SANTA PAULA CREEK SEEP SSEP: Sources

Final Report, Volume 1

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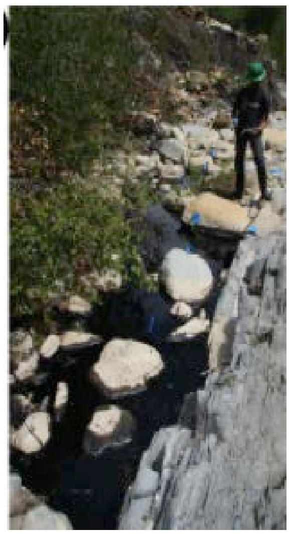 

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Executive Summary and Overview

The January 2005 Ventura Oiled Bird Incident (VOBI) was an extremely devastating oiled bird incident with at least 1500 dead or injured birds (CDFW, 2014). The VOBI affected 24 species of birds along nearly 250 miles of southern California coastline with ultimate response costs of over $1 million. Most heavily impacted were *western grebes*, which commonly raft just off the shoreline during their winter migration. Estimated loss was 5% of the west coast western grebe population and possibly as much as 25 percent of California's breeding population (a total of 1329 injured or dead western grebes were collected during the VOBI and an estimated 3000 individuals could have been affected during this event). Oiled bird locations were mapped and showed a spatial distribution, which extended primarily southward from the vicinity of Ventura with a significant concentration near the mouth of the Santa Clara River (SCR), suggesting a terrestrial source from the SCR watershed. Almost 59% of the affected birds (alive and dead combined) were collected within a 25-mile stretch of coastline from Ventura to Mugu Lagoon.

Unlike most of the spills to which OSPR responds, which are related to oil production, this incident was concluded to be the result of a catastrophic release of a large but unknown quantity of oil from natural terrestrial sources in Santa Paula Creek (SPC), a tributary to the SCR near Thomas Aquinas College, more than 22 miles from the Pacific Ocean. We propose that the cause of the VOBI was related to anthropogenic modifications and structures associated with Highway 150 Bridge 52-105.

Specifically, we propose that the VOBI was related to the major Pacific storms in the winter of 2004-05. On 7-11 Jan. 2005, nearly 23 inches of rainfall occurred in the Santa Paula Creek watershed, over 10 inches of which fell on 10 Jan. 2005, a 50-year rainfall event. This rainfall resulted in record flood flows of 27,500 cubic feet per second, which caused massive erosion and catastrophic bank failure in the SPC near Thomas Aquinas College, releasing tons of oil-saturated soil into the SPC. Evidence also reveals that flood flows washed through a large off-stream oil pool within the study area, possibly introducing a large quantity of oil into the creek. These flows also transported downstream natural oil accumulations in streambed catchment areas in the SPC. These oil-contaminated waters reached the Pacific Ocean on or about 10 Jan. 2005, where aggregations of nearshore birds were oiled causing the Jan. 2005 VOBI.

Although VOBI was one of California's largest recorded marine bird oiling events, there only was a single report of a surface oil slick near the SCR mouth on 13 Jan. 2005 (Henkel, 2005). The fact that an extensive slick was not reported on the sea surface on 12 Jan. 2005, when the first oiled birds were discovered at Ventura Harbor, is somewhat unexpected given the numbers of oiled birds. This study concludes that oil-mineral aggregation in the river allowed suspended and surface oil to be transported downriver, was a significant, but poorly understood, factor in the bird oiling (Leifer and Wilson, 2014b).

Photo surveys and instream measurements as part of a multiyear OSPR SSEP study spanning a decade of efforts, documented oil accumulation in several streambed catchment areas and riverbank erosion as well as activation and deactivation of active oil seepage sites in the riverbank and above. A study area encompassing the originally proposed oil source was established to investigate the mechanisms underlying the proposed large riverine oil release. Seepage activation appeared to relate to seasonal cycles that could be related to aquifer recharge. One of the catchment features, fed by the Cactus Slump Seep area and informally named Dead Duckling Oil Pool (DDOP), grew during the study to contain 1490 L of oil in a pool extending 10.2 m by 2 m wide by 0.2 m deep floating on top of water. This oil was released into the SPC during the 2008-09 winter storms when stream levels rose.

The DDOP oil pool was observed in the study area during two consecutive dry seasons. Observations in 2009 found the DDOP gradually filled in with sediment. However, observations in 2012 showed a new oil pool fed by the same seep located just downstream of the former DDOP location.

Although the oil released from this pool could have impacted downstream ecosystems; the extent of the effect of the oil flushed from the DDOP during the winter of 2008-2009 could not be determined as there were no follow-up studies on downstream biota and many samples from oiled birds have not been compared to those from the VOBI. It is feasible that some of the numerous marine oiled birds recovered in Ventura County each year could have riverine oil sources.

Based on our analysis, future VOBIs are possible, but can be mitigated if appropriately engineered structures are installed to reduce future oil accumulation and minimize the likelihood of bank failure in the Santa Paula Creek near Thomas Aquinas College. We conclude that the configuration and alignment of the Highway 150 bridge structure (52-105) on Santa Paula Creek near Thomas Aquinas College, just north of Santa Paula, contributed to and exacerbated the VOBI.

Furthermore, recent streambed changes by CalTrans just downstream of the Highway 150 bridge are functioning as oil catchment basins. During stormflows, these structures will be submerged, and it is unclear if they will reduce (or even amplify) erosion of the northeast bank including the segment that separates TAOP from the SPC.

Volume 1 of this two-volume final report presents:

1) The investigations, which led to discovery of the oil source;

2) The analytical studies conducted by the California Department of Fish and Wildlife–Petroleum Chemistry Laboratory (CDFW-PCL) to identify the oil source;

3) Efforts to quantify oil emissions and determine factors affecting their release seasonal and spatial, and introduction into the waterway.

Volume 2 (Leifer and Wilson, 2014a) of this two volume final report presents:

1) The spatial and temporal distribution and species of oiled birds affected;

2) The field and wildlife care operations required to rescue and rehabilitate oiled birds;

3) How real-time spatial-temporal mapping of bird capture and recovery can improve future oil spill response.

This report presents photos and data gathered in 2005, 2006, and the results of time-series quantitative and qualitative field studies conducted and observations made between Sept. 2007 and May 2010. Observations included studies of selected terrestrial natural oil seeps, oil pools, and topographic features within the ¼-mile study area within and near the bed, banks, and channel of SPC just downstream of its confluence with Sisar Creek, near Thomas Aquinas College in Ventura County, California.

Thirteen field trips to the study area were conducted between summer 2007 (when the contract was finalized) and Mar. 2012. We implemented detailed and repeated photographic surveys of the principal oil sources within this study area and measured oil emissions and in-stream accumulation of oil from seepage, which was proposed to be similar to that found on the oiled birds. These surveys allowed us to gather in-stream and off-stream data to document the major oil emission and oil accumulation sites and their changes over the course of this pilot study.

Also, data were gathered and evaluated from images taken before and after the 2004-05 winter storms to ascertain changes in the bed, banks, and channel of SPC. Information was gathered from interviews and photos with/from state and local agency personnel, news media, oil companies, and citizens who were familiar with different aspects of the incident.

We also propose that storm related erosion of the riverbank in Jan. 2005, likely activated new seepage vents and enhanced existing seepage. The erosion also likely modified the SPC bed, enabling the formation of a large oil pool in the streambed.

This report acknowledges the important contributions of Bryan Gollhofer (OSPR-CDFW) and Paul Hamdorf (OSPR-CDFW) for initial field investigation, Laird Henkel (OSPR-CDFW) for invaluable comments, Bruce Joab (OSPR-CDFW) and Michael Sowby (OSPR-CDFW) for overall study guidance, and Susan Sugarman (CDFW-PCL) for oil sample analysis and oil fingerprinting.

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1 Introduction

1.1 Investigation and Background

Incidences of oiled birds and/or bird mortalities unrelated to reported oil spills are common in central and southern California, occurring virtually every year. Oiled birds are regularly reported along the coast from Orange County to San Luis Obispo County, often during the winter and spring months. Total annual casualties usually number ~200 obviously oiled individuals (Henkel et al., 2014). Although these casualties may be attributable to natural oil seepage, little is known. Rarely is a responsible party found for these lesser but recurrent events.

Two of the largest ‘mystery’ bird oiling incidents in recent years included the S/S *Jacob Luckenbach*, which occurred in multiple winters prior to 2003 and the Ventura Oiled Bird Incident (VOBI), which occurred in January 2005.

The *Luckenbach* incident began as a ‘mystery’ bird oiling event off San Francisco Bay during which increased incidence of oiled marine birds was noted over a several year period, although the source of the oil was not identified until Feb. 2002. The source was found to be a 468-foot freighter that sank ~17 miles southwest of the Golden Gate Bridge, on 14 Jul. 1953. The Luckenbach Trustee Council (2006) reports leakage from this vessel killed or injured over 51,000 birds, mostly common murres (*Uria aalge*), and eight sea otters (*Enhydra lutris*). In an intensive response operation, the residual oil was removed from the vessel thereby eliminating the continued threat to wildlife (Hampton et al., 2003).

The Ventura Oiled Bird Incident (VOBI) began in the second week of Jan. 2005. The first oiled birds sightings were reported on 12 Jan. 2005 along the Ventura County coastline (**Fig. 1**). Lt. Paul Hamdorf and Warden Bryan Gollhofer (California Department of Fish and Wildlife – Office of Spill Prevention and Response - CDFW-OSPR) investigated these reports and, in turn, reported the event to OSPR headquarters. The CDFW–OSPR responded quickly activating OSPR staff, the Oiled Wildlife Care Network (OWCN) including the International Bird Research Rescue Center (IBRRC).

By the end of the day of 12 Jan. 2005 rescuers had captured 68 birds, virtually all were *Aechmophorus* grebes. Captures clustered mostly along the central Ventura County coastline, near Ventura Harbor and the mouth of the SCR, and near Mugu Lagoon. By the morning of 13 Jan. 2005, the effort had ramped up with 25 rescue workers capturing live oiled birds and delivering them to rehabilitation centers. By 18 Jan. 2005, a week after the first oiled bird sightings/rescues, 1033 oiled birds had been collected from along the Ventura, Los Angeles, and Santa Barbara coastlines. Most of the oiled birds were found between the Ventura Harbor and the Naval Station - Ventura County, near Point Mugu. The numbers of live oiled birds eventually rescued reached over 1,200 individuals. An additional 312 dead oiled birds were recovered during this incident. Based on population estimates the VOBI affected a significant fraction of the west coast population of western grebes (Leifer and Wilson, 2014b). The total cost of the incident exceeded **$1,000,000** (Sandy Potstada, OSPR Sacramento, Pers. Comm. 2010). An additional and unrelated bird-oiling incident, termed Ventura Birds II, was significantly smaller in magnitude, and occurred in central and southern California in Feb. 2005.

Fig. 1. Google earth image of VOBI study area showing location of focused study site near Thomas Aquinas College just north of Santa Paula. The study area was centered on a feature informally named “Cactus Slump Seep.” Also labeled are the Santa Clara River (SCR), Santa Paula Creek (SPC), and Sisar Creek (SC). Inset shows coastline where oiled birds were found from Morro Bay to Long Beach, California.

1.2 Oil Sources

Several potential oil sources were investigated as the possible cause of the VOBI. During overflights, observers noted extensive oil slicks on the sea surface offshore of Coal Oil Point (COP) and in the vicinity of Platform Holly (**Fig. 2**). Initially the VOBI was proposed to be related to a marine oil production release. Such oil would have been driven eastward from COP by wind and currents. Observers noted oil slicks and sheens as far east as offshore Carpinteria, CA. Oil sheens were extensive, covering an estimated 8 to 10 square miles of sea surface off the Santa Barbara County coastline. Marine oil sheens or slicks were not observed, however, off Ventura County where most of the oiled birds initially were observed and collected. OSPR and UCSB personnel also investigated other potential anthropogenic and natural sources of petroleum.

Fig. 2. Aerial photo showing oil slicks arising from near Platform Holly on 14 Jan. 2005. Photo courtesy of Laird Henkel, CA-CDFW.

2 Anthropogenic Oil Sources

Marine Oil Production Facilities – Marine oil producers did not report any oil spills from offshore pipelines or platforms along the Santa Barbara or Ventura County coastlines concurrently or immediately prior to the onset of the VOBI.

Vessel/Transport - No spills were reported from marine vessels concurrently or immediately prior to the VOBI.

Onshore and Inland Oil Production Facilities–Vintage Petroleum (Vintage) had a significant oil spill at the time of the VOBI. This incident occurred in one of its oil production leases in the San Miguelito Oil Field along the Rincon coast, in northern Ventura County The spill released 25 barrels of oil into a coastal canyon just east of Pitas Point on 10 Jan. 2005 (OES, 2005). The oil flowed northward along Pacific Coast Highway and entered the Pacific Ocean at Seacliff. A spill, reportedly occurred on 11 Jan. 2005 from a pipeline operated by Union Pacific Railroad in the same location, but this was probably the same spill. The Ventura River has at least two large, active oil production facilities within its lower watershed - one operated by Vintage and the other by Aera Energy, LLC. Neither company reported a significant spill in this watershed during or immediately preceding the VOBI.

There were both active and inactive oil production facilities along the main stem of the SCR and in sub-watersheds of the SPC/Sisar Creek, Wheeler Canyon Creek, Sespe Creek, and Hopper Canyon Creek in Ventura County, which also could have been potential oil source(s) related to the VOBI. These included but were not limited to: active facilities operated by Vintage, Crimson Resources LLC, Seneca Resource Corporation and other smaller companies and abandoned facilities formerly operated by UNOCAL. However, none of these producers reported a spill during or immediately preceding the VOBI within the Ventura or Santa Clara River (SCR) watersheds.

2.1 Natural Oil Sources

2.1.1 Overview

Aside from anthropogenic sources, natural oil emissions are a potentially significant source. The NRC (2003) estimates 600,000 metric tons of oil enters the oceans per year from natural seeps. Hydrocarbon (oil and gas) seeps are where hydrocarbon gases and fluids escape the lithosphere into the hydrosphere or atmosphere. During migration through the sediment, microbial oxidation alters oil and gases.

Petroleum hydrocarbon seepage is the emission of both gas and oil from a capped reservoir layer into the environment. Also important is the presence of a relatively impermeable, capping layer that prevents escape of the hydrocarbons. Erosion of the capping layer or penetration by faults and fractures can provide migration pathways for focused seepage (Hunt, 1995; Whelan et al., 2005).

Where the reservoir contains oil and gas, the gas flux drives the oil migration, although seepage also can occur by geologic pressure. In such case, the oil generally escapes as oil covered bubbles, although oil can escape without the gas due to for example, as gas pressure behind an oil-blocked pathway, or due to geologic pressure. Because natural gas dissolves in oil, effervescence (the formation of bubbles) may occur in the oil drops.

Natural seeps long have aided oil prospectors in determining where to conduct geotechnical surveys, build piers, drill wells and place platforms (Grosbard, 2002). Much of the coastline from Pt. Conception to Santa Monica was home to numerous oil piers, platforms, and wells in the nearshore and offshore waters, now abandoned. Some of the largest terrestrial petroleum seeps in the coastal mountains occur in the Ojai–Sulphur Mountain District of Ventura County (Hodgson, 1987).

2.1.2 Marine Sources

Natural marine seepage is found all along the southern California coast. A geologic rock layer known as the Monterey Formation, which is the source of most petroleum in the basin, underlies the entire Santa Barbara basin and the coastal mountains of Ventura County. Because active hydrocarbon formation occurs offshore, where depths of the Monterey Formation are greater than 3-4 km (Leifer et al., 2010), migration occurs in an onshore direction where the Monterey Formation is shallower, too. Migrating hydrocarbons become trapped in crests of anticlines, creating hydrocarbon accumulations such as the South Ellwood Anticline. Migration also occurs along the coast towards shallower sections of the Monterey Formation (**Fig. 3**).

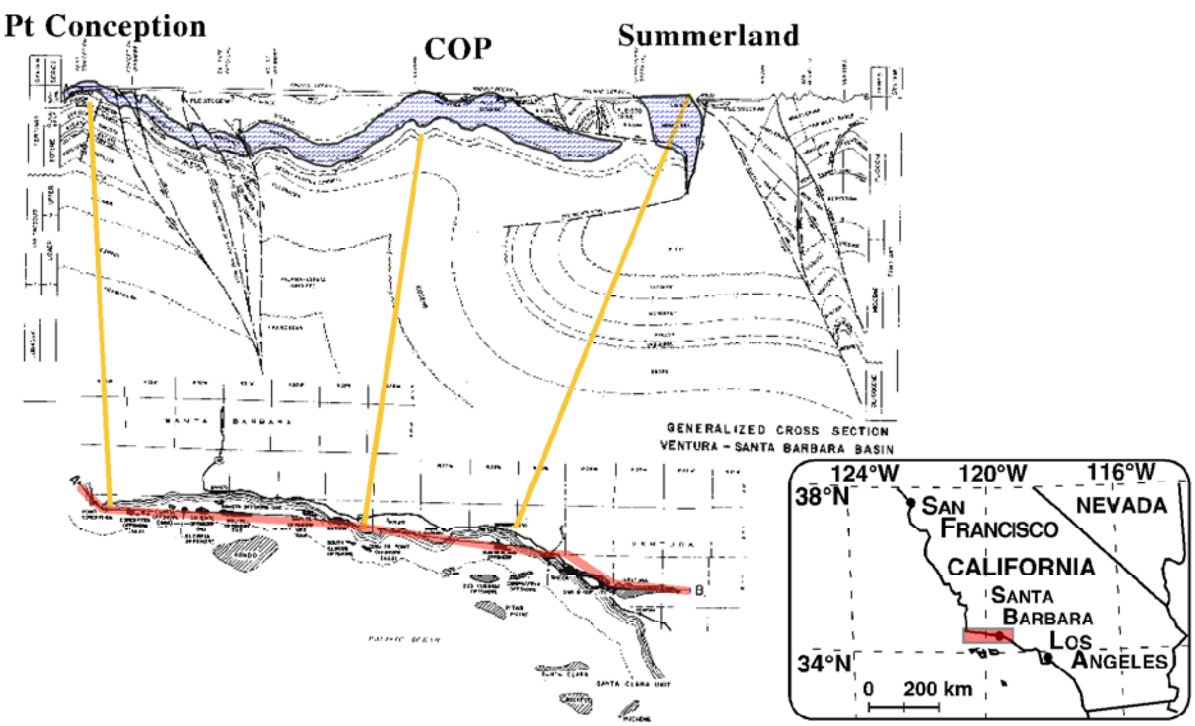

Fig. 3 - Generalized geologic cross-section of the Ventura and Santa Barbara Basins. COP is Coal Oil Point.

