Low-Cost Aerial Surveys for Coastal Studies

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***Abstract* – This paper presents three case studies where aerial surveys utilizing a small craft and digital camera proved useful in addressing coastal problems. The three case studies addressed in this paper are: 1) monitoring of thermal discharge behavior from the cooling system of the San Onofre Nuclear Generating Station; 2) responses of San Diego beaches to sand nourishment; and 3) mapping of sedimentation from Goat Canyon deposited within the southern Tijuana Estuary. These three cases address three different questions, showing the wide applicability and value of this low-cost technique.**

I. INTRODUCTION

Coastal studies are often performed under rough environmental conditions. These studies are likely to be performed in remote, difficult to access, and sometimes, environmentally sensitive areas. In addition, they must be performed over time periods that allow for the capture and comparison of natural events, such as high waves and tides, strong winds, floods, etc. Because the equipment used for coastal studies is usually expensive and there are frequently cost constraints, there is a need to develop low-cost techniques.

Time and space coverage components are especially important when attempting to design practical, effective coastal studies. One strategy that can assist in solving some of these problems involves low-cost remote sensing. Three case studies are presented here in which aerial surveys utilizing an Ultra-Light small aircraft and digital camera were used to address study questions.

Case 1: Monitoring of thermal discharge behavior from the cooling system diffusers of the San Onofre Nuclear Generating Station. Engineers and regulators are concerned with the dispersion of cooling water discharge into natural waters and the way this dispersion varies with nearshore currents under different oceanographic conditions. Because of the natural variability of coastal currents and the interaction between discharge and water column temperature, it is not always easy to predict where and how quickly the discharged water will travel in three dimensions. Aerial photographs, along with current and temperature measurements near the diffusers, enabled us to understand this complicated interaction.

Case 2: Retention of sand on beaches. The response of beaches to sand nourishment is of interest to scientists, coastal engineers, planners, and local governments. In 2001, two million cubic yards of sand were placed on 12 beaches in San Diego County. During a two-year period, aerial surveys were conducted over the San Diego County coast capturing both “before” and “after” conditions. The length of time the deposited sand remained on the beaches was estimated from these surveys. This length of time is important for planning additional sediment replenishment projects at reasonable time intervals.

Case 3: Mapping of sedimentation from Goat Canyon deposited after heavy rainfall in the Tijuana Estuary. Over the last several decades, the hydrologic, hydraulic, and sediment characteristics of the southern Tijuana Estuary have been altered by human activity. Sediment from Goat Canyon has resulted in large losses of wetland areas and undermined the long-term functionality of the southern Tijuana Estuary. Aerial surveys offered a simple and easy way to estimate the area covered by Goat Canyon sand.

In this paper, we demonstrate the value of such a simple technique, especially when conducted in conjunction with other measurements, to aid in solving coastal problems. The aerial survey effort may vary from just taking photographs (Sections III and IV) to using a digital camera and simple image processing techniques (Section V).

II. AERIAL SURVEY METHOD

A. Aircraft Platform

Based on preliminary work by NASA [1], we used an FAA-certified GT500 Ultra-Light as an inexpensive, low-altitude, remote sensing platform. The aircraft has a useful load capacity of 195 kg, a stall speed of 38 mph, a range of 300 miles, and a service ceiling of more than 18,000 feet. An added safety feature includes a ballistic parachute designed to recover the crew and aircraft in the event of an emergency. Operated in accordance with FAA visual flight rules, the aircraft provides exceptional stability in turbulent and windy weather (i.e., at winds of 25 mph and above). During this study, the aircraft was used to acquire high-resolution digital video at an altitude of 1000 ft to 2500 ft above mean sea level (MSL).

B. Remote Sensing System

We fabricated a counterweight balance camera mount and attached it to the airframe near the center of gravity with an unobstructed view of the ground below the aircraft. The video camera was mounted at nadir (looking down) and leveled to flat ground before each flight. During operation, the counterweight mount helped to dampen aircraft vibration and to compensate for pitch motion during flight, resulting in high-quality imagery output. All flights were made at low tide during clear weather between the hours of 10 AM and 2 PM solar time.

