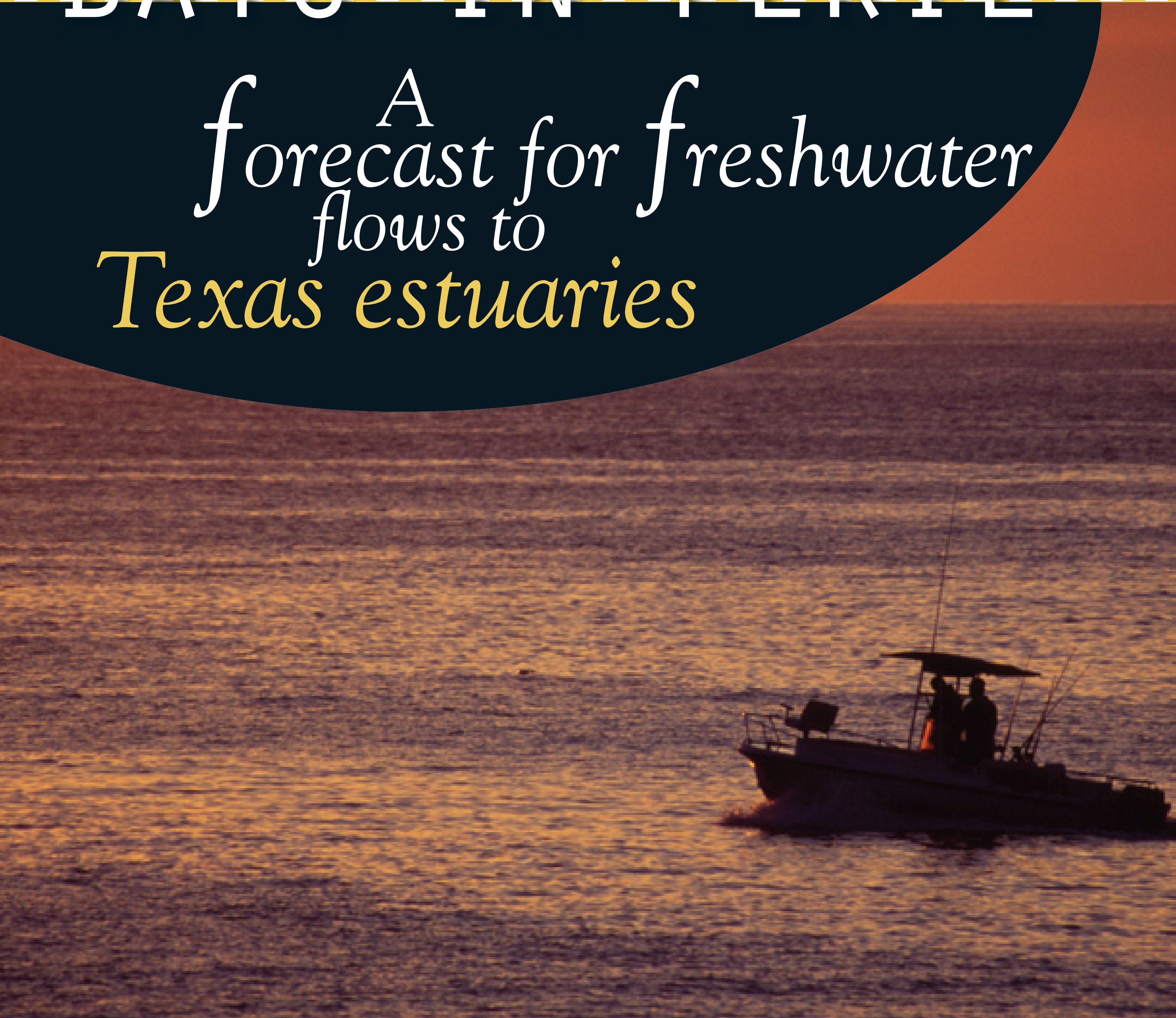
BAYS IN PERIL

A forecast for freshwater flows to Texas estuaries



NATIONAL WILDLIFE FEDERATION
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National Wildlife Federation
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Photo courtesy Texas Parks & Wildlife Dept. © 2004

A combination of drought and human water use on both sides of the U.S.-Mexico border kept the Rio Grande from flowing to the Gulf of Mexico through much of 2001 and 2002.

FOREWORD

One of the greatest conservation challenges America faces in the 21st century is the rescue and restoration of our country's great waters. The Florida Everglades, Chesapeake Bay, the Mississippi River Delta, the Great Lakes, San Francisco Bay and other major waterways have deteriorated significantly over the past century in response to poorly planned development, flood-control, shipping, and industrial and agricultural activities.

As a nation we are slowly waking up to the environmental costs of how we live and do business. We are seeing our fisheries decline, our wetlands disappear, our lakes and rivers polluted, and our native plant and wildlife communities in retreat. As this grim reality dawns, we have begun to invest the billions of dollars it will take to restore these resources for ourselves and for future generations, though much more will be required over the next few decades.

In Texas, fortunately, the outlook is more positive. Though pressure is clearly mounting as the population grows, Texas' seven major bay systems are still reasonably healthy and productive. To the state's great credit, much of the scientific groundwork that decision makers will need to protect these coastal waters has been laid. Equally important, a robust long-term water-planning effort is underway. The National Wildlife Federation has been an active participant in that planning process. We have urged state and regional planners to provide for the water needs of wildlife and the environment along with human needs. We want to ensure that our generation's legacy will include a thriving coastal ecosystem, not a massive bill for restoration.

With this report, the National Wildlife Federation takes a serious look at what could be the future for Texas' coastal waters. We hope it will shed light on what's at stake for the Texas coast and on what must be done *soon* to protect it.

Larry J. Schweiger
President and Chief Executive Officer
National Wildlife Federation

EXECUTIVE SUMMARY

WHERE THE RIVER MEETS THE SEA

Texas coastal estuaries, where fresh river water mixes with the salty waters of the Gulf of Mexico, support an amazing abundance of wildlife. Young fish and shrimp feed and hide in brackish estuary waters until they are mature enough to survive in the Gulf of Mexico. Resident and migratory birds by the thousands rest and feed in estuarine marshes. Oysters are found only in estuaries. In fact, 95 percent of the Gulf's recreationally and commercially important fish and other marine species rely on estuaries during some part of their life cycle.

What keeps these unique coastal waters healthy and productive is the freshwater flowing into them from Texas rivers. Without adequate freshwater inflows, water quality would suffer, many species would be unable to reproduce or grow, and the estuaries themselves, as nurseries and habitat for a vast array of marine life, would decline.

THREATS FROM UPSTREAM

Despite their importance, Texas estuaries face an uncertain future because they are last in line, both physically and legally, to get a share of our publicly owned rivers. More and more water is being withdrawn from our rivers upstream to meet inland water demands. Since estuaries have no legal claim on the rivers' flows, larger upstream withdrawals mean less water for the coast. In some river basins, the state has issued permits to *take out* more water than will actually be *in* the river during drier years, meaning freshwater inflows to the coast could essentially cease at times. Fortunately, much of the water now authorized for withdrawal is not actually being withdrawn each year. But that will change as Texas' population grows and current permit holders increasingly sell whatever water they're not using. With increased demand for a limited resource, full use of these existing water permits is coming closer and closer.

To compound matters, cities, businesses and other permit holders are finding new ways to *re-use* wastewater—for landscape irrigation, for example, or industrial cooling systems—rather than discharge it back into the river. While reuse can be an efficient water use, it also reduces the 'return flows' that are all that keep some rivers flowing during drier times. The challenge is to find the right balance in meeting human water needs and protecting our rivers and bays.

WHAT'S AHEAD FOR FRESHWATER INFLOWS?

In this report, the National Wildlife Federation takes a first-ever look at what would happen to the inflows to Texas' seven major estuaries if existing water permits were fully used and wastewater reuse increased. We projected what freshwater inflows would be for each estuary if holders of *all* existing permits withdrew their *full authorized amount* of water and if the amount of wastewater that was reused rather than discharged back into the river increased to roughly 50 percent.

While this 'future use' scenario may seem somewhat hypothetical, we believe these conditions are likely to be seen in the not-too-distant future if Texas does not change how it manages water. In addition, our analysis considers only impacts from current water permits and does not attempt to account for new water-use permits that are likely to be issued.

To quantify expected inflows we used computer models developed for the Texas Commission on Environmental Quality. These models predict what inflows to each estuary would have been under 'naturalized conditions,' i.e., if there were no dams or pipelines or other human-induced alterations in the river's flow pattern, and if there were a repeat of past rainfall patterns. We also used the models to predict what freshwater inflows to each estuary would be with the same rainfall but with the 'future use' (full permit use/50 percent reuse) scenario.

Having determined the freshwater inflows each bay would receive under 'naturalized conditions' and under our 'future use' scenario, we then looked at how the future-use inflows stack up against what each estuary system needs to stay healthy.

Estuary System	Periods Below Drought Tolerance Levels			Years With Low Freshwater Pulses			Overall Ranking
	Naturalized Conditions	Future Use	Increase	Naturalized Conditions	Future Use	Increase	
Sabine Lake	2	10	400%	23	34	48%	Danger
Galveston Bay	0	5	>500%	10	16	60%	Danger
Matagorda Bay	3	20	567%	16	31	94%	Danger
San Antonio Bay	2	7	250%	19	24	26%	Danger
Copano/Aransas Bays	6	6	0%	21	21	0%	Good
Corpus Christi Bay	2	6	NA	13	35	169%	Danger
Upper Laguna Madre	3	3	0%	15	15	0%	Good

See glossary on page 5

FRESHWATER: HOW MUCH IS ENOUGH?

To determine how much freshwater a given estuary needs, we used two inflow criteria we developed from state studies. The first addresses what each estuary needs during low-rainfall periods. These 'drought tolerance levels' are the inflows needed to keep salinity conditions within reasonable tolerance ranges for key species. The second criterion addresses the important 'freshwater pulses' of high inflows that naturally occur in the spring and early summer of most years. These 'freshwater pulses' support strong levels of reproduction and growth.

Even if humans were not using any water, the estuaries would not always receive enough freshwater inflows to satisfy these two criteria. Rainfall varies from year to year and the fish and wildlife that depend on estuaries are adapted to these naturally varying conditions. The challenge is to avoid patterns of water use (and reuse) that push inflows below one or both criteria so often that fish and wildlife can no longer cope.

As a starting point for our comparisons, we looked at how often the inflows predicted under 'naturalized conditions' fell below each of the two inflow criteria over roughly a 50-year period. The frequency of periods of 'below-criteria' inflows under 'naturalized conditions' became a baseline for each estuary, because it reflects *natural* variations in inflows.

We then looked at how often the inflows predicted under the 'future use' scenario (full permit use/50 percent reuse) for the same time period would fall below the inflow criteria. Finally, we compared the results by calculating, as a percentage, how much more often inflows predicted under the 'future use' scenario fell below one or both criteria when compared to the baseline. For example, if our results showed that the number of times the freshwater pulse target was not met increased from two years under 'naturalized conditions' to four years under the 'future use' scenario, we indicated a 100 percent increase in 'years with low freshwater pulses.' We calculated percentage changes for each criterion for each estuary.

EXECUTIVE SUMMARY

OUR RANKING SYSTEM

An estuary can't stay healthy and productive if it experiences too many years without strong freshwater pulses or if it endures too many prolonged periods of inflows below drought tolerance levels. Because a large increase in the frequency of either of these conditions signals real problems, we used the higher of the two percentage-increase calculations to assign an overall ranking for the estuary. We assumed, however, that the estuaries can tolerate some increase in how often inflows would fall below the criteria. We considered an estuary's prospects 'good' if our assessment showed no more than a 33 percent (or 1/3) increase in periods with inflows below either criterion. We assigned a 'caution' ranking if the increase fell between 33 percent and 67 percent. A 'danger' ranking resulted only if the analysis predicted a 67 percent (or 2/3) or greater increase in periods with inflows below at least one of the criteria. More study is needed to determine if estuaries would be seriously harmed by smaller changes than those used as the basis of assessment here. Because each estuary has developed in response to unique patterns of inflow pulses and of low inflows, our analysis does not attempt to make comparisons between different estuaries.

Photo courtesy Texas Parks & Wildlife Dept. © 2004, Earl Nottingham

WHAT WE FOUND

The results of our analysis are troubling, with five estuaries receiving a 'danger' ranking. During dry times, four of Texas' seven major estuaries would face serious problems under the 'future use' scenario, with sustained periods of very low flows happening much more frequently than under 'naturalized conditions.' During these low-flow periods, many species are on life-support and are just able to survive. If they are on life-support too often or for too long, they may be unable to recover quickly, or at all, when inflows increase with wetter times. The key spring and early summer inflow pulses needed to support strong productivity would not be impacted as heavily. Two of the seven major estuaries would face very large increases in the number of years with reduced spring and early summer inflow pulses.

Overall Ranking	Increase in Problem Conditions
Good	0% to 33%
Caution	above 33% but below 67%
Danger	67% or greater

WHAT WE CAN DO ABOUT IT

Water is the lifeblood of our Texas landscape. Texas rivers provide water and habitat for fish and wildlife throughout the state and provide the freshwater that keeps coastal estuaries functioning and healthy. Unfortunately, we haven't done a very good job of protecting our rivers. Most water-use permits were issued without any consideration of how much flow should be left in the river to protect water quality, fish and wildlife, and human recreational activities.

Even today, the state hasn't come to grips with how to protect river flows and freshwater inflows to the coast. The state and 16 regional water planning groups are developing plans to meet water demands for the next 50 years, but so far that process does not include freshwater inflows as a water demand to be met.

Water planning and management involve choices. For example, planners and managers can choose to improve water-use efficiency to support more people with the same amount of water and reduce the need for new reservoirs. Lawmakers can choose to formally set aside river flows that haven't yet been allocated to make sure those flows will remain available for fish and wildlife. We can develop voluntary methods to convert some existing unused permits from their original purpose to a new use for protecting river flows and freshwater inflows.

In short, we can avoid the severe damage to our estuaries that this analysis predicts. Texas can have water development policies that meet our increasing human demands for water while also protecting our natural heritage. The vast majority of Texans want strong protections for Texas rivers and estuaries. If we get that message to state and local leaders, we can pass on to future Texans the same beauty and bounty from Texas bays that we inherited.

GLOSSARY OF KEY CONCEPTS

Naturalized Conditions:
A computer model scenario showing freshwater inflow amounts that would have occurred during about a 50-year period if there had not been water withdrawals, dams, or other human alterations of inflow patterns. Used as a baseline for comparison.

Future Use:
A computer model scenario showing freshwater inflow amounts during the same period as for naturalized conditions if all *existing* water withdrawal permits were fully used and levels of wastewater reuse were increased to about 50%.

Periods Below Drought Tolerance Levels:
A determination of the number of periods of six consecutive months of very low freshwater inflows, within a March-October window. During such periods, inflows would not be adequate to keep salinity levels within state-determined salinity bounds for key species, resulting in stressful conditions and in reduced reproduction and survival.

Years With Low Freshwater Pulses:
A determination of the number of years during which the important spring or early summer pulses of high freshwater inflows are below target levels. These pulses are needed to support strong reproduction and growth of key estuarine species.

For More Information

You can learn more about the Texas Living Waters Project at www.texaswatermatters.org or at www.nwf.org. To get involved in protecting our rivers and bays, contact the National Wildlife Federation at 1-800-919-9151 or mcmahon@nwf.org.

INTRODUCTION

INTRODUCTION

Most Texans know the names of our major rivers: the Trinity, the Colorado, the Guadalupe, to name a few. These rivers and others are vital to Texans' wellbeing: they provide most of our drinking water, they offer scenic and recreational benefits, and they finish the job of treating our municipal and industrial wastewater. Another role our rivers play is less well known but equally critical: they support a string of coastal bays, or estuaries, along the 360-mile Texas coastline. The freshwater flowing from our rivers into bays and mixing there with the salty water from the Gulf of Mexico defines these estuaries and makes them among the most productive natural environments on the planet, on a par with tropical rainforests. The abundant fish and wildlife populations they support are important to both the ecology and the economy of the state.

Though freshwater inflows are essential to their productivity, Texas estuaries are not guaranteed the water they need. Until fairly recently, in fact, it was a common observation among many water suppliers and managers that any surface water making it all the way to the coast was wasted water and a sign of inefficiency. Inland water use, for municipal, agricultural or industrial purposes, was considered the only productive use of this resource. Now we understand better the essential role estuaries play in our economy and our coastal environment, but our water management policies and practices do not yet reflect that understanding. Texas estuaries remain last in line—not just physically but also legally—to get a share of freshwater from our rivers.

As upstream water demands increase along with a population expected to double in the next 50 years, it is less and less likely that our estuaries can remain healthy unless we take affirmative steps now to protect them. Thus Texas has reached a critical juncture in the management of its water resources. While we obviously must meet the water needs of our growing population, we must do it in a way that also provides for the needs of our coastal fish and wildlife and the people who depend on them for their livelihoods and their quality of life. If we fail to do so, we will deprive future generations of Texans of the benefit and enjoyment of the natural heritage that we inherited.

In this report, the National Wildlife Federation (NWF) looks at how Texas bays will fare if the state doesn't change its approach to water management. In particular, we examine how the future use of *existing* water-use permits is likely to affect freshwater inflows and, by extension, the wildlife, people, and economic activity that depend on those inflows. It is our hope that this analysis can contribute to better informed decisions about the future management of water in Texas.

ESTUARIES: WHAT THEY ARE, WHAT THEY DO

Texas' estuaries, or bays as they are more commonly known, are the areas where freshwater from our rivers and streams mixes with saltwater from the Gulf of Mexico. This transition zone creates a unique and highly productive habitat for fish and wildlife. The freshwater not only maintains a balance in salinity, it also delivers sediments that replenish marshlands and nutrients that form the basis of the food chain. Virtually all of the marine species that are important for recreational or commercial activities in Texas require specific, inflow-dependent estuary conditions at crucial times in their life cycles. For instance, adult shrimp and crabs lay their eggs offshore in the open Gulf, but the larval stages are transported back into the estuaries by tides during the springtime. These larval and juvenile stages thrive and grow if adequate 'nursery' conditions are found in the estuary, especially moderate salinity. Oysters are only found in estuaries and

Illustration courtesy Texas Parks and Wildlife Dept. © 2004 are directly dependent on freshwater inflow to maintain salinities and temperatures at levels that keep parasites in check.