The strongest Monterey Formation natural seepage activity is in the vicinity of COP offshore University of California Santa Barbara. The COP seep field (**Fig. 3**) is among the largest and best-studied areas of active marine seepage in the world. These perennial and continuous oil and gas seeps have been active on the northern edge of the Santa Barbara Channel for at least 500,000 years (Boles et al., 2004). Seep field bubble emissions were mapped using sonar (**Fig. 4**), which is an effective tool for mapping seeps because gas bubbles in water are strong acoustic scatterers (Hornafius et al., 1999; Leifer et al., 2010; Quigley et al., 1999). Details of the approach are provided in Leifer et al. (2010). Flux estimation from sonar mapping (Hornafius et al., 1999) and direct gas capture (Washburn et al., 2005) suggest ~1.0-1.5 x 10^5 m^3 day^{-1} gas escapes from ~3 km^2 of seafloor to the atmosphere with a roughly equal amount dissolving into the coastal ocean (Clark et al., 2000). Associated oil seepage is estimated at over 100 barrels dy^{-1} ($1.6x10^4$ L dy^{-1}) (Clester et al., 1996a, b; Hornafius et al., 1999). Seepage is associated with the offshore South Ellwood oil field that has been in production since 1966 and has yielded from the Monterey Formation, $9.49x10^6$ m^3 oil (5.97 x 10^7 barrels) and $1.48x10^9$ m^3 (5.22 $x10^{10}$ ft^3) of gas as of Sept. 2008 (Leifer et al., 2010).

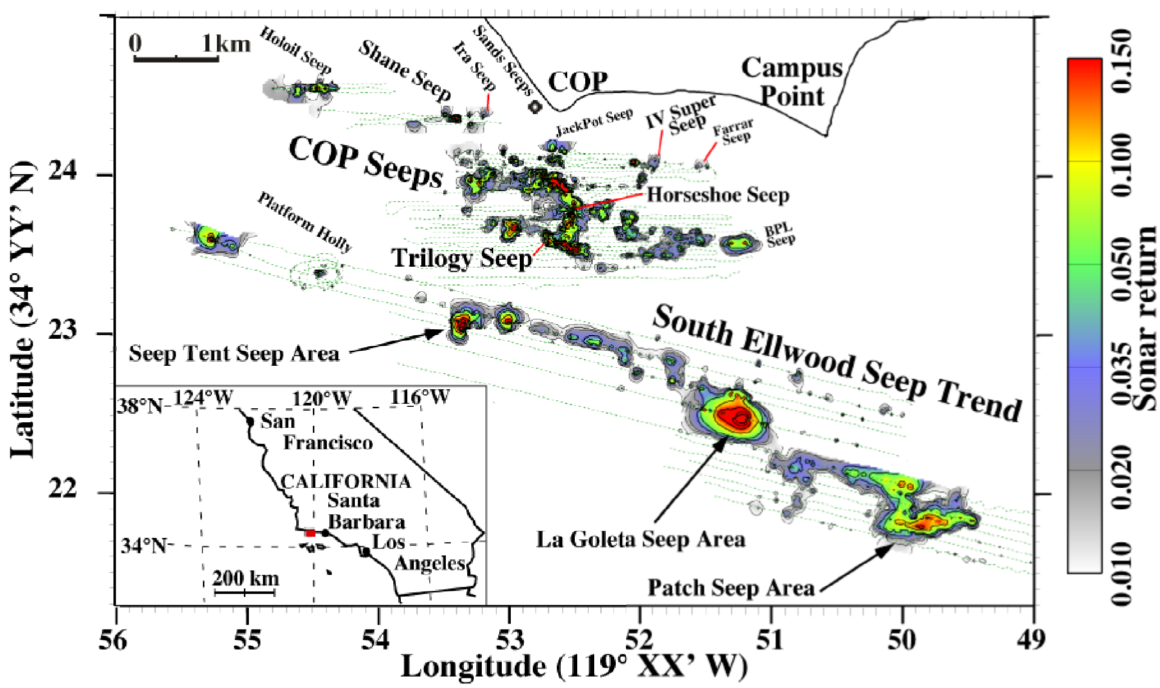

Fig. 4. Map of the Coal Oil Point seep field. All seep names are informal; seep targets determined by GPS location during small boat surveys, or submarine. Contours are logarithmically-spaced, sonar return values for gas seepage for Sept. 2005. Length scales on figure. From *Leifer et al.* (2010).

Comparatively minor oil seepage has been identified in nearshore and onshore locations near Montecito, Carpinteria, and Summerland in southern Santa Barbara County. Due to their relatively small output, these seeps appear to significantly affect only local areas. For example, in a two yearlong study of natural and anthropogenic seeps onshore and nearshore areas at Summerland, California, (Leifer and Wilson, 2007) observed that the seep oil arising from the nearshore seabed generally remained within kelp canopies and on local beaches within 1/4 mile from their sources. Seepage in the coastal Ventura area is far less notable than in Santa Barbara County based on beach tar accumulation and general lack of oil sheen reports. USGS is conducting sonar mapping surveys of these areas which will identify marine seepage.

Over 700 of the 1033 oiled birds recovered by the end of the second week of January 2005 were collected along the 25-mile stretch of coast from northern Ventura to Pt. Mugu. In an effort to determine the source of oil on the birds, aerial surveys of oil slick sources in the Santa Barbara Channel was conducted 17 Jan. 2005 by Dr. Leifer and Ken Wilson in conjunction with the California Dept. of Conservation, Division of Oil and Gas, and the CDFW-OSPR). This survey included the northern channel oil platforms and the COP seep field. For the seep field, a dramatic increase in oil and gas seepage and extent was observed compared to typical extent of oil seepage. In fact, the extent and magnitude of the seepage was much greater than any time during the last decade. This increase is shown dramatically in the before and after images (**Fig. 5**). Images taken in Nov. 2004 (not shown) confirmed typical seepage slicks, similar to **Fig. 5A**. Increased seepage was also noted on boat surveys on 18 Jan. 2005, 2 Feb. 2005, and 7 Feb. 2005, and on a second aerial survey 19 Jan. 2005.

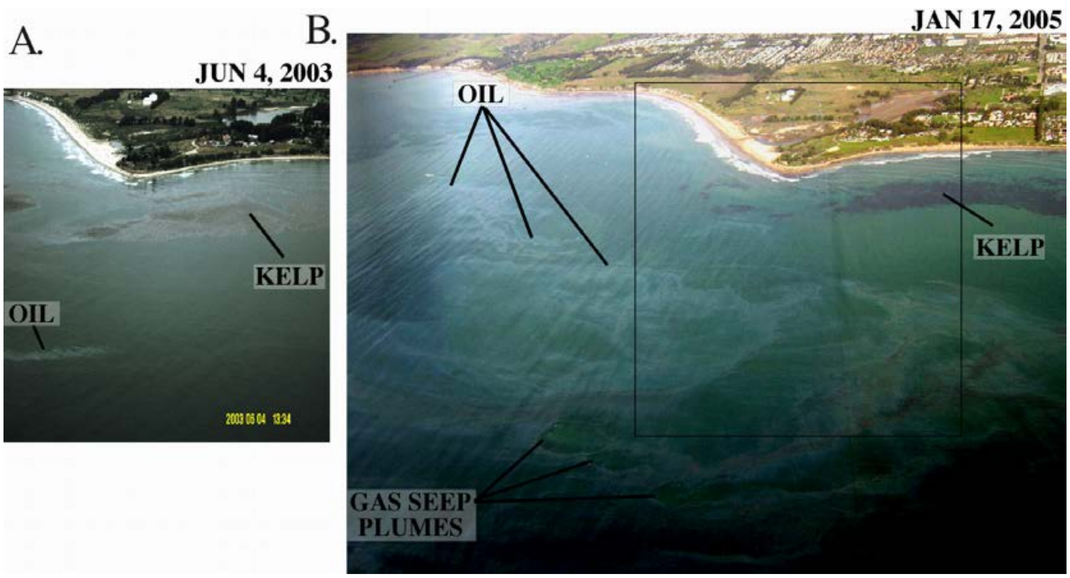

Fig. 5. A) Aerial photo taken 4 Jun. 2003, showing typical seepage in the near-shore seeps off Coal Oil Point. This image was vertically stretched to match perspective in B. **B)** Aerial image from shortly after an exceptional rain event in Jan. 2005. Box outlines same region as shown in (A) reveals vastly larger amounts of oil seepage. New and intensified gas seepage plumes also are shown. Oil-free areas around the gas seep plumes are due to bubble-driven outwelling flows.

The natural gas and oil seeps off COP were particularly active during this incident (Leifer, UCSB, unpublished observation, 2005). It has been proposed that this increased oil and gas seepage could have been related to increased aquifer pressures from the ongoing significant rain event (Bradley et al., 2009).

2.1.3 Terrestrial Natural Seepage Sources

Many active oil seeps are located within several of the larger and some of the smaller sub-watersheds of streams and rivers in Santa Barbara, Ventura, and northern Los Angeles Counties (DOGGR, 1992; Hodgson, 1987). Among the most notable onshore seeps, which are most likely to affect the riverine and coastal environments are those seeps occurring within the tributaries to the SCR. Seeps located in Carpinteria and Toro Canyon Creeks in southern Santa Barbara County are less likely to affect the riverine and coastal environments (**Fig. 6**).

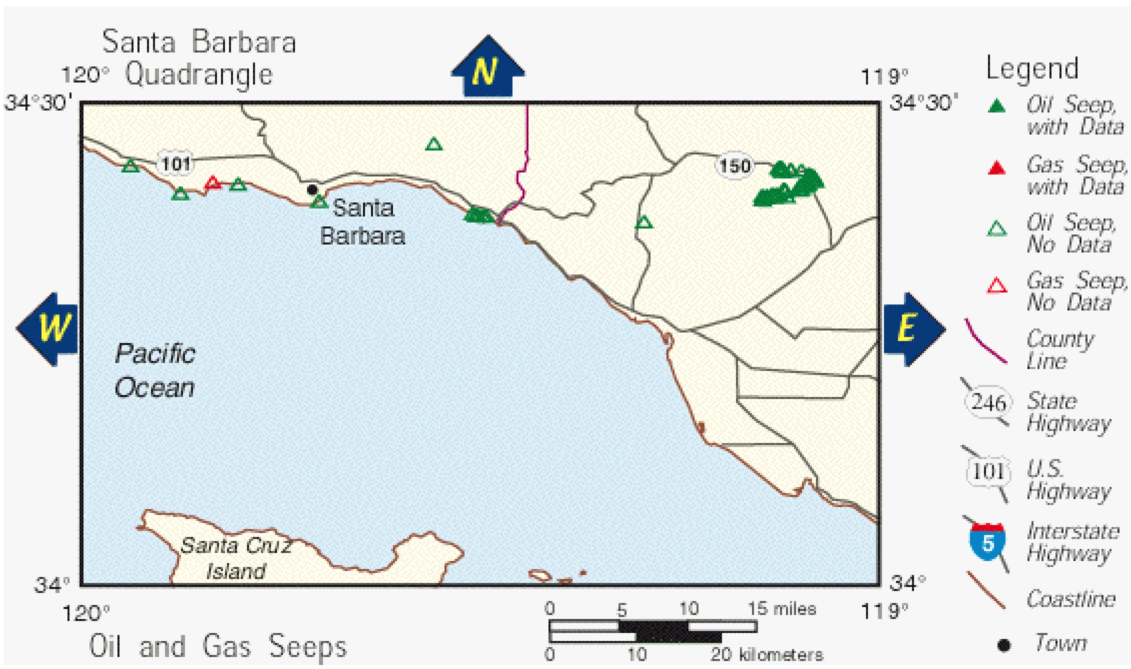

Fig. 6. Map depicting some of the natural oil seeps in the Santa Barbara-Ventura County Areas. The natural oil seeps studied in the Santa Paula Creek watershed are among those designated by green triangles in the upper right quadrant of the image (Hodgson, 1987).

Although high flow seep sites tend to be quasi-persistent, active seepage can be transient, appearing sporadically, or due to environmental forcing. Given that seepage is driven by subsurface geologic pressure, phenomena like major Pacific storms that change aquifer levels and streambed and bank configurations can influence seepage. As a result, inactive seepage vents can become activated during and after storms. Given the presence of many known seeps in the SPC riverbed, storm activation could have played a role during the VOBI.

Hundreds of significant natural terrestrial oil and gas seeps have been documented throughout California. However, few studies have quantified the output of natural terrestrial seeps - e.g., Hodgson (1987), and the fate and impacts of oil from such seeps is even less well understood. Many of the larger seep locations are well known, with some even having been exploited by man (Hodgson, 1987). For example, several natural oil seeps existed in the Adams and Wheeler Canyon watersheds near Sulphur Mountain north of the City of Santa Paula (Hodgson, 1987; Watts, 1897). Approximately 30 oil tunnels were dug into several of the more productive seeps in the early 1860s by a mining engineer, Josiah Stanford, to increase their natural outputs (Watts, 1897). By 1890 these oil tunnels were operated by the Union Oil Company of California (Unocal). Unocal eventually determined that the oil tunnels were no longer cost effective and plugged the entrances of actively producing tunnels to restore the 'natural seep' conditions in 1997, after 137 years of production. ‘Natural seep” here is a Unocal definition.

In 1999, OSPR was notified that oil was observed in Wheeler Canyon Creek watershed. A field inspection revealed that the source(s) of the oil were three of the 'abandoned' oil tunnels, a.k.a. 'restored natural seeps'. This oil flowed down Wheeler Canyon Creek and reached Foothill Rd, over 4 miles downstream (*Ken Mayer*, 1999, unpublished letter to Robert Mandel US EPA). Further, two bird researchers working at the confluence of Todd Barranca Channel and the SCR, Zev Labinger (Condor Environmental Planning), and independent bird researcher, Jim Greaves, suggested that oil seeping from the old mines may have reached the SCR, more than 8 miles downstream (*Jim Greaves*, Private Consultant, Pers. comm., 2005). These abandoned tunnels were suspected to be potential oil sources contributing to the VOBI.

Estimations of terrestrial seep emissions are few. One example is an oil emission study for an old oil production tunnel excavated into a natural oil seep in Toro Canyon Creek (34.458918ºN, 119.561293ºW – WGS84), in the foothills above Summerland in Santa Barbara County. Reported oil outputs ranged between 1.2-7.5 barrels oil per week between 1998 and 2000 (Mandel, 2001).

2.2 River Transport of Terrestrial Seepage to Oceans

2.2.1 Storm events

Severe rainfall and consequential flood events can affect seepage (Bradley et al., 2010). One of the more severe storm events occurred in the winter of 2004-2005, with the Jan. 10, 2005 event termed a 50-year storm (Barnard and Warrick, 2010), see Fig. 7. Severe rainfall from "major Pacific storms," beginning on 27 Dec. 2004 and continuing through 13 Jan. 2005, followed a few weeks later by a second major storm of lesser magnitude. These storms caused major flooding and mudslides in the Los Angeles area. "For the 5-day period January 6th -11th, over 20 inches of rain was recorded at some mountain weather stations in Santa Barbara, Ventura and LA County locations...” (NOAA, 2005).

These major storms and resulting stormflows caused severe flooding and mudslides in Ventura County. On 10 Jan. 2005, the La Conchita Mudslide killed 10 people in a coastal residential area located ~4.6 miles south of Carpinteria in northern Ventura County (Jibson, 2005). On the same day, in a nearby oilfield operated by Vintage, ~6 miles SSE of La Conchita, an oil line from an oil storage tank broke when a hillside collapsed upon it releasing approximately 3025 barrels (13,650 gallons) of produced water and 20 barrels (840 gallons) of stored crude oil into a rapidly flowing unnamed tributary to the Pacific Ocean. High stormflows carried debris, sediments, and oil onto the Pacific Coast Highway and into local coastal residences and the Pacific Ocean (Wilson, 2005).

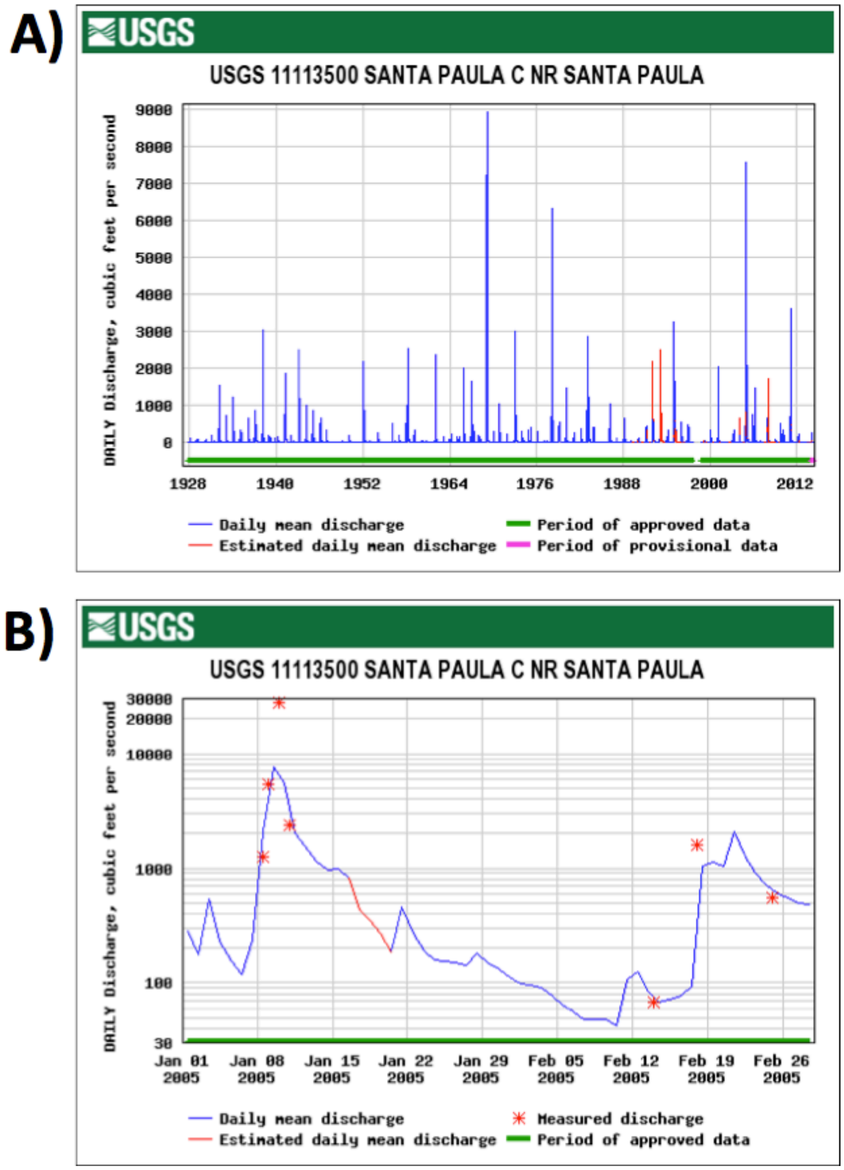

Fig. 7. A) Annual peak daily streamflow for Santa Paula Creek - USGS 11113500 Santa Paula Creek Gaging Station, 34.41333°N, 119.08139°W (NAD 27). **B)** Daily mean discharge in Jan.-Feb. 2005 and measured discharge showing details of Jan. 2005 storm-induced flow. Datakey on figure (USGS, 2014b).

