Assessing the relationships between the spatial variation in land-use spatial patterns and surface water quality

Majed A. Khater
University of Nevada Las Vegas

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ASSESSING THE RELATIONSHIPS BETWEEN THE SPATIAL VARIATION IN LAND-USE SPATIAL PATTERNS AND SURFACE WATER QUALITY

by

Majed A. Khater

Bachelor of Science in Architectural Engineering
Yarmouk University, Jordan
1986

Master of Public Urban Planning and Policy
The University of Illinois at Chicago
1993

A dissertation submitted in partial fulfillment of the requirements for the

Doctor of Philosophy Degree in Environmental Science
Department of Environmental Studies
College of Urban Affairs

Graduate College
University of Nevada, Las Vegas
December 2005
The Dissertation prepared by

MAJED A. KHATER

Entitled

ASSESSING THE RELATIONSHIPS BETWEEN THE SPATIAL VARIATION IN
URBAN LAND-USE PATTERNS AND SURFACE WATER QUALITY

is approved in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY DEGREE IN ENVIRONMENTAL SCIENCE

Examination Committee Chair

Dean of the Graduate College
ABSTRACT

Assessing the Relationships Between the Spatial Variation in Urban Land-Use Patterns and Surface Water Quality

by

Majed A. Khater

Dr. Krystyna Stave, Examination Committee Chair
Professor of Environmental Science
University of Nevada, Las Vegas

The purpose of this dissertation was to examine the association between the spatial patterns of urban land uses and surface water quality parameters at the watershed outlet. The aim of the study was to understand the strength and nature of this relationship, and examine new methods of classifying and quantifying contributing urban land-uses and their spatial patterns. The hypothesis of this research was: in an urban watershed, the variation in the spatial patterns of contributing land uses will have a significant impact on the surface water quality parameters at the watershed outlet.

This relationship between urbanization and water quality is important terms of understanding and managing urban growth to preserve water resources, especially in dry, arid regions. The outcome of this study will
establish and define relationships between patterns of urban land uses and surface water quality parameters at the watershed outlet. Policy makers, watershed managers, and land-use regulators may have special interest in understanding these relationships to develop sustainable urban growth strategies.

The urban area of the Las Vegas Valley Watershed was used as a case study to test the research hypothesis. Existing water quality monitoring stations on the four major tributaries to the Las Vegas Wash were used to define four independent watersheds. Geographic Information Systems (GIS) was used to geo-reference water quality monitoring stations and to delineate contributing watersheds at each sampling point. Rainfall events leading to water quality sampling were used to derive contributing land-uses within each watershed. The association between the total amount, types, patterns of contributing land uses, and surface water quality parameters at the watershed outlet were tested using Pearson correlation.

Correlation results showed very clearly that total amount and types of the contributing land uses cannot fully explain by themselves the variations in the surface water quality parameters at the watershed outlet. Further analysis of the association between the spatial patterns of the contributing land uses and the water quality parameters showed some of the measured water quality parameters to be more sensitive to changes in the spatial patterns of the overall contributing land uses.
Two different patterns of contributing land uses were identified: (1) fragmented pattern, the distribution is characterized by a large number of smaller patches, spread across the landscape, and (2) clustered pattern, the distribution is characterized by a smaller number of larger patches in close proximity to each other.

We found that some of the water quality parameters, such as TDS, TKN, total N, BOD, and COD to be positively correlated with landscape metrics describing fragmentation (pH was negatively correlated). The trend for the same parameters was opposite when compared to metrics describing clustered patterns. These results indicated that there is a significant association between water quality parameters at the watershed outlet and the spatial patterns of the contributing land uses.

Additionally, this study illustrates that using people oriented land-use classification method, which is based on the actual use of the land is more appropriate for highly urbanized areas compared to the resource oriented method, which is based on remotely-sensed data and often used for land use and land cover classification.
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ACKNOWLEDGMENTS

I wish to express my sincere appreciation to my advisor, Dr. Krys Stave, for her guidance and encouragement throughout my entire graduate study program at the University of Nevada, Las Vegas. Also, I wish to acknowledge the assistance and advice of the other members of my doctoral committee: Dr. David Hassenzahl, Dr. Thomas Piechota, and Dr. Helen Neill Without their assistance and constructive input, this work would have been impossible to complete.

Additionally, I would like to extend my gratitude to a number of individuals whose help was essential to the success of this project. I thank Dr. Maliha Nash for her continuous assistant and valuable input, Monica Miceli, Sonya Wilson, John Korkosz, and Mrs. Cancelleri for their participation in the review and the editing of my manuscript.

Finally, I am most grateful to my parents who taught me the importance of education, to my wife Nadia, and my daughters, Sabrina and Zaina, for putting up with me spending long hours away from home working on this research.
The purpose of this study was to examine the relationship between urban land-use patterns and surface water quality parameters. Specifically, the study explored the correlation between surface water quality parameters at the watershed outlet and the variation in spatial patterns of the contributing urban land uses. Additionally, this study introduces a new method of classifying and quantifying the amount, types, and spatial patterns of contributing urban land uses. While many studies have been done on the relationships between land-use patterns and surface water quality, few have focused on urban areas. Land-use planners can affect land-use patterns and composition; therefore, if we understand this relationship between urban land-use patterns and surface water quality, then we can use land-use controls to affect surface water quality.

Urbanization can affect the local environment by converting vacant land to urban uses, such as buildings, roads, and other impervious surfaces, reducing the infiltration capacity of the land. When it rains,
water washes over these impervious urban land uses, picking up pollutants and water contaminants. The porous terrain of natural landscapes like vacant land, forests, and grasslands retain rainwater and allow it to slowly infiltrate into the ground. Runoff tends to reach receiving waters gradually. In contrast, nonporous urban landscapes reduce water infiltration. Water remains above the surface, accumulates, and runs off in large amounts over different types of land use, reaching receiving waters quickly.

The issue of urbanization and its impact on surface water quality is becoming an important national policy issue. The majority of our fresh water resources in the U.S. are becoming more vulnerable to pollution from a wide variety of human activities, mainly caused by urban runoff. *The National Water Quality Inventory Report* to Congress in 2000 (Environmental Protection Agency (EPA), 2000) identified urban runoff as one of the leading sources of water quality impairment in surface waters.

Several existing studies have clearly documented how urban development can cause an increase in the flow rate and volume of surface water runoff. The growth of developed areas leads to an increase in impervious surface area (ISA). This increase in ISA results in storm water flowing untreated directly into the collecting stream system, carrying with it various types of pollutants. Perry and Vanderkilen (1996) showed that some correlation exists between pollution loading and land use. Bhaduri et al. (2000) showed that a measured increase in imperviousness of the
watershed can be translated into a measured change in pollutant loading at the watershed scale. Other researchers (Basnyat et al., 1999) examined the impact of joint contribution of multiple land-use and land-cover types and their spatial positioning in the watershed on stream water-quality variables. Spatial positioning was evaluated at three different scales: (1) basin scale; (2) the contributing zone scale (the area surrounding the stream that, as a result of land-use practices and other human activities, contributes nutrients and other NPS pollutant to stream waters); and (3) the stream-buffer/riparian zone scale. Their study of the Fish River watershed in Alabama showed in stream water-quality to be sensitive to alteration in land use made at these different scales.

Several other studies have documented the impact of the riparian zone on stream water quality (Peterjohn & Cornell, 1984; Prowse, 1984; Weng et al., 1997; Lammert & Alan, 1999; Carlson et al., 2000; Whiles et al., 2000). Additionally, some studies (e.g., Prowse, 1984; Weng et al., 1997; Wang & Yin, 1997) suggested that the distribution of land-uses in the watershed may be as important as the total amounts of land use in influencing the stream water quality.

Despite research on the effects of land-use and land-cover change on surface and stream water quality, very little has been done to analyze the impact of urban land-use spatial patterns on surface water quality in a highly urbanized and arid environment. The relationship between the volume of runoff and the pollutant loading is understandable; more runoff
over a period of time will result in more pollutants being loaded to the stream system. The trends and characteristics of storm events in arid and semi-arid regions are usually characterized by a high degree of temporal and spatial variability. The effect of temporal variation in a storm event can be detected in the total amount of annual runoff volume. The effect of spatial variation is still a subject of research.

This study used the case of the Las Vegas Valley, a fast growing, highly urbanized area, to examine the effect of the spatial variability of the contributing land uses on surface water quality parameters at the sub-watershed scale. In the last decade (1991-2001), the urban area has experienced an accelerated rate of urban growth and land-use change. The number of developed acres of the major land-use categories (residential, industrial, commercial, parks, and golf courses) has increased by 68%, from 70,041 acres in 1991 to 117,719 acres in 2001. (This calculation is based on GIS data available from the CCAO.)

The goal of the research was to contribute to general understanding of the relationships between spatial patterns of contributing urban land-uses and surface water quality parameters at the watershed outlet. The research also sought to contribute to methods for examining such relationships in arid, urban watersheds that are similar in urban patterns and growth characteristics to those of Las Vegas. Policy makers, watershed managers, and land-use regulators may have special interest in establishing and understanding the relationships between these variables,
which might be critical for developing sustainable urban growth strategies. Furthermore, the results study contribute to and advances knowledge in the area of the environmental effects of urbanization on surface water quality, including ongoing efforts by the Las Vegas Valley Storm Quality Management Committee, the Las Vegas Wash Coordination Committee (LVWCC) tributary monitoring program, and the U.S. Geological Survey National Water-Quality Assessment Program (NAQWA).

Background

Several studies have documented the impact of urbanization on surface runoff. Urbanization influences the nature of runoff, modifying paths and rates of flow, and delivers pollutants to streams (Goudie, 1990). As development increases, the impervious surface area (ISA) increases, where water cannot infiltrate. Instead, water accumulates and moves above ground, causing an increase in runoff (Ridd, 1995; Dow, 1997; Carlson & Arthur, 2000; Weng, 2001). Bhaduri et al. (2000) showed in their study of the Little Eagle Creek watershed near Indianapolis, Indiana, between 1973 and 1993, that, an 18% increase in ISA in the watershed resulted in an estimated 80% increase in annual average runoff volume, and estimated increases of more than 50% in annual average loads for lead, copper, and zinc. Shelton (1981) demonstrated that timber removal and changing forest land to irrigated agricultural land has increased runoff and altered stream flow.
Different types of land use may have different hydrological impacts on the watershed and can be a source of different water pollutants. Viessman and Hammer (1993) have identified agricultural activities as major sources of NPS pollutants, contributing sediments, animal waste, plant nutrients, crop residues, pesticides, inorganic salts, and minerals to surface waters. Prowse (1984) examined the spatial variability in water quality in a midsized (33.03 km), rapidly growing urban catchment, with particular emphasis on urban base-flow drainage caused by NPS runoff. This study provided clear evidence that there is some correlation between base-flow water quality and specific urban land uses. Some of the spatial variations in surface water quality were attributed to rock type, in addition to land use. Urban areas were a significant source of potassium (K+), which was attributed to the use of Potassium-rich lawn fertilizers. Sodium (Na+) and chloride (Cl-), which were attributed to the road salting in the catchment during the winter. In a similar study, Walling and Webb (1975) showed that urban land use exerted a significant influence on levels of conductivity and that values of specific conductance did vary according to rock type. Bhaduri et al. (2000) showed that urban land uses are the dominant sources for metal trace pollution, while most nutrient pollution occurs from nonurban land uses. Basnyat et al. (1999) showed the nitrate levels downstream decreased as the proportion of forest inside the contributing zone increased (or agricultural portion decreased). Urban and active agriculture areas were identified as the largest contributors of
nitrate and sediment; total suspended solids (TSS) were more associated with agricultural uses.

Howarth et al. (1991) used modeling techniques to address the question of what controls the NPS inputs of sediment and organic carbon to an estuary, and how these inputs might be affected by changes in land use and climate. Using the Hudson River watershed to apply and test the model, they concluded that urban areas, suburban areas, and agricultural fields are the dominant sources of organic, carbon, and total sediment. An increase or decrease in the area of either would be expected to alter the fluxes of materials into the estuary. These fluxes are sensitive to changes in density of urban and suburban areas. A higher density urban land use would increase the fluxes of both organic carbon and sediments. Fluxes of carbon from terrestrial ecosystems to the estuary were sensitive to changes in terrestrial ecosystems.

Considering the effect of the stream bank (riparian zone), water quality was found to be highest when passive land use, such as forest and grassland, were located adjacent to streams. Grasslands and forests were identified to act as a sink or active attenuation zone in the stream bank (Basnyat et al., 1999). Wang et al. (1997) found that upstream land use, within the stream bank (100 meter buffer), strongly affected the stream's ecosystem. Urban land use was associated with poor biotic integrity and poor habitat quality. Other studies (e.g., Peterjohn & Cornell, 1984) have shown that the presence of riparian forest significantly reduces the

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amount of nitrogen reaching streams from upland areas. While et al. (2000) demonstrated that stream biotic integrity in a watershed that is highly impacted by agricultural activities is heavily influenced by land use within a relatively narrow riparian corridor (an 18-meter width on each side of the stream). Lammert and Alan (1999) showed similar results in a study in southeastern Michigan, relating the overall biotic condition to patterns of land use and channel structure. This study concluded that land use adjacent to the tributary (a 250-meter buffer) predicted a biotic condition better than regional land use.

