

Using Satellite Imagery for an Inventory of Erodeable Vacant Land

Fred D. Hall, William F. Kemner, Chris Ore, and Marcus Borengasser

Environmental Quality Management, Inc.

6340 McLeod Drive, Suite 1

Las Vegas, NV 89120

Chatten Cowherd

Midwest Research Institute

425 Volker Blvd

Kansas City, Missouri 64110

ABSTRACT

This is a followup to a paper presented at AWMA's 98th Annual Conference in Minneapolis, Minnesota. The original paper focused on the inventory of vacant lands in the Las Vegas Valley by satellite imagery. This paper focuses on the current study where an inventory of vacant land by satellite imagery has been conducted for an expanded area of Clark County Nevada. An inventory of native desert, disturb stable vacant land, disturbed unstable vacant land, and private unpaved roads in the areas outside of the Las Vegas Valley in Clark County, Nevada was developed using satellite imagery together with "on the ground" field observations and testing. The methodology for developing this inventory used Landsat multispectral satellite imagery and ground truthing (field data collected on the ground used to "train" the computer to correlate spectral data collected by the satellite to actual conditions on the ground and also to verify that the correctness of the computer's predictions of actual ground conditions).

At each ground truthing site, the drop ball test, the rock test and the threshold friction velocity (TFV) test were performed. Site conditions such as types of vegetation, vegetation cover (height, density, and umbrella size) were noted. Satellite image data was used to map and analyze wind erosion areas based on multi-spectral data. This analysis is based on differentiating the spectral signature of erodible soil (disturbed surfaces) from signatures for desert vegetation (e.g., types, spacing) and other non-erodible elements (e.g., rock outcroppings, other stabilized soil surfaces). Urban vegetation (e.g., golf courses) and surface drainage areas were distinguished to assist in mapping wind erosion areas.

INTRODUCTION

In accordance with the Clark County Nevada PM₁₀ SIP, Environmental Quality Management and Midwest Research Institute conducted an inventory of vacant land in the Las Vegas Valley (report entitled "An Inventory of Vacant Land Soil Stability and Unpaved Private Roads in the Las Vegas Valley Using Remote Sensing Imagery", December 2006). The purpose of this study was to develop an inventory of native desert

land, disturbed stable vacant land, disturbed unstable vacant land, and private unpaved roads in the Las Vegas Valley, as defined by Nevada State Plane coordinates.

Historically, much of the investigative focus has been on Las Vegas Valley due to the population density. The population of Clark County expanded from approximately 460,000 in 1980 to 1.4 million in 2000 (U.S. Census Bureau). As of July 2007, the population of Clark County was estimated to be 2 million people, with approximately 1,925,000 residents in the Las Vegas Valley. However, even though most the population of Clark County is currently located in the Las Vegas Valley, significant construction activity is also occurring or projected in the outlying areas. These projects include (but are not limited to) proposed development of a new airport in Ivanpah Valley, residential growth in the Mesquite area of the Virgin River Valley, and residential development in Moapa Valley.

This project has been performed in order to proactively investigate the current land usage in the outlying areas of Clark County where significant construction or industrial activities are occurring or projected in order to obtain a baseline inventory of native desert land, disturbed vacant land, stabilized vacant land, and private unpaved roads in these areas. These regions include Apex Valley, Eldorado Valley, Indian Springs, Ivanpah Valley, Moapa Valley, Pahrump Valley, and Virgin River Valley. Black Mountain Area, Colorado River Valley, Paiute Valley, and Jumbo Peak Area were not included in this study. Figure 1 illustrates the Hydrographic Basins that are used to define the airsheds within Clark County.

The remote sensing methodology developed in the previous study of the Las Vegas Valley was used in this project. This methodology uses multi-spectral satellite imagery and ground-truthing (training sites) to determine unique spectral signatures for land surface characteristics. The four main categories of land surfaces considered in this project are: (1) native desert, (2) disturbed unstable vacant land, (3) disturbed stable vacant land, and (4) private unpaved roads. Stabilized surfaces include rocky soils, soils protected by vegetation, and soils that have re-crust following disturbance. Unstable surfaces include active construction sites and areas traveled by four-wheel drive and all-terrain vehicles (ATVs) where no rocky surface condition exists and no surface crust has been developed

An inventory of land areas for soil stability using satellite imagery is based on computer algorithms called supervised classification. The algorithms used in this project require a suite of “training sites” that are representative of the various soil stability categories, or classes. The training sites are established through field evaluation, ensuring that the training sites accurately represent the soil stability categories for this project, i.e., native desert, disturbed stable and disturbed unstable land.