2.2.2 Marine Transport of River Outflow

A satellite photo taken shortly after the Jan. 2005 storm (**Fig. 8**) showed sediment plumes that resulted from freshwater stormflows originating from the Santa Clara and Ventura Rivers as well as other smaller coastal streams. The plumes (upper left quadrant of photo) extended more than 22 miles offshore from the mainland, enveloping marine waters around Anacapa Island and on the east end of Santa Cruz Island, and along the coast for about 40 miles from about Pitas Point in Ventura County southward to Point Dume on the Malibu coast in Los Angeles County. At the time of the satellite photo, this sediment plume covered ~492 sq. mi.

Fig. 8. Satellite image showing sediment plumes offshore the central and southern California coastline on Jan. 2005. The light green area in the upper left quadrant of the image is the sediment plume arising primarily from the Santa Clara and Ventura Rivers.

This storm series also affected other areas. The Ventura County Watershed Protection District's (VCWPD) rain gage at the Ferndale Ranch weather station in the Santa Paula Watershed recorded 22.91 inches of rainfall between 7 and 11 Jan. 2005. Nearly 21 inches of this total was recorded between 7 and 10 Jan. 2010 (10.24 inches of which was recorded on 10 Jan. 2005). This storm series triggered severe flows in Santa Paula Creek (SPC) on 10 Jan. 2005 (**Fig. 7**).

The SPC watershed has an area of 38.4 mi². Flow records in this creek have been monitored by the USGS since October 1933 (**Fig. 7A**). The gage is located ~4.8 mi. north of Santa Paula at an elevation of 785 ft. The maximum discharge from this watershed for the period of record (1933 to 2008), 27,500 ft³/s (**Fig. 7B**), was measured on 10 Jan. 2005, two days before the first VOBI birds were collected.

Photographic evidence (**Fig. 9**) supports that proposition that oil flowed down the Santa Clara River into the Pacific Ocean on 10 Jan. 2005.

Fig. 9. Stormflows in the Santa Clara River at the Harbor Ave Bridge just over ½ mi from the Pacific Ocean. There is a silvery oil sheen (red arrows) on the water surface. A significant amount of this oil is proposed to have originated from natural seeps in the vicinity of Thomas Aquinas College, near the confluence of Sisar and Santa Paula Creeks. Photo courtesy Gary Phelps, Ventura County Star, 10 Jan, 2005).

Current radar stations onshore in the Santa Barbara Channel provide measurements of surface and near surface currents, with good coverage for offshore Santa Barbara, and to a much lesser extent the Port Hueneme coast (**Fig. 10**). Current radar is a coastal high frequency radar that is used to derive the surface current velocity field (Bassin et al., 2005). Currents offshore Port Hueneme after 11 Jan. were generally southward, consistent with the sediment distribution in the satellite photo (**Fig. 8**). Unfortunately, Current radar coverage for much of the Ventura coastline was absent. For the first few days of the VBOI, winds were very strong, above 10 m/s, and generally from the west-northwest – i.e., down-coast (**Fig. 10**). Winds are important in the advection of oil slicks. On 13 Jan. 2013; however, winds decreased dramatically, to a few meters per second, thus, after this winds likely ceased influencing the fate of the oil.

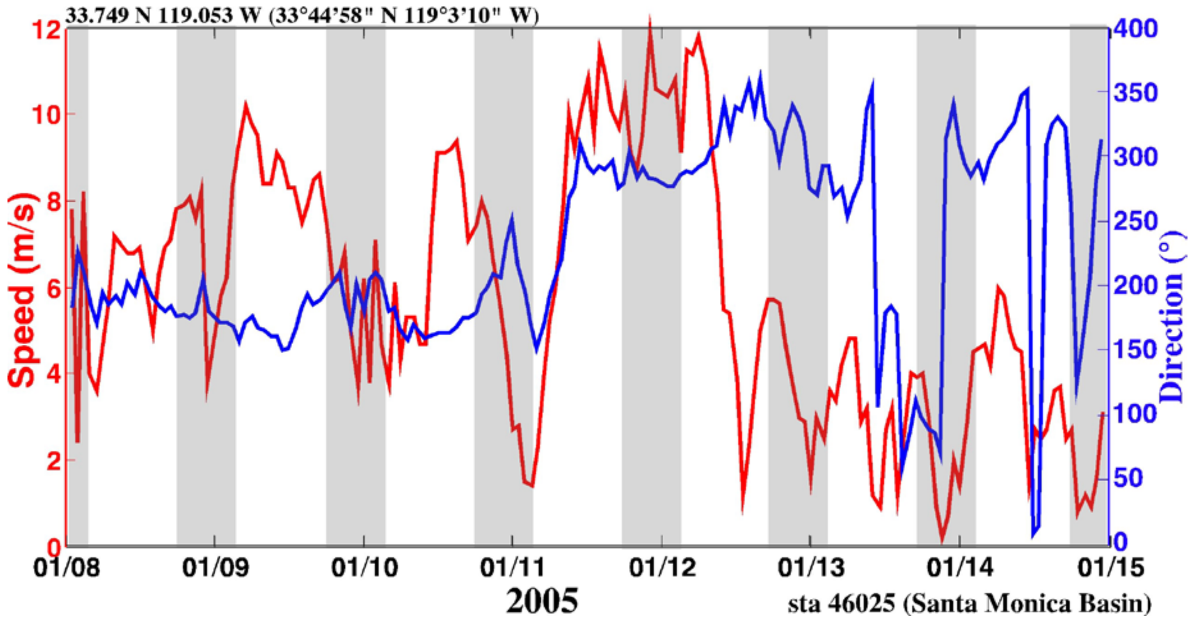

Fig. 10. Wind speed (red) and direction (blue) for Santa Monica Basin 8-15 Jan. 2005.

The VOBI was one of California's larger marine bird oiling events in recent history. Despite extensive airborne and beach observations, only a single report of a surface oil slick near the SCR mouth, which all the evidence indicates was the source, noted surface oil slicks. Specifically, an overflight to assess the magnitude and extent of the incident's effect on wildlife (Henkel, 2005) identified a localized oil sheen on 14 Jan. 2005.

The extensive beach observations included ~42 miles of coastline at 15 locations from Goleta Beach to 5th St. in Oxnard. Despite increased seepage activity near COP, beached oil deposits and oiled debris were not in excess of what is typically observed along the Santa Barbara County coastline. In Ventura County, however, oil and oiled debris were found at five of the nine sites examined–two oiled areas were north of the Ventura River and three south of the Ventura River. Investigators found little evidence of larger fresh tar patties and tarballs typical of most marine oil spills.

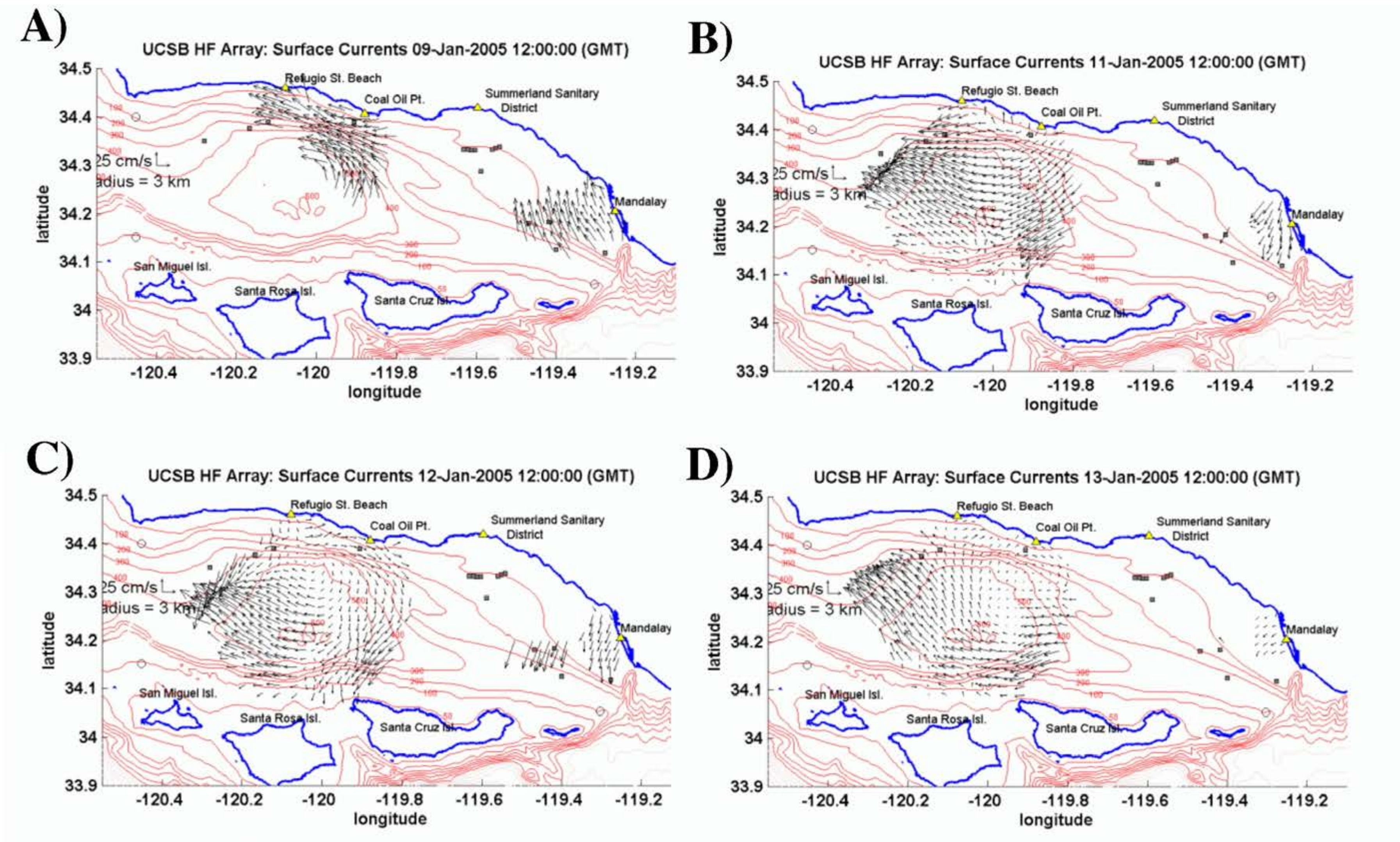

Fig. 11. Currents (24 hour mean) for 9-13 January 2005 for the Santa Barbara Channel from UCSB current radar (Washburn, 2013).

2.2.3 Oiled Sediment, Vegetation

Investigators also noted beaches were not heavily oiled in the Ventura and southern Santa Barbara areas. However, oiled birds were most numerous in the vicinities of Ventura and Channel Island Harbors and in the vicinity of Mugu Lagoon. Evidence was found on 14 Jan. 2005, that ocean surfaces likely were oiled prior to the start of the investigation. Specifically, significant oil stains on a “weather buoy” located ~1.5 km off the Ventura Harbor, suggested a recent oil slick in the area. An oil sample was taken from the buoy. This was two days after the first oiled birds were observed (12 Jan. 2005).

Fig. 12 Left. Image showing trace oil deposits on a giant cane plant in the SCR. This oil was ‘similar’ to the oil on the bird feathers. **Right.** The right image is a 1-meter diameter chunk of semi-plastic asphalt conglomerate deposited in Santa Paula Creek just below Steckel Park. Many large tar patties (semi-plastic asphalt) were observed stranded in the bed of SPC. For example, a 1-meter diameter tar patty was observed ~2.4 miles downstream of our study area.

Oil traces were noted on jetsam (vegetative debris and trash) at McGrath State Beach at the mouth of the SCR. Investigators also found oil traces on giant cane (*Arundo donax*) and other vegetation up-river from the estuary and tidal influence (**Fig. 12A**). These oil traces led investigators ~21 miles from the Pacific Ocean up the main-stem of the SCR as far inland (east-northeast) as the Sespe Creek for evidence of an oil source. Because no evidence of spilled oil or oil traces were observed in the SCR or its tributaries above its confluence with SPC, nearly 16 miles from the Pacific Ocean, it was suspected that the oil on debris near the estuary and on the weather buoy likely originated from within the SPC sub-watershed. The investigation shifted northward into the SPC watershed.

Oil also was observed on California laurels (*Umbellularia californica*) and on willows (*Salix* sp.) growing on the stream bank high above the streambed at and above the confluence of Sisar and Santa Paula Creeks (**Fig. 13**). This evidence revealed that oil also arose from sources upstream of our study area.

Fig. 13. **Left.** California laurel tree showing oil staining up to several meters above ground. This tree was located high on the bank of Sisar Creek, ~15 to 20 feet above the streambed, near its confluence with Santa Paula Creek, approximately ¼ mile upstream of the study area. CDFW Chemist Bob Todd in image. **Right.** Close-up image of oiled leaves.

3 Sample Selection, Analyses, and Findings

Linkage between SPC oil emissions and the VOBI was evaluated through comparative chemical fingerprinting by the CDFW Petroleum Chemistry Laboratory, Rancho Cordova. Gas chromatographic / mass spectrometric chromatograms were analyzed for samples from oiled bird feathers, vegetation, etc., and oil seepage sites and consistent patterns between chromatograms were identified. Also, chromatograms were compared to previously catalogued known source samples.

The following definitions are used to characterize oil fingerprinting analysis[1]:

> Consistent: The samples are almost certainly from the same source. Virtually all peaks match very closely, typically with no more than 10% difference. A very few peaks may vary up to 20% if the difference is easily explainable by weathering.
>
> Similar: The samples show some similarities and could be from the same source but there are enough differences to prevent the samples from being considered consistent. Multiple peaks may differ up to 20%, and very few peaks present in one sample may be absent in another. However, overall similarities among peak patterns indicate the samples may have a common source (with one of the samples showing differences due to weathering, microbial degradation, or slight contamination with a different substance), or they may be from very similar sources (e.g., adjacent seeps).
>
> Not Consistent: The samples are almost certainly not from the same source. Typically many peaks show large (>20%) differences in relative height and multiple peaks in one sample are likely to be absent or virtually absent in the other samples.

3.1 Oil Fingerprints

A total of 118 oil samples were collected from inland and coastal environments during the VOBI - (Appendix 1). These included: oiled feathers, oiled structures, tarballs, free oil, oiled sediments, oiled debris, and oiled vegetation. Analyses began shortly after the onset of the VOBI (Susan Sugarman, OSPR-CDFW, Pers. comm., 2010).

Samples from a number of sources were analyzed to determine if they were related to the VOBI. Four oil samples were analyzed from marine oil production facilities and marine oil seeps. These included two oil/water samples from oil slicks in the vicinity of Venoco's Platform Holly off Coal Oil Point in Santa Barbara County: sample numbers S-009-05-1 and S-009-05-2 (**Appendix 1, Figs. 2 and 4**) and a sample from a Vintage Petroleum, Inc. oil spill on the Rincon coast, located in N. Ventura County (S-008-05-1).

[1] Laird Henkel, approved by Susan Sugarman – Oil Spill Prevention and Response, Petroleum Chemistry Laboratory

One swipe sample from the oiled Ventura Weather Buoy (S-009-05-3) was analyzed. Oiled bird feather samples also were analyzed from multiple locations in Los Angeles, Ventura, and Santa Barbara Counties (Table 1). Analysis of an archived tarball collected from COP in 1995 (S-014-95-5) was compared with the above listed Jan 2005 VOBI oil samples. The analysis of these samples is detailed in the VOBI Sample Information and Analysis Reports (Sugarman, 2005), see Appendix 1, and Table 1.

Table 1 Ventura Oil Bird Incident feather locations used for *feather surrogate* oil sample (**Fig. 14**) that were consistent with Ventura Storm Weather Buoy sample.*

Sample Location	Sample ID	Bird Log	Location
Ventura Storm Weather Buoy	S-009-05-03	n/a	34.243000N, -119.289000W
Zuma Beach	S-009-05-4	D-3	
Pt. Magu (sic. Pt. Mugu)	S-009-05-5	L-184	34.087773N, -119.063631W
Venice	S-009-05-6	L-33	34.003642N -118.490067W
Santa Barbara	S-009-05-7	L-SB-09	
Ventura	S-009-05-8	L-102	34.248890N, -119.268328W
Malibu	S-009-05-9	L-293	34.031977N, -118.681139W
Long Beach	S-009-05-10	L-496	33.758059N, -118.147977W

*(Sugarman, 2005)

Analyses revealed that oil from all seven tested bird feathers and oil swiped from the Ventura Weather Buoy were 'consistent', suggesting the same source (see Appendix A). The chromatogram of the "surrogate" oil for the VOBI is shown in **Fig. 14**.

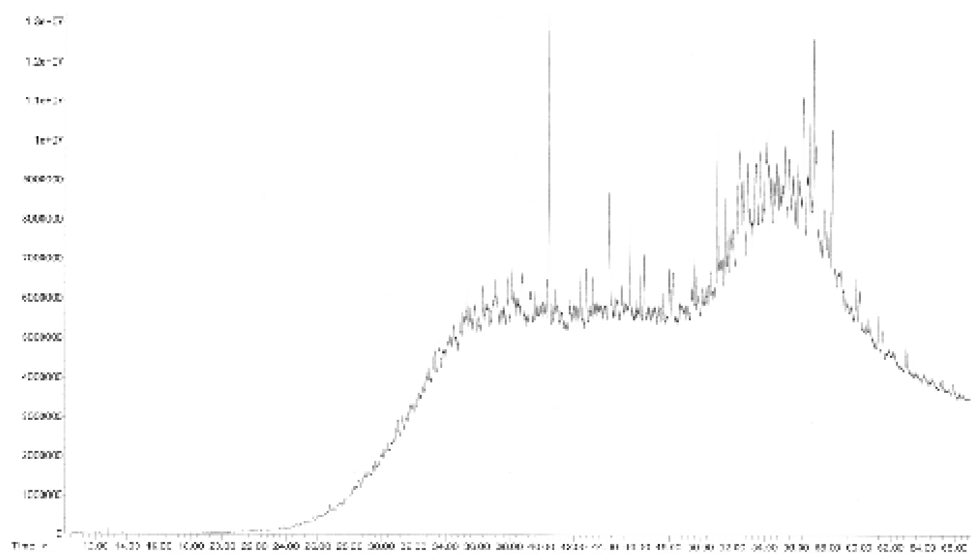

Fig. 14. The surrogate Ventura Oiled Bird Incident Feather Sample, No: S-009-05-8 was chosen as the *feather surrogate* for Samples S-009-05 Numbers 3-7, 9 and 10.

