# DETECTING WASTE TIRE PILES USING HIGH-RESOLUTION SATELLITE IMAGERY AND AN IMAGE PROCESSING MODEL IN TWO REGIONS OF CALIFORNIA

**Becky Quinlan,** San Francisco State University
**Catherine Huybrects,** San Francisco State University
**Cindy Schmidt**, NASA Ames Research Center
**J.W. Skiles**, NASA Ames Research Center
DEVELOP NASA Ames Research Center
M.S. 242-4
Moffett Field, California 94035
yogini97@sfsu.edu
chuybrechts@arc.nasa.gov
cschmidt@mail.arc.nasa.gov
joseph.w.skiles@nasa.gov

## ABSTRACT

Student interns in the human capital development program DEVELOP at NASA Ames Research Center worked with the California Integrated Waste Management Board's (CIWMB) Special Waste Division to create a proof-of-concept project investigating the use of high-resolution satellite imagery for locating and mapping waste tire disposal sites in the Sonoma and San Bernardino Counties of California. Previous methods for locating waste tire disposal sites in California included contracting with the California Highway Patrol to fly over suspected sites and take photographs, which were georeferenced with a GPS in post processing. The outputs generated from the model described in this paper reduce time and capital necessary to manage illegal waste tire disposal sites, which pose fire and disease vector risks if left unmanaged. The model and accompanying manual visual interpretation techniques identified all waste tire sites undisclosed to the team for testing purposes, and identified waste tire sites not previously known to CIWMB.

## INTRODUCTION

DEVELOP, a student-run, student-led internship program, executes pilot and demonstration projects using NASA technology, imagery and data to benefit local, county, state, federal and tribal governments. The projects aid governments by supporting their decision mechanisms enabling better use of natural resources. Within the Earth Science Division at NASA Ames Research Center (ARC), DEVELOP interns address environmental, community and policy issues. The California Integrated Waste Management Board's Special Waste Division funded a pilot research project to study the usefulness of satellite imagery to detect and map waste tire piles. The California Integrated Waste Management Board (CIWMB) has a mandate reduce material waste in the state and promote responsible refuse management practices, which includes Special Waste Division's statewide management of waste tires (CIWMB, 2001). The methodology created to detect waste tire piles in two climatic regions in California used IKONOS satellite imagery, computer image processing techniques and manual interpretation techniques. It was constructed with considerations for end-user applicability and functionality, cost effectiveness and accuracy in detecting waste tire piles.

### Background

In 2001, California was the nationwide leader in registered vehicles. California drivers disposed of more than 33 million tires in 2001, which were reused, recycled, disposed of legally into landfills, or illegally stockpiled. Approximately eight million waste tires are illegally stockpiled annually (CIWMB, 2003). These stockpiles pose a fire threat and subsequent environmental and human health risks. Standing water in tires provides a breeding ground for mosquitoes, which may carry diseases like West Nile Virus, encephalitis and dengue fever (Beavers, 1996; CIWMB, 2004b; IEPA, 2004).

State regulated legal waste tire piles are required to keep firefighting equipment and water on the premises, limit tire pile size and provide fire lanes for safety (CIWMB, 2005). Illegal waste tire sites often do not comply with these regulations. Additionally, once an illegal site becomes established, it may attract others to perpetuate the dumping (CIWMB, 2004b). In the past, the State of California has monitored legal tire stockpiles by commissioning California Highway Patrol to aerially photograph sites using a 35 mm camera, then georeference the photos in-house (CIWMB, 2004a). CIWMB also provides grants to local law enforcement to identify waste tire piles, investigate anonymous complaints, and assist with enforcement of regulations (CIWMB, 2004c).

## Literature Search Results

A survey of the literature found that there is little published research on detecting and/or mapping waste tire piles using imagery and computer assisted interpretation in the United States. In his 1996 dissertation, Beavers identified tire piles in Kentucky, Indiana and Ohio using low-altitude 0.5-meter resolution aerial videography. Data acquisition included measuring the spectral signatures using a spectroradiometer of a variety of tire brands and types. He found no significant difference in signatures between tires in different piles, of different brands, or at different heights of instrument. Beavers found some spectral variability between clean tires and those covered in soil; soil becomes the dominant spectral signature for soil-covered tires. Distinguishing spectral differences between tires, water and other dark objects proved to be difficult in the study. Beavers digitized the acquired video and processed the imagery using a band index and maximum likelihood classifier. Results for identifying small tire piles had an 83% error of omission rate due to a low occurrence of "pure" tire pixels, and high occurrence of mixed pixels.

