State Methodology for Determination of Needs in the Major Estuaries of Texas

Texas Water Development Board
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In response to Senate Bill 137 (1975), House Bill 2 (1985), Senate Bill 683 (1987), Senate Bill 1 (1997), and other legislative directives, the Texas Water Development Board (TWDB), the Texas Parks & Wildlife Department (TPWD), and the Texas Commission on Environmental Quality (TCEQ) jointly established and maintained a data collection and analytical study program focused on determining the effects of and needs for freshwater inflows to the state's bays and estuaries. Until recently, when the Senate Bill 3 (2007) process for developing environmental flow recommendations and standards was implemented, freshwater inflow studies within the State were guided by Section 11.147 of the Texas Water Code, which defines *beneficial inflows* as:

"a salinity, nutrient, and sediment loading regime adequate to maintain an ecologically sound environment in the receiving bay and estuary system that is necessary for the maintenance and productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent."

As written, this includes a foundation for developing the management goals and scientific studies upon which the recommendations are based.

Management Goals of the State Methodology

Legislative directives calling for the development of freshwater inflow recommendations for Texas' bays and estuaries can be distilled down to two management goals:

1. Ensuring the maintenance and productivity of economically important and ecologically characteristic sport or commercial fish and shellfish, and
2. Ensuring the maintenance of estuarine life upon which such fish and shellfish are dependent.

The State Methodology addresses the first goal, "*maintenance of ... fish and shellfish*", by setting a management goal to achieve more than 70% of the historical average harvest or abundance of important fish and shellfish. This requirement is set in the TxEMP optimization model (Element 6 described below) as a lower constraint.

The State Methodology addresses the second goal, "*maintenance ... of estuarine life upon which such fish and shellfish are dependent*", in the final check of needs (Element 7 described below). In this step, salinity levels resulting from the inflow solutions provided by TxEMP are examined at important locations within the estuary. This step ensures that the recommended inflows will provide conditions favorable to maintaining the fish, shellfish, and estuarine life upon which they are dependent, *i.e.,* an ecologically healthy system.

Scientific Basis of the Studies

The State Methodology was designed to answer the question: *How much water is needed to provide a beneficial inflow?* In order to do this, a great deal of information is needed. While complete descriptions of the State Methodology for determining inflow needs to the major estuaries are provided in the Longley (1994) report and in Powell *et al.* (2002), here we present only a brief summary of the seven elements of the State Methodology.

1. **Data Collection/Hydrographic Surveys** - Field studies designed to collect physical measurements (water level, velocity, *etc*.) of the bays. They include both short-term intensive inflow studies and longer-term water quality and tide gaging data collection efforts conducted by the TWDB and contracted to other agencies or universities. Complete hydrographic surveys provide the data needed to calibrate the TxBLEND hydrodynamic and salinity models (Element 2). Long-term flow and salinity data sets are used to set constraints and to develop statistical relationships between flow and salinity. These constraints and equations are used in the TxEMP optimization model (Element 6).

2. **Hydrodynamic & Salinity Modeling** - The TxBLEND hydrodynamic and salinity transport model allows simulation of circulation and salinity patterns within the estuary. Model inputs include bay bathymetry, tides, rainfall, evaporation, wind, and freshwater inflows from rivers and adjacent watersheds. The model is used to predict changes in circulation and salinity for various inflow scenarios.

3. **Sediment Analyses** - Studies relating freshwater inflows to the input of sediment to estuaries. Complete sediment analyses provide constraints for the TxEMP optimization model that directly or indirectly translate into a minimum freshwater inflow requirement to satisfy the sediment needs for maintaining river deltas and wetland habitats.

4. **Nutrient Analyses** - Studies relating freshwater inflows to the input of nutrients, primarily nitrogen, to estuaries. The purpose is to estimate nutrient needs for maintaining a positive balance in the estuary's nutrient budget. A nutrient analysis therefore depends on building a nutrient budget for the estuary and has a variety of components that represent gain and loss terms. In general, a nutrient budget is complete when a nutrient constraint can be defined. A nutrient constraint is the inflow volume required to deliver enough nutrients to the system so that there is no net annual deficit in the nutrient balance between gains and losses.

5. **Fisheries Analyses** - Analyses which estimate fisheries needs for maintaining long-term average production (harvest) or population abundance of commercially important and ecologically characteristic species within an estuary. Fisheries data are used to develop equations relating fisheries harvest or abundance to freshwater inflows. These equations are at the core of the TxEMP optimization model and are used to determine minimum flows needed to achieve a particular fisheries target.

