CHAPTER ONE

On Knowing the State of the Bay

If we don't change direction we are apt to end up where we are headed.

–Old Chinese Proverb, appropriated for estuaries by J. R. Schubel

The information summarized in this volume was gathered for a single unifying purpose: to improve our management of the valued resources of Galveston Bay. Establishing this factual foundation for management relied on defining the status of key bay resources, identifying their trend over time, and determining probable causes for any trends emerging as concerns.

In three sections, this chapter addresses the significance of this process and the resulting findings. First, a brief overview is presented concerning the relationship between scientists and resource managers, whose fundamentally different world views influence the effectiveness of bay problem-solving. Second, some significant and unexpected findings regarding the **estuary** are described, prompting a re-definition of how we manage the bay. Finally, in the bulk of the chapter, seventeen key conclusions are stated in the form of management issues. These are the problems that need to be addressed in future comprehensive management of the estuary. In total, this chapter encapsulates the management implications of the information presented in this book.

BOUNDARIES TO GUIDE SCIENTISTS AND RESOURCE MANAGERS

To manage the important and varied resources in this bay system, managers agreed they needed the right kind of information. But how can the infinite scope of possible research projects be narrowed to those which are relevant and meaningful? As Tuohy (1993) has noted:

> *There is more potential information about the world (or even a large estuary) than our intellects can grasp, so much so that the universe for all practical purposes can be described as infinite... And if the mere number of phenomena and relationships at any given time were not enough, there is constant change, adding to the complexity of the universe we are trying to understand.*

Generally speaking, scientists are interested in all of the infinite information that can be gathered about an estuary, so long as it contributes to new knowledge. Managers, by contrast, expect concise answers to certain short-term questions that help solve bay problems. Clearly, some sort of agreed-upon guidance is necessary for these diverging views about information to be reconciled. Certain conceptual boundaries therefore, apply to scientific activity aimed at providing information to managers, summarized by Shipley (1991):

> Projects must address the right questions, requiring that managers have a role in identifying and ranking project topics;
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> Work must be undertaken in the context of a perturbed ecosystem, requiring that projects focus on impact dynamics rather than traditional ecology alone;
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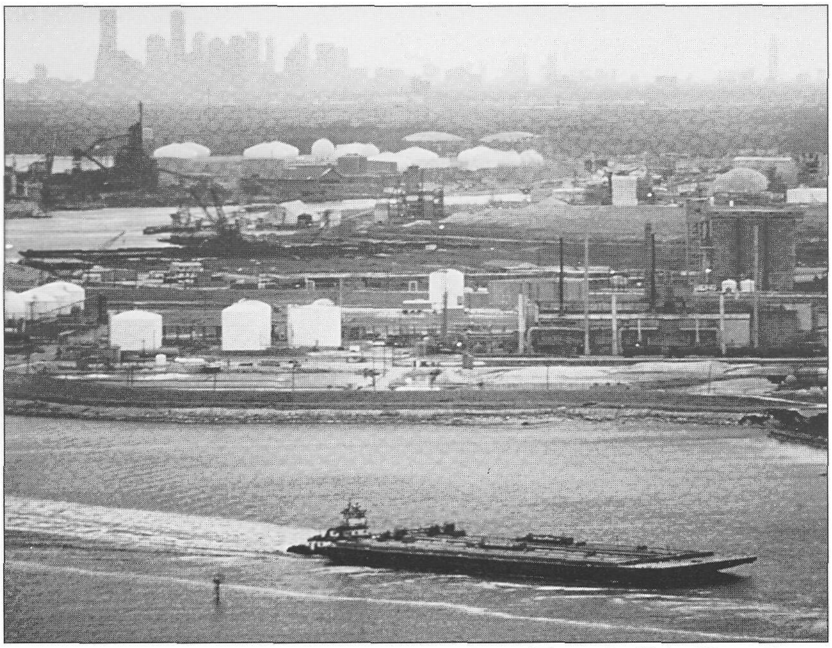
> Research must provide data at a scale of resolution

applicable to management, requiring generalized geographic ordering of projects and sampling within projects;

Results must be available to managers in an accessible, useful format, requiring that data be converted to synoptic information; and

Ongoing work must fulfill a sensory feedback function to managers, requiring a monitoring program with a direct link to management objectives.

Within these conceptual boundaries, a practical mechanism must then be agreed upon to tailor research to the particular ecosystem issues of concern. The first step for such a process was established by the National Estuary Program guidance itself, from lessons learned mainly in Chesapeake Bay. A *Priority Problems List* identifies and ranks estuarine management issues, serving as a focal point for consensus about where to begin. Generally, issues are advanced in this process if they have system-wide impact, impair designated uses, or (more practically) if they can be quickly or cheaply fixed. The key feature of the *Priority Problems List* is that it be adopted by the consensus of managers, scientists, and bay **stakeholders** represented on the Management Conference. In the event of disagreement, managers carry the day, in observance of the first conceptual boundary listed above.



Source: Galveston Bay National Estuary Program

Galveston Bay: how can we identify and solve its problems? Shown here is the upper Houston Ship Channel, surrounded by petrochemical industries (center), shipping activities (foreground) and the skyline of Houston (background).

For Galveston Bay, the preliminary *Priority Problems List* was drafted by scientists based upon joint expert opinion. The list was then adopted by consensus of the Management Committee, but not before concerns about estuarine living resources were elevated above public health issues, reversing their original order. Notwithstanding controversy engendered by managers second-guessing scientists, the list survived to guide the expenditure of more than two million dollars in research funding.

To managers, the best use of the *Priority Problems List* was to prevent distractions from scientists seeking to fund projects which (although they addressed issues intensely interesting to the proposers) did not help managers. To scientists, the list became a set of broadly-stated hypotheses to be strengthened or refuted.

