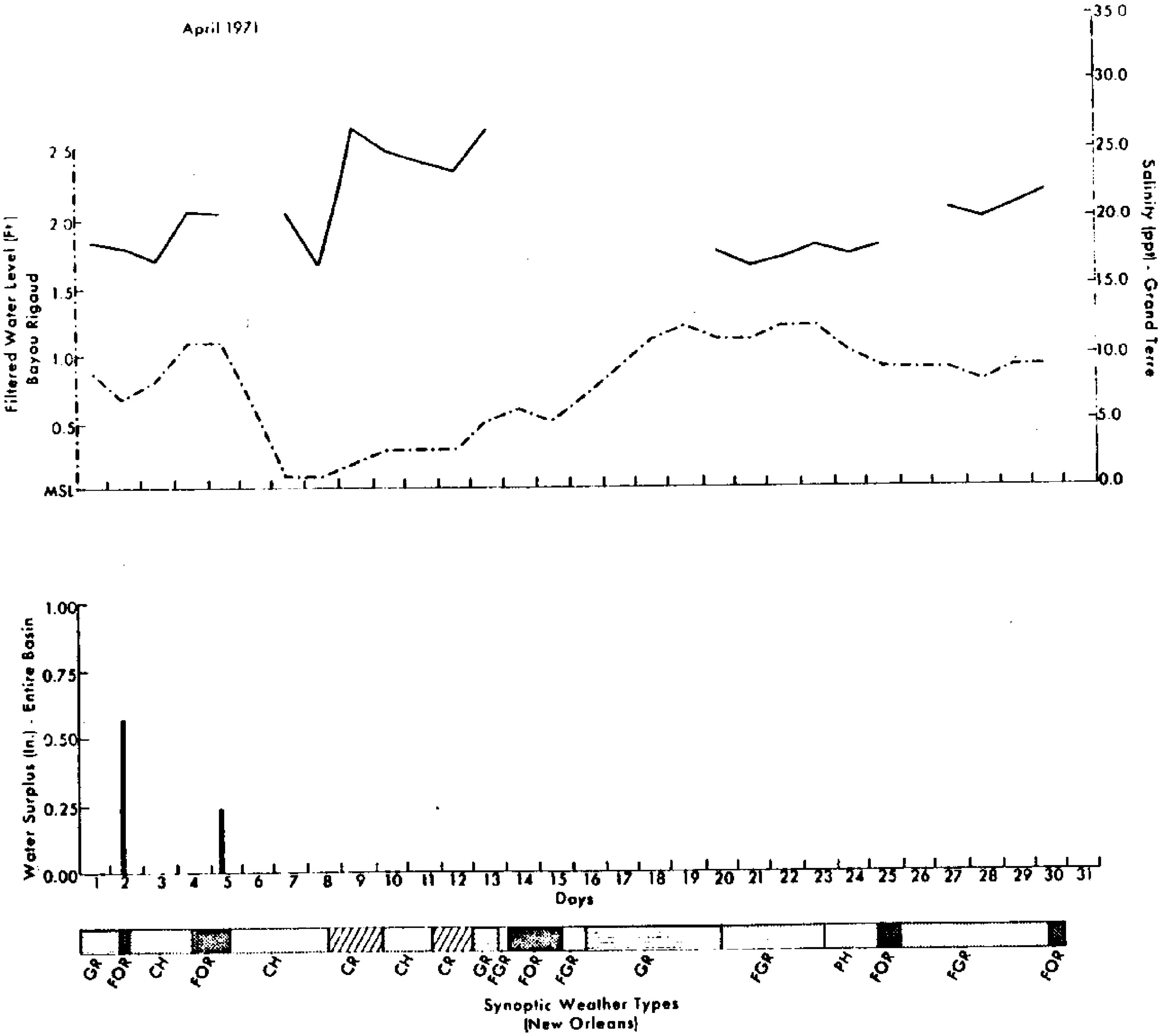

Fig. D.4. Water level/salinity variations, water surplus, and synoptic weather types for April 1971.

