V. PERTURBATIONS AND THEIR MANAGEMENT

Burton (1991) has defined **disturbance** as a discrete event that alters community structure and changes the physical environment and resource availability. A **perturbation** is a disturbance of equilibrium (Webster's Ninth New Collegiate Dictionary). Although equilibrium would appear to be a state which an estuary seldom attains, perturbation is a useful term which implies a greater intensity or effect than a disturbance.

Ward and others (1982) defined perturbation as "any activity that represents a departure from the normal state and can potentially result in effects upon the fish and wildlife resources of [Galveston Bay], either directly upon the organisms involved, or indirectly through alterations in the bay environment." They note that a key element of the definition of "perturbation" is what is regarded as the "normal" state. Dependent upon the temporal scale invoked, climatic extremes, such as floods, hurricanes and droughts, can be regarded as variations in the "normal" state rather than perturbations, although such events are certainly disruptive of the ecosystem.

The Galveston Bay National Estuary Program (GBNEP) has devoted considerable attention to perturbations. Shipley (1991) introduced the Galveston Bay ecosystem impact matrix which related 15 sources of perturbation to 17 valued ecosystem components. The ecosystem impact matrix has been modified to produce a perturbation of estuarine habitats matrix (Figure 21).

Listing the sources of perturbations does not identify the specific perturbations associated with each source. It is easy to confuse cause and effect when dealing with perturbations. For example, shoreline erosion leads to a loss of habitat, and some parts of the Galveston Bay shoreline are experiencing severe erosion. But shoreline erosion itself is an effect, rather than a cause. Wind, wave action, and water level are more likely to be the causes of shoreline erosion. Table 5 lists the physical, chemical and biological perturbations that are likely to disturb ecosystem habitats.

The GBNEP Scientific/Technical Advisory Committee attempted to define interactions between perturbations and ecosystem components. The ecosystem impact matrix was expanded by assigning specific perturbations to each source of perturbation category (Table 6). GBNEP S/TAC members were asked to address each matrix cell about which they were knowledgeable by assigning three scores (ranked 1 to 4) to each cell: (1) the influence of the perturbation on the component (slight, moderate, significant, major); (2) the scientific confidence which could be placed in the influence ranking (low, moderate, high, beyond doubt); and (3) the manageability of the perturbation (none, low, moderate, high). The objectives of the exercise were to identify the significant perturbations, evaluate the reliability of the assessment, and distinguish between perturbations which were manageable and those which were not.

Consensus on the significance of the perturbations was not achieved. There were large differences of opinion on all three rankings for most perturbation

PERTURBATION OF ESTUARINE HABITATS

SOURCE	OPEN-BAY WATER	OPEN-BAY BOTTOM	OYSTER REEF	SEAGRASS MEADOW	MARSH	MARSH EMBAY-MENT	MUDFLAT
FW INFLOW MODIFICATION	■	■	■		■		
SUBSIDENCE			■	■	■	■	■
SHORELINE DEVELOPMENT			■	■	■	■	■
DREDGE & FILL		■	■	■	■		■
POINT SOURCE	■			■			
NONPOINT SOURCE	■			■			
COMMERCIAL FISHING		■	■				
RECREATIONAL FISHING				■			
BOATING & MARINAS		■		■			
PETROLEUM ACTIVITY		■					
OIL/CHEMICAL SPILLS	■				■		■
CIRCULATION		■	■				
SHORELINE EROSION					■		
EXOTIC SPECIES					■		
STORMS & HURRICANES				■			

Figure 21. Perturbation of estuarine habitats.

categories. Although information of this nature is potentially the most valuable product of this modeling exercise, it is clear that the scientific and technical community have disparate views regarding the identification and management of perturbations to the ecosystem.

Table 5. Physical, chemical and biological perturbations affecting the estuarine environment.

PHYSICAL PERTURBATIONS	CHEMICAL PERTURBATIONS
Dissolved Oxygen	Contaminants
Dissolved Solids	Nutrients
Drainage Pattern	Organics
Inflow Quantity	Salinity
Marine Debris	Toxicants
Nutrient Transport	
pH	BIOLOGICAL PERTURBATIONS
Point of Inflow	Community Structure
Radioactivity	Entrainment
Runoff Speed	Exotic Biota
Runoff Volume	Fouling
Sediment Transport	Habitat Placement
Suspended Sediment	Habitat Structure
Suspended Solids	Impingement
Temperature	Microorganisms
Toxicant Transport	Population Density
Water Depth	Population Structure
Water Clarity	
Water Level	
Wave Action	

Cause and effect can be detailed for each source of perturbation. Figure 22 demonstrates the pathways associated with one source of perturbation - shoreline development. Each type of development produces one or more requirements or actions. For example, an industrial development may require cooling water or a point source discharge of treated or untreated effluent, a navigation channel for ship or barge access, modification of surface water or runoff patterns, the conversion of wetlands, or the construction of bulkheads. These actions result in a number of additional perturbations, or causes, that result in predictable environmental effects. Some of these "effects" in turn become perturbations that ripple through the biotic communities. Techniques such as factor train analysis (Darnell et al., 1976) can be utilized with each source of perturbation. This would produce a minimum of thirteen diagrams for the perturbation sources listed in Table 6.

In summary, designing a simple but technical model that would be useful to bay resource managers and decision-makers has proven to be the most intractable segment of the modeling exercise. A perturbation-based model that would permit bay users to visualize the interconnectedness of specific impacts quickly expands into a myriad of connections that overwhelm, rather than enlighten. Since many perturbations will affect individual species before effects on the habitat can be detected, the habitat approach may not be an effective way to evaluate perturbations.

