An Inventory of Vacant Land Soil Stability and Unpaved Private Roads in the Las Vegas Valley Using Remote Sensing Imagery

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ACKNOWLEDGEMENT

This project involved a close collaboration between the contractor team and the Clark County DAQEM Project Team. The outcome would not have been possible without the guidance and technical advice received from the Project Officer Mr. Rodney Langston and the other members of the team, John Koswan, Russ Merle, Chuck Richter, and Michael Uhl. The Clark County GIS Management Office was also critical to the success. Mr. Clint Woods and Ms. Sharon Rice provided invaluable assistance in providing and interpreting the large database of maps, road layers, and other information needed for this project. A special thanks to Chuck Richter whose practical knowledge of the County and its road network and construction activity was essential to the ground truthing effort.

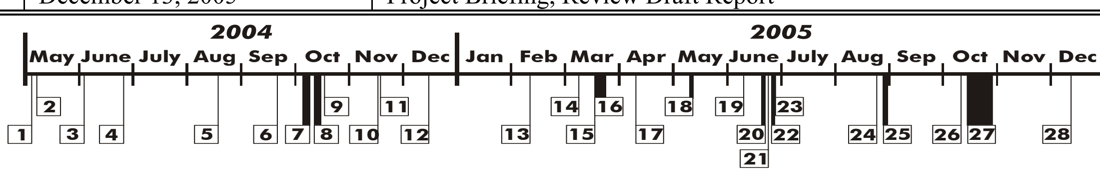
EXECUTIVE SUMMARY

Wind blown dust from vacant land is a significant source of PM-10 emissions in the semiarid Las Vegas Valley. The potential of vacant land to emit PM-10 during high wind events is related to soil stability at the surface, which depends on land characteristics. The purpose of this study was to develop an inventory of native desert land, disturbed vacant land, stabilized vacant land, and private unpaved roads in Hydrographic Basin 212 (HB 212) containing the Las Vegas Valley, as defined by Nevada State Plane coordinates.

Table I presents a time line, or project chronology, for significant milestones over the 20-month duration of this project.

TABLE I. PROJECT CHRONOLOGY

Item	Date	Activity
1	May 4, 2004	Kickoff Meeting and Preliminary Windshield Surveys
2	May 7, 2004	Obtained Spring 2004 Aerial Photography
3	June 2, 2004	Draft Work Plan
4	June 25, 2004	Revision 1 Work Plan – changed from PEP groups to WEG field training site selection methodology test procedures
5	August 18, 2004	Project Briefing
6	September 20, 2004	Revision 2 Work Plan – add Uhl methodology for vegetation WTE
7	October 6 – 8, 2004	Selected sites in North and South pilot areas
8	October 11 – 13, 2004	Took soil samples North and South
9	October 15, 2004	Revision 3 WP – defined pilot test areas
10	November 18, 2004	IKONOS Flyover for North Test Area
11	November 19, 2004	Groundtruthing North Test Area
12	December 14, 2004	Project Briefing and Project Hold– due to wet weather and wet soil conditions
13	February 9, 2005	Obtained Fall 2004 Aerial Photography
14	March 7, 2005	Project Briefing and Changed from IKONOS to Landsat approach. Reviewed North Pilot area results.
15	March 18, 1005	Selected Asphalt Sites and Gravel Sites for Further Classification
16	March 18 – 23, 2005	Groundtruthing for Asphalt and Gravel Sites
17	April 8, 2005	Revision 4 Work Plan – Change to Landsat Imagery
18	May 10-11, 2005	Attended WRAP Conference in Palm Springs
19	June 10, 2005	Met with GIS Management Office to Get Road Layers for unpaved roads
20	June 23 - 24, 2005	Selected 24 New Training Sites Throughout HB 212
21	June 26, 2005	Landsat Flyover
22	June 27 – 28, 2005	Groundtruthing
23	June 28, 2005	Obtained Road Layers from GIS Management Office
24	August 26, 2005	Project Briefing – reviewed classification of HB212 with Landsat
25	August 29 – 31, 2005	Selected Road Segments for Counting
26	October 10, 2005	Final Work Plan for Road Traffic Counts
27	October 13 – 29, 2005	Conducted Traffic Counts
28	December 13, 2005	Project Briefing, Review Draft Report



The methodology for developing this inventory used multi-spectral satellite imagery and ground truthing to develop unique spectral signatures that allowed mapping of land areas of the stated surface characteristics within HB 212. The important conclusions drawn by the investigators are as follows:

- The Landsat satellite imagery is more cost-effective for this purpose than high spatial resolution imagery, and avoids classification errors due to confounding from small pixel size.
- Aerial photography is an important tool to supplement imagery.
- There is far less unstable land in the Las Vegas Valley than previously thought.
- Soil chemistry is an important variable in classification of disturbed, unstable land.
- Erodibility is not closely correlated with Wind Erodibility Groupings (WEG), but more so the condition of the surface.
- The enforcement of regulations controlling construction-related dust has significantly decreased unstable land across the Valley.

The inventory of land areas based on soil stability using satellite imagery is based on a computer algorithm called supervised classification. This algorithm requires a suite of "training sites" that are representative of the various soil stability categories, or classes. The training sites were established through aerial photography and field evaluation, ensuring that the training sites accurately represented the soil stability categories. Additional subcategories such as urban landscape, wash areas, and concrete were developed primarily to eliminate these areas from the overall land area of interest and enhance accuracy. Several classification schemes were evaluated, but the Mahalanobis distance scheme proved to be the most effective for this particular project.

It was not feasible to classify the disturbed unstable vacant land category directly because the training sites exhibited a variation in signatures which is believed to be attributable to differences in soil chemistry. A large expanse of disturbed unstable area might provide a more reliable signature, but no such large areas existed. Therefore, the percentage of disturbed unstable vacant land was derived by inference – when all other land cover types (native desert, urban, etc.) were classified, then the remaining unclassified pixels represent an upper bound on the amount of disturbed unstable vacant land.

Table II summarizes the land classifications for HB 212 derived from the classified imagery based on the Landsat view of June 26, 2005.

TABLE II. LAND CATEGORIES

Land Category	Percent of HB 212	Square Kilometers
Native Desert	47.6	1,897.1
Disturbed Unstable Vacant Land	Less than 1.1	Less than 45.3
Disturbed Stable Vacant Land	3.1	122.8
All Other	48.2	1,918.6

The "all other" category includes wash areas (9%), concrete (0.7%), urban area (4.8%), vegetation (0.9%), and barren shadow (32.8%). Barren shadow is largely comprised of mountainous and/or rock areas plus shadowed areas. The amount of disturbed unstable vacant land is significantly less than previously reported. This is attributed to several factors:

1. A probable over-estimation in the past given the qualitative methods available at that time.
2. The success of the enforcement program requiring contractors to utilize stabilization techniques during construction.
3. The higher than average rainfall in the Valley during 2004 and 2005.

An accuracy assessment was performed to quantify the success of the supervised classification. Reference or validation sites were derived from field observations, and also were obtained from aerial photography and map data. An error matrix indicates the mapping accuracy of each soil stability category by showing the percent of correctly classified pixels.

Table III provides the error matrix for the classification process. Error matrices are very effective representations of map accuracy because the individual accuracies of each map category are plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map. A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs. Overall accuracy is the sum of the major diagonal (i.e., the correctly classified pixels or samples) divided by the total number of pixels or samples in the error matrix (Congalton and Green, 1999). The overall accuracy for the classification of HB 212 in this project is 89% (313/350).

TABLE III. CLASSIFICATION ERROR MATRIX

	B/S	Concrete	DS	Veg	Wash	Urban	ND	Row Total
B/S	43					6		49
Concrete		45						45
DS		5	50		18			73
Vegetation				50				50
Wash					31			31
Urban	7				1	44		52
ND							50	50
Column Total	50	50	50	50	50	50	50	350

A second phase of the project involved the identification of unpaved roads in HB 212 which were not already in the Clark County GIS. Roads were identified through 2-foot pixel aerial photography supplemented by field surveys. By definition, roads had to be a minimum of 22 feet wide. A total of 160 miles of unpaved roads were identified. A sample of 30 road segments was selected on which to perform traffic counts. The 30 segments were selected to be representative based on usage. All 30 segments were in the urban area and in areas of expanding home building. Average daily traffic (ADT) counts by segment are summarized in Table IV.

The reader is advised to read the entire report because there were many areas of complexity and judgments throughout the project that cannot be adequately reflected in this Executive Summary. The reader is also referred to the glossary for definition of terms unique to this field.

TABLE IV. AVERAGE DAILY TRAFFIC COUNTS

Site No.	Traffic Count Data								ADT
	Sun	Mon	Tues	Wed	Thur	Fri	Sat	Counter	
1	6	13	22					EQ01	13.7
2	9	27	23					J 1	19.7
3	21	60	54					J 2	45.0
4	Construction area - Road extremely active with earthmoving equipment - Did not use								
5&6	12	32	28					J 3	24.0
7	23	24	26					EQ02	24.3
8	50	140	89					J 5	93.0
9 a	34	32	29					J 4	31.7
9 b	34	36	28					EQ03	32.7
10	27	28	79					J 7	44.7
11	203	493	511					J 8	402.3
12	Did not use								
13	40	43	53					J 6	45.3
14					96	105	80	J 8	93.7
15 a					249	172	208	J 7	209.7
15 b					189	153	177	EQ03	173.0
16	Berm added (Dirt) - Access to unpaved road blocked								
17					58	84	137	EQ02	93.0
18					16	12	28	J 6	18.7
19					33	33	30	J 5	32.0
20					17	18	26	EQ 01	20.3
21					4	4	7	J 4	5.0
22					45	43	43	J 3	43.7
23					13	20	12	J 2	15.0
24					89	73	53	J 1	71.7
25					11	15	5	J 3	10.3
26					70	45	61	J 2	58.7
27					6	7	10	J 1	7.7
28	Old pavement - broken up - did not use								
29	Did not use								
30	Dead End street = did not use								
31					68	61	19	J 6	49.3
32 a					10	12	1	J 4	7.7
32 b					10	9	2	EQ01	7.0
33					642	693	463	J 5	599.3
34					11	11	12	EQ02	11.3
35	Did not use								
36 a					91	76	50	J 1	72.3
36 b					84	74	56	EQ01	71.3
37					35	33	23	J 7	30.3
38					3	3	0	J 8	2.0
		ADT Excluding Sites 11, 15, and 33 (ADT >150)							36.4
		ADT Including Sites 11, 15, and 33 (ADT >150)							73.2

1.0 INTRODUCTION

1.1 Background

The Las Vegas Valley is one of the fastest growing metropolitan areas in the nation. The population expanded from about 400,000 in 1980 to 1.4 million in 2000 (U.S. Census Bureau, Census 2000). As of April 2005, the population of the entire Las Vegas Valley was about 2 million people. The cities of Las Vegas, North Las Vegas, and Henderson are located in the Las Vegas Valley within Clark County, in the southern tip of Nevada.

The city estimates a new home is completed every 20 minutes, as 5,000 people move to Las Vegas every month. Las Vegas is currently building 88 new schools, and the number of hospitals has tripled in the past several years. Commercial building activity maintains pace with new shopping centers, warehousing, service stations, casinos and other entertainment, and the full complement of related businesses required to support the population growth.

The U.S. EPA in accordance with the Clean Air Act (CAA) has classified the Las Vegas Valley, also known as Hydrographic Basin 212 (HB 212), within Clark County as a "serious" nonattainment area for PM-10 (particulate matter having an aerodynamic diameter of 10 microns or less). Figure 1-1 illustrates the Hydrographic Basins which are used to define the airsheds within Clark County. HB 212 is sometimes called the "BLM Disposal Area." The BLM Disposal Area refers to the land which has been sold by the Bureau of Land Management through auction under the Southern Nevada Public Lands Management Act. These Lands represent a smaller subset of HB 212, but they represent the area where most of the anthropogenic activity takes place, and consequently most of the PM-10 emissions. HB 212 includes significant land area that is still largely undeveloped, including mountainous areas. The elevation of the valley floor is about 2,200 feet.

HB 212 has experienced violations of the 24-hour National Ambient Air Quality Standards (NAAQS) for PM-10 that are largely due to windblown dust. During 2002, four high-wind events occurred resulting in exceedances of the PM-10 NAAQS. During 2003, two high-wind events occurred that resulted in exceedances of the PM-10 NAAQS, and during 2004 two high-wind events occurred that resulted in exceedances of the PM-10 NAAQS.

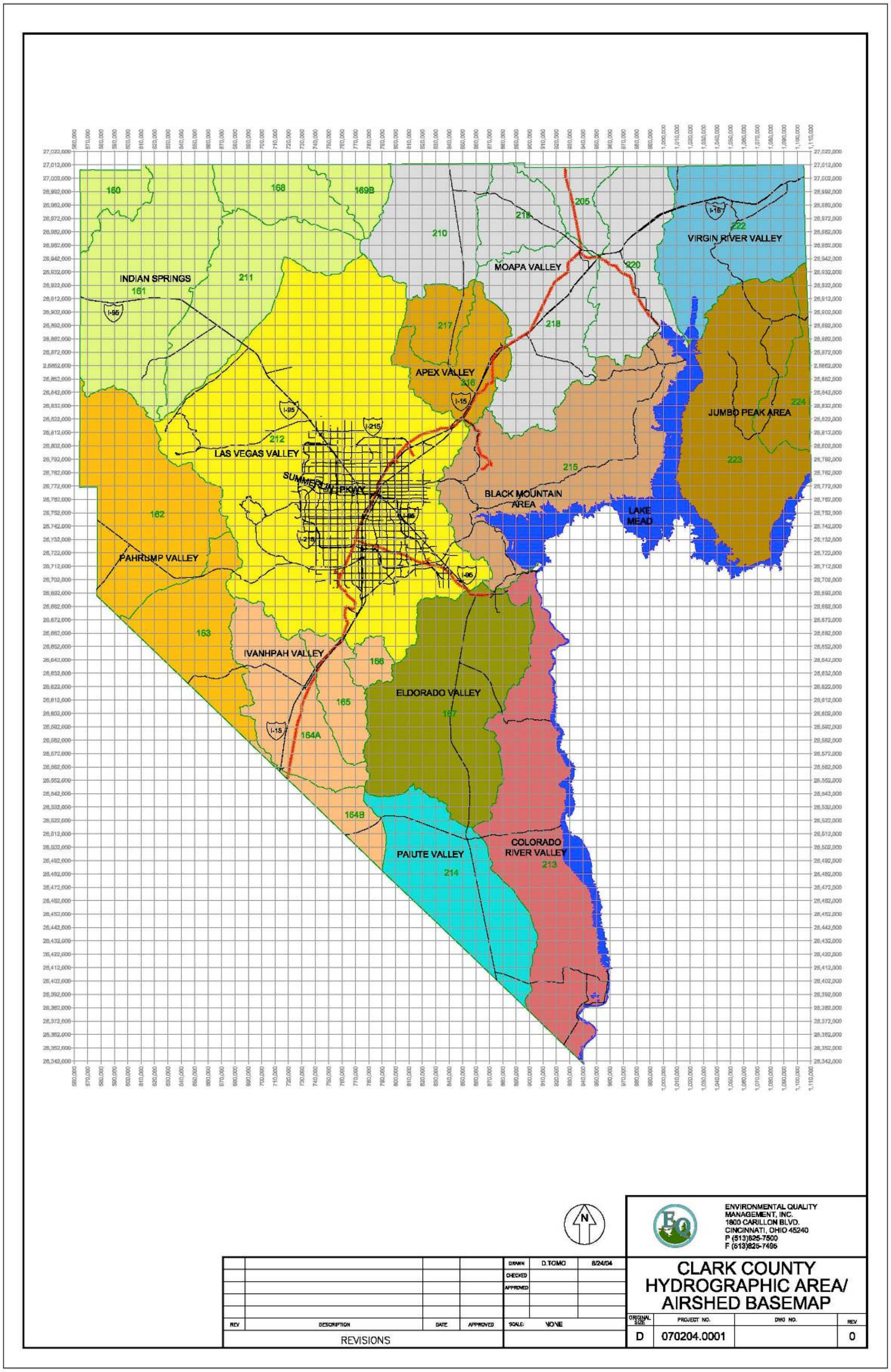


Figure 1-1. Hydrographic Area/Airshed Basemap

Conditions that create high-wind PM-10 exceedances vary from area to area and are based on soil condition (as influenced by precipitation) and wind speed. Wind erosion occurs where natural soil stability has been disturbed by human activities. This is because natural soils have a tendency to form a mineral and organic crust that is resistant to erosion by wind. Human activities can remove or break this crust, allowing dust to become airborne. Even the sparse desert vegetation found in the valley acts as a windbreak and provides some protection to the soil surface. When human activities remove vegetation, the soil is more susceptible to erosion, and as a result, airborne dust is produced.

The purpose of this study was to develop a remote sensing method for inventorying vacant land categories in the Las Vegas Valley. The methodology for developing the inventory used multi-spectral satellite imagery and ground truthing to determine unique spectral signatures for land surface characteristics. Prior studies of land erodibility in arid areas of the West have also been assessed using satellite imagery:

- Owens Lake Revegetation
  - Test for compliance with 50% coverage requirement
  - Use Landsat 7 TM and Quickbird data to characterize extent of vegetation (16 training sites)

- Antelope Valley Blowsand Areas
  - Identify blowsand areas that drive wind erosion of abandoned farmland
  - Use Landsat data to map blowsand areas (8 training sites)

The four main categories of land surfaces considered in this project are: (1) native desert, (2) disturbed and unstable vacant land, (3) disturbed and stabilized vacant land, and (4) private unpaved roads that have not been identified in existing Clark County data. Unpaved roads were identified through high-resolution aerial photography which proved to be more effective than satellite imagery. In addition, private unpaved average daily road traffic (ADT) was determined using traffic counters at selected locations. Both pneumatic and magnetic counters were utilized with data loggers. At each site, traffic counts were obtained over a consecutive 3-day period, including one weekend day.

Stabilized surfaces include rocky soils, soils protected by vegetation, and soils that have re-crusted following disturbance. Unstabilized surfaces include active construction sites and areas traveled by 4-wheel drive and all-terrain vehicles (ATVs) where no rocky surface condition exists and no surface crust has been developed.

The strategy for performing this project utilized a pilot study to assess all elements of data gathering and analysis before proceeding with the main study.

- Pilot Study (two 100-km^2 areas of HB 212)
  - Utilize limited study area to develop and test predictive algorithms derived from satellite imagery.
  - Identify training sites for specified land categories.
  - Develop ground truth training sites to verify land surface condition.

- Main Study (Remaining Area of HB 212)
  - Perform supervised classification of satellite imagery for full study area.
  - Identify and characterize verification sites for accuracy assessment of supervised classification.

Given the relatively small contribution of the area outside the BLM disposal area to the overall emission inventory, emphasis was placed on the BLM disposal area because this is where virtually all of the anthropogenic activity takes place to create land disturbances and thereby substantially increases the wind erodibility of the land. The BLM disposal area was therefore viewed as the key to developing an overall emission inventory for open areas and vacant land, for which this study will be used.

1.2 Overview of Methodology

The inventory of land areas for soil stability using satellite imagery was initially to be based on high-resolution imagery from either the IKONOS or Quickbird satellites. Due to the many uncertainties that had to be resolved in obtaining imagery, evaluating various classification algorithms, and correlating imagery to actual conditions on the ground, it was decided to utilize a pilot study of relatively small areas before attempting to study the entire hydrographic basin which consists of 1,524 square miles. Another important factor was the high cost of high-spatial resolution imagery which ranges from \$35-\$40/km^2.

During the evaluation of the first pilot area, the designated North Area (Figure 1-2), imagery from the IKONOS satellite was used as well as Landsat imagery for comparison. This analysis revealed that the greater resolution of IKONOS actually was a complicating factor in classification of the larger land areas of interest because of large pixel-to-pixel variation. Landsat, however, provided an inherent averaging of the minor variations in surface conditions across its 30-m pixel size. In addition, Landsat has six visible/near-IR spectral bands compared to IKONOS's four bands.

One of the important conclusions from the pilot study was that the small pixel size and limited spectrum of this high-resolution imagery actually confounded the classification algorithms. It was then determined that the Landsat satellite (specifically Landsat 5 TM) would not only provide better classification for this project, but also provided imagery at a fraction of the cost. This will result in significant future savings for the County as the process is repeated.

Any classification algorithm requires a suite of "training sites" which are representative of the particular soil stability categories being studied. The training sites were established through aerial photography and field evaluation, thereby ensuring that the training sites accurately represent the soil stability categories. Each site had to be uniform, accessible, and clean of debris. (Additional subcategories such as urban landscape, concrete, and wash areas were ultimately developed to increase the accuracy of the classification.)

The ground truthing was initially performed as part of the Pilot Study focused on two 100-km^2 pre-selected areas within HB 212 containing land surface conditions and private roads representative of the four specified erodibility classifications and the eight WEG categories as shown in Figure 1-2. Some training sites were used to develop the spectral signatures and others were used as verification sites for testing the reliability of the spectral signatures. These training sites were approximately 60 m x 60 m. The Pilot Study was used to develop the most efficient ways to perform supervised classification before final classification was attempted. The Pilot Study also allowed the Project Team to evaluate and refine the ground truthing methodology and data collection forms, and understand the complexities of satellite imagery acquisition. The imagery was obtained when there had not been a rain event within the past 7 days. Ground truthing was completed within 48 hours of imagery acquisition to ensure the conditions did not change between the time the imagery was obtained and the ground measurements were taken.

After the Pilot Study was successfully completed, the most recent Landsat satellite imagery was purchased. This set of satellite imagery was processed to complete the inventory of vacant land. Twenty-four additional training sites were then used to develop the classification algorithms over wider expanses of HB 212.

The initial focus was on the 12 USDA soil texture categories and the different wind erodibility groups (WEG). The soil groups are based on a set of parameters collected during a

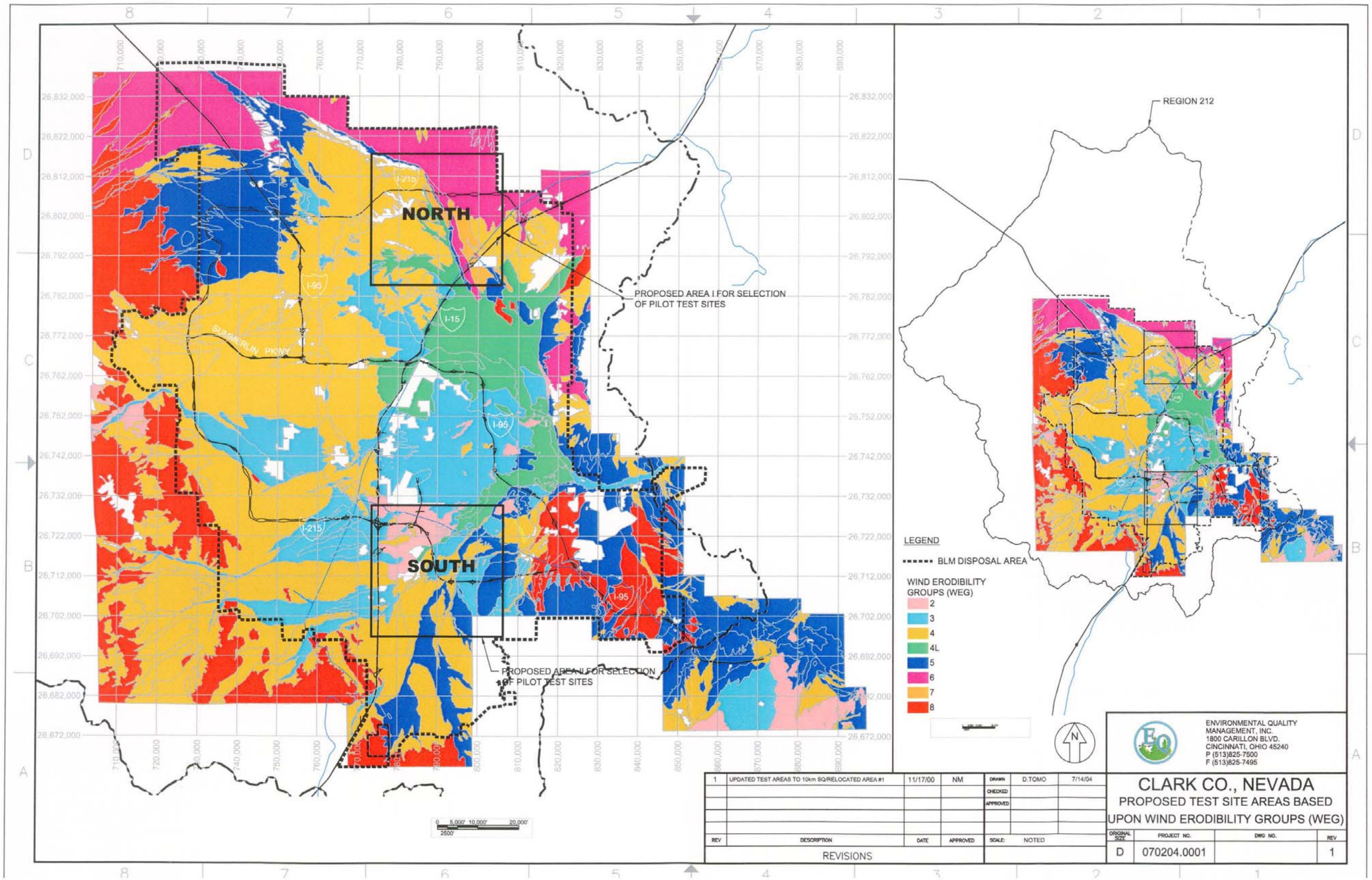


Figure 1-2. Proposed Test Site Areas Based Upon Wind Erodibility Groups (WEG)

comprehensive soil survey conducted by Speck and McKay in the early 1980s.[1] Training sites were selected to represent the WEG categories to determine if classification of the imagery could detect differences by WEG. One soil sample was taken at each site from the surface to a depth of 3 inches and analyzed for silt, clay, and sand by a geotechnical laboratory in Las Vegas (Geotechnical and Environmental Services, Inc.). The results of the testing did not correlate well with the WEG mapping of Speck and McKay. One reason may be the difference between conventional soil classification data which focuses on soil at depth versus the study of windblown dust which is a surface phenomenon. It was further determined that differences in WEG could not be accurately classified through the imagery.

