Texas Water Resources

Texas Water Resources Institute

Fall 1994
Volume 20
No. 3

A Fresh Look at Freshwater Inflows

New TWDB/TPWD Study Provides Better Methods to Assess Estuary Needs

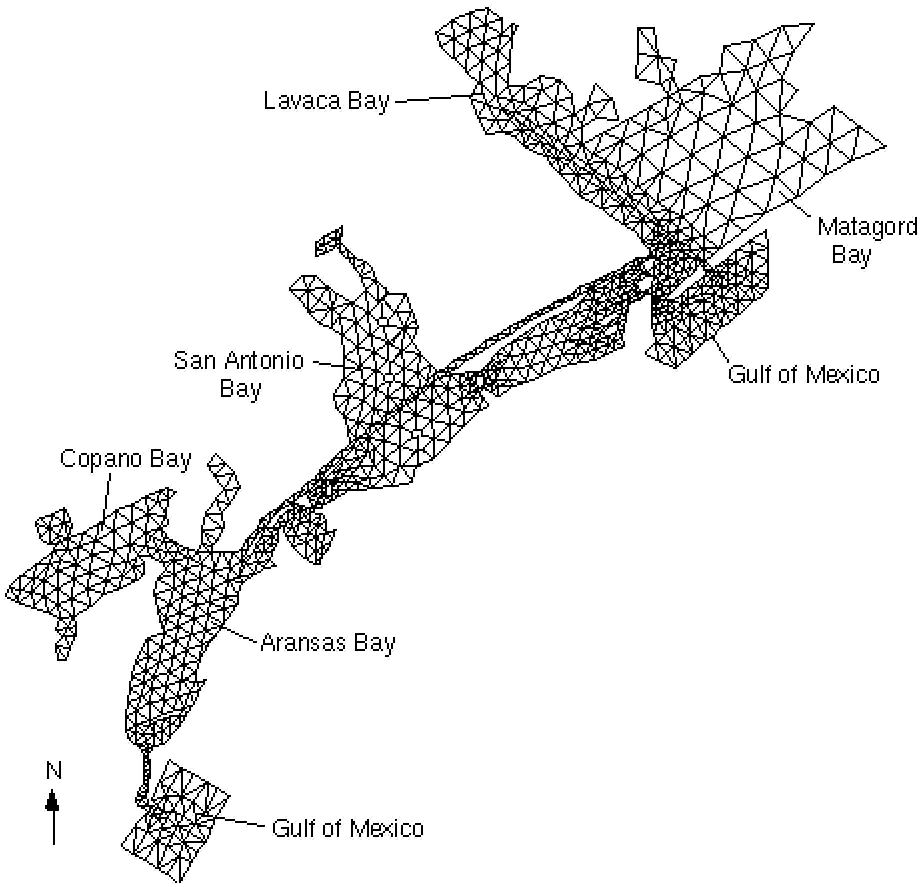
By Ric Jensen
Information Specialist, TWRI

For years, policy makers and scientists have been contemplating: "How much freshwater do Texas bays and estuaries really need to be healthy and productive?" Answering that question involves biological and policy issues. What levels of salinity and other water quality criteria do aquatic species need to survive and flourish? How do you judge which species are most important? Can freshwater releases be provided to bays and estuaries without reducing the amount of water needed by cities and other users?

A new comprehensive report, *Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs*, has been published by the Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department (TPWD). Project directors of the study are Gary Powell of TWDB and Albert Green of TPWD. The study is important for two reasons. It represents a major step forward, scientifically. Data on hydrology and biology has been expanded, and increased information has been gathered about nitrogen and nutrient budgets and loadings, and the relationships between inflows, sediment transport, and wetland habitats. It also presents state of the art optimization and circulation models that can now be used to assess freshwater inflow needs for Texas bays and estuaries.