The oil on the bird feathers and the Ventura Weather Buoy (Accession # 009-05) was identified as distinct from other oil sources, such from the Coal Oil Point seep field, Platform Holly (Venoco Inc., Carpinteria, CA, operated), and the Vintage Petroleum. After ruling out marine sources, investigators considered possible terrestrial source(s).

Analysis of *Arundo* leaves (a primarily freshwater riparian species) and tar ball samples collected from McGrath Beach and the SCR mouth were 'consistent' with the oil swiped from the Ventura Weather Buoy and the oil on the *feather surrogate* (**Fig. 14**), suggesting the possibility of a terrestrial source in the SCR watershed.

Investigators found traces of oil on vegetation and on the bed of the SCR upstream to, but not beyond, Santa Paula Creek (**Fig. 13**). Samples from several known significant terrestrial oil seeps located in tributaries to the SCR were analyzed to determine possible oil sources. These included several in SPC and in its major tributary, Sisar Creek; sources in Sespe Creek, a tributary to the SCR near Fillmore, CA, located upstream and east of Santa Paula; and seeps in from Wheeler Canyon arising from Unocal’s abandoned oil tunnels just downstream of Santa Paula. Oil samples also were collected from eleven oil producers in the SPC watershed to eliminate the possibility of spills from oil production facilities.

Analyses ruled out terrestrial oil production facilities as the source of oil causing the VOBI. Oil collected from Sisar Creek, a tributary to the SPC; from Wheeler Canyon; and an archived sample from Adams Canyon Creek, all nearby tributaries to the SCR, were not ‘consistent’ with the VOBI oil (Report dated 9 Feb. 2005). Samples of oiled leaves and oil from natural terrestrial seeps were collected near Koenigstein Rd along Sisar Creek, a SPC tributary. Several samples also were collected from SPC near its confluence with Sisar Creek. Again, samples were not ‘consistent’ among Santa Paula and Sisar Creek samples nor were they ‘consistent’ with Ventura Bird Feather oil (**Fig. 14**).

Two samples from Santa Paula Creek; however, were found to be 'similar' to the oil on the Ventura Bird Feather Surrogate and one sample was found to be ‘consistent.’ The two ‘similar’ samples were collected 'just upstream from Steckel Park' by Warden Gollhofer. One was collected on 1-31-05 - “Santa Paula Creek Tarball” (S-024-05-1), and the second (S-030-05-3) was collected 15 Feb. 2005 from atop the creek bank (34.42634ºN, 119.08757ºW, termed “Hill Seep”) above the "Santa Paula Creek Seep– ibid. Gollhofer)." Hill Seep was ~0.18 mi downstream from the confluence of the Santa Paula and Sisar Creeks. This terrace was ~30 meters NNE of and above one of the most active riverbank seeps in our study area, Cactus Slump Seep Area.

The ‘consistent’ sample was from the Santa Paula Creek, described ‘Santa Paula Creek oil/debris’ and was collected by Warden Gollhofer on 11 Jan. 2005 (S-016-05-4) and was found near Steckel Park.

The best match between the Feather Surrogate and an oil sample collected directly from an oil seep, as opposed to downriver or beach debris, some of which were ‘consistent’, was for the Hill Seep, which was ‘similar’ to that observed on the bird feathers and the weather buoy (Sugarman, 2005). Other natural terrestrial seepage in the SPC Study Area, such as the Thomas Aquinas Oil Pool (TAOP), which was not fingerprinted during the incident, also may have contributed to the VOBI. See Appendix A for chromatograms.

4 Santa Paula Creek Oil Seepage

4.1 Overview:

For this study, repeat surveys were conducted to document oil emissions into the Santa Paula Creek (SPC) and to identify the principal oil sources in our study site near Thomas Aquinas College (TAC) in Ventura County, California (**Fig. 15**). Twelve field trips to the SPC were completed from Sep. 2007 (partial-when the contract was finalized) to May 2010, described in **Table 2**. Surveys involved photographic and/or instream quantitative and qualitative observations. Note, though, that instream study protocols were only finalized in May 2008, after the rain-swollen stream had subsided enough to allow in-stream documentation of the major oil emission and oil accumulation sites and their changes.

Table 2. Summary of Photo Surveys

Date	Type
8 Sept. 2007	partial
1 Nov. 2007	instream fall reconnaissance
7 Dec. 2007	photo
10 Jan. 2008	photo
26 Feb. 2008	photo
6 May 2008	photo/instream
29 Jul. 2008	photo/instream
16 Oct. 2008	photo/partial
31 Oct. 2008	photo/instream
4 Nov. 2008	photo/instream
23 Mar. 2009	photo/instream
13 May 2010	photo

*Because of safety concerns, instream studies only spanned slightly over one hydrofluvial cycle (dry season and wet season) from May 2008 to Mar. 2009.

Based on these observations, we drafted proposed recommendations for mitigating future oil effects on wildlife. In May 2008, a large seasonal oil pool developed in the study site that was observed to have killed five ducklings (**Figs. 16** and **27**). Upon release, during the first flushing flows of the 2008-2009 high flow season, oil from this pool was proposed to have created a significant oil slick on the SPC which threatened downstream fauna**.**

4.2 Background:

There are many natural petroleum seeps in the coastal mountains of Ventura County, some of which can pose a significant threat to wildlife and fishes and their habitats in terrestrial and marine environments. In order to better understand the behavior of natural terrestrial seeps and the magnitude of threat posed by some of these seeps, studies were conducted in a seep area in SPC near Thomas Aquinas College (TAC) Oil fingerprint analyses suggested that oil from this area was similar to oil on the birds affected by the VOBI (**Fig. 15**).

4.3 Approach:

Our approach has been threefold and evolutionary. First, a photographic protocol was developed using an overview of seepage areas visible from the shoulder of northbound State Highway 150 Bridge (No 52-105). Replicate sets of high-resolution photos were taken from fixed points to document areas of seepage and oil accumulation. This photo series, taken over an interval of 24 months, allowed comparison of the changes in configuration of the streambed and bank through time thereby testing these hypotheses regarding oil seepage and accumulation processes. Through these efforts, we qualitatively documented: oil seepage; talus fall and accumulation; streambed and channel changes. These channel changes included distribution of rock, growth of aquatic and riparian vegetation; accumulation and movement of vegetative debris; stream bank erosion and collapse rates which were proposed as oil accumulation and release mechanisms.

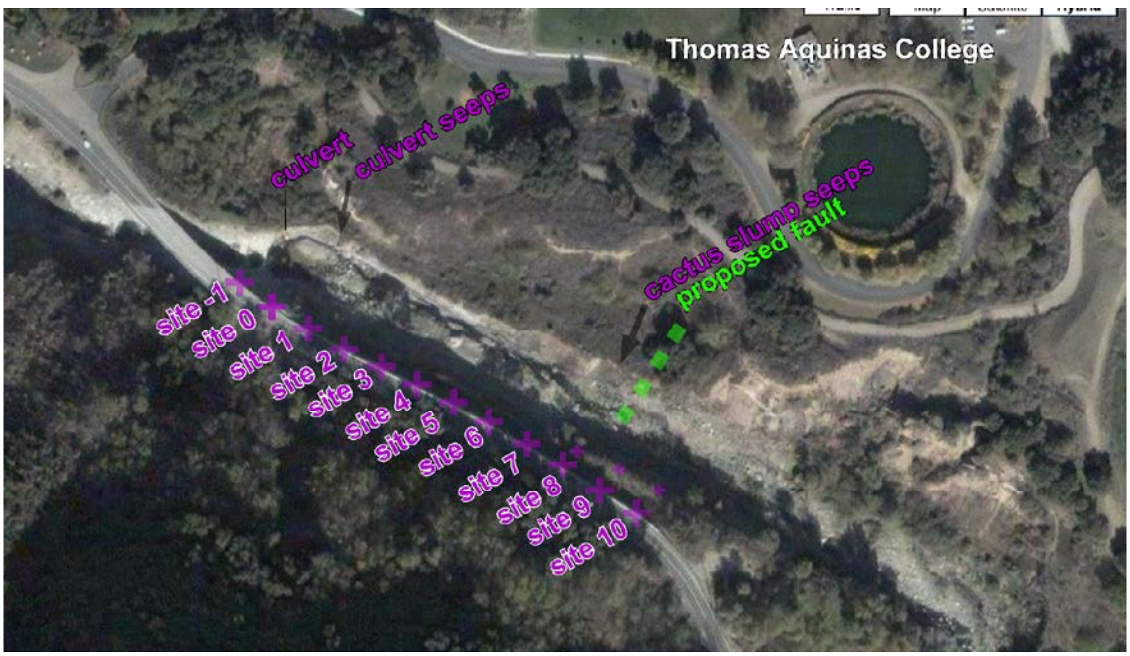

Fig. 15. Google Earth image (Feb. 2005) of study area showing photo sites. Arrows point towards the main active areas of seepage. Dashed green lines show proposed locations of a fault. Site 0 is at: 34.42633° N, 119.08925° W.

Secondly, we developed a range of oil emission measurement approaches. However, changes in emissions and streamflows occurred with each field survey–thus requiring us to adjust our methodologies. Specifically, emissions decreased fast enough that each proposed method was no longer appropriate by subsequent surveys prior to May 2008. Our approach seeks to quantify both oil and water emissions, as we hypothesize that water seepage plays a significant role in the oil emission process. Finally, instream and nearstream oil accumulation features were recorded, including but not limited to: inbed oil pools and surface slicks; water flows; off channel oil pools, oil saturated soil, rock debris, and talus piles; and other important characteristics.

Observations in 2005, 2006, and 2007, documented significant hydrofluvial changes and growth of aquatic vegetation which played short-term roles affecting oil seepage, accumulation, and release into the stream. Also documented were the locations, persistence, and significant changes in seep emissions. A formalized protocol of photo-recording the dominant areas of seepage was developed, based upon these observations. Specifically, 12 near-stream permanent photo stations, each separated by 50 ft were identified along the “K-rail” on the stream-side of the highway (**Fig. 15**). The uppermost photo station was established at the mid-point of the downstream side of the bridge, additional photo stations were established at 15.2-meter (50 ft.) intervals, downstream, a total distance of 168-meters (550 ft). Three additional stations were established on a shelf lying below the roadside photo-stations 8-10. Permanent photo stations allowed us to take multiple series of standardized photos (i.e., same camera angle and zoom) and to make detailed comparisons of changes through time. Further, the protocol allowed us to prepare a photomosaic of the study area (**Fig. 16**). This protocol has been used for surveys since December 2007. Since hundreds of photos were taken, only selected photos from each area are presented in this report. Observations also documented progressive changes in the local geomorphological setting and habitat recovery, and how they relate to oil emission, accumulation, and how the environment might be modified to mitigate oil potentially harmful oil accumulations.

Due to safety concerns following the winter storms of 2007-08 (elevated streamflows and potential landslides), we did not attempt quantitative surveys in the streambed until May 2008; however, the significantly changed emissions noted in Jan. and Feb. 2008 clearly required different approaches than those that would have been appropriate in Nov. 2007.

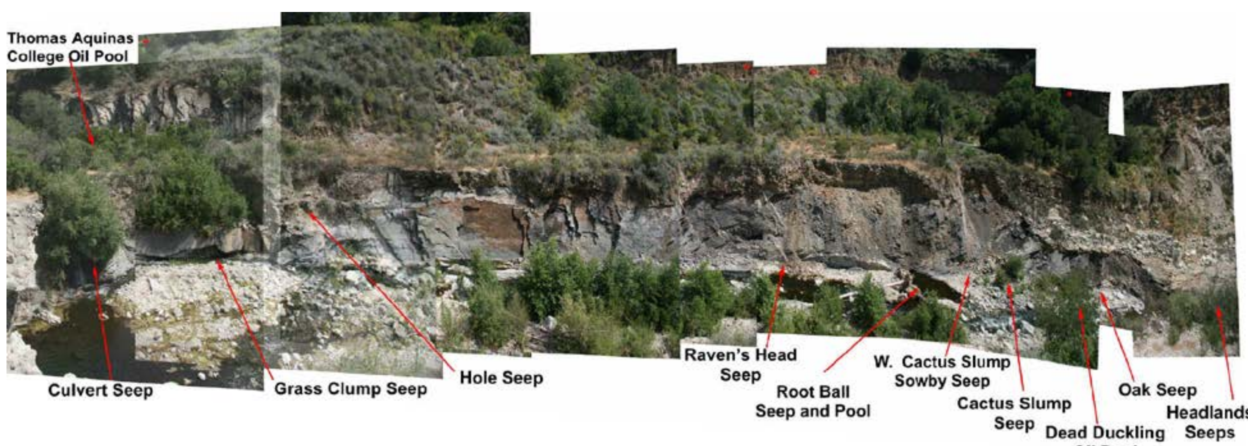

Fig. 16. Photomosaic of northern stream bank of the Santa Paula Creek in 2007- 2008. Key seepage areas are identified. See **Plate 1** for higher resolution image.

4.4 Observations

Between Nov. 2007 and Oct. 2008, seepage was observed at many points along the entire study area as well as other locations along SPC and one of its tributaries, Sisar Creek. A photo-mosaic of the northeast (NE) stream bank of the Santa Paula Creek, where the vast majority of the seepage occurs, is shown in **Fig. 16** and in greater detail in **Plate 1** at the end of this volume. The photomosaic covers ~170 m of streambed and bank along the NE side of SPC.

Informally named seeps, areas of seepage, and areas of oil accumulation in this study include, but are not limited to: Thomas Aquinas Oil Pool (TAOP) and Seep, Culvert Seep, Grass Clump Seep, Hole Seep, Ravens Head Seep, Root Ball Seep, West Cactus Slump-Sowby Seep, Cactus Slump Seeps, and the Headland Seeps. The output of some of these seeps became more apparent as the water flow diminished and oil began accumulating in the streambed and talus piles. Gollhofer (2005) first reported the West Cactus Slump-Sowby Seep as the Hill Seep.

The Culvert Seep Area (CSA), Grass Clump and Hole Seeps are located at the upstream end of the study area and may be related to the TAOP and its seep source. The Ravens Head and Root Ball Seeps are roughly centered in the study area. The Cactus Slump Seep area, located at the downstream end of the study area, appears to be the more conspicuous and productive of the seepage areas within the study site and includes West Sowby-Cactus Slump, and Headland seeps. The Cactus Slump Seepage area appears to be dominant and exhibits long-term evidence for being dominant based on an extensive layer of asphalt cemented river rock overlying a basement comprised of highly contorted bituminous bedrock. There clearly were still other sites, where evidence of past seepage (which had been observed in Nov. 2007) remained as dried asphalt stains on the streambed rock walls (e.g., Hole Seep). We observed that many of the seep sites which showed high emission rates shortly after the 2005 flood flows gradually diminished in output as asphaltization occurred and high aquifer pressures diminished. Some inactive seeps (i.e., migration pathways) no doubt will re-activate when aquifer levels increase sufficiently likely due to seasonal rains.

4.5 Culvert Seep Area

The Culvert Seep Area (CSA) includes the Culvert, Grass Clump, and Hole Seeps (**Figs. 17** and **18**). The CSA is located just downstream of the Highway 150 Bridge No. 52-105, behind the flood damaged concreted boulder rip-rap bank and damaged culvert. This culvert drains water from an unnamed tributary, near Thomas Aquinas College, into the SPC. Water and oil escape these seeps through the damaged culvert, a hanging tributary, and a hole in the cliff face and then flow downward to the streambed. In Nov. 2007, seepage also was observed escaping at the rock wall-overburden sediment interface, and then running down the rock wall face.

Where the seepage runs down the rock face, bacterial mats were visible. In this area, rock strata are oriented parallel to the streambed slope–i.e., steeply sloped. Also, in Nov. 2007, a significant overhang of dirt, clay, rocks and boulders existed (10–70 cm) that protruded beyond the rock face. In Feb. 2008, much of this overhang was gone. In most of the 2008 surveys, no emissions were noted from these seep areas, with the exception of Grass Clump Seep, which appeared to have, once again, become active in Oct. 2008.

By Mar. 2009, the CSA oil seepage activity had not obviously changed from that observed in 2008–with only Grass Clump Seep showing minor emission activity. It is important to remember that these seeps are located immediately streamward and are likely related to oil accumulations in the Thomas Aquinas Oil Pool (TAOP) (**Figs. 17A-C** and **18**).

