NUTRIENT INPUTS TO GALVESTON BAY AND UPCOMING CRITERIA CONSIDERATIONS

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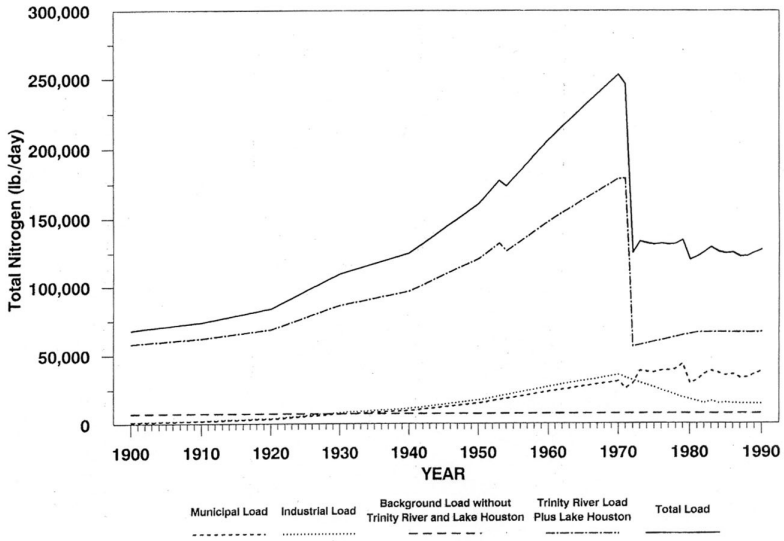
For the 1991 State of the Bay Conference, some of the authors of this paper (Jensen, et. al. 1991) analyzed total nitrogen (TN) loads to Galveston Bay over time, using published USGS flow and quality records, point source monitoring data from the City of Houston, and other sources. With the information available, it was estimated that total-N loads to Galveston Bay had peaked about 1970 and have since declined to roughly the level that was estimated for 1940. Figure 1, taken from the original paper, illustrates the findings of that work. The key points in the analysis of TN input changes over time were:

1. Increase in runoff TN levels presumed to be associated with population growth,
2. Reductions in major tributary concentrations and loads with reservoir development,
3. Reduction in TN inputs from higher levels of wastewater treatment starting in the late 1960's and early 1970's, and
4. TN inputs in 1990 approximately equal to those in 1940.

Figure 1 – Galveston Bay Nitrogen Loads from 1991 Paper



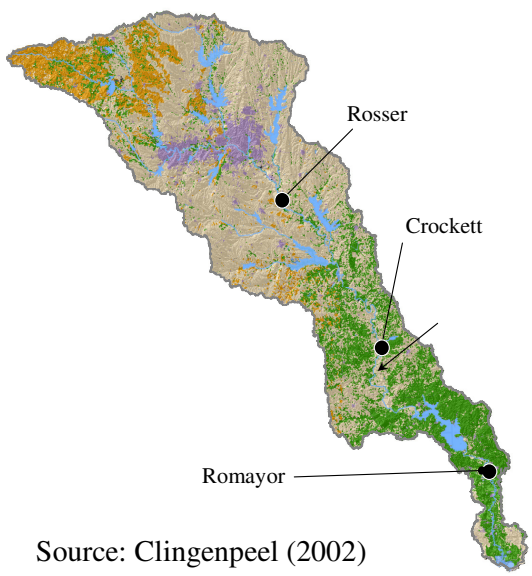
The 1991 analysis predated the Galveston Bay National Estuary Program (GBNEP) work, and the various characterization studies performed as part of the NEP process have added greatly to the available knowledge. One major study, the Ward and Armstrong (1992) characterization of trends in water and sediment quality, found statistically significant declining trends in ambient bay N levels that appear to be consistent with the reduced N inputs found over the same time period. In addition, the same

study found a significant decrease in the levels of chlorophyll a, Total Suspended Solids (TSS), and Total Organic Carbon (TOC) in the main body of Galveston Bay.

Point source loads to Galveston Bay were investigated by Armstrong and Ward (1993). Their study found total N loads from point sources to be 8,425 Metric Tons per year (MT/yr), reasonably close to our 1991 estimate of 9,200 MT/yr. Nonpoint source loads were estimated for the NEP by Newell, et. al. (1992). They estimated the average nonpoint source total N load for the entire watershed to be 23,128 MT/yr, somewhat larger than the 1991 paper estimate of approximately 12,400 MT/yr.

