GIS Tools For Assessing Source Water Protection: Las Vegas Valley Surface Waters

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Abstract

The 1996 amendment to the Safe Drinking Water Act of 1974 created the Source Water Assessment Program (SWAP) with an objective to evaluate potential sources of contamination to drinking water intakes. The major drinking water source for the Las Vegas Valley and Southern Nevada in United States is Lake Mead. This research assesses the vulnerability of the raw water intakes at Lake Mead to potential sources of contamination from the Las Vegas Valley (Wash). This is accomplished by utilizing Geographic Information System (GIS) technology in implementing prescribed steps as part of the Nevada SWAP. GIS tools are used in this analysis to identify the watershed boundary and source water protection area, visualize watershed characteristics and location of contaminants, identify drainage network and flow path, and show the spatial distribution of vulnerability in the watershed. The vulnerability is assigned based on four factors: time of travel from potential contamination activities (PCAs) to the intake, physical barrier effectiveness of the watershed, the risk associated with the PCAs, and evaluation of existing local water quality. The vulnerability analysis shows that the PCAs with the highest vulnerability rating include septic systems, golf courses/parks, storm channels, gas stations, auto repair shops, construction, and the wastewater treatment plant discharges. The drinking water intake at Lake Mead is at a Moderate level of risk for Volatile Organic Compounds, Synthetic Organic Compounds, microbiological and radiological contaminants. The drinking water intake is at a High level of risk for Inorganic Compounds contaminants. However, Las Vegas is protected by high quality water treatment facilities. Source water protection in the Las Vegas Valley is strongly encouraged because of the documented influence of the Las Vegas Wash on the quality of the water at the intake.

Keywords: water quality; watershed; contamination; risk; vulnerability.

1.0 Introduction

The protection of water resources is a concern for the health of the public, securing a safe drinking water supply, and maintaining a strong economy. The Safe Drinking Water Act (SDWA) of 1974, amended in 1986 and 1996, is the national law meant to protect public health by regulating drinking water supplies in the United States (USEPA 1999). The 1996 amendment to the SDWA created the Source Water Assessment Program (SWAP) with the objective to evaluate potential sources of contamination to drinking water intakes (surface and groundwater). This amendment required communities to delineate source water protection areas and provide funding for water system improvements, operator training, and public information (USEPA 1999). Source water is defined as all water- from rivers, streams, underground aquifers, and lakes, which can be used to supply drinking water needs (USEPA 2001). Since source water protection is site specific, each state defined its own approach to assess source water under the SWAP and the assessment plan had to be approved by the USEPA. By the beginning of 2002, all state proposals had been submitted and approved. Since this type of watershed based approach requires geographical analysis, Geographic Information System (GIS) technology provides a common framework for handling spatial data from various sources, understanding process of source water assessment, and management of potential impacts of different activities in the watershed (Tim and Mallavaram, 2003). At present, the importance of GIS technology has increased even more in these types of watershed assessments due to availability of large volume of digital data, sophistication of geo-processing functions, and the increasing use of real-time analysis and mapping.

The Nevada SWAP document, which was approved by EPA on February 1999, contains guidelines for the preparation of an assessment of vulnerability of the raw water sources (ground and surface waters) in Nevada. Various steps for developing the SWAP in Nevada as outlined by the State Health Division, Bureau of Health Protection Services (1999) incorporates- identification of watershed boundary and source water protection area, inventory of potential sources of contamination, assignment of a level of risk to each contaminant source that has a potential to reach the drinking water source, determine the vulnerability, and disseminate the final report to the public. GIS technology plays an important role in these aspects since these tasks can be easily accessed (handled) through the use of GIS tools.

Lake Mead is the primary drinking water source for the Las Vegas Valley and southern Nevada, and supplies approximately 88% of the domestic water supply; the remaining 12% is supplied by the groundwater wells. This research demonstrates the utility of GIS systems for assessing potential sources of contamination from the Las Vegas Valley to the surface drinking water intake- Lake Mead for southern Nevada. GIS technology is used in this analysis to assess the vulnerability of surface water to potential contaminating activities (PCAs) in the watershed. During the vulnerability assignment, GIS tools are used to identify the watershed boundary and source water protection area, visualize watershed characteristics and location of contaminants, identify drainage network and flow path, and show the spatial distribution of vulnerability in the watershed.

The outline of this paper is as follows. The description of the study area and its associated background materials are provided in Section 2. The methodology (procedure) in the SWAP for Las Vegas Valley surface waters is discussed in Section 3; results are provided in Section 4; and conclusions in Section 5.

2.0 Study Area

The Las Vegas Valley watershed is located in Clark County, Nevada, which is located in the arid environment of the Mojave Desert. Las Vegas is considered as the fastest growing large metropolitan region in the U.S. (Gottdienet et al. 1999). Population for the Las Vegas Valley is approximately 1.4 million, which represents more than 95% of Clark County's population and 65% of the state's population (U.S. Census Bureau 2000). The average yearly rainfall in the valley is 4.49 inches, and the dry summers are mainly characterized by high temperatures with relatively low humidity values (11 to 34%) (WRCC 2002). Most of the storm drains and channels within the valley are either dry or low flows; however, some washes that used to be ephemeral have become perennial streams. The majority of the data related to the Las Vegas watersheds and Clark County can be obtained from the Clark County GIS Management Office (GISMO) (http://gisgate.co.clark.nv.us/gismo.htm).

2.1 GIS Data

2.1.1 Watershed Boundary

The shape files available in GISMO (GISMO, 2002) were utilized to delineate the watershed boundary and subwatersheds in the Las Vegas valley (Figure 1). The watershed area is approximately 1,520 square miles. The U.S Geological Survey (USGS) watershed boundary was not utilized in this study, since the subwatersheds were not delineated in USGS available data. The available shapefiles from GISMO also have information related to stormwater drains and detention basins, which were used to determine the flows paths through the urban areas of the Las Vegas Valley. The major washes and storm channels in the watershed drain into the Las Vegas Wash and finally discharging into Lake Mead towards East as shown in Figure 1.

2.1.2 Soil Data

The soil characteristics in the Las Vegas Valley were summarized in the report "Soil Survey of Las Vegas Valley Area Nevada" (USDA 1985). The Soil Conservation Service method based on infiltration rates (High-Soil A, Low-Soil D) is used to classify soils (Maidment 1993). The soil characteristics are used for this study to determine the ability of a contaminant to migrate downstream in the watershed. Figure 2 displays the spatial distribution of the hydrologic soil groups within the Las Vegas Valley watershed boundary. A large portion of the watershed (58%) is covered by the soil group D, which has a very slow infiltration rate and high runoff potential (USDA 1985). These portions of the watershed are largely in the surrounding mountains. The valley floor of the watershed has soil type B and C.

2.1.3 Land Use Data

Land use is available from the Clark County Assessor's Office as a database file with parcel information, including land use code and parcel number, which can be displayed as a GIS map by linking tables and using Structured Query Language (SQL) queries. There are approximately 70 different land use codes that can be generalized to seven land use categories. Figure 3 displays the general land use for the Las Vegas Valley watershed. Based on the Clark County Assessor's Office parcel data (2001), the major land uses were categorized into seven types: undeveloped (1267 sq. miles, 85%), roads and highways (71 sq. miles, 4%), commercial (27 sq. miles, 1.5%), industrial (17 sq. miles, 1%), residential (107 sq. miles, 5.7%), park/golf courses (17 sq. miles, 1.1%), and public land (18 sq. miles, 1.1%). The critical areas for this source water assessment study are located in the central and southeast portion of the watershed, which are highly developed.

2.2 Drinking Water Source

The Colorado River, diverted at Lake Mead is the main source of water for Southern Nevada. As shown in Figure 4, the major inflows into Lake Mead are the Colorado River (97%), Virgin River (1.4%), Muddy River (0.1%), and Las Vegas Wash (1.5%) (SNWA 2002; Roefer et al. 1996). Although the Las Vegas Wash represents only 1.5%, it is the most likely drainage to impact the drinking water intake due to the proximity of its outlet to the drinking water intake. The Las Vegas Wash outlet is approximately seven miles upstream from the drinking water intake; other rivers are more than 40 miles from the intake (SNWA 2002a). The Wash contains urban runoff, groundwater discharges, dry and wet weather runoff, and treated domestic and industrial wastewater effluent from three municipal wastewater treatment plants (WWTPs). The discharges from the three WWTPs are responsible for almost all the flow of the wash (Stave 2001).

Drinking water for the Las Vegas Valley and Southern Nevada is withdrawn from three raw water intakes at Lake Mead, all located at Saddle Island in Boulder Basin. Thus, Lake Mead acts as a source of drinking water as well as the discharge body for treated wastewater effluent. The Saddle Island intake is responsible for approximately 88% of the Las Vegas drinking water (SNWA 2002a); hence, this intake is an important water supply for thousands of inhabitants in Southern Nevada. Various studies have indicated the influence of Las Vegas wash discharges into the intake (LaBounty and Horn 1997; Boralessa and Batista 2000; Du 2002). In addition to nutrients, there is potentially a myriad of organic, inorganic, and microbiological contaminants in the Las Vegas Wash (Sartoris and Hoffman 1971; Deacon 1976; Baker et al. 1977; Baker and Paulson 1980; Dan Szumski and Associates 1991; Beavans et al.1996; Goldstein et al.1996; Roline and Sartoris 1996; Covay and Beck 2001; Piechota et al. 2002; Rosenblatt and Amy 2002). This points towards to the importance of making source water assessment for surface waters draining to Lake Mead and the water intake at Saddle Island.

3.0 Methodology

The methodology for the source water assessment consists of four main steps: (1) identification of the source water protection area; (2) identification of the potential contaminating activities in the source water protection area; (3) performing a vulnerability assessment for each potential contaminating activity and risk that they pose to the drinking water source; and (4) informing the water purveyors and public of the assessment results. Following is a detailed description of each step.

