NON-POINT SOURCE POLLUTANT MODELING IN USING GIS ASSESSMENT IN STREAM NETWORK AND THE IRRIGATION REGION

Ju Young Lee[1] and Arvind Kutty[2]

[1,2] School of Environmental and Water Resource Engineering, Department of Civil Engineering, Texas A & M University, College Station, TX 77840

Abstract: Recently, the population growth, industrial and agricultural development are rapidly undergoing in the Lower Rio Grande Valley (LRGV) in Texas. The Lower Rio Grande Valley (LRGV) composed of the 4 counties and three of them are interesting for Non-point and point source pollutant modeling: Starr, Cameron, and Hidalgo. Especially, the LRGV is an intensively irrigation region, and Texas A&M University Agriculture Program and the New Mexico State University College of Agriculture applied irrigation district program (Guy Fipps and Craig Pope, 1998), projects in GIS and Hydrology based agricultural water management systems and assessment of prioritized protecting stream network, water quality and rehabilitation based on water saving potential in Rio Grande River. In the LRGV 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 determine the accumulation of non-point and point source and discuss the main impacts of agriculture and environmental concern with water quality related to pesticides, fertilizer, and nutrients within LRGV region. The GIS technique is widely used and developed for the assessment of non-point source pollution in LRGV region. 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 LRGV.

1. INTRODUCTION

Recently, the environmental sustainability of agricultural system has been studied about non-point and point source and its contribution make to environmental pollution and concerns in surface. The United States Environmental Protection Agency (USEPA) referred that non-point source cause for impairment of lake, river, and other water bodies (USEPA. 1994). In case of point source, effluent from wastewater treatment plants (WWTPs) make to contaminate instream and groundwater. In the hydrological aspect, when precipitation exceeds infiltration, surface water runoff on the soil surface affect not only soil quality and crop production but also groundwater and surface water quality. In the geoenvironmental aspect, the runoff of nutrient, pesticide, or fertilizer dissolved makes to contaminate on watershed and river. Especially, the impact of agriculture on environment is increasing, then, it affects on agricultural economic benefit.

Pesticide and nutrient that are washed out of an agricultural field or pollutants are distributed over large areas. The amount of pollutant leaving and area depends on the landuse and landcover. Actually, surface is composed of heterogeneous factors like landuse and landcover. Then, point and non-point source pollutant modeling can be nearly impossible without GIS tool that can account for the spatial differences in the Lower Rio Grande Valley (LRGV).

Moreover, USEPA (1992) reported that four times as many waters were found to be polluted by agricultural activities than by municipal point source discharges. Puckett (1995) reported that non-point source was the dominant source of nitrogen and phosphorus in majority of stream studied.

Recently, the population growth, industrial and agricultural development are rapidly undergoing in the Lower Rio Grande Valley (LRGV) in Texas. The Lower Rio Grande Valley (LRGV) 3 counties are interesting for Non-point and point source pollutant modeling: Starr, Cameron, and Hidalgo. Because 3 counties include in agricultural regions with irrigation restrict program. These region need to investigate about effect of nutrient effect for protecting agricultural products, groundwater and water quality and agricultural water management. ArcGIS and ArcInfo is useful tool for this analysis in the Rio Grande Valley Region. In the LRGV 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 seek to determine the accumulation of non-point and point source and discuss the main impacts of agriculture and environmental concern with water quality related to pesticides, fertilizer, and nutrients within LRGV region. The GIS technique is widely used and developed for the assessment of non-point and point source pollution in LRGV region. This project shows the losses in kg/ha/year of TN (total Nitrogen), TP (total phosphorus) and BOD (Biological Oxygen Demand) in the runoff from the surface of LRGV.

2. MATERIAL AND METHODS

2.1 Description of Study area

The Lower Rio Grande Valley of Texas is located in South Texas. It is comprised of 4 counties such as Starr, Hidalgo, Cameron, and Willacy and extends along the Rio Grande from Falcon Dam to the Gulf of Mexico. Especially, three counties as Hidalgo, Starr, and Cameron have the region's 740,000 irrigated acres. 98% of all the water used in the border region is from Rio Grande River. The region of cotton and sorghum occupied in the most acreage, and other crops as citrus and sugar cane occupied in the other region. However, recently, rapid urbanization makes to unbalance of water supply and water availability, especially, allocations to agricultural irrigation have been restricted to supply for municipal and industrial uses. Most of all, non-point and point source pollution analysis is necessarily required according to expand restrict irrigation region (Figure 1). The weather classification is belongs to sub-arid region. Annual rainfall is twenty six inches and the mean annual temperature is 72.35 F. The elevation ranges from sea level to more than 300 feet. The cities are located in along with Rio Grande River.