The US Geological Survey (USGS) (1994) assessed trends in water quality data for watersheds in Texas and found that there had been a problem with analytical methods used to measure ammonia nitrogen. After correcting for the problem, they found significant declines in the concentrations of ammonia+organic nitrogen and ammonia-N in the upper Trinity River watershed. The USGS (1996) looked at nutrient load trends along the entire Gulf coast. One finding was an insignificant increasing trend in total-N load at the Romayor gage (Trinity below Lake Livingston) that was the result of an apparent increase in flow. There was no significant change in total-N concentration in the period of record. The USGS (1995) also found no trends in the period 1974-91. They reported that Lake Livingston removed an average of 4,709 MT/yr of TN and 2,409 MT/yr of TP, despite there being 26% more flow at the downstream site than the upstream site.

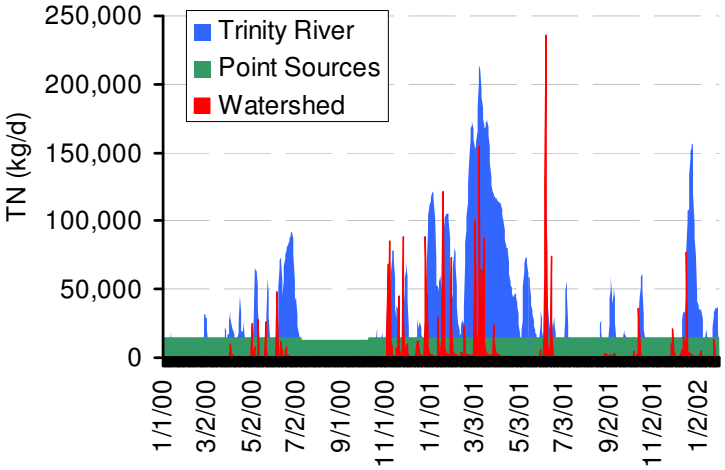
Figure 2 – Station Locations



Source: Clingenpeel (2002)

Clingenpeel (2002) examined nutrient loads to and from Lake Livingston in more depth for the years 2000 and 2001, considering the role of point sources in the metroplex area as well as inputs from the local watersheds. Figure 2 shows the stations at Rosser (south of Dallas), Crockett, upstream of the lake, and Romayor, downstream of the lake. The difference between the two upstream stations was used to estimate a rate of in-stream removal of TN and TP that was applied to the lake headwaters. Next, loadings from the 3,389 square mile immediate watershed were computed from regressions of local monitoring data. Figure 3 illustrates the TN loading results to Lake Livingston from the Trinity River with point sources,

Figure 3 - Total Estimated TN Loadings to Lake Livingston

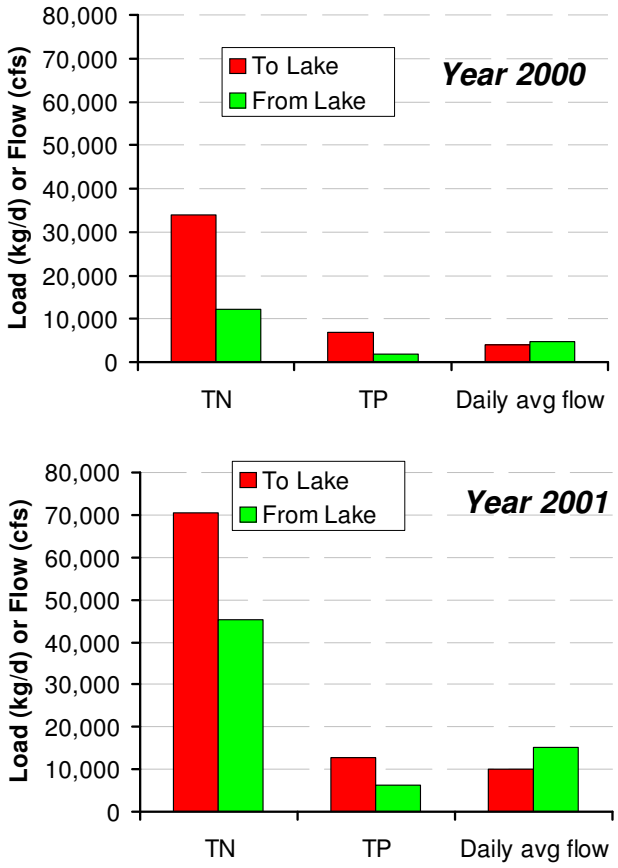


Source: Clingenpeel (2002)

runoff flows above Crockett, and the local watershed shown separately. The major role played by large rain events and the differences between 2000 and 2001 are readily apparent.

