COPY FROM BRUCE MOULTON, TWC. HE THINKS THIS WAS FROM "GALVESTON BAY IN THE 20TH CENTURY" 31 JAN 1987.

FRESHWATER INFLOW TO GALVESTON BAY

by

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ABSTRACT

Galveston Bay is the most productive estuary in Texas. The Trinity River provides one-half of the freshwater inflow and nutrients, and a substantial amount of the sediment, which reaches Galveston Bay. The Lake Livingston dam and reservoir, to date, have not reduced the annual river discharge to Trinity Bay but a slight seasonal shift has reduced flow from January to May while increasing flow from August to December. The frequency and duration of floods, important to the transport of floodplain nutrients, has not diminished. The proposed Wallisville dam and reservoir, near the mouth of the river, will potentially divert as much as 39 percent of river discharge and entrap substantial, but unknown, quantities of sediment and nutrients, leading to higher salinities in Trinity Bay and erosion of the rivermouth delta. Sheet flow of floodwaters across the delta marshes, an important nutrient transport mechanism, will be reduced. It is essential that a comprehensive environmental impact assessment, conducted by an independent third-party, be completed to consider the synergistic and cumulative effects of the several in-progress or proposed development projects which currently threaten the Galveston Bay ecosystem.

Galveston Bay is widely acknowledged to be the most productive of all estuaries in Texas. Why is this so? What environmental factors are responsible for this productivity? Has the urbanization and industrialization of the upper Texas coast affected these environmental factors? Do we know enough about these factors to ensure that existing and planned development projects will not jeopardize the biological productivity of Galveston Bay? Currently threatened by a multitude of development schemes, will the estuary survive until the 21st century? Reliable answers to these queries are urgently needed to balance the conflicting needs of the industrial, fishery, shipping, and recreational sectors of our economy.

The biological productivity of Galveston Bay can be demonstrated in several ways, one of which is the magnitude of shellfish (shrimp, crabs and oysters) harvested by commercial fishermen (Table 1). Shellfish, especially shrimp, are typically most abundant where freshwater inflows are the greatest. Estuaries are named to indicate the rivers which create them, and the Trinity-San Jacinto estuary (Galveston Bay) surpasses all others, averaging 8.59 million pounds of shellfish annually, 24.9 pounds for each acre of surface area (Armstrong, 1982). Galveston Bay ranks fourth in the commercial harvest of finfish in Texas, but first in finfish caught by recreational fishermen. This harvest may reflect the intense fishing pressure generated by the heavily populated urban centers but the fact that the bay can sustain a high recreational yield in the face of intense fishing effort is further evidence of its inherent productivity.

How does Galveston Bay differ from other Texas estuaries? It is a humid ecosystem which experiences the lowest temperatures and highest precipitation on the Texas coast. The low temperatures are particularly important during the summer when water temperature in shallow estuaries can approach lethal temperatures for the bay organisms. The low temperatures also reduce the amount of evaporation from the surface of the bay. Precipitation influencing Galveston Bay is determined by geography and climate. Rainfall on the Texas coast at the Mexican border is one-half (26 inches annually) that which occurs at the Louisiana border (52 inches).

Precipitation on the bay and, more importantly, runoff from the surrounding land are adequate to substantially dilute the Gulf water which fills the bay, creating low salinities behind the barrier island and peninsulas. While Gulf waters contain 34 parts per thousand (ppt, or 3.4 percent) salt, the waters of West Bay, inland from Galveston Island, typically range from 25 to 30 ppt. East Bay, inland from the Bolivar Pensinsula, may be 15 to 25 ppt, while upper Trinity Bay may be diluted to less than 10 ppt by Trinity River water. The salinities change constantly, affected by winds and tidal forces moving and mixing the water masses and the volumes of freshwater entering the bay. Heavy precipitation events, such as hurricanes, produce extreme dilution of the saltwater, while extended droughts permit more Gulf water to penetrate the bay and increase salinity.

Another important feature of Galveston Bay is the proportion of its shoreline covered with emergent vegetation (Shew et al. 1981). Emergent plants have their roots anchored beneath permanent water but their stems stand erect in full sunshine above the water line. Subsidized by the energy of tidal forces and gravity, which carry nutrients to the plants and remove their waste products, emergent plants can photosynthetically produce more organic molecules than any other vegetation. As their stems and leaves die and sink into the water, the organisms of decomposition chew, grind, and digest them into the basic organic molecules which support the entire detrital food chain of the bay. Submergent plants are flacid, have their rate of photosynthesis determined by water depth and clarity, are severely inhibited by turbidity, and never achieve that rate of biomass production typical of emergent vegetation.

