Coastal Hydrology for East Matagorda Bay

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Coastal Science Program
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Purpose

This technical memo describes the detailed procedures adopted by the Texas Water Development Board (TWDB) for estimating total freshwater inflow from surface water and the specifics related to producing hydrology dataset version TWDB202101 for East Matagorda Bay. This report and dataset version supersede all previous coastal hydrology datasets for East Matagorda Bay.

Introduction

A primary goal of the TWDB's Coastal Science Program is to provide estimates of historical surface inflow into Texas bays and estuaries to support environmental and water planning studies. The earliest freshwater inflow estimates were compiled in a series of reports published by the Texas Department of Water Resources (TDWR) between 1980 and 1983, in which monthly surface inflow to each of the seven major estuaries of Texas for the period 1941 – 1976 was estimated. However, minor estuaries were not included in those early studies. The TWDB began estimating freshwater inflow to the minor bay systems, including East Matagorda Bay in 2003, while continuing to update inflow to the major estuaries.

Herein, this report describes the most recent version of freshwater inflow estimates for East Matagorda Bay which includes hydrology data through December 2020. Previous coastal hydrology versions (TWDB201001 and TWDB201004) are documented in Schoenbaechler *et al*. (2011). Complete hydrology data for East Matagorda Bay is available for the period 1977 – 2020 (https://www.waterdatafortexas.org/coastal/hydrology/east_matagorda).

Estimates of Freshwater Inflow

Estimates of freshwater inflow for the areas draining into East Matagorda Bay include only the ungaged portions of small coastal basins, as there are no gaged flows that drain into the bay. These estimates do not account for groundwater contributions. The total surface inflow that reaches an estuary at any given time is illustrated in Equation 1. For a typical estuary, the freshwater inflow balance is estimated based on the surface inflow and considers the amount of precipitation onto and rate of evaporation from the estuary, which is represented by a simple relationship as in Equation 2.

$$I^{fw} = \sum Q^{gaged} + \sum Q^{ungaged} - \sum Q^{diversion} + \sum Q^{return} \qquad \text{Equation 1}$$

where I^{fw} is the total freshwater inflow to the estuary, Q^{gaged} is the flow that originated from gaged watersheds, $Q^{ungaged}$ is the flow that originated from ungaged watersheds, $Q^{diversion}$ is the flow diverted from streams in ungaged watersheds, and Q^{return} is the flow returned to streams in ungaged watersheds.

$$WB = I^{fw} - E + P \qquad \text{Equation 2}$$

where WB is the freshwater inflow balance, I^{fw} is the total freshwater inflow, E is the evaporation from the estuary, and P is the precipitation onto the estuary.

Given that there are no major rivers that drain into this system, there are no gaged data that are monitored by the United States Geological Survey (USGS). Therefore, total freshwater inflow in this case excludes the gaged portion of Equation 1.

1977 – 2020 Period of Record

The 1977 – 2020 period of record comprises the values derived only from rainfall-runoff estimates from the Texas Rainfall-Runoff (TxRR) model (Matsumoto, 1992) since there are no USGS stream gages in East Matagorda Bay watersheds for this period. These estimates for ungaged watersheds were adjusted for known agricultural, municipal, and industrial diversions and return flows obtained from the Texas Commission on Environmental Quality (TCEQ) and the United States Environmental Protection Agency (US EPA). Total surface inflow, including modeled (ungaged), diversion, and return flow data, to East Matagorda Bay for the period 1977 – 2020 are available on a daily, monthly, and annual basis.

Gaged Watersheds

East Matagorda Bay does not have any major rivers flowing into it, and as such, there are no gaged watersheds in this basin.

Ungaged Watersheds

The East Matagorda Bay watershed consists of nine ungaged watersheds (13101, 13102, 13103, 13104, 13105, 13106, 13107, 13108, and 13109; TWDB assigned watersheds), which were used to estimate freshwater inflow data for the bay. A significant update from the previously published coastal hydrology dataset (Schoenbaechler et al, 2011) includes an additional ungaged watershed (13109). This update was made based on a hydrological assessment conducted by

overlaying the TWDB watershed boundary shapefile with stream networks obtained from USGS National Hydrography Dataset (NHD; https://www.usgs.gov/national-hydrography/national-hydrography-dataset). Based on this assessment, watershed 13109 (Figure 1) was determined to drain to the East Matagorda basin rather than to the San Bernard basin. The determination was confirmed by comparison to the USGS Hydrologic Unit Codes (HUCs) Level 10 designated watersheds. Therefore, with the additional flow originating from ungaged watershed 13109, the freshwater inflow and balance data presented in this report differ from the previously published dataset and report.

The delineation of watershed boundaries for generating the hydrology dataset for the period from 1977 – 2020 are illustrated in Figure 1. The ungaged inflow component was estimated using the TxRR model and is commonly referred to as the modeled component of the freshwater inflow estimates. The model is conceptually similar to the Agricultural Research Service (ARS) rainfall-runoff model which is based on the Soil Conservation Service's curve number approach to estimate direct runoff from a precipitation event. The TxRR model, however, has four key differences: (1) use of simpler and more straightforward mathematics, (2) introduction of 12 monthly depletion factors instead of a single depletion factor, (3) introduction of a base flow component, and (4) simulation modeling capabilities on a daily basis. The TxRR model has been applied to estimate daily streamflow for 118 ungaged watersheds across the Texas coast.

