A GIS Nonpoint Source Pollution Model for the Las Vegas Valley

Marcelo Reginato* and Thomas Piechota*

*Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, 4505 Maryland Parkway, Box 454015, Las Vegas, NV 89154-4015, P: 702-895-4412; F: 702-895-3936; email: piechota@unlv.edu

Introduction

The Las Vegas Valley is located in Southern Nevada where the average rainfall rarely exceeds five inches per year. The majority of rainfall is concentrated in the winter and summer periods, thus characterizing the region as semi-arid. The Las Vegas Valley watershed is divided into nine sub watersheds that form a 3968 km^2 (1532 mi^2) watershed. The entire watershed drains first to the Las Vegas Wash and then to Lake Mead — the main source of drinking water for the Southern Nevada. Approximately 85% of the watershed is undeveloped natural desert; however, the sub watersheds Gowan (GOW), Lower Wash (LOW) and Central (CEN) (See Figure 1) are highly developed.

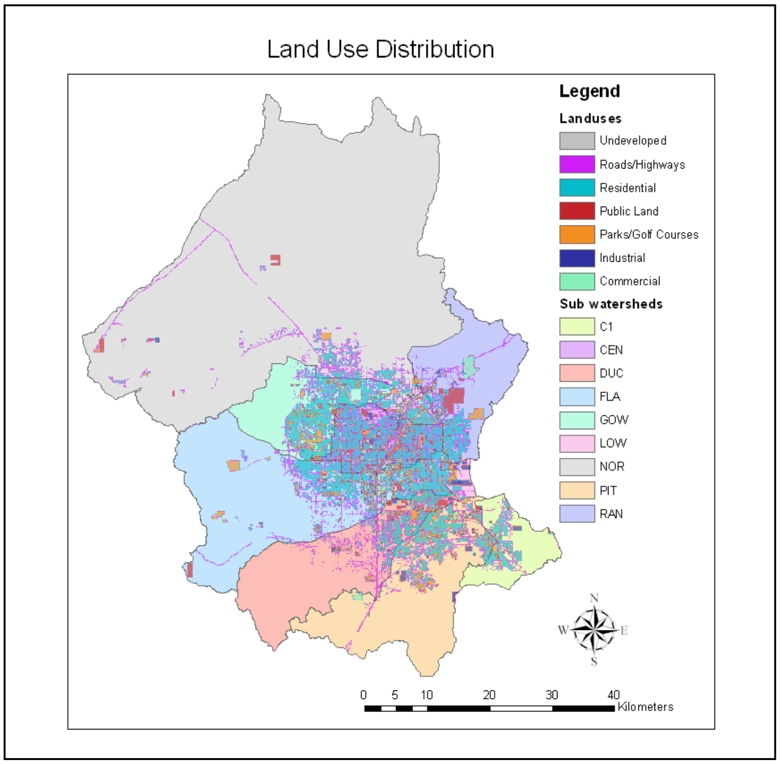

Figure 1:Land use distribution and sub watersheds of the Las Vegas Valley basin.

The nonpoint source pollution from urban runoff has direct water quality impacts on Lake Mead (the receiving water body). Excessive nutrients from nonpoint sources have been identified as one of the possible causes of excessive algae growth in the Spring of 2001. In this study, a Geographic Information System (GIS)-based model that uses the Simple Model (Schueler, 1987) is used to better understand how nonpoint sources contribute to total pollutant loads in the lake. The loads from the model are compared to waste water treatment loads for 2000 and 2001.

The Model

Total monthly and annual loads of nutrients [Total Nitrogen (TN) and Total Phosphorous (TP)] were estimated with the GIS model. The use of complex models versus models that have relatively few parameters is an area of extensive research. Chandler (1994) made a comparison between a simple model and a complex model, and concluded that there is a little quantitative reason for using more detailed models for estimating nonpoint source loads. Simple models are also justified when loads are estimated for longer time scales (e.g., monthly, annual). For this study, a simple model was selected since monthly loads are estimated, and due to the amount of data available for the watershed.

There are two steps in the Simple Method. First, runoff coefficients are estimated with the following equation based on land use percent imperviousness (Schueler, 1987):

$$R_{v,i} = 0.05 + 0.009(I_i) \qquad (1)$$

Where $R_{v,i}$ is the runoff coefficient, or the fraction of rainfall that is converted into runoff volume, and I_i is the percent of area that is impervious.

