PHILLIPPI CREEK BASIN MASTER PLAN

HUDSON BAYOU BASIN MASTER PLAN

CHARACTERIZATION OF ECOLOGICAL CONDITIONS AND IMPACTS OF STORMWATER RUNOFF

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PREFACE

As part of a planning and permitting program directed toward improvement of nonpoint source pollution in Sarasota County, Mote Marine Laboratory has prepared this report encompassing four distinct objectives:

1. To inventory and characterize ecological conditions in Sarasota Bay with special emphasis on Hudson Bayou and Phillippi Creek;

2. To identify known and probable impacts of stormwater discharge on ecological conditions in Sarasota Bay with special emphasis on Hudson Bayou and Phillippi Creek;

3. To recommend methods for the analysis of physical and chemical data from each basin that will provide insight into problems of stormwater discharge, and insight into possible mitigative measures; and

4. To recommend management objectives for improving the quantity, quality, timing and location of stormwater discharge within the Hudson Bayou and Phillippi Creek basins.

The first objective is summarized in Section 2: Environmental Setting. The second objective appears in Section 3: Ecological Effects. Objectives 3 and 4 are covered together but in different order in Section 3: Management. Section 3 begins with a discussion of management objectives. Management questions are then posed and the next section discusses analytical methods. The final part of Section 3 addresses mitigation opportunities.

Acknowledgements

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Section 1
INTRODUCTION

Services and beneficial uses of estuaries have been repaid largely by abuse. Investigators throughout the world report symptoms of significant ecological stress in estuaries and coastal waters. The most common symptoms include anoxia, eutrophication, phytoplankton and macroalgal blooms, habitat loss, contamination and biomagnification of toxic materials, declines in secondary productivity (numbers of fishes, birds, marine mammals, etc.), diseases in marine organisms, and species losses.

Nonpoint source (NPS) pollution has caused severe degradation of estuarine resources and their beneficial uses throughout the world. Nationwide, nonpoint source pollution is a significant problem, responsible for 76, 65 and 45 percent, respectively, of the impairment of lakes, rivers and estuaries. A recent review of literature pertaining to nonpoint source impacts on aquatic life throughout the United States (Cunningham, 1988) found that states most often cited agriculture as the major cause of use impairments, followed by urban sources, construction, mining, landfill, hydroperiod modification, and forestry (in order of descending importance).

Cunningham (1988) also found that bacteria was the most widely reported NPS pollution parameter, followed by nutrients, turbidity, BOD and dissolved oxygen, metals, pesticides, and acidity (pH). Cunningham (1988) did not identify impairment reports from coastal states per se, so the incidence and severity of NPS pollutants are probably biased toward inland and freshwater areas. Although a considerable literature exists regarding the effects of nonpoint source pollution on lakes and rivers, comparatively little is known about the impacts of runoff on estuarine and marine environments (Cunningham, 1988; Driscoll et al., 1990).

One reason why the estuarine impacts of NPS pollution are poorly known is that much is left to learn regarding basic estuarine structure and function. Without such knowledge it is difficult to evaluate anthropogenic stresses such as nonpoint source pollution. Sarasota Bay, for example, is a relatively data-poor estuary. Based on historical information it is viewed as an estuary that suffers more from the impacts of overuse and development, than from pollution. Numerous studies are under way that will produce

the data needed to test this hypothesis. This report appears just weeks before most of the new studies are expected to end. With this perspective, and the benefit of a large and very recent literature, it is possible to outline the general types of impacts that nonpoint source pollution are likely to have on estuarine resources of Sarasota Bay.

Section 2
ENVIRONMENTAL SETTING

2.1 Geography

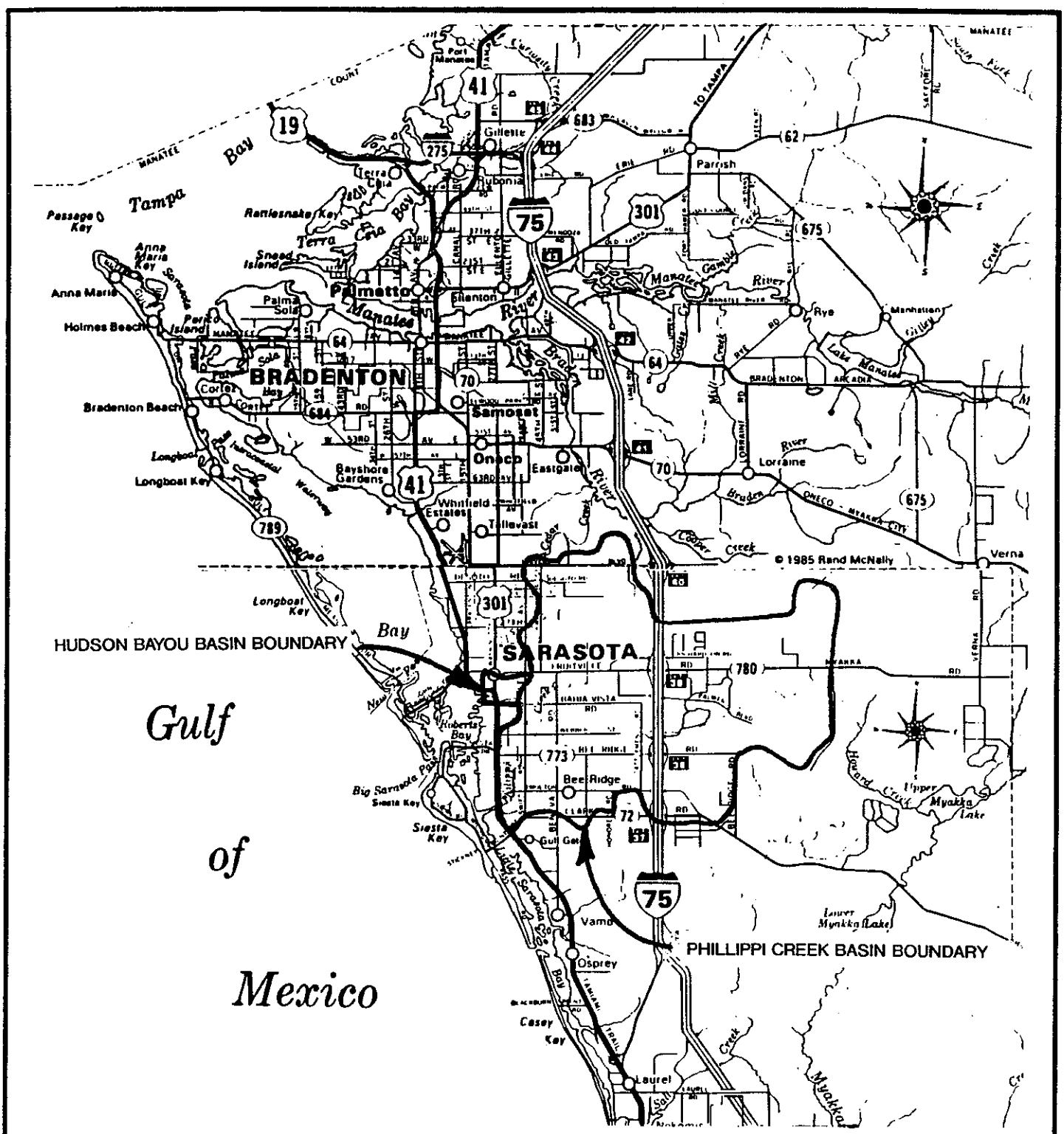
Phillippi Creek and Hudson Bayou are two tributaries to tidal waters of Sarasota County (Figure 1). Phillippi Creek drains the third largest basin in the County (Sarasota County, 1980) and the largest basin connected to the Sarasota Bay system under study by the National Estuary Program[1]. The basin's western half is urbanized and its eastern half is urbanizing and agricultural. Hudson Bayou drains the most urbanized basin. The two streams enter a southern arm of Sarasota Bay called Roberts Bay[2]; Hudson Bayou enters the eastern shore of Roberts Bay near downtown Sarasota and Phillippi Creek enters the southern terminus of Roberts Bay. Known locally as the "Narrows", the mouth of Phillippi Creek is situated in a network of mangrove forests and oyster reefs that separated Roberts Bay from Little Sarasota Bay, until construction of a connecting channel.

Both basins are situated in the Gulf Coastal Lowlands physiographic province. Elevation ranges from sea level to less than 60 feet toward the east, with only two terraces formed by higher Pleistocene sea level stands. The most westerly and lowest (8 to 25 feet) terrace is the Pamlico. A higher (25 to 42 feet) Talbot terrace meanders across part of the Phillippi basin east of the Pamlico.

As a result of very gradual slopes, and local soils (see below), most of the area is poorly drained. Lands closest to the two streams are better drained but subject to flooding. A Class 5 hurricane storm surge, for example, is predicted to affect both streams and adjacent uplands as far east from the bay as Tuttle Avenue, with parts of the Phillippi basin affected to near Beneva Road.

1/ Anna Maria Sound south to Venice, including all islands and upland drainage basins, but excluding Cow Pen Slough.

2/ Different than Dona/Roberts Bays at Venice.



PHILLIPPI CREEK AND HUDSON BAYOU BASINS
LOCATION MAP

FIGURE 1

Phillippi Creek trends northeasterly from its mouth. Heading upstream, it branches into two drainage systems south of State Road 780, between Sarasota and Fruitville. One system extends northward as several improved channels, to the Manatee County line. This northerly drainage system heads in close proximity to the headwaters of Braden River tributaries. The second system trends easterly and drains the Hyde Park and Fruitville areas, and also much land east of I-75 between S.R. 780 and S.R. 72 (Clark Road). Extensions of this system reach lands northeast of the Bee Ridge landfill and intertwine with headwaters of Cow Pen Slough and Gum Slough. Five sub-basins are recognized for planning and modelling purposes.