Hypotheses must by falsifiable to be scientifically valid, and some of the most interesting work conducted during the research program resulted in the falsifying of some long-held conventional wisdom about Galveston Bay. This process led to a productive redefinition of estuarine problems, summarized in the bulk of this chapter. First, however, consider several of the most significant novel findings which shape future specific management efforts.

UNEXPECTED FINDINGS

Good science frequently yields unexpected truths which turn out to be more interesting than the speculations which naturally begin the scientific process. For Galveston Bay, our understanding of even the most fundamental estuarine processes is being reshaped. Summarized below are four issues at the heart of managers' needs to understand the estuary.

Salinity

Conventional wisdom suggests the bay is threatened by a harmful increase in **salinity** resulting from human diversion of river **inflow** and intrusions of Gulf sea water landward through dredged channels. However, Ward and Armstrong (1992) revealed a three-decade general *decline* in bay salinity totaling more than four parts per thousand (specific trends vary throughout the bay). Supporting evidence was provided by Solis and Longley (1993) who indicated no significant decreases in inflow for both the Trinity River (the principal source of fresh water) and for the **watershed** as a whole. In their findings, four of the most urbanized bayous showed *increasing* flow since the 1960s, perhaps related to increases in **impervious cover** (development) and increased **return flows** of wastewater, including **groundwater**. Low flows along the main stem of the Trinity and in some tributaries (e.g. during droughts) are today apparently several times greater than historically. Overall, salinity dynamics in Galveston Bay have proven more obscure, complex and intractable (even to hydrodynamic modelers) than we previously knew.

Nutrients

Sixty percent of the wastewater in Texas flows to Galveston Bay, and much of the upper watershed consists of cultivated and urban lands with high nutrient runoff potential. These observations engender a concern for nutrient over-enrichment, a concern en-

Source: Frank S. Shipley

Several species of herons have shown population declines in Galveston Bay. These egrets nest in colonies (below) and disperse each day to feed along shallow marshy shorelines (above). In the Galveston Bay system, some 30,000 ac of wetland habitats have been lost since the 1950s.

Source: Frank S. Shipley

couraged by well-documented **algae blooms** and dissolved oxygen depletion in the literature for east coast estuaries. However, Ward and Armstrong (1992) revealed a substantial general *decline* in the **loading** of nutrients to Galveston Bay, with localized exceptions. We now know that lakes Houston and Livingston serve as efficient nutrient traps which alter bay nutrient dynamics.

Improved wastewater treatment by cities and industries has established a trend of reduced point source loadings. A future **phytoplankton** population crash and the demise of some of Galveston Bay's oyster reefs within the next decade have even been suggested and vigorously debated. At the least, findings have shifted management interest away from bay-wide point source and river loadings to more specific urbanized tributaries where fish kills and dissolved oxygen problems suggest **nonpoint source** problems.

Wildlife, Fish and Shellfish

White et al., (1993) have reported a 17-19 percent loss in **emergent wetlands** since the 1950s. The leading single cause of **habitat** loss (greater than 26,000 ac) was conversion to open water/barren flats (e.g. from land **subsidence** due to groundwater withdrawal). Urban development unexpectedly accounted for less than ten percent of the **wetland** loss. In spite of the substantial habitat losses, the living resources trend studies of Green et al. (1992) revealed chronic declines for just two of fourteen **finfish** and shellfish species analyzed: blue crabs and white shrimp. Perhaps the most troubling findings concerned bird species which feed at the marsh-bay interface (tricolored herons, snowy egrets, black skimmers, roseate spoon bills, and great egrets). A decline for this **guild** of estuarine-dependent species could be the direct result of habitat losses, or the indirect result of declines in habitat-dependent species preyed upon by the birds. Overall, findings lend hope that habitat losses can be stemmed before major marine species crashes occur of the sort seen in Chesapeake Bay.

Toxicants

Toxic contamination has emerged as a complex and difficult issue for Galveston Bay. Brooks et al. (1992) indicated potentially elevated risk to individual recreational or subsistence seafood consumers, based on tests of seafood organisms from four locations not associated with known potential contaminant sources. Highest concentrations of **toxicants** generally occurred in the upper bay. These findings contrasted with commercially-taken seafood (generally from the lower bay, and eaten in smaller quantities) found to be within accepted risk levels. In a separate study, Carr (1993) reported on some sites more specifically associated with contamination. Half of these locations resulted in toxicity to developing sea urchin (*Arbacia punctulata*) embryos exposed to extracted **pore water** from bay-bottom sediments. In contrast, no sites were indicated toxic with parallel tests using a different standardized exposure of **amphipods** to bay sediments. Findings highlight the need for development of sediment standards, the improvement of analytical techniques, and (perhaps most importantly) improved **risk analysis** and communication of risks to the seafood-consuming public.

Source: Bureau of Economic Geology

Source: Bureau of Economic Geology

A major cause of wetland losses in the estuary has been land subsidence, primarily due to the removal of groundwater for human use. Healthy fringing salt marsh (left) is drowned by increasing water depth (right), leading to eventual losses of vegetation and conversion to open water. These wetlands are nursery areas for numerous commercial and recreational species.

A REVISION OF MANAGEMENT EXPECTATIONS

One conclusion, at least, is clear: expert opinion alone would have failed to serve managers well in solving bay problems. The thrust of the *Galveston Bay Plan* relies upon findings summarized in this volume, validating the role of scientists in the management process. Estuarine problems were re-cast in light of the new knowledge, resulting also in a subsequent re-ordering in their emphasis.

What are Galveston Bay's management needs? Seventeen issues have emerged from the bay characterization process as worthy of our attention over the next several decades. Characteristic of any ecosystem, these management concerns can never be completely separated from one another. For example, nonpoint sources of pollution contribute to both habitat degradation and toxic contamination of sediments; declining populations of certain estuarine and estuarine-dependent species could relate to both habitat loss and/or water quality problems. These interconnections suggest that actions to solve the bay's problems also be undertaken in the context of an integrated, ecosystem-level management program.