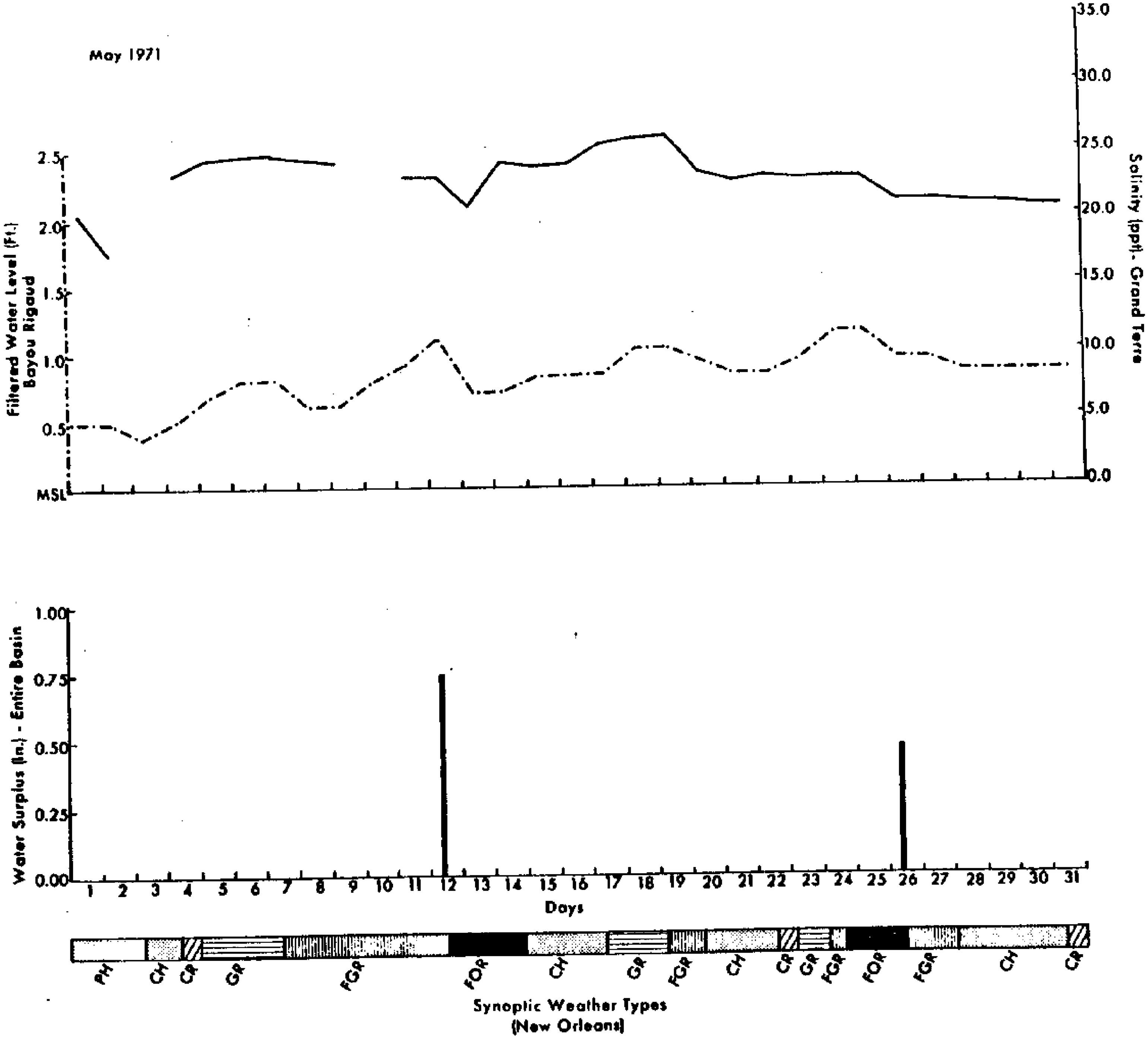

Fig. D.5. Water level/salinity variations, water surplus, and synoptic weather types for May 1971.