Hudson Bayou is much shorter and has a smaller drainage area. It drains much of downtown Sarasota. East of U.S. 41, near Sarasota High School, it branches into small streams that drain the coastal watershed west of Phillippi Creek. The basin extends south beyond Bahia Vista toward Webber, east and north along Tuttle Avenue, and north of Fruitville Road toward 10th Street, before turning southwest and south along Orange Avenue to the Bay (City of Sarasota, 1979).

2.2 Land Cover and Use

The Phillippi Creek basin encompasses approximately 36,000 acres, of which about half (44.9%) is developed. It is the most urbanized of the County's four major floodplains (Sarasota County, 1989). The second most common land cover is intensive agriculture (35.1%), followed by pine prairie (12.5%), shady hammocks (3.8%), isolated wetlands (1.6%) and high dry scrub (0.2%). About one percent of the basin is in Manatee County. In terms of land use, 37% is open space, 28% is agriculture, 26% is residential, 5% is commercial, and 4% is recreational (Sarasota County Planning Department and Mote Marine Laboratory, 1980). Between 1976 and 1990, impervious area of the Phillippi Creek watershed is calculated to have increased from 18.3% to 21.8% (Heyl and Dixon, 1986).

2.3 Geology and Soils

Soils of both basins are primarily Myakka, with inland, upland soils containing poorly to very poorly drained sands and stream-side soils with sands that are better drained (Soil Conservation Service, 1991). Soils overlie organic hardpan and alkaline material

depending on creek stage and tidal conditions. The freely-flowing nature of the creek and its tributaries is interrupted by minor instream spillways and sediment basins. One major flow control structure, a low spillway, is located in the main-stem just east of Southgate Circle, about 3 miles upstream from the mouth of the Creek. Tides are of a mixed type, with diurnal and semi-diurnal components. During the 1960 to 1978 tidal epoch, mean higher high water was 31.4 cm above mean tide level, which in turn was 12.8 cm above the National Geodetic Vertical Datum (Estevez, 1991).

Circulation in the vicinity of Hudson Bayou is affected most by the influence of Big Pass. On incoming tides, Gulf water moves east and north across the bay, toward Stephens Point. On outgoing tides, water leaving Hudson Bayou is joined by the combined discharges of northern Little Sarasota Bay, Phillippi Creek, and Roberts Bay, including the Grand Canal on Siesta Key. Wind also affects local circulation around Hudson Bayou, particularly northwest winds crossing the long axis of Sarasota Bay. This effect has been lessened by construction of Golden Gate, the Ringling Causeway, and Island Park, but more frequent southwesterly winds entering Big Pass also affect the mouth of the Bayou.

Prior to channelization, oyster reefs and mangrove islands effectively isolated Roberts Bay from Little Sarasota Bay (Heilprin, 1887), and the majority of the creek's discharge is presumed to have flowed north toward Big Pass. Since 1967, the Intracoastal Waterway has dominated hydrology of the Narrows area and creek discharge moves south on incoming tides (toward Little Sarasota Bay) and north on outgoing tides (toward Big Pass). After Midnight Pass closed, the influence of Phillippi Creek upon the northern end of Little Sarasota Bay may have increased (Camp Dresser & McKee, 1983).

2.5 Water and Sediment Quality

Drainage and water quality problems have been recognized for both basins for several decades (Smalley, Wellford and Nalven, Inc., 1967). The earliest proposals for sanitary sewers in the Phillippi Creek basin date back to the 1950s (Smalley, Wellford and Nalven, Inc., 1958). In 1966 and 1967 the Florida State Board of Health conducted a water quality study in Phillippi Creek. High coliform counts were reported

and 80 percent of the creek's water quality problems were attributed to non-point sources.

By the early 1970s, floodplain characteristics of both basins had been reported by the Corps of Engineers (1973). Stuart (1979) provided insight to water quality in Hudson Bayou. Two stations were occupied in the tidal portion of the stream, one upstream and one near the mouth. Over a four year period beginning in 1975, upstream salinity ranged from 0.0 to 33.0 parts per thousand (o/oo). Downstream salinity ranged from 25.0 to 33.5 o/oo, suggesting a limited influence of freshwater on local bay waters. Some evidence of stratification was found at the downstream station. Mean annual dissolved oxygen was significantly lower at the upstream station, whereas turbidity was higher, exceeding 300 NTU after a 1978 storm. In a corollary biological survey, Stuart (1979) found that faunal densities were higher at the mouth of the Bayou than at other bay stations, and that diversity was intermediate. By 1980, Phillippi Creek was regarded as "probably the most polluted water body in the County" (Sarasota County, 1980).

In the 1989 edition of Apoxsee, Sarasota County described water quality in Hudson Bayou as severely impaired, and water quality in Phillippi Creek as moderately to severely impaired. Water quality of both streams is regularly monitored by the Sarasota County Environmental Services Laboratory, as part of their "North Stream Run". The most common violations of state or county water quality standards occur for total coliform and dissolved oxygen, although fecal coliform is occasionally excessive (Environmental Services Laboratory, 1989).

The Florida Department of Environmental Regulation's 305(b) water quality assessment (1988) also reports that water quality in Phillippi Creek is "fair", according to the EPA water quality index, but gives no separate assessment for Hudson Bayou. FDER (1988) report that water quality --according to the Florida trophic state index-- is "good" for Roberts Bay but becomes "fair" for tidal waters south of the mouth of Phillippi Creek.

FDER (1988) states that dissolved oxygen problems are common in these waters, a finding also reported in greater detail by Windsor (1985). Windsor used FDER and STORET data, and the EPA index to classify Phillippi Creek as "poor" in water quality because of bacteria and nutrients, in addition to dissolved oxygen problems. Windsor

(1985) attributed the problems to sewage treatment plants and urban runoff. Similar findings and conclusions were made by Mote Marine Laboratory and Sarasota County Division of Pollution Control (1982), which documented high total and fecal coliform and nutrient levels, as well as low dissolved oxygen.

Historical and modern-day water quality of Sarasota Bay are subjects of intensive study by the Sarasota Bay National Estuary Program. In an analysis of temporal trends among dominant parameters, Heyl and Dixon (1986) found that salinity, pH, turbidity and ortho-phosphate have generally declined through time, particularly along the eastern shore of the bay. This finding was reaffirmed by the Florida Department of Environmental Regulation's 305(b) water quality assessment (1988) and has been documented in greater spatial detail by Camp, Dresser and McKee (1990).

Coprostanol, a breakdown product of cholesterol, is a well-established tracer of human sewage. Coprostanol associates with fine particulate matter discharged by streams and accumulated by bay sediments. A survey of coprostanol in Sarasota Bay proper showed highest levels near Whitaker Bayou, site of the City of Sarasota's wastewater treatment plant discharge (Pierce and Brown, 1984). Next highest values of coprostanol were found in sediments near the mouth of Hudson Bayou. Data are presently unavailable for Phillippi Creek but new analyses for the NEP will be completed in 1992.

In general, tidal waters of Roberts Bay are considered unapproved for shellfish harvest by the Florida Department of Natural Resources, in consideration of human sanitary wastes. The same area is designated as Class III water of the state (recreation and propagation and management of fish and wildlife), and also as Outstanding Florida Water. Phillippi Creek and an area extending 1500 feet from its mouth into the bay are excluded from the OFW designation (Florida Department of Environmental Regulation, 1986). The same exclusion applies to Hudson Bayou. Otherwise, a standard of "non-degradation" applies to Outstanding Florida Waters.

2.6 Biology

In general, Phillippi Creek and Hudson Bayou have undergone numerous and significant changes since the days of early settlement. A century ago, both streams were relatively undisturbed, and descriptions of their appearance may be found in Heilprin (1887) and

Blatchley (1932). The tidal portion of both systems resembled modern-day North Creek and Catfish Creek (except for the proliferation of brazilian pepper and other nuisance plant species). Upland areas probably resembled the non-tidal portions of South Creek described by Lugo and Snedaker (1970), where hydroperiod and fire were the primary forces controlling ecological structure and function of the landscape.

Today, the majority of tidal shorelines in both streams are extensively altered, primarily in the form of filling and hardening. Shorelines have been hardened by construction of vertical bulkheads or seawalls made of concrete, although rip-rap, wooden walls, and miscellaneous materials have also been used in places. Another major change in both streams has been the alteration of natural bathymetry. Historically, the streams were shallow, and wide shoreline areas were exposed during low tides. Now, nearshore areas are deeper because boat slips and navigation channels have been created, and there have been spot-removals of nuisance sediments. The bayshore near the mouths of both creeks are relatively undisturbed, and productive, in comparison to the confined drainage-ways in each stream.

Mangrove Systems, Inc. (1988) developed tidal habitat maps near and in both creeks, based on historic and recent aerial photography. By 1948, intertidal wetlands in Hudson Bayou were already converted to urban shorelines, whereas Phillippi Creek had tidal marshes east of U.S. 41 and a large plexus of mangroves at its mouth. By 1987, all wetlands east of U.S. 41 in Phillippi Creek had been converted and the mangrove forest complex had been reduced by about 50% of its 1948 size. Causes of mangrove loss include upland filling, construction of the Intracoastal Waterway, spoil disposal, and erosion.

Submersed aquatic vegetation (SAV) and oyster reefs also were mapped by Mangrove Systems, Inc. (1988). In 1987, seagrasses near Hudson Bayou still retained much of their 1948 dispersion pattern and some beds in nearby offshore waters may have grown. During the same period, the very large flood-tidal delta grassbeds of Bird Key were converted to uplands. Seagrass losses have been more severe near Phillippi Creek. In 1948 SAV occurred as interwoven beds among mangroves, and as large contiguous beds along the open-water areas south of the creek mouth. By 1987, seagrasses intermixed with mangrove had declined by half or more, and nearly all of the open-water beds had converted to unvegetated, muddy sand areas. Oyster reefs, once

extremely common near Phillippi Creek (Heilprin, 1887; Blatchley, 1932) were abundant in 1948 but occur in much reduced area in 1987. Oysters occur in Hudson Bayou but not extensively, due to elevated salinities caused by proximity to Big Pass.