Reference or validation sites were selected based on field observations and aerial photography. Error matrices were developed to indicate the mapping accuracy of each soil stability category by showing the percent of correctly classified pixels.

Unpaved roads were identified through a combination of high-resolution aerial photography and 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.

TRAINING SITE SELECTION AND CHARACTERIZATION

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, the pixel size of the satellite imagery, and availability of training sites meeting the specified criteria. For example, disturbed unstable sites that were large enough to be utilized as a training site were for difficult for the field personnel to discover. Therefore, only one to three sites were found for each hydrographic area. Three native desert sites were selected from each hydrographic area, and disturbed stable sites ranged from three to seven for each area. A total of sixty-three training sites were used across the study areas. Table 1 summarizes the training sites by location and stability category.

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 stable, and disturbed unstable.) 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.

Native desert is defined as 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 ball drop 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, and may have TFV values less than 100 cm/sec. However, such amounts are usually much smaller than the minimum significance threshold required for the TFV test (20 g/100 cm²) based on engineering judgment, so that the test result is considered a pass.

Sand dunes in native desert environments constitute a special case because they are inherently unstable and continue to erode as long as high winds prevail. Surface disturbance of sand dunes does not affect their behavior as an unstable surface material. Sand dunes are classified as disturbed (naturally) stable for this project.

Disturbed unstable vacant land is 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 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 is native desert that has been disturbed, but subsequently stabilized by natural phenomena or anthropogenic measures. 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. In order to classify vacant land as stable, it must pass one of three tests: 1) the drop ball drop test, 2) the rock test or 3) the TFV test. When these tests are conducted in sequence, one passing test negates the need for performing any additional tests. Figure 2 presents a decision tree for vacant land classification.

TRAINING SITE TEST METHODS

Ground truthing includes the drop ball test, the rock test, and the threshold friction velocity (TFV) test. The TFV is only done when applicable, i.e., when there is sufficient loose material on the surface to perform the test and if the rock test fails. In addition, an enhanced version of the drop ball test using a five-point penetration index is used to better characterize the soil crust.

Each test site (e.g., 3600 m²) is tested three times each in randomly selected areas, as discussed below. Each of the three “test” areas within a training site is defined as 1-meter square per the Clark County regulations. Within each test area, the drop ball test will be done five times in a 30 cm x 30 cm (one-foot) square area in the lower left-hand corner of the 1-meter square area, the rock cover test one time, and the TFV one time, as applicable. The average of the replicate tests is used to characterize each training site.

Drop Ball Test

The drop ball test is considered a pass (surface is stable) if at least two of three drops indicate sufficient crust (pass or sufficient crust is assigned if ball does not sink into surface, so that it is partially or fully surrounded by loose grains and the surface underneath has not been pulverized so loose grains are visible).¹

In addition to the regulatory drop ball test which includes only a pass or fail, expanded test results were used in this study 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

Rock Test¹

The rock test is used to indicate surface stability by measuring the wind resistance of rocks and other nonerrodible elements on a given disturbed surface. Vegetation is not counted as a nonerrodible element. Within the 1-meter square test area, the rocks greater than 1-cm diameter are mentally grouped into small, medium, and large size categories and the number of rocks are counted in each group.

Prior to the count, one or two average-size rocks in each group are selected and the length and width are measured and multiplied to determine the average area of each rock size category. The average area of small, medium, and large size rock categories are multiplied times the number of rocks in each category and then the total rock area of each size category is divided by two to estimate the frontal area of the rocks to determine the percent rock cover. The surface is considered stable if the rock cover is > 20%.

Threshold Friction Velocity Test

To perform the threshold friction velocity test, a stack of sieves is used with openings of 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, and a bottom pan. For this test, only loose surface dust is collected up to a depth of 1 cm over an area of at least 30 cm by 30 cm. This test is not conducted for hard, non-errodible surfaces where no loose material exists.