These unique features - low temperature, high precipitation, low salinity and emergent vegetation - set Galveston Bay apart from other Texas estuaries. It is also important to consider the boundaries of the Galveston Bay ecosystem. Is the ecosystem delimited by the land-water interface around the shoreline, the river mouths, and the passes to the Gulf? Certainly such a boundary would adequately define the populations of plants and animals which inhabit the bay for all or part of their lifetimes. But if we want to include the basic functions of the ecosystem - energy flow and nutrient cycling - we must extend beyond the bay shoreline. The living organisms do exactly that. No one would propose excluding the shoreline marshes from the ecosystem because marine organisms are the dominant consumers within the marsh itself. Even in such indisputable freshwater habitat as Lake Charlotte, surrounded by salt-intolerant cypress trees and bottomland hardwoods, the most conspicuous fishes are mullet and menhaden, marine species so abundant that they commonly jump into your boat or canoe while eluding predators. To include all factors which directly influence Galveston Bay, save the atmosphere, we must extend the boundaries to the limit of the watershed.

Galveston Bay receives water, and the dissolved and suspended substances transported by that water, from two river basins and three coastal basins (Figure 1). The Trinity River watershed is the largest - 18,000 square miles extending 360 miles northward, at times 100 miles wide, reaching nearly to Oklahoma, the serpentine river coursing 700 miles from headwaters to Trinity Bay (Table 2). The San Jacinto watershed is less than one-fourth that which nurtures the Trinity. The combined watershed which services Galveston Bay totals 23,583 square miles, 9 percent of Texas, but that watershed is inhabited by more than 5,900,000 people, or 42 percent of the state's population. If one also thinks of this watershed receiving the sewage effluent of nearly 6 million people, one can view treated, and untreated, wastewater as not just affecting, but to a great extent determining, water quality in the bay. When vast amounts of industrial effluent are added to that admixture, it is easy to envision Galveston Bay as a seriously threatened, perhaps endangered, ecosystem. Those stream segments which are already judged as neither fishable or swimmable are indicated in Figure 1. More than 350 stream miles in the Trinity River basin and the Houston-Galveston area do not meet the fishable and swimmable water quality standards (TWRI, 1986).

Having established that the Trinity River alone comprises 76 percent of the watershed associated with Galveston Bay, we must recognize that not all of the precipitation which falls on the watershed will reach the bay. Some will sink into the earth, to become groundwater or seep into small streams. Some will evaporate back into the atmosphere directly or via plants. A considerable amount will be diverted for various human uses - municipal and industrial water, irrigation, etc. A large fraction of the diverted water will wend its way back to the river as treated or untreated wastewater. Approximately 5.6 million acre-feet per year (mafy) will run off the land into the river system. Surface water users have already claimed 5.3 mafy as "water rights". Not one drop of this water has been designated to benefit Galveston Bay, but, on the average, 5.4 mafy will reach the bay. This comprises 48 percent of all of the freshwater which the bay receives from all sources (Table 3).

The freshwater which enters the bay carries dissolved and suspended substances, particularly sediment and nutrients. Some sediment is deposited in the delta marshes and provides for the maintenance and growth of these areas, counteracting constant erosional processes. The marshes provide critical habitat for the larvae and juvenile stages of many marine organisms. They act as both a source and a sink for nutrients. They are a source in that a great deal of plant material is grown and decomposes in these marshes. They also function as a nutrient sink in that much of the nutrients carried into the marshes by river flow are extracted from the water and incorporated into the plant and animal biomass of the marsh. While the nutrients generated within and released from the marsh are substantial, they pall in comparison with the nutrients carried into the marsh with river water (Table 4). Recognizing that nutrients are washed out of marshes with daily tidal flow, sporadically flushed out of marshes during floods, and even scrubbed from the atmosphere during precipitation events, 96 percent of all carbon, nitrogen and phosphorus, the basic building blocks of biomass, enter the bay with freshwater inflow.

The Trinity River is contributing half of the annual freshwater inflow and half of the essential nutrient inflow, plus a daily average of 1500 tons of sediment. It can truthfully be said that the Trinity River is the "engine" which drives the bay productivity. There are already 27 dams on the Trinity River and its tributaries and several more are planned. Dams and their associated reservoirs are efficient in trapping nutrients and sediments as well as water. The closest reservoir to Galveston Bay is Lake Livingston, at river mile 129. Constructed in the late 1960s, Livingston began to fill in June, 1969, and reached conservation pool level of 1,750,000 acre-feet in November, 1971. Authorized to divert 1.2 mafy, very little of this water has been used so far. Has this dam influenced the flow of water to Galveston Bay?

The final U.S. Geological Survey gaging station uninfluenced by tides on the Trinity River is located near Romayor at river mile 94. Established in May of 1924, it affords a comparison of river discharges for 45 years (1925-1969) prior to operation of Lake Livingston and 16 years (1970-1985) since the lake began to fill (Figure 2). River discharge has been highly variable, ranging from 917,000 acre-feet in 1956 to 12,280,000 acre-feet in 1945; the 61 year average is 5.23 million acre-feet. The City of Houston has water rights for 70 percent of the Livingston yield but has not built a delivery system to transfer the water from the Trinity River basin to the San Jacinto basin which serves the City. It is clear that, to date, Lake Livingston has not affected the volume of water reaching Galveston Bay (Table 5). The pre-impoundment average of 5.24 mafy is not significally different statistically from the post-impoundment 5.19 mafy average.

