Estimating Sediment and Nutrient loads of Texas Coastal Watersheds with SWAT

A case study of Galveston Bay and Matagorda Bay

Nina Omani, Raghavan Srinivasan, and **Taesoo Lee**

Spatial Sciences Laboratory,
Texas A&M University

Introduction

This project was initiated to develop and apply the SWAT model to two Texas estuaries in order to estimate sediment and nutrient loads and to evaluate model performance when compared with TWDB reports. Freshwater inflow from ungauged and gaged watersheds to coastal bays was predicted using SWAT in the first phase(Lee et al., 2011).

The sediment, total nitrogen and total phosphorus are predicted on an annual basis for both gauged and ungauged subbasins using a calibrated model setting for gauged subbasins.

Purposes

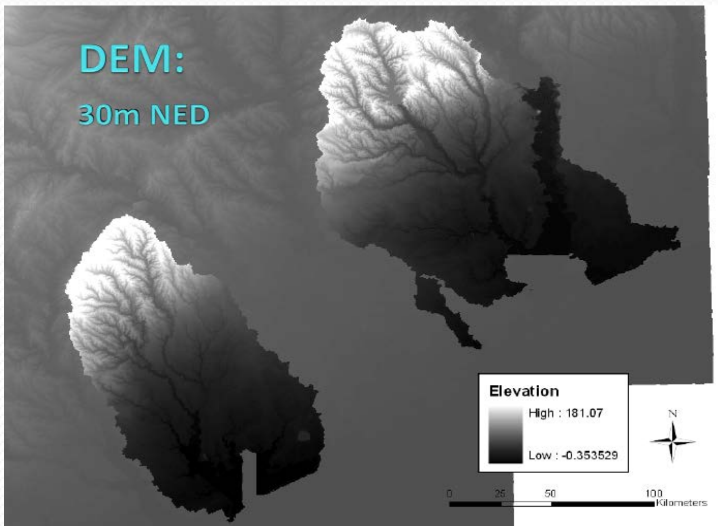
- Estimation of water flow to Bays using a recent model like SWAT over TXRR model (Lee et al., 2011)
- TXRR Model: Rainfall_runoff model using CN
- Estimation of sediment and nutrient load to Bays
- Pilot Study: Galveston Bay Watershed (Urbanized) and Matagorda Bay Watershed (Rural)

Study Area

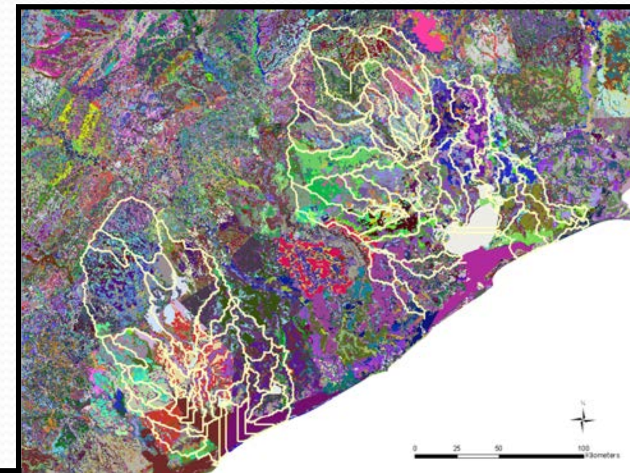
Galveston Bay Watershed 16,000 Km²
Matagorda Bay Watershed 11,600 Km²
Cameron
Huntsville
Livingston
Coldspring
Anderson
Kountze
Conroe
Orange
Beaumont
Giddings
Brenham
Hempstead
Liberty
Bastrop
Bellville
La Grange
Houston
Anahuac
Columbus
Richmond
Gonzales
Hallettsville
Wharton
Galveston
Angleton
Cuero
Bay City
Edna
Victoria
Goliad
Port Lavaca
Urban Areas
Flood Control
Water Supply
Irrigation
Study Area
Galveston Watershed
Area: 16,000 Km²
Matagorda Watershed
Area: 11,600 Km²
Miles 10 20 30
nationalatlas.gov
Where We Are

Input Data

- **GIS Data: 30m DEM**

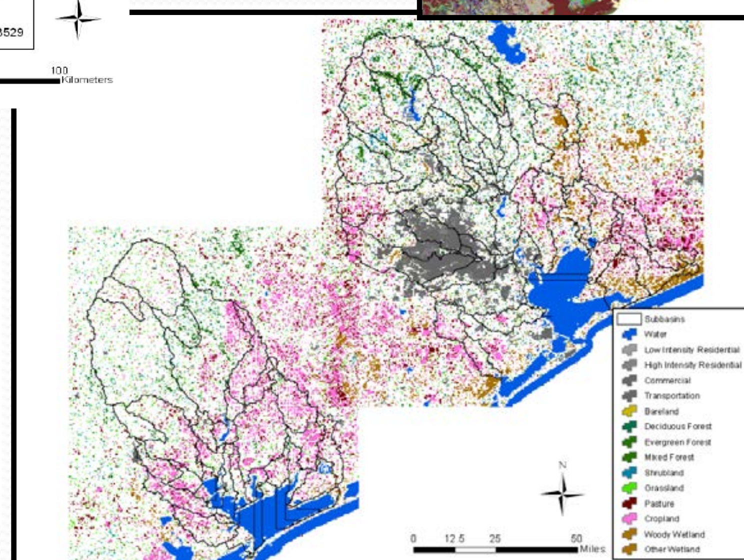


Soil: SSURGO



Landuse: NLCD 2001

Landuse Type	Galveston	Matagorda
Urban	23.8%	0.0%
Cultivated/Pasture	27.7%	70.1%
Other	48.5%	29.9%



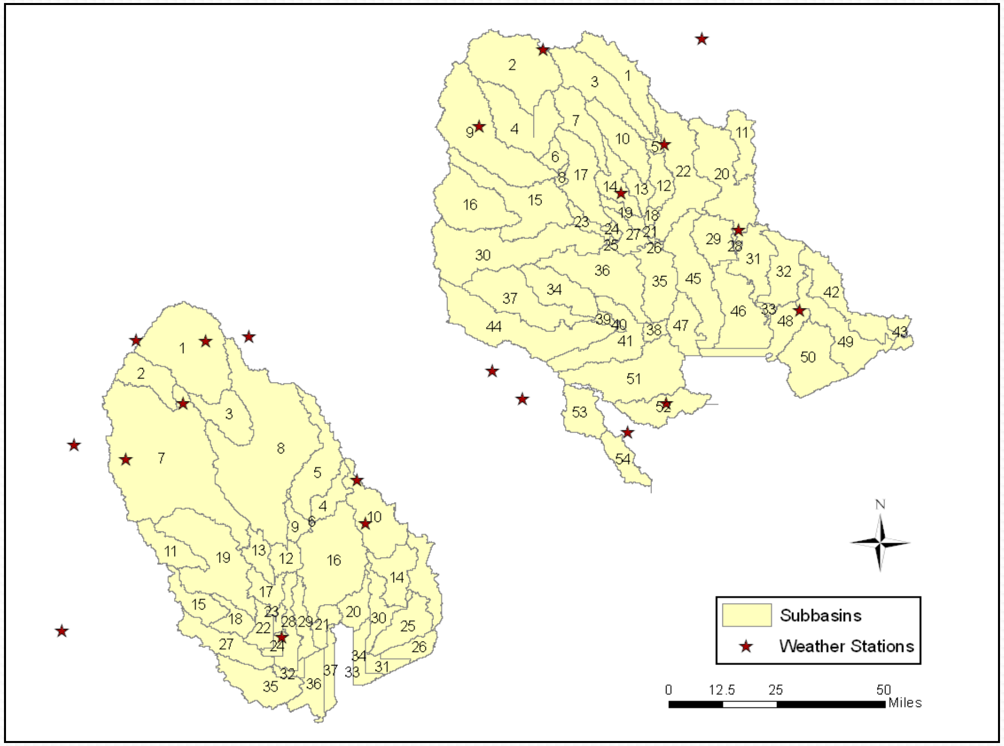
Weather: NDCD (1975-1999) and NEXRAD (2000-2008)