It is interesting to contrast the loads leaving the lake, as characterized by the data from the Romayor gage below Lake Livingston with the loads to the lake. Figure 4 shows the calculated daily loads of both TN and TP along with the flows to and from the lake for 2000 and 2001. The flow from the lake in 2001 was about three times as high as in 2000, and the loads leaving the lake were larger by a comparable amount. The percentage reduction in loads is much larger in 2000 than with the higher flows in 2001.

Figure 4 - Average Daily Loads of TN and TP to and from Lake Livingston



Another look at the topic has been made by the Bays and Estuary Freshwater Inflow Needs studies produced by the Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department (TPWD). Brock et. al. (1996) of the TWDB produced a detailed nutrient budget for Galveston Bay, using data from 1988-90. After adjustments were made to obtain a zero balance, the key components of their long-term total nitrogen budget included:

TN INPUTS	AMOUNTS (MT/YR)
Median Inflows	30,386
Wastewater	7,300
Direct Rain	700
Nitrogen Fixation	560
Entrainment from Gulf	1,749
TOTAL INPUTS	40,695

TN OUTPUTS	AMOUNTS (MT/YR)
Advection to Gulf	9,752
Entrainment to Gulf	24,460
Transfer to Fisheries	1,065
Sediment Accumulatio	2,251
Denitrification	3,167
TOTAL OUTPUTS	40,695

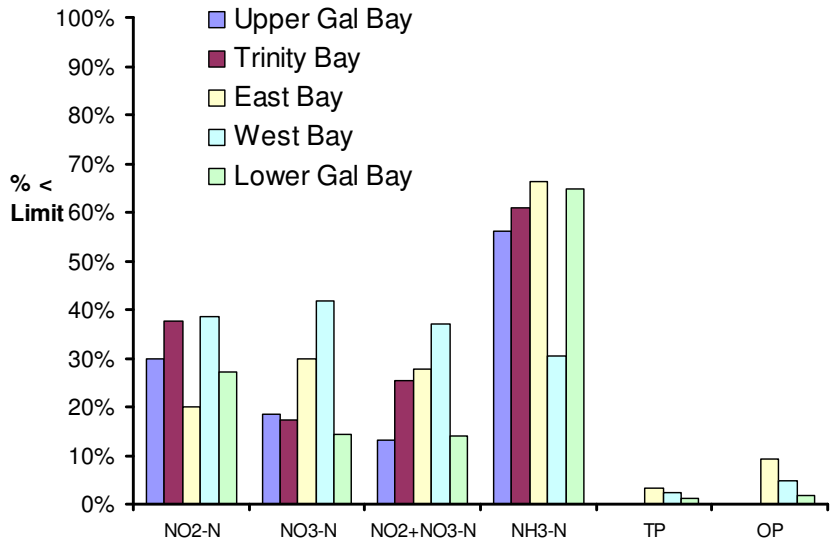
This budget reflects considerable effort in estimating inflows and the major processes involving nitrogen. The budget was ultimately considered in calculations of long-term nitrogen and freshwater inflow needs for the system.

Several points are worth noting in this budget in relation to other estimates. One is that the inputs from inflows of over 30,000 MT/yr is somewhat larger than estimated in other studies. At the same time it is important to note that neither this nor other studies include the effect of seston input (leaves, branches, and anthropogenic material such as paper). Some studies have suggested that

these "transported solids" that are larger than can be easily sampled, or which preferentially stay near the bottom of a moving stream, can represent a significant fraction of the total input during higher flow events. Finally, this budget does not represent internal cycling of nitrogen.

