Las Vegas Wash multispectral scanner survey

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LAS VEGAS WASH
MULTISPECTRAL SCANNER SURVEY

prepared for
U.S. Department of Interior
Bureau of Reclamation
Boulder City, Nevada
LAS VEGAS WASH MULTISPECTRAL
SCANNER SURVEY

Las Vegas, Nevada

by

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NOTICE

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ABSTRACT

At the request of the U.S. Bureau of Reclamation, Boulder City, Nevada, the U.S. Environmental Protection Agency's Environmental Monitoring Systems Laboratory at Las Vegas collected multispectral scanner imagery of Las Vegas Wash on October 1, 1982.

A combined maximum likelihood classification and editing procedure was used to classify the multispectral scanner imagery into 12 categories of land cover. The classification identified four categories of marsh vegetation, one category of riparian, two categories of mixed scrub, and two desert categories. Turbid water and cultivated land formed an "other" category. Area tabulations were formed by georeferencing the classification to the Universal Transverse Mercator System at a resolution of 3 meters.

A regression-based procedure was used to transform the multispectral data into categories of temperature, Secchi depth, total dissolved solids, and specific conductance for those areas in which standing water was observed.

The resulting digital maps provide baseline data for the Las Vegas Wash System. Future mapping may be compared to these maps, using digital overlay techniques, to provide quantitative environmental monitoring of this desert wetland.
LIST OF ABBREVIATIONS AND SYMBOLS

a - acre  
ch - scanner channel  
cm - Centimeter  
°C - degrees centigrade  
ft - feet  
Ha - hectare  
in - inch  
kilometer  
l - liter  
m - meter  
mg - miligram  
mile  
μm - micrometer  
μmho - micromho  
μW - microwatt  
mm - millimeter  
nm - nanometer  
pp - pages  
R² - coefficient of determination  
SE - standard error  
Spec. Cond. - specific conductance  
str - steradian  
TDS - total dissolved solids
INTRODUCTION

The Las Vegas Valley contains the largest concentration of population in the State of Nevada with a 1980 population of 443,730 and a total area of 233,775 hectares (552,960 acres). Additionally, the rate of growth has been high, with population roughly doubling every 10 years since 1950 (Clark County Staff, 1981).

Physically, the Las Vegas Valley is included within the 777,000-hectare (3,000-square mile) Las Vegas Basin in the Basin and Range Physiographic Province (EPA Staff, 1975). The Las Vegas Wash (Figure 1) forms the only valley outlet, and thus, receives all of the overland flow from surface runoff and irrigation, as well as effluent from Las Vegas' sewage treatment plants.

Increases in population, therefore, have created perennial flows through the Las Vegas Wash system, creating wetland conditions. These aquatic conditions have produced desert wetland in an area which would normally have an aridic soil moisture regime. The result is a collection of plants and animals, not normally present, which are maintained by surface runoff, irrigation of crops and lawns, and treated effluent.

Considerable differences of opinion exist about how to use this area. One proposal is for creation of a wetlands park (Bierly and Associates, 1981). It is considerably beyond the scope of this report to comment on these issues. However, the vegetative cover of the area is an item of considerable local interest as well as part of the Bureau of Reclamation's (BOR) management of tributaries to the Lower Colorado River System.

Therefore, at the request of the Bureau of Reclamation's Boulder City, Nevada, office, the U.S. Environmental Protection Agency's Environmental Monitoring Systems Laboratory at Las Vegas collected and processed multispectral scanner imagery overing the Las Vegas Wash. The collection and processing of this imagery provides baseline information on vegetation in Las Vegas Wash and water quality information in Las Vegas Bay. Subsequent image acquisitions, similarly processed, may then be compared with this investigation, to establish trends and document vegetative change.
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on evidence presented here and review of pertinent literature, it is concluded that:

- Interpretation of fall MSS imagery over a desert wetland requires both digital and visual interpretation techniques for accurate wetland mapping.
- Tamarisk (Salt Cedar) is the dominant plant of the dryer wetland areas, grading to Common Reed and, finally, to Cattail.
- Generally, the thermal regime of the Las Vegas Wash is quite uniform and cooler than the Lake Mead area.
- The turbidity plume on the image data was very small. Water quality increased rapidly from the mouth of the wash into Las Vegas Bay.