http://www.ncdc.noaa.gov/oa/climate/climatedata.html

http://www.ncdc.noaa.gov/oa/radar/radardata.html

Flow: USGS Gage stations

http://waterdata.usgs.gov/tx/nwis/sw



Weather stations used in this project

Sampling and Monitoring Stations

Sediment: USGS water quality samples

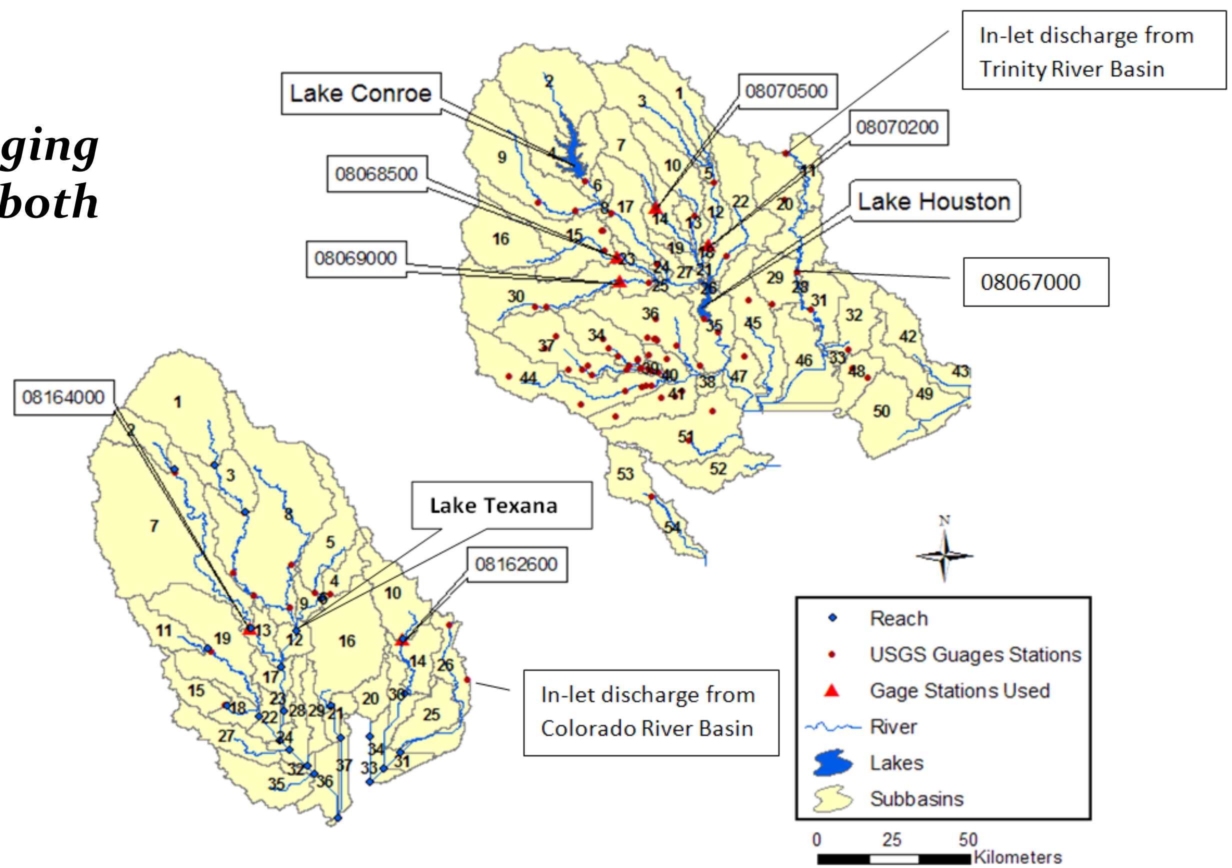
http://waterdata.usgs.gov/tx/nwis/qw

Nutrients: USGS water quality samples

http://waterdata.usgs.gov/tx/nwis/qw

Average annual sediment and nutrient data: TWDB Reports

TWDB and USGS gauging stations available in both watersheds



Calibration steps:

- Model calibration for average annual delivered sediment load based on Lower Colorado River Authority (LCRA) 1997 report. In this report sediment and nutrient loading from freshwater sources was estimated for 1984 (dry years) and 1987 (wet years).

- Model calibration using the monthly suspended sediment from Lavaca River Basin (Subbasin 7), total nitrogen, total phosphorus, organic nitrogen, organic phosphorus, NO3, and inorganic phosphorus from Lavaca River Basin (Subbasin 7) and Tres palacios River Basin (Subbasin 10).

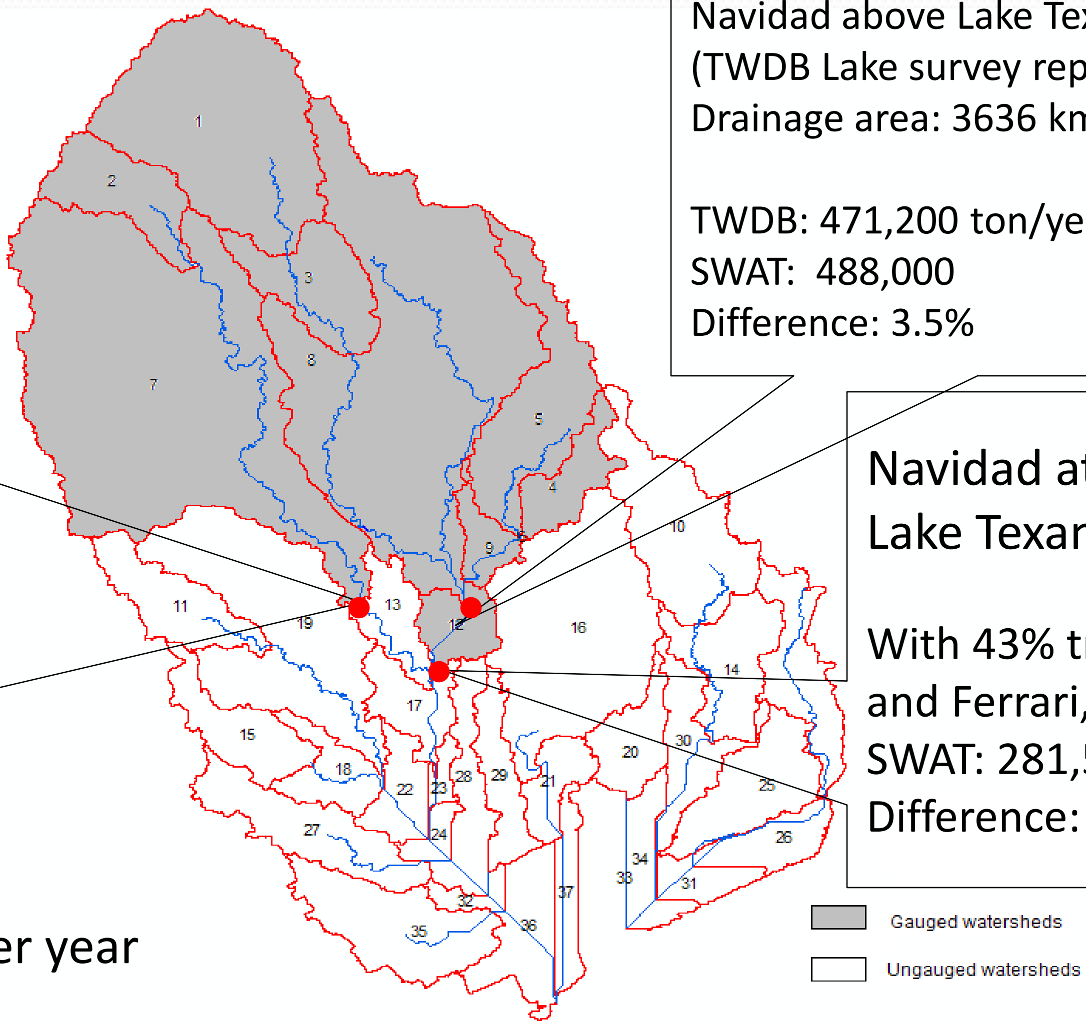
  Monthly calibration dataset was estimated using LOADEST program. Because of the lack of data the calibration periods for Subbasin 7 and 10 is different.