3.1 Delineation of Source Water Protection Areas

The SWAP requires the delineation of a protection zone for the water source, that is, a zone must be defined around the Lake Mead raw water intake. The USEPA report "State Methods for Delineating Source Water Protection Areas for Surface Water Supplied Sources of Drinking Water" (USEPA 1997b) summarizes the methods used to delineate source water protection areas. The main methods are using the topographic boundary, defined setback/buffer zones, or the time of travel (TOT). The time of travel method was not used here to delineate the source water protection zones, but it was used to identify the response time for hazardous spills. A minimum water source protection zone delineation outlined by USEPA (1997a) is to make the protection zones at least 200 feet wide around water bodies, and for it to extend at least 10 miles upstream from intake points.

In the case of the intake at Lake Mead, most potential contaminating activities are located west of the intake in the urban Las Vegas areas. Ten miles would be the point approximately two (2) miles from where the Las Vegas Wash, the major drainage channel for the entire Las Vegas Valley, enters into Lake Mead. This distance does not extend to the urban areas of Las Vegas, which are potential sources of contamination. Therefore, in this assessment the source water protection area was extended further upstream (> 10 miles) to the limits of the dry weather flows in storm water channels from the Las Vegas urban area. The rationale is that water present in these channels can transport contaminants downstream to Lake Mead, via the Las Vegas. In the State of Nevada SWAP (BHPS 1999) two zones of protection are designated –Zone A extends 500 ft around water bodies, and Zone B extends 3000 ft from the boundaries of Zone A. For this case, the extent of dry weather flows was used as a basis for delineating source water protection Zones. After defining the extent of dry weather flows through fieldwork, an ArcView script was used to select the channels downstream from the extent of dry weather flows. After establishing the limits of the source water protection area, the buffer zones were identified using ArcView GIS Buffer Wizard tool. The delineation of these buffer zones was performed using ArcMap Geo Processing Wizard.

3.2 Identification of Potential Contamination

According to Nevada's SWAP, all possible contaminants within source water protection Zone A should be inventoried for future risk analysis and susceptibility of source water contamination (BHPS 1999). Field investigations were conducted within the established water source protection area to identify potential contaminating activities (PCAs) (Table 1) that could reach the raw water intake. A

Global Position System (GPS) Trimble Geoexplorer 3 was used to mark the exact location of each contamination source. The information collected in the field includes the survey date, facility description, contaminant code, facility address, picture, and geographic coordinates. The GPS data was then downloaded to a computer, the differential correction was executed, photographs were transferred to the computer, and the database tables and shapefiles containing the field points were updated. This type of data gathered from GPS can be fused easily within GIS for analysis purpose. GIS coverage obtained from GISMO (2002) and the Clark County Health District was used to identify the location of septic tanks in the source water protection areas. The data is provided as polygons. The XTools Pro 1.0.1 ArcScript was then downloaded from the ESRI Support Center website (ESRI) to convert the septic polygons into its centroids. The output was a point shapefile representing the polygon centroids.

A list of National Pollutant Discharge Elimination System (NPDES) permits in the protection area was also obtained and different activities were summarized. Finally, other activities (e.g., restaurants, residential areas, shopping centers) that are noteworthy, but not included in Table 1, were identified. A list of PCAs and the contaminants associated with each one are presented in the Nevada SWAP. The contaminants of concern in the SWAP were grouped into five categories (http://www.epa.gov/safewater/mcl.html): volatile organic compounds (VOCs), synthetic organic compounds (SOCs), inorganic compounds (IOCs), microbiological compounds (i.e., bacteria, viruses), and radionuclides. These categories were used to identify the type of contamination from different activities in Table 1.

3.3 Vulnerability Analysis for each PCA

The vulnerability of each PCA impacting the drinking water intake was assigned based on the four factors: physical barrier effectiveness (PBE); risk potential (RISK); time of travel (TOT), and historical water quality. As outlined in the SWAP for the State of Nevada (BHPS 1999), the vulnerability of each PCA, in quantitative terms, is defined as:

Vulnerability = PBE + Risk + TOT + Water Quality + Other Relevant Information (1)

Each term in the above equation was assigned a value. The maximum score is 24, which represent the highest possibility of a PCA impacting the drinking water intake. The spatial distribution of vulnerability of the intake to each PCA was then plotted in GIS. Each term in the vulnerability equation is defined below.

3.3.1 PBE (Physical Barrier Effectiveness) is a measure of how well geological, hydrogeological, and physical characteristics of the watershed act as a barrier to prevent downstream migration of contaminants (or the susceptibility of the watershed) (CDHS 1999).

The main parameters used to compute the PBE are the type of drinking water source, travel time, general topography, general geology, soil type, vegetation cover, mean precipitation, and amount of groundwater recharge. In this study, the following values were assigned to the different PBE levels: Low =5; Moderate = 3; High 1.

3.3.2 Risk is the risk ranking associated with each PCA (Table 1). The rankings were assigned in the Nevada SWAP ("Potential Contaminant Source Inventory") based on the potential toxicity associated with the PCA. In assigning the risk associated with each activity the following rankings were used: High =5; Moderate =3; and Low =1.

3.3.3 TOT (Time of Travel) is the estimated time that would take each PCA to reach the water source, in this case, travel time for the contaminant to reach Lake Mead from the outlet of the Las Vegas Wash. The TOT was computed based on field measurements of the storm channels in the Las Vegas Valley and assumptions of flow in the Las Vegas Wash. The distance of each PCA to the drinking water intake was measured in GIS. It was possible since the exact location of each PCA was recorded by GPS (as discussed earlier). The distance was combined with the velocity of the water in the channels to determine the time of travel. The Las Vegas Wash velocity was assumed to be approximately 3 ft/sec, based on studies by Baker et al. (1977) and field investigations by UNLV (Piechota et al, 2003). The TOT were computed from the end of Las Vegas Wash to the PCA since it was unclear what the travel time would be once a contaminant enters Boulder Basin/Lake Mead. This TOT was plotted in GIS for better visualization.

Considering that the end of Las Vegas Wash is approximately six to seven miles from the intake, the time it would take a contaminant to travel from the exit of Las Vegas Wash through Boulder Basin to the intake would be approximately 3-4 days. Estimation was necessary since there was limited information on the time of travel in Lake Mead from the Las Vegas Wash exit to the raw water intake. The following values were assigned to the different TOTs to Lake Mead: 0-6 hours = 9; 6-12 hours = 7; 12-18 hours = 5; 18-24 hours = 3; > 24 hours = 1.

3.3.4 Water Quality involves evaluating historical raw water quality data at the intake to determine if the source has already been affected by contaminating activities. The EPA SWAP requires evaluating raw water quality data for all contaminants regulated under the SDWA (contaminants with a maximum contamination level – MCL), contaminants regulated under the surface water treatment rule (SWTR), the microorganism cryptosporidium, pathogenic viruses and bacteria, and not federally-regulated contaminants that the state determines it threatens human health. The Nevada SWAP has added perchlorate (ClO4-) and MTBE (methyl-tert-butyl ether) to their list of contaminants to be evaluated because these contaminants have been found in the surface waters in Nevada. If the water quality data shows the presence of contaminants in a certain category, then that category of contaminants was given a High value = 5. If a contaminant is not present, then that category of contaminant was given a Low value =0.

3.4 Community Involvement

Community involvement is a part of the development of the SWAP program and the preparation of the final SWAP document. The public meetings and presentations conducted for the final SWAP document as outlined in Piechota et al. (2003) are as follows: Three SWAP Advisory Committee meetings (Sep 28,29; Nov 19, 20, 1998; and Jan 21, 22, 1999), Public Workshops in Carson City, Elko and Las Vegas (Dec 10, 15 and 17, 1999), Presentations to Las Vegas Wash Coordination Committee (April 24, 2001), Lake Mead Water Quality Forum (July 19, 2001), USEPA Region IX, State of Nevada, and Southern Nevada Water System, Carson City (April 24, 2002), Meeting with Southern Nevada Water System (Nov 19, 2002).

4.0 Results

4.1 Summary of Field Investigations of Dry Weather Flows

The storm water channels were surveyed to determine the extent of dry weather flows in the Las Vegas Valley for the spring, summer and fall of 2001, and the summer of 2002. The extent of dry weather flows for all seasons did not vary significantly- the furthest extent of dry weather flows for summer 2001 is shown in Figure 5a. The velocity measured during the summer 2001 was used to determine the time of travel for contaminants in storm channels. All velocity measurements were less than 1 m/s in the storm channels (Figure 5a). The plot of extent of dry weather flows against a soil map (GISMO 2002) indicated that the dry weather flows cover a considerable part of the alluvium soils, with the exception of channels located in areas 1, 2 and 3 (Figure 5b). Area 1 is a well-developed commercial area, and areas 2 and 3 are well developed residential areas that may generate flows from over-irrigation and/or other urban water uses.

4.2 Identification of Source Water Protection Areas (Zones)

As noted earlier, the boundary of Las Vegas watershed, storm water channels, and washes were identified at first by using GIS data in GISMO (Figure 1). The extent of dry weather flows was identified and the source water protection Zones A and B were delineated as shown in Figure 6. Within these zones, there exists a pathway for the contaminant to reach Lake Mead and the drinking water intake. The source water protection Zones A and B represent approximately 0.8% (8,250 acres) and 3.9% (42,300 acres), with a total of 4.7% (50,550 acres or 79 mi^2) of the total Las Vegas Valley watershed (1520 mi^2) and are located in highly developed areas.

4.3 Identification of PCAs

By compiling available NPDES permits and GIS data, a total of 320 PCAs were identified, the location of which are shown in Figure 6. The number of contaminants identified in the field within the source water protection zones as well as the respective contaminant code and category are summarized in Table 2. The most common sources of contaminant were found to be septic systems (tanks) followed by medical institutions and auto repair shops.

4.3.1 NPDES Permits

As of February 2003, there were 12 permitted discharges within Zone A of the source water protection area, which discharges different contaminant categories (Figure 7). The discharges into the Las Vegas Wash included the effluent discharge from the three WWTPs (NV0020133, NV0022098, and NV0021261), an effluent discharge from an ion-exchange facility (NV0023060), discharge of cooling and scrubbing water (NV0000060), and effluent discharge a facility treating contaminated groundwater (NV0023213). The other NDPES permitted discharges were to tributaries of Las Vegas Wash and in the source water protection area. These included three facilities discharging treated groundwater (NV 0022870, NV0023078, and NV002837), one facility discharging cooling water and storm runoff (NV0000078), one facility discharging untreated groundwater (NV0022781), and one facility discharging stormwater runoff (NV0020923). All of these permitted discharges were included in the PCA list. The three NPDES discharges, which are located outside the source water protection area, also discharge into the Las Vegas Wash.

