E&B Oil Development Project

City of Hermosa Beach

Planning Application

Appendix H

Subsidence and Induced Seismicity Report

E&B Natural Resources

www.EBNR-Hermosa.com

Prepared for:

E&B Natural Resources Management Corporation
1600 Norris Road
Bakersfield, California 93308

Subsidence and Induced Seismicity Technical Report

E&B Oil Development Project

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Project Number: LA0266

November 9, 2012

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November 9, 2012

E&B Natural Resources Management Corporation
Attn: Mr. Mike Finch
1600 Norris Road
Bakersfield, CA 93308

Subject: Subsidence and Induced Seismicity Technical Report

Dear Mr. Finch,

Enclosed please find our Subsidence and Induced Seismicity Technical Report for the E&B Oil Development Project, dated November 8, 2012.

Sincerely,

Mark Grivetti
Geosyntec Consultants
924 Anacapa Street, Suite 4A
Santa Barbara, CA 93101

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EXCUTIVE SUMMARY

E&B is proposing an oil development project for the Hermosa Beach area. The Hermosa Beach area overlies the northwest portion of the Torrance Oil Field. The proposed project will utilize directional drilling from an onshore site to access crude oil and gas reservoirs located in both onshore and offshore areas. The project will involve completing wells and producing oil, gas and associated water from the project site, and re-injecting the produced water. The project will also include a comprehensive monitoring program. This report summarizes an evaluation of the potential for the project to cause land subsidence and to induce seismicity.

<u>Subsidence Evaluation</u>

Documented anthropogenic (man-made) cases of land subsidence in the Los Angeles Basin have generally been caused by either groundwater pumping or oil field extraction operations. Historical impacts associated with subsidence have included damage to structures, underground utilities, and sea water inundation. Subsidence related to oil extraction was first observed in the early 1940s in the Long Beach/Wilmington area, where a cumulative total of 29 feet of subsidence was observed. Mitigation, primarily through the replacement of the extracted fluid through the 1960s and beyond has since eliminated, or nearly eliminated subsidence in that area. The extreme amount of documented subsidence that occurred in Wilmington area will not occur in the Hermosa Beach area due to the geological differences between the areas. A closer geologic analog to the Hermosa Beach area is the Redondo Beach area where as much as 2 feet of subsidence occurred between approximately 1950 and 1990 during oil field extraction operations. The measured subsidence in the Redondo Beach would have most likely been much less or eliminated if suitable water re-injection operations had been conducted.

Based on evaluation of the site and nearby geologic conditions, comparison to other oil fields, and analysis of project components, it is concluded that the potential for damaging subsidence to occur as a result of the proposed oil development project is less than significant. This conclusion is based on the following:

- Oil operations will be planned and conducted under the oversight of the Division of Oil, Gas, and Geothermal Resources (DOGGR).
- Oil field operations will include re-injection of produced water.
- The project includes a plan for monitoring potential subsidence with triggers (action levels) for operational review and changes should evidence of

subsidence be observed. The plan is designed to detect subsidence in its earliest stages and action levels include shutdown of production should fractions of a foot of subsidence be observed.

Induced Seismicity Evaluation

The potential of the oil development project to cause induced seismicity was also evaluated. A very small fraction of oil field injection and extraction activities in the United States have induced seismicity at levels that are noticeable to the public, and induced seismicity is not expected to occur during the proposed oil development operations in Hermosa Beach. The seismicity evaluation for this project included a review of past reported induced seismic events associated with oil fields in the Los Angeles Basin and an analysis of seismicity in the northwestern portion of the Los Angeles Basin between 1981 and 2010.

There are examples of past oil field operations in the Los Angeles Basin inducing seismic events. For example, very shallow earthquakes at the Wilmington Oil Field occurred between 1947 and 1961 as well as possible fault creep at the Inglewood Oil Field in the early 1960s. These events have been associated with the extreme amounts of land subsidence that occurred in these fields that resulted from the lack of proper water re-injection operations. Very little to no subsidence is expected to occur during the proposed oil development in Hermosa Beach, and therefore, these types of "subsidence caused earthquakes or fault creep" will not be produced by the proposed operations.

Results of the seismic analysis completed as part of this investigation indicated that most of the recent seismicity (1981 to 2010) in the northwest portion of the Los Angeles Basin occurs at depths below 8 kilometers (5 miles) which are the result of natural tectonic stresses. Except for one shallow, low magnitude earthquake, located west of the Wilmington Oil Field, no shallow earthquakes (i.e., earthquakes located between depths of 0 to 4 kilometers) were recorded in the active Wilmington Oil Field or the Torrance Oil Field areas including the Redondo Beach area which is directly adjacent to Hermosa Beach. This record indicates that Hermosa Beach area should not experience an increase in seismicity as a result of oil production during the proposed project.

This conclusion is further supported by operational plans. Project re-injection pressures will be overseen by the DOGGR and reservoir pressures will be maintained below the reservoir fracture pressures except during very limited well completion operations. Conventional hydraulic-fracturing operations, where high volumes of water are injected into large areas of the reservoir formation at relatively high rates, will not be utilized during the project. In addition, E&B will monitor seismic activity in the area during oil field operations as an added precaution. As part of the project, a seismicity monitoring plan includes action levels for operational review and changes should evidence of induced seismicity be observed. These action levels include possible shutdown of drilling/production should induced seismicity be observed.

The potential for induced seismicity which could cause damage to structures or annoy residents in the area is considered less than significant for the following reasons:

- Re-injection pressures will be overseen by the DOGGR and, generally, reservoir pressures will be maintained below the fracture pressures.

- Except for one shallow low magnitude earthquake near Wilmington, there has been a lack of recent shallow earthquakes occurring near oil field operations in the Wilmington and Torrance Oil Field areas.

- The project includes a plan to monitor seismic activity in the area during oil field operations, and modify operations up to and including ceasing operations if overseeing agencies consider it necessary.

1.0 INTRODUCTION

E&B Natural Resources Management Corporation (E&B) is proposing the development of an onshore drilling and production facility (proposed project) on a 1.3-acre project site located at 555 6th Street in the City of Hermosa Beach (City). The location of the proposed project site is shown on Figure 1.

The proposed project will utilize directional drilling to access crude oil and gas reserves located in both onshore and offshore areas. The proposed project will involve drilling 30 oil wells, producing oil, gas and associated water from the reserves, and re-injecting the produced water into the reserves via water injection wells. Rigorous monitoring programs will be implemented as part of the proposed operations.

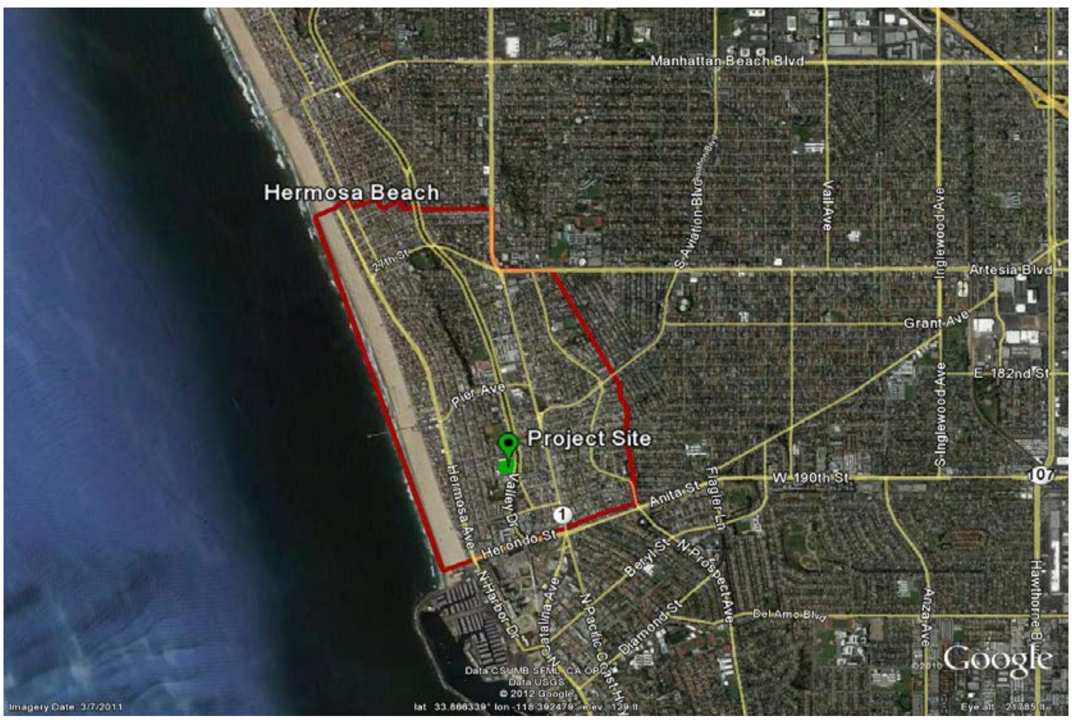

Figure 1. Regional Location Map for City of Hermosa Beach

E&B has contracted with Geosyntec Consultants (Geosyntec) to provide an evaluation of the potential for land subsidence and induced seismicity to occur as a result of the proposed project. The overall objective of Geosyntec's scope of work is to prepare a summary of the relevant existing geologic conditions and provide an analysis of the potential for the proposed project to cause land subsidence or induced seismicity. As a part of this analysis, Geosyntec took into account the proposed project's operational procedures, including monitoring programs to detect the occurrence of subsidence or induced seismicity during oil extraction and/or water injection. Using the information collected, Geosyntec has also developed monitoring programs for land subsidence and seismic activity with action levels that have been incorporated into the project design.

Geosyntec understands that the results of this evaluation will be used to prepare the final project description for the project as well as to support CEQA analysis of the project.

The report is organized into the following sections:

- *1.0 Introduction*
- *2.0 Regulatory Background* – Presents a summary of State of California regulatory information pertinent to subsidence and induced seismicity.
- *3.0 Project Description* – Provides a summary of pertinent proposed oil field operations including a description of project phases, drilling plans, oil field operation parameters, and water injection and monitoring plans.
- *4.0 Environmental Setting* – Presents background references and data relating to petroleum extraction-induced subsidence and seismicity in the Los Angeles Basin. Included in this section are the results of a historic ground movement study for the Hermosa Beach area. The study used Interferometric Synthetic Aperture Radar (InSAR) to measure recent land movement in the Hermosa Beach region. Recent seismic data obtained from the Southern California Seismic Network (SCSN) is also presented to determine background seismic activity in the Hermosa Beach area.
- *5.0 Subsidence and Induced Seismicity Discussion and Analysis* – Presents a discussion and analysis of potential subsidence and induced seismicity, including an evaluation of the potential for the project to cause subsidence and induced seismicity.
- *6.0 Potential Impacts* – Presents conclusions regarding the potential impacts of damaging subsidence and induced seismicity that may be caused by the proposed project.

2.0 REGULATORY BACKGROUND

California laws pertaining to the development of oil and gas resources are compiled in the document California Laws for Conservation of Petroleum & Gas (California Division of Oil, Gas, and Geothermal Resources [DOGGR] 2012), which consists of excerpts from the California Public Resources Code. There are selected regulations that pertain to subsidence and induced seismicity in oil fields. These regulations are discussed below.

2.1 Subsidence

The California Subsidence Act was passed in 1958 in response to the dramatic subsidence that was taking place in Long Beach, California due to oil development from the Wilmington Oil Field. This act is located in Division 3, Chapter 1, Article 5.5 of the California Public Resources Code (beginning with Section 3315). Section 3315 (c) states that "the results of studies by qualified engineers, which have been conducted in certain of such affected areas, indicate that the only feasible method that can be expected to arrest or ameliorate subsidence in such areas is by re-pressuring subsurface oil and gas formations thereunder." Furthermore, Section 3315 (e) states that "the State of California, through authority vested in the State Oil and Gas Supervisor, exercise its power and jurisdiction to require the carrying on of re-pressuring operations which will tend to arrest or ameliorate subsidence."

Section 3319 (a) gives authority to the DOGGR Supervisor to call for a public hearing to consider the need for a re-pressuring plan designed to arrest subsidence. Further, the Supervisor has the authority to adopt or amend this plan according to his judgment (Section 3319(c) and 3319.1). Few details regarding the re-pressuring plans are listed within the code, but Section 3319(c) requires that "Any field wide re-pressuring plan and general specifications shall be based upon a competent engineering study of all the pools in the field and shall provide for re-pressuring operations designed to most effectively arrest or ameliorate subsidence with respect to those land areas overlying or immediately adjacent to a producing pool or pools."

In addition to Article 5.5, the California Coastal Act of 1997 also mandates that oil and gas development "not cause or contribute to subsidence hazards unless it is determined that adequate measures will be undertaken to prevent damage from that subsidence" (Section 30262.a.5).