Average annual sediment calibration and validation

USGS gauge station on the Lavaca River at Edna:

Calibration:
USGS: 49,000
SWAT: 49,230
Difference: 0.4%

Validation:
USGS: 126,600
SWAT: 123,700
Difference : 2.3%



Navidad above Lake Texana:
(TWDB Lake survey report, 2011)
Drainage area: 3636 km2

TWDB: 471,200 ton/year (1980-2010)
SWAT: 488,000 (1980-2005)
Difference: 3.5%

Navidad at the outlet of Lake Texana:

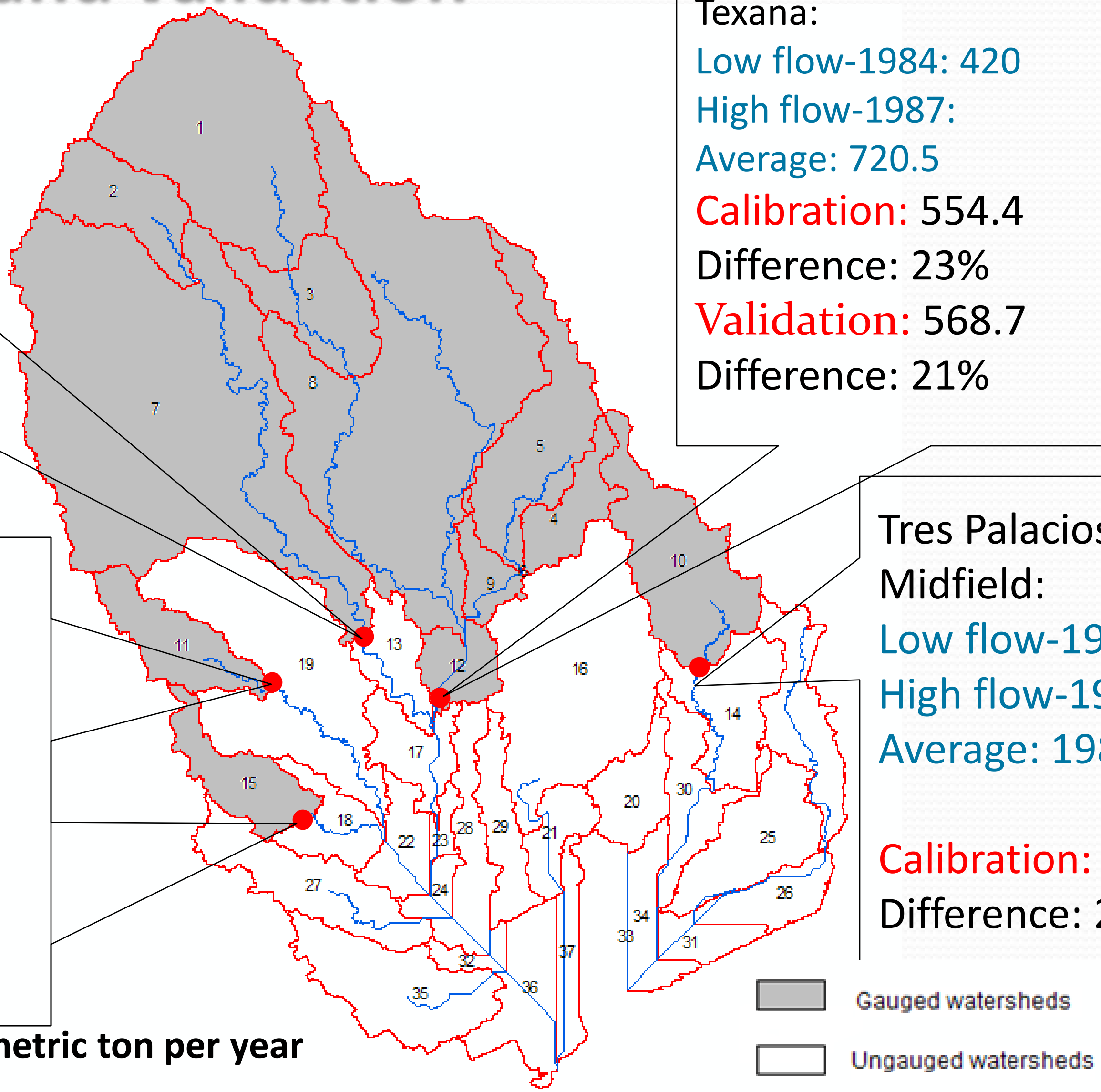
With 43% trapping (Blanton and Ferrari, 1992): 268,500
SWAT: 281,500
Difference: 4.8%

Unit: metric ton per year

Average annual total nitrogen from freshwater calibration and validation

LCRA, 1997 report:
Low flow-1984: 68
High flow-1987: 465
Average: 266.5
Calibration: 159.3
Difference: 40%
Validation: 251.1
Difference: 5.7%
Lavaca River at Edna:

Gracitas Creek at Inez/Placedo Creek at Placedo:
Low flow-1984: 28
High flow-1987: 137
Average: 82.5
Calibration: 90.1
Difference: 9%
Validation: 120.8
Difference: 46%



Unit: metric ton per year

Navidad at the outlet of the Lake Texana:
Low flow-1984: 420
High flow-1987:
Average: 720.5
Calibration: 554.4
Difference: 23%
Validation: 568.7
Difference: 21%

Tres Palacios River at Midfield:
Low flow-1984: 190
High flow-1987: 207
Average: 198.8

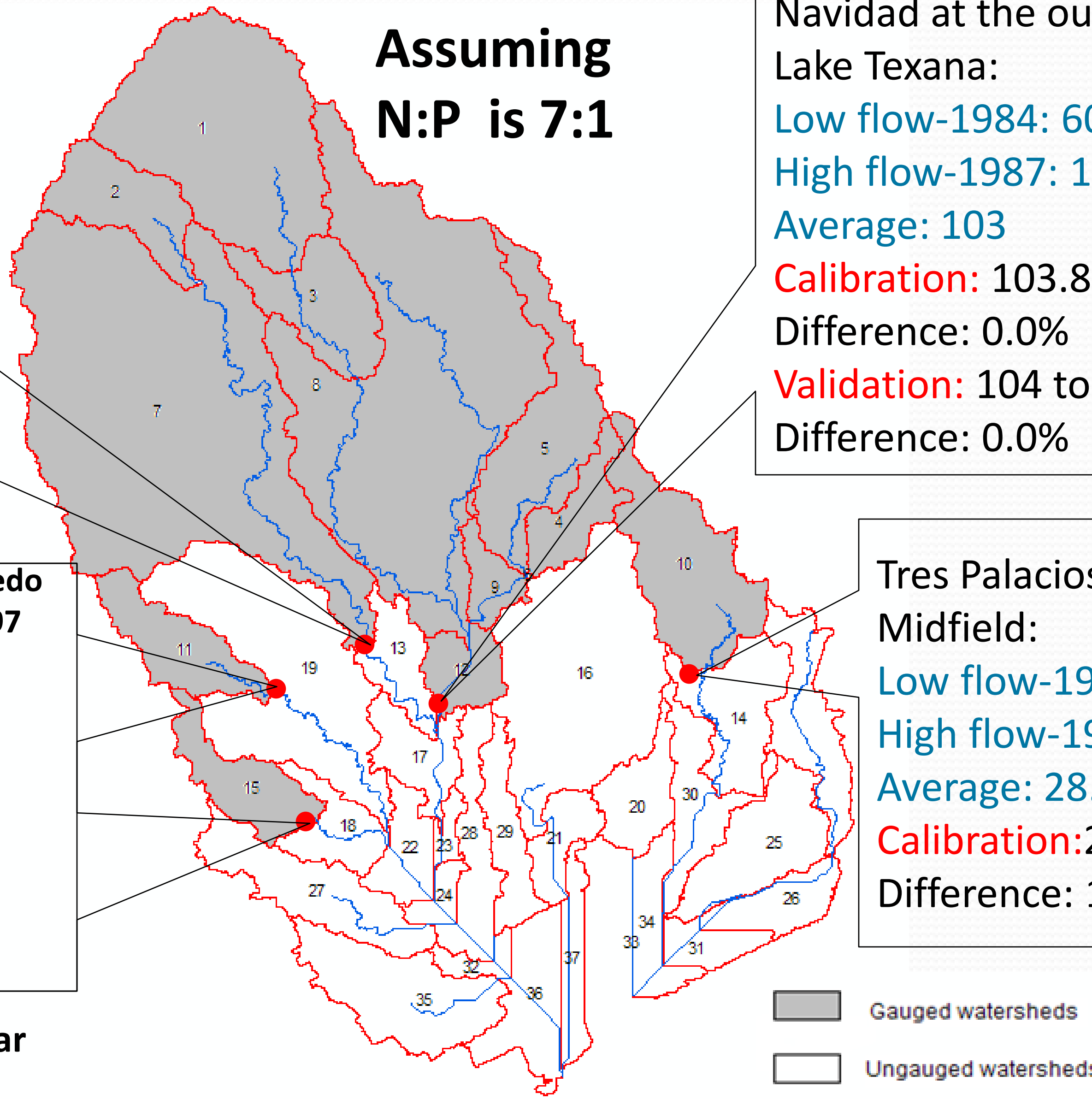
Calibration: 145.7
Difference: 27%

Average annual total phosphorus calibration and validation

Assuming N:P is 7:1

Lavaca River at Edna: LCRA, 1997 report:
Low flow-1984: 9.7
High flow-1987: 66.4
Average: 38
Calibration: 28.5
Difference: 25%
Validation: 47.7
Difference: 25%