How will the study affect the way that water is allocated to Texas bays and estuaries? So far, it's really hard to tell. Efforts were made to simulate the freshwater inflow needs of the Guadalupe Estuary using computer models. Modeling results showed that freshwater inflow needs for the Guadalupe Estuary may be much less than previously estimated. Efforts are now underway to perform additional computer simulations that could take advantage of more biological data.

Information from this and other studies is being incorporated into State agency planning efforts. Consensus-based water planning was begun in 1992 by the TWDB, TPWD, the Texas Natural Resource Conservation Commission (TNRCC), and other agencies. The goal is to reduce unnecessary conflicts about water issues. An ecological technical advisory committee is charged with evaluating and implementing freshwater inflow needs. Information developed by this process will be incorporated into new versions of the TWDB Water for Texas Plan. The Trans-Texas program is conducting feasibility studies about how pipelines, transmission, and distribution could bring additional freshwater to areas with deficits.



The TWDB/TPWD report represents several years of research by agencies and university scientists. Researchers at the University of Texas Bureau of Economic Geology (UT BEG) have studied how sediments are transported from rivers to coastal areas and how they are distributed in deltas, and have used aerial photos and other tools to measure changes in wetland habitats. Scientists at the UT Marine Science Institute (UT MSI) have studied how populations of aquatic species react to nutrients and salinity, as well as nitrogen and nutrient budgets and loads. The Conrad Blucher Institute for Surveying and Science at Texas A&M University-Corpus Christi (TAMU-CC) and Lamar University are cooperating to record water quantity and quality data in bays and estuaries. Many other universities and agencies also contributed to the research.

This newsletter will explore many of the issues contained in the new TWDB/TWDB report and provide an overview of some of the advances in research contained in the study.

Why These Studies Are Needed

Functions of freshwater inflows include creating and maintaining low-salinity and open water marsh habitats, transporting sediments and nutrients to bays and estuaries, helping distribute juvenile species within bay systems, and controlling predators and diseases. If freshwater inflows are not provided, salinities would likely increase, saltwater wedges could intrude farther upstream, predators and parasites of estuarine species could become more common, and freshwater aquifers could become contaminated by saline water.

In 1985, the Texas Legislature enacted House Bill 2, that required TWDB and the TPWD to jointly establish and maintain a continuous data collection and study program to determine bay conditions (sediments, nutrients, and salinity) needed to support a sound ecological environment. It gave TPWD the authority to be a party in hearings involving permit applications to store, take or divert water that could change the pattern or amount of freshwater inflow. The Legislature directed TNRCC to consider the effects on bays and estuaries whenever water rights permits are issued or existing permits are amended. In 1987, the Texas Legislature directed TPWD and TNRCC to review the studies to determine the specific quantities and qualities of freshwater inflow needed to maintain bays and estuaries and to provide data needed for water resources management.

The bills state that, when permits are considered within 200 river miles of the Texas coast, "the Commission shall include...conditions...necessary to maintain beneficial inflows to any affected bay and estuary system." Beneficial inflows are defined 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...of economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent."

TNRCC officials admit only a few policy options are available to provide sufficient freshwater inflows. Even if flow restrictions were placed on new or amended water rights permits, priority would still be given to downstream appropriators who obtained water rights before flow limits were put in place. TNRCC is now considering strategies to provide increased protection for freshwater inflows. Revising reservoir management strategies to pass water through lakes that receive large amounts of rainfall, storing water in small, deep lakes, or operating reservoirs as a system could "produce" more water. Other options include amending existing water rights, cancelling unperfected rights, appropriating water for public purposes, and limiting the reuse of treated effluents (TNRCC, 1994). TNRCC officials say many of these approaches will be hard to implement.

Recently, state agencies utilized innovative strategies to protect freshwater inflows. In 1990, the Nueces Estuary Advisory Council used the TXEMP model to assist in developing an interim schedule for releases from Lake Corpus Christi and Choke Canyon Reservoir. The schedule provides increased flows to Nueces Bay during critical periods. In 1994, a new permit was granted for Lake Texana that recommends that flows be passed through the reservoir and into coastal bays when lake levels and weather conditions permit.