Carlson et al. (2000) argues that further assumptions must be made when relating surface runoff to ISA. While it is true that an increase in ISA will result in a corresponding decrease in areas available for infiltration and soil storage of surface water, it may not be correct to assume that ISA changes are directly equivalent to changes in the runoff volume as reflected by river flow. Local flooding may be absorbed by surrounding surfaces that are pervious or may be contained temporarily on ISA until completely evaporated, never reaching the stream to be recorded in the hydrograph. Microclimate conditions and vegetation are some of the factors that might alter the above process.

Some researchers (e.g. Prowse, 1984; Wang et al., 1997) have suggested that watershed landforms and the distribution of land-uses within a watershed may be as important as the total amount of land use in influencing the stream ecosystem. Wang and Yin (1997) argue that land
use may interact with other landscape features to determine habitat quality and biotic integrity. They recommended that to better understand the relationships between stream ecosystems and their watersheds, a more complete analysis is needed. This analysis should include more specific land-use categories, note the patterns and spatial distributions of land uses, and incorporate the characteristics of the watershed, such as geology and topography.

McMahon and Harden (1998) showed that environmental characteristics as defined by using soil drainage characteristics, surface geology, and land-use information, could explain some of the variation in the behavior of certain physical and chemical water quality measures, such as concentration of certain sediments and nutrient constituents. For example, their study showed that concentrations of suspended sediments were generally larger in the higher gradient noncoastal plains. Developed basins had the highest concentration of total fixed solids, and coastal plain agricultural basins generally have higher nitrogen and phosphorus concentrations than noncoastal plain agricultural basins.

Basnyat et al. (1999) argued that despite that land-use activities affect water quality in the watershed, most of the research has been focused on the effect of individual land-use type, and very little has been done to analyze the joint contributions of multiple land-use activities. In their study of the watershed of the Fish River in Baldwin County, Alabama, they related the land-use patterns in the watershed to measured in-stream
nutrient (nitrogen and TSS) concentrations. Recognizing the possible sensitivity of water quality variables to the spatial positioning of land uses in the watershed, they conducted a study at three different scales: (1) the basin scale, (2) the contributing zone scale, and (3) the stream-buffer scale. The results of this study showed the importance of the spatial positioning of land uses in the contributing zone, and the relative importance of different land-use types as nutrient contributors.

It is evident from these studies that there is a strong correlation between urbanization and changes in the amount and quality of surface water runoff. Considering the temporal and spatial characteristics of urbanization, it is clear that this relationship is far more complex than a straightforward linear relationship. Some researchers (e.g., Wang & Yin et al., 1997) have pointed out the low number of studies that examine the relationship between the spatial distribution of land use and water quality at the watershed level. Prowse (1984) made a similar argument that little attention has been paid to spatial variation within large catchments to explain water quality profiles at specific locations in terms of the complex interrelationships between land use, rock type, and atmospheric inputs upstream.

This study addresses an important question not yet adequately addressed in the literature. The question that forms the center of this research is: What is the effect of the spatial variation in urban land-use patterns in the contributing watershed on the surface water quality
parameters at the watershed outlet, especially in the case of a highly urbanized, arid watershed?

The relationships between land-use change and surface water quality in the Las Vegas Valley watershed were expected to exhibit similar trends to those observed in the discussed literature. In particular, pollutants related to urban land uses, such as TSS, TDS, alkalinity, nutrients, metals, and organic materials, were expected to increase as the contributing land uses in the watershed increased. Furthermore, differences in the spatial patterns of the contributing land uses were expected to impact the association between contributing land uses and surface water quality. As storm water flows over different patterns of different types of land uses, its characteristics and pollutant concentration will be altered accordingly. For example, surface runoff in watersheds where land uses are dense and clustered is expected to show an increase in pollutant concentration, as runoff interacts with larger and more contiguous impervious areas of different land uses before collecting in the stream network. On the other hand, in watersheds where land uses are more fragmented and isolated into smaller patches of impervious surfaces, it is expected that the concentration of pollutants will decrease, as surface runoff interacts with patches of undeveloped (or noncontributing land uses), losing certain amounts to infiltration and evaporation before reaching the nearest collecting stream.
Research Question/Hypothesis

This study identifies contributing urban land-use characteristics in a watershed that might explain variations in surface water quality parameters at the watershed outlet. In particular, the study examines the extent to which variations in surface water quality parameters can be explained by spatial variation in urban land-use patterns in the contributing area.

Previous studies (e.g. Prowse, 1984; Weng et al., 1997; Wang & Yin, 1997; Basnyat et al., 1999) have shown that the water quality at a given watershed outlet may be explained by one or a combination of the following four watershed variables: (1) the total amount of urbanization (development) in the watershed, (2) the predominant land-use types, (3) the physical characteristics of the contributing watershed, and (4) the spatial positioning of the contributing land uses in the reference watershed (relative to stream buffer/riparian zone).

This study examines the fourth variable in more detail, considering the spatial distribution of contributing land uses in terms of the overall watershed, in a highly urbanized, arid watershed. The study attempts to identify the impact of changes in the spatial patterns of the contributing land-uses on surface water quality parameters at the watershed outlet.

The main hypothesis of this research is that in an urban watershed, the variation in the spatial patterns of contributing land uses will be
significantly correlated with variation in the measured surface water quality indicators at the watershed outlet. We expect urban related indicators, such as TDS, TSS, alkalinity, nutrients, metals, and organic materials to increase as the contributing land uses become more contiguous and clustered. The following two research questions will be addressed:

1. How much of the variation in the water quality parameters can be explained by the total amount and types of the contributing land uses? How might other background conditions such as climatic, seasonal, and size of contributing area affect this association? Null hypothesis: The total amount and types of contributing land uses cannot fully explain the variation in surface water quality parameters. Previous studies, mostly in nonurban watersheds showed strong association between changes in land use and changes in surface water quality parameters. Considering the differences in land-use characteristics and spatial patterns between urban and nonurban watersheds, it is not clear if the same trend will prevail.

2. What are the associations between changes in the contributing land-use spatial patterns and surface water quality parameters at the watershed outlet? Null hypothesis: In an arid, urban watershed, the variation in the spatial patterns of the contributing land uses will not make a difference in measured surface water quality
parameters at the watershed outlet. Previous studies, mostly in nonurban areas, showed that patterns of land uses in the stream riparian zone can affect in-stream water quality indicators. It is not clear if the patterns of the overall contributing land uses in an urban, arid watershed can significantly affect water quality parameters.

Approach

This study examined the overall association between changes in urban land uses in a given watershed and changes in surface water quality parameters at the watershed outlet in general terms. To test the research hypothesis, the Las Vegas Valley, a fast-growing urban area, was used as a case study. This research is different than previous—as it is focused on examining the relationships between urban land use and surface water quality in an arid region, dominated by urban land-use change, while other studies focused mainly on larger, nonurban watersheds.

The main variables in this study are the surface water properties and the amount, types, and spatial patterns of urban land use in the contributing watershed. To test the research hypothesis, correlation between changes in the surface water properties at the watershed outlet and the amount, types, and spatial patterns of the contributing land uses
were examined. Four distinct data sets were required for this study, they are:

1. Water quality data, including the location of monitoring stations.
2. Detailed land-use data, including construction date.
3. Topographic data including a Digital Elevation Model (DEM), which was used to delineate watersheds relative to water quality monitoring stations.
4. Rainfall data leading to water quality monitoring, which were used to identify contributing land uses in response to storm events leading to water quality sampling.

Using these data sets and a Geographic Information System (GIS), a detailed, spatially, and temporally varied land use layers that coincide with water quality monitoring dates were generated. Using rainfall data leading to water quality sampling, contributing land-uses were delineated. The land-use makeup and spatial distribution in every contributing watershed leading to water quality sampling were identified and tabulated to use in statistical analysis to test the research hypothesis.

Minitab statistical software package was used to perform Pearson correlation to determine the association between the contributing land uses and the water quality parameters. The calculated correlation coefficient (r) is a unitless measurement that describes the strength and direction of linear association that exists between two variables. Using a
confidence interval of 95% (\( \alpha < 0.05 \)), the correlation was categorized based on the value of \( r \) as follows (AcaStat, 2002):

- 0.9 to 1.0 very high correlation
- 0.7 to 0.9 high correlation
- 0.5 to 0.7 moderate correlation
- 0.3 to 0.5 low correlation
- 0 to 0.3 little to no correlation

The spatial variation in the contributing land-uses was identified and quantified by defining two different patterns of spatial structure of the contributing land uses in the watershed: (1) a fragmented or dispersed pattern, if the same amount of land uses dispersed into smaller size patches and more spread across the landscape; and (2) a clustered pattern, when most of the contributing land-uses are clumped into a few large size patches across the landscape. Metrics describing the number, size, and distribution of land-use patches were calculated for contributing land-uses in every watershed. These metrics were used as a measure to describe the variation in the spatial patterns of contributing land uses between fragmented and clustered patterns.

Contributing land uses can be identified as mosaics of patches that have the same land-use class and may vary in size, shape, and arrangement. In recent years, considerable progress has been made in landscape pattern analysis and quantifications. Several computer
programs, including GIS, have been developed to calculate different landscape-level metrics (more than 40 metrics); examples include the widely cited FRAGSTAT (McGarigal & Marks, 1995), the Geographical Resource Analysis Support System (GRASS) (U.S. Army CERL, 1993), and the Patch analyst (Rempel et al., 1999) extension to ESRI's ArcView software. These programs were developed to support landscape ecology focus on the patterning of landscape elements (patches), using the patch as the basic component for the analysis. A patch is defined as an area having relatively homogeneous conditions relative to other patches in a given landscape (Forman, 1995); in this case it is land use. A class is a collection of patches that have the same land-use designation. The term landscape refers to the collection of all land-use classes within a given watershed. In this study, the Patch analyst extension to ESRI's ArcView was used to calculate metrics describing patch-based indices that can be used to quantify landscape characteristics and spatial patterns/configuration (Gustafson, 1998; Alberti & Waddell, 2000).

Fragmentation involves the dividing of something into a number of smaller pieces and then characterizing it by the number, size, and distribution of these pieces (Rutledge, 1998). For example, a more fragmented area will show an increase in the number of patches, a decrease in the patch size, and an increase in the total amount of edge (the border between patches of different classes). Additionally, fragmentation should include the spatial configuration of the resulting
patches (Forman, 1995), which can be identified by indices like patch
density and contagion, which is the degree of adjacency of cells. The
following is a description of the selected landscape indices that can used
to characterize clustering/fragmentation of the contributing land uses,
from McCraigal et. al. (2002) and Ritters et. al. (1995):

1. Composition indices which describe the basic characteristics of
fragmentation:
   a. Number of patches of particular class (NUMP).
   b. Mean patch size (MPS): the average area of a patch of a
      particular class.
   c. Largest patch index (LPI): the percentage of landscape area
      occupied by the largest patch of a class (percent).

2. Shape indices attempt to quantify shape complexity:
   a. Total edge (TE): an absolute measure of the total edge length of a
      class.

3. Configuration indices refer to the spatial distribution of the land-use
patches within the landscape (Alberti et al., 2000). These indices
measure the degree of connectedness or isolation between and
among patches on a landscape. Patch configuration can be based on
two categories: indices based on distances between patches and
indices that compare the overall spatial pattern, often called texture
(Rutledge, 1998):
a. Mean nearest neighborhood distance (MNN): the mean distance between patches of the same class.

b. Mean Proximity Index (MPI): a measure of isolation between patches.

These indices can be used to describe/discard the fragmentation of the contributing land uses. Carrion and Irwin (2002) and Coppedge et al. (2002) used some of these metrics (NUMP, MPS, and TE) to analyze patterns of urban development, urban sprawl and fragmentation of urban land uses. A more fragmented land use pattern was associated with large NUMP, smaller MPS, and higher TE. MNN was used as a measure of dispersion; higher MNN indicates more dispersion of the land uses, fragmented pattern.