RECOMMENDATIONS

Based on the findings of the study, it is recommended that:

- Vegetative analysis of the Las Vegas Wash area by digital interpretation of multispectral scanner data should be conducted on imagery collected much earlier in the growing season, to maximize plant vigor and indicate unusual vegetative stress.
- Multidate analysis should be considered.
- Future studies should be conducted using a 3 m resolution element and georeferenced data so that comparison is possible with this study.
- Thermal mapping of the wash area will require much finer resolution data. It is suggested that thermal scanner data be used for the plume and bay area.
only. It would be appropriate, however, to spot check the small watercourses within the wash with a handheld radiometer to determine if the uniformity found is valid throughout the year.

The water quality classifications would become more reliable if a larger number of points would be sampled and a more uniform range of values found.
METHODOLOGY

DATA COLLECTION

Simultaneous 11-channel multispectral scanner (MSS) and color infrared photographic imagery were collected in 7 flight lines on October 1, 1982, over Las Vegas Wash at a flight altitude of 1,402 m (4,600 ft) above mean sea level (MSL). An additional data set (Flight Line 8) was collected over the Las Vegas Bay area at 5,791 m (19,000 ft) MSL (see Figure 1).

The MSS nadir picture element (pixel) size varied with terrain from 2.2 by 2.2 m (7.1 by 7.1 ft) at Winterwood Golf Course to 2.6 by 2.6 m (8.4 by 8.4 ft) at Las Vegas Bay for Flight Lines 1 through 7. Flight Line 8 pixel size was a nominal 13.5 by 13.5 m (44.4 by 44.4 ft). Average total field-of-view was 1,692 m (5,550 ft) for the low altitude lines and 10 km (6.2 mi) for the high altitude line.

The concurrent 9 by 9 in (228 by 228 mm) color infrared transparencies (imaged on Kodak 2443 film) varied similarly with terrain, maintaining a nominal scale of 1:6,000 for Flight Lines 1 through 7 and nominal scale of 1:35,600 for Flight Line 8. The camera field-of-view averaged slightly less than the MSS with 1,372 m (4,500 ft) for the low altitude lines and 8 km (5.1 mi) for the high altitude line.

Image collection began at 0858 PDT and ended at 0924 PDT for lines 1 through 7 and began at 1017 PDT, ending at 1019 PDT, for Line 8.

The reader is referred to the Appendix A for an expanded discussion of MSS characteristics.
Figure 1. Location of flight lines for Las Vegas Wash survey. Scale 1:250,000. Las Vegas Quadrangle, 1954.
The MSS data were decommutated from high density digital tape format to 9-track, 800 bit per inch computer compatible tape (CCT) format. These CCT's were then preprocessed to eliminate tangential distortion and overscan effects by means of a linear resampling technique. Conversion to ELAS (Earth Resources Applications Software) format and extraction of Channels 3, 5, 7, and 10 were also performed for Flight Lines 1 through 7.

Flight Lines 3 through 6 were determined to have covered the study area completely and were selected for intensive analysis. The ELAS image processing package, developed by the NASA Earth Resources Laboratory at NSTL Station, Mississippi, was used for subsequent digital analysis.

The first step in the image classification process was the extraction of spectral signatures (or "response patterns") for each of the resource categories. An unsupervised training set and signature extraction procedure, called SRCH, was used to generate a group of spectral response patterns consistently over the entire data set. These spectral response patterns were later used to classify the raw MSS data into spectral classes.

