

# Use of Remotely-Sensed Data in the Development and Improvement of Emission Inventories

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## ABSTRACT

This paper explores the use of satellite imagery and aerial photography in the development and improvement of emission inventories. E.H. Pechan & Associates, Inc. and the Arizona Department of Environmental Quality have used remotely-sensed data in the development of emission inventories for particulate matter less than 10 microns (PM10) and in the development of border area inventories for toxic and criteria air pollutants. Satellite imagery has been used to develop detailed land use data to support the development of bottom-up emission estimates for windblown dust and agricultural sources. These data have also been used to develop refined spatial surrogates for use in emissions modeling. Additional uses of remotely-sensed data in the development and improvement of emission inventories are explored. These uses include aerial photography in the quality assurance of geo-coded point source locations, satellite imagery/aerial photography in the identification of important land use features (e.g. disturbed natural areas), and satellite imagery in the development of temporal distributions in crop cover and related emissions. The availability, capabilities, and costs of different remotely-sensed data products are also described.

## INTRODUCTION

This paper explores the use of remotely-sensed data in the development and improvement of emission inventories. For the purposes of this discussion, remotely-sensed data include satellite imagery, data products based on satellite imagery, and aerial photography. E.H. Pechan & Associates, Inc. (Pechan) and the Arizona Department of Environmental Quality (ADEQ) have used remotely-sensed data in the development of emission inventories for particulate matter less than 10 microns (PM10) and in the development of border area inventories for toxic and criteria air pollutants. Satellite imagery has been used to develop detailed land use data to support the development of bottom-up emission estimates for windblown dust and agricultural sources. These data have also been used to develop refined spatial surrogates for use in emissions modeling. Additional uses of remotely-sensed data in the development and improvement of emission inventories are explored. Finally, the availability, capabilities, and costs of different remotely-sensed data products are also described.

The general uses of remotely-sensed data in emission inventory development include:

- *Development of refined land use data (either satellite imagery or aerial photography)* – this information can be used to develop bottom-up inventories for source categories with activity data based on land use characteristics (e.g. windblown dust, agricultural sources, paved and unpaved roads, construction, industrial sources). This information can also be used to develop refined spatial surrogates for modeling purposes;
- *Development of activity data for open burning source categories (satellite imagery)* – information from both the infrared and visible bands can be used to pinpoint the locations and sizes of burns. Infrared data show where the heat is being generated (size and location of

the burn), while information from the visible bands show the location and size of the smoke plumes generated;

- *Development of information for refining biogenic emission estimates (satellite imagery data products)* – information from the visible and near infrared bands can be used to establish when vegetated landscapes are green and growing versus barren or dormant. Theoretically, the greener the landscape, the higher the biogenic emissions; and
- *Miscellaneous uses (satellite imagery or aerial photography)* – this category includes other uses that don't fit the above categories. An example is described below, where aerial photography is used to quality assure geo-coded point source locations.

The U.S. Environmental Protection Agency (EPA) recently released a report describing the use of satellite-sensed data products in assessing both the transport of gaseous and particulate pollutants and in the development of emission inventories (SAIC, 2002). This report describes the various satellite systems and their associated imagery and data products that have applications in air pollution research. Discussions of satellite-sensed data and its application to the development of emission inventories for wildfires/prescribed burns are included. The report can be downloaded from EPA's CHIEF website (<http://www.epa.gov/ttnchie1/eiip/pm25inventory/remsens.pdf>).

### **Applications of Remotely-Sensed Data in Emissions Inventory Development**

Several examples of where remotely-sensed data can be used in the development of emission inventories are provided below.

#### **Development of Refined Land Use Data for Estimating Emissions of Windblown Dust and Other Sources**

A good example of where accurate land use data are imperative for the development of accurate emission estimates is in the estimation of windblown dust emissions. Currently, the most favored methods for developing particulate matter emission (PM) estimates for windblown dust involve the use of emission factors based on wind tunnel tests for various types of land use. These emission factors are assigned to different land uses in the inventory area (e.g. natural desert, agricultural land, construction areas, other disturbed natural areas). Local meteorological data (wind speed and precipitation) are used with the emission factors to estimate emissions. A simplified equation for estimating windblown dust emissions using these methods for a given land use type is as follows:

$$PM_{10} \text{ (tons/yr)} = EF_i \times \text{Area}_i \times T$$

Where:  $EF_i$  = emission factor for land use  $i$  (tons/acre-hour);  
Area = area of land use  $i$  (acres);  
T = time (number of hours above the wind speed threshold for land use  $i$ ).

For the Yuma Arizona Study Area (see Figure 1), Pechan and ADEQ constructed a windblown dust inventory using the following the land uses: natural (undisturbed) desert areas, disturbed areas (e.g. from construction), agricultural lands, unpaved agricultural roads, sand dunes, and alluvial plain and channels (Pechan, 2002). A challenging aspect of this inventory was that the Study Area includes portions of Baja California Norte, Mexico and Imperial County, California. In a case like this, satellite imagery allows for an accurate treatment of the entire area of interest. Figure 2 shows 15-meter LANDSAT satellite imagery for the Study Area. This figure clearly shows the extent of the Imperial Sand Dunes in Imperial County and Mexico, agricultural lands throughout the Study Area (colored polygons), urban areas, alluvial channels (dry stream beds), and natural desert areas.