2.2 Induced Seismicity

The California Laws for Conservation of Petroleum & Gas document do not reference codes that specifically address the issue of induced seismicity. However, the most probable causes of induced seismicity, decreased pore pressure or excessive injection pressure, are regulated by these laws.

Injection well pressures are regulated through Class II injection well permits. In California, all Class II injection wells are regulated by DOGGR, under provisions of the State Public Resources Code and the Federal Safe Drinking Water Act. Class II injection wells fall under the Division's Underground Injection Control (UIC) program, which is monitored and audited by the U.S. Environmental Protection Agency (EPA). In 1983, the Division received EPA primary authority to regulate Class II wells. The main features of the UIC program include permitting, inspection, enforcement, mechanical integrity testing, plugging and abandonment oversight, data management, and public outreach.

Title 14, Division 2, Section 1724.6 of the California Code of Regulations states that "Approval must be obtained from this Division before any subsurface injection or disposal project can begin. This includes all EPA Class II wells and air- and gas-injection wells. The operator requesting approval for such a project must provide the appropriate Division district deputy with any data that, in the judgment of the Supervisor, are pertinent and necessary for the proper evaluation of the proposed project." Requirements for Class II injection wells are outlined in Title 14, Division 2, Section 1724.10 of the California Code of Regulations. These requirements include notification of operational changes, reporting frequency, chemical analysis of injection fluids and pressure monitoring, among others. Item (h) of this section states that "Data shall be maintained to show performance of the project and to establish that no damage to life, health, property, or natural resources is occurring by reason of the project. Injection shall be stopped if there is evidence of such damage, or loss of hydrocarbons, or upon written notice from the Division." Most pertinent to induced seismicity is item (i) of this section which outlines the process for determining the maximum allowable injection pressure. Specifically, it requires that injection pressures be maintained below the reservoir fracture pressure.

3.0 PROJECT DESCRIPTION

3.1 Project Setting

The proposed project site is on a 1.3-acre lot located at 555 6th Street in the City of Hermosa Beach (City). The project site is bounded on the east by Valley Drive and on the south by 6th Street, approximately seven blocks to the east of the beach and the Pacific Ocean (Figure 1). The project site is owned by the City and is currently used as their City Maintenance Yard. The Maintenance Yard will be relocated as part of the proposed project.

All drilling operations will take place on the project site and the proposed project will utilize directional drilling to access the crude oil and gas reserves in the Hermosa Beach Project Area, as shown in Figure 2.

Figure 2. Hermosa Beach City Limit and Tideland and Upland Areas. *Source: E&B.*

This area includes the tidelands of Hermosa Beach and an onshore area known as the Uplands (also shown in Figure 2). These areas are located in the northwest portion of the Torrance Oil Field. The aerial extent of the Torrance Oil Field is provided in Figure 3.

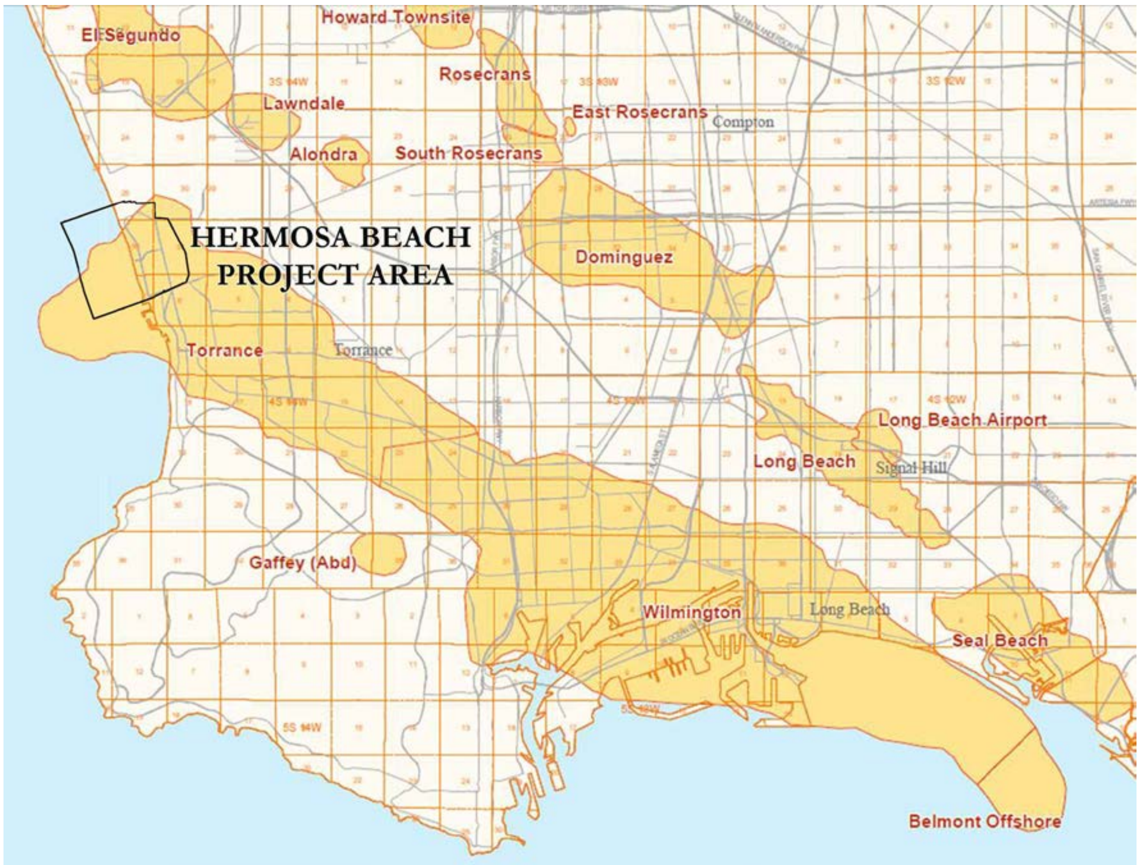

Figure 3. Torrance Oil Field with City of Hermosa Beach City Limits. *Source: DOGGR (2001)*

3.2 <u>Drilling Plans and Methodology</u>

The proposed project involves four distinct development phases consisting of the following:

- Phase 1: Site Preparation
- Phase 2: Drilling and Testing
- Phase 3: Final Design and Construction
- Phase 4: Development and Operations

The two drilling and operational phases are Phase 2 and Phase 4. Phase 2 will include drilling and testing with up to three test wells and one water injection well at the project site. The purpose of Phase 2 is to assess the quality and quantity of oil and gas to be produced. If Phase 2 produces successful results, then in Phase 4 additional wells will be drilled, for a total of up to 34 wells - 30 oil and gas producing wells and 4 water injection wells. The fully developed proposed project will consist of two well cellars that will contain all 34 wells.

All wells will be drilled and constructed in accordance with State of California Law and under the oversight of DOGGR. Wells will be drilled using a common drilling methodology called rotary drilling that utilizes mud. This method uses a drilling bit to drill through earth material and drilling fluids (called mud) are used to bring the drill cuttings to the surface. The drill bit, or auger, diameter ranges from about 18 inches at the surface to approximately 8 ¾ inches at deeper depths. During drilling, various casings and cement seals are installed to protect surface areas and designated fresh water aquifers. Generally a 13⅜-inch diameter conductor casing will be installed to a depth of approximately 80 feet and then a 9 ⅝-inch casing will be cemented in past the base of freshwater (approximately 1,000 feet to 2,000 feet depth, or 0.3 km to 0.6 km depth).

The proposed project's wells will be directional wells to access areas of the oil field that lie outside the boundaries of the drilling site. The act of "bending" a well out of the vertical axis typically begins after vertical drilling has progressed several hundred feet beneath the surface. Using this technique it is possible to achieve angles of over 45 degrees (1 horizontal: 1 vertical). A general schematic of a preliminary directional drilling pathway and the lithology beneath the Hermosa Beach is presented in Figure 4. The figure shows how a well borehole is first drilled vertically and then is drilled at an angle less than ninety degrees relative to the land surface. Site lithology is further described in Section 4.2.

Generally, the decision to stop drilling is made based on the signs, or "shows" of oil in the rock samples and various tests will be conducted to understand the potential oil production capacity of the reservoir rock. These tests identify sand formations, oil saturations, formation porosity, permeability and other formation characteristics.

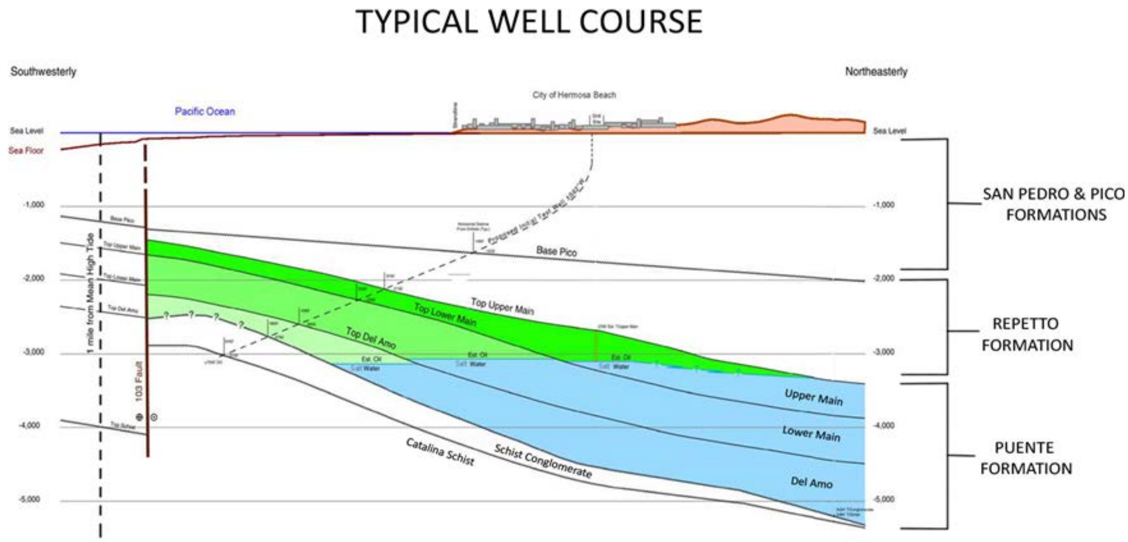

Figure 4. Schematic Geologic Cross Section of the Hermosa Beach Oil Field Area Showing Geologic Formations, Target Oil Zones and General Drilling Path. *Source E&B.*

3.3 <u>Operation and Monitoring Plans</u>

3.3.1 Operation Plans

<u>Operation Facility Design Parameters</u>

Operation facility design parameters for oil, gas and water are summarized in Table 1. Associated water is commonly produced in oil field because it is mixed with the oil and gas within the reservoir.

Table 1. Summary of Operational Parameters for Proposed Project. *Source: E&B.*

Parameter	Value
Crude oil production - Phase 2 (Drilling and Testing)	Up to 800 bpd
Crude oil production – Phase 4 (Development and Operation)	Up to 8,000 bpd
Gas production – Phase 2	Up to 0.250 million cubic feet per day
Gas production – Phase 4	Up to 2.5 million cubic feet per day
Produced water injection – Phase 2	Up to 1,600 bpd
Produced water injection – Phase 4	Up to 16,000 bpd
Maximum number of wells	34
Number of production wells	30
Number of injection wells	4
NGL production	Nil
Notes: bpd = barrels per day; NGL= Natural Gas Liquid	

<u>General Operation Plans</u>

The wells at the project site will be pumped to bring the oil to surface. All pumping equipment will be contained below ground in the well cellar. At field completion, the oil, water and gas emulsion would be pumped from the 30 production wells to a three-phase separator to start the separation of the gas, oil, and water. The three-phase separator uses the difference in density of oil, gas and water (i.e., the gas rises and the majority of the oil floats on the water). The gas is then sent to the gas unit for removal of any sulfur and other constituents to bring the gas into Southern California Gas Company (SCGC) pipeline natural gas quality specifications. The facility is designed to process up to 2.5 million standard cubic feet per day (Table 1).

The oil is sent through a series of vessels where the retained water will be further separated from the oil. The separated oil, which will contain less than 3% water, is then sent to the oil shipping tanks. The facility is designed to process up to 8,000 barrels of oil per day (bopd).

The water that is originally produced with the oil and gas is sent to the water handling facilities for additional oil removal and then is re-injected into the subsurface as summarized in the following section.

Water Injection Plan

The facility is designed to inject a maximum of 16,000 barrels of water per day (bwpd) (Table 1). The proposed project will re-inject only water that is separated from the oil during oil production operations or captured on-site during storm events and at this time does not intend to inject any additional water or makeup water. Based on current reservoir information the majority of re-injection will likely occur beneath the onshore areas. All produced water re-injected into the ground will be placed below the oil-water contact within the same producing zones. Water will be re-injected at depths between approximately 3,000 feet (1 km) and 4,000 feet (1.2 km) which is well below the designated fresh water aquifers in the area (California Department of Water Resources, 1961). Steel casing, cemented in place, will ensure that produced water cannot permeate the shallower groundwater aquifers. During Phase 4, stormwater within the perimeter block on wall of the project site will be captured on site in either the drain system or containment areas and will be treated as part of the produced water system and injected using the water injection wells.