U.S. EPA (2002) visually analyzed over 1,000 predominantly color-infrared, medium altitude aerial images from the U. S. Geological Survey (USGS) and the Mexico Instituto Nacional de Estadistica Geografia e Informatica (INEGI) archived collections. The imagery covered approximately 518 miles (824 kilometers) of terrain along the U.S./Mexico border. Using manual classification techniques, researchers identified approximately 32 sites primarily located along transportation corridors and urban areas. Tire piles were identified based on their signature identifiers, including dark-tones, coarse-textured surfaces, shape, pattern, and height distinctions in relation to the surrounding terrain; often the analyses were conducted using stereopairs. Analysts grouped the tire piles into three classes: certain, probable, and possible identifications. The result of this work was to identify the tire piles for inspectors rather than to manage the tires in the field; there were no time or cost estimates, nor was there an accuracy assessment with this work.

Identifying waste tire piles in imagery is uniquely challenging because of the feature's low reflectance. Tires may be spectrally confused with shadows and deeper water because each reflects little light to passive satellite sensors. Although no research has been reported in the literature on automatic computer mapping of tires, shadows, and water using satellite imagery, research on separating spectrally similar features is available. Some researchers found the spectral similarity of water and shadow caused classification errors, and many studies attempted to isolate water or shadow in imagery.

Beavers (1996) was able to avoid the appearance of dark shadows in his imagery by recording aerial video at low altitudes on cloudy days. Few researchers addressed isolating shadows in rural imagery, but Dare (2005) provided a thorough review of shadow detection techniques, including thresholding, classification, region growing segmentation, and three-dimensional modeling. Aside from visual interpretation and classification to isolate water or shadow, thresholding is the most commonly applied technique (Dare, 2005; Asner and Warner 2003). Dare (2005) recognized difficulty in determining appropriate thresholds for individual and between images. Asner and Warner (2003) used manual techniques to exclude water from their images before applying a threshold to isolate shadowed pixels. Dare (2005) outlined two techniques for shadow detection: region-growing segmentation and three dimensional modeling, in which a stereo image-derived digital surface model, together with knowledge of image geometry and solar illumination, may be used to isolate shadowed pixels.

Another method for separating spectrally similar classes is the use of indices and band ratios. A number of ratios and indices may be used to distinguish between dark land cover classes in remotely sensed imagery. Indices such as Normalized Differential Vegetation Index (NDVI), Atmospherically Resistant Vegetation Index (ARVI) (Kaufman and Tanre, 1992), and linearized vegetation index (Unsalan and Boyer, 2005) have been used to map land cover beneath shadows (Leblon et al, 1996), detect areas of human activity (Unsalan and Boyer, 2005), and identify burned areas (Garcia and Chuvieco, 2004). Other indices used to identify dark land cover in imagery include the Burned Area Index (BAI) and the Global Environmental Monitoring Index (GEMI) (Garcia and Chuvieco, 2004). Indices may also be useful for differentiating between land and water in images (Unsalan and Boyer, 2005). In some cases, indices have been used in conjunction with spectral signature data and to refine unsupervised

classification methods (Garcia and Chuvieco, 2004; Unsalan and Boyer, 2005). Water features can be removed from imagery using vector polygon layers (Guienko and Doytsher, 2003).

