From: Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs. TWDB and TPWD. 1994.

this model to these dynamic constituents, however, data is needed on the rates of biological and chemical processes which affect these materials.

There may be a role for the optimization approach developed here to address future water quality concerns. There are trade-offs to the estuary in a future scenario of higher rates of nutrient loading which may come with increased urbanization of estuarine shores. Increased nutrient loading may bring positive increases in productivity to some estuaries. However, increased nutrient loading also may increase risks of the development of anoxic areas, red tide blooms, or other problems. How these risks weigh against the possible increased productivity depends on many factors, including rates of water exchange, seasonality, and factors which limit the biological community. The framework of the TXEMP Model is uniquely suited to incorporate in a quantitative way our knowledge of the interactions of these various factors. Water quality standards and productivity measures could also be included as targets or controlling parameters. Relationships between loading rates and predicted dissolved oxygen concentrations or other parameters could be used as constraints. It is possible to envision the application of this model to water quality concerns in this way. However, to make it work, more detailed knowledge is required of the best way to express relationships between nutrient loading, pollutant concentrations, and the behavior of the estuarine ecosystem.

Conclusion

The models and methods needed to use the analytical procedure to determine freshwater inflow requirements have been developed. Most of the information about the hydrology of inflowing waters and fishery equations is also available. The models of circulation and conservative transport for several estuaries need to be calibrated, and the nutrient budgets using cumulative flows from these models must still be prepared. Analyses of sediment requirements for the bay systems other than the Guadalupe Estuary will have to be done on a case-by-case basis, probably aimed at determining sediment requirements for maintaining delta wetlands.

Several enhancements to the method were discussed including improved primary productivity relationships and the addition of benthic productivity and water quality components. Because the analytical procedure is somewhat modular, incremental improvements to the analytical procedure as well as new features can be added easily at any time. Some of the techniques and analyses can be applied to other important problems such as the responses of ecosystems to unusual occurrences or deleterious changes from major pollutant spills, eutrophication, or toxic algae blooms. There may be concern over the length of time required for a bay to flush out a pollutant, or the question might be whether currents will sweep a red tide bloom into a bay. The morphometry of passes, the orientation of ship channels, and the volume of freshwater inflows all influence the exchange between major secondary and tertiary bays and the circulation of fresh and salty water within the bays. The models presented here provide a way of combining information on many aspects of estuary hydrodynamics, movements of materials, and ecological processes.

9.3 POLICY DECISIONS THAT MUST BE MADE TO APPLY THE METHODOLOGY

Introduction

In response to statute directives for studies on the effects of freshwater inflows, state scientists and engineers have developed a comprehensive database and methodology for estimating the freshwater inflow needs of Texas bays and estuaries. Since freshwater inflows affect our estuarine (tidal) systems at all basic levels of interaction—physical, chemical, and biological effects—the new method was designed to include at least the minimum needs for each functional level. It also incorporates a technique for optimizing the freshwater inflow needs across all levels of interaction to maintain the ecological integrity of these valuable coastal environments.

The TXEMP Model. The TXEMP Model was cooperatively developed and tested with the Center for Research in Water Resources at The University of Texas at Austin. It allows use of a multiobjective approach to solving the inflow problem and incorporates the statistical uncertainty of correlated relationships between freshwater inflows and resulting bay salinities and fisheries harvests. This is a real advancement in this type of solution technique. Model results are displayed as "performance curves" like the illustrative examples shown in Figure 9.3.1. From these performance curves, decision-makers can select the point that best balances the needs of man and the environment for the benefit of all Texans. As a final check, the freshwater inflow needs calculated by the TXEMP Model are incorporated into the TXBLEND hydrodynamic model to evaluate the overall effects on bay circulation and salinity patterns.

Policy decisions and management objectives. While the logic and equations of the optimization model are built on scientific and engineering analyses, application of the model requires the mathematical expression of all operative constraints, limits, and state resource management objectives. Decisions about these objectives are in the realm of public policy, more than science and engineering. They are

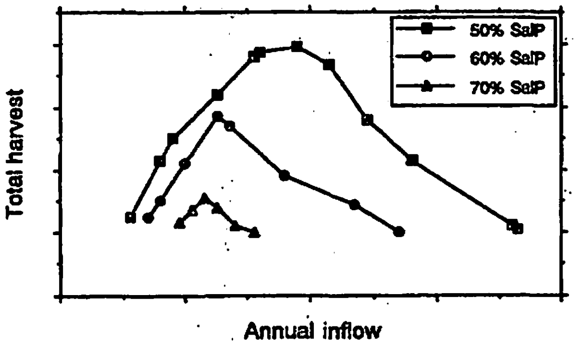

Figure 9.3.1. Example performance curves of harvest versus inflow for different probabilities of meeting the salinity constraints

most appropriately made by the state's policy makers, especially the boards and commissions which are responsible under state statutes for regulating the use and management of bays and estuaries, and their contributing river and coastal drainage basins.