The Texas Department of Water Resources has estimated that a freshwater inflow of 3.2 mafy would be adequate to maintain the fishery harvest at its historic average (1981). The normal yearly variation of the river indicates that level was not achieved 26 percent (16 of 61 years) of the time (Figure 2). When the full yield of Lake Livingston (1.2 mafy) is diverted, this shortfall may increase to 43 percent. While municipal and industrial water diverted to Houston does return to the bay, it does so via the San Jacinto River and Buffalo Bayou, both heavily polluted and without significant shoreline marshes.

The seasonal discharge of the freshwater inflow is perhaps more important than the total volume. Heavy inflow during the winter months may flush the nutrients through the system while few organisms are present and low ambient temperatures reduce photosynthesis. High volume inputs during April, June and October are most beneficial to the estuarine organisms. Changes in the seasonal distribution of the Trinity River discharge are shown in Figure 3. Largest flows occur during winter and spring, peaking in May, with minimum flows in August and September. Although none of the pre- and post-impoundment differences are statistically significant, there is clearly a trend toward less water being released from January to May, and more water released from August to December, since impoundment. The optimum release level for maintenance of fishery harvests, as recommended by the Texas Department of Water Resources, is generally maintained except for the months of April and October. The recommended discharge for April, 691,000 acre-feet, has occurred 14 times (23 percent) during the 61 year record. The recommended discharge for October, 670,200 acre-feet, has occurred only 5 times (8 percent) during the same period. The recommended levels are mathematical estimates of optimum flow which, if achieved, would increase the fishery harvest.

Nutrients are transported from the watershed to the bay in two general ways, as dissolved chemicals and particulate organic matter. The dissolved nutrients, particularly nitrogen and phosphorus, are substantially augmented by the discharge of treated and untreated wastewater in the upper Trinity River. The concentrations of nitrogen and phosphorus at various points along the Trinity River are shown in Figure 4. Concentrations are low in Fort Worth but jump drastically after receiving effluent from Grand Prairie and Dallas, then gradually decline, due to dilution and biological uptake, as the water proceeds toward the bay.

Particulate organic nutrients are produced by the decomposition of fallen leaves and litter, and removed by rising water across the floodplain several times a year. Each flood event lifts the decomposing material from the forest floor and moves it downstream. The bulk of the material is moved in the first flush of water off the floodplain. Each flood mixes, stirs, and moves this detritus closer to the bay. Thus both the frequency and magnitude of flood events are important in nutrient transport within the ecosystem. Has Lake Livingston affected flooding along the Trinity River?

At Romayor, a flow of 20,000 cfs (cubic feet per second) is sufficient to overflow the banks, and one half of the floods have a flow of 29,500 cfs or more (TDWR, 1981). Table 6 compares the pre-operational and post-operational frequency and duration of minimal and median flood events at this location. None of the differences have statistical significance. Under current operating conditions, Lake Livingston has not altered the flood regime below the dam.

Lake Livingston is 129 miles upstream from the mouth of the river, thus the input of water, sediment, and nutrients from downstream tributaries is unimpeded. The proposed Lake Wallisville dam is located only 4 miles above the mouth of the river. Proponents of this project maintain that the lake is too small (5600 acres) and the dam too low (4 ft high) to adversely affect Trinity Bay. The Wallisville project was 72 percent complete when construction was halted by a federal court injunction in 1971. The original dam stretches more than 6 miles across the brackish marshes near the bay. Three channels through this dam are still open. Acknowledging that serious environmental damage could result, the Corps of Engineers redesigned the project, reducing the original 19,700 acre impoundment to 5,600 acres. This will require abandonment of the dam already built across the marsh, and construction of a new dam up the west bank of the river. The freshwater and brackish marshes are now excluded but the cypress swamp and bottomland hardwood areas will still be inundated. Several questions remain. Will the smaller lake affect the amount of water, sediments, and nutrients reaching the bay? Will the new dam affect the marshes which lie downstream? Will the old dam, abandoned in place, affect the marshes between it and the bay?

Lake Wallisville will operate as an oscillating sump. It will be filled, with water released from Lake Livingston, to the four foot level and lowered to the one foot level frequently as water demands of the City of Houston dictate. Reputed to provide one-third of the City's surface water supply, this should occur fairly often. The maximum diversion may be 219,000 acre-feet annually, about 4 percent of the annual flow, as claimed by the Corps of Engineers (1981). But if the Wallisville reservoir yield is also 320 million gallons per day, as claimed in a companion document (1981), the diversion would be 358,392 acre-feet, or 7 percent of annual flow. Under drought conditions, when water demand would be greatest, this diversion could amount to either 22 or 39 percent of flow, depending on which, if either, of the documents is to be believed. The Corps of Engineers environmental impact statement (1981) for Wallisville states that "under future conditions ... periods of several months could occur when no releases to the bay or marshes would be made. Under these conditions a rise in marsh salinities to about 20 parts per thousand or higher could reasonably be expected." Such an interruption of river discharge to Trinity Bay would be very detrimental to marsh and bay organisms.