Seventeen Priorities

The following issues were distilled and ranked by the Galveston Bay National Estuary Program as it deliberated on both results of the technical work, and the historical and current management efforts of public agencies. These issues constitute the Galveston Bay *Priority Problems List.*

1. Vital Galveston Bay habitats including wetlands have been lost or reduced in value by a range of human activities, threatening the bay's future sustained productivity (Chapter Seven).

Wetland losses in the entire estuarine system were described by White et al. (1993). From the 1950s to 1989, there was a net 17 to 19 percent loss of vegetated wetlands totaling some 32,400 ac. Encouragingly, the rate of loss has decreased over time from about 1,000 ac per year between 1953 and 1979, to about 700 ac per year between 1979 and 1989. The leading causes of wetland loss were conversion to open water or mud flats (principally a result of subsidence from groundwater withdrawal and conversion to upland range (in which intentional draining of wetlands played a major role). Wetland conversion of some 25,000 ac to upland range dominated the conversion to other kinds of upland land uses consisting of urban, oil and gas, agricultural, and dredge disposal land uses totaling 11,000 ac.

In comparison to wetlands, a far greater proportion of the bay's historical submerged aquatic vegetation beds (primarily **seagrasses**) have been lost. Seventy to 86 percent of this significant habitat type has been lost since the 1950s, due to a complex and interactive group of causes which includes subsidence, Hurricane Carla, shoreline development, wastewater discharges, chemical spills, boat traffic, and dredging (Pulich and White, 1991).

Taken together, these declines in biologically productive habitat directly threaten future seafood productivity and the capacity for Galveston Bay to function as a healthy ecosystem. Major species declines noted in other bay systems with more advanced problems have not yet occurred in this estuary, making management intervention all the more feasible.

2. Contaminated runoff from nonpoint sources degrades the water and sediments of some bay tributaries and near-shore areas (Chapter Six).

For many pollutants of concern, loadings to Galveston Bay are dominated by nonpoint sources of pollutants, transported by runoff from the surface of the land to the bay and its tributaries (Newell et al., 1992a). For example, nonpoint loading to the estuary for many pollutants exceeds the combined total loading from all other sources: the San Jacinto and Trinity Rivers, municipal discharges from treatment plants, and industrial sources. This is true for **total suspended solids** (particularly sediment), oxygen-demanding pollutants, **fecal coliform bacteria**, total phosphorus, and oil and grease. For example, oil and grease washing into the bay in an average one-year period is approximately equivalent to 40 percent of the historic *Exxon Valdez* spill.

The geographic sources of these pollutants within the watershed were reported in an atlas of high-resolution maps (Newell et al., 1992b) which clearly associates the most severe nonpoint source problems with urban/industrial land uses. For example, some 90 percent of the oil and grease loading originates in sub-watersheds with high-density urban land uses. Within sub-watersheds, the origins of pollutants are transportation activity, **atmospheric deposition** of air pollutants, residential yards and households, purposeful and inadvertent dumping on land and to storm drains, and a host of other diffuse human sources.

The impact on the bay from all these sources, while clearly present, is incompletely defined. Runoff mingles with wastewater from point sources and river flow to produce water quality problems to which individual causes cannot easily be ascribed. We know, however, that nonpoint sources have become our greatest water quality challenge. The imposing analysis by Ward and Armstrong (1992) of 26 Galveston Bay data sets indicates the influx of conventional pollutants from both point sources and river flow (summarized in Chapter Six) peaked in the 1960s and has declined since. In contrast, all indications are that nonpoint sources of pollutants have steadily increased to the present day. Principal effects of the nonpoint source pollutants include:

- Low levels of dissolved oxygen in urban bayous and other poorly flushed tributaries;
- Possible toxic contamination of sediment and living tissue from metals or trace organics like **Polycyclic Aromatic Hydrocarbons (PAHs)** washed off streets with runoff (PAHs are a family of toxic compounds from petroleum and its combustion in engines and industrial processes); and
- Closure of half of the bay to oyster harvest, due to elevated bacteria levels.

The upper Houston Ship Channel remains the most significant region of concern, due in large part to runoff from the greater Houston area.

The diffuse sources of these pollutants, the need for widespread social and cultural changes by residents of the watershed, and the intractability and cost of retrofitting urban stormwater infrastructures pose a challenge. But on the positive side, national legislative mandates for stormwater cleanup under the National Pollution Discharge Elimination System (NPDES) and special mandates for coastal zones will contribute much of the momentum and some of the dollars necessary to address the issue.

3. Raw or partially treated sewage and industrial waste enters Galveston Bay due to design and operational problems, especially during rainfall runoff (Chapter Six).

As cities in the Galveston Bay watershed have grown, their aging sewage collection systems have suffered from soil settlement, corrosion, and larger-than-design flows. As a result, leaks allow entry of stormwater during wet periods, exceeding the capacity of lines, lift stations, and treatment plants. The ultimate result is sewage bypasses to the bay's tributary waters. Conversely, sewage can also leak out of broken lines and flow to groundwater or the storm sewer system (Jensen et al., 1991).