Without healthy and productive estuaries, populations of shrimp, redfish, crabs, and oysters, as well as many other species of aquatic life, would decline. The birds and other wildlife that rely on those species would also suffer. And because fish and wildlife support commercial and recreational fishing and coastal tourism activities, billions of dollars of economic activity would be sacrificed. [1]

FRESHWATER INFLOWS: HOW MUCH AND WHEN?

It has long been recognized by scientists that sufficient amounts of freshwater inflows arriving at the appropriate times are critical to maintaining healthy and productive estuaries. However, it is no simple matter to figure out just what those right amounts and rights times are.

At the direction of the state Legislature, the Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department have been studying this topic for decades.[2] These state agencies have gathered detailed data on inflows and made hundreds of measurements of temperature, nutrient levels, salinity, and abundance for key species at dozens of sites in the estuaries along the Texas coast. The data were then used by the TWDB to develop a range of inflow amounts and patterns that would provide differing levels of protection for bay productivity. Using the TWDB options, the Texas Parks and Wildlife Department (TPWD) has developed a set of recommended monthly freshwater inflow values for each major estuary. These 'target' inflows represent amounts determined to be adequate to maintain strong productivity of the principal recreational and commercial species in each of Texas' seven major estuaries[3].

Even if there were no diversions of water for human use upstream, these target inflows would not be met consistently during a serious and prolonged drought. Basically, during a drought, estuarine-dependent organisms are on life support. If enough of them survive the drought, they can quickly repopulate the estuary when inflow levels increase. Droughts are a natural occurrence in Texas, and our estuaries have survived them in the past. But if human diversions of water upstream have the effect of seriously extending drought conditions in the estuary, or if they reduce drought-period inflows too dramatically, that recovery may never come. To allow comprehensive assessments of inflow adequacy and to fully inform management decisions, drought-period inflow criteria are also needed.

Although TPWD did not develop explicit drought-period inflow recommendations, the state's methodology does include a set of significantly lower monthly values called MinQsal inflows. Those inflows are calculated to be sufficient just to maintain salinity levels in the estuary within tolerance limits for key species. These lower values, which we will refer to as 'drought-tolerance levels,' reflect the inflow amounts needed "to avoid reproductive failure and loss of biodiversity" during lower inflow periods.[4] As discussed in the Methodology section, we have made use of both the 'target' values, which are incorporated into the 'freshwater pulse' criteria, and 'drought-tolerance levels' in our assessment of the adequacy of future inflows to Texas estuaries.

The seven major estuaries in Texas vary tremendously. Each has unique characteristics and each developed in response to unique circumstances. Accordingly, the modeling results and inflow recommendations for the estuaries also vary widely. There simply is no "one size fits all" inflow prescription.

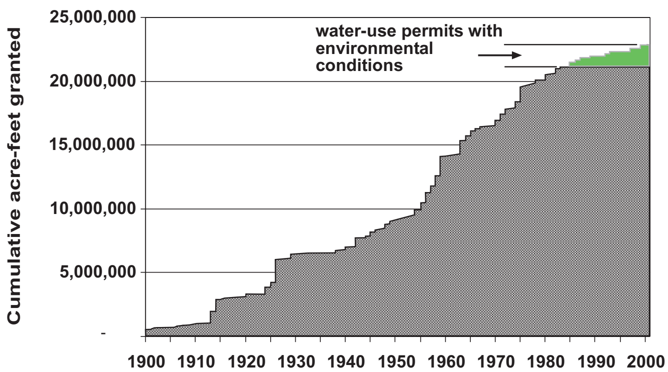
WATER-USE: WHY INFLOW AMOUNTS ARE CHANGING

Texas bays are at risk because human water demands are increasing and because the state's system for allocating water does not adequately recognize environmental water needs. The population of Texas is projected to almost double by 2050. Much of this anticipated growth is concentrated in the river basins that nourish our bays. For example, the combined population of the Houston and Dallas-Fort Worth areas is expected to nearly double, to 19.2 million, by 2050. Both of these metropolitan areas consume the waters that drain to Galveston Bay. We have choices to make about how we meet the water needs of that growing population. If we continue to use all the water we can capture, we will eventually reach a point where the environmental and economic impacts of our water use become unacceptable. If we can use water more efficiently and find ways to set aside some water for coastal inflows, we can keep the estuaries productive for generations to come.

In Texas, surface water—the water in rivers, lakes, and streams—is public property, owned in common by all Texans. For more than 100 years, the state has granted cities, farmers, businesses and other water users the legal right to withdraw specified amounts of surface waters for their own use. Rights to withdraw water under this permitting system are perpetual (i.e., they never expire) and with limited exceptions, are administered through a 'prior appropriation' system. This means that the person or entity with the oldest water-use permit (also known as the 'senior permit') has the first claim on the water.[5]

When Texas was sparsely populated, its rivers flowed primarily to the benefit of fish and wildlife. Those flows seemed so abundant and human water demands so modest that when Texas adopted the beginnings of its system of permits for water withdrawals in 1889, lawmakers had little cause to consider how water diversions might affect fish and wildlife or the quality of water in the rivers themselves. As more and more river flows were diverted to other uses, however, the effects on fish and wildlife

Figure I1 - Timeline of all consumptive water-use permits granted by state of Texas.



Source: data from Texas Commission on Environmental Quality.

intensified. Unfortunately, not until 1985 did the state formally recognize that water permits should include conditions to protect fish and wildlife resources and associated recreational activities. By then, the state had already granted perpetual permits for more than 21 million acre-feet[6] of water per year, or about 92 percent of all the water-use permits issued up to the present. (See Figure I-1 above.) Only the rarest of those older permits includes any type of condition to protect fish and wildlife.

The protective conditions included in post-1985 water permits are vitally important for many reasons. Those conditions, which often require that some amount of water be allowed to flow past a dam or point of withdrawal, help to minimize adverse impacts to fish and wildlife especially during dry periods. However, those conditions do nothing to address the problems created by senior permits granted without such protections.

As our population and economy have grown, more and more of our surface water has been authorized for use. (And much of what isn't yet spoken for might soon be authorized under new water-permit applications that are pending today.) There is good news and bad news regarding existing water-use permits. The bad news is that, statewide, we have authorized the use of more water than would be available during drier years. In other words, we've effectively authorized permit holders to pump some of our streams and rivers dry. The good news is that many permit holders are not even close to withdrawing and using all the water they are legally entitled to. Of course that situation is changing; with population on the rise, permit holders with water to spare are increasingly selling their water-use permits to other users. Before long, more of our rivers could end up like the Rio Grande, which in recent years dried up before it reached the Gulf of Mexico and even ceased to flow in Big Bend National Park.[7] But right now we have the opportunity, if we act quickly, to avoid seriously damaging most of our rivers and the estuaries that depend on them.

NATIONAL WILDLIFE FEDERATION STUDY

Using state computer models and starting with the results of the inflow studies by the state agencies, we have analyzed how anticipated growth in human water use will decrease the likelihood that Texas estuaries will get the freshwater they need to stay productive. In a nutshell, NWF used the state studies to develop specific inflow criteria for each estuary system and then used state computer models to predict how often those criteria would be met.

As a result of state agency efforts, Texas has made a great start in quantifying the freshwater inflow needs of its estuaries. However, some additional factors must be addressed before these inflow recommendations can be used as management tools. River flows vary naturally with variations in weather conditions, and it is not reasonable to expect all inflow criteria to be met at all times. It is therefore essential to consider *how often* the recommended inflow values must be met, and if they won't be met, *how much deviation* from the recommended magnitude, timing, or duration of freshwater inflows is acceptable. As discussed further in the Methodology section, NWF has developed ecologically-based criteria that offer a way to consider these critical questions.

NWF assessed two sets of flow conditions for each estuary. One assessment, called the 'spring/early summer freshwater pulse' analysis, considers the adequacy of inflows under normal rainfall conditions. Those are the times when the estuaries would be expected to be thriving and highly productive. The second assessment, called the 'drought tolerance' analysis, evaluates inflows during low rainfall, or drought-like conditions. Under those conditions, the estuaries are expected to be under significant stress; the key management concern is the survival of key species rather than strong productivity.

For each assessment, NWF first established a baseline by determining how often the assessment criterion would have been met under 'naturalized conditions.' 'Naturalized conditions' are a computer model prediction of what flows would have been, given a repeat of weather patterns over a particular historical period, without any dams or pipelines or other human-induced alterations in a river's flows. NWF then determined, using the same state computer models, how often the criterion would be met if existing water-use permits were fully exercised. Because weather patterns are the same for each model run, a comparison of these two computer runs makes it possible to isolate the changes caused solely by different water-use levels.

In this analysis, NWF looks only at how increased use of *existing* water-use permits along with increased wastewater reuse may impact freshwater inflows. Although applications are pending for additional water-use permits that could dramatically reduce freshwater inflows from the levels evaluated here, those impacts are not included in our assessments. Evaluating the impacts of those additional diversions would require assumptions about protective conditions that may or may not be included in requested permits and is beyond the scope of this analysis.

The results of NWF's analysis are presented and interpreted in the following pages. Because the long-term health of an estuary depends on both maintaining strong productivity and surviving droughts, NWF based its overall score for each estuary on whichever assessment (freshwater pulse or drought tolerance) showed the greater change from the baseline. For each estuary, we assigned an overall ranking of 'good', 'caution', or 'danger', based on the prognosis for inflows with the full use of existing water rights.

The seven bay systems that line the Texas coast are natural treasures as well as economic engines for our state. The National Wildlife Federation hopes this study will alert Texans to the incomparable value of our coastal resources and to the urgent need to protect them for future generations.

[1] McKinney, L.D. 2004. Why Bays Matter. Texas Parks and Wildlife Magazine, pg. 24-25, July.

[2] Loeffler, C. 2003. How Do We Know How Much Fresh Water Bays Need? Texas Parks and Wildlife Magazine, pg. 25, July.

[3] For example see, Texas Parks and Wildlife Department, 1998. Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas.

[4] The low-flow criteria is know as MinQsal in all estuaries. MinQsal definition is from Powell, G., Matsumoto J., and Brock, D. A., .2002. Methods for Determining Minimum Freshwater Inflow Needs of Texas Bays and Estuaries, Estuaries, Vol. 25, pg 1271.

[5] In wetter periods when water is plentiful, seniority date is largely irrelevant because there is enough water to satisfy all permits. In drier periods, however, there may not be. Under the prior appropriation system, a junior (later in time) water permit holder is not entitled to take any water unless those with older water-use permits have already exercised their rights.

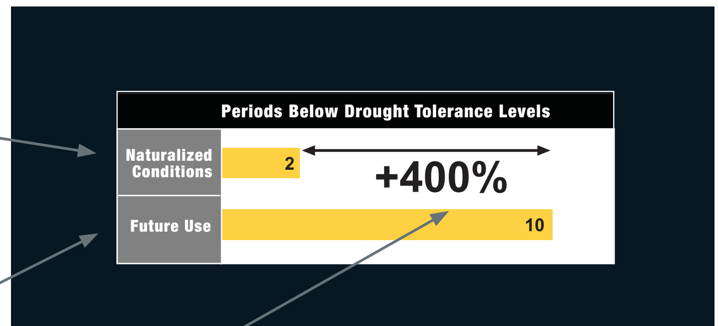
[6] An acre-foot of water is the amount that would cover an acre to a depth of one foot. One acre-foot equals approximately 326,000 gallons.

[7] The Rio Grande is somewhat unique because it is an international river; water management in Mexico as well as in Colorado, New Mexico, and Texas affects its flow. It is also a dramatically altered river system that in many places functions more as a water delivery canal than as a river. As a result, the fish and wildlife resources along the Rio Grande are impaired. Those problems came to a head in recent years as a combination of overuse and drought caused the river to dry up at key locations. Fortunately, rains have been good in 2004 and conditions in the Rio Grande have improved greatly, at least for now.

SHORT-HAND GUIDE TO

This short-hand guide is provided for quick reference and basic interpretation of the bay-by-bay results on the following pages. For the full details of our assessment method, please see the explanation in the Methodology section on page 28.

Step 1:
Assessment of 'Periods Below Drought Tolerance Levels'
We assessed how often each estuary would experience 'periods below drought tolerance levels.'



A. First, we modeled freshwater inflows under 'naturalized conditions' and assessed how often the predicted freshwater inflows fell below the drought tolerance criterion. This became the baseline.

B. Next, we used the same computer models to predict freshwater inflows under a 'future use' scenario (full use of existing permits and 50% wastewater reuse). Again, we assessed how often the predicted freshwater inflows fell below the drought tolerance criterion.

C. Finally, we compared the results of the 'naturalized conditions' and the 'future use' scenario and calculated the percentage increase in how often freshwater inflows fell below the drought tolerance criterion.

Step 2:
Assessment of 'Years With Low Freshwater Pulses'
We repeated all three stages in Step 1, but this time using the 'years with low freshwater pulses' criterion.

Step 3:

Assigning Each Bay an Overall Ranking
Meeting both the drought tolerance and freshwater pulse criteria is vital to the health of a bay system. Therefore, we assigned an overall ranking of 'good,' 'caution,' or 'danger' based on the assessment step that indicated the largest percentage increase in how often freshwater inflows fall below a criterion. The more inflow patterns are changed, the more likely the estuary system will be adversely affected, perhaps permanently.

INTERPRETING THE BAY-BY-BAY RESULTS

GLOSSARY OF KEY CONCEPTS

Freshwater Inflows:
The water that flows into estuaries from rivers and streams. This water keeps coastal bays healthy and productive by lowering salinity levels and by delivering valuable nutrients and sediments that have made their way down the river systems. Without adequate freshwater inflows, water quality would suffer, many species would be unable to reproduce or grow, and the estuaries themselves, as nurseries and habitat for a vast array of marine life, would decline.

Naturalized Conditions:
A computer model scenario showing freshwater inflow amounts that would have occurred during about a 50-year period if there had not been water withdrawals, dams, or other human alterations of inflow patterns. Used as a baseline for comparison.

Future Use:
A computer model scenario showing freshwater inflow amounts during the same period as for naturalized conditions if all existing water withdrawal permits were fully used and levels of wastewater reuse were increased to about 50%.

Periods Below Drought Tolerance Levels:
A determination of the number of periods of six consecutive months of very low freshwater inflows, within a March-October window. During such periods, inflows would not be adequate to keep salinity levels within state-determined salinity bounds for key species, resulting in stressful conditions and in reduced reproduction and survival.

Years With Low Freshwater Pulses:
A determination of the number of years during which the important spring or early summer pulses of high freshwater inflows are below target levels. These pulses are needed to support strong reproduction and growth of key estuarine species.

Overall Ranking	Increase in Problem Conditions	Interpretation
Good	0% to 33%	Good Projected increase in occurrence of problem conditions is small to moderate. Impacts to bay health are also expected to be no worse than moderate.
Caution	above 33% but below 67%	Caution Projected increase in occurrence of problem conditions is moderate to high. Although bay health would suffer, the impacts are not expected to be severe.
Danger	67% or greater	Danger Projected increase in occurrence of problem conditions is severe. Resulting impacts to bay health also are expected to be severe.

SABINE LAKE

Photo courtesy Texas Parks & Wildlife Dept. © 2004 Earl Nottingham

Sabine Lake lies on the boundary between Louisiana and Texas and it has a distinctly different character from Texas' other estuary systems. It is the smallest of the state's major estuaries and receives inflows from the wettest portions of the state. As a result, it is almost as much a freshwater lake as it is a coastal estuary. Formed by the Sabine and Neches rivers, it is the only place in Texas where it is occasionally possible to find redfish and flounder swimming alongside largemouth bass.

Sabine Lake has been dramatically altered over the years. Not only is it home to numerous refineries and petrochemical plants, its opening to the Gulf—once a mere 50 feet wide—has been dredged and widened. The resulting saltwater encroachment has left the estuary in a precarious position. If more saltwater is allowed into the bay, or if freshwater inflows are substantially reduced, the increased salinities will make Sabine Lake far less productive than it is today.

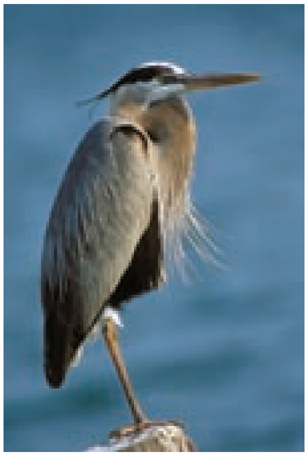
Maintaining adequate and properly timed inflows from the Sabine and Neches rivers is critical to maintaining the health of Sabine Lake's unique and fragile ecosystem. Currently, about 1.2 million acre-feet of water are withdrawn every year from the Sabine Lake watershed. Existing water-use permits authorize withdrawals up to about 4.6 million acre-feet/year, including 750,000 acre-feet/year in the State of Louisiana. Our analysis is based on these existing permits. Applications are pending for new permits that could divert an additional 300,000 acre-feet of water from the basin.

ANALYSIS OF PROJECTED FRESHWATER INFLOW

This analysis looks at the potential impact to Sabine Lake's freshwater inflows if all of the currently authorized water-use permits were fully used and if wastewater reuse levels increased to 50%. For consistency with state agency assumptions, no return flows are assumed for the Louisiana water permits[1]. As with all the estuaries, we focused on two inflow criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the early season freshwater-inflow pulse important for maintaining strong productivity. For Sabine Lake, the key freshwater pulse comes early, during the January-April period.