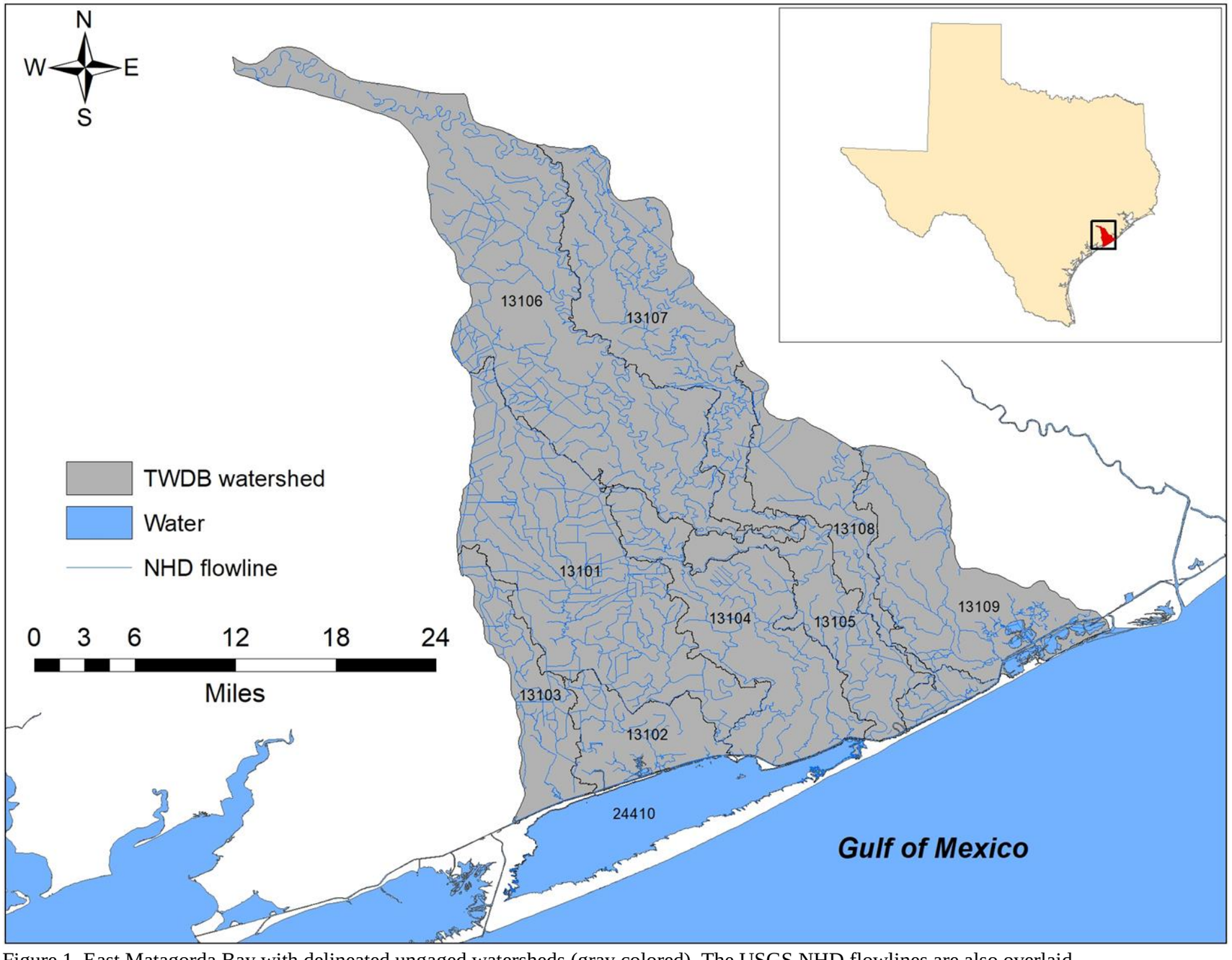

Figure 1. East Matagorda Bay with delineated ungaged watersheds (gray colored). The USGS NHD flowlines are also overlaid into the watersheds. The bay segment is colored blue.

Diversion and Return Flow Data

Rainfall-runoff estimates from the TxRR model were adjusted for known diversions and return flows within the ungaged watersheds. The major diversion and return flow locations in the watersheds surrounding East Matagorda Bay are shown in Figure 2. The diversion and return flow data for 1977 – 2009 were derived from TCEQ and other agencies including Texas Natural Resource Conservation Commission (TNRCC) and TWDB Irrigation Water Use estimates (Schoenbaechler et al., 2011). For the 2010 – 2020 period of record, diversion and return flow data were obtained from the TCEQ (https://tceq.maps.arcgis.com/home/webmap/viewer.html?webmap=796b001513b9407a9818897b4dc1ec4d) and US EPA's National Pollutant Discharge Elimination System (NPDES; https://echo.epa.gov/tools/data-downloads/icis-npdes-dmr-and-limit-data-set), respectively. This report has the complete diversion and return annual flow data for the period 1977 – 2020; however, the daily and monthly data can be provided upon request.