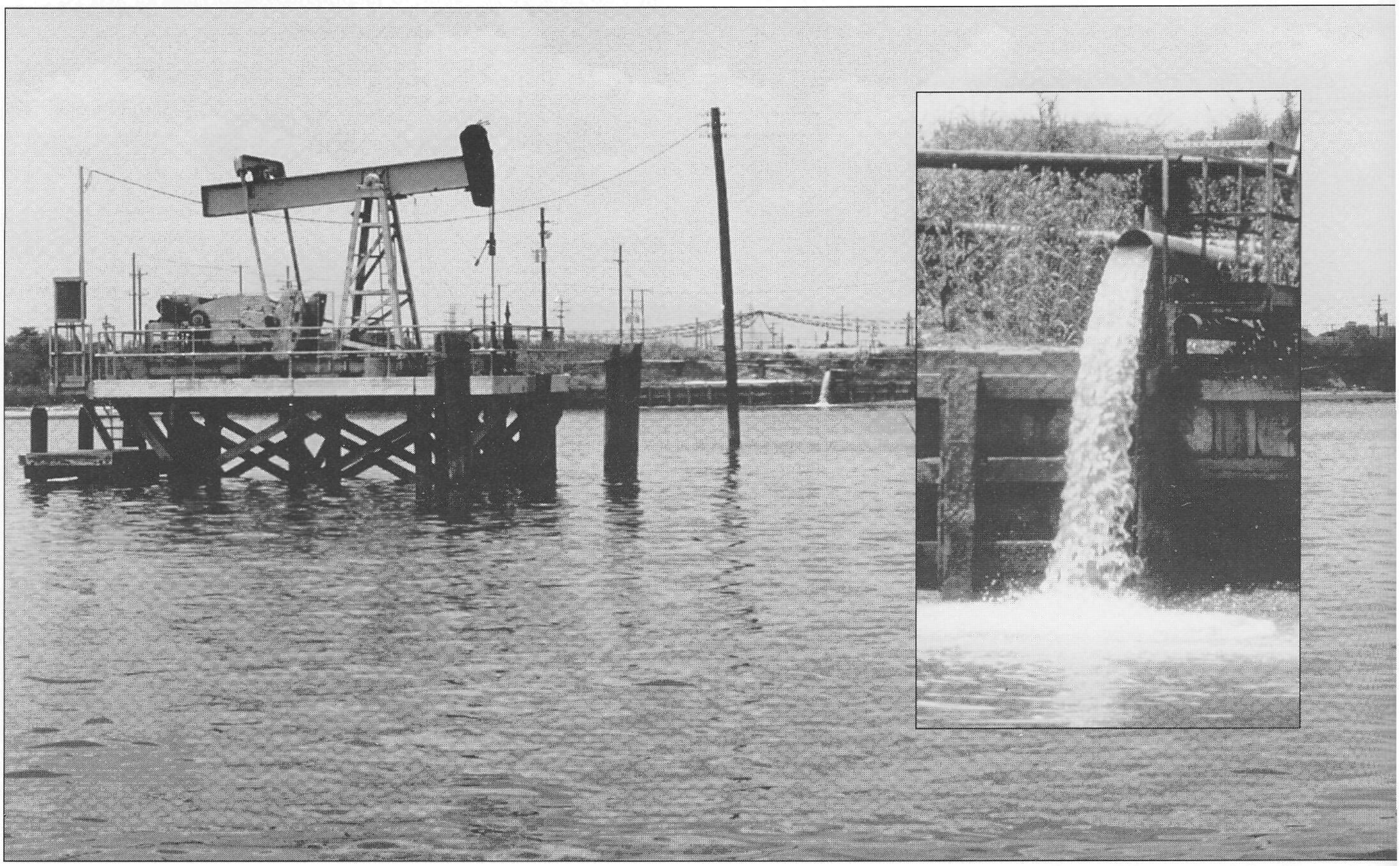
One study (Winslow and Associates, 1986) indicated that the total loading of Biochemical Oxygen Demand (BOD) from bypasses and overflows to the Houston Ship Channel was 3.1 million kilograms per year (equivalent to an average value of 18,900 pounds per day) or about 11 percent of the annual BOD load to the Houston Ship Channel from all sources. In response to an Environmental Protection Agency initiative, the City of Houston undertook a major construction project to improve and expand the city's underground wastewater collection system. A series of deep tunnels are being constructed to eliminate bypasses and overflows for all but the largest rainfall events (greater than two to five year frequency storms).

More recent information (Guillen et al., 1994) provided a total of 789 and 578 reported instances of sewage bypasses in the Galveston Bay watershed during 1991 and 1992 respectively. An estimated 237.3 and 451.0 million gallons of partially treated sewage were discharged from these bypasses during 1991 and 1992 respectively. The majority (85 to 93 percent) of these occurred in the immediate Galveston Bay Watershed.

This issue involves more than the City of Houston. Surrounding Houston, but still in the Galveston Bay watershed, are numerous small independent utility districts. These small operations are not subject to state and federal regulatory requirements as stringent as larger metro treatment works, and individually, the districts cannot afford the same level of operation and maintenance attention. Collectively their discharges have substantial effects on several urban bayous which are dominated by wastewater during dry periods.

ary, and many species of fish, wildlife, aquatic plants, and shellfish depend on adequate fresh water inflows for survival. The continued high productivity of Galveston Bay is due to a great degree on the maintenance of adequate, high-quality fresh water inflow.

The increased demands for fresh water by a growing population along with the construction of surface impoundments and diversions are widely perceived as having reduced fresh water inflow to the bay over time. (Of course, natural variability in rainfall explains far more of the variability in inflow to Galveston Bay than does human activity.) However, an analysis of fresh water inflow trends for the period from 1968 to 1987 did not identify statistically significant trends which would indicate a reduction of fresh water inflow volume from the Trinity River, or within the estuary as a whole. Four of the most urbanized streams which discharge into the bay (White Oak Bayou, Brays Bayou, Sims Bayou, and Greens Bayou) all exhibit increasing flow since the 1960s (one to three percent per year on average), likely due to increases in impervious cover (such as parking lots, buildings, and roads) and increased return flows of wastewater.



Source: Galveston Bay National Estuary Program

Toxic contamination of sediments and the bottom-dwelling biological community results from discharges of "produced water," a by-product of oil and gas production. Here, wells in the Goose Creek oil field collect produced water for ultimate discharge at a shoreline outfall (background and inset).