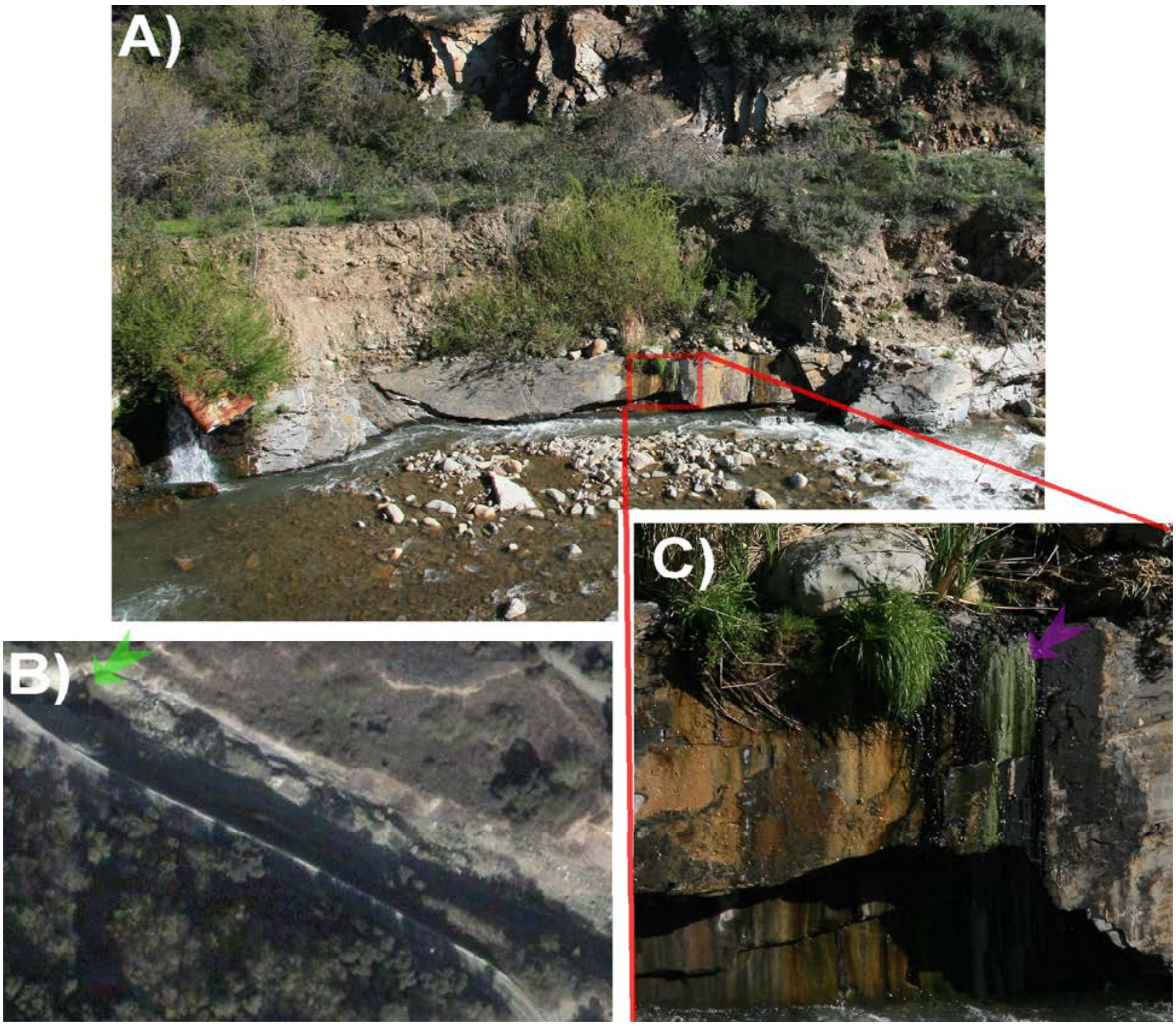

Fig. 17. Culvert Seep Area photos. **A.** Wide field of view, culvert is to left. Thomas Aquinas Oil Pool is in the upper left quadrant of this photo **B.** Google earth overview (Feb. 2005) showing approximate location of Culvert Seep Area and TAOP. **C.** Narrow field of view image of oil and water seepage at Grass Clump Seep. Note green colored bacterial mat. Photos from Site 0.

Fig. 18. Northeast of the Culvert Seep Area (foreground), the Thomas Aquinas Oil Pool is in the upper left quadrant of the photo and may be recognized as the light straw-colored vegetation behind the concreted rock rip-rap bank protection. The damaged culvert and soil bank downstream of the rip-rap were heavily eroded by the Jan. 2005 storms. (Photo taken 26 Feb. 2008).

4.6 Thomas Aquinas Oil Pool (TAOP)

This large oil pool is located on the NE side of SPC near the entrance to Thomas Aquinas College. It is covered by a cattail marsh and hidden within a willow riparian woodland abounding with poison oak. Bordering the oil pool is an unnamed perched tributary with seasonal flows that discharge into the SPC through a culvert (**Fig. 18**). This pool is in the vicinity of the Culvert, Grass Clump, and Hole Seeps and is likely the source for these oil seeps. For safety reasons, the size and oil volume of the TAOP were difficult to measure and because it is densely vegetated, photographs clearly depicting the magnitude of the TAOP were virtually impossible to capture (**Fig. 18**). However, the pool appears to have an area of at least 75 m^2. It has an approximately 2 to 10-cm thick layer of asphaltized oil on its surface, was at least 38-cm deep at one point, and could contain tens of thousands of liters of free oil.

The TAOP is contained, in part, on its streamward boundary by the concrete boulder rip-rap bank protection associated with CalTrans Bridge No. 52-105. The TOAP is located in the former bed, banks, and channel of Santa Paula Creek (Mary Larson, Environmental Scientist, Dept. Fish Game, Pers. comm., 2010). The earthen bank, beginning at the downstream end of the rock rip-rap, forms the downstream boundary of the pool and was heavily eroded during the Jan. 2005 flood flow.

Fig. 19. Study area image from Google Earth. Orange dotted line represents the toe of slope of Santa Paula Creek on Sept. 2004 and Blue dotted line the toe of slope on Feb. 2005 showing post erosion bank line. CalTrans Bridge (No. 52-105) is in the upper left corner of the image. Note, red circle and blue and orange lines along Highway 150 were for aligning images only and have no other significance.

Based upon a detailed examination of aerial images taken before and after the Jan. 10, 2005, storms (**Fig. 19**), we propose that a section of earthen streambank, ~75-m long by 5-10 m wide by 6-m high, between the Raven's Head Seep and Headland Seep and another soil bank section extending from the downstream end of the concrete rip-rap to Raven's Head Seep collapsed. This volume of likely oil-saturated soil was estimated at ~75-m long, by 5-m wide by 6-m high (1125 m^3, assuming a prism shape) and was washed away during the Jan. 2005 storms (**Fig. 20**). A separate area of the streambank, near the TAOP also collapsed, and was estimated at 10-15 m long, by 3-m wide, by 6-m high (225 m^3, assuming a box shape) or a total of 1350 m^3.

Fig. 20. Raven's Head Seep was venting underwater in this Feb. 2008 photo. The seep is located just to the left of photo center. Though inconspicuous, brown and black droplets are floating on the water surface.

4.7 Raven's Head Seep

This is a small oil seep that vents at the interface of the fracturing shale cliff-face and the streambed (**Fig. 20**). Brown and black oil droplets may be seen upon close examination at the front of the Raven's neck at water level, just to the left of photo center. As the stream flows diminished, oil flowed through the cobbles and vented in the streambed alluvium in the lower left quadrant of the photo. This oil seep did not form large pools due to the streambed configuration.

4.8 Root Ball Seep and Pool

The Root Ball Seep and Pool was located at the streambed-cliff interface, ~7-m upstream of a prominence on the cliff-face, which we designated as the upstream boundary of the Cactus Slump Seep Area (**Fig. 21**). A dark bituminous shale deposit runs vertically from top of bank to the toe of slope on the cliff-face above the Root Ball Seep. Oil seeps into the Root Ball Oil Pool from the base of this oil shale deposit.

The Root Ball Oil Pool provides transient instream storage for free oil and several mechanisms for oil accumulation may be observed (**Fig. 21**). The pool is bounded on the upstream side by two conglomerate boulders (deposited in 2004 - 2005) and a fallen tree, which was carried into the area by the storm flows that occurred during the winter of 2007- 2008. These objects created a stream eddy, which captured oil and, as water flows diminished, led to the creation of the oil pool. A large oil pad was observed which was approximately 1 cm thick and covered an area of ~25 m^2 in Nov. 2007.

Accumulated oil flushed during the winter of 2007-2008 and again reformed in Jul. 2008. Despite continued oil seepage, oil tolerant algae and other aquatic vegetation developed annually and helped to retain oil. Seasonal changes in stream flows and streambed morphology alternately cause oil pooling and flushing in this area. Oil saturated streambed materials and talus were observed along the cliff base at the oil/water interface, including aquatic vegetation and oil that had been washed out by winter stormflows.

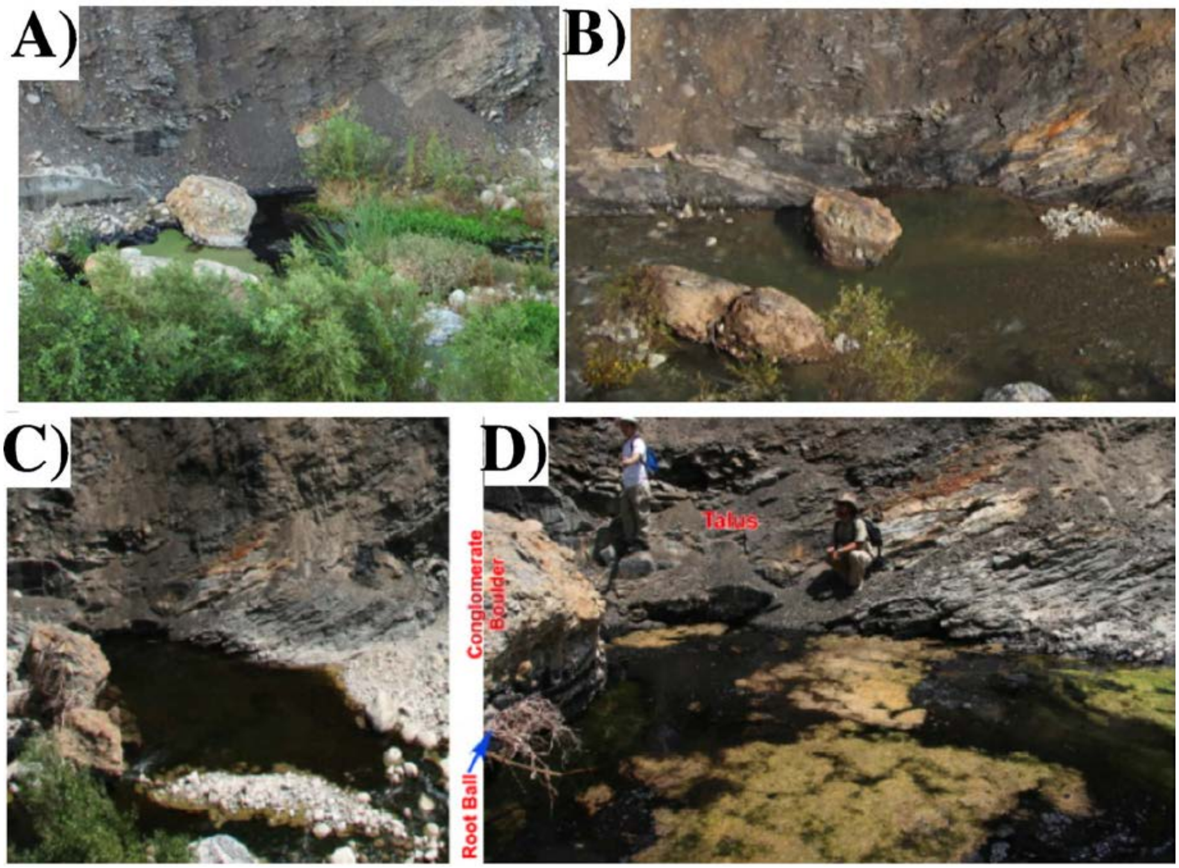

Fig. 21. A) Root Ball Seep and Pool. Top left photo taken 1 Nov. 2007 shows the oil pool at photo center has formed behind boulder and aquatic vegetative barriers. Oil saturated streambed materials and talus may be seen along the horizontal mid-line of photo. **B)** Photo upper right dated 1 Oct. 2008 shows oil, temporary barriers, and oiled sediments are not present in winter 2007-08. **C)** Note oil pad began re-forming in May 2008, and **D)** was well developed in Jul. 2008. From left to right, students Daniel Culling and Chris Stubbs. Photo taken Jul. 2008.

Based upon the geo-morphological structure of the cliff-face, orientation of the shale layers, and the conspicuous rocky prominence, it is our view that the Root Ball Seep and Oil Pool are located to one side of the fault that provides the primary migration path for the Cactus Slump Seeps and Tar Cap Seep.

4.9 Cactus Slump Tar Cap and Cactus Slump Seep (A.K.A. Hill Seep)

Approximately 8-m above the streambed there is a terrace-like upland (**Fig. 22**) area that follows the northeastern side of the Santa Paula Creek. This terrace extends downstream from the Culvert Seep area beyond the Cactus Slump Seeps until it ends at a bend in the stream somewhat downstream from Cactus Slump seeps. The terrace is ~5-m wide in the vicinity of the Culvert Seeps; however, in the Cactus Slump Seep Areas, it widens to several tens of meters.

Fig. 22. January 2005 photo of Santa Paula Creek near, but below, flood stage. The dark cliff face between the Cactus Slump Seep and the photo's left edge is proposed to be the remnant of the oil-saturated soil that washed away on 10 Jan. 2005. The tar cap and Cactus Slump Seep Area are identified on photo. See **Fig. 25** for 2008 photos. Future Dead Duckling Oil Pool below Cactus Slump Seep. Photo courtesy of CDFW.

An extensive tar cap tens of meters across was noted on this terrace and was bordered by cacti on the streamward (southwest) side (**Figs. 22** to **24**). Below this tar cap were instream oil seeps we named the Cactus Slump Seeps. The cap's central area was mostly un-vegetated, with two large dead trees standing in the middle. The surface of the petroleum comprising tar cap was asphaltized and somewhat flexible (i.e., could not be walked on), suggesting liquid oil and/or water underneath, with fresh oil seepage noted at one or two locations. The tar cap had no sediment overburden for a diameter of tens of meters, beyond which it is sediment covered. In the direction of the stream (south), this sediment overburden extends right to the terrace's edge. The tar is far more plastic in the summer than winter, while the absence of dirt over the central portions suggests a slow (decadal) time scale for production of the tar cap; note, this hypothesis does not preclude transient emission events releasing rapidly moving oil and water from this site. Portions of the asphaltized tar layer are exposed at the terrace's edge and large (meter size) pieces have fallen (slumped) along with cactus plants (**Fig. 23**). Presumably, by the time the tar has migrated several tens of meters from its source, it has accumulated sufficient sediment overburden and weathered sufficiently to allow cacti to survive.

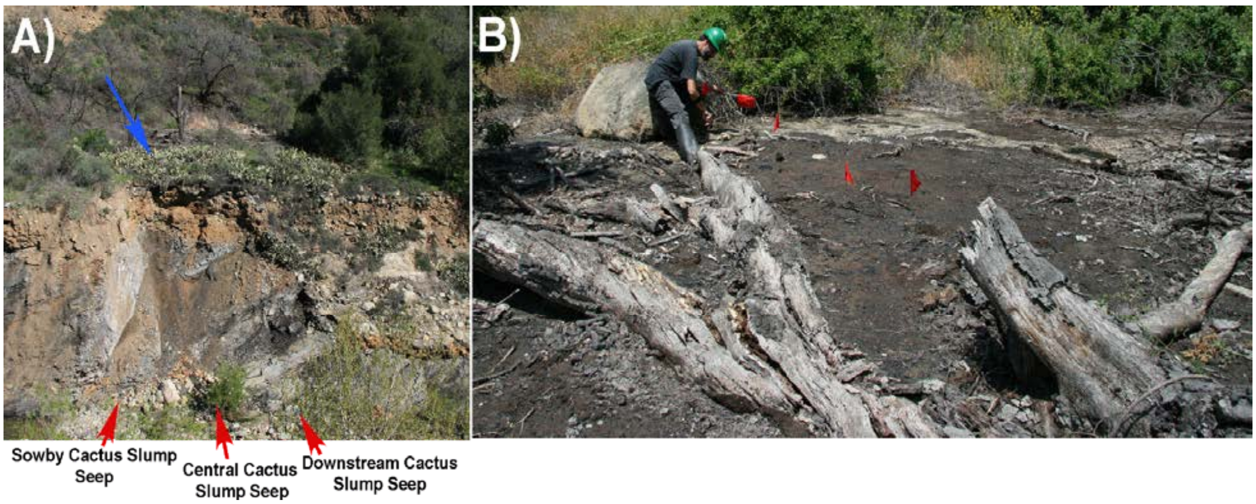

Fig. 23. Tar Cap above Cactus Slump seep is located on the terrace. **A)** Blue arrow indicates the Tar Cap location. Cactus Slump Seeps are shown by red arrows. **B)** Mission scientist Ira Leifer is placing flags 1-meter apart on the tar cap. 6 May 2008.

Evaluation of previous reports suggests that this area was identified as Hill Seep in initial investigations (Gollhofer, 2005) and likely was related to recent erosion and/or streambank collapse. Specifically, Gollhofer (2005) reports for 31 Jan. 2005 that:

> ". . . . we observed an area of the creek bank that had been washed out from the extremely high flow water from both creeks (sic. Sisar and Santa Paula). The area had numerous recently exposed oil seeps that were still actively producing oil that was flowing into the creek. . . . we also observed several seep locations with pooled seep oil on the opposite side of the creek from the active seeps. . . . During the heavy storm period, it is obvious that the bank areas were heavily eroded, and likely exposed these seeps. . . . the debris level in the creek. . . indicates that the water level was approximately 15 to 20 feet above current levels, if not higher."

4.10 Cactus Slump Seep Area

The Cactus Slump Seep Area (CSSA) was the most active seep in our study area and is the proposed principal source of the oil in the VOBI along with the Thomas Aquinas Oil Pool. On the cliff-face above the talus rock layers were distorted (see **Fig. 23A** under blue arrow and **Fig. 24**), preventing determination of a preferred bedding plane, with evidence of folding. Seepage downstream of the Central CCSA primarily occurred near the streambed level as it existed in May 2008. Rock bedding planes here were steeply tilted into the streambed, at ~20 to 30 degrees from vertical with a northward dip. In the streambed itself, rounded streambed cobbles and boulders appear to have accumulated in the streambed in a pile below the cliff-face. This pile has been relatively stable during high-stream flows since the Jan. 2005 event and the underlying rounded boulders appear to be held in place by an asphaltic tarmac matrix created by petroleum seepage, sediments, and volatilization of lighter petroleum fractions. A similar rust colored tarmac conglomerate may be seen just below the horizontal mid-line of **Fig. 24A** in the right side of the photo.