Equally important would be the alteration of flow patterns to the marshes. At normal water levels, the flow of water through the marshes is limited to the serpentine marsh channels. Tidal movements flush chemicals back and forth but displace little detritus. When the marsh floods, and water levels reach the tops of the plants or higher, the decomposing vegetation is lifted free and clear of the plant stems and moved downstream. Under these conditions the bulk of the water moves as sheet flow, a thin, broad expanse of water moving over the marsh, rather than through the channels. The Wallisville dam, even though only four feet high, will seriously interfere with this process because water will have to rise a minimum of four feet before sheet flow can even begin. Minor flood events will not top the dam and sheet flow will be precluded. Sheet flow will be truncated on both the rise and the fall of larger floods because the dam raises the threshhold which must be overcome for sheet flow to commence or persist.

Furthermore, most of the wetlands to be inundated by the Wallisville reservoir are forested cypress swamp or bottomland hardwoods. The trees will not be cut. A 5,600 acre permanent swamp will be created, not an open-water lake, as most people envision a lake or reservoir. This swamp, oscillating between 1 and 4 feet deep, will clog with aquatic weeds and wetland vegetation, trapping a substantial portion of the sediment and nutrients passing into the reservoir. That portion of the Trinity River delta surrounding the mouth of the river, currently stable or slowing growing, will be starved for lack of replacement sediment and may recede.

What of the existing dam, to be abandoned in place whether or not the new

Wallisville reservoir is constructed? This 33,900 foot structure has been interfering with sheet flow through the brackish marsh for more than 15 years. Has the dam adversely affected the marshes, and will it continue to do so? Decreased sediment flow interrupts delta building and leads to accelerated subsidence and erosion of existing marshes. A comparison of wetland habitat within a 4650 acre plot immediately adjacent to, and downstream of, the dam, based on wetland maps made in the 1950s and 1979, revealed substantial losses (Mueller and Baker, 1985). Emergent vegetation had declined 14 percent, mudflats had declined 51 percent, and open-water habitat had increased 49 percent, all within 6 years or so of dam construction. Six hundred acres of marsh had reverted to a less productive habitat type. The bay shoreline is conspicuously eroding in this zone. While this study is semi-quantitative and does not establish that the dam is the sole agent responsible for the observed changes, it does indicate that one cannot complacently assume that the dam is beneign.

In summary, it is clear there is much we do not know regarding the Trinity River, its vital input of freshwater, sediment, and nutrients to Galveston Bay, and the effect of Lake Livingston and the proposed Wallisville Lake on productivity of the estuary. Lake Livingston was constructed before the era of the National Environmental Policy Act and no assessment of its potential environmental impact has ever been attempted. Since its full yield will likely be utilized by the turn of the century, it is essential that we gain further understanding so that decisions affecting the rest of Galveston Bay can be made wisely. The origins and quantities of nutrients entering the bay need to be determined. The potential impact of the Wallisville dam and reservoir on Trinity Bay has never been assessed. This must be done before construction resumes. Other proposed development projects which will affect Galveston Bay must be viewed in an integrated, holistic fashion. If we are to insure that Galveston Bay enters the 21st century intact and highly productive, it is essential that a comprehensive assessment of the cumulative impact of each project, reacting synergistically with all other stressors in the bay ecosystem, be completed by an objective and independent third party as quickly as possible.

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Table 1. Average Annual Commercial Shellfish Harvest in Texas Estuaries, 1942-76 (after Armstrong, 1982).

ESTUARY	MILLION POUNDS	POUNDS PER ACRE
Sabine-Neches	0.93	21.1
Trinity-San Jacinto	8.59	24.9
Lavaca-Tres Palacios	3.03	12.1
Guadalupe	2.16	15.6
Mission-Aransas	1.67	14.6
Nueces	0.59	5.4

Table 2. Galveston Bay Drainage Basin Area (from TDWR, 1984)

BASIN	SQ. MILES	PERCENT
Trinity River	17,969	76.2
San Jacinto River	3,976	16.9
San Jacinto-Brazos	961	4.1
Trinity-Neches	430	1.8
Trinity-San Jacinto	247	1.0

Table 3. Freshwater Inflow to Galveston Bay, 1941-1976 (from TDWR, 1981)

SOURCE	MILLION ACRE-FEET	PERCENT
Trinity River	5.381	47.5
San Jacinto River	1.597	14.1
Other Inflow	2.794	24.7
Precipitation	1.569	13.9

Table 4. Sources of Nutrient Input to Galveston Bay (from Armstrong, 1982)

NUTRIENT	FRESHWATER INFLOW	MARSH TIDAL FLOW	MARSH FLOODS	PRECIPI-TATION
Carbon	96.1 %	3.7 %	0.1 %	---
Nitrogen	95.9	1.0	0.3	2.8 %
Phosphorus	95.4	2.4	1.1	1.1