Water produced by the proposed project will be run through the previously described separators and injected at an estimated pump pressure of 900 to 1,100 pound-force per square inch (psig). Prior to the beginning of injection operations, DOGGR will require and approve a plan for water re-injection.

3.3.2 Subsidence and Seismicity Monitoring Programs

The proposed project includes operational procedures consisting of monitoring programs to address the occurrence of potential subsidence or induced seismicity during oil extraction and/or water injection. These programs are defined below.

Subsidence Monitoring Program

A comprehensive Subsidence Monitoring Program will be implemented as part the proposed project. The Subsidence Monitoring Program will include land surface monitoring using Global Positioning Survey (GPS) and InSAR technology. The purpose of the program is to facilitate the early identification of potential subsidence caused by oil extraction. Details of the Subsidence Monitoring Program are presented in Appendix A.

The primary objective of the Subsidence Monitoring Program is to measure potential vertical ground movement (either up or down), collect information that could definitively distinguish between measurable subsidence caused by oil extraction operations and subsidence attributable to other human activity or natural processes (regional background), and implement defined action level requirements (see below) thus minimizing or eliminating the potential for damaging subsidence. This will be achieved through the following five monitoring program components:

- Continuous GPS surveying at three locations, as shown in Figure 5.
- Bi-annual GPS surveying at 16 benchmark locations, as shown in Figure 5.
- Bi-annual InSAR imagery analysis (to correspond with the GPS survey).
- Reservoir pressure monitoring and continuous monitoring of oil fluid extraction volumes and water injection volumes. Reservoir pressure monitoring in wells will be conducted during scheduled maintenance operations.
- Implement requirements and mitigation activities in accordance with the action levels listed below.

The Subsidence Monitoring Program and frequency of monitoring will be re-evaluated after the first five years of oil field operation. If extraction related subsidence is below the action levels outlined in this program in the first five years, the monitoring frequency for GPS surveying and InSAR imagery analysis may be reduced to once per year if there is sound rationale to support the reduced monitoring and as long as oil operations remain consistent. If extraction related subsidence has been measured in the first five years of operation of the proposed project, monitoring will continue on a bi-annual basis or more if it is deemed necessary. If a change in monitoring frequency is considered appropriate at any time, a Revised Subsidence Monitoring Program that will include an evaluation of new monitoring methodologies and technologies will be prepared by E&B. The Revised Subsidence Monitoring Program would be submitted to the City and the overseeing agencies for review and approval. A similar reevaluation of the monitoring program will occur after ten years of operation or if any action levels are exceeded.

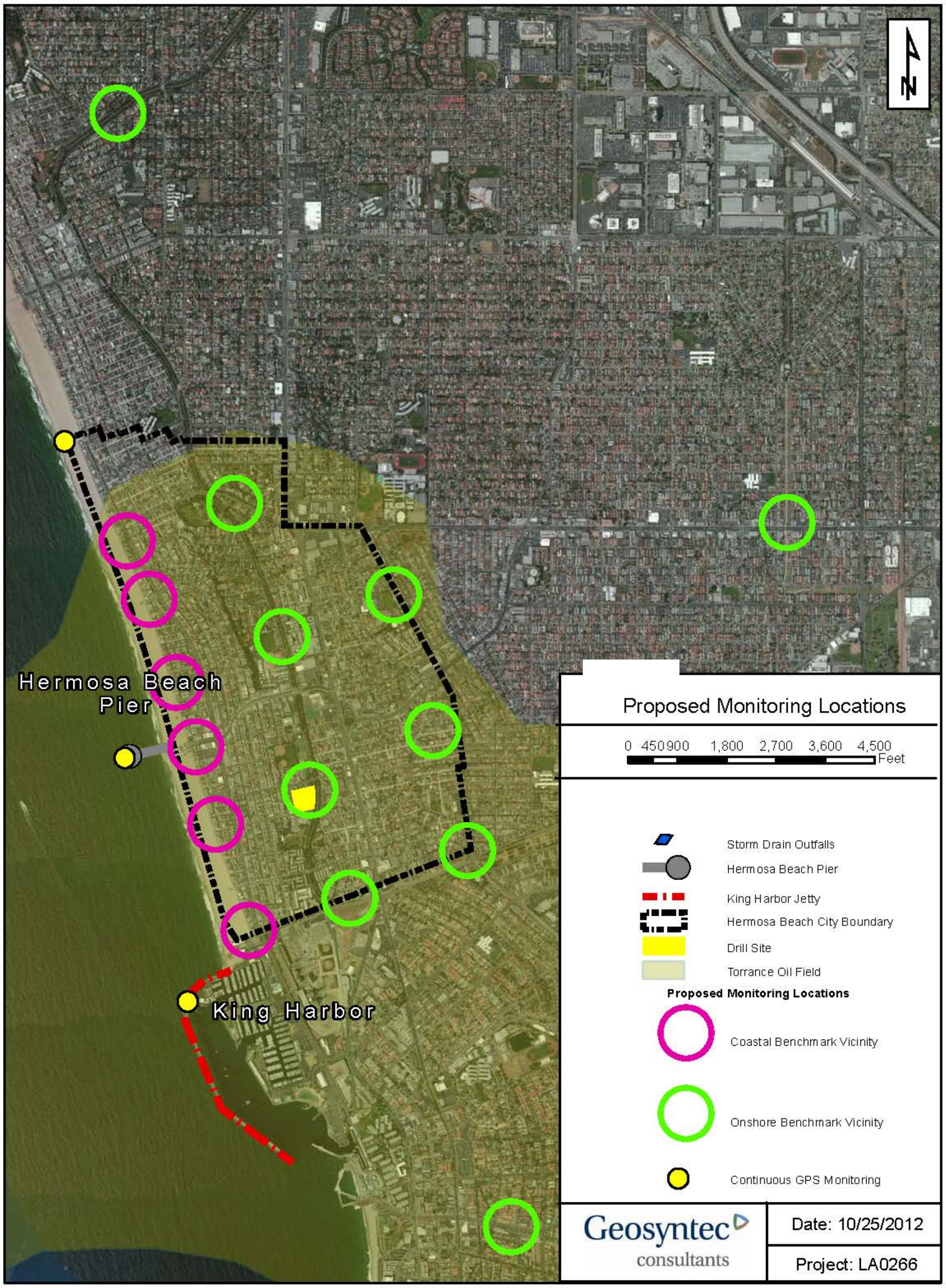

Figure 5. Subsidence Monitoring Program Monitoring Locations

As part of the monitoring program, a subsidence monitoring report will be prepared and submitted to the City and the overseeing agencies after each monitoring event. This report will include an analysis of ground movement trends, based on all data sources (GPS Survey and InSAR). Additionally, the report will present salient oil extraction data, including fluid production volumes and/or operational changes, water injection volumes and pressures, and reservoir pressure data. These data will be compared with any ground movement trends to evaluate whether causative relationships exist.

Subsidence Action Levels

Specific thresholds, or “action levels”, for subsidence have not been established by State or Federal agencies. For this specific project, the objectives of the action levels are to establish further safeguards to avoid subsidence as a result of oil extraction that could potentially cause damage to property and the environment. The action levels will also provide an early warning system and sufficient time to implement activities or necessary modifications to the operation of the proposed project to minimize or eliminate the potential for damaging subsidence. More aggressive action may be required depending on the rate of subsidence. The action levels are defined as follows:

- If monitoring identifies a bowl-shaped subsidence feature, with subsidence centered above the oil field, greater than 0.05 feet (1.5 cm) above regional background levels at any one benchmark (GPS location) or area (InSar), the operator will: (a) immediately evaluate subsidence trends and geometry; (b) notify the City and overseeing agencies if evaluation indicates measured subsidence is associated with oil field operations; (c) perform internal review of injection and reservoir re-pressurization programs and implement changes to oil field operations, if necessary; and (d) increase monitoring frequency, if necessary.

- If monitoring identifies a bowl-shaped subsidence feature, with subsidence centered above the oil field, greater than 0.10 feet (3.0 cm) above regional background levels at any one benchmark (GPS location) or area (InSar), the operator will: a) immediately notify City and overseeing agencies; (b) immediately evaluate subsidence trends and geometry; (c) if evaluations indicate measured subsidence is associated with oil field operations, re-evaluate oil field operations including water injection and reservoir re-pressurization programs with overseeing agencies; (d) submit report with proposed modifications to oil field operations to the City and overseeing agencies for approval, if necessary; and (e) implement approved modifications, if necessary. If projected trends in (b) indicate that subsidence greater than 0.3 feet will be reached during the lifetime of the project more aggressive action may be required.

- If monitoring identifies a bowl-shaped subsidence feature, with subsidence centered above the oil field, greater than 0.20 feet (6.1 cm) above regional background levels at any one benchmark (GPS location) or area (InSar) then the operator will: (a) immediately notify City and overseeing agencies; (b) appoint outside experts or panel to review data and oil field operations, including evaluation of subsidence trends and geometry, evaluation of effects on environment and critical structures, and review of water re-injection and re-pressurization programs; (c) provide results of analysis and expert recommendations to the City and overseeing agencies including submittal of reports presenting the analyses and recommendations; (d) obtain approval from overseeing agencies for oil field operation modifications; and (e) implement approved modifications, if necessary. If projected trends in (b) indicate that subsidence greater than 0.3 feet will be reached during the lifetime of the project more aggressive action may be required.

- If monitoring identifies a bowl-shaped subsidence feature, with subsidence centered above the oil field, greater than 0.30 feet (9.1 cm) above regional background levels at any one benchmark (GPS location) or area (InSar) the operator will: (a) immediately notify City and overseeing agencies; (b) reduce or halt production from wells in subsidence zones at the direction of the overseeing agencies; (c) appoint outside experts or panel to review data and oil field operations, including evaluation of subsidence trends and geometry, evaluation of effects on environment and critical structures, and review of oil field operations including water re-injection and re-pressurization programs; (d) provide results of analysis to City and overseeing agencies, including submittal of reports, and obtain approval for any recommended modifications; and (e) if recommended modifications are not approved or modification are approved but found to be ineffective, then the overseeing agencies have the prerogative of halting oil field operations. Monitoring of subsidence would continue past any halting of oil field operations.

Induced Seismicity Monitoring Program

A comprehensive Induced Seismicity Monitoring Program will be implemented as part of the proposed project in order to monitor seismic activity in the area during oil extraction and water injection. The Induced Seismicity Monitoring Program will monitor seismic activity using the Southern California Seismic Network (SCSN). The SCSN has more than 350 seismic stations in Southern California and yearly, daily and evenly hourly data is available for download (http://www.scsn.org/). Earthquake magnitudes (M) less than M1.0 can be detected with the SCSN. A map of the seismic station locations in the Los Angeles Region is presented in Figure 6.

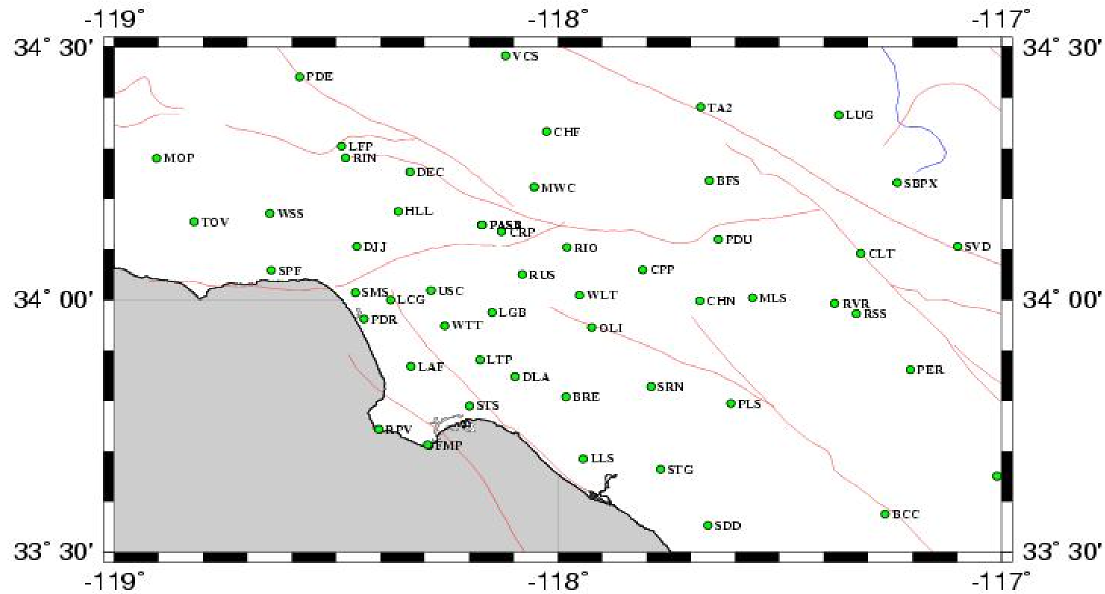

Figure 6. Location of Seismic Monitoring Stations (BH Stations) in the Los Angeles Region. *This map was downloaded from the Southern California Earthquake Data Center (SCEDC) website (http://www.data/scec.org. The SCEDE and the SCSN are funded through the U.S. Geological Survey Grant G10AP0091 and the Southern California Earthquake Center, which is funded by NSF Cooperative Agreement EAR-0529922 and USGS Cooperative Agreement 07HQAG0008.*

The primary objective of the Induced Seismicity Monitoring Program is to measure potential induced seismicity, if it occurs, associated with the proposed oil extraction, collect information that would allow determination of the causes of any measurable seismicity due to oil extraction or water injection, and implement defined action level requirements (see below) thus minimizing or eliminating the potential for continued induced seismicity. The Induced Seismicity Monitoring Program will consist of the following activities:

- Acquire data from the Southern California Earthquake Data Center (SCEDC) on an annual basis by a qualified outside contractor.