Our analysis shows that Sabine Lake will be severely affected by water diversions during periods of low rainfall. **Under 'naturalized conditions,' there would have been only two periods when inflows stayed below the drought tolerance level for six consecutive months. That would increase by 400%, to ten periods of six consecutive months, under the 'future use' scenario (full permit use and 50% wastewater reuse).**

The assessment of freshwater pulses showed changes that are also cause for concern. **Under 'naturalized conditions,' there would have been**



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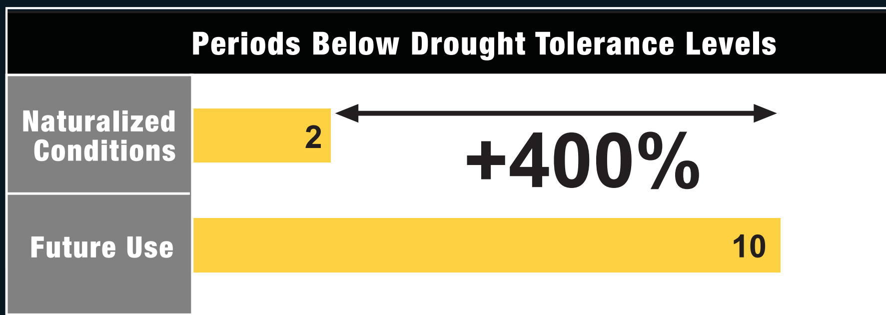
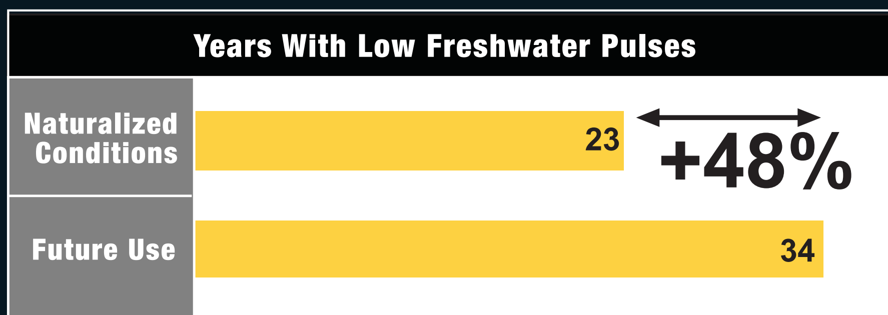


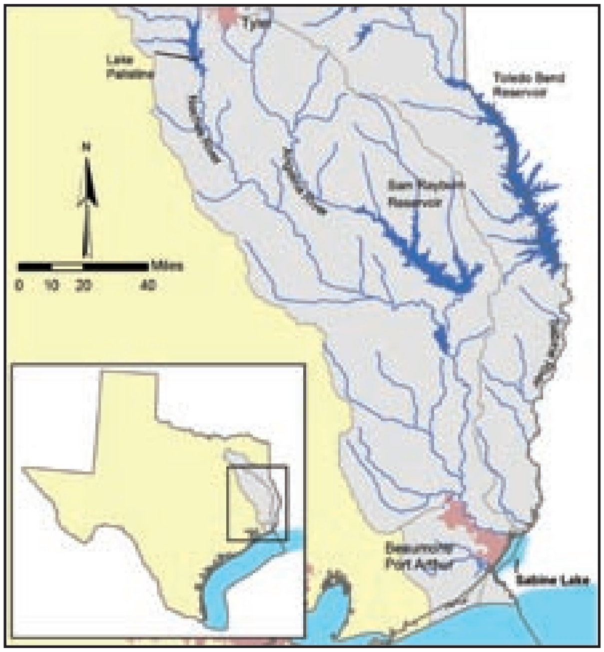


23 years with low freshwater pulses in the January-April window. Under the 'future use' scenario, the number of years with low freshwater pulses climbs to 34, an increase of 48%.

The 400% increase in six-month periods below the drought tolerance levels triggers an overall 'danger' ranking for Sabine Lake.

Protecting inflows to Sabine Lake presents some special challenges for Texas planners and policy-makers because water-management decisions made in Louisiana will also affect inflows. Fortunately, current water use in the contributing watersheds in both states is still relatively small so there are many opportunities to avoid the impacts shown in our analysis. It is likely that the greatest increases in water use will come about as a result of transfers of water to users outside Sabine Lake's drainage area. Because these interbasin transfers require special permits, the state could impose permit conditions that would protect critical inflows. Even so, the movement of water outside of the drainage area poses a potential threat to the estuary, since it eliminates the benefits of wastewater return flows.

[1] As a check, we also ran an evaluation that did assume return flows for the Louisiana rights. It did not affect the drought-tolerance assessment. With that assumption, the predicted increase in years with low freshwater pulses went from 48% to 43%.



GALVESTON BAY

Photo courtesy Texas Parks & Wildlife Dept. © 2004, Earl Nottingham

The Galveston Bay system, which also includes Trinity, East, and West bays, is the largest and most productive estuary in Texas. The shallow waters covering the bay's 600 square miles produce more oysters than any other body of water in the country. The area's blue crab and shrimp harvests are some of the largest in the state. The bay is vast and varied, ranging from brackish bayous to tidal marshes, from oyster beds to mud flats. These diverse waters are also home to Atlantic croaker, flounder, spotted seatrout, and many other species of finfish. Nearly three hundred different kinds of birds have been seen in the area around Galveston Bay.

Galveston Bay is clearly a functioning ecosystem, but it is far from pristine. It is home to petroleum refineries, chemical plants, oil drilling rigs and the Houston Ship Channel. The bay receives copious amounts of urban runoff. Due to subsidence and other impacts, the bay has lost tens of thousands of acres of wetlands over the last century.

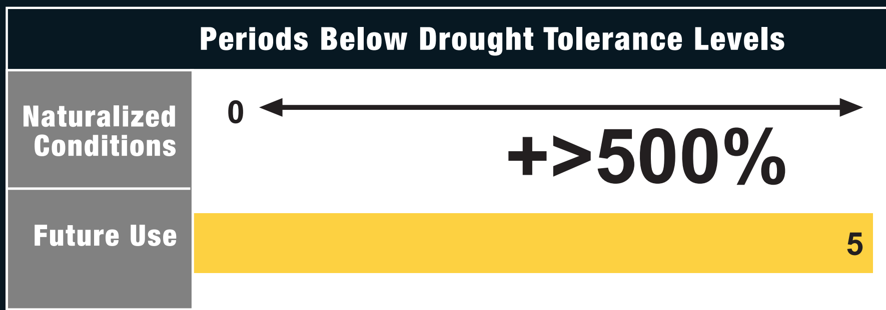
The bay's continued productivity is due in no small measure to the large amounts of freshwater inflows it receives from the Trinity and San Jacinto rivers and several smaller bayous. The Trinity River alone contributes approximately half of the freshwater inflow to the bay. These inflows contribute nutrients and sediments, create the moderate salinities that are crucial for many species, and help flush pollutants out into the Gulf.

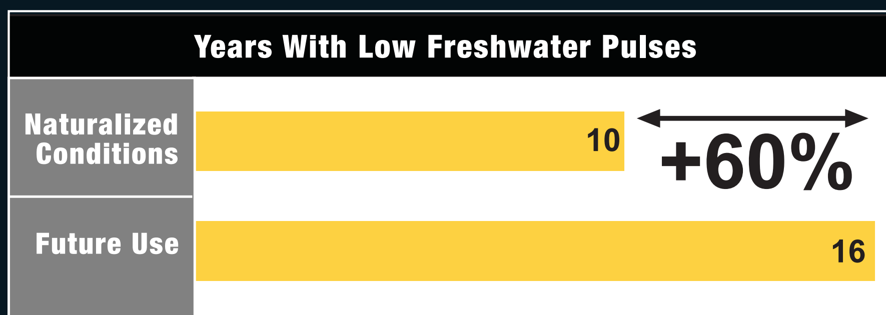
The Trinity and San Jacinto rivers are also the primary sources of water for two of the nation's largest and fastest-growing metropolitan areas. The combined population of the Houston and Dallas-Fort Worth areas is projected to grow to 19.2 million by 2050, nearly double today's total. Currently, about 2.2 million acre-feet are withdrawn every year from the rivers and streams nourishing Galveston Bay, but existing water permits authorize withdrawals to increase to 4.9 million acre-feet/year. Various wastewater reuse projects, involving hundreds of thousands of acre-feet, are already underway or planned. Also, applications have been filed for permits to authorize almost 250,000 acre-feet of additional withdrawals.

ANALYSIS OF PROJECTED FRESHWATER INFLOWS

Our analysis examined the potential impact to Galveston Bay's freshwater inflows if all of the currently authorized permits to withdraw water are fully utilized and if wastewater reuse increases to 50%. We focused on two inflow criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the spring/summer freshwater inflow pulse that is important for maintaining strong productivity.

Photo courtesy Texas Parks & Wildlife Dept. © 2004, Earl Nottingham



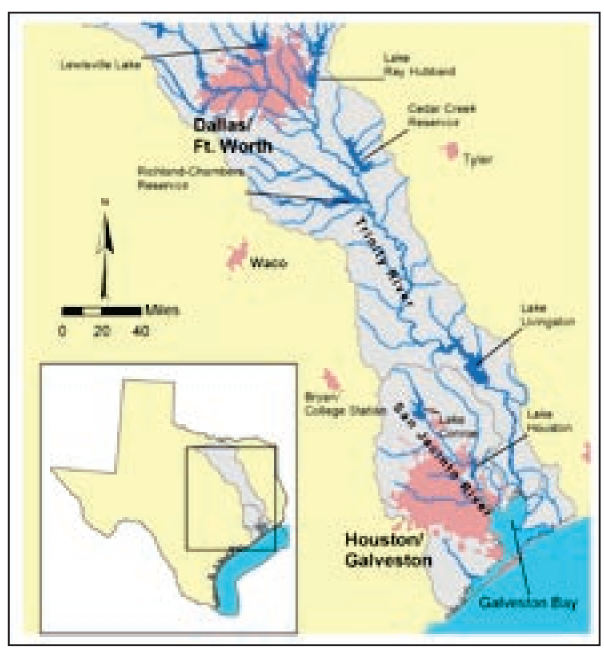


Our analysis shows that Galveston Bay will experience severe impacts during periods of low rainfall. **Under 'naturalized conditions,' inflows never stayed below the drought tolerance levels for six consecutive months. However, with the 'future use' scenario (full permit use and 50% wastewater reuse), five such periods of six consecutive months would occur. That is equivalent to an increase of over 500%.**

The results of the assessment of freshwater pulses also showed troubling changes. **The number of years with low fresh water pulses during the March-June window increases from 10 under 'naturalized conditions' to 16 under the 'future use' scenario, a 60% increase.**

The increase of over 500% in 'periods below drought tolerance levels' results in an overall 'danger' ranking for Galveston Bay.

With two of the state's largest population centers, the watersheds feeding Galveston Bay have been greatly altered by many dams and withdrawals for consumptive use. Fortunately, because many water permits are not yet fully used, we have the opportunity to make changes to avoid these projected results. One key measure that would help avoid prolonged periods of inflows below the drought tolerance levels would be the dedication of a significant amount of return flows to freshwater inflow purposes. Additionally, some existing, but currently unused, water permits could be converted to use for protection of freshwater inflows.



MATAGORDA BAY

Photo courtesy Texas Parks & Wildlife Dept. © 2004

The name Matagorda, which loosely translates to "dense cane," reflects the abundant saltwater grasses that lined the bay's shores when Spanish explorers came. Today, marshes are still Matagorda Bay's dominant feature. The marshes are a critical source of food and habitat for shrimp, blue crab, and many recreational and commercial species of fish.

The Matagorda Bay system, which is the second-largest estuary system in Texas, also includes Lavaca Bay and the smaller Keller, Carancahua, Chocolate, and Tres Palacios bays. This bay system has been spared much of the industrial development surrounding several of Texas' other estuaries. The bay is ringed instead by rice fields and by small towns that largely depend on the bay for their livelihoods. Although shrimp and oyster production have suffered in the past during periods of drought[1], generally, Matagorda Bay's ecosystem has rebounded and is still quite healthy. Saltwater anglers refer to the area as the "best-kept secret in Texas."

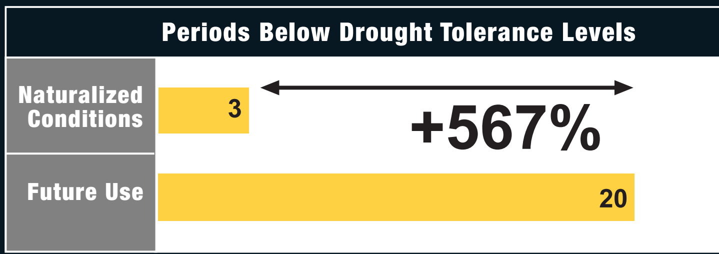
Matagorda's current good fortune could run out. The Colorado, Navidad, and Lavaca rivers provide most of the freshwater inflows to the Matagorda Bay system. A major dam on the Navidad River, multiple large dams on the Colorado River and other major water diversions have significantly altered river flows. The biggest users of Colorado River water are the residents of Austin and other cities, and rice farmers. A proposed new project that would pump 150,000 acre-feet/year from the river to San Antonio, using a combination of existing and new water rights, is currently under consideration.

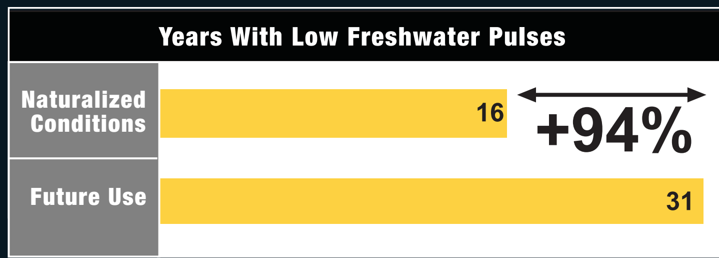
The Lower Colorado River Authority (LCRA), which holds rights to much of the water in the lower portion of the Colorado River, oversees a court-ordered Water Management Plan that provides some protection for freshwater inflows to Matagorda Bay. However, those protections are very limited during extended periods of low rainfall.

Currently, about 1.36 million acre-feet are withdrawn every year from the Matagorda Bay watershed, 96% of that from the Colorado River. Existing water-use permits authorize the withdrawal of an additional 870,000 acre-feet/year. Our analysis is based on these already authorized water-use permits. Applications have been filed seeking permits to withdraw almost a million acre-feet more per year, as well as authorizations for wastewater reuse projects.

[1] See Chapter 4 in Ward, G. H. and N. E. Armstrong, 1980. Matagorda Bay, Texas: Its Hydrography, Ecology and Fishery Resources.

Photo courtesy Texas Parks & Wildlife Dept. © 2004





ANALYSIS OF PROJECTED FRESHWATER INFLOWS[2]

This analysis looks at the potential impact to Matagorda Bay's freshwater inflows if all of the currently authorized water-use permits were fully used and if wastewater reuse increased to 50%. The computer modeling for the 'future use' scenario assumes that the LCRA's current Water Management Plan will continue to be in effect. As with all the estuaries, we focused on two inflow criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the spring/early summer freshwater pulse important for maintaining strong productivity.

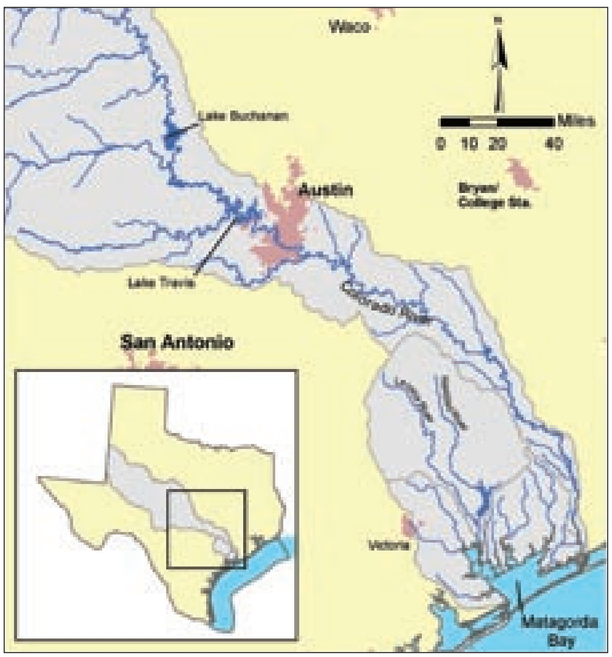
Our projections show that increased water use will cause serious problems during periods of low rainfall. **Under 'naturalized conditions,' inflows would have been below the drought tolerance level for six consecutive months only three times. However, with the 'future use' scenario (full permit use, 50% wastewater reuse), there would be 20 such periods, representing a 567% increase.**

The assessment of freshwater pulses also shows troubling changes. **Under 'naturalized conditions,' freshwater pulses would have fallen below target levels in the March-June window in only 16 years. However, with the 'future use' scenario, the number of years below target levels would increase to 31, a 94% increase.**

The large increase in six-month periods below the drought tolerance levels results in a 'danger' ranking for Matagorda Bay. The increase in years with low freshwater pulses also supports a 'danger' ranking.

The LCRA's Water Management Plan (WMP) could be used to help avoid these projected problems. With adjustments to the WMP and dedication of wastewater return flows to freshwater inflow protection, the potential for damage to Matagorda Bay could be significantly reduced.

[2]Determination of inflows to Matagorda Bay here assumes that all flows from the Colorado River reach the bay, which reflects the current situation. Around 1940 and again in 1991, the configuration of the mouth of the river was altered. These changes introduce some uncertainty about precisely what percentage of inflows would have entered the estuary in the past. However, the comparisons and percentage changes listed here accurately reflect expected changes in river flow.



U.S. Fish and Wildlife Service

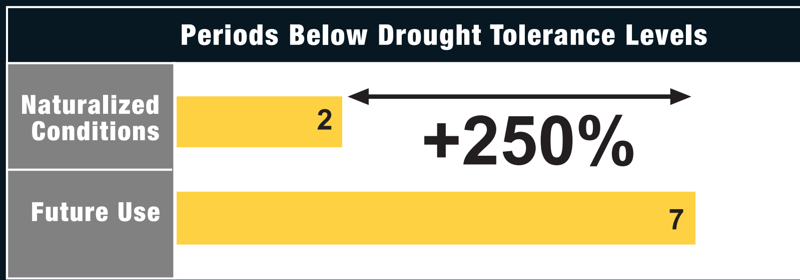
San Antonio Bay is the winter home of the whooping crane, possibly the Texas coast's most famous winged resident. Whooping cranes—with their enormous wingspan and dramatic white, red, and black markings—are gorgeous creatures and their recovery from the brink of extinction is one of the best-known conservation success stories. Despite promising population increases, the future of the whooping crane is uncertain and depends in part on the Guadalupe River, the principal freshwater source for the San Antonio Bay system, which also includes Espiritu Santo and Mesquite bays. The whoopers' winter diet is made up almost entirely of blue crabs. In years when freshwater inflows are low, the availability of blue crabs decreases, causing stress and possibly increased mortality for whoopers.