While the 15-meter image provides a great deal of useful information for quantifying windblown dust and other emission sources at regional scales, the resolution of this imagery is not adequate for characterizing small features (e.g. unpaved roads, urban features). Figure 3 depicts the use of satellite imagery of differing resolution to identify features in Phoenix, Arizona. As can be seen in this figure, 15 meter imagery (low resolution) is not adequate for identifying features such as the locations of

individual agricultural fields or paved/unpaved roads. The medium resolution imagery can be used to identify the locations of agricultural fields and the location of paved/unpaved roads; however high resolution imagery (1-meter) is necessary in order to assess the smallest features, such as whether or not an agricultural field has been tilled. For the Yuma project, Pechan and ADEQ used data from medium resolution satellite imagery (5-meter) to quantify the fraction of unpaved agricultural roads to total agricultural acreage. In addition, the City of Yuma digitized the disturbed areas within the city boundaries from a 1-meter LANDSAT image.

### **Development of Bottom-Up Inventories of Criteria and Toxic Air Pollutants**

ADEQ conducted a 14-month air quality monitoring program along the U.S./Mexico border in the Douglas, Arizona and Agua Prieta, Sonora, Mexico area. The study was motivated by the need to assess the risks to human health of air pollutants in that area. As a followup to the monitoring program, an emissions inventory was developed for the Douglas/Agua Prieta area for Year 1999. The inventory included point, area, mobile, biogenic, and wind erosion sources. The air pollutants of interest were volatile organic compounds, oxides of nitrogen, carbon monoxide, oxides of sulfur, hazardous air pollutants, PM<sub>10</sub>, and PM<sub>2.5</sub>.

The study area was 32 kilometers by 40 kilometers with a grid cell size of 500 meters by 500 meters. GIS and satellite image processing software were used to process and analyze satellite images of Douglas/Agua Prieta to estimate emissions from land use, roads, and industrial sources. This was a four-step process: (1) ADEQ staff made field trips to Douglas/Agua Prieta to identify and locate land use, roads, and industrial sources contributing to emissions. While in the field, staff annotated printouts of the satellite images with the type and location of the different emissions sources. Figure 4 shows the 1-meter satellite image of Agua Prieta overlaid with the index of field maps; (2) In the office, ADEQ staff digitized the annotated satellite printouts using GIS and satellite imaging processing software. Figure 5 shows an example of this for an urbanized printout; (3) A grid was overlaid on the satellite image and the spatial area, length or point location of the emission sources were estimated for each grid cell in the study area using GIS; and (4) The area and length data associated with the emissions sources in each grid cell were converted to emissions based on U.S. EPA emission factors. The emissions were then allocated to the grid cells by hour for a typical weekday and weekends by season. The emissions inventory will be used in air quality models to predict air pollutant concentrations and to investigate possible control measures to improve air quality in the Douglas/Agua Prieta area.

### **Development of Wildfire and Prescribed Burning Emission Inventories**

The recent report issued by EPA (SAIC, 2002) provides descriptions of recent efforts to use satellite imagery to locate and quantify emissions from wildfires and prescribed burns. For most inventory efforts, it might not make sense to use satellite imagery to develop annual emission estimates. However, detailed emission estimates can be developed for specified modeling scenarios. By focusing the effort only on the time period of interest for modeling, the level of effort and expense can be reduced dramatically. Indeed, by reviewing imagery of only the modeling periods, one may determine that open burning emissions did not occur during these periods of interest.

### **Additional Uses of Remotely-Sensed Data**

**Normalized Difference Vegetation Index (NDVI).** A useful satellite data product is called the NDVI. NDVI data can be used to identify areas where vegetation is healthy and growing versus being either dormant or barren. Data from both the visible and infrared bands of satellite-based advanced very high resolution radiometers (AVHRR) are used to calculate the NDVI. Healthy vegetation will absorb incoming solar radiation in the visible red band, while reflecting energy in the infrared band. NDVI data are available from a number of sources including the National Aeronautics and Space Administration (NASA) and the National Ocean and Atmosphere Administration (NOAA). Generally, the data are available as weekly or monthly averages (see SAIC, 2002 for details and data sources).

The most obvious use for NDVI data are the development of refined temporal profiles for use in biogenic emissions modeling. Pechan investigated the use of NDVI data to determine the locations of

active versus vacant) agricultural lands for use in modeling windblown dust (agricultural lands with a crop canopy are not considered to be significant sources of windblown dust, while vacant crop lands can be a source). Figure 6 shows NDVI data for southeastern Washington during the months of July and December 1996. As shown in these figures, much more vacant agricultural land exists in July than in December. Hence, the potential for windblown dust emissions during July is much greater.

**Quality Assurance (QA) of point source locations.** An emerging trend in the development of emission inventories for modeling purposes is to geo-code the location of important stationary emission sources that are typically handled as area sources. By specifying the locations of these sources, the accuracy of the modeling can be increased dramatically. For example, one may want to geo-code the locations of plating operations so that dispersion modeling can be performed for risk assessment purposes. In another example, Pechan was involved in the development of the latest ammonia emission inventory for the San Joaquin Valley of California (SJV). In this project, the locations of approximately 600 confined animal operations in the SJV were geo-coded based on the physical addresses obtained from a survey of county agencies (See Figure 7).

Several geographic information system (GIS) software packages, including ArcMap™, have geo-coding capabilities. In some cases, the GIS program will have trouble matching the address provided. In other cases, there may be errors in the physical addresses provided from the source. For source categories where the locations of sources tend to stay constant over time, aerial photography can provide a good QA check of these point source locations. As described in the conclusions section below, aerial photography is widely-available on the internet and new aerial photography libraries are constantly being created. Figure 8 shows the locations of two geo-coded dairies relative to the actual locations shown on aerial photographs. The first shows a good match (yellow geo-coded point in the middle of the dairy), while the second shows the actual location may be several hundred meters to the southeast (alternatively, this second location could be a new dairy established after the date of the aerial photo).