4.3.2 Septic Tank Locations from GIS

There were a total of 123 septic systems that are within Zone A (500 feet buffer) of the source water protection area. The point locations shown in Figure 8 represent the centroid of the properties that were identified as having a septic system. A large portion of the septic systems was located along Duck Creek in the vicinity of Pecos Road and Green Valley Parkway. These were also the closest septic systems to Las Vegas Wash and the drinking water intake. The other tributaries with septic systems include Flamingo Wash and Las Vegas Creek.

4.3.3 Distance and TOT of each PCA to Drinking Water Intake (Lake Mead)

As noted earlier, the source water protection areas extent up to 35 miles which is beyond the 10 miles required by the USEPA. The distance from the drinking water intake to each PCA is shown in Figure 9a. Approximately 33% (107 PCAs) of the PCAs were closer than 20 miles to the intake, 7% were within 15 miles, and nine PCAs were within 10 miles. Approximately half of the PCAs within 20 miles were septic systems. The other main PCAs within 20 miles were medical, golf courses/parks, and storm drains. The medical PCAs include facilities such as hospitals and physician offices. The three WWTPs were all within 15 miles of the intake. This distance was used with the velocities to determine the time of travel for each PCA from its source (Las Vegas Wash) to the source water (Lake Mead).

Figure 9b summarizes the TOT for all the PCAs. The TOT in Lake Mead is uncertain and depends on the particular contaminant of concern. The velocities in Las Vegas Wash are the highest of all the channels in the watershed due to the effluent from the WWTPs during dry weather conditions. The PCAs that are located closest to Las Vegas Wash will have the lowest TOT. Approximately 22% (70 PCAs) of the PCAs reach Lake Mead in 12 hours or less. The main activities with TOT less than 12 hours to the intake were medical, septic systems, stormwater drains, and golf course/parks. The effluent from the three WWTPs reaches Lake Mead in less than 12 hours. Contaminant sources located close to a water intake would pose higher risk than those located further upstream because the time for response would be longer for the latter.

4.4 Physical Barrier Effectiveness (PBE) for the Watershed

The PBE for the watershed was Low, which means that the watershed and climate conditions of the watershed do not act as an effective barrier for preventing downstream migration of contaminants (Piechota et al. 2003). The single criterion that forces the rating to be low is the influence of groundwater. Many of the tributaries for Las Vegas Wash are influenced by shallow groundwater flow. All of these tributaries were included in the source water protection areas. A Low PBE rating receives a score of 5 to be used in the vulnerability assessment for each PCA.

4.5 Water Quality at the Intake

The ratings for the water quality portion of the vulnerability determination were adopted from the final report prepared for the Bureau of Health Protection Services, State of Nevada (Piechota et al. 2003). The ratings were assigned based on observed records of water quality at the intake, and is one of four variables used to make the final vulnerability determination for the intake. Based on the report, the contaminant levels for VOC, SOC, IOC, microbiological, and Radiological were assigned as Low, Low, High, High, and Low respectively. The detailed analysis for existing local water quality can be obtained from the same report (Piechota et al., 2003).

4.6 Land Uses within the Source Water Protection Areas

The land use data shown in Figure 3 was used to identify land use within the source water protection zones (A and B). If any part of a parcel was within the buffer, the whole parcel area was taken into account. Therefore, boundary parcels have some of their area outside Zone B. Figure 10 presents the land uses within the source water protection zones. A large portion (45%) of the land use within the source water protection zones was undeveloped, provided almost all undeveloped regions were in Zone B towards the Lake Las Vegas and Lake Mead. In relation, approximately 83% of the entire watershed is undeveloped. The next highest land uses within the source water protection zones were residential (22.8%), highways (13.3%), commercial (7.2%), industrial (4.2%), park/golf courses (3.9%), and public land (3.6%). This suggests that any control of pollutants from these areas will have a high impact on the protection of the drinking water intake.

4.7 Vulnerability Analysis for each Contaminant Category

The vulnerability of each category of contaminant in relation to the drinking water intake was determined by combining the information discussed in the above sections. A maximum vulnerability score of 24 represents a PCA that has a High Risk rating (5), a Low PBE rating (5), a TOT less than six hours (9), and a High Water Quality rating (5). A minimum vulnerability score of 3 represents a PCA that has a Low Risk rating (1), a High PBE rating (1), a TOT greater than 24 hours, and a Low Water Quality rating (0). Within the range of vulnerability scores (3 to 24), ratings were established based on statistics of all the possible combinations of vulnerability scores. The ratings are as follows:

- High = vulnerability score in the upper 10% of the possible scores (> 19).
- Low = vulnerability score in the lower 10% of the possible scores (< 8).

- Moderate = vulnerability scores between 8 and 19.

A summary of the vulnerability of the drinking water intake to different contaminant categories is presented in Table 3. As an example, the spatial distribution of the vulnerability of IOC contaminant is shown in Figure 11. The vulnerability scores for each category were calculated based on the average score of each PCA associated with the different contaminant categories. For instance, VOCs were associated with 121 PCAs and the average vulnerability score was 13. Based on the vulnerability calculations, none of the contaminant categories have a Low vulnerability rating (< 8) due to the High rating assigned to the PBE term in the vulnerability equation. The drinking water source is an open reservoir and is influenced by groundwater.

For VOCs and SOCs, the majority of the individual PCAs have a vulnerability score between 11 and 17, which corresponds to a Moderate rating. The average vulnerability score for all PCAs with VOCs and SOCs was 13 and 15 respectively. Therefore, the vulnerability of the drinking water intake prior to treatment to VOCs and SOCs is Moderate. It is noteworthy that a Moderate rating is assigned even though no MCL violations were noted in the record for VOCs and SOCs and the water quality rating in Section 4.5 was Low. This occurs since the other factors (TOT, PBE and Risk) were rated High, and this warrants an overall vulnerability rating of Moderate.

For the IOC category, the majority of the PCAs have a High rating due to the water quality term (see Section 4.5) in the vulnerability equation. A total of 173 PCAs were identified among which almost 120 PCAs show higher vulnerability and 50 PCAs show moderate vulnerability. Therefore, the vulnerability of the drinking water intake to IOCs is High. Of the PCAs with a High vulnerability score (> 19), septic systems were the major activities followed by golf courses, parks and storm water drains. For the Microbiological category, a total of 196 PCAs were identified. More than half of the PCAs (120) have a High rating and almost 75 PCAs show moderate rating. The overall average of the PCAs was a vulnerability score of 18 (See Table 3), which corresponds to a Moderate vulnerability of the drinking water prior to treatment. Similar to the IOC category, septic systems were the major activity associated with the PCAs with a High vulnerability score. The Radiological category has only one PCA and a Moderate vulnerability rating since the score was 19.

7.0 Conclusions

As a preliminary assessment, the SWAP's goal was to identify contaminating activities and assign a potential risk to these activities. The objective of determining the vulnerability of the water intake at Lake Mead to specific sources of contamination is to call attention to those PCAs and contaminate categories that pose the greatest risk to the water source. The vulnerability analysis shows that the PCAs with the highest vulnerability rating include septic systems, golf courses/parks, storm channels, gas stations, auto repair shops, construction, and the wastewater treatment plant discharges. The drinking water intake is at a Moderate level of risk for VOC, SOC, microbiological and radiological contaminants, and at a High level of risk for IOC contaminants. Further this study illustrates the applications of GIS in developing a SWAP for a surface water intake in Lake Mead. The GIS tools were applied from the identification of potential contaminant sources to identification of overall susceptibility of the raw water intake: for example, management of large data sets, field data compilation, watershed delineation, source water protection zones designation, geo-processing, and mapping the risk associated with each potential contaminant source. Source water protection in the Las Vegas Valley is strongly encouraged because of the documented influence of the Las Vegas Wash on the quality of the water at the intake.

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References

1. Baker. J. R. and L. P. Paulson. (1980). "Influence of the Las Vegas Wash Intrusion on Nutrient Distribution and Phytoplankton Growth in Las Vegas Bay, Lake Mead." In: Proceedings of Symposium on surface Water I. Impoundment. American Society of Civil Engineers, Minneapolis, MN, June 2-5; P. 1638-1646.
2. Baker, J.R., Deacon, J.E., Burke, T.A., Egdorf, S.S., Paulson, L.J., Tew, R.W. (1977). "Limnological Aspects of Lake Mead, Nevada-Arizona". A report prepared and submitted to the Bureau of Reclamation, Lower Colorado region, Boulder City, Nevada, June 1977.
3. Beavans, H.E., Goodbread, S.L., Miesner, J.F., Watkins, S.A., Gross, T.S., Denslow, N.D.,
4. Schieb, T. (1996). "Synthetic organic compounds and carp endocrinology and histology in Las Vegas Wash and Calville Bays of Lake Mead, Nevada, 1992-1995." U.S. Geological survey Water Resources Investigation Report 96-4266, 12p.