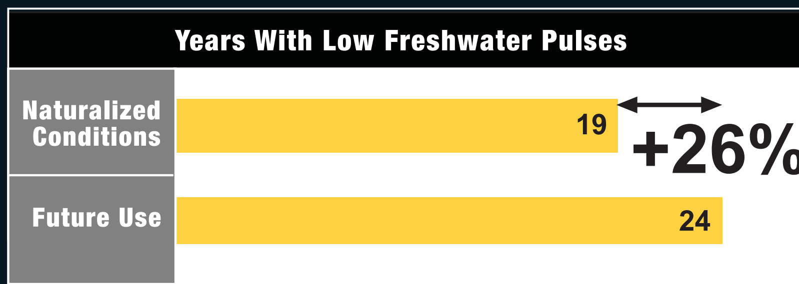
Whooping cranes and blue crabs certainly are not the only species dependant on inflows from the Guadalupe. Oyster, shrimp, striped mullet, and gulf menhaden populations are among those that would decline dramatically without adequate freshwater inflows. Indirectly, birds and other wildlife that feed on aquatic organisms could also be affected.

Unfortunately, Guadalupe River flows are seriously threatened. Currently, about 339,000 acre-feet of surface water are withdrawn every year in the Guadalupe River basin. Existing water-use permits authorize a total of 651,000 acre-feet of diversions, almost twice that amount. One project currently under evaluation, known as the Lower Guadalupe Water Supply Project, would use more than 20% of the water that is authorized but unused under current permits. That project also involves an application for new permits to divert an additional 289,000 acre-feet/year. Our analysis assumes the full use of all of the existing permits but does not consider the pending application.

This analysis looks only at surface-water usage. However, flows in the Guadalupe River, especially in dry times, are greatly influenced by changes in springflows from the Edwards Aquifer. These springs are, in turn, greatly affected by groundwater pumping. Our analysis, using the same approach as the state's modeling, assumes rigorous management of the Edwards Aquifer to meet legislatively mandated pumping caps. However, there are open questions about whether those caps may be changed or simply may not be met. As a result, freshwater inflows may fall below the levels shown here.

Photo courtesy Texas Parks & Wildlife Dept. © 2004





ANALYSIS OF PROJECTED FRESHWATER INFLOWS

This analysis looks at the potential impact to freshwater inflows to San Antonio Bay if all of the currently authorized surface water permits were fully used and if wastewater reuse increased to 50%. As with all the estuaries, we focused on two criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the spring/early summer freshwater pulse important for maintaining strong productivity.

Our projections show that the San Antonio Bay system will be significantly threatened during periods of low rainfall. **Under 'naturalized conditions,' inflows would have fallen below the drought tolerance level for six consecutive months only twice. However, that would occur seven times under the 'future use' scenario (full permit use and 50% wastewater reuse). This is an increase of 250%.**

The results of the assessment for freshwater pulses do not indicate major alterations. **Under 'naturalized conditions,' there would have been 19 years with freshwater pulses below target amounts in the April-July window. Under the 'future use' scenario, the number of years with pulses below target levels goes up to 24, a 26% increase.**

The 250% increase in periods below drought tolerance levels results in a 'danger' ranking for San Antonio Bay.

The future of freshwater inflows to the San Antonio Bay system is tied closely to management of the Edwards Aquifer as well as the management of surface water rights. Our modeling results show that during prolonged dry periods, the Guadalupe River could cease to flow into the bay, even with just currently authorized water-use permits. One mechanism that could help to avoid the results predicted here for low rainfall periods would be the conversion of some existing, but not fully used, water-use permits from consumptive use to inflow protection purposes. It may even be possible to arrange for temporary conversions during drought periods. The dedication of wastewater return flows for inflow purposes could also be beneficial.

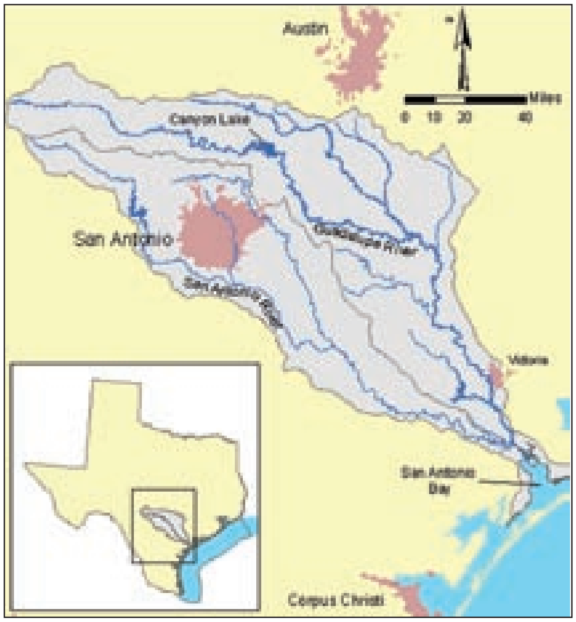


Photo courtesy Texas Parks & Wildlife Dept. © 2004

The Copano and Aransas system includes the smaller Mesquite, St. Charles, Port, and Mission bays, and the northern portion of Redfish Bay. The principal sources of freshwater to this estuary are the Mission and Aransas rivers and several smaller streams such as Copano, Willow, and Chiltipin creek.

The Copano and Aransas system supports a thriving commercial fishery based on shrimp, crabs, oysters, black drum, and flounder. Sport fishing, primarily for redfish, seatrout, flounder and black and red drum is also an important economic activity in this estuary. With fishing, bird watching, and other activities, this is among the most heavily visited coastal areas of Texas. As is true for San Antonio Bay, freshwater inflows play a role here in supporting endangered whooping cranes that winter on some of the land bordering these bays.

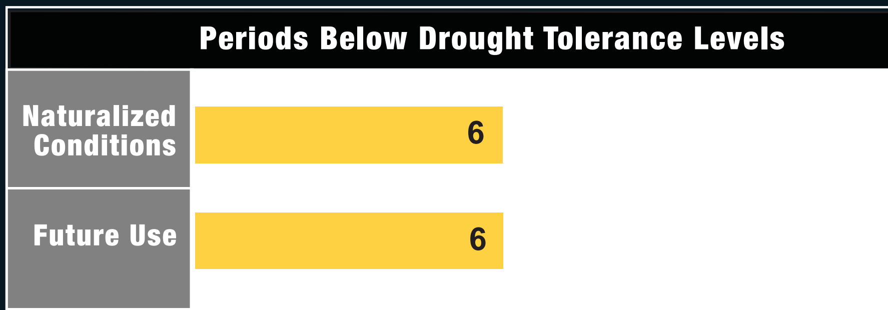
The Copano and Aransas system has seen relatively little change in freshwater inflows. With minimal surface water use, there has been little alteration in the flow of the streams that drain to the estuary. Currently, only about 750 acre-feet/year are withdrawn from the rivers and streams that drain into the Copano and Aransas system. Existing water-use permits authorize about 1,900 acre-feet/year of diversions. Currently, most water demands in the area, such as for the City of Refugio, are met through groundwater pumping.

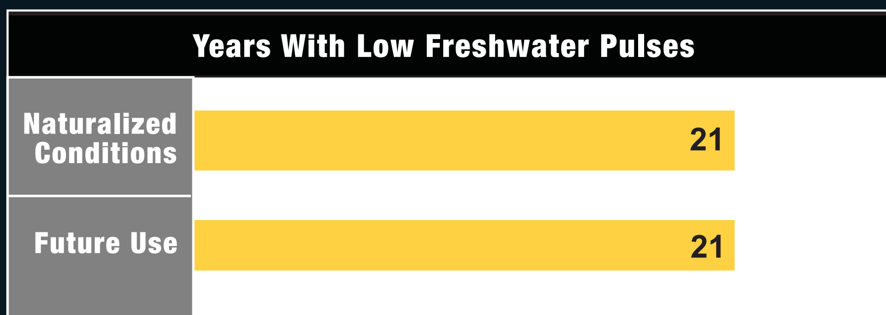
ANALYSIS OF PROJECTED FRESHWATER INFLOWS

This analysis looks at the potential impact to freshwater inflows to the Copano and Aransas system if all of the authorized surface water-use permits were fully used and if wastewater reuse increased to 50%. As with all the estuaries, we focused on two criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the spring/early summer freshwater pulse important for maintaining strong productivity.

As one would expect, our projections do not show major changes in freshwater inflows to the Copano and Aransas system. **Under 'naturalized conditions,' inflows would have fallen below the drought tolerance level for six consecutive months six times. Although there is some increase in water use with the 'future use' scenario (full permit use and 50% wastewater reuse), it does not result in any change in result for our assessment.**

Photo courtesy Texas Parks & Wildlife Dept. © 2004

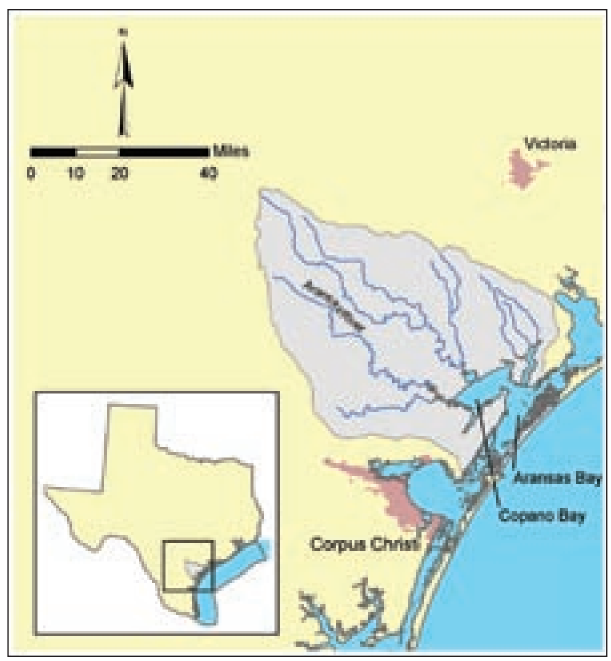




Similarly, our assessment of the occurrence of spring/early summer freshwater pulses does not show any significant change. **Under 'naturalized conditions,' there would have been 21 years with low freshwater pulses in the March-June window. That result is unchanged for the 'future use' scenario.**

With no predicted change in either assessment parameter, the Copano and Aransas system receives an overall 'good' ranking.

Although existing surface water-use permits do not present a threat to the Copano and Aransas system, there is uncertainty about future inflows. Some studies have indicated a high dependence of inflows, particularly during dry periods, on groundwater contributions from local aquifers. Because proposals for large-scale groundwater exports from the area are under serious study, freshwater inflows to this system may face significant threats that are not identified through this analysis.



CORPUS CHRISTI BAY

Photo courtesy Texas Parks & Wildlife Dept. © 2004, Earl Nottingham

The Corpus Christi Bay system, which also includes the smaller Nueces, Redfish, and Oso bays, has a combined area of approximately 195 square miles. The Frio and Nueces rivers are the major freshwater supply sources.

The Corpus Christi Bay system, home to the nation's third-largest petroleum refining complex and the sixth-busiest port, has experienced many significant changes. Among the most significant alterations were the construction of two large dams (creating Lake Corpus Christi and the much larger Choke Canyon Reservoir) on the rivers that supply freshwater to this bay. One estimate suggests that significant freshwater-inflow pulses to the uppermost portions of Nueces Bay, an extensive wetland area, have decreased by 99% since the construction of these two dams[1].

Very high levels of shell mining from the bay's once abundant oyster reefs also have impacted the estuary system. The combination of shell mining and reduced freshwater inflows has lead to the near total disappearance of oysters from the estuary. In spite of these changes, the Corpus Christi Bay system continues to support a variety of organisms including blue crabs and shrimp, although there are indications that shrimp have become less abundant[2]. The estuary is known for speckled trout, redfish, and black drum.

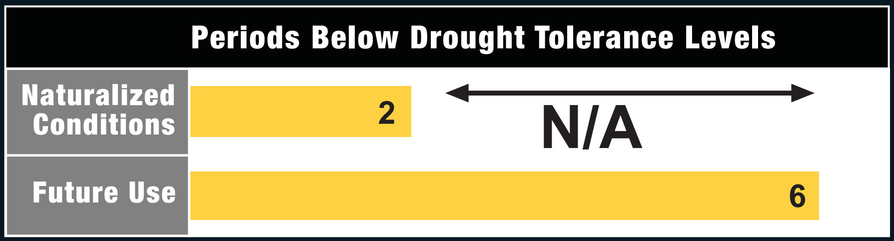
Though the dams have impeded larger pulses of freshwater, a special condition in the City of Corpus Christi's water-use permit requires limited amounts of freshwater to be passed through the Lake Corpus Christi/Choke Canyon reservoir system. Those requirements have helped to avoid more severe impacts to bay productivity during drier times. The reservoirs are the primary source of freshwater for the City of Corpus Christi and for the industrial base around the bay. Population in the region is projected to grow by 58%, to nearly 854,000, by 2050. Current surface water use is about 210,000 acre-feet per year across the Nueces basin, but existing water-use permits authorize withdrawals up to nearly 590,000 acre-feet/year

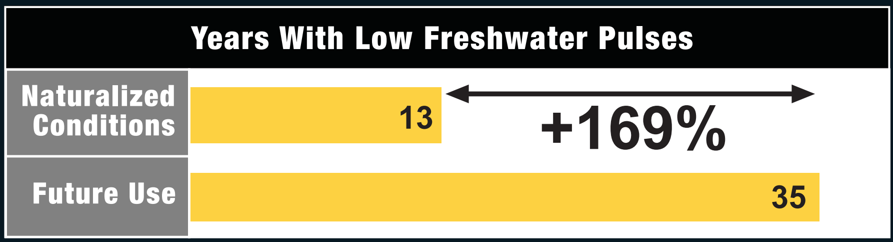
[1] Irlbeck, M.J. and G. H. Ward, 2000. Analysis of the Historic Flow Regime of the Nueces River into the upper Nueces Delta and of the Potential Restoration Value of the Rincon Bayou Demonstration Project, in US Bureau of Reclamation, Rincon Bayou Demonstration Project: Concluding Report .

[2] Montagna, P., et al., Characterization of Anthropogenic and Natural Disturbance on Vegetated and Unvegetated Bay Bottom Habitats in the Corpus Christi Bay National Estuary Program Study Area.

ANALYSIS OF PROJECTED FRESHWATER INFLOWS

As it was for the other Texas estuaries, our analysis is based on the full utilization of existing water-use permits and an increase in wastewater reuse to 50%. However, because of the special condition in the City of Corpus Christi's water-use permit, which requires some freshwater to be supplied to the estuary by wastewater return flows or by passing river flows through the dam, wastewater reuse may remain more limited than otherwise expected. Accordingly, we have qualified our results for this system. Again, we focused on two inflow criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the spring/early summer freshwater inflow pulse important for maintaining strong productivity.





Our projections show that, with increased reuse, the Corpus Christi Bay system could experience severe additional impacts from reduced inflows. **Under 'naturalized conditions,' there would have been only two periods when inflows stayed below the drought tolerance level for six consecutive months. The projections indicate that would occur six times under the 'future use' scenario (full permit use and 50% wastewater reuse).** However, because this result is quite dependent on the 50% reuse assumption, which may not be appropriate for this system, we did not use this 200% increase in our ranking[3].

With regard to the freshwater pulses assessment, under 'naturalized conditions,' there would have been 13 years with a low inflow pulse in the April-July window. With the 'future use' scenario, the number of years with low freshwater pulses would increase to 35. Although there is the same uncertainty regarding future levels of wastewater reuse, the amount of reuse has a more limited effect in this assessment. Even if current use and reuse levels were continued into the future, the analysis predicts 26 years with low freshwater pulses, a 100% increase. **Accordingly, the freshwater pulses assessment results in a 'danger' ranking.**

Inflows to the Corpus Christi Bay system already have been heavily modified, adversely affecting the bay system and its oyster and shrimp populations. Fortunately, a condition imposed on the permits for the major reservoirs helps to ensure that some freshwater inflows are passed through to the bay. Continued efforts to refine the permit condition and improve delivery of those inflows offer cause for hope.

[3]As a check, we evaluated the impacts of full use of existing permits, with no additional reuse of wastewater. With this scenario, there would be 3 periods with inflows below the drought-tolerance level for six consecutive months, a 50% increase.

UPPER LAGUNA MADRE

Photo courtesy Texas Parks & Wildlife Dept. © 2004

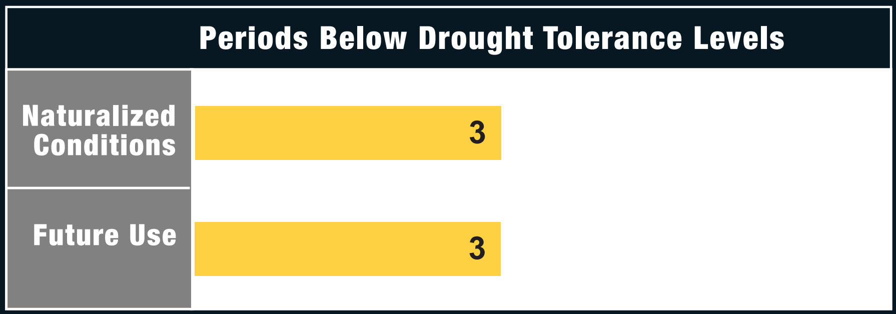
The Upper Laguna Madre, which includes Baffin Bay, is the southernmost of Texas' major estuaries and this geographic position makes it unique. Due to the combination of low rainfall—only about 26 inches annually—and sandy soils, which soak up the rain like a sponge, the small streams draining to the coast here provide little freshwater inflow and sediment. This explains the estuary's two defining characteristics: strikingly clear water and high salinities. Those characteristics, along with just the right mix of sand, silt, and clay, and generally good water quality produce another defining attribute: abundant seagrass beds.