The National Ocean Service (NOS, 1999) published a national estuarine eutrophication assessment. The report presents a characterization of estuaries on all the major coasts, including 38 estuaries on the Gulf coast. The degree of eutrophication is graded as high, moderate or low, and measures of expression and influencing factors are also rated. The document is interesting in its attempt to deal with complex issues on a national level, but suffers from a lack of common data. Part of the information used in the rankings appears to have been developed from surveys filled out by individuals in various regions. While there is nothing inherently wrong with the use of survey information, it does appear to have produced some questionable results at least in Texas. For example, Galveston Bay, along with San Antonio Bay, Corpus Christi Bay, Upper Laguna Madre and Lower Laguna Madre are indicated to have a high degree of eutrophication. On the moderate eutrophication list are Matagorda Bay, Sabine Lake and Aransas Bay. It appears inconsistent that Matagorda Bay and Sabine Lake, with large freshwater flows and nutrient inputs, are ranked as moderate while Upper and Lower Laguna Madre, with extremely low flow and nutrient inputs, are classed as highly eutrophic. The report acknowledges the complexity of the characterization process and notes that it was difficult to define any use impairments directly related to eutrophication. In the case of Galveston Bay, a characterization as highly eutrophic can be understood in light of the relatively large freshwater inflows and wastewater sources, despite the major reductions in nutrient inputs and chlorophyll *a* levels documented in other studies.

Figure 5 - Percentage of Data Below Reporting Limits



To assess current conditions, nutrient data collected in Galveston Bay from 1993 to 2002 were retrieved from the TCEQ database. Figure 5 shows the percentage of data that are below reporting limits. Even at a rather high reporting limit of 0.01 or 0.05 mg/L, well above the concentration reported to limit phytoplankton growth, only a very small percentage of the phosphorus data are reported as a non-detect and all are above the reporting limit in Upper Galveston Bay and Trinity Bay. On the other hand, about 52% of the ammonia-nitrogen data and 26% of the nitrate-nitrite nitrogen data are below the reporting limit. These observations indicate that Galveston Bay phytoplankton chlorophyll *a* appear much more likely to be nitrogen-limited than phosphorus-limited. This conclusion is consistent with earlier studies of limiting nutrients in Galveston Bay. For example, Ward & Armstrong 1992 also found that N is the limiting nutrient.

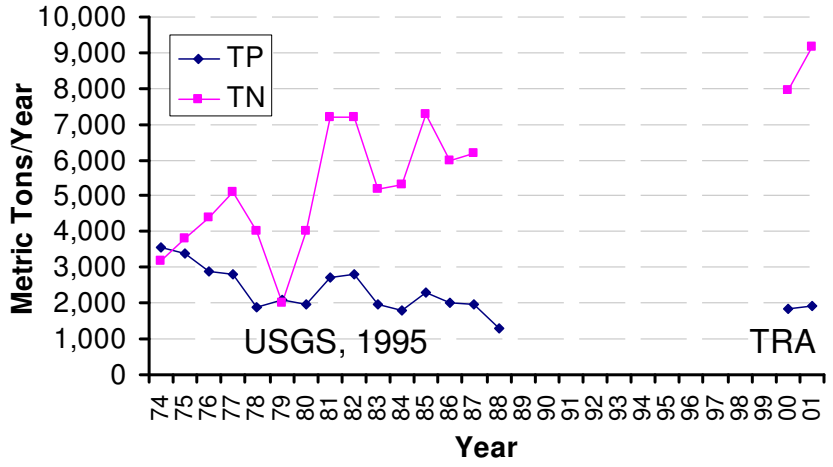
TRENDS

At the 1999 State of the Bay Symposium the authors (Jensen, et. al., 1999) presented an update on the nitrogen budget situation. The major findings were that despite population increases in the watershed, there was a continued decline in nutrient inputs from improvements in wastewater treatment, reductions in row crop agriculture and reductions in NOx emissions. Greater exchanges with the Gulf from navigation channel expansion were also noted to act to reduce ambient bay concentrations of nutrients. More recent data suggests that these trends are continuing. Further NOx reductions, primarily to control ozone formation are mandated for the area, and new developments are being required to institute stormwater controls that will remove particulate matter that includes nutrients.

The Galveston Bay Estuary Program has recently published a characterization of the Galveston Bay Ecosystem (Lester and Gonzales, 2002). Their findings on nutrient trends are summarized as follows. Based on monthly averages of data across the bay, both ammonia-nitrogen and total phosphorus concentrations have seen a declining trend over the past three decades. The drop in ammonia-nitrogen concentration mainly occurred in the mid 1980s and has remained low to the present. On the other hand, total phosphorus concentration was variable but high throughout the 1980s followed by a sharp drop in about 1990. Nitrate-nitrogen data show an increasing trend from 1969 until 1994, and then little trend to 2001.