Gracitas Creek at Inez/Placedo Creek at Placedo: LCRA, 1997 report:
Low flow-1984: 4
High flow-1987: 19.6
Average: 11.8
Calibration: 10.9
Difference: 0.0%
Validation: 13.6
Difference: 15%



Navidad at the outlet of the Lake Texana:
Low flow-1984: 60
High flow-1987: 145.8
Average: 103
Calibration: 103.8
Difference: 0.0%
Validation: 104 ton/year
Difference: 0.0%

Tres Palacios River at Midfield:
Low flow-1984: 27
High flow-1987: 29.8
Average: 28.4
Calibration:24
Difference: 15.5%

Unit: metric ton per year

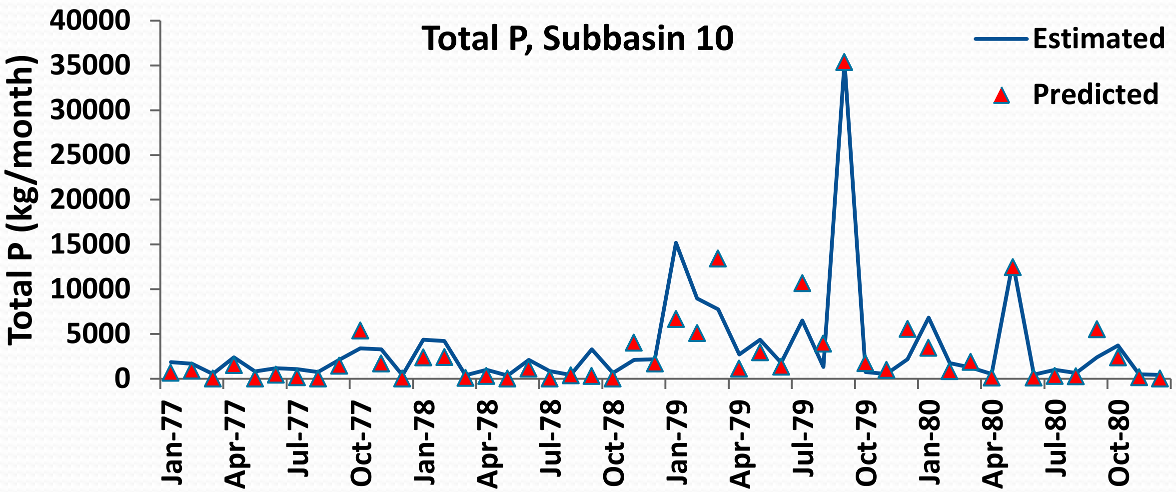
Calibration results for monthly suspended sediment and nutrient

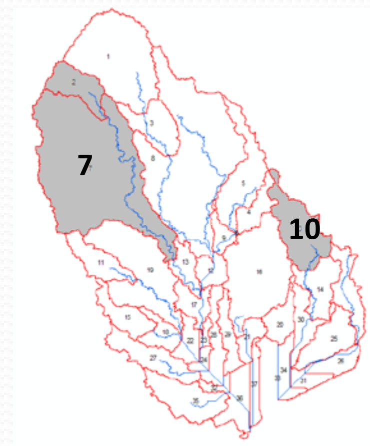
	Subbasin #	Calibration		Validation	
		R^2	NS	R^2	NS
TSS	7	0.68	0.62	0.61	0.60
TN	7	0.68	0.64	0.47	0.44
	10		0.42	-	-
TP	7	0.74	0.50	0.45	0.26
	10		0.50	-	-
ORGN	7	0.76	0.73	0.44	0.39
	10		0.66	-	-
ORGP	7	0.79	0.64	0.42	0.23
MINP	7	0.63	0.35	0.47	0.24
NO3	7	0.61	0.45	0.63	0.47
	10		0.13	-	-

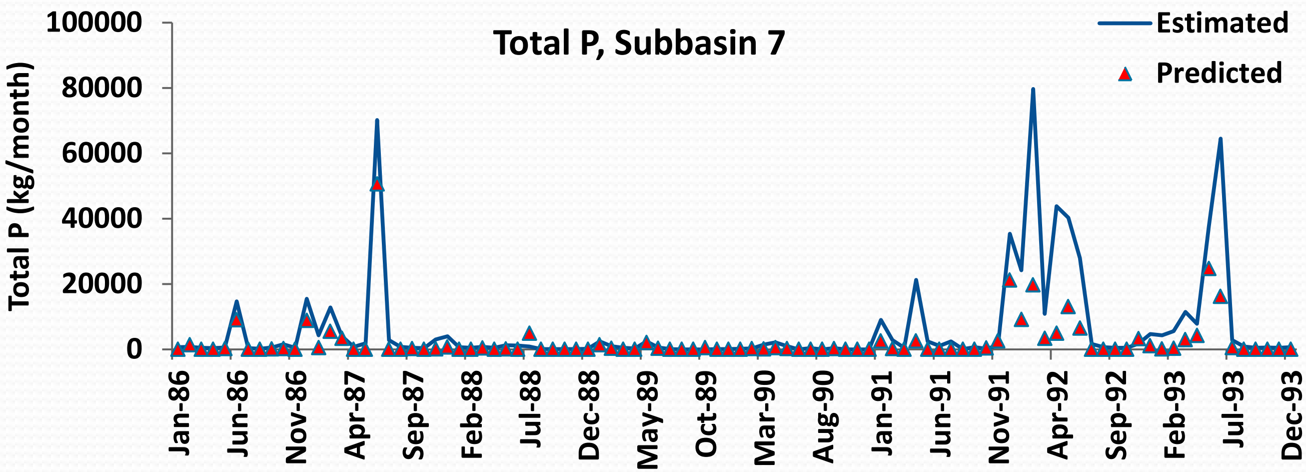
Lavaca River near Edna (Subbasin 7)

Subbasin 10 Tres Palacios River near Midfield

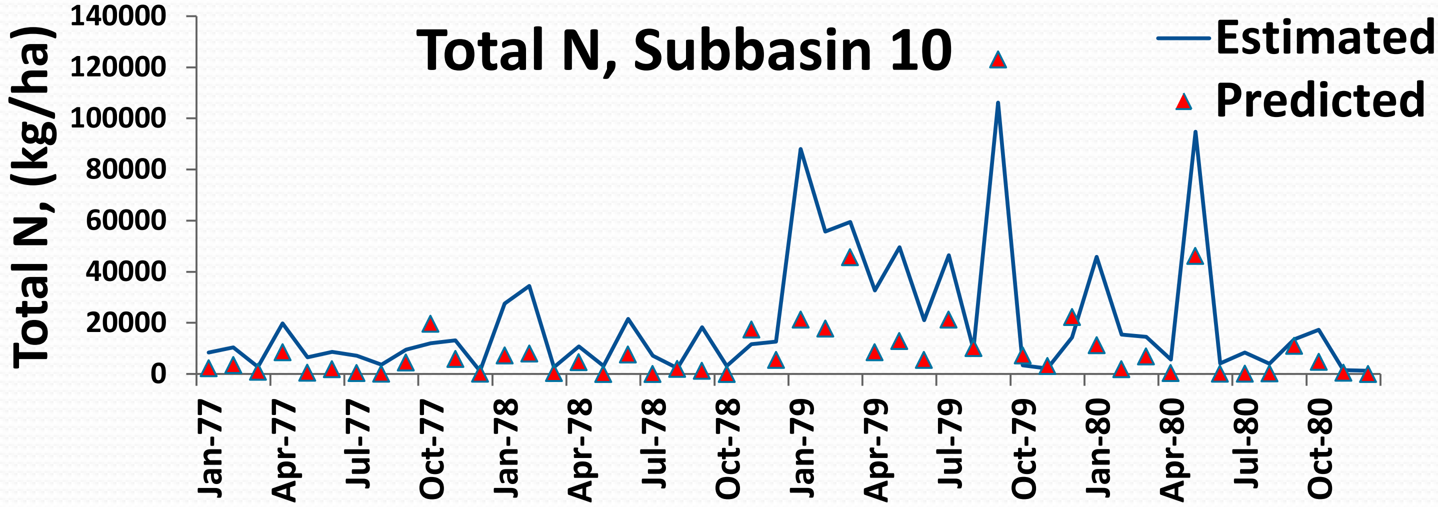
Total phosphorus graphs for calibration period