A Sony Model DCR-TRV900 progressive-scan, 3-CCD camcorder served as the data acquisition system. The standard optics of the video camera provides a 1-mb digital picture output in a 720 by 480 pixel format. The individual pixel resolution ranged from 8 inches to 23 inches depending on the flight altitude (1000 and 2500 ft, respectively). Spatial resolution as small as 1 inch was accomplished during "ground-truthing" by using the camera's 24:1 telephoto lens at an altitude of 1000 ft (MSL). The electronic shutter speed was set to 1/500 sec with automatic exposure to gain control and make image stabilization operable. Each image frame was time-tagged in seconds and cross-referenced to the Universal Time Code of a Garmin Model III Plus Global Positioning System (GPS), which recorded every second and was constantly updated. This allowed the imagery to be geo-referenced to the GPS flight track record for post-flight data indexing. In addition, the camera's broadband color (blue, green, red) separation provided a high-resolution approximation of landscape spectral reflectance patterns in the visible wave lengths (400nm to 700nm). The system recorded about 11,500 images on a one-hour tape.

C. Measurement Procedure

Digital video imagery from repeat flights over coastal beaches and wetlands was imported via an IEEE fire wire connection for computer processing. Individual RGB images were selected with 60 percent forward overlap. The computer-captured images were mosaiced together to form one or more image strips of each flight line. The mosaic strips were then ortho-rectified using PCI Geo-Works software. At least 40 ground control points (GCPs) scattered across an image scene were used to compute the Root Mean Standard Error (RMSE) values. GCPs with high RMSE values were replaced with points having low RMSE values. All GCPs were collected using 1994 USGS 1-m resolution ortho-rectified imagery. A cubic convolution resampling algorithm was used to determine UTM pixel values based on a 1-m grid and a NAD 27 mapping projection. The resulting ortho-rectified image mosaics were saved in Geo TIF format and archived on CDs. In the case of wetlands, ortho-rectified image mosaics were combined to form a seamless ortho-image map.

D. Ground-Truthing

Field verification of image map features (i.e., ground-truthing) was deemed too expensive and time-consuming for the Case 2 and Case 3 studies. As an alternative, very high-resolution digital video imagery was acquired using the camera's 24:1 telephoto lens. Flying at an altitude of 1000 ft (MSL) produced individual pixel resolutions of 1-inch. Flight samples of the study area were stratified by general cover and condition to ensure adequate and representative video coverage. The total number of required "ground-truth" images varied with the heterogeneity of the landscape, but generally ranged from 50 to 150 geo-reference images per area flown.

III. CASE STUDY 1: THERMAL PLUME MONITORING

The San Onofre Nuclear Generating Station (SONGS) is located on the coast south of San Clemente, California, and is about equidistant between Los Angeles and San Diego. SONGS has two 1100 MW units that use once-through cooling systems. These cooling systems each utilize a series of 63 jet ports spaced along 800 m of conduit submerged below the ocean floor in 10 to 16 m of water. The diffuser ports emerge about 1.5 m off the seafloor, and the jets are directed 20º upward and 25º alternating to either side of seaward direction. They discharge about 100 m^3/sec of heated water into ambient waters. Unit 2's diffuser is located just offshore of and in deeper water than that of Unit 3. The resultant flows in the vicinity of SONGS are complex and have been discussed in detail [2,3,4]. The objective of this section is to demonstrate the value of aerial photos in assisting with the understanding of flow patterns around SONGS. The reader is referred to previously published work for a complete discussion.

During the period between 1 April 1986 and 31 December 1986, weekly aerial photographs were taken of the study area offshore of SONGS. The purpose of these photographs was to synoptically document the turbidity plume, which is known to occur due to the discharge of cooling water from the Unit 2 and 3 diffusers and the Unit 1 outfall.

