San Antonio Bay, Sheet-flow Calculations

San Antonio Bay is an important estuarine system located near the center of the Texas Gulf Coast. The ecology of the San Antonio Bay estuary is affected by the inflow of fresh water and the resulting balance between salt and fresh water. The San Antonio River confluences with the Guadalupe River approximately 12 miles northwest of where the Guadalupe flows into the northern part of San Antonio Bay. Water discharged from the Guadalupe River system is one of three main sources of fresh water supplied to the estuarine system of the Bay. Two additional sources of fresh water inputs to the Bay are direct precipitation interception and runoff originating from bordering watersheds.

The quantity of discharge from the Guadalupe River into the Bay is measured at USGS gage station 08188810, described as Guadalupe River at State Highway 35 near Tivoli, TX. The quantity and quality of water contributed from the Guadalupe River system has been the focus of modeling efforts by TWDB and is one of the primary goals of the EDYS modeling currently being conducted in Wilson, Karnes, Goliad, Refugio, and Victoria counties within the San Antonio and Guadalupe River basins. The amount of precipitation directly intercepted by the Bay can be calculated using rainfall amounts measured at numerous NOAA and USGS precipitation gages surrounding the Bay, e.g., NOAA gages at Austwell and Seadrift and the USGS stream-flow gage described above. Runoff from watersheds bordering San Antonio Bay is not measured and must be modeled.

Modeling of runoff from watersheds bordering the Bay have been completed by TWDB using TxRR and Texas Tech University using the EDYS model. Subsequently, runoff data from both the EDYS and TxRR models have been used as input to subsequent salinity and circulation modeling in San Antonio Bay. The two models, however, differ in their methods of calculating runoff volumes in response to varying precipitation conditions. Because these watersheds are ungaged, data from studies on similar gaged watersheds must be used to provide perspective addressing the volume differences calculated by the two models. Several studies conducted by USGS within the Coastal Bend area provide particularly relevant data.

Three reports published by USGS have focused on the hydrology of watersheds within the Coastal Bend area of south Texas. These watersheds due to their proximity to the bay and estuarine system are characterized by soils, vegetation, and general physiography similar to the watersheds surrounding San Antonio Bay. Ockerman and Fernandez (2010) published data from two row crop dominated watersheds, West Oso Creek (WOC) and Oso Creek Tributary (OCT), associated with Oso Creek near Oso and Corpus Christi Bays. Precipitation and resulting gaged runoff data from both Oso Creek watersheds are presented by precipitation event from October 2005 through September 2008. Ockerman and Petri (2001) published precipitation event and gaged runoff data, from May 1996 through November 1998, for a row crop dominated watershed on the Kleberg and Nueces County line (KN) that flows to Baffin Bay. A third study published by Ockerman (2002) presents precipitation event and gaged runoff data, from March 2000 through November 2001, for three rangeland dominated watersheds, Moody Creek watershed and two watersheds on Welder Wildlife Refuge (MC_WWR), that flow into the tidal reach of the Aransas River.

These three USGS reports provide important data that exhibit interactions between precipitation and runoff across rangeland and cropland areas within the Coastal Bend of Texas. Each of the six watersheds were unique and the specific magnitude, timing, and intensity of rainfall events during the study periods were variable. Three key interactions between precipitation and runoff in Coastal Bend watersheds, however, were apparent. First, 1-2 inches of precipitation is required to produce runoff from these watersheds, even under wet antecedent soil conditions. While the significant amount of precipitation needed to produce the smallest amounts of runoff may seem unexpected, it was consistent across the three studies. Second, cropland dominated watersheds produced runoff with smaller precipitation events (< 2 inches) compared with rangeland watersheds (> 2 inches). Third, cropland dominated watersheds produce more units (e.g., inches) of runoff per unit of precipitation than rangeland watersheds. Differences between cropland and rangeland watersheds would be expected and demonstrate the importance of representing spatially varying land use within modeled watersheds.

Seven generalized watershed units surrounding San Antonio Bay were used by TWDB for TxRR modeling (Fig. 1) of runoff volumes calculated for input during TxBLEND circulation and salinity modeling (TWDB 2010a). These watershed units are described here as generalized because each has several separate locations where channelized or overland surface water will flow into San Antonio Bay. This means that each of the seven generalized watershed units used by TWDB contain sub-watersheds. In all cases the sub-watersheds vary in dominant land surface condition (e.g., cropland, rangeland/native, general soil type, and amount of vegetative cover). The level of watershed unit generalization used by TWDB is likely related to the spatially ambiguous manner in which runoff estimates, calculated using TxRR for each of the seven TWDB watershed units, were used as input to TxBLEND.

In the TxBLEND modeling of San Antonio Bay conducted by TWDB, runoff water volumes calculated as originating from watersheds bordering the Bay were combined with the input flows from the Guadalupe-San Antonio River at an input point north of Mission Lake (Figure 3 of TWDB (2010b)). This effectively concentrated the inflow of fresh water to San Antonio Bay through Mission Lake and Guadalupe Bay. In contrast, the EDYS model linked with a multi-layer aquatic model developed for San Antonio Bay can calculate overland flow from each bordering watershed and/or sub-watershed and assign the respective water volumes to specific inflow locations based on measured terrestrial elevations and expected hydrology. The domain for TxBLEND circulation and salinity modeling by TWDB specifically did not include shallow marsh areas along the periphery of San Antonio Bay. The domain and philosophy of the San Antonio Bay EDYS model does specifically include these shallow marsh sub-systems. The EDYS model must, therefore, strive to calculate spatially explicit locations of runoff volumes flowing into the San Antonio Bay system.