The second step is the load estimation based on the following:

$$L_i = \left(\frac{P \times P_j \times R_{v,i}}{12}\right) \times C_i \times A_i \times 2.72 \qquad (2)$$

$$L = \sum_{i=1}^{n} L_i \qquad (3)$$

Where L_i is the pollutant load in pounds for land use i, P is the grid precipitation depth in inches, P_j is the storm correction factor, $R_{v,i}$ is the runoff coefficient from (1) for land use i, C_i is the pollutant concentration in mg/l for land use i, A_i is the area in acres of the grid cell with a land use i, and 12 and 2.72 are unit conversion factors. There are 4,409,751 grid cells (30 meter x 30 meter) in the watershed and GIS was used to apply equation (2) to each cell (900 m^2) in the watershed. The sources of input data for each variable are described below.

Precipitation

Rainfall data was acquired online at the Clark County Regional Flood Control District web site (http://www.ccrfcd.org/) as part of the Flood Recognition Threat System. Monthly rainfall data from 121 stations was retrieved for the years of 2000 and 2001. The spatial distribution of rainfall was then accomplished by using an interpolation method. The nine closest stations were used in the Inverse Distance Weighted (IDW) method to determine monthly rainfall amounts for each grid cell. Average annual rainfall for the lower elevations of the Las Vegas Valley are approximately four to five inches per year. The annual rainfall for 2000 and 2001, and the rainfall station locations are presented in Figure 2. Rainfall distribution is the only variable that changes in the model for each month. Pollutant concentrations and runoff coefficients remain constant for all months.

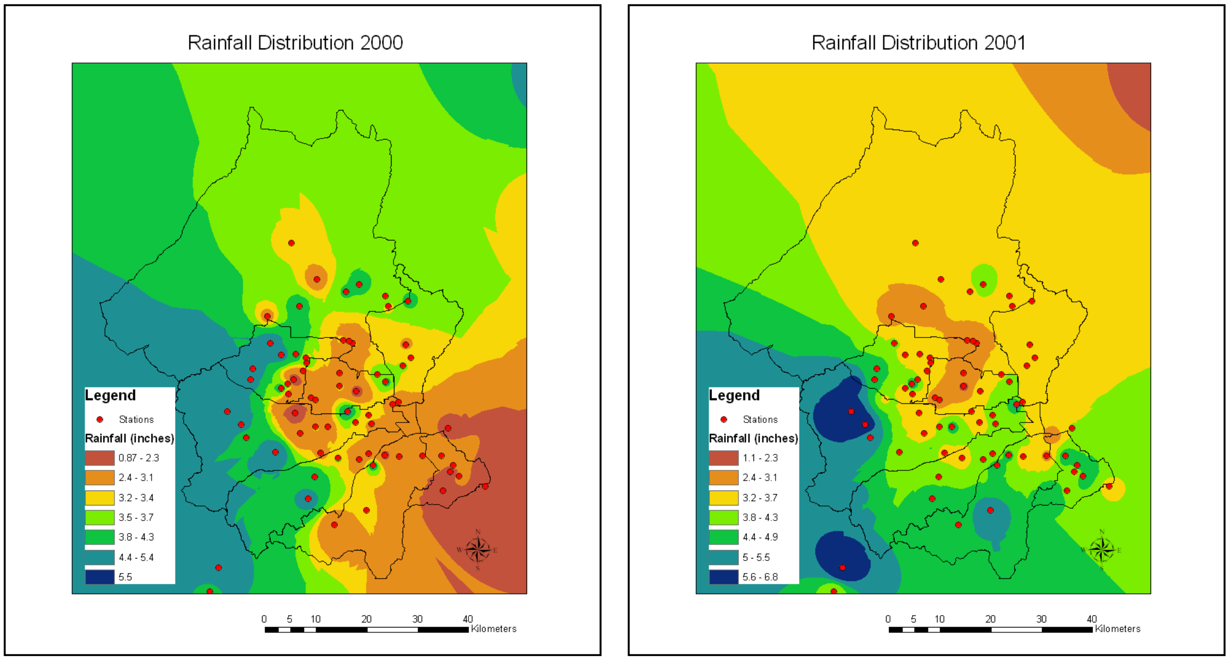

Figure 2: **Annual rainfall for 2000 and 2001 in the Las Vegas Valley watershed. Interpolation is accomplished using the Inverse Distance Weighted (IDW) procedure.**

