ASSESSMENT AND CONTROL OF TOTAL NUTRIENT LOADS IN WATERSHED AND STREAM NETWORK IN SOUTH-WEST TEXAS

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Abstract: Recently, the population growth and agricultural development are rapidly undergoing in the South-West Texas. The junction of three river basins such as Lavaca river basin, Colorado-Lavaca Coastal basin and Lavaca-Guadalupe Coastal basin, are interesting for non-point and point source pollutant modeling: Especially, the 2 basins are an intensively agricultural region (Colorado-Lavaca Coastal/ Lavaca-Guadalupe Coastal basins) and several cities are rapidly extended. In case of the Lavaca river basin, there are many range land. Several habitat types wide-spread over three relatively larger basins and five wastewater discharge regions are located in there. There are different hazardous substances which have been released. Total nutrient loads are composed of land surface load and river load as Non-point source and discharge from wastewater facilities as point source. In 3 basins region, where point and non-point sources of pollution may be a big concern, because increasing fertilizers and pesticides use and population cause. This project objective seeks to how to assess and control the accumulation of non-point and point source and discuss the main impacts of agriculture and environmental concern as non-point source with water quality related to pesticides, fertilizer, and nutrients and as point source with wasterwater discharge from cities. The GIS technique has been developed to aid in the point and non-point source analysis of impacts to natural resource within watershed. This project shows the losses in kg/km^2/year of BOD (Biological Oxygen Demand) , TN (Total Nitrogen) and TP (Total Phosphorus) in the runoff from the surface of 3 basins. In the next paper, sediment contamination will show how to evaluate in Estuarine habitats of these downstream.

Keywords: total nutrient load, land surface load, non-point and point source, river load

1. INTRODUCTION

The U.S.Environmental Protection Agency (EPA), in cooperation with other Federal agencies that have resource management, monitoring, and research responsibilities, is implementing a long term monitoring program, the Environmental Monitoring and Assessment Program(EMAP), that will provide the public, scientists, and interested parties with information that can be used to evaluate the overall health of the nation's ecological resource (U.S.EPA 1988; NRC 1990). EMAP has been conducting regional surveys to measure indicators of the health of plants and animals, the quality of their surroundings, and the presence of pollutants. During 1990~2000, data were collected from approximately 100 sampling stations located in Lavaca river basin, Colorado-Lavaca Coastal basin and Lavaca-Guadalupe Coastal basin. At each of the sampling locations, measurement were made of kinds and abundance of stream water qualities, habitats and concentrations of contaminants in sediments and toxicity of sediments to sensitive organisms (Holland, 1990). The objectives of analysis of point and non-point source are to provide information that helps explain, when unacceptable ecological conditions are observed, why these unacceptable conditions may be occurring. Also, human activities or urbanization within watershed make a role of point source loading of pollutants. The environmental sustainability of agricultural system has been studied about non-point and urbanization and human activities has been studies as point source and its contribution make to environmental pollution and concerns in surface. Especially, this region has very important because Corpus Christi bay is one of Texas's several bays and estuaries located on the Gulf of Mexico in a region known as the Coastal Bend. Recently, effluent from big or small cities makes to contaminate instream and estuary. The amount of pollutant leaving and area depends on the landuse/landcover and runoff. Actually, surface is composed of heterogeneous factors like landuse/landcover and runoff. Then, point and non-point source pollutant modeling can be nearly impossible without GIS tool that can account for the spatial differences in the Lavaca river basin, Colorado-Lavaca Coastal basin and Lavaca-Guadalupe Coastal basin. In two regions of all, Figure 1 show that agricultural region occupied a big part and several extending cities are located in upstream region. Puckett (1995) reported that non-point source was the dominant source of nitrogen and phosphorus in majority of stream studied. This project shows the losses in kg/ha/year of TN (Total Nitrogen), TP (Total Phosphorus) and BOD (Biological Oxygen

