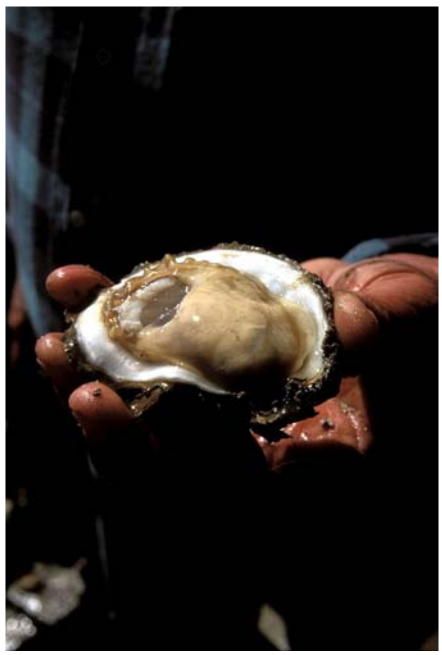
Applying an Inflow Pattern Approach to Derive a Low-Inflow Criterion for Galveston Bay with Oysters (*Crassostrea virginica*) as the Focal Species



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NATIONAL WILDLIFE FEDERATION

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Submitted to: Trinity / San Jacinto Bay Basin Expert Science Team

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Introduction

The Trinity-San Jacinto Bay and Basin Expert Science Team (BBEST) was created under the auspices of Senate Bill 3 of the 2007 Texas Legislature. The BBEST is tasked with developing an environmental flow regime to support a "sound ecological environment" for Galveston Bay as well as the Trinity and San Jacinto River basins.

The recent SB 3 Science Advisory Committee report (SAC 2009a) on methods for establishing an estuarine inflow regime recognizes a variety of potential approaches. Among the approaches is the National Wildlife Federation's Inflow Pattern Approach (NWF 2009). The goal of all of these approaches is to link freshwater inflows, and its various attributes such as timing and volume, to the biologic response of organisms in the estuary. While it is generally acknowledged that freshwater inflows to an estuary play the important roles of governing salinity and delivery of sediments and nutrients (e.g. Ward and Montague 1996), the NWF approach focuses on identifying specific naturally-occurring inflow patterns that appear to be ecologically important for the estuary. These patterns may be evident as fairly predictable intra-annual occurrences, such as seasonal inflow variation, or they may be less frequent high or low inflow levels that re-occur within multi-year time frames, but are still important ecologically. The focus of the analyses herein is specifically on developing a low-inflow / high salinity criterion that has occurred infrequently in the historic record.

Although the inflow pattern approach is primarily hydrologic, utilizing the historic record, it also relies on biologic and chemical (salinity) lines of evidence to identify key inflow patterns and events. An explicit goal of the inflow pattern approach is to maintain the timing, magnitude, duration, and frequency of these key inflow patterns within some reasonable range of departure from their historic occurrence levels with the expectation that this will maintain the ecological health of the estuary.

The SAC also recognized the utility of focusing on one or more characteristic estuary "Key Species".

"[The] basis for selection of a key species is either (1) that the species enjoys some prominence, typically as a favored recreational target, as a commercial fishery hence having economic significance, or as a charismatic species commanding widespread public interest, or (2) that the species typifies in some way a key element of the ecosystem."

For the purposes of establishing an estuarine inflow regime, the SAC goes on to state that:

"The utility of key species is enhanced if they exhibit sensitivity to inflow-controlled parameters such as salinity or nutrient concentrations."

In the present analyses we have chosen to focus on oysters (*Crassostrea virginica*) because they are abundant and commercially important in Galveston Bay. Furthermore, because of their commercial importance, oysters have been subject to extensive investigations regarding organism health as a function of salinity patterns, including parasite and disease susceptibility.

The availability of a set of existing salinity data at a location of high oyster abundance (mid Galveston Bay in the vicinity of Dollar Point), and daily inflow information, both from the Texas

Water Development Board, greatly facilitates the examination of how this species is likely to respond to freshwater inflows and associated salinity patterns.

Methodology

As mentioned above, the primary focus of the assessments herein is to develop a low-inflow portion of an overall estuarine inflow regime for Galveston Bay. We focus on the Dollar Point area of Galveston Bay which has abundant oyster reef areas (Figure 1). Oysters are not only a commercially important species, but owing to their reef-building capacity, they collectively are a significant estuarine habitat (Coen et al. 1999).