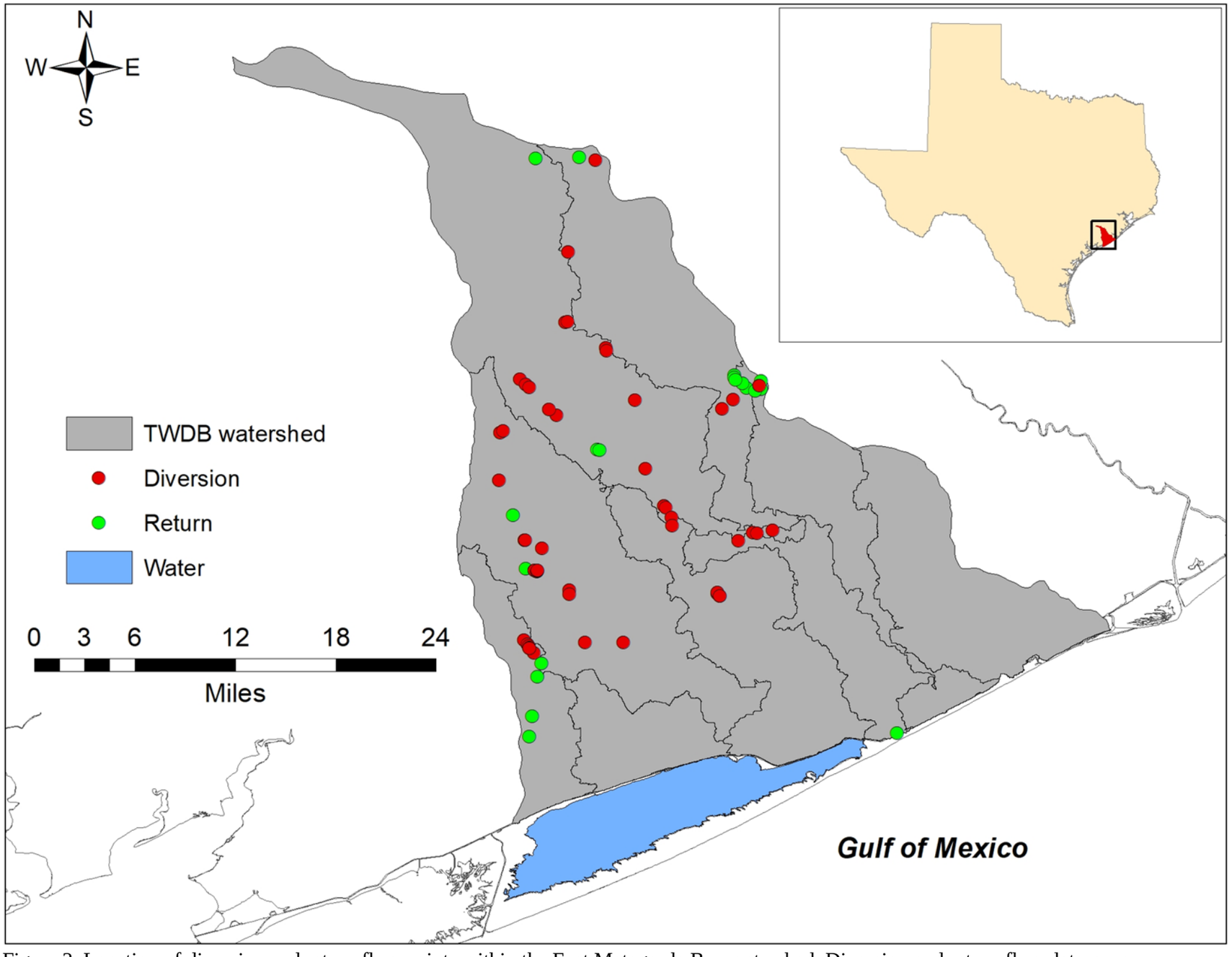

Figure 2. Location of diversion and return flow points within the East Matagorda Bay watershed. Diversion and return flow data were used to estimate the surface inflow component for ungaged watersheds. Diversion data were obtained from the TCEQ and return flow data were obtained from the US EPA. Water right and discharge permit numbers and owners can be provided upon request.

Estimates of Freshwater Inflow Balance

Total freshwater inflow includes an estimation of surface inflow to the estuary plus precipitation onto the surface of the estuary. The freshwater balance further considers the effect of evaporation from the estuary. Therefore, the freshwater inflow balance of an estuary includes estimates of surface inflow, precipitation, and evaporation as shown in Equation 2. Due to a lack of ungaged daily inflow data prior to 1977 and daily estimates of evaporation throughout the period of record, freshwater inflow balance estimates are available only on a monthly basis for the entire period of record. Total bay surface area for East Matagorda Bay is 57 mi^2 which was used to calculate precipitation and evaporation in order to estimate the freshwater inflow balance.