By allowing us to directly view the surface shape, location, and extent of the plume, photographs can provide some insight into how the SONGS discharge interacts with other nearshore parameters to produce a "turbidity plume." It must be noted that the aerial photographs can only reveal a surface manifestation of the SONGS discharge when such manifestation has some unique characteristic, such as increased turbidity or change in water color. Therefore, in the following discussions, the term "plume" refers only to those surface features that can be observed in the photos.

From the aerial photo collection, we have chosen two photographs to be displayed (Figs. 1 and 2). These photos, in conjunction with measurements made in-situ, demonstrate how the discharge plume may interact with other parameters such as current speed, water column temperature, kelp beds, and the operational status of SONGS. We have included with each photo set a graphical summary of the physical measurements taken at the time of the aerial survey.

A photograph taken on 29 August 1986 (Fig. 1) shows plume interactions with ambient current and water temperature. There are many features that can be seen in this photograph, including:

1. The presence of individual turbidity boils along Unit 3 and partially along Unit 2.
2. The plume is advected upcoast and appears larger upcoast from Unit 3 than from Unit 2.
3. There is a sharp boundary where the upcoast extent of the plume appears to end.
4. Turbidity in the water near the intake is low.

Because the temperature stratification on this day was about 7º C from surface to bottom, the entrained water mass must be considerably denser than the surface waters. The momentum of the jets carries the discharge and entrained water mass to the surface, where it is advected upcoast. (The longshore currents measured at this time were about 14 cm/second upcoast.) The sharp boundary where the plume disappears (sinks) occurs when the buoyancy effects of the heavier-than-surface water mass overcome the upward momentum and turbulence given to the plume by the jets. Thus, the plume with its turbidity signature sinks out of sight.

The portion of the plume farther offshore is seen to sink closer to the discharge structure than the portion that is closer to shore. This occurs for two reasons. First of all, the discharge farther from the shore lies in deeper water, and as the jets push towards the surface, their momentum is lost. In fact, it may be seen that the discharge from the outer portion of Unit 2 never reaches the surface. Second, at greater depths, the entrained water mass is colder, and therefore the density differences between ambient and plume water are smaller, and the plume sinks more quickly.

A different example of the way the discharge water interacts with the local nearshore environment can be seen in Fig. 2, taken on 16 December 1986. This set of photos is similar to others taken in late November and the entire month of December, and as such, we believe it to be representative of plume-ambient interaction during the winter of 1986.

In Fig. 2, the nearshore turbidity is high, resulting from wave interaction with the beach. The fine sediments are moved seaward by rip currents into coastal currents and the circulation pattern around the SONGS intake/diffuser system. From current meter studies, it has been observed that the SONGS cooling water system perturbates the south-flowing currents, causing the flow to meander onshore north of the diffusers and offshore south of the diffusers. In Fig. 2, it appears that this offshore flow is transporting the nearshore turbid waters to a position farther offshore.

Engineers and regulators are concerned with the dilution and mixing patterns of discharges into natural waters and the way dilution varies with current speed and density stratification in the receiving waters. Ocean discharge systems are usually designed and built on the basis of numerical models and/or scaled physical (tank) models. These models predict or estimate dilution statistics at various ranges by factoring in: 1) the characteristics of the discharged water and receiving water; 2) the configuration and velocity of the discharge; 3) the water depth; and 4) the statistics for ambient current and vertical stratification of receiving water [5]. In many outfall modeling exercises, it may be impossible to properly estimate and scale all the important parameters of the models to allow for accurate dilution calculations. Understanding the interactions between discharges and environmental conditions, such as current and water temperature, can result in improved numerical dilution models.

IV. CASE STUDY 2: BEACH SAND DISPERSION TRACKING

San Diego beaches are important to the economies of local communities. The San Diego coast naturally has narrow beaches, which have been further reduced by human activities that impede the natural movement of sand. In 2001, the San Diego Association of Governments implemented a program where approximately 2 million cubic yards of beach quality sand were placed on beaches throughout the county. During this program, 12 receiver sites were chosen to receive sand from 6 offshore borrow sites along the coast. Sand was dredged from the borrow sites and transported to the beach by pipe, and heavy equipment then distributed the sand on the beach [6].