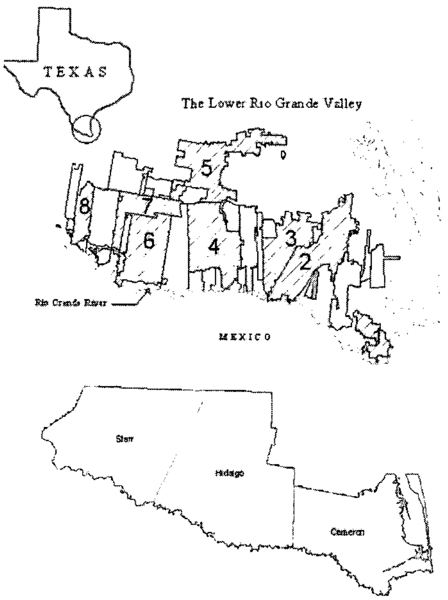

Figure 1. The 8 irrigation districts in the Lower Rio Grande Valley in using GIS based (Source: Implementation of a district management system in the Lower Rio Grande Valley of Texas, Guy Fipps and Craig Pope, 1998)

2.2 The non-point source pollutant model

Generation of Runoff Grid data from ArcGIS 8.2 and ArcView 3.2

In Lower Rio Grande Valley (LRGV), runoff cause by excess irrigation and precipitation. To calculate the average annual runoff for a landuse 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 30 years from 1971 to 2000(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. Moreover, the improved runoff volume is obtained by using TOPMODEL in GIS. This result is not mentioned in this paper.

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

Where:

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

S : potential infiltration (mm/yr)

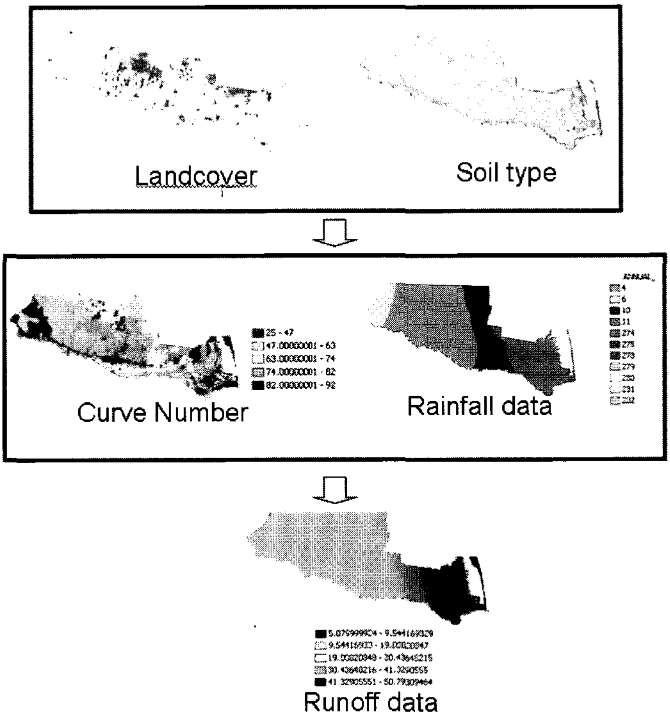

Figure 2. Methodology for Runoff volume (mm/year)

Generation of nutrient loads (kg/year) grid data from EMC

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(1,000,000m^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 . Figure 3 shows loading of non-point source about BOD, TN and TP.

