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NUTRIENT CONTRIBUTION OF NONPOINT SOURCE RUNOFF IN THE LAS VEGAS VALLEY[1]

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ABSTRACT: A Geographic Information System (GIS) based nonpoint source runoff model is developed for the Las Vegas Valley, Nevada, to estimate the nutrient loads during the years 2000 and 2001. The estimated nonpoint source loads are compared with current wastewater treatment facilities loads to determine the nonpoint source contribution of total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS) on a monthly and annual time scale. An innovative calibration procedure is used to estimate the pollutant concentrations for different land uses based on available water quality data at the outlet. Results indicate that the pollutant concentrations are higher for the Las Vegas Valley than previous published values for semi-arid and arid regions. The total TP and TN loads from nonpoint sources are approximately 15 percent and 4 percent, respectively, of the total load to the receiving water body, Lake Mead. The TP loads during wet periods approach the permitted loads from the wastewater treatment plants that discharge into Las Vegas Wash. In addition, the GIS model is used to track pollutant loads in the stream channels for one of the subwatersheds. This is useful for planning the location of Best Management Practices to control nonpoint pollutant loads.
(KEY TERMS: nonpoint source pollution; Geographic Information Systems; modeling; storm water management; watershed management; surface water hydrology.)

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INTRODUCTION

The role of nonpoint source pollution from urban runoff has been identified as a major component in total loading to receiving water bodies. In the United States, 42 percent of the states have indicated that the pollutants from nonpoint sources are greater in magnitude than point sources, such as sewage and industrial discharges (Wanielista and Yousef, 1992). In Las Vegas Valley, located in southern Nevada, nonpoint source runoff is primarily from return ground water flow, excessive watering of irrigation areas, household uses, and storm water. The rapid urban growth in Las Vegas Valley during the past four decades has greatly increased the size of urban areas and basin imperviousness. The most common water resource problems due to land use change are increases in runoff and pollutant loads. For Las Vegas Valley, there is a particular concern about nonpoint source nutrient loads since the entire watershed drains to Lake Mead, the regions' drinking water supply. Furthermore, Lake Mead periodically experiences algal blooms due to excessive nutrient loads. The Algae Task Force, Nevada Division of Environmental Protection, listed nonpoint sources as a possible cause of the algal problem.

Currently, communities in the U.S. are required to monitor nonpoint source runoff as part of the National Pollutant Discharge Elimination System (NPDES). In Phase I of the NPDES storm water program, the focus was on storm water systems serving populations greater than 100,000 people. In response, monitoring programs have been set up in communities to assess the quality of urban runoff. The monitoring stations are located in channels or washes that drain large areas. For instance, the communities in Las Vegas Valley are covered under one NPDES permit issued to Clark County Regional Flood Control District (CCRFCD) as the lead agency. Under this permit, monitoring takes place at six outfalls to Las Vegas

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Wash (MWH, 2001). These monitoring locations are adequate for providing the average pollutant loads from these large watersheds and assessing the impacts to receiving water bodies. However, the specific source of the pollutants in urban runoff is still unknown and can only be identified by focusing on small watersheds.

Modeling of nonpoint source runoff is necessary to better understand the contributing factors in the watershed. Several nonpoint source runoff models are available and the complexity of the models depends on factors such as data availability, knowledge of model parameters, and desirable level of spatial and temporal detail. After selecting a model and obtaining results, it is critical to assess the uncertainties and the limitations of the model.

Nonpoint source runoff models can be "simple" or "complex." Differences between simple and complex models can be expressed by the amount of input data and other model details, such as calibration. Simple models include the Continuous Annual Load Simulation model (CALSIM) (Pandit *et al.,* 2002) and PLOAD, which is included in the U.S. Environmental Protection Agency (USEPA) Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) software (USEPA, 2001). Simple models are usually sufficient for modeling monthly to annual loads from nonpoint sources.

Complex models include the well known USEPA Stormwater Management Model (SWMM), and Hydrologic Simulation Program – Fortran (HSPF) and Soil Water Assessment Tool (SWAT), which are integrated into BASINS. Chandler (1996) investigated the results of simple and complex nonpoint source models using four case studies and 124 comparisons. It was concluded that quantitative differences are not relevant for annual pollutant loads; the differences between the simple and complex model results are in the same order of magnitude, and uncertainties regarding pollutant concentrations are high. These concentrations can vary by more than one order of magnitude for storm events in a given region.

Several studies note the importance of GIS for modeling nonpoint sources (e.g., Lee and Terstriep, 1991; Ventura and Kin, 1993; Hromadka and Yen, 1996; Tsihrintzis *et al.,* 1997). A Geographic Information System (GIS) is useful for managing high amounts of data, combining layers, performing spatial analysis, and presenting quality maps. Ventura and Kim (1993) used GIS as a tool to create an empirical nonpoint source loading model. The pollutant loads were obtained based on precipitation data, soil type, existing Best Management Practices (BMPs), pollutant load coefficients, and area of each land use.

The study presented here uses a GIS based nonpoint source model to determine the contribution of nonpoint sources to total nutrient loads (TN, TP, and TSS) from the Las Vegas Valley. A simple model is used since monthly and annual loads are needed, and the watershed does not have adequate water quality data that would support the use of a complex model. In addition, the GIS model is able to track the accumulation of the pollutants in the watershed. Last, an innovative approach is used for calibrating the model parameters, runoff coefficient, and pollutant concentrations, based on limited historical data. It is important to note that the model developed here is specific to Las Vegas Valley, and for certain land use and climate conditions. Investigators should be cautious if the modeling approach is used for different regions and/or under different land use and climate scenarios.

WATERSHED DESCRIPTION

The Las Vegas Valley watershed is located in Clark County, Nevada, with an average valley floor elevation of approximately 600 meters, and mountain ranges from 2,000 to 3,300 meters. The watershed is approximately 3,940 square kilometers and first drains to Las Vegas Wash, and then to Lake Mead. There are nine major subwatersheds (Figure 1) as noted in the CCRFCD 1996 master plan update. Most of the storm drains and channels within the valley are either dry or have low flows; however, some streams that used to be ephemeral have become perennial. One of the primary sources for these perennial flows appears to be overirrigation of ornamental landscaping and turf (Mizell and French, 1995). In addition to overirrigation, the three wastewater treatment plants (WWTPs) have a major contribution to dry weather flows in Las Vegas Wash. The central portion of the watershed is highly developed; however, only 15 percent of the entire watershed is developed at this time.

DATA

The major datasets for the analysis include the precipitation and land use distribution for the watershed, and nonpoint source runoff water quantity and quality data within the watershed.