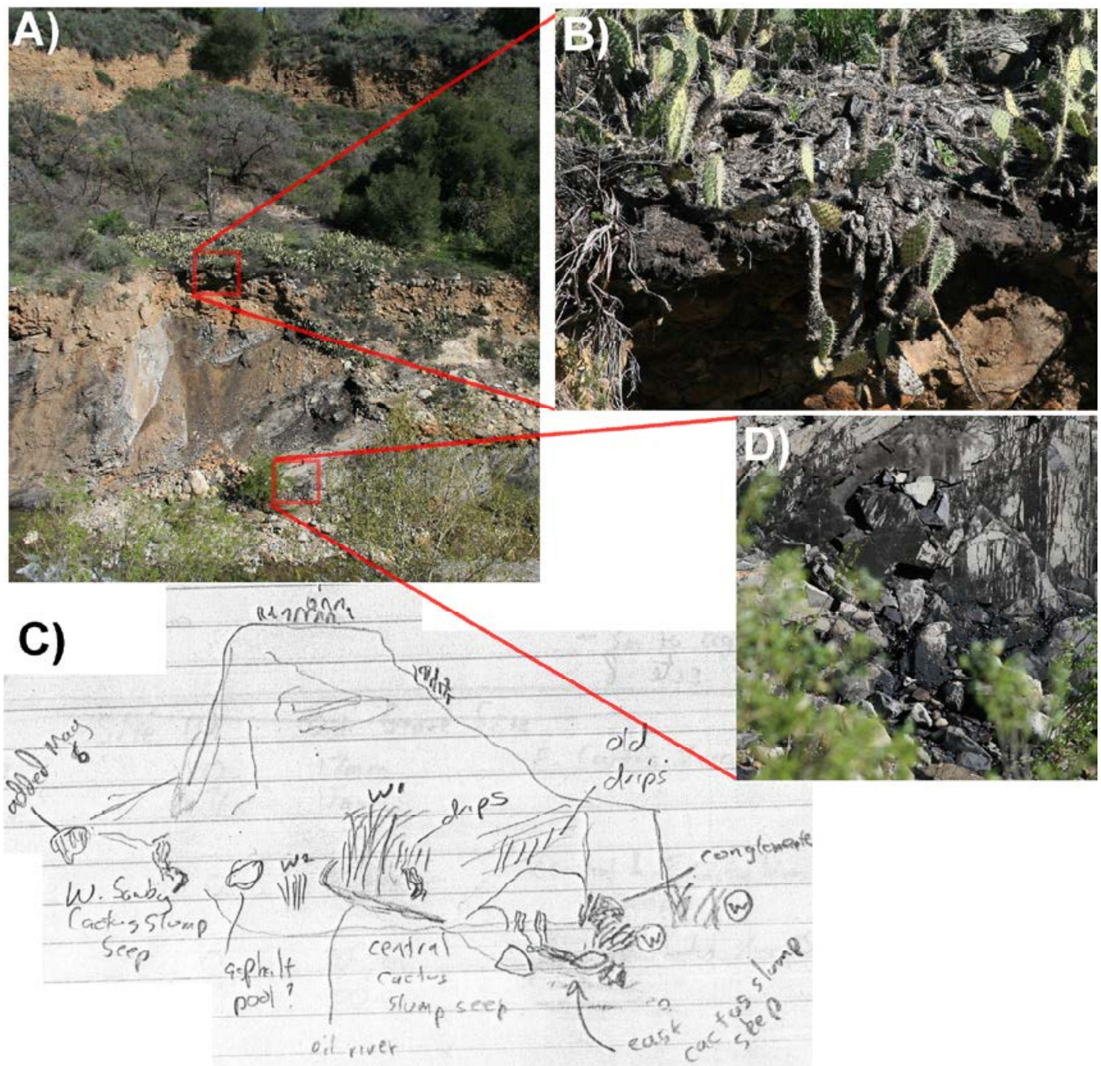

Fig. 24. Cactus Slump Seep Area and Tar Cap photos. **A)** Wide field of view (Dead Duckling Oil Pool is in the lower right corner of the photo behind the trees and the Cactus Slump Tar Cap is in the upper central portion of the photo. **B)** Narrow field of view image of tar mat at edge of stream bank showing slumping of cactus. **C)** Sketch of Cactus Slump Seep Area. **D)** Narrow field of view image of oil seepage and accumulation at bottom of the stream bank. Photos from Site 5.

4.11 East Cactus Slump Seep and Dead-Duckling Oil Pool (DDOP)

By the end of Jan. 2005 oil from the East Cactus Slump Seep began to accumulate in a low area of the streambed at below the Cactus Slump Tar Cap (**Fig. 25**).

Fig. 25. By the end of Jan. 2005, a large oil pool formed in the streambed of Santa Paula Creek as the floodwaters began to recede. The area in the lower right quadrant of the photo will become the site Dead Duckling Oil Pool (DDOP) will form in 2008 approximately 3-m streamward of the oil pool at photo center. See **Figs. 26** and **27**.

By Jan. 2008, actively flowing water had rearranged the streambed alluvium to form a channel approximately 3-m streamward of the cliff-face (**Fig. 24**). By May 2008, as the water levels dropped, some of the oil from the central and downstream seeps in the Cactus Slump Seep Area continued to flow across the streambed directly into the actively flowing channel and some, arising from a seep site behind a conglomerate boulder at the cliff-base, pooled in a secondary channel braid which had formed between the accumulated streambed alluvia and talus and a large bedrock outcropping in the streambed. This pool was named the Dead Duckling Oil Pool (DDOP) in memory of five dead oiled ducklings, which were discovered in the growing pool, (**Figs. 26-30**).

Fig. 26. This Jan 2008 shows where DDOP formed as water levels began to recede and the secondary stream channel braid was isolated. Submerged bedrock outcropping in lower right corner of photo formed the streamward boundary of the pool in May 2008. Also note conglomerate boulder below contorted shale and dislodged tree in **Fig. 21**.

Fig. 27. A. Photo of Dead Duckling Oil Pool, located under Cactus Slump Seeps, at the edge of the Santa Paula Creek. Inset shows an oiled duckling. **B.** East view, showing flags located (and held upright by the oil viscosity) every 1 m. Photo from Jul. 2008.

Fig. 28. On 24 Nov. 2008, under low water conditions, Dead Duckling Oil Pool (DDOP) was 10.4-m long by 2.1-m wide (maximum) 0.22-m thick at location of maximum thickness.

The DDOP appeared to be growing rapidly and it was decided that it would be advisable to measure the oil volume so we could estimate the threat to wildlife. The standing oil volume in the DDOP was estimated according to the following protocol. Every 1 m along the pool's longitudinal axis, the pool width was measured. At each of these transects, several measurements of the oil thickness were made with a rod. Thicknesses varied between a few centimeters and 25 cm of oil, often overlying layers of water and sediment. Oil thickness was determined by plunging the rod to various depths, then vigorously lifting the rod to see if any of the deeper water was sucked upwards atop the oil layer, then re-plunging the rod to a deeper depth. These measurements then were integrated with the trapezoidal-method over the pool dimensions.

Analysis of 2008 photo data showed that stream flow levels from the winter of 2007-2008 diminished sufficiently to allow the oil pool to form between Feb. and May 2008. The pool's oil volume increased from 665 L on 6 May 2008 to 1360 L on 29 Jul. 2008. The pool measured 7-m long, by a maximum of 3-m wide (generally 1-2 m) and 0.2-m deep in Jul. 2008. In Oct. 2008 the volume was 1340 L, and by Nov. 2008 (**Fig. 27**) the volume had increased to 1490 L.

Oil from the seep saturates streambed materials in and around the DDOP. This streambed alluvium forming the oil pool has an asphalt matrix from chronic oil seepage similar to the rust-colored conglomerate above the East Cactus Slump, which formed in an ancient riverbed (**Figs. 26** - **28**). Thus, it is possible that some oil is being absorbed into the non-cemented (primarily sandy and larger cobble sediments) streambed alluvium surrounding the pool. Because the asphalt cobble matrix was resistant to water flows, the pool structure persisted over the winter of 2008-2009.

Fig. 29. In Mar. 2009. Oil surface was disturbed bringing some of the water underlayer to the surface. Water will resettle to the bottom. As the lighter components volatilize and the oil becomes denser, water and oil form layers.

The DDOP maintained its oil volume until river flows once again increased during the winter of 2008-09 causing the pool to overtop and to discharge the oil into the actively flowing stream. **Fig. 29** shows water suspended on the oil pad; the water will eventually settle to the bottom. The pool again formed in Mar. 2009 as the flows receded and was estimated to contain 697 L oil. The footprint of the pool remained relatively unchanged between Nov. 2008 and Mar. 2009, but the oil volume decreased.

The DDOP was photographed in May 2010 but not measured. Its dimensions and apparent volume decreased markedly since the Mar. 2009 survey (**Fig. 30 top**). The 3-m long primary oil pool area adjacent to the bedrock outcropping had filled with sand, consequently much of its former volume had been lost and, because the streambed configuration had changed downstream of the bedrock, 7 meters of oil pool no longer existed and the oil pool now emptied into SPC immediately downstream of the bedrock outcropping rather than downstream as in earlier photos.

Fig. 30. The DDOP decreased markedly in footprint and volume between Mar. 2009 (**Fig. 29**) and May 2010 (upper image). Note sand fills much of the pool, oil is emptying just downstream of the bedrock outcropping, and talus and vegetation at the cliff-face in comparison with **Figs. 26** and **27**. Larger area view Mar. 2012 at the center of left 1/3 of photo (bottom image).

Measurements of the Dead Duckling Oil Pool dimensions were integrated to determine the total oil volume (**Fig. 31**) in the pool for observations in 2008-2009, covering a complete hydrologic cycle. Total oil volumes in Apr. 2008 and Apr. 2009 were similar; however, visual observations that the pool contained negligible to no oil in Jan. 2009 suggested the pool had been flushed. Direct measurements were not attempted in Jan. 2009 due to high river levels preventing safe access to the streambed, thus observations were visual from Route 150. Based on an assumed zero oil value during winter seasonal storms and high river flows, oil in the pool increased approximately linearly from the beginning of the year through early summer (Jul. 2008), and then increased little into the fall. This is consistent with hydrologic and/or aquifer influencing oil emissions, which would be at a minimum late in the dry season, i.e., fall 2008.

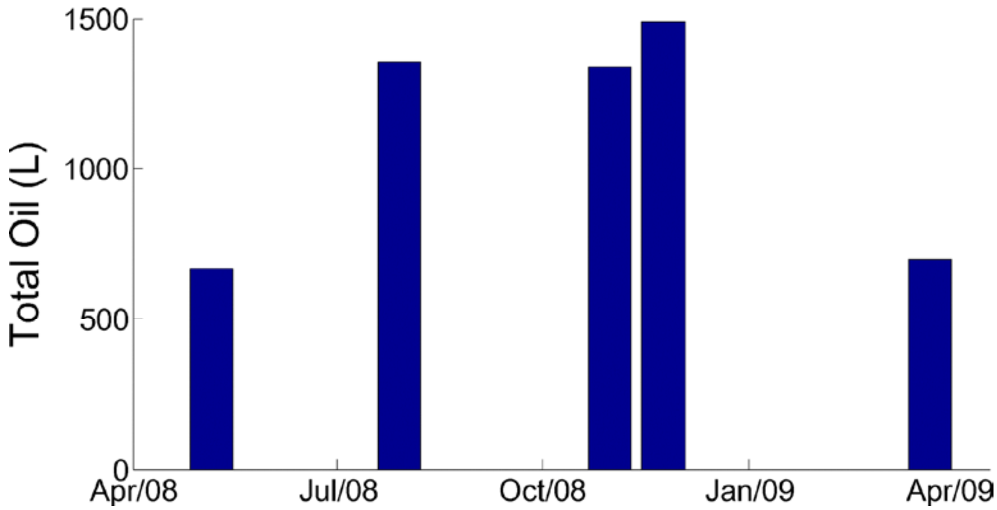

Fig. 31. Time series of total oil volume in Dead Duckling Oil Pool. Total oil in Jan. 2009 may have been zero had the pool been flushed by rains.

On 6 Mar. 2012, the surface area of the contained oil in DDOP was similar to that documented in 2010 (**Fig. 30 Bottom**) but, again, the volume was not measured. A large eddy cut into the streambed may be seen at the center of the right 1/3 of the photo. The water surface within the eddy was covered by an oil slick. Note the steep angle of the exposed cobble face of the concavity reveals that the cobbles are held in a fresh asphaltic conglomerate similar to the older rust colored conglomerate seen above.

4.12 Bacterial Mat Pool

There is some fluid (primarily water) seepage on the creek's southwest bank (nearest Highway 150) of the Santa Paula Creek within the study area. Here, several sites produced fluid with extensive bacterial mats and generally producing little or no oil. The primary example of this occurs across the low flow channel from Cactus Slump Seep, where small amounts of oil escape below the creek surface and accumulate in a pool in the streambed (e.g., **Fig. 32**). In contrast to the northeastern side of the creek, bacterial mats are absent from the Cactus Slump Seep Area, although they also are observed at the Culvert Seeps.

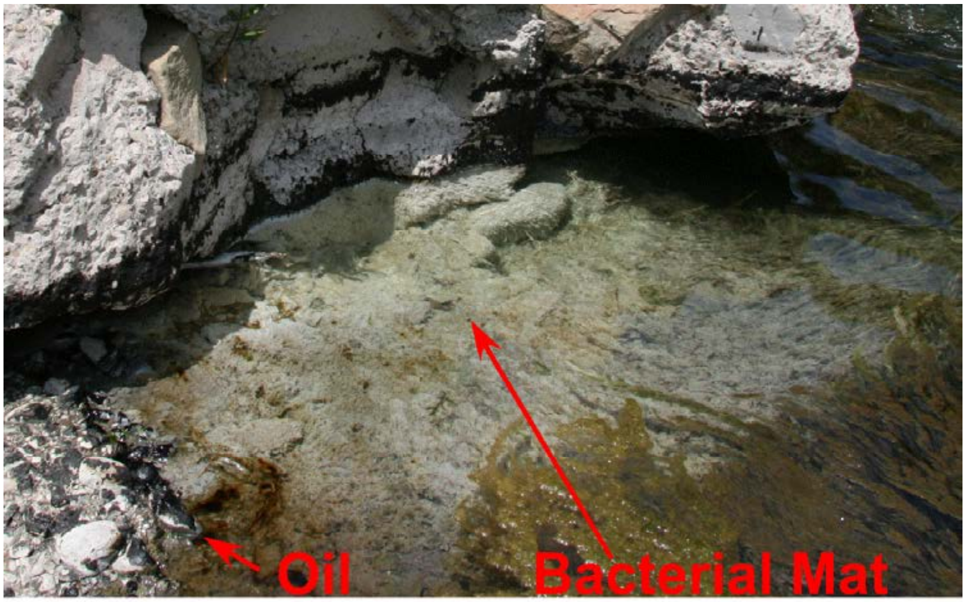

Fig. 32. Oil seep, small oil slick, and bacterial mat indicative of fluid seepage from the south bank of the Santa Paula Creek. 6 May 2008 in the Bacterial Mat pool.

4.13 Cattail Perched Oil Pool

On 23 Mar. 2009 a small, oil covered pool was discovered on the southwest bank of SPC southwest of the Cactus Slump Seep Area and may be part of the same bedrock formation which was intersected and downcut by SPC. The downstream, open water portion of the pool was approximately 2.5-meters long and 1-meter wide (**Fig. 33**). The upper portion of the pool was not measured but was occupied by a dense growth of cattails. The pool was fed by spring water with a sulphurous smell, with small amounts of petroleum gas and oil also discharging from the spring source. Oil and white bacterial mats (likely sulphur reducing) were floating on the water surface; a green alga was growing commensally on the bacterial mats.

Fig. 33. Left - Cattail oil pool highly weathered oil and whitish bacterial mats. **Right** - Image of one of the sulphur water springs that feeds the pool – note oil splattering on rock suggests there are gaseous discharges from the spring. Photo Mar. 2009.

5 Streambank Instability

Additional evidence from historical USGS topographic maps suggests collapse of the northern banks associated with relocation of the road into Thomas Aquinas College and its intersection with CA-135 (**Fig. 34**). Our survey data also indicates bank instability. During our Nov. 2007, survey we observed deep cracks running parallel to the cliff edge along the top of the NE bank of the SPC just upstream of Cactus Slump Seep and Tar Cap (**Fig. 35**). These cracks, the dislodged cacti hanging from the bank (**Figs. 24A** and **24B**), and pre-Jan. 2005 aerial photos (**Fig. 19**) suggest that massive soil erosion has occurred in at least two locations on the northeast bank of SPC within our study area.

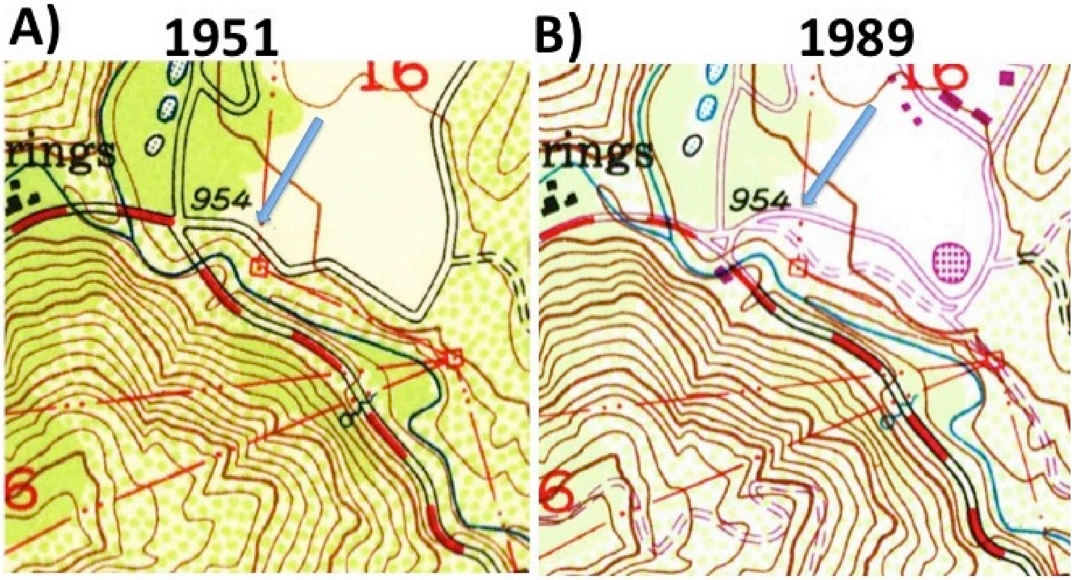

Fig. 34. USGS historic topographic maps from A) 1951 and B) 1989, showing changes in roadways and bridges in study area (USGS, 2014a).

Once the 2005 flood flows receded, sediment overburden loss largely ceased while the summer diurnal heating cycle caused rock wall fragmentation and collapse of shale layers, leading to formation of a sediment overhang, while the lower stream flow allowed talus piles to accumulate. These talus piles and boulders and cobbles deposited in the streambed also likely accumulated oil that seeped into and through the interstitial spaces. Observations made of this area in 2012 revealed that the bank streamward of the previously-described fissures, collapsed into the SPC.