4. Future demands for fresh water and alterations to circulation may seriously affect productivity and overall ecosystem health (Chapter Five).

The biological communities living in and around Galveston Bay are largely defined by the volume, timing, and quality of fresh water inflows into the bay from surrounding drainage basins. Fresh water inflows affect **circulation** and water quality within the estu-

On a seasonal basis, fresh water inflow to the estuary is normally characterized by peak springtime inflows in May followed by minimum inflows in August. Comparison of monthly mean flows before dam construction (1941-1969) and after dam construction (1972-1987) indicates that peak flows have been cropped and low flows have been increased, and that the timing of peak flows have been delayed slightly. Increasing return flows to the Trinity River and other watersheds have elevated **base flow** during critical low-flow periods. These return flows, in conjunction with inter-basin transfers of water, will likely continue to significantly dampen seasonal flow variations in the future.

5. Certain toxic substances have contaminated water and sediment and may have a negative effect on aquatic life in contaminated areas (Chapter Six).

Human activity in the bay's watershed produces a complicated array of toxic compounds, many of which are routinely discharged, spilled, or washed into the estuary in a water solution or suspension. Once in the bay, toxicants can remain in the water, or (more commonly) are incorporated in bottom sediments. Water and sediment-dwelling species can accumulate toxic compounds, affecting the composition and health of living estuarine communities. Toxicants can cycle back and fourth among the water, sediment, and tissues of living organisms. These patterns are shaped by hundreds of influences: which chemical compounds are involved; bay water chemistry; sediment grain size; and overall patterns of water circulation and movements of life forms. Measurement technologies, which are complex and expensive, impose another layer of uncertainty on our state of understanding. In addition some water quality limits are set below analytical detection limits, further complicating the issues.

In *water*, Ward and Armstrong (1992) described elevated levels of oil and grease, metals, and trace organics in regions of waste discharge and runoff, with generally the highest values in the upper Houston Ship Channel. Encouragingly, most of the metals are declining in areas of maximal concentrations, possibly because suspended solids (to which metals bind) have shown a decline. Typically, levels of toxic contaminants in open bay waters are below detection limits.

In *sediments*, Ward and Armstrong also showed elevated contaminant concentrations in regions of runoff, inflow, and waste discharges. Carr (1993) measured elevated concentrations of PAHs of a composition that suggested both long-term chronic and short-term acute sources (depending upon sampling location). PCBs (Polychlorinated Biphenyls, once common in transformer and hydraulic oil) were detected at several stations.

In *tissue*, various studies have measured contaminants in a variety of species. Oysters, for example, are employed as a **sentinel species** (a biomonitor for contamination) in the National Oceanic and Atmospheric Administration's National Status and Trends "Mussel Watch" program. In reports by Wade et al. (1991), PAHs were measured in a form suggesting contamination by combustion products. Concentrations of contaminants in oysters from the upper estuary were generally above Gulf of Mexico averages. Sericano et al. (1991) transplanted oysters from an open bay reef to the Houston Ship Channel (above Morgans Point) and demonstrated dramatic concentration increases over a period of seven weeks for most organic compounds measured (including toxic PAHs and PCBs).

Ultimately, toxic contaminants have effects on both the bottom-dwelling bay **community** (Carr, 1993; Roach et al., 1993a, 1993b), on estuarine-dependent species like **colonial-nesting** birds (Rice and Custer, 1991), and upon the risk associated with human consumption of seafood (Brooks et al., 1992; see problem nine, below and Chapter Nine). Conditions appear to be improving, but problems remain near urban areas, points of surface runoff, waste discharges, and shipping facilities.

6. Certain species of marine organisms and birds have shown a declining population trend (Chapter Eight).

The total human harvest of animals that depend on Galveston Bay has increased by 2000 percent during the last century (Green et al., 1992). Intensive harvest of seafood, combined with habitat losses and contamination of the ecosystem, have resulted in widespread concern over possible species reductions. Population crashes have already occurred in other bay systems subject to similar human influences (for example oysters and striped bass in Chesapeake Bay).

The Galveston Bay National Estuary Program study led by Green et al. (1992, summarized in Chapter Eight) confirmed that a well-balanced number of species still remain in all **trophic levels**, indicating a generally healthy estuarine community. Resource managers have surmised that (at least for water quality) the estuary reached its "low point" in the 1960s, and therefore analysis of recent data would reveal either no trends or increasing populations. However, apparent declines in several species provide continuing reasons for concern.

Of the fourteen different marine species that were analyzed, blue crab and white shrimp showed distinct chronic problems since the early 1980s (white shrimp are apparently rebounding). For each of these species, the decline included older age classes (first-time spawners), implicating over-harvest as a possible cause. For white shrimp, juveniles also declined, indicating habitat loss or pollution could also be involved. Several much longer-term changes are evident in old commercial fishery records. The commercial striped bass fishery apparently collapsed in the early 1900s, and the disappearance of the green turtle and diamondback terrapin fisheries almost a century ago also indicate declines of a longer-term nature. Review of old maps of the Texas coast archived in the Texas General Land Office (Quast et al., 1988) indicated an extensive loss of **intertidal** oyster reefs along the bay's shoreline. In spite of these declines, it is surprising to find most species have done so well. The data testify to the resilience of estuarine species, which evolved to withstand drastic natural variability in their environment.

Estuarine-dependent species analyzed included shorebirds, waders, waterfowl, and the American alligator. A decreasing population trend was noted for snowy egrets, black skimmers, tricolored

Source: United States Fish and Wildlife Service

Rosaeate spoonbills are among the valued species which depend upon Galveston Bay. The flattened bill, unique among all North American species, is specialized to capture minute marine life.

herons, and roseate spoonbills. These are colonial nesting species which generally feed on shoreline marsh edges. It is currently unknown whether habitat (and therefore prey) reductions have caused this decline, or changing nesting conditions combined with bird movements. Other kinds of estuarine-dependent species showed variable results: 1) populations of American alligators and six shorebird species appear to be stable or increasing: 2) mottled ducks, northern pintails, and blue-winged teal are apparently declining; and 3) olivaceous cormorants, in contrast to other colonial-nesting waterbirds, appear to be increasing. The bird data were particularly difficult to interpret, due to the variety, limitations, and conflicting results from available surveys.