   5a. **Fisheries Harvest Analyses** - Harvest analyses produce species-specific equations relating annual commercial harvest (biomass) of fish and shellfish with freshwater inflow to an estuary. A complete analysis includes a set of equations for representative species for which harvest data is available through the Texas Parks and Wildlife Department and other published sources.

   5b. **Fisheries-Independent Analyses** - Fisheries analyses produce species-specific equations relating species abundance (as catch per unit effort or as density) with freshwater inflow, for commercially and recreationally important fish and shellfish. A complete analysis includes a set of equations for representative species for which data is available through the Texas Parks and Wildlife Department Coastal Fisheries Monitoring Program.

6. **Freshwater Inflow Optimization Modeling** - This analysis relies on the Texas Estuarine Mathematical Programming model (TxEMP) which uses information from hydrographic surveys including: seasonal inflow hydrology constraints, salinity-inflow equations, and salinity constraints (Element 2); sediment and nutrient constraints (Elements 3 & 4); and, fisheries-inflow equations and biomass/harvest constraints (Element 5). A complete analysis generates products that include performance curves relating harvest or abundance to annual inflow as well as the monthly distribution of flows for a given annual inflow. Annual performance curves are continuous from a MinQ value, representing the absolute minimum inflows necessary to meet desired management constraints for inflows, salinity, nutrients, sediments, and fisheries, to an inflow representing maximum harvest value (MaxH (or MaxC for fisheries-independent Catch)), and finally to a maximum inflow (MaxQ) that satisfies all management constraints. The purpose of the optimization approach is to provide solutions which meet all specified constraints, limits, and stated management objectives with a *minimum* amount of freshwater inflows

7. **Verification of Needs** - A final check of TxEMP results serves to evaluate the inflow solutions and provide assurance that the estimated needs will maintain ecological health and productivity. There are two kinds of checks, (1) graphic examination of the simulated monthly pattern of salinity from a hydrodynamic and conservative transport salinity model (TXBLEND) and (2) daily checks of salinities at selected nodes that are also generated by the TXBLEND model. This step is complete when the calculated salinity patterns in the monthly or daily simulations do not violate the salinity constraints more frequently than a predefined level of acceptance.

Frequently Asked Questions about the State Methodology

Why use commercial harvest (fisheries-dependent) data? Commercial harvest data are commonly used in fisheries management, although with known and accepted limitations. Much of the information is self-reported by fishermen and subject to certain biases, such as fishing effort and market price. However, when the bay and estuary studies were started in the late 1980s, reported harvest was the only data set that had been collected for a long enough period (since 1959) to be useful. Consequently, the earlier inflow studies are based on commercial harvest data.

Can TPWD Coastal Fisheries monitoring data be used instead of harvest data? TPWD's Coastal Fisheries Monitoring database, which contains information on species abundance, distribution, and seasonality for many species, has been used to check model results based on harvest data. However, more recent freshwater inflow studies (*e.g.*, Sabine Lake (2005), Laguna Madre (2004), and Matagorda Bay (2006)) have been able to use this source of fisheries-independent data to develop abundance-inflow regression equations based on species abundance. TPWD's monitoring program began in 1976, and so the database now spans enough years to encompass statistically meaningful natural variation. The TPWD monitoring data is complex, and naive use of the data can lead to misleading conclusions if the sampling and data reporting protocols are not fully understood. Because the program aims to characterize species distributions and abundances throughout an estuary, sampling effort is randomly distributed and is not concentrated in areas where capture success may be highest (in contrast to commercial harvests). Additionally, TPWD uses a range of gear types which target different habitats and life-stages. Therefore, while both the harvest and TPWD monitoring data sets may be valid measures of estuarine productivity, they differ in detail. Abundance values from TPWD monitoring samples can be expected to differ from commercial harvest due to differences in collection methods and data reporting.

The fishery equations used by the agencies for some of the target species do not appear to have strong correlations (i.e., low r^2 values) between inflow and harvest/abundance. Is this a problem? Although there are biological reasons for presuming a strong role of inflows in the life history of many species, inflows are only one of a number of important factors. Because these equations reflect only the natural variation as explained by a single factor (inflow) and not by other important factors (such as temperature), correlations (r^2) between inflow and harvest may not be particularly high. We would not expect to obtain a very high correlation unless inflow was the predominate influence on a species. Nonetheless, only statistically significant ($p < 0.05$) equations are included in the TxEMP analysis. Equations with moderate r^2 values are not flawed, but they allow us less certainty in the answers produced. TxEMP incorporates both the answers from the equations and the uncertainties associated with those answers.