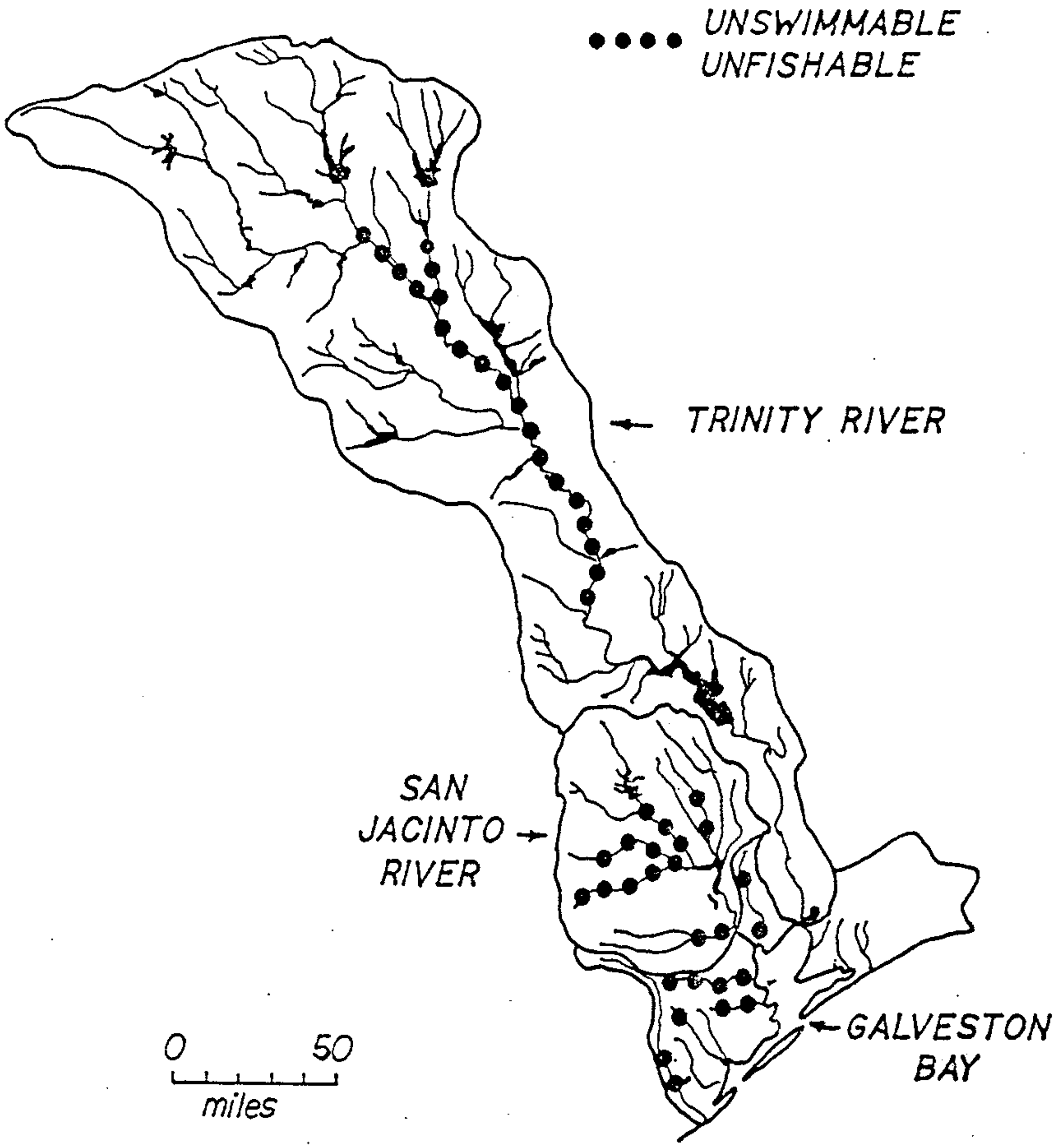
Table 5. Trinity River Discharge at Romayor, River Mile 94 (in million acre-feet)

PERIOD	AVERAGE	STD. DEV.
1925-1969	5.24	2.874
1970-1985	5.19	2.460

Table 6. Comparison of Trinity River Flood Events at Romayor Before (1925-1969) and After (1970-1985) Construction of Lake Livingston.

	AVERAGE	STD. DEV.	RANGE	NUMBER
FLOODS OF 20,000 CFS OR MORE				
Number of Flood Events per year				
1925-1969	3.5	2.56	0-9	45
1970-1985	2.9	2.35	0-10	16
Duration of Flood Event (days)				
1925-1969	10.6	13.98	1-78	158
1970-1985	11.7	9.25	1-46	47
Total Flood Days per year				
1925-1969	34.8	31.60	0-115	45
1970-1985	34.5	29.38	0-78	16
FLOODS OF 29,500 CFS OR MORE				
Number of Flood Events per year				
1925-1969	1.7	1.94	0-10	45
1970-1985	2.1	1.88	0-7	16
Duration of Flood Event (days)				
1925-1969	11.7	12.61	1-63	76
1970-1985	8.3	5.91	1-28	33
Total Flood Days per year				
1925-1969	19.7	22.73	0-80	45
1970-1985	17.1	15.44	0-58	16

Figure 1. The Galveston Bay Watershed (after TDWR, 1984)