Precipitation

Precipitation data are available from the CCRFCD (2001). There are more than 120 precipitation

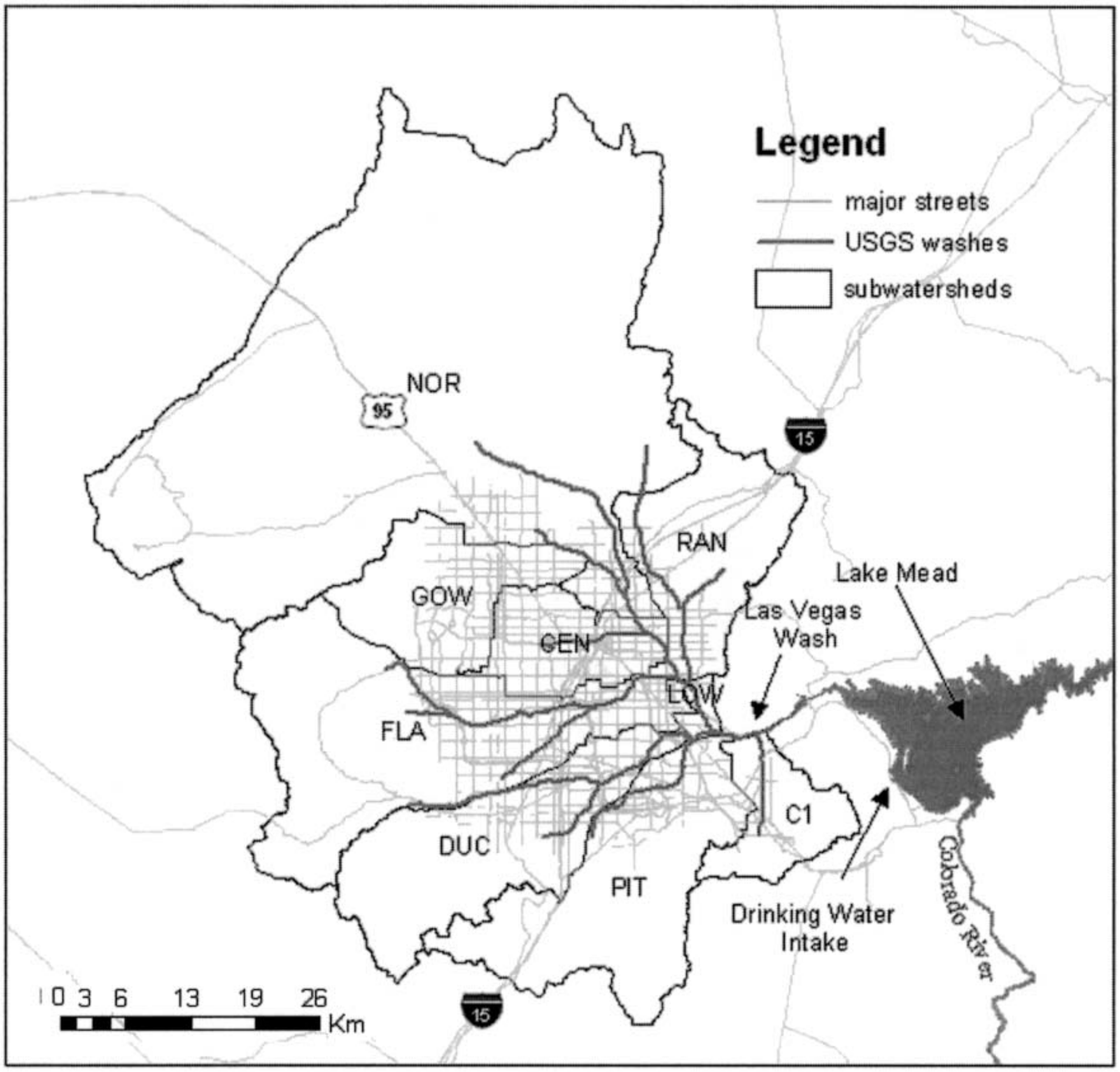

Figure 1. An Overview of the Las Vegas Valley Watershed, Subwatershed Boundaries, and the Proximity to Lake Mead and the Drinking Water Intake Point. The subwatersheds are: C1 (C1 Channel), PIT (Pittman Wash), DUC (Duck Creek), FLA (Flamingo/Tropicana Wash), LOW (Lower Las Vegas Wash), CEN (Central Basin), GOW (Gowan Basin), RAN (Range Wash), and NOR (North Basin).

stations in this database for the watershed. The model calculates loads on monthly and annual time scales so annual and monthly average precipitation is calculated for each station. The precipitation point measurements (monthly and annual) are then interpolated with the inverse distance weighting (IDW) method (Smith, 1993) in a 30-meter by 30-meter grid cell resolution to be used in the watershed model. The results of interpolated watershed precipitation for the years 2000 and 2001 are shown in Figure 2. The interpolating routine used here does emphasize the values at individual stations, but this bias should not impact the overall results of this study, which is for a large watershed.

Land Use

The Las Vegas Valley land use data were previously compiled by Reginato and Piechota (2002) using the Clark County Assessor's Office land use table and parcel data from the Clark County GIS Management Office (GISMO) (Figure 3). The original land use vector data from GISMO was converted to a grid map with a 30-meter by 30-meter resolution. The conversion from vector to grid format comprises some of the resolution in the original land use data; however, the land use resolution should be sufficient for the study presented here (see Figure 4).

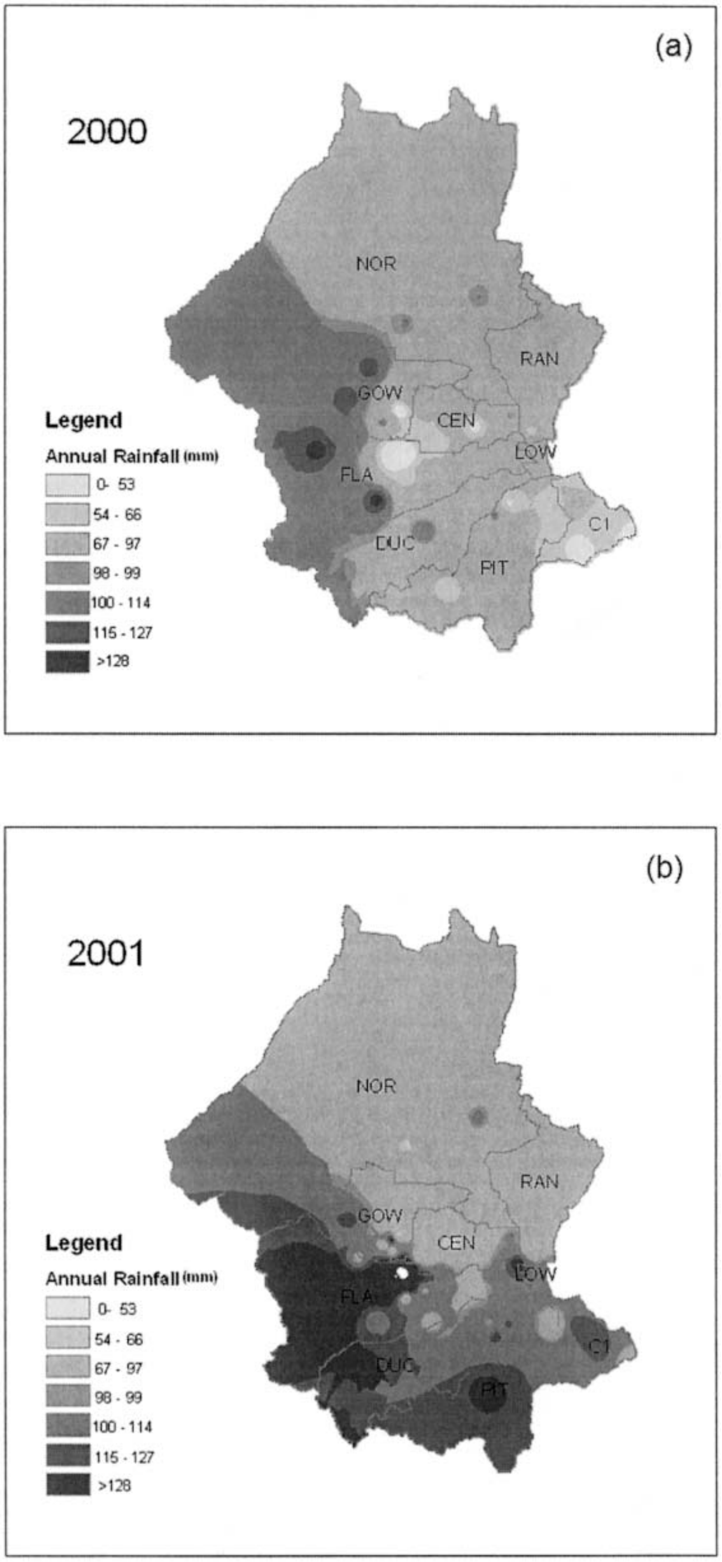

Figure 2. Inverse Distance Weighting (IDW) Interpolation of Las Vegas Valley Annual Precipitation (millimeters) for the Years (a) 2000 and (b) 2001.