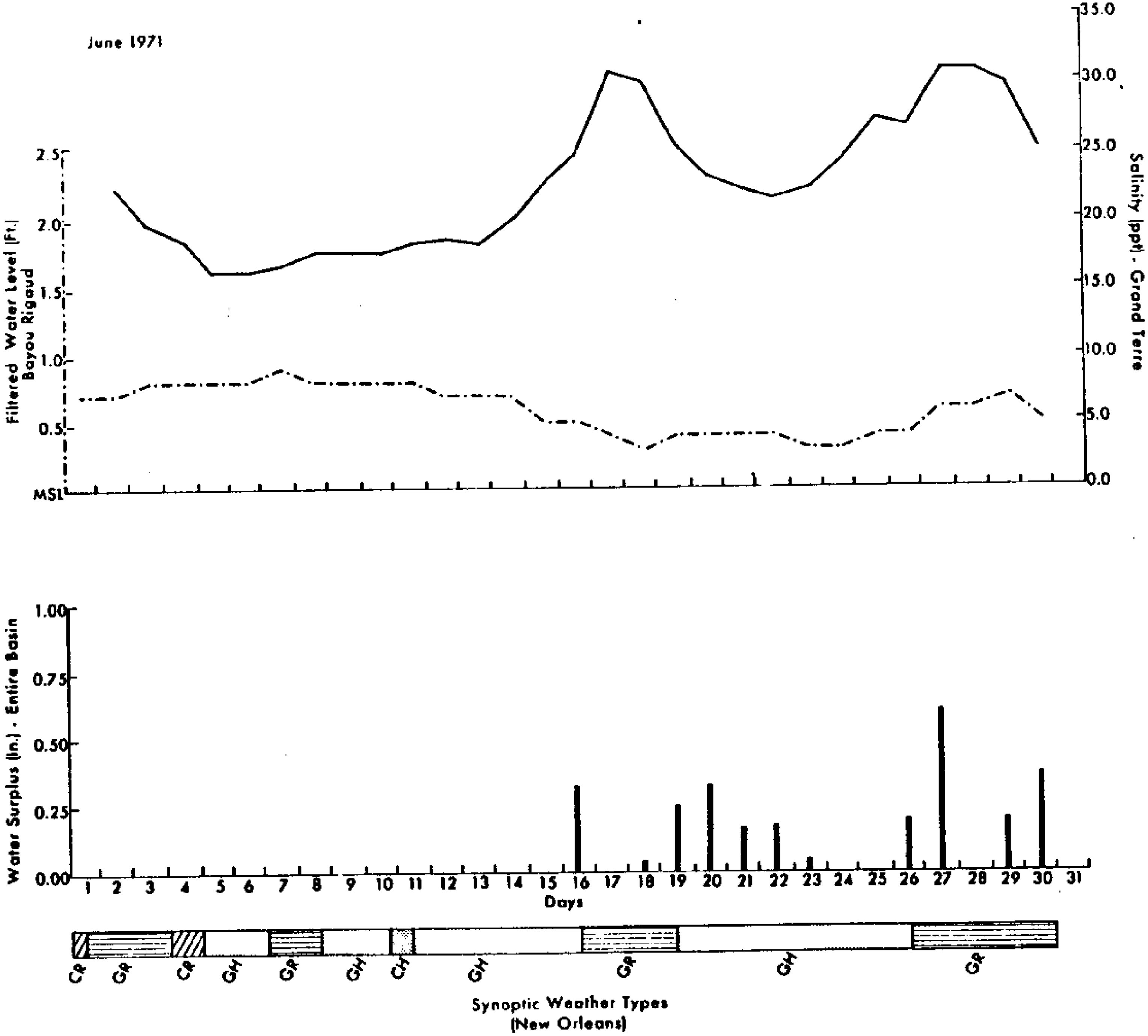

Fig. D.6. Water level/salinity variations, water surplus, and synoptic weather types for June 1971.