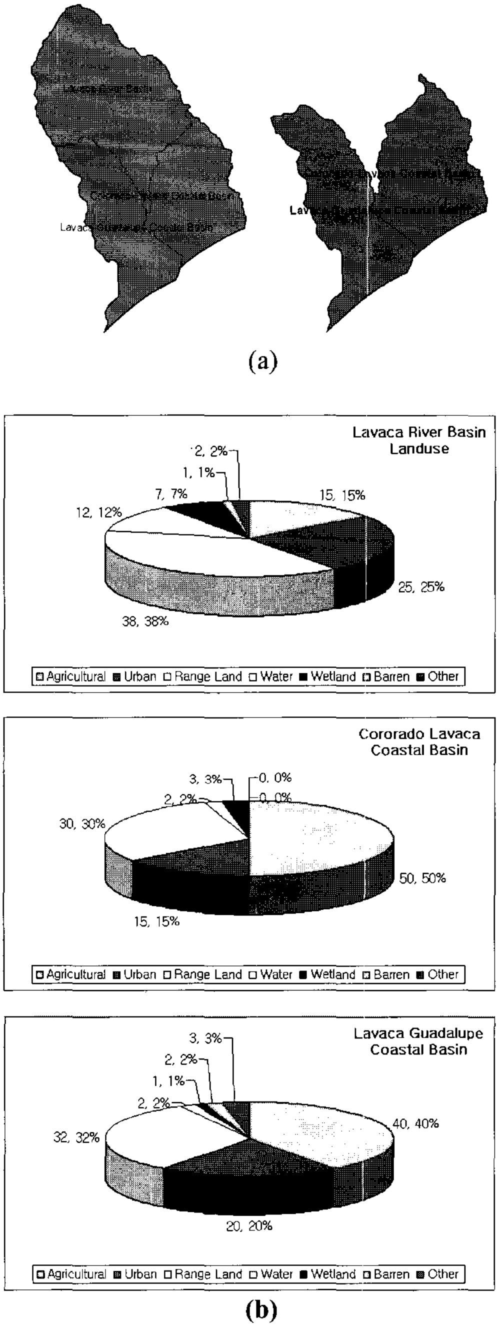

Figure 1. 3 watershed characteristics for analysis of non-point and point source in the south-west Texas (*A great portion of agricultural regions are located in Colorado-Lavaca Costal and Lavaca-Guadalupe basin)*

Demand) in the runoff from the surface of the Lavaca river basin, Colorado-Lavaca Coastal basin and Lavaca-Guadalupe Coastal basin. However, verification test is not performed in this paper. If it is performed, several observational locations will be selected as many as possible including downstream and sediment in whole study basins. Then it can be verified.

2. MATERIAL AND METHODS

2.1 Description of study area

The 3 river basins are located in South-West, Texas. 3 river basins are Lavaca river basin (LB), Lavaca Guadalupe Coastal basin (LGC-B), and Colorado-Lavaca Coastal basin(CLC-B). Especially, two of 3 basins as LGC-B and CLC-B have 40.4% and 50.5% agricultural regions. 68% of all the agricultural water used from river and 32% is source from groundwater. The two regions of cotton occupied in the most acreage, and other crops as sorghum occupied. However, recently, rapid urbanization makes happen to water contamination. Especially, it make contamination to the Corpus Christi Bay. The Corpus Christi Bay is one of Texas's several bays and estuaries located on the Gulf of Mexico in a region known as the Coastal bend. It is the gateway to the nation's sixth largest port and the third largest refinery and petrochemical complex. It has serious contaminated causes. One is source from non-point source and the other is from refinery and petrochemical complex.

2.2 Generation of runoff grid data

In the south-west Texas, runoff cause by excess irrigation and precipitation. To calculate the average annual runoff for a land-use configuration based on annual precipitation data. First, annual precipitation dataset is obtained from Natural Resource Conservation Service National Water and Climate Center (NRCS- NWCC) and Spatial Climate Analysis Service (SCAS) at Oregon State University. Frequently, what it is called "PRISM (Parameter-elevation Regression on Independent Slopes Model). PRISM dataset are composed of grid cells. Each grid cell provided as total annual depth (mm/yr) of precipitation averaged over the 32 years from 1971 to 2003(Figure 2). To calculate Curve number(CN) method, by combining the land use and land cover, a curve number grid can be generated. Landuse-Landcover(LULC) data files as GIS polygon coverage were created by the USGS and obtaining soil information is classified by STATSGO. U.S.Soil Conservation Service (SCS) curve numbers are parameters for calculating abstractions from ArcGIS 8.2 and ArcView 3.2(Figure 2). Figure 2 shows that Runoff volume(Q(mm/yr)) and potential infiltration(S(mm/yr)) are calculated for average daily rainfall by using the SCS curve number equations(U.S.Department of Agriculture, Soil Conservation Service 1972) from ArcGIS 8.2-ArcView 3.2. In addition, this study has a limitation that runoff volume is obtained from the use of annual average precipitation like using equation (1). But this objective of this study shows that GIS is useful tool to handle spatial nutrients distribution and impacting on stream network within study region for one year.