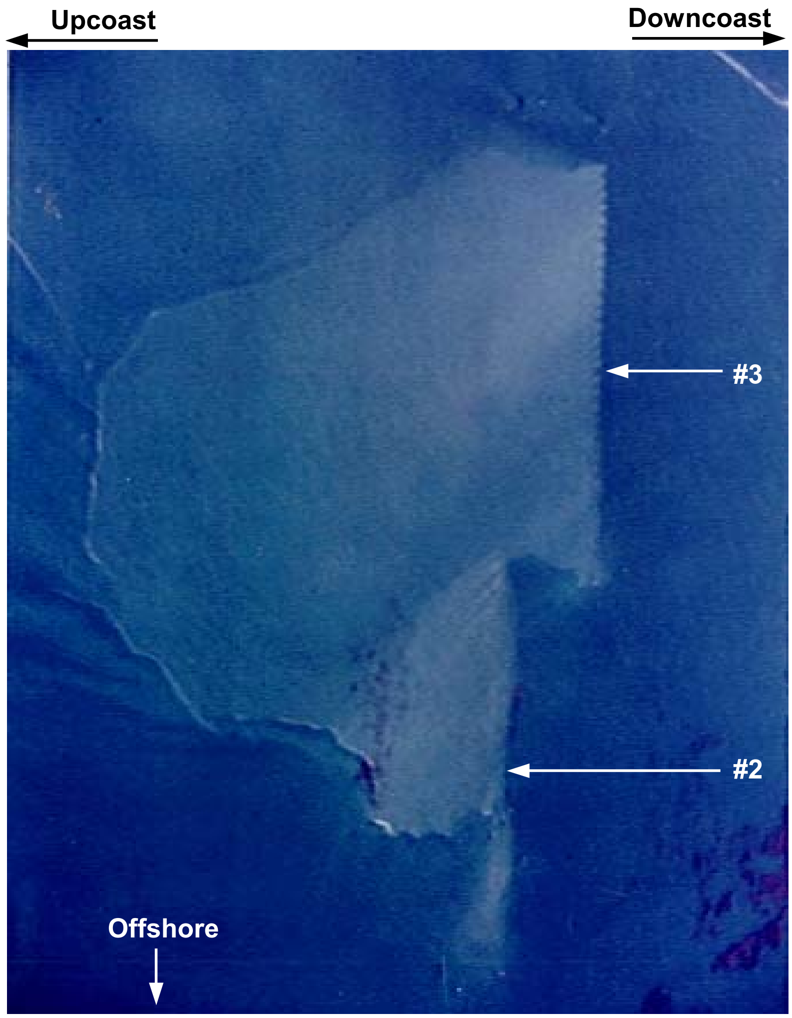

Fig. 1. Aerial photograph taken on 29 August 1986 showing upcoast plume with sharp boundaries from the diffusers of Units 2 and 3.