Calculations of runoff volumes from areas surrounding San Antonio Bay are expected to differ between TxRR and EDYS. These differences in calculated runoff volume, in combination with differences in the specific model input locations representing flow into San Antonio Bay, will also likely produce different spatial and temporal dynamics for salinity and circulation. The objective of this report is to: (i) describe the differences between the two models' methods of runoff calculation, (ii) quantify resulting differences in calculation of runoff volumes from seven generalized watershed units surrounding San Antonio Bay for a wet and a dry year, and (iii) analyze runoff volume differences in reference to gaged runoff studies conducted on similar watersheds within the Coastal Bend.

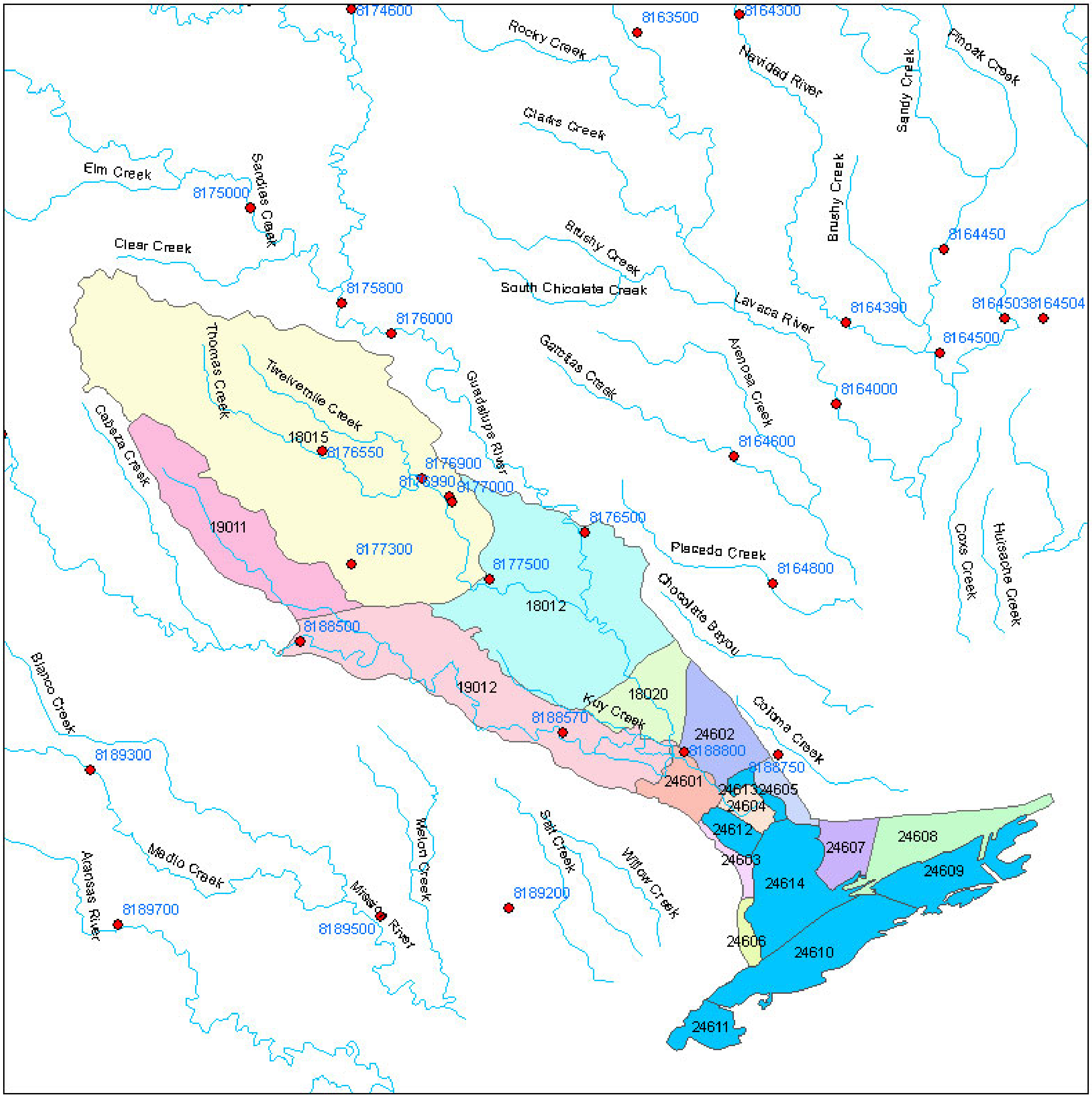

Figure 1. Watershed boundaries used for TxRR modeling by the Texas Water Development Board (TWDB). Graphic downloaded from http://www.twdb.texas.gov/surfacewater/bays/coastal _hydrology/index.asp.

Models

Both TxRR and EDYS calculate surface runoff as an amount of excess precipitation that is not initially abstracted from precipitation by interception, depression retention, or infiltrated into available soil water storage. The EDYS model assigns variable and parameter sets used to calculate surface runoff allowing for spatially representative influences of slope, vegetation, and surface conditions on a cell-by-cell basis across the landscape. The TxRR model uses variable and parameter sets that average conditions over an entire watershed unit.