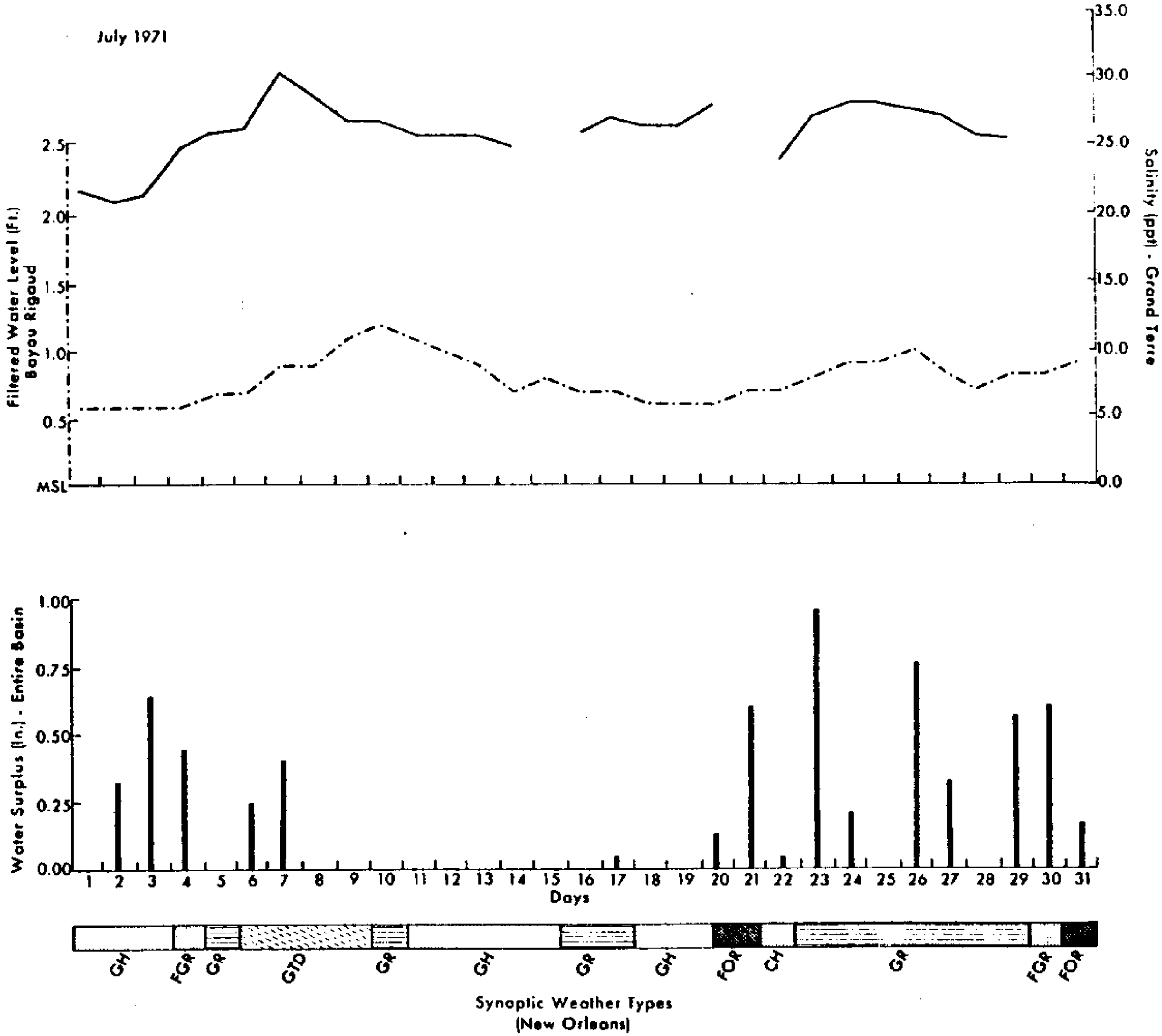

Fig. D.7. Water level/salinity variations, water surplus, and synoptic weather types for July 1971.