Selection of sites was based on Wind Erodibility Groups (WEG) consistent with Speck and McKay and the previous wind tunnel tests by Dr. James[2] and the emission inventory approach developed by MacDougall and Uhl.[3] Suspended wind-blown dust was estimated by James using an empirical formulation derived from a series of field observations made with a mobile wind tunnel over a representative set of "wind-erodible" soils and soil conditions. Soils covering eight distinct wind erodibility groups were sampled in the Las Vegas Valley, and the results of this study are provided in Appendix C.

The phenology of vegetation in the region was also studied to determine chlorophyll concentrations during the course of the year. It was initially believed that chlorophyll might enhance satellite recognition of vegetation because of the distinct signature it provides relative to un-vegetated areas. In the end, no specific conclusions could be drawn regarding the optimum

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[1]SIP June 2001 PM_{10} State Implementation Plan for Clark County, Appendix B - Emission Inventories, Methodology, Emission Factors, and Emission Estimates, Page B-37 Native Desert Fugitive Dust, and Appendix C – Section II, Estimation of Valley-Wide PM_{10} emissions using UNLV 1995 wind tunnel-derived emission factors, 1998-1999 emission factors, revised vacant land classifications, and GIS-based mapping of vacant lands, – Draft Final Report, David James, et al., Civil and Environmental Engineering Department, University of Nevada Las Vegas, dated September 12, 2000.

[2]SIP June 2001 PM_{10} State Implementation Plan for Clark County, Appendix B - Emission Inventories, Methodology, Emission Factors, and Emission Estimates, Page B-37 Native Desert Fugitive Dust, and Appendix C – Section II, Estimation of Valley-Wide PM_{10} emissions using UNLV 1995 wind tunnel-derived emission factors, 1998-1999 emission factors, revised vacant land classifications, and GIS-based mapping of vacant lands, – Draft Final Report, David James, et al., Civil and Environmental Engineering Department, University of Nevada Las Vegas, dated September 12, 2000.

[3] MacDougall, C. R. and M.F. Uhl. 2002. *Empirical method for determining Fugitive dust emissions from wind erosion of vacant land: "The MacDougall Method."* Clark County Department of Air Quality Environmental Management.

time of year for imagery acquisition. A more significant factor for obtaining imagery was clear weather conditions with minimal haze.

The effect of the nadir angle was determined to not be as significant as previously thought due to imagery technology and software enhancements since 2000. A larger angle actually provides more opportunities for image acquisition. Figure 1-3 illustrates the relationship of the geometry of satellite imagery.

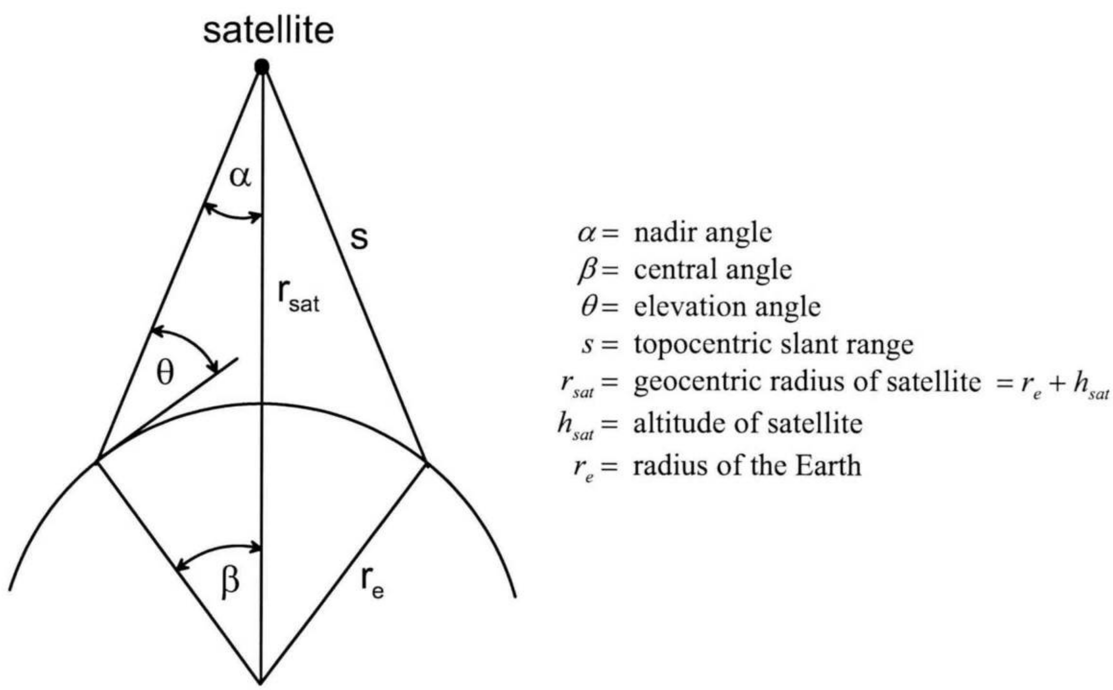

Figure 1-3. Coverage Geometry of a Satellite in Orbit Above a Spherical Planet with a Nadir-Pointing Conical Sensor or Field-of-View

An accuracy assessment was performed to quantify the success of the supervised classification. Reference or validation sites were derived from field observations, and also from aerial photography and map data. An error matrix was developed to indicate the mapping accuracy of each soil stability category by showing the percentage of correctly classified pixels.

2.0 TRAINING SITE SELECTION AND CHARACTERIZATION

This section describes the selection and characterization of training and verification sites for the Pilot Study. Ground truthing tests document gradations of erodibility for the sites selected as representative for each specific category of land inventoried. Three different field test procedures were used to confirm the erodibility of a particular soil surface area as described in Clark County Air Quality Regulations Section 90.4: drop ball, rock test, and threshold friction velocity test.

The number and size of training sites was based upon the number of soil stability categories, the degree of variation within a category, and the pixel size of the satellite imagery. For example, native desert is considered a composite category and multiple training sites were needed to fully capture this variability (vegetation and desert pavement). The actual number of training sites for the study was selected through an iterative process between the field crew and the image analyst. Thirty sites were selected as training sites: 15 in the northern pilot area and 15 throughout Hydrographic Area 212.

Ground truthing tests documented the gradations of erodibility for the sites that were selected as representative for each specific category of land to be inventoried. (The categories of vacant land included in this study are native desert, disturbed stabilized, and disturbed unstabilized.) The drop ball test, rock test, and threshold friction velocity test were used to confirm the erodibility of a particular soil surface area. Field data was collected during dry conditions (i.e., no precipitation for a period for at least 5 to 7 days prior to collection of field data). Weather data for the project was obtained from the National Weather Bureau, the Clark County Flood Control rain gauge data, and local weather reports. These vacant land categories are defined as follows:

- <u>Native desert</u>: desert land in its natural state with no evidence of disturbance by anthropogenic activities. Native desert is characterized by (a) stable soil that is highly consolidated and (b) natural vegetation that is scattered across the surface except in wash areas with rocky surfaces. Typically native desert soil is impregnated with small rocks that in conjunction with natural mineralogical cementation, form a desert pavement. In any case, the soil is crusted so that it passes the ball drop test (i.e., the ball does not penetrate the crust and form a crater containing loose dust). Even if there are small soil areas that do not pass the drop ball test, these areas are likely to pass the rock test (more than 20 percent coverage with non-erodible elements such as rocks or stones larger than 1 cm). Finally, any pockets of loose soil are likely to pass the threshold friction velocity test (TFV equal to or greater than 100 cm/sec). It should be noted that small amounts of loose dust may have been deposited on stable soil crust (especially in wind-depletion shadows of vegetative structures) during or after high wind events; such amounts, however, are usually much smaller than the minimum (significance threshold) required for the TFV test.

- Disturbed unstable vacant land: native desert that has been disturbed by removal of vegetative groundcover and soil surface layers such that the natural crust on the soil is destroyed. Typically this occurs in association with construction or other land development activities. Disturbed unstable land by definition is characterized by unstable soil, i.e., unconsolidated soil that is unprotected against wind erosion. In order to classify vacant land as disturbed unstable, the soil must fail all three tests conducted in sequence: the drop ball test, the rock test, and the TFV test.
- Disturbed stable vacant land: native desert that has been disturbed by removing natural crusts and vegetation and re-stabilized by natural phenomena or anthropogenic measures. Disturbed stable land by definition is characterized by stable soil, i.e., soil that is protected against wind erosion. If the soil is sufficiently rocky (such that it passes the rock test or the TFV test), it remains stable, even immediately after mechanical disturbance. If the soil is not sufficiently rocky, it may take years to reform a stable surface by natural processes, or the soil may be stabilized after the next rain event. Non-erodible surface cover (e.g., vegetation or soil stabilizers of a physical or chemical nature) can be applied to stabilize the soil immediately, but stabilizers may lose effectiveness in time. In order to classify vacant land as stable, it must pass only one of the drop ball drop tests, the rock test, or the TFV test. When these tests are conducted in sequence, one passing test negates the need for performing any additional tests.

Figure 2-1 presents a decision tree for vacant land classification.

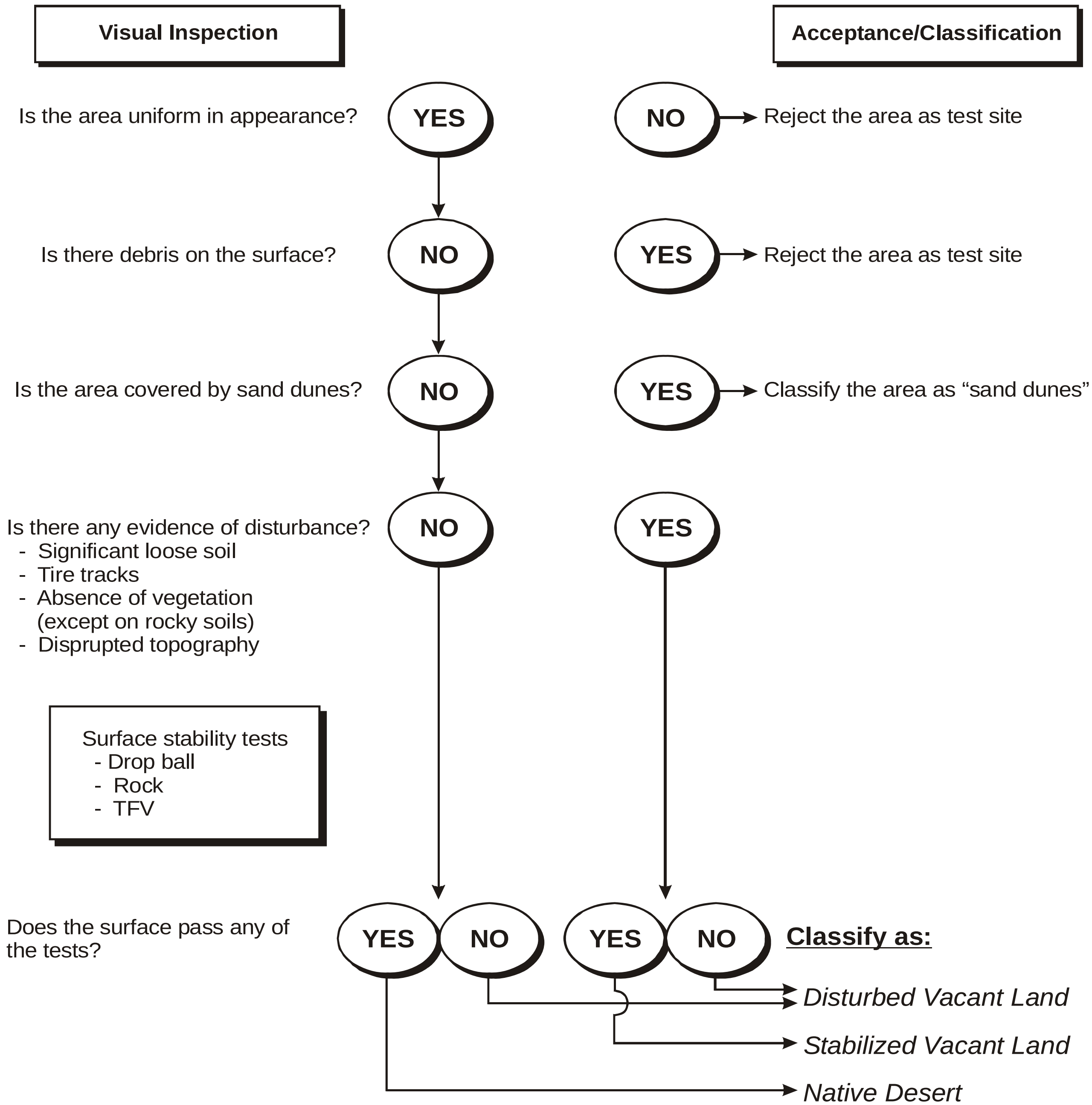

Figure 2-1. Decision Tree for Vacant Land Classification

2.1 Site Selection Methodology

Surveys were made to visually evaluate and access site conditions, uniform areas of sufficient size, and other factors at potential training sites. Windshield surveys were performed to locate potential training sites. Aerial photographs from the Clark County GIS files were also reviewed with the County to evaluate site locations. Clark County DAQEM representatives provided site suggestions and assistance in selecting the training sites.

In addition to field observations, another resource used to select test sites was the soil classification schemes such as the USDA Soil Textural Triangles and the USDA Wind Erodibility Groups (WEG) used for the characterization of vacant land and determining fugitive dust emissions using emission factors based on wind tunnel data. The WEG groups, however, were developed to characterize total soil movement rather than PM-10 emissions. PM-10 emission potential is more related to clay particles which have less mobility than the larger particles that make up sand and silt.

The sites were located within the BLM disposal area (Figure 1-2) because of its dominance in the estimated wind generated emission inventory for Hydrographic Area 212. Most land outside the BLM Disposal area consists of native desert, and therefore was not selected for training sites. Sites were selected by the WEGs based on the soil classifications and aerial photographs annotated with the WEGs as shown in Figure 2-2. Bulk soil samples were taken in the first phase of the pilot study at a depth of 3 inches and analyzed for silt, sand, and clay content to verify the WEG and classify the ground truthing sites relative to the soil textural triangle.

Thirty locations with uniform surface characteristics were selected as training sites to determine their relative potential wind erodibility using the procedures outlined in Section 2.3. These test locations were used either for training or validation of the remote sensing algorithms. (Some additional validation sites were selected and evaluated from available aerial photography. For example, native desert land could be identified from photography representing large areas (many pixels) and of obvious uniform characteristics. Such sites could then be compared to the corresponding satellite imagery classification.)

Two initial study areas were selected to represent the full range of WEG groups (Figure 2-3). Fourteen additional sites were selected outside of these areas to complete the ground truthing. (Please see Table 2-1 for the total number and type of ground areas that were characterized.)

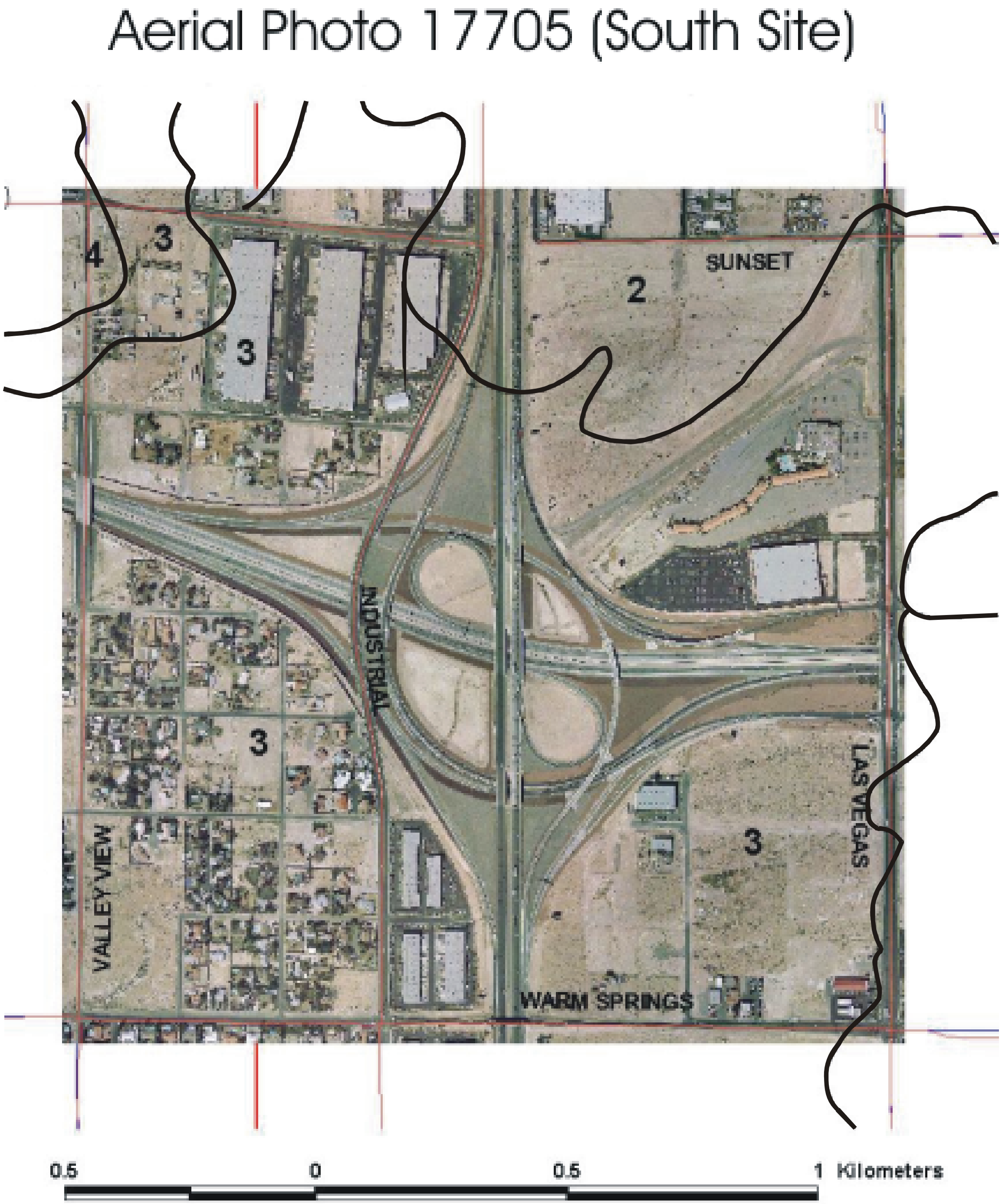

Figure 2-2. Example Map Labeled with Wind Erodibility Groups

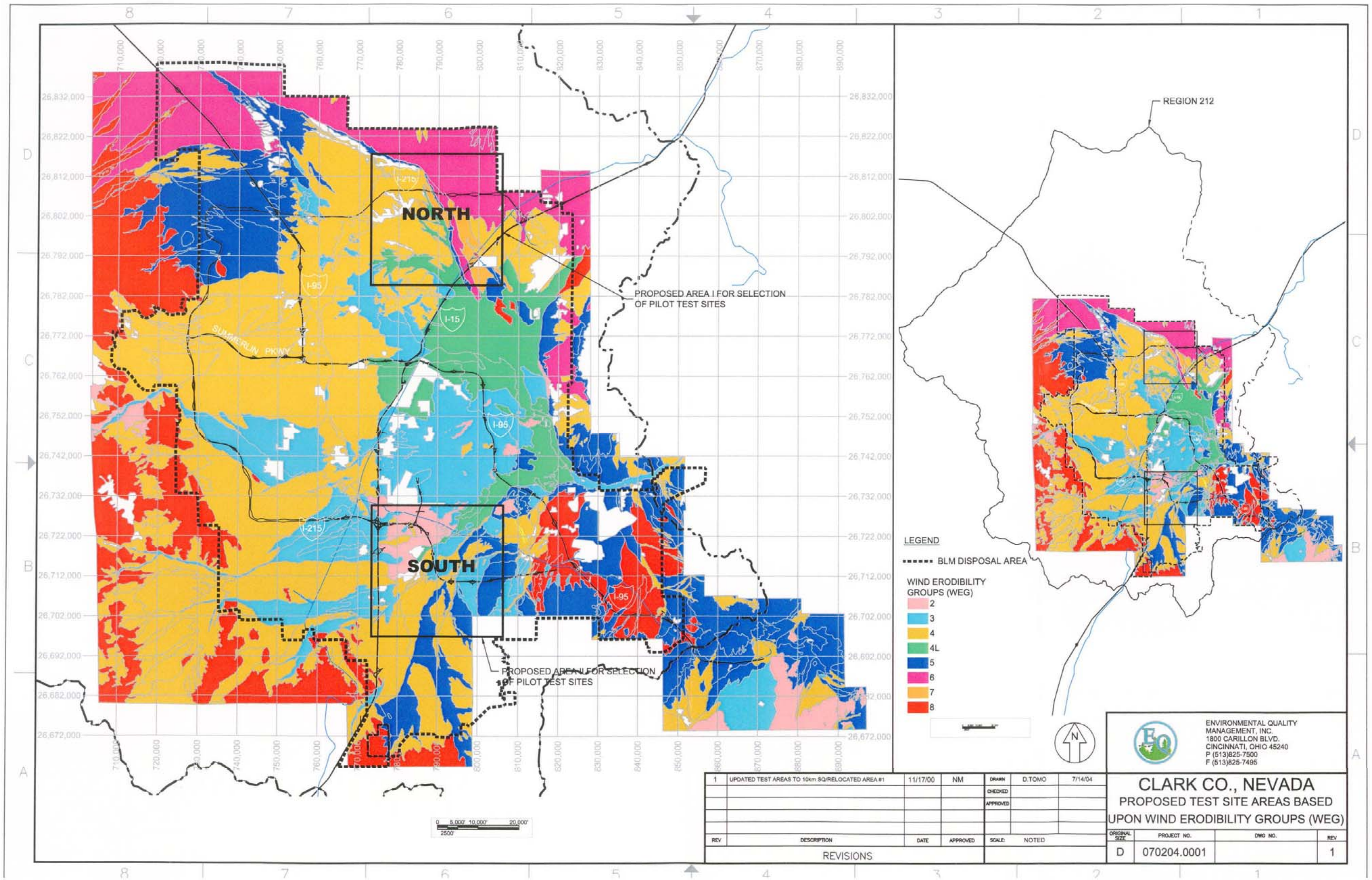

Figure 2-3. Proposed Test Site Areas for Pilot Study

TABLE 2-1. STUDY SITES

Type of Land Surface	No. of Sites (spanning major WEGs)
Disturbed unstable land	4
Native desert	5
Disturbed stable land	18
Unvegetated rocky surface (e.g., washes)	10 (by Aerial Photographs)
Anthropogenic areas: urban landscaping and asphalt	10 (by Aerial Photographs)
Unpaved roads	30
Water soaked areas (construction watering or heavy rains)	4

Site inspections performed in this study indicated a high degree of difficulty in locating disturbed unstable land. The selected test locations were used either for training or validation of the classification algorithms. Ground truthing was typically conducted within 24 hours of verified image acquisition.

2.2 Site Characterization Selection Methods and Results

2.2.1 Site Selection

In the north pilot study area, training and verification test locations were selected to represent surface uniformity over an area of at least 60 m x 60 m in size. Approximately 15 test areas were characterized for ground truthing. In the south study area and other Hydrographic area 212 training sites, the primary tools for site selection were aerial photography and recommendations from Clark County DAQEM, with no prescribed limits as to how large a site could be, as long as uniformity of surface conditions was verified by site inspection.

Once the satellite imagery was collected over an area, ground truthing was performed at each of the applicable test sites within 48 hours following the generation of the images, as long as atmospheric conditions were acceptable. It was critical to minimize the time between imagery collection and ground truthing in order to minimize the likelihood of uncontrolled events changing the land surface. Such events included rainfall, wind events, or human activity disturbing the surface. To limit the effort that was required in the 48-hour period after the recording of the satellite images, the test surfaces were preselected as described above, and surveyed in advance. Within the 48-hour period, visits were made to each pre-selected site to perform the ground truthing inspection. If the site changed during the brief period between the initial survey and actual testing, the site was reclassified. For example, if a stable site had become disturbed by human activity, we reclassified the site as disturbed unstable. Digital photographs were taken during ground truthing at each site to document soil condition, vegetative cover, and surrounding land area.

Specific ground truthing methods were used to classify each pilot study site into one of the three specified vacant land categories. It was important that each ground truthing site was sufficiently homogeneous that its entire ground surface fit the characteristics on only one of the three vacant land categories. In addition no debris from construction or other activities was present at a ground truthing site. Dry runs of the ground truthing procedures were done to refine the approach and determine the time required for implementation.

