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In cooperation with the Texas Water Development Board

Water Budget for the Nueces Estuary, Texas, May–October 1998

The Texas Water Development Board (TWDB), Texas Parks and Wildlife Department (TPWD), and Texas Natural Resource Conservation Commission (TNRCC) are charged by the Texas Legislature with determining freshwater inflows required to maintain the ecological health of streams, bays, and estuaries in Texas. To determine required inflows, the three agencies collect data and conduct studies on the needs for freshwater inflows to Texas estuaries.

The U.S. Geological Survey (USGS), in cooperation with the TWDB, conducted a study in the Nueces estuary (fig. 1) during May–October 1998 to provide water-budget data for calibration of a TWDB model that will be used to estimate the effects of different freshwater inflow volumes on circulation and salinity in the estuary. The water budget (inflows and outflows) for the Nueces estuary was estimated by using (1) data collected during this study, (2) data collected at two upstream streamflow-gaging stations previous to this study, and (3) evaporation and return-flow data obtained from other agencies. This fact sheet describes the data-collection methods and the results of the water-budget estimates for the Nueces estuary.

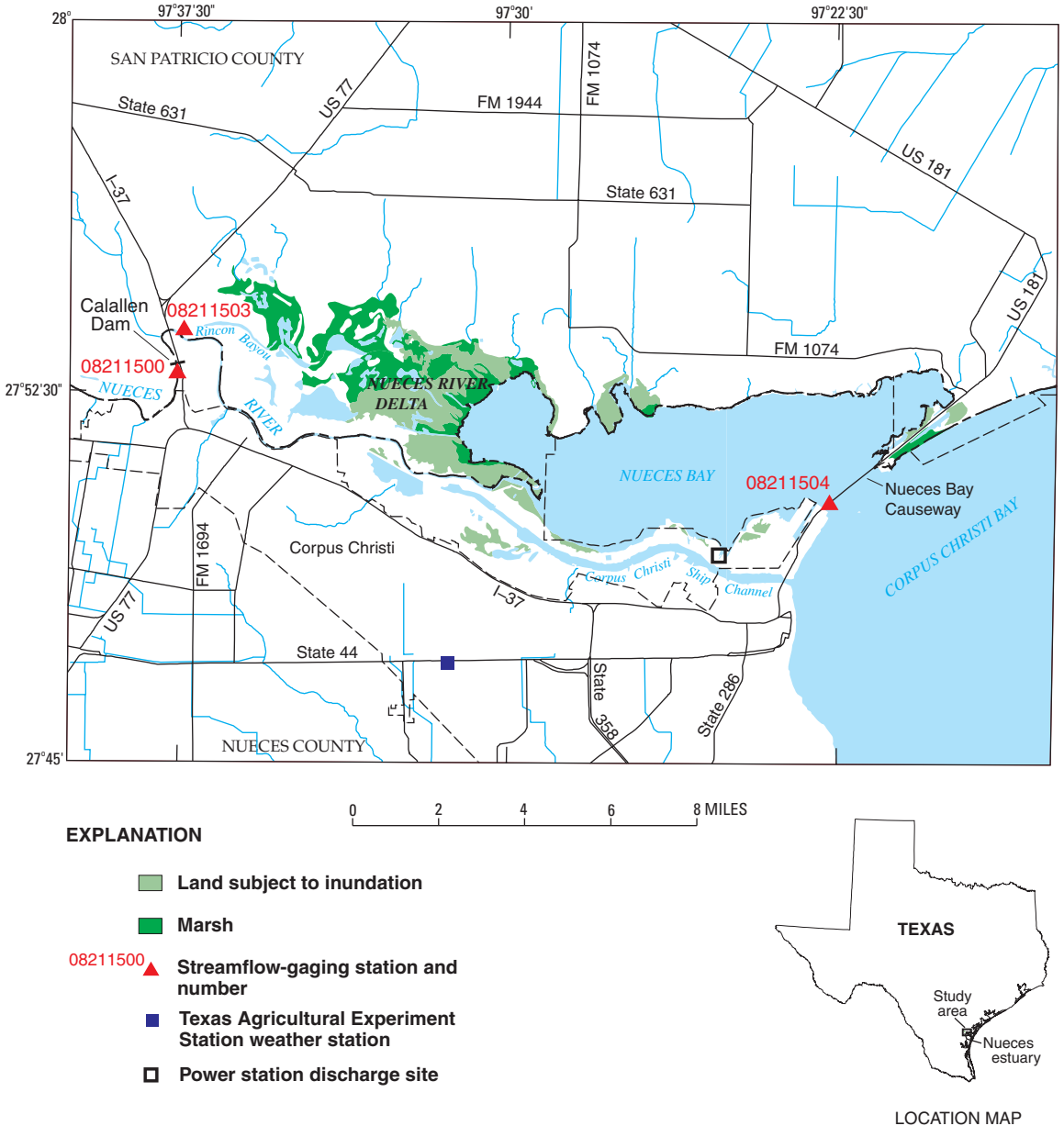

Figure 1. Location of Nueces estuary, Texas.

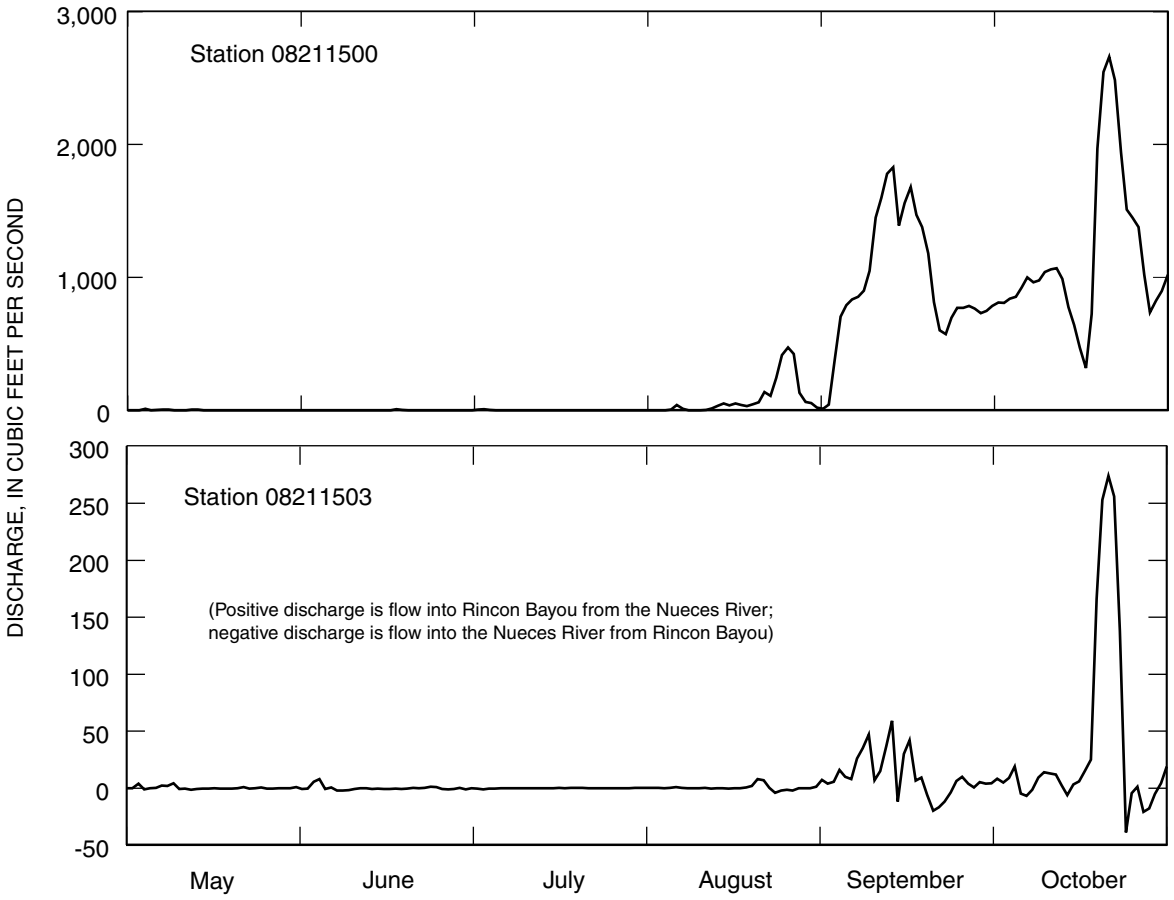

Figure 2. Daily mean discharge at stations 08211500 Nueces River at Calallen and 08211503 Rincon Bayou Channel near Calallen, May–October 1998.

