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Abstract.--Aerial color-infrared (CIR) photography was used to detect and catalog unauthorized solid waste disposal sites around Donna Reservoir in the Lower Rio Grande Valley (LRGV) of southern Texas. Qualitative visual evaluation of the positive transparencies showed 25 possible disposal sites randomly scattered throughout the study area, located in sites ranging from bare soil to grass and mixed brush/woods. These sites were transposed onto a computer-generated area map for ground survey confirmation and use by organizations planning to clean-up the sites. Ground-truthing was used to identify waste contents at each site and to estimate waste volumes and areas covered. Unauthorized solid waste sites were verified in 23 of the 25 locations. Two sites contained only broken concrete and asphalt being utilized as erosional fill material. The ground survey identified ten solid waste sites missed on the aerial photos. These sites were missed due to their small size (< 2 [m.sup.2]) and because they were covered by lodging guinea grass (Panicum maximum) or giant reed (Arundo donax). The addition of these missed sites to the other 25 locations hindered the overall accuracy of the aerial photographic survey (71.4%).

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In 1991, the U.S. Environmental Protection Agency (USEPA), concerned about a high rate of infants born with neural tube defects in the Lower Rio Grande Valley (LRGV) of southern Texas, conducted a contaminant exposure study of nine families residing in Cameron and Hidalgo counties (USEPA 1994). During this study, a carp (Cyprinus carpio) fillet removed from a Brownsville freezer contained an estimated 399 mg/kg of polychlorinated biphenyls (PCBs). PCBs are environmentally persistent, toxic, aromatic compounds and are probable human carcinogens (USEPA 1994a). This fish had been caught in the 11.2 km long Donna main canal, which delivers water from the Rio Grande to Donna Reservoir, a 162 ha drinking and irrigation water storage reservoir located in southeastern Hidalgo County. Fish tissue samples collected in Donna Reservoir, the Donna main canal and the adjacent Arroyo Colorado by the Texas Natural Resource Conservation Commission (TNRCC) and the Texas Department of Health (TDH) documented tissue PCB concentrations between 0.55 and 24 mg/kg in 23 of 50 fish collected. No PCBs were detected in any fish collected in the nearby Rio Grande (Webster et al. 1998). No. PCBs were detected in the analysis of over 50 sediment samples collected from these same waters. One sediment collected in Hidalgo Drainage Ditch #2, located approximately 0.5 km west of Donna Reservoir, contained approximately 0.097 [micro]g/kg PCBs, dry weight. Sequential analysis of sediment from this same location was not possible, because the ditch was dredged shortly after initial sample collection.

Webster et al. (1999) suggested that unauthorized solid waste disposal sites near these waterbodies might be sources of the PCB contamination. These dump sites contained both municipal and construction waste that were distributed over variable terrain in a broad area, suggesting that additional sites could be hidden in dense grass and brush/woods.

Unauthorized dumping of municipal and construction solid waste is common in the LRGV, where poverty levels are high and citizens seek easy and inexpensive ways of disposing trash and garbage. Discarded electrical appliances are often found in these dumps (Webster et al. 1999).

A rapid method to detect and inventory unauthorized solid waste disposal sites that could potentially be contributing to PCB contamination in Donna Reservoir was needed. Approximately 30% of the reservoir shoreline and adjacent agricultural areas were difficult to access, due to thick brush, rough terrain or restricted access to private land. The efficacy of aerial photography in natural resource inventory and assessment had been widely demonstrated (Heller & Ulliman 1983; Everitt & Villarreal 1987; Judd et al. 1993; Repic et al. 1995; 1996; Lonard et al. 1997; Webster et al. 1999).

In 1997, the remote sensing laboratory of the U.S. Department of Agriculture, Agricultural Research Service, Integrated Farming and Natural Resources Research Unit (USDA-ARS, IFNRRU) in Weslaco, Texas took CIR photographs of the reservoir from an altitude of 3,000 m. Qualitative evaluation of these images resulted in the discovery of a large, unauthorized solid waste disposal site near the northwest corner of the reservoir. In addition, low altitude digital, conventional color, oblique and vertical photographs (0.2 m pixel resolution) of this and other suspect sites identified in the high altitude images were obtained and used to qualitatively inventory the wastes present.

In October 1999, the IFNRRU remote sensing laboratory acquired additional, high and low altitude CIR photography of the reservoir. The objectives of this aerial photography were: (1) to provide more data to accurately locate, map and inventory unauthorized solid waste disposal sites in weed and brush infested areas, and (2) to support a TNRCC project intended to provide accurate site information to local organizations planning to clean up these sites.

STUDY AREA AND METHODS

The study area is made up of clay and clay loam soils of the Harlingen and Raymondville series (Jacobs 1981). It is heavily vegetated with a diversity of woody plants, cacti, grass and wetland species. Dominant woody species include honey mesquite (Prosopis glandulosa), hackberry (Celtis laevigata), dryland willow (Baccharis neglecta), huisache (Acacia minuata), retama (Parkinsonia aculeata) and lotebush (Ziziphus obtusifolia). Prickly pear cactus (Opuntia engelmannii) is the dominant cactus species. Major grasses include guinea grass (Panicum maximum), Bermuda grass (Cynodon dactylon) and giant reed (Arundo donax). Guinea grass is the dominant species throughout the study area and in some places comprises nearly 100% of the ground cover. Cattail (Typha domingensis) and giant reed are common around the lake perimeter.