Prior to sieving the dust, rocks > 1 cm diameter are removed. The dust is placed in top of the stack, the stack is covered, and the stack is rotated with at least 20 circular arm movements (10 clockwise and 10 counterclockwise). Following the sieving, the stacked sieves are separated and the relative quantities of catch in each are inspected. After visually determining the sieve catch with the greatest volume, Table 1 of Section 90 of Clark County Air Quality Regulations is used to determine TFV.¹ The TFV is corrected for non-erodible elements using Table 2 of Section 90 of the Regulations.

SATELLITE IMAGERY COLLECTION

Landsat TM imagery was used for this study. The 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) and within 48 hours of the ground-truthing tests in each hydrographic basin.

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 (e.g., IKONOS) 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. Figure 3 shows the Landsat TM coverage of Clark County.

SPECTRAL ANALYSIS PROCEDURES

The image processing software used is ENVI 4, ArcView 3.2, and ArcInfo 8.0.2. GIS software was used for the vector analysis. 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. Figure 4 shows an example the supervised classification of the Landsat TM imagery using Mahalanobis Distance classification.

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 algorithm 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.

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 sub-areas”) within the pilot study area.
2. Inspect and collect soil samples within training sub-areas 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. Perform field checks to determine the reliability of the land classification.
6. Complete the pilot study using the new approach to identify training areas.
7. Evaluate Landsat imagery as the basis for the vacant land classification

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

10. Perform final field verification of the inventory.

Table 2 shows the land category areas for each of the hydrographic basins included in the study. For an overall area of 15,037 km², 13,367 km² (89%) were determined to be native desert, 1,178 km² (7.8%) were determined to be disturbed stable, and 492 km² were determined to be disturbed unstable.

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. It is not practical to ground truth or otherwise test every pixel of a classified image. Therefore, a set of reference pixels are used. Reference pixels are points on the classified image for which actual data are known. The reference pixels are 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 are the basis of the classification. By allowing the reference pixels to be selected at random, the possibility of bias is lessened or eliminated.

Table 3 shows the accuracy assessment for Pahrump Valley. Based on ground observations of selected pixels, the accuracy for this area is estimated to be 89%.

RESULTS OF PRIVATE UNPAVED ROAD ANALYSIS

Identified Roads and Areas of Concentration

A GIS layer of unpaved roads was produced for this project. No unpaved roads were previously mapped in these areas. To be considered as a road for this evaluation, a minimum width of 22 feet was required. This was consistent with the evaluation of the Las Vegas Valley, and eliminated bike paths, forest service roads, and off-road disturbances.

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 160 miles of unpaved private roads were identified.

Average Daily Traffic (ADT) Results

ADT counts were performed for the unpaved roads shown in Figure 5. ADT ranged from 0 to 595 ADT. Only one of the counts was greater than 150 ADT (595 ADT for White Rock Road, Virgin River Valley).

CONCLUSIONS

In general, the conclusions of the study are as follows:

- Landsat TM imagery is effective for land use mapping.
- Areas without urban features can be mapped with fewer land use categories.
- Naturally disturbed areas (playas, alluvial fans) are often mapped as Disturbed Stable/Unstable.
- Training sites for Disturbed Unstable are difficult to locate and are unevenly distributed.
- Mapping unpaved roads with satellite imagery and aerial photography is reasonably accurate.

ACKNOWLEDGMENTS

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REFERENCES

1. Clark County Nevada Air Quality Regulations, *Section 90 – Fugitive Dust from Open Areas and Vacant Lots, Amended July 1, 2004.*

KEYWORDS

Erodible Land
Erodibility Test Methods
Ground truthing
PM₁₀ Emission Inventory
Satellite imagery

Figure 1. Clark County Hydrographic Basins.