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

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

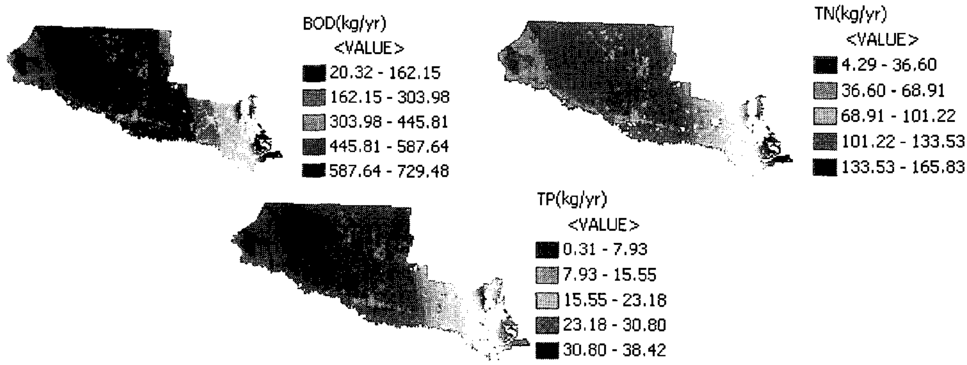

Figure 3. BOD, TN and TP loads

Watershed Delineation and Loading nutrients using ArcInfo-ArcGIS

For Non-point modeling, the watershed has to be defined properly to obtain the exact river network. 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 shows 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 5 shows accumulation mass amount of TN, TP, and BOD for 1 year. Figure 7 shows that the principle of flow direction-accumulation, weighted pollutants concentration and spatial statistics is applied to calculate mean, standard deviation, maximum and minimum grid value of accumulation nutrients load.

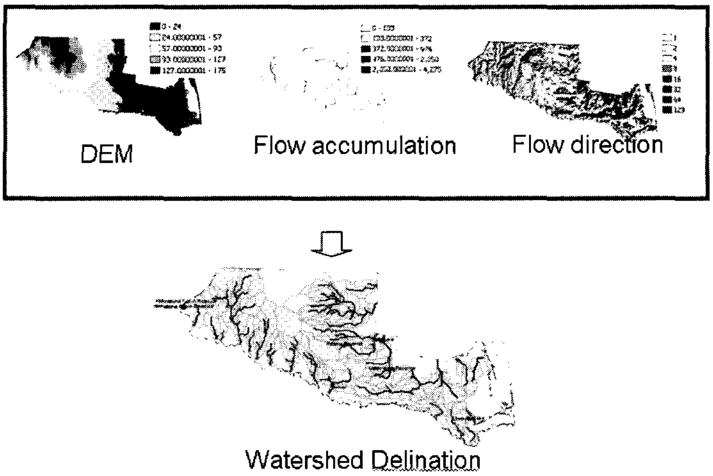

Figure 4. Watershed Delineation

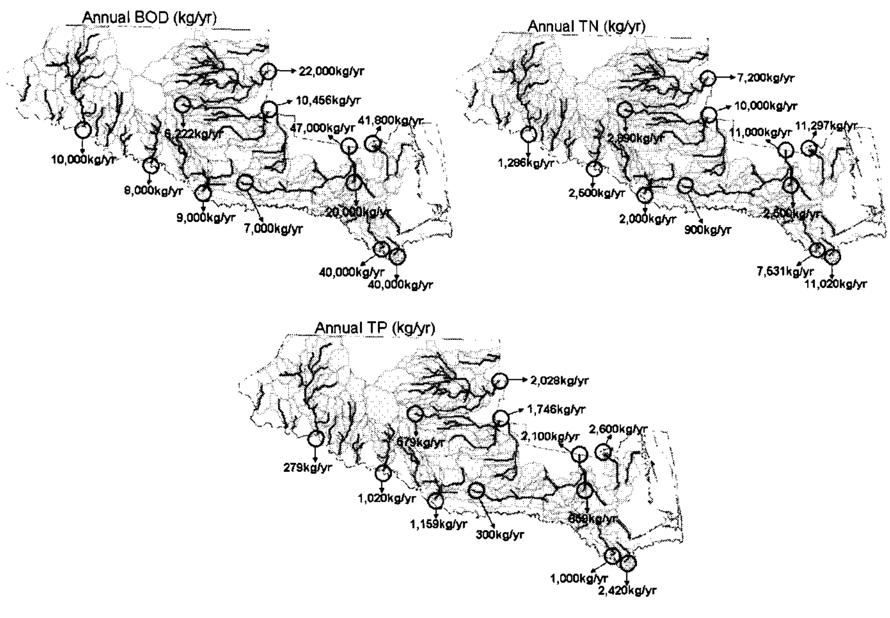

Figure 5. Accumulation of annual nutrients Load in stream network and irrigation region