TxRR

The TxRR model, described in the User's Guide for the TWDB's Rainfall-Runoff Model (Matsumoto 1992), is similar to the 'curve number' model developed by Williams and LaSeur (1976). As described by Matsumoto (1992), direct runoff and base flow from a given amount of rain are calculated on a daily time step by TxRR based on equations (equations 1-7 and 12-22 of the User's Manual) using seven parameters:

1. SMMAX – the maximum soil water storage in a watershed's profile,
2. SM_i – the initial soil water storage in the profile at the start of the model,
3. α_m – a set of monthly soil water depletion factors,
4. abst1 – the initial rainfall abstraction coefficient,
5. K – the baseflow recession coefficient,
6. w_b – the baseflow weighting coefficient
7. β – the coefficient for peak stream flow lag time.

Runoff from seven watersheds bordering San Antonio Bay (within the San Antonio Bay EDYS model domain) was modeled by TWDB to provide input for TxBLEND circulation and salinity modeling in the Bay. These modeling efforts used distinct values of SMMAX for each of the seven watersheds and the same values for all of the other five parameters across all seven watersheds (Tables 1 and 2). An optimized value for SMMAX was derived for a gaged watershed (Coleto Creek, near Victoria) upstream from San Antonio Bay. Optimization of SMMAX used a set of procedures in TxRR that allows calibration of parameters using monthly gaged flow and precipitation values (equations 8-11 of the User's Guide). None of the seven watersheds bordering San Antonio Bay were gaged. Therefore, values of SMMAX for each watershed were derived, by TWDB, using a ratio of curve numbers as described for equation 23 of the User's Manual.

Table 1. Area and parameter values used by TWDB in TxRR to model runoff and baseflow from seven watersheds bordering San Antonio Bay. Units for the parameters are not provided in the User's Manual (Matsumoto 1992).

Watershed	Area (sqmi)	Area (m^2)	SMMAX	SM_i	α	abst1	K	w_b	β
24601	22.9	59,310,727	8.63	2.5	*	0.05	0.97	0.001	0.1
24602	42.38	109,763,696	8.28						
24603	7.02	18,181,716	8.77						
24604	10.93	28,308,570	8.07						
24605	11.69	30,276,961	9.96	*Same for all eight watersheds.*					
24606	6.83	17,689,619	14.16						
24607	22.45	58,145,233	8.98						

* Monthly values for α are listed in Table 2.

Table 2. Twelve monthly values of α; units not provided in the User's Manual (Matsumoto 1992).

Month	α	Month	α
January	0.0073	July	0.0118
February	0.0074	August	0.0141
March	0.0087	September	0.0111
April	0.0091	October	0.0107
May	0.0125	November	0.0099
June	0.0121	December	0.0094

Using the Coleto Creek, near Victoria watershed for calibration of TxRR and adjusting only SMMAX for each of the watershed units surrounding San Antonio Bay led to the carryover of baseflow parameters in TxRR modeling. As none of the three USGS studies referenced baseflow, the assumption of baseflow similar to that observed in the calibration watershed occurring in the watershed units surrounding San Antonio Bay is questionable.

EDYS

The EDYS model calculates the balance between interception, infiltration, runoff, and export to groundwater for the volume of water from each daily precipitation event for each cell in the model domain. Precipitation in the model is accounted for as a volume, since the depth of precipitation is applied to each square cell in the model domain, e.g., 0.01 m precipitation × 40 m × 40 m = 0.16 m^3 of water. If a precipitation event is indicated for a given day, the model uses a specific set of equations to calculate the amount of precipitation that is intercepted by trees, shrubs, and herbaceous species. Interception by trees and shrubs is proportional to the basal and canopy cover of the species and interception by herbaceous species is proportional only to the canopy cover. The amount of precipitation not abstracted by interception is then reduced by the available water holding capacity of the litter layer. Any precipitation that is not abstracted by interception of the plant canopy or held in the litter layer is available for infiltration into the soil profile.

Remaining (daily) precipitation is divided into five segments, representing 10%, 20%, 40%, 20%, and 10%. Each segment is then compared with the available water holding capacity of various portions of the soil profile. Specifically, the first segment, i.e., 10% of the remaining precipitation amount, is allowed to infiltrate into the first soil horizon. Any volume of this segment that is more than the available water holding capacity of the first soil horizon is designated as runoff. Segments 2, 3, 4, and 5 are allowed to infiltrate into progressively deeper soil horizons in series. For example, segment 2 is allowed to infiltrate into horizons 1 and 2 and segment 5 is allowed to infiltrate into horizons 1-5. Volumes of segments that exceed the water holding capacity of their respective sets of horizons are designated as runoff.

After infiltration into the top five soil horizons is calculated, any soil water amounts above the field capacity of a horizon is redistributed to lower horizons. In series, starting from the top at horizon 1, the daily water content of the horizon is compared to the horizon's water content at field capacity. If the water content exceeds the field capacity value the difference in volume is moved to the next lower horizon. This process is continued downward through each successive horizon until a volume added from an upper horizon does not increase the water content of a lower horizon above its field capacity value. If a volume of water remains after processing all of the horizons in the profile, this volume of excess water is then used to saturate each horizon starting at the bottom of the profile and moving in series upward. Any excess water volume remaining after all horizons are saturated during this process is designated as runoff.

At the end of each daily time step, volumes of soil water content above horizons' field capacity values are drained from the profile and the excess volumes are designated as export to groundwater. This process begins with draining the shallowest horizon with water content exceeding field capacity, moving the difference in volume between the water content of the horizon and its field capacity value into the next horizon below. This drainage process is continued downward until all soil horizons in the profile are reset to field capacity and the excess water volume is exported to the groundwater. Overall, these processes reset each soil horizon, above the groundwater table, to their respective field capacity water content values at the end of each daily time step.