Land Use Data

Land use data was compiled from assessors parcel data with land use information acquired in 2001. Assessors office land use codes are very detailed (approximately 30 different land uses). This level of detail is not necessary for nonpoint source modeling; therefore, a more general land use code was generated by grouping the land uses into the following classes:

Figure 3: **30 meter resolution of raster data (left) compared with the vector data (right) land use parcels.**

- Undeveloped
- Roads and Highways
- Commercial
- Industrial
- Residential
- Park/ Golf Courses
- Public Land

The vector file was converted to a 30-meter resolution raster file. Figure 3 show a small area of Las Vegas where land use parcels (right side) are compared with the 30-meter raster file (left side). A 30-meter resolution was reasonable to work considering the computer processing time. In this model, runoff coefficients and pollutant concentrations are associated with land uses, thus an updated and detailed land use data is desirable. Las Vegas is known as the nation's fastest growing metropolitan region (Gottdiener et. al, 1999), thus having 2001 land use data improves the estimates made from the model.

Runoff Coefficient and Storm Correction Factor

After obtaining the total rainfall amounts, the next step is to define the percentage of rainfall that is converted into runoff. This is defined by the runoff coefficient, which depends on the imperviousness of the land use and the storm correction factor.

There is a lot of uncertainty in the selection of a storm correction factor. For the Las Vegas Valley there is no previous study that states one value for this coefficient, so the value commonly used by others (0.9) was applied in this study; this means 90% of the storms in a given time period generate runoff.

The runoff coefficients were obtained from the 2000-2001 Annual Report for Las Vegas Valley NPDES Municipal Stormwater Discharge Permit prepared by Montgomery Watson Harza (2001). The base runoff coefficients calculated in (1) are not always applicable, especially when observed rainfall and runoff data is available. The NPDES study used observed rainfall and runoff data in Las Vegas Wash to calibrate the runoff coefficients. Table 1 shows the base and the calibrated runoff coefficients as a function of land use type.

Table 1: Base and calibrated runoff coefficients

Land Use	Base R_v	Calibrated R_v
Roads/Highways	0.860	0.206
Commercial	0.815	0.195
Industrial	0.698	0.167
Public Land	0.545	0.131
Residential	0.392	0.094
Park/Golf Courses	0.095	0.023
Undeveloped/Desert	0.050	0.012

Pollutant Concentrations

Historical water quality data from other regions of the southwest U.S. were used as a starting value of pollutant concentrations for each land use in Las Vegas. Linear programming was then used to calibrate pollutant concentrations for each land use based on observed water quality data in the NPDES report. Data was available for five out of nine watersheds. The linear program then minimizes the difference between the calibrated concentrations and the observed data for the five sub watersheds. Table 2 presents the comparison of the calibrated concentrations for each land use and the concentrations from historical water quality data in other Southwest U.S. regions. The pollutants concentrations compared are, Total Nitrogen (TN) and Total Phosphorous (TP)

Table 2: Nutrient concentrations comparison between historic water quality data and Las Vegas Valley calibrated concentrations.

Land use Type	Calibrated TN (mg/l)	Historic Southwest U.S. TN (mg/l)	Calibrated TP (mg/l)	Historic Southwest U.S. TP (mg/l)
Commercial	7.5	4.99	0.84	0.49
Highways/Roads	8.1	5.40	1.25	0.60
Industrial	2.3	4.59	1.15	0.77
Park/Golf Courses	1.5	3.07	0.36	0.09
Public Land	2.1	4.21	2.40	0.60
Residential	6.4	4.27	1.13	0.46
Undeveloped	7.4	1.46	1.59	0.09

Results

The model was run for each month of 2000 and 2001 and then the total annual loads were summarized in Table 3. There was a slight significant increase in the total annual loads from 2000 to 2001 mainly due to an increase in annual precipitation. The increase in precipitation and resulting 14% increase in nutrient loads may be one of the factors in excessive algal growth in Lake Mead during spring 2001. The Total Phosphorous loading from three wastewater treatment plants that discharge into Lake Mead was approximately 142 tons in 2000. Thus, nonpoint sources contributed to about 10% of the Total Phosphorous loading.