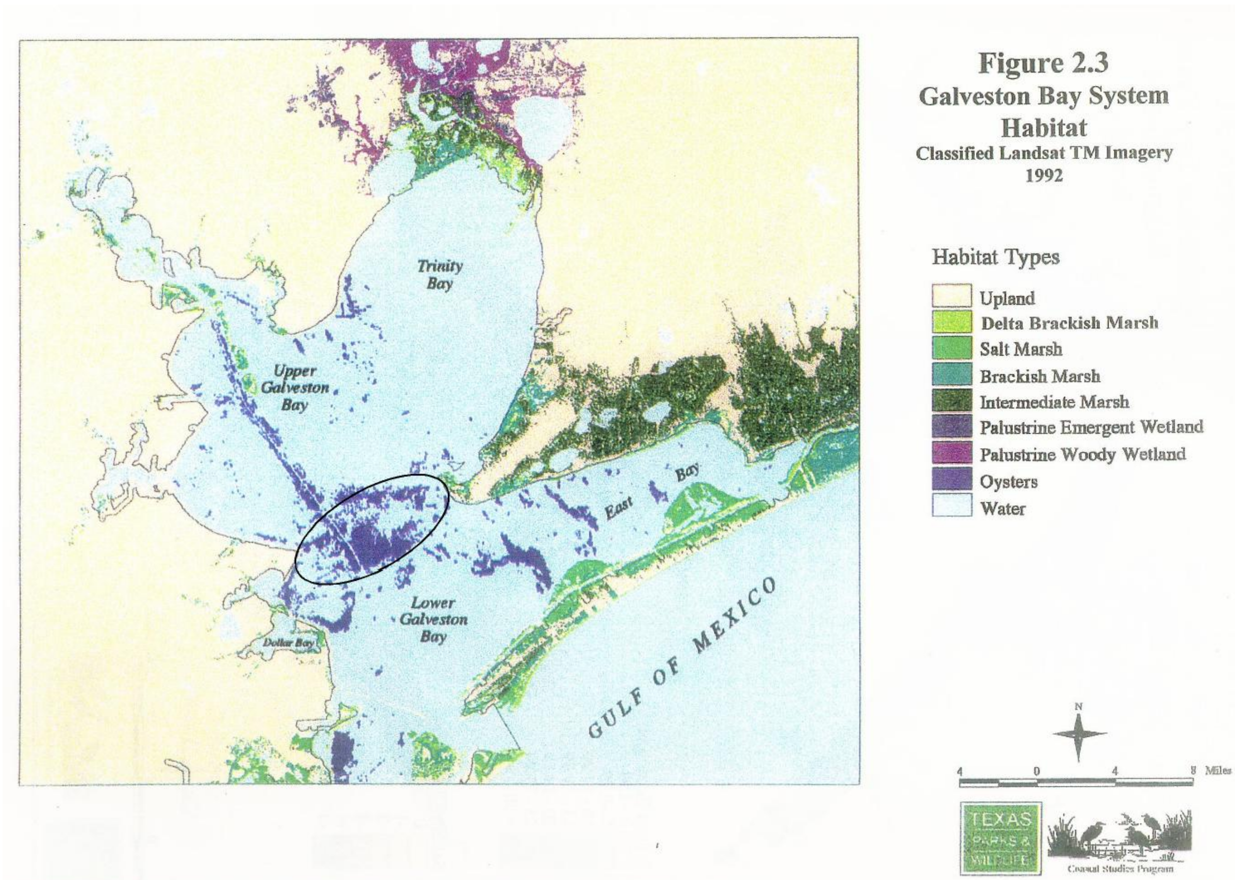


Figure 1 – Map of Galveston Bay showing the abundant oyster reef habitats in the mid-bay area (from TPWD).

Because periods of low inflows have historically occurred for Galveston Bay, it is generally accepted that the estuary is resilient and can withstand such periods, at least within the historical limits of duration, magnitude, and frequency. The goal of specifying an estuarine inflow regime component to cover these low-inflow events is to ensure that future low inflow periods are not so far removed in frequency, duration, or magnitude from historical periods of low inflow that their deleterious effects are unduly amplified.

Low Inflow / High Salinity Effects on Oysters

One of the more pronounced deleterious effects of low inflows to Galveston Bay would be if they cause a co-occurrence of high salinities with high temperatures of the summer or early fall period. Such a period can be very detrimental for the eastern oyster (*Crassostrea virginica*), an extremely important commercial species in Galveston Bay (TPWD and TWDB 2001). Although adult oysters themselves can tolerate high salinity periods, there is a marked increase in the incidence of parasite and disease problems when high temperatures coincide with high salinities (Ray 1966; Andrews and Ray 1988).

Figure 2 summarizes the principal relationships of adult oyster health as a function of temperature and salinity. Many authors have proposed ideal ranges of salinity for oysters, among them Kinne (1971) and Cake (1983) as illustrated, with ranges of approximately 10-20 ppt. Oyster mortality due to the parasite protozoan P*erkinsus marinus* ("dermo"), the most important limiting agent for oysters (Cake 1983), can be very high during the Texas summer and early fall period. The specific growth curves of the protozoan P*erkinsus marinus* ("dermo") from Hoffman et al. (1995) are shown in the upper right. At temperatures above 20°C, the growth of dermo begins to increases, becoming especially pronounced as temperatures exceed 25°C and salinity exceeds 25ppt.