Runoff Quantity

Runoff quantity of nonpoint source runoff is determined from U.S. Geological Survey (USGS) Stations 09419756 (Las Vegas Wash Overflow at Lake Las Vegas Inlet) and 09419790 (Las Vegas Wash below Lake Las Vegas) (Figure 5). The summation of these two stations represents the total flow (from the WWTPs and nonpoint sources) in Las Vegas Wash. T. Piechota, D. James, J. Batista, and P. Amy (2002, unpublished report to the Nevada Division of Environmental Protection) subtracted the base flow from this time series to estimate the nonpoint source runoff volume. The nonpoint source runoff volume is used with the watershed precipitation data to determine the runoff coefficients for the watershed (see Runoff Coefficient section).

Pollutant Concentrations

The modeling approach used here requires that pollutant concentrations be assigned for each land use in the watershed. This is accomplished by calibrating the model pollutant concentrations with historical nonpoint source water quality data collected as part of the NPDES program for Las Vegas Valley (MWH, 2001). Data have been collected from five wet weather stations within Las Vegas Valley since 1992 (Figure 5). The current location of the water quality stations does not allow sampling from each one of the nine subwatersheds within Las Vegas Valley (see NPDES stations in Figure 5). Table 1 shows all the available water quality sampling points and the respective subwatersheds that drain to the points. The wet weather data from the NPDES report (MWH, 2001) are comprised of storm date, the pollutant load for that storm, and the overall median and average for all events from 1992 to the present. Median concentrations of TN, TP, and TSS for each subwatershed were used for the calibration of nonpoint pollutant concentrations for the entire watershed (see Pollutant Concentration section).

The NPDES report also compares Las Vegas Valley pollutant concentrations with other regions. Arid and semi-arid locations seem to have a higher concentration of pollutants when compared with other nonarid locations (MWH, 2001). Caraco (2000) presents a table comparing pollutant concentrations from a national average with pollutant concentrations from arid and semi-arid regions. Table 2 presents data from Caraco

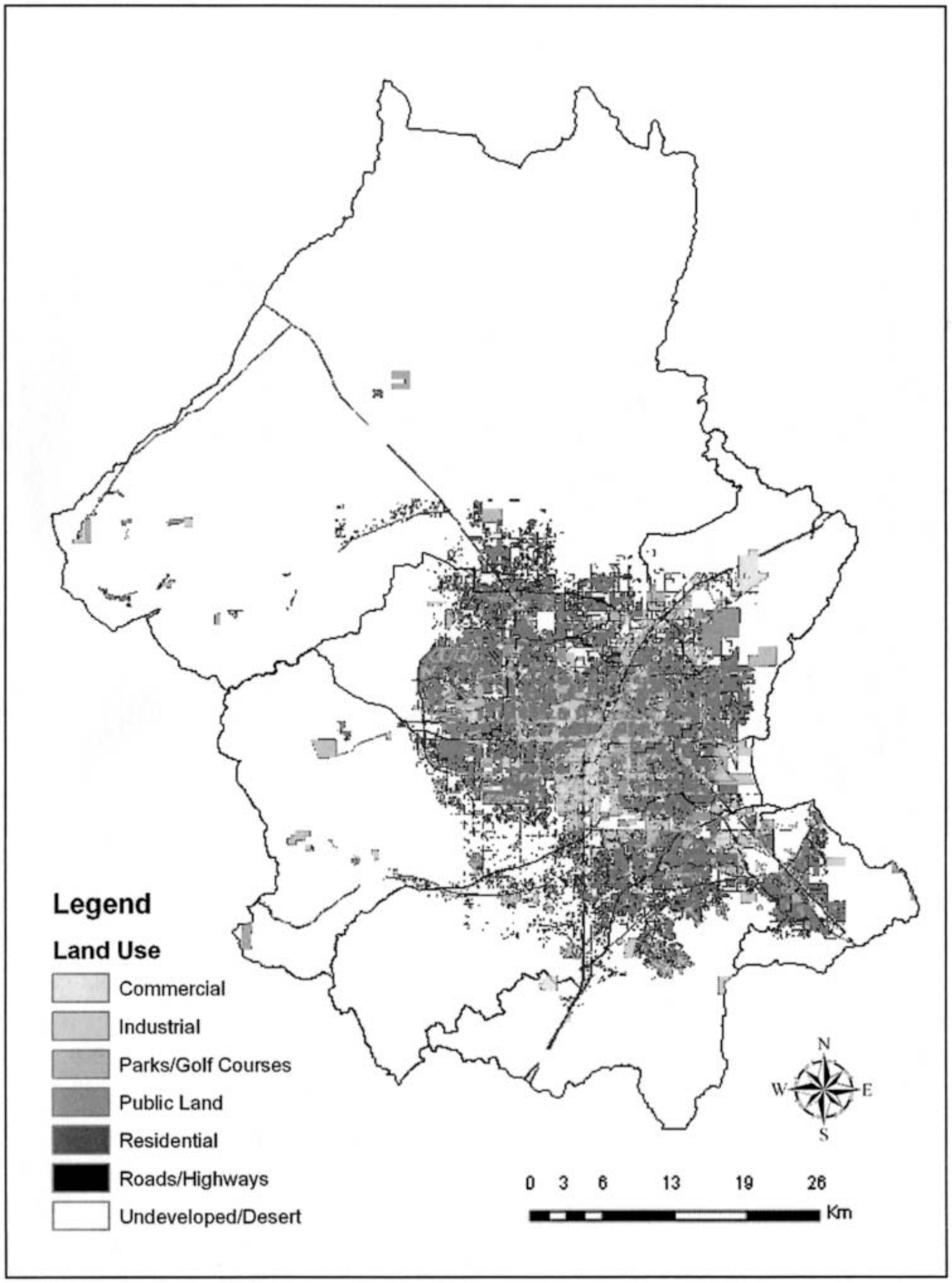

Figure 3. Overview of Land Use for the Las Vegas Valley (2001) Based on Unpublished Data From the Clark County Assessor's Office.

(2000) and those from the NPDES report for Las Vegas Valley. For all these pollutants, the concentrations are higher in Las Vegas Valley.