Study Area

The Nueces estuary consists of two areas of nearly equal size: Nueces Bay and the Nueces River delta (fig. 1). Nueces Bay is a shallow, 27-square-mile (mi^2), secondary bay of Corpus Christi Bay. Nueces Bay has a mean depth of about 2.3 feet (ft) and a volume of about 39,700 acre-feet (acre-ft) (Ward, 1997, p. 10). The Nueces delta in southern San Patricio County is a 28-mi^2 area of vegetated marshes, mud flats, and open water formed where the Nueces River flows into Nueces Bay.

The Nueces estuary is located between a humid subtropical region to the northeast and a semiarid region to the west and southwest. Annual rainfall in the study area is about 30 inches (in.). Annual lake evaporation is about 57 in. (Texas Department of Water Resources, 1981). Prevailing winds are from the southeast.

Instrumentation and Data Collection

Streamflow-gaging station 08211500, Nueces River at Calallen (fig. 1), is located at the Calallen Dam, a small (crest altitude about 5 ft above sea level) rock-fill dam that serves as a barrier to saltwater intrusion from Nueces Bay. Streamflow in the Nueces River at Calallen is regulated by upstream reservoirs.

About 1.6 miles (mi) downstream from the Calallen Dam is the Nueces overflow (Rincon Bayou) channel. This channel was constructed by the Bureau of Reclamation in 1995 to divert flow from the Nueces River into Rincon Bayou in the upper Nueces delta. Streamflow-gaging station 08211503, Rincon Bayou Channel near Calallen, was installed to measure rainfall in the study area and streamflow in the Rincon Bayou channel.

Table 1. Rainfall and rainfall volumes for the Nueces estuary, May–October 1998

Month	Nueces delta (17,920 acres)		Nueces Bay (17,280 acres)	
	Rainfall[1] (inches)	Rainfall volume (acre-feet)	Rainfall[2] (inches)	Rainfall volume (acre-feet)
May	0	0	0	0
June	.21	310	.07	101
July	.76	1,130	1.30	1,870
Aug.	4.75	7,090	3.52	5,070
Sept.	4.16	6,210	2.72	3,920
Oct.	9.67	14,400	9.67	13,900
Total[3]	19.55	29,100	17.28	24,900

[1] At station 08211503.
[2] At station 08211504.
[3] Total volumes are rounded.

Table 2. Monthly inflow to the Nueces estuary and discharge into Rincon Bayou, May–October 1998

[In acre-feet]

Station no.	Station name	May	June	July	Aug.	Sept.	Oct.	Total
08211500	Nueces River at Calallen[1]	76	28	44	4,920	55,900	69,200	130,000
08211503	Rincon Bayou Channel near Calallen	8	[2]-1	[2]-10	13	640	2,280	2,930

[1] Total measured inflow.

[2] Flow from Rincon Bayou into Nueces River.

Streamflow-gaging station 08211504, Nueces Bay at Nueces Bay Causeway, was installed at the entrance to Nueces Bay to measure tidal exchange between Nueces and Corpus Christi Bays. This station measured rainfall, water-surface elevation (stage), and water-current velocity at 15-minute intervals. Discharge measurements also were made at this site under various tidal conditions and correlated with station records of stage and velocity to develop a discharge rating at the site. From this rating, continuous (15-minute interval) discharge estimates were computed.

Water-Budget Components

Components of the Nueces estuary water budget considered in this study were rainfall, measured inflow, unmeasured inflow, return flow, evaporation, and net tidal flow. Gains from and losses to ground water were not included. Withdrawals from Nueces Bay were negligible.

Rainfall

Rainfall volumes onto the Nueces delta and Nueces Bay were computed as the product of area and rainfall from the Rincon Bayou and Nueces Bay rain gages, respectively (table 1).

Measured Inflow

Inflow from the Nueces River provides most of the freshwater inflow to the Nueces estuary, and the station at Calallen accounts for all of the measured inflow to the estuarine system. The Rincon Bayou channel station does not measure additional inflow to the system but only measures the flow that is diverted from the Nueces River to the upper Nueces estuary through the Rincon Bayou channel. Monthly inflows measured at the two stations are listed in table 2. Hydrographs of daily mean discharge at the Calallen and Rincon Bayou channel stations (fig. 2) indicate that freshwater inflow to the Nueces estuary during May–July was low compared with inflow during August–September.