Specifically, the SRCH algorithm passed a 3- by 3-pixel "moving window" through the data array. Mean values, variances, and covariances were calculated for each "window." If the standard deviation of a window was greater than 0.1 and less than 1.0, and if the coefficient of variation was less than 5 percent, then the window was designated as a training set. The statistics for the training set were then checked for similarity with other statistics in the collected "list" using a scaled distance measure (Junkin, et al., 1980) of class separability. If the training set was found to be similar to any of the list it was merged with the least separable class. If the new training set was different, it was added to the list (if necessary, the two most similar classes in the list were merged to make room for the new class). Fifty-nine classes were collected in Flight Lines 3 and 4 using this method. (The reader should note that a spectral class may be composed of many training sets, and there ay be several spectral classes for the same resource class.)
An additional 48 supervised training sets were taken using the ELAS POLY and SUPE polygon extraction and statistics calculation routines. These training sets were selected by referencing six ground study transects (Figure 2) to their corresponding locations on the aerial photography and extending the communities found along the transects to the remaining imagery.

The 107 sets of class statistics were then reduced to 56 final sets of statistics using an automated merging routine within the SRCH overlay. Any class pairs with a scaled distance of less than 1.5 were combined. This final set of 56 class means, variances, and covariances formed the basis for the land cover classification of Flight Lines 3 through 6.

A maximum likelihood classifier (MAXL) was used to classify each pixel of the multispectral data into one of the 56 spectral classes. The classification algorithm calculated, for each pixel, the probability of the pixel belonging to each class, choosing the class with the highest probability. The exception was that if the probability of the "best" class was less than a predetermined threshold, the pixel was assigned to Class 0 (unclassified).

The classifications were then color-coded and reproduced on 8- by 10-in Polaroid™ paper exposed by a Dunn Instruments™ camera. These Polaroid™ prints and enlargements of the color infrared photography over the transects were given to the Bureau of Reclamation for field checking.

After determining that vegetative patterns were well characterized, but some of the species were not uniquely defined, several other image processing techniques were attempted. When compared to the field data, maximum likelihood classifications including principal components data channels, texture transformations, and thermal infrared data all proved no better than the originally selected data set classification.

Therefore, a visual interpretation and edit procedure (PGUD) was used to change selected class values within prescribed polygons to selected class values greater than 56 (the highest class number used by the classifier). This permitted identification of the changed classes as well as increased accuracy in classification. This
Figure 2. Ground study transects for Las Vegas Wash survey. Scale 1:24,000. Las Vegas SE and Henderson, 1970.
Hybrid procedure involved outlining areas visually interpreted on the large-scale 
photography as being erroneously classified. All pixels with confused class numbers 
within the polygon were then changed to the correction class. Thus, in selected 
areas of the classification, patterns were mapped by digital interpretation and class 
names were added by stereoscopic visual interpretation of large-scale photographic 
imagery. The use of this procedure had the effect of combining the best attributes 
of both types of interpretation to produce the most reliable classification of the 
MSS data.

The classified data sets were then georeferenced to the Universal Transverse 
Mercator (UTM) earth coordinate system using an overall cubic fit to control points 
and nearest neighbor resampling routine (ACGE). Seventy-seven control points were 
selected along the four flight lines, and their UTM and image coordinates were found. 
Control points with calculated residual errors greater than 10 pixels were deleted. 
Mean residual errors differed slightly with each flight line, but were approximately 
5 pixels with respect to both scan lines and elements. Resampling was performed 
producing 3- by 3-m pixels throughout the data.

The georeferenced data sets were color-coded and a legend produced in conjunc-
tion with Bureau of Reclamation personnel. The study area was further defined with a 
polygon, and all values outside of the defined area were set to zero.

Final classification maps were produced using the Dunn Instruments™ film 
recorder and Polaroid™ film. Each map covered 1,024 by 1,024 pixels or 3.072 by 
3.072 km (1.9 by 1.9 mi).