Precipitation

The amount of precipitation that occurred on the surface of East Matagorda Bay was calculated using a Thiessen-weighted precipitation technique as described in LP-106 (TDWR, 1980). Station-based precipitation data were obtained from the National Centers for Environmental Information (NCEI; https://www.ncdc.noaa.gov/cdo-web/datatools/findstation) and processed using ARC Macro Language (AML). These datasets were also used as the primary inputs to the TxRR model to generate the surface inflow component from ungaged watersheds. One bay segment with the TWDB number 24410 (internally defined by TWDB) was used to calculate precipitation on the bay by summing area-weighted rainfall of the Thiessen polygon segment within the watershed. The polygons that were generated to be coincident with precipitation stations are shown in Figure 3. To improve the inflow component for ungaged watersheds, the TWDB is exploring the potential use of higher-resolution multi-sensor processed precipitation data.

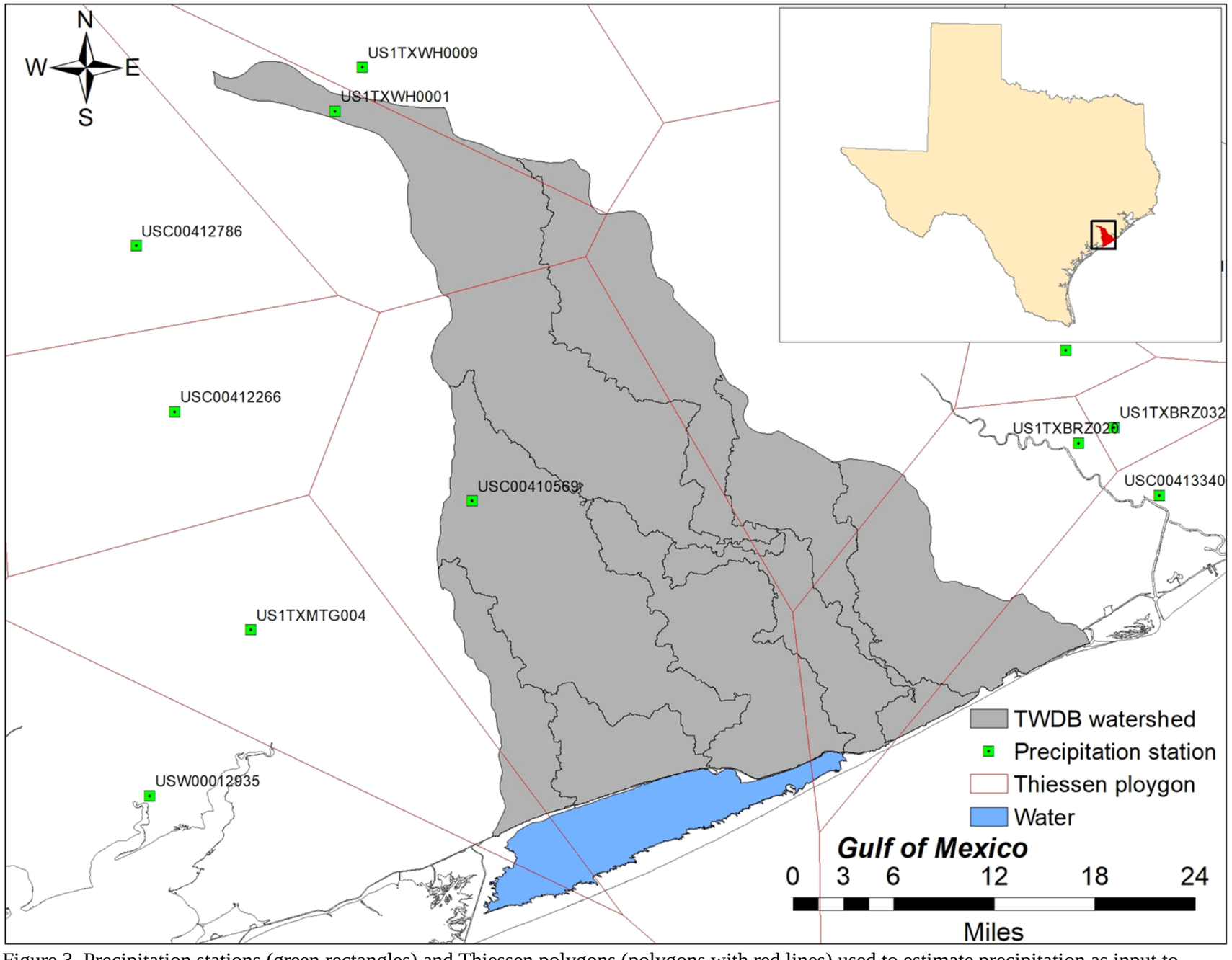

Figure 3. Precipitation stations (green rectangles) and Thiessen polygons (polygons with red lines) used to estimate precipitation as input to the TxRR model to generate the ungaged inflow component for East Matagorda Bay.