MODEL DESCRIPTION

The monthly and annual loads of TN, TP, and TSS are estimated with a GIS based model that uses the Simple Method (Schueler, 1987). The Simple Method is appropriate for estimating monthly/annual loads, and consists of two major steps to obtain pollutant loads. First, the runoff coefficients are estimated based on land use percent imperviousness

$$R_n = 0.05 + 0.009\,(I_n) \qquad (1)$$

where R_n is the runoff coefficient (the fraction of rainfall that is converted into runoff volume) for land use

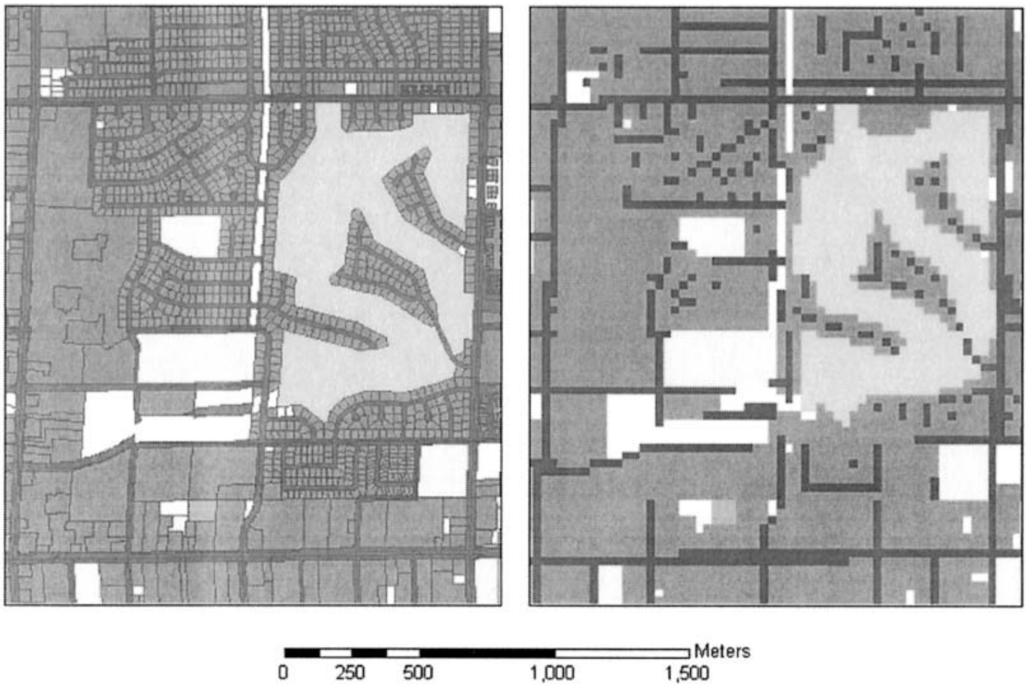

Figure 4. Vector Land Use Parcel Data (left) Compared With the Converted 30-Meter Resolution Raster Data (right).

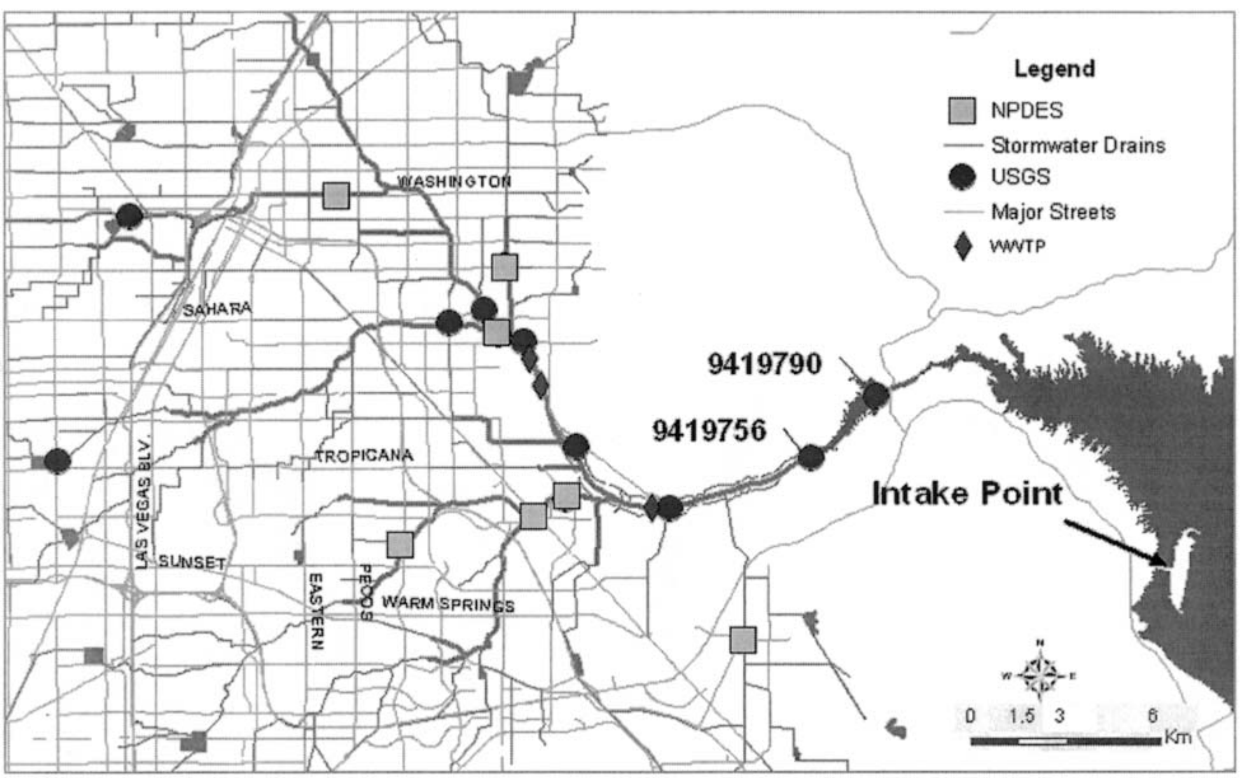

Figure 5. Wet Weather Sampling Locations as Part of NPDES Reporting for the Las Vegas Valley and USGS Gage Locations. Gages 9419756 and 9419790 are used to estimate the total flow in the Las Vegas Wash.

TABLE 1. Wet Weather Sampling Points and the Respective Watersheds.

Water Quality Sample Locations	Watersheds Contributing to the Sample Location
Las Vegas Creek (Washington Channel) at Lena Street	CEN
Range Wash (Sloan Channel) at Charleston Boulevard	RAN
Duck Creek at Boulder Highway	DUC and PIT
C1-Channel at Warm Springs Road	C-1
Las Vegas Wash Downstream of Desert Rose Golf Course	FLA, CEN, GOW and NOR

TABLE 2. Comparison Between National Average Pollutant Concentrations and Arid/Semi-Arid Pollutant Concentrations (based on Caraco, 2000; and MWH, 2001).

Pollutant	Clark County Nevada	National Average	Phoenix Arizona	Denver Colorado	Dallas Texas
	Concentration (mg/l)				
TSS	950	78	227	384	663
TN	6.9	2.4	3.3	4.8	2.7
TP	0.97	0.32	0.41	0.80	0.78

n, and I_n is the percent of area that is impervious for each land use n. The percentage of impervious area is obtained from the CCRFCD Hydrologic Criteria and Drainage Design Manual (CCRFCD, 1999) for different land uses. Business areas are 85 percent impervious, and roads are 90 percent impervious including the roadside shoulder, swales, and right-of-way. It is noteworthy that the runoff coefficient for the desert areas is very low (0.05). Studies (e.g., McCuen, 2001) have shown that desert areas may have higher runoff coefficients due to creation of impermeable desert pavements. The initial runoff coefficients are calculated and then calibrated based on flow data from the USGS stations. The runoff coefficient used in this study represents general partitioning of rainfall into runoff over longer time scales (e.g., monthly, annual) and is different than those used in traditional rainfall/runoff models that are event based.