Methods and Approach

Model Input Changes

The EDYS model domain does not correspond with the TxRR model domain used by TWDB. The EDYS domain focuses on areas directly surrounding San Antonio Bay, while the TxRR domain included watershed units directly surrounding the Bay in combination with watersheds to the northwest of the Bay along the San Antonio and Guadalupe Rivers. Some adjustment of the seven TWDB watershed units surrounding the Bay was necessary to coincide with similar watershed units defined by the elevation data used in the San Antonio Bay EDYS model. A shapefile of the TWDB watershed unit outlines was obtained from TWDB. This shapefile was used to define the segments of the San Antonio Bay shoreline that corresponded to each of the seven generalized watershed units used by TWDB. These shoreline segments were then used to define "pour points" for use in the ArcGIS Watershed tool, which delineates a set of contributing watershed cells that would be expected to collectively drain to the pour point cells. Output from the Watershed tool, produced a new set of generalized watershed units similar to the TWDB watershed units, but defined by the elevation data used in the EDYS model (Fig. 2).

The San Antonio Bay EDYS model domain included all of the area covered by TWDB watershed units 24603, 24605, and 24606. The TWDB watershed units 24601, 24602, 24604, and 24607 were, however, truncated by the EDYS model domain. In all cases, the new watershed units' areas, defined using the EDYS elevation data, differed from the areas used by TWDB. The original TWDB and the subsequent EDYS derived area values for each watershed unit are listed in Table 3. The EDYS derived area values were used to modify the TxRR input files for each of the seven watershed units and obtain new TxRR runoff output.

Table 3. Areas of generalized watershed units as originally defined by TWDB compared with values defined using the San Antonio Bay EDYS model domain and elevation data.

Watershed Unit	Original TWDB Area (sqmi)	EDYS Area (sqmi)
24601	22.9	9.3
24602	42.4	11.7
24603	7.0	10.2
24604	10.9	10.1
24605	11.7	22.5
24606	6.8	11.9
24607	22.5	15.2

Figure 2. Generalized watershed unit outlines derived from EDYS elevation grid.

Another difference between the TxRR modeling completed by TWDB and the EDYS modeling completed by Texas Tech University was daily precipitation input. To address this difference, new daily precipitation input files for TxRR were created using the daily precipitation values that were used in the EDYS model. The new precipitation input files were used in combination with the modified TxRR parameter input files, where watershed unit areas were changed as described above, to support new TxRR model runs for comparison to EDYS model runs. Within the EDYS precipitation data set, the average annual precipitation was 44.4 inches for years 2000-2010. Precipitation during the year 2000 was 54.1 inches, approximately 22% higher than the average value. During 2001, precipitation was 34.7 inches or approximately 22% lower than the average value. The years 2000 and 2001 were chosen as the wet and dry years, respectively, during which TxRR and EDYS were compared.

Using the same seven watershed units (i.e., the modified versions defined by the EDYS elevation data) TxRR and EDYS were run for years 1999, 2000, and 2001. The models were run during 1999 in order to minimize any possible differences caused by initial conditions within the two models. Model output data from the year 2000 were considered representative of a wet or above average precipitation year and output data from the year 2001 were considered representative of a dry or below average precipitation year.

Model Output

Both TxRR and EDYS produce runoff volume output tables. The TxRR model produces separate output for each watershed unit and includes a runoff volume in acre-feet, even if that value is zero, for each date. The EDYS model produces an output file that lists runoff volumes in acre-feet for all watershed units that produced runoff, greater than zero. Runoff values in the EDYS output are only listed for date and watershed unit combinations when runoff was calculated as greater than zero. To support comparison between the two sets of runoff output and precipitation events, precipitation, TxRR, and EDYS data were merged by date.

Daily precipitation data were reformatted into a file with vertical columns of year, month, day, and precipitation depth. This provided a data file that included one row of data for each day of 2000 and 2001. These daily precipitation records were copied seven times and runoff output from TxRR for each of the seven watershed units were merged with the precipitation data. The 'vlookup' function in MS Excel was used to merge daily EDYS runoff output for each separate watershed unit to the respective precipitation and TxRR runoff data. This process produced a data file for each watershed unit that included year, month, day, precipitation in inches, TxRR runoff in acre-feet, and EDYS runoff in acre-feet. The area of each watershed unit (Table 3) was added as a column in each data file and used to transform runoff volumes in acre-feet from each model to inches.

In a method similar to that used in the USGS studies discussed in the introduction section, the relationship between precipitation and runoff was examined on a precipitation event basis, rather than a daily basis. Distinct precipitation events were defined as single or consecutive days where precipitation was > 0.1 inches. The sum of precipitation, TxRR runoff, and EDYS runoff (all in inches) during distinct precipitation and (potential) runoff events, over consecutive days were determined. Sequential days were included in the sum for a distinct precipitation event until there were two consecutive days with zero inches of rain.

At least the first of the two days with zero inches of rain was included in the precipitation event sums. Including these 'extra' days in a precipitation event was necessary to capture continuing runoff calculated by TxRR related to baseflow. For each distinct precipitation event, enough days were included to ensure that the lagging baseflow runoff calculated by TxRR had effectively reduced to near zero or was < 5% of the peak calculated runoff during the precipitation event. During 2000 and 2001 most precipitation events were ≤ 4 days long, with two events being five days and one event being seven days. Accumulating precipitation events in the manner described above produced 29 discreet events in 2000 and 26 discreet events in 2001. Additionally, in all cases the reduction of baseflows after the last day of rain took two days or less.