Building Blocks for the Models

As the project began, TWDB and TPWD identified data that would be necessary to build improved models. The modeling and research had to provide quantitative monthly estimates of inflow needs, and must address how inflows affect estuarine life. To accomplish this, the agencies extended the database on coastal hydrology from 1977 through 1987, improved methods to estimate the amount of runoff from ungauged watersheds, and expanded the amount of hydrologic information needed for input into other analyses. Objectives were to compile inflow, hydrographic, and biological data into computer compatible files, to develop circulation and salinity models, to assess water quality trends, and to measure the effect of salinity changes on estuarine plants and animals. Another goal was to assess the impact of freshwater inflows on plant production, the population and diversity of estuarine species, sediment transport, and delta formation using geographic information systems (GIS).

University researchers and agency personnel compiled information on coastal hydrology, nutrients, sediment, plankton, sea grasses, vegetation, benthic organisms, and juvenile and adult fish and shellfish. Dynamic processes that were studied include relationships between inflow volumes, salinity, and nutrient and sediment loading, photosynthesis, plankton production, nutrient and, specifically, nitrogen processes, the spawning and larval development of fish, and the effect of salinity on metabolism and growth of adult fish.

Salinity data were gathered from five sources: the TWDB Coastal Data System and Datasonde Network, the TNRCC Statewide Monitoring System, the Texas Department of Health Shellfish Sanitation program, and the TPWD Coastal Fisheries Resource Monitoring Program. Most of these programs collected measurements on a regular basis, but the Datasonde network continuously recorded short-term data so that daily variations could be analyzed. Salinity data were analyzed by dividing estuaries into upper, middle, and lower regions, so that salinity gradients could be evaluated.

Freshwater Inflow Trends

The studies examined patterns of freshwater inflows and salinity regimes for the major Texas estuaries. There are dramatic differences in the amount of inflow each estuary receives. In general, Texas estuaries can be divided into three groups. The two northern estuaries (the Sabine-Neches and the Trinity-San Jacinto) typically receive inflows of more than 800,000 acre feet (AF) per month. The two middle estuaries, the Lavaca-

Colorado and Guadalupe, receive about 200,000 AF monthly. The two southern estuaries, the Mission-Aransas and Nueces, average less than 60,000 AF per month. Seasonal inflow patterns vary for each estuary. Between 25% to 33% of the freshwater that exits the Guadalupe Estuary flows into the Mission-Aransas Estuary or to the Lavaca-Colorado Estuary.

Even though many major reservoirs were built from 1941 to 1987, there is no clear evidence they have significantly altered the annual amount of inflows. Since 1967, annual freshwater inflows for the Sabine-Neches, Trinity-San Jacinto, Lavaca-Colorado, Guadalupe and Mission-Aransas estuaries have not changed significantly. Inflows to the Nueces Estuary have decreased, primarily due to increased water demand from the Corpus Christi area and a lack of increase in runoff.

Nutrients and Sediments

Nutrients and sediment loads carried by the gauged and ungauged portions of their watersheds were also evaluated (in gauged parts of a watershed, river levels and flow rates are actually measured, while runoff is estimated from ungauged areas). Estuaries receive nutrients from river flows and runoff. Generally, estuaries become more productive biologically as they receive increased nutrients, but excessive levels of nutrients can lead to problems with waterweeds, algae, and fish kills. In most estuaries, nutrient levels are highest near river mouths and decrease toward the Gulf.

Research shows that there are sufficient levels of nutrients to support phytoplankton production in most Texas estuaries. Generally, the highest proportion of nutrient loads comes from river inputs. However, in the Nueces Estuary ungauged flows provide most of the nutrient load since much of the lower part of this watershed is ungauged. Return flows from treated wastewater provide much of the nutrient inputs in the Guadalupe and Trinity-San Jacinto estuaries.