The second step in the Simple Method is to estimate the pollutant load. The pollutant load for each grid cell (as well as the total load) is computed as

$$L_{n,g} = \left(\frac{P_g \times P_j \times R_n}{1000} \right) \times C_n \times A \times 10 \qquad (2)$$

$$L = \sum_{n=1}^{7} \sum_{g=1}^{4,409,751} L_{n,g} \qquad (3)$$

where n represents the land use category, g represents the grid cell number (4,409,751 in the watershed), $L_{n,g}$ is the pollutant load (kilograms) for the grid cell g and land use n, P_g is the precipitation depth (millimeters) for grid cell g for the time scale assumed (monthly and annual values), P_j is the storm correction factor, R_n is the runoff coefficient for land use n, C_n is the pollutant concentration (mg/l) for land use n, A is the area (hectares) of the respective grid cell, 1,000 and 10 are unit conversion factors, and L is the total load (kilograms) for the study area.

CALIBRATION

Runoff Coefficient

The base runoff coefficient calculated from Equation (1) is not always representative of the amount of rainfall converted into runoff. Observed rainfall and runoff data are available for Las Vegas Valley; therefore, it is possible to calibrate the runoff coefficient for each land use based on observed data for large areas.

The measured stormwater volume (V_m) is calculated from observed runoff data in Las Vegas Wash as noted previously. The sum of USGS Stations 09419756 and 09419790 represents flows from (1) WWTP flows, (2) storm water, and (3) dry weather nonpoint source flow. Storm water volume was calculated by subtracting the base flow (as determined with a 30-day moving average) from the total measured flow.

For comparison, the Schueler runoff coefficients found in the previous section are used to determine the calculated stormwater volume (V_c). The GIS tool, map calculator, is used to multiply the precipitation (annual and monthly) grid cell values by the grid containing base runoff coefficients for each land use. The values for each grid are then summed to obtain the V_c for each year. The V_c values are much higher than the observed stormwater volume (V_m). This difference highlights the importance of obtaining runoff coefficients for the specific study region. To account for the unique climate and physical conditions in arid regions, an adjustment factor (A_f) is calculated as

$$A_f = \frac{V_m}{V_c} \tag{4}$$

The adjustment factor is calculated for each year that measured stormwater volume is available. The A_f value is then used to adjust base runoff coefficient values for different land uses, so that the total flows from the model are the same as the measured flow. Table 3 presents the base coefficients as suggested by Schueler (1987) and the calibrated runoff coefficients as a function of land use. The considerable difference between measured stormwater volumes and volumes calculated with the Schueler coefficients demonstrates the large amount of uncertainty in runoff coefficients for arid and semi-arid regions such as Las Vegas Valley.

The runoff volumes $V_{n,m}$ and V_m are also calibrated with a Linear Programming (LP) procedure. The objective function minimizes the difference (V_{dif}) between storm water volume obtained from USGS data and storm water volume calculated from land use and rainfall interpolation. The value of V_{dif} is calculated as

$$L_{dif} = \sum_{j=1}^{9} \sum_{n=1}^{7} P_{vol} LU_{n,j} R_n - V_t \tag{5}$$

where P_{vol} (m^3), is the volume of precipitation over land use n in the subwatershed j, $LU_{n,j}$ is the percentage of area in land use n and subwatershed j, R_n is the calibrated runoff coefficient for land use n (see Table 3), and V_t (m^3) is the known watershed storm water volume based on USGS data. P_{vol} is the unknown variable and is calculated from the objective function. The only constraints are nonnegative values for P_{vol}. Using the P_{vol} calculated in the LP, $V_{n,m}$ and V_m are calculated as

$$V_{n,m} = P_{vol} \, LU_{n,m} \, R_n \tag{6}$$

$$V_m = \sum_{n=1}^{7} V_{n,m} \tag{7}$$

It is noteworthy that the runoff coefficients in Table 3 are much different than typical values that may be used in modeling runoff processes. The relative low runoff coefficient values (approximately 0.10 to 0.15) are probably due to the longer time scale used in this model. Runoff coefficient values of 0.80 to 0.95 for impervious areas are appropriate for models that are simulating event storm runoff; however, that is not the case in this study. The runoff coefficients were developed separately for each year (see Table 3), but it is encouraging that there is much agreement between the results for each year and the various land uses within the subwatersheds.

TABLE 3. Comparison of Runoff Coefficients Using (b) the Base Runoff Coefficient From the Schueler Equation, (c) the Calibrated Runoff Coefficient, and the Runoff Coefficients Adjusted for (d) 2000 and (e) 2001.

(a) Land Use	(b) Base Runoff Coefficient (from Schueler Equation 1)	(c) Runoff Coefficient Calibrated (all years)	(d) Runoff Coefficient Calibrated (2000)	(e) Runoff Coefficient Calibrated (2001)
Commercial (COM)	0.82	0.11	0.17	0.11
Industrial (IND)	0.70	0.09	0.14	0.09
Parks and Golf Courses (PAR)	0.10	0.01	0.02	0.01
Public Land (PUB)	0.55	0.07	0.11	0.07
Residential (RES)	0.39	0.05	0.08	0.05
Roads/Highways (ROA)	0.86	0.11	0.18	0.11
(Undeveloped) UND	0.05	0.01	0.01	0.01

Pollutant Concentrations

The estimation of pollutant concentrations for specific land uses based on observed water quality data is a challenge since the observed data represent many land uses. An LP procedure was also utilized to calibrate the land use pollutant concentrations based on the observed water quality data noted previously. The LP calibrates pollutant concentrations based on procedures described by Hodge and Armstrong (1993) where the difference between measured and calculated pollutant loads was minimized by adjusting pollutant concentrations for different land uses. The LP objective function for this study minimizes the absolute value of error (E) defined as

$$E = \sum_{m=1}^{5} \sum_{n=1}^{7} C_n V_{n,m} - \sum_{m=1}^{5} C_{s_m} V_m \tag{8}$$

where m represents the five water quality sample points (see Table 2), n represents the seven land use categories, C_n (mg/l) represents the unknown pollutant concentration for land use n, $V_{n,m}$ (liters) represents the runoff volume for land use n that drains to water quality station m, C_{sm} (mg/l) is the observed median concentration at water quality station m, and V_m (liters) is the total runoff volume that drains to water quality station m.

The LP objective function is composed of seven unknown variables (C_n) that represent the pollutant concentration from different land uses; however, data from only five water quality stations (C_{sm}) are available. Thus, the system is underdetermined, and an LP is necessary to optimize land use pollutant concentrations by minimizing the error defined in Equation (5). The LP constraints consist of minimum pollutant concentration values based on data for the southwestern United States (MWH, 2001). Table 4 summarizes the calibrated pollutant concentrations for the various land uses. It is noteworthy that these pollutant concentrations are based on 2000 and 2001 runoff volume and water quality data. These pollutant concentrations may not be applicable for different climate and land use scenarios.

RESULTS

2000 and 2001 Annual and Monthly Loads

The nonpoint source runoff model is used to estimate the pollutant loads during the years 2000 and 2001. The calibrated pollutant concentrations are assumed to be the same for each year; however, interpolated annual rainfall data and the runoff coefficients are different for each year (see Table 4 for model parameters).

TABLE 4. Calibrated Pollutant Concentrations for Total Suspended Solids (TSS), Total Nitrogen (TN), and Total Phosphorus (TP), and for Various Land Uses.