As explained in the studies of Hoffman et al. (1995) and Powell et al. (1996), the overall infestation rate and the mortality of oysters due to "dermo" infestation is a cumulative process, at temperatures above 20°C and salinities above 20 ppt. Other oyster pathogens and predators, such as the southern oyster drill, are also much more prevalent in high salinity periods (Stanley and Sellers 1986). Thus, potential dire effects on oyster populations would be likely to accompany prolonged low freshwater inflow (high salinity) periods, especially if they coincide with elevated temperatures of the summer to early fall months.

Because the cumulative time of high salinity exposure appears to be a biologically important consideration for oysters, a low inflow criterion focused on periods of continuous low inflow is suggested as the appropriate criterion. Under the inflow pattern approach, the volume and duration attributes of such a low inflow criterion will be based on approximating, to some reasonable degree, those that occurred in the historic record. Thus, the aim is to avoid the creation of conditions much more harmful, because of reduced volume, increased duration, or increased frequency, than those experienced in the historical period.

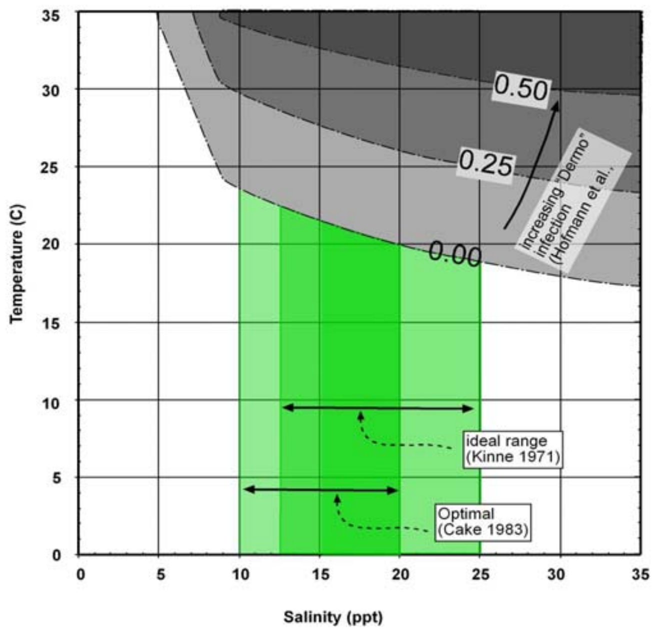


Figure 2 - Summary of the major salinity and temperature constraints on adult oysters.

Due to the above biological considerations of oysters, the present analysis focuses on periods in which low inflows may cause a co-occurrence of high salinity and high temperature. The TWDB has daily inflow estimates for all Galveston Bay dating back to 1977. However, salinity and temperature data for the oyster rich mid-bay area (the Midgal and Dollar sites on Figure 3) dates back to only 1987.

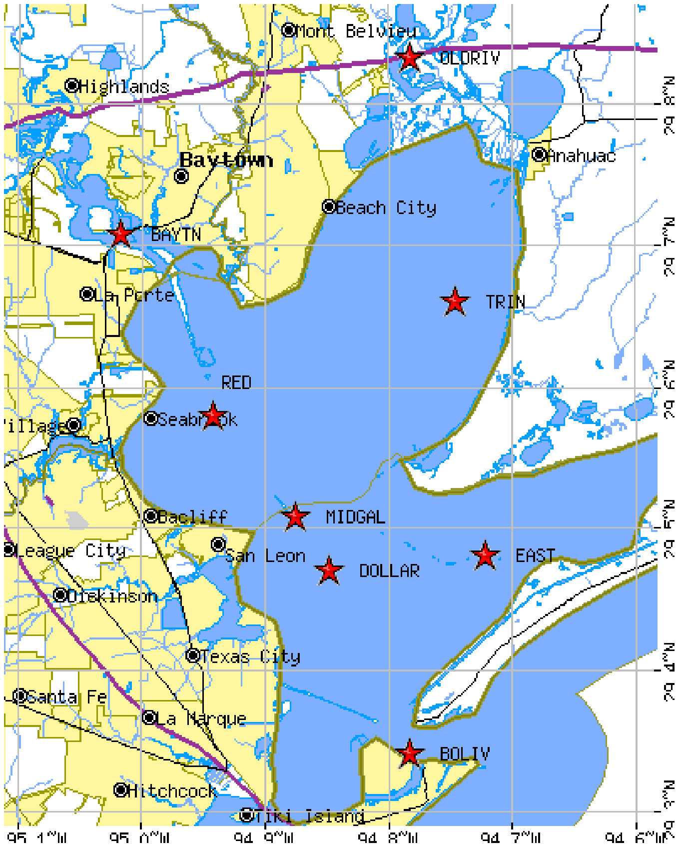


Figure 3 – TWDB data sonde sites in Galveston Bay.

As shown in Figure 4, high water temperatures in much of the year occur at the Dollar Point (=Dollar or Midgal) location in Galveston Bay (based on the TWDB sonde data for the 1987-2000 period). Thus it would appear that the May through October period, with median temperatures at or above about 23°C, would be the most likely to have the co-occurrence of high water temperatures and high salinity.