Tiffany (1974) assessed benthic habitat features and communities at several bay stations, including one in proximity to the mouth of Hudson Bayou and another at the mouth of Phillippi Creek. Hudson Bayou sediments were 93 percent silt and clay by weight, whereas Phillippi Creek sediments were well-sorted sands. Hydrogen sulfide was noted in the Hudson Bayou sediment. Total faunal diversity was much greater at Phillippi Creek than at Hudson Bayou, in part because salinities at Phillippi Creek were low enough to support oyster reefs. In an ongoing benthic mapping study by Mote Marine Laboratory, for the Sarasota Bay National Estuary Program, rock bottom was encountered in the tidal portion of the creek. The habitat value of these areas is presently unknown (J. Culter, Mote Marine Laboratory, personal communication). Tiffany (1974) concluded that poor conditions near Hudson Bayou were caused by combined (stormwater and sanitary) sewer discharges and sewage from live-aboard pleasure craft, and that this area was "the most unhealthy sampled", even more so than the mouth of Whitaker Bayou.

According to ES&E (1977 a and b), Phillippi Creek is a "detrital based ecosystem" with a significant (34%) contribution of phytoplankton to food-chains. Their ecosystem modelling indicated that the creek was plankton-dominated whereas the bay near the creek mouth was benthic-dominated. Other ES&E studies found comparatively low zooplankton (29,530 organisms per cubic meter) and benthic infaunal (111-6,170 organisms per square meter) densities. Community metabolism was estimated at 16.5 g O_2 per square meter per day, commensurate with a sequestering rate of 9.4 grams of organic matter per square meter per day. This rate was calculated as the equivalent of 61 percent of the system's organic load from all sources (ES&E, 1977b).

Bird (1980) found that fish diversity in Sarasota Bay was relatively high but significantly dominated by a few species, notably pinfish (Lagodon rhomboides). Fish diversity was depressed near Phillippi Creek. Bird (1980) also found that the incidence of diseases and parasites of fishes collected at the mouth of Phillippi Creek (27.3% annual average) was greater than at any of 9 other stations sampled throughout the bay, and attributed the high incidence with "adverse site conditions observed there during

those periods". Based on the results of a single seine station near the mouth of Phillippi Creek, present-day fish communities were typical of those found along the eastern shore of Sarasota Bay (R. Edwards, Mote Marine Laboratory, personal communication).

2.7 Summary of Environmental Setting

Hudson Bayou and Phillippi Creek are typical of small to medium coastal drainage systems in peninsular Florida, insofar as they are relatively recent in terms of development (50-75 years) and, in the latter basin, still undergoing change. All of the past development proceeded toward single-mission management objectives (flood control, drainage, waste disposal, navigation, etc.) with little concern for cumulative instream or downstream consequences to living resources or beneficial uses. As a result, the streams are greatly modified from natural conditions, and available data portrays each as seriously polluted. Based on the area of bay waters excluded from OFW designation (Florida Department of Environmental Regulation, 1986), the streams already have a combined direct adverse effect covering about 162 acres in Roberts Bay. The area of tidal water that is indirectly but significantly affected by the combined effects of the two streams is presently undocumented, but based on circulation data, may extend into the northern third of Little Sarasota Bay (CDM, 1983).

Section 3
ECOLOGICAL EFFECTS

Nationwide, nonpoint source pollution is a significant problem, responsible for 76, 65 and 45 percent, respectively, of the impairment of lakes, rivers and estuaries. Although a considerable literature exists regarding the effects of nonpoint source pollution on lakes and rivers, comparatively little is known about the impacts of runoff on estuarine and marine environments (Cunningham, 1988; Driscoll et al., 1990). For example, a recent electronic search in the DIALOG Information Retrieval System was made for this project, using {[nonpoint source pollution] <u>or</u> [stormwater runoff]} <u>and</u> {estuary} as the search strategy and BIOSIS, WATER RESOURCES ABSTRACTS, and POLLUTION ABSTRACTS as data bases. Fewer than 50 citations were returned, and the majority of these added little to the present report.

Specific effects of particular stressors, especially contaminants, on certain estuarine and marine species have been studied in detail. Journals such as *Marine Environmental Research* and *Environmental Contamination and Toxicology* report effects of contaminants on living systems at cellular-to-organismic levels, and syntheses are available for entire classes of contaminants (Fowler, 1990), but comprehensive reviews are unavailable for the **inclusive** effects of nonpoint source pollution on **inclusive** marine resources.

It is beyond the scope of the present report to undertake such a synthesis. Instead, an attempt is made to catalog known and potential impacts of nonpoint source pollution, illustrate the most important, and identify those which may exist in Hudson Bayou, Phillippi Creek, or Roberts Bay. Results of this attempt can then be used to guide screening, evaluation and design recommendations made in Part IV.

3.1 <u>Overview</u>

It is customary to view the impacts of nonpoint source pollution primarily in terms of constituent loads and effects, e.g., the delivery of sediment, nutrients, toxic materials, et cetera. The analysis of loading rates requires an understanding of hydrological

characteristics, and in some cases, the impacts of hydrological changes per se are secondarily evaluated as direct impacts.

A more comprehensive catalog of NPS impacts is considerably larger (Table 1). For example, environmental impacts of the conveyance systems should be included, such as habitat loss, erosion, and secondary impacts of human use. Hydrological effects of NPS systems include groundwater and circulation changes, especially near tidal waters. Changes in physical parameters such as transparency, or chemical properties such as pH, may have more widespread impact than metal or hydrocarbon contaminants. Because estuaries are the final receiving waters for all nonpoint stresses, there are also cumulative ecological effects to consider, such as anoxia, eutrophication, habitat loss, and declines in secondary productivity. Finally, social and economic effects (odor, health risks, loss of property value, etc.) must be reckoned as consequences of nonpoint source pollution.

TABLE 1
KNOWN AND PROBABLE IMPACTS OF STORMWATER ON SARASOTA BAY

General Effect of the Conveyance System

1 Habitat loss
2 Erosion and sedimentation
3 Increased proximity of human activity to aquatic areas
4 Secondary uses of the conveyance systems
    - Navigation
        - Channels
        - Docks
        - Vessels (paint, bilge and propeller effects)
    - Waste disposal other than NPS

Hydrological Effects

1 Movement of deep aquifer water to surface waters
2 Water table decline
3 Groundwater contamination of tidal water
4 Groundwater contamination by salt water
5 Surface water changes
    - Quantity
    - Timing
    - Location
    - Circulation
6 Additive effect of instream structures
    - Impoundment
    - Barrier

Constituent Effects

1 Physical
    - Temperature
    - Dissolved, suspended and settleable solids
    - Light attenuation
    - Flotsam and debris
2 Chemical
    - pH
    - Salinity
    - Color
    - Nutrients
    - Contaminants
        - Inorganic (metals)
        - Organic (petroleum hydrocarbons)
3 Biological
    - Oxygen and oxygen-demanding substances
    - Bacteria and viruses
    - Chlorophyll and algae

TABLE 1 (CONTINUED) KNOWN AND PROBABLE IMPACTS OF STORMWATER ON SARASOTA BAY
Cumulative Ecological Effects 1 Anoxia 2 Eutrophication • Blooms • Epiphytes 3 Habitat loss 4 Contamination and biomagnification 5 Declines in secondary productivity • Species losses • Changes in overall community or trophic structure
Social and Economic Effects 1 Odor 2 Loss of visibility 3 Health risks • Contact • Consumption 4 Closure of harvestable areas 5 Loss of property value 6 Cost of rehabilitation

3.2 General Effects of the Conveyance System

Mature conveyance systems such as Phillippi Creek efficiently drain upland areas because drainage-ways have been enlarged and lengthened. In the southeastern United States, this process began during the conversion of natural land-cover to agriculture, in the early settlement of coastal areas (Heimlich and Vesterby, 1989; Zarbock, 1991). Isolated wetlands are either filled or connected by ditches to permanent streams, and these hydrological alterations often destroy the wetland. Clear-cutting of forests can also promote rapid soil loss, erosion, and sedimentation, as was postulated by Morrill et al. (1977) for the Cape Haze peninsula and Lemon Bay.

Deepening and widening of a stream increases its capacity to convey water. Unless hardened, steeply sloped banks erode and sediment loss undermines riparian vegetation, resulting in further wetland habitat loss. Bank failure is a major cause of unwanted sedimentation in Clower Creek, a tributary of Little Sarasota Bay (Briley-Wild Associates, 1992). Excessive sedimentation degrades instream benthic habitats, even in areas unaffected by local bank failure. Removal of snags, sand bars, and other micro-habitat features utilized by juvenile fishes (Edwards, 1991) further degrades the stream's natural habitat value.

As streams are modified to improve nearby drainage, more intensive settlement and use becomes possible. Streams attract development because they are interesting landscape features and often afford scenic views (Baker et al., 1977). Tidal streams are doubly attractive for their promise of navigation access. Clearing and construction along streams further disrupts natural ground cover and habitat, and interrupts the wildlife corridor value of stream-side areas. Access to the water, and access to the bay, cause additional habitat impact. Isolated structures such as docks, piers, boat ramps, and minor channels may have significant cumulative impacts (Mulvihill et al., 1980) when concentrated in small streams such as Hudson Bayou or Phillippi Creek.

Tidal streams that harbor vessels face additional stresses unrelated to nonpoint source pollution, as usually defined. Tidal streams in Florida tend to be very shallow, and many have been deepened to provide navigable depths during low tide. Spoil disposal often displaces natural terrestrial or underwater habitat. Channels that are too deep accumulate fine sediments and are uninhabitable by desireable forms of benthic fauna (J.