Precipitation to Runoff Metrics

Three specific metrics describing the relationship between event precipitation and subsequent model calculated runoff were of interest: 1) the threshold amount of precipitation required to produce runoff amounts between 0.01-0.1 inches; 2) the number of non-zero runoff events (i.e., ≥ 0.01 inches); and 3) the annual, cumulative runoff to precipitation coefficient. These three metrics were derived for 2000 and 2001, relatively wet and dry years respectively, using data from each watershed unit and model combination (Table 4). Threshold and annual event count metrics are both indicators of how likely a model or, in the context of measured runoff data, a watershed is to initiate runoff given a certain amount of precipitation. A negative correlation between threshold and annual event metrics would be expected, with lower threshold numbers leading to more annual events and fewer annual events occurring as threshold values increased. The annual, cumulative runoff coefficient metric indicates the general relationship between any annual precipitation amount and runoff generated by a model or a watershed.

Table 4. Precipitation to runoff metric values for each watershed unit, year, and model combination.

		Threshold precipitation required to produce 0.01-0.1 inches of runoff		Number of runoff events		Annual, cumulative runoff coefficient	
Watershed Unit	Year	TxRR	EDYS	TxRR	EDYS	TxRR	EDYS
24601	2000	0.80	1.80	28	10	0.38	0.18
	2001	0.86	1.40	19	6	0.22	0.08
24602	2000	0.81	2.03	29	7	0.40	0.19
	2001	0.73	2.15	19	4	0.25	0.10
24603	2000	0.80	3.61	28	6	0.38	0.09
	2001	0.83	2.15	19	4	0.21	0.01
24604	2000	0.75	1.93	29	11	0.41	0.21
	2001	0.73	1.40	19	6	0.26	0.11
24605	2000	1.01	3.50	28	6	0.32	0.11
	2001	0.91	2.15	17	4	0.16	0.03
24606	2000	1.56	2.07	17	14	0.20	0.15
	2001	1.13	1.51	12	7	0.07	0.05
24607	2000	0.81	2.07	28	13	0.36	0.13
	2001	0.86	1.65	19	7	0.20	0.04

These three metrics were also derived from the USGS published data (Ockerman and Petri 2001; Ockerman 2002; and Ockerman and Fernandez 2010) discussed in the introduction section (Table 5). The study focusing on three rangeland dominated watersheds (Ockerman 2002) provided data over ~ 18 months, during which precipitation was about 15% below the long-term average for the area. Both studies focusing on row crop dominated watersheds (Ockerman and Petri 2001 and Ockerman and Fernandez 2010) provided precipitation and runoff data across three years with varying amounts of precipitation. Precipitation during one of the three years in both studies was > 28% above the area's long-term average. This variability in precipitation during the study years provided the opportunity to derive separate sets of metrics for wet years and dry-to-average years. Data from both row crop dominated watershed studies were grouped to derive a set of combined cropland relationships.

Data from each model, watershed unit, and year combination were analyzed to calculate the average threshold amount of precipitation required for each model to calculate runoff between 0.01-0.1 inches. Data from each watershed unit and year combination were filtered in MS Excel to include only TxRR calculated runoff values between 0.01-0.1 inches. The average precipitation amounts associated with these runoff values of 0.01-0.1 inches were recorded (Table 4). This filtering process was repeated for EDYS calculated runoff. These steps allowed an average threshold event precipitation amount for each model to calculate a non-zero amount of runoff, i.e., 0.01-0.1 inches (Table 4). A similar filtering technique was used to determine the number of runoff events ≥ 0.01 inches for each watershed unit, year, and model combination (Table 4). Threshold values and annual event counts for the three published data sets are summarized in Table 5.

Total event precipitation and runoff during 2000 and 2001 were summed for each watershed unit. The annual sum of event runoff amounts was divided by the annual sum of event precipitation amounts. These quotients provided the annual, cumulative runoff to precipitation coefficient (Table 4). Coefficients for the published data sets are summarized in Table 5.

Table 5. Precipitation to runoff metric values for published watersheds.

Watershed / Relative Precipitation	Year(s)	Predominant land surface condition	Precipitation % of long term average	Precipitation required to produce 0.01-0.1 inches of runoff:	Number of annual runoff events	Cumulative Runoff Coefficient
Ockerman (2002)						
Moody Creek	2000-01	rangeland	85	2.8	5.4	0.04
Welder Watershed 1				2.0	4.8	0.05
Welder Watershed 2				2.0	3.0	0.01
Aransas River near Skidmore, TX	1964-2001	rangeland	100	---	---	0.05
Mission River at Refugio, TX	1939-2001					0.07
Ockerman and Petri (2001), Kleberg/Nueces Counties						
Kleberg/Nueces Counties						
Wet	1997	row crops	128	1.3	5	0.21
Dry-to-average	1998		89		6	0.15
Ockerman and Fernandez (2010)						
West Oso Creek						
Wet	2007	row crops	142	1.4	8	0.18
Dry-to-average	2005-06, 2008		75		7	0.13
Oso Creek Tributary						
Wet	2007	row crops	143	1.9	11	0.10
Dry-to-average	2005-06, 2008		96		6	0.08
Combined Row Crop Data						
Row crops (Wet)	1997, 2007	row crops	128-143	1.9	8	0.16
Row crops (Dry-to-average)	1996, 1998, 2005, 2006, 2008		66-96	1.5	5.3	0.11
Row crops (all data)	**1998-08**	**row crops**	**66-143**	**1.6**	**6.2**	**0.14**