5. Boralessa, R. and Batista, J.R. (2000). "Historical Perchlorate levels in the Las Vegas Wash and Lake Mead." Proceedings of the 2000 American Water Works Association (AWWA), Inorganic Contaminants Workshop, Albuquerque, NM, February 27-29, 2000.
6. Boralessa, M. (2001). Transport of Perchlorate in the Las Vegas Wash and Lake Mead. M.S.
7. Thesis, Department of Civil and Environmental Engineering, University of Nevada Las Vegas, Las Vegas, NV.
8. Bureau of Health Protection Services (BHPS), State of Nevada. (1999). "State of Nevada Source Water Assessment Program (SWAP)".
9. California Department of Health Services (CDHS). (1999). "Drinking Water Source Assessment and Protection Program". Division of Drinking Water and Environmental Management. Access http://www.cdph.ca.gov/certlic/drinkingwater/pages/dwsap.aspx.
10. Clark County Regional Flood Control District (CCRFCD) (2002). Access http://www.ccrfcd.org/
11. Colorado River Water Users Association (CRWUA) (2002). Access http://crwua.mwd.dst.ca.us/
12. Covay, K. J., and Beck, D. A. (2001). "Sediment-Deposition Rates and Organic Compounds in
13. Bottom Sediment at Four Sites in Lake Mead, Nevada, May 1998". U.S. Geological Survey, Open File Report 01-282, Carson City, Nevada.
14. Dan Szumski & Associates (1991). "Lake Mead Eutrophication Model Development and Provisional Calibration". Clark County Sanitation District, Las Vegas, Nevada.
15. Deacon, J.E. (1976). "Lake Mead monitoring program". Final Report to Clark Co. Sanitation
16. District No. 1, Waste Treatment Physical Development Section. 182 p.p.
17. Du, X. (2002). "Algal Growth Potential and Nutrient Limitation in the Las Vegas Bay, Lake
18. Mead, Nevada". M.S. Thesis, Department of Civil and Environmental Engineering, University of Nevada Las Vegas, Las Vegas, NV.
19. Geographic Information System Management Office (GISMO) (2002). Access
20. http://www.co.clark.nv.us/ceit/gismo/gismo.htm
21. Goldstein, S. T., Juranek, D. D., Ravenholt, O., Hightower, A. W., Martin, J.L., Mesnik, S.S., Griffiths, S.D., Bryant, A.J., Reich, R.R. and Herwaldt, B. L. (1996). "Cryptosporidiosis: An outbreak associated with drinking water despite state-of-the-art water treatment." *Annals of Internal Medicine*, 124:459-468.
22. Maidment, D., 1993. *Handbook of Hydrology*, United States of America: McGraw-Hill, Inc.
23. Piechota, T., Batista, J., Reginato, M. and Albuquerque S. (2003). "Source Water Assessment for the Las Vegas Valley Surface Waters". Final Report for the State of Nevada, Bureau of Health Protection Services, Carson City, Nevada, June 2003.
24. Piechota, T., James, D., Batista, J., Amy, P., Du, M., Harbour, S., Reginato, M., Rosenblatt, A. and Brown, C. (2002). "Microbiological, Limnological, and Nutrient Evaluations of the Las Vegas Wash/Bay System". Final Report for Nevada Division of Environmental Protection, Feb 2002, 170 p.
25. Roefer, P. A., Monscvitz, J.T., Rexing, D. J. (1996). "The Las Vegas Cryptosporidiosis Outbreak". *Journal of the American Water Works Association*, 88 (9): 95-106.
26. Roline, R.A., and Sartoris, J.J. (1996). "Las Vegas Wash Water Quality Monitoring Program: 1995 Report of Findings". Tech. Mem. No. 8220-96-13, Bureau of Reclamation, Technical Services Control, 11p.
27. Rosenblatt, A. L., and Amy, P. S. May. (2002). "Antibiotic resistance of the Las Vegas Wash enterococci: A public health issue?". 2002 Annual meeting of the American Society for Microbiology, Abstract Q-377.
28. Sartoris, J.J., and Hoffman, D.A. (1971). "Measurement of Currents in Lake Mead with the Deep Water Isotopic Current Analyzer (DWICA)". U.S. Department of the Interior, Bureau of Reclamation, Oct 1971, REC-ERC-71-38.
29. Southern Nevada Water Authority (SNWA) (2002a). "Water Resources Plan". Access at www.snwa.com.
30. SNWA (2002b). "Arsenic Input to Lake Mead from the Las Vegas Wash, Colorado, Muddy and Virgin Rivers". Internal Memorandum from Steve Acheampong (Hydrologist II) to Kay Brothers (Director of SNWA Resources), March 13, 2002.
31. Stave, A.K. (2001). "Dynamics of wetland Development and Resource Management in Las Vegas Wash, Nevada". *Journal of*

the American Water Resources Association, 37(5):1369-1379.

32. Tim, U.S. and S. Mallavaram (2003). "Application of GIS Technology in Watershed based Management and Decision Making". *AWRA, Watershed Update*, 1(5):1:6.
33. U.S. Census (2000). Access at http://www.census.gov/
34. U. S. Department of Agriculture (USDA) (1985). Soil Conservation Service. Soil Survey of Las Vegas Valley Area, Nevada.
35. U.S. Environmental Protection Agency (USEPA). (1997a). "State Source Water Assessment and Protection Programs Final Guidance". Fact Sheet, August 1997.
36. USEPA (1997b). "State Methods for Delineating Source Water Protection Areas for Surface Water Supplied Sources of Drinking Water". U.S. Environmental Protection Agency.
37. USEPA (1999). "Understanding the Safe Drinking Water Act". EPA 816-F-04-030, June 2004. Access at http://www.epa.gov/ogwdw/sdwa/pdfs/fs_30ann_sdwa_web.pdf
38. USEPA (2001). "What is Source Water?" Access at http://www.epa.gov/safewater/protect/swbasics.html#Anchor-What-49575
39. Western Regional Climate Center (WRCC) (2002). Access at
40. http://www.wrcc.dri.edu/cgi-bin/clilcd.pl?nv23169

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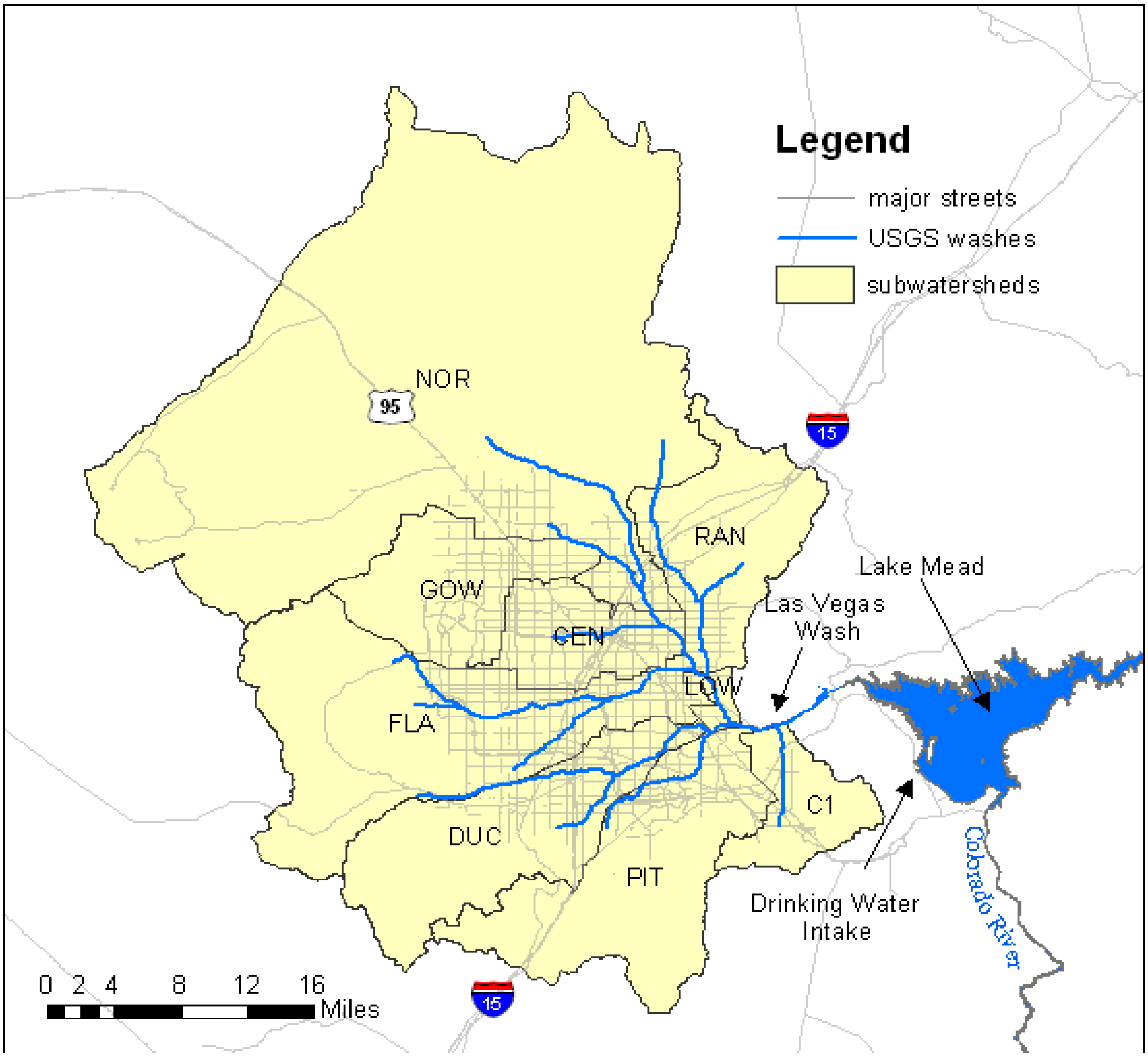


Figure1 Overview of the Las Vegas Valley watershed, sub-watershed boundaries, and the proximity to Lake Mead and the drinking water intake point.