By May 2010, riparian trees and shrubs, stripped from the study area during the winter of 2004-2005, re-grew (from undisturbed root masses) to form a dense overstory canopy covering at least 60 meters of our study area. As the perennial overstory trees and shrubs re-grew and shaded the streambed and channel, the aquatic vegetation became less abundant and played a less significant role in accumulating oil than it did in the first two years following the Jan. 2005 flood event**.**

Fig. 35. **Left)** Location of unstable soil and cracks. **Right)** Examples of soil fissures at top of bank just upstream of the Cactus Slump Seep Area.

Photographic evidence suggests that the Jan. 2005 stormflows entrained boulders, cobbles, pebbles, and sand, which scoured, hammered, and eroded the NE bank, bed, and channel of SPC (**Figs. 36** and **37**). These flows broke chunks off the concreted rock rip-rap wing wall and apron, folded a culvert in half, and destroyed energy dissipaters downstream of the Hwy 150 Bridge 52-105 Bridge. We found a 1.5 m (5 ft.) diameter piece of concrete and boulder rip-rap, estimated to weigh close to 3000 kg, separated from the bridge's channel structure had been moved downstream approximately 61 meters (200 ft) from its proposed point of origin (**Fig. 36**).

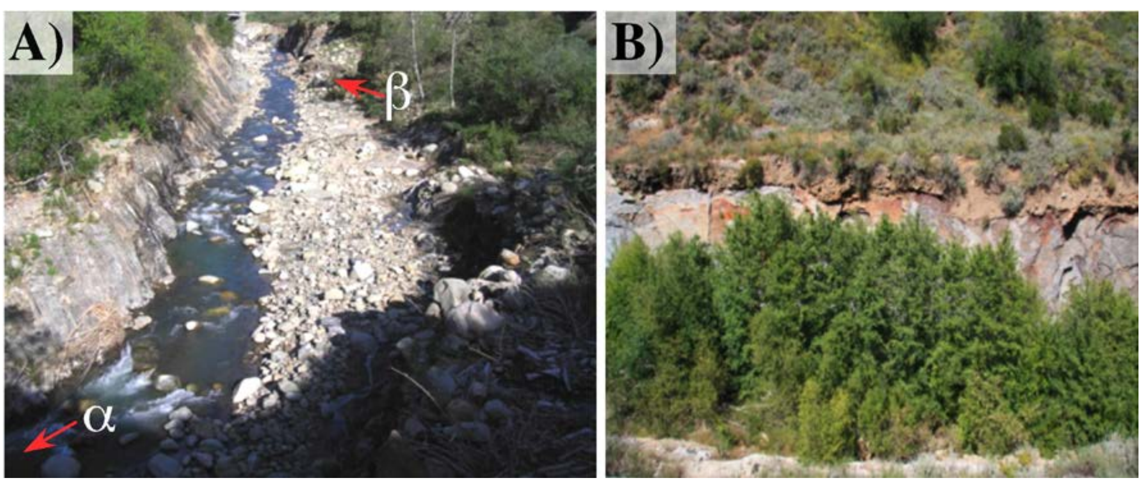

Fig. 36. **A)** In April 2005, three months following the Jan. 2005 storm event, note absence of vegetation (Image looking upstream was taken from approx. 380 meters downstream of the Hwy 150 Bridge concrete channel). **B)** Photo taken ~45 to 65 meters downstream of the concrete riprap channel depicts typical vegetative regrowth in the SPC streambed ~5 yrs after the storm. The 1.5-meter diameter piece of concrete riprap (β) is cloaked in vegetation regrowth at the right edge of photo, and originated at (α).

Fig 37. Left. East-southeast-looking photo from the Hwy 150 bridge showing the channel alignment is directed toward the North bank. The upstream end of Thomas Aquinas Oil Pool lies behind the rip-rap to the left. Most of the North bank is unprotected. **Right**. East-Northeast looking Google Earth overview of valley showing proposed stream water flow during storms.

6 DISCUSSION

6.1 Potential sources

Although seep oil was collected from multiple potential sources in the SPC watershed following the Jan. 2005 storm event, virtually all these sources were determined by the Petroleum Chemistry Laboratory to be “not consistent” with the oil on the Ventura weather buoy and bird feathers. However, a fragment of oil-saturated conglomerate debris, dislodged from an unspecified location, was sampled in SPC below Steckel Park and above Harvey Dam. The sample was found to be consistent with the oil on the Ventura Weather buoy and bird feathers. The oil sample taken from a site termed “Hill Seep” that we propose is the Cactus Slump Seep Area (CSSA) was determined to be “similar” to the oil on the Ventura weather buoy and bird feathers. See Section 3 for oil fingerprinting terminology definitions. Our study area, located near Thomas Aquinas College, encompasses two principal oil seep areas and some of the largest instream oil accumulations. There are seeps upstream that feed into the Thomas Aquinas Oil Pool and the Culvert and Grass Clump Seeps, while downstream, is the CCSA and the associated tar cap.

6.2 Streambed changes and Oil Accumulation

The most conspicuous seasonal change we found during our review of historical images and field studies was the relationship between diminishing streamflows and progressive accumulation of pooled oil in the streambed, which occurred annually as water levels diminished. This phenomenon was noted as far back as Jan. 2005 (**Fig. 25**). For example, emitted seep oil from oil tunnels (anthropogenic) and natural terrestrial seepage can accumulate in pools and behind debris dams along creeks beginning in the late spring as the winter streamflows begin to diminish. Over the summer, oil will continue to accumulate in the streambed until the first significant rainfall and storm flows (winter) at which time it is likely to be transported downstream *en masse*. Depending on the fraction of the oil that is composed of lighter, more volatile hydrocarbons, volatilization will reduce (potentially significantly) the accumulated seep oil volume (and toxicity), while increasing its density. If the accumulated quantity is sufficient, the seep oil could reach the Pacific Ocean under higher flow conditions.

The largest instream accumulation of free oil in our study area was the Dead Duckling Oil Pool (DDOP), which formed in an isolated channel braid in the streambed below the Cactus Slump Seep. The channel braid, which held the DDOP, was comprised of pebbles, cobbles, and boulders many of which appeared to have been cemented together by seep oil to form a semi-permeable to impermeable asphalt-cobble conglomerate. An historic hanging streambed channel formed of hardened asphalt conglomerate of rounded river stone is located 3-4 meters above the existing streambed and immediately downstream of the Cactus Slump Tar Cap, Cactus Slump Seep Area, and Headland Seeps, suggest persistent seepage in this area for decadal time scales or much longer (**Figs. 22** and **30**).

By Jul. 2008, the DDOP grew to over 10 meters in length, reached a maximum width of about 2 meters and contained approximately 1500 liters of oil floating on nascent water (**Fig. 31**). Other smaller pools and oil saturated streambed alluvium accumulated and were fed by other persistent seeps. We found evidence that rising streamflows flushed the DDOP during the winter of 2008-2009 releasing oil into the SPC, likely over a short time. The volume of standing oil in DDOP, diminished between Nov. 2008 and Mar. 2009. This likely was due to active flushing by winter flows, which could have reduced mid-winter oil accumulation even lower than that of Mar. 2009. The fluid volume in DDOP diminished further between Mar. 2009 and May 2010 due to changes in the configuration of the streambed alluvium and sedimentation.

Also, free oil accumulated in the stream channel in eddies behind barriers of debris and aquatic vegetation. Our Sept. 2007 survey revealed the beginning of re-growth of aquatic plants in the stream in pools, which is hypothesized to play a transient but significant role in oil accumulation. This understory aquatic vegetation alternately grows and is removed by annual winter flows. For example, aquatic vegetation present in fall 2007 was scoured by Mar. 2008. As the perennial overstory trees and shrubs re-grew and shaded the streambed and channel, the aquatic vegetation became less abundant and played a less significant role in accumulating oil than it did in the first two years following the Jan. 2005 flood event**.**

The oil that accumulated in the bed of SPC in pools and in aquatic vegetation, was likely to have affected local wildlife and aquatic species in SPC, including but not limited to: macro-invertebrates, fishes, amphibians, birds, and mammals. However, these instream oil reservoirs were unlikely to have contained enough oil to flow 22 miles to the ocean where it would be capable of oiling over 1500 nearshore birds and a weather buoy ¾ mile offshore of the SCR.

Our observations suggest that accumulations of oil in aquatic vegetation, which occupies the lowest, but calmer portions of the channel, would progressively flush as water levels and flows increased during wet weather conditions. The flushing of oil from the DDOP was likely affected by at least two factors–rainfall and local runoff and stormflows in SPC. The first, rainfall and local runoff, enters the oil pool causing its fluid level to rise to its maximum containment volume. Second, the DDOP is a minimum of 0.2 to 0.6 meter in elevation above late season low flow levels. Thus, the oil pool would likely have flushed when water levels in SPC rose sufficiently to cause streamflows to overtop the pools and release the contained oil.

6.3 Santa Paula Creek Streambank Erosion and Collapse

Under normal winter flow conditions, the existing concreted boulder riprap and wingwall on the northeast bank downstream of the bridge appear to be non-critical for erosion reduction. However, during significant storm events, e.g., the 10 Jan. 2005 storm, we propose the stormflows and debris passed through the concrete bridge channel, virtually un-dissipated. Furthermore the boulder riprap armoring the northeast bank may not have extended downstream sufficiently far to protect the soil bank from the erosive forces of these flows.

This would imply that the January 2005 VOBI was caused by heavy rainfall (over 21 inches in 4 days with 10 inches of rain on 10 Jan. 2005). The resulting flood flow, which reached 27,500 ft^3/s on 10 Jan. 2005 (**Fig. 7**) was the highest flow event ever recorded on the SPC flow gage since its installation in 1933. Evidence suggests that these flows entrained boulders, cobbles, pebbles, and sand, which scoured, hammered, and eroded the NE bank, bed, and channel of SPC (**Figs. 35** and **36**). A 10 ft. length of this culvert was crushed and down-folded by the flood flows and debris. These stormflows broke chunks off the concreted rock rip-rap wing wall and apron, folded a culvert in half and destroyed energy dissipaters downstream of the CalTrans Bridge No. 52-105 including a massive concrete piece and boulder rip-rap (**Fig. 35**).

A detailed examination was made of aerial photographs taken before and after the Jan. 2005 storms and of high-resolution photographs of the northeast streambank before and after the storms (**Fig. 19**). This revealed the flood flows scoured and undermined rain-sodden earthen banks and caused catastrophic bank failure in significant areas of natural seepage. The seepage areas were located in the upstream (TAOP) and central portions (CSSA) of the study area. The streamflows stripped layers of soil, shale, and weathered asphalt off bedrock banks and exposed underlying rock faces. This erosion damage to the northeast bank began immediately below the bridge and extended downstream for a distance of approximately 200 meters.

Aerial photographs and field observations reveal that the open concrete trapezoidal channel that underlies the CalTrans Bridge No. 52-105 directs the Santa Paula Creek flow towards an area along the northeast bank between 45 to 60 meters downstream of the end of the existing concrete rip-rap channel – i.e., Culvert Seep (**Fig. 18**). It appears that under the extremely high flow conditions occurring on 10 Jan. 2005, the alignment of the CalTrans Bridge No. 52-105 exacerbated or caused the bank erosion that led to collapse, which resulted in the VOBI.

Continued of evidence of streambank instability was found during a Nov. 2007, survey when we observed deep cracks running parallel to the cliff edge along the top of the NE bank of the SPC just upstream of Cactus Slump Seep and Tar Cap (**Fig. 34**). These cracks, the dislodged cacti hanging from the bank (**Figs. 24A** and **24B**), and pre-Jan. 2005 aerial photos (**Fig. 19**) suggest that massive soil erosion has occurred in at least two locations on the northeast bank of SPC within our study area. Evidence of continuing instability in the northeast streambank below the bridge in our study area was found in cracks (Fig. 35). More recent observations in 2012 and 2013 showed that the bank streamward of the previously-described fissures had collapsed into the SPC.

One implication of the erosion and collapse of the northeastern bank following the 2005 storm events was the opening of fresh seepage vents in existing seep areas, which formerly were covered with earth and layers of shale. The flows reconfigured the streambed and banks causing the formation of seepage pools, numerous oil seepage accumulations, and formation of tarmac-like oil/asphalt conglomerate which cements the streambed materials. This process is certain to occur again in riverine seep areas after significant erosion events leading to greater oil emissions into the river until weathering and other processes lead to their re-sealing.

6.4 Thomas Aquinas Oil Pool Storm Damage and Oil Release

The Thomas Aquinas Oil Pool (TAOP) was well hidden by dense vegetation and first was discovered by the authors in Oct. 2008 when field studies were nearing their end. Because it was well out of the SPC and protected by concreted rock rip-rap associated with the CalTrans bridge, we initially assumed it was not implicated in the VOBI, therefore, we did not collect oil samples for testing. In was in early May 2010 when we received from CalTrans photographic evidence that the Jan. 2005 stormflows over-topped the rock riprap wing-wall constraining the TAOP and likely backflowed through the culvert and flushed through the TAOP we realized that oil from this pool could have contributed significantly to the VOBI.

Thus, oil from the TAOP contributed to oil from seep-saturated soil released from the CCSA. Specifically, a number of factors could have led to oil releases from the TAOP. A CalTrans photograph showed evidence that the concrete rip-rap on the streamside bank of the TAOP was over-topped by the stormflows (**Fig. 38**) Also, SPC stormflows would have increased water to a level where water backflowed into the pool through the culvert that normally drains the TAOP. Additionally, turbid flows from SPC flowed under the bridge directly impacted the filled earthen bank of the TAOP. Stormwaters accumulated in and overflowed the streamside bank of the TAOP dislodging and flushing much of the accumulated oil over the top of bank. The dislodged oil and then flowed freely through the TAOP, into SPC at the Culvert Seep area.

Fig. 38. Silt in grass along top of bank behind the rip-rap and the line of vegetative debris at photo left provides evidence that flood flows overtopped the boulder riprap on the Hwy 150 bridge possibly flushing free oil from the TAOP into the SPC. Photo courtesy of Glen DeSanno, CalTrans-Fillmore Office.

6.5 Streambank Accumulation and Release

Given the number of birds oiled during the VOBI, the amount of oil, which reached the ocean, must have been significant. Observations of the Santa Paula Creek study area (**Fig. 15**) revealed a number of potential sources that could have contributed a large volume of oil into the streamflow during the Jan. 2005 storm event. Sources included: streambank collapse of potentially-oil saturated sediments in the northeastern bank of the SPC, oil accumulated in the TAOP, and oil accumulated in the streambed.

The presence of debris and talus on creek banks and erosion of hillside and stream bank sediments could have played a significant role in oil release. The amount of soil estimated to have been released into the river was ~1350 m^3. The fraction of oil in these sediments from the northeast streambank is completely unknown; however, evidence of oil on the riverbank, and in the tar cap above (**Fig. 22**) indicates a significant oil fraction. This oil fraction likely was quite high in some areas, such as Cactus Slump Seep Area. As a guideline, if one assumes 10% sediment oil, then 1000 barrels of oil could have been released into the SPC from riverbank collapse and erosion. The TAOP was found to have ~100 bbl of asphaltized and partially asphaltized oil during the surveys. Thus, it is possible that up to several multiples of the surveyed oil had accumulated in the TAOP that was flushed into river, or 10 to 50% of the potential streambank erosion contribution. Streambed accumulation in our study area could have accounted for at most a few tens of barrels of oil based on surveys of the DDOP (**Fig. 31**), which contained at most 9 barrels of oil.

Based on these estimates, collapse of highly oil-saturated streambank is most likely to pose the greatest risk in future VOBI-like events. Note, this estimate of oil contributions to the VOBI from our study area is a lower estimate, because evidence (**Fig. 13**) shows other sources contributed.

Prior to the Jan. 2005 flood flows, the culvert was undamaged, and bank extended streamward an additional 2 m. Should the unprotected soil bank immediately downstream of the concrete rip-rap collapse, the TAOP could drain and contribute to future bird oiling incidents. This pool’s origin is uncertain, but may have formed following the construction of the Hwy 150 Bridge and the related diversion of Santa Paula Creek and damming effect caused by the concreted riprap bank protection.

6.6 River biota impact

Macroinvertebrate studies were conducted in Santa Paula Creek in (Wilson, 2001). These studies were conducted in response to an oil spill, which occurred as a result of a trucking accident near Steckel Park on 28 Feb. 2000 (OES# 00-0944). Studies showed that macroinvertebrate populations were largely restricted to oil tolerant species downstream of chronic seepage areas due to chronic oil in Sisar and Santa Paula Creeks, from the many natural oil seeps upstream of Steckel Park (Harrington, 2000). However, even oil-tolerant macroinvertebrates can be affected by massive oil releases from either natural or anthropogenic events. It is anticipated that future bird oiling incidents could occur as a result of natural disturbances and erosion of oil saturated soil and talus accumulated in and adjacent to the streambed during catastrophic high flow events.

6.7 Oil Transport to the Ocean

Although VOBI was one of California’s largest recorded marine bird oiling events, there only was a single report of a surface oil slick near the SCR mouth on 14 Jan. 2005 (Henkel, 2005). Based on the number of birds oiled (Leifer and Wilson, 2014b), it was inferred that a significant amount of oil must have entered the ocean and encountered the birds (and the Ventura weather buoy). This oil was not obvious to on-the-ground or on-the-water observers.

The fact that an extensive slick was not observed on the sea surface on 12 Jan. 2005, when the first oiled birds were discovered at Ventura Harbor, is somewhat unexpected given the numbers of oiled birds. One possible explanation could relate to weathering processes during transport to the ocean in the SCR, specifically dispersion in highly turbulent wave environment and/or river flows in conjunction with oil-mineral aggregate formation of small oil droplets suspended in the water column.

Initially, wind waves and surf driven by the storm were high, which efficiently disperses surface oil (Farmer and Li, 1994) as would turbulence in the river environment under stormflow conditions (**Figs. 9 and 10**). This oil then remains in suspension until conditions calm and the droplets can rise back to the surface, re-forming an oil slick, unless it forms oil-mineral aggregates. This occurred during the Braer Spill off Shetland Islands, Scotland, in 1993 (Farmer and Li, 1994). Importantly, reports during VOBI did not notice any re-surfacing oil slicks or unusual tar ball or free oil accumulations on local beaches.