7. Shoreline management practices frequently do not address negative environmental consequences to the bay, or the need for environmentally compatible public access to bay resources (Chapter Five).

While **bulkheading**, docks, and revetments usually generate low volumes of dredge and fill material compared to channel construction, the environmental impact may be larger than the actual physical modifications would suggest. As estimated by Ward (1993), about 70 miles of the bay shoreline has been either bulkheaded or converted to docks or revetments. By one estimate, this corresponds to ten percent of the entire bay shoreline. Continued development of the shoreline contributes to shore erosion, loss of wetlands, increased point and nonpoint source pollution, and reduced public access to beaches and the shore.

8. Bay habitats and living resources are impacted by spills of toxic and hazardous materials during storage, handling, and transport (Chapter Six).

Accidental spills or deliberate dumping affect both aesthetic and ecological aspects of Galveston Bay. Intensive petrochemical and refining industries, shipping operations, and the highly urbanized local watershed puts the bay at risk from these major sources of pollution. Clearly the most effective means to deal with spills and dumping is to prevent them. Secondarily, when these incidents inevitably occur, improved cleanup becomes important. Much progress has been made toward these goals as a result of federal and state legislation since the landmark *Exxon Valdez* spill.

Several factors must be considered to evaluate the effect of spills on the bay. In general, the more material released, the greater the repercussions on natural resources. However, even a small amount of a very toxic or concentrated substance has the capacity to affect large volumes of water. Most spills that occur in the Galveston Bay area on a regular basis are relatively small and involve constituents which degrade.

Although spills of all sizes cannot always be prevented, compensation for environmental damages can be provided by the responsible party. The award of compensation for damaged natural resources, however, has not been an effective process in Galveston Bay. Of the numerous spills, fewer than five have proceeded through the damage assessment process to final payment.

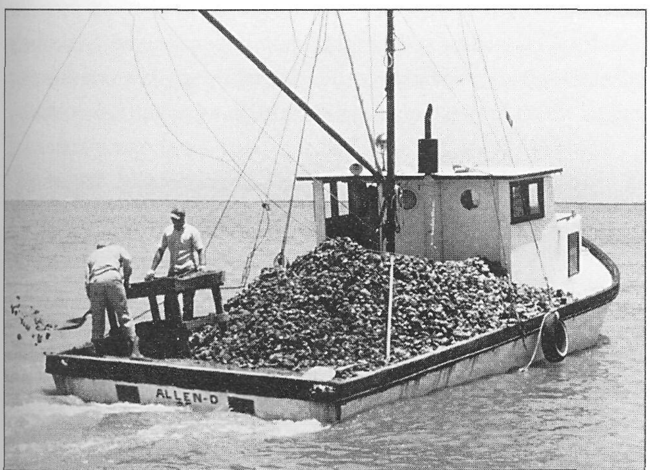
9. Seafood from some areas in Galveston Bay may pose a public health risk to subsistence or recreational catch seafood consumers as a result of the potential presence of toxic chemicals (Chapter Nine).

The contaminants known to occur in the tissue of estuarine organisms from Galveston Bay are most prevalent in the upper Houston Ship Channel, where, for example, a dioxin advisory has been issued to restrict harvest for human consumption. A Galveston Bay National Estuary Program study by Brooks et al. (1992) involved analysis of contaminants (including heavy metals, hydrocarbons, pesticides, and PCBs) in five species of seafood organisms (oyster, blue crab, spotted seatrout, black drum and southern flounder) from four widely separated sites in Galveston

Bay. Collection sites included Morgans Point, Eagle Point, Carancahua Reef in West Bay, and Hanna Reef in East Bay.

The study determined that oysters were generally the most contaminated species, fish were intermediate, and crabs were the least. Although results varied among compounds and organisms, higher contaminant levels were generally confirmed at Morgans Point, near the Houston Ship Channel, and decreased down-bay. Compounds of concern included PAHs and PCBs. Specific concentrations of these contaminants provided few surprises; they fell within the expected range based on previous studies.

What do these findings imply about seafood safety? In general, risk is expressed as the probability for a 154-pound human to contract cancer as a result of eating the assumed amount of seafood (about one pound per month) over a 70-year lifetime. Based on the contaminant values from Galveston Bay, most average consumers would experience a risk roughly similar to that of eating other commonly consumed foods not associated with the estuary. However, risk levels for recreational or subsistence fishermen (resulting primarily from PCBs and PAHs) who eat large quantities of seafood (about ten pounds per month) would exceed the Environmental Protection Agency benchmark risk level at all sites examined in the study. Most people believe that seafood from Galveston Bay is routinely monitored for toxic contamination, or they are not sure



Source: Texas Parks and Wildlife Department

Loaded to the brim with oysters. About half the bay is closed to the taking of shellfish due to risk of disease to consumers. Oysters taken from the open areas provide high quality seafood that is marketed throughout the nation.

(Philips, 1993). In fact, fish and shellfish from Galveston Bay are not routinely sampled for toxic contaminants, nor are consumer risks routinely assessed and communicated to the public, nor are fishermen prohibited from fishing contaminated areas.