Culter, Mote Marine Laboratory, personal communication). Docks, piers, and hulls may be treated with anti-fouling preservatives containing highly toxic constituents. Some hull treatments such as tributyl tin are exceedingly toxic and bio-accumulate in marine flora and fauna, including seagrass communities (Kelly et al., 1990). Bottom communities, including seagrasses, may be significantly disturbed by propeller scour (Zieman, 1976). Seagrasses near the mouth of Hudson Bayou bear propeller scars and oyster reefs in Phillippi Creek bear signs of motorboat damage.

It is evident from the brief review above that numerous environmental stresses are associated with stormwater conveyance systems, irrespective of their specific hydrological or chemical nature, and that these are multiplied for systems with tidal reaches connected to navigable water. In practice, it is difficult to separate these unique conveyance impacts from the impacts of pollutants delivered to the bay. On the other hand, knowledge of these conditions may help to make nonpoint pollution control strategies more responsive to local conditions.

3.3 Hydrological Effects: Groundwater

The hydrology of runoff is the subject of extensive geophysical and engineering study and is well beyond the scope of this project to review. First principles and applications are available in Stephenson (1981), Kibler (1982), and Wanielista (1990), and a recent bibliography on stormwater management is available in Ferguson (1989). This section addresses nonpoint source impacts of a hydrological nature, following the list of relevant parameters given in Table 1. After noting groundwater impacts, this section attempts to establish that the amount, timing, and location (including circulation) of freshwater inflow are as important to consider as the constituents freshwater carries.

Several classes of groundwater impact are possible, at least in southwest Florida. First, the improved connection of agricultural areas to coastal streams makes possible the movement of tailwaters, often highly mineralized water from the Floridan Aquifer, into surface water ecosystems. Such waters constitute a measurable component of dry-season base flow in the Myakka River (Hammett, 1990), although its ecological effects are unstudied. Known constituent effects of agricultural runoff are described later. Second, improved drainage means that water tables may be lowered, possibly affecting interior wetlands. Bays and Winchester (1986) showed that sloughs and isolated wetlands in

west-central Florida are maintained by a combination of water table and surface water contributions, and that alterations to water table levels promote the invasion of exotic plant species. Drainage effects can be widespread and affect regional resources in addition to wetlands (Black and Black, 1989).

In a similar vein, when coastal streams are deepened the seaward movement of the water table in residential areas is accelerated. This process facilitates eutrophication where residential septic tanks are used (Hicks and Cavinder, 1975; Tomasko and LaPointe, 1991). Finally, coastal drainage systems and canals facilitate saltwater encroachment (Miller, 1988), especially where pumping demands are large. Joyner and Sutcliffe (1967) documented an early case of saltwater contamination in Siesta Key wells.

3.4 Hydrological Effects: Surface Water

The hydrological characteristics of runoff would be ecologically important even if the runoff contained no suspended or dissolved constituents, whatsoever. Quantity of inflow determines how much littoral area is affected around a lake or stream floodplain. The velocity of inflowing water controls bed load and shoaling, the formation of point bars and riffle areas, and other important habitats in streams and along lake margins. In general, small lakes and streams are affected more by small inflow changes.

Freshwater inflow is as important to estuaries as it is to lakes or streams. Freshwater is intrinsic to the definition of an estuary:

> "Estuaries are features of the coastal landscape where the mainland, barrier islands, or vegetation semi-enclose a water body made brackish by the mixing of salt and fresh water."
>
> Estevez et al. (1984)

Specific hydrological aspects of inflow are noteworthy because freshwater is so important to estuaries, namely, the total quantity of inflow; the timing of inflow; and the location of inflow. Each is discussed below with an emphasis on their significance apart from that of pollutant delivery.

3.4.1 Quantity

Hydrographs integrate quantity and timing of flow, two equally important aspects of runoff, but total quantity is also significant in terms of estuarine impacts. In tidal tributaries or small estuaries, total event quantities affect stage (tide), water velocities, scour, and salinity duration. In larger estuaries, total event quantities affect circulation and salinity fields and total annual quantities affect salinity duration.

The effect of inflow quantity on stage can be significant in tidal streams, delta systems, or confined estuaries. In such environments, small changes in inflow may determine whether marshes or other tidal wetlands are inundated, which in turn plays a critical role in regulating nutrient exchange and utilization of wetlands by larvae or juveniles of invertebrates and fishes. Depending on the size and geometry of tidal waters receiving freshwater, inflow quantity can also control stratification, oxygen exchange between surface and bottom waters, or the upstream movement of residual currents. The latter process facilitates migration of larvae to low salinity and predator-free nursery areas.

Salinity duration is the same as the frequency at which given salinities occur at a specified geographic point. The salinity duration requirements of some important species are known while others are still being studied. For example, it has been shown that optimal salinity for oyster growth and reef formation is between 20 to 25 parts per thousand (ppt), but that lower salinities are periodically required to repel marine predators. Salinity duration curves may differ for surface and bottom waters at the same place, with surface waters generally being fresher than bottom waters. Thus, oligohaline (very low salinity) areas in estuaries may have freshwater shoreline vegetation but estuarine benthic fauna. Tidal freshwater areas are critically dependent upon amounts of freshwater inflow
adequate to prevent higher salinity.

Salinity fields refer to the areal or volumetric space occupied by waters with salinity of a specified range. The size and actual location of a particular salinity field depends on the interplay of inflow volume, tidal forces, wind, and bathymetry. Browder and Moore (1981) refer to salinity fields required by specific life-stages of invertebrates or fishes as their "dynamic habitat". The overlap between dynamic and "stationary" habitat determines the productive area of an estuary for that species. Important salinity fields

for fishes are freshwater to 4 ppt, 2 to 15 ppt, 11 to 19 ppt, and 15-28 ppt (Bulger et al., 1990). Florida seagrasses also appear to have species-specific salinity fields (C. Montague, University of Florida, personal communication).

Numerous studies have documented the relationship between estuarine productivity and quantity of freshwater inflow. Two examples of international scale include the Nile River (Aleem, 1972) and Caspian Sea (Rozengurt and Hedgpeth, 1989). Other international examples are reviewed by Mahmud (1985). Deegan et al. (1986) illustrated the role of total annual inflow to fishery landings in the Gulf of Mexico, and Browder (1985) reached similar conclusions for pink shrimp landings and Everglades discharge. Disruptive effects of inflow volume on estuaries was shown in the St. Lucie estuary by Haunert and Startzman (1985); Naples Bay by Collier Conservancy (1979); and Dona and Roberts Bay in Sarasota County by Lincer (1975).

Effects of inflow quantity are unstudied in both Hudson Bayou and Phillippi Creek. Hudson Bayou is very close to Big Pass, a tidal inlet leading to the Gulf, and this situation implies that the Bayou never had extensive low salinity reaches. The major issue related to freshwater inflow volumes in Hudson Bayou is whether inflows are large enough to physically disrupt bottom sediments.

Phillippi Creek is a different situation. Prior to hydraulic dredging that connected Roberts and Little Sarasota Bays, salinity in the Creek mouth area was low and the creek itself was probably tidal but freshwater during most times. Now its tidal reach is mesohaline and low salinity areas only occur farther upstream (Environmental Services Laboratory, 1989). Because a salinity barrier exists in the creek, there is a limit to upstream penetration of low salinity waters and also a physical barrier to upstream access by animals. Because both the stationary and dynamic habitats (sensu Browder and Moore, 1981) have been reduced in size, it may be reasonable to conclude that the creek's productivity is significantly less than it used to be. This conclusion leads to the possibility that Phillippi Creek might benefit by receiving more water than it does, at least in terms of base flow. Quantities delivered during peak flows are probably deleterious and need to be moderated, as discussed in the next section on timing.

3.4.2 Timing

Hydrographs portray runoff changes through time and it is widely accepted that natural hydrographs, with protracted "tails" after event peaks, are preferable to hydrographs of more perfectly drained systems. In the latter case, flows increase and decrease precipitously and peak discharges are frequently greater than would otherwise occur in natural systems. Because wetland and soil storage contribute to natural hydrographs it is understandable that highly modified hydrographs are damaging to wetland structure and function, and to soils. This is particularly true for freshwater wetlands which may occur as isolated units, sloughs, floodplain systems, or deltaic formations.

The effects of altered event hydrographs on estuarine and marine environments is less well documented but can be inferred from other studies. Impacts in tidal streams include bed transport and resuspension of settled sediments; physical displacement of biota; and mortality of sessile and sedentary organisms, due primarily to osmotic shock. Bank impacts include erosion; shunting and loss of sediments that would otherwise contribute to maintenance of wetland substrata; and scouring of propagules. Impacts on adjacent uplands include altered water tables; invasion of nuisance or weedy species; and loss of wetland communities that require modulated exposures to water. These impacts are independent of any constituents that may be transported to tidal waters by event runoff.

Seasonal variation is a critical component of inflow timing. Parameters such as dry season flow, wet season flow, and the rate of change between seasonal flows can be significant in terms of estuarine ecology. In southern Florida, the spring dry season (and early summer) is a period of active spawning for many marine and estuarine fish and invertebrate species (Comp, 1985). Larvae and juveniles seek low salinity areas, the size and location of which are determined by dry season runoff. Among other factors, the size, location and permanence of low salinity areas affects secondary productivity. Often, dry season flows of a given year affect the abundance of a species in subsequent years, as shown for pink shrimp by Browder (1985) and for oysters by Wilbur (in prep.). Small changes in inflow during the dry season can have profound effects on salinity fields (Browder and Wang, 1988).

Wet season inflows are important because heightened primary productivity sustains juveniles and adults of fishes and invertebrates. Wet season flow reductions may

seriously affect estuaries (Halim, 1990), but the usual effect of stormwater runoff is to increase wet season inflow. Browder (1991) reviewed the effects of excessive wet season flow and the adverse impacts of sudden releases of freshwater into estuaries.