Sediment loads are dependent on inflows and appear to be strongly influenced by dam construction. Studies show that sediment transport in the Trinity River was greatly reduced after Lake Livingston was built in the 1960s, and that Lavaca Bay now receives only about 67% of its historic sediment loads. A U.S. Geological Survey (USGS) study showed that Lake Corpus Christi trapped 97% of the sediment that flowed into it, leaving little for the Nueces Estuary and delta areas. One study (White and Calnan, 1990) suggests this is a general trend for Texas reservoirs. The TWDB/TPWD study concludes that the amount of sediment transported by rivers can be related to inflows. Inadequate knowledge about sediment size fractions, circulation patterns, and currents makes it hard to predict how sediments are distributed in estuaries during high inflows.

The impact of inflows on aquatic species was the focus of many studies. Scientists investigated how "primary consumers" (different types of plankton, benthic or bottom dwelling organisms, and vascular aquatic plants) respond to changes in inflows. Many zooplankton species depend on specific salinity levels. A large storm that produced freshwater runoff could temporarily lower the salinity in a bay, killing marine species and creating an environment where freshwater plankton could flourish. Studies by UT MSI scientists (Montagna, 1990) suggests that nutrient cycling is affected by inflow levels. Researchers analyzed benthic organisms, fish, and shrimp to trace how carbon compounds that are produced on land are distributed within bays and estuaries. They found that terrestrial carbon products were occasionally transported by freshwater inflows into the mouths of coastal rivers and estuaries, where they were used by estuarine species.

How do freshwater inflows affect the distribution and population of fish and shellfish? Many estuaries serve as nursery areas for juvenile species. Research has shown that higher densities of juvenile shellfish were found in areas with lower salinities, but that salinity tolerances and preferences broadened as fish matured. Large inflow events allowed some species to move into flooded wetlands where they feed directly on plankton and vegetation. Many estuarine species live as close to sources of freshwater as they can, so that they can take advantage of the high numbers of benthic organisms, plankton, sediment, and detritus. Research assessed the extent that fish and shellfish adjust their metabolism to adjust to extremely high and low salinities, and how freshwater inflows and salinity changes affect reproduction.

Modeling Efforts

Relationships between commercial fishery harvests and freshwater inflows were modeled, based on more than 25 years of data. Equations were developed that relate harvests to seasonal inflows, temperature, and fishing effort for all Texas estuaries, but the Laguna Madre. Regression analyses showed that these factors explain 44 to 90% of harvest variations. TPWD uses gill nets, trawls, and seines to gather data on estuarine fish populations that may provide a more accurate picture of how species react to varying inflow levels.

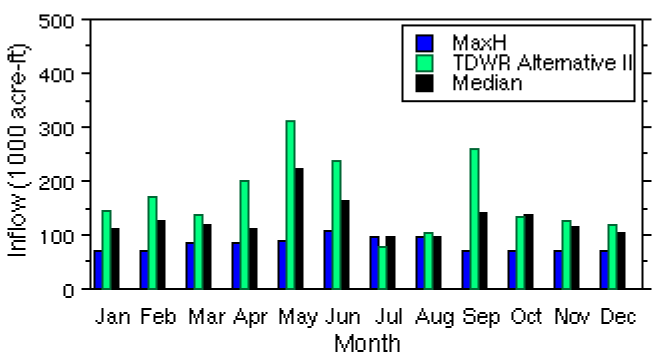
Computer simulation models will provide improved tools managers can use to determine the amount of freshwater inflows that are needed. The Texas Estuarine Mathematical Programming Model (TXEMP) is a stochastic, non-linear, multi-objective optimization technique that simulates how inflows affect estuarine ecology. TXEMP is a second generation model that builds upon previous TWDB efforts. It was developed by Y. Bao, George Ward, and Larry Mays of the Center for Research in Water Resources at UT Austin (1987), and TWDB staff. TXEMP uses the following inputs: hydrology data, sediment loads, inflow-salinity relationships, nutrient balances, and inflow-fishery regressions. A hydrodynamic and conservative transport model is used with TXEMP to verify inflow estimates. TXEMP can be used generate monthly inflow needs, based on defined management objectives. Table 1 (see page 2) summarizes information that has been developed for Texas estuaries.