These metrics were calculated for all watersheds. Each metric was used separately as a measure to indicate spatial patterns of contributing land uses. For example, when comparing a group of watersheds that have similar amount of contributing land uses, watersheds that have higher NUMP can be considered more fragmented than watersheds with lower NUMP. The change in NUMP across several observations was used as a linear measure to indicate change in spatial pattern, and an increase in NUMP indicates that the contributing land-use pattern is becoming more fragmented.
CHAPTER 2

DATA AND RESEARCH METHODS

The Study Area

A watershed is defined as an area of land that drains water or runoff to a single point. The Las Vegas Valley Watershed is a bowl-shaped basin, located in southern Nevada. The watershed is about 1,446 square miles (925,533 acres). The urban area of the watershed is about 517 square miles (331,413 acres). The Bureau of Land Management Disposal Boundary defines the urban area; this is the area where urban growth is allowed. The urban area is highly developed and accounts for 35% of the total watershed area. Figure 1 shows the urban area to be close to the southeastern edge of the watershed and to the Las Vegas Wash (LVW) inlet into Lake Mead, the major source of drinking water in the valley.

The watershed drains to the southeast through the LVW into Lake Mead. The Valley is bounded virtually on all sides by mountain ranges that reach a maximum elevation of almost 12,000 feet above sea level (the highest point being in the Spring Mountains to the west). The Valley floor elevations range from about 3,000 feet in the west at the foot of the Spring Mountains to 1,500 feet in the east at the outflow of the Valley (Pavelko et al. 1999; Las Vegas Wash Coordination Committee (LVWCC), 2002). The
The hydrographic basin is characterized by a series of generally north-south trending mountain ranges and intervening valleys filled with eroded sediments. These alluvial fans are coated with calcium carbonate, which is part of the geologic composition of limestone—better known as caliche; it is almost impervious (Pavelko et al. 1999).

Figure 1. The Study Area, Las Vegas Valley Watershed

The history of Las Vegas goes back to 1855 when Mormon missionaries first settled in the area. In 1905, the town of Las Vegas was established, and in 1911, the city of Las Vegas was incorporated. The first growth surge occurred in the 1930s, it was driven by the construction of the
Hoover Dam, the legalization of gambling, and the liberalization of divorce laws in the state of Nevada, all of which caused a continuous population growth until today (Pavelko et al., 1999; Acevedo et al., 1997; LVWCC, 2002). For example, the amount of development in the watershed has increased by 547% from 1970 to 2002 (total developed acres in 1970: 23,530 and in 2002: 128,701 acres). Las Vegas is known to be one of the fastest growing metropolitan regions in the U.S. (Gottdiener et al., 1999). According to the U.S. Census Bureau (2000), the Clark County population increased from 741,459 in 1990 to 1,375,765 in 2000. As of July 2003, the county population was 1,661,529 (Clark County Department of Comprehensive Planning, 2003).

The watershed climate displays typical desert southwest characteristics where wide variations of temperature and rainfall are common. According to historical data obtained from the Western Regional Climate Center (WRCC) (2005), the mean annual temperature in the valley is in the middle 60s; daily summer high temperatures typically exceed 100 degrees. The average percentage of possible sunshine days in the valley exceeds 80%. This prolonged period of sunshine, coupled with low humidity, leads to rapid evaporation. The amount of evaporation, in the area as measured in evaporation pans, can average more than 100 inches annually (WRCC, 2005).
Thunderstorms are in frequent in the valley, on average, 15 days annually, where thunderstorms are observed (WRCC, 2005). Dust and sand storms occur occasionally during the spring, but generally, winds are light, especially in the morning. For example, winds of zero to three miles per hour are most common around 8 a.m., the peak automobile traffic period, which may lead to a higher degree of pollutant accumulation due to light winds (WRCC, 2005).

The annual average rainfall in the watershed is 4.19 inches (Clark County Regional Flood Control District (CCRFCD), 2002). The precipitation in the region is characterized by a high degree of variability. Long-term precipitation records for the region show the occurrence of significant precipitation and stream flow fluctuations on interannual to decadal time scales, as reflected in the stream flow of the Colorado River between 1890 and 1990 (Diaz et al., 1995). Additionally, there is a large variability in the monthly rainfall from year to year and from month to month. The rainfall records available from the CCRFCD from 1990 also reflect a large degree of spatial variability in the rainfall. Figure shows the rainfall distribution in the valley from the storm event that lead to the October 24, 1992, water quality sampling. This figure shows rainfall totals for a 24-hour period to vary from 0.31 to 1.69 inches.
Data Acquisition

Four data sets were required for this research. They are: land-use data, water quality data, watershed topographic data, and rainfall data.

Land-Use Data

Land use is an attribute of the human use of the land. The level of details in the classification of land use is a function of the purpose of the classification. Typically, the Assessor’s office data has the most details of the actual use of the property because that is the base for taxation. Land
use reflects the importance of land as a key resource for most human activities. It is a fundamental factor for economic production, and through much of the course of human history, it has been tightly coupled to economic growth (Turner & Meyer, 1991). For the purpose of this study, the significance of land-use characterization lies in the impact land use might have on the surface runoff coefficient and in the types and amount of pollutants different land uses might generate.

Land-Use Classification Systems

There are several land-use classification systems. Anderson's Land Use and Land Cover (LULC) classification system for use with remotely sensed data is one of the most cited systems in the literature (Anderson, 1976). In this system, LULC classifications are broken down into two levels; level I is a broad classification system with 9 categories, such as urban or agricultural land. Level II is more specific with 37 classifications, such as residential and commercial classes for urban land use (Anderson, 1976).

Anderson's classification is a resource oriented classification system in contrast with the people oriented system used by the Clark County Assessor's Office (CCAO), which is based on the Standard Land Use Coding Manual, developed by the U.S. Urban Renewal Administration and the Bureau of Public Roads (1965). The primary difference between the two systems is the emphasis of the Anderson system on remote sensing as the primary data source. This means land use activities must be interpreted
using land cover as the principal surrogate, in addition to the image interpreter's customary reference to pattern, geographic location, etc. In this system, an industrial warehouse and a regional shopping center might be given the same classification, which might be true in terms of land cover, but not true in terms of actual land use and human activities. Anderson (1976) suggested that special attention should be given to providing the potential users of the LULC data with sufficient information so that they may either compile the data into more generalized levels or aggregate more detailed data into existing classes. The system used by the CCAO allows the user of the data the ability to generalize it or derive a highly detailed level of classification.

CCAO uses a different coding system to track land use on developed properties for assessment purposes; land cover is not tracked under this system. Three separate data sets are used to maintain a parcel-based land-use database. The first considers the parcel layer that includes the geometry (shape, size, and geographic location) of each parcel of land, and a unique parcel identifier (parcel number) as the main elements of this data set. The second is an extract file (AOEXTRACT), which is a tabular data file with the ownership data, land use, and development date as the main elements. The third is another extract file (AOCOMM), which is more specific for the details of nonresidential uses. Numeric codes are used to describe the actual use of the property, such as shopping centers, casinos, and golf courses. Undeveloped properties are coded with a zero land-use value.
code. The overall structure of this system is similar to the Anderson classification in terms of having several levels of detail. This system is very comprehensive in tracking land use at a high level of resolution (the parcel level).

Proposed Land-Use Classifications

Since the valley is a highly developed urban area, the CCAO data sets were used to derive a detailed, urban, land-use layer. The CCAO maintains a complete parcel-based GIS layer for the whole county, with three levels of details of land uses. Table 1 shows the broader level of details (basic land-use category).

Table 1. Existing CCAO LU Classification

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Vacant</td>
</tr>
<tr>
<td>1</td>
<td>Residential</td>
</tr>
<tr>
<td>2</td>
<td>Industrial</td>
</tr>
<tr>
<td>3</td>
<td>Commercial</td>
</tr>
<tr>
<td>4</td>
<td>Nonprofit and Community Facilities</td>
</tr>
<tr>
<td>5</td>
<td>Agricultural, Ranching, Wildlife, and Natural Resources</td>
</tr>
<tr>
<td>6</td>
<td>Transportation, Communication, and Utilities</td>
</tr>
<tr>
<td>7</td>
<td>Minor Improvements</td>
</tr>
</tbody>
</table>
This table was used to derive some of the land-use classifications, such as vacant land and residential and industrial uses. Other uses such as golf courses and parks were identified using additional data sets and attributes. For example, the golf courses in the assessor database are classified under commercial and given a secondary land-use code of 345. The golf course parcels were extracted and coded as agricultural. Similarly, parks were identified from a separate data set (available from the Clark County Department of Comprehensive Planning); parcels corresponding to parks were also coded as agricultural. Other uses such as community facilities, transportation, and minor improvements were classified as commercial as they are more related to commercial uses. The streets are not identified by the CCAO under a land-use code, but can be identified using additional codes available in the parcel layer (PCLSUBD between 90 and 99). The construction year is included in the parcel attributes for land uses 1 through 4 only.

For the purpose of this study, the land use was initially reclassified using categories to match categories used by the Las Vegas Valley Storm Water Quality Management Committee as part of the NPDES Municipal Storm Water Discharge Permit, constituent load model (Harza, 2000-2001 report), as shown in Table 2.
Table 2. Proposed Land-Use Classifications

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Vacant</td>
</tr>
<tr>
<td>1</td>
<td>Residential</td>
</tr>
<tr>
<td>2</td>
<td>Industrial</td>
</tr>
<tr>
<td>3</td>
<td>Commercial</td>
</tr>
<tr>
<td>4</td>
<td>Agriculture, Parks &amp; Golf Courses</td>
</tr>
<tr>
<td>5</td>
<td>Streets</td>
</tr>
</tbody>
</table>

Coding the developed parcels with the corresponding development date was straightforward from the attributes in the CCAO data files, except for the streets, which has no specific attributes, other than an indication as right-of-way. One way to code the streets with development date was to use proximity tools in GIS to assign a date equal to that of adjacent parcels. This method assumes that the streets will be developed prior to or at the same time the parcels are developed; however, this may not be true all the time, especially in the case of highways and major streets. Additionally, most of the streets’ polygons are continuous and are not divided to match the surrounding parcels. For this method to be effective and interactive, manual verification will be needed, which involves inspecting annual aerial photographs of the urban valley and will require an enormous amount of time that is beyond the scope of this study. Another method would have been to use satellite images and image analysis tools and software to derive an inventory of the street network,
but again, such a process will require an annual satellite image of the valley that is not available. Therefore, streets were eliminated from the contributing land uses, and the focus of the study was put on the main category of urban land uses and their related water quality parameters.

When we considered the industrial and commercial land uses within the urban valley, we found it difficult to distinguish between the two uses in terms of their possible impact on water quality. For example, a warehouse that is used for receiving and shipping merchandise can be classified as industrial, while an outlet where the merchandise is sold can be classified as commercial. Industrial land uses in the urban valley do not indicate manufacturing activities. To simplify the land-use classifications, industrial and commercial categories were combined into one category. The following three classes of land use were selected for this study:

1. Residential, including all single family homes, multi-family units, apartments, townhomes, and mobile home parks.
2. Nonresidential, including all other uses, such as commercial and industrial facilities, hotels, and government buildings.
3. Parks and golf courses, including all agricultural uses and ranches.

The output of this process was a valley-wide, land-use layer, including the attributes of the three selected land-use classifications and the construction year, classified up to 1992 and through 2002 by year. Individual land-use layers by year were generated from this layer and used
in identifying contributing land uses for each of the selected water quality monitoring events. The maps in Figure 3 show an example of the classified valley-wide land use in 1991 and 2001.

![Image of classified land use maps for 1991 and 2001]

Figure 3. Valley-Wide Classified Land-Use, 1991 and 2001

Water Quality Data

In 1990, the Nevada Division of Environmental Protection (NDEP) issued a National Pollutant Discharge Elimination System (NPDES) Permit to the municipalities in the Las Vegas Valley, allowing them to discharge from storm water outfalls to the LVW and its tributaries (NPDES Permit No. NV0021911). As part of the co-permitees’ compliance with the conditions of this permit, they were required to conduct storm water quality monitoring and report annually on the quality of urban runoff.
water as it enters the LVW from the different tributaries. These reports have been prepared annually since 1991 by the consulting engineering firm Montgomery Watson Harza for the Las Vegas Valley Storm Water Quality Management Committee.

Two separate monitoring programs are conducted to meet the permit requirements:

1. Dry weather-monitoring program. Monitoring started in 1991. The objectives of this program were to target potential illegal or illicit discharges to municipal sewer system and to develop a baseline of dry weather surface water quality. Initially, this program collected samples from six sites. In 1998, some modifications were made to this program, including disabling some monitoring stations and some changes to the measured parameters. Starting in 2000, the Southern Nevada Water Authority (SNWA) administered this program; additional changes were made to the program including adding new monitoring sites. Only two sites on the major tributaries to the LVW had monitoring history long enough to be considered for this study—Duck Creek and Flamingo Wash—both with 10 years history of historical data; both sites are shown in Figure 4.

2. Wet weather-monitoring program. Monitoring started in 1992. Samples were collected at several tributaries to the LVW. The locations on the four major tributaries were selected for this study; Duck Creek (DC), Flamingo Wash (FW), Western Tributaries (WT),
and Sloan Channel (SC). These four locations and their reference watersheds are shown in Figure 4.