Because of tidal influence, discharge through the Rincon Bayou channel is not always a result of freshwater inflow into the Nueces River. During high tides, saltwater from Nueces Bay can move up the Nueces River into Rincon Bayou through the Rincon Bayou channel. Also, during low-to-moderate discharges at the Calallen station, flow at the Rincon Bayou channel station might be into or out of Rincon Bayou, depending on tidal conditions. However, during August–October most of the flow into Rincon Bayou was freshwater inflow resulting from higher discharges in the Nueces River.

Unmeasured Inflow

Periods of heavy rainfall result in unmeasured inflow into the estuary and Nueces Bay from about 148 mi^2 of ungaged area (not including 28 mi^2 of Nueces delta). Most of the unmeasured inflow enters Nueces Bay directly, but some of the inflow enters through the Nueces River. Several rainfall events during August–October resulted in runoff in the ungaged area. Runoff volumes from the ungaged area were estimated from unit-runoff computations using data from streamflow-gaging station 08189700, Aransas River near Skidmore, about 27 mi north of the Rincon Bayou channel station. Hydrologic conditions and land use in the 247-mi^2 Aransas River watershed are similar to the ungaged area adjacent to Nueces Bay. Monthly runoff coefficients—ratios of runoff volume to rainfall volume—were computed for the Aransas River near Skidmore station. The rainfall volumes used for these computations were estimated using rainfall data from the National Oceanic and Atmospheric Administration rain gage at the Welder Wildlife Refuge in San Patricio County (about 18 mi north of Nueces Bay). The computed coefficients were then applied to the rainfall measured at the Rincon Bayou channel station to estimate unmeasured inflow (table 3).

Table 3. Estimated unmeasured inflow to the Nueces estuary, May–October 1998

[--, not computed]

Month	Runoff coefficient (acre-feet per inch-square mile)	Runoff (acre-feet)
May	--	0
June	--	0
July	--	0
Aug.	1.08	760
Sept.	1.41	870
Oct.	3.84	5,500
Total	--	7,130