**Development of micro-inventories.** Micro-inventories are detailed emission inventories conducted in the immediate vicinity of receptor locations (e.g. ambient monitors, Federal Class I areas). Remote sensing data can be a valuable source of information during the development of micro-inventories to identify sources, characterize surrounding land use, or to quantify attributes of known sources. An example of this is shown in Figure 9 using aerial photography of Saguaro National Park, Arizona. Mining and quarrying operations were first identified using point locations from the U.S. Geological Survey's (USGS's) National Atlas. In order to use this information in a windblown dust inventory, however, the size of the disturbed desert area is needed. At this point, aerial photography can be incorporated to quantify the area of disturbed desert for use in windblown dust emissions modeling. Figure 10 shows an aerial photo of one of the sand and gravel operations identified from the National Atlas. GIS software can be used to estimate the disturbed natural area associated with this source.

Although the above example was shown relative to the development of information for use in windblown dust inventories, a similar approach could be employed to gather information on other source categories in and around Class I areas (or other receptors of interest). These source categories include paved and unpaved roads, airstrips, campgrounds (e.g. campfires), and residences (e.g. woodstoves).

## CONCLUSIONS

There are numerous sources of remote sensing data and the number of sources is continually growing. The recent EPA report provides information on many sources of satellite imagery and associated data products (SAIC, 2002). It is important to match satellite imagery with the intended use of the inventory. For example, if accurate information on general land use (e.g. agricultural areas, urbanized areas, natural areas) is needed for use as a base map or for developing spatial surrogates, a low resolution satellite image (e.g. 15-meter resolution) may be sufficient. However, if the intended use calls for the identification of smaller features (e.g. buildings, parking lots, unpaved roads); medium level resolution (4- or 5-meter) or high level (1-meter) satellite imagery will be needed. For regional inventory development, the best approach may be to acquire low level resolution imagery of the region

for use as a base map and then to identify smaller areas where higher level imagery is needed (e.g. urbanized areas).

Four things to consider when using satellite imagery are:

- Spatial Resolution - the size of the smallest feature on the image that can be detected (e.g., for high resolution imagery 1 pixel = 1 meter);
- Temporal Resolution - how often a satellite revisits the same place on earth), and spectral resolution (how many bands does a satellite sense;
- Spectral Resolution - how many bands (or what portion of the electromagnetic spectrum, visible, infrared, etc.) is the satellite able to sense: Panchromatic/Monochromatic, Visible & Near Infrared, Multispectral Thermal, Synthetic Aperture Radar, etc.; and
- Cost of Images - The costs for low resolution imagery are in the hundreds of dollars range, medium resolution imagery is in the range of thousands of dollars, and high level resolution imagery can run into the tens of thousands of dollars.

Table 1 compares the spatial and temporal resolution of images from some of the commercial and government satellites that are available. The choice of spatial resolution and temporal resolution will in large part depend on the type of features of an emissions inventory that need to be identified and the funding available for the project. For example, for developing a seasonal emissions inventory for a large area that is predominantly vegetation, the LANDSAT Extended Thematic Mapper would provide images with adequate spatial, temporal, and spectral resolution at a reasonable cost. However, if the emissions inventory is being developed for a small urban area with emphasis on areas with disturbed top soil from construction which changes from week to week; the IKONOS satellite with its high spatial and temporal resolution would be a better choice. This is because disturbed areas as small as 1 meter could be identified and quantified (however, costs would be significantly higher).

As stated above, currently available high resolution imagery of 1 meter or less is relatively expensive. However, the overall cost effectiveness of these products can be significantly less than using low level resolution products when multiple factors of project development and implementation are incorporated into a pre-purchase cost effectiveness analysis. The cost effectiveness analysis should include the issues cited above as a consideration of whether there are any other agencies that could take part in cost sharing (e.g. counties, cities; or various divisions such as air and water programs in the same agency).

Aerial photography is available free of charge from many sources (e.g. state agencies). Aerial photos are often provided as U.S. Geological Survey's (USGS) digital orthophoto quarter quadrangles (DOQQs). In addition, third party vendors sell aerial photographs for a fee (e.g. combining many DOQQs into a single image). A sampling of aerial photography sources follows:

- Arizona DOQQs and other imagery: <http://aria.arizona.edu/>;
- California: <http://casil.ucdavis.edu/casil/usgs.gov/>;
- Virginia: [http://fisher.lib.virginia.edu/doq/doqq\\_download/mrsid\\_frameset.html](http://fisher.lib.virginia.edu/doq/doqq_download/mrsid_frameset.html);
- Microsoft's Terraserver: <http://terraserver.homeadvisor.msn.com/>;
- Florida resampled county-level DOQQs: <http://www.labins.org/doqq/county.htm>;
- Panama City and Bay County, Florida: <http://www.pcbaygis.com/>; and
- USGS list of data sources (check out the link to the EROS data center): <http://mapping.usgs.gov/nsdi/>.

