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
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.
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
Input Data

- GIS Data: 30m DEM

Landuse: NLCD 2001

<table>
<thead>
<tr>
<th>Landuse Type</th>
<th>Galveston</th>
<th>Matagorda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>23.8%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Cultivated/Pasture</td>
<td>27.7%</td>
<td>70.1%</td>
</tr>
<tr>
<td>Other</td>
<td>48.5%</td>
<td>29.9%</td>
</tr>
</tbody>
</table>

Soil: SSURGO

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
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.
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%

Unit: metric ton per year

Navidad at the outlet of Lake Texana:

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

Navidad above Lake Texana:

(TWDB Lake survey report, 2011)
- Drainage area: 3636 km²
- SWAT: 488,000 (1980-2005)
- Difference: 3.5%
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:

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

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%

Tres Palacios River at Midfield:
Low flow-1984: 190
High flow-1987: 207
Average: 198.8
Calibration: 145.7
Difference: 27%

Unit: metric ton per year
Average annual total phosphorus calibration and validation

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%

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%

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%

Assuming N:P is 7:1

Unit: metric ton per year
## Calibration results for monthly suspended sediment and nutrient

<table>
<thead>
<tr>
<th>Subbasin #</th>
<th>Calibration</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²</td>
<td>NS</td>
</tr>
<tr>
<td>TSS</td>
<td>7</td>
<td>0.68</td>
</tr>
<tr>
<td>TN</td>
<td>7</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.42</td>
</tr>
<tr>
<td>TP</td>
<td>7</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.50</td>
</tr>
<tr>
<td>ORGN</td>
<td>7</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.66</td>
</tr>
<tr>
<td>ORGP</td>
<td>7</td>
<td>0.79</td>
</tr>
<tr>
<td>MINP</td>
<td>7</td>
<td>0.63</td>
</tr>
<tr>
<td>NO3</td>
<td>7</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.13</td>
</tr>
</tbody>
</table>

- **Lavaca River near Edna (Subbasin 7)**
- **Subbasin 10 Tres Palacios River near Midfield**
Total phosphorus graphs for calibration period

**Total P, Subbasin 10**

- Estimated
- Predicted

**Total P, Subbasin 7**

- Estimated
- Predicted
Total nitrogen graphs for calibration period

Total N, Subbasin 10

Total N, Subbasin 7
### Input variables for calibration of sediment at gauged subbasins and average variables at ungauged subbasins

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Definition</th>
<th>Default Value</th>
<th>Gauged Subbasins</th>
<th>Ungauged Subbasins</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH_N2.rte</td>
<td>Manning’s n value for the main channel</td>
<td>0.014</td>
<td>0.014-0.07</td>
<td>0.05-0.07</td>
<td>coefficient</td>
</tr>
<tr>
<td>CH_COV1.rte</td>
<td>Channel cover factor</td>
<td>Bagnold Equation</td>
<td>0.5-0.6</td>
<td>0.5</td>
<td>coefficient</td>
</tr>
<tr>
<td>CH_COV2.rte</td>
<td>Channel erodibility factor</td>
<td>Bagnold Equation</td>
<td>1</td>
<td>1</td>
<td>coefficient</td>
</tr>
<tr>
<td>SPCON.bsn</td>
<td>Linear parameter for calculating the maximum amount of sediment</td>
<td>0.0001</td>
<td>0.004</td>
<td>coefficient</td>
<td></td>
</tr>
<tr>
<td>PRF.bsn</td>
<td>Peak rate adjustment factor for sediment routing in the main channel</td>
<td>1</td>
<td>0.70</td>
<td>coefficient</td>
<td></td>
</tr>
<tr>
<td>SPEXP.bsn</td>
<td>Exponent parameter for calculating sediment re-entrained</td>
<td>1</td>
<td>1</td>
<td>coefficient</td>
<td></td>
</tr>
</tbody>
</table>
## Input variables for calibration of nitrogen at gauged subbasins and input variables at ungauged subbasins