![Figure 4. Selected Water Quality Monitoring Sites](image)

Wet-weather data was selected for this study as it provided us with more observation over the study period. One of the objectives of the wet-weather monitoring program is to collect up to two runoff samples from a representative or typical storm event. In order to evaluate the seasonal effects, the program included the objective to sample from one storm in the winter/spring period and one storm in the summer/fall period when possible.
Table 3. Water Quality Monitoring Dates and Locations

<table>
<thead>
<tr>
<th>Date of WQ Collection</th>
<th>Watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WT</td>
</tr>
<tr>
<td>8/30/1992</td>
<td>X</td>
</tr>
<tr>
<td>10/24/1992</td>
<td>X</td>
</tr>
<tr>
<td>2/8/1993</td>
<td>X</td>
</tr>
<tr>
<td>5/14/1993</td>
<td>X</td>
</tr>
<tr>
<td>6/5/1993</td>
<td>X</td>
</tr>
<tr>
<td>8/4/1993</td>
<td>X</td>
</tr>
<tr>
<td>8/5/1993</td>
<td>X</td>
</tr>
<tr>
<td>2/4/1994</td>
<td>X</td>
</tr>
<tr>
<td>3/25/1994</td>
<td>X</td>
</tr>
<tr>
<td>7/19/1994</td>
<td>X</td>
</tr>
<tr>
<td>8/9/1994</td>
<td>X</td>
</tr>
<tr>
<td>8/19/1994</td>
<td>X</td>
</tr>
<tr>
<td>1/24/1995</td>
<td>X</td>
</tr>
<tr>
<td>5/24/1995</td>
<td>X</td>
</tr>
<tr>
<td>8/12/1995</td>
<td>X</td>
</tr>
<tr>
<td>1/31/1996</td>
<td></td>
</tr>
<tr>
<td>2/20/1996</td>
<td></td>
</tr>
<tr>
<td>3/13/1996</td>
<td>X</td>
</tr>
<tr>
<td>7/14/1996</td>
<td></td>
</tr>
<tr>
<td>11/21/1996</td>
<td>X</td>
</tr>
<tr>
<td>4/2/1997</td>
<td></td>
</tr>
<tr>
<td>7/22/1997</td>
<td></td>
</tr>
<tr>
<td>7/28/1997</td>
<td>X</td>
</tr>
<tr>
<td>8/8/1997</td>
<td></td>
</tr>
<tr>
<td>9/1/1997</td>
<td>X</td>
</tr>
<tr>
<td>9/25/1997</td>
<td></td>
</tr>
<tr>
<td>2/3/1998</td>
<td></td>
</tr>
<tr>
<td>2/24/1998</td>
<td></td>
</tr>
<tr>
<td>8/14/1998</td>
<td></td>
</tr>
<tr>
<td>9/8/1998</td>
<td>X</td>
</tr>
<tr>
<td>6/2/1999</td>
<td>X</td>
</tr>
<tr>
<td>9/22/1999</td>
<td>X</td>
</tr>
<tr>
<td>2/16/2000</td>
<td>X</td>
</tr>
<tr>
<td>8/30/2000</td>
<td>X</td>
</tr>
<tr>
<td>2/26/2001</td>
<td></td>
</tr>
<tr>
<td>7/6/2001</td>
<td></td>
</tr>
</tbody>
</table>
Representative events are defined as having a total rainfall depth of 0.1 to 0.8 inches at any rain gauge within the drainage area tributary to a monitoring station. Whenever possible, flow-weighted composite samples were collected for the first three hours of the runoff event or for the entire event, whichever was shorter. When sampling equipment was not functioning properly, or not effective due to low-flow depths, grab samples were then taken from the flow. These samples were then composited in the laboratory for analysis (Harza, 2001-02 report). Table 3 shows the available monitoring dates and locations in the selected watersheds.

Water Quality Parameters

The constituents analyzed as part of the NPDES wet and dry-weather monitoring program included more than 47 parameters. Many of those parameters were not consistently measured at every sampling event. Some parameters were not measured at every event, while others were indicated to be lower than a certain value, such as oil and grease being <3 most of the time, which does not allow for the ability to detect change over time. Only 15 parameters were analyzed frequently enough to support this study. These parameters are shown in Table 4. Previous studies (e.g. Bahduri et al., 2000) showed many of these parameters to be related to urban NPS pollution.
Selecting Water Quality Parameters

Pollutants that occur in urban areas vary by land-use source of runoff.

The major pollutants found in urban runoff include sediments (Howarth, 1991; McMahon, 1998), nutrients (EPA, 2003; Basnyat, 2000), increased alkalinity (Wang & Yin, 1997), phosphorous, nitrate and nitrogen (Halls, 2002; Soranno, 1996; Tong et al., 2002), metals (Bahduri 2000, Tong et al., 2002; EPA, 2003), petroleum hydrocarbons (EPA, 2003), salts (Prowse, 1984; Wang & Yin, 1997), and BOD (Tong et al., 2002). These pollutants vary by the land-use source of the runoff.

Table 4. Measured Water Quality Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Oxygen Demand (BOD)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Boron</td>
<td>mg/L</td>
</tr>
<tr>
<td>Chemical Oxygen Demand (COD)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Copper</td>
<td>mg/L</td>
</tr>
<tr>
<td>Lab PH</td>
<td>units</td>
</tr>
<tr>
<td>Lead</td>
<td>mg/L</td>
</tr>
<tr>
<td>Nitrogen as Ammonia (NH3-N)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Nitrogen as Nitrate (NO3-N)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Ortho Phosphate (OP4)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen (TKN)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Nitrogen (TN)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Phosphorous (TP)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS)</td>
<td>mg/L</td>
</tr>
<tr>
<td>Zinc</td>
<td>mg/L</td>
</tr>
</tbody>
</table>
Different land uses may contribute different amounts and ratios of pollutants. To understand the dynamic interaction between land-use and surface water quality, the known sources of specific pollutants were identified and tabulated in Table 5 below based on these studies.

Table 5. Water Quality Parameters and Their Land-Use Sources

<table>
<thead>
<tr>
<th>Pollutant/Urban Land-use sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Suspended Solids (TSS):</td>
</tr>
<tr>
<td>TSS are solids in water that can be trapped by a filter. Sources include particles and debris from impervious surfaces, construction sites, loss of vegetation cover (soil erosion), decaying plants and animals, and effluent from wastewater treatment plants (Moran et al., 1980; Carpenter et. al, 1998).</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS):</td>
</tr>
<tr>
<td>TDS is a measure of the amount of material dissolved in water, such as salts, carbonate, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and other ions. Sources include salts and fertilizers from lawns, soil erosion, construction, mining and decaying plants and animals (dissolved organic particles released), and effluent from wastewater treatment plants (phosphorus, nitrogen, and organic matters). Natural sources include certain rock types that dissolve under water like rocks containing calcium and carbonate ions (Prowse, 1984; Wang &amp; Yin, 1997).</td>
</tr>
</tbody>
</table>
Table 5. Cont.

Alkalinity (pH):

<table>
<thead>
<tr>
<th>pH is a measure of the water acidity (concentration of carbonate, bicarbonate, and hydroxide content) on a scale of 0 to 14. pH for neutral water is 7, alkaline water has higher pH values (8-14), and acidic water has low pH values (0-6). Sources of pH include agricultural return flow. Organic acids produced by decaying organic matters (plants and leaves) increase acidity, lowering pH to under 7. Other sources of acid include acid mine drainage and atmospheric acid deposition. Dissolved metals increase alkalinity (Nordstrom et al., 2000).</th>
</tr>
</thead>
</table>

Nutrients:

<table>
<thead>
<tr>
<th>Sources include residential and commercial lawns, agricultural and golf courses runoff (fertilizers), organic decomposition, decaying of human and animal waste, wastewater treatment plants, septic tanks, and the burning of fossil fuel and industrial waste (Barth, 1995). TKN is organically bound nitrogen (combination of ammonia and organic nitrogen). OP₄ is an inorganic water-soluble form of phosphorus that comes from fertilizers, animal waste, laundry detergents, and some natural rocks. TP represents a combination of orthophosphate, condensed phosphate, and organic phosphate (EPA, 1993).</th>
</tr>
</thead>
</table>

Metals:

<table>
<thead>
<tr>
<th>General sources include atmospheric depositions from vehicle and power plant emissions, roads and parking lot deposits (Santa Clara Nonpoint</th>
</tr>
</thead>
</table>
Source Pollution Program (NPSPG, 1992), mining, smelting, and processing of metal containing materials, industrial waste discharge, and agriculture (fertilizer and pesticides). Lead sources include batteries, gasoline, paints, caulking, and rubber. Sources of copper include electrical equipment, pesticides, paint additives, preservatives, corrosion in condensation systems, and heat exchangers. Zinc is present in much of the earth's crust; common sources of zinc include deterioration of galvanized iron, dezincification of brass, and industrial pollution (Bahduri, 2000; Tong et al., 2002; EPA, 2003).

Organic Material (BOD and COD):

BOD is a measure of the amount of oxygen consumed in the biological process that breaks down organic matters in water. COD is a measure of oxygen required to oxidize all compounds (organic and inorganic) in water. Both BOD and COD provide an indirect measure of the concentration of biologically degradable and organic material present in water. Sources include plant decay, leaf fall, grass clippings and yard waste in water, pulp and paper mills, meat and food processing plants, vehicles (engine coolants/antifreeze), agricultural runoff, livestock operation, and treatment plant loading. COD values are generally higher than BOD, because more compounds can be chemically oxidized than biologically oxidized by bacteria (EPA, 1993).
Boron:

Boron is a naturally occurring element in the environment, primarily obtained from mines in arid regions, and it is used in flares, propellant mixtures, nuclear reactor control elements, and hard metallic alloys. Human activities releasing boron into the environment include: using fertilizers containing borate and herbicides; burning of domestic waste, wood, and fossil fuel; leaching from treated wood and paper; and the disposal of sewage and sewage sludge (USGS, 1998).

Watershed Delineation

The Digital Elevation Model (DEM) is a digital representation of a topography. In GIS, DEM is a grid data structure, which consists of a matrix of square cells. Each cell stores the mean elevation of the area it covers. The most widely available DEMs are those distributed by the U.S. Geological Survey (USGS). They are produced mainly using elevation data derived from existing contour maps, usually available in grid spacing of 30 by 30 meters.

Using the USGS DEM data set for watershed modeling in a highly urbanized area like the Las Vegas Valley proved to be ineffective for two reasons:
1. Because the study areas have been highly developed, the topography has been altered, and the USGS DEM is not a true representation of the current topography.

2. The Clark County Regional Flood Control District (CCRFCD) has implemented several flood control projects (conveyance system), which have altered the natural flow of the surface runoff.

The issue of the flood control facilities is critical, as several sub-watersheds might be diverted completely around or to the selected water-quality monitoring site. To address this issue, a DEM data set that was generated from rectified digital aerial photographs by the Clark County GIS Management Office (GISMO) (2003) was used. The DEM generated from this data set reflects and accounts for urban development in the valley, such as roadways and new drainage facilities. This DEM covers only the urban area of the valley and can be considered a high resolution DEM, with a cell size of 40 feet by 40 feet.

The process of generating watersheds from a DEM is involved and requires several steps. First, the DEM data has to be preprocessed for hydrological analysis to address issues of data discrepancies. The following steps describe this process (Maidment & Djokic, 2000):

1. Fill the sinks in the elevation grid (DEM). This process will remove small imperfections in the data by removing peaks and sinks, which are often errors due to resolution of the data, rounding of the elevations to the nearest integer value, or joining several tiles.
together. The fill algorithm eliminates the sinks by either raising the
elevation value of the sink point to that of its lowest neighbor or
lowering the elevation of the saddle point surrounding the sink. This
process allows the system the ability to generate a continuous flow
direction network by computing the flow direction through adjacent
cells to the watershed outlet.

2. Stream burning is the process of enforcing an existing drainage
network in the DEM to force the flow through the grid cells
corresponding to the streamline network, in this case, the flood
control facilities and the existing LVW. This process modifies the
elevation values of the grid cells corresponding to the burned stream
network to maintain local uniform descent, putting these cells at the
bottom of their surrounding cells.

3. Create a flow direction grid. This step computes the direction of flow
through each cell in the grid. The flow in each cell will be
determined by comparing the cell elevation value to its eight
neighboring cells. The flow direction will be assigned from the cell to
its steepest down-slope neighbor.

4. Create a flow accumulation grid, which computes the accumulated
flow in each cell. The accumulation here is a count of all up-gradient
cells that contribute flow through a cell. The cells that have the
highest flow will represent the stream network. The stream network
can be created at any desired detail by choosing the appropriate
volume value, which corresponds to the number of cells flowing into one cell to make it part of the stream network (500 cells threshold was used in this study).