Land Use	TSS (mg/l)	TN (mg/l)	TP (mg/l)
COM	80	5.7	0.75
IND	316	4.8	1.04
PAR	126	3.6	0.47
PUB	726	4.2	0.66
RES	118	5.8	0.47
ROA	1150	8.4	0.89
UND	4834	13.3	3.42

The results for the monthly and annual nonpoint source loads are presented in Table 5. The model considers just nonpoint source runoff during wet weather; therefore, the pollutant loads vary according to the amount of rainfall in each month. The largest pulses of pollutants occur in the winter rainy season (January through March) and the summer monsoon (July through September). Total annual rainfall for 2000 and 2001 was similar for much of the watershed; however, there were small variations in the spatial distribution of precipitation that can be seen in Figure 4. The Gowan Basin received more rainfall in 2000 than 2001. In 2001, the southern subwatersheds of Duck Creek, Pittman Wash, and C1 Channel received more rainfall than 2000. Regardless, the different spatial distribution of rainfall between 2000 and 2001 did not result in a large change of the proportion of runoff from the different land uses.

Comparison to WWTP loads

The model results are also used to assess the total contribution of nonpoint source load to Lake Mead. The wet weather nonpoint source loads are calculated using the GIS model and dry weather loads are based on a previous analysis by T. Piechota, D. James, J. Batista, and P. Amy (2002, unpublished report to the Nevada Division of Environmental Protection). Nonpoint source storm flow was calculated by subtracting the base flow (as determined with a 30-day moving average) from the total measured flow (combination of point and nonpoint, wet and dry, flows).

TABLE 5. Monthly Wet Weather Nonpoint Source Pollutant Loads for 2000 and 2001, for Total Suspended Solids (TSS), Total Nitrogen (TN), and Total Phosphorus (TP) in the Las Vegas Valley.

	2000			2001		
(a) Month	(b) TSS (kg)	(c) TN (kg)	(d) TP (kg)	(e) TSS (kg)	(f) TN (kg)	(g) TP (kg)
January	111,457	318	91	2,879,041	12,803	2,361
February	7,879,170	34,640	6,401	5,755,903	27,240	4,812
March	1,869,118	7,536	1,453	671,648	2,906	545
April	24,561	91	0	248,247	863	182
May	14,256	45	0	52,982	182	45
June	7,446	45	0	681	0	0
July	71,096	454	45	1,091,779	4,495	863
August	4,094,853	17,978	3,314	686,857	2,679	545
September	1,952	0	0	28,784	136	45
October	2,834,140	13,257	2,361	34,958	91	45
November	6,583	45	0	489,594	2,134	409
December	22,700	91	0	163,213	817	136
Total (kg)	16,937,332	74,500	13,665	12,103,687	54,346	9,988

Figure 6 presents the nonpoint source loads during dry and wet weather for 2000 and 2001 in comparison to the point source loads from the three WWTPs. The dry weather nonpoint source load is relatively small compared to the wet weather loads. The total nonpoint load of TN is approximately 4 percent of the total load (point and nonpoint) to Lake Mead. Possible sources of TN include naturally occurring high levels of nitrate and impacts due to the approximately 16,000 septic systems in Las Vegas Valley. Total nitrogen loads are relatively low compared to those from WWTPs; thus, it is more reasonable to control point sources of TN than nonpoint sources (nonpoint contribution is less than 10 percent of the total). The TP load is primarily from wet weather flows and total nonpoint source TP loads are approximately 23 percent of the total TP load to Lake Mead.

A closer evaluation of the nonpoint source nutrient loads on a monthly basis is important for identifying important times of the year when nonpoint loads are high and how these loads compare to WWTP loads. During both years (2000 and 2001), the nutrient (TN and TP) loads in the winter are higher than other times of the year. The high TP loads in summer 2000 are followed by high TP loads in winter 2001. Furthermore, the TP loads from nonpoint sources are comparable to the WWTP TP loads during the same winter months. This is significant in identifying possible factors of the spring 2001 algal bloom in Lake Mead. Wet weather winter nonpoint TP loads for 2000 and 2001 approach the current seasonal (from March to October) permit level for the WWTPs (152 kg/day, or 4,540 kg/month), and also exceed the amount assumed by the Nevada Division of Environmental Protection (NDEP) for nonpoint sources (45 kg/day, or 1,362 kg/month).

Land Use Contribution

The GIS model is also used to track the contribution of different land uses to the total annual nutrient loads. Figure 7 presents a summary of the TN load contributions from each land use for 2000 and 2001. Figure 8 presents a summary of the TP load contributions from each land use for 2000 and 2001.

It is noteworthy that approximately 25 percent of the TN load and 18 percent of the TP load is from roads/highways, which account for only 4 percent of the watershed area. Possible sources of nutrients from roads/highways may include the adjacent right-of-way, landscape areas, and accumulated nutrients on the road surface that get washed off during storm events. This issue warrants further study. It is also noteworthy that approximately half of the TN and TP loads originate from undeveloped areas (i.e., background levels of nutrients are high). This is important since undeveloped areas are difficult to control the quality of runoff.

The contributions from the individual watersheds are shown in Figure 9 as load per unit area. The urban subwatersheds of Gowan, Lower Wash, and Central have the highest loading values per unit area and are the most critical for controlling the total loads