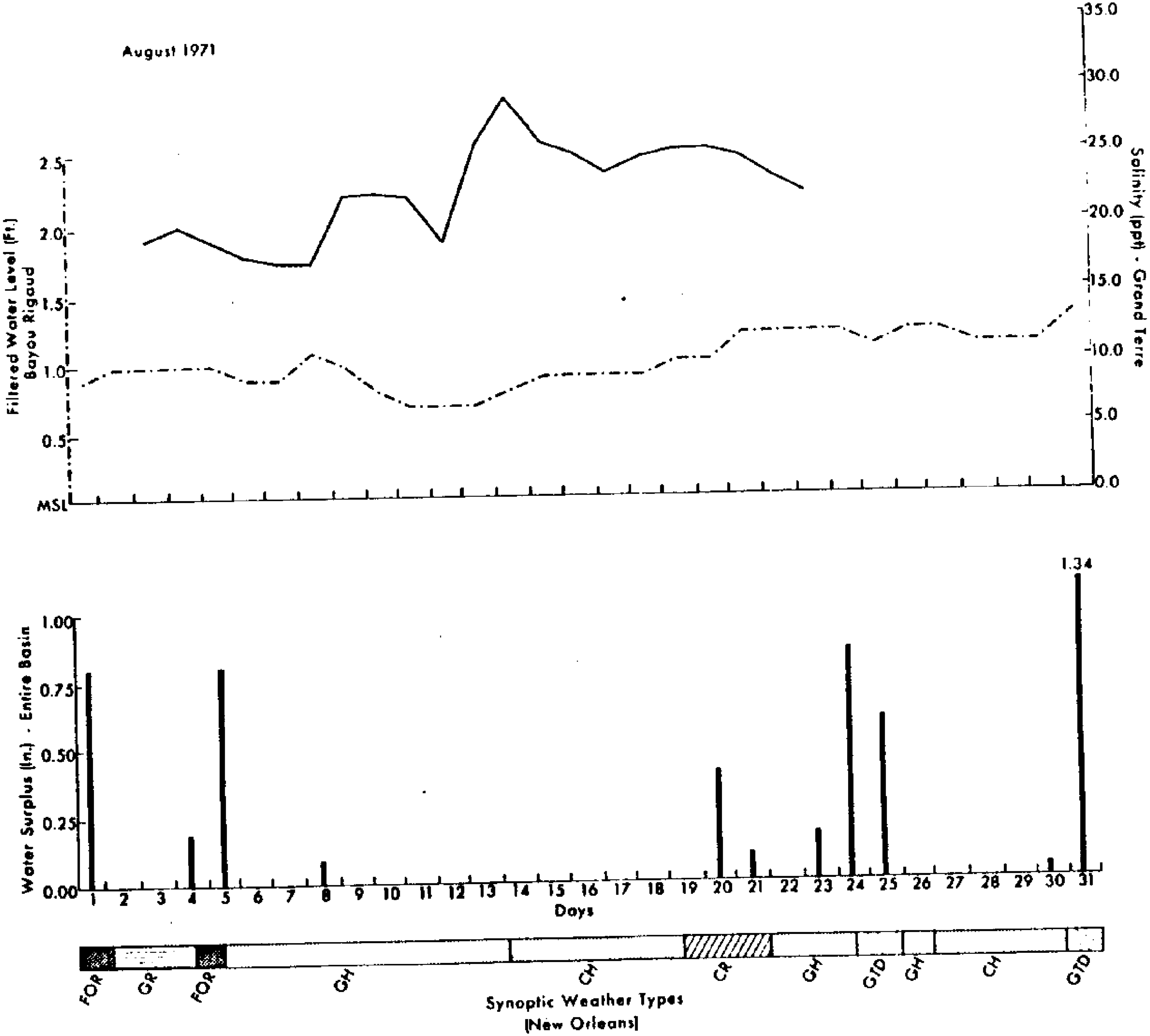

Fig. D.8. Water level/salinity variations, water surplus, and synoptic weather types for August 1971.