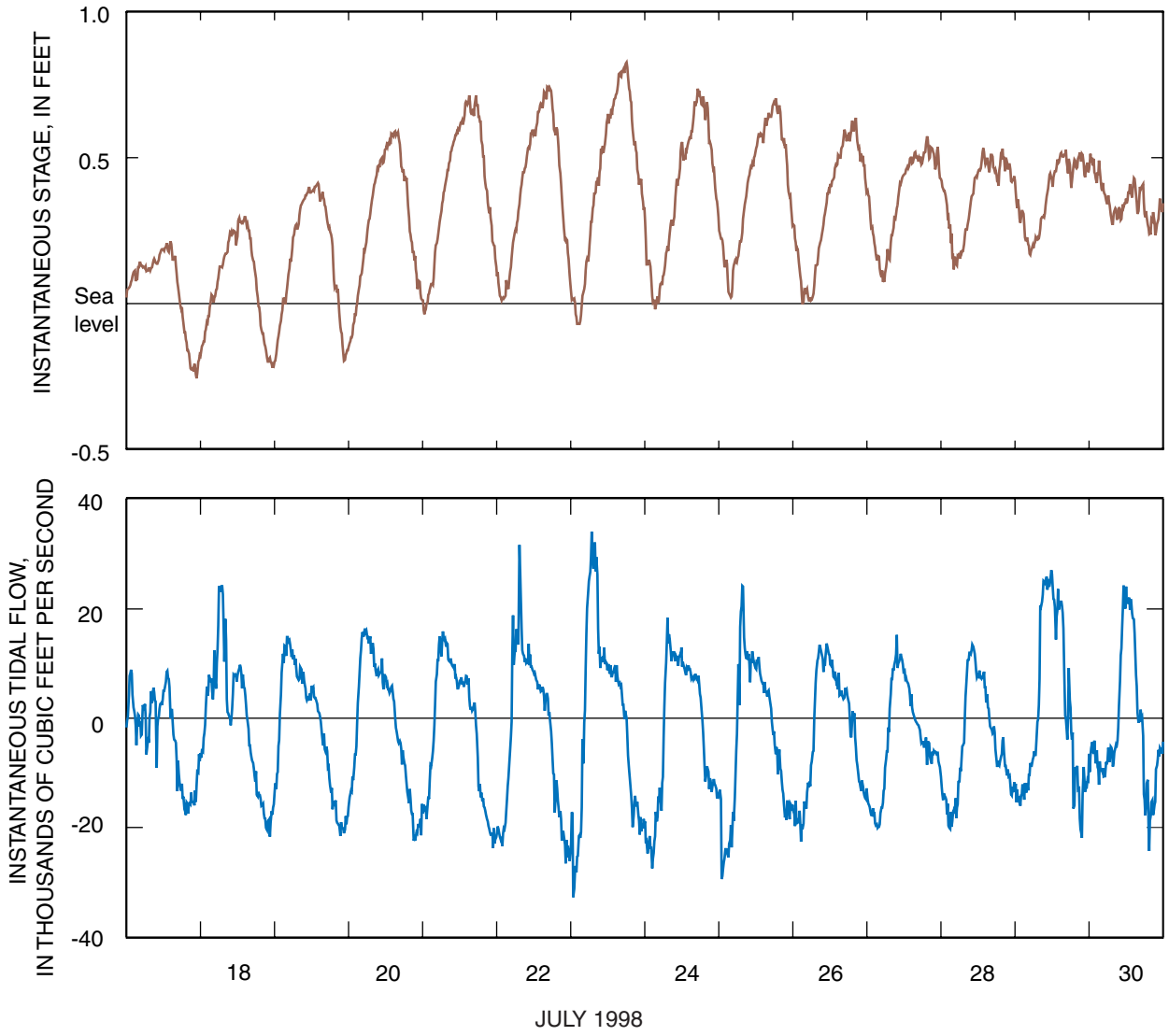

Figure 3. Instantaneous stage at Nueces Bay Causeway and tidal flow into and out of Nueces Bay, July 17–30, 1998.

Return Flow

The primary return flow to Nueces Bay is cooling water discharged from a power station. The cooling water is saltwater that is withdrawn from Corpus Christi Bay and returned to Nueces Bay on the southeastern shore (fig. 1). The average monthly saltwater return flow (34,900 acre-ft) constitutes about 88 percent of the nominal bay volume. Freshwater return flows discharged to Nueces Bay are relatively small and consist primarily of wastewater discharges. Estimated monthly return flows (obtained from the TNRCC) are listed in table 4.

Evaporation

Two methods were used to estimate evaporation from Nueces Bay. The first method consisted of compiling pan-evaporation data collected by the National Weather Service

Table 4. Estimated monthly return flow to the Nueces estuary, May–October 1998

[In acre-feet]

Water type	May	June	July	Aug.	Sept.	Oct.	Total[1]
Saltwater	29,500	39,300	35,900	37,300	37,900	29,500	209,000
Freshwater	320	420	400	400	420	350	2,310
Total[1]	29,800	39,700	36,300	37,700	38,300	29,800	212,000

[1] Total might not equal sum because of rounding.

(NWS) at a station near Lake Corpus Christi (about 33 mi northwest of Nueces Bay). The data were then multiplied by a coefficient of 0.7 to convert pan evaporation to estimated lake evaporation (Rao, 1995). The second method consisted of computing potential evaporation using the Penman equation (Shuttleworth, 1992). Meteorological data (temperature, solar radiation, humidity, and wind speed) for this computation were collected by the Texas Agricultural Experiment Station (TAES) in Corpus Christi; the data were collected at a site about 5 mi southwest of Nueces Bay (fig. 1).

Both methods yielded similar estimates of monthly evaporation (table 5). Total evaporation computed from TAES weather station data was about 3 percent lower than that computed from NWS pan evaporation. Because the NWS data were collected inland from the study area and TAES data were collected closer to Nueces Bay, the evaporation amounts derived from TAES data were used for water-budget computations.

Table 5. Monthly evaporation estimates using two methods for Nueces Bay, May–October 1998

Month	Pan-evaporation method		Penman equation method	
	Inches	Acre-feet	Inches	Acre-feet
May	6.24	8,990	6.14	8,840
June	7.98	11,500	7.80	11,200
July	9.17	13,200	8.99	12,900
Aug.	6.95	10,000	6.56	9,450
Sept.	4.64	6,680	4.53	6,520
Oct.	4.16	5,990	3.96	5,700
Total[1]	39.14	56,400	37.98	54,600

[1] Total might not equal sum because of rounding.