Table 3: Total loads results for nutrients in 2000 and 2001

Pollutant/Year	Annual Load (tons)
Total Nitrogen/ 2000	67.73
Total Nitrogen/ 2001	77.31
Total Phosphorous/ 2000	13.20
Total Phosphorous/ 2001	15.00

A closer evaluation of the nutrient loads on an annual basis is presented in Figure 4. During both years, the nutrient loads in the winter are high; however, the high nutrient loads in the summer of 2000 were followed by high winter 2001 loads. This observation is also significant in identifying possible factors of the spring 2001 algae bloom in Lake Mead.

The contributions from the individual watersheds were closely evaluated. Figure 6 presents the loads per unit area for each of the sub watersheds. The urban sub watersheds of Gowan, Lower Wash and Central (See Figure 1), have the highest loading values per unit area and are the most critical for controlling the total loads from the watershed. This is expected from urban watersheds where a high concentration of pollutants is present due to high runoff and pollutant wash off that originate from highly impervious areas. This type of analysis may assist in the identification of areas where Best Management Practices (BMP's) would be most beneficial.

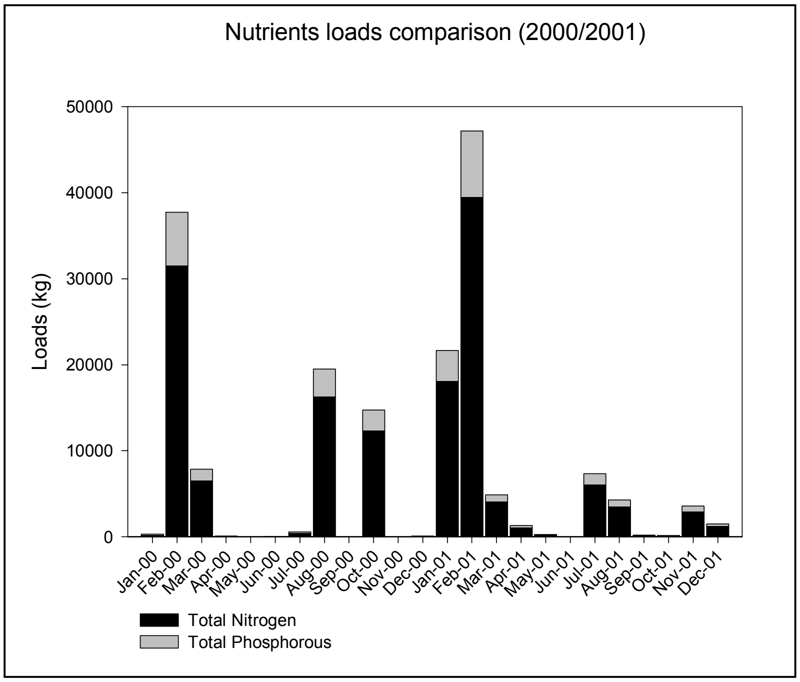

Figure 4: **Total Nutrient bar chart from January 2000 to December 2001**

GIS was used to divide the annual nutrient loads into the different land uses categories. Figure 6 presents a summary of the contributions from each land use for 2000 and 2001. The total annual rainfall for 2000 and 2001 was similar for much of the watershed; however, small variations in the spatial distribution of precipitation (see Figure 2) can change the proportioning of runoff from the different land uses. For example, the percent TN load from roads/highways increased from 32% in 2000 to 46% in 2001 (Figure 5a and 5b). The percent TN from undeveloped areas for the same time periods decreased from 37% to 10% (Figure 5a and 5b). This suggests that more precipitation occurred in developed areas in 2001, even though the watershed average was similar for 2000 and 2001.

Conclusions

There are several noteworthy observations from this study:

- Total nonpoint source nutrient loads are approximately 10% of the total nutrient loads to Lake Mead.
- Urban nonpoint source runoff may have been a contributing factor to the algae bloom in the spring of 2001 in Lake Mead. This is based on high nutrient loads in the summer of 2000 and the winter of 2001.
- Uncertainties in the GIS model include: (1) estimation of the loading factors for each land use; (2) exclusion of detention basin facilities; (3) estimation of the runoff coefficient; and (4) absence of precipitation data for high elevations in the watershed.