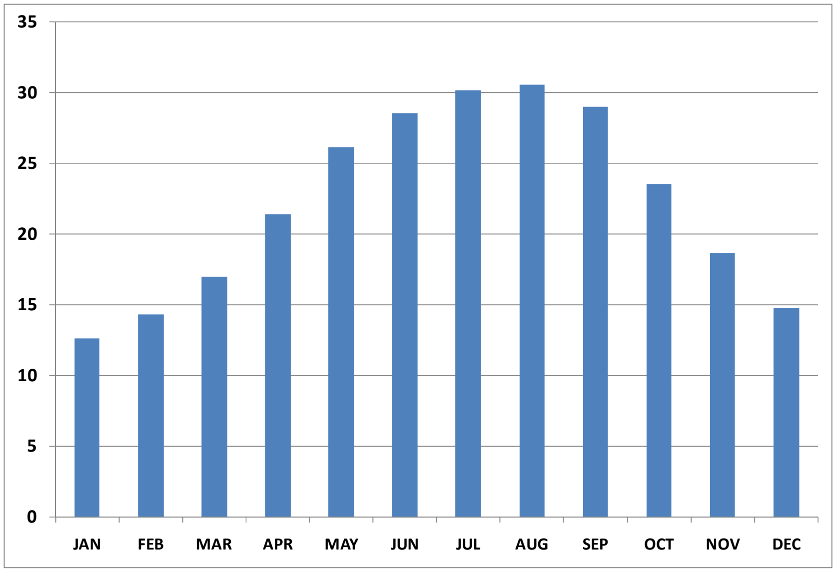
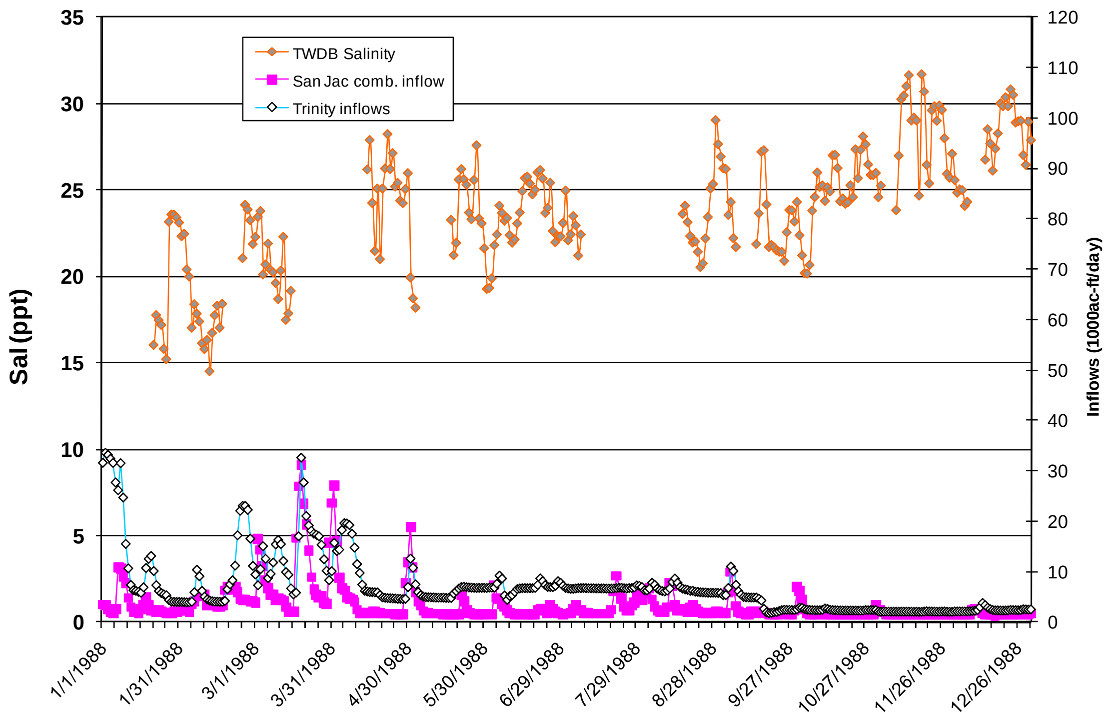


Figure 4 - Median monthly temperatures (°C) at the Dollar Point site based on the 1987-2000 data of TWDB.

Salinity – Inflow Characteristics of the Dollar Point Area

Figure 5, in two panels, illustrates the salinity response at the Dollar Point mid-estuary site for 1988 and 1999, years with a prolonged low inflow period and corresponding high salinity (above about 24 ppt) response. By inspection of the historic inflow and salinity data records, some fairly consistent trends in inflow and high salinity periods emerge. In the Sept. – Dec. period in 1988, when salinity was ranging from 24 – 32 ppt, combined San Jacinto River, Trinity River, and coastal basin inflows were in the range of 3,500 – 4,200 ac-ft/day (about 105,000 to 126,000 ac-ft/month). In the Aug. – Dec. 1999 period when salinity was in the range 22-30 ppt, combined inflows were again fairly steady and in the range of 4,600 – 5,200 ac-ft/day (about 139,000 to 155,000 ac-ft/month).