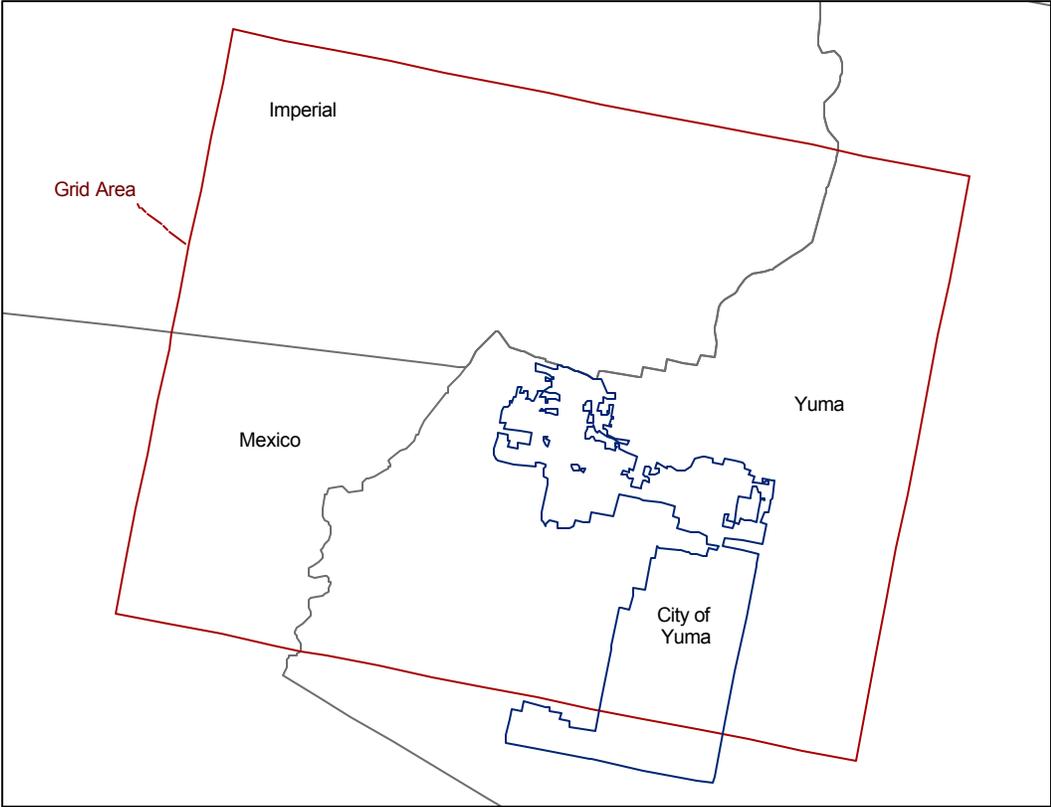
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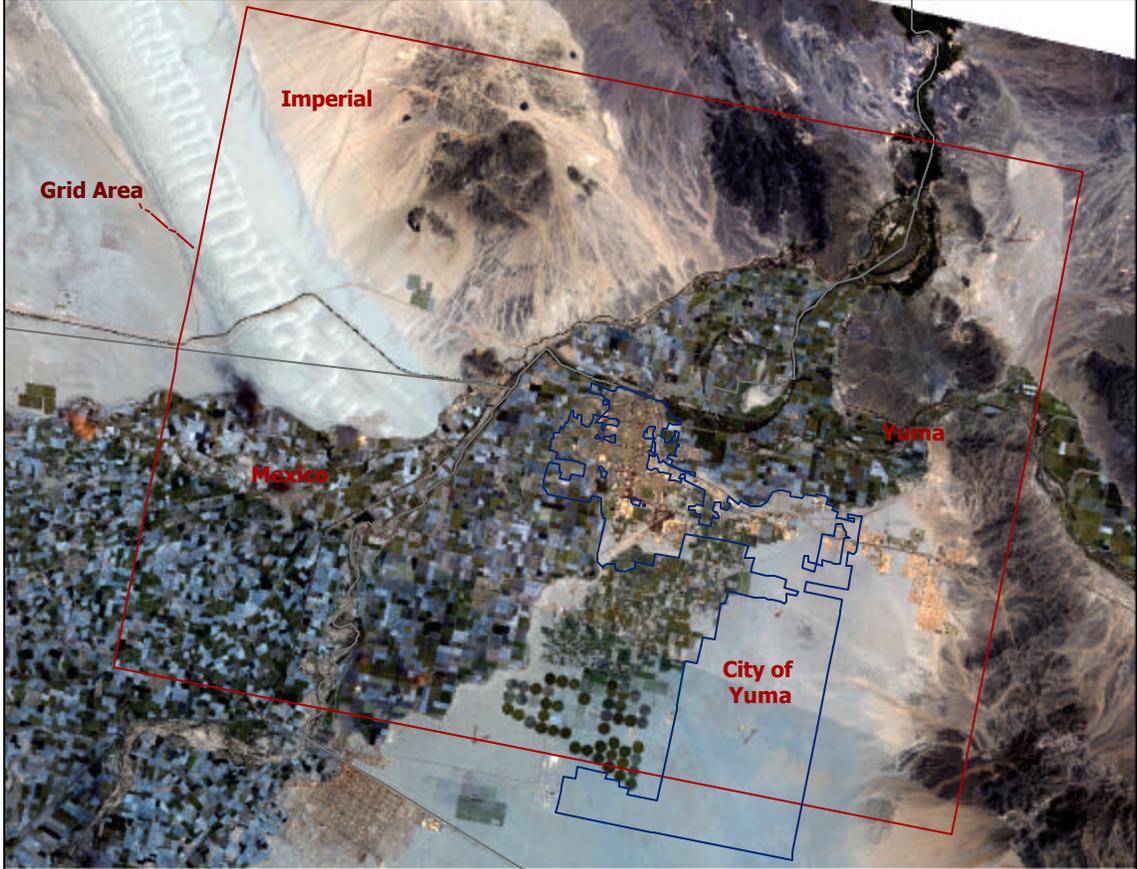
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SAIC, 2002. *An Examination of the Application of Remote Sensing Data in Detecting and Characterizing Air Pollution Transport and Emissions*, Science Applications International Corporation, prepared for the U.S. EPA, April 2002.