Twelve ground truthing sites were selected for the pilot study on October 6 through 8, 2004, and 15 additional sites were selected on June 16 and 17, 2005. Fifteen test sites were selected in the north pilot test area, and 12 sites were selected in the south test area and throughout the BLM area of Hydrographic Basin 212. The test sites were selected based on WEG soil categories and land category (i.e., native desert, disturbed stable, and disturbed unstable land). The pilot study was performed using the sites in the north pilot area. Due to weather delays (rain and wet ground), most of the sites (10) in the south area were not used and other sites were added. All ground truthing sites were inside HB 212. Figures 2-4 and 2-5 show the test sites selected for the north pilot area, and the locations of the remaining test sites. Table 2-2 lists the locations and classifications of these sites.

2.2.2 Site Characterization Methods

During ground truthing, three interior test areas measuring 1 m x 1 m were visually selected at each test site to be representative of the overall site. (Figure 2-6 shows an illustrated view of what a typical test site should look like, and Figure 2-7 depicts an actual test site used in the study, with the 1-m^2 squares denoted in red.) Each 1-m^2 square was characterized by using the following methods:

The drop ball test, the rock test, and the threshold friction velocity (TFV) test were performed as described in Section 90 of the Clark County Air Quality Regulations. The TFV was done only when applicable, i.e., when there was sufficient loose material on the surface to perform the test and when the rock cover test failed. In addition, an enhanced version of the drop ball test using a five-point scale was used to better characterize the soil crust.

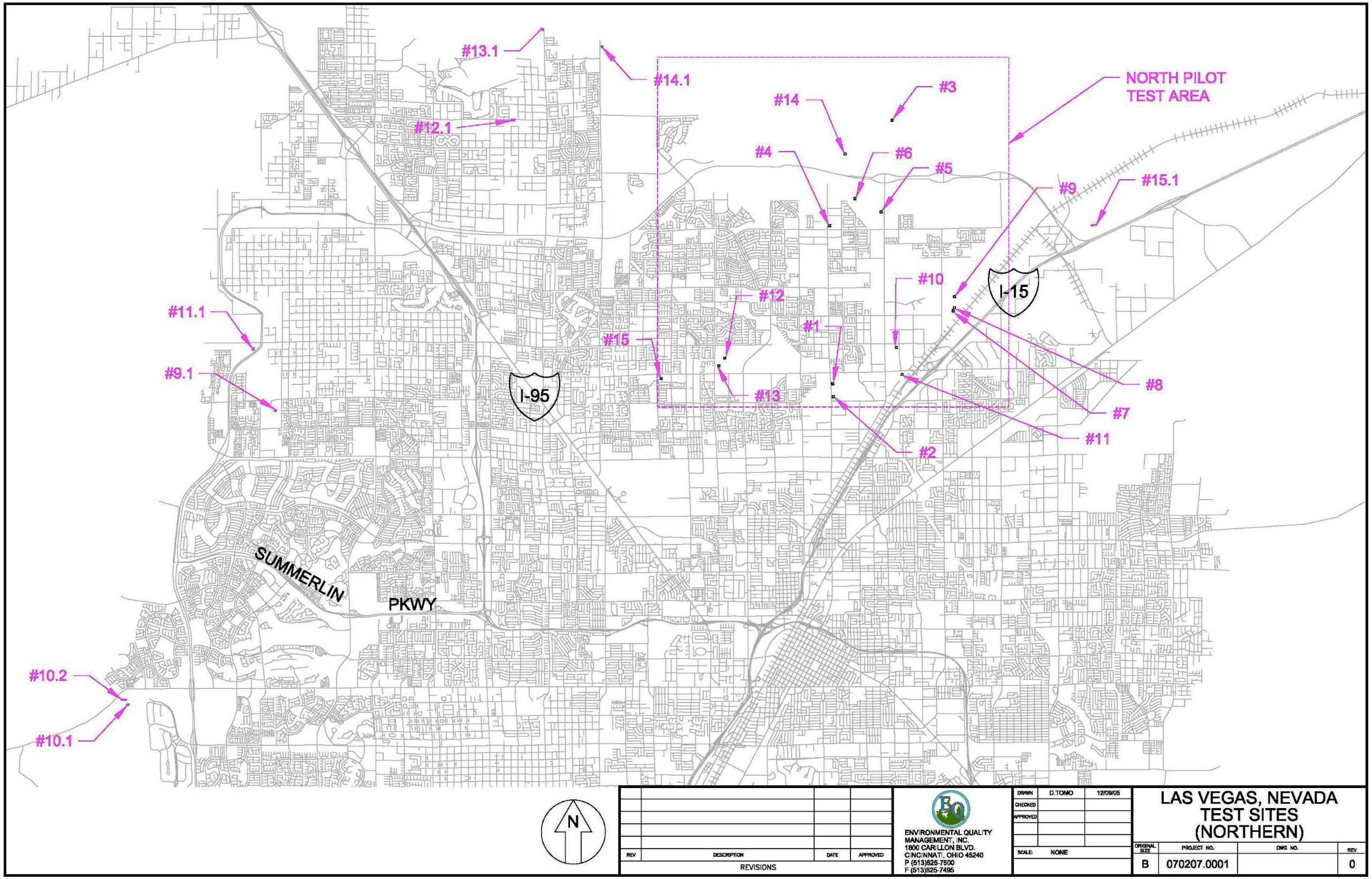

Figure 2-4. Test Sites (Northern)

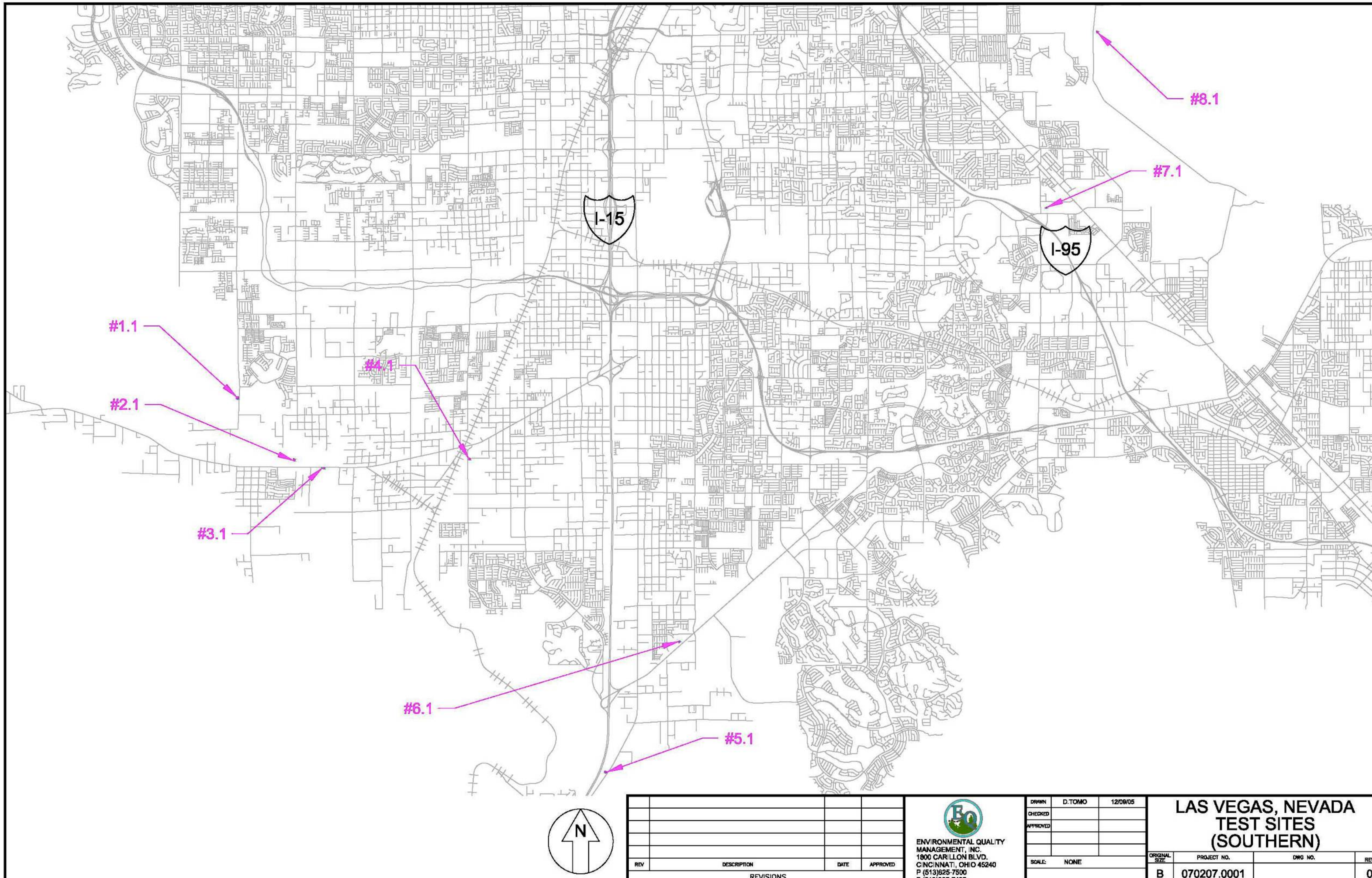

Figure 2-5. Test Sites (Southern)

TABLE 2-2. GROUND TRUTHING LOCATIONS

Sample Area	Site No.	Location	Date Ground Truthing	Disturbed Stabilized	Disturbed Unstable	Native Desert	GPS Coordinates SW corner	GPS Coordinates NW corner	GPS Coordinates NE corner	GPS Coordinates SE corner
North	1	N. 5th Street and Craig Road North section of vacant lot	11/18/04	X			007-88-666 E 267- 88-258 N	007-88-883 E 267 88-282 N	007-88-940 E 267 88-084 N	007-88-723 E 267 88-030 N
North	2	N. 5th Street and Craig Road South section of vacant lot	11/18/04	X			007-88-759 E 267 87-062 N	007-88-967 E 267 87-077 N	007-88-993 E 267 86-861 N	007-88-759 E 267 86-832 N
North	3	N. Losee, North of 215	11/19/94			X	007-94-261 E 268 12-941 N	007-94-471 E 268 12-950 N	007-94-489 E 268 12-749 N	007-94-288 E 268 12-706 N
North	4	N. 5th Street and Centenniel	11/19/04	X			007-88-415 E 268 03-056 N	007-88-618 E 268- 03-073 N	007-88-626 E 268 02-865 N	007-88-415 E 268 02-849 N
North	5	N. Losee, South of 215	11/19/04			X	007-93-225 E 268 04-335 N	007-93-438 E 268 04-377 N	007-93-461 E 268 04-125 N	007-93-258 E 268 04-132 N
North	6	Deer Springs and Lawrence Northwest corner	11/19/04	X			007-90-801 E 268 05-609 N	007-91-005 E 268 05-633 N	007-90-997 E 268 05-397 N	007-90-792 E 268 05-397 N
North	7	E. Washburn Road and N. Pecos Road	11/19/04	Construction watering - Site saturated			007-99-979 E 267 95-114 N	008-00-230 E 267 95-045 N	008-00-181 E 267 95-841 N	007-99-982 E 267 94-909 N
North	8	E. Washburn Road and N. Pecos Road	11/19/04	Construction watering - Site saturated			008-00-087 E 267 95-398 N	008-00-287 E 267 95-393 N	008-00-293 E 269 95-196 N	008-00-087 E 267 95-202 N
North	9	E. Washburn Road and N. Pecos Road	11/19/04			X	008-00-125 E 267 96-432 N	008-00-324 E 267 96-432 N	008-00-326 E 267 96-223 N	008-00-124 E 267 96-224 N
North	10	E. Lone Mountain Road and Berg Street	11/19/04	X			007-94-658 E 267 91-649 N	007-94-857 E 267 91-652 N	007-94-873 E 267 91-457 N	007-94-664 E 267 91-451 N
North	11	Craig Road East of Losee	11/18/04	X			007-95-213 E 267 89-140 N	007-95-412 E 267 89-134 N	007-95-403 E 267 88-933 N	007-95-211 E 267 88-939 N
North	12	Craig Road and Clayton Street, North of Canal	11/19/04			$X_{high\ veg}$	007-78-588 E 267 90-687 N	007-78-792 E 267 90-683 N	007-78-790 E 267 90-478 N	007-78-596 E 267 90-485 N
North	13	Craig Road and Clayton Street, NE Corner	11/19/04			$X_{low\ veg}$	007-78-042 E 267 89-955 N	007-78-246 E 267 89-960 N	007-78-243 E 267 89-757 N	007-78-040 E 267 89-755 N
North	14	Retention Basin, N. Losee, North of 215	11/19/04	X			007-89-870 E 268 09-769 N	007-90-070 E 268 09-759 N	007-90-068 E 268 09-561 N	007-89-867 E 268 09-563 N
North	15	Craig Road and Allen Lane, SE Corner	11/19/04	$X_{almost\ native}$			007-72-648 E 267 88-742 N	007-72-845 E 267 88-740 N	007-72-848 E 267 88-539 N	007-72-646 E 267 88-541 N
South	1.1	Fort Apache & Long Boat Key Ave. - SW corner	6/28/05	X			007-40-541 E 267- 15-444 N	007-40-546 E 267 15-653 N	007-40-734 E 267 15-641 N	007-40-721 E 267 15-423 N
South	2.1	Durango & Blue Diamond Rd. - NW corner	6/28/05	Standing water			007-45-790 E 267 09-757 N	007-45-810 E 267 09-931 N	007-45-993 E 267 09-904 N	007-45-966 E 267 09-694 N
South	3.1	Cimmeron & Blue Diamond Rd. - SW corner	6/28/05	X			007-48-426 E 267 09-016 N	007-48-424 E 267 09-112 N	007-48-699 E 267 09-088 N	007-48-711 E 267 08-991 N
South	4.1	Jones & Oleta - SE corner	6/28/05	H2O	H2O		007-62-011 E 267 09-813 N	007-62-017 E 267- 09-966 N	007-62-159 E 267 09-973 N	007-62-197 E 267 09-813 N
South	5.1	Las Vegas Blvd. & St. Rose Pkwy. (SR 146) - Across from auction lot	6/28/05		X		007-74-541 E 266-80-885 N	007-74-626 E 266-81-024 N	007-74-844 E 266-80-950 N	007-74-747 E 266-80-817 N
South	6.1	St. Rose Pkwy. (SR 146) & Bermuda - W of Vegas Rock	6/28/05	X			007-81-487 E 266 92-883 N	007-81-394 E 266-93-002 N	007-81-566 E 266 93-078 N	007-81-618 E 266 92-992 N
South	7.1	Stephanie & Russell Rd. - NE corner	6/28/05	X			008-15-364 E 267 33-089 N	008-15-360 E 267 33-176 N	008-15-555 E 267 33-204 N	008-15-557 E 267 33-119 N
South	8.1	Hollywood & Desert Inn Rd. - NE corner	6/28/05		X		008-20-087 E 267 49-352 N	008-20-111 E 267 49-506 N	008-20-286 E 267 49-479 N	008-20-256 E 267 49-310 N
North	9.1	Hualapai & Alexander (N of Cheyenne) - Lone Mountain WRB	6/27/05	X			007-36-472 E 267-85-530 N	007-36-535 E 267-85-732 N	007-36-699 E 267-85-658 N	007-36-660 E 267-85-491 N
North	10.1	2-15 & Charleston - Red Rock WRB	6/27/05	X			007-22-673 E 267 57-957 N	007-22-637 E 267 58-125 N	007-22-875 E 267 58-154 N	007-22-832 E 267 57-992 N
North	10.2	2-15 & Charleston - Red Rock WRB	6/27/05		X		007-22-150 E 267 58-456 N	007-22-160 E 267 58-586 N	007-22-670 E 267 58-569 N	007-22-643 E 267 58-494 N
North	11.1	2-15 & Lone Mountain - Quarry	6/27/05	X			007-34-415 E 267 91-250 N	007-34-407 E 267 91-445 N	007-34-583 E 267 91-514 N	007-34-634 E 267 91-237 N
North	12.1	Torrey Pines & Grand Teton - SW corner - S of school	6/27/05	X			007-58-698 E 268 12-737 N	007-58-692 E 268 12-891 N	007-59-046 E 268 12-894 N	007-59-035 E 268 12-747 N
North	13.1	N. Jones & N of Iron Mountain @ end of road	6/27/05		X		007-61-455 E 268 21-260 N	007-61-479 E 268 21-382 N	007-61-730 E 268 21-366 N	007-61-679 E 268 21-161 N
North	14.1	N. Decatur and Iron Mountain - NE corner	6/27/05	X			007-67-118 E 268 19-544 N	007-67-108 E 268 19-758 N	007-67-274 E 268 19-739 N	007-67-279 E 268 19-560 N
North	15.1	Range Rd. & 2-15 - NE of Army Nat. Guard - section of unpaved road	6/27/05		X		008-13-041 E 268-02-906 N	008-13-035 E 268-02-985 N	008-13-526 E 268-03-003 N	008-13-543 E 268-02-920 N

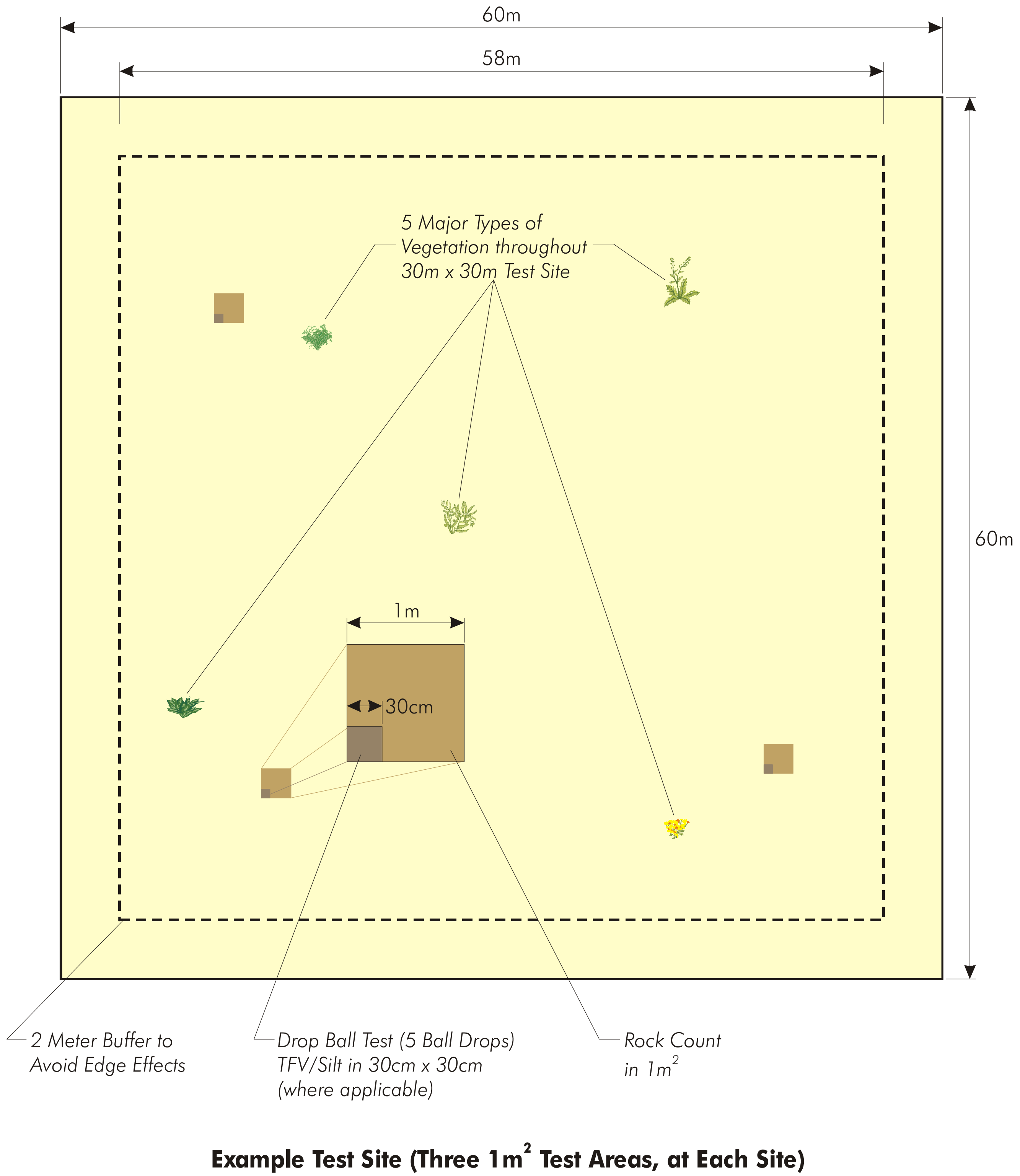

Figure 2-6. Example Test Site

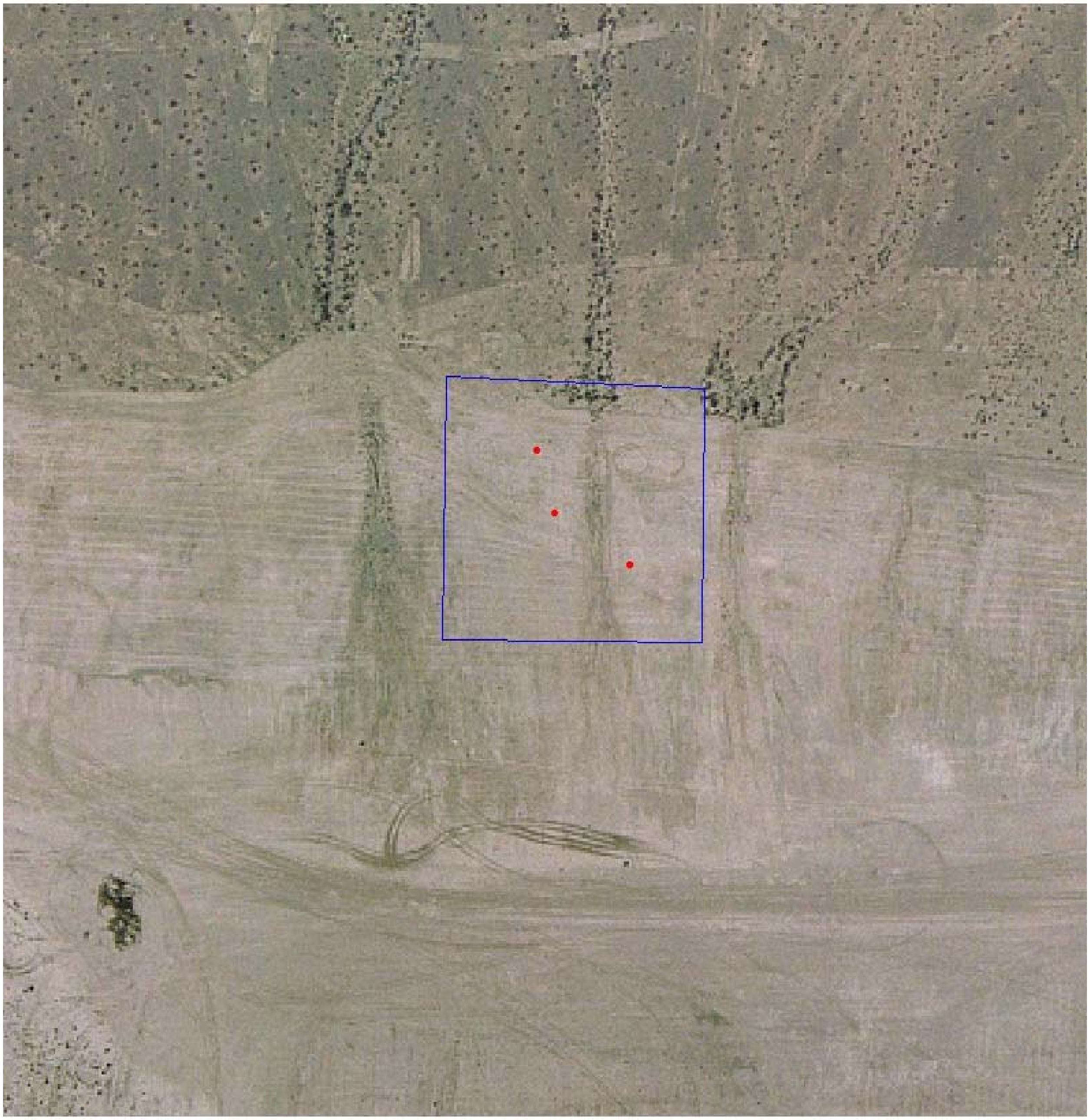

Figure 2-7. Aerial Photo Showing One Training Site and Soil Test Locations

Each test site was tested three times each in representative areas, as discussed below for the drop ball, rock test, and TFV tests. Within each test area, the drop ball test was done five times in a 30-cm x 30-cm (1-foot) square area in the lower left-hand corner of the 1-meter square area, the rock cover test was done one time, and the TFV was done one time, as applicable. The average of the replicate tests was used to characterize each training site. All field sheets completed during ground truthing are available in Appendix D and summarized in Table 2-2. Each ground truthing method is described below and included in Figure 2-6.

Drop Ball Test

In addition to the regulatory pass-fail drop ball test, the drop ball test was scored on a 5-point scale as follows:

Drop Ball Penetration Index

1. Surface consists of powdery soil with no clods.
2. No crust on surface, but clods are present.
3. Ball breaks/penetrates crust leaving a powdery crater.
4. Ball leaves dimple in crust.
5. Ball does not penetrate crust.

As shown in Figure 2-6, the drop ball test was performed within a 30-cm x 30-cm (about 1 square foot) area within each of the three 1-square-meter areas at each test site. Within this 30-cm x 30-cm area, the ball was dropped three times and assigned both a pass-fail score as well as a drop ball penetration index (1 through 5) for each drop. The sample area passed if at least two of three drops indicated sufficient crust, meaning the ball does not sink into the surface. This is represented by a penetration index of 4 or 5.