Results and Discussion

Runoff amounts calculated by TxRR and EDYS in response to measured precipitation amounts during 2000 and 2001 differed across all seven of the watershed units bordering San Antonio Bay. Three main trends in the TxRR and EDYS metrics were observed in the data. First, runoff to precipitation response metrics calculated from TxRR model data indicated a higher level of response than the same metrics calculated with EDYS data. Precipitation threshold metrics calculated from TxRR model data were lower in all cases and annual runoff events and cumulative runoff coefficient metrics were higher in every case compared to the same metrics calculated from EDYS model data. Second, metrics calculated from EDYS model data were closer to the value of metrics calculated from the published data. Third, the seven watershed units had considerable variability in proportions of row crop and rangeland across their areas. Coefficient values calculated from TxRR model data, however, did not emulate these relative proportions as well as those calculated from EDYS data.

Threshold and Event Number Metrics

Analysis of precipitation event data indicated that precipitation threshold values calculated from TxRR data were lower in all watershed unit and year combinations than thresholds calculated from EDYS data. Only one of the 14 TxRR threshold values were within the 1.3-2.8 inch range of values calculated from the published data (Table 5), with the other 13 values being below this range. The one exception was watershed unit 24606. Watershed unit 24606 was assigned a SMMAX value 14.16 inches, which was 42% higher than the next highest SMMAX value, specifically 9.96 inches in 24605, in the other six watershed units (Table 1). The higher value of SMMAX used in TxRR for this watershed unit increased the threshold metrics and lowered the other two metrics for both years to levels closer to the EDYS metrics compared with the other six watershed units (Table 4).

Threshold values from TxRR data were ≤ 1.01 inches for six of the seven watershed units during both years. All three published data sets contained instances of precipitation < 1.0 inches producing runoff, but these instances were only during wettest antecedent soil conditions. Within the context of the published threshold values, TxRR threshold values being consistently < 1.01 inches of precipitation can be considered low.

Twelve of the 14 EDYS threshold values were within the range of values calculated from the published data. Two of the EDYS threshold values are above the maximum published value of 2.8. For perspective, precipitation of > 2.0 inches was identified in Ockerman and Petri (2001) and Ockerman (2002) as a general threshold for production of runoff from both rangeland and crop land. Precipitation < 2.0 inches resulted in only 4.1% of the total runoff measured from cropland in the Ockerman (2002) study. Greater than 80% of the total runoff in this study was associated with precipitation events > 5.0 inches.

The number of annual runoff events > 0.01 inches, a metric expected to be correlated with threshold values, were higher in all combinations for TxRR compared to EDYS (Table 4). The number of events during 2000 and 2001, respectively, ranged from 17-29 and 12-19 for TxRR and 6-14 and 4-7 for EDYS. The ranges of values for TxRR and EDYS did not overlap during either year. Event number values from TxRR were 2.2-4.7 with a median of 3.5 and 2.8-4.8 with a median of 3.7 times higher than EDYS values in 2000 and 2001, respectively when excluding watershed unit 24606. For watershed unit 24606, TxRR values were 1.2 and 1.7 times higher than EDYS values in 2000 and 2001. The number of annual runoff events recorded in the published data ranged from 7-11 during wet years and 2-10 during dry-to-average years on cropland, with a range of 3-5 events on rangeland during dry-to-average years (Table 5). The number of annual runoff events derived from the TxRR data were, in all cases, greater than the range of values from the published data. Compared to published data, this consistently high estimation of annual runoff events further supports the idea that the TxRR precipitation threshold metrics were low.

Runoff Coefficients

Cumulative, annual runoff coefficients derived from TxRR model data were, in all cases, higher than those calculated from EDYS model data. Coefficients during 2000 and 2001, respectively, ranged from 0.2-0.41 and 0.07-0.26 for TxRR and 0.09-0.21 and 0.03-0.11 for EDYS. Although there was one instance of overlap between TxRR and EDYS ranges in 2000 and several instances in 2001, the magnitude of difference by watershed unit were considerable. The smallest difference was for watershed unit 24606, where TxRR coefficients were 1.3 and 1.4 times higher than those for EDYS in 2000 and 2001. Across the other six watershed units, TxRR coefficients were 2.0-4.2 with a median of 2.4 and 2.4-21 with a median of 3.9 times higher than EDYS coefficients in 2000 and 2001.

Coefficients derived from published data collected from the MC_WWR rangeland dominated watersheds ranged from 0.01-0.05, but were only available for two dry-to-average years. Additional coefficients for rangeland dominated watersheds can be calculated using long-term precipitation and runoff data presented in Ockerman (2002) for two USGS stream-flow gaging stations on the Aransas River near Skidmore (gage 08189700) and the Mission River at Refugio (08189500), these coefficients were 0.05 and 0.07, respectively (Table 5). The Aransas River near Skidmore watershed (247 square miles) and the Mission River at Refugio watershed (690 square miles) are larger and further away from the coast than the study watersheds studied by Ockerman (2002) near MC_WWR. The calculated coefficients, however, are close to and provide support for the coefficients calculated from the Ockerman (2002) data. Coefficients for row crop dominated watersheds derived from published data ranged from 0.10-0.21 during wet years and 0.08-0.13 during dry-to-average years.

Combining coefficient values from rangeland and cropland dominated watershed studies can provide general ranges of coefficient values useful for comparing to model output. Data from the MC_WWR watersheds were collected during two dry-to-average years and, therefore, might be best combined with the dry-to-average year cropland coefficients. This would propose a general coefficient range of 0.01-0.13 during dry-to-average years. Data reported for the Aransas and Mission River watersheds included a broad variety of relative precipitation years. Combined with the wet year cropland coefficients, this proposes a general coefficient range of 0.05-0.21 during wet years.