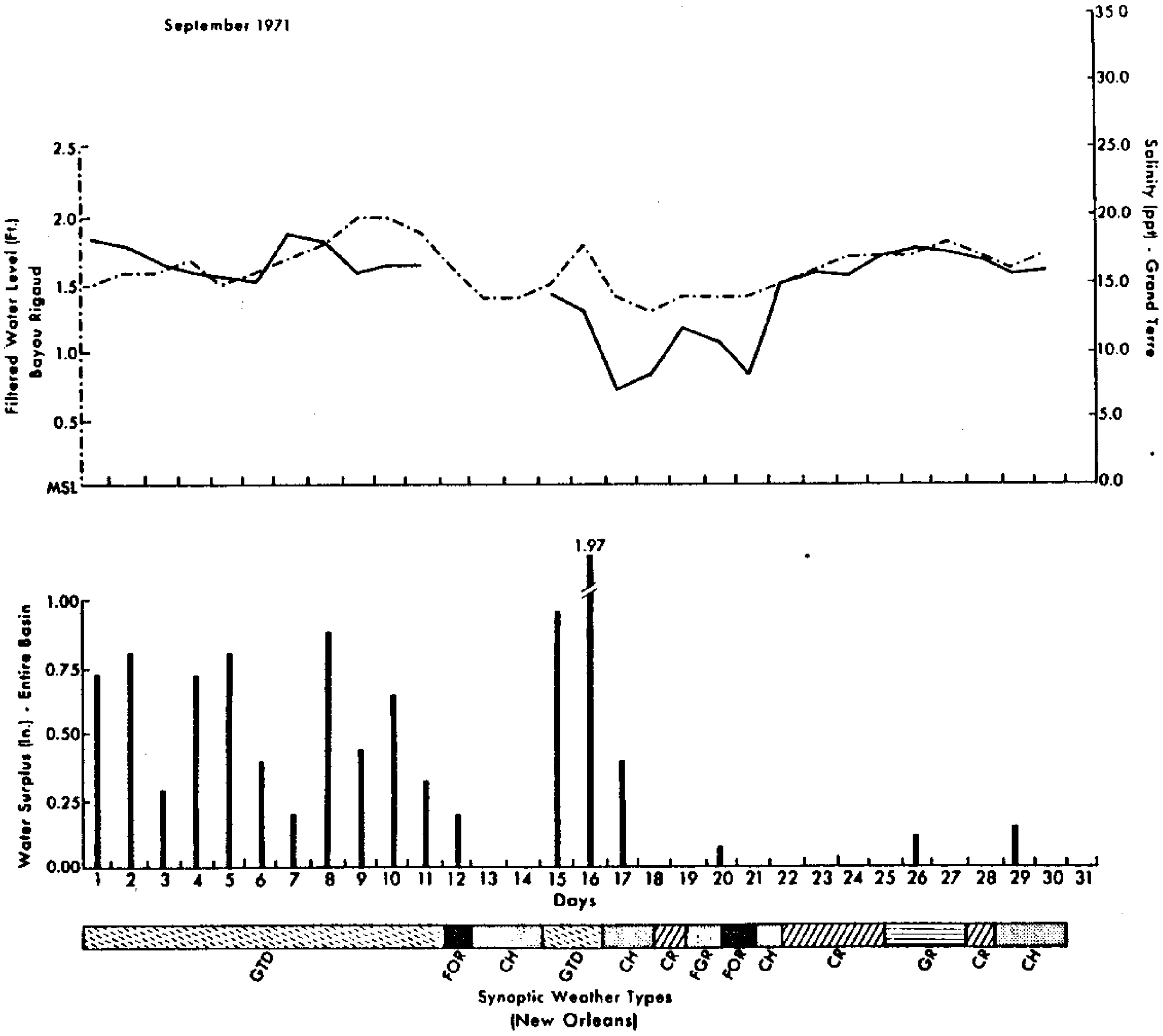

Fig. D.9. Water level/salinity variations, water surplus, and synoptic weather types for September 1971.