Using the location of the water quality monitoring points, the flow direction and flow accumulation grids; the contributing watershed for every point was delineated interactively. The monitoring point was snapped to the nearest stream grid cell. The point must be located exactly over a grid cell that is a member of the defined stream grid; otherwise, delineating a watershed will result in a small, incomplete watershed (Maidment & Djokic, 2000). Repeating the process for the selected four monitoring points, the overall contributing watersheds were generated, as shown in Figure 4.
CHAPTER 3

DATA ANALYSIS AND RESULTS

Contributing Land Uses

To establish the association between water quality parameters at the watershed outlet and land uses in the watershed, first we must identify the contributing land uses based on runoff events leading to water quality sampling. Contributing land uses are defined as the land-use cells generating surface runoff at the time of collecting the water samples.

Rainfall events are the driving force behind the timing and location of water quality sampling. The National Pollutant Discharge Elimination System (NPDES) monitoring process established that water quality samples were collected at any sampling point if a rainfall event with a depth of 0.1 to 0.8 inches were recorded at any rain gauge within the drainage area. Rainfall data is available from the Clark County Regional Flood Control District (CCRFCD) website (CCRFCD, 2002). Data can be summarized and reported as monthly totals by a gauging station. Custom reports can be extracted from the samples obtained at a gauging station and for any specific time frame.

Annual NPDES reports from 1992 through 2003 provide a good summary and tables of the measured water quality parameters. Water
quality sampling was carried out when precipitation was detected in the reference watershed for at least three hours. Since the sampling time was not clearly recorded for every sampling event, tracing back the amount of rainfall for the defined three-hour period cannot be done. Therefore, the preceding 24 hours' total rainfall was used as an estimate of the storm event leading to water quality sampling.

Using the interactive reporting methods on the CCRFCD website (CCRFCD, 2002), total rainfall for the 24 hours preceding WQ monitoring was extracted by gauging station and exported to a GIS tables. Using GIS table join functionality, these tables were assembled and related to a GIS layer showing the location of the rainfall gauging stations. For every sampling event, a new layer of the rainfall gauging stations and the 24-hour total rainfall was created. To convert this discrete rainfall data to a continuous rainfall grid, the Inverse Distance Weighting (IDW) spatial interpolation method in ArcGIS was used (Maidment, 1993). A rainfall grid (120 feet cell size) was generated for every storm event leading to water quality sampling. The cell value in the rainfall grid represents the estimated, 24-hours total amount of rain at that location.

Using GIS spatial overlay functionality and by overlaying the corresponding land-use layer, the amount of rainfall on every land-use cell was determined. Based on each land-use cell runoff coefficient and total rainfall, cells generating runoff were identified and considered to be part of the contributing land uses for that storm event.
Surface Runoff Coefficient

The runoff coefficient is the fraction of rainfall that is converted to surface runoff in storm event. This ratio, which depends mainly on the surface condition of the land (land use/land cover), can be greatly affected by several factors, such as climate and physical conditions and soil types, including saturation level and moisture content.

There are several ways to estimate surface runoff caused by a storm event. The Soil Conservation Service (SCS) presents the most popular method for estimating direct runoff from storm rainfall, based on a runoff Curve Number [United States Department of Agriculture (USDA), 1972]. The curve number is a function of land use and soil type. The principal application of this method is in estimating quantities of runoff in flood hydrographs, in relation to flood peak rates. It is understood that surface runoff occurs only when the rainfall rate is greater than the infiltration rate, and after the initial demands of interception, infiltration, and surface storage has been satisfied, surface runoff flowing down dry channels of watersheds in dry, arid climates is reduced by transmission loss, which can be large enough to eliminate runoff entirely (USDA, 1972).

In this method, the accumulated runoff \( Q_t \) at time \( t \) can be expressed by this formula:

\[
Q_t = \frac{(Pt - la)^2}{(Pt - la + S)}
\]
Where \((Pt)\) is the accumulated precipitation, \(I_a\) is the initial abstraction (maximum amount of water which can be retained on the surface before runoff occurs).

\[
I_a = 0.8S
\]

Where \(S\) is the potential maximum retention of water after runoff begins, \(S\) is defined as:

\[
S = \left\lfloor \frac{1000}{CN} \right\rfloor - 10
\]

Where CN is the Curve Number, which is a function of land use, land cover, and soil type, as defined in the hydrological soils group classification.

This method is more appropriate for agricultural and forested watersheds. It was used by some researchers (Yu et al., 2001; Weng, 2001) to build spatially distributed models to simulate storm flow using GIS. Other researchers (Wood & Blackburn, 1984), however, have pointed out that using the Curve Number method is not appropriate for highly urbanized, arid and semi-arid regions, as is the case in the Las Vegas Valley. Additionally, the soil types in the urban area seem to be limited to types B and C (mostly type B), which makes this method less effective for this study. Figure 5 shows the variation in soil types (Hydrological Soils Group HSG) in reference to the selected watersheds.
Schueler (1987) introduced a different method to estimate runoff coefficient base on land-use percent impervious. Using data from three catchments in the Washington D.C. area and 44 small urban catchments monitored during the Nationwide Urban Runoff Program (NURP), Schueler developed a regression formula estimating the runoff coefficient ($R_v$) as a function of imperviousness (Reginato & Piechota, 2004):

$$R_v = 0.05 + 0.009 I$$
Where \( I \) is the percent impervious, for the Las Vegas Valley, the percent impervious is given in the *Hydrologic Criteria and Drainage design Manual* adopted by the Clark County Regional Flood Control District (CCRFCD, 1999).

This regression formula, as recommended by Schueler (1987), was adopted by the Las Vegas Valley Stormwater Quality Management Committee to generate base runoff coefficients for use in pollutant load computation and modeling. However, when considering storm-based surface runoff in a highly urbanized and arid area like the Las Vegas Valley, several issues should be considered:

1. The magnitude of the rainfall is important because the fraction of rainfall converted to runoff becomes larger as the size and intensity of the storm does.
2. The temporal distribution of the storm event is important because the magnitude of surface runoff depends on whether the total rainfall was in a single short storm event or was in smaller storms over a longer period of time.
3. Antecedent moisture conditions also affect the fraction of rainfall, which can be converted to runoff.

The Schueler (1987) formula incorporates the important variable of imperviousness in determining the base runoff coefficient, which is critical for an area like the Las Vegas Valley, but it does not address any of the other important issues discussed above. Additionally, none of this
information is available for the time frame of this study; therefore, calibrating the base runoff coefficients using measured rainfall and runoff values seemed to be the best option for generally estimating land-use-based runoff coefficients specific to the Las Vegas Valley.

This calibration effort was done by Montgomery Watson as part of the Las Vegas Valley pollutant load model, discussed in the NPDES annual reports of 1998-1999 and 2000, and by Reginato and Piechota (2004), in an effort to calculate the annual pollutant loading to the Las Vegas Wash from nonpoint sources. These calibrated runoff coefficients may be very different than typical values used in modeling storm-based runoff processes, and taking into consideration the large amount of uncertainty in runoff coefficients for arid and semi-arid regions such as the Las Vegas Valley (Reginato and Piechota, 2004), we believe these coefficients are the best available estimate for the study area. Industrial and commercial coefficients were averaged to generate the nonresidential coefficients.

Using these runoff coefficients, based on the corresponding land-use grid, a new runoff coefficient grid was generated for every year from 1992 to 2001. Using the ArcGIS raster calculator function, the rainfall grid was multiplied by the runoff coefficient grid, which resulted in the calculated runoff for every land-use cell. Those cells that generated runoff more than zero (0.05") were considered to be part of the contributing landuses for that storm event. Depending on the amount and distribution of the
rainfall, the contributing land uses can be very different than the actual land-uses in the watershed.

Table 6. Calibrated Runoff Coefficient Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential</th>
<th>Nonresidential</th>
<th>Golf/Parks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.067</td>
<td>0.130</td>
<td>0.016</td>
</tr>
<tr>
<td>1993</td>
<td>0.050</td>
<td>0.097</td>
<td>0.012</td>
</tr>
<tr>
<td>1994</td>
<td>0.046</td>
<td>0.088</td>
<td>0.011</td>
</tr>
<tr>
<td>1995</td>
<td>0.051</td>
<td>0.100</td>
<td>0.012</td>
</tr>
<tr>
<td>1996</td>
<td>0.083</td>
<td>0.160</td>
<td>0.020</td>
</tr>
<tr>
<td>1997</td>
<td>0.128</td>
<td>0.246</td>
<td>0.031</td>
</tr>
<tr>
<td>1998</td>
<td>0.126</td>
<td>0.244</td>
<td>0.031</td>
</tr>
<tr>
<td>1999</td>
<td>0.237</td>
<td>0.458</td>
<td>0.057</td>
</tr>
<tr>
<td>2000</td>
<td>0.094</td>
<td>0.181</td>
<td>0.023</td>
</tr>
<tr>
<td>2001</td>
<td>0.055</td>
<td>0.106</td>
<td>0.013</td>
</tr>
</tbody>
</table>

Contributing land uses can be very different from actual land-uses in the watershed. For example, Figure 6 shows the total land uses in the Duck Creek watershed for 2001 (on the left) and the contributing land-uses for the storm event on July 6, 2001, (on the right). Contributing land uses for every storm event were summarized in GIS and exported into an excel table that included the total number of cells in each land-use class and the corresponding water quality parameters for use in the statistical analysis software. Table 12 in Appendix I shows contributing land uses, and Table 13 in Appendix I shows measured water quality parameters for every storm event.
Spatial Analysis of Land-Use Data

Before examining the relationships between land-use spatial patterns and surface WQ, land-use patterns must be identified and quantified in a meaningful way. For the purpose of this study, spatial patterns were classified into two different categories: clustered and fragmented patterns.

Clustered patterns can be identified when most of the contributing land uses are clumped into fewer large-size patches across the landscape. The pattern is considered fragmented if the same amount of land uses are dispersed into a larger number of smaller size patches and more spread across the landscape (Rutledge, 2003).

In general, land uses in a given landscape can be considered to have two basic components: (1) composition and (2) configuration (Rainis, 2003). Composition is a nonspatial characteristic that measures the
amount and types of land uses without reference to their spatial geometry or geographic location. Configuration, on the other hand, relates to the spatial characteristics of land uses in a given area.

Spatial configuration references a complex set of patch and landscape based statistical measures or metrics. These metrics describe the landscape composition by quantifying several attributes that describe the geometry, size, shape, and spatial positioning of land-use patches in the reference watershed (Rutledge, 2003; Rainis, 2003). In this study, a patch is defined as a group of contiguous raster cells that have the same land-use classification.

More than 45 metrics have been developed by different researchers for the analysis and quantification of landscape patterns and structure, mainly in the field of landscape ecology (McGarigal & Marks, 1995). For the purpose of this study and based on previous research (Ritters, 1995; Herzog & Lausch, 1999; Irwin, 2002; Rutledge, 2003; Rainis, 2003), six landscape metrics were identified to describe the spatial patterns (fragmentation/clustering) of urban land uses. These metrics are described in Table 7.

Several commercial and public domain GIS-based software packages are available and can be used as tools to calculate different sets of metrics. In this study, Patch Analyst (Rampel et al., 1999), an extension to ArcView GIS, was used to calculate the identified metrics for every observed event, as shown in Table 14 in Appendix I.
<table>
<thead>
<tr>
<th>Metric (Abbreviation)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Patches (NUMP)</td>
<td>Number of patches of a particular class. <em>Large</em> NUMP suggests more fragmentation</td>
</tr>
<tr>
<td>Mean Patch Size (MPS)</td>
<td>Average area of a patch of a particular class. <em>Small</em> MPS indicates more fragmentation</td>
</tr>
<tr>
<td>Largest Patch Index (LPI)</td>
<td>Percent of landscape area occupied by the largest patch of a class, value from 0 to 1. <em>Small</em> LPI indicates more fragmentation</td>
</tr>
<tr>
<td>Total Edge (TE)</td>
<td>Total edge length of a class in map units. <em>Large</em> TE indicates more fragmentation</td>
</tr>
<tr>
<td>Mean Nearest Neighbor (MNN)</td>
<td>The mean distance between patches of the same class (edge-to-edge); this is a measure of the degree of isolation and fragmentation. <em>Large</em> MNN indicates more fragmentation; patches are further away from each other. <em>Small</em> MNN indicates that patches are more clustered together.</td>
</tr>
<tr>
<td>Mean Proximity Index (MPI)</td>
<td>Another measure of isolation (similar to MNN). <em>Large</em> MPI indicates that patches are less isolated and less fragmented in the distribution (more contiguous). <em>Small</em> MPI indicates more fragmentation</td>
</tr>
</tbody>
</table>
Watershed/Land Use Variables

Land-use variables were classified into four main variables based on the amount and types of contributing land uses. They are:

1. Total contributing area (TCA), which includes all land-uses in the watershed regardless of type.
2. Total residential land uses (TC_R), where only residential uses were considered.
3. Total nonresidential land uses (TC_NR), which includes a combination of commercial and industrial uses.
4. Total agricultural, parks and golf courses (TC_GP).