Runoff coefficients derived from TxRR model data in 2000 were greater than the range of values derived from the published data during wet years in all but one case; the exception being watershed unit 24606. Similarly, TxRR coefficient values from the 2001 data were greater than the range of values derived from the published data during dry-to-average years. The minimum TxRR coefficient in 2000 was > 50% higher and the minimum TxRR coefficient in 2001 was > 23% higher than the respective maximum published data coefficients for wet and dry-to-average years, excluding watershed unit 24606. Both TxRR coefficient values, 2000 and 2001, for watershed unit 24606 were within the respective ranges of values derived from the published data. The range of coefficient values derived from EDYS model data in 2000 and 2001 were in all cases within the range of values derived from the published data during wet and dry-to-average years, respectively. The consistency with which TxRR runoff coefficients were greater than the ranges of the published data values indicates that TxRR, as parameterized by TWDB for six of the seven watershed units, tended to overestimate runoff for a given amount of precipitation. This indication of runoff overestimation is in agreement with threshold and event number results.

Another way to evaluate coefficient values is using an assumption that the coefficients would be expected to vary with the proportions cropland and rangeland/native area within the watershed units. For example, land surface condition across watershed unit 24601 is approximately 30% cropland and 70% native/rangeland. Based on a proportional calculation using the published coefficient values for rangeland and cropland (Table 5), runoff coefficients might be expected to range from 0.07-0.11 during wet years and 0.03-0.08 during dry-to-average years (Table 6). Coefficient values calculated from the TxRR data are considerably higher than both ranges. The EDYS Coefficient value for 2000 is higher than the range for wet years and the value for 2001 is at the high end of the range for dry-to-average years. Coefficients for TxRR across all seven watershed units and both years are higher than the proportional ranges; on average 3 times higher. Coefficients for EDYS follow a different trend.

Table 6. Proportions of cropland and rangeland/native land surface condition, with the total proportion of wetland land area, for each watershed unit. Proportional coefficient values are calculated using the minimum and maximum cropland and rangeland/native coefficient values from the published studies (see footnote).

		Land Surface Condition			Proportional Coefficient*	
Watershed Unit	**Year**	**Cropland**	**Rangeland / Native**	**Wetland**	**Minimum**	**Maximum**
24601	2000	0.3	0.7	0.59	0.07	0.11
	2001				0.03	0.08
24602	2000	0.1	0.9	0.77	0.06	0.08
	2001				0.02	0.06
24603	2000	0.6	0.4	0.09	0.08	0.15
	2001				0.05	0.11
24604	2000	0.2	0.8	0.87	0.06	0.10
	2001				0.02	0.07
24605	2000	0.6	0.4	0.12	0.08	0.15
	2001				0.05	0.11
24606	2000	0.0	1.0	0.43	0.05	0.07
	2001				0.01	0.05
24607	2000	0.0	1.0	0.61	0.05	0.07
	2001				0.01	0.05

*Extreme values from Table 5		Minimum	Maximum
Cropland	Wet	0.10	0.21
	Dry	0.08	0.15
Rangeland	Wet	0.05	0.07
	Dry	0.01	0.05

Coefficients for EDYS associated with rangeland/native dominated watershed units (24601, 24602, 24604, 25606, and 24607) were on average 2 times higher for 2000 than the range of values for wet years and for 2001 were ~ 1.6 times higher or just lower than the maximum values for dry-to-average years. Coefficients for EDYS associated with cropland dominated watershed units (24603 and 24605) are within the range of wet year values in 2000, but below the minimum dry-to-average year values in 2001. It is hypothesized that the difference between EDYS coefficient values and the expected value ranges for rangeland/native dominated watershed units can be attributed to the proportion of the watershed units that are wetlands. It is hypothesized that the differences between 2001 EDYS coefficient values on cropland dominated watershed units can be attributed to a combination of the proportion of cropland areas that are managed as improved pasture and the negligible slope across the majority of the two watershed units.

The U.S. Fish and Wildlife Service maintains and publishes the Wetland Inventory for the state of Texas (USFWS 2012). This ArcGIS shapefile can be used to estimate the proportion of wetlands in any of the published or modeled watersheds. Comparing the Wetlands Inventory map with the map of the MC_WWR watersheds in Ockerman (2002) indicates that the area of each of the three watersheds, Moody Creek and Welder Watersheds 1 and 2, are estimated to contain less than 5% wetlands. Rangeland/native areas of the five rangeland/native dominated watershed units surrounding San Antonio Bay, however, were between 43-87% wetlands.

The wetland areas surrounding San Antonio Bay are low elevation, < 1.5 m above sea level, and as seen in the aerial photo (Fig. 1) many contain open water. The low elevation and high proportion open water indicate that soil profiles within and surrounding the wetland areas would be expected to be partially to completely saturated. The high water content of soil profiles within and surrounding the wetland areas would limit the amount of soil pore space available to store precipitation. Compared to the MC_WWR watersheds, the high proportion of wetland areas in the watershed units surrounding San Antonio Bay in combination with high water contents of the soil profiles would be expected to produce higher runoff coefficients. These differences in coefficient values, due to wetland extent and associated high soil water content, would be increased during wet years.