Evaporation

The rate of evaporation from East Matagorda Bay was estimated by applying the TWDB's monthly gross lake evaporation rates which are compiled for Texas at a broad spatial scale, specifically at gridded one-degree latitude by one-degree longitude quadrangles (https://www.waterdatafortexas.org/lake-evaporation-rainfall). East Matagorda Bay falls within quadrangle 912 (Figure 4), and the evaporation rates for this quadrangle were applied to the total area of bay segment 24410 (internally defined by TWDB) to estimate total water evaporated from the estuary. This estuary-wide estimate of gross evaporation was then used in calculating the freshwater inflow balance for East Matagorda Bay.

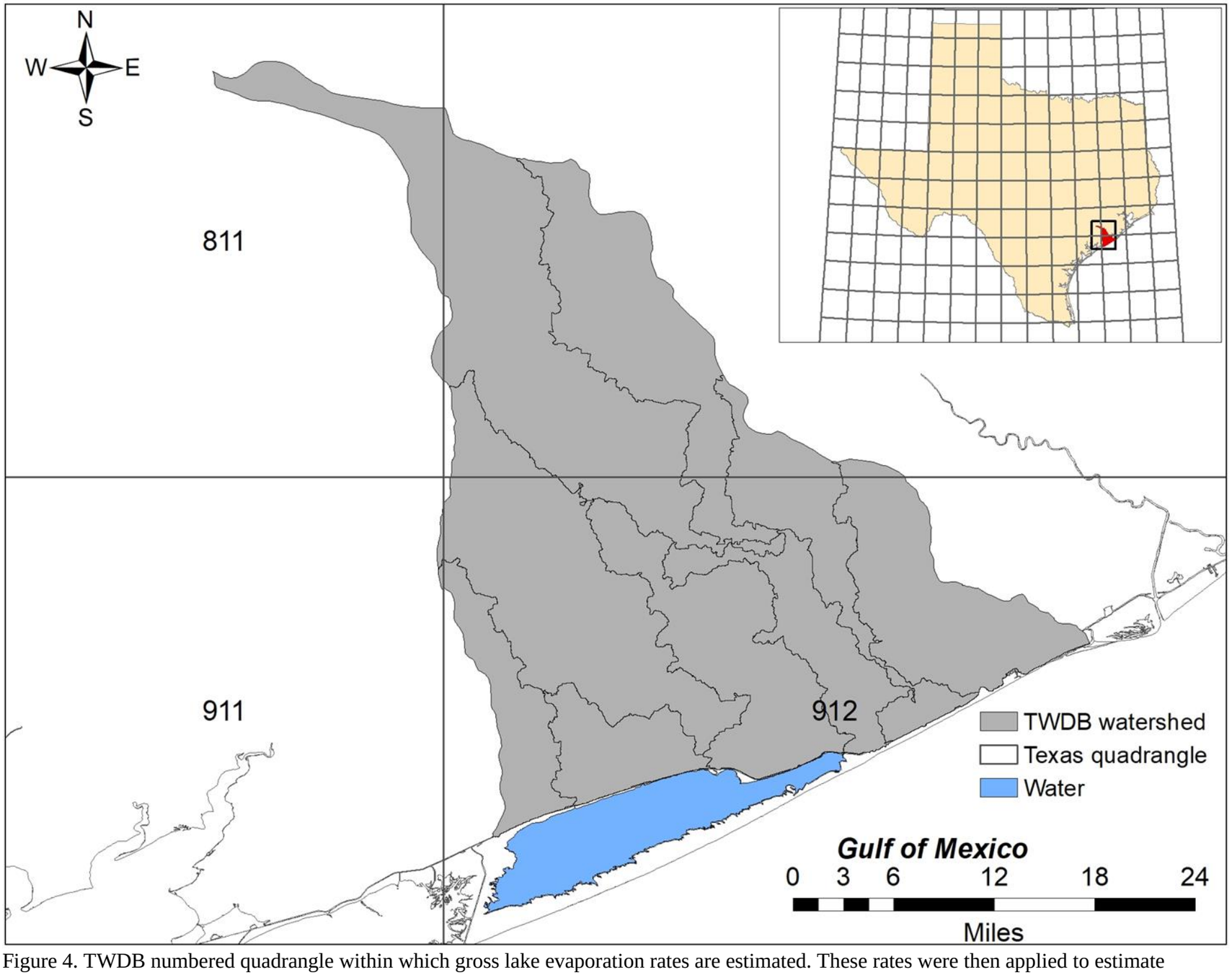

Figure 4. TWDB numbered quadrangle within which gross lake evaporation rates are estimated. These rates were then applied to estimate evaporation from East Matagorda Bay. The gridded quadrangles are spatially defined at one-degree latitude by one-degree longitude.

Discussion

The TWDB coastal hydrology version TWDB202101 for East Matagorda Bay is the most up-to-date, complete dataset representing total surface inflow values and individual component values for ungaged (modeled), diversion, and return flows as described herein. Appendix A summarizes the data used to develop hydrology version TWDB202101 for East Matagorda Bay. Appendix B lists total annual freshwater inflow including the values for six other components (ungaged/modeled, diversion, return, evaporation, precipitation, and freshwater balance) estimated for the bay. Appendix C presents summary statistics of all the components for the period 1977 – 2020.