WATER TEMPERATURE CLASSIFICATION

MSS Channels 10 (0.9-1.1 μm) and 12 (8.0-14.0 μm) were extracted from the data 
for Flight Lines 3 through 7. Water surface temperature measurements, taken by BOR 
personnel during the overflight, were used to establish the relationship between 
scanner count values in the thermal infrared channel (12) and water surface 
temperature.
A parallelepiped classifier (BOXCLS) was then used to perform a land-water separation, to density slice the land features by their Channel 10 response, and to characterize water surface temperatures by the calibrated Channel 12 response.

Color-coded output maps were made for only those areas in which standing water was resolved. Though the data were partially rectified, no georeferencing of this classification was performed.

WATER QUALITY CLASSIFICATIONS

Bureau of Reclamation personnel collected surface water samples and made in situ measurements at 11 stations in Las Vegas Bay. The sampling was conducted between 0925 and 1105 PDT on October 1, 1982, concurrent with the aerial overflight. The location of each station was recorded on a map, and a written description was made containing compass bearings to prominent landmarks. No quality assurance data were provided, nor was there a description of methodology used, but it is assumed that, for the purposes of this report, the data provided by the BOR were produced by the Lower Colorado Region, Soil and Water Laboratory in accordance with quality assured methods.

Multispectral scanner Channels 1 through 10 (0.38-1.10 μm) from Flight Line 8 were decommutated to CCT format. The ELAS analysis programs were used to display the Channel 10 data on a DEANZA image processing system.

Eleven training sets were selected over the 11 stations and a 4- by 4-pixel matrix of data was extracted over each station in each of the 10 channels. Mean values of covariance matrices were calculated for each station. These mean values were then converted to radiance (in μW cm⁻²-str-nm).

The radiance values and their corresponding water quality measurements were then input to program P9R (Best Possible Subsets Multiple Linear Regression) of the Biomedical Computer Programs-P Series (Dixon, 1977). Program P9R then selected the multiple linear regression for the variables minimizing the Mallows Cp statistic.
Radiance and water quality values are presented in Appendix B. Regression equations were produced for Secchi depth, total dissolved solids, and specific conductance.

The regressions were evaluated using the procedures recommended by Whitlock, et al. (1982). The F-test was used to determine if the regressions were linear and possessed a nonzero slope. Mallows Cp divided by P (the number of predictors) was used to evaluate bias in the independent variables. R^2 was used to describe the variance explained by the regression. Finally, the standard error (SE) was used to describe the distribution of errors about the regression line.

Each pixel of the 10-channel data set was evaluated using the regression equation for the selected water quality parameter. The calculated water quality parameter value (coded to an integer from 0 to 255) was placed in that pixel for Channel 1 of the output data file (ODF). The Channel 10 value of the pixel was copied into Channel 2 of ODF. The result was a 2-channel file with transformed data as Channel 1 and reflected infrared data (Channel 10) as Channel 2.

The two-channel file, for each of the water quality parameters, was then input to the BOXCLS classifier. Channel 1 was used to categorize the water quality data into ranges approximating one standard error, and Channel 2 provided the land-water separation and land feature categorization.

Color-coded maps of the classification were made using the DEANZA* image processing system and the Dunn Instruments* film recorder.
RESULTS AND DISCUSSION

WETLAND LAND COVER CLASSIFICATION

Figures 4 through 9 depict the results of the maximum likelihood land cover classification. Color-coding of the classes is as shown in Figure 3. Each figure depicts an area of 1,024 by 1,024 pixels (3.072 by 3.072 km), and north is at the top of the figure.