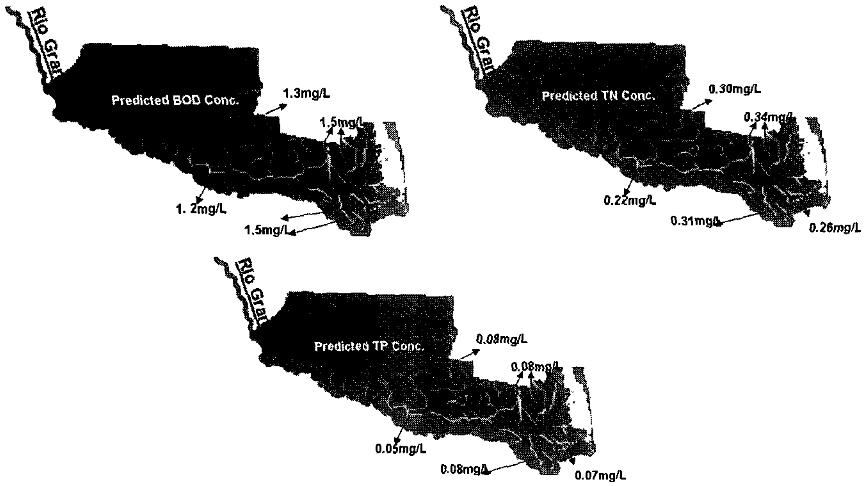

Figure 6. Predicted nutrients concentration in stream network

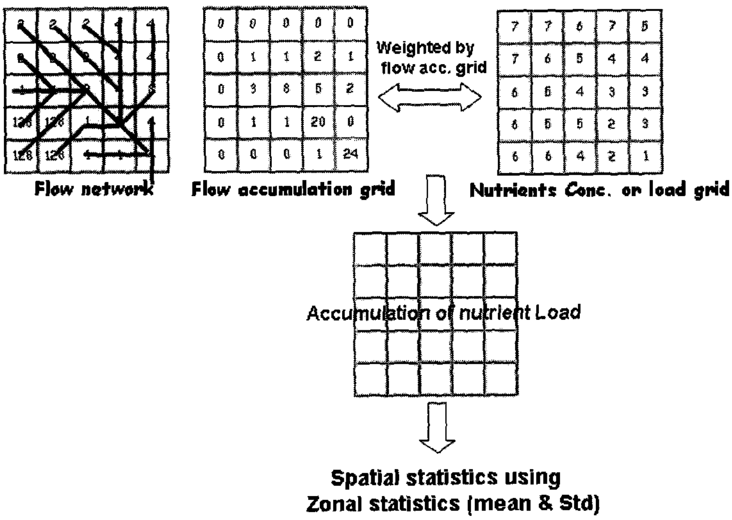

Figure 7. Methodology for accumulation of nutrient load and statistic parameters

Transportation and degradation of Downstream nutrient concentration using ArcInfo- ArcGIS

Transport and decay of nutrients are calculated mathematically according to following equation for this research.

$$C(mg/L) = \frac{L(kg/yr)}{R(m^3/yr)} \times 10^6 mg/kg \times 0.001 m^3/L \quad (3)$$

Where:

C : the average concentration at location(mg/L)

L : the annual cumulative loading(kg/yr)

R : the annual cumulative runoff(m^3/yr)

$$TN_{transport} = N_R \times e^{-k_{TN,runoff} \times d_{river}}$$
$$TP_{transport} = P_R \times e^{-k_{TP,runoff} \times d_{river}} \quad (4)$$
$$BOD_{transport} = BOD \times e^{-k_{BOD,runoff} \times d_{river}}$$

Where: $TN_{transport}$ is total Nitrogen transported into the river (kg TN/ km^2). TP and BOD have the corresponding. N_R is total N in runoff in a given subcatchment (kg TN/ km^2). TP and BOD are the same. $k_{N,runoff}$ is first order N-decay rate in the runoff (km^{-1}). d_{river} is travel distance from subcatchment location to river (km). The predicting nutrients concentration is showed in figure 6. $k_{BOD,runoff}$ = 0.26 day^{-1}, $k_{TN,runoff}$ =0.16 day^{-1}, $k_{TP,runoff}$ =0.09 day^{-1}

3. RESULTS AND DISCUSSION

3.1 Runoff BOD, TP, and TN load

Run-off BOD load shows in Figure 3 and Table 2. In LRGV region, especially, Cameron County has irrigation restrict program and larger husbandry region comparing to other two counties; Starr and Hidalgo counties. As shown Table 2, average BOD load is 220.3 kg/year in Cameron County comparing to Starr County (41. 64kg/yr) and Hidalgo County (36.61kg/yr).