The prototype analysis, prepared jointly by the TWDB and the TPWD and presented in Chapter 8, uses a set of more or less reasonable constraints, limits, and objectives. While these input parameters were sufficient for demonstrating the example, they may not be completely satisfactory for regulatory or judicial purposes. A number of related policy issues must be examined and decisions must be made for this method to be effectively used in the future.

Policy-level Decisions for the Analysis

Species to be included. The indicator organisms that will be used in the analysis must be chosen. At the present time, the choices for this decision are limited. As noted in Section 9.2 and Table 9.2.2, equations relating freshwater inflow to commercial seafood harvest are available for up to seven fishery species in six estuaries, although equations for all species are not available for all estuaries. These species represent a wide spectrum of animals that includes mollusks, crustaceans, and vertebrates. The fishery data were discontinuous in one estuary, and confidence in the resulting equations was low. In the other estuaries, there were only a few instances where no statistically significant equations could be constructed.

Some of the commercial harvest equations may be improved in the future with additional harvest and inflow data. If abundance relationships can be developed from TPWD's fishery-independent monitoring data, it may be possible to provide response equations for more species than just those that are commercially harvested. TPWD's monitoring data can already be used to describe the distributional abundance of many common species, thereby providing another way to biologically interpret results from the hydrodynamic (circulation and salinity) models. Every effort should be made to include species that cover as much of the ecosystem's trophic spectrum as possible.

Relative weighting of species. Also to be decided is the issue of the relative importance of species in the analysis. Should all species be treated equally, or should some be given more preference than others? There may be appropriate policy reasons to justify weighting one species more heavily than another in the analysis. If so, the problem remains of determining what the weighting should be. The prototype analysis includes examples showing results from the use of several different species weightings, including one based solely on the economic value of harvested species. Experience with the TXEMP method has shown that extreme weighting factors are likely to distort the analysis.

Selection of inflow-response equations. Sources of freshwater inflow to the estuary must be considered and will determine which group of inflow-response equations are used, those based on gaged flow alone or the total combined inflow from all contributing drainage basins. Although it is the gaged river flows that are most affected by impoundment and diversion activities, bay salinities and fisheries are affected by inflows to the estuary from all sources. While the use of gaged inflow data alone simplifies the interpretation of the analysis, it may allow additional unexplained error into the optimization procedure. This is particularly true for estuaries with large ungaged drainage areas or where there is a low correlation between gaged and ungaged inflows. For this reason, it may be better to use combined inflows in the model. Another option would be to perform the analyses with both types of inflow records to better evaluate the problem and its solution.

Inflow constraints. Historical inflow information provides a general picture of the volume and patterns of inflow that are characteristic of the river basin. A measure of central tendency is appropriate for use in the model since it provides a realistic estimate of how much water the basin can provide. In the demonstration analysis, the upper bounds on freshwater inflow was set at the median (50th percentile) monthly historical flow, a significantly smaller value than the mean (average) monthly flow, which is skewed upwards by infrequent but large flood events in the historical record. The argument for using the median recognizes that it is more representative of the normal hydrologic conditions since the median inflow is exceeded half the time while the mean inflow is usually encountered much less frequently. For some analyses, however, it may be appropriate to set the upper bound at the mean flow or some other desired level.

After numerous test runs, TPWD and TWDB staff agreed, for demonstration purposes, to use the 10th percentile of the historical monthly flow rate as the lower bounds on inflow. However, existing state or federal minimum streamflow requirements or other considerations could be used to set the required lower bound.

In addition to monthly inflow bounds, seasonal inflow bounds were also set to prevent extrapolating harvests beyond the inflow levels for which the equations are valid (the fishery harvest regressions were derived using two-month seasons in the analysis). Should new types of harvest or abundance equations be prepared, the seasonal period used for the inflow bound may have to be changed to reflect the inflow time span used in the analysis.

Area-specific salinity limits by month. The model provides for the use of monthly upper and lower salinity bounds that are specific to particular areas of the estuary. These bounds represent salinity viability limits within which the economically important and ecologically characteristic fishery species can survive, grow, and reproduce. The number of areas for which salinity bounds are selected will depend on the availability of inflow-salinity regression equations for the estuary; the model can test only the salinity bounds at sites for which there are enough data to develop the equations. Setting the bounds will require interaction between biological scientists, who can interpret the effects of salinity on different life stages at various times of the year, and policy makers or regulators, who have the authority to make the salinity boundary decisions.

Nutrient loading constraint. The nutrient loading constraint (Section 7.4) presented in the example analysis was based on consideration of nitrogen loading to the estuary and the assumption that the minimum acceptable loading should at least balance nutrient losses from the estuary. Indications are that primary production in Texas estuaries is more likely to be limited by nitrogen than phosphorus or carbon. Policy makers may want to consider loading of these other materials, and may wish to refine the minimum acceptable nutrient loading requirement based on information from the nutrient balance analysis.