**Figure 1.** The Yuma Arizona, PM<sub>10</sub> Study Area.



**Figure 2.** 15-Meter LANDSAT Imagery of the Yuma Study Area.



**Figure 3.** High (1-meter), Medium (4-meter), and Low (1-meter) Resolution Satellite Imagery for Use in Land Use Classification.

**Land Use Classification Using Satellite Images - Disturbed Areas**

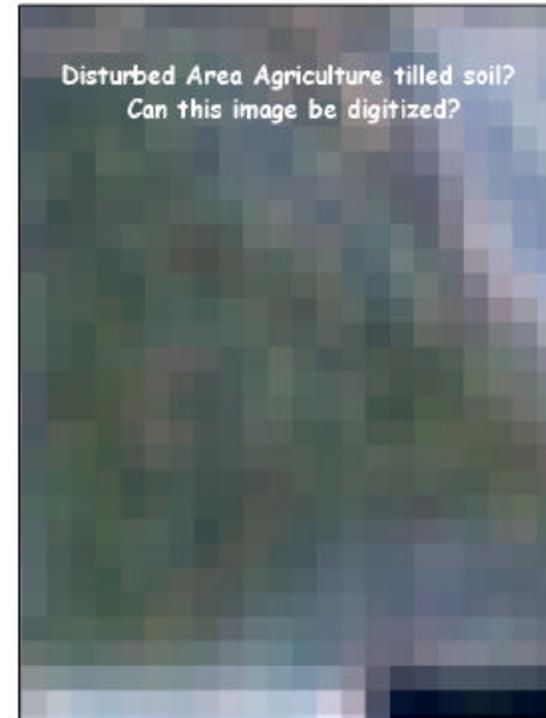
