Chapter 3: PHYSICAL-CHEMICAL CHARACTERISTICS OF THE RIVER

The physical-chemical characteristics of the lower Sittee River are described below based on 1000s of measurements taken over more than 15 years. These measurements include temperature, salinity, dissolved oxygen, pH, water depth, current velocity, transparency of the water and concentrations of nutrients. The averages, ranges, statistical variations, seasonal changes and spatial distributions of these data characterize the river in various ways and they provide an environmental context for understanding the river's biodiversity and the ecosystem. Because of their importance as a natural disturbance, flood conditions are treated in a separate section after "normal flow" conditions are described.

Channel Morphology

Channel morphology refers to the geometric shape of the river channel. Basic dimensions of width and depth are shown in Table 3-1 and three representative cross-sections are depicted in Figures 3-1 to 3-3. Cross-sectional area increases downstream from 31.9 m2 at the sand bar, to 149.3 m2 at Bocatura Bank, finally to 400 m2 at the rivermouth. The channel shape changes across the study area from the freshwater zone to the rivermouth, in relation to geology and to the balance between erosion and deposition. The river changes from an alternation of riffles and pools in the freshwater zone to wider and deeper reaches below the fall line. Depths of the river generally increase downstream (Table 3-2) but the shallowest site is at the rivermouth due to a bar formed by deposition as the river enters the ocean.

Temperature and Salinity

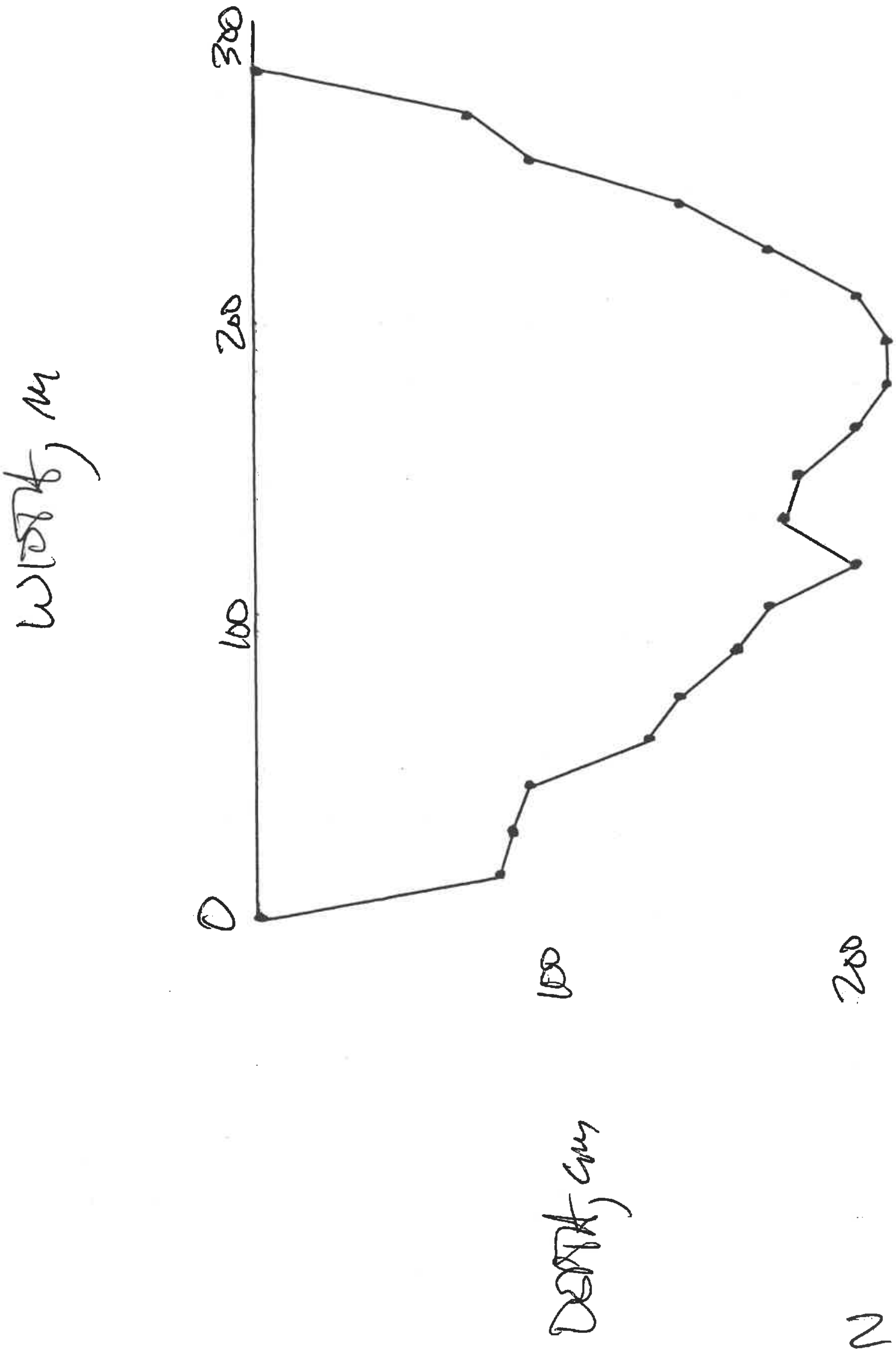
Data on temperature and salinity are the most determinative characteristics of the lower Sittee River. Patterns of temperature make the river tropical and patterns of salinity make it an estuary. Data on these parameters were gathered as longitudinal transects, as depth profiles and as diurnal curves. Longitudinal transects are sets of measurements taken on one day at different sites along the river extending from the rivermouth to the freshwater zone. These data demonstrate variation/patterns horizontally across the length of the river. The longitudinal transects represent the most extensive data set in the 15-year Sittee River study with data sets taken at least once every year and, over time, during all periods of the annual cycle. Usually measurements were made at the surface and at two or three meters depth at each station to account for the typically stratified conditions of the river. Depth profiles are sets of measurements taken from the surface to the bottom at one point in time at a particular site along the river. These data demonstrate variation/patterns down the water column of the river (eg., the presence or absence of stratified conditions). Finally, diurnal curves are sets of measurements taken over a 24-hour cycle at a particular site. These data demonstrate variation/patterns over time at one spot along the river. Temperature and salinity were measured with a YSI model 85 meter with a 10 meter long cable.

Obviously, water temperature data is important for characterizing the environmental conditions of the river and it relates to the discussions made earlier in the book about the

Table 3-1. Characteristics of channel morphology based on transects made across the river, for cross-sectional areas.

Site	width, meters	maximum depth, centimeters	average depth, centimeters
MAIN RIVER CHANNEL			
Kendal	58	45	33
Sand bank	32	230	33
First Run	50	95	65
Bocatura Bank	58	395	328
Crocodile Cove	83	366	322
Canal	70	620	459
Rivermouth	285	210	150
TRIBUTARIES			
Fanny Young	4.3	111	77
Boom Creek, 1.5 km upstream from river	8.0	95	64
Boom Creek, 400 m upstream from river	9.2	175	124

Figure 3-1. Cross-section of the river channel at the rivermouth.