$$Q=\frac{(P-0.2S)^2}{P+0.8S}=\frac{\left[P-0.2\left(\frac{1000}{CN}-10\right)\right]^2}{P+0.8\left(\frac{1000}{CN}-10\right)},S=\frac{1000}{CN}-10 \quad (1)$$

Where:

P: total annual depth of precipitation (mm/yr)

S: potential infiltration (mm/yr)

Non-Point source analysis (Land surface load): Generation of nutrient loads (kg/year) grid data from EMC

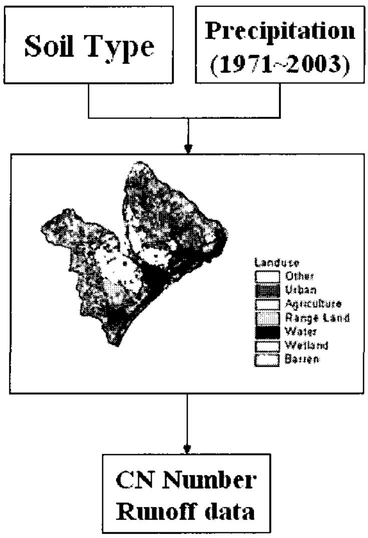

Figure 2. Generation for runoff data

The pollutant mass contribution in each cell depends largely on the amount of surface runoff.

Estimated Mean Concentrations (EMCs) are mainly pollutant values found in the runoff. A is the area of one grid cell(1,000,000 m^2).EMC values directly depend on the each land use. The Table 1 shows that EMC values are concentrations of pollutant dissolved in runoff water in southern Texas region (Saunders, W. and Maidment. D., 1995). From EMC value, the pollutant loading is obtaining from eq. (2). Each cell area is 1,000,000 m^2.

$$Load\ (kg/yr) = A(1{,}000{,}000m^2) \times EMC(mg/L) \times Q(mm/yr) \times 10^{-6}\ (kg{\cdot}m{\cdot}L/\ mg{\cdot}mm{\cdot}m^3) \quad (2)$$

Point source analysis: Watershed Delineation and Loading nutrients using ArcInfo –ArcGIS

Table 1. Relationship between land use and EMCs (Source: Saunders, W. and Maidment, D., 1995)

Constituent	Urban Res 11	Urban Comm 12	Urban Ind 13	Urban Trans 14	Urban Mixed 16/17#	Agr 2*	Range 3*	Undev/ Open 7*
Total Nitrogen (mg/L)	1.82	1.34	1.26	1.86	1.57	4.4	0.7	1.5
Total Kjeldahl N. (mg/L)	1.5	1.1	1	1.5	1.25	1.7	0.2	0.96
Nitrate + Nitrite (mg/L as N)	0.23	0.26	0.3	0.56	0.34	1.6	0.4	0.54
Total Phosphorus (mg/L)	0.57	0.32	0.28	0.22	0.35	1.3	<0.01	0.12
Dissolved Phos (mg/L)	0.48	0.11	0.22	0.1	0.23			0.03
Suspended Solids (mg/L)	41	55.5	60.5	73.5	57.9	107	1	70
Dissolved Solids (mg/L)	134	185	116	194	157	1225	245	
Total Lead (ug/L)	9	13	15	11	12	1.5	5	1.52
Total Copper (ug/L)	15	14.5	15	11	13.9	1.5	<10	
Total Zinc (ug/L)	80	180	245	60	141	16	6	
Total Cadmium (ug/L)	0.75	0.96	2	<1	1.05	1	<1	
Total Chromium (ug/L)	2.1	10	7	3	5.5	<10	7.5	
Total Nickel (ug/L)	<10	11.8	8.3	4	7.3			
BOD (mg/L)	25.5	23	14	6.4	17.2	4	0.5	
COD (mg/L)	49.5	116	45.5	59	67.5			40
Oil and Grease (mg/L)**	1.7	9	3	0.4	3.5			
Fec Coliform (col./100 ml)**	20,000	6,900	9,700	53,000	22,400		200	
Fecal Strep (col./100 ml)**	56,000	18,000	6,100	26,000	26,525			