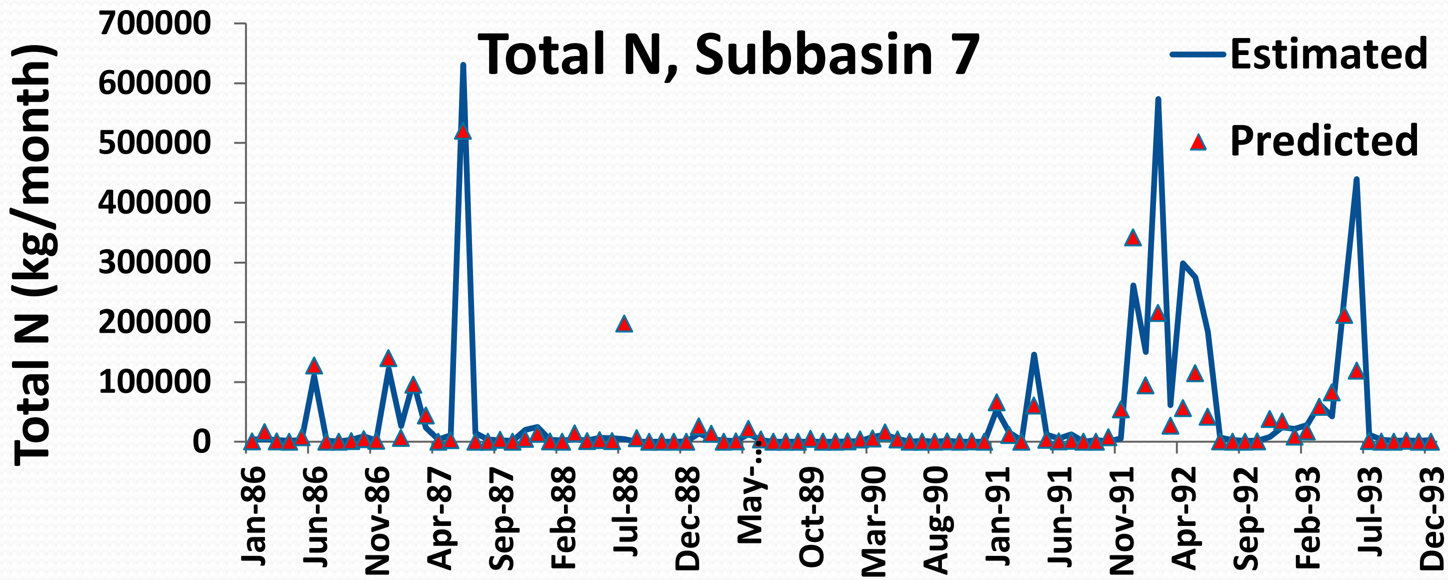






Total nitrogen graphs for calibration period





Input variables for calibration of sediment at gauged subbasins and
average variables at ungauged subbasins

Variable Name	Definition	Default Value	Gauged Subbasins	Ungauged Subbasins	Units
CH_N2.rte	Manning's n value for the main channel	0.014	0.014-0.07	0.05-0.07	coefficient
CH_COV1.rte	Channel cover factor	Bagnold Equation	0.5-0.6	0.5	coefficient
CH_COV2.rte	Channel erodibility factor	Bagnold Equation	1	1	coefficient
SPCON.bsn	Linear parameter for calculating the maximum amount of sediment	0.0001	0.004		coefficient
PRF.bsn	Peak rate adjustment factor for sediment routing in the main channel	1	0.70		coefficient
SPEXP.bsn	Exponent parameter for calculating sediment re-entrained	1	1		coefficient

Input variables for calibration of nitrogen at gauged subbasins and input variables at ungauged subbasins

Variable Name	Definition	Default value	Gauged Subbasins	Ungauged Subbasins	Units
BIOMIX.mgt	Biological mixing efficiency	**0.2**	**0.4 - 0.46**	**0.43**	coefficient
ERORGN.hru	Nitrogen enrichment ratio for loading with sediment	**Calculated (Menzel 1980)**	**1 - 5**	**3**	ratio
RS3.swq	Benthic NH4 source rate coefficient	**0.5**	**0.54**	**0.54**	mg N/m^2-day
RS4.swq	Organic N settling rate coefficient	**0.05**	**0.07**	**0.07**	day^{-1}
BC1.swq	Decay rate for NH_4 to NO_2	**0.55**	**0.8**	**0.8**	day^{-1}
BC2.swq	Decay rate for NO_2 to NO_3	**1.1**	**1.54**	**1.54**	day^{-1}
BC3.swq	Rate constant for hydrolysis of organic N to NH4	**0.21**	**0.2 – 0.4**	**0.2-0.30**	day^{-1}
CH_ONCO	Organic nitrogen concentration in the channel	**0**	**0.0008-0.005**	**0.003-0.005**	ppm
RCN.bsn	Concentration of Nitrogen in rainfall	**1**	**0.85**		mg N/Liter
SDNCO.bsn	Denitrification threshold water content	**0.05**	**0.9**		ratio
N_UPDIS.bsn	Nitrogen uptake distribution	**20**	**50**		scaling constant
NPERCO.bsn	Nitrate percolation coefficient	**0.2**	**0.32**		coefficient
RSDCO.bsn	Residue decomposition coefficient	**0.05**	**0.047**		coefficient
CDN.bsn*	Denitrification exponential rate coefficient	**1.4**	**1.76**		ratio
CMN.bsn*	Rate factor for humus mineralization of active organic nutrients (N and P)	**0.0003**	**0.001**		ratio

***Basinwide parameters affect either nitrogen and phosphorus loading**

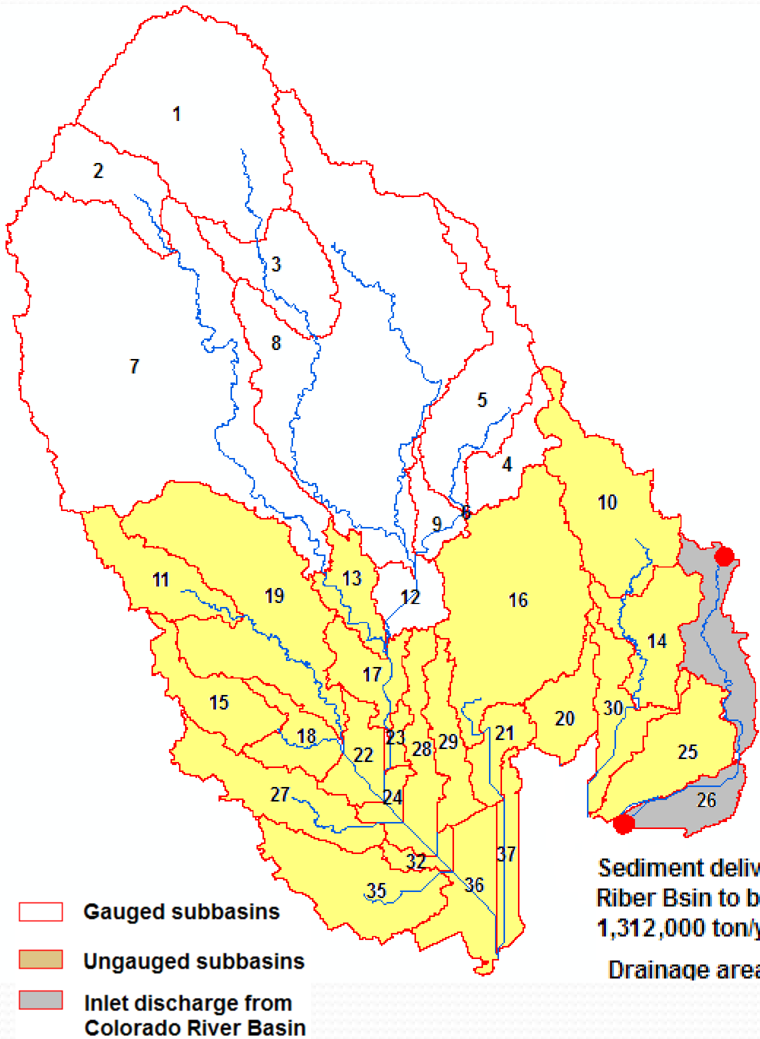
SWAT input coefficients adjustments for calibration of Nitrogen at gauged and ungauged subbasins