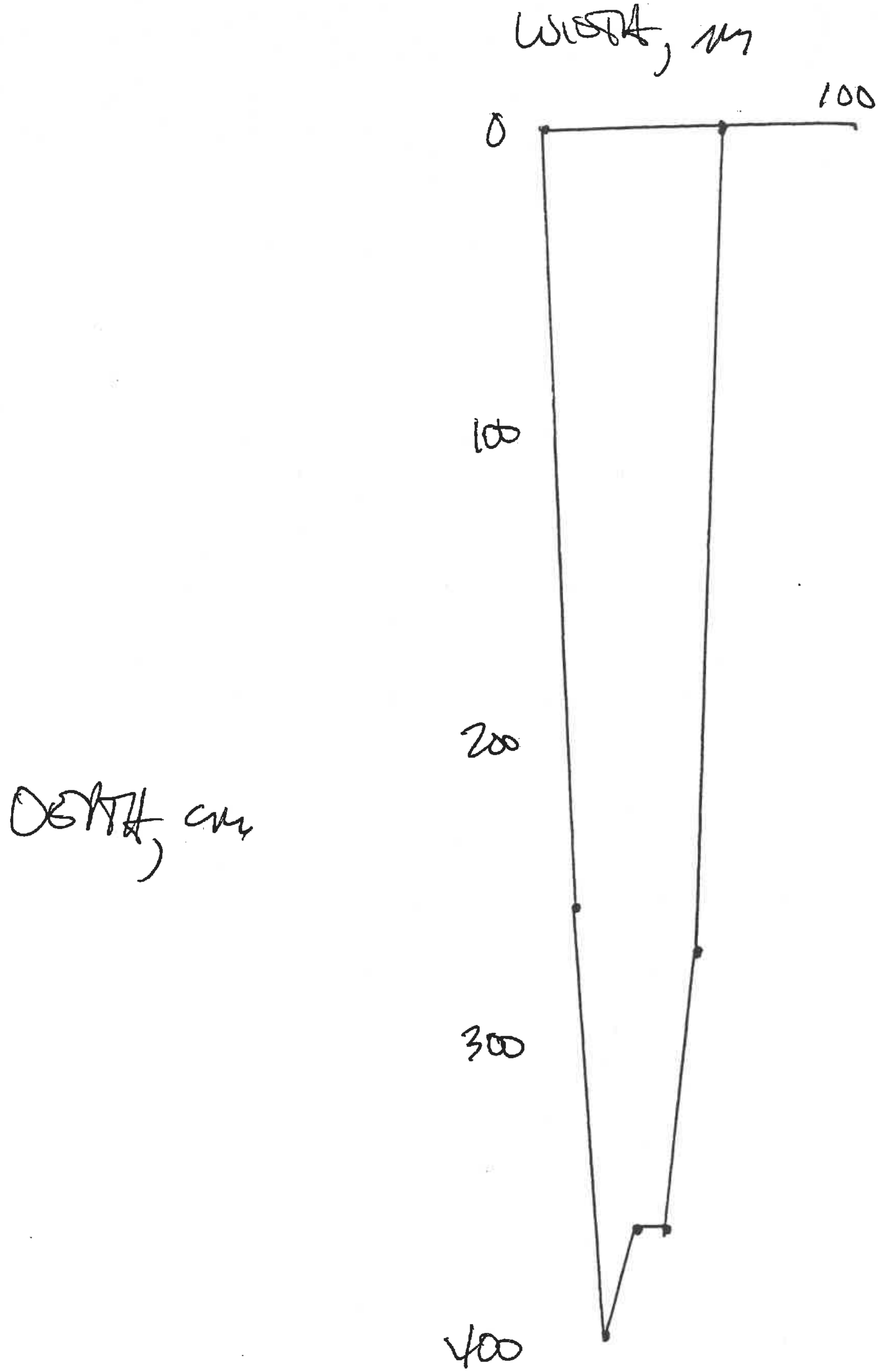


Figure 3-2. Cross-section of the river channel at Bocatura Bank.

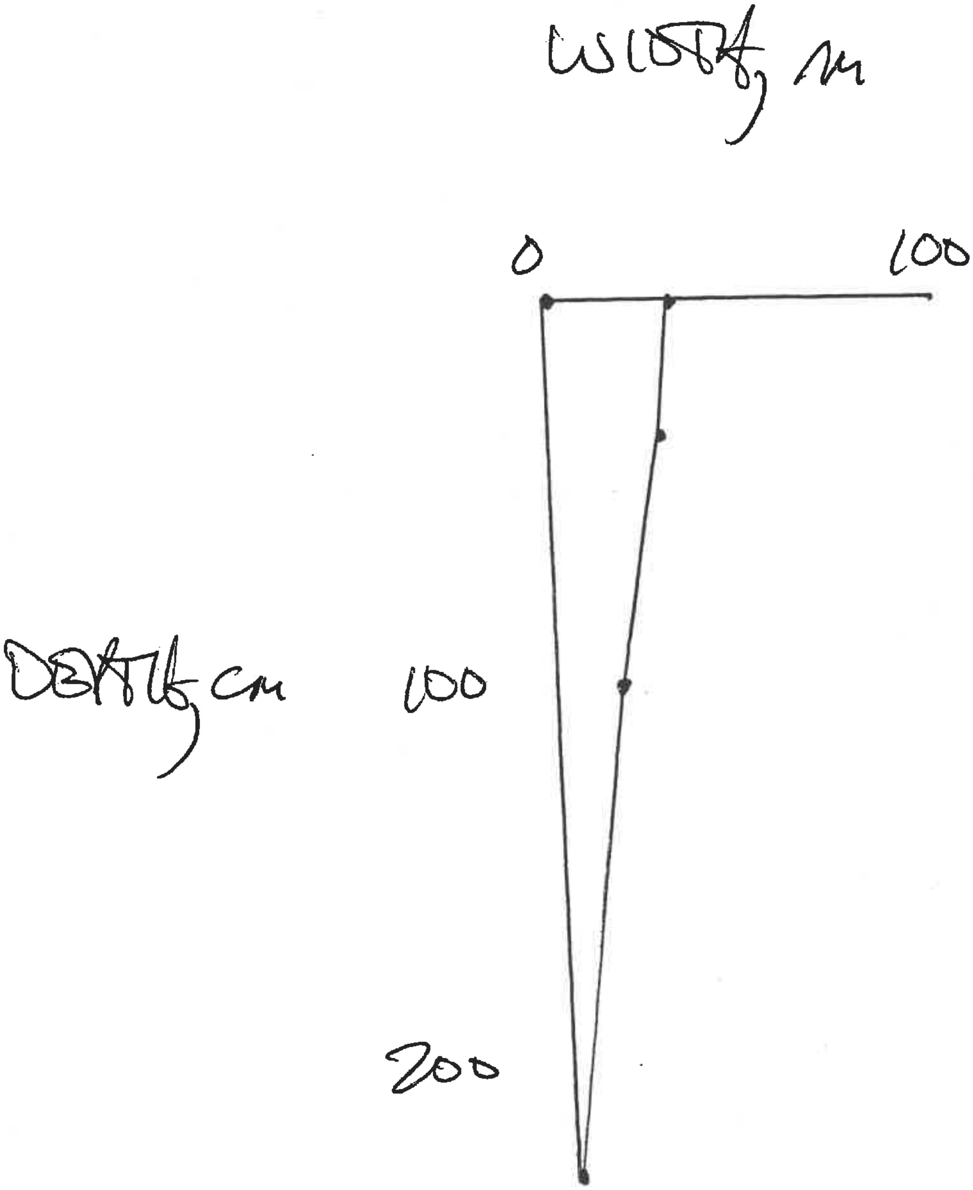


Figure 3-3. Cross-section of the river channel at the sand bar.

Table 3-2. Water depths measured during transects along the river.

Site	sample size	maximum depth, cm	average depth, cm
Rivermouth	14	241	196
Pass at the First Bend	14	480	411
Canal	14	880	769
Kaway Swamp	10	475	370
Crocodile Cove	14	1185	671
Bocatura Bank	9	600	473
Possum Point	13	1035	525
Sittee Dock	13	520	416
Old Church	6	838	732
Cattail Patch	6	840	702
Old Lowe Patch	8	572	419
Bat Bank	10	508	437
Red Bank	10	569	412
Paul Culbert's Farm	12	492	356
First Iguana Tree	11	341	287
Old Stump	10	300	242
Base of the First Run	6	283	224

climate of the site. In this regard temperature data is especially relevant to establishing patterns of seasonality. Table 3-3 shows basic temperature data for surface waters from the longitudinal transects at three sites along the river. The rivermouth site was sampled on every transect and it reflects coastal conditions of the Caribbean Sea. The Possum Point site is in the middle of the brackish zone. The Paul's Farm site is near the freshwater end of the brackish zone and it was included in the table because it was the farthest upstream site that had been measured in at least 30 of the transect studies. Water temperature averages about 28 degrees C in the river annually with only about 1 degree C difference between the rivermouth and the upstream zones on any particular sample date. The ranges of temperatures in Table 3-3 provide a view of the extremes in variation over the years of the study. The upstream site had the greatest range of 8.2 degrees C between the highest (31.7 degrees C) and lowest (23.5 degrees C) temperatures recorded. The range decreases downstream with 7.3 degrees C at Possum Point and 6.0 degrees C at the rivermouth. This patterm of decreasing temperature range from freshwater to saltwater probably reflects the increasing role of seawater content in buffering annual changes in temperature.

A sample of the profile data from Possum Point is shown in Figure 3-4. This graph includes data for temperature, salinity and dissolved oxygen concentration. The typical pattern of stratification is illustrated with two distinctly different water masses: the surface layer of brackish water over the bottom layer of saline water. Temperature is higher in the bottom layer because of the higher retention of heat in the denser saltwater as compared to the surface layer, which has very low salt content.