Extremely low runoff is probably not a problem for Hudson Bayou because nearby bay waters are highly saline. The bayou probably receives much more wet season inflow than it did under natural conditions. Given the impervious cover of the bayou's watershed, the delivery of wet season inflow is probably highly pulsed rather than continuous. Pulsing of freshwater into marine environments is probably deleterious, especially for sedentary and sessile fauna, and submerged aquatic vegetation.

Based on a number of studies worldwide (Rozengurt et al., 1987; Rozengurt and Hedgpeth, 1989), a general rule of thumb has arisen for determining the limits beyond which alterations of freshwater inflow exceed an estuary's natural resilience (Halim, 1990; Safina, 1991). Basically, flow alterations should be held to within the coefficient of natural hydrological variability[1]. This term varies from 0.2 to 0.3 for Florida latitudes (McMahon, 1982), meaning that flow reductions or enhancements of 20-30 percent may not be damaging to receiving estuaries.

There are insufficient data to compute the coefficient of natural hydrological variability in either Hudson Bayou or Phillippi Creek, although it is theoretically possible to do so with runoff models calibrated to pre-development conditions[2]. Lack of a dry season base flow was identified earlier as a possible problem in Phillippi Creek. Entry of freshwater at the head of Roberts Bay would help maintain a salinity gradient by which migrating marine life could navigate in order to enter the Creek or Little Sarasota Bay. The inflow would also help to maintain a low salinity reach of the Creek, thought to be important for juveniles of such species as snook (R. Edwards, Mote Marine Laboratory, personal communication). Unless it exceeds thresholds of bank or stream-bed stability, excessive wet season inflow per se is probably not a problem in the creek. The possibility that pulsed wet-season inflows cause rapid swings in salinity is a greater hazard. The pulsing

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1/ Standard deviation of inflow, divided by the mean inflow computed for 50 years or more.

2/ This approach is presently being attempted for the Tampa Bay National Estuary Program.

effect of an instream salinity barrier in Phillippi Creek deserves to be investigated in this context.

3.4.3 Location

Location of inflow is not usually recognized as an issue in surface water management, but it can have significant effects on estuarine environments, especially low salinity areas. The most extreme cases involve relocation of river mouths or distributaries, as in the case of the Mississippi River's distributaries. Rerouting of water in the Santee-Cooper Rivers is another well documented case. A Florida example involved the distribution of inflowing water to Faka Hatchee, Faka Union and Pumpkin Bays (Browder et al., 1986). In coastal areas the problem has more to do with increased amounts of inflow near the mouth of a stream, and decreased inflows from headwater areas. The major hydrological impact of such redistribution concerns the salinity structure of tidal reaches, although contaminants introduced near the mouth of a stream could form a toxic barrier preventing successful movement into or out of the stream, by marine animals (Helz and Huggett, 1987). No major redistributions of inflow to either Hudson Bayou or Phillippi Creek are known. On the other hand, connection of Roberts and Little Sarasota Bays constitutes a major relocation in the sources of tidal water across the mouth of Phillippi Creek.

3.5 Constituent Effects

The traditional emphases of nonpoint source management are the concentration, load, fate, and effect of runoff constituents. Although narrower in focus than the approach taken here, the science and management of pollutants are nevertheless broad and complex fields. The environmental impact of nonpoint source pollution is equally broad and complex (Overcash and Davidson, 1980).

The scope of this section is limited to nonpoint source pollutants known or suspected to occur in the Sarasota Bay area, and the scope is limited further to discussion of ecological effects (rather than provenance, transport, storage, or other physical and chemical processes) in estuarine settings.

By way of introduction to pollutant impacts, it is important to recognize that nonpoint source pollution has caused severe degradation of estuarine resources and beneficial uses throughout the world (Palmer and Espirito, 1980). In terms of general theory, marine and estuarine organisms have a tolerance for pollutants within which the exposure does not cause stress. At higher exposures the pollutant causes sub-lethal stress which can accumulate to impair reproduction or other vital activity. Greater exposures are directly lethal to the organism, and the interaction of sub-lethal exposures to multiple pollutants can also be lethal (James, 1979).

More is known about specific pollutant effects on marine organisms than can be summarized in this report. For example, Volume 28 (Nos. 1-4, the entire annual issue) of *Marine Environmental Research* is given to a review of the sub-cellular, cellular, tissue, and physiological responses of marine organisms to pollutants (Roesijadi and Spies, 1989). Pollutant effects span all levels of biological organization, up to and including behavior (Neff and Anderson, 1981). Ecosystem-level impacts of nonpoint source pollutants tend to be better known for certain pollutants, and for freshwaters, although ecosystem studies of toxic materials in rivers are being extended into estuarine environments (Allan et al., 1990).

It is noteworthy that most (47%) of the literature specific to nonpoint pollution effects is given to macroinvertebrates and that impacts to other groups are not evenly studied (Cunningham, 1988). On the other hand, much of the literature on wastewater impacts can be useful in understanding nonpoint source pollution impacts (see, for example, EPA 1984 for a review of ecological impacts of wastewater on wetlands).

A recent review of literature pertaining to nonpoint source impacts on aquatic life throughout the United States (Cunningham, 1988) found that states most often cited agriculture as the major cause of use impairments, followed by urban sources, construction, mining, landfill, hydroperiod modification, and forestry (in order of descending importance). The review also found that bacteria was the most widely reported NPS pollution parameter, followed by nutrients, turbidity, BOD and dissolved oxygen, metals, pesticides, and acidity (pH). Cunningham (1988) did not identify impairment reports from coastal states per se, so the incidence and severity of NPS pollutants are probably biased toward inland and freshwater areas.

Some insight to nonpoint pollutants in Hudson Bayou and Phillippi Creek is available from ongoing studies performed by Mote Marine Laboratory as part of the Sarasota Bay National Estuary Program. These studies are incomplete and unpublished but preliminary results can be presented in a general way so that readers may decide whether to obtain the final reports for use in related projects. Excessive levels of coliform bacteria in water or tissues have not been measured, due largely to antecedent weather conditions (L.K. Dixon, Mote Marine Laboratory, personal communication). However, Sarasota County Environmental Services Laboratory (1989) reported chronically high levels of coliform in both streams. Likewise, nutrient, turbidity, and suspended solid levels reported from NEP sampling tend to be lower than extreme concentrations measured over a longer period by Sarasota County. Violations of dissolved oxygen standards have been measured by both sampling programs.

Sediments in Hudson Bayou contain high levels of nitrogen but sediments in both streams contain relatively little phosphorus. Copper and zinc concentrations reach pollutant levels in Hudson Bayou and lead is a sediment pollutant in both streams. Hydrocarbon analyses of sediments are ongoing (L.K. Dixon, Mote Marine Laboratory, personal communication).

On a bay-wide basis, heavy metal contamination in shellfish is not excessive. Where it occurs, zinc, lead and arsenic tend to be relatively high and copper and mercury tend to be comparable to other Florida areas. Hudson Bayou's shellfish metal load exceeds that of Phillippi Creek. Pesticide contamination of shellfish is not excessive in either stream, and neither is contamination by petrogenic or pyrogenic hydrocarbons (L.K. Dixon, Mote Marine Laboratory, personal communication).

3.5.1 Physical Constituents

Temperature (thermal enrichment) is not usually a problem associated with nonpoint source pollution and there is no reason to suspect it in Sarasota Bay. *Dissolved, suspended and settleable solids* are a recurring nonpoint source pollutant. The adverse impacts of this material were described in Dona and Roberts Bay by Lincer (1975) and in Naples Bay by Collier Conservancy (1979). In Sarasota Bay, solids attenuate light which affects benthic vegetation. In very high concentrations, solids can alter the sediment structure or sediment chemistry of receiving waters, which affects benthic

fauna. Other pollutants adsorb onto solids and enter food webs that involve filter feeding or deposit feeding animals. Pierce and Brown (1984) demonstrated the dispersion through Sarasota Bay of coprostanol, a sewage tracer, on fine particulate matter. Detectable levels of coprostanol were measured near the mouth of Hudson Bayou but the Phillippi Creek area was not sampled[3].

Heyl (1992) reported on the precipitation of calcium carbonate in Sarasota Bay near Whitaker Bayou. The spatial patterns of acid-soluble TSS and turbidity coincide with circulation of Bayou water in the bay, suggesting that discharge from Sarasota's waste water treatment plant contributes to light attenuation through the indirect mechanism of enhancing precipitation. The effect could also be caused by Sarasota's reverse osmosis plant, which discharges reject water to the bay near the bayou. If further study finds that the STP effluent enhances precipitation, the discharge of other STP effluents into Phillippi Creek may have a similar effect.

Sedimentation appears to be a serious problem in Hudson Bayou. Deeper parts of the main channel and large parts of connecting channels are filled with fine organic silts and clays. Such bottom areas do not support useful animal communities. Organic muds alter nutrient concentrations in overlying waters and constitute a major source of oxygen demand. Such sediments also occur in Phillippi Creek but to a lesser degree. The extent to which sediments from nonpoint sources contribute to this problem is not presently known. In fact, deep protected waters naturally collect large amounts of sediment, detritus and dying phytoplankton introduced by tidal action from open bay areas. If Hudson Bayou is similar to the Grand Canal on Siesta Key, its sediments are probably a mixture of materials from both origins (Estevez, 1983).

3.5.2 Chemical Constituents

Although forestry operations have been shown to promote runoff of acidified water into Apalachicola Bay, resulting in mass movements of juvenile and adult blue crabs from the area (Livingston et al., 1976), waters of low *pH* have not been suspected as a problem affecting Sarasota Bay.

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[3]/ The NEP has sampled Phillippi Creek for coprostanol and analyses are ongoing.

The humic and tannic acids from terrestrial and wetland plants cause pH reductions but also contribute *color* to tidal waters. Darkly-stained water is a characteristic of peninsular Florida streams, including Phillippi Creek, but it is probably not a dominant characteristic of Hudson Bayou's discharge. The principal environmental role of color is that it absorbs underwater light and thereby affects the illumination of benthic vegetation. Studies on the ecological effect in Florida estuaries of light per se are few, but ongoing water quality monitoring by the National Estuary Program suggests that color may be the underlying control of light penetration into Sarasota Bay (David Tomasko, Sarasota Bay NEP Project Office, personal communication).