Figures 5 and 6 display the freshwater inflow estimates on an annual and monthly basis, respectively, estimated for East Matagorda Bay based on version TWDB202101. Five- and ten-year moving average values are also presented in the annual hydrograph (Figure 5). Five-year moving average values indicate a distinct cyclic trend for East Matagorda Bay. There is no clear trend for decadal moving average values. However, higher overall inflow values were found during the 1992 to 2010 period for the bay. There was no gaged data used and thus gaged inflow contribution was zero percent of the total inflow estimate. During the period from 1977 – 2020, the ungaged flow accounted for approximately 99 percent of total freshwater inflow. Average annual diversions were one percent and return flows were two percent of the total freshwater inflow. The long-term mean freshwater inflow for the bay during the study period was 0.6 million acre-feet per year, ranging from a minimum of 68,455 acre-feet in 2011 to a maximum of 1.7 million acre-feet in 2004.

Finally, when calculating the total freshwater inflow balance, the amount of precipitation and evaporation occurring upon the bay should be considered. For the period 1977 – 2020, the mean freshwater inflow balance was 0.6 million acre-feet per year, ranging from a minimum of negative 30,685 acre-feet in 2011 to a maximum of 1.8 million acre-feet in 2004.

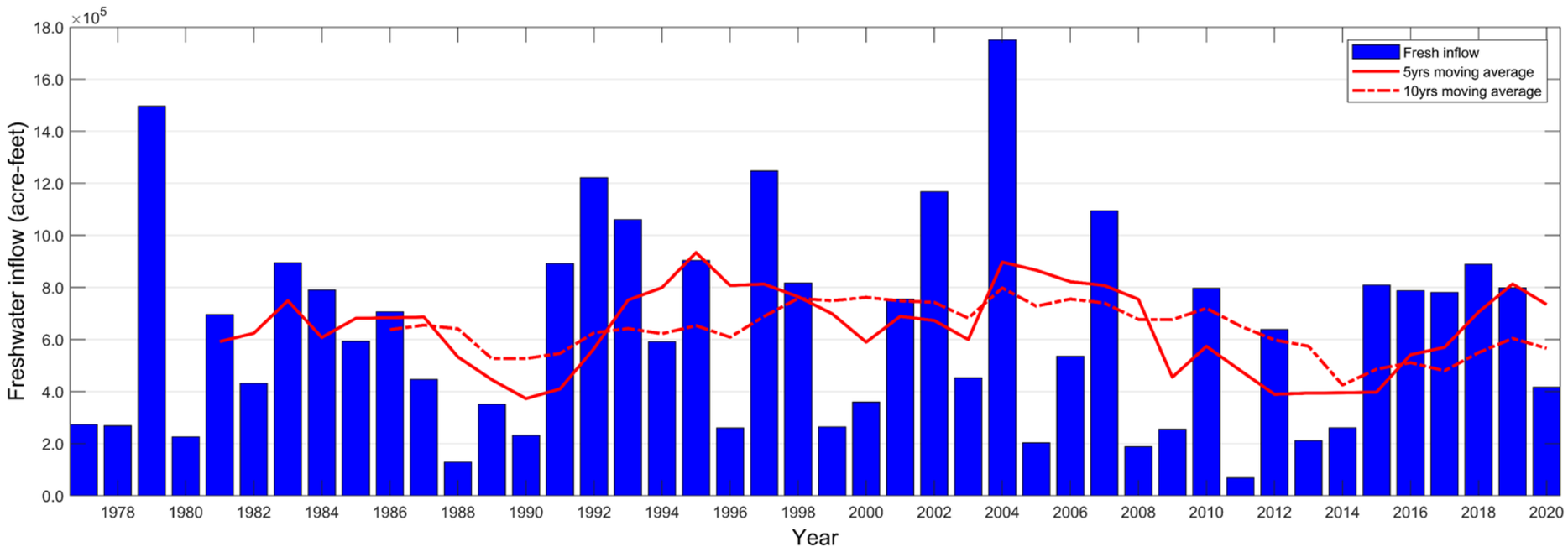

Figure 5. Annual freshwater inflow estimates including five-year and ten-year moving averages for East Matagorda Bay as calculated for version TWDB202101 for the period 1977 – 2020. Average annual freshwater inflow for this period was calculated to be 0.6 million acre-feet.