The diurnal curve data illustrate another view of temperature variation. These data were usually gathered specifically for calculating ecosystem metabolism based on dissolved oxygen change but the diurnal temperature data are also interesting for the variation they depict. Although relatively few diurnal curves have been measured, they have been conducted at all times of the year so annual variation is included in the data set. Table 3-4 shows data on ranges of variation in diurnal temperature change at three different sites. The sand bank site is in the freshwater zone, data from Bocatura Bank and Possum Point are combined for representation of the brackish zone and Wee Wee Caye is included for perspective on full seawater conditions. The average range between high and low temperatures during these diurnal cycles was about 2 degrees C, which represents the typical daily change in water temperature. The largest daily range in water temperature was found at the freshwater site (3.5 degrees C) while the smallest daily range was found at the marine site (2.6 degrees C). A gradient in maximum daily temperature range from freshwater to seawater is suggested, as was noted earlier for data from the transects.

Overall, the water temperature data indicate the tropical nature of the Sittee River with high values and relatively little variation along all dimensions (annually, diurnally, vertically and horizontally). These qualities are caused by the air temperature, which is kept high and constant by the year-round high amounts of solar radiation found globally in the lowlands of the Tropics. However, an interesting difference in patterns of temperature between air and water is suggested in this study, in terms of Von Humbolt's criteria mentioned earlier. While Von Humbolt's criterion for tropical designation seems to hold for air temperature in the Sittee River area (ie., the maximum daily range exceeds the maximum annual range or, in other words, "night-time is the winter of the Tropics"),

Table 3-3. Summary of surface temperature measurements taken along river transects.

Site	average surface temperature, degrees C	temperature range	number of sample dates
rivermouth	28.5	25.0-31.0	38
Possum Point	27.8	24.4-31.7	35
Paul Culbert's farm	27.6	23.5-31.7	31

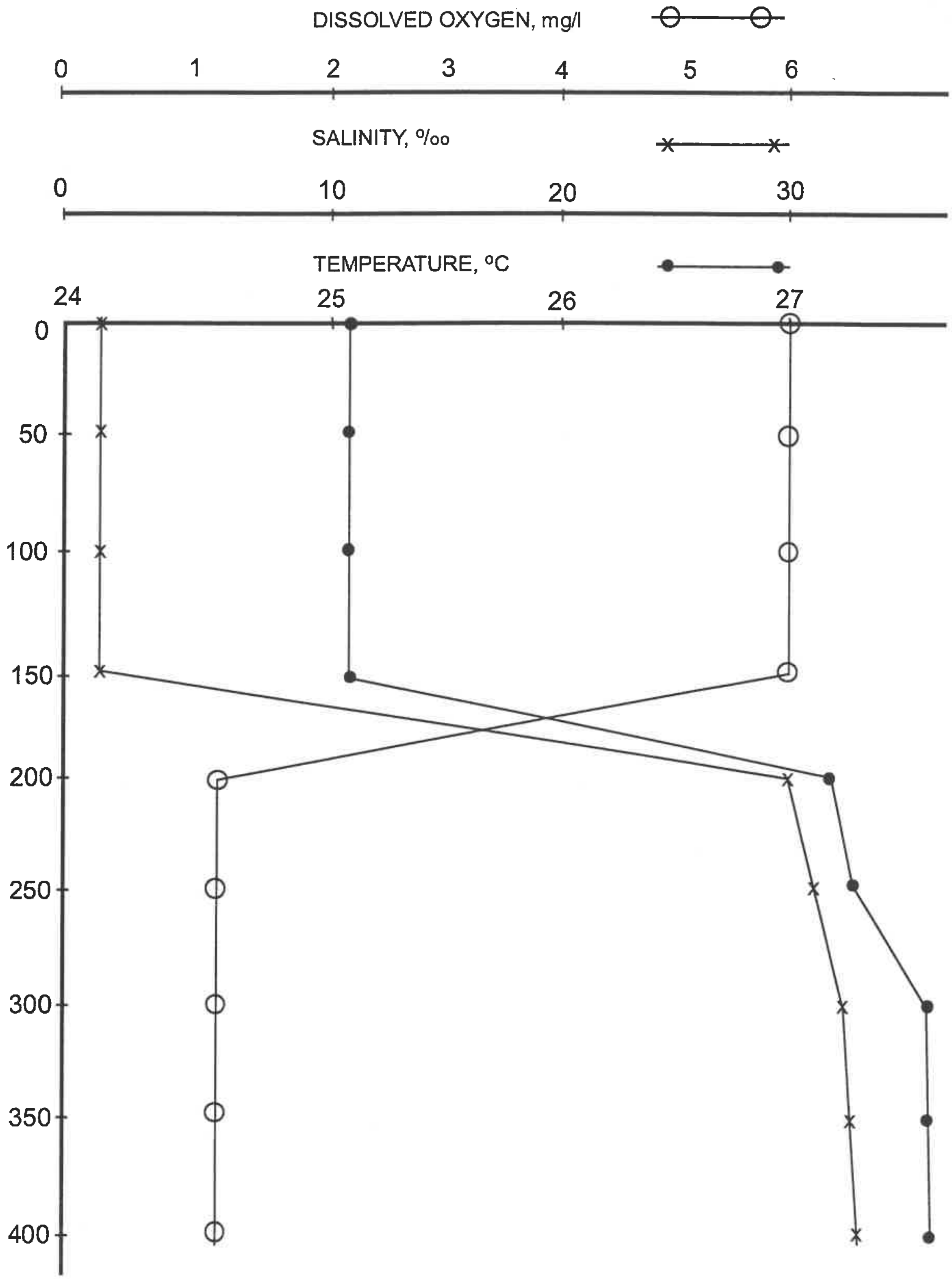


Figure 3-4. Depth profiles of temperature, salinity and dissolved oxygen at Bocatura Bank.

Table 3-4. Summary of diurnal changes in surface water temperature. Data are based on 13 diurnal curves at the sand bank, 8 diurnal curves at Bocatura Bank and Possum Point together, and 5 diurnal curves at Wee Wee Caye.

Site	average difference between high and low temperatures, degrees C	maximum difference between high and low temperatures, degrees C
Sand bank	2.0	3.5
Bocatura Bank/ Possum Point	2.1	3.0
Wee Wee Caye	1.8	2.6

it does not hold for water temperature. The much higher specific density of water, as compared with air, buffers diurnal changes in water temperature so that the maximum daily range is less than the maximum annual range. Thus, according to Von Humbolt's metaphor, night-time is not the winter for aquatic animals in the Sittee River, even though it is for their terrestrial counterparts!

Patterns of salinity distribution influence temperature and many other features of the river ecosystem. Saltwater pushing upstream from the Caribbean Sea mixes with freshwater flowing downstream from the Maya Mountains along the lower Sittee River making it an estuary. Different types of estuaries are recognized according how the saltwater mixes with freshwater, which is best portrayed by the vertical pattern of salt content (Pritchard 1967). A well-mixed estuary has a constant salt content (salinity) from the surface to the bottom, while a stratified estuary has a layer of lighter freshwater essentially floating on top of a layer of the denser saltwater. During normal flow conditions the lower Sittee River is consistently stratified at all times of the year. A typical depth profile has an approximately 2 meter thick surface layer or strata of low salinity water on top of a much thicker layer of high salinity water with very little mixing at the margin between the two layers (Figure 3-4). The bottom layer has essentially full strength salinity of seawater (32 – 34 o/oo, which has units of parts of salt per thousand parts of water, or parts per thousand) and it is called a salt wedge. The surface layer has a small salt content (1 – 5 o/oo), creating brackish conditions. The zone of mixing between the two strata is very narrow and it is called a halocline. The full extent of this pattern of stratification is seen in the transect studies in which salinity is measured at the surface (in the fresher top strata) and at a depth of 2 – 3 meters deep (in the saline bottom strata) (Figure 3-5). The salinity of the saltwedge (at 2 m depth) remains high from the rivermouth extending nearly 10 miles (___ km) upstream from the Caribbean Sea. The salt wedge disappears at the upstream end of the transect, not because of mixing per se but just because of the depth of the river. Moving upstream the depth becomes shallow near the fall line (Table 3-2) creating a small cross-sectional area. Under these conditions the power of the freshwater moving downstream is strong enough to limit the upstream extent of the salt wedge. The position of the limit of the salt wedge changes seasonally so that it is farther upstream in the dry season when freshwater discharge is low and it is pushed downstream in the wet season when freshwater discharge is high. The salinity of the surface water remains low over most of the length of the river with a gradual increase from freshwater conditions at the upstream end of the transect. However turbulent energies increase dramatically at the rivermouth with waves from the Caribbean Sea and higher wind which cause mixing to occur. Sometimes mixing is complete at the rivermouth but often a plume of brackish water floats out of the river and complete mixing doesn't occur until some distance off shore.