## Study Area

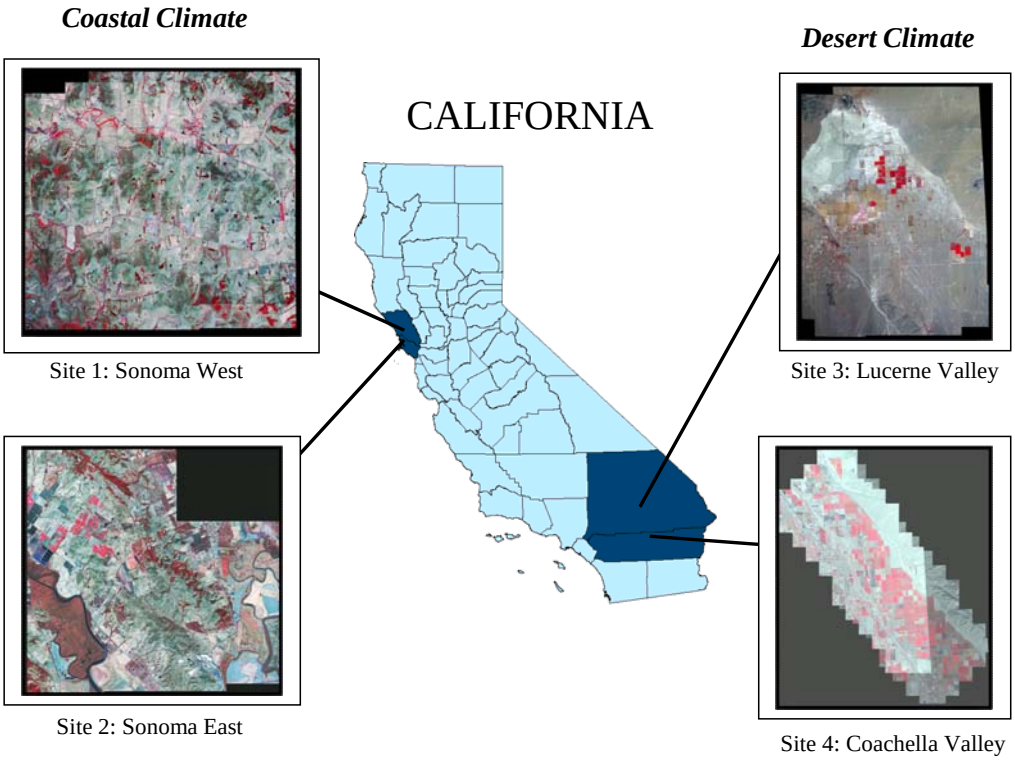


**Figure 1.** Waste tire pile detection study area sites in California. IKONOS images, 2005, Space Imaging.

**Table 1. Waste tire piles disclosed by CIWMB**

| Study Area | Site Description | Tire pile | Area ($m^2$) |
|---|---|---|---|
| Site 1 | Family farm. Tires in gullies. Some tires obscured by trees. | 1 | 473 |
| | | 2 | 206 |
| | | 3 | 61 |
| Site 2 | Family farm. Tires in one long gully. Some tires obscured by trees. Standing water in tires. | 1 | 1,120 |
| | | 2 | 1,165 |
| | | 3 | 275 |
| | Family farm. Tires in gullies. Grasses and some blackberry bushes among tires. Metal and wood waste along edge of tire piles. | 1 | 1,254 |
| | | 2 | 498 |
| Site 3 | Desert scrub and some trees present. Largest pile stacked against fence. Smallest obscured by trees. | 1 | 52 |
| | | 2 | 4 |
| | | 3 | 4 |
| | | 4 | <4 |
| Site 4 | Tire recycling facility. Six large tire piles separated by firebreaks. Some tires covered in soil. Some neatly stacked, others piled akimbo. | 1-6 | 4,224 |
| All measurement estimates taken from imagery. Smallest pile for Site 3 too small to measure using imagery. | | | |

Study areas, chosen by CIWMB, included four sites in two climatic/geographic regions of California, a Mediterranean climate of Northern California and a Southern California desert climate (Figure 1). CIWMB revealed waste tire piles in each of the study areas for the purpose of calibrating the model developed for this project (Table 1). Each study area site encompassed over 100 $km^2$.

Fieldwork was needed to observe, understand, and chronicle typical characteristics of tire sites. In all study areas, tires were stored illegally on private property for a fee. In order to take data from the field into the lab a synced GPS/PDA programmed with EcoNab, a database tool developed for biological fieldwork by the National Resource Ecology Lab at Colorado State University, was used. Data were uploaded into a GIS software package and used as a reference data layer to identify waste tire pile locations.