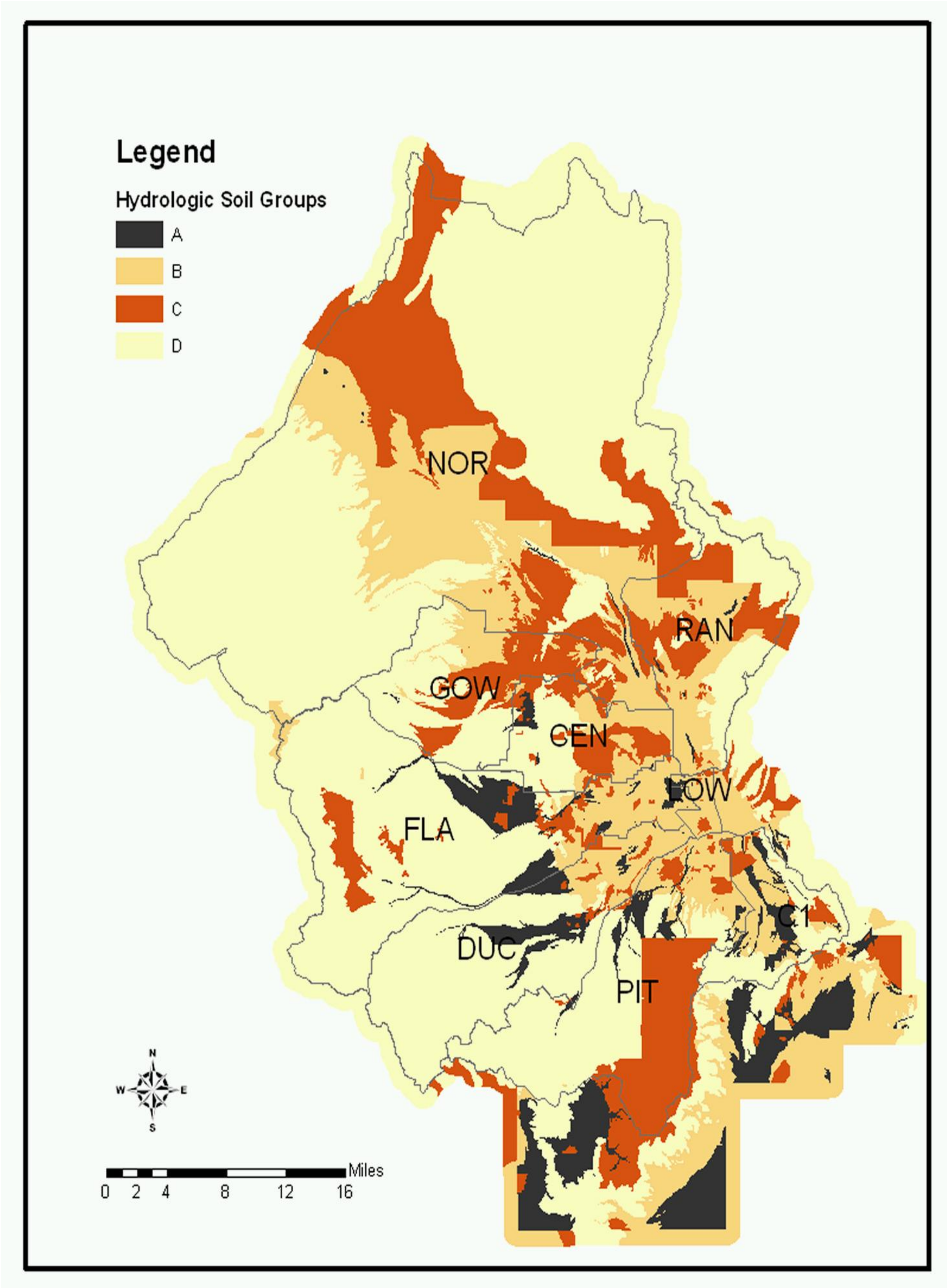


Figure 2. Hydrologic soil groups for the Las Vegas Valley based on data from Clark County GIS Management Office and the U.S. Department of Agriculture (USDA 1985)

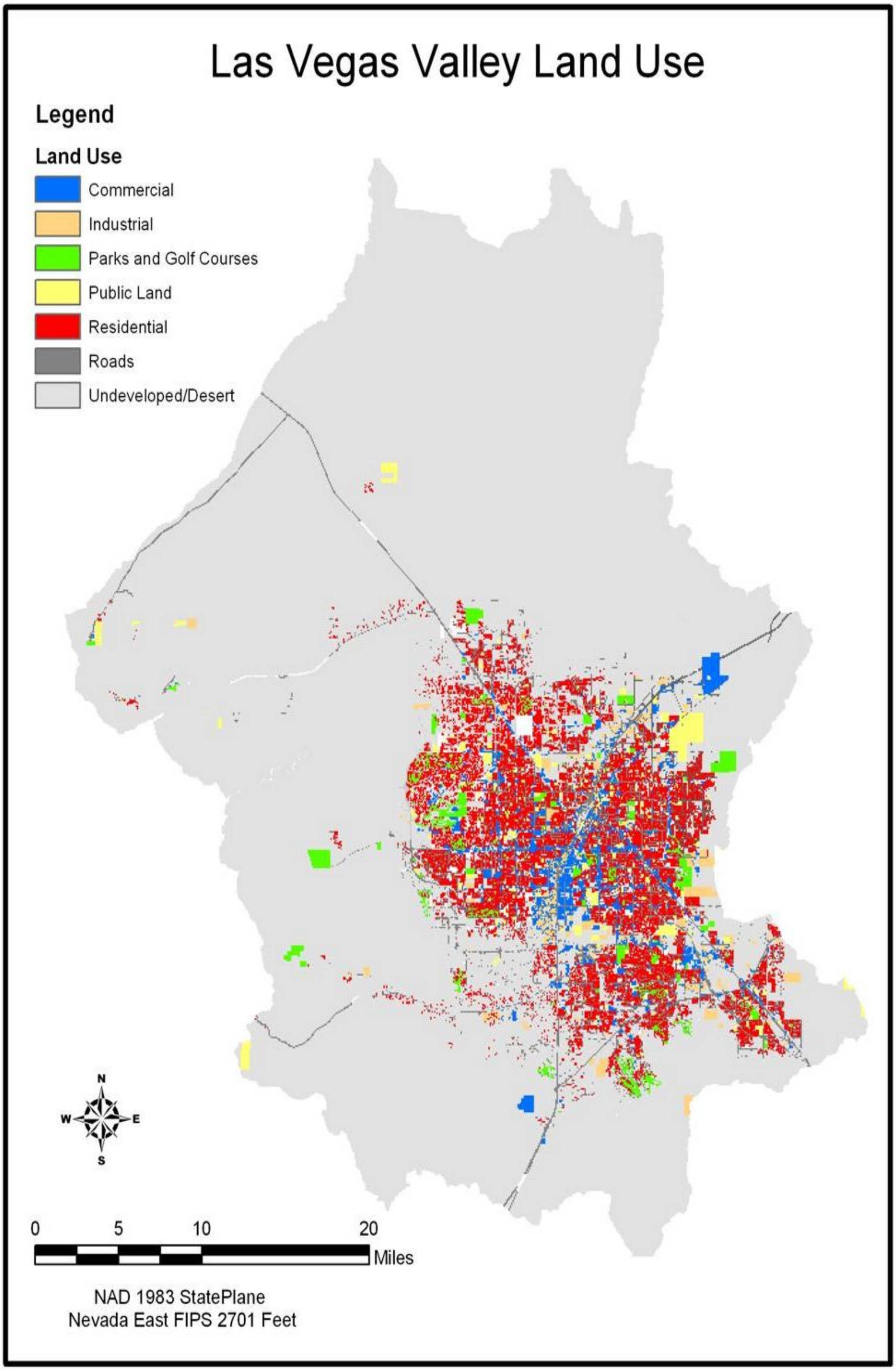


Figure 3. Overview of land use for the Las Vegas Valley compiled from Clark County Assessor's Office data (2001).

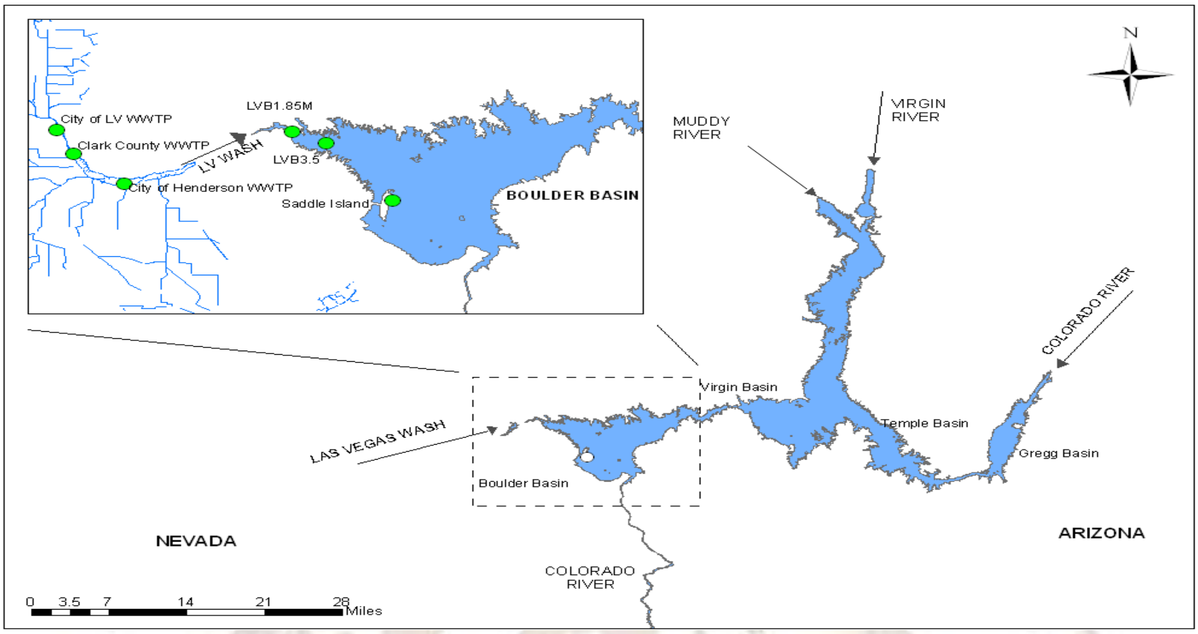


Figure 4.Overview of Lake Mead and the various basins. Inset figure displays the key water quality stations used in this study, the drinking water intake at Saddle Island and the wastewater treatment plants (WWTP) along the Las Vegas Wash.