Galveston Bay Salinity@ Dollar Pt. and Inflows- 1988



Galveston Bay Salinity@ Dollar Pt. and Inflows- 1999

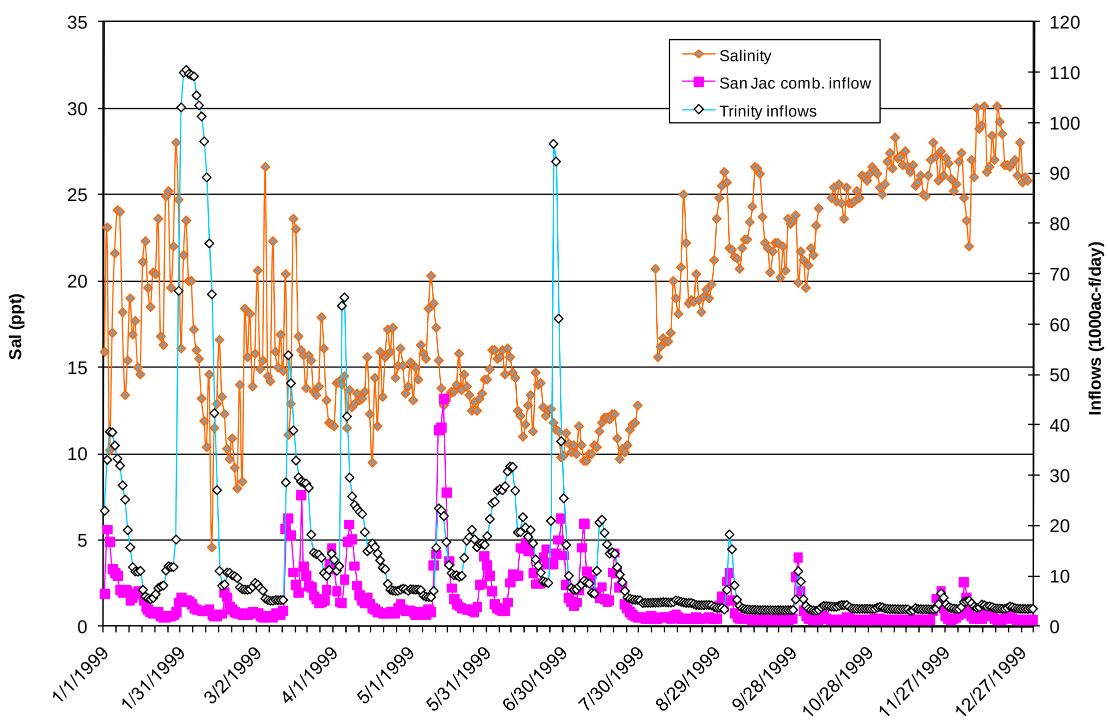


Figure 5–.Salinty and inflows to Galveston Bay in 1988 and 1999.

Predicting the Salinity Response in Galveston Bay

To facilitate the analyses herein, it is highly desirable to develop a relationship between inflows and salinity. If a suitable relationship can be found, this will allow for comprehensive assessment of salinity trends and occurrences of long periods of high salinity. Such an inflow-salinity relationship could also allow for predicting salinity in the period of record before the initiation of sonde data in the mid-bay area. For this step we relied upon previously developed inflow – salinity regression equations as presented in Espey and Trungale (2009) as well as a supplementary NWF regression that appears to better predict the higher salinities of concern. These equations were derived for the Dollar Point / Midgal area as shown in Figure 3.

The regression equations from Espey and Trungale, based on inflows and salinity data for the 1987-2005 period, are :

$$Sal = 89.097 - 5.3716 \cdot \ln(Q); \quad [r^2=0.739] \qquad (1)$$
$$Sal = 87.767 - 5.3034 \cdot \ln(Q); \quad [r^2=0.790] \qquad (2)$$

Where
Sal is predicted salinity, ppt;
Q = cumulative inflow volume over previous 30 days (ac-ft);