Aerial photography.--High altitude photographs of Donna Reservoir and the surrounding terrain were taken from an altitude of 3,167 m on 17 October 1999, between 1200 and 1300 hours, Central Standard Time, using a Fairchild KA-2 camera, mounted vertically on the floor of a fixed wing Cessna 206 aircraft provided by the USDA-ARS/IFNRRU. Additional, low altitude photographs were acquired at an altitude of 500 m. Photographs were acquired under mostly sunny conditions. The camera used 23 cm by 23 cm Kodak CIR type 2443 film. High altitude photos were taken at a scale of 1:9,500, with an aperture setting of f9.6 at 1/100 s. Two photos were required to cover the entire reservoir. The same camera and settings were used to acquire low altitude photos of selected, densely vegetated areas. These images had a scale of 1:1,500, providing a ground resolution of less than 5 cm.

Analysis of aerial photographs.--Positive photographic transparencies were visually scanned on a Richards light table utilizing a variable power, binocular zooming, magnifying scope. Suspect sites were marked on prints developed from selected transparencies, then transposed onto a Hidalgo County road map using natural and manmade features on both prints and the map as reference points.

Ground-truthing.--A four wheel drive vehicle was used on 23 March 2000 to ground-truth the sites marked on the map, and to survey the surrounding areas. Public access to the dumping areas had been restricted by locked gates. All unauthorized disposal sites observed, whether or not they were identified from the aerial photographs, were inventoried. Waste types, area covered ([m.sup.2]), and volume of waste ([m.sup.3]) were estimated at each site. Global Positioning System (GPS) coordinates were collected using a Trimble GeoExplorer GPS with real-time correction utilizing U.S. Coast Guard beacons via Star Link MRS-2A. In addition, vegetation types were recorded for each site.

Generation of site map.--Solid waste disposal sites were numbered and inventoried. The GPS coordinates of each site were entered into a computer, utilizing MapInfo Professional software, version 5.01. A map of Donna Reservoir and the surrounding vicinity was made, using MapInfo StreetWorks, version 3.0. (Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the United States Department of Agriculture). The GPS coordinates of each site were used to plot the location on the map. Different geometric figures were used to designate sites based on the method of discovery and accuracy of the original identification (Figure 1). Circles represented solid waste sites accurately identified on the aerial photos. Squares represented sites that were not detected on aerial photographs, but were discovered during the ground survey. Triangles represented dump sites for waste concrete, asphalt and construction lumber.

[FIGURE 1 OMITTED]

RESULTS AND DISCUSSION

Small, unauthorized solid waste sites ([less than or equal to] 2 [m.sup.2]) were not obvious in the high altitude photographs because ground resolution was not adequate to accurately identify sites lying beneath lodging guinea grass. The thick grass broke up the site outlines, effectively camouflaging the wastes. However, the high altitude photos provided an excellent mosaic image of the study area, allowing investigators to select the easiest access routes into various properties and terrains surrounding the reservoir. County road maps did not show several farm tracks and small, dirt roads running through the area. These access routes were located on the high altitude images, then drawn on the computer-generated map using the Mapinfo software (Figure 1).

Scrutiny of the low altitude positive photographic transparencies resulted in identification of 25 potential unauthorized solid waste sites, ranging in area from 0.5-40 [m.sup.2], and 10 probable broken concrete/ asphalt erosional fill sites. Improved ground access attributed to visual observation of the high altitude photographs resulted in the discovery of 10 additional small, solid waste disposal sites ([less than or equal to] 2 [m.sup.2]) overgrown with vegetation. The addition of these additional sites hindered the overall accuracy (71.4%) of the aerial survey. Lodging guinea grass covered eight of the ten sites. The remaining two sites were masked by stands of giant reed grass and sandbar willow. In all, eight species of native grasses, trees and shrubs helped mask these sites from aerial observation at the lowest altitude (500 m) and ground resolution (5 cm) utilized in this study. The survey was conducted during October, when grass, brush and foliage cover was dense. Vegetative cover should be less dense during winter or early spring months, and would likely result in improved remote sensing accuracy.

CONCLUSIONS

High altitude CIR photography (3,167 m) can be used to rapidly detect medium to large scale (> 4 [m.sup.2]) unauthorized dump sites in rough terrain in rural areas infested with thick native grasses, dense weeds and brush. Dense, late summer or fall vegetation in rural areas appear to present some problems in the identification of small sites (<4 [m.sup.2]), which are commonly camouflaged by overlying or matting vegetation. High altitude CIR is also useful in depicting ground access routes in difficult areas, where road and county maps provide inadequate information. Low altitude (500 m) photography is much better suited to detect waste disposal sites as small as 0.5 [m.sup.2] located in tall grass or brushy overgrowth. However, distinguishing waste through dense vegetation, even at this low altitude, is not always possible. In this study, 23 of 25 waste sites were correctly identified (92.0%) from the photography; however, the addition of 10 hidden sites, missed in the photographs, hindered overall accuracy (71.4%). Overall results demonstrate the potential use of airborne photography for this purpose. Additional aerial surveys should be conducted during winter and early spring months to test the efficacy of aerial remote sensing during months when vegetative cover is less dense.

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