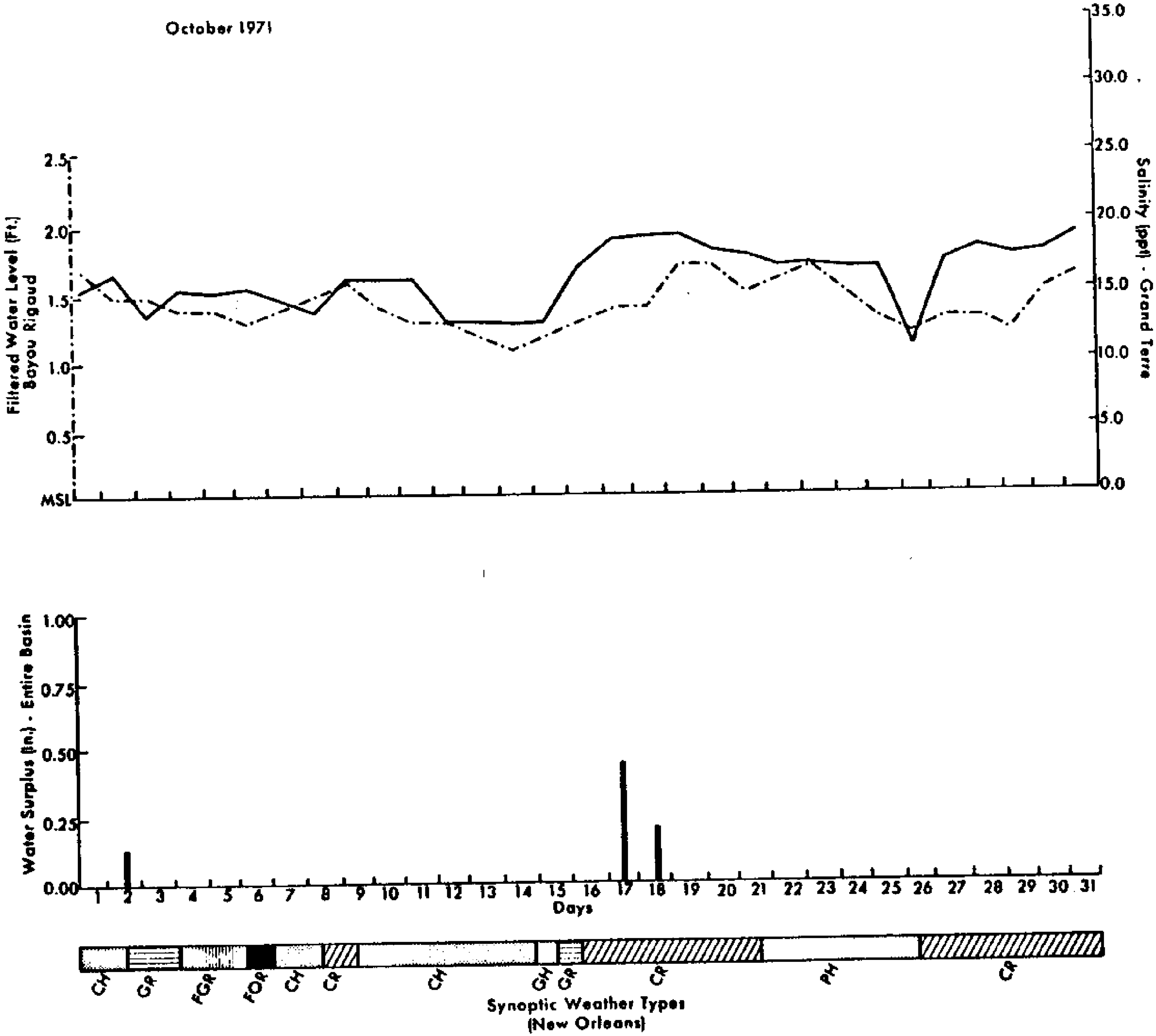

Fig. D.10. Water level/salinity variations, water surplus, and synoptic weather types for October 1971.

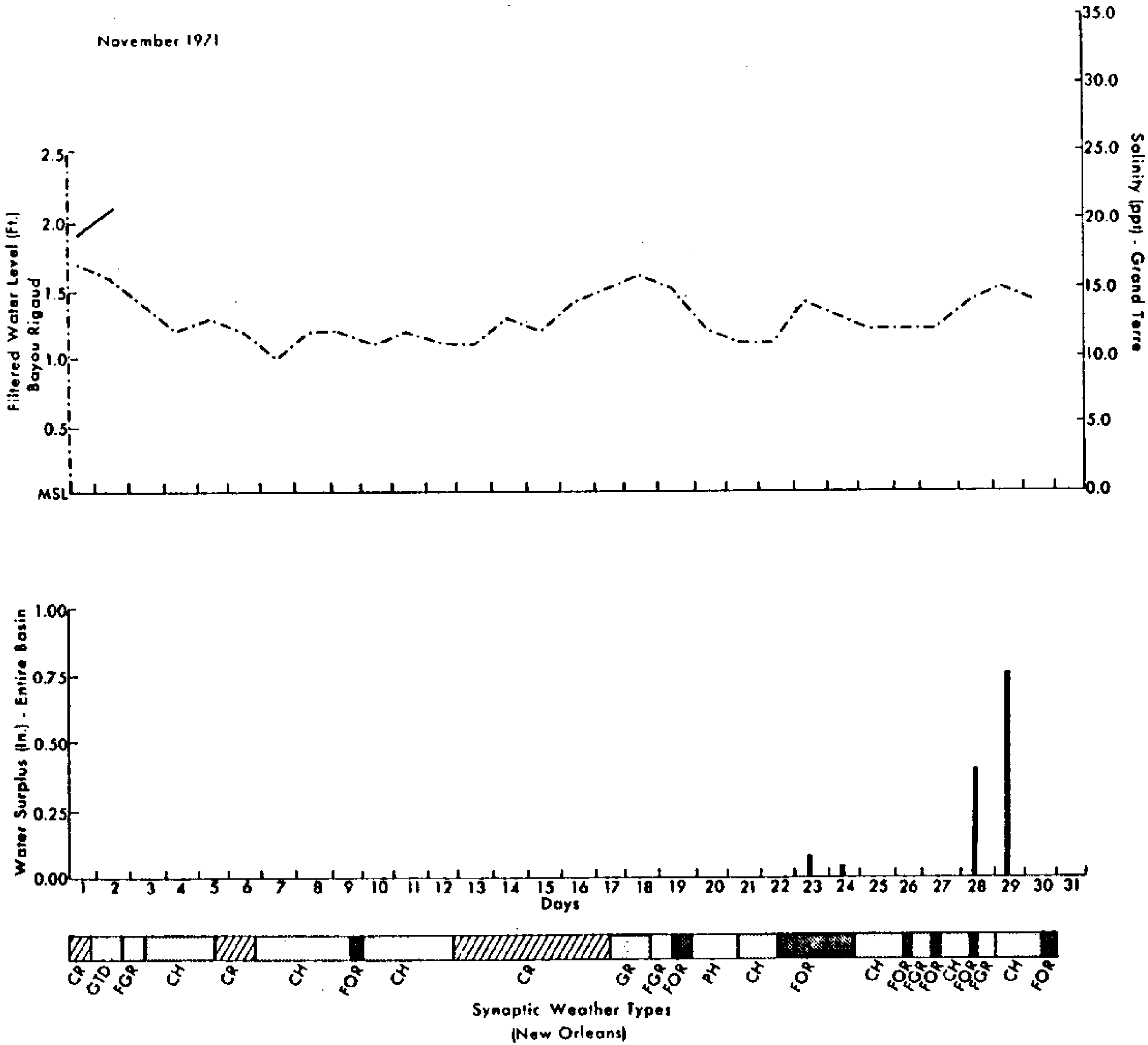

Fig. D.11. Water level/salinity variations, water surplus, and synoptic weather types for November 1971.