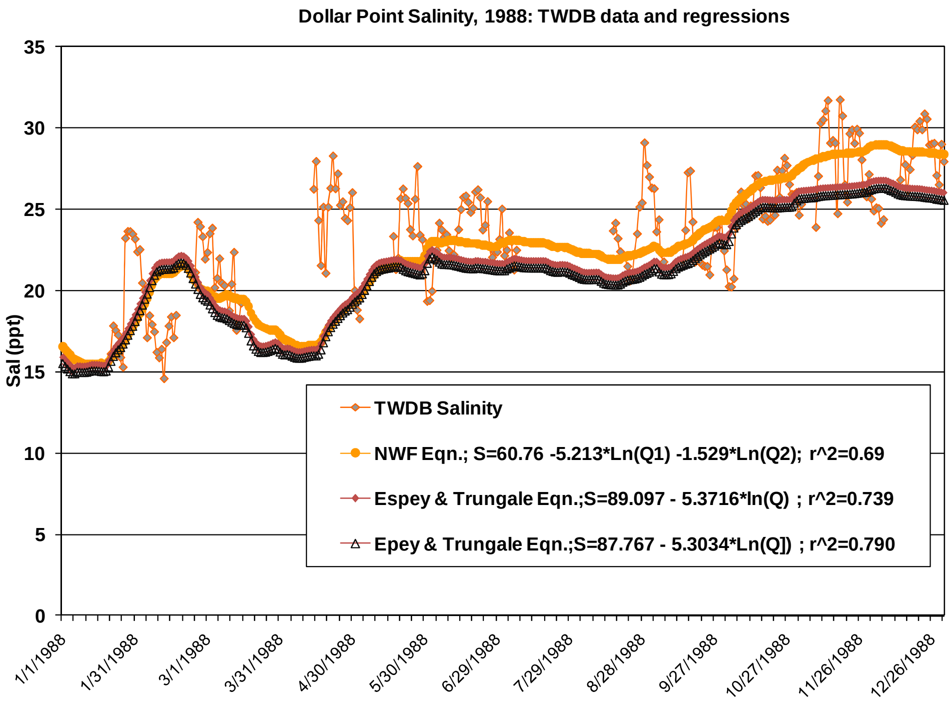
note: the two equations differ in that the dependent variable, salinity, is either the actual TWDB sonde data or that predicted by the TxBlend model.

Additionally, the National Wildlife Federation (NWF) developed a regression equation for the same TWDB data, for the period 1987-Sept. 2000. The NWF equation is:

$$Sal = 60.759 - 5.213 \cdot \ln(Q1) - 1.529 \cdot \ln(Q2); \quad [r^2=0.69] \qquad (3)$$

Where
Sal is predicted salinity, ppt;
Q1 = cumulative inflow volume over previous 30 days, 1000 ac-ft;
Q2 = cumulative inflow volume for previous 31-60 days, 1000 ac-ft

Figure 6 in two panels, again illustrates the salinity response at the Dollar Point mid-estuary site for the years 1988 and 1999, both with recorded high salinity (>24 ppt) periods. Also shown are the various regression-predicted salinity responses. Although the NWF equation (3) has a reported lower r^2 value, this equation does a better job at replicating the higher salinities that are of particular focus in these analyses. However, since the Espey and Trungale equations are utilized in derivation of other portions of the overall estuarine inflow regime for Galveston Bay, we will track the results of all 3 of these for comparative purposes.



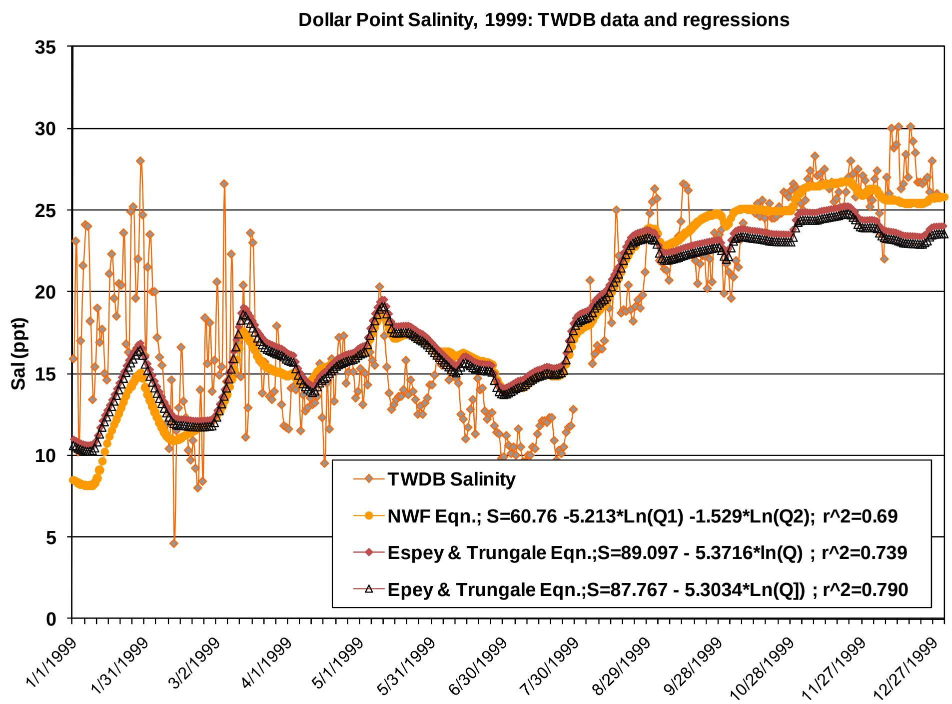


Figure 6 – Illustration of the predicted salinity in Galveston Bay at Dollar Point with the various derived salinity-inflow regression equations for 1988 and 1999.

Calculation of Durations of High Salinity Periods.