**Scale 1: 2,500**



**1 - Meter IKONOS Pansharpen image**



**4 - Meter IKONOS Multispectral image**

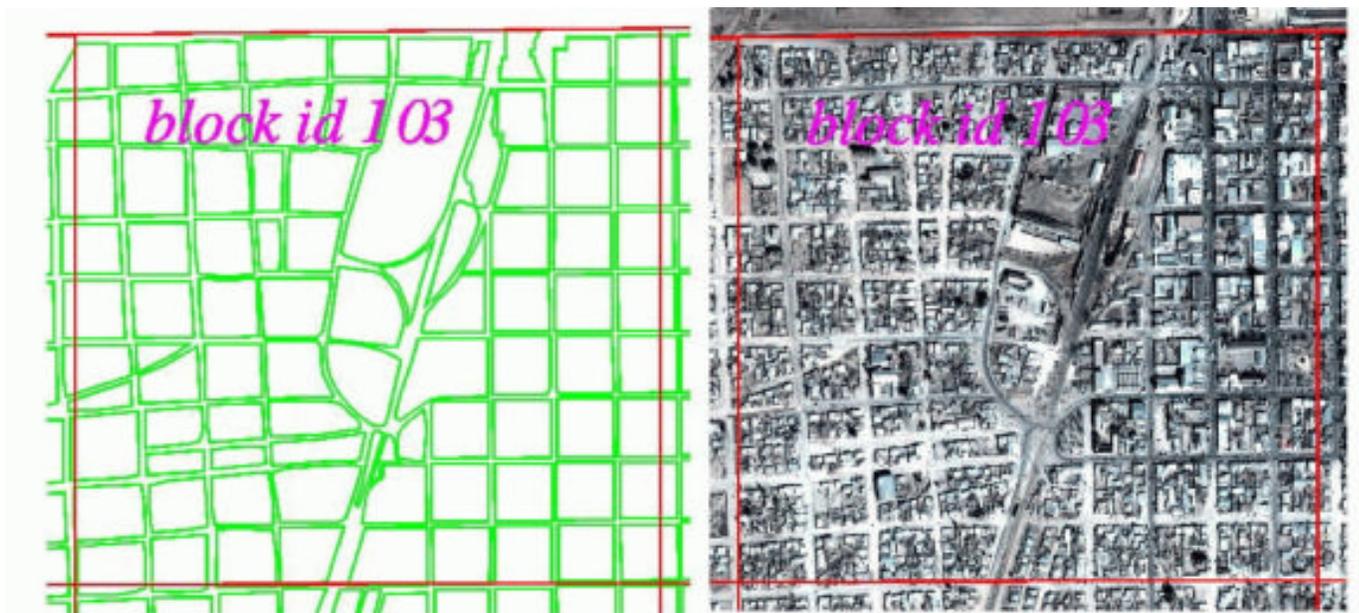


**15 - Meter Landsat +7 Pansharpen image**

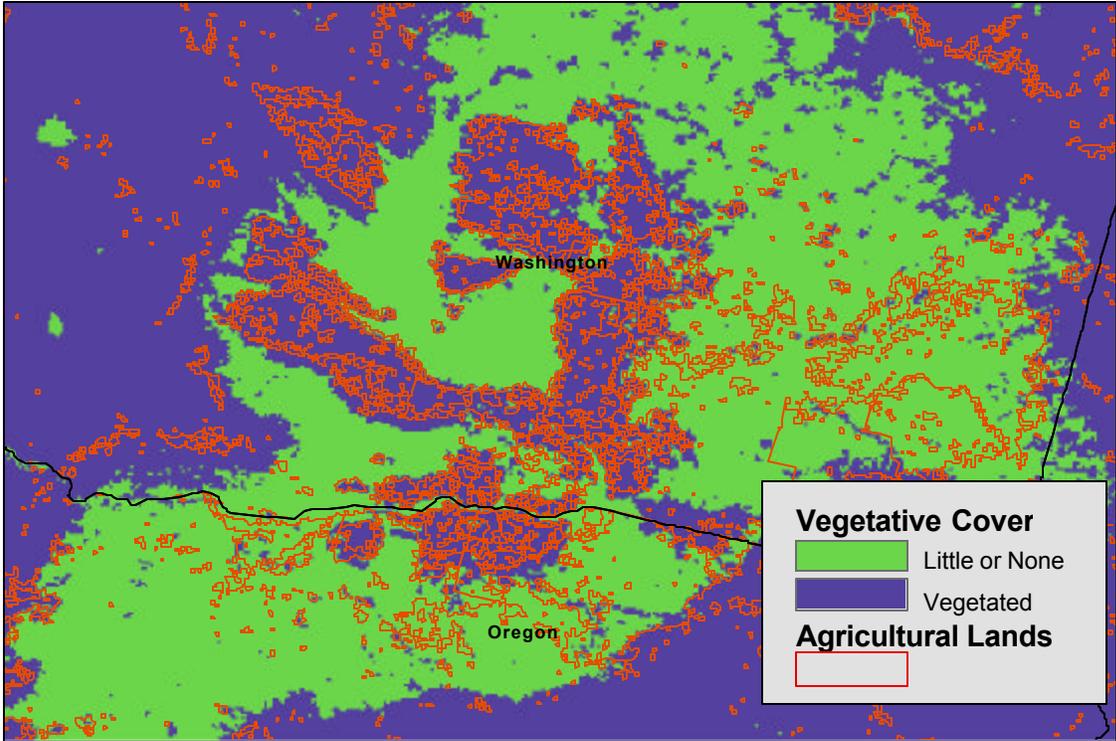
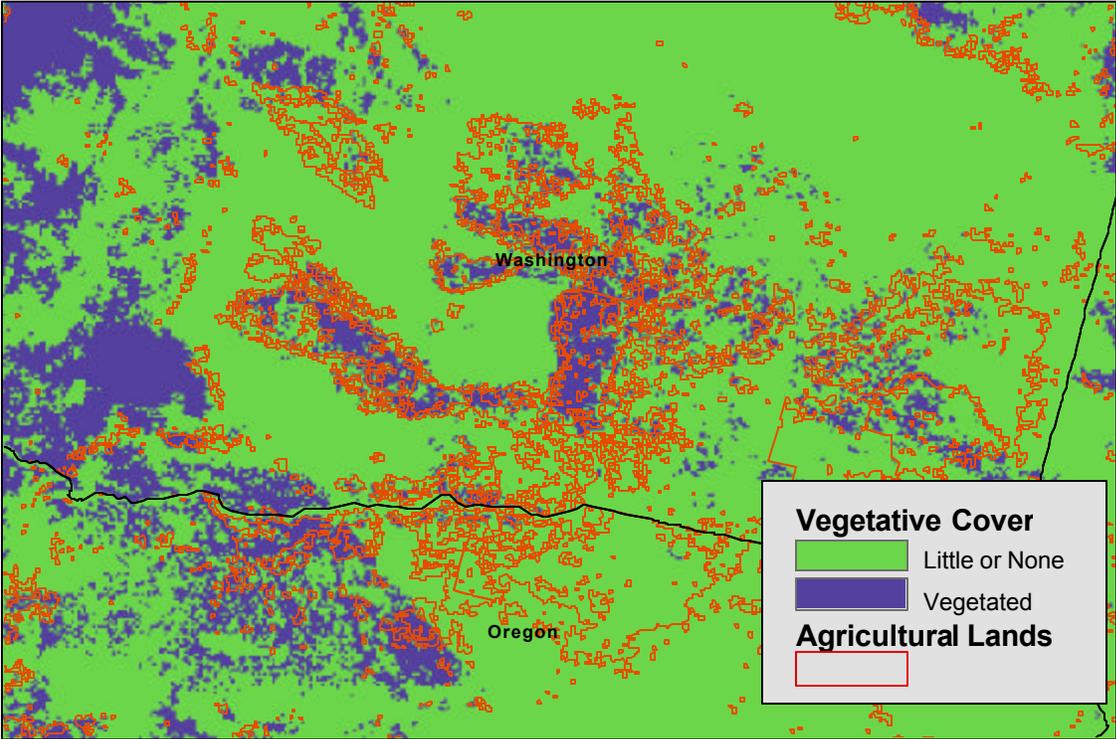
**Figure 4.** Index Grid Overlaid on Ikonos 1-Meter Satellite Image of Agua Prieta, Sonora, Mexico.