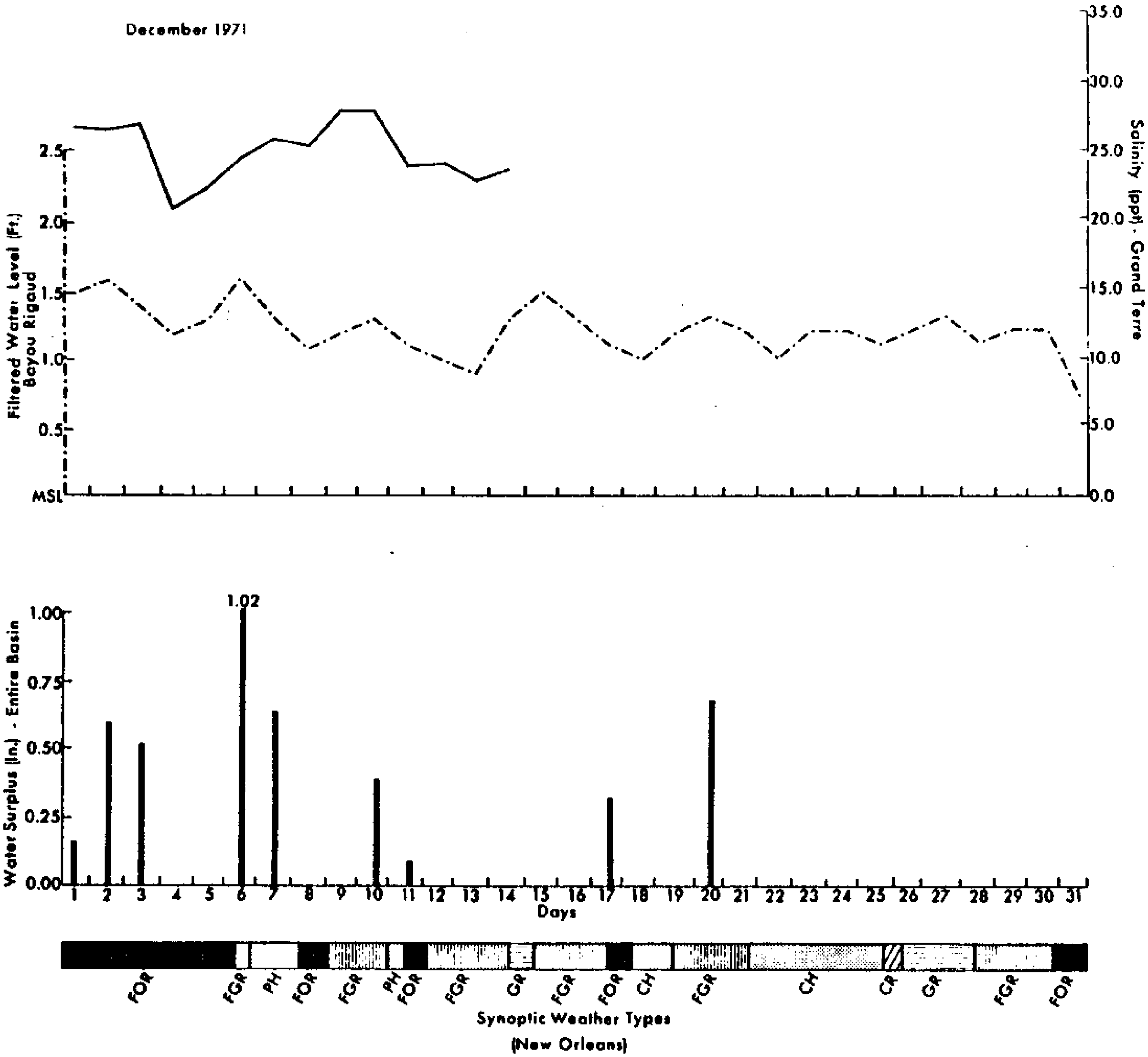

Fig. D.12. Water level/salinity variations, water surplus, and synoptic weather types for December 1971.

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