With the inflow-salinity regression equations above and the daily inflow record extending back to 1977, we are able to predict what salinity at the Dollar Point site would have been with a reasonable degree of accuracy. Furthermore, we can also find and describe periods of long duration in which salinity was above certain threshold levels. These derived statistics are summarized in Table 1 and reveal some notable features of the salinity behavior at Dollar Point. For example, based on the NWF equation, there was a maximum period length of 180 consecutive days in the high temperature period of May-Oct in which salinity was above 20 ppt[1]. The Espey and Trungale equations yield nearly identical results for the 20ppt threshold level. Similarly, for the higher level of 25 ppt, the NWF equation predicts that salinities were above this level for about a 50 day maximum (48). Clearly, as the salinity threshold is raised the predicted maximum durations values begin to diverge among the regression equations. As stated above, it appears that the NWF equation is somewhat better at predicting high salinity values.

	Maximum consecutive days above specified salinity					
salinity	NWF Eqn.		Trungale & Smith eq.(1)		Trungale & Smith eq.(2)	
(ppt)	All year	May-Oct	All year	May-Oct	All year	May-Oct
20	301	180	282	181	277	179
22	227	112	217	111	159	89
24	168	66	107	27	106	26
25	128	48	100	21	94	18
26	102	21	62	17	21	15
27	82	18	16	11	0	0
28	70	12	0	0	0	0
30	0	0	0	0	0	0

Table 1 – Summary of longest duration high salinity periods for Dollar Point site as calculated by the three inflow-regression equations.

Calculation of Steady Inflows to Achieve a Specific Salinity

As was illustrated in Figure 5, the high salinity periods at the Dollar Point site typically occur with fairly steady inflows over extended multi-month periods. Thus, it is also possible to utilize the inflow-salinity regression equations above to "back calculate" a theoretical steady or near-steady inflow that would lead to a desired salinity, also more or less steady, over an extended multi-month period. This derivation of inflow volumes will be necessary in the final step of designing the actual criterion meant to limit periods of high salinity to similar durations and magnitudes as in the historic record.

For the Espey and Trungale equations (equations 1 and 2 above) in the form of:

Sal= a + b*ln(Q)

the relation between a theoretical steady or near-steady inflow (criterion inflow) and salinity is:

Qcrit= exp[(Salcrit-a)/b] (4)

[1] This occurred in 1978 according to the NWF regression prediction, though we do not have actual sonde data.

Where
SalCrit is the desired criterion salinity, ppt;
Qcrit =cumulative steady inflow volume over previous 30 days (ac-ft); and
a , b= the regression equation coefficients.

For the NWF equation (equation 3 above) in the form of:

$$Sal= a + b*\ln(Q1)+ c*\ln(Q2)$$

the relation between a theoretical steady inflow (criterion inflow) which occurs for at least 2 consecutive 30 day periods (Q1 roughly equals Q2) and salinity is:

$$Qcrit= \exp[(Salcrit-a)/(b+c)] \qquad (5)$$

Where
SalCrit is the desired criterion salinity, ppt;
Qcrit =cumulative steady inflow volume over previous 30 days and 30-60 days (ac-ft); and
a , b, c= the regression equation coefficients.

Table 2 summarizes the results of this analysis for the steady or near-steady inflows that would lead to a specific salinity at Dollar Point.

	Steady Flows (1000 ac-ft/30 days) to just maintain specified salinity		
salinity criterion (ppt)	NWF Eqn.	Trungale & Smith eq.(1)	Trungale & Smith eq.(2)
20	422.3	385.9	354.3
22	313.9	266.0	243.0
24	233.3	183.3	166.7
25	201.2	152.1	138.0
26	173.4	126.3	114.3
27	149.5	104.8	94.7
28	128.9	87.0	78.4
30	95.8	60.0	53.8

Table 2 – Calculation of steady or near-steady combined inflows to Galveston Bay that would lead to specific constant salinity levels at the Dollar Point site (based on the three inflow-regression equations presented above).

Recommended Low-Inflow Criterion

As indicated above the goal of these analyses is to: a) identify periods of long duration in the historic record in which salinity was high enough to cause problems for oyster physiology and, b) design a criterion to assure that these periods are not overly amplified in duration or intensity in the future. As indicated in Figure 2 when salinity rises above 20 ppt in the high temperature (>about 23°C) portion of the year (May-Oct) the growth of the “dermo” parasite in oysters increases. Inspection of that figure also reveals that salinity above about 24 ppt with warm water temperature leads to substantial increases in the “dermo” growth rate. For the design of a meaningful criterion, we want to be sure and address high salinity periods that are actually problematic. For this purpose we are choosing the salinity levels of 24 ppt and 26 ppt as benchmarks.