The decline in the ammonia-nitrogen concentration and increase in nitrate-nitrogen concentration can be attributed to improved wastewater treatment in the Ship Channel area, primarily during the 1980s. The decline in the total phosphorus concentration may be partially due to a switch to low-phosphate detergents. Another possible factor could be increased biological phosphorus removal as a result of more widespread nitrification in wastewater treatment plants. Another factor could have been the declining trend in suspended solids noted by Ward and Armstrong (1992), since much of the waterborne P is particulate.

Figure 6 - TN and TP Removal Through Lake Livingston

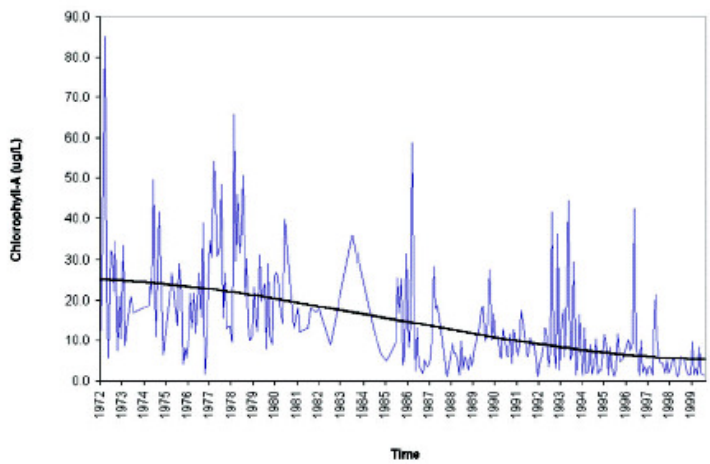


Another factor in nutrient load trends may be changes in flows from the largest input, the Trinity River. The load reductions across Lake Livingston discussed above are substantial and may be showing some changes. Figure 6 shows the average annual reductions at Lake Livingston from 1974-88 computed by the USGS (1995) along with the 2000 and 2001 reduction results computed by Clingenpeel (2002). There appears to be

a long-term trend of less removal of TP and an increase in the removal of TN. However, the reader should be aware that there are small differences in methodology between the two studies.

These possible trends in the amount of nutrient removed at Lake Livingston are not easily explained. Whatever the explanation, the increased removal of TN and decreased removal of TP in the largest single inflow to Galveston Bay may be of some significance.

Figure 7 – Monthly Average Chlorophyll *a* Concentrations in Galveston Bay



Source: Lester and Gonzales (2002), citing from Criner and Johnican (2001)

Lester and Gonzales (2002) also reported that monthly average chlorophyll *a* concentration values show a declining trend from 1972 to 1999. As shown in Figure 7, the decline is fairly dramatic, with 1999 values less than 25 percent of the 1975 values. Ward and Armstrong (1992) found a factor of two decline per decade. Apparently this trend has continued over the decade since the conclusion of their study. Three hypotheses are presented in their report to explain this very large observed decline. These are increased zooplankton population, decreased concentration of a limiting nutrient, and increased population of filter-feeders such as oysters. Since the zooplankton population varies widely in response to food availability and predation, and the filter feeding population also varies widely from year to year in response to a number of environmental variables, it would seem that of those listed the only factor capable of exerting a long-term effect consistent with the major and extended chlorophyll *a* data decline would be the availability of a limiting nutrient.

Lester and Gonzales (2002) also addressed trends in living resources, drawing from TPWD data and analyses. A brief summary of results from 1977-2000 is:

Species	Method	Trend
Brown shrimp	Bag Seine	Stable
	Trawl	Stable
White shrimp	Bag Seine	Decline
	Trawl	Decline
Blue crab	Trawl	Decline
Gulf menhaden	Bag Seine	Decline in last 10 yrs
Atlantic croaker	Trawl	Increase
Southern flounder	Bag Seine	Stable
Spotted seatrout	Gill net	Increase

From this no clear pattern is evident. Most of these species are subject to harvest pressure and management measures as well as year-to-year variations in environmental conditions, making it difficult to detect a long-term effect. However, Lester and Gonzales (2002) discuss probable causes of fish and shellfish declines. In addition to reduced planktonic primary

production, the possible causes they note include shrimp trawl bycatch, recreational fishing bycatch, entrainment and impingement at once-through cooling systems, fish kills and habitat loss. These could all play important roles for individual species at a given time, but most of these processes have not changed a great deal in the study period.