UNSWIMMABLE
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TRINITY RIVER
SAN
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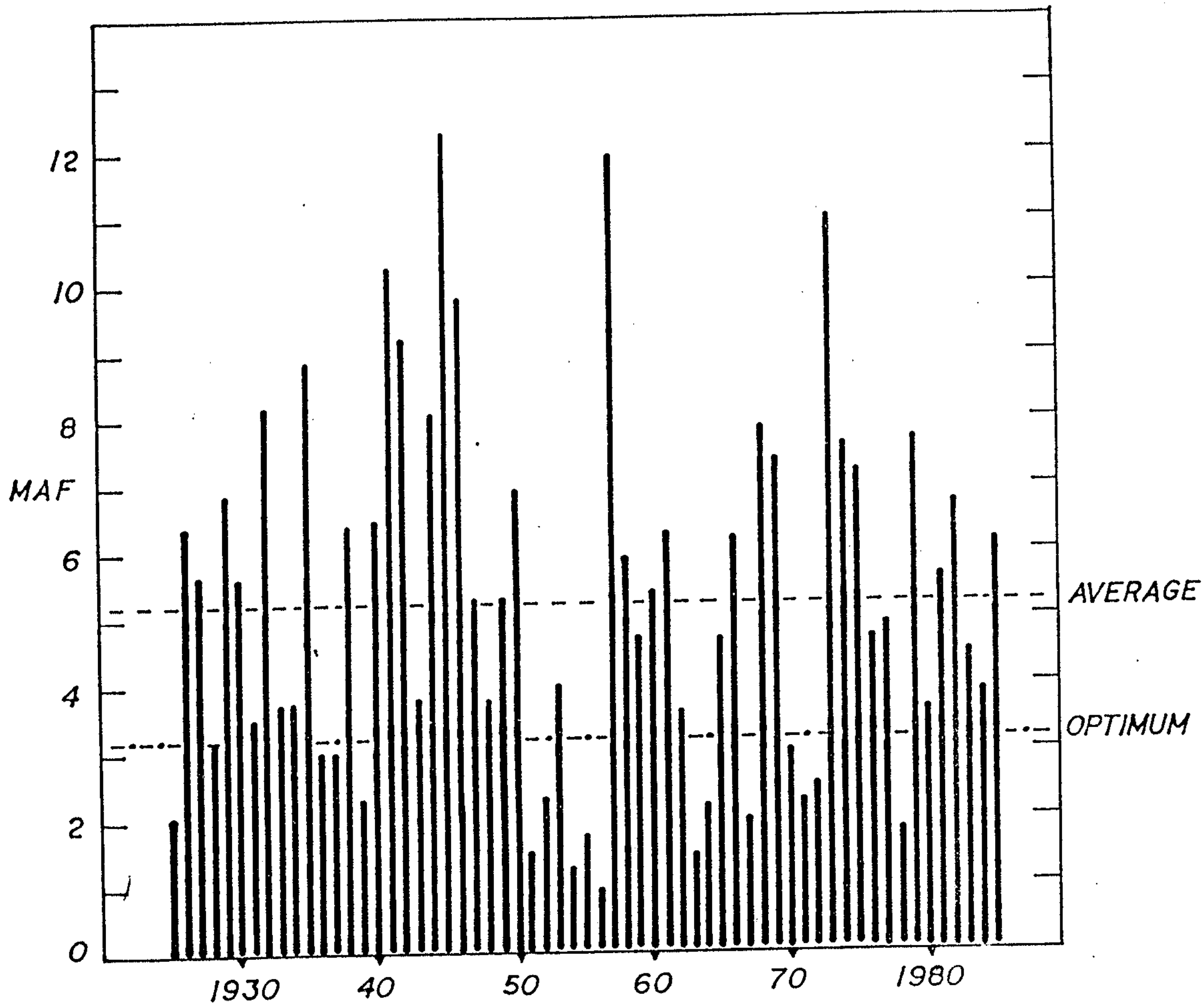
Figure 2. Annual Trinity River Discharge to Trinity Bay.