10. Illegal connections to storm sewers introduce untreated wastes directly into bay tributaries (Chapter Six).

Despite improvements to point sources and reductions in bypass/overflows discharged into Buffalo Bayou, overall water quality in that urban tributary of Galveston Bay remains poor. To determine the reason for this unexpected result, the City of Houston conducted a special survey of illicit discharges of sewage to the storm drainage system for Buffalo Bayou. This survey found several accidental and intentional connections of sanitary sewage lines to the storm sewers that were responsible for elevated concentrations of fecal coliform bacteria in Buffalo Bayou. By eliminating these discharges, there was a marked improvement in dry-weather water quality in the bayou.

There is no reason to believe that illegal connections are confined to Buffalo Bayou, and therefore most of the urbanized streams in the Galveston Bay area are probably subjected to water quality degradation from these sources. Illegal connections are indicated when water remains degraded between runoff incidents. Additional work is required to determine the severity of this problem in other parts of the bay.

11. Dissolved oxygen is reduced in certain tributaries and side bays, harming marine life (Chapter Six).

Dissolved oxygen (DO) is generally high throughout the bay, averaging near saturation through large areas of open water. Exceptions to this are in poorly flushed tributaries subjected to runoff inflow and waste discharges. A remaining problem area is the upper Houston Ship Channel, which has improved from essentially zero dissolved oxygen twenty-five years ago, to levels that support an improving living community of fish and other organisms. In the upper Houston Ship Channel, oxygen remains most depleted in bottom waters.

Ward and Armstrong (1992) have provided the most complete description of water quality status and trends characterizing dissolved oxygen conditions in Galveston Bay. In the Houston Ship Channel above Morgans Point, deficits in dissolved oxygen (the increment below saturation level) range to seven parts per million. The concentration has been improving over the last two decades at about 0.1 mg/L/yr in the worst areas near the turning basin, and at a higher rate downstream nearer the open bay. Oxygen-demanding pollutants (BOD) remain highest in the upper Houston Ship Channel, but are declining commensurate with the improvement noted in DO levels.

The bay's western, urbanized tributaries (e.g. Clear Lake, Buffalo Bayou) also remain problem areas. These waters receive the bulk of the bay's nonpoint source pollutants in runoff, and have the greatest frequency of fish kills related to oxygen depletion–particularly in areas with poor circulation. The **DO deficit** near the outlet of Clear Lake is increasing, in contrast to the improving trend in much of the estuary. On a smaller scale, marinas, particularly in Clear Lake, have clear localized problems associated with boat sewage and other wastes (see Problem 13).

12. About half of the bay is permanently or provisionally closed to the taking of shellfish because of

high fecal coliform bacterial levels that may indicate risk to shellfish consumers (Chapter Nine).

Approximately 300 sq mi (200,000 ac) of Galveston Bay are subject to some form of shellfish harvest restriction and are deemed by the Texas Department of Health to pose a risk of disease to shellfish consumers. The risk of disease is not determined directly, but is addressed by measuring concentrations of fecal coliform bacteria as an indicator organism. These bacteria indicate the contamination of waters by wastes from birds or mammals (including humans) that could also contain much more dangerous **pathogens**, for example those causing typhoid fever.

Oysters, which filter bacteria from the water as they feed, are by far the most important species involved in Galveston Bay shellfish regulation. Based on measurements of fecal coliform bacteria in water and oysters, and by establishing relationships between rainfall runoff and elevated fecal coliforms, closure maps are produced by the Texas Department of Health and utilized by commercial fishermen and the public to determine where oyster harvest can legally occur.

Wet weather runoff is the most significant source of bacteria (Jensen et al., 1991), but no single land use dominates the contribution of bacteria to the bay. Furthermore, no trends in fecal coliforms levels since 1950 can be tied to human development of the watershed (Jensen, 1992), although some human activities like leaking septic systems and illicit sewage connections to storm sewers clearly affect localized receiving waters. While extensive areas violate the bacteria standard for legal oyster harvesting, near-shore areas and tributaries frequently have levels much higher than the standard. This has contributed to the lack of any substantial changes in closures over time.

In spite of difficulties in defining the specific sources of the problem, the closure of substantial oyster reefs to the commercial market represents a large loss to the local economy, and oysters taken from closed areas (intentionally or unintentionally) remain a public health concern. Therefore, actions that could result in opening of some currently restricted and conditionally approved reefs would be of great benefit. These actions could take the form of:

Increased frequency of measurement. Many restricted or conditionally approved reefs do not necessarily have high long-term indicator levels. In some cases, restriction results from either a small portion of the data exceeding higher values after rains, or a judgment made about the potential for upland facilities to introduce pathogens (Jensen et al., 1991).

Improved indicator measures. Although the fecal coliform approach has a long and successful history of preventing disease, its success results in part from conservative restrictions that are more extensive than true measures of the actual pathogens would dictate if they could be measured. Indicators that more accurately parallel pathogen risk have long been sought and are currently being researched under the "National Indicator Study," a multi-million dollar cooperative research program.

Source reductions. Source reduction actions could be tailored to target specific bacterial sources–for example, failing shoreline septic systems or wet weather bypasses and overflows of sewage collection systems (see Problem Three). This solution is limited by the possibility that natural sources of bacteria are a substantial source of the problem.

13. Water and sediments are degraded in and around marinas from boat sewage and introduction of dockside wastes from nonpoint sources (Chapter Six).

Marinas, particularly in Clear Lake, pose significant localized water quality problems. Raw or partially treated sewage has traditionally been discharged directly from boats to estuarine waters, due to lack of pump-out facilities and lax enforcement. Boat maintenance activities result in wastes which wash into the bay with runoff, and deliberate dumping of debris like batteries has been common. These activities result in high bacterial levels, low dissolved oxygen, and toxic contamination of water and particularly sediment–all of which are exacerbated by marina construction designs which limit circulation in boat slip and maintenance areas.

Guillen et al. (1993) described conditions at four marinas and one canal subdivision, all in the western portions of the estuary. Fecal coliform bacteria increased in concentration toward the inner part of each marina, and violations of the state water quality standard were common in "dead ends" and other areas with limited circulation. Dumping of untreated human waste–which contains approximately one million fecal coliform bacteria per gram-represents an aspect of the problem which is both well-defined and correctable.