These patterns of salinity are typical of a salt wedge estuary but they still seem remarkable out on the river. At a far distance from the ocean a layer of near full strength seawater lies just below the surface! A good way to experience the estuary is by swimming. The surface waters are cool and fresh but by diving down the relatively warmer, salty waters of the salt wedge are quickly felt. This sensory experience makes the abstraction of the temperature-salinity data easily understandable.

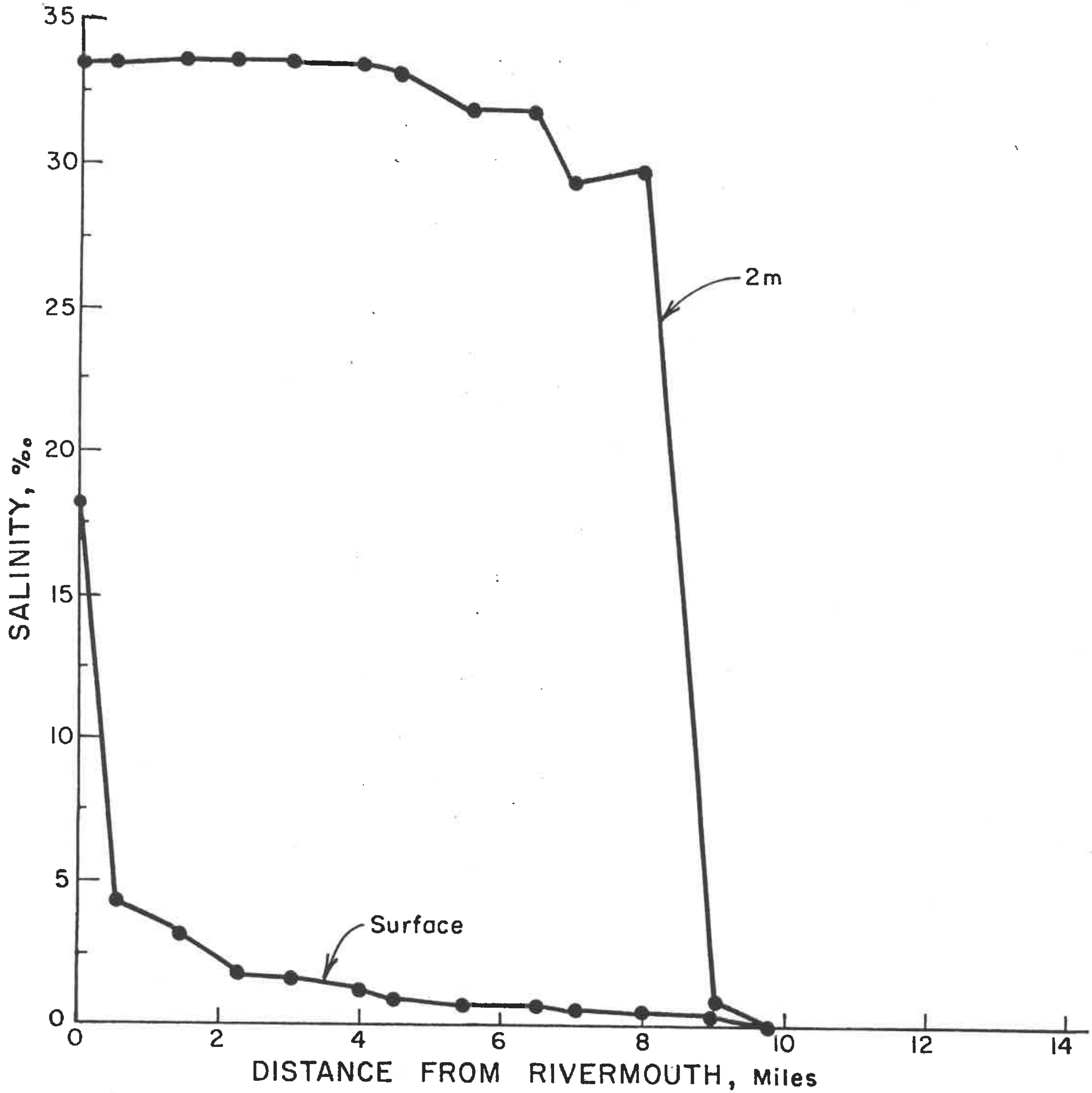


Figure 3-5. Longitudinal patterns of salinity change along the Sittee River estuary.

Currents and Tides

Currents and tides are important physical factors that characterize the lower Sittee River and that affect its biology, chemistry and geomorphology. Both of these factors represent mechanical energy inputs to the river ecosystem. These kinds of factors have been called auxiliary energy sources or energy subsidies to differentiate them from energy inputs that directly fuel the metabolism of organisms: sunlight for higher plants and phototrophic microbes and organic matter for animals and heterotrophic microbes (H. T. Odum 1967, E. P. Odum 1971). Auxiliary energy inputs can amplify the driving energy inputs of an ecosystem and estuaries are well known to have high productivity because of the confluence and interaction of various inputs from the terrestrial watershed and coastal ocean. Current flows are caused by rainfall in the watershed moving into the river channel in baseflow and overland flow while tides are caused by movements of seawater being pushed and pulled by gravitational forces of the moon. Energy in the tides and currents is in the form of kinetic energy that is primarily dissipated by friction with the river bed. Movements of water in tides and currents mix and transport dissolved and particulate materials in the river and require special adaptations by aquatic organisms. Nixon (1988) reviews some of the physical energy inputs to estuaries; good general introductions are given by Davis and Fitzgerald (2004) for coastal energies and by Morisawa (1968) and Leopold (1994) for river energetics.

Currents in the lower Sittee River were measured with the float method. The rate of speed of materials floating in the surface water was recorded over known distances. Current velocities measured with this method were made for the main river channel away from the shoreline during times of the day when wind speeds were minimal (mostly in the morning and late afternoon). Current velocities are known to vary in different locations across vertical profiles and across the horizontal length of the channel, so the values reported here are only indices of the whole currents. However, the method is easy to use and the results are reproducible. Most measurements were made in the early 1990s at the sand bar in the freshwater zone and at Bocatura Bank and Possum Point in the brackish zone. Under normal flow conditions (non-flood times) current velocities were more than twice as fast at the sand bar station as compared with the brackish water stations, both of which had similar velocities (Table 3-5). These differences are probably due to differences in the cross-sectional areas of the river at the different sites. Flows are more rapid at the sand bar because the river is shallower and not as wide compared with the downstream stations.

Tides in the lower Sittee River were measured by recording changes in water level over a diurnal cycle at a particular location. Water level was usually recorded every three hours to develop the pattern of tidal variations. There were usually two tidal periods per day with the following sequence: high/high tide (the highest water level of the day), high/low tide, low/high tide and low/low tide (the lowest water level of the day). These tidal variations alternately submerged and exposed portions of the shoreline and caused movements of sediments and aquatic animals. Table 3-6 shows details of tidal measurements for several sites on the river along with some data from Wee Wee Caye for perspective. The sand bar site in the freshwater zone had the lowest tidal ranges because it was farthest from the ocean, located about 10 miles (km) upstream from the rivermouth. Average tidal ranges were similar for the two brackish water sites of

Table 3-5. Current velocities in the lower Sittee River during normal flow conditions.

Site	number of sample dates	total number of measurements	average velocity (cm/sec)	range
Sand bank	23	320	0.43	0.14-0.65
Bocatura Bank	19	227	0.18	0.04-0.36
Possum Point	31	236	0.13	0.03-0.32

Table 3-6. Tidal variations in the lower Sittee River. Tidal ranges are the differences in water level elevation between high/high tides and low/low tides.

Site	tidal range (cm)	maximum tidal range (cm)	minimum tidal range (cm)	number of sample dates
Sand bank	6.9	14.0	3.7	8
Bocatura Bank	22.0	34.3	9.5	16
Possum Point	22.6	29.3	13.0	11
Wee Wee Caye	16.8	32.2	7.5	7

Bocatura Bank and Possum Point with a range of slightly more than 20 cm between the low/low tide and the high/high tide.

Water Quality

Water quality is a subjective assessment of the capacity of an aquatic ecosystem to support life. It is subjective because the "life" referred to above is biodiversity that humans normally value, such as fishes that people like to catch. In practice, good water quality refers to an aquatic ecosystem with clean or unpolluted conditions, while poor water quality refers to a polluted aquatic ecosystem. There are natural systems that have "poor water quality" conditions, such as the hypolimnion of lakes or hot springs, but water quality assessment is usually applied in regard to pollution by humans. Ecosystems with good water quality generally have a higher diversity of species than those with poor water quality. Species found in poor water quality conditions are described as tolerant while species found only in good water quality conditions are described as intolerant. In this section a set of physical-chemical parameters often used in water quality assessment are described for the lower Sittee River including dissolved oxygen concentration, nutrient concentrations, hydrogen ion concentration (pH) and the transparency or physical clarity of the water. Good water quality conditions for these parameters would be: high dissolved oxygen, low nutrients, intermediate values of pH and high transparency. The use of freshwater macroinvertebrates as indicators for water quality assessment will be described later in the biodiversity section.