Variable Name	Description	Default value	Gauged Subbasins	Ungauged Subbasins	Units
ERORGP.hru	Phosphorus enrichment ratio for loading with sediment	Calculated (Menzel 1980)	1 - 3.5	2.25	ratio
RS2.swq	Benthic P source rate coefficient	0.05	0.05	0.05	mg P/m^2-day
RS5.swq	Organic P settling rate coefficient	0.05	0.05 – 0.1*	0.05	day^{-1}
BC4.swq	Rate constant for hydrolysis of organic P to mineral P	0.35	0.05 – 0.5	0.27	day^{-1}
P_UPDIS.bsn	Phosphorus uptake distribution	20	90		Scaling
PPERCO.bsn	Phosphorus percolation coefficient	10	11		coefficient
PHOSKD.bsn	Phosphorus soil partitioning coefficient	175	200		M^3/Mg
PSP.bsn	Phosphorus availability index	0.4	0.22		weighted constant
MUMAX.wwq**	Maximum specific algal growth rate at 20˚ C	2	1.0		day^{-1}
RHOQ.wwq**	Algal respiration rate at 20˚	0.3	0.3		day^{-1}

*Organic phosphorus settling rate above Lake Texana

**Basinwide parameters affect either nitrogen and phosphorus loading

Estimated annual sediment loading from freshwater to Matagorda Bay from 1977 to 2005



Sediment delivery from Colorado Riber Bsin to bay
1,312,000 ton/year

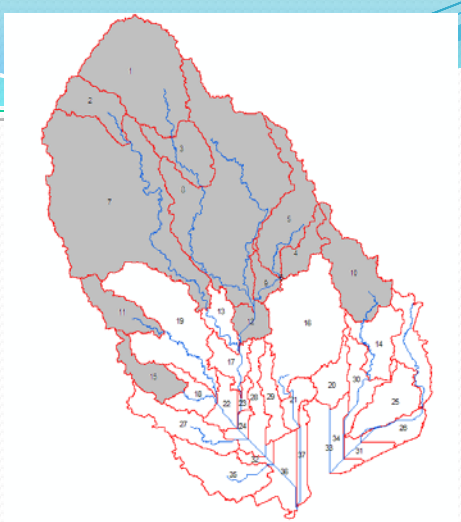
Drainage area: 109152.1 km2

	SWAT estimated drainage area (km^2)	Sediment (t/yr)	Sediment (t/ha)
Gauged subbasins*	5,711	314,270	0.55
Ungauged subbasins	5,323	447,730	0.84
Matagorda Bay Watershed (Ungauged+gauged)	11,034	762,000	0.69
Colorado River Basin to the Bay	109,152	1,312,000	-
Total loading to the Matagorda Bay	120,404	2,107,730	-

***Lake Texana trapping efficiency: 43%**

Channel deposition 27%

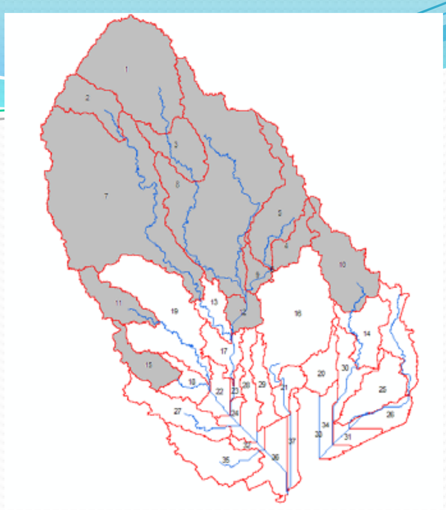
Estimated annual total nitrogen loading from feshwater to Matagorda Bay from 1977 to 2005



	SWAT estimated drainage area (km^2)	Nitrogen SWAT (ton/yr)	LCRA, 1997 1984 and 1987 (Average)	Gorham-Test (ton/yr)	Longley, 1994 Average annual from 1977-1987 (ton/yr)
Gauged subbasins	**6,553.7**	**1403.9**	**706-1830 (1268)**	**1300**	**2130**
Ungauged subbasins	**4,480.3**	**1174**	**1290-1585 (1438)**	**1290**	**3950**
Matagorda Bay Watershed (Ungauged+gauged)	**11,034**	**2578**	**1996-3415 (2706)**	**2590**	**6080**

The estimated annual returned nitrogen load from wastewater does not include in the values

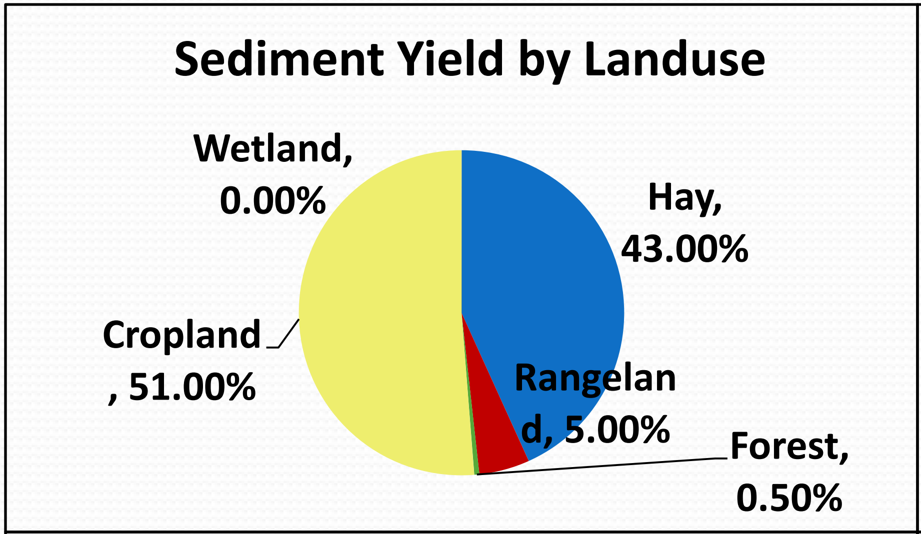
Estimated annual total phosphorus loading from feshwater to Matagorda Bay from 1977 to 2005