### Imagery

IKONOS imagery from Space Imaging was chosen for this project because of its relatively low cost and 4-meter spatial resolution in the multi-spectral bands. It was necessary to choose the 11-bit radiometric resolution option and request that the Dynamic Range Adjustment (DRA) be deselected; DRA truncates the spectral distribution of the data and forces a Gaussian distribution (Kaninski, 2005). High radiometric resolution imagery was critical, since tires, water and shadows are spectrally similar, have low reflectance values, and are found at the far low end of spectral data in each of the available multi-spectral bands. In order to maintain the radiometric integrity of the images, the only pre-processing step performed was georeferencing by Space Imaging.

### Pre-Processing

Each study area site was covered by multiple images. All images were georeferenced to freely available USGS Digital Raster Graphics (DRG's) to aid illustration of final results to stakeholders and associates in the field. Mosaicing of the georeferenced imagery was not performed because it impeded results due to radiometric distortion and the significantly larger files slowed model execution. Therefore, each image, once georeferenced, was processed through the Tire Identification from Reflectance (TIRe) model separately; redundancy from image overlap was valuable for manual visual interpretation. Once all images of a study area site were processed, images were mosaiced together for final map production.

## METHODS

Leica Geosystems' ERDAS Imagine Model Builder was used to create an automated model to isolate tires in imagery from both climate regions. The sole geospatial data input to the TIRe model was the georeferenced image. Analysis began by determining where tires lie spectrally within the imagery. Thresholding, a common image processing technique for separating features, was not useful because the digital number (DN) values of tires varied between images. Histogram equalization between imagery to minimize spectral variation would alter DN values preventing the TIRe model's ability to accurately separate features.

To isolate tires from other features in the imagery a variety of band indices were tested. A land/water index, found on the Leica Geosystems website was modified for use with IKONOS imagery: (100*((G/NIR) + 0.0001). The index consistently isolated tires by eliminating all significant vegetation and some dark water features. In order to further separate tires from features in the imagery, Hue was derived from the Blue, Green, and Red bands using ERDAS Imagine's HUE function. Hue successfully eliminated non-tire pixels from the original image, including some water and dark soils. The two functions were combined and used to subset the original image, eliminating between 83% and 99% of each image.

Thresholding of indices and bands used after the initial subset were found to be effective on all images, but the thresholds were not found to be image independent. Different thresholds were used for different images. In order to extend the usefulness of methods to all images, the standard deviations (sd) of individual bands or indices were used. Standard deviation has been used to indicate change in scenes over time (Lu et al, 2004). Standard deviation of NIR and R bands, NIR/(B+G+R), B+G+R, and $(NIR/R)^{-2}$ (Table 2) were effective at isolating pixels containing tires regardless of input imagery. In each case, the band or index results were divided into bins of 0.5 standard deviations from the mean, up to 5.5 standard deviations on each side of the mean.

**Table 2. Indices used to separate tires from other features**

| Index or band | Lower threshold (sd) | Upper threshold (sd) |
|---|---|---|
| NIR | -3.0 | 0.0 |
| NIR/(B+G+R) | -3.5 | 1.5 |
| R | -2.5 | 1.0 |
| B+G+R | None | 0.5 |
| $(NIR/R)^{-2}$ | -0.5 | 3.0 |

The model removed all features in the imagery except for tires and some other dark objects, like the dark agricultural lands found in Site 4. With an educated assumption that unknown tire piles should be smaller than 800 pixels (3,200 $m^2$), or smaller than 1 million tires, the ERDAS Imagine functions Clump, using a 3x3 pixel window, and Sieve, eliminating groups of pixels smaller than 800, were applied to the imagery. This produced a binary image of groups of pixels greater than or equal to 800. A similar Clump/Sieve combination was performed to eliminate groups of pixels smaller than 2. The two resulting masks were combined to create two outputs.

The first output, a binary mask, was used in the next phase of analysis, visual interpretation. Once the imagery was processed through the TIRe model, less than 1% of the original image remained, consisting only of dark pixels containing tires or spectrally similar features. In some images, some separability between features remained, a 20-class ISODATA classification of the second output, an original image subset, was used to aid the visual analysis step.

The binary mask output of the TIRe model was overlain on top of the original image for visual interpretation (Figure 2). The use of accepted visual interpretation methods like association and shape required some knowledge of the area and of typical tire piles to accept or reject the results of the TIRe model. As the automated spectrally based analysis proved more reliable than visual analysis in identifying tires, when doubt remained, the analyst should accept the results of the TIRe model and allow an on-site inspector to verify the presence of tires.