Dissolved oxygen

Dissolved oxygen concentration in water is important because it determines the composition of biodiversity and the types and rates of ecosystem processes. Most organisms, and all higher animals such as fish, require oxygen for metabolism. However, a variety of microbes and some invertebrates metabolize without oxygen and, in fact, oxygen is actually toxic for these organisms. Aquatic systems that are well oxygenated are termed aerobic and the organisms found there are called aerobes, while those systems lacking oxygen are termed anaerobic and the organisms found there are called anaerobes. Even though aerobic metabolism is much more efficient than anaerobic metabolism, anaerobic organisms are critical because they extend the ecosystem into zones of soil or water that lack oxygen and because they carry out different kinds of biogeochemical processing as compared to aerobic organisms.

Oxygen dynamics in water are determined by several different kinds of processes. At a particular location in the river:

1) oxygen can be physically carried in or carried away with water flow by the process of advection;

2) oxygen can move in or out of the water by the process of diffusion, either between the atmosphere and the surface water or between strata in the water column, depending on the gradient in concentration;

3) oxygen is generated during the daylight hours through the process of photosynthesis by aquatic plants in the water;

4) oxygen is consumed during both the daylight and the night-time hours through the process of respiration by all organisms (microbes, plants and animals) in the water.

The equation describing oxygen dynamics is thus:

Change in oxygen concentration = (advection in - advection out) + or - diffusion, depending on the concentration gradient + photosynthesis - respiration.

Dissolved oxygen was measured in the Sittee River with a YSI meter with the approaches described earlier for temperature and salinity: longitudinal transects, vertical profiles and diurnal curves. A typical longitudinal transect is shown in Figure 3-6. Surface waters are always well oxygenated but low oxygen conditions are typically found in the salt wedge. This pattern is found at all times of the year during normal flow conditions. Water in the salt wedge has low oxygen concentration because respiration dominates the oxygen balance equation. Processes representing the positive terms in the equation (photosynthesis, diffusion inwards, advection from upstream) are low in the deeper waters of the river, because the denser saltwater in the lower layer does not mix with the less dense, fresher water of the surface layers, due to stratification. Thus, oxygen concentration is reduced in the lower layer of the water by the consumption of oxygen through biotic respiration. This same pattern can be seen at any one point along the transect with the vertical profile data (Figure 3-4). Higher values of oxygen at the 2 meter depth are found at either end of the transect because of the physical conditions found there – advection of aerated water occurs from tidal flow at the lower end of the transect and from river current flows at the upper end of the transect. Also, shallow water depths at either end of the transect facilitate mixing of the low oxygen bottom layer with the high oxygen surface layer and the breakdown of stratification.

Diurnal curves of oxygen concentration change were of special interest because they can be used to calculate ecosystem metabolism of the entire water column. This can be done through a graphical analysis of diurnal oxygen change as long as the physical processes of advection and diffusion can be separated from the biotic processes of photosynthesis and respiration. This kind of diurnal curve analysis was possible for the freshwater site at the sand bar which had well-mixed conditions but it was not possible for the brackish sections of the river where the changes in oxygen concentration were more complex. Results of the diurnal oxygen curve analysis are described in the biodiversity section of the book. A typical curve for oxygen change at the sand bar is given in Figure 3-7, showing the rise of oxygen during the daylight period due to the net effects of photosynthesis and the fall of oxygen during the night-time period due to respiration of aquatic organisms.

In terms of limits on biodiversity, the water column of the lower Sittee River never reaches anaerobic conditions. The sediments of the river bottom probably are anaerobic which limits diversity of invertebrates and this condition is verified by the paucity of organisms seen during snorkeling. The low oxygen values within the salt wedge (0 – 2 mg/l) are termed anoxic conditions which are physiologically stressful but not toxic to

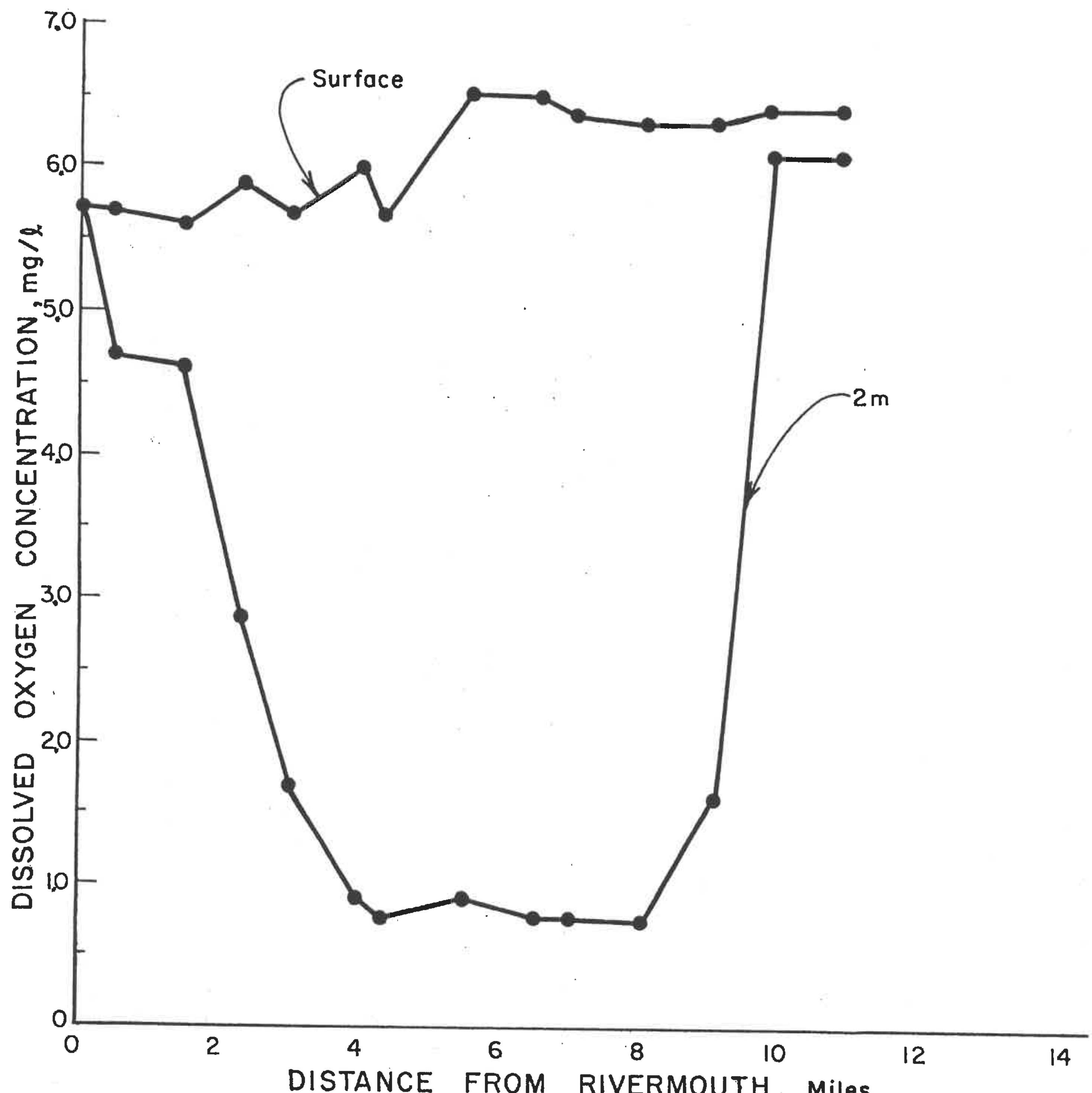


Figure 3-6. Longitudinal patterns of dissolved oxygen along the Sittee River estuary