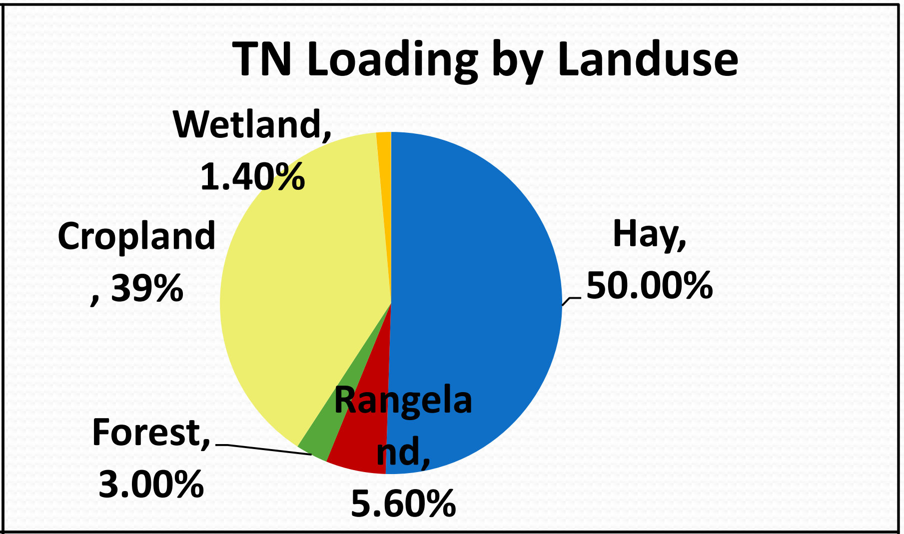


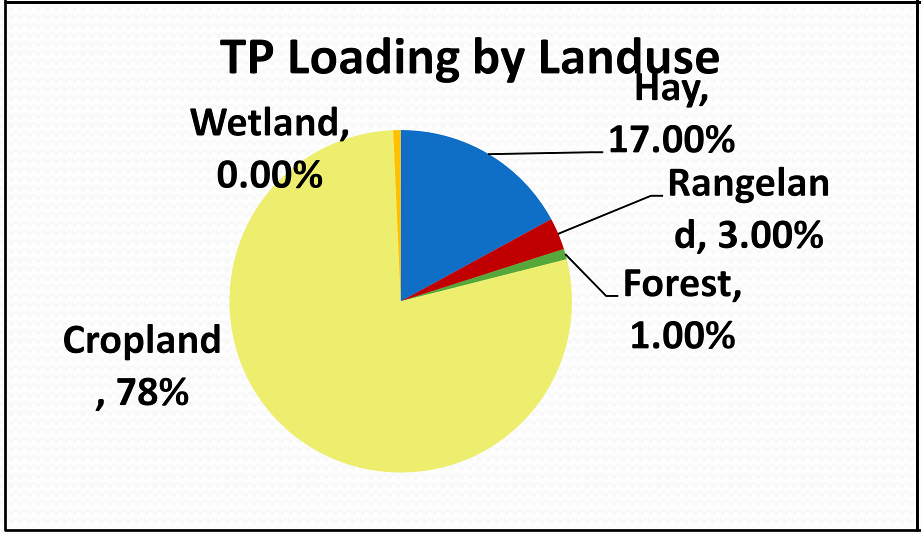
	SWAT estimated drainage area (km^2)	Phosphorus SWAT (ton/yr)	Longley, 1994 Average annual from 1977-1987 (ton/yr)	Ward and Armstrong (ton/yr)
Gauged subbasins	6,553.7	254	-	-
Ungauged subbasins	4,480.3	272	300	200
Matagorda Bay Watershed (Ungauged+gauged)	11,034	526	-	-
Total loading to the Matagorda Bay	120,404	1034	820	1090

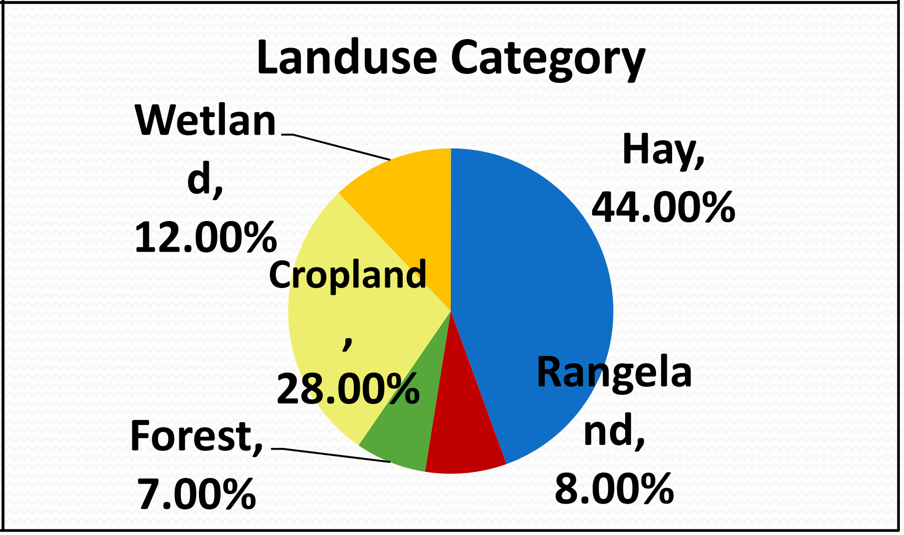
The estimated annual returned phosphorus load from wastewater does not include in the values