Several land-use and watershed variables can affect the relationship between the contributing land uses and the surface water quality parameters. These variables involve the amount, types, and distribution of contributing land uses, but also other background and physical watershed characteristics, such as the climate conditions at the time of water sampling, the amount of the contributing land uses, the size and characteristics of the rainfall event, and the first-flush factor.

Preparing the data for correlation analysis (64 independent observations were assembled from available water quality monitoring records), the selected watersheds were categorized into four groups based on additional land uses/watershed variables that were expected to impact the effect of land use on surface water quality. In each of the groups, the
identified land use variables (total amount, types and spatial patterns) were used in the correlation analysis; these four groups were based on:

1. Size of total contributing area. Two groups were identified: large watersheds (larger than the median) and small watersheds (smaller than the median).

2. The season of water quality sampling. This variable was mentioned as an objective of the NPDES monitoring program. The difference in the climate conditions between these seasons might affect the amount and characteristics of surface flow and have some impact on the correlation between the water quality parameters and the contributing land uses.

3. First-flush factor (rainfall events after prolonged dry period). Based on the amount of rainfall in the month preceding water quality sampling, two conditions were identified: dry and wet conditions. Dry classification indicates there were zero inches of rainfall in the preceding month of water sampling. Wet classification indicates the watershed had either a wet month prior to the water sampling or more rainfall was recorded in the same month prior to water sampling. This identification of a wet or dry event was based on the monthly average of recorded rainfall in each watershed. Monthly rainfall data was extracted from the CCRFCD website (CCRFCD, 2002) and coded into a GIS database, by rainfall gauging station. The monthly average of all gauging stations by watershed was
calculated and used as an indication of the amount of rain for that month. The season and dry or wet classifications are shown in Table 36 in Appendix I.

4. For observations over time in the same watershed, correlation analysis was carried out against observations in each of the four watersheds separately.

Using these categories, the association between the contributing land uses and the surface water quality parameters at the watershed outlet were analyzed using the Pearson correlation method with a 95% confidence level ($P < 0.05$). This step identified the land-use conditions and watershed characteristics that have an impact on the relationship between the contributing land uses and the surface water quality parameters. Variables that showed no association with water quality parameters were excluded. Variables with significant correlation were used to test the research hypotheses.

**Land-Use Correlation Analysis**

To examine the overall association between changes in land use and changes measured in surface water quality parameters, the Minitab Pearson correlation method with a significance level of 95% ($\alpha = 0.05$) was used to calculate the correlated r-values.

Initially all observations across the four watersheds were considered ($n = 64$). The total amount and types of contributing land uses were
correlated with all measured water quality parameters. A weak but significant correlation was observed between zinc and TCA \((r = 0.263, p = 0.036)\); the results are shown in Table 15 in Appendix I. Considering the types of the contributing land uses, the correlation results showed a weak but significant correlation between TC_NR and zinc \((r = 0.295, p = 0.018)\) (Table 15 in Appendix I).

Based on the established watershed/land-use characteristics that were expected to impact the surface water quality parameters, the available observations were grouped according to the aforementioned established criteria. The same correlation analysis was carried out in each of the groups, which is discussed below:

1. Size of the total contributing area: The available watersheds ranged in size from 6,758 to 53,012 cells, with a median of 32,079 cells. The watersheds were classified into two groups: Large watersheds (larger than the median, 32 observations), and small watersheds (smaller than the median, 32 observations). Some weak but significant correlations were observed in the small watersheds group between: TCA (TDS, NH3-N, Total N, and BOD), TC_R (Total N and BOD), and TC_NR (copper and zinc), as shown in Table 8 and Figures 7 to 9. All results are shown in Table 16 in Appendix I. The group of large watersheds did not show any significant correlation between the land uses and water quality parameters. Results are shown in Table 17 in Appendix I.
Table 8. Correlated Variables in Small Watersheds, (n= 32)

<table>
<thead>
<tr>
<th></th>
<th>TCA</th>
<th>TC_R</th>
<th>TC_NR</th>
<th>TC_GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDS</td>
<td>0.365</td>
<td>0.317</td>
<td>0.030</td>
<td>0.109</td>
</tr>
<tr>
<td></td>
<td>0.040</td>
<td>0.077</td>
<td>0.870</td>
<td>0.552</td>
</tr>
<tr>
<td>NH3-N</td>
<td>0.374</td>
<td>0.264</td>
<td>0.166</td>
<td>0.086</td>
</tr>
<tr>
<td></td>
<td>0.035</td>
<td>0.144</td>
<td>0.365</td>
<td>0.640</td>
</tr>
<tr>
<td>TOTAL N</td>
<td>0.354</td>
<td>0.367</td>
<td>-0.048</td>
<td>-0.025</td>
</tr>
<tr>
<td></td>
<td>0.047</td>
<td>0.039</td>
<td>0.794</td>
<td>0.890</td>
</tr>
<tr>
<td>COPPER</td>
<td>0.020</td>
<td>-0.148</td>
<td>0.419</td>
<td>-0.208</td>
</tr>
<tr>
<td></td>
<td>0.914</td>
<td>0.419</td>
<td>0.017</td>
<td>0.253</td>
</tr>
<tr>
<td>ZINC</td>
<td>0.038</td>
<td>-0.136</td>
<td>0.422</td>
<td>-0.190</td>
</tr>
<tr>
<td></td>
<td>0.838</td>
<td>0.459</td>
<td>0.016</td>
<td>0.297</td>
</tr>
<tr>
<td>BOD</td>
<td>0.377</td>
<td>0.428</td>
<td>-0.149</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>0.044</td>
<td>0.020</td>
<td>0.411</td>
<td>0.796</td>
</tr>
</tbody>
</table>

Cell Contents: Pearson correlation
P-Value

Figure 7. TCA vs. WQ Parameters (Small Watersheds), the X-Axis Indicates TCA, the Y-Axis Indicates WQ Parameters
Figure 8. TC_R vs. WQ Parameters (Small Watersheds), the X-Axis Indicates TC_R, the Y-Axis Indicates WQ Parameters

Figure 9. TC_NR vs. WQ Parameters (Small Watersheds), the X-Axis Indicates TC_R, the Y-Axis Indicates WQ Parameters
2. Season of water quality sampling: Based on the seasonal timing of the water quality sampling, two groups of observations were established: summer/fall (36 observations), winter/spring (28 observations). Winter/spring observations showed a low correlation between TC_GP and pH ($r = 0.411$, $p = 0.041$) and TCA and zinc ($r = 0.385$, $p = 0.043$). In the summer/fall observations, a low correlation was observed between TC_NR and copper ($r = 0.329$, $p = 0.050$). All results are shown in Tables 18 and 19 in Appendix I.

3. Pre-storm event classification/first-flush factor: Based on the dry/wet event classification, two groups of watersheds were identified: 38 dry observations and 26 wet observations. The wet weather observations did not show any significant correlation. In the dry weather observations, zinc was weakly but significantly correlated with TCA ($r = 0.398$, $p = 0.013$) and TC_NR ($r = 0.324$, $p = 0.047$). All results are shown in Tables 20 and 21 in Appendix I.

4. Observations in the same watershed. There are a total of 64 independent observations across the four watersheds for the time frame of this study (16 observations in Flaming Wash (FW) and Western Tributaries (WT), 19 in Duck Creek (DC), and 13 in Sloan Channel (SC) (Table 9). The available watersheds have some differences in size, the amount of development, the number of observations, and the water quality monitoring history. Duck Creek watershed showed the most significant association between land
uses and some of the water quality parameters. TDS and boron were highly correlated with TCA, TC_R and TC_NR. Zinc was correlated with TCA and TC_GP.

Table 9. Correlated Variables by Watershed

<table>
<thead>
<tr>
<th></th>
<th>TCA</th>
<th>TC_R</th>
<th>TC_NR</th>
<th>TC_GP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duck Creek, (n = 19)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>-0.687</td>
<td>-0.697</td>
<td>-0.707</td>
<td>-0.315</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.190</td>
</tr>
<tr>
<td>ZINC</td>
<td>0.469</td>
<td>0.428</td>
<td>0.419</td>
<td>0.549</td>
</tr>
<tr>
<td></td>
<td>0.043</td>
<td>0.068</td>
<td>0.074</td>
<td>0.015</td>
</tr>
<tr>
<td>BORON</td>
<td>-0.627</td>
<td>-0.644</td>
<td>-0.657</td>
<td>-0.229</td>
</tr>
<tr>
<td></td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
<td>0.346</td>
</tr>
</tbody>
</table>

| **Western Tributaries, (n = 16)** |           |           |           |           |
| LEAD              | 0.571     | 0.601     | 0.582     | 0.018     |
|                  | 0.021     | 0.014     | 0.018     | 0.498     |

| **Sloan Channel, (n = 13)** |           |           |           |           |
| LEAD              | 0.681     | 0.707     | 0.693     | 0.239     |

Cell Contents: Pearson correlation
P-Value

Flamingo wash observations showed no correlation, western Tributaries and Sloan Channel showed some moderate correlation between lead and TCA, TC_R, and TC_NR, Table 9 above shows the correlated variables in each watershed. All results are shown in Tables 22, 23, 24, and 25 in Appendix I.
Spatial Patterns Correlation Analysis

Landscape metrics identified in Table 7 were used to describe the spatial patterns of contributing land uses and to measure the sensitivity of the water quality parameters to changes in the spatial patterns of the contributing land uses.

Correlated variables are shown in Table 10. When analyzing the correlation results, we can identify a trend and some association between changes in these metrics and changes in surface water quality parameters. There are more water quality variables correlated with the landscape metrics than with the total amounts or types of contributing land uses. Even though the correlation is still low, what is interesting is that the direction of this association for the same parameters seems to change as the land-use spatial pattern changes from a fragmented to a clustered pattern. All results are shown in Table 26 in Appendix I.

It is noticeable in the data that when water quality parameters showed some correlation with the composition (amount and types) of the contributing land uses, the same parameters showed a stronger correlation with the changes in patterns (structure) of the contributing land uses. This trend was obvious when we compared the correlation results in the small watersheds category and observations in the same watershed.
Table 10. Landscape Metrics vs. WQ Variables (TCA, All Watersheds (n = 64))

<table>
<thead>
<tr>
<th></th>
<th>NUMP</th>
<th>TE</th>
<th>MPS</th>
<th>LPI</th>
<th>MPI</th>
<th>MNN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>-0.206</td>
<td>-0.151</td>
<td>0.240</td>
<td>0.256</td>
<td>0.261</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>0.103</td>
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<td>0.056</td>
<td>0.041</td>
<td>0.037</td>
<td>0.981</td>
</tr>
<tr>
<td>TDS</td>
<td>0.250</td>
<td>0.121</td>
<td>-0.388</td>
<td>-0.328</td>
<td>-0.376</td>
<td>-0.119</td>
</tr>
<tr>
<td></td>
<td>0.046</td>
<td>0.342</td>
<td>0.002</td>
<td>0.008</td>
<td>0.002</td>
<td>0.349</td>
</tr>
<tr>
<td>PH</td>
<td>-0.301</td>
<td>-0.192</td>
<td>0.394</td>
<td>0.299</td>
<td>0.359</td>
<td>0.174</td>
</tr>
<tr>
<td></td>
<td>0.026</td>
<td>0.160</td>
<td>0.003</td>
<td>0.026</td>
<td>0.007</td>
<td>0.204</td>
</tr>
<tr>
<td>TKN</td>
<td>0.309</td>
<td>0.258</td>
<td>0.247</td>
<td>-0.293</td>
<td>-0.231</td>
<td>-0.246</td>
</tr>
<tr>
<td></td>
<td>0.013</td>
<td>0.039</td>
<td>0.049</td>
<td>0.019</td>
<td>0.066</td>
<td>0.050</td>
</tr>
<tr>
<td>TOTAL N</td>
<td>0.266</td>
<td>0.204</td>
<td>-0.254</td>
<td>-0.285</td>
<td>-0.231</td>
<td>-0.273</td>
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<tr>
<td></td>
<td>0.033</td>
<td>0.106</td>
<td>0.042</td>
<td>0.022</td>
<td>0.067</td>
<td>0.029</td>
</tr>
<tr>
<td>BORON</td>
<td>0.147</td>
<td>0.033</td>
<td>-0.301</td>
<td>-0.231</td>
<td>-0.238</td>
<td>-0.018</td>
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<td>0.245</td>
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<td>0.016</td>
<td>0.066</td>
<td>0.024</td>
<td>0.891</td>
</tr>
<tr>
<td>BOD</td>
<td>0.290</td>
<td>0.195</td>
<td>-0.339</td>
<td>-0.321</td>
<td>-0.313</td>
<td>-0.212</td>
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<tr>
<td></td>
<td>0.032</td>
<td>0.154</td>
<td>0.011</td>
<td>0.017</td>
<td>0.020</td>
<td>0.120</td>
</tr>
<tr>
<td>COD</td>
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<td>-0.239</td>
<td>-0.290</td>
<td>-0.232</td>
<td>-0.255</td>
</tr>
<tr>
<td></td>
<td>0.023</td>
<td>0.032</td>
<td>0.079</td>
<td>0.032</td>
<td>0.088</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Cell Contents: Pearson correlation
P-Value

Hypothesis Testing

Two hypotheses were tested. The objective of the first hypothesis was to determine the level of association between the total amount and types of contributing land uses and water quality. Can the amount and types of contributing land uses fully explain the changes in surface water quality parameters at the watershed outlet?
H$_0$: The total amount and types of land uses in the contributing watershed cannot fully explain by themselves the variations in the water quality parameters at the watershed outlet.