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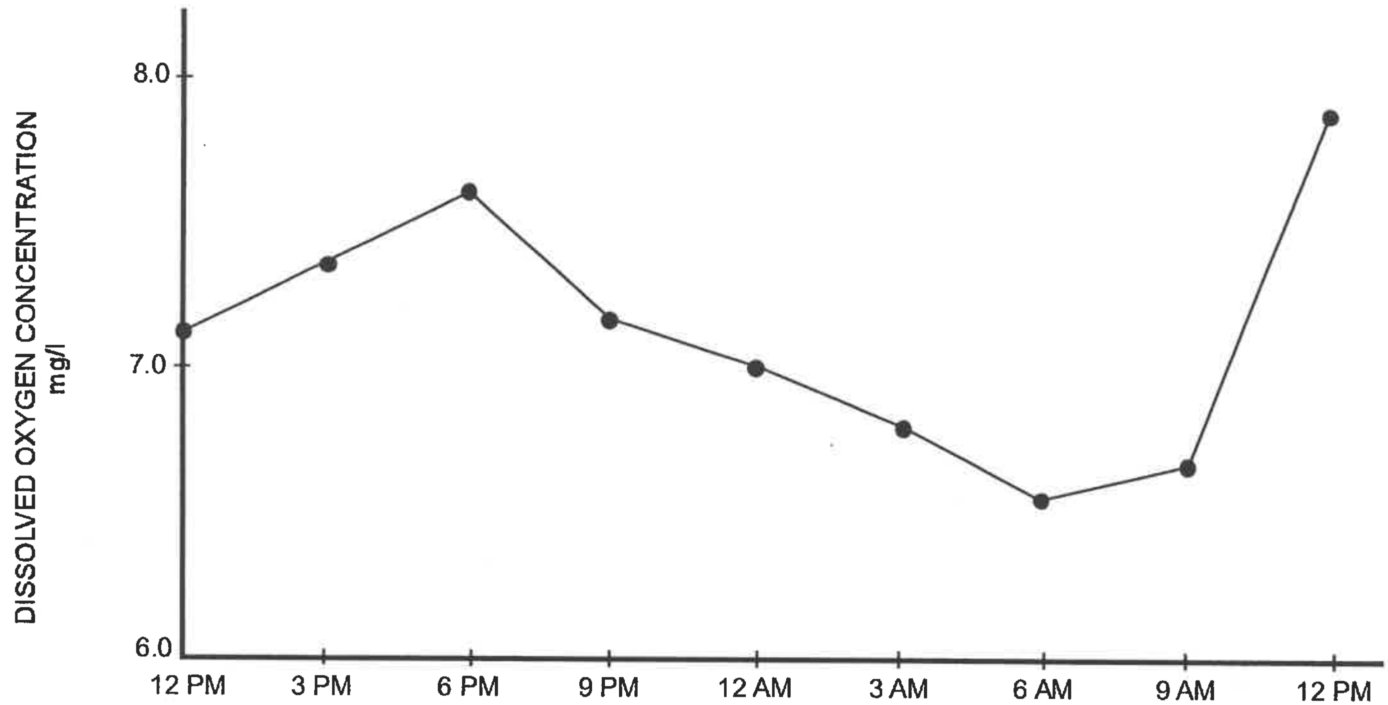

Figure 3-7. A typical diurnal curve of dissolved oxygen at the sand bar.

aerobic organisms. Fish can tolerate anoxic conditions for short periods of time but most species require greater than 5 mg/l of dissolved oxygen for growth and reproduction (Welch 1980). Thus, fishes use the anoxic salt wedge for movements along the river but they periodically swim up to the aerobic surface waters for respiration.

pH

The hydrogen ion concentration or pH is a measure of the relative acidity vs. alkalinity of natural waters. pH has a logarithmic scale of 0 to 14 with a value of 7 considered neutral. Thus, a change of one pH unit represents a ten-fold change in hydrogen ion concentration. Measurements less than 7.0 are acidic and measurements above 7.0 are alkaline. Most aquatic organisms are found in a pH range from 6.5 – 9.0.

pH was measured with a Accumet model AP 63 meter in the lower Sittee River. This meter has a short cable so only surface water values of pH were measured in the study. pH data was gathered along longitudinal transects and several diurnal curves. Values were generally near neutral in the main river channel though a slight increase from upstream to downstream stations was often found. The pH range at the rivermouth was 6.40 – 8.16 (n=18), at Possum Point the range was 6.33 – 7.16 (n=14), and at the sand bank the range was 6.30 – 7.10 (n=10). Diurnal curves of pH change were measured on several dates but no distinct patterns were evident, probably due to mixing of water masses between tidal and river current flows. Maximum diurnal changes were always less than one pH unit and often less than 0.2 units at a site.

Nutrients

Nutrient concentrations in water are important for growth of aquatic plants. Polluted conditions can occur when excessive amounts of nutrients, primarily compounds of nitrogen and phosphorus, run into a water body, usually from fertilizers applied to agricultural fields. In the Sittee River watershed inputs of fertilizer are expected in runoff from the citrus plantations which are the most common local land use. Concentrations of nitrate (NO3), ammonia (NH3) and phosphate (PO4) were measured in surface water of the lower Sittee River, mostly in the early 1990s. All measurements were made with portable water quality test kits, since there was no electricity available in Sittee River until the late 1990s. DePew (1991) sampled water with a LaMotte field chemical kit in the summer of 1991. After 1991, water was sampled with Hach field chemical kits. Figure 3-8 shows data gathered on nitrogen and phosphorus compounds at a number of sites from the rivermouth to Kendal. Concentrations are low with most values below detectable limits of the field chemical kits. For the measurements that were within the detectable limits, the ranges of concentration values were as follows: nitrate (0.05 - 1.20 mg/l), ammonia (0.04 - 0.78 mg/l) and phosphate (0.01 - 1.75 mg/l). These values are relatively low and suggest that fertilizer inputs to the river are not excessive. This finding is supported by the low levels of primary productivity that were calculated with the diurnal oxygen curve analysis to be discussed in the biodiversity section.

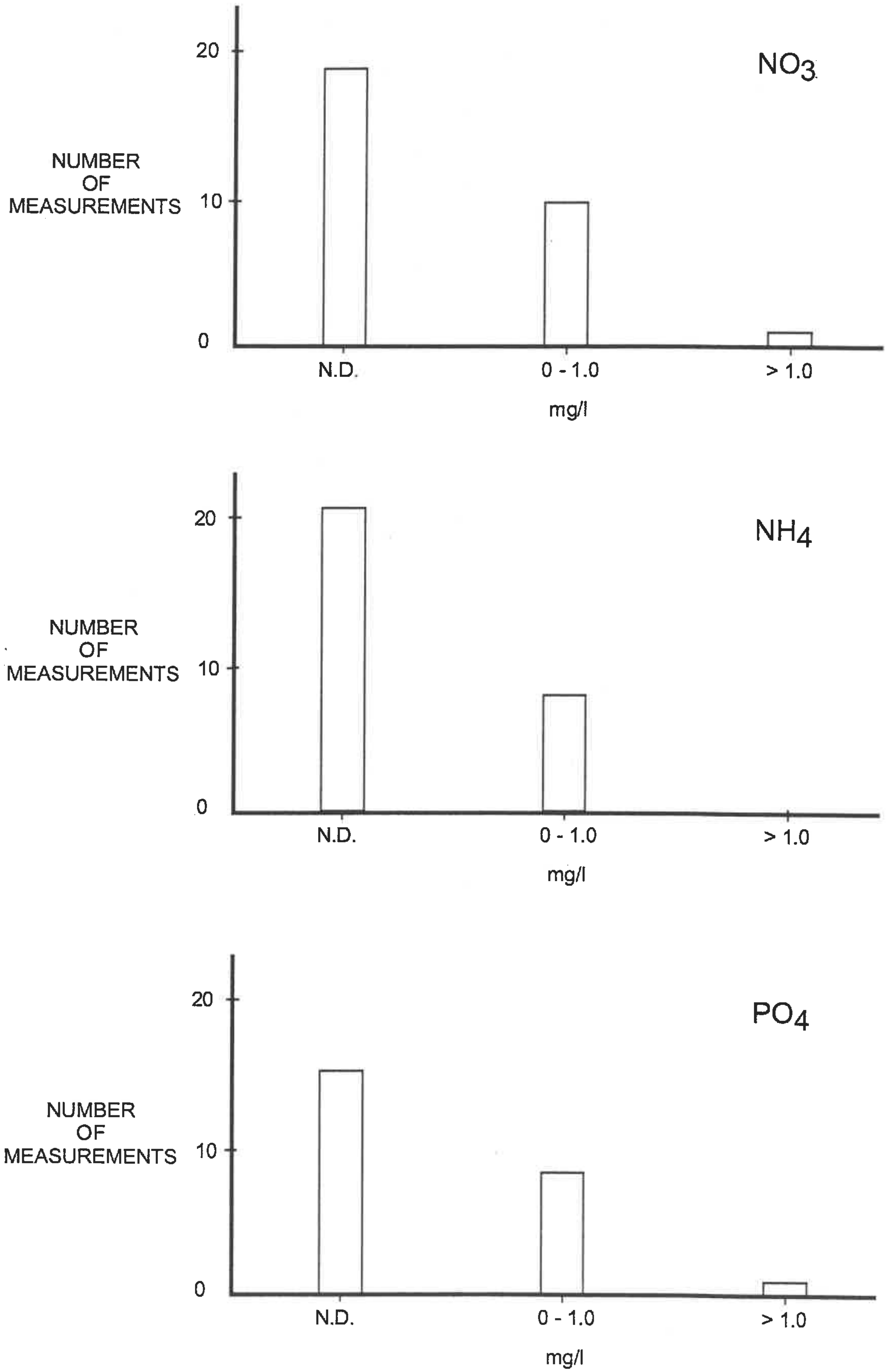

Figure 3-8. Distributions of nutrient concentrations in the Sittee River.