- Review and analyze data to evaluate the possible occurrence of shallow earthquakes associated with the oil field operations.

- Prepare annual report to be submitted to the City and overseeing agencies. Data retrieval, data analysis, and report submittal frequency would increase if any shallow earthquakes or detectable earthquake swarms occur in the oil field.

- Implement requirements and mitigation activities in accordance with the action levels listed below.

Induced Seismicity Action Levels

Thresholds, or "action levels", for induced seismicity have not been established by state or federal agencies. Generally, induced seismicity associated with oil field operations would be identified if the seismic activity occurred; (a) at relatively shallow depths (approximately 0-4 km or 2 ½ miles) within or near (approximately 1 km or 0.6 miles) the boundary of the oil field area, and (b) in a non-random manner or specific time period so as to be linked to a specific oil field operation such as fluid extraction or injection. These identification criteria may be adjusted, based on geological information collected during drilling and final oil field operations.

For this specific project, the objective of the action level is to establish further safeguards to avoid induced seismicity as a result of oil extraction or water injection that could potentially cause damage to property and the environment. The action level will also provide an early warning system and sufficient time to implement activities or necessary modifications to the operations of the proposed project to minimize or eliminate the potential for continued induced seismicity. The action level is as follows:

- If monitoring identifies shallow earthquakes above M2 associated with oil field operations, or earthquake swarms[1] of any magnitude associated with oil field

[1] A swarm is herein defined as a series of earthquakes occurring in a relatively short time frame. For example several shallow earthquakes over a month period or six or more shallow earthquakes occurring over a six month period. The analyst and the overseeing agencies have the prerogative of identifying a swarm, based on the data collected.

operations that are either noticeable or not noticeable, the operator will (a) immediately notify City and overseeing agencies; (b) prepare a report with an evaluation of the seismic activity and recommendations to modify oil field operations including production volumes, re-injection volumes and reservoir pressure maintenance: (c) implement approved recommendations or halt oil field operations, if necessary. Overseeing agencies have the prerogative of halting oil field operations if noticeable swarms or damaging earthquakes occur that are associated with oil field operations.

4.0 ENVIRONMENTAL SETTING

4.1 Regional Geology and Los Angeles Basin Oil Fields

The project site is located in a geological structural feature called the Los Angeles Sedimentary Basin or the Los Angeles Basin. The Los Angeles Basin is bounded by well-known physiographic features including the Santa Monica, San Gabriel, and Santa Ana Mountains to the north and east, and the Pacific Ocean and the Palos Verdes Hills to the west and south. The Basin is approximately 70 miles long and 10 miles wide.

Geologically, the Los Angeles Basin is a structural basin formed in the mid Miocene epoch as a result of tectonic processes. As the basin formed, it filled with a thick sequence of sedimentary materials that are as much as 35,000 feet thick. Often geologists refer to the Los Angeles Basin as a “depositional basin” to describe the simultaneous deepening of the basin by tectonic processes and the infilling of the basin with sediment. Prior to about 5 million years ago, the basin was submerged under the ocean and much of the sediment was deposited in a marine environment.

The thick sequence of sedimentary materials in the Los Angeles Basin provides a large reservoir for oil and gas. Forty three active oil fields occur in the Los Angeles Basin (Bilodeau et. al., 2007), including approximately 35 fields that produce from Upper Miocene and Pliocene age sandstone reservoirs (Allen and Mayuga, 1969). The Hermosa Beach oil field area is part of one of the oil fields in the Los Angeles Basin, the Torrance Oil Field. Oil was discovered in the Torrance field in 1922 (Yerkes and Castle, 1969). A map of the oil fields in the Los Angeles Basin is presented in Figure 7.

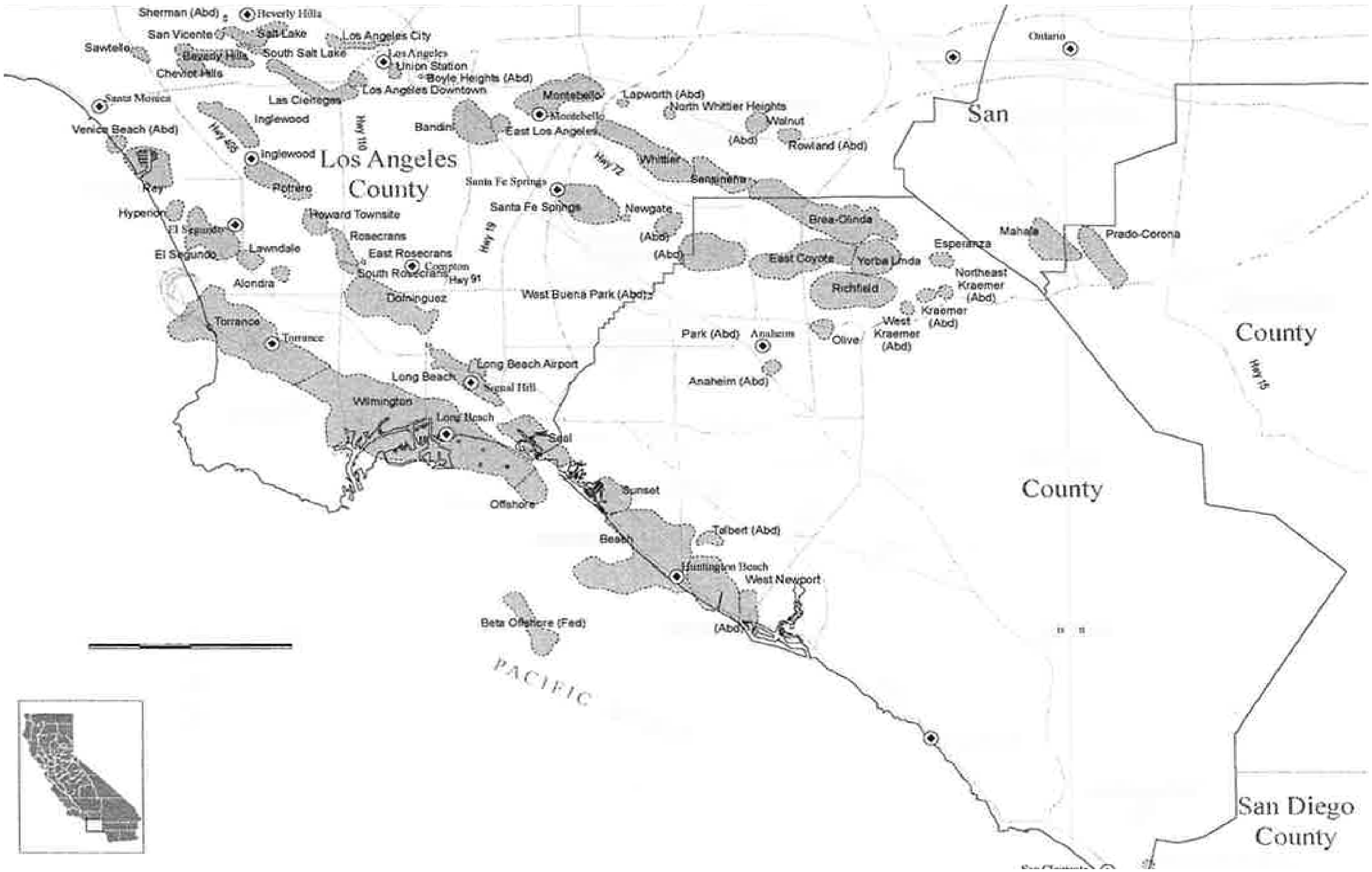

Figure 7. Los Angeles Basin Oil Fields

The City of Hermosa Beach is located in the western portion of the Los Angeles Basin. The area is referred to as the Los Angeles Western Shelf (Figure 8). The Western Shelf is a region located between two major faults, the Newport-Inglewood fault zone on the east and the Palos Verdes fault on the west (Wright, 1991). The northwest-striking Newport Inglewood fault zone is a right-lateral wrench system defined by a series of discontinuous left-stepping en-echelon faults and folds. To the southwest, the high angle, west-dipping Palos Verdes fault exhibits northeast vergent right lateral oblique slip. Both of these faults are considered active. Basement rock underlying the Western Shelf is Catalina Schist (Yeats, 1973) which is the predominant basement rock of the inner California Continental Borderland and the Palos Verdes Hills.

Oil fields in the Western Shelf occur along three distinct northwest-trending linear alignments that parallel three regional geological structural features: the Newport-Inglewood fault zone to the east; the "Schist Ridge" in the middle; and the "Torrance-Wilmington Anticline" to the south. The Schist Ridge is delineated by a lineament of oil fields which extend from the Venice Beach Oil Field to the northwest to the Alondra Oil Field to the southeast (Figure 8), The oil fields that occur along these linear alignments are described below.

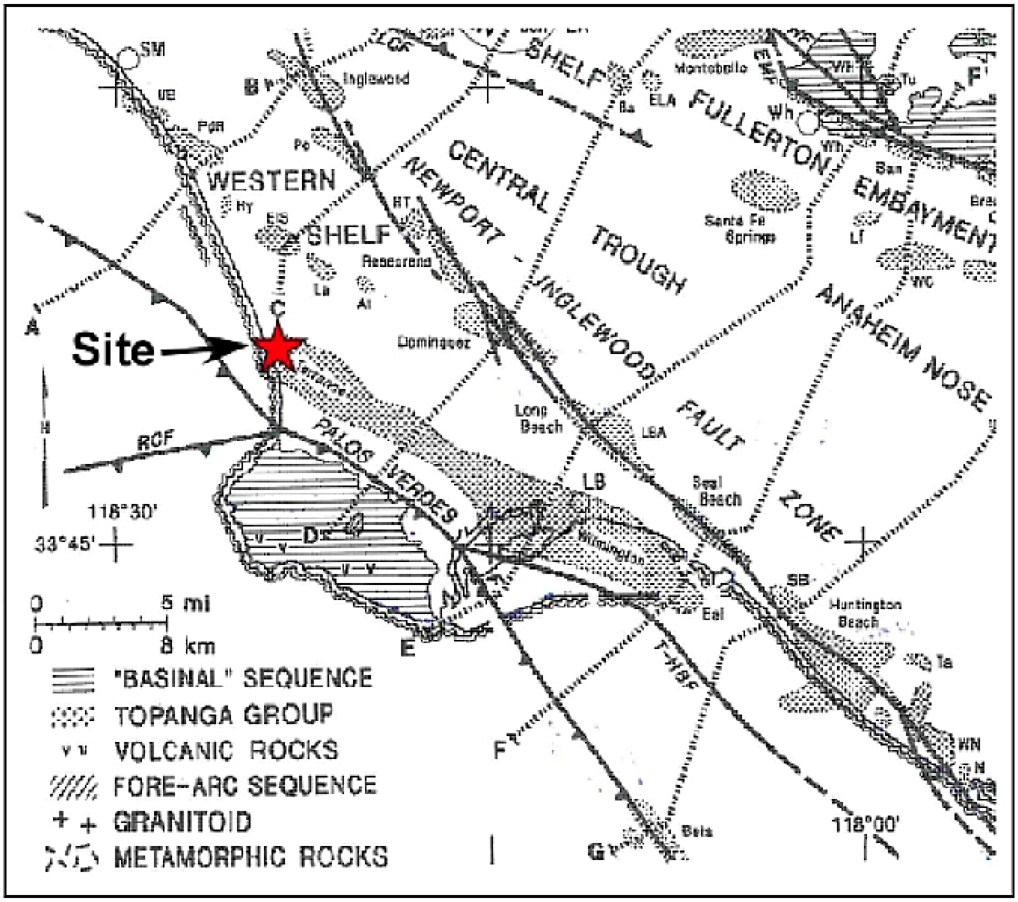

Figure 8. Los Angeles Basin Western Shelf Located Between the Newport-Inglewood Fault Zone and the Palos Verdes Fault (Wright, 1991). *Oil fields are shown in dot pattern. The two productive trends in the Western Shelf are the Schist Ridge on the north, including the following oil fields, from NW to SE, Venice (VB), Playa del Rey (PdR), Hyperion (Hy), El Segundo (EIS), Lawndale (La), and Alondra (Al), and the Torrance-Wilmington anticlinorium on the south. The Newport-Inglewood trend includes the following oil fields of concern to this review: Inglewood, Potrero (Po), Howard Townsite (HT), Rosecrans, Dominguez, Long Beach, Long Beach Airport (LBA), and Seal Beach. The horizontal lined pattern marks the Palos Verdes Hills west of the Palos Verdes fault.*

The eastern boundary of the Western Shelf is the Newport-Inglewood fault zone. The zone coincides with a structural break between a relatively shallow depositional system to the southwest in the Western Shelf area and a deeper depositional system in the northeast portion of the basin. A lineament of topographic highs occurs along the Newport-Inglewood fault zone including the Baldwin Hills, Cherry Hill, and Signal Hill. Structurally, the fault zone is a complicated series of folds and faults. The faults are short and discontinuous with strike-slip, normal, and reverse components. Several of the faults segments have been assigned as Alquist-Priolo Earthquake Fault Hazard Zones by the California Division of Mines and Geology. The complicated series of folds and faults act as oil traps and consequently numerous oil fields occur along the Newport-Inglewood fault zone including from northwest to southeast, the Inglewood, Potrero, Howard Townsite, Rosecrans, Dominguez, Long Beach, Long Beach Airport, Seal Beach, Sunset Beach, Huntington Beach, and West Newport oil fields (Figure 8). More discussion of the Newport-Inglewood fault zone is presented in Appendix B.