calculated as avg of land uses 11-14

* applied to all subcategories within the land use type

**average concentrations base on instantaneous rather than flow-averaged samples

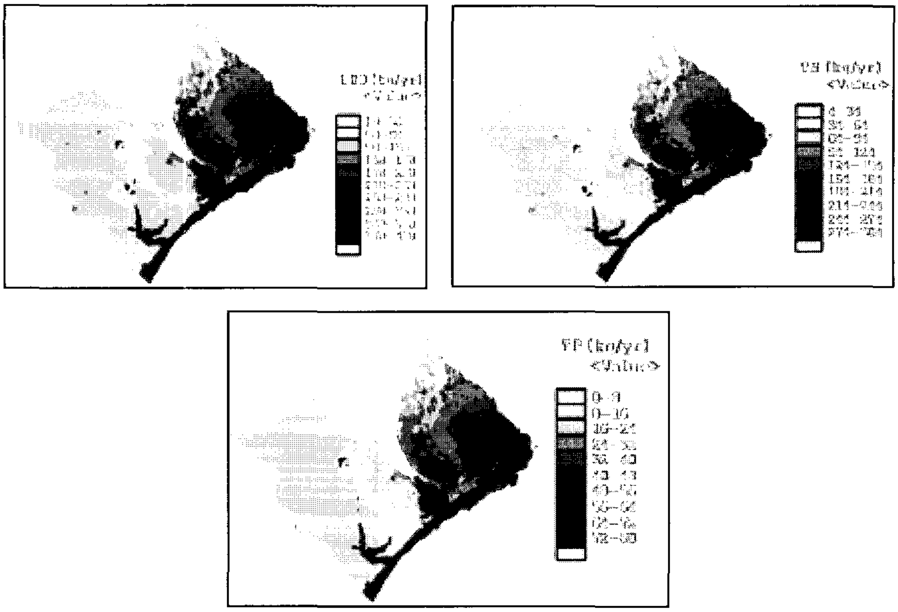

Figure 3. BOD, TN and TP loads as land surface load

For point and non-point source modeling, the watershed has to be defined properly to obtain the exact river network. Also Wastewater discharge facilities are located in near stream network. They are regarded as point source. The general methodology is delineation based on using Digital Elevation Models (DEM). DEM data are obtained from USGS. The principle of delineation is based on eight- pour point algorithm which identified the grid cell out of the eight surrounding cells by gravity force (Jenson, S.K. and Domingue, J.O., 1988). Figure 4 and 5 show that flow accumulation and flow direction through delineation is used to calculate a weighted flow accumulation of each pollutant using ArcInfo-ArcGIS and weighted pollutants are used for this research. Its principle is that pollutants are assigned to each cell by weighted flow accumulation, flow direction, and loading pollutant using ArcInfo. Figure 6 shows the location of wastewater discharge region. In this region, there are 5 facilities along river and lake.

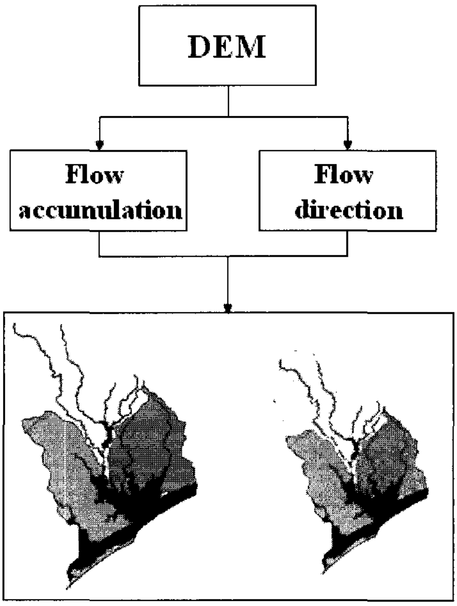

Figure 4. Watershed delineation

Average BOD/TN/TP effluent concentration is 90 ppm/65ppm/45ppm in 5 regions as point sources. Therefore, total constitute loading are obtained from Eq.(3).

$$[Loading]_{total} = [Effluent.from.facilities]_{point} + [Land.Surface.Load + River.Load]_{non-Point} \quad (3)$$

Figure 5 shows that the principle of flow direction-accumulation, weighted pollutants concentration and how to process accumulation mass amount of BOD, TN, and TP. BOD, TN and TP loading amounts are estimated by sum of non-point and point source values. Figure 7 shows accumulation mass amount of TN, TP, and BOD for 1 year.