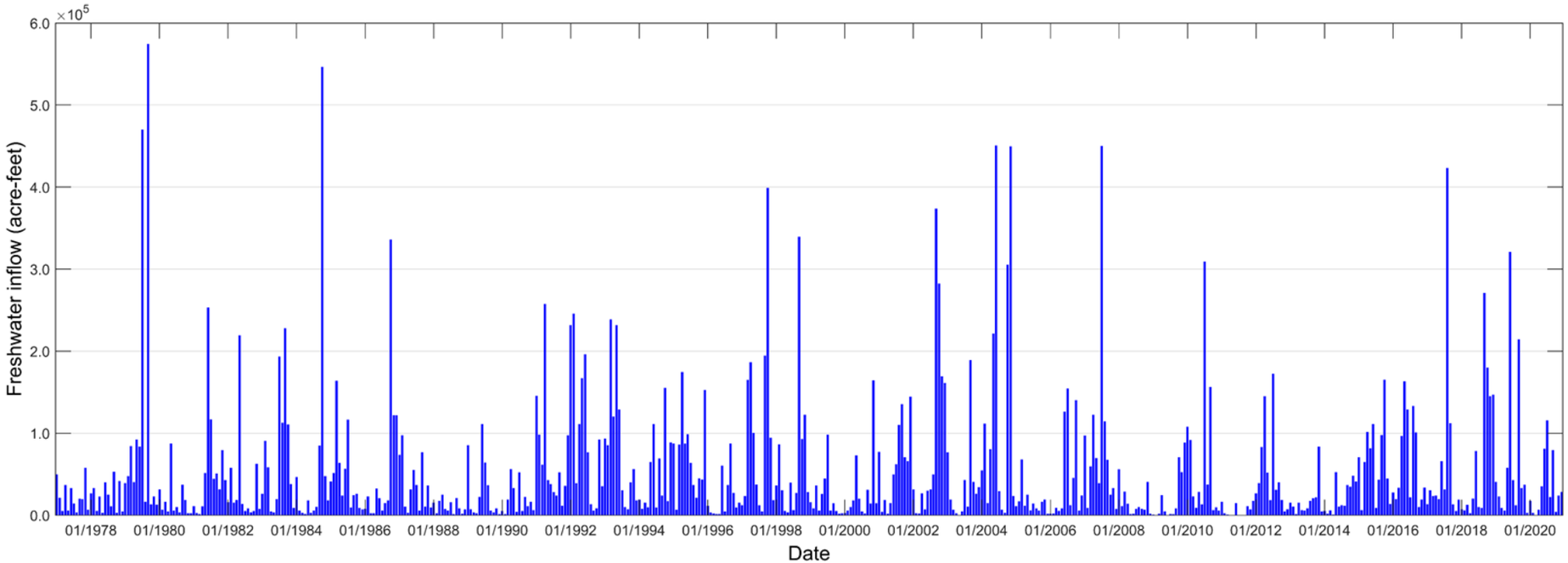

Figure 6. Monthly freshwater inflow estimates for East Matagorda Bay as calculated for version TWDB202101 for the period 1977 – 2020. Monthly average freshwater inflow for this period was calculated to be 53,044 acre-feet.

References

Matsumoto, J., 1992. User's Manual for The TWDB's Rainfall-Runoff Model. Texas Water Development Board, Austin, TX. 28pp.

Schoenbaechler, C., Guthrie, C.G., Lu, Q., 2011. Coastal Hydrology for East Matagorda Bay. Texas Water Development Board, Austin, TX. 13pp.

TDWR. 1980. *Lavaca-Tres Palacios Estuary: A study of the influence of freshwater inflows*. LP-106. Texas Department of Water Resources, Austin, Texas.

Appendix A: Summary of coastal hydrology dataset version TWDB202101 developed by the TWDB Coastal Science Program including the details of data availability for all ungaged (modeled), diversion, and return flows for East Matagorda Bay.

Bay	Version	Period of record	Gaged flow	Modeled flow	Diversion flow	Return flow	Data generated
East Matagorda	TWDB202101	1977 - 2020	N/A	1977 – 2020 (TxRR)	1977 – 2020 (TCEQ)	1977 – 2007 (TWDB) 1977 – 2009 (TCEQ) 2009 – 2020 (US EPA)	03/2022

Note: Previous coastal hydrology versions (TWDB201001and TWDB201004) are documented in Schoenbaechler *et al*. (2011).

Appendix B: Annual hydrology for East Matagorda Bay, version TWDB202101. The table presents modeled, diversion, return, freshwater inflow, evaporation, precipitation, and freshwater balance values for the period 1977 – 2020. All values are in acre-feet. The inflow values, specifically the modeled flows, in this version are different than in the previous version (TWDB201004) since there is an addition of an ungaged watershed (13109) used for the calculation. Missing data are indicated as not available (n/a).