As witnessed by the 1990 International Conference on Marine Coastal Eutrophication, in Bologna, Italy, nutrient enrichment is a problem of international scope. It constitutes a major research focus in every temperate and tropical ocean and sea, and most developed estuaries. Several literature reviews and case studies are available (e.g., Webb et al., 1979; LUMCON, 1991).

Nitrogen and phosphorous are the nutrients of primary concern in estuaries, although carbon and silicon are also treated as nutrients in certain cases. Nitrogen and phosphorous occur in inorganic and organic molecular forms and may be dissolved or particulate. Complex reactions govern the concentration of each form in estuaries (Stickney, 1984). Both elements are essential for maintenance and growth of plants and animals but the elements are considered macronutrients in plants (Continental Shelf Assoc., 1991). The productivity of marine and estuarine plants (primarily algae) along the southwest coast of Florida is determined primarily by nitrogen availability (Montgomery and McPherson, 1991), although nitrogen and phosphorous together can stimulate production at lower salinities (Vargo et al., 1991).

Nutrients are a commonplace form of nonpoint source pollution, and may originate from agricultural lands, urban lands serviced by septic tanks, forestry, and other land-uses. Details of watershed features to nutrient loads are well documented, but links between nutrient loads and estuarine conditions are still being discovered:

> A single variable indicator which might be used as an index of estuarine eutrophication has been suggested by Garber and Boynton, 1991. They propose that annually-averaged depth integrated chlorophyll-a has a strong relationship with nutrient loading to a system. With data from five

> Chesapeake Bay subsystems and mesocosms they have demonstrated a good correlation ($r^2 = 0.81$) with annual area-based total nitrogen (N) loading (in mg $N/m^2/day$) normalized by mean depth and hydraulic retention time. The slope of the relationship indicates that an increase of 0.5 mg $N/m^2/day$ in nitrogen loading will result in an increase in average integrated chlorophyll biomass of 1 mg/m^2 (Garber and Boynton, 1991). The relationship, which provides a "Vollenweider-like" model of estuarine eutrophication, has yet to be verified with data from other systems, but seems to promise a means of predicting the trophic state of an estuary from the annual rate of nitrogen inputs[4].

The value of linking nutrient loads to chlorophyll is that other relationships have been established relating pigment to transparency, dissolved oxygen, and other important ecological features in estuaries that are mediated by phytoplankton:

> Phytoplankton has long been the subject of study relative to nutrients. An EPA review of biological indicators of eutrophication dismissed phytoplankton diversity and abundance as once-or-twice yearly descriptors, but found that more frequent sampling revealed nutrient impacts (Scott, 1990). Strong correlations have been demonstrated between mean annual chlorophyll a concentration in Chesapeake Bay and mean annual area-based loadings of nitrogen (Garber and Boynton, 1991), and such relationships are being used to suggest management goals for Tampa Bay (Johannson, 1990). Nutrient enrichment of estuaries may promote oxygen depletion by phytoplankton population flushes (blooms), or change phytoplankton community structure (as in promoting flagellates over diatoms). Indirect effects mediated by phytoplankton responses to nutrients include changes in secondary production among zooplankton, nekton, and benthic communities, and reduced light penetration to submerged aquatic vegetation (Day, Hall, Kemp and Yanez-Arancibia, 1989).

Impacts of nutrients on other estuarine resources are also known:

> Macroalgae are affected by nutrient enrichment in two forms, as epiphytic growth on seagrass, and as proliferations of drift algae. Epiphytes are natural elements of seagrass communities but in excess can reduce light

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[4]/ Indented text is adapted from Mote Marine Laboratory (1991), General decision model for the design of estuarine eutrophication monitoring programs --Task 1 report, literature review and method description, submitted to the South Florida Water Management District, West Palm Beach.

reaching seagrass leaves (Borum and Wium-Anderson, 1980). Nutrient enrichment enhances epiphyte growth and may cause seagrass decline in estuaries (Twilley et al., 1985). Attached (rhizophytic) and especially drift (planktonic) macroalgae have been used for decades as indicators of nutrient enrichment and sewage pollution (Perkins, 1979). Algal tumours form near severe sewage pollution (North et al., 1970). Accumulations of single species such as Ulva or Gracilaria can reach nuisance proportions in estuaries of south Florida (Lewis and Estevez, 1988), and Codium has been reported covering offshore reefs (Brian LaPointe, personal communication). Round (1981) provides a thorough review of trophic indices based on macroalgae in temperate waters.

Sea grasses are considered a valued estuarine ecosystem component (Scott, 1990). Sea grass decline is widespread in Florida estuaries and a number of causes have been documented or suspected (Gulf of Mexico Program, 1991). Some involve nutrients and nutrient impacts to sea grasses are probably made manifest by more than one pathway (Kenworthy and Haunert, 1991). One pathway related to light is listed below.

> Nutrient Load ----> Phytoplankton Bloom ----> Increased Chlorophyll ----> Increased Scattering and Absorption ---> Decreased Transparency ---> Sea Grass Loss.

Seagrass declines through loss of water transparency or epiphyte proliferation is widely recognized as a primary impact of nutrient enrichment (Zieman, 1975). Cases studies are available from Australia (Cambridge and McComb, 1984), Chesapeake Bay (Bayley et al., 1978; Orth and Moore, 1983) and Tampa Bay. In Tampa Bay, sewage treatment and phosphate chemical plant discharges caused massive eutrophication of Hillsborough Bay, and SAV loss. Following abatement of nutrient loads, there has been a regrowth of rhizophytic algae and SAV (Johannson and Lewis, in press). Tomasko and LaPointe (1991) showed that productivity and biomass of turtle grass, and epiphyte loads, were related to nutrient enrichment from septic tanks in the Florida Keys.

Benthic faunal species and communities have documented responses to nutrient enrichment. A number of macroinvertebrate species of epibenthic or infaunal habit are recognized as indicators of polluted or healthy water (Perkins, 1979). In Tampa Bay, moderate nutrient enrichment from a sewage treatment plant increased polychaete density, richness and biomass (Dauer and Conner, 1980). Greater eutrophication leads to shifts from suspension feeders to deposit feeders (Pearson and Rosenberg, 1978). Severe eutrophication of Hillsborough Bay led to hypoxic conditions and annual defaunation (Santos and Simon, 1980).

Flannery (1991) compiled comparative nutrient data for 19 streams in Tampa and Sarasota Bays, for the period 1980 - 1985. Data for Hudson Bayou were not considered. Phillippi Creek had the fourth highest mean value of total phosphorous, 0.97 mg/l (Whitaker Bayou was highest with 1.53 mg/l). Not counting Delaney Creek, an industrially polluted stream in Hillsborough County, Phillippi Creek had the second highest mean value of total nitrogen, 2.98 mg/l (Whitaker Bayou was highest with 6.14 mg/l). Phillippi Creek had the sixth highest mean value of organic nitrogen, 1.2 mg/l. Whitaker Bayou had the highest value after Delaney Creek. Phillippi Creek had the third highest mean value of nitrate plus nitrite and the third highest mean value of ammonia. These data place Phillippi Creek among the most eutrophic tributaries in west-central Florida, including tributaries of Tampa Bay.

Heavy metals naturally associated with nonpoint source pollution come from the atmosphere as dry-fall and as a constituent of precipitation, from soils, and ground waters. Anthropogenic sources add to atmospheric loads or add metals directly to surface and ground waters. These include incinerators, fossil fuel electric power stations, automobiles (exhaust and tire wear), land-fills, sewage treatment plant effluents, anti-fouling boat paints, runoff from eroding agricultural lands, urban runoff, and point-source discharges to drainage systems.

As much is known about the health effects and ecological impacts of heavy metals as is known about other NPS pollutants. By the same token, it is probably true that less is known about the marine and estuarine impacts of heavy metals than is known about their impacts in freshwater environments. Heavy metals tend to occur in sediments, in concentrations that decrease with distance from their sources. The concentration of a metal in Florida sediments of a given size is considered polluting when it exceeds a specified ratio to aluminum[5] (Schropp and Windom, 1988).

Metals such as zinc, copper, iron, cobalt and strontium are necessary in trace amounts and therefore occur naturally in marine plants and animals (Stickney, 1984). When metals reach contaminant levels, they have the same dispersion pattern in sessile and sedentary organisms that is seen in sediments. Heavy metals are directly toxic to most

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[5]/ Aluminum is used to normalize metal concentrations because it is very abundant and refractory, and is not usually affected by anthropogenic sources.

forms of aquatic life. At sublethal exposures, metals reduce growth and photosynthesis of phytoplankton. Macroalgae concentrate certain elements and copper is very toxic to many species of macroalgae (Furness and Rainbow, 1990). Seagrasses accumulate trace metals (Pulich, 1987). The distribution of heavy metals within seagrasses depends on the element and the anatomy and age of the plant (Lyngby and Brix, 1989). Direct toxicity of heavy metals to seagrasses is not well known but eelgrass can accumulate some elements (Drifmeyer et al., 1980). Wetlands tend to act as sinks for heavy metals (Windom, 1975; Habison, 1986).

Invertebrate responses to metal exposure vary widely, and in many cases are salinity-dependent. Mercury, copper, [tributyl-] tin and magnesium are highly toxic and many other metals cause significant changes in the structure of benthic invertebrate communities. Some elements that are not independently toxic to invertebrates can facilitate toxicity of other elements. Marine vertebrates (fishes and mammals) and sea birds are poisoned by lead and mercury. Mercury accumulates in food-chains so predators, including humans, are exposed to significantly higher toxic doses (Furness and Rainbow, 1990). Serious effects of heavy metals on human physiology, reproduction, growth and behavior have been observed (Foulkes, 1990).