The Schist Ridge is located in the middle of the Western Shelf area and is coincident with the on lap of basin sediments (transgressive sandstones and conglomerates) on the northeast against a ridge or high of schist to the southwest. An alignment of several oil fields, the Venice Beach Oil Field to the northwest to the Alondra field to the southeast, is located on the Schist Ridge (Figure 8). In the part of the Schist Ridge closest to the City of Hermosa Beach, the Hyperion, El Segundo, Lawndale, and Alondra Oil Fields produce oil from Catalina Schist and an overlying transgressive sandstone and conglomerate of early late Miocene age. The sandstone and conglomerate materials were deposited on an erosion surface (Schist-Conglomerate).

The southern trend is the broad Torrance-Wilmington anticline. Several oil fields including the Wilmington Oil Field and the Torrance Oil Field are located on this anticlinal structure (Figure 8). Oil production in the Torrance-Wilmington anticline is concentrated in marine sedimentary reservoirs of late Miocene to early Pliocene age materials. Oil production in the Hermosa Beach area, located in the northwest portion of the Torrance Oil Field, will be from these same Pliocene and Miocene age materials.

A longitudinal cross-section through the Wilmington and Torrance Oil Fields is presented in Figure 9. The cross-section extends northwestward into the Redondo offshore area. As shown in the cross-section, the Torrance Oil Field is located west of a structural saddle that occurs in the anticlinal structure (Crowder, 1957). The structural saddle is the boundary between the Torrance Oil Field and the Wilmington 0il Field. Although, reservoir rocks in the two fields include the Repetto and Puente Formations, the reservoir rocks are different due to an observed significant thinning of vertical section of the reservoir sands to the northwest along the anticline (Figure 9). The sedimentary section in the Wilmington Oil Field is generally thicker and contains a greater amount of sand compared with the Torrance Oil Field (Yeats and Beall, 1991, Wright, 1991). The net sand thickness at Wilmington averages 800 to 1,200 feet (240 m to 370 m) as reported by Mike Henry (personal communication, 2012). In contrast, net sand thickness in the Torrance oil field, including the Redondo Beach area is approximately 140 to 210 feet or 40 to 65 meters (Mike Henry, personal communication, 2012). In addition, the sands appear to become finer to the west. The trend of sands thinning and becoming finer to the northwest along the anticline is generally interpreted to be a gradual changing of the depositional environment that the rock materials were originally deposited in (Mike Henry, personal communication, 2012). Reservoir materials in the Wilmington field are interpreted to have been deposited in a central submarine environment while reservoir materials in the Torrance field are interpreted to have been deposited in a more central fan edge to distal submarine fan environment (in deeper water).

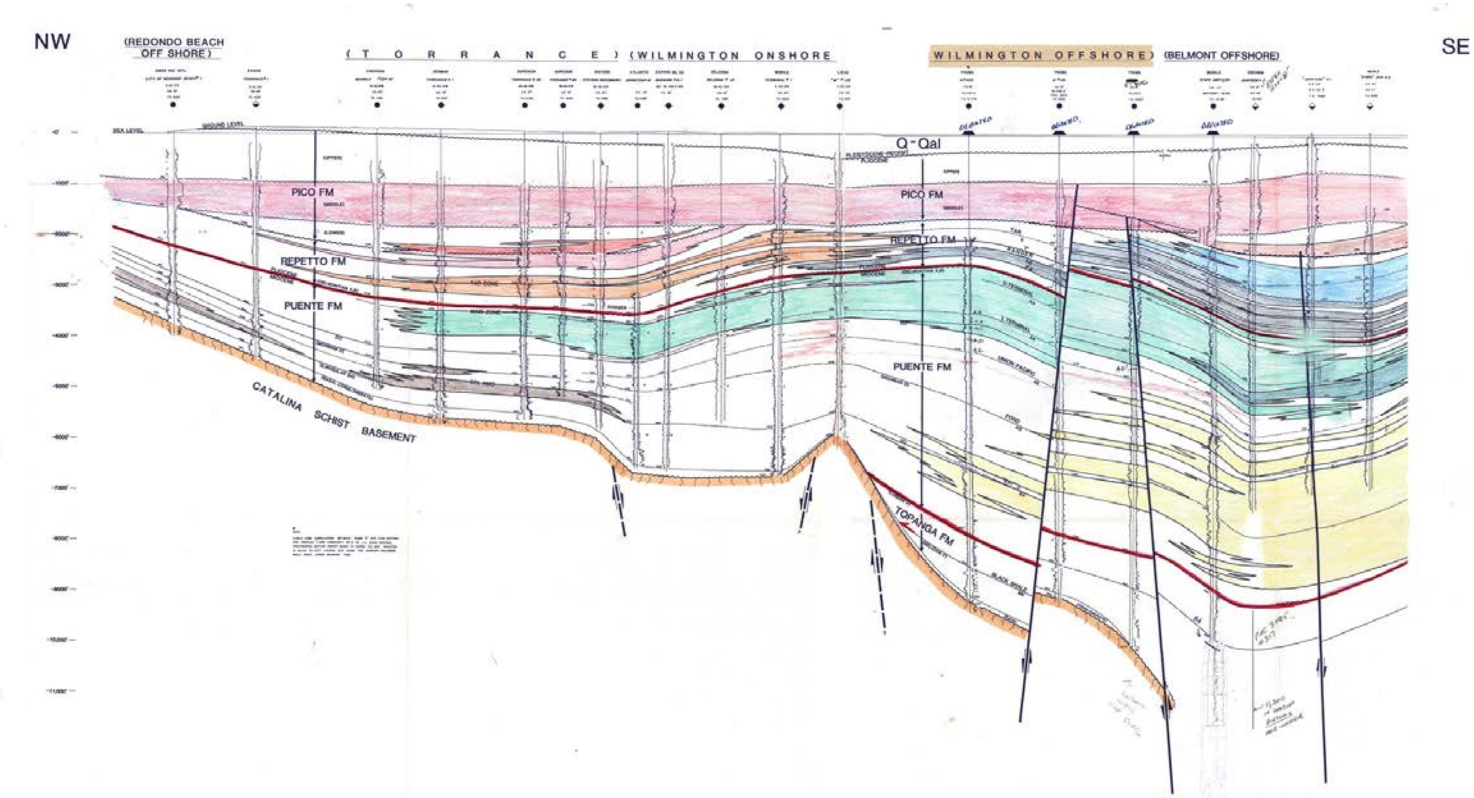

Figure 9. Longitudinal Geologic Cross-Section- Redondo Offshore to Wilmington. *Source: M. J. Henry*.

4.2 Local Geology - Hermosa Beach Area

4.2.1 General Structure of Hermosa Beach Oil Field Area

As discussed above, Hermosa Beach is located above the very northwest portion of the Wilmington-Torrance Anticline in the Torrance Oil Field. The anticline is what is called a plunging anticline, and plunges to the southeast towards Wilmington. A schematic geologic cross-section of the Hermosa Beach area is shown in Figure 4 (see page 8). The cross-section depicts the geology across a general west to east trend and shows an interpreted fault named the 103 fault occurring approximately a mile offshore at the northwest end of the anticline. The 103 fault is interpreted to act as an oil trap. The evidence for the 103 fault is the offset of formations and an abrupt change from oil to water on formation tests in several wells. The 103 fault is also northwest trending and is believed to be a splay of the Palos Verdes Fault (Figure 4). Numerous smaller faults are known to bisect the anticline in the southwest portion of the anticline in the Wilmington area and provide barriers to water and oil. These types of faults may be encountered beneath Hermosa Beach.

4.2.2 Stratigraphy and Oil Zones

The general stratigraphy of the Hermosa Beach area is summarized in Figure 10.

AGE	FORMATION/LITHOLOGY	APPROXIMATE THICKNESS (feet)	PROJECT TARGET OIL ZONES
Holocene and Upper Pleistocene	Undifferentiated sands and gravels, and Lakewood Formation (?)	~0-100	--
Lower Pleistocene	San Pedro Formation	~200- 400	--
Pliocene	Pico Formation	~800-1,500	--
	Repetto Formation	~100 – 1,200	--
Miocene	Puente Formation	~1,000 – 2,000	*Upper Main* *Lower Main* *Del Amo*
	Schist Conglomerate	~100-400	*Schist Conglomerate*
Cretaceous-Jurassic	Catalina Schist Basement Rock	--	--

Figure 10. General Stratigraphic Section for Hermosa Beach Oil Field Area

Nearly directly beneath Hermosa Beach is the Pleistocene age San Pedro Formation. The San Pedro Formation generally consists of unconsolidated and semi-consolidated stratified sands with some beds of clays, silts, sands and gravels. Beneath the San Pedro Formation is the late Pliocene age Pico Formation which generally consists of marine siltstones and sandstones. The region's freshwater aquifers are located in the San Pedro Formation and upper portion of the Pico Formation, although in the area of the project site these waters are significantly degraded with seawater (Poland et. al., 1959). The water in the freshwater aquifers directly beneath the project site is not currently used for potable supply.

Beneath the Pico Formation is the early Pliocene age Repetto Formation which mostly consists of siltstones with layers of sandstones and conglomerates. The Repetto Formation is approximately 100 to 1,200 feet (30 to 370 meters) thick as it thins significantly to the southwest in the Hermosa Beach area. Beneath the Repetto Formation is the Miocene age Puente Formation which is the primary oil reservoir in the Hermosa Beach area. The top of the Puente Formation occurs at a depth of 1,500 to 3,000 feet (450-900 meters) below mean sea level and is approximately 1,000 to 2,000 feet (300 to 600 meters) thick. The Puente Formation has been divided up into three target zones for oil production purposes (Figure 10). The target zones are the Upper Main Zone, Lower Main Zone, and the Del Amo Zone. These zones are described below.

Upper Main Zone. The Upper Main zone is the upper-most part of the Puente formation and is expected to be the shallowest oil productive section in Hermosa Beach. It was productive to the south in Redondo Beach where the formation is contiguous with Hermosa Beach. Of the three known producing horizons in the Torrance Oil Field, the Upper Main Zone is the most prolific. The Upper Main zone beneath Hermosa Beach is expected to be over 300 feet (90 meters) thick and composed of interbedded thin sands and shales. The shales are fractured and provide both fracture porosity and permeability. The fractures are critical to the performance of the reservoir in this area due to the fine grained and thin bedded nature of the sands. The Puente formation shales are source rock for the oil in this part of the Los Angeles Basin.

Lower Main Zone. The Lower Main zone is also part of the Puente formation and lies immediately below the Upper Main zone. The Lower Main is similar to the Upper Main except it has fewer interbedded fine grained sands and is over 500 feet (150 meters) thick. Similarly to the Upper Main zone, the shales of the Lower Main are fractured and important for production.

Del Amo Zone. The Del Amo zone lies beneath the Lower Main zone. The Del Amo contains the least amount of thin bedded sandstone and is thus the poorest producing zone in the Puente formation. As with the zones above, fractures are present and important for production. Thin interbeds of limestone and dolomite are also present. The Del Amo varies in thickness the most of the three zones. It on laps the underlying Schist Conglomerate and could vary in thickness from 200 feet to up to 700 feet (60 to 200 meters) in the Hermosa Beach area.