Water transparency or turbidity

Turbidity or water visibility is an indicator of suspended materials in the water column. Materials causing turbidity are usually inorganic sediments, such as clay or silt-sized particles, or planktonic organisms, such as phytoplankton or zooplankton. Excessive turbidity due to inorganic sediments is usually caused by inputs of materials from erosion in the watershed while turbidity due to high concentrations of phytoplankton is usually caused by high concentrations of nutrients from pollution. In the Sittee River turbidity is dominated by inorganic sediments since low nutrient concentrations limit phytoplankton growth. Stresses caused by high turbidity include reduced light transmission which can limit aquatic photosynthesis and vision by predators and physiological impacts to aquatic animals from irritation of gills and physical siltation. Benthic organisms with limited mobility are more susceptible to turbidity impacts as compared to fish and aquatic birds which can move away from turbid sites.

Turbidity was measured in the lower Sittee River with a Secchi disk which is a standard, weighted circular plate, 20 cm in diameter, painted with black and white markings (Lind 1979). The disk is attached to a line and measurements are made by lowering the disk into the water column. The depth at which the disk disappears from sight is termed the Secchi depth. Although data from this method are somewhat variable due to position of the sun, turbulence of the water and visual acuity of the observer, Secchi depth is useful in a relative way, as a measure of turbidity. Basically, the depth of visibility is inversely proportional to sediment concentration or turbidity. Secchi depth measurements were often taken during longitudinal transect on the river. At the upstream sites and at the rivermouth, where water depths are shallow, the Secchi disk could often be seen on the bottom of the river. At other sites along the river visibility ranged from 1-4 m during normal flow conditions. These values are relatively high compared to many kinds of estuaries. However, visibility is much greater offshore on the coral reef where values greater than 30 meters have often been measured. The average Secchi depth at Possum Point under normal flow conditions was 245 cm (n=21) and the maximum Secchi depth ever recorded along the river was 430 cm, measured at Possum Point on March 23, 1998.

Floods

The principal physical interaction between the river and the riparian forest is a flood event. In terms of a basic water balance, a flood occurs when the volume of water in the channel (W) exceeds the volume of the channel (C), during times of high rain fall (Figure 3-9). This is shown in the model with a switch function (the concave box symbol) which compares the two volumes. If C>W, then normal downstream river flow takes place. However if C<W, then the excess water above C floods on to the floodplain. This water carries certain materials on to the floodplain (such as sediments) and carries other materials back into the river (such as leaf litter) as the flood recedes.

Dramatic changes take place in the Sittee River during a flood. The physical-chemical conditions described throughout this chapter are for "normal flows" but during a flood all of the values of parameters change in very predictable ways (Table 3-7). Some parameters increase (current velocity, water level, dissolved oxygen concentration in the

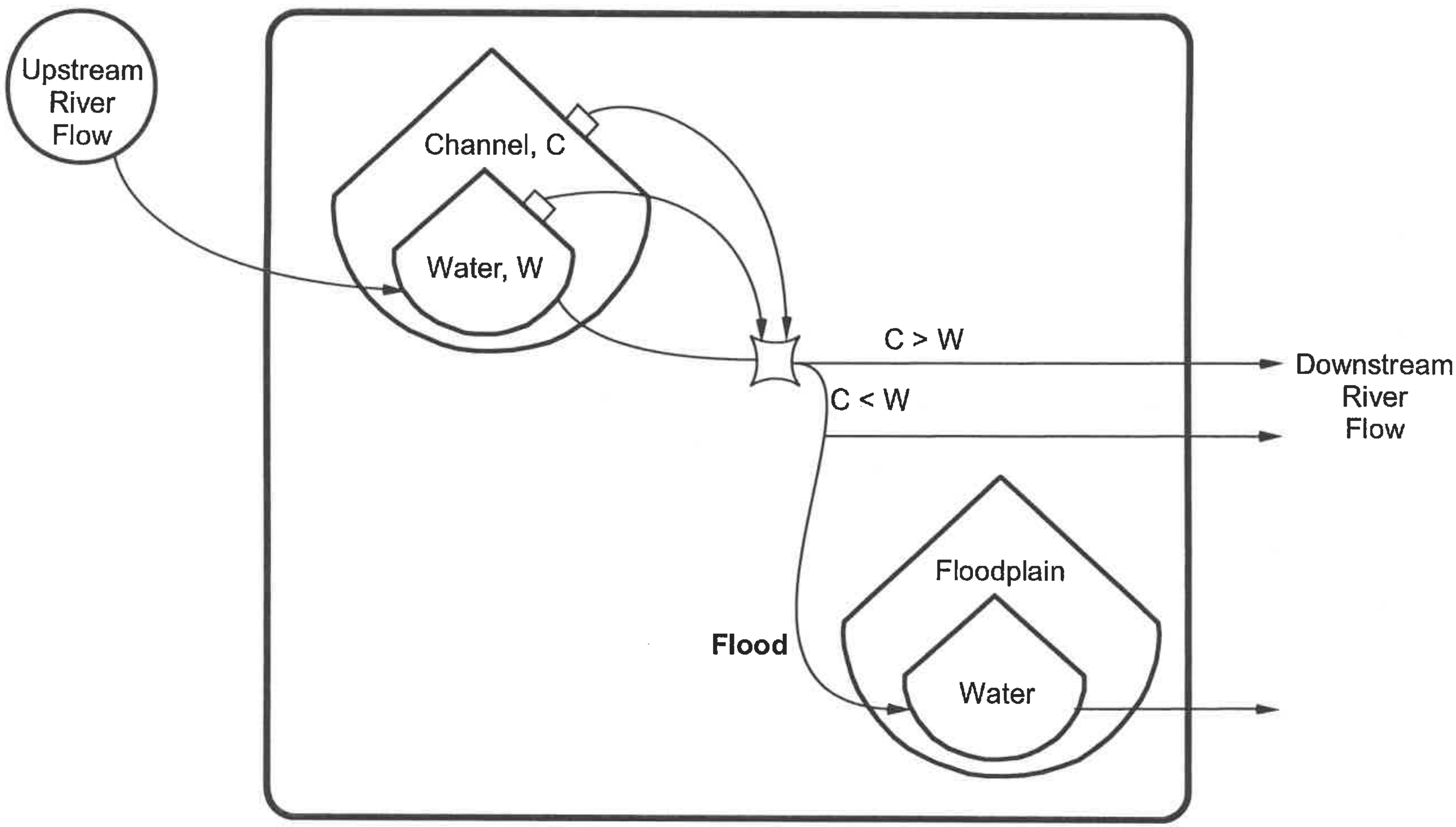

Figure 3-9. Energy circuit diagram showing the conditions for flooding vs. normal flow.

Table 3-7. Major flood effect on the lower Sittee River.

Parameter	change during a major flood
Current velocity	increases five times
Water level	increases 0.5-1 meter
Dissolved oxygen	increases five times in the bottom waters
Salinity	from stratified with brackish water on the surface and saline water on the bottom to freshwater from surface to the bottom
Temperature	decreases 2 – 4 degrees C
pH	decreases by 0.5 – 1.0 units
Secchi depth	decreases five to ten times
Surface water color	from blue-green to bright brown

bottom waters) while others decrease (salinity, temperature, pH and Secchi depth). Even the color of the water changes, from a peaceful blue-green at normal flows to a turbid, bright brown or almost yellow during flood conditions, because of the eroded sediments being carried by the currents. Floods act in a similar fashion in rivers anywhere in the world and their behaviors are well known (Hoyt and Langbein 1955, Barrows 1948).