NUTRIENT CRITERIA

Since 1998 the EPA has had an initiative to require states to implement numerical nutrient criteria. Currently, Texas like most states, has narrative criteria for nutrients

TWC 307.4(e) *"Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use. Site-specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing."*

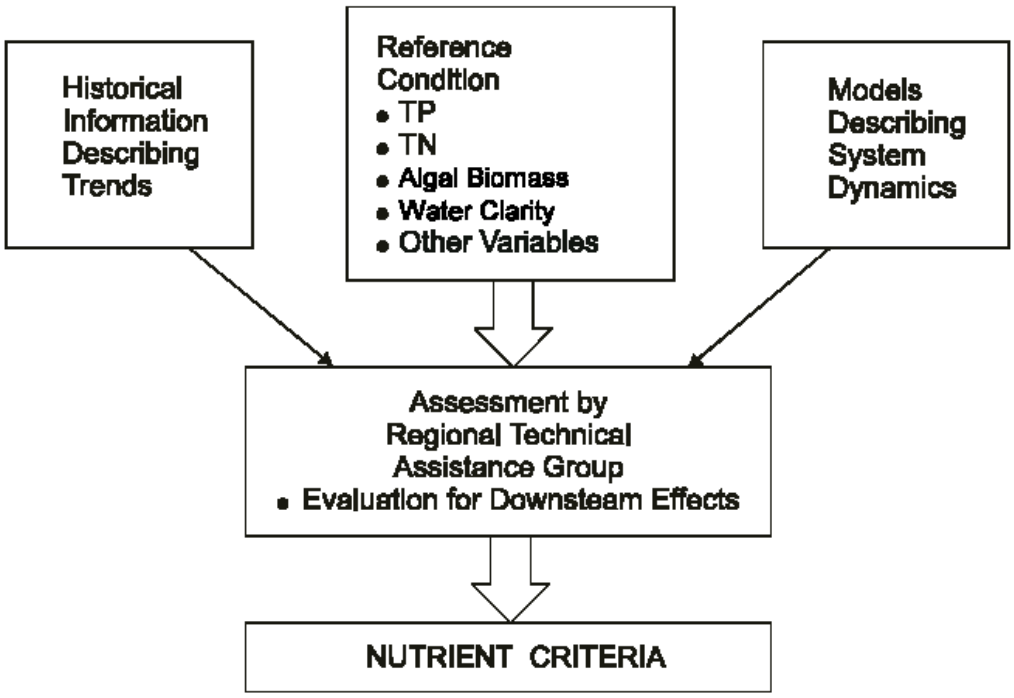
Narrative criteria have the advantage of allowing flexibility in determining if an impairment exists. However, they are essentially reactive and offer little opportunity for taking proactive measures to avoid a future impairment. Setting numerical criteria mandates a process for analysis that is likely to improve the quality of decision-making. At least that is presumed to be the rationale behind EPA numerical criteria initiative. Even if numerical criteria are not adopted immediately, some form of numerical values or quantitative measures would likely be required before any action on water quality standards could be taken.

Before getting too far into the criteria setting process, it is useful to note that water quality standards consist of three parts—designated uses, criteria, and an anti-degradation policy. The designated uses are what we expect our water to provide and the criteria are a means of measuring the extent to which the use is achieved. The anti-degradation policy (307.5) is designed to insure that existing uses are maintained. The current designated uses for Galveston Bay segments include High Quality Aquatic Habitat, Contact Recreation, Oyster Waters, Navigation, and Industrial Supply. The aquatic habitat criteria include dissolved oxygen, pH, Temperature, and toxics. The contact recreation and oyster water criteria have historically employed the same parameter, Fecal Coliform bacteria, but with different levels (200 cfu/dL for contact recreation and 14 cfu/dL for oyster harvesting). In 2000 the Enterococci test was adopted for saltwater contact recreation. There are no specific criteria associated with the Navigation or Industrial Supply uses.