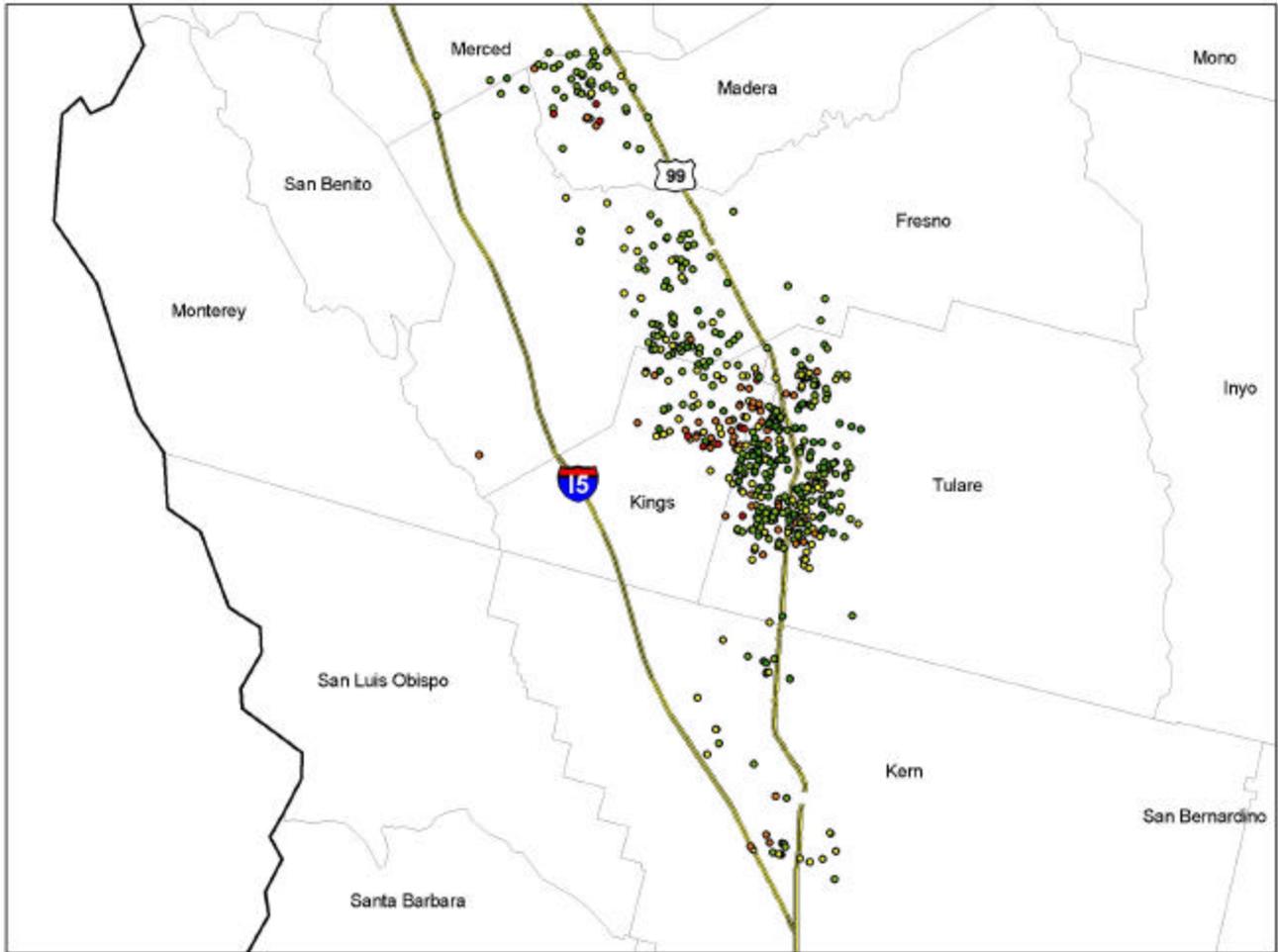
**Figure 5.** Digitized Urban Area (left) and Pan Sharpened Satellite Image.



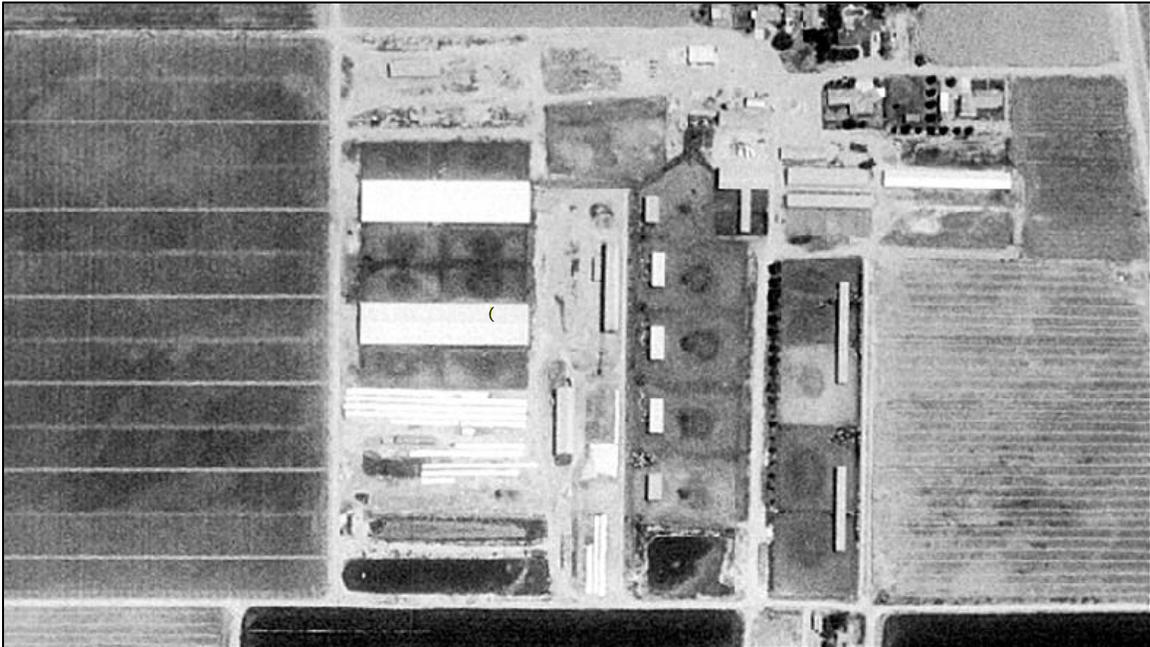
**Figure 6.** Seasonal Distribution of Vacant or Sparsely-Vegetated Crop Land in Southeastern Washington Using July 1996 NDVI (top figure) and December 1996 NDVI (bottom figure).