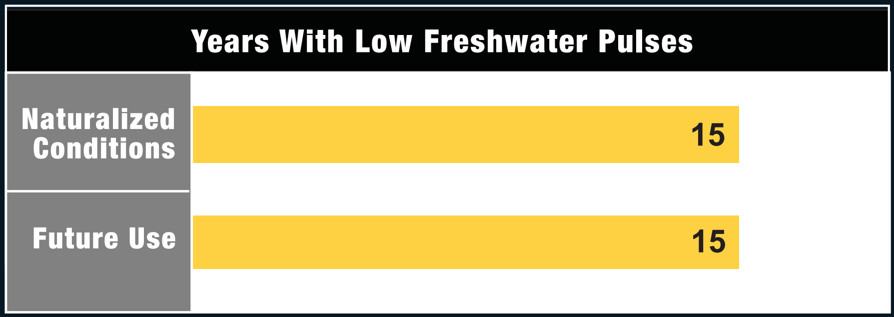
As one of only a few estuary systems in the world with salinities commonly higher than that of seawater, the Upper Laguna Madre system simply does not behave as the state's other major estuaries do. The mix of species inhabiting the Upper Laguna Madre is reflective of these conditions. Production of white shrimp is very low and oysters are generally not found here because of the high salinity levels. Pink and brown shrimp are present. But mostly, the Upper Laguna Madre is a finfish bay. There is a large commercial fishery for black drum, and recreational fisherman can certainly attest to the abundance of other fish, especially seatrout, using the rich foraging grounds provided by the seagrass.

Compared to most of Texas' estuaries, the Upper Laguna Madre system has not been subject to major changes in freshwater inflows. With essentially no reliable surface water supplies there has been little alteration of the flows of the streams that drain to the estuary. Currently, about 6,900 acre-feet per year of surface water is withdrawn from the small streams that drain into the Upper Laguna Madre. Existing water-use permits authorize the diversion of up to about 10,300 acre-feet/year.

The largest municipality in the area is Kingsville which gets most of its water from groundwater and through a pipeline from the City of Corpus Christi's supplies on the Nueces River.

Photo courtesy Texas Parks & Wildlife Dept. © 2004





ANALYSIS OF PROJECTED FRESHWATER INFLOWS

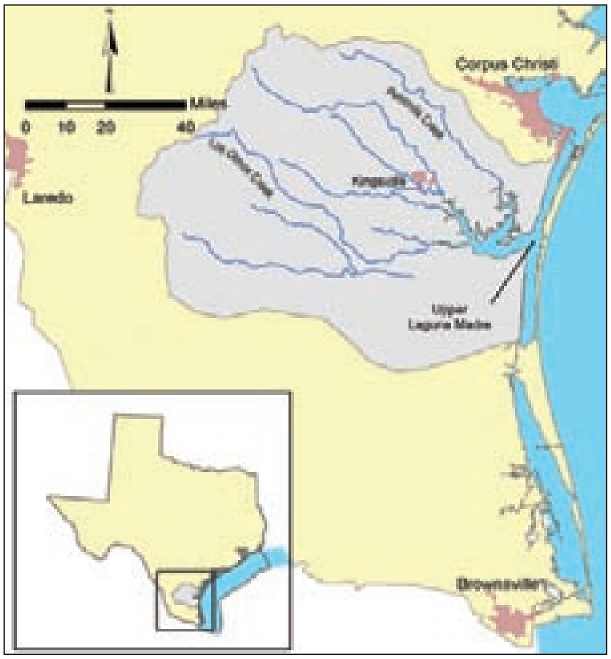
Our analysis looks at the potential impact to freshwater inflows to the Upper Laguna Madre if all of the currently authorized water-use permits were fully used and if wastewater reuse increased to 50%. As with all the estuaries, we focused on two criteria that are critical for bay health: the incidence of six-month periods of very low inflows and the spring/early summer freshwater pulse important for maintaining strong productivity.

As one might expect, our assessment does not predict much change in freshwater inflows. **Under 'naturalized conditions,' inflows would have fallen below the drought tolerance level for six consecutive months just three times. Although there is some increase in water use for the 'future use' scenario (full permit use and 50% wastewater reuse), it does not result in any change in this assessment measure.**

Under both 'naturalized conditions' and the 'future use' scenario, there would be 15 years with low freshwater pulses in the April-July window.

With no change from the baseline in either assessment, the Upper Laguna Madre estuary receives an overall 'good' ranking.

From the perspective of freshwater inflows, the Upper Laguna Madre is the only one of Texas' major estuaries that does not face obvious threats. However, other factors could adversely affect overall bay health. Dredging activity is causing re-suspension of sediments, which affects water quality, and careless boating is scarring seagrass beds, which serve as important habitat for marine species.



RECOMMENDATIONS FOR ACTION

To protect our estuaries for future generations, Texans must make sure these coastal waters get the freshwater inflows they need. As this report has demonstrated, most of our bays will *not* get enough freshwater if we don't change how we manage and use water in Texas. With some basic changes, we *can* meet human water needs and protect our estuaries. The National Wildlife Federation's recommendations for these changes fall into three areas: Permitting and Management, Water Conservation, and Water Planning.

PERMITTING AND MANAGEMENT

Freshwater is a limited resource. Existing water-use permits authorize the withdrawal of much of the water that would be in rivers and streams during drier times. Fortunately, many of those permits are not yet being fully used. That means we have an opportunity if we act quickly. Because the amount of unallocated water (i.e., water that has not been authorized for use under a permit) varies from one estuary system to another, protecting adequate freshwater inflows will require using a range of strategies. Here are some options for the state:

- **Reserve unallocated water for freshwater inflows.** The state should 'reserve' or formally set aside water to meet freshwater inflow needs before issuing any new water-use permits. However, as this report shows, in many locations there is not sufficient unallocated water available to fully meet inflow requirements.
- **Purchase water for freshwater inflows.** In river basins where there is not enough unallocated water to provide needed inflows, the state should provide funding for purchase of existing water permits from willing sellers for dedication to freshwater inflow protection.
- **Add inflow protection when permits are amended.** Since 1985, Texas has placed environmental-protection conditions on most *new* water-use permits. But when permit holders seek *amendments* to their existing permits – often so they can sell a portion of the water they're not using to another user – such conditions are rarely imposed. The state should begin to include protective measures on most permit amendments, for example dedicating a portion of return flows to freshwater inflow needs, or otherwise requiring that some water be allowed to pass downstream.
- **Encourage permit holders to donate water for freshwater inflow protection.** The state offers incentives to private landowners interested in managing or dedicating land for wildlife habitat. A similar approach should be used to encourage water-use permit holders to dedicate a portion of their water rights to freshwater inflow protection.

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WATER CONSERVATION

To meet the water needs of a growing population and still protect our estuaries, we must all use water more efficiently. A state-appointed Water Conservation Implementation Task Force has developed recommendations for water-conservation Best Management Practices. All Texans can help put these and other conservation measures into effect by:

- Practicing better water conservation in our own homes and workplaces.
- Supporting improved water conservation programs in our communities and in the state as a whole.

WATER PLANNING

To accomplish meaningful inflow protection, we must include this objective in the state's long-term water planning process. Under state law, 16 regional water planning groups develop and periodically update plans for meeting regional water needs over a 50-year horizon. When combined into the State Water Plan (the next one is due in 2007) they will guide state funding and permitting decisions. Without a change in direction, those plans will not include freshwater inflows for our bays as a category of water need to plan for.

- The state should expressly make adequate freshwater inflows to coastal bays a category of water need to be planned for and should provide regional water planning groups sufficient funds to support that effort.
- Even without further direction from state officials, regional water planning groups should include adequate freshwater inflows as a planning goal.

CONCLUSIONS

Five of Texas' seven major estuary systems received a 'danger' ranking in this assessment because already issued water-use permits, when fully used, would seriously reduce freshwater inflows. That is sobering. However, we have time to avoid that damage to our estuaries. Find out more about how you can help by going to www.texaswatermatters.org or by contacting the National Wildlife Federation at 1-800-919-9151 or at mcmahon@nwf.org .

Photo courtesy Texas Parks & Wildlife Dept. © 2004, Earl Nottingham

METHODOLOGY

As discussed earlier in this report, much of the anticipated increase in water demands will probably be met through increased use of already existing permits that authorize the diversion and use of freshwater from our streams and rivers. In certain river basins, the volume of those existing permits far exceeds current usage. Many of the existing permits, especially those pre-dating 1985, have no environmental safeguards attached to their use. This report assesses the potential impacts that full utilization of these permits would cause to the freshwater-inflow lifeline of our estuaries.

To accomplish this evaluation, the National Wildlife Federation developed a three step process as shown in Figure M1, which was applied to each of seven major Texas estuaries from Sabine Lake on the Louisiana border southward to the Upper Laguna Madre estuary just below Corpus Christi. Step One involves using the state's water availability models to estimate future inflows into our estuaries if rainfall patterns do not change and if existing water rights are fully used. Step Two involves using the results of the state's studies of each estuary's freshwater inflow needs to assess the significance of the changes in freshwater inflows predicted in Step One. Finally, in Step Three, we assign risk levels to each of the seven estuaries based on the results of Step Two.

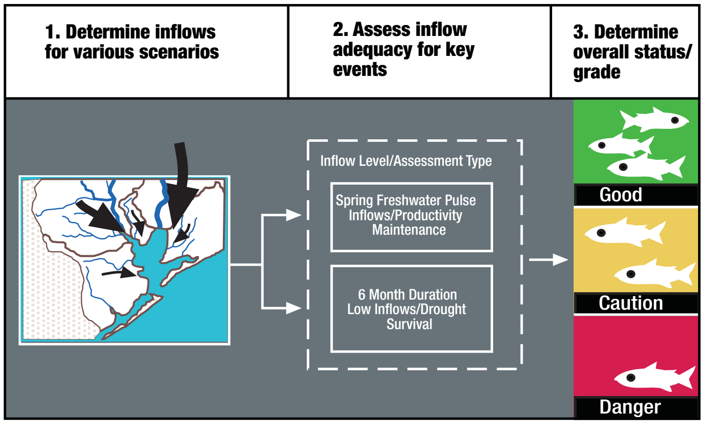


Figure M1- National Wildlife Federation's method for assessing freshwater inflow status of Texas estuaries.

FRESHWATER INFLOW DETERMINATION

In-depth exploration of the freshwater inflow issue for Texas estuaries was, until just recently, greatly impeded by a dearth of analytic tools to predict anticipated freshwater inflows under any given scenario. This deficiency has been largely eliminated with the recent (1999 – 2004) completion of computer-based river simulation models. These models, more commonly known as WAMs (water availability models),[1] predict the amount of water that would be in a river or stream, including at its junction with an estuary, under a specified set of conditions. For this assessment effort, the results from one or more WAMs for the rivers and streams draining to a particular estuary were used to forecast the freshwater inflows under various scenarios as detailed below.

The basic premise of each WAM is that a river is simulated for a period, usually about 50 years in length, corresponding to actual history (e.g. 1940-1996 for the Trinity River), but with new conditions of water use imposed on the basin. Basically, the process starts with the assumption that historic weather patterns will repeat themselves, and then assesses how changes in water use affect flow levels. That weather assumption, which is the standard approach used for hydrological calculations including the state's water rights permitting process, allows the assessment to focus directly on how human impacts affect inflows.

The start of the period of record for each WAM is in the mid-1930s to early 1940s time frame and generally corresponds with the beginning of regular measurement of actual stream and river flows across that particular basin.[2] These historical data are required because they are the starting point used to derive the set of so-called 'naturalized' flows which are at the foundation of each WAM. 'Naturalized' flows are estimates of those that would have occurred in a river free of human influence. To establish these estimates, the Texas Commission on Environmental Quality and subcontractors made adjustments to actual historical measured flows. Adjustments include additions to historical flows to add back in the amounts not reflected in the measured flows because the water had been impounded or diverted upstream for human use and because the water had evaporated from storage reservoirs. Analogous subtractions are made from historical data to account for 'return' flow that was present in the stream only because of discharges of water that otherwise would not be present. Return flows are usually discharges of municipal wastewater, but can also be from industrial facilities, and, in some limited instances, from agricultural operations.

Once the 'naturalized' values have been established, alternative conditions of water use and return flows can be evaluated. These include evaluations of differing levels of use from existing permits and differing levels of reuse of wastewater. There are a number of standard WAM scenarios, or 'runs' that were created for each river basin as part of the State's ongoing water availability modeling process. In addition to the 'naturalized' inflows themselves, other important water availability modeling scenarios are:

Present use conditions: generally reflective of current conditions, with water use for each individual permit set to its maximum annual diversion during the previous 10-year period. Wastewater return flows are set to their minimum, on a percentage basis, over the previous five-year period.[3] An abbreviation of 'Present use' is used in this report for discussion of results of this scenario.

Full permit use, 100% wastewater reuse: in this scenario all existing permits are utilized at their full authorized amount. Wastewater return flows are set to zero corresponding to 100% reuse and consumption of wastewater. An abbreviation of 'Full permits, 100% reuse' is used in this report for discussion of results of this scenario. However, these results are presented only in Appendix A.

Full permit use, 50% wastewater reuse: in this scenario all existing permits are utilized at their full authorized amount. Wastewater return flows are set to 50% levels corresponding to 50% reuse and consumption of wastewater. An abbreviation of 'Future use' is used in this report (see below).

This last scenario, 'Full permits, 50% reuse' is of particular importance for our analysis because we consider it to be the most reasonable depiction of the future flow conditions resulting from water permits that have already been granted. Therefore, in discussion of results we refer to this as our 'future use' condition. Even though existing permits generally allow complete reuse and consumption of wastewater, we do not consider that level of reuse likely in the near future. Although the precise timing for reaching this 'future use' level will vary across the state, as of this writing, some river basins are moving rapidly toward the full utilization of existing rights and there are new initiatives to reuse large volumes of current wastewater discharges.[4] In addition to the use of modeling scenarios, the historical data for estuary inflows of freshwater, as estimated by TWDB, are also referenced in this analysis for limited comparison purposes (more on this below).

ASSESSING FRESHWATER INFLOW ADEQUACY

While predicting future freshwater inflows is obviously crucial to the NWF analysis, another fundamental issue is how to determine if these inflows are adequate, and, if they are not, how to gauge the seriousness of the inadequacy. As a starting point, it is critical to recognize the high variability of Texas weather and the resulting fluctuation of freshwater inflows to the estuaries.[5] Not only are inflows variable between years, but there are recognizable patterns of fluctuation within most years. Typically, there is a fairly pronounced peak in inflows during the spring to early summer period, followed by a marked decline during the summer months as hot dry weather often prevails over much of Texas. The low inflows of summer are quite often followed in late summer to early fall by another increase in flows, sometimes sizeable if associated with tropical storm activity. Figure M2, which depicts the medians of measured historical inflows to Galveston Bay,[6] illustrates this intra-year variability.

To a great extent, Texas estuaries, like all ecosystems, are resilient and have adapted to some degree of variability and, indeed, depend on it. Because of this expected variability of freshwater inflow to our estuaries, both within a year and between years, we believe that no single criterion will serve as an adequate yardstick for evaluation of their adequacy. Recognition of variability and the use of multiple measures of flow adequacy is a key concept in emerging approaches for aquatic ecosystems management.[7]

In addition, rather than attempting to construct some wholly artificial test for a healthy bay system, we

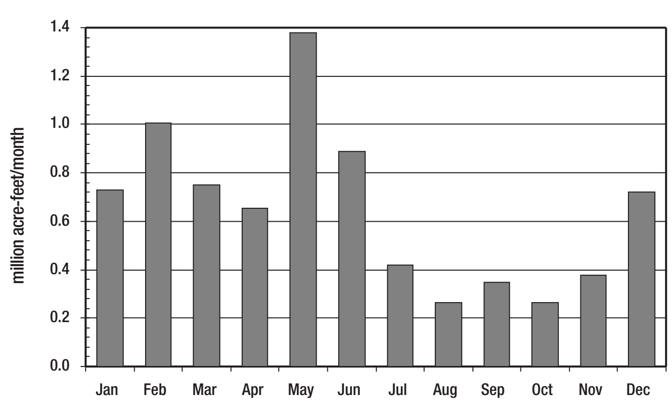


Figure M2 - Historical monthly median freshwater inflows to Galveston Bay for the 1941 - 1996 period.

have chosen to compare future inflow patterns to the naturalized flow patterns representing the conditions that Texas estuaries would have experienced without human impacts. As is discussed further below, we recognize that, because of their resiliency, our estuaries likely can tolerate some worsening of conditions from those 'naturalized' conditions. In fact, the estuaries have already experienced a reduction in freshwater inflows as a result of historical water diversions. Therefore, in our ranking system we kept that in mind in developing the breakpoints at which we express concerns about the degree of predicted changes in inflows. Underlying this approach is the basic tenet that variability of inflows is normal, and that maintaining natural patterns is crucial to the life-cycle of certain species, such as shrimp, as was discussed in the Introduction section of this report.

With this ecologically-based evaluation approach in mind, we have focused on two key assessments for Texas estuaries as illustrated in the second panel of Figure M1. These assessments are both conducted using the estuary inflows predicted by using the WAMs. First, we examine how often adequate spring-to-early-summer pulses of inflows would occur. These spring/summer 'freshwater pulses' are considered to be vital for maintaining strong overall productivity in the estuary (details below). Thus, the 'freshwater pulse' evaluations represent an assessment of how well the estuaries would be expected to fare under 'future use' conditions during years that rainfall is in the normal to high range.

However, we also believe it is critical to look at how well the estuaries would fare during drier years. Accordingly, we undertook a second assessment focused on whether enough freshwater would be available to enable sufficient populations of organisms such as fish, shrimp, crabs, and oysters to survive drought periods so that they are able to reproduce and quickly restore healthy populations when weather and estuary conditions improve.