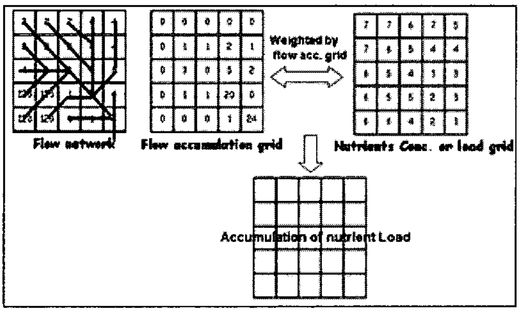

Figure 5. Methodology for accumulation of nutrient load

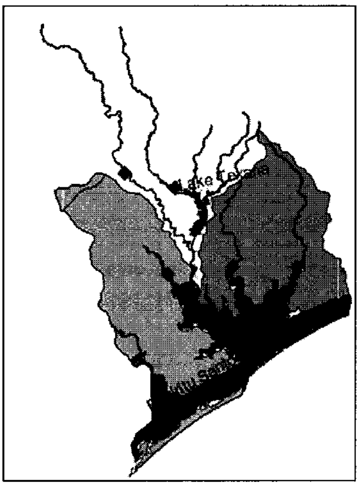

Figure 6. The location of wastewater discharged region as point source

3. RESULTS AND DISCUSSION

3.1 Runoff BOD, TP, and TN load

Surface runoff BOD/TN/TP load shows in Figure 3 and Table 2. In this region, especially, Colorado Lavaca Coastal and Lavaca Guadalupe Coastal basins are agricultural irrigation regions and larger range land region comparing to Lavaca River basin. As shown Table 2, each average BOD load is 280/140 kg/year in Colorado Lavaca Coastal basin(CLC-B) and Lavaca Guadalupe Coastal basin(LGC-B) comparing to Lavaca River basin (60kg/yr).

Table 2. Land surface load in 3 basins in South-West Texas

BOD load

Basin Name	Area(sq km)	Ave(kg/sq km/yr)
L-B	3600	60
CLC-B	1800	280
LGC-B	2800	140

TN load

Basin Name	Area(sq km)	Ave(kg/sq km/yr)
L-B	3600	50
CLC-B	1800	190
LGC-B	2800	90

TP load

Basin Name	Area(sq km)	Ave(kg/sq km/yr)
L-B	3600	38
CLC-B	1800	45
LGC-B	2800	20

* L-B: Lavaca River Basin, CLC-B: Colorado Lavaca Coastal Basin, LGC-B: Lavaca Guadalupe Coastal Basin

As shown Table 2 and Figure 3, in CLC-B and LGC-B, land surface load about TN, TP and BOD has higher BOD and TN because there are located in larger agricultural region.

Table 3 and Figure 7 show total mass accumulation of 3 nutrients (BOD, TN, and TP) based upon the principle of watershed delineation which is made by combination of water direction and weighted pollutants. Agricultural

Table 3. Accumulation of annual total nutrients load in the stream network

	BOD	TN	TP
Location	Ave(kg/yr)	Ave(kg/yr)	Ave(kg/yr)
A	14000	11000	1280
B	15000	13800	6000
C	17000	16000	5300
D	5200	3200	1000
E	6450	4000	2000
F	13500	10050	4800
G	4880	3100	990
H	12000	9650	3400
I	6800	3200	2300
J	10800	9800	2680
K	1250	550	272
L	2000	1500	840
M	3700	2200	680
N	2500	1800	720

region and downstream network including discharge from facilities have higher nutrient load. Many agricultural regions are located in LGC-B and CLC-B.

Most of all, Impact of downstream network is very important for this study, because total accumulation nutrients occurred flow into downstream and near estuary along with watershed. In the long run, in downstream, the Corpus Cristi bay can be contaminated. The important thing is that total nutrient load in downstream network and bay is much higher than other regions.