Average annual load by landuse

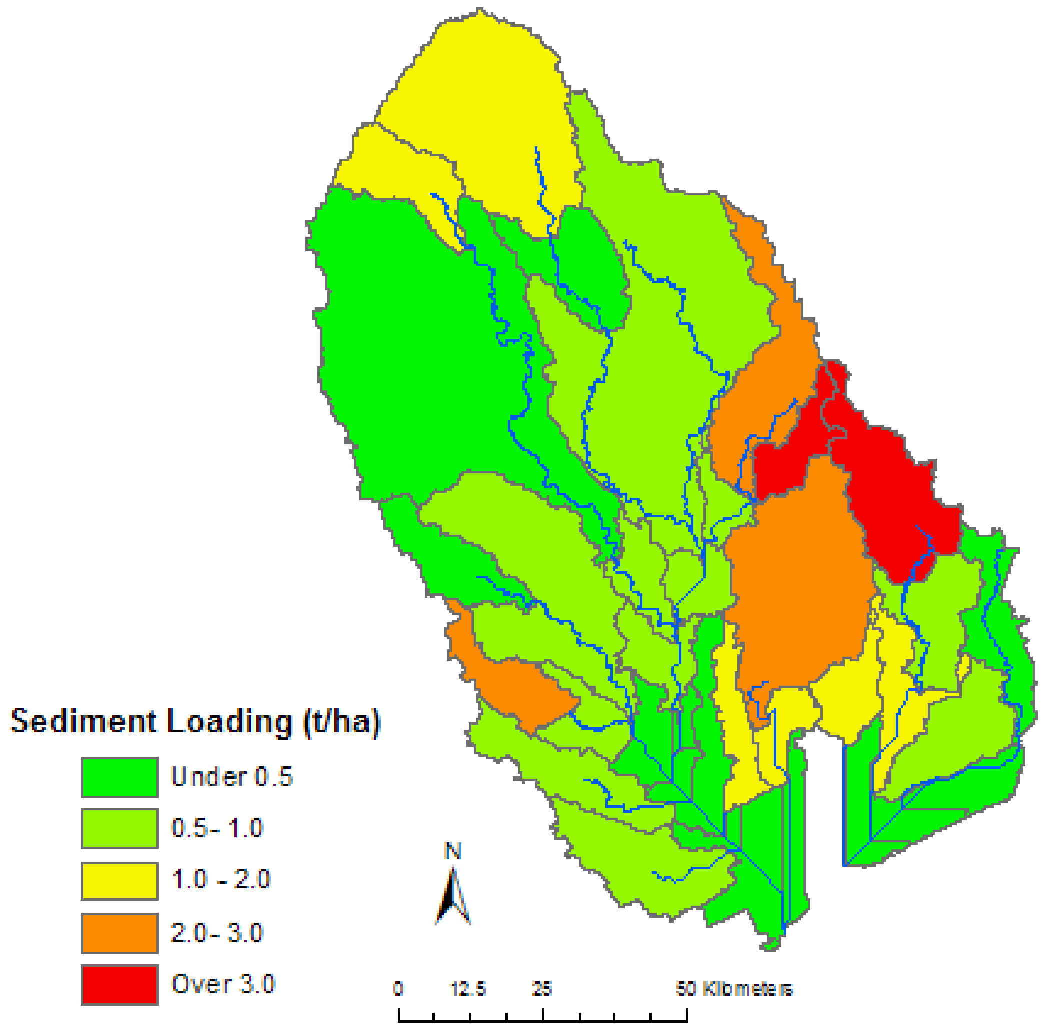




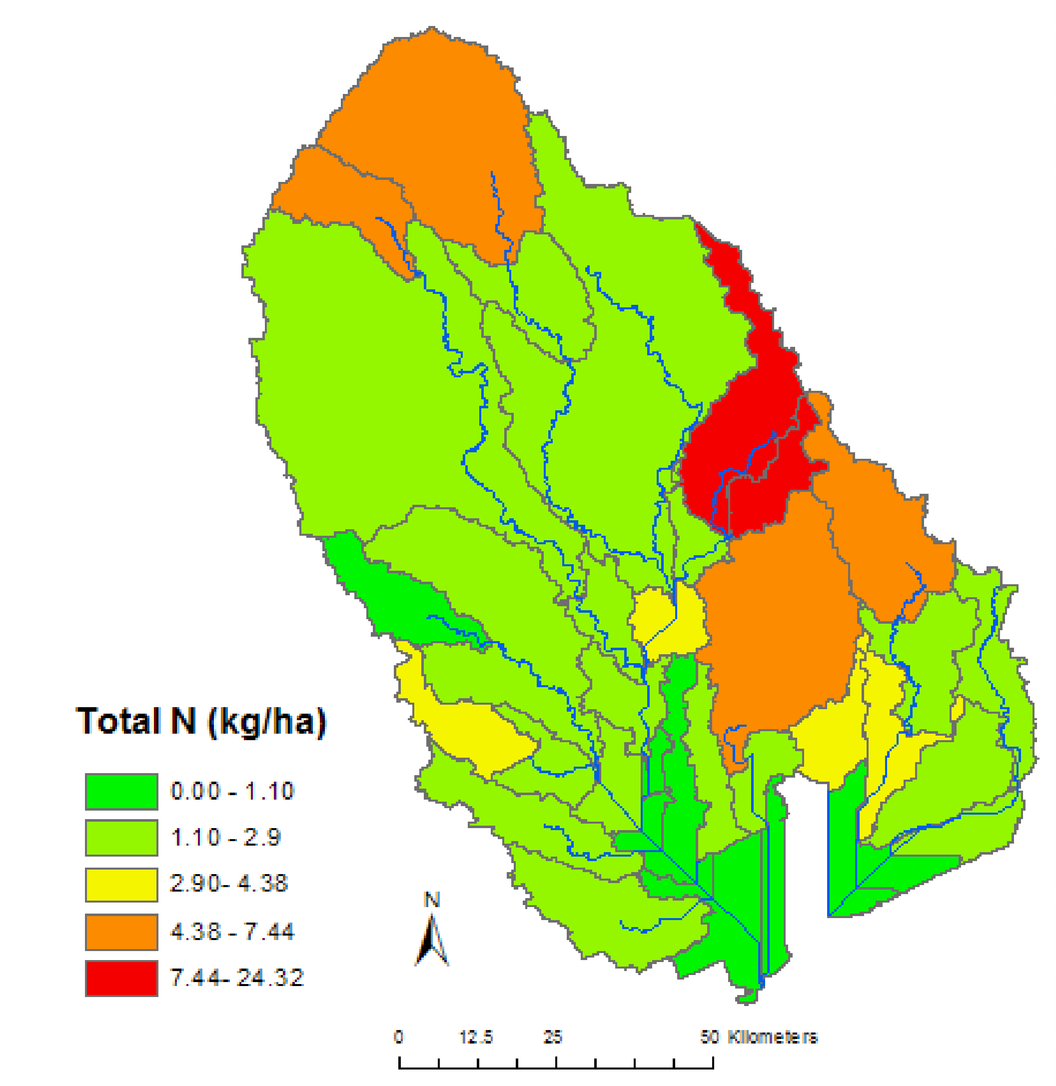




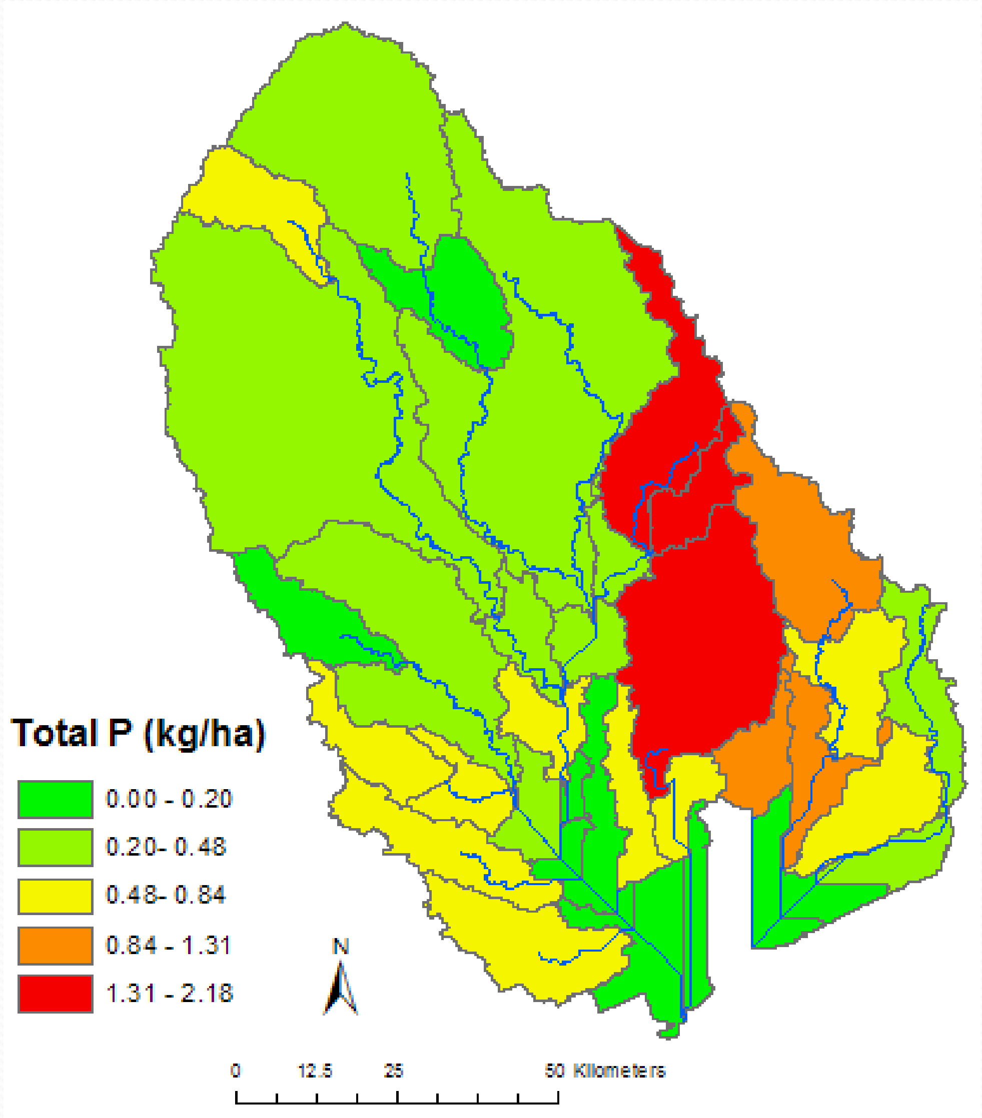
Average annual sediment yield by subbasin



Average annual total nitrogen loading by subbasin



Average annual total phosphorus loading by subbasin



Conclusion and Recommendations

SWAT model well predicted the annual and monthly suspended sediment and nutrient load from freshwater at gauged watersheds based on the statistical evaluation, TWDB and LCRA sediment and nutrient loading estimations.

The model was then validated and the adjusted parameters were extended to ungauged subbasins.

SWAT estimated the total N 25% and 15% lower than the reported nitrogen loading from Lavaca River Basin (Subbasin 7) and Tres Palacios River Basin (Subbasin 10) by LCRA.

One reason could be the land use conversion and changing the fertilizer applications frequency during the past 30 years.

Conclusion and Recommendations

- The channel sediment deposition was estimated about 30%.

  Sediment deposition is highly sensitive to channel erosion factors that should be selected based on literatures or field measurement.

- Only about 52% of total N and 43% of total P from the watershed reaches the bay. The high nutrient deposition could be due to the high sediment deposition in the channels. The literatures indicate that the SWAT needs further improvement to in-stream modeling routines.

- Nitrogen loading from channels bedload has critical role in total N estimation. Channel bedload contributes high level of organic nitrogen within the croplands.

Thank you