Rock Test

The rock test was used to indicate surface stability by estimating the rocks and other nonerodible elements on a given disturbed surface. Such elements provide a degree of wind resistance and decrease erodibility. Vegetation was not counted as a nonerodible element. The 1-meter by 1-meter square area was used for the rock test. Within this 1-meter square area, rocks with a diameter greater than 1-cm were mentally grouped into small, medium, and large size categories and the number of rocks were counted in each group. This is a visual qualification process, but generally the classification is:

Small = 1 to 2 cm
Medium = 2 to 4 cm
Large = > 4cm

Following the count, one or two typical rocks were selected in each group, and the actual length and width measured to determine an average size of each category. The average area of the small, medium, and large size rocks were multiplied by the estimated number of rocks in each category, and the total area of each size category was then divided by two to estimate the frontal area of the rocks. This calculation determines the percent of estimated rock cover. The surface was considered stable if the rock cover exceeded 20%.

Threshold Friction Velocity Test

To perform the threshold friction velocity test, sieves were used with screen sizes of 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. They were attached in size order with the larger screen sizes on top and the catch pan on the bottom. For this test, only loose surface dust up to a depth of 1 cm (other than sandy areas, most loose surface dust will not be present at a depth of 1 cm) was collected over an area of at least 30 cm by 30 cm. The test was not conducted for hard, non-erodible surfaces where little or no loose material exists. Prior to sieving the dust, rocks larger than 1-cm in diameter were removed. The dust was then placed on top of the sieve stack, the stack covered, and rotated at least 20 circular arm movements (10 clockwise and 10 counterclockwise). Following the sieving, the stacked sieves were separated and the relative quantities of each catch were inspected. After a visual determination was made of the sieve catch with the greatest volume, Table 1 of Section 90 of Clark County Air Quality Regulations was used to determine TFV provided in Appendix E. The TFV was corrected for non-erodible elements using Table 2-1 of Section 90 of the Regulations (Appendix E). The silt content was estimated using a fractional part of the sieve pan contents as described in the Clark County Air Quality Regulation Section 91.4.1.2 (Appendix F).

Vegetation

The extent of vegetative cover (vegetation density) was estimated for each training site. The umbrella and height of the vegetation was recorded and the percent of vegetative cover for each site was visually estimated. This was done by dividing the site into quadrants and using a 6-foot step ladder to get a visual perspective of the area. The predominant species was also identified. This data was used for background information and possible insight into differences in imagery that could be caused by differing greenness of each species at various times of year. Digital photo documentation was taken at each site.

A literature search was conducted on the subject of discriminating vegetative cover relative to the greenness of vegetation. The chlorophyll cycle of vegetation in the Mohave species is complicated, but can generally be characterized as short cycles of greenness occurring shortly after rainfall. It is optimal to wait 5-7 days after a rainfall to avoid the effects of rain on soil conditions.

A literature search was conducted on phenology, but no quantitative data was found. Qualitative information sources all agree that chlorophyll peaks during the rainy season, and desert plants quickly decrease activity in the summer.

Soil Texture

Overall, soil texture classification (e.g., wind erodibility groups or WEGs) is typically based on sampling down to a depth of several feet and may not be a good predictor of the erodibility of the surface soil that is exposed to the wind. Field sampling to characterize the textural classification of the soils at the ground truthing sites was beyond the scope and funding of this project.

Fifteen soil samples were collected and analyzed from the test sites in the north pilot area and 10 from the south pilot area. These samples were submitted to Geotechnical and Environmental Services (GES) in Las Vegas to determine sand, silt, and clay analysis. The samples were taken from the top 3 inches of the surface. Samples were placed in 1-quart cans and transported with a chain-of-custody form. Table 2-3 summarizes the GES lab results for the percentage of sand, silt, and clay content of these 25 samples. The calculated WEG group for each soil shown in the "Lab WEG" column is based on the laboratory results and the application of the WEG Soil Triangle in the Uhl/MacDougall paper, "Determining Aeolian Fugitive Dust Emissions for the Western U.S.: Methodologies and Assumptions). The WEG for each site based on the existing maps are shown in the "Map WEG column." Note that only 3 of the 25 mapped WEGs and laboratory-determined WEGs agree (Sites 4 and 9 in the North area and Site 7 in the South area). Also note that adjacent Sites 7 and 8 in the North area (the sites eliminated from ground truthing because of construction activity and the water-saturated condition of the soil from watering) show very different soil types, i.e., WEG 7 and WEG 4.

TABLE 2-3. WIND ERODIBILITY GROUP (WEG) CATEGORIES FOR SELECTED GROUND TRUTHING AREAS

Sample Area	Site No.	Map WEG	Lab WEG	Laboratory Soil Analysis, %			Native Desert	Disturbed Stabilized	Disturbed Unstable
				Sand	Silt	Clay			
North	1	4L	6	25.5%	56.7%	17.8%		X	
North	2	3	3	62.2%	24.4%	13.4%		X	
North	3	6	4L	52.3%	37.1%	10.6%	X		
North	4	4L	2	54.2%	25.0%	20.8%		X	
North	5	7	2	59.8%	14.1%	26.1%	X		
North	6	7	5	24.5%	58.7%	16.8%		X	
North	7	7	7	11.1%	79.7%	9.2%		X	
North	8	7	4	28.5%	21.2%	50.3%		X	
North	9	4	4L	47.0%	42.7%	10.3%	X		
North	10	5	4L	40.6%	40.3%	19.1%		X	
North	11	5	3	61.2%	25.4%	13.4%		X	
North	12	4L	6	3.1%	69.4%	27.5%	$X_{\text{high veg}}$		
North	13	4L	3	60.8%	28.3%	10.9%	$X_{\text{low veg}}$		
North	14	6	4L	51.1%	35.2%	13.7%		X	
North	15	3	4L	48.6%	28.5%	22.9%		$X_{\text{almost native}}$	
South	1	Sand	1	78.5%	5.9%	15.6%	X		
South	2	3	1	86.9%	-0.2%	13.3%	X		
South	3	4	1	88.1%	-1.8%	13.7%			X
South	4	3	2	79.0%	-3.9%	24.9%			X
South	5	3	2	72.1%	5.3%	22.6%		X	
South	6	2	1	80.9%	3.6%	15.5%	X		
South	7	2	2	66.2%	13.2%	20.6%		X	
South	8	8	3	71.1%	10.4%	18.5%	X		
South	9	8	3	67.2%	20.3%	12.5%		X	
South	10	5	3	73.3%	11.3%	15.4%	X		

Note: Information in this table is based on Gismo records (MAP WEG) and laboratory results (LAB WEG).
See Figures 2-4 and 2-5 for site locations.
See Appendix G for description of WEG classifications.

2.2.3 Ground Truthing Results

Initial ground truthing began after IKONOS satellite imagery of the north area was collected on Thursday, November 18, 2004. The ground truthing for the North Pilot area was completed by end of day Friday, November 19, well within the 48-hour period allowed. Sites 7 and 8 were not tested because of site preparation for construction activity. A water truck was continuously watering the area, and these two sites were wet with standing water in several places.

Several sites in the South Pilot area were surveyed prior to subsequent IKONOS and Landsat flyovers, but the ground was so wet and hardened by rain from December 2004 through March 2005 that further satellite imagery and ground truthing in the South was halted.

Based on the results of the pilot study of the north area and comparison of the results of the space imagery analysis comparing IKONOS with Landsat 5 TM, the decision was made to use Landsat 5 TM imagery for the remainder of the study. Landsat imagery included additional spectra (7 vs. 4), and the less-detailed resolution of Landsat (30-meter pixels vs. 1-meter pixels) provided an automatic averaging effect that was very effective in avoiding the need to subdivide the feature classes such as native vegetation. Section 3 provides additional rationale for selecting Landsat over IKONOS imagery.

In June 2005 the soil in the Las Vegas Valley was judged to be sufficiently dry to resume ground truthing. Prior to the Landsat imagery of June 26 and July 12 (Landsat TM imagery of the Las Vegas Valley is taken every 16 days), 24 new ground truthing sites, including several in the disturbed unstable category, were selected with the assistance of DAQEM personnel. Table 2-2 shows the ground truthing sites used for this study. Ground truthing was performed at 15 of these sites within 48 hours following each of the Landsat TM flyovers on June 27 and 28 and July 13, 2005. Based on the ground truthing tests of all 30 sites, 3 sites were disturbed unstable, 18 sites were disturbed stable, 5 sites were native desert, and 4 sites were stable with standing water due to construction watering or recent rains. A summary of the results of these tests is presented in Table 2-4.

TABLE 2-4. ERODIBILITY GROUND TRUTHING RESULTS

Site	Site Description	Test Area	Soil Stability				Site Stability, Stable/Unstable
			Drop Ball		Rock Test	TFV	
			P/F	No.			
N-1	Disturbed Stabilized	1	P	4	0	NA	S
	Map WEG 4L	2	P	4	<1%	NA	S
	Lab WEG 4L	3	P	4	1.20%	NA	S
	Summary		P	4	<1%	NA	S
N-2	Disturbed Stabilized	1	P	4	<1%	NA	S
	Map WEG 3	2	P	4	<1%	NA	S
	Lab WEG 3	3	P	5	<1%	NA	S
	Summary		P	4	<1%	NA	S
N-3	Native Desert	1	P	5	50	NA	S
	Map WEG 6	2	P	5	>45	NA	S
	Lab WEG 3	3	P	5	50%	NA	S
	Summary		P	5	>45	NA	S
N-4	Disturbed Stabilized	1	P	5	<1%	NA	S
	Map WEG 4L	2	P	5	<1%	NA	S
	Lab WEG 2	3	P	5	<1%	NA	S
	Summary		P	5	<1%	NA	S
N-5	Native Desert	1	P	4	40%	NA	S
	Map WEG 7	2	P	4	40%	NA	S
	Lab WEG 2	3	P	4	45%	NA	S
	Summary		P	4	42%	NA	S
N-6	Disturbed Stabilized	1	P	4	45%	NA	S
	Map WEG 7	2	P	4	42%	NA	S
	Lab WEG 3	3	P	4	45%	NA	S
	Summary		P	4	44%	NA	S
N-7	Soil saturated with water. Preconstruction site watering being performed. Site stable, no tests run. Map WEG 7 Lab WEG 4L						
N-8	Soil is saturated with water. Preconstruction site watering is being performed. Site is stable, no tests run. Map WEG 7 Lab WEG 1						
N-9	Native Desert	1	P	5	42%	NA	S
	Map WEG 4L	2	P	4	35%	NA	S
	Lab WEG 3	3	P	5	45%	NA	S
	Summary		P	5	40%	NA	S
N-10	Disturbed Stabilized	1	P	4	1.9%	NA	S
	Map WEG 5	2	P	4	1.0%	NA	S
	Lab WEG 2	3	P	4	0.2%	NA	S
	Summary		P	4	1.0%	NA	S
N-11	Disturbed Stabilized	1	P	5	<1%	NA	S
	Map WEG 5	2	P	5	3.8%	NA	S
	Lab WEG 1	3	P	4	0.0%	NA	S
	Summary		P	5	1.6%	NA	S
N-12	Nat. Des. Hi Veg.	1	P	5	<1%	NA	S
	Map WEG 4L	2	P	5	<1%	NA	S
	Lab WEG 4L	3	P	4	<1%	NA	S
	Summary		P	5	<1%	NA	S
N-13	Nat. Des. Low Veg.	1	P	4	<1%	NA	S
	Map WEG 4L	2	P	4	<1%	NA	S
	Lab WEG 3	3	P	5	<1%	NA	S
	Summary		P	4	<1%	NA	S
N-14	Disturbed Stabilized	1	P	5	2.3%	NA	S
	Map WEG 6	2	P	4	6.8%	NA	S
	Lab WEG 1	3	P	4	5.3%	NA	S
	Summary		P	4	4.8%	NA	S
N-15	Dis. Stab. Near Nat.	1	P	4	<1%	NA	S
	Map WEG 3	2	P	4	<1%	NA	S
	Lab WEG 4L	3	P	4	<1%	NA	S
	Summary		P	4	<1%	NA	S

TABLE 2-4. (continued)

Site	Site Description	Test Area	Soil Stability: Drop Ball P/F	Drop Ball No.	Rock Test	TFV	Site Stability, Stable/Unstable
1-1	Disturbed Stabilized	1	P	5	<1%	NA	S
		2	P	4	<1%	NA	S
		3	P	5	<1%	NA	S
	Summary		P	5	<1%	NA	S
2-1	Disturbed Stabilized	1	NA	NA	NA	NA	S
	Stable with standing	2	NA	NA	NA	NA	S
	water	3	NA	NA	NA	NA	S
	Summary		NA	NA	NA	NA	S
3-1	Disturbed Stabilized	1	P	5	1.2	NA	S
		2	P	4	1.2	NA	S
		3	P	5	<1%	NA	S
	Summary		P	5	<1.1%	NA	S
4-1	Disturbed Stabilized	1	NA	NA	NA	NA	S
	Stable with standing	2	NA	NA	NA	NA	S
	water	3	NA	NA	NA	NA	S
	Summary		NA	NA	NA	NA	S
5-1	Disturbed Unstable	1	F	3	4.3	60 cm/s	U
		2	F	3	3.1	60 cm/s	U
		3	F	3	2.6	60 cm/s	U
	Summary		F	3	3.3%	60 cm/s	U
6-1	Disturbed Stabilized	1	P	4	<1%	NA	S
		2	P	4	1.8	NA	S
		3	P	5	2.8	NA	S
	Summary		P	4	<1.9%	NA	S
7-1	Disturbed Stabilized	1	P	5	0	NA	S
		2	P	5	<1%	NA	S
		3	P	5	<1%	NA	S
	Summary		P	5	<1%	NA	S
8-1	Disturbed Unstable	1	F	3	0.5	30 cm/s	U
		2	F	3	2.0	60 cm/s	U
		3	F	3	0.4	30 cm/s	U
	Summary		F	3	<1%	30 cm/s	U
9-1	Disturbed Stabilized	1	P	5	1%	NA	S
		2	P	4	2.5	NA	S
		3	P	4	<1%	NA	S
	Summary		P	4	<1.5%	NA	S
10-1	Disturbed Stabilized	1	P	5	0	NA	S
	Some areas unstable	2	P	4	0	NA	S
		3	P	5	0	NA	S
	Summary		P	5	0.0%	NA	S
11-1	Disturbed Stabilized	1	F	3	2.7	NA	S
		2	P	5	42	NA	S
		3	P	4	35	NA	S
	Summary		P	4	27.0%	NA	S
12-1	Disturbed Stabilized	1	P	4	2.5	NA	S
		2	P	5	2.5	NA	S
		3	P	5	1	NA	S
	Summary		P	5	2.0%	NA	S
13-1	Disturbed Unstable	1	F	1	<1%	30	U
		2	P	4	2.5	NA	S
		3	F	3	1.5	86	U
	Summary		F	3	<1.7%	86	U
14-1	Disturbed Stabilized	1	P	4	22.5	NA	S
		2	P	5	10	NA	S
		3	P	5	20	NA	S
	Summary		P	5	17.5%	NA	S
15-1	Disturbed Unstable	1	P	4	7.5	NA	S
		2	F	2	0.7	43	U
		3	F	2	0.4	43	U
	Summary		F	3	2.9%	86	U

3.0 SATELLITE IMAGERY SELECTION AND PROCESSING

3.1 Remote Sensing Data Sources

IKONOS satellite imagery of the north pilot area was obtained for evaluation as part of the Pilot Study. In addition, Landsat TM data was purchased because of its low cost and applicability to the large, relatively homogeneous area outside the BLM disposal area.

Imagery at various nadir angles was received from Space Imaging and evaluated by Midwest Research Institute (MRI) and Clark County. It was clear that there was no significant difference in the quality of the imagery from different nadir angles, and that the wider angle was acceptable for this project.

The use of Landsat 5 TM was investigated for the largely homogeneous native desert land outside the BLM disposal area. Based on Landsat's longer wavelength bands for broader spectral signatures, larger pixels to remove undesirable influence of unimportant micro-features, and less cost, it was decided that the Landsat 5 TM satellite imagery would be used for the entire Hydrographic Area 212 including the BLM Disposal Area (see detailed rationale in Sections 3.3 and 3.4).

Landsat TM imagery was acquired from a period when there had not been a rain event within the past 7 days and clear sky conditions were present (i.e., no cloud cover). Days with fog, haze, and smog were avoided.

Landsat TM imagery was obtained, and the registration accuracy was verified using aerial photography. Use of Landsat TM imagery was much more useful and cost-effective than high spatial resolution imagery (IKONOS or QuickBird) that lacks the additional infrared wavelength bands. High spatial resolution imagery can pick up micro-features (e.g., vehicles, large trash piles, individual rocks) that are difficult to categorize by selective classification and have only localized effects on wind erodibility. The larger pixel size provided by the Landsat TM sensor (30m x 30m) is more appropriate for land areas with micro-features that do not affect wind erodibility.

The larger pixel size for Landsat TM provides an averaging effect that is very useful for characterizing the vast areas of native desert outside of the BLM disposal area. Because there is no advantage to distinguishing subcategories of native desert with varying amounts of vegetation, the averaging of reflectance across different vegetative densities greatly simplifies the process of identifying and mapping native vegetation.

In addition, the extra IR wavelength bands available from Landsat TM have been demonstrated to be very useful in distinguishing senesced vegetation and soil moisture. Landsat TM in conjunction with QuickBird is being used effectively in evaluating vegetation and other dust control strategies at Owens Dry Lake in California. The other obvious advantage of Landsat TM imagery is the much lower cost, which makes periodic updates of land category inventories economically feasible.

Figure 3-1 shows the Landsat TM coverage of the Clark County area and the BLM area.

3.2 Other Studies

Prior studies of land erodibility in arid areas of the West have also been based on satellite imagery. Two relevant studies are summarized below.

The first study dealt with the tracking of the revegetation of parts of Owens Dry Lake in California. On the revegetated part of the lake surface, it was necessary to test for compliance with the 50 percent coverage requirement. For this purpose, satellite imagery was collected using Landsat 7 TM and Quickbird to characterize the South Farm area where 16 training sites were located. The results are reported in the Owens Lake Vegetation Compliance Report (2003).

The second study was directed to the mapping of blowsand areas in the Antelope Valley of California. For the past 5 years, MRI has been performing research on the role of blowsand in driving wind-generated emissions from abandoned farmland. This has involved the use of a portable wind tunnel and the instrumentation of two large blowsand sites to determine sand fluxes and vertical fluxes of PM-10 during high wind events. In the satellite imagery study, Landsat data was used to map blowsand areas based on signatures developed from eight training sites.

3.3 Landsat vs IKONOS and QuickBird

The major issues for the Clark County study were the classification methodology for vacant land, and which of the available satellite imagery sources would be most appropriate to use. In the early stages of the project, Quickbird or IKONOS were targeted for characterizing the BLM

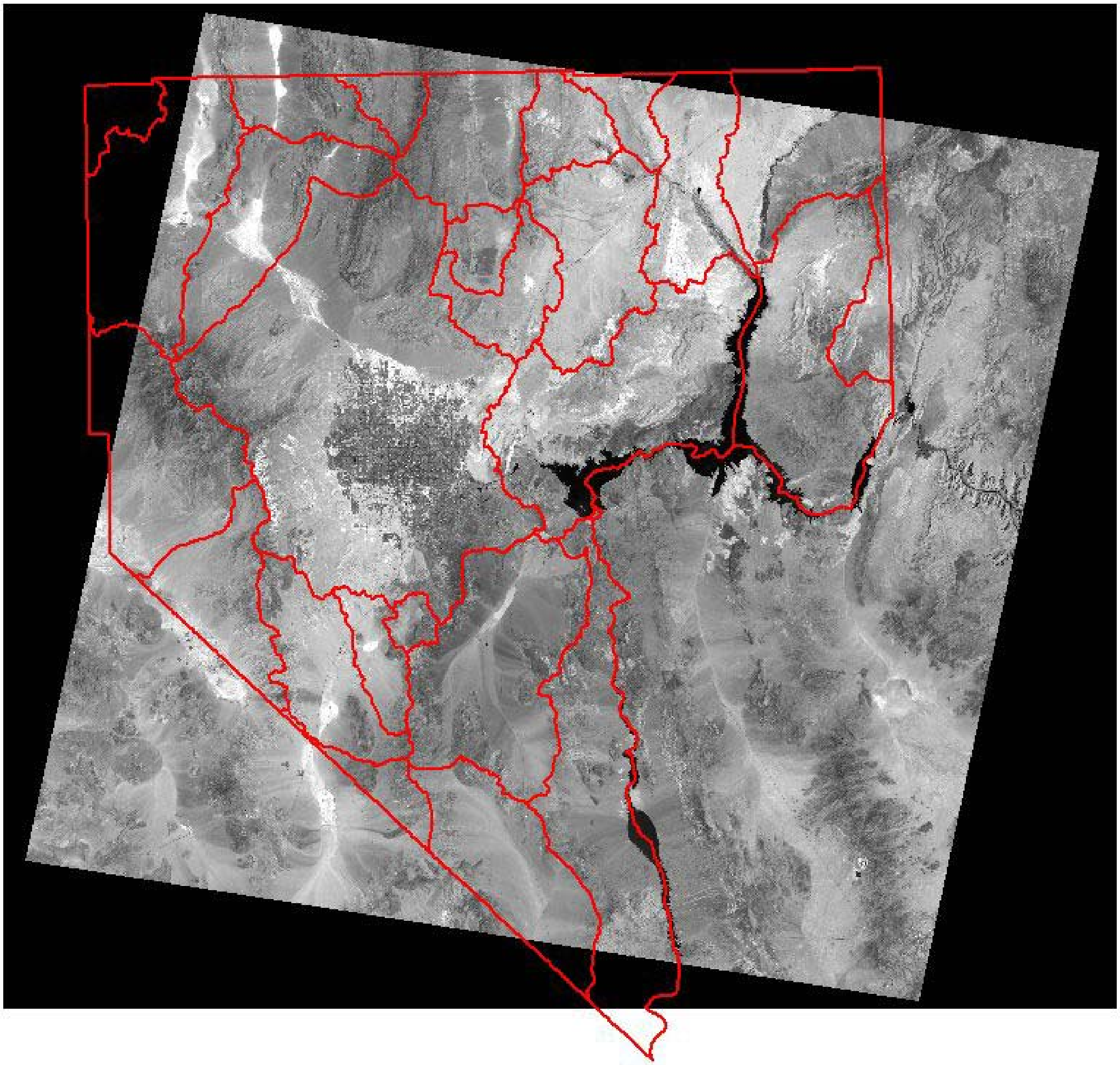

Figure 3-1. Landsat 5 TM Coverage of Clark County

disposal area, and Landsat for the remainder of Hydrographic Area 212. The features of each of these satellites are described in Table 3-1.

TABLE 3-1. SATELLITE FEATURES
LANDSAT TM VS. IKONOS VS. QUICKBIRD

	Landsat TM	IKONOS	QuickBird
Spatial Resolution	30 meters	1 meter	0.6 meter
Spectral Resolution	6 bands	4 bands	4 bands
Coverage of Imagery	49,425.82 km^2	200 km^2	200 km^2
Cost for Project	$425.00	$7785.00	>$7785.00
Cost per km^2 per band	$0.00143	$9.73	>$9.73

- IKONOS (Space Imaging)
  - 3 visible bands (blue, green, red), 1 near IR band
  - Resolution: 4-m multispectral, pan-sharpened to 1 m

- QuickBird (Digital Globe)
  - 3 visible bands (blue, green, red), 1 near IR band
  - Resolution: 2.4-m multispectral, pan-sharpened to 0.6 m

- Landsat 5/7 TM (NASA/NOAA/USGS)
  - 6 visible/near-IR bands (same as above plus 3 others)
  - Resolution: 30-m multispectral sharpened to 15 m

The main advantage of the IKONOS or QuickBird imagery is the high spatial resolution. However, the cost of the imagery is three orders of magnitude higher than the cost of the Landsat TM data as shown in Table 3-1. IKONOS and QuickBird costs are very similar; a formal quote was only obtained from IKONOS.