4. CONCLUSION

The nutrients loading in downstream network and terrain region depends on the types of land-use and location of discharge facilities. Especially, it is indicated that farmers in agricultural region consume a lot of fertilizer and

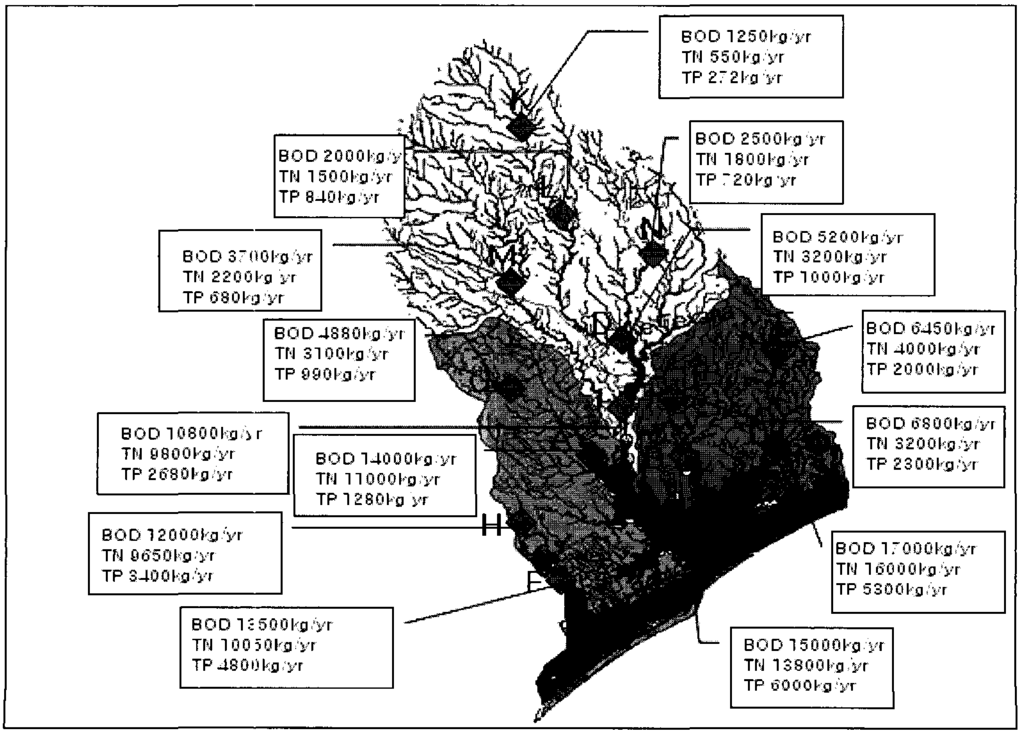

Figure 7. Accumulation of annual total nutrients load in stream network

pesticide to improve crop yield and urban wastewater discharge from facilities to river. Then, this river and watershed can be created as larger nonpoint source and point source. Spatial analysis of combined GIS containing habitat and contaminant information helps researchers compare the relative extent and distribution of contaminants in relation to habitats, enhancing the analysis of potential ecological exposures to hazardous substances. Further studies will focus on sediment contaminants selected for analysis in Corpus Christi bay.

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REFERENCES

Holland, A.F. (1990). Near Coastal Program Plan for 1990: Estuaries. EPA 600/4-90/033. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Narragansett, RI

Jenson, S.K. and Domingue, J.O. (1998). Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis. Photogrammetric Engineering and Remote Sensing. Vol. 54, No. 11. pp.1593-1600

National Research Council. (1990). Managing troubled waters: the role of marine environmental monitoring. National Academy Press. Washington, D.C.

Puckett, L.J. (1995), Identifying the Major Sources of Nutrient Water Pollution, Environmental Science & Technology, 29, 408A-414A.

Saunders, W.K. and D.R. Maidment (1995), Grid-Based Watershed and Stream Network Delineation for the San Antonio-Nueces Coastal Basin; Proceedings, Texas Water Resources Engineering, August 16-17, 1995, American Society of Civil Engineers, San Antonio, TX.

U.S. Environmental Protection Agency. (1988). Future risk: research strategies of the 1990s. U.S. Environmental Protection Agency, Science Advisory Board, Washington, D.C. SAB-EC-88-040.

U.S. Department of Agriculture. (1972). Soil Conservation Service

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