A final map was produced for CIWMB inspectors using ArcGIS. The mosaiced image of each site was overlain with roads from USGS DRG's, a UTM grid and a shapefile of potential tire sites. Areal estimates and UTM coordinates were also provided to aid field inspection.

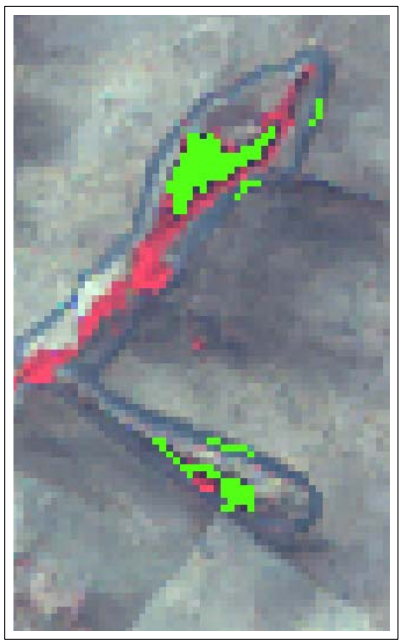

**Figure 1.** Binary image resulting from TIRe model overlain on top of original CIR image. Bright green pixels indicate tires. IKONOS Image, 2005, Space Imaging.

## RESULTS

In all four study area sites, the TIRe model and subsequent visual analysis identified the 13 target waste tire sites which were unknown to NASA for the duration of the project. Using the methodology developed for this project NASA was able to identify at least two new sites in Sonoma West (Site 1) and Coachella Valley (Site 4). CIWMB inspectors continue to visit sites in each study area and there is a possibility that new tires sites will be revealed. Previous studies using image analysis were able to find tire piles larger than one acre (4,047 $m^2$) (U.S. EPA, 2002), whereas the TIRe model located waste tire piles as small as 12 $m^2$.

The TIRe model produced false positives at each study site. False-positives were commonly attributed to shadows, water, debris piles and features with tire material content such as black tarps, polyethylene tubing and parking lots. Continued communication with field inspectors will dramatically reduce the number of false positives.

In order to test the accuracy of the model outputs, CIWMB withheld information on all of the waste tire sites in each study area, except the calibration sites. In all cases, the TIRe model identified the withheld sites (Table 3). For

Site 4, Coachella Valley, the two withheld sites, though correctly identified by the TIRe model, were rejected during the visual analysis phase.

**Table 3. Statistics complied on waste tire piles found using project methodology**

| **Study Area** | Site 1: Sonoma East | Site 2: Sonoma West | Site 3: Lucerne Valley | Site 4: Coachella Valley |
|---|---|---|---|---|
| Target sites for study (unknown to NASA) | 3 | 3 | 4 | 3 |
| Target sites identified by NASA in study | 3 | 3 | 4 | 3 |
| Number of new sites located by NASA using TIRe model, to date | 0 | 1 | 0 | 1 |

## DISCUSSION

Visual interpretation requires geographic knowledge of the area and of typical waste tire disposal practices and patterns. Future visual analysis should assume a correct result from the TIRe model unless a high level of confidence can be achieved to classify the site as non-tire.

Challenges in TIRe model development included processing imagery collected during winter and summer months. In winter, lower sun angles produce long shadows, which decrease the ability of the model and analyst to effectively identify tires in hilly regions. The TIRe model will perform better with imagery obtained under relatively consistent summertime insolation conditions. This recommendation for consistency in image seasonality when combined with radiometric requirements stated in the Imagery section of this paper will produce the most accurate results from the TIRe model.

Large bodies of water skew the radiometric balance of an image and may impede the TIRe model's results. Standard deviations of bands and indices in the model were used to separate dark features from one another; therefore, by reducing the coverage of large water bodies in imagery, remaining dark features became more easily separable. If an image is greater than 25% water, large areas of water should be masked out in preprocessing using a digitizing method.

Waste tire sites disclosed to the team varied in size from <4 to 4,224 $m^2$. For future projects, the authors recommend imagery with finer spatial and spectral resolution to find smaller sites.

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