Along the Sittee River major floods are relatively rare events, often occurring only two to four times per year. However, many smaller floods can also occur which result in significant, though less dramatic changes in the river. When a series of floods occur in succession over time, flood conditions shown in Table 3-7 can be maintained for weeks at a time. The local people have names for floods at different times of the year. An "iguana flood" occurs in the dry season (in the early spring) and is associated with the hatching of iguana eggs that have been laid along the shoreline, while a "top gallon flood" is a major flood that occurs during the rainy season (usually in the summer). Different sized floods can be easily distinguished by water color: in a minor flood the water color appears as a dirty green, perhaps due to a higher concentration of dissolved organic materials without much inorganic sediments, while in a major flood the water color appears as a bright brown due to the high load of inorganic sediments. Floods are sometimes caused by hurricanes but a high rainfall event in the Maya Mountains at any time of the year can result in a flood in the lowlands along the Sittee River.

A single, major flood event usually only lasts three to five days and each one has a characteristic "life history" of stages (Table 3-8). The flood is triggered by rainfall in the mountains and a time lag occurs before any change appears in the lowlands. It is interesting to note that floods can occur with no rainfall at all in the lowlands, which demonstrates that they are a large-scale (ie., watershed) phenomena. Major changes in the river begin to occur about 6 – 12 hours after the storm and these changes persist for a day or two depending on the magnitude of the rainfall. As the flood begins to end, different parameters recede from flood values back to normal flow values in a predictable sequence: first water level, followed by current velocity and water color and, finally, by the re-establishment of stratified conditions as the salt wedge returns. Change in water level is usually indicative of a flood's life history and it is often described by a hump-shaped hydrograph of water level change over time. However, because the lower Sittee River is tidal, changes in water level due to tide and due to the flood interact in a complex pattern. Change in water color is more indicative of the flood's life history than the hydrograph in the Sittee River to some extent. Color and current velocity are closely related because the color is caused by suspended sediments carried in the water flow. As the current velocity recedes there is less energy available to maintain the sediments in suspension and they settle out of the water column, causing the color to change back to blue-green. Figure 3-10 shows the recession curves for current velocity and Secchi depth for a flood at Possum Point illustrating the coupled patterns of current velocity and turbidity as measured by Secchi depth. Return of the salt wedge requires the longest amount of time of any of the changes due to the flood. The salt water in the bottom strata slowly is pushed back upstream by tidal flows and mixing with the freshwater occurs gradually in the surface waters to restore brackish conditions. This change in salinity pattern may be the most dramatic of all changes in the flood since the river changes qualitatively from a stratified, salt water estuary to a well-mixed, freshwater stream and back again over nearly a week long time period. Only the major floods cause this degree

Table 3-8. Sequence of events that occur at a particular location during the life history of a major flood.

Elapsed time (hours)	Event
0	rainfall occurs in the Maya Mountains
6-12	water color turns brown and water level and current velocity increase, saltwedge gets pushed downstream and the water column becomes fresh and well-mixed
12-18	floating debris appears – bamboo stems, coconuts, tree branches in a small flood; whole trees in a large flood
30-36	water level recedes to normal
48-60	current velocity recedes to normal and water color returns to blue-green
122	stratification is re-established with the return of the saltwedge

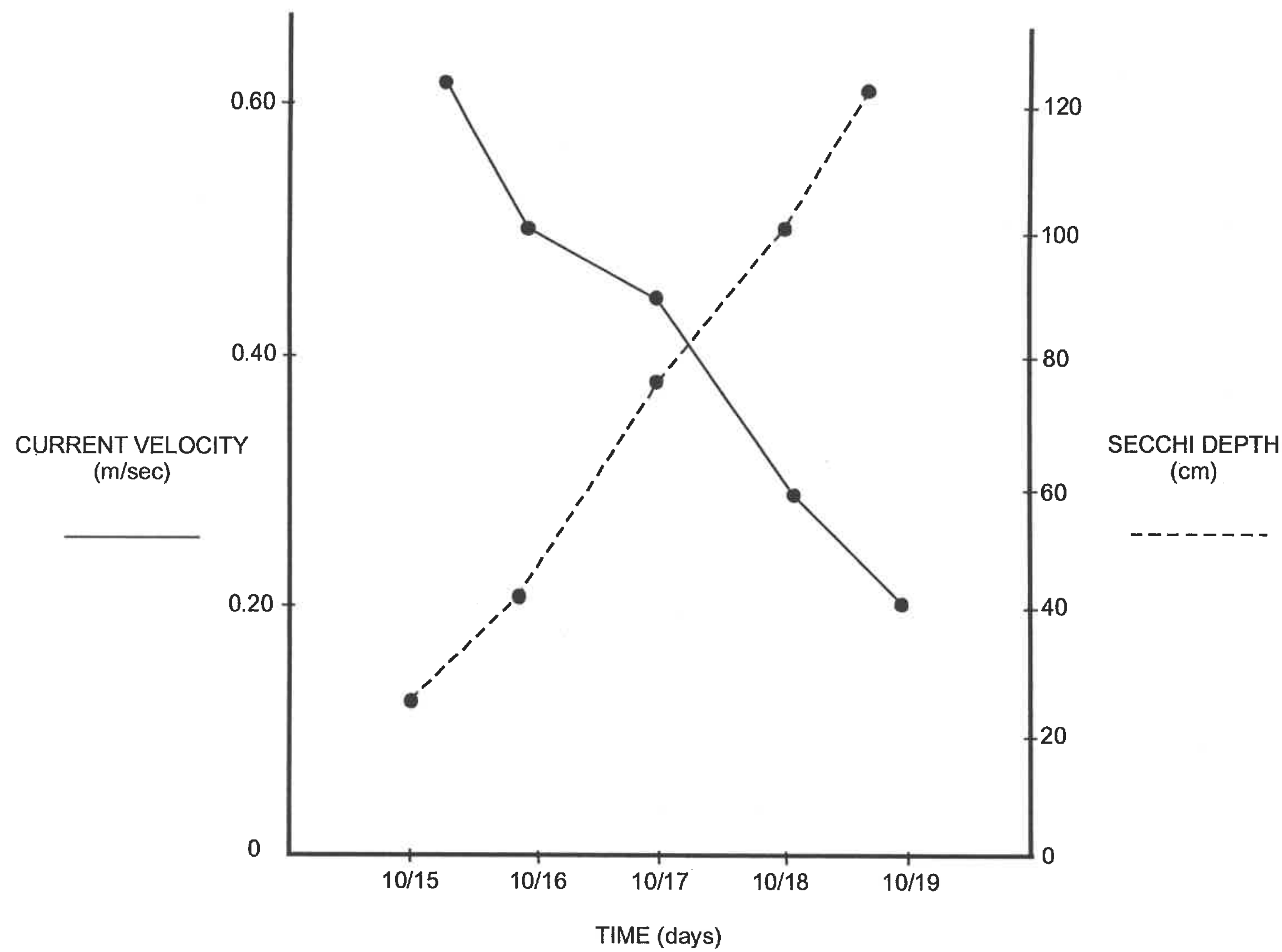

Figure 3-10. Change in current velocity and turbidity (as measured by Secchi depth) after a flood event in the Sittee River.

of change. Mixing of freshwater and saltwater actually occurs offshore beyond the rivermouth during a major flood, creating what is termed external estuarine conditions since mixing takes place outside of the river channel.

Even though physical-chemical changes in the flood are relatively short-term, the biota and processes in the river ecosystem are strongly affected. Because all species are adapted to particular salinity levels, floods along an estuary such as the lower Sittee River cause osmoregulatory stress for sessile, benthic organisms and cause mobile organisms to move with the flow. Shoreline habitats can be changed with erosion in some locations and deposition in other locations. Increased turbidity during the flood reduces predation by visual predators such as aquatic birds, clogs the gills of benthic species and reduces primary productivity by aquatic plants. However, not all of the effects of floods are negative for the river ecosystem. Floods represent natural disturbances and aquatic organisms have adapted to the changes they cause (Michener and Haeuber 1998). Floods wash nutrients and organic matter into the river thereby supporting energy flow and nutrient uptake in the ecosystem. In this sense floods actually act as an energy subsidy and are a positive factor in the overall ecology of the river. This conception of the flood is explained by the theory of natural disturbances in ecology (Connell 1978, Odum et al. 1995, Reice 2001) which suggests that intermediate levels of disturbance play a positive role in ecosystems. The flood-pulse concept has been developed to explain the importance of flood disturbances in large river-floodplain systems (Bayley 1995) and this concept seems to apply to the Sittee River. An open question remains however about the impacts of human development in altering the watershed through deforestation. Humans may be changing the effects of floods from a positive subsidy as a natural disturbance to a negative stress as a man-made disturbance by altering hydrology through the conversion of forests to citrus plantations and other land uses.