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Definition</th>
<th>Default value</th>
<th>Gauged Subbasins</th>
<th>Ungauged Subbasins</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOMIX.mgt</td>
<td>Biological mixing efficiency</td>
<td>0.2</td>
<td>0.4 - 0.46</td>
<td>0.43</td>
<td>coefficient</td>
</tr>
<tr>
<td>ERORGN.hru</td>
<td>Nitrogen enrichment ratio for loading with sediment</td>
<td>Calculated (Menzel 1980)</td>
<td>1 - 5</td>
<td>3</td>
<td>ratio</td>
</tr>
<tr>
<td>RS3.swq</td>
<td>Benthic NH4 source rate coefficient</td>
<td>0.5</td>
<td>0.54</td>
<td>0.54</td>
<td>mg N/m²-day</td>
</tr>
<tr>
<td>RS4.swq</td>
<td>Organic N settling rate coefficient</td>
<td>0.05</td>
<td>0.07</td>
<td>0.07</td>
<td>day⁻¹</td>
</tr>
<tr>
<td>BC1.swq</td>
<td>Decay rate for NH₄ to NO₂</td>
<td>0.55</td>
<td>0.8</td>
<td>0.8</td>
<td>day⁻¹</td>
</tr>
<tr>
<td>BC2.swq</td>
<td>Decay rate for NO₂ to NO₃</td>
<td>1.1</td>
<td>1.54</td>
<td>1.54</td>
<td>day⁻¹</td>
</tr>
<tr>
<td>BC3.swq</td>
<td>Rate constant for hydrolysis of organic N to NH4</td>
<td>0.21</td>
<td>0.2 – 0.4</td>
<td>0.2-0.30</td>
<td>day⁻¹</td>
</tr>
<tr>
<td>CH_ONCO</td>
<td>Organic nitrogen concentration in the channel</td>
<td>0</td>
<td>0.0008-0.005</td>
<td>0.003-0.005</td>
<td>ppm</td>
</tr>
<tr>
<td>RCN.bsn</td>
<td>Concentration of Nitrogen in rainfall</td>
<td>1</td>
<td>0.85</td>
<td></td>
<td>mg N/Liter</td>
</tr>
<tr>
<td>SDNCO.bsn</td>
<td>Denitrification threshold water content</td>
<td>0.05</td>
<td>0.9</td>
<td></td>
<td>ratio</td>
</tr>
<tr>
<td>N_UPDIS.bsn</td>
<td>Nitrogen uptake distribution</td>
<td>20</td>
<td>50</td>
<td></td>
<td>scaling constant</td>
</tr>
<tr>
<td>NPERCO.bsn</td>
<td>Nitrate percolation coefficient</td>
<td>0.2</td>
<td>0.32</td>
<td></td>
<td>coefficient</td>
</tr>
<tr>
<td>RSDCO.bsn</td>
<td>Residue decomposition coefficient</td>
<td>0.05</td>
<td>0.047</td>
<td></td>
<td>coefficient</td>
</tr>
<tr>
<td>CDN.bsn*</td>
<td>Denitrification exponential rate coefficient</td>
<td>1.4</td>
<td>1.76</td>
<td></td>
<td>ratio</td>
</tr>
<tr>
<td>CMN.bsn*</td>
<td>Rate factor for humus mineralization of active organic nutrients (N and P)</td>
<td>0.0003</td>
<td>0.001</td>
<td></td>
<td>ratio</td>
</tr>
</tbody>
</table>

*Basinwide parameters affect either nitrogen and phosphorus loading
### SWAT Input Coefficients Adjustments for Calibration of Nitrogen at Gauged and Ungauged Subbasins