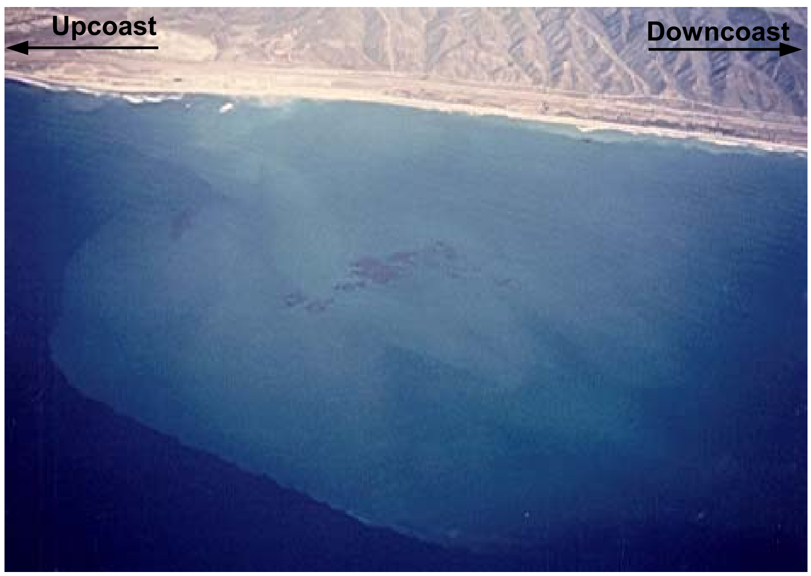

Fig. 2. Aerial photographs taken on 16 December 1986 showing downcoast plume with nearshore turbidity extending offshore.

In order to determine the necessary frequency of such replenishment, monitoring of beach sand elevations would be needed. Typically, monitoring of beach profile elevations is accomplished by measuring them with topographic survey instruments. Monitoring the beach through this process is accurate but time-consuming and costly.

Beach surveys are necessary to address scientific questions, such as where sand goes and how it impacts nearby marine resources and lagoons, in situations where surveys at one or two locations might be sufficient to answer these questions. Questions of beach management, such as how long sand is retained and which events will impact sand losses, may be addressed using aerial photographs. Although this method can provide only a rough estimate of beach width, it can also provide data over a large area at more frequent intervals and at a more reasonable cost.

Fig. 3 shows three photographs taken at Torrey Pines Beach, one of the nourishment beaches. The photographs were ortho-rectified and are on the same scale. The left photo was taken on 14 April 2001 and shows the beach before sand was placed. The center photo was taken on 26 June 2001 after 260,000 yd^3 of sand were placed on the beach. This addition increased beach width by approximately 100 ft. The right photo was taken on 28 March 2003, 23 months after sand placement. A time series of such photographs could be used to determine how long the sand stayed on the beach.

V. CASE 3: SEDIMENTATION IN TIJUANA ESTUARY

The Tijuana River Estuary (Fig. 4) is a wetland-dominated coastal plain estuary and flooded river valley. It is divided into two main areas, the north and south marshes, with the north marsh containing the majority of tidal salt marsh within the estuary [7,8]. The Tijuana Estuary is intertidal in nature and consists of salt marsh, sand flats, mudflats, tidal channels, and ponds. The approximate acreage of wetland habitat is 1,780 acres, with 350 acres consisting of tidally induced salt marsh.

A 20-acre (8 ha) wetland restoration project, the Model Marsh, was completed and opened to tidal flushing in February 2000 [9]. It was constructed through excavation of flood plain materials. The objective of the project was to determine the best way to restore ongoing wetland projects and grow salt marshes. Sediment inputs within the Tijuana Estuary occur from several source areas, including tidally induced flow, sediment from the Tijuana River, and sediment from canyons surrounding the estuary.

Over the last several decades, the hydrologic, hydraulic, and sediment characteristics of both the Goat Canyon watershed and the Goat Canyon creek channel have been altered by human activity. Sewer discharges from Mexico have altered the creek’s natural flow regime. Flood control structures, channelization in Mexico, and extensive land use changes have increased peak flows. The changes that have greatly increased sediment yield from the Goat Canyon watershed include: 1) farming and grazing; 2) filling and vegetation removal; 3) concentrated residential development in Mexico; and 4) the construction of routes and roads by the U.S. Border Patrol [9]. These changes have impacted the steep canyons and sandy soils found within the canyon, thereby increasing debris and sediment discharge during rainfall events [11]. The increase in sediment discharge is now threatening sensitive wetland vegetation at the mouth of Goat Canyon and undermining the long-term functioning of the Model Marsh. These sediments are being deposited within the Model Marsh and South Slough and on the flat estuary saltpans in the southern portion of the marsh.