Class tabulations are presented in Table 1.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Spectral Subclass Numbers</th>
<th>Hectares</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marsh Cattail</td>
<td>2,11,33,40,41,43*,44,50,54</td>
<td>220.70</td>
<td>545.36</td>
</tr>
<tr>
<td></td>
<td>55,56*,61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Reed</td>
<td>3,9,19,39,42,49</td>
<td>69.40</td>
<td>171.49</td>
</tr>
<tr>
<td>Cattail/Reed</td>
<td>52</td>
<td>2.68</td>
<td>6.62</td>
</tr>
<tr>
<td>Open Water</td>
<td>22,53</td>
<td>36.81</td>
<td>90.96</td>
</tr>
<tr>
<td>Riparian Tamarisk</td>
<td>4,17,23,27,51,57,60</td>
<td>158.95</td>
<td>392.77</td>
</tr>
<tr>
<td>Mixed Scrub Grass/Pickelweed</td>
<td>13,18</td>
<td>30.40</td>
<td>75.12</td>
</tr>
<tr>
<td>Saltbush/Mixed Scrubs</td>
<td>14,25,29</td>
<td>108.80</td>
<td>268.85</td>
</tr>
<tr>
<td>Desert Creosote</td>
<td>1,5,6,7,12,15,16,20,21,24,</td>
<td>988.67</td>
<td>2,443.06</td>
</tr>
<tr>
<td>Barren</td>
<td>26,28,30,31,32,38,46,48</td>
<td>18.15</td>
<td>44.85</td>
</tr>
<tr>
<td>Other Turbid Water</td>
<td>34,62</td>
<td>9.93</td>
<td>24.54</td>
</tr>
<tr>
<td>Cultivated</td>
<td>58</td>
<td>3.12</td>
<td>7.71</td>
</tr>
<tr>
<td>Burned</td>
<td>8,47</td>
<td>55.90</td>
<td>138.13</td>
</tr>
</tbody>
</table>

*Burned subclass, cattail regeneration.
The computed areas are as presented in Figures 4 through 9, except that overlap areas have been counted only once in the computations. An additional class, Burned, has been added beyond those depicted in Figure 3. This class may be included in the Barren category and appears as a darkened area in the classifications.

While no statistical accuracy assessment was performed, transect data and photo interpretation of large-scale imagery provide some qualitative observations which fall into two categories: 1) technical comments about the classifications and 2) descriptions of the vegetation of the Las Vegas Wash.

Technically, the multispectral classifications are unique when compared to other published results. Most studies have emphasized only digital (Scarpace, et al., 1981) or visual (Carter, et al., 1979; Mead and Gammon, 1981) techniques. The hybrid technique described here has not been reported in the literature. Moreover, most successful applications reported in the literature have used multidate imagery for analysis (Carter, et al., 1979; Gammon and Carter, 1979). Also in situ studies of wetland reflectance characteristics have reported conflicting results on the optimum timing for single-date analyses (Ernst-Dottavio, et al., 1981; Bartlett and Klemas, 1981; Hardisky, et al., 1983). The imagery used in this study was acquired on a single date, and no published results were available on optimum timing for a single overflight of a desert wetland. Classifier confusion between dead Cattail and dead Common Reed, and between most wetland species and Tamarisk, was probably the result of image acquisition occurring too late during the growing season. Multidate image acquisition may be necessary, and it is hypothesized that mid-summer may be a better time for single-date mapping of desert wetlands.

The image classifications show that north of the Advanced Waste Treatment Plant and east of Pabco Road, the Las Vegas Wash vegetation is dominated by the Tamarisk (Salt Cedar) community. The remainder of the wash consists of zones whose species composition appears to depend on topographic position. Soil salinity may also be a contributing factor, as Tamarisk and Saltbush seem to dominate positions with visible crusting of soil salts.
Figure 3. Legend for the wetland land cover classifications.
Figure 4. Wetland land cover classification, Area 1, Las Vegas Wash, October 1, 1982. Average scale 1:15,000.
Figure 5. Wetland land cover classification, Area 2, Las Vegas Wash, October 1, 1982. Average scale 1:15,000.
Figure 6. Wetland land cover classification, Area 3, Las Vegas Wash, October 1, 1982. Average scale 1:15,000.
Figure 7. Wetland land cover classification, Area 4, Las Vegas Wash, October 1, 1982. Average scale 1:15,000.
Figure 8. Wetland land cover classification, Area 5, Las Vegas Wash, October 1, 1982. Average scale 1:15,000.
Figure 9. Wetland land cover classification, Area 6, Las Vegas Wash, October 1, 1982. Average scale 1:15,000.
Where water is perennially available, Cattail dominates and, in the wettest areas, has grown to a height of 3 m or better. Strong winds have caused these large plants to be "blown over" in places, giving an erroneous indication of plant stress and creating classifier confusion.