Using the NWF equation relating inflow and salinity, the maximum duration of historic periods with salinity at or above 24 ppt and 26 ppt were 66 and 21 days, respectively (as indicated in Table 1). Table 3 summarizes a two-tier criterion aimed at assuring that such high salinity periods in the future remain within a reasonable degree of those in the historic record. For the 24 ppt level, historically occurring for a maximum duration of 66 days, we allow this to extend to 90 days maximum duration. The corresponding total Galveston Bay inflow necessary to just maintain that salinity level (from Table 2) would be 233,300 ac-ft/month for three months. Thus inflows may drop below that level, but only for three months straight. Furthermore, the 26 ppt level, historically occurred for a maximum duration of just 21 days. If we allow this to extend somewhat to a 30 day maximum duration, the corresponding total Galveston Bay inflow necessary to maintain that salinity level would be 173,400 ac-ft/month for a single month.

These criteria are detailed in Table 3, which gives the intent of the criteria levels and the corresponding inflow constraints associated with that criteria level. An important interpretation note is warranted. The criteria are couched focusing on the maximum duration that salinities can be above the indicated threshold, but inflows may fall below the indicated level and still be within the aim of the criteria. Although the inflows may drop below the indicated level, these criteria give a maximum duration that this should occur in order to maintain the maximum salinity duration. Also, the two tiers form a tandem: inflows can drop below 233,300 ac-ft/month within a 3 month period, but then only 1 month of that period can be below 173,400 ac-ft/month (2 months between 173,400 and 233,300). These two tiers assure that the characteristics of future periods of high salinity will not be vastly different than those of the historic record.

Also given are the alternate inflow amounts indicated by the Espey and Trungale inflow-salinity regression equations.

Low Inflow Criterion Level	Goal of Criterion	Inflows Constraints Associated with the Criterion[1] (ac-ft/month)		
		NWF eqn.	Trungale & Smith Eqn. 1	Trungale & Smith Eqn. 2
A	Maintain salinity at Dollar Pt. at or above 24 ppt for no longer than 3 consecutive months in the May-Oct period.[Historic maximum duration 66 days]	233,300	183,300	166,700
B	Maintain salinity at Dollar Pt. at or above 26 ppt for no longer than 1 month in the May-Oct period.[Historic maximum duration 21 days]	173,400	126,300	114,300

Note: 1) Inflows may drop below these levels, but for not more than 3 consecutive months in the case of criterion level A and not more than 1 month for level B.

Table 3 – Summary of a two-tier criterion to maintain duration of high salinity periods at Dollar Point within a reasonable degree of departure from those of the historic record.

References

Andrews, J. D., and S. M. Ray. 1988. Management strategies to control the disease caused by Perkinsus marinus. American Fisheries Society Special Publication 18:257–264.

Cake, E. W., Jr., 1983. Habitat suitability index models: Gulf of Mexico American oyster. U.S. Department of the Interior Fish and Wildlife Service, FWS/OBS-82/10.57.

Coen, L.D., M.W. Luckenbach, D.L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. In *Fish Habitat: Essential Fish Habitat and Rehabilitation*. Benaka, L.R. (ed.), American Fisheries Society, Symposium 22, Bethesda, MD, pp. 438–454.

Espey Consultants & Trungale Engineering & Science. 2009. Technical Support for the Analysis of Historical Flow Data from Selected Flow Gauges in the Trinity, San Jacinto, and Adjacent Coastal Basins: Galveston Bay Salinity Zonation Analysis. Report to the Trinity-San Jacinto Bay and Basin Expert Science Team. August 2009.

Hofmann, E. E., E. N. Powell, J. M. Klinck, and G. Saunders. 1995. Modeling diseased oyster populations I: Modeling Perkinsus marinus infections in oysters. Journal of Shellfish Research 14:121–151.

Kinne, O. 1971. Salinty:invertebrates. In *Marine Ecology. Vol. I, Environmental Factors, Part 2.* O. Kinne (ed.), Wiley-Interscience, New York, NY. [as cited in Longley, 1994]

Longley, W.L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX.

National Wildlife Federation. 2009. An Inflow Pattern Approach for Establishing and Inflow Regime for Texas Estuaries. Sept. 2009. Available at www.texaswatermatters.org .

Powell, E. N., J. M. Klinck, E. E. Hofmann, and M. A. McManus. 2003. Influence of Water Allocation and Freshwater Inflow on Oyster Production: A Hydrodynamic-Oyster Population Model for Galveston Bay, Texas, USA. Environmental Management 31:100-121.

Ray, S. M. 1966. Notes on the occurrence of Dermocystidium marinum on the Gulf of Mexico Coast during 1961 and 1962. Proceedings of the National Shellfish Association. 54: 45-54.

Science Advisory Committee (SAC). 2009a. Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process. Report # SAC-2009-03. June 5, 2009.

Stanley, D.W., Sellers, M.A. 1986. Species profile: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) — American oyster. US Fish Wildlife Service Biological Report 82(11.64) US Army Corps of Engineers, TR EL-82-4, 25 pp.

Texas Parks and Wildlife Department (TPWD) and Texas Water Development Board (TWDB). 2001. Freshwater Inflow Recommendation for the Trinity - San Jacinto Estuary of Texas. Austin, Texas.