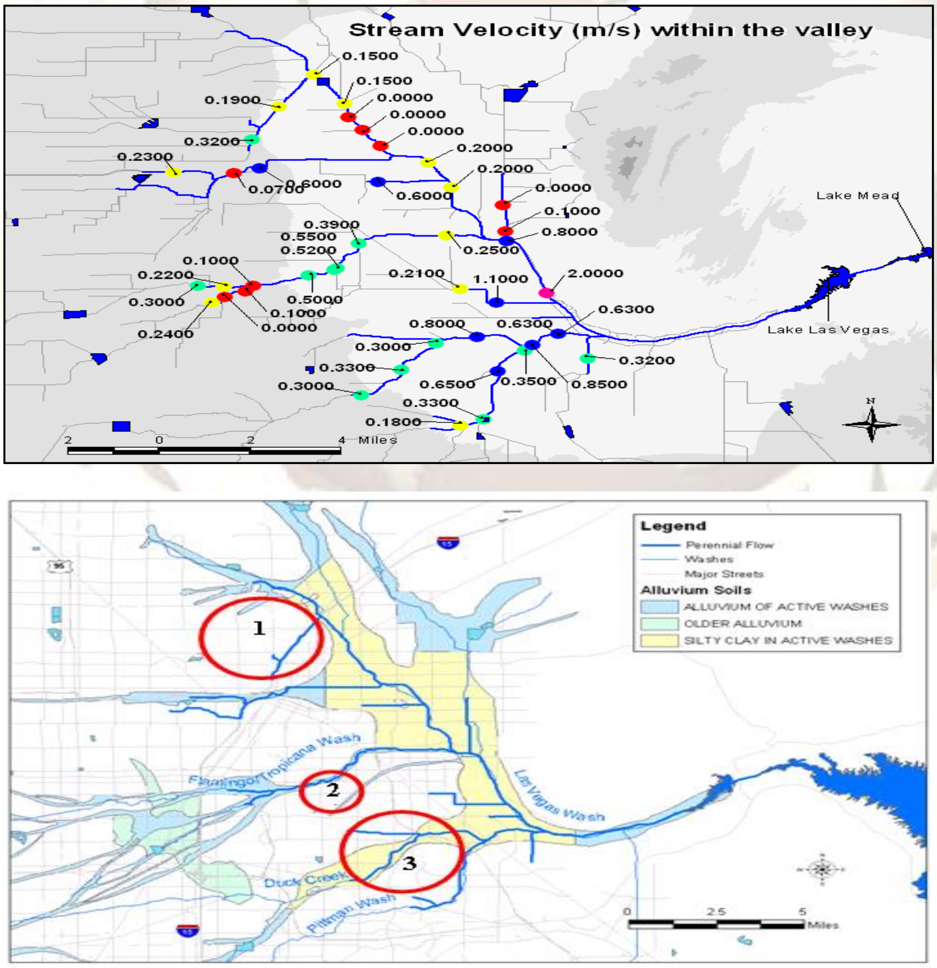


Figure 5. (a) Extent of dry weather flows for summer 2001 and flow velocities (m/s) measurements for the dry weather flows in the Las Vegas Valley (b) Alluvium soils and dry weather flows in the Las Vegas Valley.

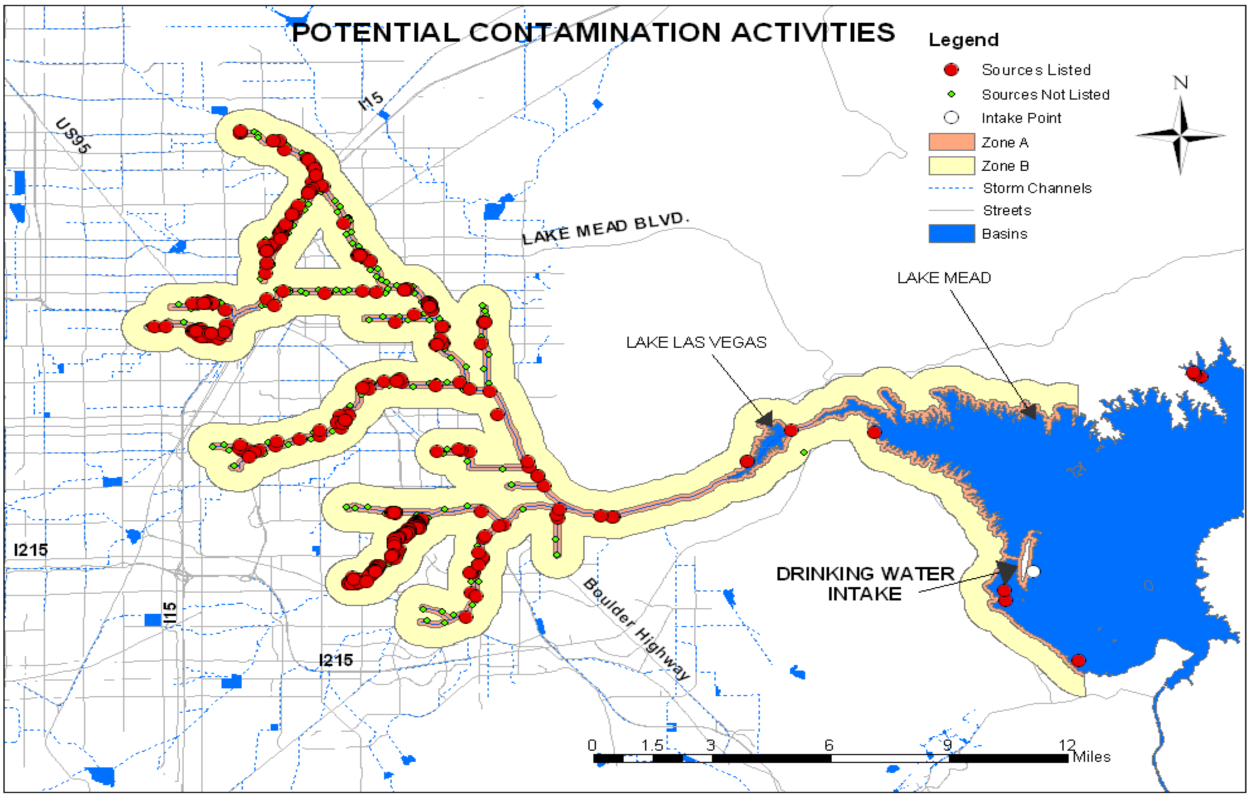


Figure 6.Source water Protection Zones A and B for the Las Vegas Valley watershed. It also shows the location of Potential Contamination Activities (PCAs) and other sources not included in the list (Table 1).

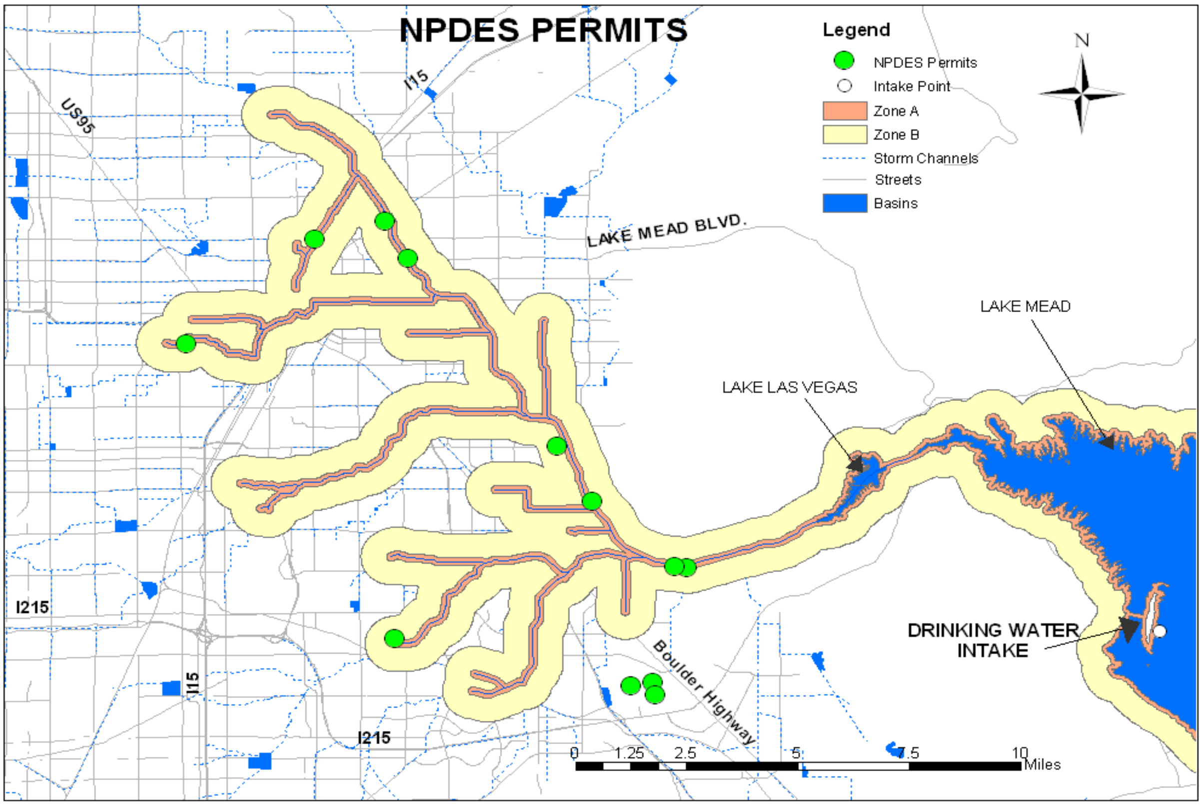


Figure 7. Location of National Pollutant Discharge Elimination System (NPDES) permits in the Las Vegas Valley.