SPRING/EARLY SUMMER 'FRESHWATER PULSE' INFLOWS FOR PRODUCTIVITY MAINTENANCE

Consistent with the acknowledgement of the importance of key hydrologic events for aquatic ecosystems generally, estuarine scientists are finding that certain key patterns of seasonal inflow are critical.[8] When looking at seasonal inflows, the focus is on a cumulative sum of inflow occurring within a multi-month period, rather than on the flows in each individual month within the period. While other seasons may also be important, in Texas estuaries the spring/early summer period appears to be particularly important for supporting strong productivity of commercial and recreational species. For example, in the Nueces estuary (Corpus Christi Bay), the Texas Parks and Wildlife Department has identified a pulse of freshwater inflow occurring within an April-July window as being highly important for supporting strong estuary productivity.[9] Accordingly, the first of our key assessments focuses on these important spring/early summer period seasonal inflow pulses.

The state inflow studies result in a recommended monthly distribution of flows for bay productivity. For our analysis, we have chosen to concentrate on inflows within the spring to early summer period and have chosen to group a subset of those monthly inflows together. We then compare how often these seasonal inflows were less than a 'target' (defined below) under 'naturalized conditions' to how often they would be less than that 'target' under the 'future use' scenario of 'full permits, 50% wastewater reuse'.

The spring through early summer season is critically important in Texas estuaries due to a coincidence of several major ecologic and hydrologic factors. Ecologically, the arrival of freshwater is more important if it is keyed to certain life-history stages of key species. Many commercially and recreationally important species such as brown shrimp, blue crab, croaker, and flounder reach their peak abundance of juveniles and young adults during the spring/early summer period (March through July).[10] This is the period in which these larval and juvenile life stages of crab, shrimp, and some finfish immigrate into the estuaries from the Gulf. If a reasonable volume of freshwater inflow occurs in this season, these young will encounter favorable salinities and sufficient food supplies.

Furthermore, inflows in the spring/early summer period are also important for another ecological reason. The geographic characteristics of Texas estuaries are such that a spring/early summer freshwater inflow of sufficient volume can establish a regime of moderate salinities and prepare the estuary to persist through the common long, hot Texas summer and early fall period of low inflows. Water residence time of most Texas estuaries allows these systems to experience a period of two to three months after a significant seasonal pulse of inflows before the salinities in the upper portion of the bays become too high for sensitive aquatic species.

As mentioned above, the spring period is also generally observed to be the predictable season when most Texas bays receive peak inflows often in the form of well-defined periods of reasonably high flows. Such inflow pulses are commonly referred to as 'freshetes' because they have the effect of freshening the water in the bay as a result of the large influx of freshwater into the higher salinity bay waters. For the purposes of this report we will refer to these as 'spring / early summer freshwater pulses' or simply 'freshwater pulses'.

For the analysis here, for each estuary we identified a seasonal spring/early summer window of four consecutive months during which the occurrence of a 'freshwater pulse' would be assessed. The four months included varied by estuary. For each estuary, we chose the four months with the highest consecutive 'target' level inflow criteria in the state's studies of freshwater inflow needs (either MinQ or MaxH or MaxC, see Appendix B). This was an attempt to focus on the most critical four-month spring/early summer period, occurring no later than July. For each estuary, the sum of the target criteria for the four months was used as the benchmark or target volume for the freshwater pulse.[11] Details on the respective four-month window and magnitude of the benchmark freshwater pulse are given in Table M1.

Estuary	4 month period	Target Volume (million acre-feet)
Sabine Lake	Jan-Apr	5.488
Galveston Bay	Mar-Jun	3.399
Matagorda Bay	Mar-Jun	1.386
San Antonio Bay	Apr-Jul	0.526
Copano & Aransas Bays	Mar-Jun	0.040
Corpus Christi Bay	Apr-Jul	0.089
Upper Laguna Madre	Apr-Jul	0.007

Table M1 – Details of Spring/Early Summer 'Freshwater Pulses' Used in Assessment of Texas Estuaries

Freshwater inflows during a given year are more likely to meet a seasonal total than a particular monthly distribution. The same total volume of water would be required to satisfy either standard, but with the seasonal approach higher flows in any of the four months apply toward the target cumulative sum of inflows. For our assessment, we used a frequency measure in which we tabulated how many years would not have a freshwater pulse volume at least equal to the target amount within the roughly 50 year period of record for the WAM(s). We computed the results for 'naturalized conditions' and for the 'future use' condition. Although not used as a key assessment, we also performed an additional analysis, based on a duration measure, in which we evaluated the number of consecutive years with a four-month cumulative freshwater pulse lower than the target volume. These results are found in Appendix A.

LOW FLOWS: ENOUGH FOR DROUGHT SURVIVAL?

Texas estuaries can clearly rebound from periodic low inflows and have done so in the past. However, we would expect repeated occurrences of long durations of low inflows to have pronounced adverse effects. Thus, our key assessment for low-flow periods is an analysis of the number of long periods of consecutive months with inflow below a 'drought tolerance' level.

In addition to the 'target' criteria used above (and detailed in Appendix B), the state's freshwater inflow study results for each bay also include a set of much lower 'drought tolerance' values. Officially known as MinQsal (see Appendix B) these inflows reflect the amount needed "…to avoid reproductive failure and loss of biodiversity…" during lower inflow periods.[12] As noted in the state's studies, for inflows between the target and the drought tolerance values "biological productivity and fisheries harvest … are significantly reduced from average historical levels."[13] Basically, these inflows are calculated to maintain salinity levels in the estuaries within identified salinity bounds. Thus, inflows equaling drought-tolerance values would just maintain salinity levels within tolerance limits for key species at various points in the estuary. Inflows at these levels would not be expected to maintain substantial fishery production over any extended period.

For this analysis, we chose to use periods of six consecutive months because such a period represents a significant portion of the life-cycle of several principal estuarine species. Under a half-year-long period of inflows below the MinQsal level, the area of lower salinity would be greatly compressed into the upper estuary near the mouths of major rivers and streams. Upper estuary marshes could begin to become saltier. Direct effects on populations of fishery species (crabs, shrimp, and some finfish) would be anticipated due to lack of food and habitat, or to unfavorable salinities, especially if occurring in the spring/early summer period. Thus, a six-month consecutive period is considered in this assessment to be indicative of a serious deprivation of freshwater inflows.

We also limited this analysis to periods of six consecutive months falling only within the March-October window because that window of time is particularly important for biological activity within Texas estuaries. The early part of the March-October window is critical for shrimp reproduction, as was discussed earlier in the Introduction section. The later portion of the March-October window is particularly important because of potential dire effects on oyster populations. While oysters can withstand the direct effects of elevated salinity for short periods, longer duration periods create serious problems because the immobile oysters are particularly vulnerable to elevated predation from the oyster drill and protozoan parasites which normally are held in check by moderate salinity. Oyster mortality from these causes has been shown to be related to the cumulative time of exposure to high salinity and elevated temperatures[14] which would accompany low freshwater-inflow periods in the late summer to early fall. In this report, we will refer to this key assessment simply as a calculation of 'periods below drought-tolerance levels.' Although not always fully labeled, the assessment always considers periods of the specified six-month length and limited to just the March-through-October time frame.

Other evaluations of low-flow conditions, including a maximum duration below drought tolerance levels and an analysis for cumulative inflow deficits, were also performed. Although not used in our actual assessment, the results are included in Appendix A.

RANKING THE FRESHWATER INFLOW STATUS OF AN ESTUARY

The final step in our evaluation of the potential loss of freshwater inflows to Texas estuaries is to evaluate the severity of any forecast changes in compliance with the two key assessment criteria. Essentially this is an assessment of the risk that the estuary could suffer a significant blow to its overall health due to a loss of vital freshwater inflow. Such losses of freshwater inflow could be manifest either as an increase in the number of years with a diminished spring/early summer freshwater pulse and/or as an increase in the number of periods below drought tolerance levels.

For each of these key assessments, we evaluated the number of occurrences of problem conditions for the 'future use' scenario (full permits, 50% reuse) as forecast by the WAM(s). The number of occurrences for the 'future use' scenario was then compared to the number of occurrences under 'naturalized conditions,' which provides the baseline, to find the percentage increase. The higher the percentage increase in problem conditions, the higher the risk of harm to the estuary's productivity as the use of existing permits increases and as more wastewater reuse projects are implemented.

We chose the WAM-generated naturalized flows as our baseline of comparison. We also considered using historical data, which includes a combination of measured and calculated flows, as the baseline. However, because of concerns about inherent variations between model outputs and historical data and because of the difficulty of assessing against what is basically a moving target, we determined that the naturalized flows provided a more consistent comparison.[15]

Overall Ranking	Increase in Problem Conditions	Interpretation
Good	0% to 33%	Good Projected increase in occurrence of problem conditions is small to moderate. Impacts to bay health are also expected to be no worse than moderate.
Caution	above 33% but below 67%	Caution Projected increase in occurrence of problem conditions is moderate to high. Although bay health would suffer, the impacts are not expected to be severe.
Danger	67% or greater	Danger Projected increase in occurrence of problem conditions is severe. Resulting impacts to bay health also are expected to be severe.

Table M2 – National Wildlife Federation's Ranking System for the Freshwater Inflow Status of Texas Estuaries

For each estuary, each key assessment—'freshwater pulse' and 'periods below drought-tolerance levels'—is independently important. Analogous to a health checkup for heart and lungs, a significant problem in either assessment indicates a problem overall. Therefore, we assign each bay an overall ranking based on the assessment that shows the largest percentage increase in occurrence of problem conditions.

We used rankings of 'good,' 'caution,' or 'danger.' The relationship between the percent change calculated and the assigned ranking is set out in Table M2.[16]

[1] Water availability models are available from the Texas Commission on Environmental Quality's website at http://www.tnrcc.state.tx.us/permitting/waterperm/wrpa/wam.html.

[2] The United States Geological Survey in conjunction with Texas river authorities and others maintains an extensive network of streamflow gauging stations across the state. See http://waterdata.usgs.gov/tx/nwis/sw

[3] This is referred to as Run 8 in any particular river basin. Some adjustments to Run 8 were made in order to have more representative "present use" conditions (see Appendix C on modeling techniques).

[4] There are several large water-use projects proposed on the lower reaches of the Colorado River and Guadalupe Rivers that would tap much of the remaining unused-but-already-permitted water. Also, there are applications pending at the Texas Commission on Environmental

Quality for large volumes of municipal wastewater return flows originating in the Dallas-Ft. Worth, Houston, and Austin areas in the Trinity, San Jacinto, and Colorado River basins.

[5] For example, the measured historical inflows to Galveston Bay have ranged from 1.87 million acre-feet/year (MAFY) in 1956, at the height of a record-breaking 1950s drought that gripped the entire state, to over 25 MAFY in 1992. Similar variability in annual inflows is the norm all along the Texas coast. An acre-foot of water is that amount that would cover an acre to a depth on one foot. One acre-foot equals approximately 326,000 gallons.

[6] See previous note for units definitions.

[7] Under these approaches, the focus is on several flow regimes, and the management objective is to try to mimic natural variability, rather than to manage for a single flow or condition. These modern approaches focus on the frequency, timing, and duration of key hydrological events that are strongly linked to ecological functions, such as a seasonal peak, or a low-flow period. See discussion in Richter, B. D., R. Mathews, D. L. Harrison, and R. Wigington. 2003. Ecologically Sustainable Water Management: Managing River Flows for Ecological Integrity. Ecological Applications, Vol 13, pgs. 206-224.

[8] Alber, M. 2002. A Conceptual Model of Estuarine Freshwater Inflow Management. Estuaries, Vol. 25, pgs. 1246-1261. Also postulated by G. Ward in 1999. Technical Basis for Establishing Freshwater Inflow Requirements for Galveston Bay. pg 44.

[9] See pages 34-35 in Pulich Jr., W., J. Tolan, W. Y. Lee, and W. Alvis, 2002. Freshwater Inflow Recommendation for the Nueces Estuary. Texas Parks and Wildlife Department.

[10] Longeley, W. L., editor. 1994, Chapter 6 of Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs.

[11] This corresponds to the approach used in the TPWD recommendation for freshwater inflows to the Nueces Estuary.

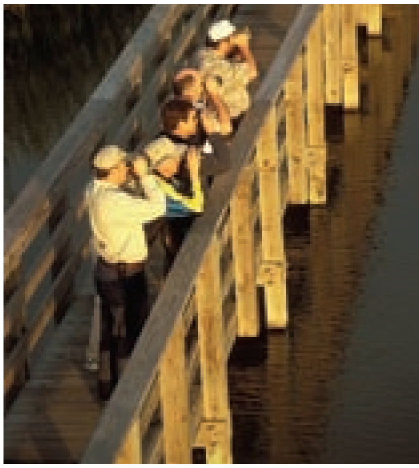
[12] The low-flow criteria are known as MinQsal in all estuaries. MinQsal definition is from Powell, G., J. Matsumoto, and D. A. Brock. 2002. Methods for Determining Minimum Freshwater Inflow Needs of Texas Bays and Estuaries. Estuaries, Vol. 25, pg 1271.

[13] Pulich, et al., pg 7.

[14] Copeland, B. J. 1966. Effects of Decreased River Flow on Estuarine Ecology. Journal of the Water Pollution Control Federation, Vol 38, pgs. 1831-39.

[15] There are several concerns with using historical data as the baseline. The first concern is related to the degree of alteration that many river basins have already experienced and hence, the potential alteration in magnitude, timing, and frequency of key hydrological events at the estuary itself. While the argument could be made that historical inflows should be used as the baseline because current estuary conditions are considered acceptable, there remain significant drawbacks in these data with regard to developing a consistent grading technique across the state. For example, if historical inflows were the baseline, it would be inconsistent to accept the same amount of future change for two estuaries if one had already experienced large historical alterations while the other had not. The only universally comparable baseline values are the naturalized flows. Another drawback to the potential use of historical inflows would be that the grade would be based on a comparison of model-generated inflows (future) to real-world data. Under historical conditions, running roughly from 1940-1990s, actual water use was variable and trended upward with population growth. In the WAMs, under any particular scenario, such as recent conditions or fully permitted use, the amount of water demand from streams and rivers exercised by the water permits are constant each year. Also, although the WAMs are the best tools available for forecasting stream and river flows under various future conditions, they should not be thought of as exact representations of the real world. The derivation of naturalized flows for the WAM, the basis for all future calculations, involves subjective choices such as how much effort to devote to adjusting historical records for the effects of smaller reservoirs and changes in land use (see discussion in Wurbs, R. A. 2001. Reference and Users Manual for the Water Rights and Analysis Package (WRAP). Technical Report No. 180, Texas Water Resources Institute, Texas A&M University System, pg. 98). By comparing two model-generated sets of inflow data, the treatment of these issues is at least constant in each set.

[16] While the choice of breakpoints, and the grading of an estuary's status with labels such as 'good', 'caution', or 'danger' is obviously subjective, there are a few other similar recent ecosystem measures which can be consulted for comparison. A national inventory, prepared by the Heinz Center, compared changes in the magnitude and timing of four key hydrological events in streams across the nation. (Freshwaters in The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States, H. John Heinz III Center for Science, Economics, and the Environment, 2002, Washington D.C.) For each of the four events, a change of less that 25% compared to the baseline was considered 'low' alteration. Greater than 75% change from baseline conditions was considered 'high' alteration. Secondly, in the Environmental Protection Agency's 2004 Draft National Coastal Condition Report II a variety of water quality, sediment toxicology, and fish-contaminant measures are used to categorize coastal areas. Breakpoints of 5%, 5%-15%, and greater than 15% were used to rank estuarine sediment-contamination measures as 'good', 'fair', and 'poor'.



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APPENDIX A

DETAILED ASSESSMENT RESULTS

As described in the Methodology section, our rankings of the status of freshwater inflows to the major Texas estuaries relied on two key ecologically based assessments: the increase in occurrences when the target for the spring/early summer pulse of freshwater inflow are not met; and the increase in occurrences of severe six-month-duration droughts. The detailed results of these assessments are shown below, in Tables A1 and A2. We also looked at the frequency, duration, and magnitude of various other possible measures of the adequacy of freshwater inflows. Although not used for NWF's rankings, the results are presented below because they may prove useful for additional reviews.

The results in Tables A1 through A6 are for analyses using the freshwater-inflow criteria developed through the state's bay and estuary inflow studies either for regular-inflow periods (MinQ, MaxH, or Target criteria) or for low-inflow periods (MinQsal criteria). In contrast, the results shown in Tables A7 through A9 are for analyses that use straight hydrological criteria. In other words, the criteria are not based on the results of the estuary studies, they simply represent a statistically based calculation. For example, there are various comparisons using the 25th percentile naturalized inflow. This benchmark is the inflow level the respective WAM(s) indicate would have been exceeded 75% of the time under naturalized conditions.

In each table, in addition to the standard scenarios used in our ranking (columns A and D), we also present the results for historical inflows, which are not generated through use of the WAM model, and another WAM-generated scenario of "Full permits, 100% reuse," a worst-case scenario based on currently granted water-use permits.

Table A1- Key Assessment: number of years with low 4 month spring/early summer[1] freshwater inflow pulse[2] defined by state criteria.

Estuary name	4 month period	tot. no. yrs	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	Jan-Apr	56	23	26	24	34	36	1.48
Galveston Bay	Mar-Jun	56	10	12	13	16	22	1.60
Matagorda Bay	Mar-Jun	56	16	31	26	31	31	1.94
San Antonio Bay	Apr-Jul	49	19	19	21	24	25	1.26
Copano & Aransas Bays	Mar-Jun	49	21	20	21	21	21	1.00
Corpus Christi Bay[4]	Apr-Jul	56	13	18	26	35	46	2.69
Upper Laguna Madre	Apr-Jul	49	15	20	15	15	15	1.00

Table A2- Key Assessment: number of occurrences of 6 month or longer periods below drought tolerance level (MinQsal[3]) within critical (Mar-Oct) months.

Estuary name	no. months analyzed	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	672	2	2	5	10	12	5.00
Galveston Bay	672	0	0	2	5	11	>500
Matagorda Bay	672	3	12	16	20	21	6.67
San Antonio Bay	588	2	3	5	7	7	3.50
Copano & Aransas Bays	588	6	3	6	6	6	1.00
Corpus Christi Bay	672	2	5	0	6	18	n/a[4]
Upper Laguna Madre	588	3	5	3	3	3	1.00

Table A3- Maximum number of consecutive years with low 4 month spring/early summer[1] freshwater inflow pulse[2] defined by state criteria.