Table 6. Sources of significant perturbations.

MODIFY FW INFLOW	POINT SOURCES	NONPOINT SOURCES
Inflow Quantity	Temperature	Water Level
Point of Inflow	Water Level	Water Clarity
Inflow Seasonality	Water Clarity	Nutrients
Nutrient Transport	Nutrients	Toxicants
Sediment Transport	Toxicants	Suspended Solids
Salinity	Suspended Solids	Dissolved Solids
	Dissolved Solids	Organics
SUBSIDENCE	Microorganisms	Dissolved Oxygen
Water Level	Dissolved Oxygen	pH
	Salinity	Salinity
DEVELOP SHORELINE	pH	Microorganisms
Wave Action	Radioactivity	
Nutrient Transport	Impingement	COMMERCIAL FISHING
Habitat Placement	Entrainment	Suspended Sediment
		Toxicants
DREDGE & FILL	BOATING & MARINAS	Habitat Structure
Suspended Sediment	Wave Action	Population Density
Salinity	Nutrients	Population Structure
Water Depth	Toxicants	Community Structure
Toxicants	Microorganisms	
Habitat Placement	Habitat Structure	RECREATION FISHING
		Population Structure
OIL & CHEM. SPILLS	PETROLEUM	Population Density
Toxicants	ACTIVITY	
Fouling	Water Depth	EXOTIC SPECIES
	Salinity	Habitat Structure
STORMS/HURRICANES	Toxicants	
Wave Action	Habitat Structure	MARINE DEBRIS
Water Level		
Salinity		
Temperature		

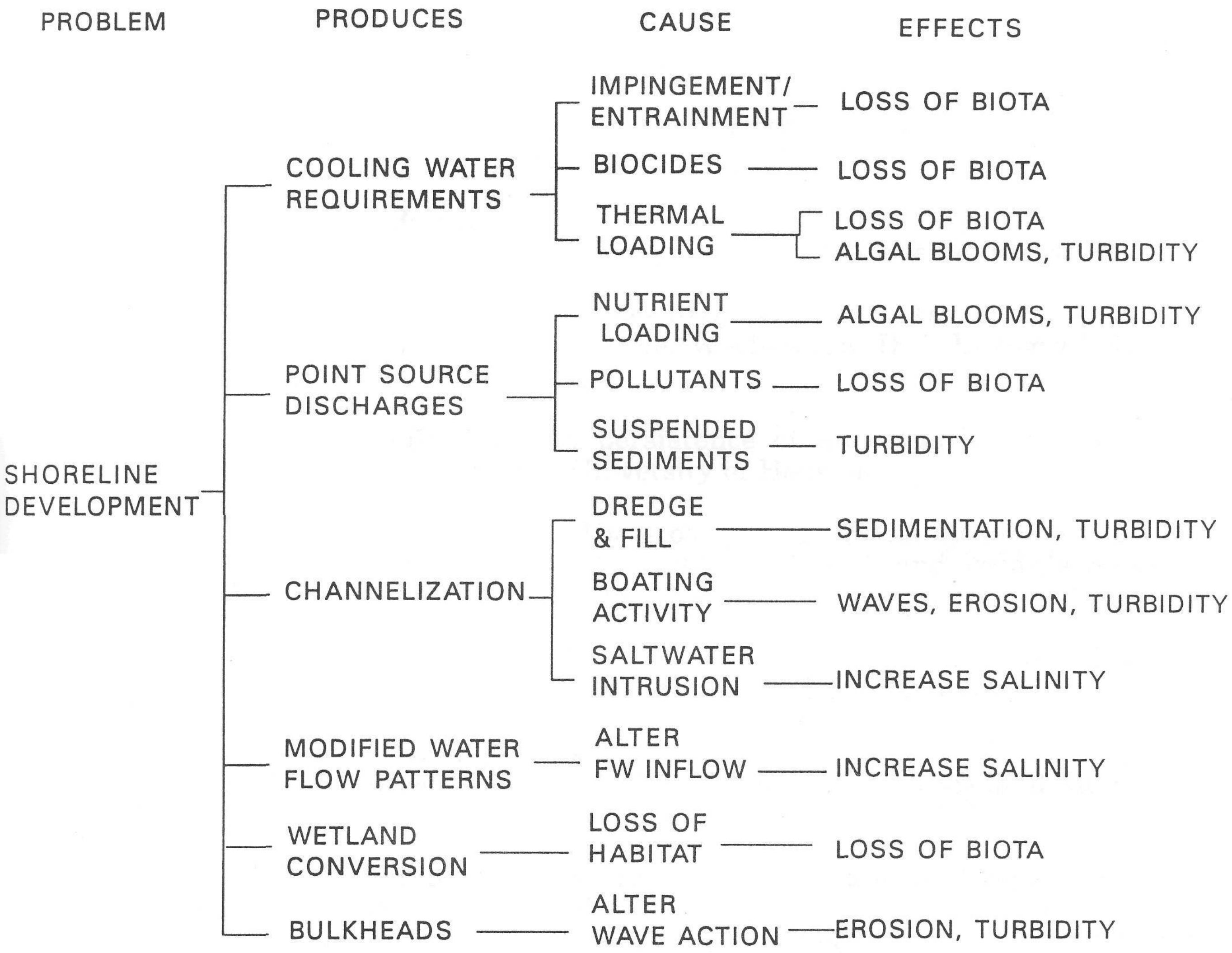

Figure 22. Shoreline development cause and effects. Development results in various actions that produce secondary actions that affect the biota.