Between 1977 and 2003, evidence revealed that increased sedimentation from Goat Canyon was occurring within the estuary. The evidence included: 1) the development of rills and incised tributaries throughout the watershed; 2) the aggradation of the Goat Canyon creek channel; and 3) the development of several sediment deltas that spawned growth of the alluvial fan at the canyon mouth. Fed by numerous avulsion channels carrying primarily sands and silts, portions of the alluvial fan have grown vertically by upwards of 3 feet. More importantly, the growth of the fan has contributed to the loss of intertidal wetland areas in the Tijuana River Estuary since 1852 [12,13].

In order to map the sediment coverage from the Goat Canyon into the southern Tijuana Estuary, an aerial survey was conducted on 2 December 2002 to produce a detailed image of the southern estuary using an Ultra-Light aircraft and digital video camera. The survey was flown at an altitude of 1000 ft (305 m). The images obtained from this aerial survey have a resolution of approximately 0.85 ft (25 cm). The ground-truthing technique, as explained in Section II of this paper, was utilized to ensure accurate mapping of the sediment from Goat Canyon into the south Tijuana Estuary (Fig. 5). Material discharged from Goat Canyon during flood events consists of light-colored sediments of the Linda Vista Formation. These sediments are easily distinguished from the surrounding flood plain sediments in the southern portion of the estuary, enabling us to easily determine distribution throughout

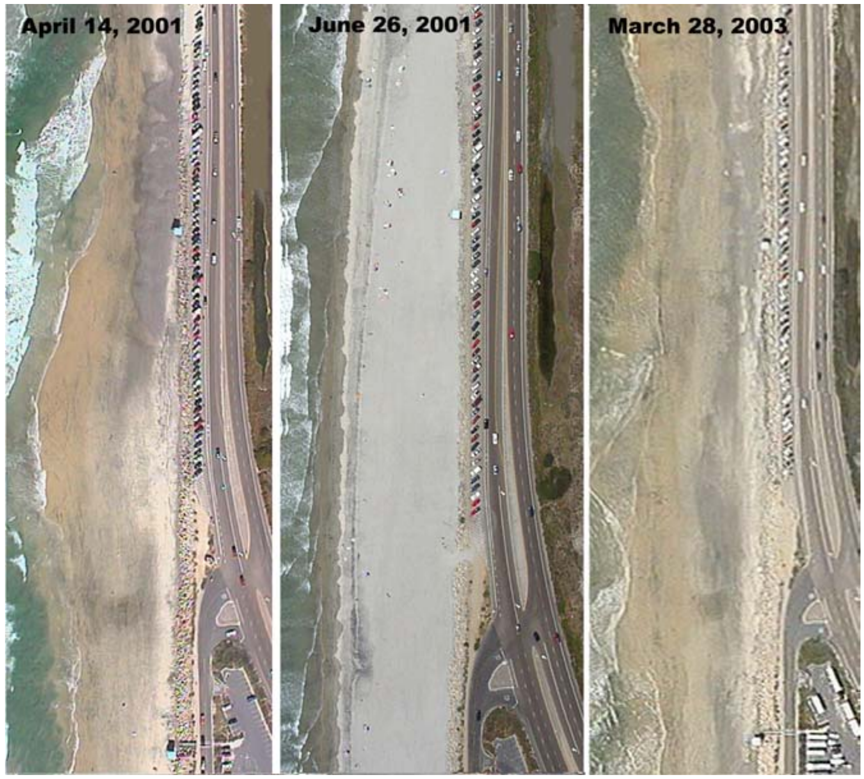

Fig. 3. Photograph showing Torrey Pines Beach before and after 260,000 yd3 sand placement on the beach in late April 2001.