Common Reed occupies the topographic position between the Tamarisk and Cattail communities, and its distribution and condition appear to be good indicators of stress induced by increases in soil salinity or decreases in soil moisture.

In summary, this study has established, through hybrid interpretive means, maps of the wetland land cover of Las Vegas Wash. The results of this study also indicate at the unique soil salinity, water budget, and general environmental conditions surrounding Las Vegas Wash may require multidate analysis to discriminate between all the major species present with a digital classifier. It is hypothesized that peak growth of Common Reed should determine the proper time for a single overflight. In any way, stress induced by factors other than normal senescence may be evaluated.

**TER TEMPERATURE CLASSIFICATION**

The legend and water temperature classifications are presented as Figures 10 through 18. North is approximately at the top of the page, although no georeferencing was performed. Only those images in which standing water was detected are shown. The open water temperatures should be accurate to 0.5°C.

It is apparent from these maps that the water temperature throughout the Wash is relatively constant and several degrees cooler than the ambient lake temperature. The thermal plume entering Las Vegas Bay drops rapidly. Surface temperatures throughout the bay are quite constant, and some wind effects are served (Figure 18).
Figure 10. Legend for the Las Vegas Wash water temperature classification.
Figure 11. Las Vegas Wash water temperature classification. Approximate scale 1:13,000.
Figure 12. Las Vegas Wash water temperature classification. Approximate scale 1:13,000.
Figure 13. Las Vegas Wash water temperature classification. Approximate scale 1:13,000.
Figure 14. Las Vegas Wash water temperature classification. Approximate scale 1:13,000.
Figure 15. Las Vegas Wash water temperature classification. Approximate scale 1:13,000.
Figure 16. Las Vegas Wash water temperature classification. Approximate scale 1:13,000.
Figure 17. Las Vegas Bay water temperature classification. Approximate scale 1:13,000.
Figure 18. Las Vegas Bay water temperature classification. Approximate scale 1:13,000.
Summary statistics for the regressions performed are presented in Table 2. All of the regressions were characterized by high $R^2$ values, low probabilities for the null hypothesis, Cp/P ratios approaching 1.0, and low standard errors. It should be noted that Channel 3 radiance values were dropped from the regressions due to high correlations with other channels.

Table 3 presents the $R^2$ values for single-channel predictors. While the $R^2$ values seem high, the Cp/P ratios (not shown) are very high when only one predictor is used, indicating bias in the individual predictors. This is consistent with earlier findings that the pattern of response, not the response in any one channel, is the determining factor (Mace, 1983).

It is also useful to present the results of the regressions in plot format. Figures 19, 20, and 21 are plots of predicted versus observed values for the multiple linear regressions presented in Table 2. The reader should note that the relation between Secchi depth and MSS radiance is logarithmic. Therefore, the plot

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**TABLE 2. SUMMARY STATISTICS—WATER QUALITY STUDY**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$R^2$</th>
<th>(F-Test)</th>
<th>Cp/P</th>
<th>SE</th>
<th>Range</th>
<th>Units</th>
<th>Channels Used</th>
<th>No. of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secchi depth</td>
<td>0.999</td>
<td>&lt;0.0000</td>
<td>1.06</td>
<td>1.03</td>
<td>0.5-25.5</td>
<td>ft.</td>
<td>1, 2, 4, 5,</td>
<td>11</td>
</tr>
<tr>
<td>TDS</td>
<td>0.999</td>
<td>&lt;0.0000</td>
<td>0.89</td>
<td>5.35</td>
<td>728-2056</td>
<td>mg/l</td>
<td>2, 4, 6, 7,</td>
<td>11</td>
</tr>
<tr>
<td>Spec. Cond.</td>
<td>0.999</td>
<td>0.0001</td>
<td>1.04</td>
<td>3.96</td>
<td>1108-2776</td>
<td>µhos/cm</td>
<td>2, 4, 5, 6,</td>
<td>11</td>
</tr>
</tbody>
</table>