Should a non-linear fisheries regression equation be used in place of the linear fisheries equation? We will continue to explore the best way to quantify correlations and causal relationships between inflows and estuarine responses. The TxEMP model can accept a variety of model forms. At this time we may still lack, to some extent, the amount of data required to support more complex models.

How does TxEMP come up with a solution? A further description of TxEMP is provided in Longley 1994; here instead is a summary. TxEMP is a nonlinear, stochastic, multi-objective mathematical programming model that seeks a combination of inputs which produce the most favorable (optimized) result. TxEMP uses an algorithm to satisfy many, often conflicting requirements as it produces a solution to a problem. The user specifies what system responses to optimize (the objective functions), such as harvest level, and provides data on the driving inputs, such as monthly inflows. The user then sets requirements or limits (constraints) which determine how much the algorithm can change the driving variables and still be acceptable. Some requirements are limits of biological function; some are limits of resource availability. Since the problem is one of determining an estuary's response to inflow, limits and targets are expressed as functions of inflow to the best of our knowledge. TxEMP finds a solution through repeated trials of input combinations, recalculating responses and testing for violation of constraints within each iteration of the model. In this way, the model tunes the levels of monthly inflows to find a combination which will produce the best outcome. TxEMP generates and tests a large number of inflow schedules and amounts. TxEMP then produces a curve displaying a range of feasible solutions between alternative desired states. Each point along the curve represents a combination of monthly inflows which produces a result that is viable (not violating any constraints). Specific points along the curve can be identified as optimal solutions satisfying particular goals.

Is it necessary to set model constraints on inflow, salinity, and harvest? Yes, constraints are needed to keep the model from producing physically unreachable or ecologically undesirable solutions. Also on a practical level, the model should deal only with inflows that are in the range of management options. In water-use permitting, water volumes pertinent to establishing the permit are related to the availability and frequency of particular inflows. Likewise, planning for future inflows to the estuary may require acknowledging the historical range of inflow. Harvest constraints similarly reflect a management goal for the system that is based on historical data. For example, we may choose to set a constraint which will maintain >75% of historical harvest (in pounds per year) according to the historical proportions of the target species in the estuary.

Salinity constraints - Salinity constraints define one set of upper and lower limits on the TxEMP solution. They are based on the statistical characteristics of salinity within the estuary combined with known salinity preferences and tolerance limits of the target species. Salinity constraints help to ensure that the TxEMP solutions are reasonable and that the management goals are achieved.

Inflow Constraints - Specified as monthly upper and lower bounds and/or seasonal (bi-monthly) upper and lower bounds. Upper bounds on monthly inflows generally are set at the median historical monthly flow, while lower bounds are set at the 10^{th} percentile flows.

Harvest (Fisheries) Target - A constraint set so that harvest or catch as calculated by the model is at least some percentage of the historical average (70% and 80% have been used).

Biomass Ratio (or Relative Abundance) - A constraint set to produce solutions which include harvest/catch for a set of species that reflect the historically observed proportions.

Salinity and Harvest Probability - Constraints can be set on the probability that the solution produced meets the salinity or harvest criteria. When probabilities are defined to be high, the model may be very limited in the range of solutions which can be explored.

Nutrient and Sediment Constraints - These constraints are expressed in terms of inflows. To ensure a minimum supply of beneficial nutrients and sediments, constraints can be set on the inflows.

In the context of the TxEMP optimization model, which is more important to assuring maximum fisheries harvests: total volume of inflow or timing of inflows to the bay? TxEMP produces results in terms of monthly inflows, which are then summed to an annual total inflow. Therefore, timing of inflows is an integral part of the solution. From an ecosystem perspective, both volume and timing are important. An otherwise beneficial inflow volume could hurt productivity if the timing was dramatically skewed. Many estuarine species depend on the right seasonal sequence of high and low inflows for critical life history stages.

How are the inflow recommendations produced by TxEMP evaluated? TxEMP produces an inflow schedule and an annual inflow volume. The main way these are evaluated is to use the inflow schedule product as input to the TxBLEND salinity and hydrodynamic circulation model and then to evaluate how such an inflow affects the salinity gradient within the estuary. The resulting salinity regime produced by TxBLEND is inspected by technical staff familiar with the system. The salinity regime also is compared to the distribution of important estuarine species and habitats inside the bay, as determined by TPWD monitoring. The salinity regimes simulated in areas with important habitat features, such as oyster reefs, wetlands, and fishery nurseries, are evaluated for suitability. TPWD technical staff examines the salinity gradient simulated by TxBLEND, based on the TxEMP inflow results, for correspondence with the salinity preference zones of species in the estuary.