3.4 Rationale for Selection of Landsat

In the course of the project, tests of the effectiveness of Landsat imagery showed it to have many advantages over IKONOS or QuickBird imagery. The expanded wavelength components proved very useful in isolating distinctive fingerprints of the vacant land categories of interest. The response to vegetation was particularly important. An example is illustrated in Figure 3-2 (Band 7 is the 6th band for Landsat). In addition, the larger pixel size provides an automatic averaging effect is very effective in avoiding the need to subdivide the feature classes such as native vegetation. For example, it was anticipated that desert shrubs that stabilize soils and provide windbreaks might be difficult to characterize by satellite imagery because of their

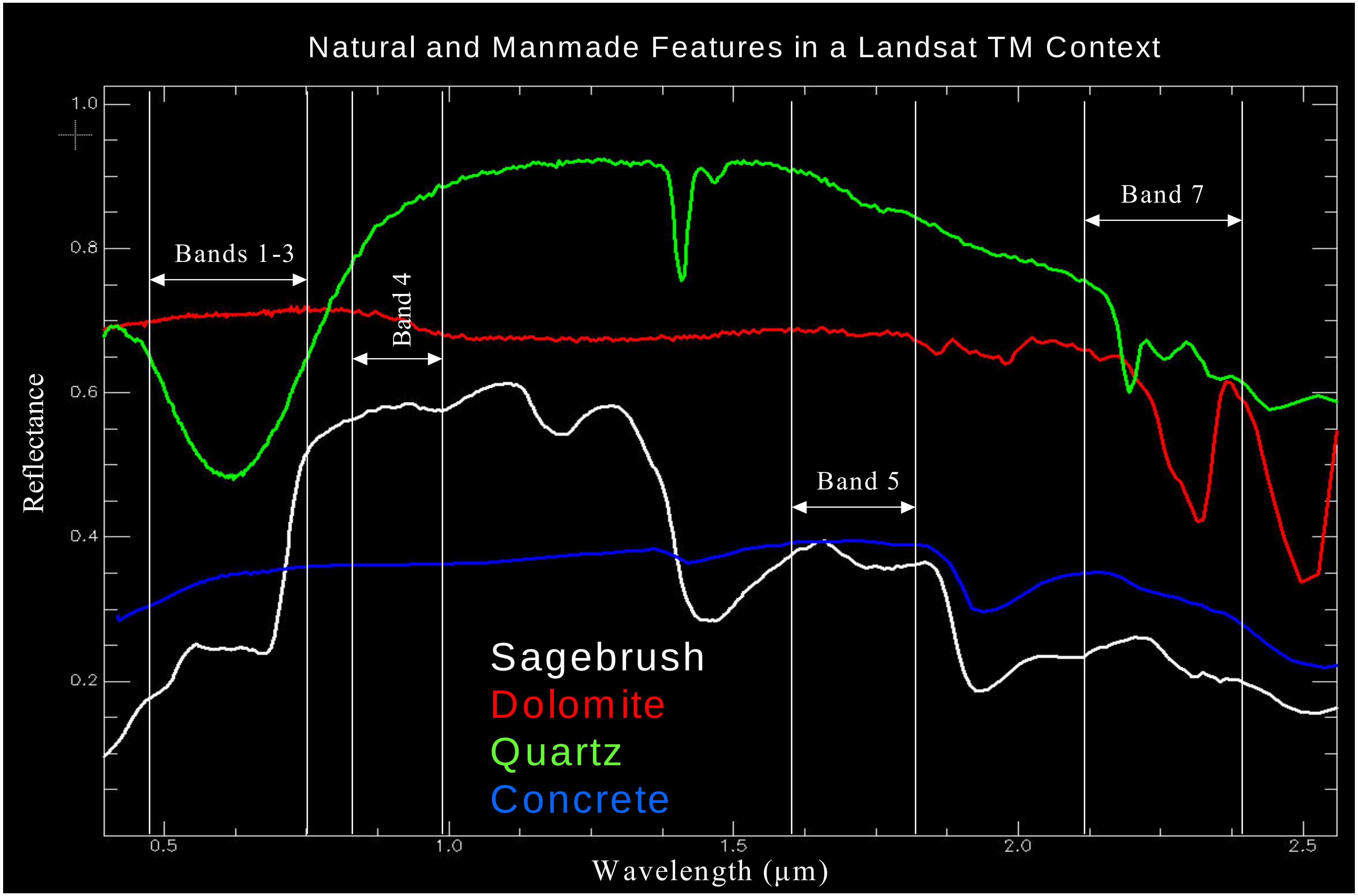

Figure 3-2. Reflectance Response Curves of Natural and Manmade Features Using Landsat Imagery

indistinct spectral signatures, mostly small size (< 1 sq m), and sparseness. Also, it was anticipated that disturbed land with small rocks might provide a challenge for identification by satellite imagery. However, these potential problems were overcome with use of imagery from Landsat 5 TM.

Another advantage was the ability to incorporate the entire study area in a single Landsat scene collected at one point in time. Finally, the very affordable cost of the imagery produced a much higher cost-effectiveness for this project. It is important to note that the available high-resolution aerial photography provided a necessary element in the accuracy assessment process.

4.0 SPECTRAL ANALYSIS PROCEDURES

The purpose of the Pilot Study was to establish firm relationships between the ground surface data (as described in Section 2) and remote satellite images of the same area. Landsat TM satellite imagery was used to remotely characterize ground surface types for wind erodibility. The satellite imagery was provided as GEOTIFF files.

Satellite images were obtained within 2 days of the verified field data collection described in Section 2. The BLM Disposal Area was an important focus of the imagery in order to ensure the identification of the vacant land scattered throughout the urban area. This area is also the highest contributor to the overall emission inventory for Clark County.

IKONOS satellite imagery of the pilot test areas was attempted several times (October 11, 16, and 19, 2004) but cloud cover in the Las Vegas Valley prevented clear imagery of the pilot test areas. IKONOS satellite imagery of the north pilot test area was finally collected Thursday, November 18.

Additional data was collected on asphalted areas to add the surface drainage category to the imagery analysis. Urban vegetation was also added as a category by using the spectral signature of green areas (e.g., golf courses) in the Landsat TM imagery. Figure 4-1 shows the visible spectra (red, green, and blue) from the Landsat TM imagery, and Figure 4-2 shows the supervised classification of the Landsat TM imagery using Mahalanobis Distance classification.

Unpaved road data from the various municipalities and the spring 2005 aerial photography of the Las Vegas Valley were provided by the County Geographic Information System Management Office (GISMO). The delineation of the unpaved roads was initiated using the available unpaved road data along with the Las Vegas Valley aerial photography. A sampling of the unpaved roads not included in the available GIS data was investigated by direct on-site observation. Many of the unpaved roads were located in areas under development. These roads will be paved as the development is completed. Other roads were extensions of single-lane utility roads or roads to private residences located in the rural areas of the Las Vegas Valley. These roads are generally less than 12 feet wide (observed roads of this type ranged from 6 to 12 feet wide). Many of these roads are rarely traveled. In other cases, the GIS data

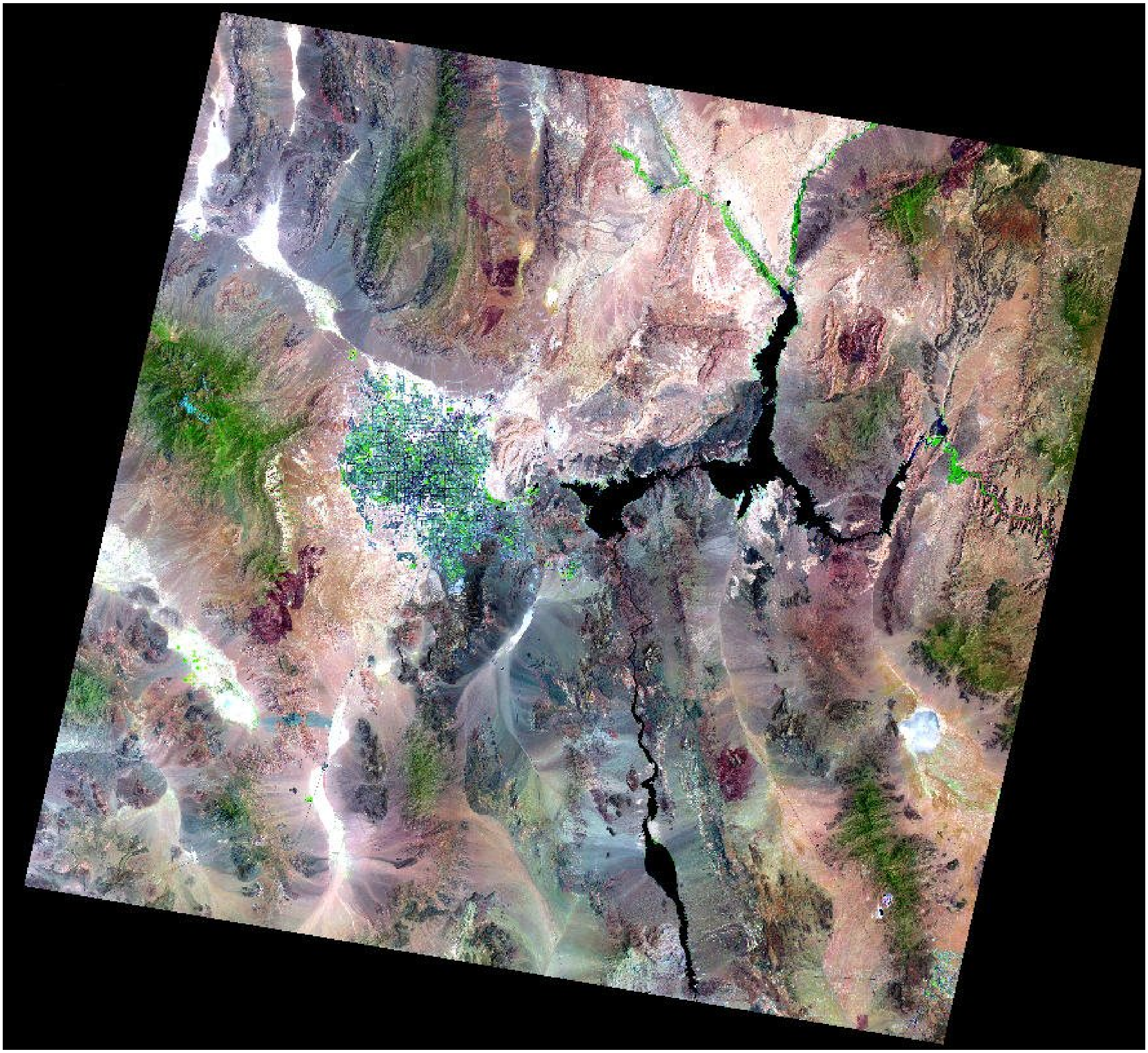

Figure 4-1.Visible Spectra from Landsat TM Imagery

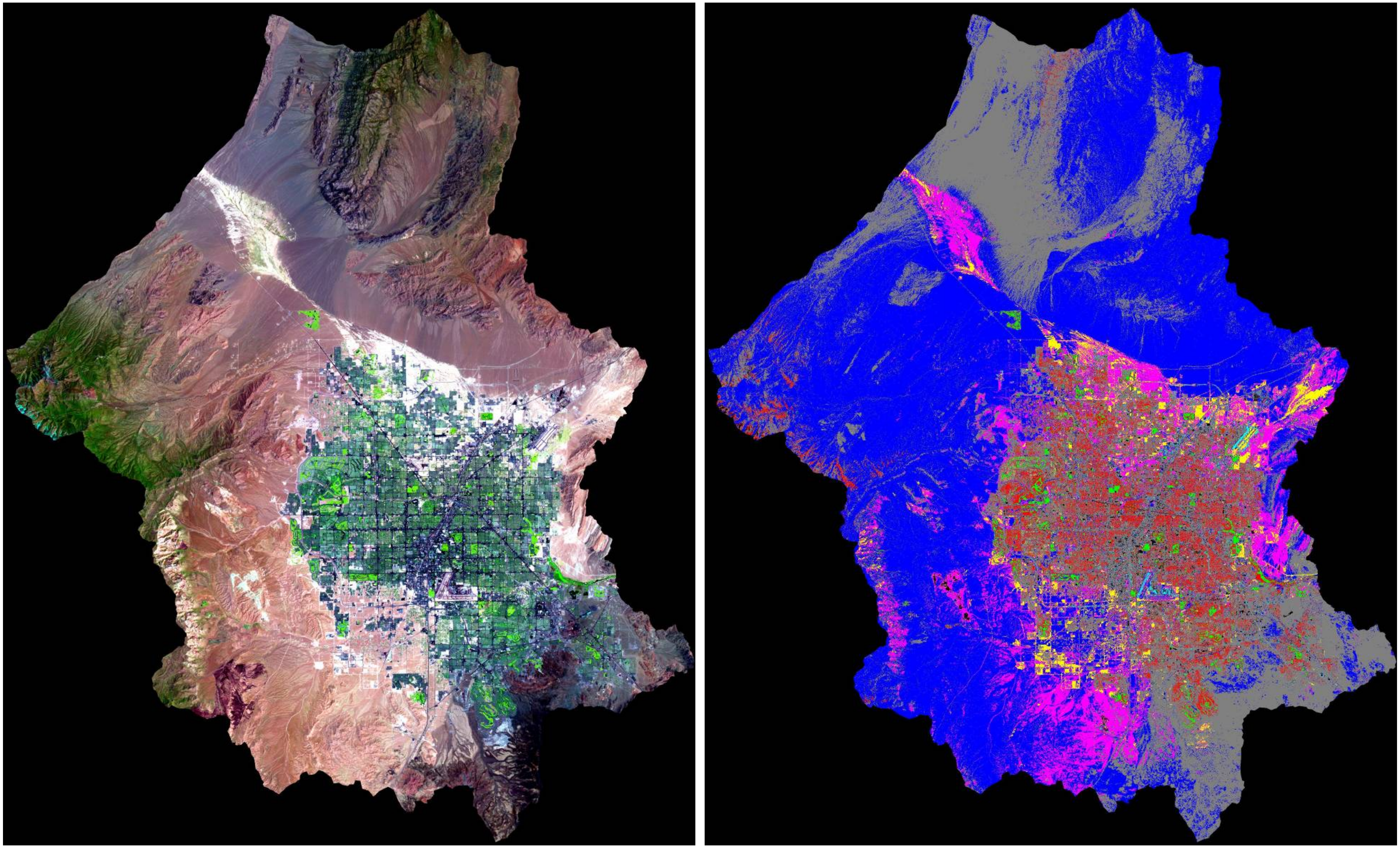

Figure 4-2. Mahalanobis Supervised Classification

showed unpaved roads that no longer existed. These unpaved roads were shown in heavily developed areas where all the streets were paved. These roads were probably old utility roads once maintained by the county, but were built over as Las Vegas grew and power lines were moved underground. These roads no longer exist, but the GIS data has not been updated.

The input and output files from the classification process are raster images: i.e., each image is treated as an array of values. The classification results were converted to polygon vector layers that are compatible with Environmental Systems Research Institute (ESRI) products.

4.1 Land Category Characteristics

Four categories of erodible land surfaces were to be mapped in this project: (1) native desert, (2) disturbed stable vacant land, (3) disturbed unstable vacant land, and (4) private unpaved roads or other unpaved roads not previously identified in existing Clark County data. The first two categories were mapped with supervised classification techniques. An analyst using aerial photography mapped the fourth category, unpaved roads.

The disturbed unstable land category was problematic because of a lack of training sites (reference sites) to use for the classification process. For Landsat TM, a training site must be at least 210 square meters (210 x 210 m), so that no pixel overlaps into another land classification. In the disturbed unstable category, however, only one training site was large enough to meet this criterion. The results were inconsistent with this one training site because of the wide range of soil reflectance that can occur with disturbed unstable soil. As a consequence, the percent of disturbed unstable vacant land was derived by inference; when all other land cover types (native desert, urban, etc.) were classified, then the remaining unclassified pixels represent an upper bound on the amount of disturbed vacant land.

Five other land cover types were also mapped. Because of their abundance, non-vegetated rocky surfaces (washes), concrete, urban areas, urban vegetation, and barren/shadow were included in the supervised classification procedure. The last category, barren/shadow, was added to account for land cover types that were not classified in one of the other categories, and to lower the upper bound of the estimate for the disturbed vacant land category. This category includes shadows from mountains, buildings, and rocky areas.

4.2 Supervised Classification

Multi-spectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their spectral reflectance value. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to those criteria.

The analyst closely controls supervised training. In this process, image pixels were selected that represent the land cover features listed above, i.e. training sites. These pixels were identified primarily from ground truth data, with GISMO layers as ancillary data.

By identifying these representative ground truth sites, the computer algorithim was trained (calibrated) to identify pixels with similar characteristics. Based on the classification accuracy, the resulting classes represent the land surface categories within the Landsat TM data.

It was important that training samples be representative of the classes that are being identified. This does not necessarily mean that they must contain a large number of pixels or be dispersed across a wide region of the data. The selection of training samples depended largely upon knowledge of the data, the pilot study area, and the classes to be extracted.

Once a set of reliable signatures was created and evaluated, the next step was to classify the data. Each pixel was analyzed independently. The measurement vector for each pixel was compared to each signature, according to a decision rule, or algorithm. Pixels that passed the criteria that were established by the decision rule were then assigned to the class for that signature.

4.3 Choice of Mahalanobis Method

The Mahalanobis distance classifier is designed so that clusters that are highly varied will lead to similarly varied classes, and vice-versa. For example, when classifying urban areas, typically a class whose pixels vary widely, correctly classified pixels may be farther from the mean than those of a class for water, which is usually not a highly varied class (Swain and Davis, 1978). The classifier was chosen because it was superior in its ability to classify the highly varied land cover types in Hydrographic Basin 212.

4.4 Definition of Land Subcategories

The following procedure was used to define land subcategories:

1. Use aerial photography to define large subareas of distinct appearance ("training subareas") within the pilot study area.

2. Inspect and collect soil samples within training subareas to determine the land category of each subarea.

3. Acquire Landsat 5 TM imagery for the pilot study area and perform supervised classification.

4. Use analysis results to characterize land categories (disconnected areas with same appearance).

5. Apply cross checks with IKONOS imagery.

6. Perform field checks to determine the reliability of the land classification.

7. Complete the pilot study using the new approach to identify training areas.

8. Evaluate Landsat imagery as the basis for the vacant land classification (with IKONOS cross checks).

9. Acquire Landsat imagery for the whole study area and develop the inventory for erodible lands.

10. Perform final field verification of the inventory.

4.5 Special Challenges

In the course of the project, it was found that areas of disturbed unstable lands were widely scattered and small in size in comparison to the requirements for determining unique spectral signatures. Some of this difficulty related to unusually wet weather conditions during the study period that tended to restabilize disturbed areas. In addition, there was wide use of intensive watering on construction sites to comply with permit conditions.

The few disturbed unstable areas that were identified as marginally suitable for ground truthing tended to exhibit differing spectral signatures because of differences in soil types and associated chemical compositions. When areas such as native desert are crusted, it appears that the surface chemistry is more uniform and relatively independent of the parent soil type beneath the crust. In addition a high wind event during a dry period typically produces a large area of deposition as the well-mixed atmospheric particulate loading settles to the ground at the end of the wind event.

Consequently, there were insufficient, unstable areas to reliably train the classification software. An acceptable option was to determine the disturbed, unstable land area by difference. This involved subtracting all of the other identified land area types from the total land area being considered. The impact of this change in procedure is believed to be small because the prevalence of this land type is a relatively insignificant part of the total study area. Table 4-1 presents the issues and resolutions.

TABLE 4-1. ISSUES AND RESOLUTIONS

Issue	Resolution
Incidental variations of land condition are accentuated by IKONOS imagery	Landsat TM imagery has superior spectral resolution (more wave length bands).
Large Investment and Uncertainties in Imagery Acquisition/Analysis	July 2004 – Modify technical approach to incorporate focus area pilot study within ground truthing at 30 locations.
Prohibitive Cost to Acquire High-Resolution Imagery for Entire Las Vegas Valley	August 2004 – Propose use of Landsat TM imagery for areas of low land disturbance (outside of BLM Disposal Area).
Intrusion of Rain Events	November 2004 to February 2005 – Postpone imagery acquisition until soil dries.
Registration Errors in Imagery	February 2004 – Make linear shifts in imagery positional files to match ground truthing site coordinates.
Stay Within Cost Ceiling on Imagery Acquisition for Main Study	March 204 – Rely primarily on Landsat for imagery data with IKONOS imagery for quality assurance cross-checking.

Other areas of special challenge and the steps taken to resolve them are summarized in Table 4-2.

4.6 Accuracy Assessment

Accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true in order to determine the accuracy of the classification process. For the pilot study, the assumed-true data were derived from aerial photography and ground truth data. This validation procedure determined the quality of the image processing algorithms used to distinguish vacant land categories of varying erodibility.

TABLE 4-2. RISK AREA, IMPACT, AND MITIGATION

Risk Area	Risk Impact	Risk Mitigation
Extension of ground truthing sites to entire Hydrographic Area 212	Unrepresentative erosion sites used for ground truthing would result in spectral signatures that could not reliably identify wind erosion sites in entire area of interest.	Use of Pilot Study sites selected to contain samples of the largest areas susceptible to wind erosion. Pilot Study sites contained representative sites of the most erodible lands in the Las Vegas Valley.
Excessive costs to purchase complete imagery for State Hydrographic Area 212	Purchase of imagery of non-erodible urban land is not cost-effective.	Purchase of expensive satellite imagery for subareas of proven non-erodible land in urban Clark County was eliminated, and lower resolution imagery was used for these areas to reduce costs.
Substantial costs to analyze complete satellite imagery for State Hydrographic Area 212	Excessive costs may not allow for proper development of the spectral signatures for erosion areas or to complete other parts of the study.	A two-phase study was proposed to make sure that all analysis procedures were able to be efficiently managed before comprehensive analysis of Area 212.
Lack of correlation between spectral signatures and ground truth data on erodibility (as occurred in the prior study)	The validity of the technical approach will be compromised if good correlations are not obtained in the Pilot Study.	Lack of correlation in the prior study was likely related to the inability of pass/ fail erosion tests to characterize the type of wind eroded lands. Ground truthing tests included continuous gradations of erodibility (e.g., drop test will have 5 options); moreover, at least three different field test procedures confirmed the erodibility of a particular soil surface.
Seasonal cycles of surface erodibility, due to moisture	Soil moisture inhibits wind erosion and develops a crust to prevent future wind erosion and causes the satellite imagery not to identify source areas of erosion.	Ground truthing performed during “dry” periods.
Computer processing time for very large satellite imagery data file	As demonstrated in prior study, very large processing times are required.	The relatively small Pilot Study was used to develop the most efficient ways to process data before large-scale data processing was attempted.
Delays in collecting and delivering satellite data for analysis (as occurred in 2000 study)	Poor correlation of ground truth data with out-of-date satellite spectral signatures.	Ground truthing performed within 48 hrs of satellite imagery collection.

It is usually not practical to ground truth or otherwise test every pixel of a classified image. Therefore, a set of reference pixels were used. Reference pixels are points on the classified image for which actual data was (or will be) known. The reference pixels were initially randomly selected, and then accepted or rejected based on accessibility.

If the analyst selects the reference pixels, it is often tempting to select the same pixels for testing the classification as were used in the training samples. This biases the accuracy assessment because the training samples were the basis of the classification. By allowing the reference pixels to be selected at random, we could lessen or eliminate the possibility of bias.

The number of reference pixels was an important factor in determining the accuracy of the classification. It has been shown that approximately 50 reference pixels are needed to estimate the accuracy of a class. Therefore, 50 reference pixels were used in this study.

5.0 RESULTS OF SATELLITE IMAGERY ANALYSIS

5.1 Control of Misregistration Errors

Because of problems with the Landsat 7 TM satellite (failure of the scan line corrector), imagery from Landsat 5 TM was used. The Landsat 5 TM satellite was launched more than 20 years ago, and there can be problems with the registration of the imagery. The Landsat 5 TM imagery that was purchased was evaluated and an unacceptable amount of misregistration was observed.

For the August 2004 Landsat 5 TM scene, the registration error was corrected by collecting a series of “tie points” from the 2-foot pixel GISMO aerial photography. These tie points were used to “warp” the Landsat TM image back to the correct registration.

The June 2005 Landsat 5 TM scene was also misregistered. Since the tie point collection and warping process were very time consuming, a decision was made to reposition the training sites so that they still represented the correct land cover type. Some training sites, such as native desert, were not repositioned because the land cover category was much larger than the Landsat 5 TM registration error.

5.2 Mapping of Land Categories

As described above, it was not feasible to classify the disturbed vacant land category because of a lack of training sites and the effects of highly variable soil chemistry. Therefore, the percent of disturbed vacant land was derived by inference; when all other land cover types (native desert, urban, etc.) were classified, then the remaining unclassified pixels represent an upper bound on the amount of disturbed vacant land. Figures 5-1a and 5-1b show comparisons of high resolution aerial photography with Mahalanobis supervised classification of example subareas within HB 212. Table 5-1 shows the classification results, with the area for each category, for both HB 212 and the BLM disposal area.