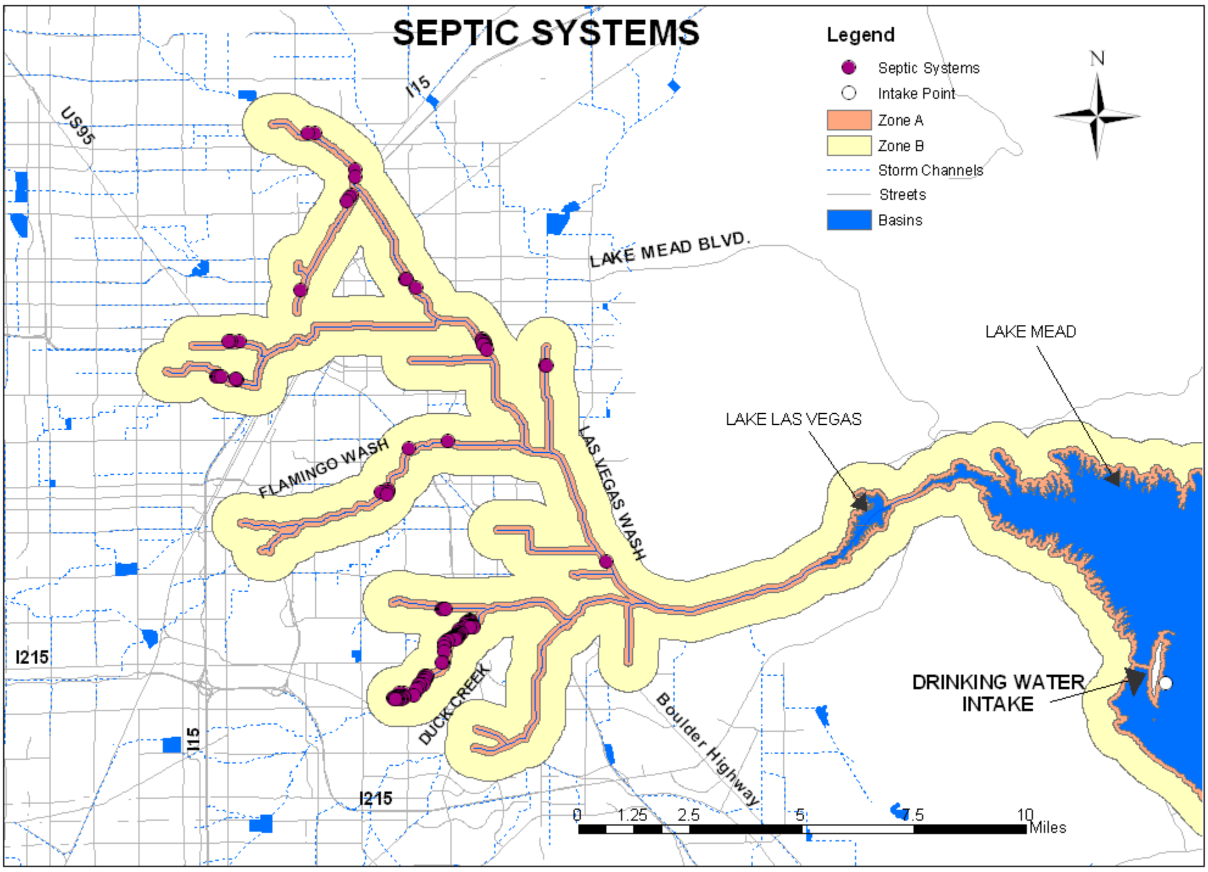
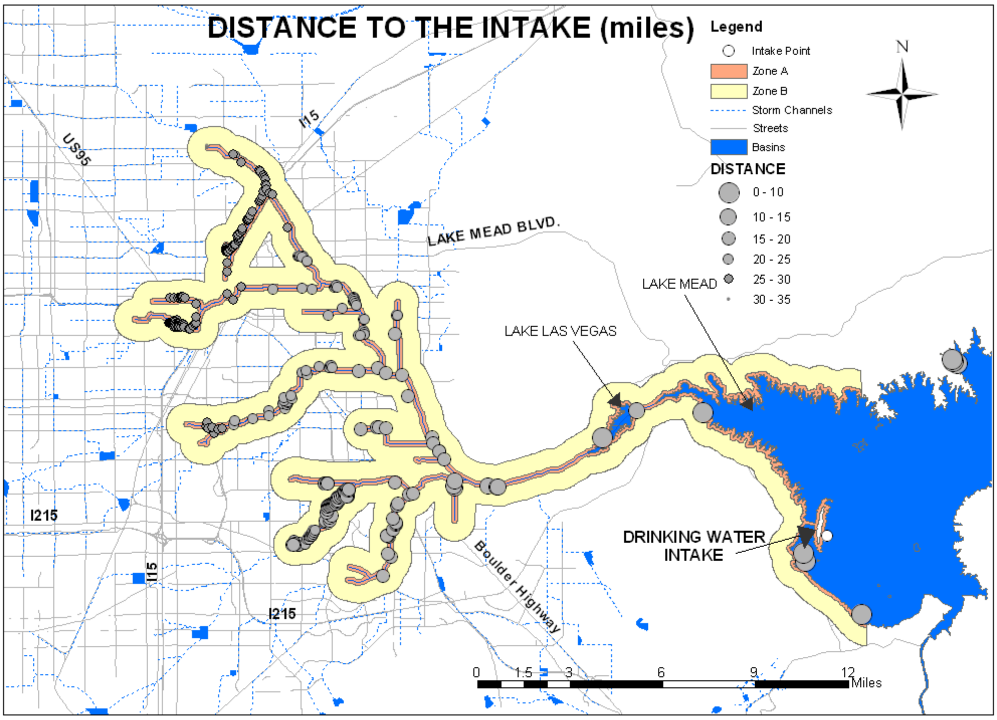


Figure 8. Septic tank locations within the source water protection area (Zone A) of the Las Vegas Valley.



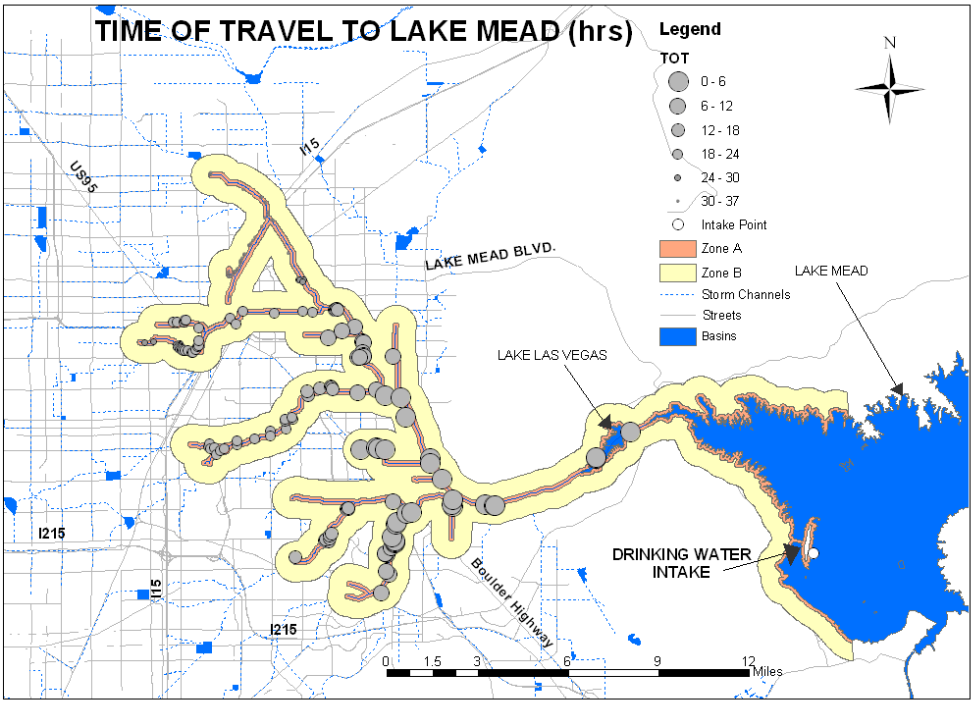


Figure 9. (a) Distance of each Potential Contamination Activity (PCA) from the drinking water intake (b) Time of travel (TOT) of each PCA to Lake Mead / Las Vegas Bay.