Estimated evaporation from Nueces Bay during May–October 1998 was about 54,600 acre-ft, equivalent to about 137 percent of the nominal bay volume or about 33 percent of the total freshwater inflow (rainfall, measured inflow, unmeasured inflow, and freshwater return flows). Estimated evaporation losses are from the surface of Nueces Bay only and do not include evapotranspiration losses from the Nueces delta.

Net Tidal Flow

The 24.8-hour diurnal tidal range at the entrance to Nueces Bay usually is less then 1 ft, although two tropical storms in August and September 1998 generated higher-than-normal tides. The changing tide causes an exchange of water between Nueces and Corpus Christi Bays (fig. 3). Water flows into Nueces Bay during the rising tide, and flows out of Nueces Bay during the falling tide. The period shown in figure 3 is typical of tidal flow into and out of Nueces Bay.

Tidal prism is defined as the volume of water transported during the flood part (flow into Nueces Bay) of the tidal cycle (Ward, 1997). During the 14-day period shown in figure 3, the tidal prism ranged from 1,550 acre-ft on July 17 to 14,700 acre-ft on July 23, with an average of 8,650 acre-ft.

The monthly net flow into or out of Nueces Bay was not computed directly from the data collected at the Nueces Bay entrance. The flood and ebb tide volumes usually are much greater than the net inflow or outflow during a tidal cycle. Errors in discharge ratings (5 to 10 percent) can result in large percentage errors (greater than 100 percent) in computed net discharge, especially when ratings for inflow and outflow are different.[1] Instead, net tidal flow was computed as the unknown component in the monthly bay water budget, assuming that inflow equals outflow plus change in bay volume:

Rainfall + Measured inflow + Unmeasured inflow + Return flow = Evaporation + Net tidal flow + Volume change. (1)

Therefore,

Net tidal flow = Rainfall + Measured inflow + Unmeasured inflow + Return flow – Evaporation – Volume change. (2)

Monthly change in bay volume was computed as

Nominal surface area of bay (17,500 acre-ft) X Monthly change in daily mean stage. (3)

Estimated Water Budget

Monthly inflows, outflows, and changes in volume of Nueces Bay for May–October 1998 are summarized in table 6. Net tidal flow was out of Nueces Bay for each month during the study period. During May–August, net tidal flow was roughly balanced by saltwater return flow. During September–October, tidal flow out of Nueces Bay was much larger than saltwater return flow as a result of much larger inflows of freshwater.

[1] For example: During a tidal cycle, consider a measured inflow of 105 acre-ft that was actually 100 acre-ft (5 percent error) and a measured outflow of 90 acre-ft that was actually 95 acre-ft (-5 percent error). The true net flow into the bay is 5 acre-ft, but the net flow based on measurements is 15 acre-ft. The error in measured net inflow during the tidal cycle is 200 percent.

Table 6. Monthly water budget for the Nueces estuary, May–October 1998

[In acre-feet]

Component	May	June	July	Aug.	Sept.	Oct.	Total[1]
Inflows:							
Rainfall (Nueces delta)	0	310	1,130	7,090	6,210	14,400	29,100
Rainfall (Nueces Bay)	0	101	1,870	5,070	3,920	13,900	24,900
Measured inflow	76	28	44	4,920	55,900	69,200	130,000
Unmeasured inflow	0	0	0	760	870	5,500	7,130
Saltwater return flow	29,500	39,300	35,900	37,300	37,900	29,500	209,000
Freshwater return flow	320	420	400	400	420	350	2,310
Total[1]	29,900	40,200	39,300	55,500	105,000	133,000	403,000
Outflows:							
Evaporation (Nueces Bay)	8,840	11,200	12,900	9,450	6,520	5,700	54,600
Net tidal flow	25,800	28,200	31,100	29,700	85,900	106,000	307,000
Total[1]	34,600	39,400	44,000	39,100	92,400	112,000	362,000
Change in bay volume:	-4,700	500	-5,800	9,500	6,800	7,300	13,600

[1] Total might not equal sum because of rounding.

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Information on technical reports and hydrologic data related to this and other studies can be obtained from:

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