**TABLE 3. SINGLE-CHANNEL $R^2$ VALUES**

<table>
<thead>
<tr>
<th>Variable</th>
<th>CH 1</th>
<th>CH 2</th>
<th>CH 4</th>
<th>CH 5</th>
<th>CH 6</th>
<th>CH 7</th>
<th>CH 8</th>
<th>CH 9</th>
<th>CH 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secchi depth</td>
<td>0.904</td>
<td>0.903</td>
<td>0.949</td>
<td>0.935</td>
<td>0.916</td>
<td>0.911</td>
<td>0.902</td>
<td>0.955</td>
<td>0.975</td>
</tr>
<tr>
<td>TDS</td>
<td>0.979</td>
<td>0.988</td>
<td>0.980</td>
<td>0.990</td>
<td>0.992</td>
<td>0.996</td>
<td>0.994</td>
<td>0.972</td>
<td>0.885</td>
</tr>
<tr>
<td>Spec. Cond.</td>
<td>0.978</td>
<td>0.986</td>
<td>0.979</td>
<td>0.989</td>
<td>0.991</td>
<td>0.995</td>
<td>0.993</td>
<td>0.972</td>
<td>0.883</td>
</tr>
</tbody>
</table>
Figure 19. Predicted versus observed Secchi depth (ft).
Figure 20. Predicted versus observed total dissolved solids (mg/l).
Figure 21. Predicted versus observed specific conductance (μhos/cm).
shows a log-log relationship which has been converted to the measured values by taking the antilogarithm of the predicted value. The plots for specific conductance and total dissolved solids reveal dependence on the only sample taken in the turbidity plume. This dependence on a single sample is not a desirable condition, and future studies should attempt to acquire samples whose distribution is more form throughout the observed range.

The final water quality classifications are presented in Figures 22, 23, and 24. The scale of these presentations varies slightly in the horizontal and vertical directions due to a combination of scanner geometry, relief displacement, and ordering camera errors. However, the average scale is approximately 1:55,000. These scenes have not been georeferenced, and north is to the right of each image.

In each of the classifications, a small plume is present at the mouth of the Las Vegas Wash. Water quality appears to improve rapidly, becoming clearer towards the inlet of the lake. However, lowest conductance and TDS values appear near the

\* It is possible that this effect is caused by a slight bottom reflection, but likelihood is low, as Secchi depth is recorded as less than water depth.
Figure 22. Secchi depth classification, Las Vegas Bay.
Average scale 1:55,000.
Figure 23. Total dissolved solids classification, Las Vegas Bay. Average scale 1:55,000.
Figure 24. Specific conductance classification, Las Vegas Bay. Average scale 1:55,000.
REFERENCES