MAF
12
10
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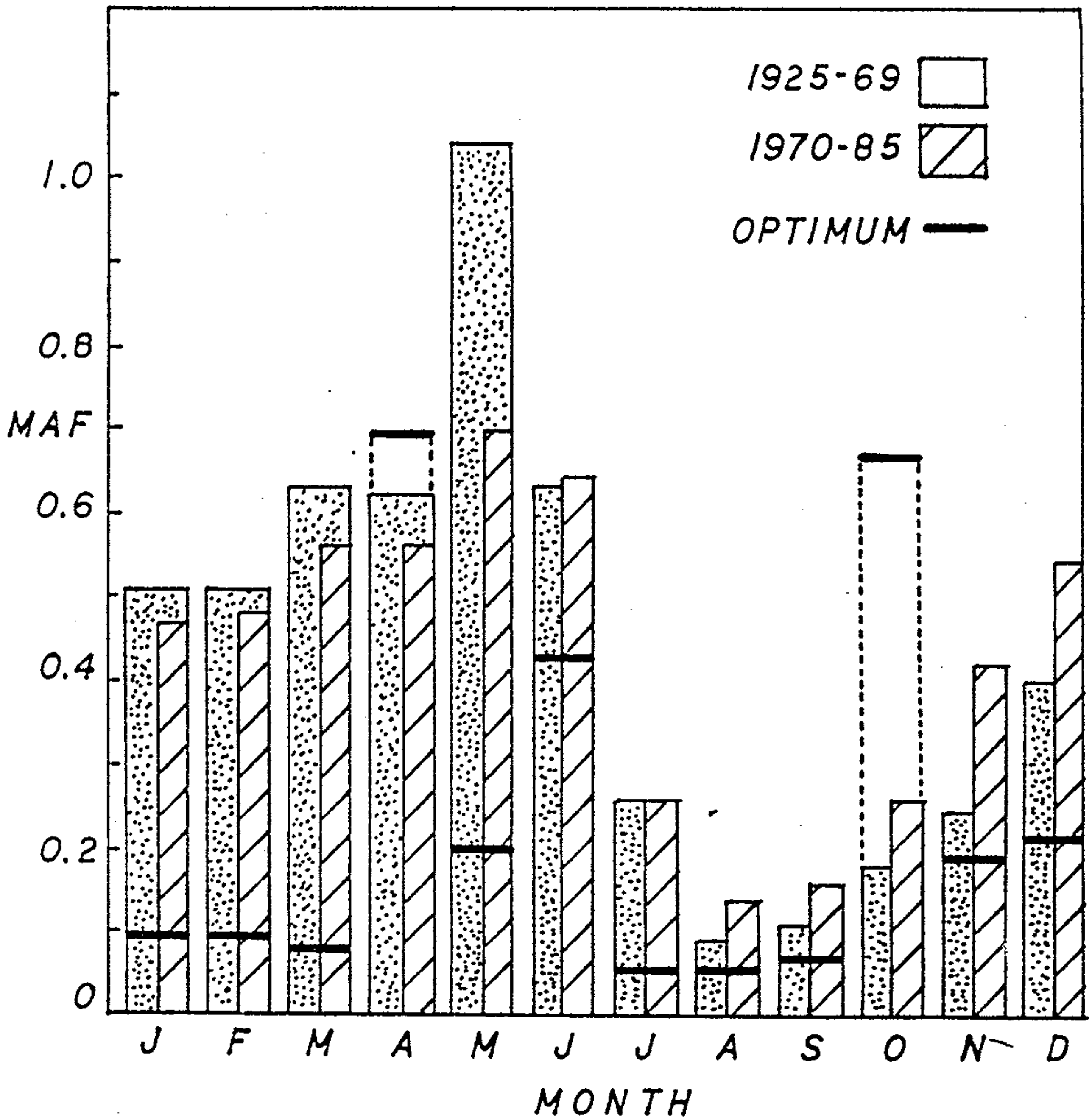
6
4
2
0
1930
40
50
60
70
1980
AVERAGE
OPTIMUM

Figure 3. Monthly Trinity River Discharge to Trinity Bay.