Sediment loading constraint. Sediment loading and transport are among the least understood of the processes that occur in estuaries. The example analysis included a sediment constraint that was determined in part through a process of elimination. A whole estuary approach, such as used with the nutrient constraint, was not possible. Data availability and other considerations eliminated other specific areas for analysis; maintenance of depth in Mission Lake was one of the few feasible topics left.

Other estuaries have similar problems involving the lack of data and the lack of a clear analytical method. The other estuarine systems will undoubtedly also require an ad hoc approach to sediment load analysis. It may be useful for the policy makers and regulators to evaluate, at the onset, whether such a limited approach is sufficient, and to endorse a general approach such as focusing attention on maintenance of the delta wetlands, as suggested in Section 9.2.

The methods for determining sediment loading requirements for other estuaries are also likely to involve the determination of a minimum sediment load to maintain an elevation, depth, or area. This minimum annual load will represent a balance point at which there will be no net loss or gain. Policy makers may wish to refine this minimum loading requirement based on other considerations such as restoring past losses of certain habitat areas.

Chance constraints for salinity and harvest. This model allows optimal solutions to be calculated that take into account the statistical error (uncertainty) of the salinity and fisheries equations. Using the fishery harvest equation error, the TXEMP model calculations of inflow provide that a given probability level of achieving a particular harvest target will be equaled or surpassed. Using the salinity equation error, the TXEMP model calculations of inflow ensure that a given probability of not violating salinity limits at either the upper or lower bounds will be equaled or exceeded. The probability is usually expressed as a percentage of reliability (usually a value between 50% and about 80%). Policy makers and regulators will have to decide whether to use the stochastic form of the model or to do the analysis in an entirely deterministic manner (setting the probabilities to 50%). If the statistical nature of the salinity or harvest equations were important considerations for the decision at hand, the policy makers or regulators will have to determine the levels of probability that are appropriate for the analysis.

Harvest targets. Harvest targets are the minimum levels of fishery harvests that must be maintained throughout the analysis. Since fishery harvests are used as a surrogate for biological productivity, the harvest targets are important because they define levels of biological productivity that must be maintained by beneficial inflows, which is part of the legislative direction in TEXAS WATER CODE 11.147(a). In the prototype analysis, harvest targets fixed at the mean (average) harvest level for each species proved too restrictive for model operation, so they were reduced to no less than 80% of the means from the data used in the fishery regression analyses. Although this constraint is an important one for policy makers and regulators to set, depending on the management objectives of the estuary, there will have to be some flexibility in selecting the levels to allow the model maneuvering room to find a feasible solution.

Objective function for optimization. Six objective functions for optimization are possible with this model: minimize inflow, maximize harvest, maximize inflow, minimize harvest, maximize probability of achieving harvest targets, and maximize probability of satisfying salinity constraints. The first two objective functions are the ones of most interest in decision-making. Using the 50% salinity probability performance curve in Figure 9.3.1 as an example, the point farthest to the left on the graph represents minimizing freshwater inflows while maintaining fisheries harvests near their mean historic levels. The highest point along the vertical axis of the graph represents the second objective function, maximizing fisheries harvests while maintaining freshwater inflows at levels not to exceed the median historic flows. Solutions between and including these two points will be of greatest interest to the policy and decision makers.

As long as the harvest remains above historic mean levels, the minimum inflow objective function appears to best express the requirements of the statute: determine bay conditions (i.e., sediments, nutrients, and salinity-gradients) adequate to maintain a sound ecological environment necessary for maintenance of the productivity of fish and shellfish (seafood) resources. However, there could be cases where the minimum inflow objective function was not appropriate. These would have to be determined by the policy and decision makers, and another objective or region along the performance curve would have to be selected for inflow decisions.

Conclusion

The policy-level decisions that must be made by state policy makers and regulators to apply this assessment method involve choices about state management objectives, species analyzed, freshwater inflow records, salinity limits, nutrient and sediment loading requirements, fishery harvest targets, and chance constraints on the statistical uncertainties. Some of the decisions are straightforward; several will require interaction with knowledgeable biological or hydrological experts, or specialists operating the model. A few of the policy decisions involve the overall management objectives for an estuary and raise issues of importance to many citizens. It seems appropriate that some guidelines should be established before regulatory use of the model occurs.

9.4 CONCLUSIONS

This study has focused on the effects that freshwater inflows have on the major components of estuarine ecosystems, and the development of a methodology to determine freshwater inflow needs, given natural resource management policies and objectives for an estuary. The tools, data, and knowledge to determine estuarine inflow needs are now available. While these tools and our understanding of estuarine relationships are imperfect, they are complete enough that they may be applied to produce answers. The scientists and engineers who developed the tools and data are confident that the techniques presented here capture the essential relationships between freshwater inflow and the productivity of fish, shellfish, and other estuarine life, and that the levels of beneficial inflows needed to maintain that productivity can be determined. The methods can be applied to Texas estuaries to improve the management of the renewable resources therein, so the resources these estuaries provide will be available for future generations. The same tools serve to guide further investigations and refinement to our understanding estuarine ecology and freshwater inflow requirements.