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
<th>Default Value</th>
<th>Gauged Subbasins</th>
<th>Ungauged Subbasins</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERORGP.hru</td>
<td>Phosphorus enrichment ratio for loading with sediment</td>
<td>Calculated (Menzel 1980)</td>
<td>1 - 3.5</td>
<td>2.25</td>
<td>ratio</td>
</tr>
<tr>
<td>RS2.swq</td>
<td>Benthic P source rate coefficient</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>mg P/m²-day</td>
</tr>
<tr>
<td>RS5.swq</td>
<td>Organic P settling rate coefficient</td>
<td>0.05</td>
<td>0.05 – 0.1*</td>
<td>0.05</td>
<td>day⁻¹</td>
</tr>
<tr>
<td>BC4.swq</td>
<td>Rate constant for hydrolysis of organic P to mineral P</td>
<td>0.35</td>
<td>0.05 – 0.5</td>
<td>0.27</td>
<td>day⁻¹</td>
</tr>
<tr>
<td>P_UPDIS.bsn</td>
<td>Phosphorus uptake distribution</td>
<td>20</td>
<td>90</td>
<td></td>
<td>Scaling</td>
</tr>
<tr>
<td>PPERCO.bsn</td>
<td>Phosphorus percolation coefficient</td>
<td>10</td>
<td>11</td>
<td></td>
<td>coefficient</td>
</tr>
<tr>
<td>PHOSKD.bsn</td>
<td>Phosphorus soil partitioning coefficient</td>
<td>175</td>
<td>200</td>
<td></td>
<td>M³/Mg</td>
</tr>
<tr>
<td>PSP.bsn</td>
<td>Phosphorus availability index</td>
<td>0.4</td>
<td>0.22</td>
<td></td>
<td>weighted constant</td>
</tr>
<tr>
<td>MUMAX.wwq**</td>
<td>Maximum specific algal growth rate at 20° C</td>
<td>2</td>
<td>1.0</td>
<td></td>
<td>day⁻¹</td>
</tr>
<tr>
<td>RHOQ.wwq**</td>
<td>Algal respiration rate at 20°</td>
<td>0.3</td>
<td>0.3</td>
<td></td>
<td>day⁻¹</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th></th>
<th>SWAT estimated drainage area (km²)</th>
<th>Sediment (t/yr)</th>
<th>Sediment (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauged subbasins*</td>
<td>5,711</td>
<td>314,270</td>
<td>0.55</td>
</tr>
<tr>
<td>Ungauged subbasins</td>
<td>5,323</td>
<td>447,730</td>
<td>0.84</td>
</tr>
<tr>
<td>Matagorda Bay Watershed</td>
<td>11,034</td>
<td>762,000</td>
<td>0.69</td>
</tr>
<tr>
<td>(Ungauged+gauged)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado River Basin to the Bay</td>
<td>109,152</td>
<td>1,312,000</td>
<td>-</td>
</tr>
<tr>
<td>Total loading to the Matagorda Bay</td>
<td>120,404</td>
<td>2,107,730</td>
<td>-</td>
</tr>
</tbody>
</table>

*Lake Texana trapping efficiency: 43%

Channel deposition 27%
The estimated annual total nitrogen loading from freshwater to Matagorda Bay from 1977 to 2005

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauged subbasins</td>
<td>6,553.7</td>
<td>1403.9</td>
<td>706-1830 (1268)</td>
<td>1300</td>
<td>2130</td>
</tr>
<tr>
<td>Ungauged subbasins</td>
<td>4,480.3</td>
<td>1174</td>
<td>1290-1585 (1438)</td>
<td>1290</td>
<td>3950</td>
</tr>
<tr>
<td>Matagorda Bay Watershed (Ungauged+gauged)</td>
<td>11,034</td>
<td>2578</td>
<td>1996-3415 (2706)</td>
<td>2590</td>
<td>6080</td>
</tr>
</tbody>
</table>

The estimated annual returned nitrogen load from wastewater does not include in the values
## Estimated annual total phosphorus loading from freshwater to Matagorda Bay from 1977 to 2005

<table>
<thead>
<tr>
<th></th>
<th>SWAT estimated drainage area (km²)</th>
<th>Phosphorus SWAT (ton/yr)</th>
<th>Longley, 1994 Average annual from 1977-1987 (ton/yr)</th>
<th>Ward and Armstrong (ton/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauged subbasins</td>
<td>6,553.7</td>
<td>254</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ungauged subbasins</td>
<td>4,480.3</td>
<td>272</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td><strong>Matagorda Bay Watershed (Ungauged+gauged)</strong></td>
<td><strong>11,034</strong></td>
<td><strong>526</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total loading to the Matagorda Bay</strong></td>
<td><strong>120,404</strong></td>
<td><strong>1034</strong></td>
<td>820</td>
<td>1090</td>
</tr>
</tbody>
</table>

The estimated annual returned phosphorus load from wastewater does not include in the values.
Average annual load by landuse

Sediment Yield by Landuse
- Wetland: 0.00%
- Cropland: 51.00%
- Hay: 43.00%
- Rangeland: 5.00%
- Forest: 0.50%

TN Loading by Landuse
- Wetland: 1.40%
- Cropland: 39%
- Hay: 50.00%
- Rangeland: 5.60%
- Forest: 3.00%

TP Loading by Landuse
- Wetland: 0.00%
- Cropland: 78%
- Hay: 17.00%
- Rangeland: 3.00%
- Forest: 1.00%

Landuse Category
- Wetland: 44.00%
- Hay: 44.00%
- Cropland: 28.00%
- Forest: 7.00%
- Rangeland: 8.00%
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