1925-69
1970-85
OPTIMUM
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0.2
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1.0
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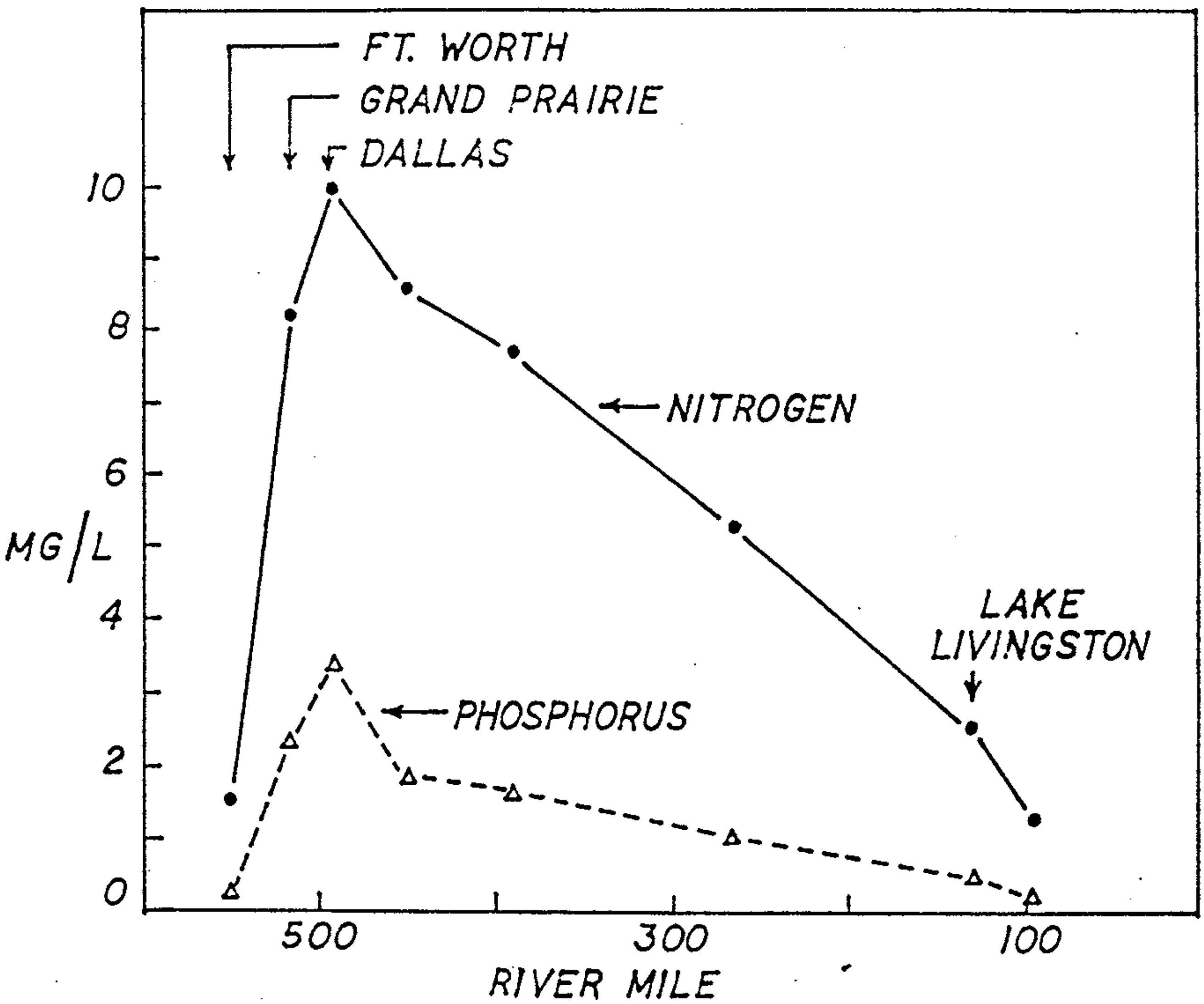
Figure 4. Nitrogen and Phosphorus Levels in the Trinity River.
(after USGS, 1984).


FT. WORTH
GRAND PRAIRIE
DALLAS
10
8
6
4
2
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MG/L
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LAKE LIVINGSTON
PHOSPHORUS
500
300
100
RIVER MILE

TRINITY RIVER LOW FLOW ANALYSIS

PURPOSE: The Trinity River Authority (TRA) and City of Houston are legally obligated to release up to 1000 cubic feet per second (cfs) of stored water from Lake Livingston as needed during the irrigation season to control saltwater intrusion. The amount of water which actually has been released to control salinity in the lower Trinity River is not known. Construction of a saltwater barrier at Wallisville will eliminate the need to release stored water for salinity control. A reliable estimate of the amount of water which will be saved is needed to compare the projected benefits and costs of the Wallisville Reservoir.

OBJECTIVE: To estimate the amount of water needed to control saltwater intrusion during the 124 day irrigation season, May 15 to September 15.

ASSUMPTIONS: (1) A flow of 500 cfs is adequate to overcome saltwater intrusion; and (2) river discharge for the period 1924-1968, before closure of the Livingston Dam, is equivalent to river discharge following dam closure.

In two documents (a 1979 retrospective review of water released for salinity control during the 1978 drought, and a 1983 hydroelectric license application to the Federal Energy Regulatory Commission) TRA has stated that 500 cfs of flow are adequate for salinity control. The average annual discharge of the Trinity River at Romayor was 5.24 million acre-feet for the period 1925-1969 and 5.19 million acre-feet for the period 1970-1985; there is no statistically significant difference between these two values.

METHOD: U.S. Geological Survey data for mean daily flow for the period May 15 to September 15 were analyzed. Days with flows less than 500 cfs were tabulated and averaged.

RESULTS:

1924 - 47 days	1933 - 0 days	1942 - 0 days	1951 - 18 days	1960 - 2 days
1925 -100	1934 - 83	1943 - 11	1952 - 61	1961 - 0
1926 - 0	1935 - 0	1944 - 0	1953 - 31	1962 - 0
1927 - 25	1936 - 32	1945 - 0	1954 - 64	1963 - 17
1928 - 23	1937 - 51	1946 - 0	1955 - 47	1964 - 58
1929 - 39	1938 - 0	1947 - 0	1956 - 89	1965 - 0
1930 - 49	1939 - 56	1948 - 0	1957 - 0	1966 - 0
1931 - 31	1940 - 3	1949 - 13	1958 - 0	1967 - 22
1932 - 0	1941 - 0	1950 - 0	1959 - 0	1968 - 0

Average number of days with flow less than 500 cfs = 21.6 days

500 cfs x 0.646 = 323 MGD x 22 days = 7110 million gal / 365 days = 19.5 MGD

Salinity control would have been unnecessary 47 percent of the years (21 of 45)

CONCLUSION: Construction of a saltwater barrier at Wallisville will save an average 20 MGD of water annually. The City of Houston 70% share will be 14 MGD.

R. W. McFarlane, April 1987