The Schist Conglomerate of late Miocene age underlies the Del Amo zone and it rests on metamorphic basement rock called the Catalina Schist (Figures 5 and 10). There may be some potential production from the Schist Conglomerate as it is a source rock for oil fields located north and northeast of Hermosa and in the Wilmington area. The Schist Conglomerate is composed of reworked fragments derived from erosion of the underlying Catalina Schist basement rock. The schist fragments are interspersed in sandstone. It is unknown if the Schist Conglomerate is productive beneath Hermosa Beach, but it is a viable exploration target. The Schist Conglomerate could be as much as 400 feet (120 meters) thick.

4.3 Subsidence Background Information

4.3.1 Definition and Causes of Subsidence

Land subsidence is defined as the downward settling of the earth's surface with little or no horizontal motion. There are various causes of land subsidence, including natural causes and human-induced causes. Natural subsidence can occur due to tectonic subsidence (sediment loading), and compaction and consolidation of young sediments (Baum et. al., 2008). Natural compaction of sediments in deep sedimentary basins, such as the Los Angeles Basin, where sediment loading causes the compaction or consolidation of sediment at depth, is well documented. Regional natural subsidence can also be caused by the cooling and thinning of the earth's crust. Natural decomposition of organic material can also produce high rates of subsidence. The U.S. Army Corps of Engineers (1990) reported that decomposition of peat deposits in Orange County has produced as much as 14 feet of subsidence in localized areas.

In addition to natural subsidence, there are various anthropogenic causes of subsidence including subsurface fluid withdrawal, drainage of organic soils, underground mining and hydrocompaction (Baum et. al., 2008). Subsurface fluid withdrawal includes the pumping of groundwater aquifers and the extraction of oil, gas, and water. Subsurface fluid withdrawal can produce a reduction in pore pressure within both freshwater aquifers and oil field reservoirs resulting in compaction of the material and subsequent land subsidence.

Subsurface fluid withdrawal as a cause of subsidence has been documented in the Los Angeles Basin. Subsidence due to pumping of groundwater aquifers is a well-documented phenomenon. Significant amounts of land subsidence (i.e., on the order of feet) due to groundwater pumping has occurred in several areas of southern California including the Santa Clara Valley, Ventura, Lancaster and the City of Chino (Leake, 2012, and Kleinfelder, 1996). Smaller amounts of subsidence due to groundwater withdrawal have been recently documented in the Los Angeles Basin in the Santa Ana area by Bawden et. al. (2001). Subsidence due to oil extraction is also well documented in the Los Angeles Basin. Relatively larger amounts of subsidence (5 feet or over) have been documented in the Wilmington, Inglewood, and Huntington Beach Oil Fields while smaller amounts of subsidence have occurred in numerous basin oil fields such as Torrance, Dominguez and Playa del Ray (Yerkes and Castle, 1969). The mechanisms and historical incidences of subsidence in Los Angeles oil fields, and specifically the Wilmington and Torrance Oil Fields, are discussed below in Sections 4.3.2 and 4.3.3.

4.3.2 Mechanisms of Subsidence in Oil and Gas Fields

Land subsidence in oil and gas fields is commonly thought to be the result of the reduction of pore pressure during oil production and the subsequent compaction of the reservoir rock (pore space and fractures) and adjacent fine-grained layers. The compaction of rock material is propagated to the land surface causing a lowering of land surface elevation.

The compaction of reservoir and adjacent rock materials occurs due to several mechanisms including the repacking and rearrangement of sand grains, the plastic and elastic deformation of softer mineral grains, sand grain fracturing, and the dewatering of porous clays (Mike Henry, personal communication, 2012). These mechanisms cause a more ordered and denser packing of mineral grains and thus compaction (Figure 11).

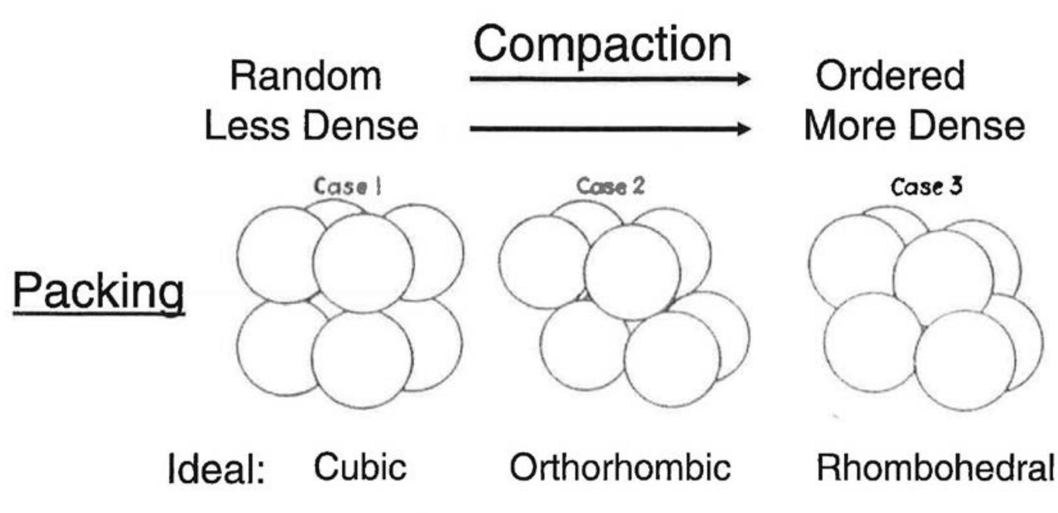

Figure 11. Conceptual Compaction of Soil Matrix. *Source: M.J. Henry.*

Some oil fields are more susceptible to land subsidence. Van der Knapp (1967)[2] concluded that weakly consolidated rocks seem to be candidates for significant compaction. That is, immature rocks, those that are poorly sorted, softer and less compacted with lesser amounts of cementation are more prone to compaction than mature rocks. A diagram depicting mature and immature sandstone is presented in Figure 12.

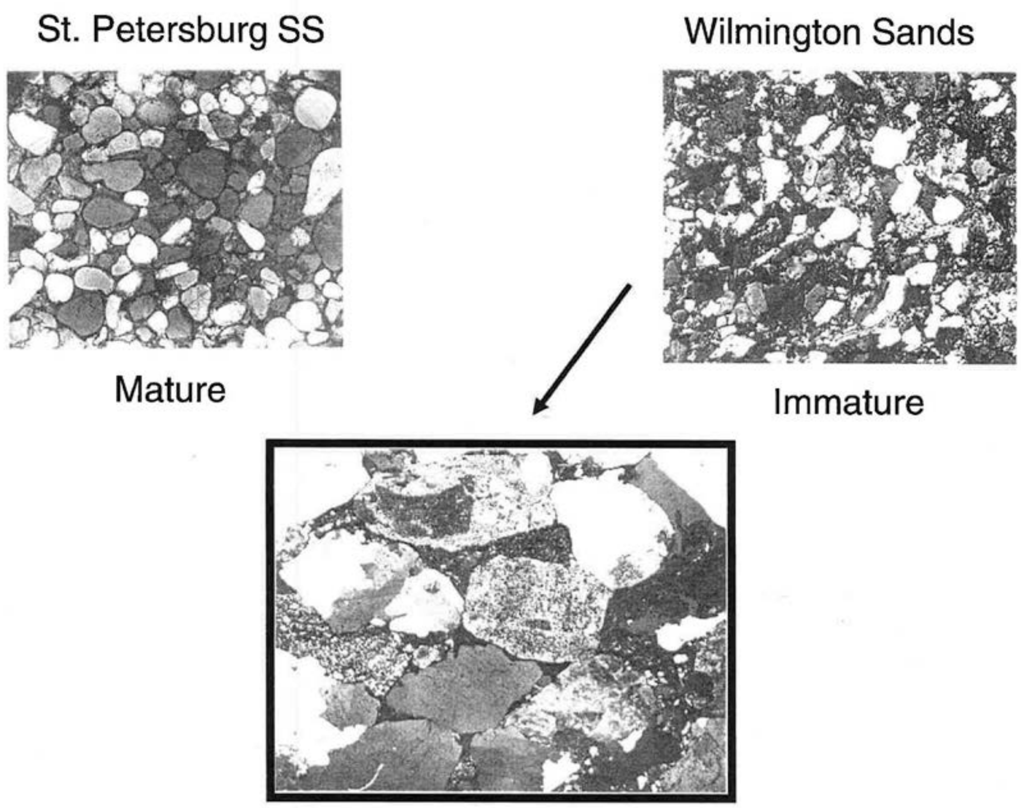

Figure 12. Mature Versus Immature Sandstones. *Source: M.J. Henry.*

In Figure 12 the immature sands are from the Wilmington Oil Field. Sandstones in oil fields in the Los Angeles Basin, including the Wilmington and Torrance Oil Fields, are generally considered immature and thus susceptible to subsidence.

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[2] As cited by Geretsma et. al. (1973).

On a regional scale, the consolidation of the rock material is dependent on several factors including the age of the rock, the depth of the rock or overburden above the rock, the depositional environment of the rock, and the different vertical and lateral stresses the rock may have been subjected to. Geretsma et. al. (1973) listed four simple factors, including geological and oil field operation factors that make oil and gas reservoirs more susceptible to subsidence:

1. Significant reduction in reservoir pressure during production;
2. Production occurs from a large vertical interval;
3. Oil and gas contained in loose or weakly consolidated or cemented rock; and
4. Reservoir has a relatively small depth of burial (relatively small overburden).

When land subsidence does occur in oil fields, it is often bowl-shaped in geometry with the base of the bowl or the largest amount of subsidence centered in areas where the largest amount of oil extraction occurs.

4.3.3 Historical Incidences of Subsidence in the Wilmington and Torrance Oil Fields

Subsidence has been observed in numerous oil fields in Los Angeles Basin (Yerkes and Coat, 1969). Subsidence is generally relatively small, although significant subsidence has been observed in some fields including the Wilmington Oil Field, located southeast of Hermosa Beach and the Inglewood Oil Field. Because the Hermosa Beach area is located in the Wilmington-Torrance anticline and in the northwest portion of the Torrance Oil field, historical subsidence in these areas was reviewed and summarized below.

Land subsidence in the Wilmington Oil field has been well publicized and documented due to the large amount of subsidence that occurred in the field between 1932, when oil extraction began, and the late 1960s when subsidence was stopped. Subsidence in the Wilmington Oil Field occurred as an elliptical bowled shaped depression, which is typical of oil field induced subsidence. Total vertical subsidence was measured at approximately 29 feet (9 m) near the center of the bowl (Mayuga and Allen, 1969, and Allen and Mayuga, 1969). The large amounts of subsidence in the Wilmington Oil Field was the result of the compaction of shallow and generally unconsolidated rock materials caused by the substantial reduction in reservoir pressures produced by high volumes of oil extraction. Yerkes and Castle (1969) reported that subsurface compaction in Wilmington mostly occurred in the shallower production zones between 650 to 1,200 meters (2,100 to 4,000 feet). These production zones are referred to as the Tar, Ranger and Terminal Zones. Allen and Mayuga (1969) reported that two thirds of the compaction in Wilmington Oil Field occurred in sands and one third in shales.

Due to damage caused by the large amounts of subsidence in the Wilmington Oil Field, including flooding during high tides and damage to structures, a massive reservoir re-pressurization program was initiated in 1958. As part of the re-pressurization program water was injected into the oil reservoir to replace the volume of fluids extracted. The re-pressurization program successfully reduced the surface area and vertical rate of subsidence (Mayuga and Allen, 1969). The rate of vertical subsidence in the center of subsidence depression was reduced from a maximum rate of 28 inches per year (71 cm/yr) in 1951 to 0.0 inches per year (0.0 cm/yr) in 1968. It took approximately 10 years for subsidence to completely stop after the re-pressurization program was initiated in 1958.

Subsequent to 1968 there has been some reported subsidence in the Wilmington Oil Field caused by steam flooding in heavy oil sands (Mike Henry, personal communication, 2012). Steam flooding is a production method that improves extraction volumes of heavier oils. As much as 2.4 feet (0.7 meters) of subsidence was reported to have occurred between 1993 and 1996. The subsidence occurred in the western portion of the field in a relatively localized area. In 1999, the steam flooding was curtailed and surface elevations stabilized by 2006.

Based on experiences in the Wilmington Oil field, oil field operators learned to control and monitor subsidence. Currently, subsidence is carefully controlled in the Wilmington and Long Beach areas by water injection programs and by monitoring surface elevations and reservoir pressures (Henry et. al, 2009 and Baghdkian, et. al. 2010).