The Oso Creek (Ockerman and Fernandez 2010) and Kleberg/Nueces (Ockerman and Petri 2001) cropland dominated watersheds are described as predominantly annual row crops. Cropland in the Oso Creek watersheds is designated as being 98% cotton and sorghum fields, with the remaining 2% of the area being roads. Cropland in the Kleberg/Nueces watershed is described as being 92% cotton and sorghum fields, 6% corn and wheat fields, and 2% fallow or pasture. The 2001 EDYS coefficient for watershed unit 24605 is 0.03 compared to a minimum proportional coefficient of 0.05 (Table 6). Watershed unit 24605 has > 18% of its cropland area managed as improved pasture, compared with < 2% improved pasture on the Oso Creek and Kleberg/Nueces watersheds. Due to continuous vegetative cover, improved pasture fields would be expected to produce less runoff in at least part of the year compared to annual row crops. This situation points to a potential benefit in grid based modeling, like that used in EDYS. The difference in runoff between annual row crop and improved pasture fields would be expected to be more prevalent during a dry year.

Watershed unit 24603 has < 4% of its cropland managed as improved pasture, but has a larger deviation from the range of proportional coefficients, 0.01 compared to a minimum value of 0.05 (Table 6). The similar amount of improved pasture in watershed unit 24603 and the Oso Creek and Kleberg/Nueces watersheds indicates that some other factor is contributing to the low coefficient calculated from the EDYS data during the dry year. Areas of negligible slope are hypothesized for 24603; and may also contribute to the difference seen in 24605. Ockerman and Fernandez (2010) stated that the negligible slope across the Oso Creek Tributary watershed may have physically inhibited or stopped runoff, i.e., ponding may have occurred, from some areas within the watershed. A similar concept can occur within the EDYS code. Areas within a watershed unit may have negligible slope, as calculated from the digital elevation model, and the code may calculate zero overland flow across these sub-areas. This situation would be also be more prevalent during a dry year. Additionally, this situation would be expected to diminish with smaller digital elevation grid sizes, as are planned for use in later phases of the San Antonio Bay modeling efforts.

Summary

Runoff from watersheds surrounding San Antonio Bay is an ecologically important source of fresh water in the peripheral marshes and the main body of the Bay. Fresh water from runoff, direct precipitation interception, and inflows from the Guadalupe River represent primary sources of fresh water in the Bay's salinity balance. These sources of fresh water are also important in driving the circulation of water in the Bay. Quantifying the amount of runoff entering the peripheral marshes and eventually the Bay is an important factor in modeling the salinity balance, water circulation, and ecological dynamics of the San Antonio Bay estuary. The watersheds surrounding San Antonio Bay are not gaged and, therefore, quantification of runoff must be modeled. Modeling of runoff has been conducted by TWDB using TxRR and TTU using EDYS.

The relationship between runoff and precipitation calculated by TxRR and EDYS for the watersheds surrounding San Antonio Bay are demonstrably different. Values of three metrics used to quantify the relationship between runoff and precipitation calculated by the two models for seven water shed units surrounding San Antonio Bay during the years 2000 and 2001were evaluated. Metric values indicated that TxRR consistently calculated runoff during lower amounts of precipitation and more runoff per unit of precipitation than did EDYS. The average threshold amount of precipitation at which non-zero runoff calculated by TxRR was lower than the threshold calculated by EDYS for all seven watershed units during both years. The lower threshold calculated by TxRR resulted in more runoff events being calculated for all seven watershed units during both years compared to EDYS. Additionally, TxRR calculated higher runoff coefficients in all seven watersheds during both years compared to EDYS, indicating that TxRR calculated higher amounts of runoff for a given amount of precipitation.

The seven watershed units surrounding San Antonio Bay are not gaged. Therefore, differences in values of the runoff to precipitation metrics calculated using data from TxRR and EDYS were compared to published results from gaged watershed studies within the Texas Coastal Bend. Analysis indicated that TxRR consistently calculated runoff to precipitation metric values outside the range of values derived from the published data for all three of the metrics evaluated. Exceptions were for watershed unit 24606, which was assigned a higher amount of soil profile water holding capacity (i.e., a 42% higher SMMAX parameter value) compared to the other six watershed units.

References

Matsumoto, J (1992) User's manual for the TWDB's rainfall–runoff model. Texas Water Development Board, Austin

Ockerman, D. J. and Petri, B.L. 2001. Hydrologic Conditions and Water Quality in an Agricultural Area in Kleberg and Nueces Counties, Texas, 1996–98: U.S. Geological Survey Scientific Investigations Report 01-4101. 54 p.

Ockerman, D.J. and Fernandez, C.J. 2010. Hydrologic conditions and water quality of rainfall and storm runoff for two agricultural areas of the Oso Creek watershed, Nueces County, Texas, 2005–08: U.S. Geological Survey Scientific Investigations Report 2010–5136. 63 p.

TWDB. 2010a. TxBLEND Model Validation for the Upper Guadalupe Estuary Using Recently Updated Inflow Data. Texas Water Development Board, Austin, Texas. 25 p.

TWDB. 2010b. TxBLEND Model Calibration and Validation for the Guadalupe and Mission-Aransas Estuaries. Texas Water Development Board, Austin, Texas. 46 p.

U.S. Fish and Wildlife Service. 2012. Wetlands Inventory; State Dowloads. http://www.fws.gov /wetlands/Data/State-Downloads.html. Accessed: 14 April 2015.

Williams, J.R. and W.V. LaSeur. 1976. Water yield using SCS curve numbers. J. Hyd. Div. Am. Soc. Civ. Eng. 102:1241-1253.