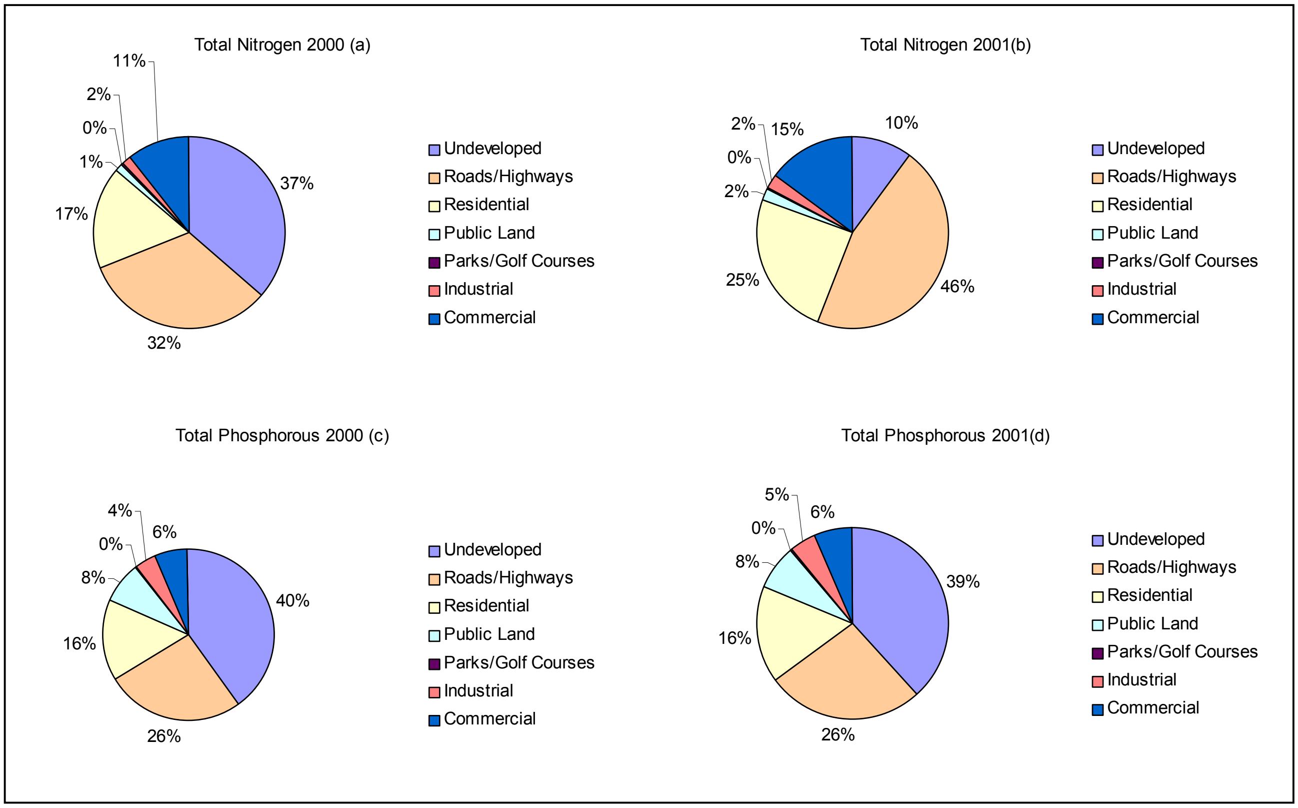

Figure 5: Pie charts showing percentage of total nutrient loads associated to land uses