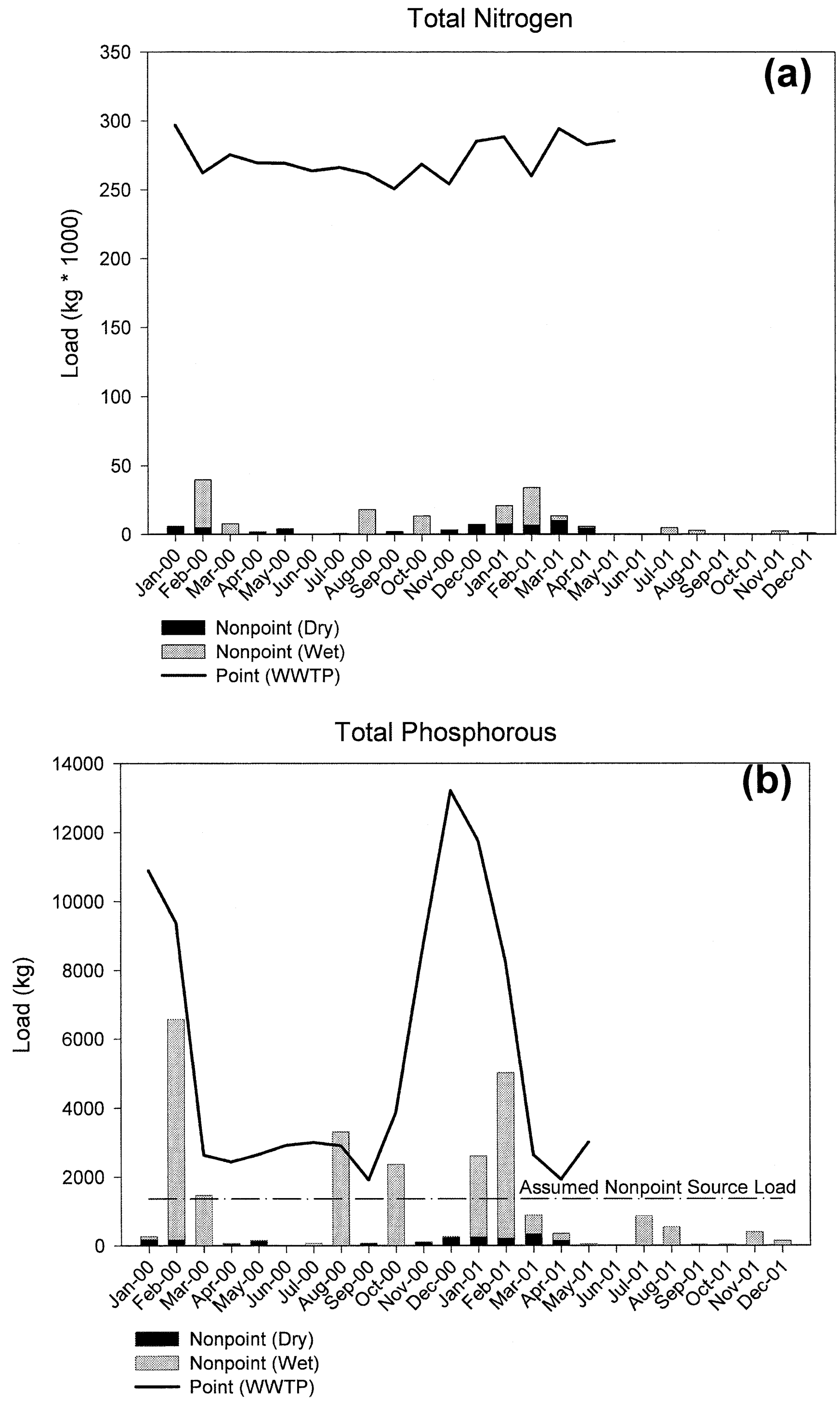

Figure 6. Nonpoint and Point Source Monthly Loads for (a) Total Nitrogen and (b) Total Phosphorus for 2000 and 2001.

from the watershed. This is expected from urban watersheds where a high concentration of pollutants is present due to high runoff and pollutant washoff that originate from highly impervious areas.

Pollutant Load Accumulation in Channels

The loading map shown in Figure 9 can be used to determine the accumulation of pollutant loads in downstream cells and in the watershed streams. This

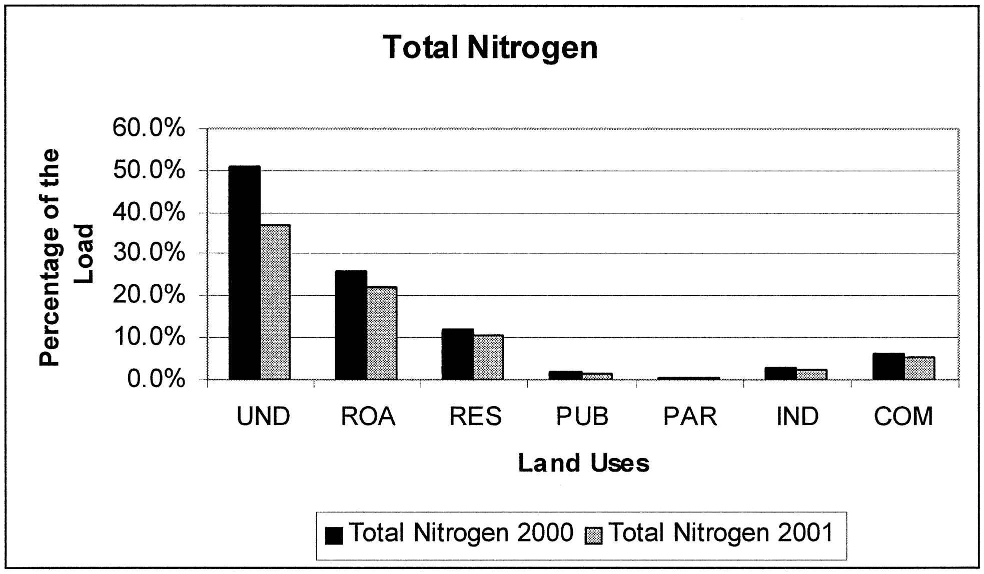

Figure 7. Land Use Percentage Contributions of the Total Nitrogen Load Generated in 2000 and 2001.

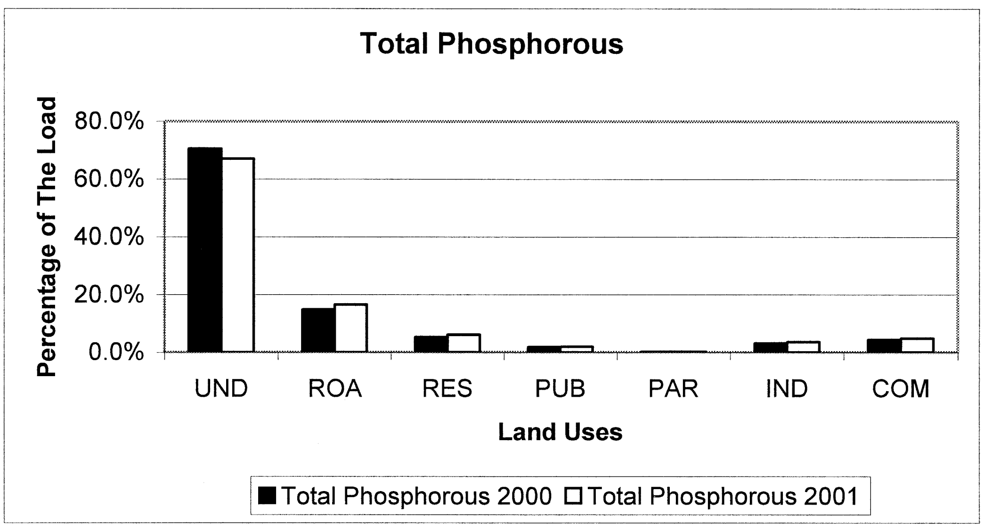

Figure 8. Land Use Percentage Contributions of the Total Phosphorus Load Generated in 2000 and 2001.

is important for identifying areas where BMPs may be necessary due to a large amount of pollutant accumulation. This analysis is performed for the Flamingo/Tropicana (FLA) subwatershed (see Figure 1), which is reasonably well developed compared to other subwatersheds. Table 6 summarizes the land uses in the Flamingo/Tropicana watershed area. The data needed to perform the tracking of pollutants in a watershed are a digital elevation model (DEM) of the watershed (USGS, 2001), the watershed boundary, stream/channel locations, and the pollutant load map for all the land uses.

The stream/channel locations are "burned" into the DEM using a procedure described by F. Oliveira (1996, unpublished manuscript). The hydrologic extension ArcGIS defines the direction of flow based on the DEM. The load for a particular grid cell is determined by knowing the direction of water flow in a given watershed (flow direction) and having a grid map where the cells have load values for pollutants (annual model result). The GIS extension sums the load values for all cells that are upstream from a defined point. The pollutant accumulation is determined with the defined streams/channels, the flow