The airborne multispectral scanner (MSS) acquires data at altitudes ranging from 370 to 6,100 meters (1,200 to 20,000 feet) above ground level. This is an 11-band system designed to collect and record radiant energy data in the near-ultraviolet through the thermal infrared portions of the electromagnetic spectrum (see Table on MSS Wavelength Bands). The scanner has a rotating mirror that scans across the ground scene, perpendicular to the line of flight. Radiant energy from the ground surface is reflected through focusing optics to a beam splitter which diverts the visible radiation (Channels 1-10) to a 10 channel spectrometer and the thermal infrared radiation (Channel 11) to a solid state detector. Electronic signals from the 11 detectors are digitized and recorded on magnetic tape in a high density format. During operation, the MSS scan rate is controlled and synchronized to the aircraft ground speed and altitude, resulting in scan line contiguity at nadir (see Figure on MSS Imaging Characteristics). The scanner is equipped with internal visible and thermal reference sources, which provide information for calibration of the data. The aircraft sensor tape is processed on a ground based Data Analysis System (DAS) to display, analyze, and create images of the surveyed scene.
MULTISPECTRAL SCANNER IMAGING CHARACTERISTICS (SIMPLIFIED)
<table>
<thead>
<tr>
<th>Channel</th>
<th>Wavelength</th>
<th>Color/Spectrum</th>
</tr>
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<td>New Ultraviolet</td>
</tr>
<tr>
<td>2</td>
<td>0.42-0.45μm</td>
<td>Blue</td>
</tr>
<tr>
<td>3</td>
<td>0.45-0.50μm</td>
<td>Blue</td>
</tr>
<tr>
<td>4</td>
<td>0.50-0.55μm</td>
<td>Green</td>
</tr>
<tr>
<td>5</td>
<td>0.55-0.60μm</td>
<td>Green</td>
</tr>
<tr>
<td>6</td>
<td>0.60-0.65μm</td>
<td>Red</td>
</tr>
<tr>
<td>7</td>
<td>0.65-0.70μm</td>
<td>Red</td>
</tr>
<tr>
<td>8</td>
<td>0.70-0.79μm</td>
<td>Near Infrared</td>
</tr>
<tr>
<td>9</td>
<td>0.80-0.89μm</td>
<td>Near Infrared</td>
</tr>
<tr>
<td>10</td>
<td>0.92-1.10μm</td>
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</tr>
<tr>
<td>11</td>
<td>8.00-14.00μm</td>
<td>Thermal Infrared</td>
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</table>
MULTISPECTRAL SCANNER DATA PROCESSING

Processing and analysis of multispectral scanner digital data is accomplished or the EMSL-LV Data Analysis System (DAS). The DAS (see attached figure) consists of a sensor tape playback unit, a high-speed digital computer, an interactive color TV display system, and an off-line film recorder. The functional steps in processing MSS digital data are summarized in the following diagram (MSS Data Processing - Simplified).

The MSS sensor data must be preprocessed before image analysis can be initiated. Preprocessing entails converting the data into a digital format compatible with the DAS processing software. In addition, the data can be calibrated and geometric corrections applied to rectify scan line distortions.

Primary data analysis and processing begin when software programs contained in the Image Analysis block are implemented. A variety of enhancement and classification procedures can be utilized by the image analyst. Single or multi-channel images, as well as enhanced and classified images can be viewed and analyzed on the color TV display. In addition, statistical parameters computed from the data can be extracted for detailed analysis. Hard copy records that can be generated at this stage in data processing include black and white film images, electrostatic paper plots from each MSS channel, and statistical printouts.

Following Image Analysis, further processing is required before the final output product can be produced. Classified data is color-coded and enlargement/reduction factors are computed by the analyst. Optional programs in this phase include a geographic rectification routine to match the image to selected UTM (Universal Transverse Mercator) map projection scales, and inputting image annotations.

Final output products from the MSS processing includes hardcopy color and/or black and white film images (positive or negative), and electrostatic paper plots. The classified and/or enhanced images can also be viewed in color and black and white on the TV display. Again, statistics computed from the data can also be viewed on the display. Class statistics such as pixels per class, acres per class, or square miles per class are output in the form of tabulated data.
DATA ANALYSIS SYSTEM

OPERATOR'S TERMINAL AND CARD READER

PLAYBACK SYSTEM AND CENTRAL COMPUTER

INTERACTIVE DISPLAY SYSTEM

COLOR FILM RECORDER

RACK MAGNETIC DISK DRIVES
APPENDIX B  

MSS RADIANCE VALUES $\mu W/cm^2-str-nm$ AND WATER QUALITY DATA

<table>
<thead>
<tr>
<th>Sample</th>
<th>CH 1</th>
<th>CH 2</th>
<th>CH 3</th>
<th>CH 4</th>
<th>CH 5</th>
<th>CH 6</th>
<th>CH 7</th>
<th>CH 8</th>
<th>CH 9</th>
<th>CH 10</th>
<th>Secchi depth (ft)</th>
<th>Specific conductance (µhos/cm)</th>
<th>TDS (mg)</th>
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