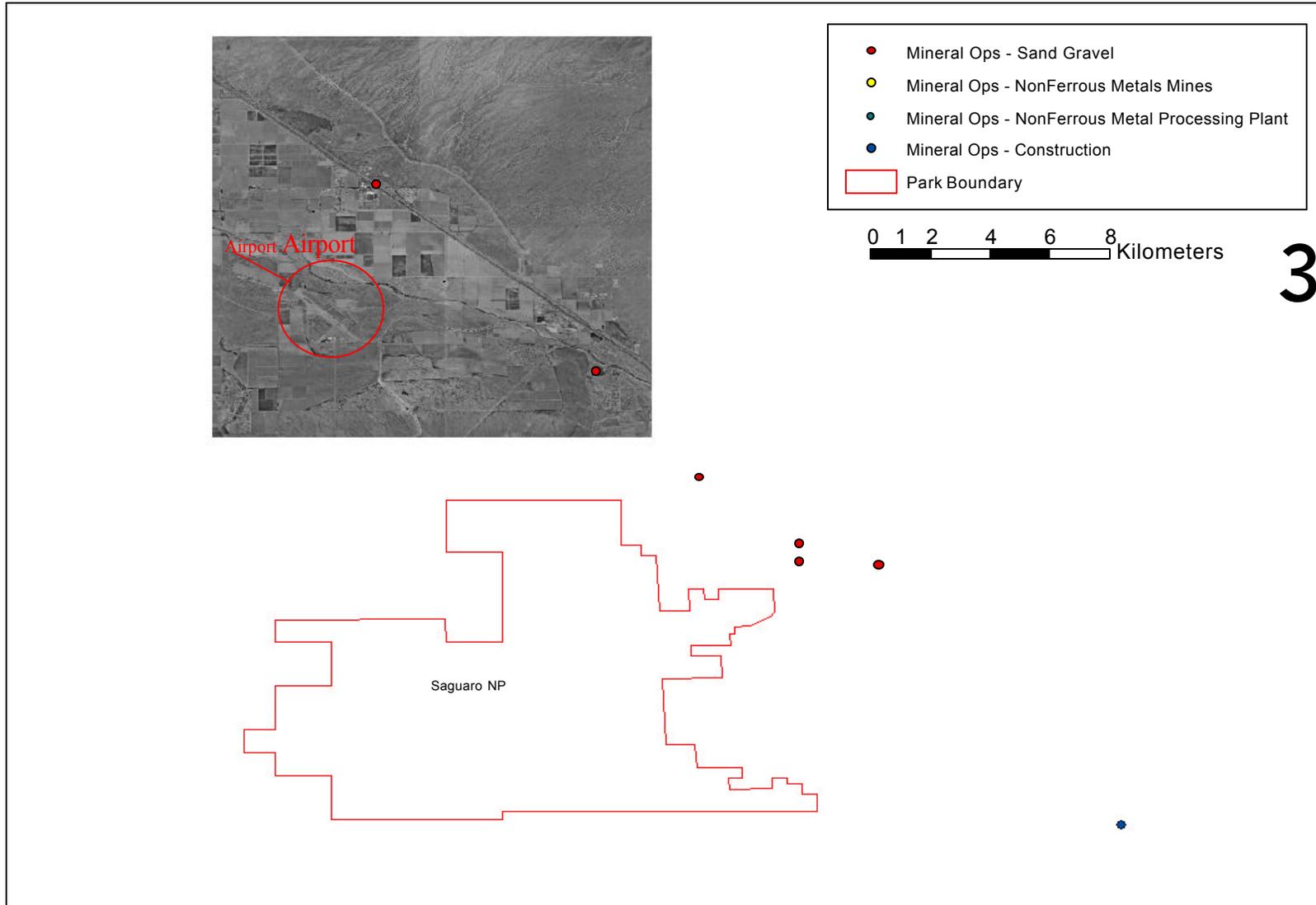
**Figure 7.** Geo-Coded Locations of Dairies in the San Joaquin Valley of California (Mansell and Roe, 2002).



**Figure 8.** Quality Assurance of Geo-Coded Point Source Locations Using Aerial Photography.



**Figure 9.** Disturbed Natural Areas In and Around Saguaro NP, AZ.



**Figure 10.** Sand and Gravel Operation North of Saguaro NP, AZ.



**Table 1.** Spatial and Temporal Resolution of Imagery from Several Satellite Systems.

<b>Satellite</b>	<b>Spatial Resolution</b>	<b>Temporal Resolution</b>
Ikonos	4 meter / 1 meter	3 days
Landsat Thematic Mapper	30 meter	16 days
Landsat Extended Thematic Mapper	30 meter / 15 meter	16 days
AVHRR	1 kilometer	1 day
MODIS	250 meters	2 days
SPOT		

## **KEYWORDS**

Remote Sensing

Geographic Information Systems

Emission Inventories

Windblown Dust

PM

Area Sources