To run TXEMP, managers and policy makers develop management objectives and make decisions that affect them. Examples include determining the relative importance of key species (should all species be treated equally?), selecting the likelihood that key salinity bounds and harvests will occur, estimating probable maximum and minimum volume of inflows, and selecting the level of sediments that are needed to maintain deltas. Policy constraints could include limiting salinity to "safe" levels. Constraints can then be incorporated into new calculations for monthly inflow distributions. The modeling software lets users create a number of different answers to respond to specific concerns and goals. TWDB and TPWD staff are now working to improve the data needed to run TXEMP including relationships between inflows and phytoplankton and benthic production, and by incorporating dissolved oxygen, nutrients, and other water quality criteria into the simulations.

Freshwater inflow needs generated by TXEMP are then incorporated into TXBLEND, which is a two-dimensional, finite element model that simulates water circulation and salinity patterns in estuaries. Inputs required to run TXBLEND include daily inflows, tides, evaporation, wind, and precipitation. TXBLEND can be used to assess the changes in circulation and salinity that result from various levels of inflows, the shape of the bay system, or the number and location of inlets. TXBLEND projects and displays the range and distribution of salinity patterns in a bay or estuary ecosystem.

A Test of the Guadalupe Estuary

To demonstrate how this methodology can be applied, TWDB and TPWD conducted several case studies of the Guadalupe Estuary using the TXEMP model. Salinity and inflow data from 1968 to 1987 were used in regression analyses. At first, the model was tested so that no individual species would be preferred. The harvest probabilities were set to 50% for all species, except black drum. Boundary conditions were also set for monthly and seasonal inflows and salinity. Ten runs of the model were made to maximize the populations of different combinations of species.



Projected Freshwater Inflow Needs for the Guadalupe Estuary. This figure shows the amount of inflows needed each month in the Guadalupe Estuary, if the objective is to maximize harvests (MaxH). Other modeling efforts show the amount the Texas Department of Water Resources estimated that is needed to maintain harvests, using a 1980 model. Median flows are also represented.

Next, TWDB staff used TXBLEND to develop a grid-based model that simulates flows in three interconnected major bay systems (the Mission-Aransas, Guadalupe, and Lavaca-Colorado). Modelers divided the bay system into triangular units called elements. Areas where complex natural processes occur were divided into smaller elements for more detailed computations. Together, the elements form a computational grid (see map on page 1). Modeling results depicted the flow of water in the system in a 24-hour tidal cycle. Simulated flows were most rapid in areas where bay waters interact with the Gulf of Mexico. Roughly 7.3 million acre-feet (AF) were exchanged at the eastern boundary of the region, while only 1.2 AF flowed through the southwest edge.

What did the modeling results show? The most significant finding is that the freshwater inflow needs developed by TXBLEND are much lower than those generated by previous efforts (see Figure 2). A 1980 TWDB study estimated that 2 million AF of freshwater inflows were needed annually to "maintain" harvests. The TXEMP model showed that only 1 million AF are needed annually to "sustain" harvests. TXEMP projected that reduced inflows would be needed during most of the year, except in July and August. During other scenarios, inflow requirements escalated to as much as 1.5 million AF, depending on which key species were selected for maximum harvests. The model set the inflows as high as possible for the months when high inflows benefited annual harvests, and as low as possible for months when annual harvests would not benefit. The modeling studies show that some species have conflicting inflow needs.