El Dorado
Ivanpah
Apex
Virgin River
Indian Springs
Pahrump
Moapa

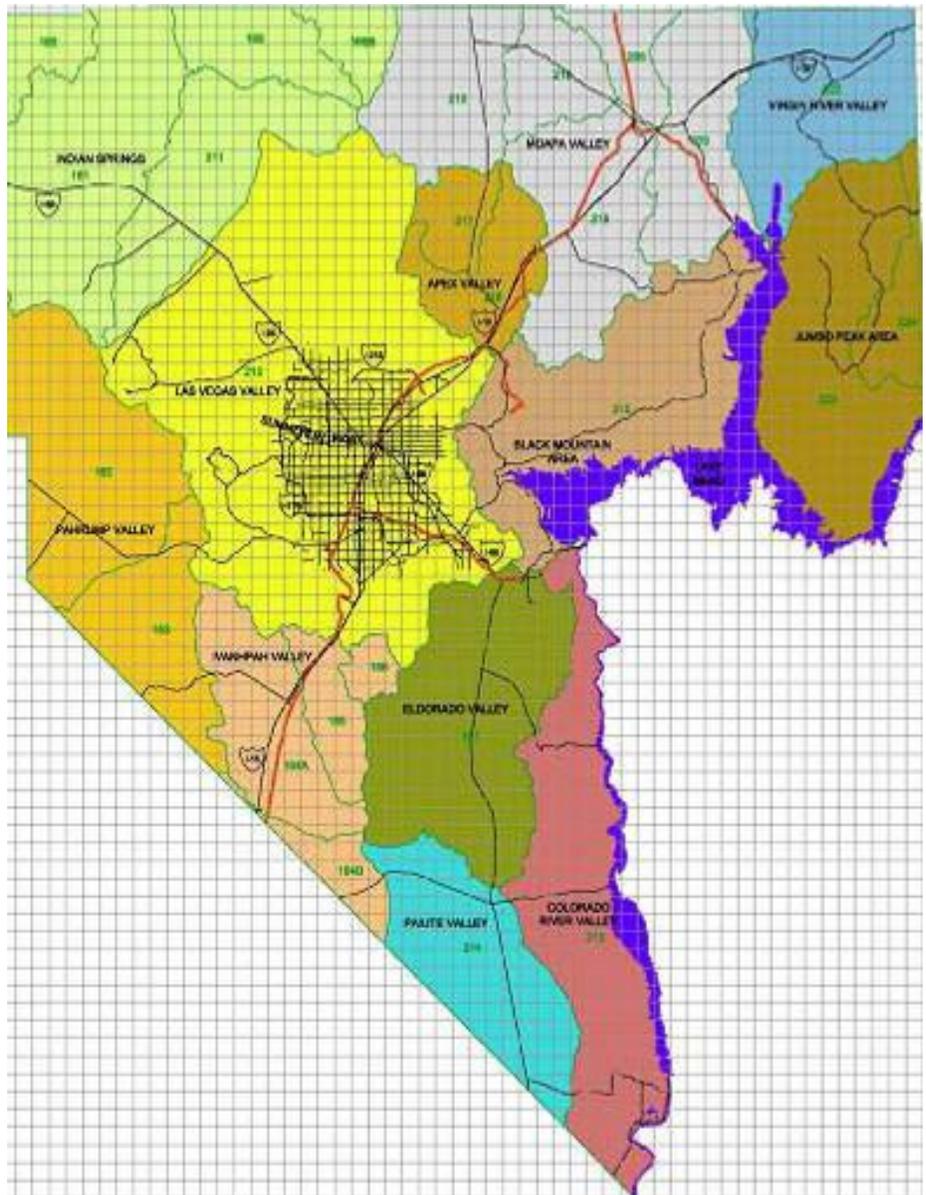


Figure 2. Decision tree for vacant land classification.