Smaller amounts of subsidence have been reported in the Torrance Oil Field including the Redondo Beach area. Oil production began in the Torrance Oil Field in 1922 and in the Redondo Beach area in the late 1950s. The California Division of Oil and Gas (CDOG) indicates that about ½ to 1 foot of subsidence occurred in Torrance and about ¼ to ½ feet of subsidence occurred in Redondo Beach (King Harbor area) from 1953 to 1970 (CDOG, 1974). The U.S. Army Corps of Engineers (1990) reported that surveys indicated that land beneath King Harbor subsided approximately 1.5 feet from 1975 to 1988 or about 0.11 feet/year. The U.S. Army Corps of Engineers also reported that a benchmark located in City of Redondo Beach showed 2.1 feet (0.6 meters) of subsidence from 1945 to 1988. As will be discussed in Section 5.1, the smaller amount of subsidence observed in the Torrance Oil Field relative to the Wilmington Oil Field is due to geologic differences between the fields.

The U.S. Army Corps of Engineers (1990) concluded that subsidence in the Redondo Beach area may have been the result of fluid withdrawal from the underlying oil field. The U.S. Army Corps noted that water injection did not begin in the Torrance Oil Field until 1970 and that generally no water injection occurred in the vicinity of King Harbor in the Redondo Beach area. Johnson et. al. (2006) indicated that lagoonal sediments occur beneath King Harbor. At least some of the measured subsidence in the King Harbor area may have resulted from the compaction or decomposition of these lagoonal sediments. More recently, Hodgkinson et. al. (1996) reported subsidence rates of 2 millimeters per year (mm/yr) or 0.08 inches per year (in/yr) between 1989 and 1994 at Redondo Beach. The lower rate of subsidence may be the result of oil operations ending in approximately 1992.

4.3.4 Assessment of Recent Baseline Conditions Using InSAR

Earth Consultants International (ECI) was subcontracted to perform a baseline subsidence analysis for the Hermosa Beach area and region using InSAR. InSAR uses satellite technology to measure regional changes in the earth's surface elevation on the millimeter-scale. ECI's objectives were twofold: (1) assess recent surface deformation in the vicinity of Hermosa Beach using readily available satellite data; and (2) assess the viability of using InSAR technology to monitor local and regional surface deformation during proposed oil field operations.

InSAR methodology used in the study is described in detail in Appendix B. ECI found two available sources of satellite acquired Synthetic Aperture Radar (SAR) data for the Hermosa Beach area, the European ERS-1 and -2 satellites for the period between 1990 and 2000, and the Japanese ALOS satellite for the period between 2000 and 2010. Two interferograms (comparable pairs of satellite imagery) for the target area were generated. The first for a 5.6-year period between June 17, 1992 and January 31, 1998, and the second for a 2.5-year period between January 20, 2008 and July 28, 2010.

For the 1992 to 1998 time period, the prepared interferogram image was of high quality and a large number of sources of deformation could be observed (Figure 13).

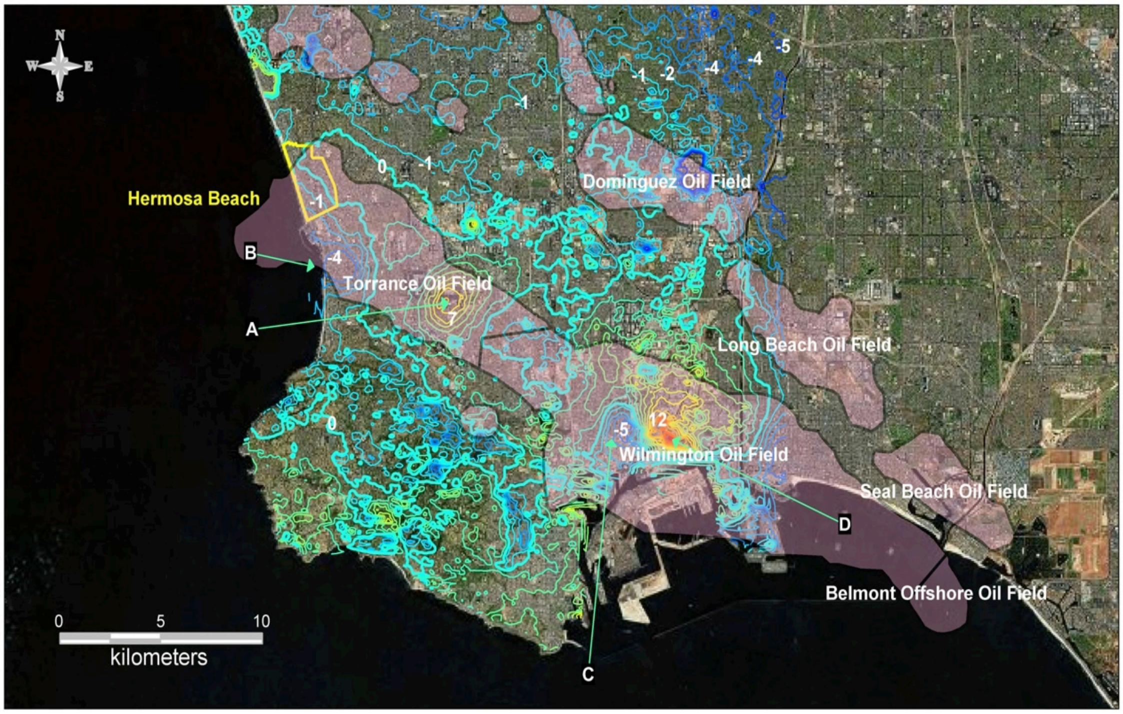

Figure 13. Interferogram Generated with Data Acquired on June 17, 1992 and January 31, 1998 (5.6 year period). *The contour lines represent a 1-mm/year displacement. Blue-Green is 0; Blue represents subsidence and Green-Yellow-Red uplift. At A and D there are areas with uplift and at B and C areas with subsidence.*

On Figure 13, an area centered on the southeastern portion of the Torrance Oil Field located approximately 7.5 km or 4 ½ miles southeast of the proposed project site shows about 7 mm/year (0.27 in/yr) of uplift occurring between June 1992 and January 1998. This observed uplift may be caused by water injection in the Torrance Oil Field area. In contrast, approximately 4 mm/yr (0.16 in/yr) and 1 mm/year (0.04 ins/yr) of subsidence is shown for the Redondo Beach area and Hermosa Beach area, respectively. The estimated 4mm/year of subsidence in Redondo Beach between 1992 and 1998 is slightly higher than the subsidence rate of 2 mm/yr (0.08 in/yr) for Redondo Beach reported by Hodgkinson et. al. (1996) between 1989 and 1994. Hodgkinson et. al. used InSAR to evaluate land surface deformation.

Also of note, subsidence, possibly caused by groundwater management in the Santa Ana Basin, is seen landward or eastward of Hermosa Beach. An InSAR study by Bawden et al. (2001) first observed annual oscillations of land surface in the Santa Ana area. The oscillations of the land surface were attributed to aquifer pumping and recharge operations. Land deformation over the Santa Ana aquifer amounted to 50 mm (2 in) of uplift during the refill-phase in late fall through to mid-spring, followed by a period of 60 mm (2.3 in) subsidence when groundwater water is withdrawn at a higher rate during the summer months (Bawden et. al., 2001). Due to compaction of the strata in the aquifer there is also a net subsidence in the area of approximately 10-15 mm/year (0.4-0.6 in/yr). Though the Santa Ana Basin is located well outside the target area, the deformation appears to be still detectable in an area 10 km (6 miles) or more from the edges of the actual aquifer. It should be noted that extraction and injection volumes of groundwater in the Santa Ana Basin are much larger than the extraction volumes estimated for the proposed project. In addition, the reported subsidence highlights the fact that there are causes of subsidence in the Los Angeles Basin other than oil field operations.

The prepared second interferogram is for the 2008 to 2010 time period. An error in the processing software found by ECI did not allow estimates of absolute numbers in the Hermosa Beach area for this time period (Appendix B). However, ECI was able to conclude that there was no rapid detectable deformation near Hermosa Beach and that subsidence was less than 1 mm/year (0.04 in/yr) in Hermosa Beach for this time period (Figure 14).

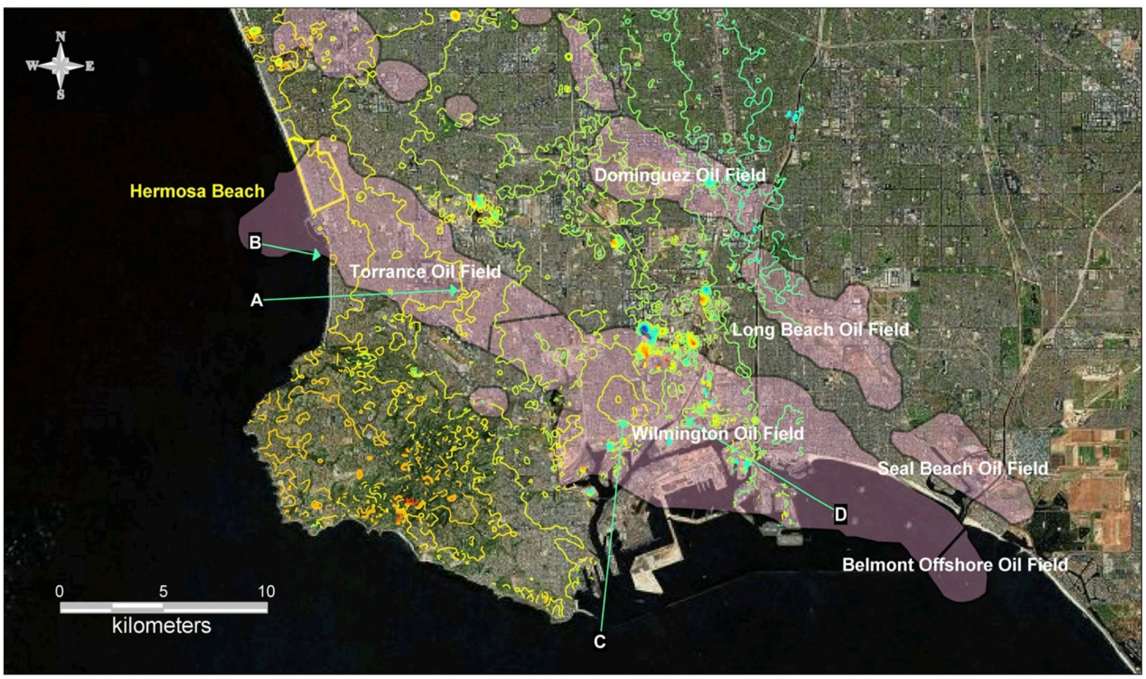

Figure 14. Interferogram Generated with Data Acquired on January 20, 2008 and July 28, 2010 (2.5 year period). *No ground movement was observed in Hermosa Beach or Redondo Beach.*

ECI's study along with other previous InSAR studies (Hodgkinson, 1996 and Bawden et. al., 2001) indicates that land deformation (subsidence and uplift) is occurring in the Los Angeles Basin. This deformation appears to be caused by tectonic processes and groundwater pumping and injection activities, as well as oil field operations such as the observed uplift in the Torrance Oil Field. Based on the results of these studies, it is concluded that InSAR is a valuable tool for measuring regional land surface deformation.

4.4 Induced Seismicity Background Information

4.4.1 Description and Mechanisms of Induced Seismicity

Earthquakes caused by human activities are called "induced seismic events" or "induced earthquakes." The National Research Council (NRC) reports that a very small fraction of injection and extraction activities in the United States have induced seismicity at levels that are noticeable to the public (NRC, 2012). Seismic events caused by or likely related to energy development have been measured and felt in numerous states including California (NRC, 2012). These induced seismic events are generally related to injection and extraction activities, however, the incidence of induced seismicity specifically associated with oil and gas extraction operations is considered to be rare.

Induced seismicity associated with fluid injection or withdrawal is caused by change in pore fluid pressures and/or change in stress in the subsurface in the presence of faults. The mechanisms of induced seismicity associated with fluid withdrawal and injection are discussed below:

- Seismicity Induced by Fluid Withdrawal: Fluid extraction from a reservoir can cause a decline in pore pressure. A decrease in pore pressure may cause a volume contraction of the reservoir and produce stress changes in the surrounding rock (Segall, 1989). Increasing horizontal stress above and below the reservoir can lead to faulting. These events are considered relatively rare (NRC, 2012).

- Seismicity Induced by Fluid Injection. Injection of fluid in rocks may cause an increase in pore pressure and modify the state of the stress in the reservoir rock. Pore pressure increases in joints and faults are potentially destabilizing since they cause a reduction of slip resistance along the plane of the joint or fault.

4.4.2 Historical Incidences of Induced Seismicity

The Los Angeles Basin is a tectonically active region with many active faults and reported historical earthquakes. In the portion of the Los Angeles Basin where Hermosa Beach is located, oil fields are in close proximity to faults (Figure 15).