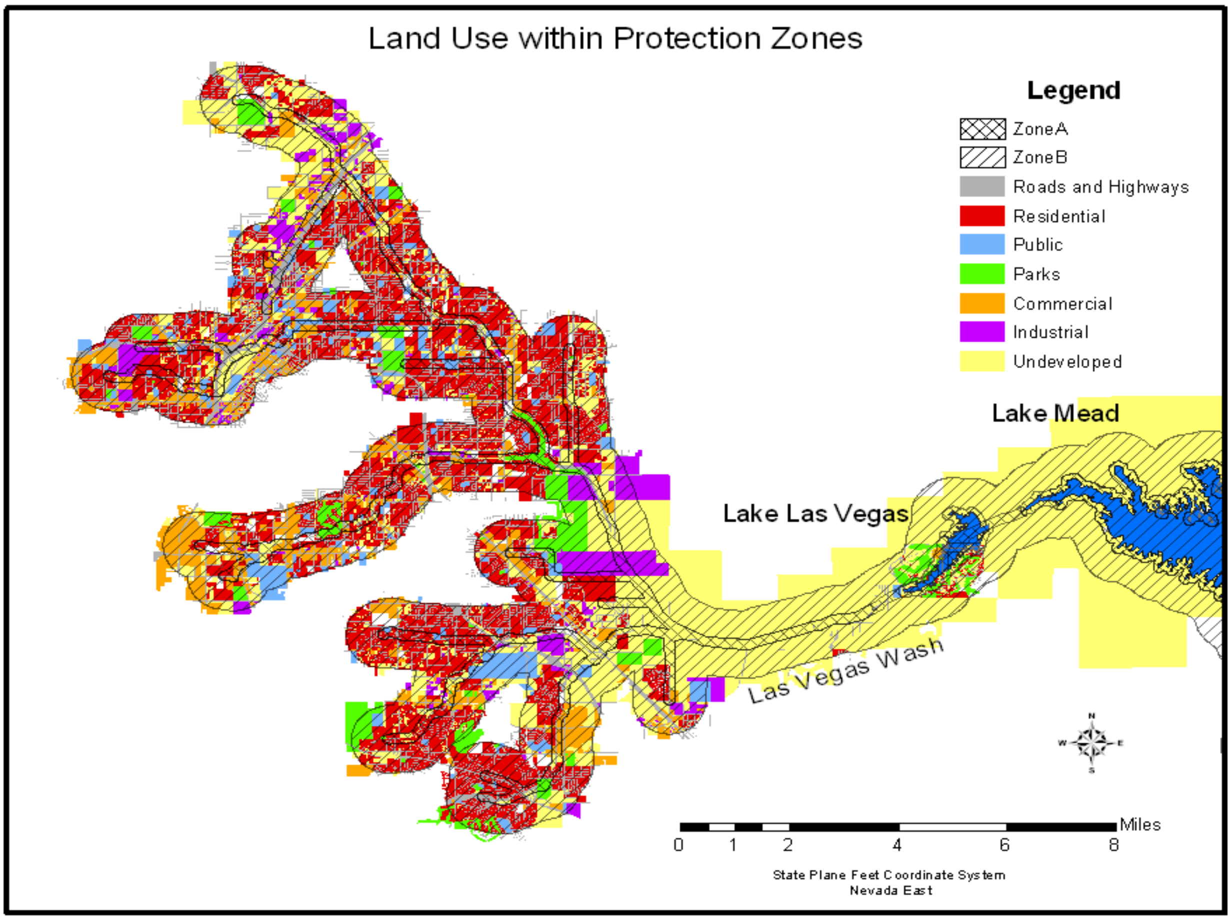
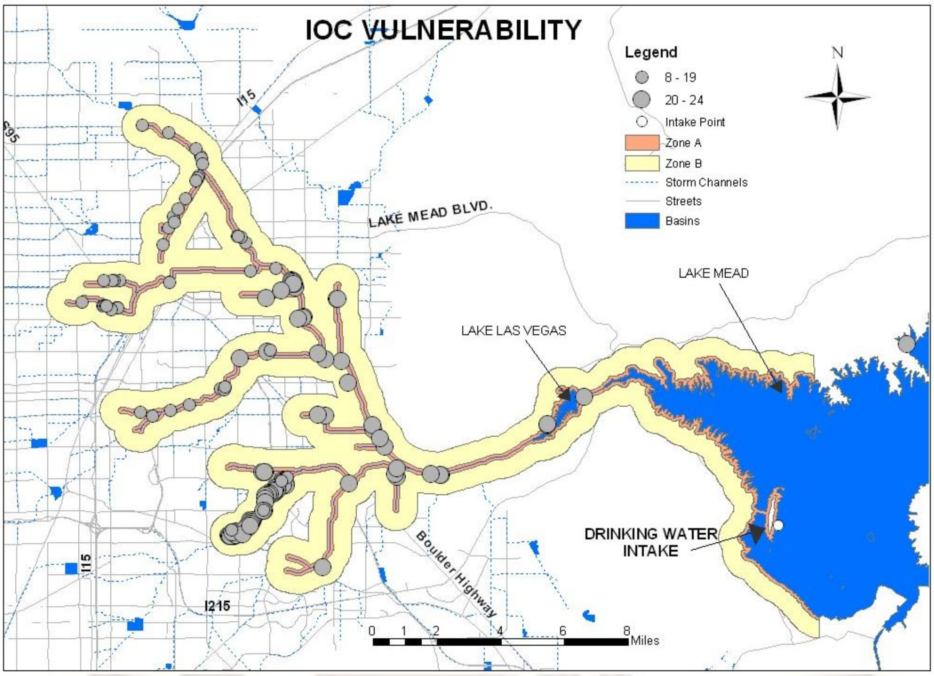


Figure 10. Land use within source water protection Zones A and B for the Las Vegas Valley extension of dry weather flows.



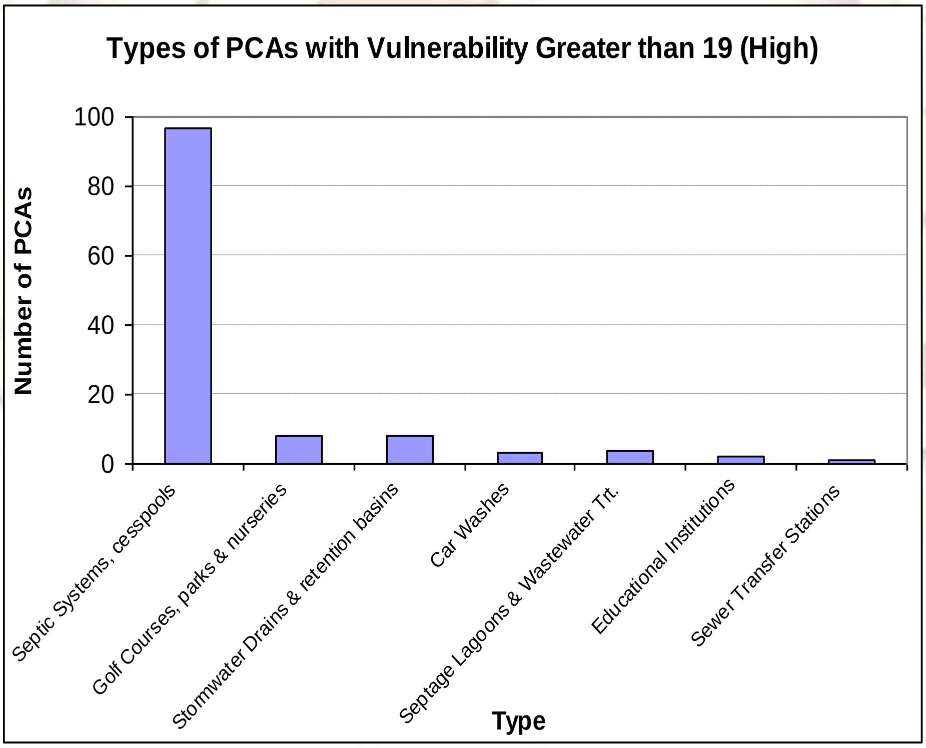


Figure 11.Vulnerability of inorganic compounds (IOC) to the drinking water intake. The bar graph represents the number and type of PCAs for IOC with vulnerability greater than 19 (High).

List of Tables

Table 1 Potential contamination sources (Categories – A=VOC, B=SOC, C=IOC, D=microbiological, E=radionuclides)

Code	Contaminant	Category	Risk Ranking	Code	Contaminant	Category	Risk Ranking
1	Animal burial areas	C, D	High	28	Educational institutions	B, C	Moderate
2	Animal feedlots	B, C, D	High	29	Medical institutions	D	Low
3	Chemical Application	B, C	High	30	Research laboratories	A, B, C, D	High
4	Chemical mixing & storage areas	A, B, C	High	31	Aboveground storage tanks	A	High
5	Irrigated fields	B	Moderate	32	Underground storage tanks	A	High
	Irrigation ditches	C	High	33	Public storage	A	Low
6	Manure spreading & pits	A, C	Moderate	34	Radioactive materials storage	E	High
7	Unsealed irrigation wells	A, C	High	35	Dumps and landfills	A,B,C,D,E	High
8	Chemical manufacturers, warehousing/distribution activities	A, B, C	High	36	Municipal incinerators	B, C, D	Moderate
				37	Recycling & reduction facilities	C	High
9	Electroplaters & fabricators	C	High	38	Scrap & junkyards	A, C	High
10	Electrical products and manufacturing	C	High	39	Septage lagoons, wastewater treatment plants	B, C, D	High
11	Machine & metalworking shops	A	High	40	Sewer transfer stations	B, C, D	High
12	Manufacturing sites	A, B, C	High	41	Airports	A	High
13	Petroleum products production, storage & distribution center	A	High	42	Asphalt plants	A	High
				43	Boat yards/Marinas	A	High
14	Dry cleaning establishments	A	High	44	Cemeteries	D	Moderate
15	Furniture & wood stripper & refinishers	A	High	45	Construction areas	A	Moderate
				46	Dry wells	A, D	High
16	Jewelry & metal plating	C	High	47	Fuel storage systems	A	High
17	Laundromats		Low	48	Golf courses, parks & nurseries	B, C	High
18	Paint shops	A	High	49	Mining	A, C	High
19	Photography establishments & printers			50	Pipelines	A	High
				51	Railroad tracks, yards & maintenance	A, B, C, D	High
20	Auto repair shops	A	High				
21	Car washes	A, C, D	Moderate	52	Surface water impoundments, streams / ditches	D	High
22	Gas Stations	A	High				
23	Road deicing operations: storage & application areas	C	Moderate	53	Stormwater drains & retention basins	A, B, C, D	High
24	Road maintenance depots	A, C	High	54	Unplugged abandoned well	A, B, C, D	High
25	Household hazardous products	A, B, C	Moderate	55	Well: operating		High - Low
26	Private wells	A, B, C, D	Moderate	56	Other		
27	Septic systems, cesspools	B, C, D	High				

Note: Table adopted from BHPS (1999).VOC- Volatile Organic Compounds; SOC- Synthetic Organic Compounds; IOC- Inorganic Compounds.

Table 2 Summary of the different contaminant sources within the source water protection Zone A (includes all field investigations, GIS data, and NPDES permits)

Number of sites within buffer zone	Code	Contaminant	Number of sites within buffer zone	Code	Contaminant
123	27	Septic Systems, cesspools	6	45	Construction areas
49	29	Medical Institutions	5	43	Boat yards / Marinas
40	20	Auto Repair Shops	4	17	Laundromats
19	22	Gas Stations	4	19	Photography establishments & printers
10	14	Dry Cleaning Establishments	4	28	Educational Institutions
10	21	Car Washes	3	8	Chemical manufacturers / warehouse / distrbution activities
10	33	Public storage	3	30	Research laboratories
10	48	Golf courses, parks & nurseries	2	11	Machine and metalworking shops
8	39	Septage Laggons, Wastewater Treatment Plants	1	15	Furniture & wood stripper refinishers
8	53	Stormwater drains & retention basins	1	40	Sewer Transfer Stations
			1	56	Other

Table 3 Summary of the number of PCAs for contaminant categories and the final vulnerability ratings based on PBE, TOT, Risk, and Water Quality. (Low = 3-7, Moderate = 8-19, and High = 20-24)

Contaminant Category	Number of PCAs	Maximum	Minimum	Average	Rating
VOC	121	19	7	13	Moderate
SOC	158	19	11	15	Moderate
IOC	173	24	14	20	High
Microbiological	196	24	12	18	Moderate
Radiological	1	19	19	19	Moderate