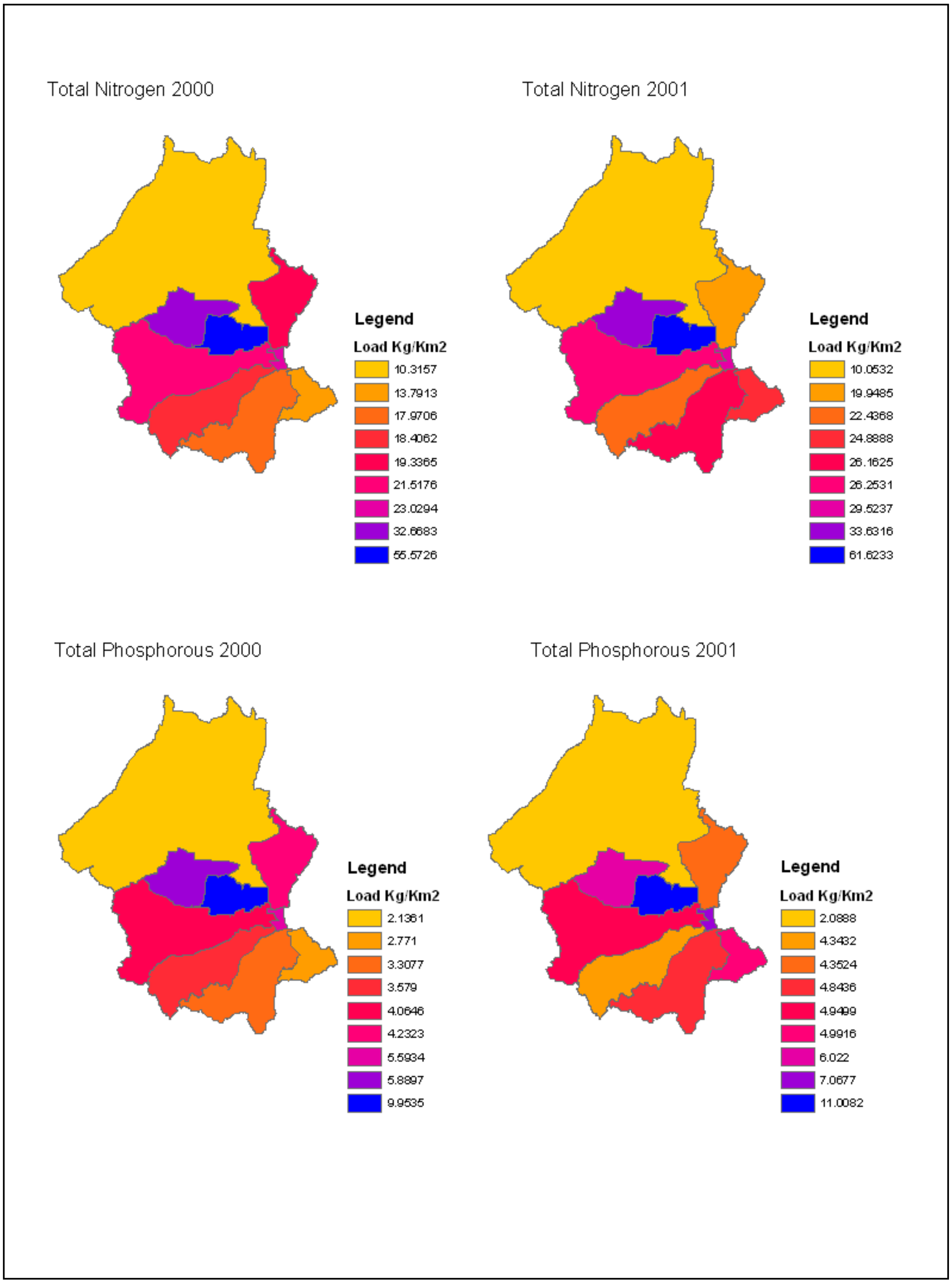

Figure 6: Load per area for Total Nitrogen, Total Phosphorous during years 2000 and 2001.

Acknowledgement

This work is supported under research contracts with the Nevada Division of Environmental Protection, State of Nevada Bureau of Health Protection Services, and the University of Nevada, Las Vegas.

References

Chandler, R. D. (1996) Estimating Annual Urban Nonpoint Pollutant Loads. Journal of Management in Engineering v10, 6, Nov-Dec 50-59.

Gottdiener, M., Collins, C. C., and Dickens D. R. (1999). Las Vegas The Social Production of an All-American City. Las Vegas: Blackwell

Montgomery Watson Harza. (2001). Las Vegas Valley NPDES Municipal Stormwater Discharge Permit NPDES Permit.No.NV0021911. Las Vegas, NV

Schueler, T.R. (1987). Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMP's. Publ.No.87703. Metropolitan Washington Council of Governments, Washington, DC.