H$_A$: WQ parameters can be fully explained by the total amount and types of the contributing land uses.

To reject this null hypothesis, a strong correlation between changes in the total amount and types of the contributing land uses and changes in the water quality parameters is expected. Considering the correlation results discussed in the previous section, the results do not present enough evidence to reject the null hypothesis. The strongest observed correlation was in the small watersheds category between TC$_R$ and BOD ($r = 0.43$, $p = 0.020$, and $r$-sq = 0.18), which indicates only 18% of the variation in the BOD can be explained by the contributing residential uses.

Some of the correlation results in the same watershed were very strong and more significant. However, these results were not consistent across the four watersheds. For example TDS and boron were significantly correlated with TCA, TC$_R$ and TC$_NR$ in DC watershed only. Only lead was significantly correlated with the same land-use variables in SC and WT watersheds. These results do not present evidence of an overall association between the total amount and types of contributing land uses and surface water quality parameters. Therefore, it is expected that other
land-use variables in the watershed will have a significant impact on this relationship.

The objective of the second hypothesis was to determine the associations between variations in the contributing land-use patterns and changes in the water quality parameters. The association was evaluated using the same Pearson correlation method to examine the sensitivity of the water quality parameters at the watershed outlet to variation in the spatial patterns of the contributing land-uses, and to determine whether the patterns of contributing land uses can be a significant factor affecting water quality parameters.

H₀: The variation in the spatial patterns of contributing land uses will have no association with changes in the surface water quality parameters at the watershed outlet.

Hₐ: The variation in the spatial patterns of the contributing land uses will have an association with the surface water quality parameters at the watershed outlet.

The correlation results between the two variables (landscape metrics describing spatial patterns and water quality parameters) were still low (r < 0.4) (Table 10). However, some trends in the association between the landscape metrics and some of the water quality parameters can be observed.

Landscape metrics were used to identify two different spatial patterns in the contributing land uses, as shown in Figure 7:
1. Fragmented pattern: The distribution is characterized by a large number of smaller patches, spread across the landscape. A fragmented pattern can be indicated by an increase in NUMP, TE, or MNN. A decrease in MPI indicates more fragmentation (McGarigal & Marks, 1995; Rainis, 2003).

2. Clustered pattern: The distribution is characterized by a smaller number of larger patches in close proximity to each other. A clustered pattern can be indicated by an increase in (MPS, LPI, or MPI). A decrease in MNN indicates more clustering (McGarigal & Marks, 1995; Rainis, 2003).

Figure 10. Spatial Patterns of Land-Use Distribution

Initial analysis of the correlation results showed some of the water quality parameters to be sensitive to variation in some of the landscape
metrics. The observed trend was that for the same parameters that were positively correlated with metrics indicating fragmented pattern, the correlation was negative (opposite) with the metrics describing clustered patterns.

For example, considering all observations (n = 64), correlating variation in landscape metrics of the total contributing area (TCA), the results showed TDS, TKN, Total N, BOD, and COD to have significant positive correlation with NUMP, indicating that these variables would increase as the contributing land-uses become more fragmented. The same variables showed negative correlation with mean patch size (MPS), largest patch index (LPI) and mean proximity index (MPI), indicating these parameters would decrease as the contributing area became more clustered. pH was negatively correlated with NUMP, indicating that pH will decrease in fragmented pattern; positive correlation with MPS, LPI, and MPI indicates pH will increase in clustered patterns (Figures 8, 9, and 10), correlation results are shown in Table 26, Appendix I.
Figure 11. Number of Patches (NUMP) vs. WQ Parameters (TCA, All Observations), the X-Axis Indicates NUMP, the Y-Axis Indicates WQ Parameters

Figure 12. Mean Patch Size (MPS) vs. WQ Parameter (TCA, All Observations), the X-Axis Indicates MPS, the Y-Axis Indicates WQ Parameters
Observations in other categories of watersheds supported the aforementioned results. For example, when we looked at the correlation results in the small watersheds category, the same water quality parameters showed similar associations with the same landscape metrics, except the correlations were a little stronger (higher r-values), as shown in Tables 27 and 28 in Appendix I and in Figures 14 and 15:
Considering changes in spatial patterns of individual land-use type in the watershed, the results did not reveal the same consistent trend—only
TDS showed some association with TC_R. TDS increased with fragmentation and decreased in clustered patterns.

Considering TC_NR and TC_GP, more parameters were associated with the landscape metrics, but the trend was still not as consistent. For example, some parameters were correlated with metrics describing clustering, but not with the metrics describing fragmentation; however, the direction of the associations was consistent with the established trend (Tables 29, 30, and 31 in Appendix I and Figures 16 to 21).

Figure 16. Number of Patches (NUMP) vs. WQ Parameters (TC_R, All Watersheds), the X-Axis Indicates NUMP, the Y-Axis Indicates WQ Parameters
Figure 17. Mean Patch Size (MPS) vs. WQ Parameters (TC_R, All Watersheds), the X-Axis indicates MPS, the Y-Axis Indicates WQ Parameters

Figure 18. Number of Patches (NUMP) vs. WQ Parameters (TC_NR, All Watersheds), the X-Axis Indicates NUMP, the Y-Axis Indicates WQ Parameters
Figure 19. Mean Patch Size (MPS) vs. WQ Parameters (TC_NR, All Watersheds), the X-Axis Indicates MPS, the Y-Axis Indicates WQ Parameters

Figure 20. Number of Patches (NUMP) vs. WQ Parameters (TC_GP, All Watersheds), the X-Axis Indicates NUMP, the Y-Axis Indicates WQ Parameters
Observations in the same watershed were not consistent with the overall observations or across the four watersheds; however, correlated variables showed higher r-values, and they were more significant. For example, TDS was strongly correlated in the DC watershed only, while lead was correlated in the WT and SC watersheds. No correlation was observed in the FW watershed. All results are shown in Tables 32 to 35 in Appendix I.

The above results indicate that there is an association between changes in some of the water quality parameters and variation in landscape metrics describing land-use patterns. Further analysis of the landscape metrics showed some of these metrics to be strongly correlated with the total amount of contributing land uses, indicating that changes in these metrics can be driven by two factors: the change in pattern
and/or the change in the amount of land uses in the watershed. For example, a watershed with more land uses (higher TCA) will have higher NUMP and higher TE. Correlation analysis indicates very strong association between TCA and the selected landscape metrics (except for MPS and MPI), as shown in Table 11 and Figure 22.

For these metrics to be effective in identifying variation in landscape patterns, they should be compared across watersheds that have the same amount of land use (TCA). The available observation did not provide enough watersheds with the same amount of TCA to analyze this association in more details. Therefore, landscape metrics that have little or no correlation with TCA were used as indicators of landscape patterns. Only MPS and MPI showed low correlation with TCA.

Table 11. TCA vs. Landscape Metrics (All Observations, n = 64)

<table>
<thead>
<tr>
<th></th>
<th>NUMP</th>
<th>MPS</th>
<th>TE</th>
<th>MNN</th>
<th>MPI</th>
<th>LPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCA</td>
<td>0.802</td>
<td>-0.332</td>
<td>0.946</td>
<td>-0.664</td>
<td>-0.424</td>
<td>-0.699</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.007</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Cell Contents: Pearson correlation
P-Value
Both MPS an MPI can be used as a measure of fragmentation. An increase in MPS indicates that patches are larger and less fragmented. MPI is a measure of isolation between patches, and an increase in MPI indicates that patches are less isolated and more clustered. Figures 12 and 13 showed positive association between MPS, MPI, and pH, indicating that pH will increase as MPS and MPI increase (as contributing land uses become more clustered). The same figures show that other water quality parameters (TDS, TKN, Total N, BOD, and COD) will decrease as MPS and MPI increase (as contributing land uses become more clustered).

The above results show clear association between variation in some of the landscape metrics describing contributing land-uses spatial patterns.
and some of the surface water quality parameters at the watershed outlet and provide enough evidence to reject the null hypothesis. From these results, it can be concluded that variation in the contributing urban land-uses spatial patterns can affect surface water quality.

The association between water quality parameters and the other landscape metrics including NUMP, TE, LPI, and MNN support this conclusion, even though these metrics can indicate an increase in the amount and the pattern of the contributing area. The fact that water quality parameters showed stronger correlation with these metrics compared to the TCA is an indication of this association between contributing land-use patterns and surface water quality parameters.
CHAPTER 4

DISCUSSION

Introduction

The main objective of this study was to examine the relationship between the spatial patterns of contributing urban land uses and surface water quality parameters at the watershed outlet. A new method of classifying and quantifying contributing urban land uses and their spatial patterns was also introduced.

Two specific questions related to the overall relationship between contributing land uses and surface water quality parameters in an urban environment were examined: (1) Can differences in surface water quality parameters at the watershed outlet be explained by considering only the amount and types of the contributing land uses? and (2) Do the spatial patterns of the contributing land uses in the watershed affect the water quality parameters at the watershed outlet?

This chapter discusses the results of the study with respect to the research questions and presents recommendations for further research in this area.
Results

The correlation results were not strong enough to indicate strong association between differences in the amount, types, or spatial patterns of the contributing land uses and differences in surface water quality parameters. Considering the first research question, whether the variation in the water quality parameters can be explained by the variation in the total amount and types of the contributing land uses, the most significant correlation was a low correlation between BOD and TC_R ($r = 0.428$), indicating that no more than 18% of the variability in BOD can be explained by TC_R (total contributing area in residential use). This indicates that there are additional variables affecting water quality, including land use and watershed characteristics such as the size of the contributing area, climate, and weather conditions in the analysis did not improve the correlation results.

Based on previous studies of the relationship between land use and its impact on surface water quality, it was hypothesized that some of the differences in surface water quality indicators at the watershed outlet could be attributed to differences in the spatial distribution of contributing land-uses. In other words, it was thought that different patterns of contributing land uses could be correlated with differences in water quality indicators.

In an urban environment, such an association between land use patterns and water quality indicators is expected to exist based on the
nature of urban development and its impact on urban hydrological processes. As storm water flows over different land-use types at different positions in the sub-watershed, collecting into a natural and man-made stream network, the property of surface water can change significantly; different land uses can introduce different pollutants to urban runoff. For example, construction sites can introduce TSS to runoff (Moran et al., 1980), while lawns and golf courses can increase TDS and nutrients (EPA, 1993), roads and industrial activities can be a significant source of metals (Tong et al., 2002; EPA, 2003), dissolved metals can increase alkalinity (Nordstorm et al., 2000), and plant decay and yard waste can be a source of organic material (EPA, 1993). Different configurations of contributing land-uses may alter surface water properties in different ways, based on surface runoff interaction with its surroundings as it flows to the collecting stream system, such as local storage, infiltration, and evaporation. Atmospheric inputs may introduce additional pollutants to surface water, such as dissolved metals and atmospheric acid deposition. What is unknown is the nature and strength of this association between land-use patterns and surface water quality.

It was expected that clustered patterns of land use would show higher pollutant concentrations at the outlet than when compared to fragmented patterns. Clustered patterns provide larger and more contiguous patches of impervious surfaces, which can collect larger amounts of pollutants over time. In storm events, surface water can accumulate in large
amounts on these impervious surfaces, then move quickly to the nearest collecting channel. Large amounts of fast moving surface water can pick up even more pollutants.

However, correlation analysis showed the relationships between land-use patterns and water quality to be opposite from the expected trend. All water quality parameters examined—except pH—showed higher values in fragmented patterns. This unexpected result can be explained by comparing the structure of the contributing land uses in both patterns. In a clustered pattern, land-use patches are larger and more contiguous, allowing runoff to flow directly from contributing land-use patches to the nearest channel and be delivered faster to the watershed outlet, as shown in Figure 23.