As shown table 2 and figure 3, in Starr and Hidalgo counties, runoff Load about TN, TP and BOD is the similar. Meanwhile, in Cameron County with having larger agricultural region, it has higher TP, TN and BOD load. Impact of Pollutant Flow/Accumulation in the Downstream Network and irrigation region.

Table 3, 4 and Figure 5 show 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. Irrigation region and stream network have higher nutrient load. For irrigation region, many irrigation regions are located in Cameron and also, its nutrient load has higher as 1057 BOD kg/year, 303.6 TN kg/year, and 65.6 TP kg/year relative to other.

Table 2. Nutrients Runoff Load in 3 counties in Lower Rio Grande Valley

BOD Load

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average	Min
Hidalgo	3952	2397	170.38	36.61	20.34
Cameron	2066	8806	729.48	220.3	29.13
Starr	3110	1982	106.99	41.64	20.32

TN Load

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average	Min
Hidalgo	3952	2397	38.7	11.16	4.29
Cameron	2066	8806	165.83	62.86	9.83
Starr	3110	1982	24.3	11.35	4.62

TP Load

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average	Min
Hidalgo	3952	2397	8.97	2.25	1.16
Cameron	2066	8806	36.4	12.8	8.61
Starr	3110	1982	5.6	1.78	1.12

Table 3. Accumulation of annual nutrients runoff load in irrigation region

Accumulation BOD Load in irrigation region

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average	Std
Hidalgo	3952	2397	18673	422	1332
Cameron	2066	8806	31473	1057	3052
Starr	3110	1982	17547	283	971

Accumulation TN Load in irrigation region

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average	Std
Hidalgo	3952	2397	5754	128.6	410.9
Cameron	2066	8806	7967	303.6	863.2
Starr	3110	1982	4400	76.19	252.5

Accumulation TP Load in irrigation region

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average	Std
Hidalgo	3952	2397	1219	26.82	88.59
Cameron	2066	8806	1781	65.6	183.3
Starr	3110	1982	591	10.65	35.05

Table 4. Accumulation of annual nutrients runoff load in downstream network

Accumulation BOD Load in downstream network

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average
Hidalgo	3952	2397	22000	6800
Cameron	2066	8806	47000	24000
Starr	3110	1982	19000	11000

Accumulation TN Load in downstream network

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average
Hidalgo	3952	2397	7600	4000
Cameron	2066	8806	11297	8800
Starr	3110	1982	8000	6800

Accumulation TP Load in downstream network

Counties	Area (km2)	Used Fertilizer (kg/km2/yr)	Max (kg/total County area/yr)	Average
Hidalgo	3952	2397	2028	1500
Cameron	2066	8806	2600	2200
Starr	3110	1982	1200	800

Most of all, Impact of downstream network is very important for this study, because runoff nutrients occurred flow into downstream along with watershed. In the long run, in downstream, Lower Rio Grande River can be contaminated. As shown table 4, of course, in case of Cameron county, it has higher nutrients concentration, most of all, the important thing is that nutrient load in downstream network is much higher than in irrigation region. In case of maximum nutrient load, it is happened to downstream.

4. CONCLUSION

The nutrients loading in downstream network and irrigation region depends on the amount of use of fertilizer and pesticide. In Table 2, 3 and 4, especially, farmers in Cameron County consume a lot of fertilizer and pesticide to improve crop yield net profit. Then, this region can be created as larger nonpoint source area for nutrients and the intensity of run-off by excess irrigation water. And many sediment and used irrigation water with including high nutrients can be discharged into Rio Grade River.

ACKNOWLEDGMENT

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School of Environmental and Water Resource Engineering, Department of Civil Engineering, Texas A & M University, College Station, TX 77840

(E-mail: wayincrezki@hanmail.net)

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