Long et al. (1991) reported on the status and trends of toxicants and the potential for their biological effects in Tampa Bay. The study encompassed six heavy metals in surface sediments and tissues. Storm drains and marinas were among toxicant "hotspots". Sediments appear enriched by cadmium, copper, lead and zinc. Mercury, arsenic and zinc have been relatively high in oysters. Lead, mercury and zinc appear to pose the greatest hazard but supporting biological data are inconclusive.

As described previously, preliminary NEP data suggest that Hudson Bayou has a higher heavy metal burden than Phillippi Creek sediment and that sediment contaminants include lead, copper and zinc. Compared to other Florida sites, shellfish tissue burdens of lead, zinc and arsenic are moderate to high, mercury is moderate, and copper values vary widely. Tiffany (1974) also reported relatively high levels of zinc in tissues collected from the bay area. No data are available on the ecological impact of metals in these areas although Bird (1980) reported a very high incidence of fish disease and parasitism near Phillippi Creek.

Organic contaminants include pesticides, polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and related substances. Major pesticide groups include chlorinated hydrocarbons, carbamates, organophosphates, and pyrethroids. The PAH may be grouped as petrogenic, pyrogenic, or biogenic and both former groups also occur from natural and anthropogenic sources.

The fate and effect of organic pesticides are complex and depend on the specific chemistry of each pesticide and specific hydrologic and biochemical features of the receiving water (Faust, 1974; Neff and Anderson, 1981). Pesticide use is widespread in citrus groves. A study of pesticide, herbicide and acaricide movement was made in a citrus grove near Ft. Pierce, Florida, which showed that pesticide export was a function of tillage and drainage methodology (Mansell et al., 1977). Because the study was performed in flatwood soils similar in drainage to the soils near Sarasota, similar runoff characteristics may be expected in the Phillippi basin.

Van Vleet (1985) reviewed hydrocarbon data for Tampa Bay and Pierce et al. (1986) surveyed Charlotte Harbor sediments and tissues for hydrocarbons. Anthropogenic hydrocarbons of most types were low throughout both estuaries with highest concentrations of oils and greases near marinas and shipyards, or urbanized areas. Pesticide levels typically were low or below detection limits. This pattern of contaminant dispersion is typical in estuaries and coastal areas.

More recently, Long et al. (1991) reported on the status and trends of toxicants and the potential for their biological effects in Tampa Bay. The study encompassed PAH, PCB and pesticides. Storm drains and marinas were among toxicant "hotspots". Total PAH, PCB and DDT levels may pose moderate threats to organisms (although DDT levels seem to have declined from earlier periods), but biological data are generally inconclusive. Interested readers are referred to this report for a more thorough review of existing hydrocarbon <u>and</u> <u>metals</u> data.

Effects of hydrocarbons on marine organisms have been widely studied and reviews are available in Faust (1972), Wolfe (1977), Neff and Anderson (1981), National Research Council (1985), and Fowler (1990). Conditions of exposure have significant effects on toxicity and general ecological impacts. Biomagnification of some pesticides is known to occur, with significant deleterious effects to top predators. Oil spills cause extensive

short term damage to marine ecosystems and, depending on the type of oil, exposure, and affected resources, recovery may take years to decades (National Research Council, 1985).

Data are presently unavailable for hydrocarbon burdens in estuarine organisms near Hudson Bayou or Phillippi Creek and it is therefore premature to speculate on the specific contaminants that cause or may cause ecological problems in these areas. If other studies in Tampa Bay and Charlotte Harbor are transferable to Sarasota Bay, pesticide, PCB and other hydrocarbon levels may not be extreme, but oils and greases may be present near centers of boating activity in Hudson Bayou and Phillippi Creek. Hydrocarbons (and heavy metals) affect the organization of intertidal mudflat benthic communities, with extreme contamination selecting for small, opportunistic species, low species richness, and low faunal densities (Roper et al., 1988) --characteristics of Roberts Bay infauna (Tiffany 1974; 1980)

3.5.3 Biological Constituents

Biological oxygen demand (BOD) is a measure of water's oxygen consumption potential resulting from the aerobic respiration of marine organisms. Bacteria, fungi, and protists contribute significantly to BOD, and so can phytoplankton or benthic algae. The combination of BOD with chemical oxygen demand is approximately equal to the European concept of saprobity (Sladecek, 1979). Oxygen demand is offset by biological oxygen production (photosynthesis) and dissolved oxygen is the net result of the two processes. Dissolved oxygen is the ecologically relevant parameter.

Dissolved oxygen below levels of about 2 mg/l (hypoxia) and the complete absence of dissolved oxygen (anoxia) are injurious to marine organisms. Oxygen stress causes short term behavioral changes in Indian River fishes (Peterson et al., 1991); mass migrations of benthic fauna in Charlotte Harbor (Environmental Quality Laboratory, 1989), and complete defaunation of estuarine areas of Tampa Bay (Santos and Simon, 1980).

Dissolved oxygen levels in Roberts Bay are widely reported as stressful (Tiffany, 1980; Windsor, 1985; FDER 1986 and 1988; Environmental Services Laboratory, 1989). Windsor (1985) reported frequent violations of state water quality standards which have continued through the present, according to NEP water quality monitoring data (S.

Lowrey, Mote Marine Laboratory, personal communication). Because most DO data for Hudson Bayou and Phillippi Creek are based on day-time measurements, actual DO stress is probably much more severe than presently documented.

Bacteria (and viruses) are natural constituents of surface water runoff and also result from the movement of human wastes into surface waters. The number of coliform bacteria colonies plated from a sample of water is used as a water quality parameter. Fecal coliform and fecal streptococci are progressively more accurate as indicators of human septic wastes. Their presence is often but not always associated with the presence of pathogenic viruses. Excessive counts result in closures of water to human contact or shellfish harvesting (Glendening, 1985). Nationally, bacteria are the leading NPS parameter responsible for the impairment of receiving-water uses (Cunningham, 1988).

Direct measurements of coliform in Hudson Bayou and the mouth of Phillippi Creek regularly show violations of state standards, and upstream, freshwater reaches of Phillippi Creek also exhibit excessive levels of fecal coliform bacteria (Environmental Services Laboratory, 1989). The fecal sterol, coprostanol, occurs in sediments near Hudson Bayou at concentrations greater than 50 ng/g dry wt. of sediment (Pierce and Brown, 1984), but this value may include past contributions from nearby live-aboard boats.

The bacterium genus Vibrio contains several pathogenic species and can cause gastrointestinal and wound infections. A recent survey found Vibrio species in waters of Sarasota Bay and the Gulf of Mexico, and in a wide variety of fishes and shellfish. Vibrio species were also found in gull and pelican droppings (Buck, 1990).

The Hudson Bayou basin is sewered whereas large parts of the Phillippi Creek basin is serviced by septic tanks. Maps of septic tank areas are rudimentary and data on their failure rates are even scarcer (M. Heyl, Camp, Dresser and McKee, Inc., personal communication). Given the high concentrations of coliform reported for this stream, and known pathogenic risks associated with bacteria and enteric viruses, stream sanitation should be a high priority for NPS improvements in Phillippi Creek.

3.6 Cumulative Effects

Preceding sections have dealt with the independent effects of various hydrological, physical, chemical and biological stressors known or suspected to occur in Sarasota Bay, with special reference to Hudson Bayou and Phillippi Creek. It is necessary to recognize that marine organisms are exposed to the cumulative effect of these stressors. It is also instructive to recognize that marine organisms must deal with natural stress (hurricanes, droughts, freezes, hurricanes, etc.) in addition to anthropogenic stress (Estevez, 1984).

Indicators of cumulative estuarine decline include decreased light penetration, anoxia, eutrophication, phytoplankton and macroalgal blooms, proliferation of epiphytic algae on seagrasses, habitat loss, contamination and biomagnification of toxic materials, declines in secondary productivity (numbers of fishes, birds, marine mammals, etc.), diseases in marine organisms, species losses, and changes in overall community or trophic structure.

In light of the published literature reviewed above, and new data being generated by ongoing NEP studies, Hudson Bayou and Phillippi Creek have significant detrimental effects on the overall ecological health of Roberts Bay. A complete accounting of stressors to Roberts Bay would have to include the effects of the Grand Canal and local drainage on Siesta Key. Phillippi Creek may also have an adverse effect on the northern end of Little Sarasota Bay. Nonpoint sources play a major role in the impact of both streams. Neither stream appears to have significant direct impacts on Sarasota Bay proper but indirect effects are plausible.

3.7 Social and Economic Effects

Although a detailed documentation or analysis of the social and economic effects of nonpoint source pollutants on Sarasota Bay are beyond the scope of the present report, it is still worthwhile to recognize links between ecological condition and overall use and enjoyment of the bay by area residents and tourists (Environmental Protection Agency, 1985). Undesirable *odor* is associated with putrefaction of organic matter in the water (algae) or sediment. *Loss of visibility* impairs navigation and recreational uses such as snorkeling, shelling, and fishing. *Health risks* result in limited access to waters for contact recreation. *Closure of harvestable areas* also restricts recreational activity and eliminates the potential of local waters to support commercial shellfishing. *Loss of*

property value is also a possibility because of proximity to polluted waters but documentation for this impact is difficult to identify. Finally, the *cost of stream rehabilitation* has to be recognized as an NPS impact. The costs of this report, the larger engineering assessment of which this report is a part, design, permitting, construction, and maintenance tasks represent social expenditures that could have been used for other purposes.

Section 4
MANAGEMENT

4.1 Management Objectives

It is desireable to know the goals or objectives for resource management before undertaking detailed technical assessments, mitigation, or other measures. Data should be collected to support the use of specific methods. One's choice of methods should be responsive to the management questions for which answers are sought, and questions should be driven by management goals (Estevez et al., 1991).