Dissolved oxygen levels were depressed within the marinas studied by Guillen et al. (1993). Potential causes included the nutrients contained in dumped sewage, the oxygen demanding materials in both sewage and runoff from maintenance areas, parking lots, and other adjacent shoreline areas, and the lack of circulation. The more open the marina design (e.g. bulkheads that do not extend to the bottom), the less severe was the problem.

A definite trend of increasing copper, lead, and arsenic in sediments toward the inner portions of marinas was also present. The trend suggests a chronic source–for example, leaching from treated boat hulls, battery leakage, and use of toxic maintenance products.

14. Some bay shorelines are subject to high rates of erosion and loss of stabilizing vegetation due to past subsidence/sea level rise and current human impacts (Chapter Five).

Sixty-one percent of Galveston Bay's 232 miles of shoreline is composed of highly productive fringing wetlands. This shoreline is eroding at an average annual rate of 2.4 feet (Paine and Morton, 1991). The erosion is exacerbated by hurricanes, global sea level rise of some three to five cm/year, and most importantly, historical land subsidence of up to ten feet elevation. These factors have combined to cause major losses of estuarine wetlands (White et al., 1993).

The erosion problem has significant elements related to human activity which could be subject to management. Wave energy and subsequent shoreline erosion have been increased as larger ships in greater numbers use deeper channels. Subsidence has been caused by both groundwater and petroleum withdrawal for human use. Structures like **riprap** and bulkheads have slowed erosion locally. Reductions in riverine sediments resulting from reservoir construction slow expansion of the Trinity delta (the only area of extensive shoreline **progradation** in the last century).

Some human activities that contribute to erosion are already being addressed. For example, the Harris-Galveston Coastal Subsidence District was created in 1975 to regulate groundwater withdrawal. Their periodically updated *District Plan* has reported that subsidence of Galveston Bay's shoreline has slowed to near zero. Other elements remain to be addressed with future management actions. For example, smooth **cordgrass** plantings have been accomplished by the Galveston Bay National Estuary Program on a demonstration scale to re-establish fringing wetlands. These erosion management activities could be expanded to an estimated 40 percent of the bay's shoreline (Seidensticker, 1993).

15. Illegal dumping and water-borne and shoreline debris degrade water quality and aesthetics of Galveston Bay (Chapter Six).

Estuarine debris represents a serious aesthetic concern in Galveston Bay, particularly to citizens who live along the shoreline or who use the bay for recreational activities such as fishing or sailing. Floating debris–particularly plastic–can also harm wildlife, entangle propellers and clog the intakes of marine engines and industrial facilities.

Plastic products are a major component of debris in Galveston Bay. In a Galveston Bay National Estuary Program study conducted by citizen volunteers and the Texas Parks and Wildlife Department, Morgan and Lee (1993) reported plastic products to compose over 50 percent of the items collected overall, at 37 shoreline stations, in 88 near-shore bay seine samples, and 104 open-bay trawl samples. Debris was most concentrated along the shoreline itself, where it tends to accumulate with the actions of winds, currents, and waves.

A large source of floatable debris in the estuary is stormwater. In samples of the Houston Ship Channel, Radde et al. (1991) indicated most items to be stormwater-related, rather than sewage-related. Items included plastic pellets, bags, cups, fast food containers, toys, bottles, jugs, and general street litter. In comparison to other U.S. harbors, their study showed the Houston Ship Channel to have the highest incidence of plastic pellets, a debris type known to be ingested by more than 60 species of birds.

16. Some tributaries and near-shore areas of Galveston Bay are not safe for contact recreational activities such as swimming, wade-fishing, and sailboarding due to risk of infection (Chapter Nine).

The current Texas water quality criterion for **contact recreation** is 200 fecal coliform bacteria colonies per 100 mL of water. All open bay areas of the estuarine system are generally in conformance with this standard. Fecal coliform concentrations within western bay tributaries declined dramatically during the 1970s and 1980s, reflecting the influence of improved wastewater treatment. However, fecal coliform levels above the standard have recently been reported from three tidal tributaries on the west side of the bay: Buffalo Bayou Tidal, Clear Creek Tidal, and Dickinson Bayou Tidal. Additional contact recreation violations have also been observed in many urbanized fresh water segments as well.

Potential risks from pathogens associated with contact recreation in the bay system are considered to be relatively low. Variation in recreational water quality due to rainfall and changes in circulation patterns make real-time information concerning water quality virtually impossible to attain. Currently, no routine sampling is conducted within the estuary to monitor fecal coliform or toxicant concentrations in contact recreation areas, nor are contact recreation warnings or advisories routinely issued.

17. Some exotic/opportunistic species (e.g. nutria and grass carp) threaten desirable native species, habitats, and ecological relationships (Chapter Eight).

In many locations worldwide, the introduction of **exotic species** has had a dramatic impact on the ecology of estuarine systems. For example, within San Francisco Bay, the unintentional introduction of the Asian marine clam *Potamocorbula amurensis* has resulted in a ten-fold reduction in the phytoplankton levels within a two year period and has caused a potentially catastrophic disturbance of the estuarine **food web**. The development of faster cargo ships and increased worldwide trade has heightened the potential for such unintentional introductions of harmful species.

Within the Galveston Bay Estuary, the introduction and proliferation of exotic **opportunistic species** has also contributed to the degradation of some portions of the estuarine habitat. Significant populations of nutria, a large beaver-like rodent which strips vegetation within fresh water and brackish water marshland, and grass carp, which consumes aquatic vegetation, have been reported in the Trinity River and San Jacinto River portions of the estuary. The encroachment of fire ants into the estuarine ecosystem may pose an increasing threat to nesting bird populations.

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