The BLM disposal area is a boundary, mostly within HB 212, adopted by the Bureau of Land Management, that identifies federally-owned land that is available for purchase, trade, or

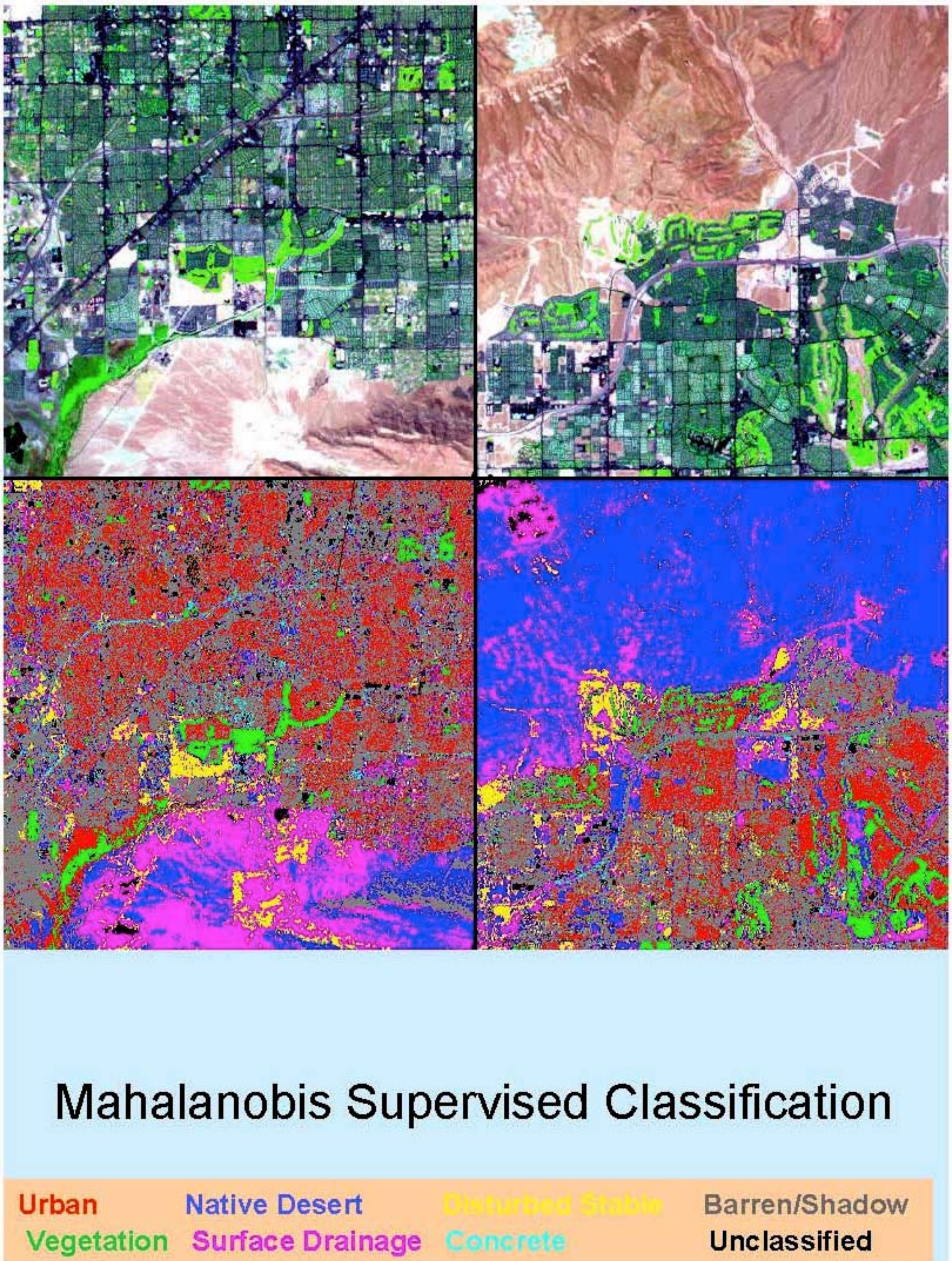

Figure 5-1a. Mahalanobis Supervised Classification

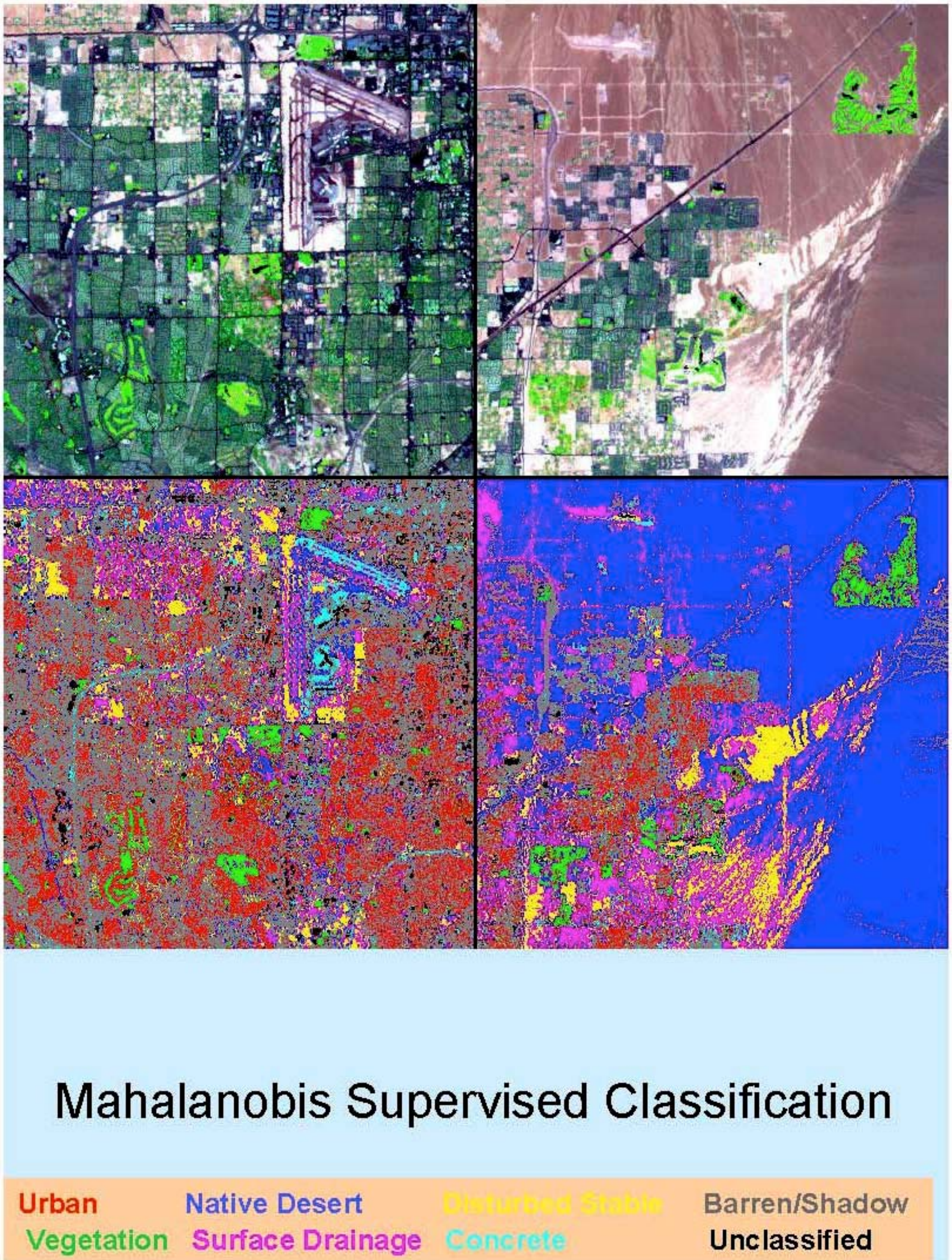

Figure 5-1b. Mahalanobis Supervised Classification

TABLE 5-1. AREA OF LAND CATEGORIES

Land Category	Hydrographic Region 212, km^2	Hydrographic Region 212, % of area	BLM Only, km^2	BLM Only, % of area
Native Desert	1897.11	47.6	284.95	21.2
Disturbed Stabilized	122.78	3.1	94.86	7.1
Disturbed Unstable Vacant Land	< 45.26	< 1.1	< 45.98	< 3.4
Wash – Drainage	357.15	9.0	150.61	11.2
Concrete	26.11	0.7	25.09	1.9
Urban	192.32	4.8	171.21	12.8
Vegetation	35.79	0.9	34.18	2.6
Barren/Shadow	1307.2	32.8	534.51	39.9

lease by public or private interests. The BLM disposal area contains nearly all of the anthropogenic sources within the non-attainment area, and this area was used for attainment demonstration in the PM10 State Implementation Plan for Clark County (June 2001).

One issue with the supervised classification was the orientation of elongated concrete surfaces in relation to the orbit of Landsat 5. As shown in Figure 5-2, the orbit of Landsat is skewed in relation to the compass directions. In classifying concrete runways at McCarran International Airport, the runway in Figure 5-3 was not classified as concrete for two reasons. First, much of the runway was covered with a layer of rubber tire fragments. Second, the narrow width of the runway in relation to the Landsat pixel size and the orientation of the runway in relation to the Landsat orbit produced the results that most pixels were not overlayed onto a predominately concrete surface. In contrast, the runway in Figure 5-4 was readily classified as concrete because of its orientation and the absence of the tire particle layer.

Similarly, the primary runway at Nellis Air Force Base was successfully classified as concrete because of the runway orientation and relative lack of a tire particle layer. This is illustrated in Figure 5-5a and Figure 5-5b.

5.3 Accuracy Assessment

An accuracy assessment was performed with an error matrix. An error matrix compares information from reference sites to information on the map for a number of sample areas. For this purpose, comparison pixels were randomly selected from widely spaced areas within HB 212. This is illustrated in Figures 5-6 and 5-7. The error matrix is a square array of numbers set out in rows and columns that express the labels of samples assigned to a particular category in one classification relative to the labels of samples assigned to a particular category in another classification. On the error matrix in Table 5-2, the columns were assumed to be correct and are termed the reference data. The rows were used to display the map labels or classified data generated from the remotely sensed data. To gauge the accuracy, two labels from each sample are compared to one another (Congalton and Green, 1999).

Error matrices are very effective representations of map accuracy because the individual accuracies of each map category are plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map. A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs. In addition, the error matrix can be used to compute overall accuracy. Overall accuracy is the sum of the major diagonal (i.e., the correctly classified pixels or samples) divided by the total number of pixels or samples in the error matrix (Congalton and Green, 1999). The overall accuracy is 89% (313 / 350).

The accuracy assessment effort also involved a calculation of producer's accuracy and user's accuracy. Producer's and user's accuracies are ways of representing individual category accuracies instead of just the overall classification accuracy. For example, producer's accuracy was calculated by dividing the total number of correct sample units in a given category by the total number of sample units as indicated by the reference data. The user's accuracy is calculated by dividing the total number of correct pixels in a given category by the total number of pixels classified as the category. Table 5-3 shows the producer's and user's accuracy for each land cover category.