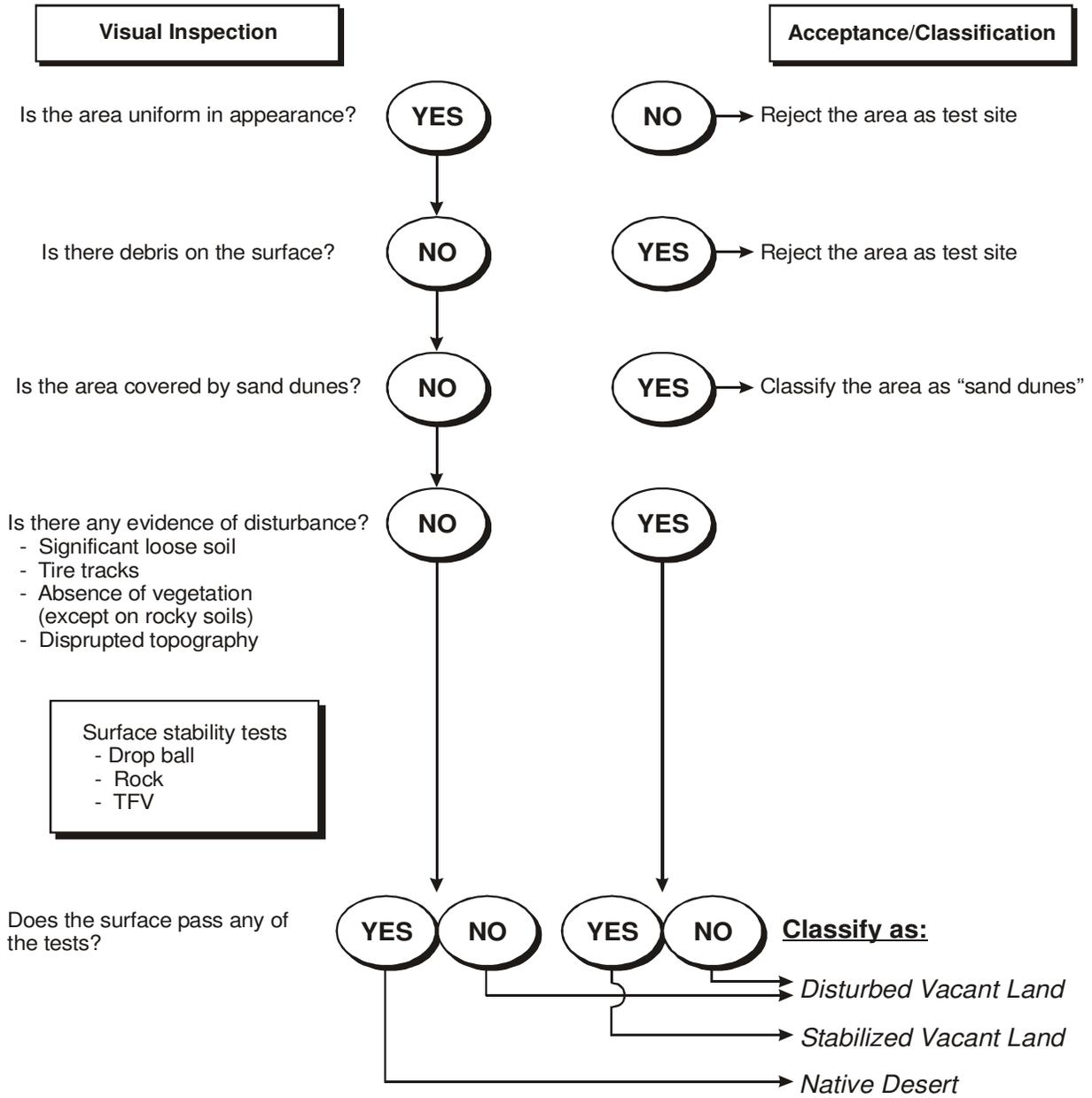


Figure 3. Clark County Landsat scene.