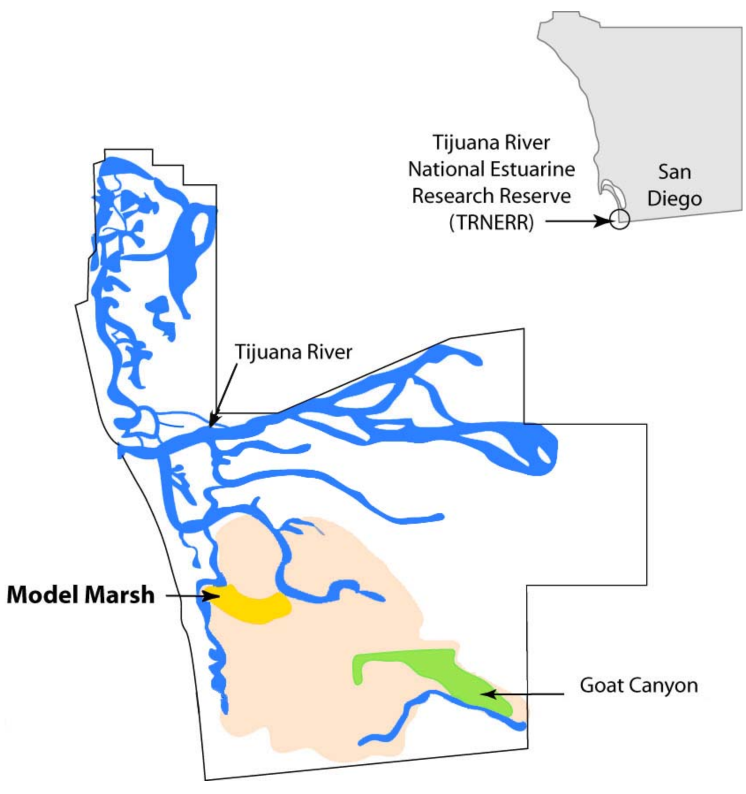

Fig. 4. Location map of Tijuana Estuary showing the Model Marsh (Courtesy of Southwest Wetlands Interpretive Association).

GPS Referenced, Large Scale Image Ground-Truthing

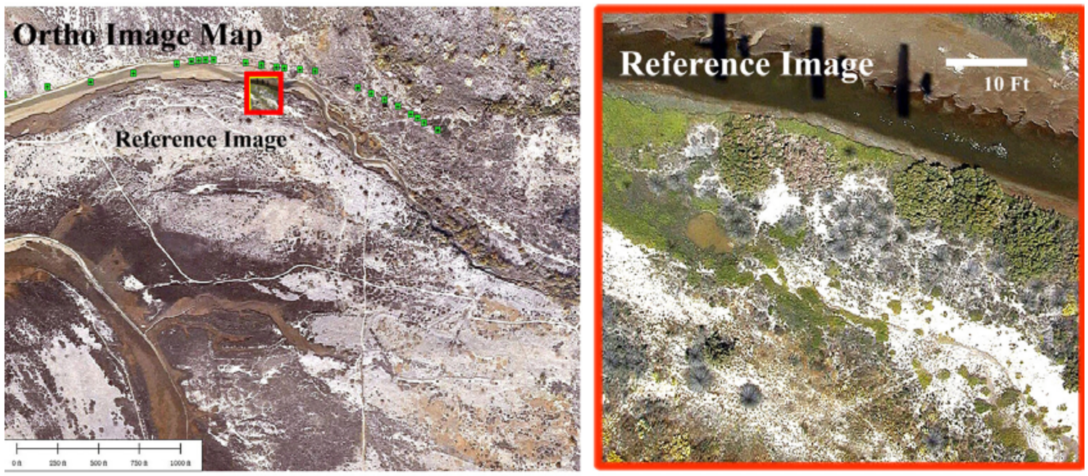

Fig. 5. Ground-truthing. The square on the left photo is enlarged in the right photo to identify habitat and features.

the study area using aerial photo interpretation. Fig. 6 shows the ortho-rectified aerial photograph taken on 2 December 2002 of the southern Tijuana Estuary. Sediments from previous flood events have been deposited throughout the Tijuana Estuary along the entire extent of Monument Road, making their way to the junction of Monument Road and the southernmost part of the South Slough.