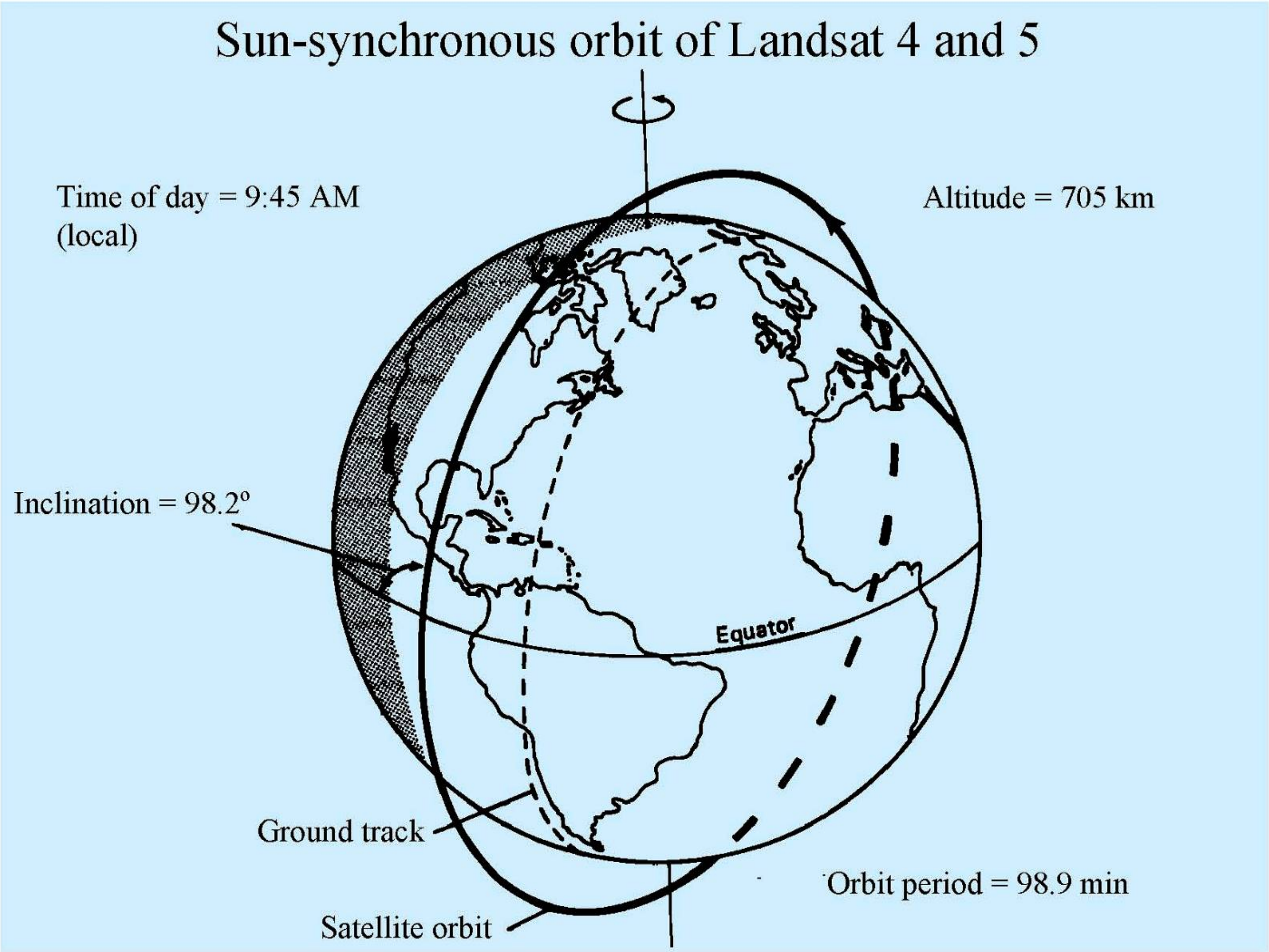

Figure 5-2. Sun-Synchronous Orbit of Landsat 4 and 5

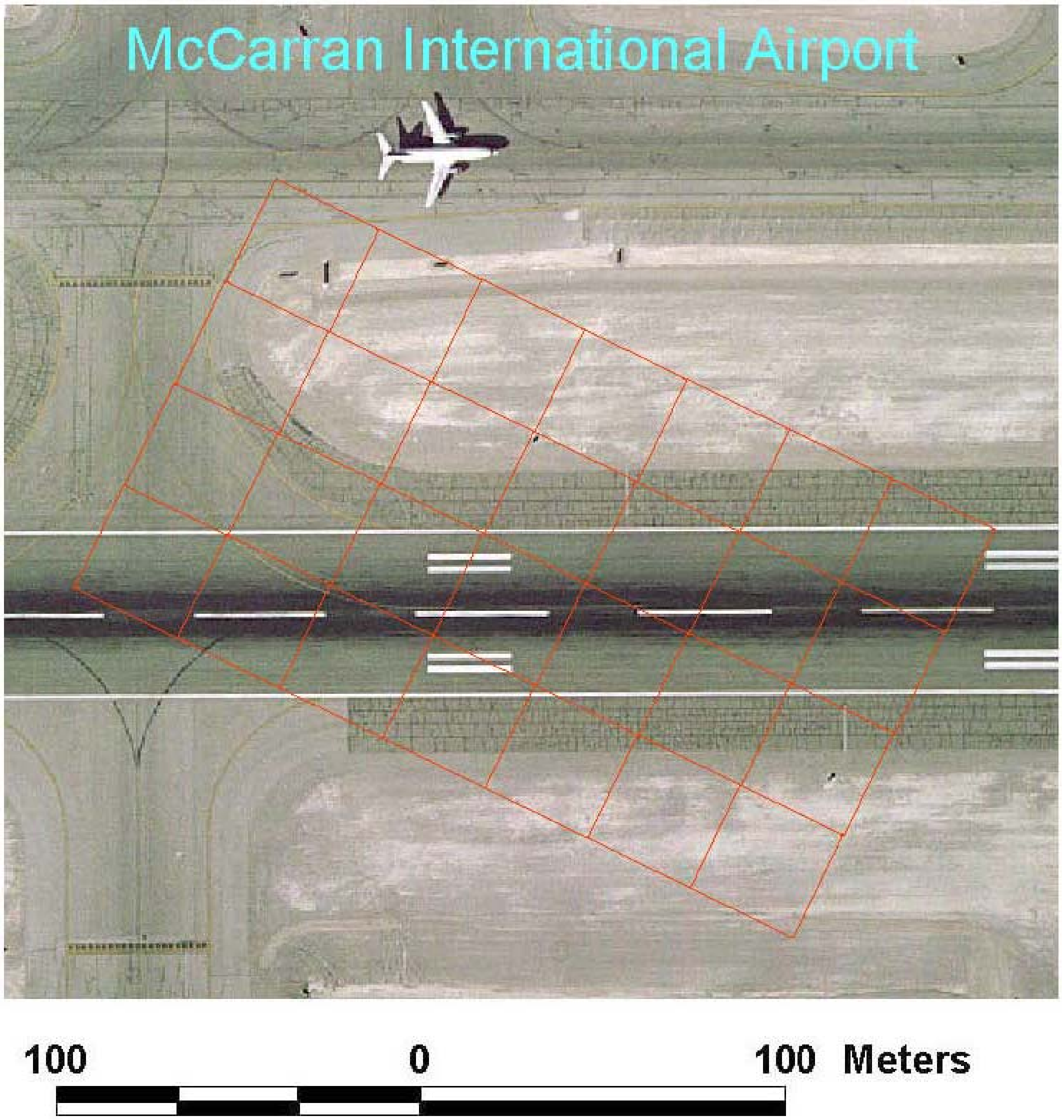

Figure 5-3. Non-Concrete Runway at McCarran International Airport

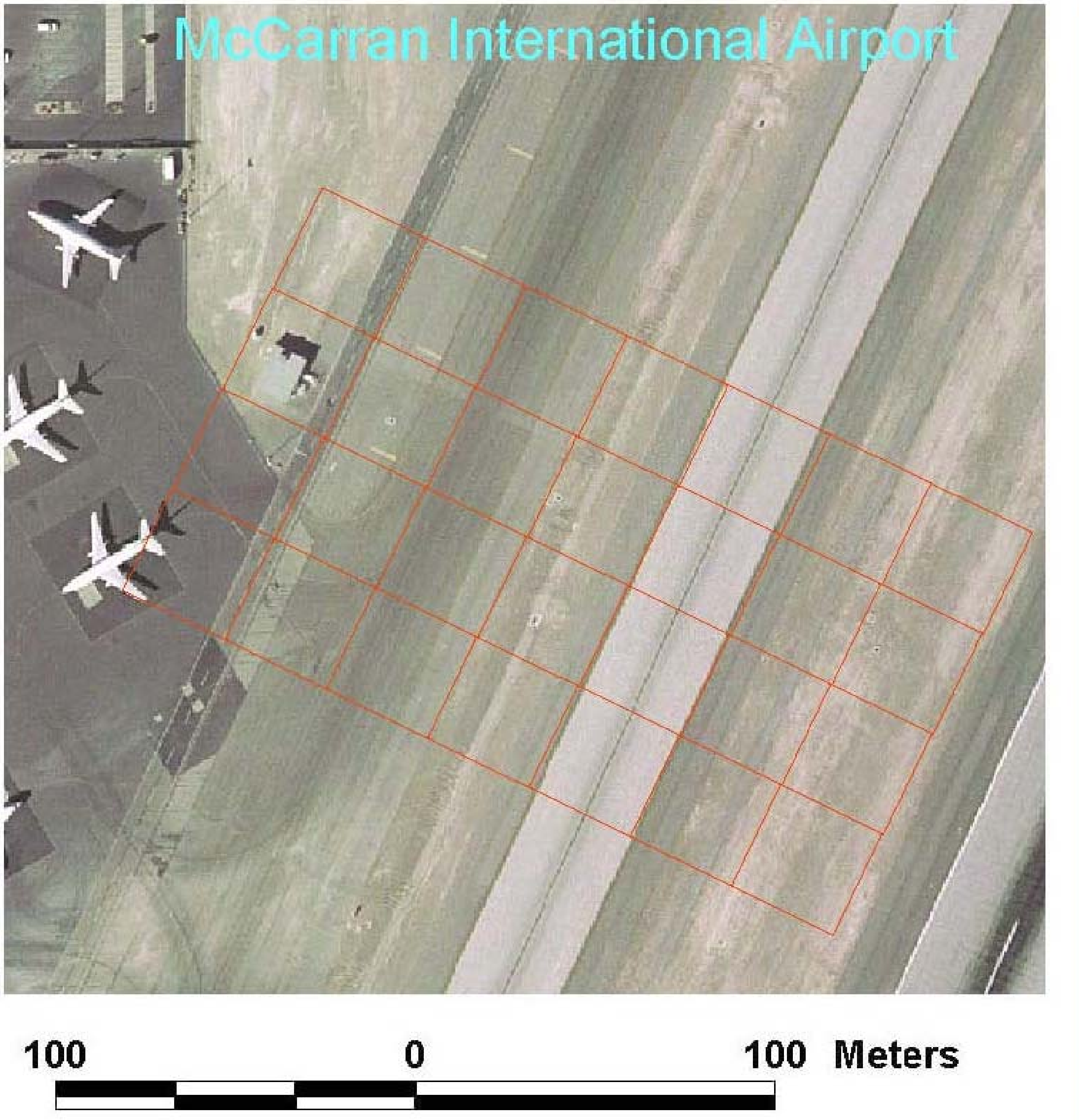

Figure 5-4. Concrete Runway at McCarran International Airport

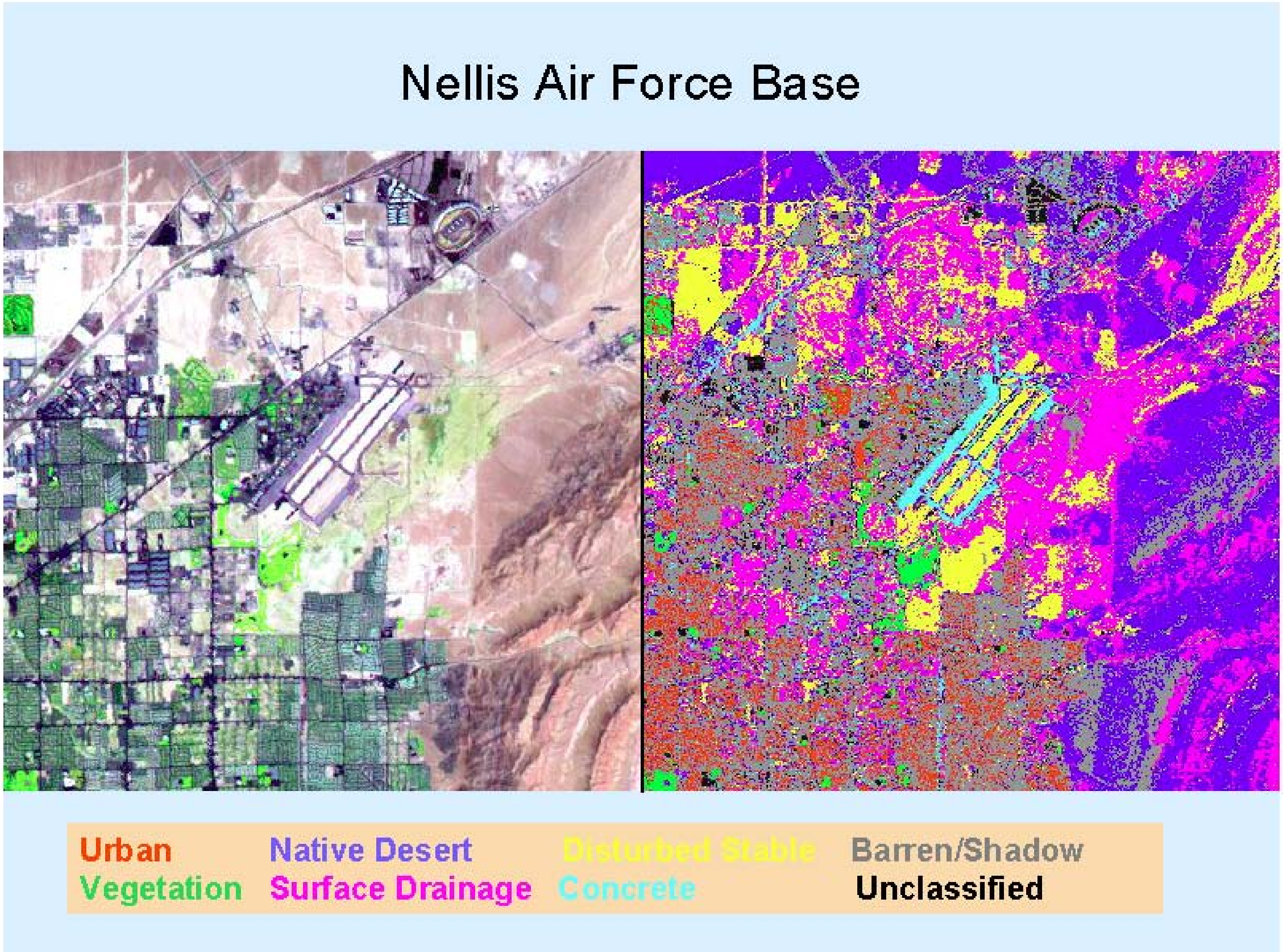

Figure 5-5a. Land Classification at Nellis Air Force Base

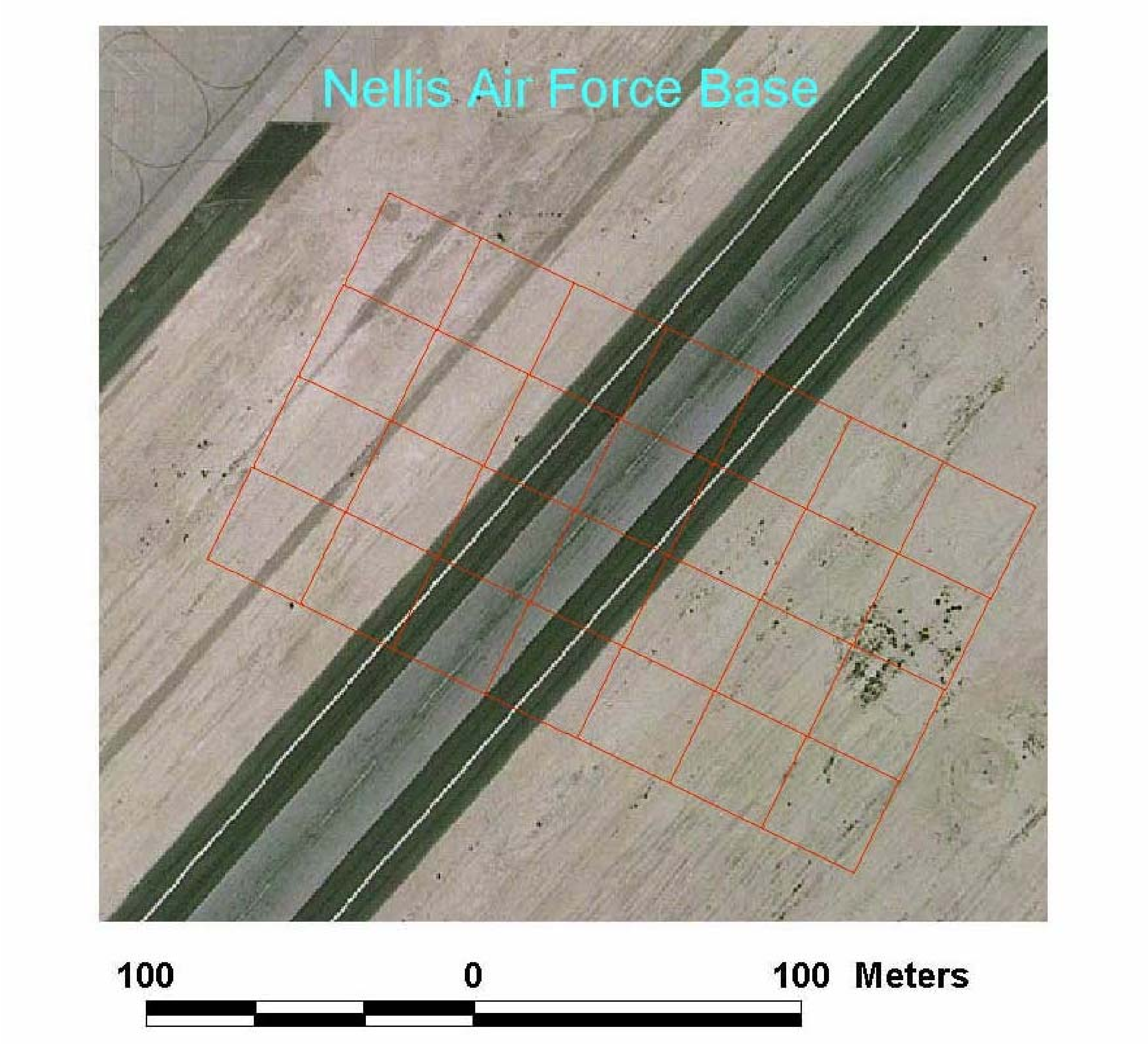

Figure 5-5b. Runway at Nellis Air Force Base

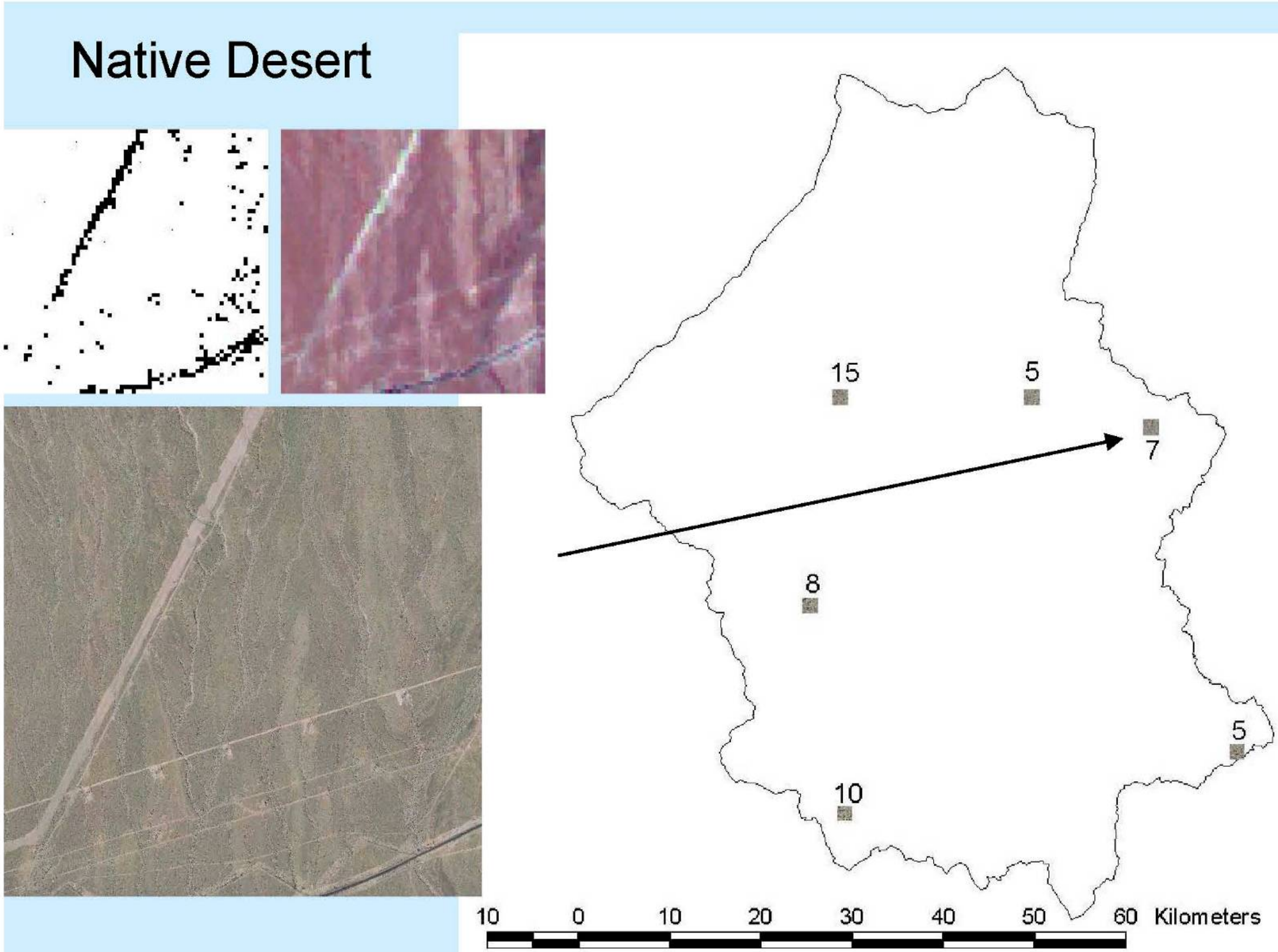

Figure 5-6. Native Desert

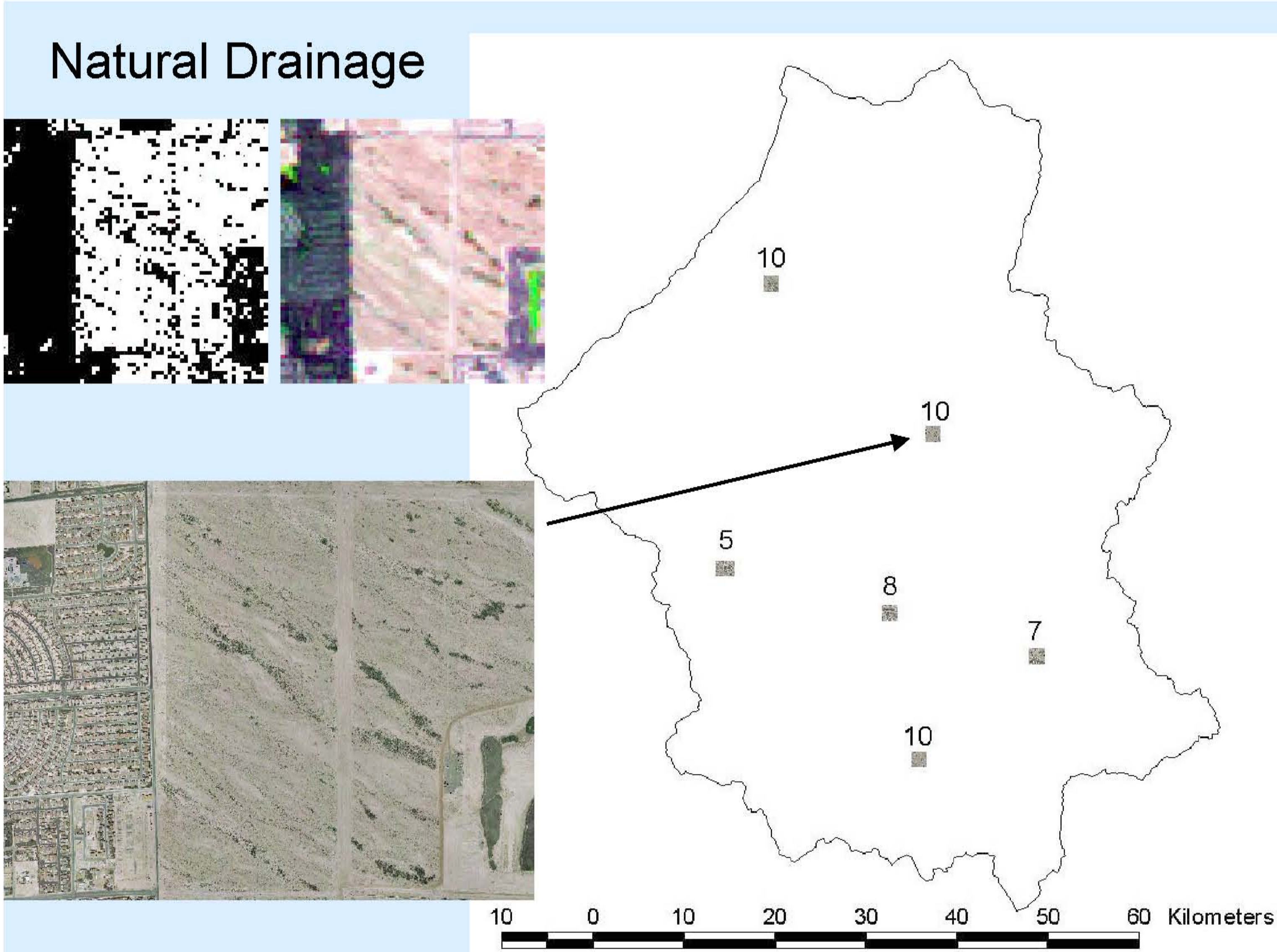

Figure 5-7. Natural Drainage

TABLE 5-2. ERROR MATRIX

Reference Data

Classified Data	Barren/ Shadow	Concrete	Disturbed Stable	Vegetation	Natural Drainage	Urban	Native Desert	Row Total
Barren/Shadow	43					6		49
Concrete		45						45
Disturbed Stable		5	50		18			73
Vegetation				50				50
Natural Drainage					31			31
Urban	7				1	44		52
Native Desert							50	50
Column Total	50	50	50	50	50	50	50	350

Overall accuracy = 313 / 350 = 89%

TABLE 5-3. ACCURACY ASSESSMENT

Producer's Accuracy

Barren/Shadow	43 / 50	86%
Concrete	45 / 50	90%
Disturbed Stable	50 / 50	100%
Vegetation	50 / 50	100%
Natural Drainage	31 / 50	62%
Urban	44 / 50	88%
Native Desert	50 / 50	100%

User's Accuracy

Barren/Shadow	43 / 49	88%
Concrete	45 / 45	100%
Disturbed Stable	50 / 73	68%
Vegetation	50 / 50	100%
Natural Drainage	31 / 31	100%
Urban	44 / 52	85%
Native Desert	50 / 50	100%

6.0 PRIVATE UNPAVED ROAD TRAFFIC COUNTS

6.1 Identified Roads and Areas

The private unpaved road traffic count consisted of three major activities:

1. Delineating the private unpaved roads for traffic counts,
2. Conducting the traffic counts, and
3. Interpreting and reporting the data.

6.2 Delineating the Private Unpaved Roads for Traffic Counts

The extent of "private" unpaved roads is defined by subtracting currently identified unpaved roads under Public Works from the unpaved roads identified through image analysis. RS 2477 roads were not considered private and therefore were subtracted along with public roads. Stretches of non-maintained roads were considered private if they are not currently in the Public Works database.

It should be noted that all unpaved roads in Clark County with average daily traffic (ADT) of greater than 150 vehicles were projected to be paved. Many roads with ADT of less than 150 vehicles were also paved. Most uninventoried private unpaved roads have surfaces of compacted native soil, and most unpaved roads appeared to overlap with the disturbed stable vacant land category.

The unpaved roads identified for traffic counts were selected using the available unpaved road data from North Las Vegas, Las Vegas, Henderson, and the BLM along with the Las Vegas Valley aerial photography and ground surveys by Clark County DAQEM and EQ. The unpaved roads already identified in the existing GIS data were excluded from traffic counts. A sampling of the unpaved roads not included in the available GIS data was investigated by direct on-site observation. Many of the unpaved roads were located in areas under development. These roads will be paved as the development is completed. Other roads were extensions of single-lane utility roads or roads to private residences located in the rural areas of the Las Vegas Valley. These roads are generally less than 12 feet wide (observed roads of this type ranged from 6 to 12 feet wide). Many of these roads are rarely traveled. In other cases, the GIS data showed unpaved roads that no longer existed. These unpaved roads were shown in heavily developed areas where all the streets were paved. These roads were probably old utility roads once maintained by the county but were built over as Las Vegas grew and power lines were moved underground. These roads no longer exist but the GIS data has not been updated. In a few cases, unpaved roads between busy paved roads appeared to have traffic counts above 150 ADT.

Based on the above considerations and a ground survey by Chuck Richter of Clark County DAQEM and Victoria Hansen of EQ, the roads presented in Table 6-1 were selected for traffic counting. Traffic counts were performed on approximately 30 of these unpaved roads as described in the next section. Figure 6-1 shows the relative locations of these unpaved roads. Appendix B shows maps with the detailed locations.

6.3 Conducting the Traffic Counts on Private Unpaved Roads

Vehicle count data for 72-hr periods was obtained using both eight pneumatic counters which are rubber tubes positioned across the road, and three magnetic sensor counters which respond to the metal in a vehicle. Eight Jamar TRAX 1 Plus pneumatic traffic counters were used for the majority of the traffic counts. To minimize damage to the rubber tubes placed across the unpaved roads by abrasion from heavy vehicles rolling over rough ground, gravel, or sharp stones, Jamar RoadRAMP Rural™ pneumatic tubes were used in place of the standard road tubes where necessary. This product consists of a rubber ramp, covered by wear-resistant tape, that contains a built-in road tube.

Three Trafx magnetic vehicle counters were also used for vehicle counts. These units were buried in the middle or on the side of an unpaved road. To verify the proper operation of the Trafx vehicle counters, comparative counts were done using both a Jamar pneumatic counter and a Trafx counter on a sample of one out of ten unpaved roads.

Each traffic count sampling period was 3 days, and the equipment was checked twice daily during the counts for proper performance and placement. Each 3-day count included 2 weekdays and 1 weekend day. Eleven traffic counters were used to produce approximately 30 traffic counts for approximately 30 representative private unpaved roads.

The traffic counts were performed over a period of 2 to 3 weeks beginning October 11, 2005 as follows:

TABLE 6-1. UNPAVED ROADS SELECTED FOR TRAFFIC COUNTS

Site No.	GPS Coordinates Starting Point	Starting Point Location	GPS Coordinates Ending Point	Ending Point Location
1	007-54-207 E 267-27-485 N	W Sunset Rd & S Tenaya Way	007-54-135 E 267-29-113 N	Sundown Glen Ave & S Tenaya Way
2	00751-954 E 267-30-084 N	W Patrick Ln & Buffalo Dr	007-51-186 E 267-30-053 N	W Patrick Ln & W of Maccan St
3	007-51-415 E 267-32-686 N	W Russell Rd & Buffalo Dr	007-51-506 E 267-28-698 N	N of W Sunset Rd & Buffalo Dr
4	007-40-665E 267-22-705 N	Boulder Opal Ave & S Fort Apache Rd	007-40-701 E 267-22-055 N	W Warm Springs Rd & S Fort Apache Rd
5	007-46-123 E 267-14-040 N	W Wigwam Ave & S Durango Dr	007-44-935 E 267-13-969 N	W Wigwam Ave & S Riley St
6	007-44-935 E 267-13-969 N	W Wigwam Ave & S Riley St	007-44-817 E 267-12-723 N	W Ford Ave & S Riley St
7	007-29-018 E 267-11-968 N	W Torino Ave & W of Fortney Rd	007-29-985 E 267-11-959 N	W Torino Ave & Kulka Rd
8	007-35-215 E 267-10-233 N	Blue Diamond Rd. & S Hualapai Way	007-35-205 E 267-08-527 N	Serene Ave & S Hualapai Way
9	007-35-205 E 267-08-527 N	Serene Ave & S Hualapai Way	007-33-178 E 267-08-552 N	Serene Ave & Orduno St
10	007-67-129 E 267-07-450 N	Gary Ave & S Decatur Blvd	007-65-930 E 267-07-433 N	Gary Ave & Edmond St
11	007-82-971 E 266-94-902 N	N of St. Rose Pkwy & Bermuda Rd	007-82-933 E 266-96-935 N	Liberty Heights & Bermuda Rd
12	007-80-277 E 266-97-699 N	Chartan Ave & Gillespie St	007-80-274 E 266-96-465 N	Starr Ave & Gillespie St
13	007-71-164 E 267-14-783 N	Wigwam Ave & Hinson St	007-72-935 E 267-14-822 N	Wigwam Ave & W of Procyon Ave
14	008-23-366 E 267-62-752 N	Stewart Ave & Los Feliz St	008-24-011 E 267-62-751 N	Stewart Ave & Probst Way
15	008-03-262 E 267-77-293N	Cartier Ave & Lincoln Rd	008-03-586 E 267-77-296 N	Cartier Ave & Desert Edge St
16	007-83-400 E 267-79-772 N	Brooks Ave & Revere St	007-34-404 E 267-79-471 N	N of Rev Wilson Ave & Revere St
17	007-67-009 E 268-18-722 N	N Decatur Blvd @ NE corner of power station	007-66-888 E 268-23-308 N	N Decatur Blvd & S of water tower section
18	007-66-896 E 268-23-897 N	N Decatur Blvd & N of water tower section	007-66-976 E 268-25-028 N	N Decatur Blvd & short distance N towards mine
19	007-64-571 E 268-19-988 N	Gilbert Ln & Bradley Rd	007-61-767 E 268-21-377 N	Gilbert Ln & Jones Blvd
20	007-59-870 E 268-17-882 N	Maggie Ave & Mustang St	007-59-851 E 268-18-522 N	Iron Mountain Rd & Mustang St
21	007-59-235 E 268-18-583 N	Iron Mountain Rd & N Torrey Pines Dr	007-61-771 E 268-18-436 N	Iron Mountain Rd & Jones Blvd
22	007-59-896 E 268-15-728 N	Horse Dr & Mustang St	007-57-996 E 268-15-770 N	Horse Dr & Gareheim St
23	007-56-003 E 268-10-902 N	Donald Nelson Ave & Balsam St	007-55-995 E 268-10-306 N	Farm Rd & Balsam St

TABLE 6-1. (continued)

Site No.	GPS Coordinates Starting Point	Starting Point Location	GPS Coordinates Ending Point	Ending Point Location
24	007-55-305 E 268-04-941 N	Deer Springs Way & Rio Vista St	007-55-284 E 268-03-762 N	Rome Blvd & Rio Vista St
25	007-54-410 E 268-01-296 N	W Azure Dr & Starlight Dr	007-54-424 E 268-00-114 N	W Tropical Pkwy & Starlight Dr
26	007-54-856 E 268-00-109 N	W Tropical Pkwy & Moonlight Dr	007-54-861 E 268-00-741 N	S of W Azure Dr & Moonlight Dr
27	007-61-078 E 267-98-956 N	Corbett St & N Bronco St	007-61-582 E 267-98-894 N	Corbett St & Jones Blvd
28	007-61-020 E 267-93-782 N	S of W Washburn Rd & N Bronco St	007-61-020 E 267-92-992 N	W La Madre Way & N Bronco St
29	007-32-545 E 268-05-347 N	Deer Springs Way & Alpine Ridge Way	007-32-554 E 268-04-741 N	Deer Springs Way & Bath Dr
30	007-33-917 E 268-04-366 N	Deer Springs Way & Egan Crest Dr	007-33-917 E 268-04-725 N	Tate & Egan Crest Dr
31	007-39-244 E 268-13-393 N	Gilcrease Ave & N Tee Pee Ln	007-39-242 E 268-12-740 N	Grand Teton Dr & N Tee Pee Ln
32	007-45-860 E 268-02-132 N	Regena Ave & Grand Montecito	007-44-228 E 268-02-108 N	Regena Ave & E of N Juliano Rd
33	007-45-620 E 268-00-179 N	W Tropical Pkwy & W of N Durango Dr	007-45-250 E 268-00-168 N	W Tropical Pkwy & N Bonita Vista St
34	007-42-800 E 267-99-451 N	Corbett St & W of N El Capitan Way	007-42-135 E 267-99-432 N	Corbett St & E of Campbell Rd
35	007-42-472 E 267-99-439 N	Corbett St & N Kevin Way	007-42-476 E 267-99-743 N	S of W Tropical Pkwy & N Kevin Way
36	007-40-571 E 268-01-417 N	Fort Apache Rd & Azure Dr	007-40-878 E 268-01-426 N	Dapple Gray and Azure Dr
37	007-22-802 E 268-21-429 N	Rantool St & Log Cabin Way	007-21-867 E 268-21-415 N	Nickelson St & Log Cabin Way
38	007-31-246 E 268-23-682 N	Trails End Way & Power Transfer Station	007-33-260 E 268-24-104 N	Trails End Way & Frontage Road

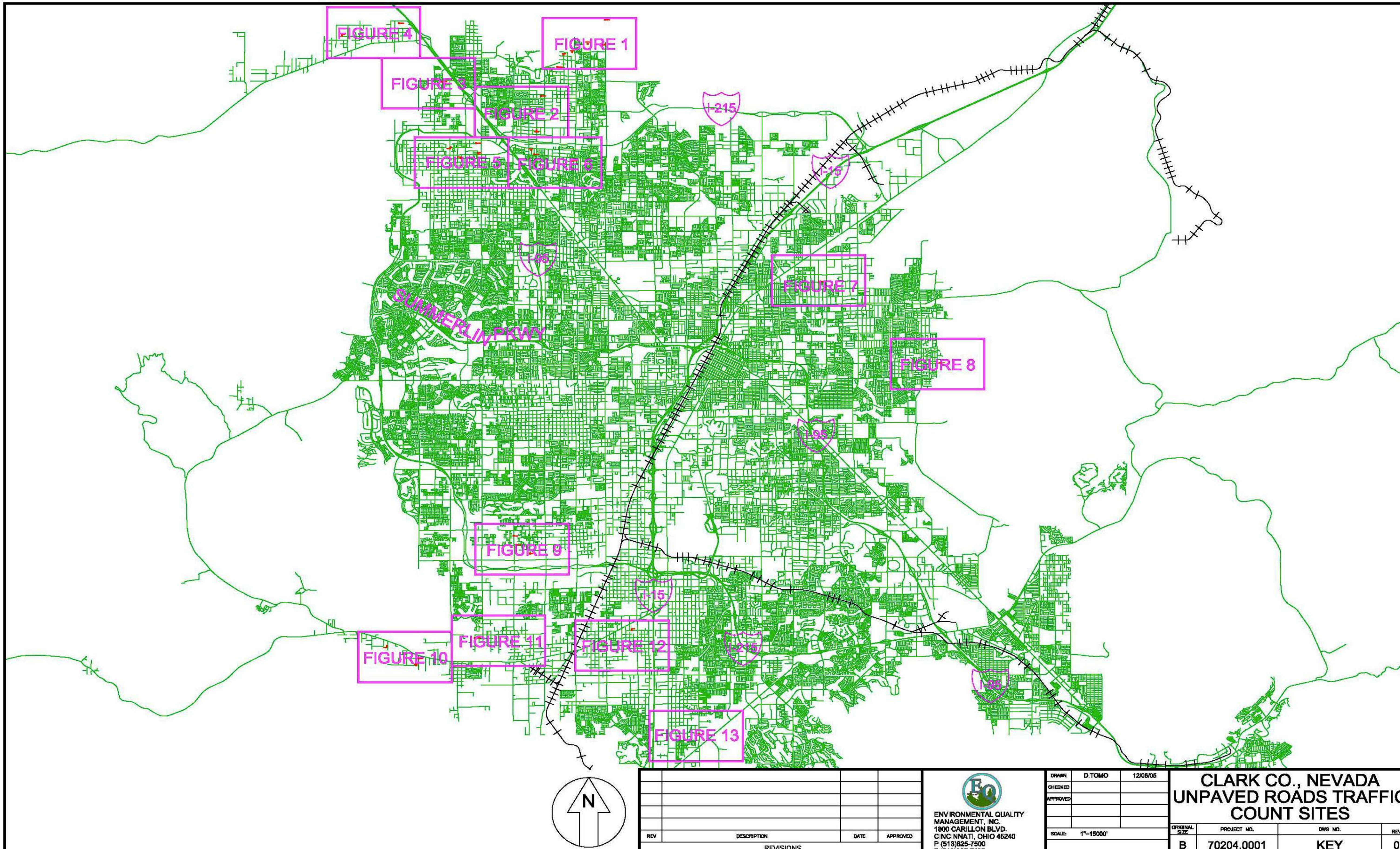

Figure 6-1. Unpaved Road Traffic Count Sites

1.	Receive and check equipment	October 11-12, 2005
2.	Set up equipment for counts 1 through 10	October 13-15
3.	Traffic counts 1 through 10	October 16-18
4.	Set up for counts 11 through 20	October 19
5.	Traffic counts 11 through 20	October 20-22
6.	Set up for counts 21 through 30	October 24-26
7.	Traffic counts 21 through 30	October 27-29
8.	Makeup counts	November 3-5

The one-tube layout was used with the pneumatic counters to collect the traffic data for the unpaved roads. One tube was placed and anchored across both lanes of traffic. This layout collected traffic volume information only and did not detect direction, speed, or type of vehicle. The traffic counter was set for a straight axle count (as opposed to the divide-by-two setting). For the unpaved roads with a high traffic count, it was assumed that each two counts denote one vehicle. For traffic counts less than about 50 ADT, the data was reviewed and vehicles were counted based on the time interval between axles crossing the tube. The Trafx magnetic counter parameters were set for low volume conditions to prevent double counting for large vehicles. Vehicle types (i.e., two axle, four axle, etc.) traveling the road will be noted during the twice per day equipment checks if applicable. Because of the small traffic volume expected on most unpaved roads, it was not practical to develop detailed traffic-type information.