In fragmented patterns (Figure 24), the contributing land-uses are more dispersed throughout the landscape. Additional land-use types, which are not contributing land-uses or are parcels of vacant land, can occupy areas in between the contributing land-use patches. Runoff from contributing patches would be expected to move slowly over noncontributing areas or patches of vacant land, due to local storage of surface water, infiltration, and evaporation before collecting in the channel system. In a highly urbanized and dense watershed, the areas between contributing patches are most likely occupied by noncontributing land uses, which can adversely affect surface runoff properties before reaching the collecting channels.
Figure 23. Example of Clustered Contributing Land-Use Pattern. Sloan Channel Watershed, 11/21/1996 Observation

When surface water from contributing cells travels over noncontributing land-use cells before reaching a collecting channel system, it can pick up extra pollutants. Additionally, in fragmented patterns, surface water will travel over longer distances once in the channel system before reaching the watershed outlet; runoff water can then be subjected to even more conditions that might affect its property, such as atmospheric deposition and the mixing of waters from different land-use sources.
In this study, the streets were not considered part of the contributing land use due to the difficulty of establishing their specific construction date. Streets can be a significant factor in this trend, as the areas between contributing patches are more likely occupied by an extensive roads network, linking different land-use patches and delivering surface runoff to the channel system.

Figure 24. Example of Fragmented Contributing Land-Use Pattern. Duck Creek Watershed, 03/25/1994 Observation
Land Use

In order to examine the correlations between land use and water quality, the first required step was to delineate the contributing land uses as a result of storm events leading to water quality sampling. Since the goal of the study was to examine the relationship between land uses and the surface water quality parameters, it was critical to identify actual land uses that generated runoff leading to the sampling events. Initially, it was expected that only land-use patches generating surface runoff would impact surface water quality. In a highly urbanized and arid environment, where rainfall is characterized by a large degree of spatial variability, this distinction is critical as the total amount and distribution of contributing land uses can be very different than total land uses in the watershed, and can vary by storm event.

Several methods have been used to extract and classify land-use data, many of which are based on remote sensing. These methods are not always appropriate in the case of fast growing, highly-urbanized areas for three reasons. First, it is difficult to interpret the image and identify the actual land-use classification. An industrial warehouse and a manufacturing plant might look the same to the image interpreter, for example, but they might have very different potential contributions to surface runoff. Second, the resolution of the remote sensing data depends on the resolution of the image. High resolution images can be very expensive and are not always available. Land-use data based on
remote sensing can be general in terms of its classifications and spatial resolution. It is very common to have cell sizes of 1 kilometer or larger in remotely sensed data. Such resolution is not appropriate in classifying densely urbanized areas. Third, the frequency of water quality sampling will require at least one or more images per year, which can be very expensive and time consuming.

In this study, land uses were derived based on the actual use of individual parcels as identified by the Clark County Assessor’s office. This people oriented method provided a high resolution and detailed land-use classification layer, including the development time frame (construction year). Using this method, land uses could be easily classified into more detailed categories or generalized into broader categories to meet the research objectives. For example, residential uses could be reclassified into more details, such as types and density of dwelling units if needed (single-family, apartments, and townhomes), a similar level of details can be applied to other land-uses.

Runoff Coefficients

Contributing land uses were identified as a function of the amount of rainfall and land use based runoff coefficient. By multiplying the amount of rain and the runoff coefficient, land-use cells generating runoff amount more than 0.05" were considered to be part of the contributing land-uses.
The estimation of runoff coefficient based on urban land-use type is critical. There are no studies specific to the Las Vegas Valley, in which a storm-based runoff coefficient was calculated. After reviewing several methods that can be used to estimate storm-based surface runoff and due to the lack of details on the storm event leading to water quality sampling, calibrated runoff coefficients that were specific to the study area were used. These coefficients were calculated based on an annual total rainfall and measured surface flow. It should be noted that while these coefficients can be different than actual storm-based events, they were the best available option. As an estimated runoff coefficient, they may be as good or better than calculating new coefficients using any of the other previously discussed methods using available data.

Contributing land uses were a direct product of total rainfall and runoff coefficients. Comparing calculated runoff based on the calibrated coefficients and other runoff calculation methods, such as the Curve Number and Schueler methods, indicated that these runoff estimates have underestimated the actual runoff, and consequently, the contributing land uses, which can be one of the possible reasons why the correlation results were not strong.

Characterizing Spatial Patterns of Land Use

Defining and quantifying spatial patterns of urban land uses was another key component of this study. The concept of quantifying
landscape structure was borrowed from the field of landscape ecology, and applied to urban land-uses to identify different spatial patterns. Six basic landscape metrics were used to indicate two different spatial patterns: fragmented and clustered.

Each of these metrics was used independently as a linear measure to indicate differences in the contributing land-use spatial pattern, as shown in Figure 25. Scatterplot diagrams of each of these metrics against each of the measured water quality parameters were used to identify the response in water quality indicators to changes in land-use patterns as indicated by these metrics. Pearson correlation was used to calculate the strength and significance of the association between landscape metrics and water quality parameters.

Figure 25. Landscape Metrics as an Indication of Spatial Patterns
This analysis examines only the correlation between spatial patterns and water quality. To further understand the possible causal relationships between spatial distribution of urban land uses and surface water quality, more spatial statistical analysis is needed. Techniques such as cluster analysis would allow for the partitioning of the contributing land uses into more homogeneous subsets, based on additional similarities that can include other watershed background and Physical characteristics such as land cover, soil types, and slopes. The spatial patterns of the identified clusters can then be spatially analyzed using multivariate techniques within the overall watershed, in reference to other critical spatial variables, such as noncontributing patches, the distance to the nearest stream, and the flow distance to the watershed outlet. To carry on such level of statistical analysis, the data used in this study would need to be more detailed in many aspects, such as accurately defining the contributing land uses based on more accurate rainfall and runoff coefficients data. Land uses such as roads, vacant land, and other land-cover types cannot be excluded.

Water Quality Parameters

The available water quality data covered a period of ten years, from 1992 to 2001. With several monitoring events every year, a total of 64 independent observations were available across four different sub-watersheds.
One might argue that ten years is not long enough to study the effects of land-use change. A 10-year time frame is acceptable for this study for two reasons: (1) the accelerated rate of growth and urban change in the Las Vegas Valley presented enough variation over a 10-year period, and (2) since the objectives were to look at different spatial patterns of contributing land uses and how they might affect water quality, taking into consideration the temporal and spatial variability of rainfall, 64 events created enough variations in the contributing land uses and their spatial patterns to support this study.

Since one of the goals of this study was to identify general trends in the overall associations between land-use patterns and water quality parameters, all available water quality parameters that were measured consistently over the study period were used in the analysis.

Conclusions and Recommendations

The results of this research were not strong enough to make a clear statement about the relationship between land use in arid, urban watersheds and surface water quality. To improve this kind of analysis, several issues need to be addressed. These issues involve water quality data, identification of contributing land uses, and watershed delineation.

1. Water quality data: The measured water quality parameters were not consistent or reported accurately at all events. Many parameters were indicated to have a value less than a given number instead of
an exact value. For example, oil and grease were indicated to be $< 3$ (mg/l) most times. Lead, mercury, cadmium, and other metals also were indicated as such. Many variables were not measured at every event, causing several of these parameters to be excluded from the study. Some of these excluded parameters could be more reflective of urban land-use characteristics, such as oil and grease. To enhance the results of this study, water quality parameters related to urban land-use in the Las Vegas Valley should be identified, measured, and reported in a more consistent and accurate methods. Monitoring programs, until recent years, were not comprehensive or coordinated across the different agencies carrying such programs. In the future, as more data is collected and consolidated, more data for studies of this type will be available. Rainfall events were the driving force behind the timing and location of water quality sampling. Contributing land-use cells were determined, based on the amount of rainfall and the runoff coefficient in every cell. To accurately identify contributing land uses, better information is needed to estimate both variables (rainfall and runoff coefficient).

2. Rainfall information such as intensity, duration, and temporal variation are critical in identifying the amount of rainfall in every cell for calculating surface runoff. In this study we used the total rainfall for the 24 hours leading to the water quality sampling. Knowing that water samples were collected in the first three hours
of the storm event, this assumption may lead to incorrect representation of the actual contributing land uses.

Runoff coefficients were an estimate of an annual average coefficient calculated based on calibrated total annual rainfall and total annual surface flow. This estimate is a good approximation on annual basis, but it may not be a true representation of the actual partitioning of a storm-based rainfall event in an urban environment; a more accurate runoff coefficient is needed to derive actual contributing land uses based on rainfall events.

Some of the other methods discussed for estimating surface runoff, such as the Curve Number (CN) and Schueler's method, were not expected to provide better results considering the high degree of urbanization in the valley and the limited details available concerning the rainfall events, soils, and land cover. Another option to determine the runoff coefficients would have been to accurately model a smaller watershed under controlled conditions and under different rainfall scenarios to arrive at convincing results; however, such a modeling exercise was beyond the scope of this study.

3. Watershed delineation: The extent of the flood control facilities in urban areas might require additional verification of the effective watersheds. Flood control channels might divert runoff water to or around monitoring points. To address this issue, existing channels were burned into the DEM to incorporate them in the process of
watershed delineation. Some field verification may be still required in areas where channels are under ground or close to watershed boundaries.

Another possible impact of the flood control facilities includes the hydrological alteration of surface runoff. As water collects in flood control facilities and detention basins from different sources, it gets mixed and usually moves faster down stream, which may obscure the background land-use sources by the time water is collected at the sampling stations. To compensate, monitoring points might be placed on branches of the main wash (especially in the larger watersheds). This will lead to smaller watersheds, but it will be more accurate in sampling the water shortly after it leaves its contributing sources.

4. Land-uses classifications: Land uses were classified based on the actual use of the whole parcel as identified by the Clark County Assessor's office. This may not necessarily be a fair representation, as there can be a large parcel with only one corner developed and the rest vacant. In this study, the whole parcel would have been classified as developed. This is a result of the way the Assessor's GIS database is structured and maintained.

Using the Clark County Assessor's data as the main source for land-use classification deviates from several other studies that used remote sensing to derive land-use and land-cover data. This method
may be appropriate in highly urbanized areas; however, it does not address the land-cover characteristics of the contributing land uses, especially in cases of large, developed parcels with only small buildings on them. In this type of scenario, the whole parcel will be considered developed for the purposes of land-use data. Using land-cover classification, the appropriate portion of that parcel will be considered as developed. For such situations, it might be useful to use a method that combines both remote sensing and the Assessor’s data. The Assessor’s data would be the source for land-use type, and remote sensing would be the source for land cover. This method is possible, considering that rectified, high-resolution aerial images of the study area are available. However, this method would require a great deal of time and effort that was not possible in this study.

5. Temporal land use data: To create a temporally varied land-use layer, matching the water quality monitoring dates, the parcel construction year attribute available in the Assessor’s database was used. Water quality sampling was done about four times a year. Matching the land use and water quality sampling dates was not possible. This may not seem as a critical issue, but considering the rate of growth in the Las Vegas Valley, the amount of land use could easily change between January and December of the same year.

Additionally, the streets were not considered as part of the contributing land uses due to the difficulty in establishing their
construction date, which is not available in any of the available databases. Initially, the streets were assigned the same construction year as the parcels adjacent to them, which might be appropriate most of the time, as streets are usually built at the same time parcels are developed, according to the County off-site development standards. But, at the same time, there are many other streets, such as major streets and highways that may not follow this rule. Additionally, most of the streets exist in the GIS layers as a contiguous polygon adjoining several parcels, making it difficult for this method to be effective. This method was applied as a test on a few selected years, and the results showed minimum variation in the amount of streets from year to year.

Using historical satellite images and aerial photographs would have made it possible to identify streets by year, but also would have been time consuming beyond the scope of this study. Therefore, we elected not to consider the streets in this initial analysis and focus the study on the three main urban land-use categories (residential, nonresidential, and golf courses and parks).

We suggest that future research should consider the streets, especially if we consider smaller watersheds where it would be easier to identify streets construction time. Additionally, in an urban environment, roads represent a major source of surface runoff and
can affect the surface water quality through air-to-water deposition of pollutants.

In conclusion, even though the results of this study were not all conclusive, the study achieved its goal of clarifying the association between urban land-use characteristics and surface water quality parameters at the watershed outlet. Additionally, this study has set the stage for additional, more detailed research in this area.
APPENDIX I

TABLES OF CONTRIBUTING LAND USES, WATER QUALITY DATA, LANDSCAPE METRICS, AND CORRELATION RESULTS

(ON CD IN POCKET)
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VITA

Graduate College
University of Nevada, Las Vegas

Majed A. Khater

Address:
8911 Venetia Street
Las Vegas, Nevada 89123

Degrees:
Bachelor of Science, 1986
Yarmouk University, Jordan

Master, Urban Planning & Policy, 1993
The University of Illinois at Chicago

Dissertation Title: Assessing the Relationships Between the Spatial Variation in Urban Land-Use Patterns and Surface Water Quality

Dissertation Examination Committee:
Chairperson, Dr. Krys Stave, Ph.D.
Committee Member, Dr. David M. Hassenzahl, Ph.D.
Committee Member, Dr. Helen Neill, Ph.D.
Graduate Faculty Representative, Dr. Thomas Piechota, Ph.D.