The modeling shed new light on processes that affect the Guadalupe Estuary. The estuary has received increased inflows since 1968, due to increases in runoff from urbanization and return flows. The case study assessed trends in nutrient (specifically nitrogen) transport and sediment loadings. UT researchers (White, 1990) found that a major delta that enters San Antonio Bay is being adversely affected by erosion and subsidence. The study projects that freshwater inflows of 355,235 AF per year will be needed to provide the 182,415 metric tons of sediment the bay system and Mission Lake need.

University Involvement

To prepare the report, TWDB and TPWD sponsored many studies by researchers at universities and Federal and State agencies. Research included hydrology, water quality monitoring, hydrodynamics, coastal geology, water chemistry, nutrient dynamics and processing, and the distribution, abundance, and productivity of estuarine organisms. Some of these studies are summarized below.

William White and Robert Morton at the University of Texas Bureau of Economic Geology (UT BEG) studied how sediments are transported from rivers to coastal areas and how they are distributed in deltas. The goal was to develop a method that links river flows to changes in the delta areas. White took core samples to gather data on top sediments and is using naturally occurring isotopes to trace their origin. He also compared photographs of major deltas taken in the 1930s and recently. White found evidence of major changes in wetland habitats. More data analysis is still needed about sediments, even though monitoring has been reduced and, at many sites, is no longer being done.

Ed Holley of the UT Civil Engineering Department investigated how sediments are transported in the Lower Guadalupe and San Antonio Rivers (1991) in a study funded by TWRI. Jurgen Schmandt of the Houston Advanced Research Center, George Ward of the UT Center for Research in Water Resources, and Susan Hadden of the UT LBJ School of Public Affairs assessed how global warming may affect coastal water supplies, freshwater inflows, and sea level rise. TWDB staff published a study (Longley and others, 1993) that assesses how global warming may alter salinity patterns and fishery harvests in estuaries. Their work suggests that estuaries that now receive large amounts of freshwater are most likely to see reduced inflows and fishery harvests because of climate change.

Many studies are being conducted at UT MSI. Pat Parker and Ken Dunton showed that many estuarine species flourish because of nutrients provided by inflows. Ron Benner and W.B. Yoon led efforts to quantify bacterial uptake and regeneration in the water column and denitrification and that a large amount of nitrogen that is lost. In that study, they cooperated with David Brock of TWDB, who developed balanced nitrogen and nutrient budgets for Texas estuaries . Scott Holt, G. Joan Holt, and Connie Arnold investigated the abundance and distribution of shrimp in the Laguna Madre and studied how finfish and shellfish in south Texas bays use nursery habitat.

Rezneat Darnell and J.D. McEachern of Texas A&M University investigated how juvenile and larval fish and invertebrates are recruited to and migrate into estuaries. The Conrad Blucher Institute for Surveying and Science at TAMU-CC and Lamar University are cooperating in the Texas Coastal Offshore Observation Network. The goal is to record water quality data in bays and estuaries.

Ongoing Efforts, Future Needs

Of course, much more work still needs to be done.

Agencies have been heavily involved in the work. Roger Zimmerman of the National Marine Fisheries Service has developed a device called a macro core drop sampler. The machine, which is like a giant cookie cutter, can be used to gather quantifiable data about organisms that live at vegetated marshes and other sites in bay systems. He was surprised at the diversity of marine life that was found, even after storm surges.

The Corpus Christi National Estuary Program is now funding a hydrodynamic and salinity study and circulation model of the Corpus Christi Bay System from Baffin Bay to San Antonio Bay. It's an adapted version of the model used in the TWDB study. The USGS will assist with the modeling of the Laguna Madre and Baffin Bay and will apply a USGS model to a shallow part of the Laguna Madre.

The U.S. Fish and Wildlife Service is now updating wetland inventory maps based on photographs taken in 1992 and 1993. It hopes to produce statistical summaries of the change that has occurred in wetland areas, plant communities, species use and other factors.