The traffic count data from the TRAX 1 Plus and Trafx traffic counters were downloaded to a computer following each traffic count. Each traffic counter time stamps the raw data and also stores the traffic count data until cleared from the memory.

The data survey forms shown in Appendix H were used to record traffic counts and auxiliary information as follows:

- Traffic counter location (GPS coordinates)
- Date and start/stop times
- Individual person developing traffic count data
- Road width and condition (e.g., 12-ft width with vegetated center area; well-used road)
- Road length (measured by truck odometer)
- Vegetation surrounding private road (e.g., type, character, height, coverage)
- Land identification including land use (e.g., construction site, mining area, open desert)
- Likely purpose of road (e.g., recreational traffic; construction traffic)
- Traffic count between start and stop times, and translated to ADT
- Comments (e.g., vehicle types using road, developing or undeveloped area, speed limit if available)
- Photographs of road area where counter is located

7.0 RESULTS OF PRIVATE UNPAVED ROAD ANALYSIS

7.1 Identified Roads and Areas of Concentration

A GIS layer of private unpaved roads was produced for this project. The GIS layer was developed in conjunction with GIS layers (provided by Sharon Rice of GISMO) that showed the location of a subset of private unpaved roads. Thus, the GIS layer produced through this project was only for previously unmapped private unpaved roads.

The mapping of private unpaved roads was done with the 2-foot pixel aerial photography from the GISMO archive. The roads were mapped by visually examining the digital aerial photography (outside the boundaries of Las Vegas, North Las Vegas, Henderson, and Nellis Air Force Base) and digitizing all unpaved roads 22 feet wide or greater. A total of 158 miles of unpaved private roads were identified.

Even though aerial photography was not available for the entire HB 212 area, analysis of the photography showed the absence of roads well before the boundary of the photography was reached. Therefore, it can be concluded that the roads identified represent the entire HB 212 area. To be considered as a road, a minimum width of 22 feet was required. This eliminated bike paths, trails, and off-road disturbances.

7.2 Average Daily Traffic Results

ADT for each of the roads selected is presented in Table 7-1. For those roads using both the Jamar and Trafx counters, the data from the Jamar counters was used. Figure 7-1 shows an overview of the 160 miles of private unpaved roads. Figure 7-2 presents an example of unpaved roads identified by the aerial photography analysis. The red lines represent unpaved roads not identified in the county GIS system.

ADT ranged from 2 to 599 ADT. Three of the counts were greater than 150 ADT (402 ADT for Site 11, 210 ADT for Site 15, and 599 ADT for Site 33).

The ADT agreement between the Jamar and Trafx counters was very good for those roads with ADT less than 150 (32 vs. 33 ADT for Site 9, 8 vs. 7 ADT for Site 32, and 72 vs. 71 ADT for Site 36). At Site 15, ADT based on the Jamar count was 210 and ADT based on the

Trafx count was 173. This difference is believed to be due to the low traffic settings on the Trafx counters. A few of the sites originally selected were not used for traffic counts due to the road segment being paved (Sites 12, 28, 29, and 35) and heavily used by construction equipment and blocked on a dead end street (Sites 16 and 30).

TABLE 7-1. AVERAGE DAILY TRAFFIC COUNTS

Site No.	Traffic Count Data								ADT
	Sun	Mon	Tues	Wed	Thur	Fri	Sat	Counter	
1	6	13	22					EQ01	13.7
2	9	27	23					J 1	19.7
3	21	60	54					J 2	45.0
4	Construction area - Road extremely active with earthmoving equipment - Did not use								
5&6	12	32	28					J 3	24.0
7	23	24	26					EQ02	24.3
8	50	140	89					J 5	93.0
9 a	34	32	29					J 4	31.7
9 b	34	36	28					EQ03	32.7
10	27	28	79					J 7	44.7
11	203	493	511					J 8	402.3
12	Did not use								
13	40	43	53					J 6	45.3
14					96	105	80	J 8	93.7
15 a					249	172	208	J 7	209.7
15 b					189	153	177	EQ03	173.0
16	Berm added (Dirt) - Access to unpaved road blocked								
17					58	84	137	EQ02	93.0
18					16	12	28	J 6	18.7
19					33	33	30	J 5	32.0
20					17	18	26	EQ 01	20.3
21					4	4	7	J 4	5.0
22					45	43	43	J 3	43.7
23					13	20	12	J 2	15.0
24					89	73	53	J 1	71.7
25					11	15	5	J 3	10.3
26					70	45	61	J 2	58.7
27					6	7	10	J 1	7.7
28	Old pavement - broken up - did not use								
29	Did not use								
30	Dead end street = did not use								
31					68	61	19	J 6	49.3
32 a					10	12	1	J 4	7.7
32 b					10	9	2	EQ01	7.0
33					642	693	463	J 5	599.3
34					11	11	12	EQ02	11.3
35	Did not use								
36 a					91	76	50	J 1	72.3
36 b					84	74	56	EQ01	71.3
37					35	33	23	J 7	30.3
38					3	3	0	J 8	2.0
		ADT Excluding Sites 11, 15a, 15b, and 33 (ADT >150)							36.4
		ADT Including Sites 11, 15a, 15b, and 33 (ADT >150)							73.2

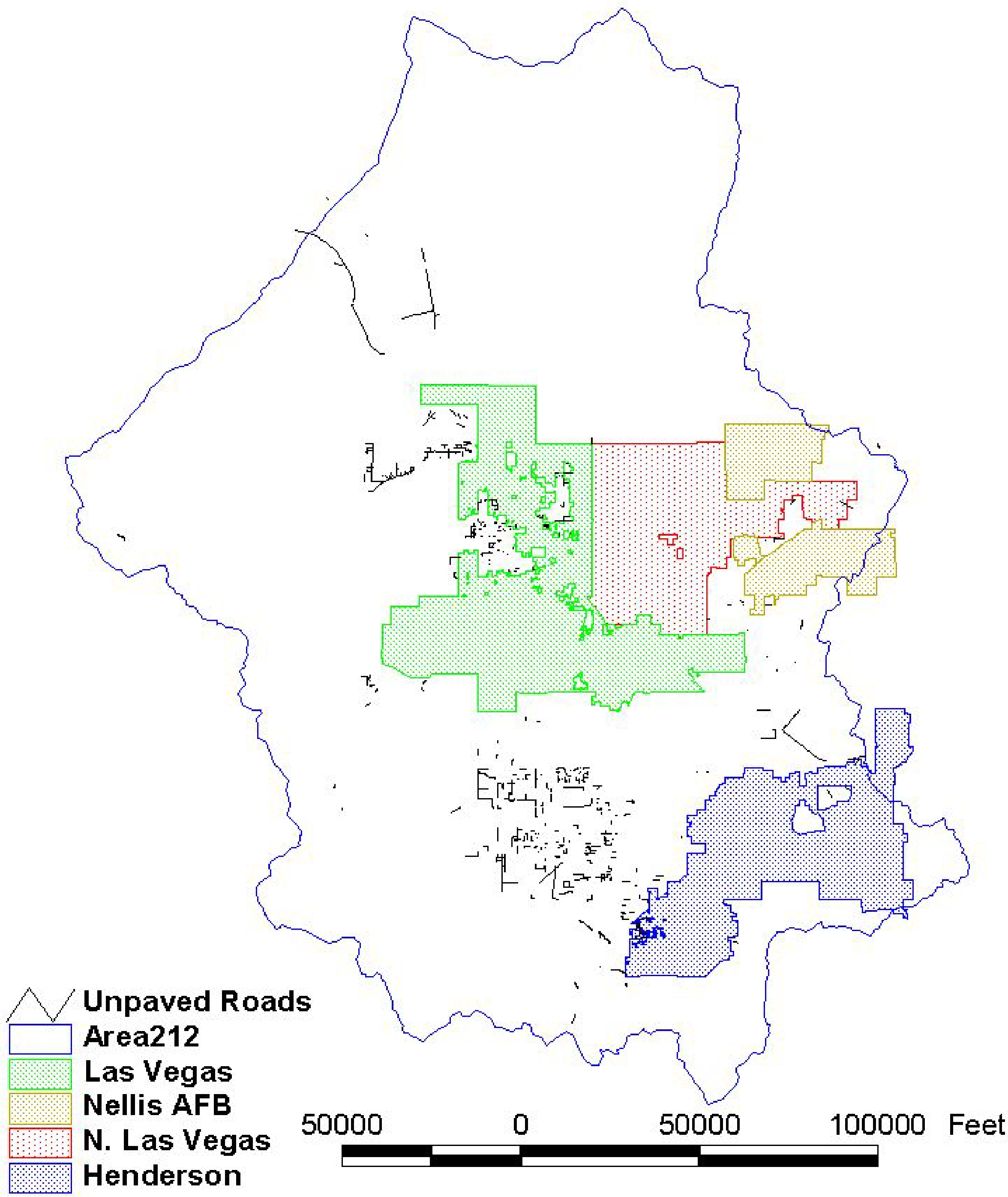

Figure 7-1. Overview of 160 Miles of Private Unpaved Roads

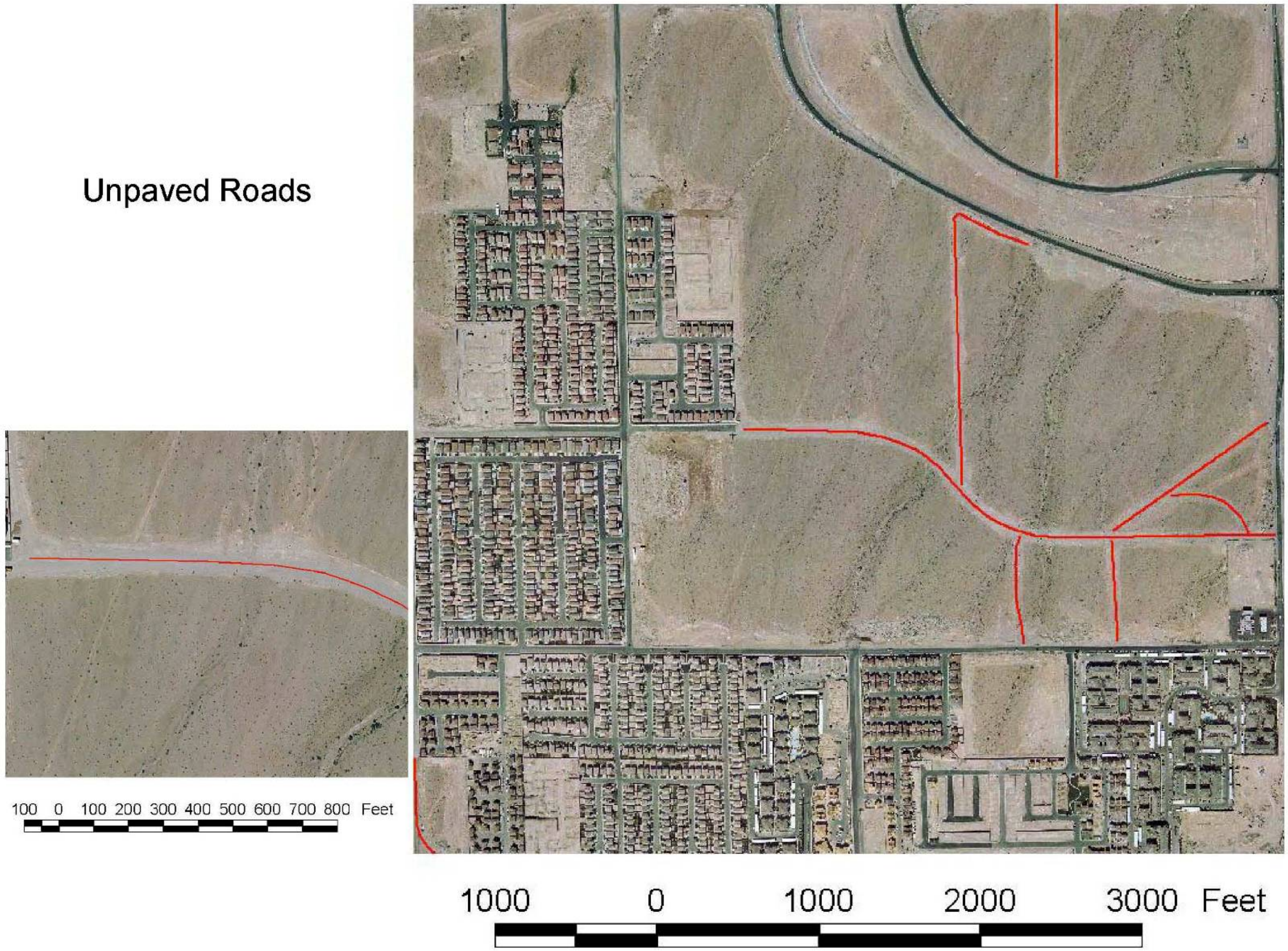

Figure 7-2. Example of Unpaved Roads Identified by Aerial Photography Analysis

8.0 CONCLUSIONS

- The Clark County emission inventory calculation procedure requires an inventory of erodible land areas in Las Vegas Valley (Hydrographic Area 212)
  - Native desert (natural state)
  - Disturbed, unstabilized vacant land (loss of surface protection)
  - Disturbed, stabilized vacant land (restoration of surface protection)
  - Private unpaved roads (dirt or gravel)

- WEG values developed by USDA/NRCS to indicate the susceptibility of surface soil to blowing (nine WEG values) are useful only for disturbed unstable land.

- Soil blowing is correlated with:
  - Soil texture
  - Organic matter content
  - Effervescence due to carbonate reaction with HCl
  - Rock and pararock fragment content
  - Mineralogy
  - Soil moisture and frozen soil

- Supervised classification gives reliable results for mapping all land categories except for disturbed unstable lands that constitute less than 1 percent of the total land area.

- Stratified random sampling, used with aerial photography, is an effective approach to generate reference data for accuracy assessment.

8.1 Vacant Lands

Table 8-1 summarizes the land classifications for HB 212 derived from the classified imagery based on the Landsat view of June 26, 2005.

TABLE 8-1. LAND CATEGORIES

Land Category	Percent of HB 212	Square Kilometers
Native Desert	47.6	1,897.1
Disturbed Unstable Vacant Land	Less than 1.1	Less than 45.3
Stabilized Vacant Land	3.1	122.8
All Other	48.2	1,918.6

The “all other” category includes wash areas (9%), concrete (0.7%), urban area (4.8%), vegetation (0.9%), and barren shadow (32.8%). Barren shadow is largely comprised of mountainous and/or rock areas plus shadowed areas. The amount of disturbed unstable vacant land is significantly less than previously reported. This is attributed to several factors:

1. A probable over-estimation in the past given the qualitative methods available at that time.

2. The success of the enforcement program requiring contractors to utilize stabilization techniques during construction.

3. The higher than average rainfall in the Valley during 2004 and 2005.

8.2 Applicability Limitations of WEG Classification

As part of the subject project, data obtained from UNLV wind tunnel tests was analyzed to investigate the dependence of the PM-10 flux rate on the WEG category. Results for both undisturbed and disturbed (manually raked) surfaces were evaluated. The results of the analysis showed that no clear dependence of the flux rate on WEG is observable for either disturbed or undisturbed surfaces. The spike results also showed no observable correlation with WEG.

It should be noted that the WEG classification of the wind tunnel test areas appears to be based on soil classification maps, and not on actual analysis of the soils that were tested. In the ground truthing work under the current project, little if any correlation was found between the WEG map classification and the actual analysis results for soil samples collected from the test sites as noted earlier in Table 2-3.

It is important to note that the WEG classification was developed in an agricultural context and was designed to predict total soil erosion and not PM-10 emissions. For example, loose sandy soils (WEG 1) are the easiest to move by the wind, but typically do not have a large PM-10 component, in comparison with other soil types. This observation is supported by field tests using the MRI wind tunnel in California's Antelope Valley (western Mojave Desert).

8.3 Private Unpaved Roads

A second phase of the project involved the identification of unpaved roads in HB 212 which were not already in the Clark County GIS. Roads were identified through 2-foot pixel aerial photography supplemented by field surveys. Roads had to be a minimum of 22 feet wide to be considered as a road. A sample of 30 road segments was selected on which to perform traffic counts. The 30 segments were selected to be representative based on usage. All 30 segments were in the urban area and in areas of expanding home building. A total of 160 miles of unpaved roads was identified. Excluding three sites with ADT counts exceeding 150, the average daily traffic count was 36.

8.4 Inventory Accuracy Assessment

The accuracy assessment indicates a high level of classification accuracy. Lower values of classification accuracy were achieved in the user's accuracy for the disturbed stable category. The error matrix indicated that samples for the "wash" category (natural drainage) were included in the disturbed stable category (an error of commission). Considering the definition of disturbed stable, the wash/natural drainage land cover can also satisfy the definition of disturbed stable. Wash/natural drainage areas are disturbed by infrequent overland drainage and then can stabilize during the interval between rainfalls. In summary, the overall, producer's, and user's accuracy indicate an acceptable level of confidence in the classification process and the derived areas of the land cover types (Table 5-2).

8.5 Protocol for Inventory Updating

The mathematical procedure that Clark County uses to calculate PM-10 emissions from wind erosion of vacant lands utilizes a series of emission factor equations for the various land categories: native desert, disturbed stable vacant land, and disturbed unstable vacant land. Each of these categories is assigned a set of emission rates that depend on the wind speed, as developed from on-site wind tunnel tests. The extent of source measures utilized in these calculations is the areal extent of each land category.

This project has generated procedures that can be replicated to develop updated land area values as development in the Las Vegas Valley continues. The procedures utilize Landsat 5 TM imagery that can be purchased for all of Clark County at a modest price. Then the spectral signatures of the different land categories can be used to map each land category corresponding to the time of imagery acquisition. This provides not only the total area of each land category, but also the spatial distribution of each category within the boundaries of Hydrographic Area 212.

The same is true for the procedure used to locate uninventoried segments of private unpaved roads. However, the procedure is much more labor intensive in that it involves careful inspection of aerial photographs to find road segments that meet the identification criteria and are not contained in the GIS layer for private unpaved roads. It should be noted that private unpaved roads tend to cluster around land development projects, and many such roads are paved as the area development continues.

This project has provided a protocol for updating the source extent measures needed to develop future inventories of wind generated particulate emissions from vacant lands and traffic-generated emissions from private unpaved roads. The same source extent measures are also appropriate for the development of particulate emission inventories for other particle size fractions, provided that the applicable emission factor equations contain adjustment factors for application to the desired size fractions.

9.0 REFERENCES

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APPENDIX A

GLOSSARY

GLOSSARY

Airport Disposal Lands - That property owned and controlled by the Clark County Department of Aviation used primarily as a buffer for the airport proper for flight paths.

Desert Pavement - The relatively strong and durable crust of native desert land formed by a combination of natural mineralogical cementatious processes in combination with rock or stone fragments. A varnish on the rocks is a coating built up over many decades by windblown clay particles containing iron and manganese combined with bacteria. Several theories exist on the formation of the stony surface ranging from deflation of finer particles to erosion by water to repeated wetting and drying cycles.

Disturbed Vacant Land (or Disturbed Soil) - Vacant land that has been disturbed by removal of the vegetation and grading, or by vehicle movement or in some other way such that the natural crust on the soil is destroyed. Disturbed land can become stabilized by natural processes such as rainfall or revegetation if it is not repeatedly disturbed.

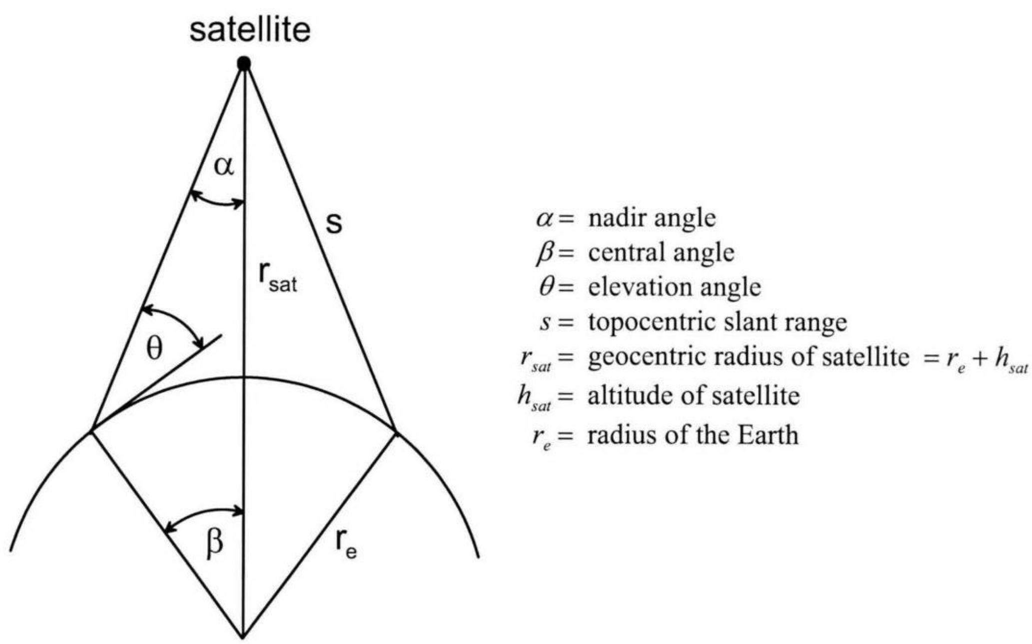
GEOTIFF Files - A standard for storing georeference and geocoding information in a TIFF 6.0 compliant raster file.

Ground Truthing - Observations and testing performed at ground level to verify the properties and parameters of a given land area for correlation to satellite imagery.

IKONOS - The trade name of the satellite used in this study, operated by a private consortium.

Multi-Spectral Satellite Imagery - Satellite data simultaneously collected in several wavelength bands.

Nadir Angle –



Native Desert (or Native Desert Soil) - Desert land in its natural state that has not been disturbed by anthropogenic activities.

NITF Files - Electronic files using the National Imagery Transmission Format Standard (NITFS). NITFS is the standard for formatting digital imagery and imagery-related products and exchanging them among members of the Intelligence Community (IC), the Department of Defense (DOD), and other departments and agencies of the United States Government as governed by Memoranda of Agreement (MOA) with those departments and agencies.

Private Unpaved Roads - Roadways that are at least 22 feet in width, used for transiting from point to point with no paving of the surface. Unpaved roads may be surfaced with native soil or with aggregate materials brought into the area for road construction. Pathways used as hiking trails and off-road vehicle recreation are not considered roadways. Roadways typically will follow a property boundary, have a destination point, or provide a shortcut between unconnected paved roads. Private means roads that are not maintained by a governmental authority such as Clark County, the cities of Clark County, or NDOT. Roads designated as RS that are under BLM control are not considered private.

QuickBird – The trade name of a satellite with imagery capabilities, operated by a private consortium.

Soil Stability - That characteristic of soil that relates to the tendency to resist wind erosion. The more dust that is generated at a given wind speed, the more the soil is considered unstable. Stability is not specifically defined by a universally accepted wind speed, but a soil which emits no dust at a sustained wind speed of 25 mph would generally be considered stable.

Soil Stability Categories - Any set or grouping of soil types that is used to define the relative stability (i.e., resistance to wind erosion) of various soils. Formalized categorizations include the Soil Textural Triangle and Wind Erodibility Groups formulated by the U.S. Department of Agriculture.

Stabilized Vacant Land (or Stabilized Soil) - Vacant land that has been stabilized either by the application of palliatives, or by natural crusting or re-vegetation, or that is protected by rock cover. Stationary soils are considered stable when they are in compliance with the standard set forth in Regulation Section 90.4.

Supervised Classification - A type of classification where the image analyst "supervises" the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene.

Training Site - A specific area on the ground that is defined by various tests to be of a certain class of soil that can then be used to "train," or calibrate, the software that processes satellite imagery so a given spectral signature relates to a given type of land surface or cover type.

Verification Site - A verification site is the same as a training site except it is used after the imagery is classified, as an independent verification to develop an accuracy assessment of the classification procedure.

APPENDIX B

UNPAVED ROAD TRAFFIC COUNT LOCATIONS

APPENDIX C

DR. JAMES WIND TUNNEL CLASSIFICATIONS

APPENDIX D

GROUND TRUTHING DATA FORM FIELD SHEETS

APPENDIX E

TABLE 1 & TABLE 2-1 OF SECTION 90
CLARK COUNTY AIR QUALITY REGULATIONS

APPENDIX F

CLARK COUNT AIR QUALITY REGULATION SECTION 91.4.1.2

APPENDIX G

WIND ERODIBILITY GROUPS

(Source: U.S. Department of Agriculture,
Natural Resources Conservation Services, 2005.
National Soil Survey Handbook, title 430-VI.
Exhibit 618-16.
Online: http://soils.usda.gov/technical/handbook/)

APPENDIX H

TRAFFIC COUNT DATA FORM FIELD SHEETS