Estuary name	4 month period	tot. no. yrs	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	Jan-Apr	56	7	7	7	10	10	1.43
Galveston Bay	Mar-Jun	56	3	3	3	3	6	1.00
Matagorda Bay	Mar-Jun	56	3	10	7	10	10	3.33
San Antonio Bay	Apr-Jul	49	7	7	7	7	7	1.00
Copano & Aransas Bays	Mar-Jun	49	4	4	4	4	4	1.00
Corpus Christi Bay	Apr-Jul	56	2	3	4	7	10	3.50
Upper Laguna Madre	Apr-Jul	49	3	6	3	3	3	1.00

Table A4 - Longest consecutive month period below target inflow criteria.[5]

Estuary name	no. months analyzed	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	672	12	16	21	35	35	2.92
Galveston Bay	672	12	12	14	18	20	1.50
Matagorda Bay	672	11	24	26	26	51	2.36
San Antonio Bay	588	17	17	22	40	40	2.35
Copano & Aransas Bays	588	28	16	28	28	28	1.00
Corpus Christi Bay	672	9	20	7	25	36	2.78
Upper Laguna Madre	588	11	24	10	11	11	1.00

Table A5 - Longest consecutive month period below drought tolerance inflow (MinQsal[3]).

Estuary name	no. months analyzed	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	672	8	13	12	19	19	2.38
Galveston Bay	672	8	8	9	11	18	1.38
Matagorda Bay	672	10	18	24	25	26	2.50
San Antonio Bay	588	14	14	17	40	40	2.86
Copano & Aransas Bays	588	19	12	19	19	19	1.00
Corpus Christi Bay	672	9	20	5	10	36	1.11
Upper Laguna Madre	588	10	24	10	10	10	1.00

Table A6 - Maximum cumulative deficit for inflows below drought tolerance level (MinQsal[3]) measured in million acre-feet.

Estuary name	no. months analyzed	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	672	1.771	1.973	2.744	4.680	5.054	2.64
Galveston Bay	672	0.966	1.071	1.139	1.655	2.763	1.71
Matagorda Bay	672	0.606	1.648	2.411	2.580	2.887	4.25
San Antonio Bay	588	0.399	0.499	0.694	1.839	1.874	4.61
Copano & Aransas Bays	588	0.029	0.029	0.030	0.031	0.032	1.07
Corpus Christi Bay	672	0.053	0.114	0.039	0.080	0.259	1.51
Upper Laguna Madre	588	0.015	0.035	0.013	0.015	0.015	1.00

Table A7- Percent of years with low 4 month spring/early summer freshwater pulse with volume of natural 25th percentile magnitude[6] or less.

Estuary name	4 month period	tot. no. yrs	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	Jan-Apr	56	25.0%	30%	27%	43%	43%	1.71
Galveston Bay	Mar-Jun	56	25.0%	25%	30%	38%	48%	1.50
Matagorda Bay	Mar-Jun	56	25.0%	50%	45%	54%	55%	2.14
San Antonio Bay	Apr-Jul	49	24.5%	27%	39%	41%	43%	1.67
Copano & Aransas Bays	Mar-Jun	49	24.5%	18%	24%	27%	27%	1.08
Corpus Christi Bay	Apr-Jul	56	25.0%	32%	46%	66%	82%	2.64
Upper Laguna Madre	Apr-Jul	49	24.5%	27%	18%	24%	24%	1.00

Table A8- Longest consecutive month period below natural 25th percentile inflow[7].

Estuary name	no. months analyzed	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	672	9	13	12	28	28	3.11
Galveston Bay	672	18	12	18	18	23	1.00
Matagorda Bay	672	9	15	24	38	38	4.22
San Antonio Bay	588	17	17	40	40	40	2.35
Copano & Aransas Bays	588	8	12	12	10	12	1.25
Corpus Christi Bay	672	5	10	3	10	38	2.00
Upper Laguna Madre[8]	588	n/a	n/a	n/a	n/a	n/a	n/a

Table A9- Number of occurrences of 6 month periods below natural 25th percentile inflow[7] within critical (Mar-Oct) months.

Estuary name	no. months analyzed	(A) Natural	(B) Historical	(C) Present use	(D) Full permits 50% reuse	(E) Full permits 100% reuse	Impact Ratio (D)/(A)
Sabine Lake	672	1	1	5	14	16	14.00
Galveston Bay	672	2	2	2	4	12	2.00
Matagorda Bay	672	1	5	14	14	16	14.00
San Antonio Bay	588	5	5	7	10	11	2.00
Copano & Aransas Bays	588	1	1	2	2	2	2.00
Corpus Christi Bay	672	0	0	0	3	14	>300
Upper Laguna Madre[8]	588	n/a	n/a	n/a	n/a	n/a	n/a

[1] The period is defined as the four consecutive month period with highest cumulative target inflows based on recommended or established target inflow criteria. The Texas Parks and Wildlife Department has recommended target criteria at the Max H or Max C level for Sabine Lake, San Antonio Bay, Copano & Aransas Bays, and Corpus Christi Bay estuary systems and at the MinQ level for Galveston Bay and Upper Laguna Madre estuary systems. Not all recommendations have been finalized and published. In addition, the Lower Colorado River Authority has developed and established target inflow levels for the Matagorda Bay estuary system (see Appendix B for details).

[2] The volume of the freshwater inflow pulse in each year is the WAM or historical total cumulative inflow volume for the four month period specified. The benchmark freshwater inflow pulse is the total cumulative inflow volume for the four months of target criteria as described in the previous note (volumes shown in table in Methodology section).

[3] See Appendix B for details on MinQsal criteria.

[4] Special conditions in the City of Corpus Christi's water-use permit require some freshwater to be supplied to the estuary by wastewater return flows or by passing river flows through the Corpus Christi/Choke Canyon reservoir system. Because this creates a disincentive for large-scale wastewater reuse, the 50% reuse level, the basis for the results in column D, may not be realistic for this estuary. The amount of reuse greatly affects the low-flow analysis of Table A2 therefore we chose not to use the 200% increase over 'natural' conditions in our ranking. As a sensitivity check, we also ran an evaluation that assumed full use of existing permits, but no additional reuse of wastewater. For this case there would be three periods when inflows stayed below the drought-tolerance level for six consecutive months, a 50% increase. In the freshwater inflow pulse analysis presented in Table A1 the reuse issue is not as significant. With full use of existing permits, but no additional reuse of wastewater, there would still be 23 years with a low freshwater pulse, a 77% increase over 'natural' conditions.

[5] Target criteria are described in note 1 above.

[6] In this analysis, the four month period was defined in the same manner as for Table A1 (note 1). In this case though, the volume of the freshwater pulse is defined as that which was exceeded in 75% of the years under 'naturalized' conditions.

[7] 25th percentile inflows are fairly low inflows; those that would be exceeded in 75% of the months. In this case 'naturalized' inflows from the WAMs are used in lieu of the typical historic record.

[8] Because of the prevalence of months with zero freshwater inflow in the historic record, 25th percentile flows are zero for each month and the analysis for this estuary is not possible.

APPENDIX B

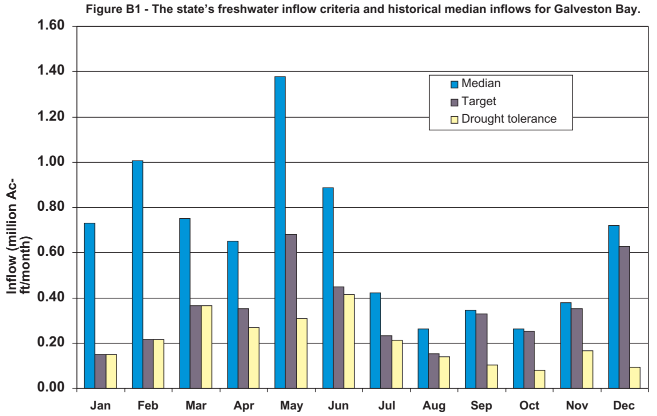
THE TEXAS FRESHWATER INFLOW CRITERIA

Scientists at the Texas Parks and Wildlife Department (TPWD) and Texas Water Development Board (TWDB) were faced with a novel problem when charged by the Legislature to determine estuary freshwater inflow needs: there was no established technique to develop the inflow requirements. The beginning point for those efforts was to develop a statistical procedure that relates measured monthly inflows of freshwater to the observed salinities and species abundance measures. However, because of differences in the magnitude and timing of freshwater inflows that are beneficial for each species and because of many complex intra-species interactions, there is no single set of inflow values that is uniquely the best answer.

To address this problem, the state developed an innovative computer model, called TxEmp, which is based on a numerical technique called linear programming.[1] TxEmp finds sets of inflow values to achieve a pre-specified estuary-management goal while also simultaneously limiting inflow amounts to fairly conservative levels. For instance, one set of inflow values, called the MaxH solution (shorthand for maximum harvest), is designed to maintain good overall productivity even though the recommended inflow for any particular month cannot exceed the measured historical median inflow for that month. In the MaxH solution, with these limited inflows pre-specified, total harvest of the key commercial and recreational species[2], is then optimized. A second solution set called MinQ (shorthand for minimum flow), seeks to determine the minimum amount of inflow that would achieve a goal of supporting, for each individual species considered, a harvest at about 80% of the historical average harvest.[3] For six of the seven major estuaries, TPWD uses the results from the calculations to recommend 'target' inflows within the range between MinQ and MaxH to maintain estuarine productivity[4].

For example, the derived set of monthly target inflows for Galveston Bay (see Figure B1) is intended to support healthy production of oysters, white shrimp, brown shrimp, blue crabs, spotted seatrout, flounder, red drum, and black drum with a total annual inflow of 4.16 million acre-feet/year (MAFY)[5]. Although that seems like an enormous volume of water, it is actually relatively moderate given the historical inflows, which ranged from 1.87 to 25.15 MAFY with an average of about 11 MAFY. This issue is discussed further in the Methodology Section. In the 1941-96 period, historical annual inflows to Galveston Bay were greater than the target level in 87% of the years. As shown on Figure B2, when the target inflows for each estuary are examined as a yearly total, they are near the low end of the expected range of inflows for that estuary, even though, based on the results of the state's studies, they would be expected to maintain good estuarine productivity.

Figure B1 - The state's freshwater inflow criteria and historical median inflows for Galveston Bay.



Another set of considerably lower inflow values calculated as part of the state's studies, called the MinQSal inflow, seeks to satisfy just salinity threshold values. These MinQsal values for each estuary reflect the amount needed "to avoid reproductive failure and loss of biodiversity" during lower inflow periods[6].

The magnitudes of the MinQsal, or drought-tolerance freshwater-inflow criteria, are shown on Figure B3, again as compared to the actual historic annual values for each estuary.

[1] Longley, W. L., editor. 1994, Chapter 8 of Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs.

[2] Although it varied somewhat from one estuary to another, the species considered in the analysis included oysters, white shrimp, brown shrimp, blue crabs, spotted seatrout, flounder, red drum, and black drum. The list was influenced both by seeking to get a reasonably representative group of species and by a limitation of needing to select species for which significant amounts of data about historical abundance were available.

[3] Because of limitations on sufficient amounts of available data, historical levels of harvest generally were used as a tool to measure species abundance

[4] The target criteria value recommended by TPWD is known in the state's methodology as the MaxH level for San Antonio Bay, Copano and Aransas Bay system, and Corpus Christi Bay. It is the Max C level for Sabine Lake (Max C is comparable to Max H), and the MinQ level for Galveston Bay and Upper Laguna Madre. Some of the TPWD recommendations have not been finalized and reduced to writing. For Matagorda Bay, the criteria are formally referred to as the target level and fall just 6% above the MinQ level on a total annual basis. The Lower Colorado River Authority undertook the studies and preparation of the inflow recommendation for the Matagorda Bay system with the cooperation of the state agencies. A process is underway currently that could result in some revision of the Matagorda inflow recommendations.

[5] An acre-foot of water is that amount that would cover an acre to a depth of one foot. One acre-foot equals approximately 326,000 gallons.

[6] The low-flow criteria is know as MinQsal in all estuaries. MinQsal definition is from Powell, G., Matsumoto J., and Brock, D. A., .2002. Methods for Determining Minimum Freshwater Inflow Needs of Texas Bays and Estuaries, Estuaries, Vol. 25, pg 1271.

Figure B2 - Annual total of target freshwater inflow criteria for Texas estuaries as measured against their observed historical annual Inflows, 1941-96.

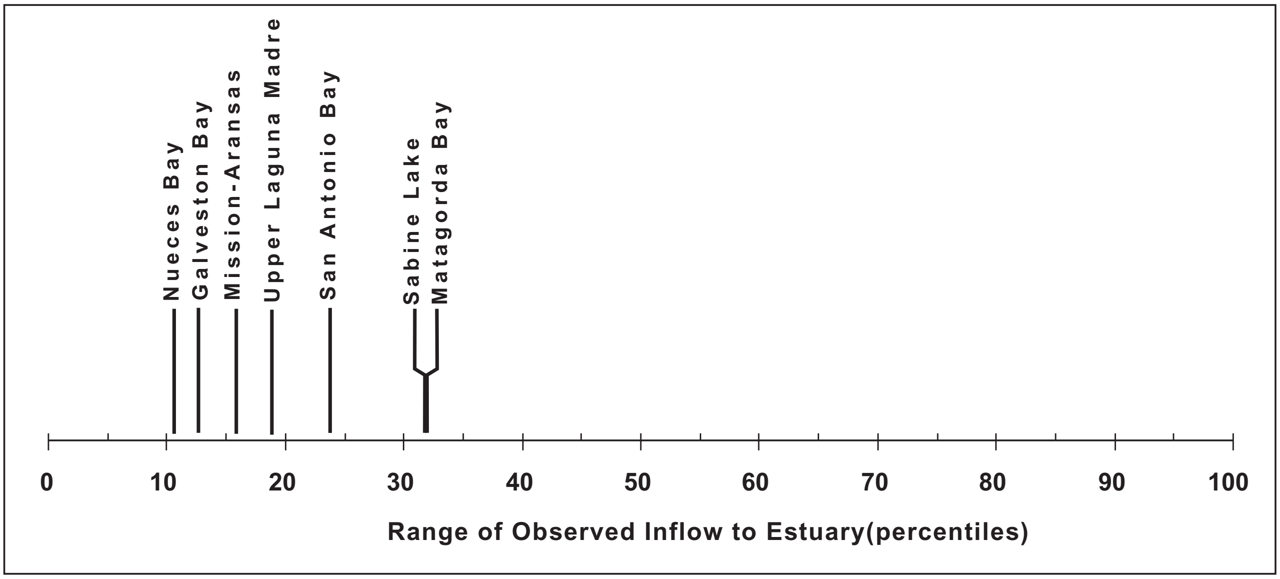
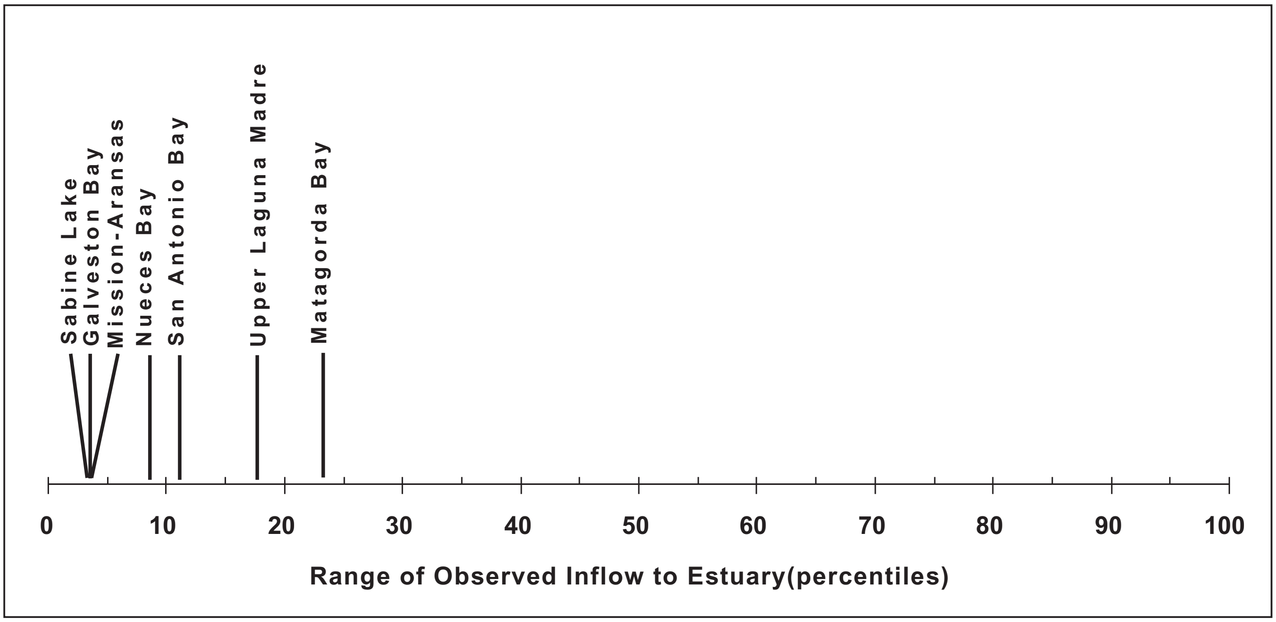


Figure B3 - Annual total of drought tolerance freshwater inflow criteria for Texas estuaries as measured against their observed historical annual Inflows, 1941-96.



APPENDIX C

WAM MODELING TECHNIQUES

The Water Availability Models (WAMs), developed as a result of the Texas Legislature's passage of Senate Bill 1 in 1997, provide the basis for the inflow calculations used in this report. Each river basin WAM consists of the computer code, based on the WRAP model developed at Texas A&M University, and several sets of standard input data. Except as noted below, all estimates of freshwater inflow to Texas estuaries were made using the December 2003 version of the WRAP model. This version of the WRAP code and the associated data for each river basin were tailored by the TCEQ as a generic model suitable for the entire state.