Existing goals and objectives pertinent to Hudson Bayou, Phillippi Creek and Roberts Bay are found in Chapters 17-3 and 17-4 FAC concerning Outstanding Florida Waters, and in the Sarasota Bay National Estuary Program Conference Agreement. The Florida OFW program is meant to afford "the highest protection" to Roberts Bay, excluding areas near the mouths of Hudson Bayou and Phillippi Creek. Highest protection means that the Florida Department of Environmental Regulation will not, under most circumstances, issue permits for activities which lower *existing ambient water quality*. Indirect discharges which would significantly degrade Roberts Bay are also impermissible. Existing ambient water quality refers to state standards and also to parameters for which there may be data but not standards. No reference is made to living resources and the overall goal of OFW is to maintain the status quo.

The NEP addresses physical, chemical, biological and social aspects of the bay, and NEP goals apply to all of Roberts Bay including Hudson Bayou and Phillippi Creek. Goals of the Sarasota Bay NEP project are to:

- Reduce the quantity and improve the quality of stormwater runoff into Sarasota Bay.

- Improve water transparency to the maximum allowable by the gulf and local weather conditions.

- Prevent further losses of seagrass beds and shoreline wetlands, and restore lost habitats.

- Restore and sustain fish and other living resources in Sarasota Bay.
- Provide increased levels of managed access to the bay.
- Coordinate beach/inlet/channel activities to enhance the bay.

NEP goals differ from OFW objectives by improving on the status quo. The first goal states that total NPS runoff should be less than it is now and its water quality should be better. The second goal aims to make the clarity of bay water significantly greater. The third and fourth goals protect existing habitat and other bay resources and provide for their restoration. The fifth and sixth goals are also meant as enhancements.

The first four goals are directly pertinent to the management of NPS pollution in Hudson Bayou and Phillippi Creek. Total annual quantity of runoff should be reduced in both streams. In Phillippi Creek there is some evidence that the decrease should be accomplished so as to provide for a prolonged base flow, and transitions from dry to wet season flows should be modulated instead of pulsed.

Runoff water quality should be improved in both streams. Because of the importance of transparency, signified by a separate NEP goal, highest priority should be given to parameters that directly and indirectly affect transparency. From a physical stand-point the velocity of discharges should not exceed that required to resuspend bottom sediments. The closed canopy of brazilian pepper growing in Hudson Bayou near U.S. 41 could be opened to let in light and wind.

Chemically, priority parameters should include color, total dissolved solids, total settleable solids, total suspended solids, nutrients (especially nitrogen), and chlorophyll. The value of these parameters near Big Pass may be useful as targets for Hudson Bayou. Reference data for Phillippi Creek are suggested in a later section. Based on existing information, secondary priority should be given to contaminants such as metals and anthropogenic hydrocarbons.

Natural habitat is extremely scarce in both streams. Creation of wetlands, shallow unvegetated areas, and increased surface area along tidal shorelines offer greater management potential than habitat restoration. In Phillippi Creek, wetland creation in the watershed will most likely have direct NPS management benefits (Livingston, 1990). In tidal, freshwater reaches of the creek, wetland creation will benefit marine and

estuarine fish and invertebrates. Specific mitigation ideas are presented in a subsequent section.

4.2 Management Questions

The status, trends, and goals identified in previous sections for Hudson Bayou and Phillippi Creek can be used to define empirical management questions. Not all are directly related to NPS pollution control because management goals for the streams are broader than that, but most have some bearing on the impacts of NPS pollution.

4.2.1 Hydrology

- What was pre-settlement land cover?
- What was the pre-settlement quantity and timing of runoff?
- What is the water table's role in stream flow; how does it differ from presettlement time and what will it be at build-out?
- What are the effects of instream structures on the amount and timing of stream flow?
- What is the present day coefficient of flow variation at the mouth of each stream and at head of tide for Phillippi Creek?
- What are the hydrological characteristics of dry season flow; wet season flow?

4.2.2 Water Quality

- What is the composition and origin of existing sediments in tidal reaches of each stream?
- How does sedimentation from runoff compare to sedimentation of materials from the bay?

- At what bottom velocity of stream flow is sediment resuspended?

- Does "whitening" contribute to turbidity of Phillippi Creek water where it enters Roberts Bay?

- What are present day salinity duration curves like at the mouth of each stream?

- What are the contributions of color, turbidity and chlorophyll to light attenuation in fresh and saltwater reaches of each stream?
- What are present day salinity fields like for the tidal portion of each stream, and for Roberts Bay within 1500 ft. of each stream?

- What is the relationship between discharge and salinity during high tide; during low tide?

- What effect do salinity barriers have on upstream salt wedge movement; if removed, how much base flow would retard upstream movement of the salt wedge?

- How does benthic oxygen demand in tidal areas compare to the BOD of inflowing water?

- What is the effect of tidal action on dissolved oxygen?

- What is the nature of diurnal variation in dissolved oxygen?

- Where and with what frequency does hypoxia occur; anoxia?

- Can aerators significantly improve dissolved oxygen concentrations in tidal waters?

- Where are septic tanks in use; how many function properly; and what loads do functional and dysfunctional septic tanks contribute?

- What is the source of fecal coliform in freshwater reaches of Phillippi Creek?

- What is the source of high sediment nitrogen in Bowlees Creek?

- What are the main sources of arsenic, copper, mercury, lead and zinc to each stream; what is the contribution of direct highway runoff?

- What are the main sources of oils and greases to each stream; what is the contribution of direct highway runoff?

4.2.3 Human Use

- What is the role of vessel traffic in creating or prolonging turbidity in the tidal reach of each stream?

4.3 Analytical Methods

A comparative approach is recommended as a framework for analyzing data collected to answer the questions listed above. Several reference data can be employed. In OFW terms, the standard of non-degradation is fairly clear. A problem with using NEP goals as reference terms is that the amount of desired improvement beyond existing conditions is not specified in most cases. The transparency goal is least ambiguous because inshore gulf data may be used as a basis for comparison of transparency near Hudson Bayou. But how much should the amount of runoff be decreased, and how much should its quality be increased, in order to meet other NEP goals unrelated to transparency?

These questions are particularly important in Phillippi Creek because its basin is so large and still being developed. For all practical purposes there are no comparable but unpolluted streams against which Phillippi Creek improvements can be evaluated. This is a general problem for most Florida streams (Estevez et al., 1991). Water quality conditions and possible improvements can be compared to the typical values of other Florida streams. This can be done using raw data for several parameters (Friedemann and Hand, 1989) or water quality indices that integrate several parameters (Florida Department of Environmental Regulation, 1988).

The problem of optimizing the amount and timing of runoff is more difficult. Direct monitoring can show whether NPS improvements in the basin are reducing total flow, an NEP goal. Direct monitoring can also demonstrate that pulsing has been reduced or that a dry season base flow has been provided (goals recommended in this report). However, typical value or index methods used in water quality monitoring do not apply for hydrological characteristics so the question remains as to how much hydrological improvement is necessary.

One promising answer exists in the technique already in use by hydrologists and land use planners, whereby future runoff and load conditions are simulated in order to compare conditions at build-out to present conditions. Dames and Moore (1990) used a spread sheet model to simulate runoff in the Tampa Bay watershed under present-day and future conditions. Camp, Dresser and McKee is modeling existing and future runoff to Sarasota Bay as an NEP project. This approach estimates future improvements in runoff but does not answer the question of whether the improvements are sufficient to fulfill environmental goals.

The method could provide useful guidance as to desireable quantities and timing of flow if a *pre-settlement scenario* was modeled. Land cover, soils, drainage, wetlands, and stream features could be returned to their original condition using historic data, and runoff characteristics for rainfall over a given period can be computed. Total flow, dry and wet season flows, rates of change, coefficients of flow variation, and other parameters could be calculated. These parameters could then be compared to the same parameters generated by a model of modern conditions, in which the model was driven by the same rainfall file.

Statistical tests of significance could be used to determine whether specific aspects of flow were different now than under natural conditions, and this information could guide the planning of future NPS improvements. This method will be attempted for a tributary of Tampa Bay as part of the Tampa Bay NEP. The application will focus exclusively on the amount, timing (and location) of freshwater inflow in order to evaluate salinity changes caused by development in the basin and river. The method is arguably as accurate as the modeling of future conditions and may be more accurate because presettlement conditions were certain and actual runoff data for natural soils, wetlands, etc. are available in the current literature.

Although it has not yet been attempted, it is also presently feasible to link presettlement basin-and-stream models to bay circulation models in order to discover the role of natural runoff on circulation, residual currents, flushing, and related hydrodynamic features.

4.4 Mitigation Ideas

Browder (1991) reviewed mitigative measures for NPS pollution control that may be useful in the Tampa Bay area. In Hudson Bayou and Phillippi Creek, potential mitigation projects may include:

- Creation of wetlands in association with stormwater facilities, or on the banks of Phillippi Creek where space is available for regrading of steep slopes.

- Capping of noxious sediments and filling of deep areas not used for navigation, to bring the bottom closer to the water surface, and light.

- Replacement of seawalls by rip rap or artificial reef material.

- Removal of instream salinity barriers.

- Installation of aerators in tidal basins.

- Removal of brazilian pepper, australian pine, punk trees (cajeput) and other exotic plant species that invade wetlands.

- Elimination of point source discharges to Phillippi Creek.

- Diversion of runoff from bridges and bridge approaches.

- Education of boat owners in tidal basins on proper use and disposal of petroleum products and boat paints.

- Education of stream-side property owners on proper use and disposal of household and landscape chemicals, yard wastes, and plantings.

The two latter ideas are not mitigation options per se but they do offer considerable promise for building a public constituency for stream restoration. The Sarasota Bay NEP has already produced and distributed a *Bay Repair Kit* and, with the help of county agencies, sponsors a gutter-painting program wherein citizen groups label storm drains with the message, "dumping here pollutes our bay". The NEP, state and local agencies, and the public are collaborating on a *Florida Bay Yard* program that promises to redefine community expectations and behavior regarding household and landscape maintenance.

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