The criteria are supposed to be tied to the support of specific uses, in the case of nutrients, the aquatic habitat, oyster protection and to some extent the recreation uses. This will be a challenge because the specific dimensions of these uses and their relation to nutrient levels are not well defined, and it is difficult to define the desired conditions. Typically this is a natural condition, but in Galveston Bay there is a limited basis to define a natural condition. One reason is that the level of fishing harvest pressure today is far greater than it was before the coming of European man in large numbers. With such a high harvest pressure where heavy overfishing and possible extinction is only restrained by limitations imposed by the Texas Parks and Wildlife Department (TPWD), a natural condition simply does not exist.

The procedure outlined by the USEPA (2001) for establishing nutrient criteria is illustrated in Figure 8. It envisions a process of examination and collective analysis that leads eventually to consensus. EPA's general process of criteria development involves determining a reference condition, understanding the historical status and trend of the water resource to help put the reference condition in perspective, modeling to help better understand present and historical information and to project future consequences, investigating effects of any criteria development on downstream receiving waters, and compiling and assessing all the information by a skilled body of regional experts. Five approaches were proposed for reference condition determination, three of which were based on in situ observations, one based on watershed nutrient loading characteristics, and the other an index site approach for estuaries and coastal waters. EPA has recently (Jan. 6, 2003) recognized that the applicability of the reference condition percentile level approach for reservoirs and streams might be severely limited for estuaries due to the lack of physically similar systems.

Figure 8 – Elements of EPA's Proposed Nutrient Criteria Development process



Source: USEPA (2001)

Another approach to establishing numerical criteria is that currently under consideration by the TCEQ for reservoirs is basing the criteria on existing monitoring data from each reservoir. A method under consideration is to use the upper bound of the 95% confidence interval to set criteria. Other percentages are also under consideration. This approach has a number of advantages. One is that the criterion would be grounded in existing ambient data. With that grounding, the criterion established would not result in instant listing, as would be the case if the EPA procedures for criteria development (25th percentile of all waters) were followed in many of the state's reservoirs (PBS&J, 2002). It is effectively an anti-degradation approach. If levels

remain as they are today, it will be acceptable. Such criteria would only come into play if today's levels were exceeded in the future for some reason. The TCEQ is also considering other approaches to deal with those reservoirs that are more heavily impacted by nutrients.

EPA's initiative to require states to develop numerical nutrient criteria may be viewed as an opportunity to address a significant bay management issue. For many years there have been major changes made in nutrient inputs to Galveston Bay with little or no consideration of the effects on the bay and people who depend on the bay. Simply trying to establish freshwater inflow needs may not be sufficient to address nutrient requirements. Stated another way, bay health and productivity may be more related to nutrient inputs than freshwater inflows. Making some explicit choices on the uses we want to support and the trade-offs required is essential if we are to take our responsibilities for bay management seriously.

The choices would be hard and multi-dimensional. To take a simple example, if the designated use would be to maximize production of sport and commercial fish and shellfish, a valid pathway would be to not limit the fishery yield by restraining primary production, the base of the food web. On the other extreme, if the goal were to attempt to recreate conditions before heavy settlement by European man and the current level of fishery harvest, a valid strategy might be to try to limit the availability of nutrients. Before realistic choices can be made we need to develop a reasonable level of understanding of the relationships between nutrient inputs, their form and timing and the response of key environmental resources. This will require continued development of quantitative ecosystem models and the involvement of key decision makers in understanding the abilities and limitations of such models. We can't continue to make radical changes with no attempt to understand the consequences of the actions.

While the focus of numerical criteria development for reservoirs and streams has been on setting upper limits to avoid eutrophication problems, the situation with estuaries may be substantially different. The combined effects of reservoirs and other processes removing nutrients and our expectations for a sport and commercial fishery suggest that criteria might need to include both an upper and a lower bound. Whatever numerical criteria are ultimately adopted, a consideration needs to be avoidance of harm to one of the designated uses, sport and commercial fisheries. One mechanism for harm could be continued reductions in nutrient inputs, primarily nitrogen, without considering the needs of the Bay ecosystem. Avoiding that potential harm will require a direct analysis and consensus building around the uses we want to support and decision-making on the nutrient needs, including form and timing, to support these uses. It will also require continued monitoring and analysis.

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