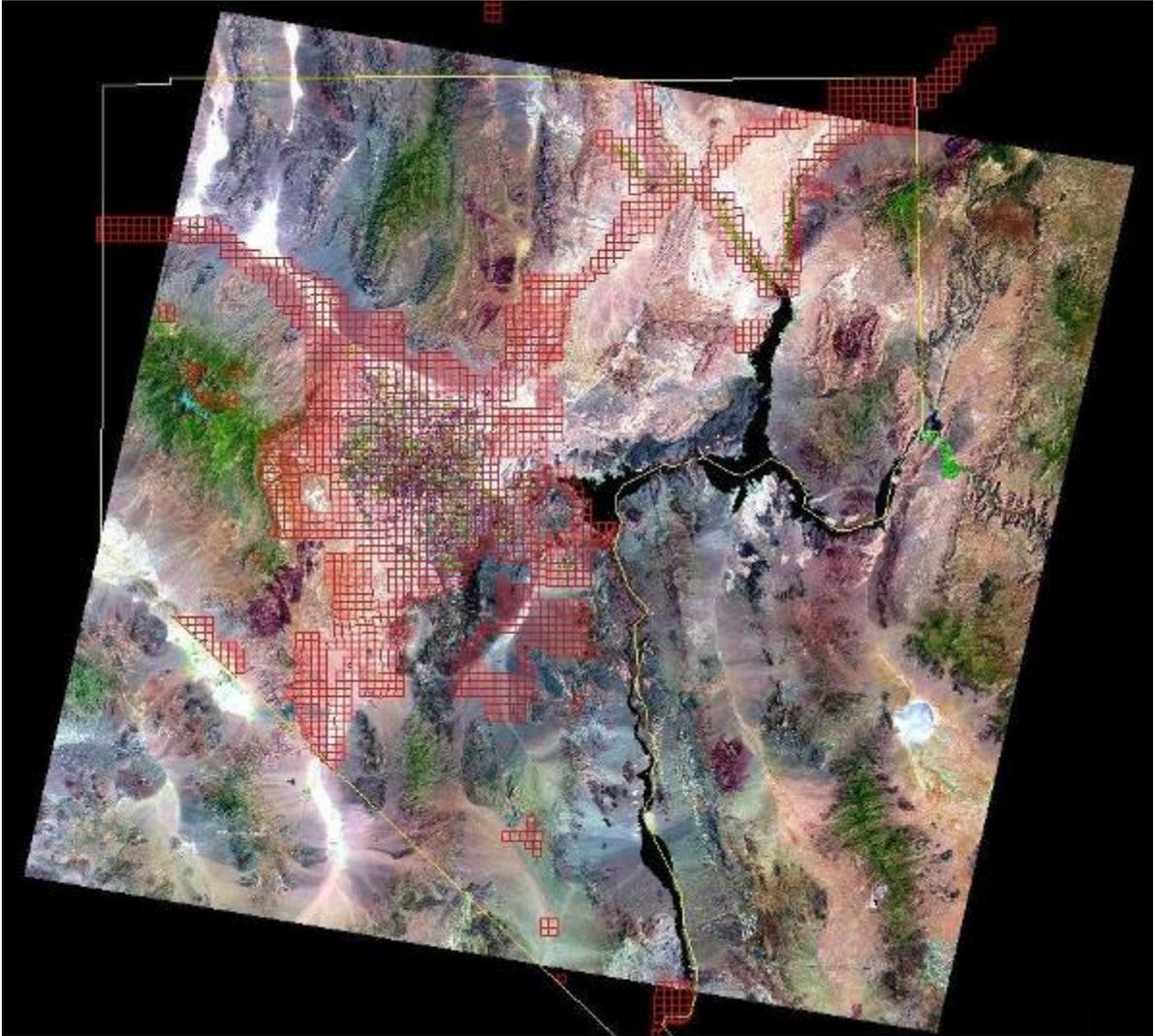


Figure 4. Imagery analysis of Eldorado Valley by Mahalanobis Classifier.