Year	Gaged	Modeled	Diversion	Return	Freshwater inflow*	Evaporation	Precipitation	Freshwater balance**
1977	n/a	266,891	3,156	9,186	272,921	157,475	112,232	227,678
1978	n/a	259,811	4,626	13,458	268,643	152,285	118,760	235,118
1979	n/a	1,486,179	5,198	15,639	1,496,620	150,503	281,235	1,627,352
1980	n/a	212,046	3,236	17,060	225,870	160,657	114,189	179,402
1981	n/a	682,530	4,856	17,954	695,628	147,006	176,007	724,629
1982	n/a	419,538	6,216	18,664	431,986	154,443	111,643	389,186
1983	n/a	884,053	5,093	15,519	894,479	151,554	171,252	914,177
1984	n/a	779,170	6,268	17,299	790,201	158,556	172,382	804,027
1985	n/a	585,447	6,677	14,083	592,853	152,461	148,405	588,797
1986	n/a	699,539	6,274	13,108	706,373	154,590	170,196	721,979
1987	n/a	436,443	5,074	14,883	446,252	148,024	107,790	406,018
1988	n/a	120,689	5,909	13,489	128,269	159,548	101,902	70,623
1989	n/a	343,905	5,701	13,163	351,367	140,468	125,241	336,140
1990	n/a	222,161	3,718	12,782	231,225	149,250	118,797	200,772
1991	n/a	884,247	6,331	13,752	891,668	148,785	197,178	940,061
1992	n/a	1,212,868	4,458	13,324	1,221,734	130,639	192,660	1,283,755
1993	n/a	1,055,328	5,404	10,215	1,060,139	158,613	146,711	1,048,237
1994	n/a	582,781	5,896	14,126	591,011	139,360	117,860	569,511
1995	n/a	894,875	5,763	14,410	903,522	145,195	142,390	900,717
1996	n/a	251,907	5,212	13,904	260,599	143,737	80,401	197,263
1997	n/a	1,233,997	1,750	15,301	1,247,548	149,426	183,209	1,281,331
1998	n/a	807,412	5,509	15,401	817,304	155,989	155,523	816,838
1999	n/a	253,077	3,524	14,560	264,113	140,060	82,068	206,121
2000	n/a	362,544	5,083	1,588	359,049	209,985	74,560	223,624
2001	n/a	758,994	6,805	2,874	755,064	136,270	103,772	722,566
2002	n/a	1,170,504	6,129	3,136	1,167,511	139,372	143,031	1,171,170
2003	n/a	455,855	5,648	2,400	452,607	135,567	119,116	436,156
2004	n/a	1,749,397	4,979	6,609	1,751,027	135,480	192,891	1,808,438
2005	n/a	205,861	5,540	2,849	203,170	159,368	104,361	148,163
2006	n/a	537,972	5,499	2,942	535,416	147,746	162,272	549,942
2007	n/a	1,095,331	5,192	3,730	1,093,869	152,194	197,197	1,138,872
2008	n/a	190,356	5,397	3,107	188,066	201,055	81,088	68,099
2009	n/a	258,696	6,637	2,874	254,933	154,478	114,143	214,598
2010	n/a	799,804	5,892	2,566	796,478	134,589	129,249	791,138
2011	n/a	74,198	7,713	1,970	68,455	164,669	65,530	-30,685
2012	n/a	639,141	3,837	2,755	638,059	135,012	129,611	632,658
2013	n/a	212,104	4,054	2,814	210,864	152,963	122,913	180,814
2014	n/a	263,191	4,743	2,665	261,113	139,024	129,611	251,700
2015	n/a	802,839	n/a	6,201	809,040	142,162	184,400	851,278
2016	n/a	789,128	4,389	2,802	787,541	141,408	175,289	821,422
2017	n/a	775,483	31,301	36,563	780,745	144,908	162,195	798,032
2018	n/a	883,698	30,864	35,838	888,672	137,848	169,677	920,501
2019	n/a	796,053	31,139	33,869	798,783	145,511	164,760	818,031
2020	n/a	374,035	30,419	73,053	416,669	144,938	126,172	397,903

*Freshwater inflow = Gaged + Modeled - Diversion + Return

**Freshwater balance = Freshwater inflow - Evaporation + Precipitation

Appendix C: Annual freshwater inflow statistics (in acre-feet) for East Matagorda Bay from 1977 – 2020, version TWDB202101. Missing data are indicated as not available (n/a).

	Gaged	Modeled	Diversion	Return	Freshwater inflow	Evaporation	Precipitation	Freshwater balance
Minimum	n/a	74,198	1,750	1,588	68,455	130,639	65,530	-30,685
5%ile	n/a	138,106	3,172	2,077	143,218	134,695	76,020	68,730
10%ile	n/a	208,954	3,602	2,615	207,017	135,524	81,578	163,783
25%ile	n/a	260,656	4,743	2,891	265,246	140,162	112,710	224,638
Median	n/a	612,294	5,499	13,244	615,456	148,405	129,611	610,728
Mean	n/a	631,138	7,607	12,829	636,533	150,072	140,452	626,913
75%ile	n/a	864,627	6,268	15,376	870,830	154,562	170,988	888,357
90%ile	n/a	1,191,686	21,337	26,266	1,194,623	160,103	192,776	1,226,251
95%ile	n/a	1,423,134	31,084	36,382	1,434,352	191,959	197,192	1,541,453
Maximum	n/a	1,749,397	31,301	73,053	1,751,027	209,985	281,235	1,808,438
Total	n/a	27,770,078	327,109	564,486	28,007,455	6,603,170	6,179,870	27,584,155

Note: Summary statistics for diversion flow have been calculated using the data from all years except 2015 since there was no diversion flow data available for that year.