The WAM input data sets were developed by the Texas Commission on Environmental Quality (TCEQ) and its subcontractors to represent several scenarios of water use and wastewater reuse important for water planning and permitting purposes. Each of these scenarios is known as a "Run." They range from Run 1 through Run 8. Runs 2, 3, and 8, described below, were used to varying degrees in our evaluations. The actual estuary rankings are based only on the use of the naturalized flow data and the Run 2 results. Run 8 and Run 3 data are used for comparative purposes and those full results appear in Appendix A. Unfortunately, only Runs 3 and 8, which are used by TCEQ for evaluation of new temporary and permanent water-use permits, respectively, are being continuously updated by TCEQ. Therefore, it was necessary for us to update Run 2, as described below.

Run 8 is the standard WAM scenario that comes closest to representing 'present use' conditions of water use and wastewater return flows. Water-use levels for each permit are set to the maximum use level reported during any one of the previous ten years. Wastewater returns flows are were set at the minimum level of the previous five years. In some instances, the standard Run 8 convention of setting all permitted diversions to their individual maximum use over the last ten years can be an impediment to getting a reasonable view of 'present use' conditions. The convention is a conservative approach that TCEQ uses for evaluating applications for new temporary permits to ensure no harm to existing permits[1]. However, with each permit's use set to its individual maximum in any one of the ten years, the total use sum of these can be much higher than the actual current maximum use levels in any single year. This was evident for the Guadalupe-San Antonio and Nueces WAMs as noted below in the itemization of alterations and corrections. Except as noted, the latest version of Run 8 data available from TCEQ, was utilized to represent the 'present use' conditions in this report.

Runs 2 and 3 both represent the condition of full and simultaneous utilization of all water-use permits that have been granted by the state. In Run 3 it is assumed that all wastewater is reused and there are no return flows to rivers or streams. Since only a handful of water-use permits in the state have explicit return flow requirements, Run 3 represents the ultimate level of water use and reuse, and the worst case for freshwater inflow, that is possible based on existing water-use permits. Run 3 data for each WAM were used in this report to represent the "Full Permits, 100% Reuse" condition itemized in Appendix A tables.

In Run 2, wastewater return flows are set to a level representing 50% reuse of wastewater discharges. Even with interest in wastewater reuse projects on the rise, as reflected by several extremely large indirect-reuse permit applications in a number of basins, we do not believe 100% reuse is likely in the foreseeable future. We believe that Run 2 is a more likely representation of future conditions of water use and reuse. Therefore, we used the "Full Permits, 50% Reuse" condition, which is based on Run 2 data sets for the WAMs, as the basis for our inflow assessments (generally labeled 'Future Use'). It was necessary to update the original Run 2 data as delivered to TCEQ with new water rights changes or additions. For added or changed water permits, the full water-use levels and other permit information (monthly demand pattern, priority date, etc) were set to those in the most recent version of Run 3. For new or changed permits in Run 2, return-flow levels were set to the 50% reuse level based on the water-use and reuse information for that particular permit type (municipal or industrial, etc.) as in the original Run 2.

WAM SPECIAL CONSIDERATIONS

Several alterations or corrections were made to WAM data sets as detailed here.

San Jacinto River - Under the full-permitted-use scenarios, a very large (680,680 ac-ft/yr) import of water from the Trinity River basin is included in this WAM. This water is entered into the San Jacinto WAM as a constant input. This imported water, along with the City of Houston's wastewater discharges originating from several large surface-water rights in the San Jacinto basin itself, is placed into the WAM at synthetic points not corresponding to any actual location. In order to redistribute this water to actual discharge locations, a host of synthetic water-use permits divert from these synthetic control points and discharge at actual wastewater treatment plant locations. This is an innovative modeling technique that allows the efficient handling of surface-water rights which discharge to multiple locations. However, in the original Run 2 delivered to TCEQ, the return flows originating from this import were mistakenly set to the 50% reuse level twice over. The initial import was set at the 50% level and then the return flows in the secondary diversion / redistribution step were set to 50% reuse levels. This led to the artificial loss of a little over 170,000 ac-ft/yr in wastewater discharges in the San Jacinto basin. After consultation with TCEQ[2], we corrected this by setting the initial import level back to the 100% level. The effects of this correction are most noticeable in lower-flow months where wastewater discharges become more important for maintaining freshwater inflows to Galveston Bay. This correction results in a prediction of increased inflows in our 'Future Use' scenario as compared to the uncorrected Run 2.

Colorado River – A unique consideration in the Colorado River WAM is the necessity of simulating the special conditions of the Water Management Plan (WMP) governing the Lower Colorado River Authority's permits for the Highland Lakes system (Buchanan, Inks, LBJ, Marble Falls, Travis, and Austin). The original version of the Colorado River WAM completed in March 2002 was

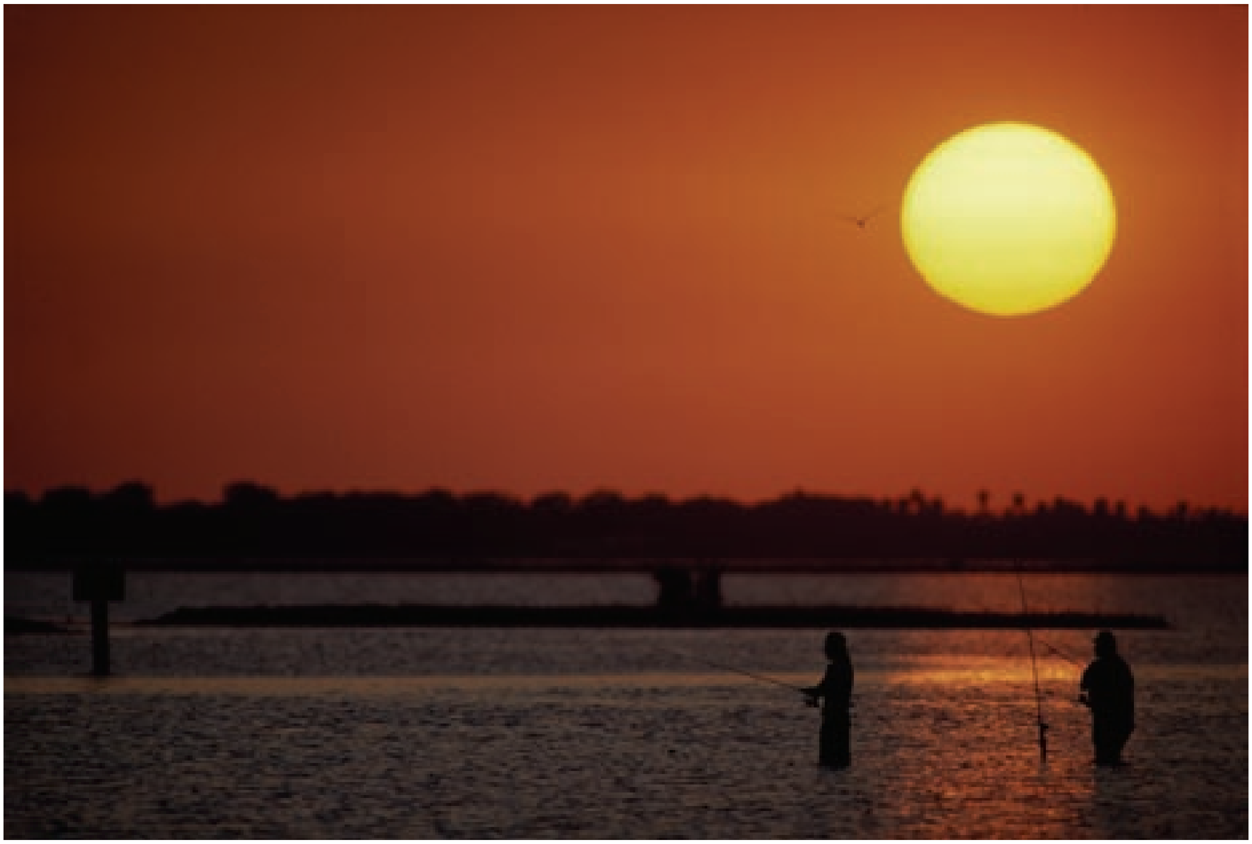


Photo courtesy: Michael A. Murphy/TxDOT

found to be lacking in the rigor with which it tracked the WMP's provisions and was updated considerably. The latest version dated August 2004 was used in this report.

Generally speaking the firm yield of the Highland Lakes is committed to several purposes. These include direct water supply, such as to the City of Austin, and also as backup water to several other water permits, such as those of large rice irrigation operations in the lower basin. For full-permit conditions (Run 3) in the updated Colorado River WAM, there is a special water permit (61405482001C) which represents the remaining firm yield of the system which is permitted but uncommitted. In the August, 2004 version of Run 3 data from TCEQ this amount is set at 157,600 ac-ft/yr.

In the creation of the corresponding Run 2 data with the 50% reuse convention, the monthly return flow for each permit was set based on the information in the original Run 2. The only addition was for the permitted, but uncommitted portion, which was not present in the original Run 2 data. This special water permit was set to a municipal return-flow pattern and, by volume, one-half was treated as being returned above Lake Travis and one-half below.

Guadalupe and San Antonio Rivers – While every river basin in Texas derives some of its surface-water flow from the discharge of springs, the Guadalupe and San Antonio Rivers are unique in regard to the magnitude of the influence of this phenomenon. The discharges of Edwards Aquifer springs, primarily Comal and San Marcos Springs, but also some smaller springs in the San Antonio area, have a large effect on surface-water flows in the Guadalupe and San Antonio Rivers. In this basin therefore, predicting river flows available to current water-permit holders and future applicants, as well as water available for environmental purposes, can only be done after specifying assumptions about how the Edwards Aquifer is to be managed and what springflows are anticipated.

In the Guadalupe and San Antonio Rivers WAM (GSA WAM), anticipated springflows that would result from a constant level of pumping of 400,000 ac-ft/yr from the Edwards Aquifer were assumed for purposes of calculating water availability in all Runs other than naturalized conditions. These springflows were predicted with the Texas Water Development Board's GWSIM model[3] and become a vital part of the input data for the GSA WAM. A specific data set is input to the GSA WAM which adjusts the model output to reflect the anticipated change in springflows from historical levels to those of the 400,000 ac-ft/yr pumping scenario. This technique means that the GSA WAM's predictions of surface-water availability and inflow to the Guadalupe Estuary for current and full-permit scenarios are predicated upon the management of the Edwards Aquifer to a constant 400,000 ac-ft/yr pumping level.

Another important consideration for the freshwater-inflow evaluation was the manner in which naturalized flows were derived for this WAM. 'Naturalized' flows are supposed to be those 'free of human influence' and are derived by starting with measured gage flows and then adjusting these back in time, accounting for changes from natural conditions due to such things as evaporation from reservoirs and historical surface water diversions and return flows. In the GSA WAM, however, no such correction was made to measured flows to account for changes in Edwards Aquifer springflows from natural conditions. Rather, unadjusted historic springflow levels are left in the 'partially naturalized' data of the GSA WAM.[4] The GSA WAM uses the change-in-springflows data set, mentioned above, to adjust springflow assumptions in calculating water availability and streamflows under the standard WAM Runs. While this technique is fine for analyzing surface-water availability and inflow to the Guadalupe Estuary for current and full-permit scenarios, the original naturalized flows in the GSA WAM do not correspond to the 'free of human influence' conventions of other basins. They are not the actual naturalized-flow conditions, which, in this report, provide the basis for assessing the degree of alteration of freshwater inflow under various scenarios.

To overcome this limitation in naturalized flows for the GSA WAM we reran the TWDB's GWSIM model of the Edwards Aquifer to derive a better approximation of actual springflows that would have resulted under natural conditions with no pumping. Although this application of GWSIM is somewhat outside of the normal use of the model, it should provide a reasonable approximation of naturalized springflows[5]. These resulting "fully naturalized" springflows were then used to derive an alternative data set for computing naturalized conditions that reflect "naturalized" springflow contributions. To derive the set of "fully naturalized" inflows at the estuary, the

GSA WAM was run with these new springflows and zero surface water diversions and no return flows. Thus the 'fully naturalized' springflows were subject to the same evaporation and channel losses of the regular GSA WAM simulations as these waters are transported to the Guadalupe Estuary.

As described earlier, in Run 8 the convention is that water-use levels for each permit are set to the maximum reported use level during any one of the previous ten years. However, for recently granted permits with no history of water use, current practice by TCEQ is to set the diversion level to its full-permit level in Run 8 for the interim. This represents a very conservative assumption for evaluation of subsequent temporary permit applications. While understandable for permitting needs, this practice led to a very non-representative picture of inflows under 'present use' conditions for the Guadalupe Estuary. In 1999, an amendment for an additional 40,000 ac-ft/yr of use was granted for the Canyon Lake reservoir, one of the larger permits in the basin, which prior to the amendment authorized 50,000 ac-ft/yr use. Therefore, in the standard Run 8 data, the use of this amended portion of the permit was set to 40,000 ac-ft/yr although the original 50,000 ac-ft/yr portion of the permit still only has a use level of about 15,000 ac-ft/yr. To arrive at a better depiction of actual 'present use' conditions we set the diversion amount of the amended portion of this permit to zero.

For the Guadalupe-San Antonio River WAM, the Run 8 convention of setting each permit's use at its individual maximum level also created another impediment to getting a reasonable view of 'present use' conditions. The largest permitted water diversions in the basin are a group of six permits owned jointly by the Guadalupe-Blanco River Authority and Union Carbide Corporation. These permits have diversion points just above the estuary and have a total permitted diversion of just over 172,500 ac-ft/yr, a little over 26% of the total consumptive use permitted for the entire basin. In the standard GSA WAM Run 8, these permits were set to a total diversion of 117,800 ac-ft/yr, a total that was verified by comparing to data supplied by the South Texas Watermaster office[6]. However, the South Central Texas Regional Water Plan (Region L Plan) proposes a large diversion project (SCTN 16) based on these "presently under-utilized surface water" diversion permits. According to the Region L Plan, the total use from these permits did not exceed 62,000 ac-ft/yr between 1991-97.[7] To get a more realistic portrayal of 'present use' conditions, we scaled each of these water permits diversion amounts in Run 8 so that they totaled 70,000 ac-ft/yr, allowing for some growth in use.

Nueces River – Similar to the Colorado River WAM, the Nueces River WAM has conditions attached to some water permits that necessitate special consideration. The water-use permit granted to the City of Corpus Christi for the Choke Canyon reservoir completed in 1982 has special operating conditions to provide some freshwater inflow to Corpus Christi Bay. Because the implementation of the conditions is controlled by a TCEQ Agreed Order, we refer to them as the "Agreed Order Provisions." Under the Agreed Order, a schedule of flows that must be passed through the Corpus Christi/Choke Canyon reservoir system was established. The schedule is a three-tiered set based on the amount of water in storage in the reservoir system and on implementation of demand-management measures during drought. Credit, in the form of a reduction in pass-through obligations, is given to the City for wastewater discharged to the estuary system. Additionally, pass-through requirements are reduced when measured salinity levels at a designated spot in the upper portion of the estuary are already low.

Because of this multitude of very specific conditions, and others in the basin, the original WAM for the Nueces River was modified into a so-called "basin-specific" version. Modifications were made to both the input data and the actual WRAP computer code[8]. However, TCEQ desires to have one standard generic WRAP computer model with just the input data differing from basin to basin. Thus TCEQ no longer distributes this "basin-specific" version. To accommodate the special conditions of the basin with the generic WRAP model, the WAM data for the Nueces were tailored with synthetic water rights and reservoirs that attempt to represent the Agreed Order provisions. However, after extensive testing of both versions, we believe that the original "basin-specific" version provides the better portrayal of freshwater inflows to Nueces Estuary (Corpus Christi Bay). That version was used in our analysis.

Similar to the discussion earlier on the Guadalupe-San Antonio WAM, the Run 8 convention of setting each

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permit's use at its individual maximum level was again an impediment to getting a reasonable view of "present use" conditions in the Nueces River basin. This is especially the case here because just a few large water permits located very near the estuary dominate in terms of permitted volume and current-use levels. The largest permitted water diversions in the basin are by far those of the City of Corpus Christi and the Nueces River Authority for waters impounded in the Corpus Christi/Choke Canyon reservoir system. Under the full-permit conditions, these total nearly 444,000 ac-ft/yr, which is a full 75% of all permitted consumptive use in the basin. The diversions under these permits actually take place not far above the estuary after the water is released from the reservoir system. Also, just above the estuary is the nearly 12,000 ac-ft/yr permit of the Nueces County Water Control and Improvement District # 3 (WCID 3).

In the standard Nueces Run 8 data, the total use under these permits is set at 247,567 ac-ft/yr, just over 69% of the total in the basin. However, data from the TWDB[9], for the 1991-2000 period, indicate that the yearly diversion of water along the lower reach of the river below Lake Corpus Christi averaged a little over 101,000 ac-ft/yr with a 1991 maximum of just under 120,000 ac-ft. For this report, in order to get a more realistic portrayal of 'present use' conditions, we prorated the water diversions to the average level over the 1991-2000 period. Also, based on the TWDB data, return flows for these diversions, except for a minor portion devoted to irrigation, were set to 42% in our "present use" evaluation. These were set at 21% in the "full permits, 50% reuse" scenario.

[1] Personal communication, Kathy Alexander, Texas Commission on Environmental Quality, July 27, 2004.

[2] Personal communication with Kathy Alexander, Texas Commission on Environmental Quality, Sept. 9, 2003.

[3] HDR Engineering, 2002, Water Availability in the Guadalupe-San Antonio River Basin, pg. 4-22.

[4] Personal communication with David Dunn, HDR Engineering, April 9, 2003.

[5] Personal communication with Dr. Tommy Knowles, formerly of Texas Water Development Board and primary author of GWSIM model, Nov. 14, 2002.

[6] Spreadsheet data provided by South Texas Watermaster Office, November 2003.

[7] HDR Engineering and Texas Water Development Board, 2001 South Central Texas Regional Water Plan Vol III, pg 3.2-1 through 3.2-3.

[8] Personal communication with David Dunn, HDR Engineering, April 9, 2003.

[9] Spreadsheet data provided by Texas Water Development Board as an e-mail attachment, April 20, 2004.

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The mission of the National Wildlife Federation is to educate, inspire and assist individuals and organizations of diverse cultures to conserve wildlife and other natural resources and to protect the earth's environment in order to achieve a peaceful, equitable and sustainable future.

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