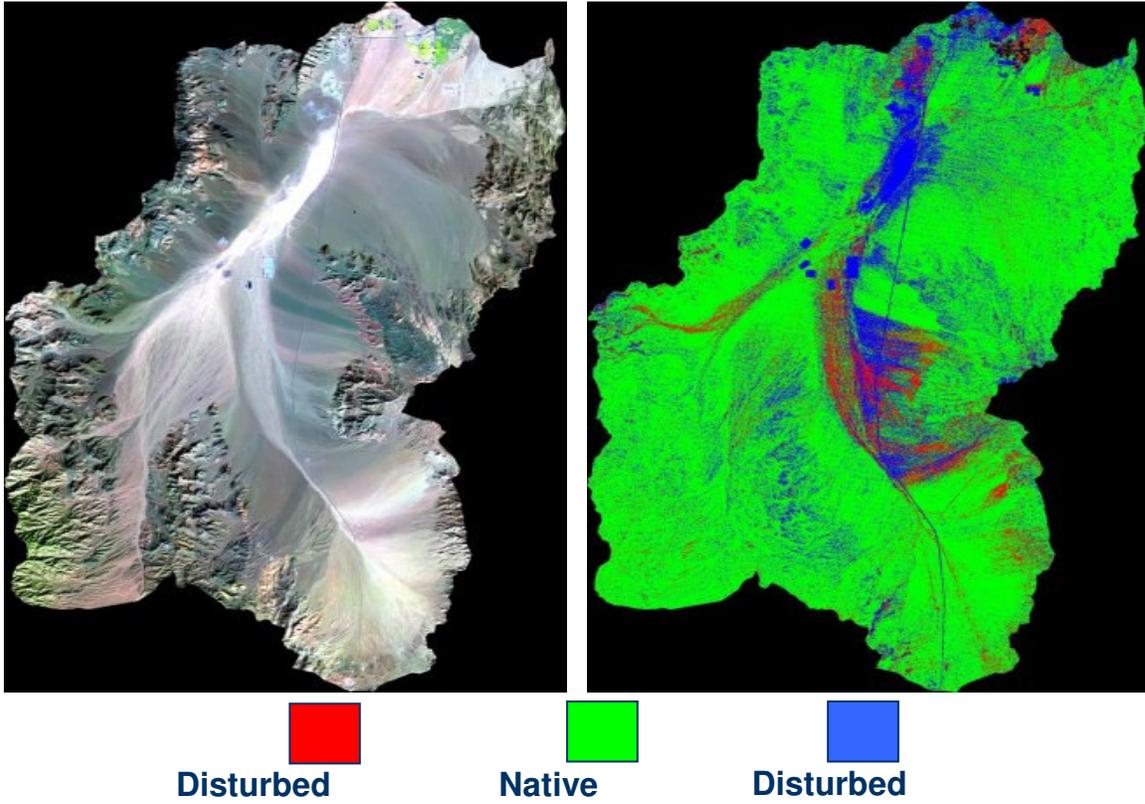


Figure 5. Locations of traffic counts in Clark County.

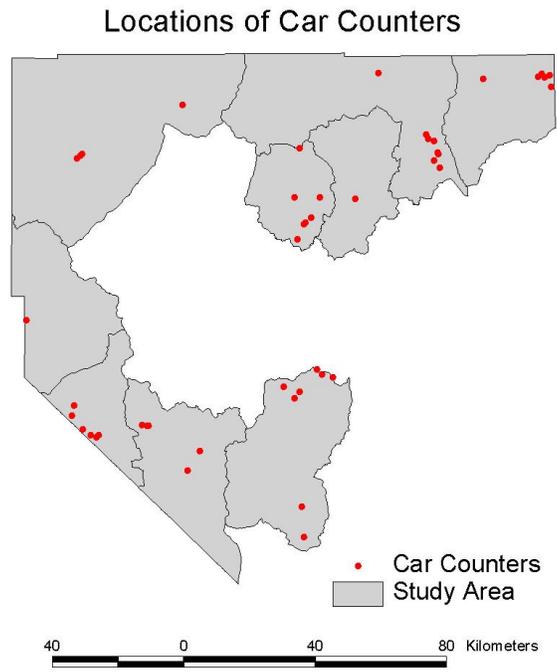


Table 1. Training site classifications in each hydrographic basin.

Valley	Disturbed Stable	Disturbed Unstable	Native Desert
El Dorado	7	1	3
Ivanpah	3	1	3
Apex	4	1	3
Virgin River	3	1	3
Indian Springs	5	1	3
Pahrump	5	2	3
Moapa	7	3	3

Table 2. Vacant land classification results.

Valley	Native Desert	Disturbed Stable	Disturbed Unstable	Total
Apex Valley	859 km ²	64 km ²	6 km ²	929 km ²
Virgin River Valley	1,219 km ²	17 km ²	163 km ²	1,399 km ²
Indian Springs Valley	3,654 km ²	444 km ²	141 km ²	4,239 km ²
Eldorado Valley	1,054 km ²	229 km ²	99 km ²	1,382 km ²
Ivanpah Valley	1,027 km ²	110 km ²	42 km ²	1,179 km ²
Pahrump Valley	3,251 km ²	171 km ²	2 km ²	3,424 km ²
Moapa Valley	2,303 km ²	143 km ²	39 km ²	2,485 km ²
Total	13,367 km ² 89%	1,178 km ² 7.8%	492 km ² 3.3%	15,037 km ²

Table 3. Example accuracy assessment.

Vacant Land Type		Field Reference Data			
		Native Desert	Disturbed Stable	Disturbed Unstable	Row Total
Classified Data	Native Desert	32			32
	Disturbed Stable	8	20		28
	Disturbed Unstable		1	23	24
	Total	40	21	23	84
Overall Accuracy = $75 / 84 = 89\%$					