The area image mapping discussed above cannot be used to determine the sedimentation rates from Goat Canyon to the southern estuary. It can, however, give an excellent idea of where survey transects and sediment pipes could be located to quantify the annual volume of sand that is delivered to the estuary [14].

VI. CONCLUSIONS

This paper presents three cases demonstrating the value of low-cost aerial surveys for coastal studies, especially for those projects that require large-scale spatial coverage. While the technique in some cases can only provide qualitative information, this information can be useful in assessing and addressing project issues. The value of the technique increases when combined with conventional methods. In addition, there are many cases where access is limited because the coast is surrounded by high cliffs or private property. This technique is suitable for such cases. Aerial surveys and the ground-truthing technique presented here provide a cost-effective way to delineate wetlands and watersheds and to monitor plumes, pollutant dispersion, and beach width changes. There are many other examples besides those presented here that demonstrate the usefulness of such low-cost aerial survey techniques [15,16].

ACKNOWLEDGEMENTS

The authors would like to thank Southern California Edison (SCE) and the Southwest Wetlands Interpretive Association (SWIA) for supporting this study. Our thanks also go to Mr. Chris Nordby, who recommended us to SWIA to conduct sediment mapping for the Tijuana Estuary and provided us with valuable information during this study. Our thanks also go to Robert Grove, David Hansen, William Boyd, Martha White, and Margie Garrett for their help in reviewing and editing the paper and providing valuable input. We thank Ms. Socorro Ruiz for preparing the manuscript.

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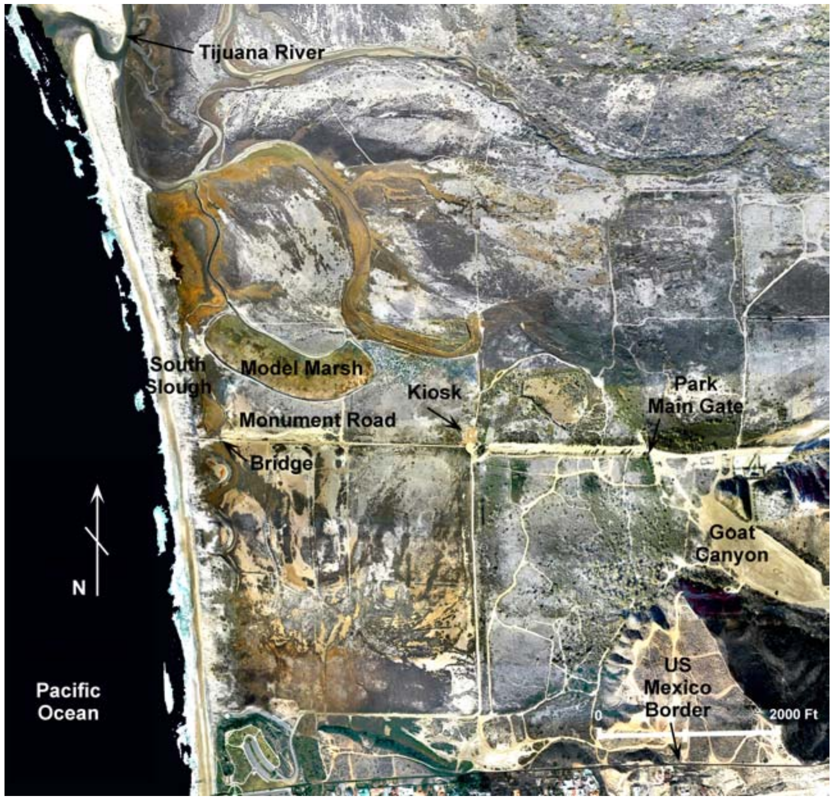

Fig. 6. Aerial photograph of the southern Tijuana Estuary and Model Marsh, dated 2 December 2002, showing the dispersion of sand from Goat Canyon into the southern estuary.

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