Given the sediment load carried by the river (**Figs. 8 and 9**) oil-mineral aggregate formation likely was important. Aggregation is the process, where small oil droplets are attracted to and aggregate on clay-sized particulate matter (<2 μm) suspended in the water column. These aggregates form under environmental circumstances, which involve the presence of oil, clay-sized particles, and sufficient water turbulence to disperse the oil slick into micron sized droplets. These droplets then bond to the sediments and generally remain suspended in the water column due to turbulence (Farmer and Li, 1994). Aggregation of oil and clay increases the oil droplet density. Once the turbulence subsides, these particles will settle to the bottom (Payne et al., 2003). Note, the available observations cannot discriminate between aggregation in the river or the coastal ocean.

Thus, the river stormflow would have transported most of the oil below the water surface. Some of this oil would re-surface in the ocean as storm conditions calmed, but this fraction must have been small given the absence of observations of extensive slicks and beach oiling despite many observers. The extensive sediment plumes in the satellite imagery (**Fig. 8**) shows the enormous load of fine sediments that were carried by the river well out into the ocean, actually reaching at least to Santa Cruz Island.

6.8 Seasonal Oil Seepage Activation and Deactivation

There are a number of processes that lead to seasonality in oil emissions. These include processes related to aquifer pressure, but rains and elevated streamflows was demonstrated to erode capping layers leading to seepage activation. Elevated stream levels also will overflow (natural) oil catchments, leading to a seasonal release.

Seasonal rains in California raise water tables and aquifer pressures. These physical changes have been hypothesized in the Coal Oil Point seep field to lead to enhanced emissions, by increasing reservoir pressure (Bradley et al., 2010). Thus, oil accumulated in subsurface migration pathways will be forced out more rapidly after storms. Unfortunately, data were inconclusive with respect to whether there was an overall (or local) significant decrease in seepage over the hydrologic cycle beginning with winter rains.

A different seasonal rain impact lies in the flushing of oil accumulations within the streambed such as the DDOP when streamflows increase (**Fig. 31**). For example, the 1500 L found to have accumulated in the DDOP was released as a single pulse in Jan. 2009. Over the course of the study, winter flows changed streambed contours, minimizing opportunities for oil accumulation in pools. Oil trapped by aquatic vegetation (**Fig. 21A**) also is released simultaneously during high flow conditions.

The surveys revealed a third process that was affected by seasonal rains related to erosion and streambank collapse. Increased flows wash away clay and tar caps, which plug oil migration pathways, forming open wounds (to use an analogy), allowing increased oil emissions in the first few months following storms. These emissions, likely will begin to seal through oil and tar accumulation and weathering over a period of years to decades to form asphaltic plugs that block hydrocarbon migration. Weathering is the loss of volatile components from oil due to exposure to air and sunlight.

In the 5 years since the record flows and bank erosion of Jan. 2005, some of the smaller point source seeps, e.g., the Culvert Seep Area (**Fig. 18**) and many small seeps weeping from hairline fractures in the cliff-face, became inactive.

6.9 Seep Geologic Setting

The orientation of geologic rock layers, terrain topography, and the presence of significant seepage, strongly suggests that the Cactus Slump Seep Area (**Fig. 16**) is located at or near a fault. This seep area was located at a point along the streambank where higher up there was a valley between two ridges, which is consistent with a fault interpretation.

There likely is poor subsurface connectivity between the Cactus Slump Seep Area and the Culvert Seeps (including the TAOP). This conclusion is based in part on the differences in the character of the fluid emissions; the Culvert Seeps exhibit bacterial mats and has high water content, while the Cactus Slump Seeps do not. At two places on the roadside of the highway, springs produce strong hydrogen sulfide odors with pools that are heavily colonized by bacterial mats, one of which is across from Photo site 0 (**Fig. 15**). The presence of bacterial mats argues that the fluid seep emissions are primarily water rather than primarily oil.

7 Recommendations

7.1 Mitigation Considerations

7.1.1 Streambed

We proposed in an earlier annual project report that modifying streambed morphology could be a possible mitigation strategy–specifically, through emplacement of a shallow concrete dome in the concave hollow between the bedrock outcropping and the northeast bank of the Santa Paula Creek where the DDOP forms to prevent oil accumulation. However, recent surveys showed sediment deposition had filled the concave hollow obviating at this time the need for a concrete dome. Note, erosional processes at some point (absent a dome) may return the streambed configuration to a concave hollow, re-creating the DDOP. Thus, streambed mitigation efforts were considered as not advisable as it would be a temporary solution. Meanwhile, the study concluded that oil associated with the TAOP and in streambank sediments posed a significantly larger threat, discussed below.

Despite increasing amounts of pooled oil accumulated in the study area during the dry season of 2008 and the flushing of as much as 1490 liters of oil from the DDOP into SPC during the winter of 2008-2009 (**Fig. 31**), no significant oiled bird event was reported, indicating that the VOBI resulted from a far greater oil release. This suggests that significant oil did not reach the ocean, although close to DDOP there could have been impacts. Thus, the effect of released oil on biota in normal rainfall years likely decreases with downstream distance from the seep source(s). However, for high flow conditions, such as during the VOBI, riverine oil biota impacts primarily were on vegetation (**Fig. 13**) and should extend between the source and the ocean.

7.1.2 Streambank

These massive storm events cause erosion that undercuts and collapses riverbanks, potentially leading to the addition of oil-saturated soils to floodwaters. Seasonal increases in streamflows and raised river levels also can cause overtopping of pools formed by natural or anthropogenic barriers. Where these pools accumulate oil, their contents can be released into the active streamflows by overtopping. Higher stream flows associated with storms also increase the rate and efficiency of oil transport to downstream areas.

Our observations strongly suggest that the VOBI was related to and exacerbated by the configuration and alignment of the Highway 150 bridge structure (52-105) over the Santa Paula Creek near Thomas Aquinas College, just north of Santa Paula (**Fig. 38)**. It is our conclusion that future VOBIs from Santa Paula Creek can be mitigated if the *appropriate* structures are installed to prevent future oil accumulation and bank failure.

Other stream-related anthropogenic activities also could affect the likelihood and severity of future incidents arising from the natural oil seepage areas near Thomas

Aquinas College. In March 2010, CDFW issued a Lake and Streambed Alteration Agreement to CalTrans to build a series of 14 rock weirs downstream a distance of 400 feet below the apron of the Hwy 150 bridge to improve fish passage and to act as energy dissipaters to slow stream flow velocity downstream of the bridge (**Fig. 39**). Based on our extensive observations in this area, we are concerned that these new constructions will do little to reduce the velocity of streamflow storm flows discharging from the trapezoidal channel, which underlies the bridge, under conditions of extremely high flow, such as occurred during VOBI. Where such stormflows are comparable to those observed in Jan. 2005, they could cause further significant erosion of the unprotected NE northeast-filled soil bank of the SPC immediately downstream of the end of the concrete rip-rap below the Highway 150 bridge. This risks large-scale erosion and disturbance of the TAOP and possibly causing another major oil release. Furthermore, we propose the rock weirs likely will act as oil catchment dams, accumulating substantial amounts of free oil during seasons when streamflows are low. Accumulated oil will be transported downstream, *en masse* during stormflows and likely could affect downstream biota and potentially marine life.

In addition, the Google Earth image of the recent changes by CalTrans to the streambed and banks (**Fig. 39**) shows oil accumulation at the highest catchment basin. These "functionally oil catchment basins," are upstream of the Cactus Slump seep area, thereby accumulating oil from further upstream seepage in and further upstream in the watershed. During stormflows, these structures will be submerged and it is unclear if they will reduce (or even amplify) erosion of the northeast bank including the segment that separates TAOP form the SPC, whose overtopping was identified in this study as a significant factor in the VOBI.

Fig. 39. Google Earth image of study site in 2013, showing recent CalTrans riverbed modifications. Arrows show schematically the high flow direction (which extended further downstream than shown). TAOP – Thomas Aquinas Oil Pool.

We are concerned that these recent CalTrans modifications may not address the underlying factors behind oil accumulation and release that led to the VOBI. At a minimum, mitigation of future VOBI events requires appropriately armoring the northeast bank to prevent the earthen bank enclosing the TAOP to erode releasing oil into the Santa Paula Creek. Furthermore, oil accumulated in the CalTrans structures will impact downstream habitats at elevated streamflows when accumulated oil is released (even from normal storm flows, such as in Jan. 2009 – **Fig. 31**). In fact, the DDOP only accumulated oil for half a year, and then allowed it to pass through. The multiple weirs will accumulate oil more effectively because they are a series of containment structures.

> We advise CalTrans to extend armoring of the damaged rip-rap bank protection further downstream to protect the filled-soil bank that contains the TAOP. We hypothesize that if the armoring of the northeast bank of the SPC had extended further downstream and/or adequate energy dissipation structures been in place within and downstream of the bridge, then bank failure during VOBI (**Fig. 19**) would have been diminished (**Fig. 39**). Note, this does not imply erosion could have been prevented during an event of this magnitude; however, the lack of sufficient armoring could have played a role in the VOBI.

7.2 Recommendations for further investigation

This study revealed a number of important processes that are at best poorly understood. For example, based on laboratory tests, Lee et al. (2001) hypothesized that oil-mineral aggregation was important in a river oil spill; however, there is no field observational literature and very few published laboratory studies. Given that extensive and persistent oil slicks were not observed, but numerous birds were oiled, we hypothesize that oil-mineral aggregates and suspended oil near the sea surface played a role in oiling marine birds in addition to the well studied oiling of birds by surface oil slicks. Certainly personal experience suggests that placing an object below the surface where mousse exists in near surface suspension, oils the object. Thus, it is reasonable to hypothesize that oil-mineral aggregates and suspended oil pose a risk to birds and other wildlife; however, this is an area that clearly is poorly understood and merits further research.

Terrestrial seepage is common in many areas of California and leads to oil-saturated soil. Where such soil is eroded by rivers and streams, there always is the potential for large-scale releases; yet, other than the risk associated with the SPC studied and reported herein, other similar sources along coastal and inland streams and rivers remains largely unknown and unmapped. Assembling lists of rivers with potential for large-scale oil releases would aid future oil spill responders to more quickly identify potential sources for fingerprinting. Furthermore, the literature on terrestrial seepage is minimal compared to that for marine seepage. Research on terrestrial seepage is needed to quantify their chemistry, magnitude, and biological impacts.

Some of these riverine seeps could be responsible for some of the numerous marine oiled birds recovered in Ventura County each year, such as the SPC. We propose that an oil chromatogram library should be created for these seeps to aid in fingerprinting oiled birds along the coastline. For example, although all the evidence reported herein suggests a source from the Cactus Slump Seep and TAOP, no source oil location was pinpointed that was ‘consistent’ – i.e., a good match with the oiled bird feathers. A comprehensive library of source oil chromatograms would enable more precise source attribution and discrimination from anthropogenic riverine oil spills.

Significant oil accumulation in the Dead Duckling Oil Pool was documented and quantified – up to almost 1500 L, which then was released by overtopping during rains in Jan. 2009, with an unknown impact on downstream river biota. Recent CalTrans riverbed modifications (**Fig. 39**) create numerous cascading catchment basins. It is unknown what effect these will have in terms of overall oil accumulation and pulse release. Certainly, multiple catchment basins should be more efficient at oil accumulation and would lead to potentially larger instream releases than observed from DDOP. Therefore, oil accumulation in these structures should be monitored to assess build up and then impacts on biota surveyed.

The questions raised in this study highlight the need for further investigation of riverine seepage and river oil spill processes. In general, there are few to no publications on most aspects that were investigated in this study; yet as the VOBI clearly illustrates, the ecological impacts can be severe.

For example, some key questions:

What quantity of oil release is required to reach the coast from an inland area?

What are the key water flow parameters affecting the fate of oil in streams and rivers?

What is the roll of oil-mineral aggregation oil suspension, and surface oil, in river transport of spilled oil?

Et cetera.

8 Summary

The investigation by CDFW-OSPR Wildlife Protection concluded that the VOBI was unrelated to oil production or transportation. Instead, we conclude that it was caused by a synergistic combination of natural riverine oil seepage and accumulation, stormflows, erosion, and possibly mineral aggregation. Also playing an important role was the presence and distribution of migratory birds during the VOBI.

Our study area was located just downstream of Thomas Aquinas College between Steckel Park and the Highway 150 Bridge No 52-105 in Ventura County California, more than 22 miles from the Pacific Ocean. Despite this great distance, the CDFW Petroleum Chemistry Laboratory found that the oil on the bird feathers and weather buoy collected during the Jan. 2005 VOBI was ‘similar’ to the oil from one of the major instream natural seeps within our study area – Hill Seep a.k.a. Cactus Slump Seep. An oil that was ‘consistent’ with the VOBI bird feathers was found in a Santa Paula Creek debris sample of unspecified location, as well as with beach tar balls.

A review of rainfall and streamflow data in the Santa Paula Creek watershed between 7 and 11 Jan. 2005, revealed that nearly 23 inches of rain fell in the Santa Paula watershed during this five-day period with over 10 inches of rainfall occurring on Jan. 10, 2005. This excessive rainfall resulted in flows that peaked on 9 and 10 Jan. 2005, reaching 13,900 cfs and 27,500 cfs, respectively. The stormflows on 10 Jan. were the highest ever observed at the Santa Paula flow gauge since it was installed in 1933.

We propose that stormflows entrained boulders, cobbles, pebbles, and fine-grained sediments causing bank erosion and slumping of massive amounts oil-saturated sediments near the Cactus Slump Seep Area into actively flowing waters in our study area near Thomas Aquinas College. Evidence also suggested that floodwaters flowed through a large streamside oil pool (the Thomas Aquinas Oil Pool) in the same area, likely causing a large amount of oil to be washed into Santa Paula Creek.

The photographic time-series observations within our study area from 2005 through 2010 revealed changes a range of processes. These included changes in natural seepage emissions, oil accumulation in the Dead Duckling Oil Pool and its periodic drainage, rock falls and talus accumulation and erosion, changes in the configuration of the bed, banks, and channel of Santa Paula Creek, a range of flow regimes, and natural recovery of instream riparian and aquatic habitats.

Based on aerial images and field observations of bridge alignment and erosion patterns, it is proposed that the CalTrans Bridge No. 52-105 is aligned in such a manner as to direct stormflows toward the northeast bank of the Santa Paula Creek. This alignment either caused or contributed to catastrophic bank failure along a 200-meter or longer streambank section on or about 10 Jan. 2005. During this storm event, water also overtopped the concreted boulder rip-rap along the northeast streambank just downstream of the bridge. Flows washed into and through the Thomas Aquinas Oil Pool, a large oil pool confined on its southwest side by the riprap and a filled-soil bank. This flood streamflow was reported to have caused bank erosion just downstream of the culvert and may have released additional oil from the Thomas Aquinas Oil Pool into the Santa Paula Creek.

Our studies revealed that the largest oil pool in our in-stream study area, Dead Duckling Oil Pool, overtopped during the winter of 2008-09 as water levels increased and the accumulated oil flushed into the actively flowing Santa Paula Creek. Although the pool contained approximately 1500 liters of oil, no significant bird oiling was reported in the Ventura area, suggesting that VOBI would have involved far larger quantities of oil.

Although oil was observed being transported down the Santa Clara River and entering the ocean on 10 Jan. 2005, the only oceanic oil surface slick was reported during a single overflight as an oil sheen on 14 Jan. Thus, the region over which birds were oiled was inferred from circumstantial evidence, i.e., small tarballs on beaches, oiled jetsam, the Ventura weather buoy off Ventura Harbor. The possible extent was evaluated from satellite imagery of silt plumes and the known behavior and distribution of affected birds, discussed in Volume 2, this report. Based on this evidence, and the extreme streamflows in the Santa Paula Creek, we conclude that oil entered the Pacific Ocean from the river mouth sometime on/or shortly before 10 Jan. 2005 affecting approximately 15 to 17 miles of coastal waters from Ventura southwards to the south of Mugu Lagoon. Based on the oiled buoy, the affected area extended offshore at least to ¾ mile offshore of Ventura Harbor.

Photographic evidence (**Fig. 9**) documented an oil sheen entering the Pacific Ocean on 10 Jan. 2005 from the Santa Clara River. Oil also was found on the Ventura weather buoy, which was consistent with oil on bird feathers. However, despite one of the largest bird oiling events in California, no significant and persistent oil slicks or significant beach oiling were reported. Given the turbulence of the river stormflow and the ocean, during the storm, significant surface oil slicks could not form until waters calmed, and the oil would have remained in suspension while conditions were highly turbulent in the river and ocean, likely forming oil-mineral aggregates. If significant oil had remained unaggregated we propose it would have reformed surface slicks after the storm conditions abated that the large numbers of observers on beaches, on boats, and in aircraft likely would have reported. Therefore we conclude that the birds likely were oiled by suspended oil and possibly oil-mineral aggregates.

To our knowledge, this is the first strong evidence supporting large-scale bird oiling associated with submerged oil, and merits further study.

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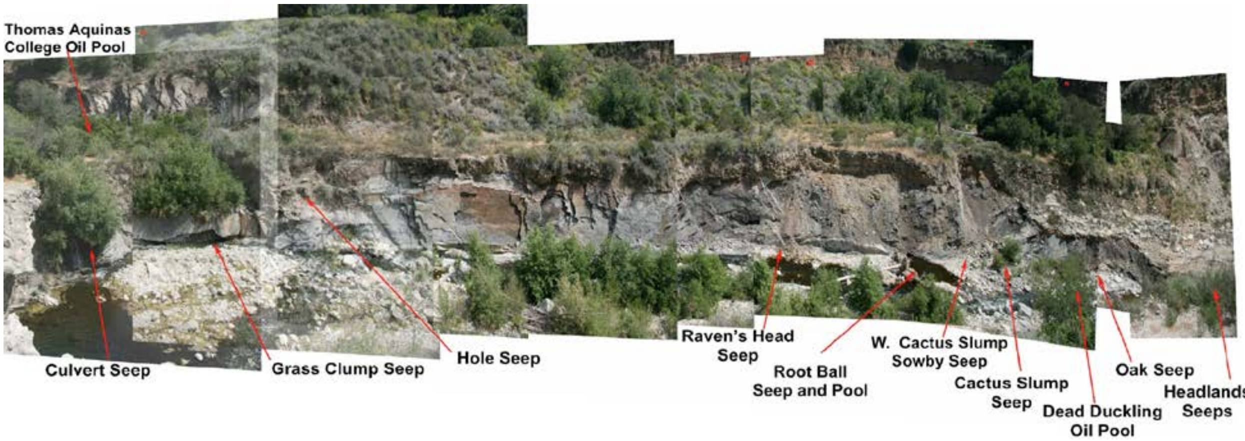

Plate 1. Photomosaic of the Santa Paula Creek study area.

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Appendix A – Oiled Bird Chromatograms