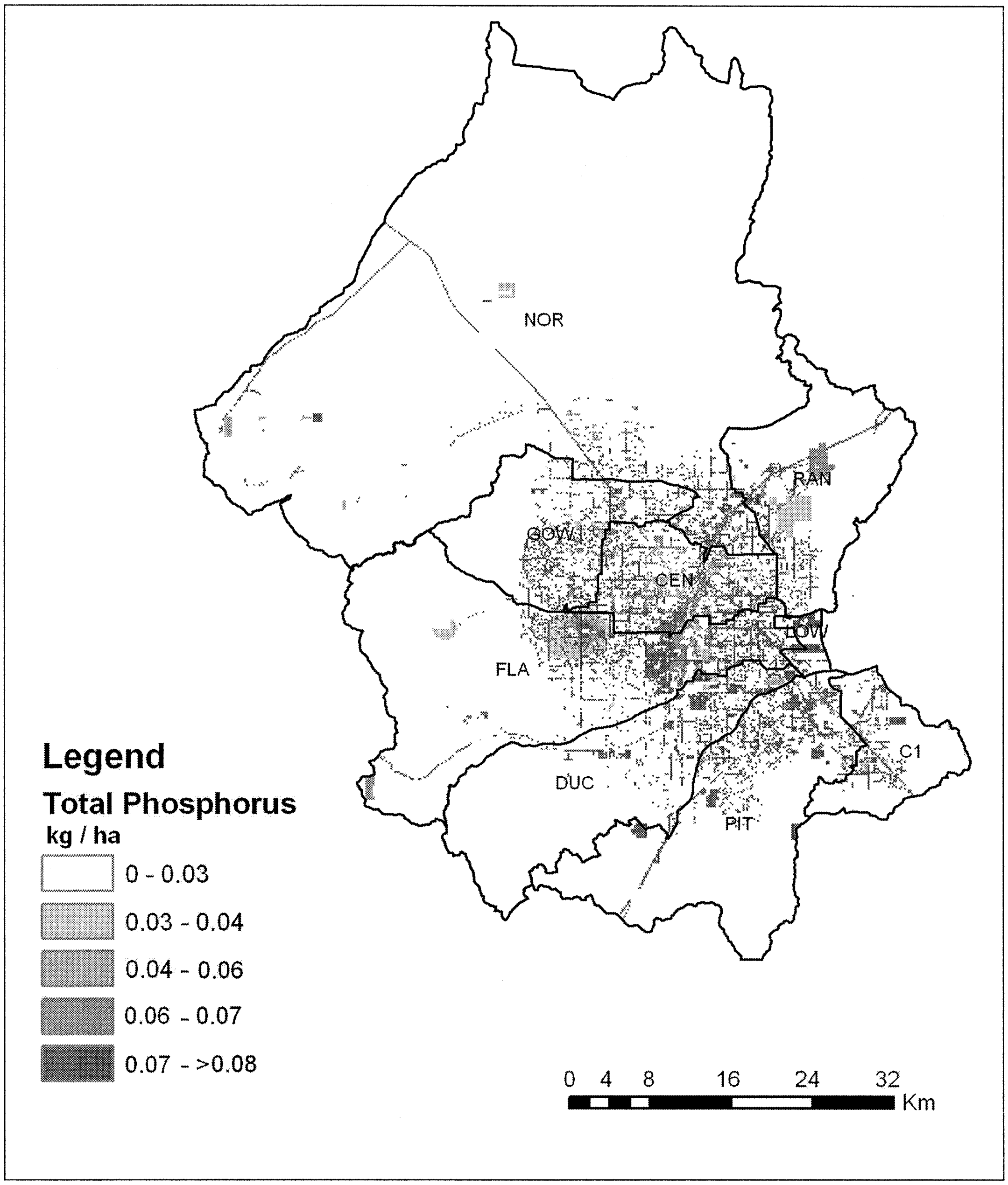

Figure 9. Spatial Distribution of Total Phosphorus (TP) Loads (kg/ha) for the Entire Las Vegas Valley for the Year 2001. Legend is divided into five intervals of one standard deviation each.

direction, and the pollutant map presented in Figure 9. An example of this analysis is presented for TP in the year 2001 (Figure 10). This simulation of pollutant accumulation in the stream/channel does not account for pollutant removal in detention basins, which can have high removal rates (e.g., Bingham, 1994; Carleton *et al.,* 2000; England, 2002). The pollutant removal could be incorporated into the pollutant accumulation analysis if the efficiency for the basin is well known.

CONCLUSIONS

A GIS based nonpoint source model is developed here to determine the contributions of nonpoint source loads to the receiving water body and the changes through the year. An innovative calibration procedure is utilized to determine pollutant concentrations for specific land surfaces based on observed water quality data at the subwatershed outlets. Results indicate that the pollutant concentrations and runoff coefficients are higher for Las Vegas Valley than previous published values for semi-arid and arid regions.

TABLE 6. Flamingo/Tropicana Subwatershed Area and the Percentage for Each Land Use.

Land Use	Area (hectares)	Percentage
COM	1,895	3.3
IND	773	1.4
PAR	1,177	2.1
PUB	754	1.3
RES	5,232	9.2
ROA	3,412	6.0
UND	43,659	76.7

Model results suggest that the high nutrient loads from high rainfall in summer 2000 and winter 2001 may have been contributing factors to the algal bloom in spring 2001 in Lake Mead. Total nonpoint source loads during wet and dry weather should be reevaluated considering that TP loads from nonpoint sources are approximately 15 percent of the TP loads to Lake Mead. This was primarily from wet weather nonpoint source runoff. Total phosphorus levels during wet periods (approximately 70 to 130 kg/day) approach the WWTP permit levels (152 kg/day) and exceed the value assumed by NDEP for nonpoint sources (45 kg/day). Total nitrogen loads are comparable for wet and dry weather flows, and amount to approximately 3 to 4 percent of the TN load to Lake Mead.

The contribution of pollutant loads from highways was approximately 32 percent of the wet weather TN nonpoint source load, and 26 percent of the wet weather TP nonpoint source load. This is noteworthy since only 4 percent of the watershed is classified as highways/roads. The large loads could be due to the large amount of impervious surface in Las Vegas Valley that accumulates pollutants over long dry periods. Mapping of pollutant accumulation in streams/channels is useful for planning BMPs. The map can identify critical streams that receive high loads of nonpoint source runoff pollutants.

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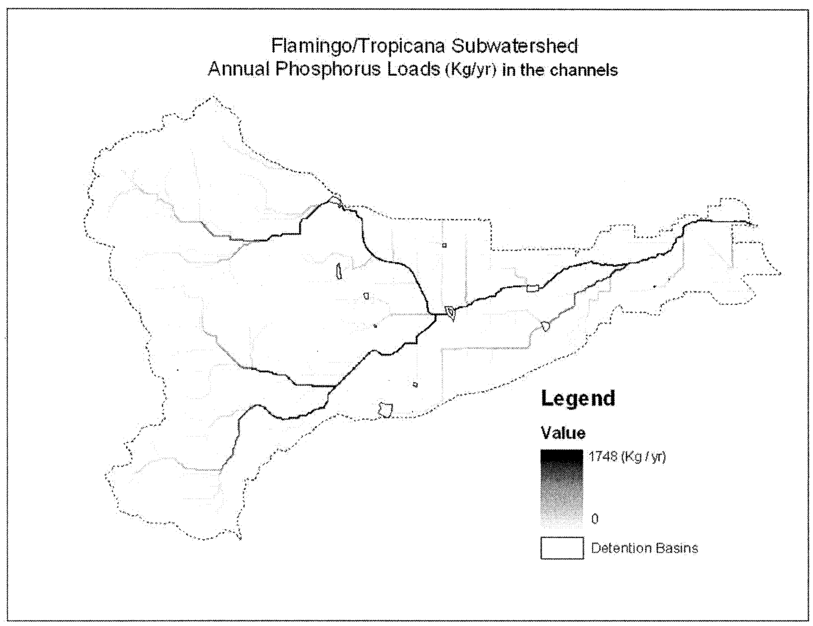

Figure 10. Total Phosphorus Annual Pollutant Accumulation (kg/year) in the Flamingo/Tropicana Watershed for the Year 2001.

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