Summary

Certainly, the new study by TWDB and TPWD represents a major advance in our understanding of how freshwater inflows affect various components of bay and estuary ecosystems. Information from these and other studies has given scientists and policy makers new tools that they can use to develop more accurate estimates of freshwater inflow needs. In some areas like sediments, the analytical capability has increased, even though the amount of data that has been collected has declined.

These studies all illustrate that simulating the individual components of an ecosystem is very complicated. Much more information still needs to be gathered, before we can understand how these ecosystems work.

Finally, after all the scientific data on freshwater inflows has been assembled and analyzed, policy makers and legislators still must decide if and how freshwater releases for bay and estuary needs can be provided while still providing freshwater for urban, industrial and agricultural uses.

For More Information

Bao, Y., Y-K. Tung, L. Mays, and G. Ward, 1989, *Analysis of the Effect of Freshwater Inflows on Estuary Fishery Resources*. Center for Research in Water Resources, UT Austin, 1989. Report Submitted to TWDB.

Benner, R., and W.B. Yoon, *Nitrogen Cycling and Bacterial Production, UT Marine Science Institute*, Port Aransas, TX, 1989. Report Submitted to TWDB.

Blanchard, G.F., and P. Montagna, "Photosynthetic Response of Natural Assemblages of Marine Benthic Microalgae to Short- and Long-Term Variations of Incident Irradiance in Baffin Bay, TX," *Journal of Phycology*, Vol. 28, pp. 7-14.

Darnell, R., and J.D. McEachern, *Larval Recruitment of Estuarine Related Fishes and Invertebrates of the Texas Coast*, Texas A&M University, College Station, TX, 1989, Report Submitted to TPWD.

Holley, Edward R., *Sediment Transport in the Lower Guadalupe and San Antonio Rivers*, TR-141, 1987, TWRI, Texas A&M University, College Station, TX.

Holt, S., and C. Arnold, *Nursery Habitat Utilization by Finfish and Shellfish in Lavaca, San Antonio, and Mesquite Bays and their Relationship to Freshwater Inflow*, 1989, UT MSI. Report Submitted to TWDB.

Holt, S., G.J. Holt, and C. Arnold, *Abundance and Distribution of Larval Shrimp in the Laguna Madre*, 1990. Report Submitted to TWDB.

Kalke, R.D., and P. Montagna, "The Effect of Freshwater Inflow on Macrobenthos in the Lavaca River Delta and Upper Lavaca Bay," *Marine Science*, Vol. 32, pp. 49-71.

Longley, W., R. Solis, D. Brock, G. Powell, and G. Malstaff, *Global Warming and Effects of Global Climate Change on Estuarine Salinity Distribution Patterns and Fisheries Harvests in Texas*, TWDB, 1993.

Longley, W. (Editor), *Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs*, TWDB, Austin, TX 1994.

Pulich, W., *Effects of Freshwater Inflows on Estuarine Vascular Plants of Texas Bay Systems*, Texas Parks and Wildlife Dept., 1990. Report Submitted to TWDB.

Regulatory Guidance Document for Applications to Divert, Store and Use State Waters, (Draft), TNRCC, Austin, 1994.

Schmandt, J., G. Ward, and S. Hadden, *Texas and Global Warming: Emissions, Surface Water Supplies, and Sea Level Rise*, LBJ School of Public Affairs, UT, Austin, 1992.

White, W.A., and T.R. Calnan, *Sedimentation and Historical Changes in the Fluvial-Deltaic Wetlands Along the Texas Gulf Coast with Emphasis on the Colorado and Trinity River Deltas,* BEG, UT, Austin, 1990.

TWRI Prints Proceedings from 1995 Water for Texas Conference

TWRI has just published a Proceedings from a major conference, "Water for Texas: Setting the Research Agenda," that was held in Austin in January, 1995. The conference focused on recent water and environmental research by Texas universities and state agencies. A limited number of the proceedings are now for sale at $30 a copy. If you want more information on the speakers and their talks that were included in the proceedings, or how to order a copy, please contact TWRI.