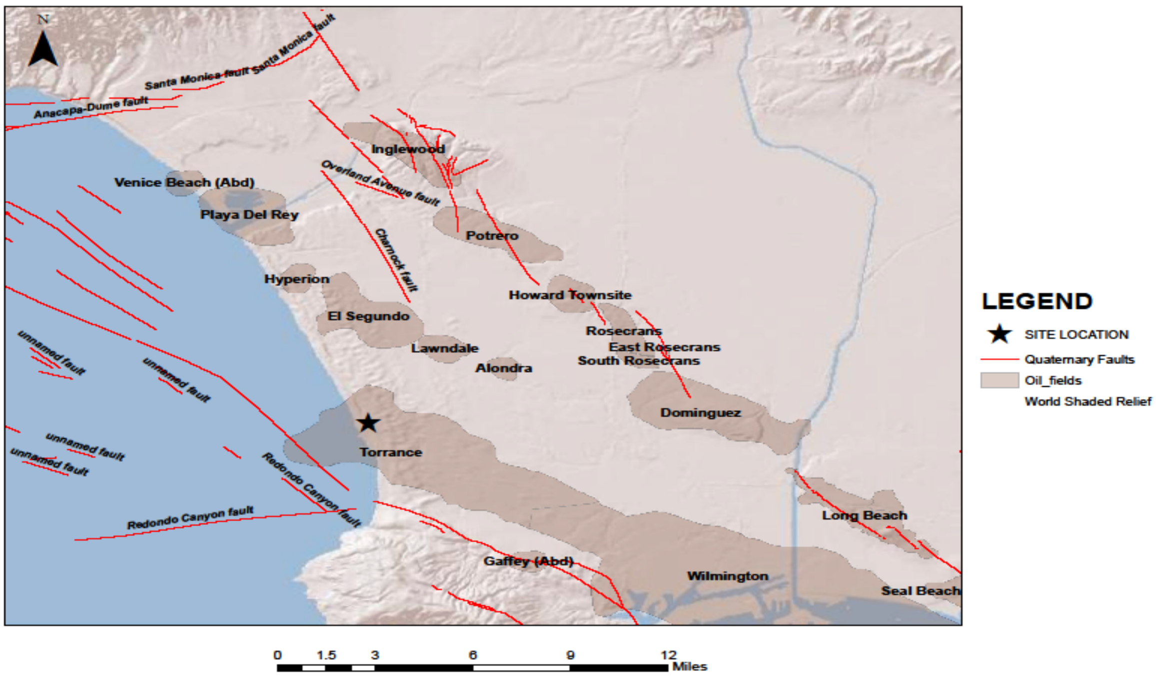

Figure 15. Los Angeles Basin Oil Fields with Faults

As a part of an evaluation of seismic activity in the Hermosa Beach area, ECI prepared a figure showing locations of earthquake epicenters recorded between 1981 and 2010 in the northwest portion of the Los Angeles Basin (Figure 16). Details of ECI's study are presented in Appendix B. The data were acquired from several catalogues kept at the Southern California Earthquake Data Center (SCEDC).

Figure 16 illustrates the distribution of earthquakes in the Los Angeles Basin. Because the Los Angeles Basin is a tectonically active area, any discussion of induced seismicity for the area must distinguish natural tectonic processes (i.e., natural earthquakes) with those earthquakes that could be associated with man-made causes. Generally, seismic activity at seismogenic depths below 8 km (5 miles), where temperature and pressure conditions favor earthquake nucleation, is more likely due to natural tectonic stresses and can be considered part of the natural background seismicity. Seismicity in the vicinity of oil fields, especially small earthquakes at shallow depths between 0-4 km or

0-2½ miles could possibly be related to anthropogenic causes such as oil field extraction and injection activities.[3] However, this relationship is not at all conclusive because natural earthquakes can also occur at this depth.

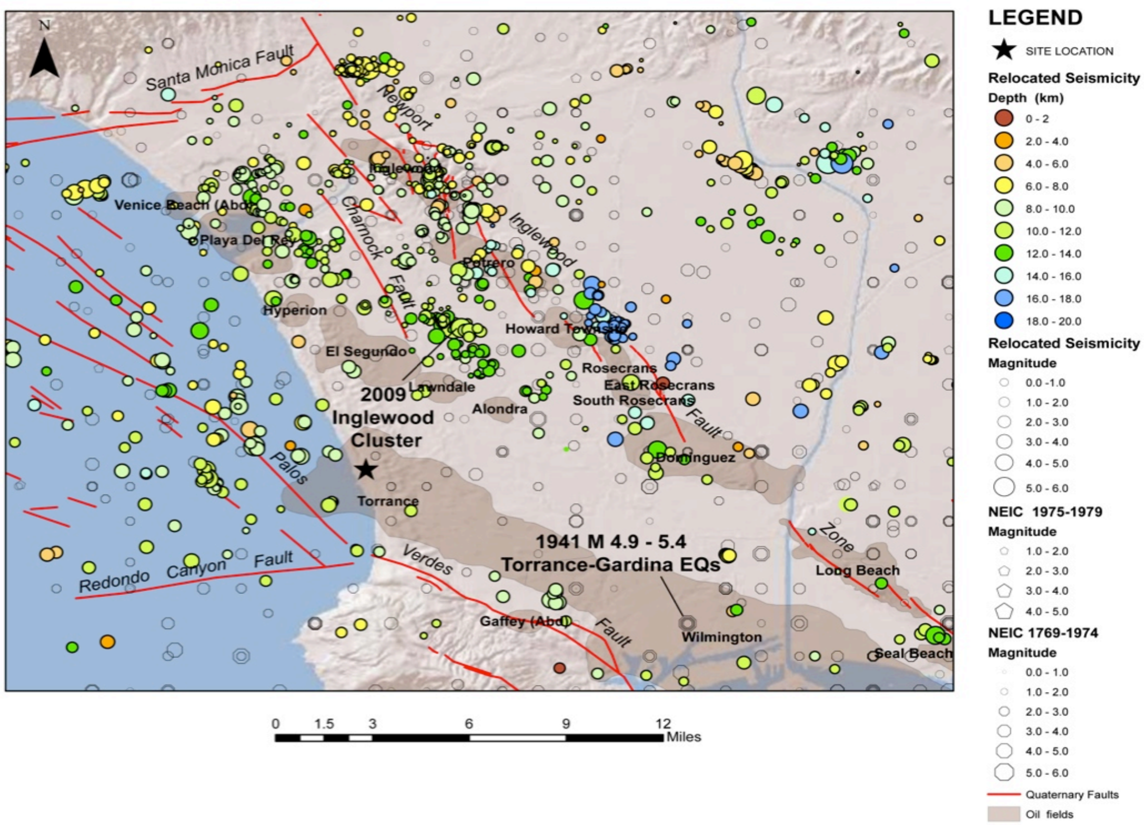

Figure 16. Distribution and Depth of Earthquakes in the Los Angeles Basin

A well-publicized report on possible induced seismicity in 1971 in the Los Angeles Basin was authored by Teng et. al. in 1973. Teng et. al**.** reported on seismic activity in and adjacent to 14 oil fields in the Los Angeles Basin where water injection or flooding was taking place. Many were located along the Newport-Inglewood fault zone. Much of the seismicity detected occurred at depths well below oil reservoirs and most of the earthquakes were small in magnitude, and consequently a definitive correlation between oil field operations and the seismicity was not made. A more recent study by Petersen and Wesnousky (1994)[4] evaluated seismic events greater than M2 on the Newport-Inglewood fault zone. Their evaluation also found that most of the earthquake

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[3] Oil production zones in the Los Angeles Western Shelf area generally occur at depths between approximately 0 and 4 km.
[4] As sited by Cardno ENTRIX (2012).

epicenters along the fault zone occurred at much deeper depths than where oil field operations were taking place.

Known examples of induced seismicity in the Los Angeles Basin associated oil and gas extraction are the Wilmington Oil Field and the Inglewood Oil Field. A series of shallow earthquakes occurred between 1947 and 1961 in the Wilmington oilfield. The earthquakes occurred in 1947, 1949, 1951, 1954, 1955, and 1961 (Kovach, 1974). The location of these earthquakes is shown on Figure 16. It has been recognized that the earthquakes were the result of “sudden horizontal movement” along very shallow and low angle bedding planes at depths between 470 and 530 meters (i.e., ½ km depth). The earthquakes were believed to have resulted from the horizontal and vertical movement caused by the extremely large amounts of subsidence in the area which was caused by the lack of fluid replacement (water injection) during early development of the oil field. After water injection operations began in the Wilmington Oil Field to mitigate the subsidence (see Section 4.3.3), the earthquakes stopped. In the Inglewood Oil Field, water flooding operations may have accelerated normal faulting, and produced seismicity starting in 1962 (Nicholson and Wesson 1992). The movement along the fault in Inglewood, often referred to as fault creep, possibly led to the failure of a water reservoir. Again, this activity, like the shallow earthquakes in Wilmington, is thought to be the result of the significant amount of subsidence (10 feet) that occurred in the Inglewood area. The extreme levels of subsidence believed to have produced the “subsidence caused earthquakes or fault creep” in Wilmington and Inglewood are not expected to occur during the proposed oil development operations in Hermosa Beach.

There have been no reported incidences of induced seismicity associated with oil field operations in the Torrance Oil Field including the Redondo Beach area. Seismic monitoring systems installed in the Torrance Oil Field (presumably in the late 1970s) showed no effect of oil production or water injection on seismicity over an approximately 11 year period (Ultrasystems Inc., 1990). Furthermore, Wright (1994) indicated that nine earthquakes between 1.5M and 3.0M occurred in the area of the Torrance Oil Field between 1972 and the early 1990s, and only one occurred above a depth of 5 km (3 miles). Wright (1994) further indicated that no seismic activity was associated with water injection in the Redondo Beach area which occurred briefly in the early 1970s. Seismic information collected during this investigation by ECI corroborates these findings (see the following Section 4.4.3 and Figure 16).

4.4.3 Baseline Seismic Assessment

ECI prepared a report summarizing seismic data available from three sources at the SCEDC: (1) the Relocated Southern California Seismic Catalogue, (2) the National

Earthquake Information Center California Catalog, and (3) the National Earthquake PDE Earthquake Catalogue (see Appendix B for references). All the catalogs generally include earthquake locations, depth, timing, and magnitude. The primary purpose of this investigation was to evaluate background seismicity in the Hermosa Beach area. A secondary goal was to evaluate the temporal and spatial patterns of seismicity in other developed oil fields in the vicinity of the proposed project. Full results of the study are presented in Appendix B. The time frame from 1981 to 2010 was analyzed.

A seismic linear trend is a relatively higher density of earthquake occurrence distributed linearly. Results of the seismic evaluation identified two distinct linear trends in the study area (Figure 16). One linear trend occurs along the Newport-Inglewood fault zone. As discussed in Section 4.1, the Newport-Inglewood fault zone consists of a series of short and discontinuous faults, many of which are known to be active. The other seismic trend occurs to the west between the Newport Inglewood fault zone and the Venice Beach - Alondra Oil Field alignment (Schist Ridge). The orientation of this seismic trend is not coincident with any surface faults, and obliquely crosses the Charnock fault. More diffuse or spread out zones of seismicity occurred to the southwest, in the offshore area, and in the eastern portion of the ECI study area (Figure 16). This seismicity is coincident with offshore faults and blind thrust faults. The Torrance and Wilmington Oil Fields, including the Hermosa Beach area, are notable for their relative lack of seismic activity in the last 30 years during which active oil field operations in the Torrance and Wilmington areas were occurring (Figure 16).

ECI evaluated the depth, magnitude, and timing of earthquakes along three geological structural trends where oil fields occur: the Newport-Inglewood fault zone, the Schist Ridge, and the Torrance-Wilmington Anticline. These structural features along with the oil fields that occur along each of these features are described in Section 4.1. ECI's analysis indicates that the majority of recent seismicity in the region occurs between depths of 8 and 14 km (5 to 8½ miles). These deeper seismic events are the result of natural tectonic stresses. As described above, only a few shallow low magnitude earthquakes between 0-4 km (0-2½ miles) could possibly be associated anthropogenic causes such as oil field operations: one shallow earthquake west of the Wilmington field, two shallow earthquakes in the vicinity of the Venice Beach – Alondra alignment, and six shallow earthquakes in fields along the Newport Inglewood fault zone. The Wilmington Oil Field and the oil fields along the Venice Beach - Alondra trend are considered to have a similar geologic structural setting as the Hermosa Beach area, whereas the oil fields along the active Newport- Inglewood fault zone are in a generally different structural setting. Figure 17 shows the depth and magnitude of earthquakes in and near the Wilmington/Torrance Oil Field area. The one shallow earthquake that occurred in the area of the Wilmington Oil Field was located slightly west of the oil field at a depth of less than 2 km and had a magnitude of 2.2. As noted above, shallow earthquakes can occur in the Los Angeles Basin as the result of natural tectonic processes. The causes of these shallow earthquakes (either natural or induced) have not been determined.

A similar figure for the oil fields along the Venice Beach-Alondra Oil Field alignment (Schist Ridge) and the Newport-Inglewood fault zone is presented in Appendix B. No other earthquakes in the databases could be associated with near surface oil operations.

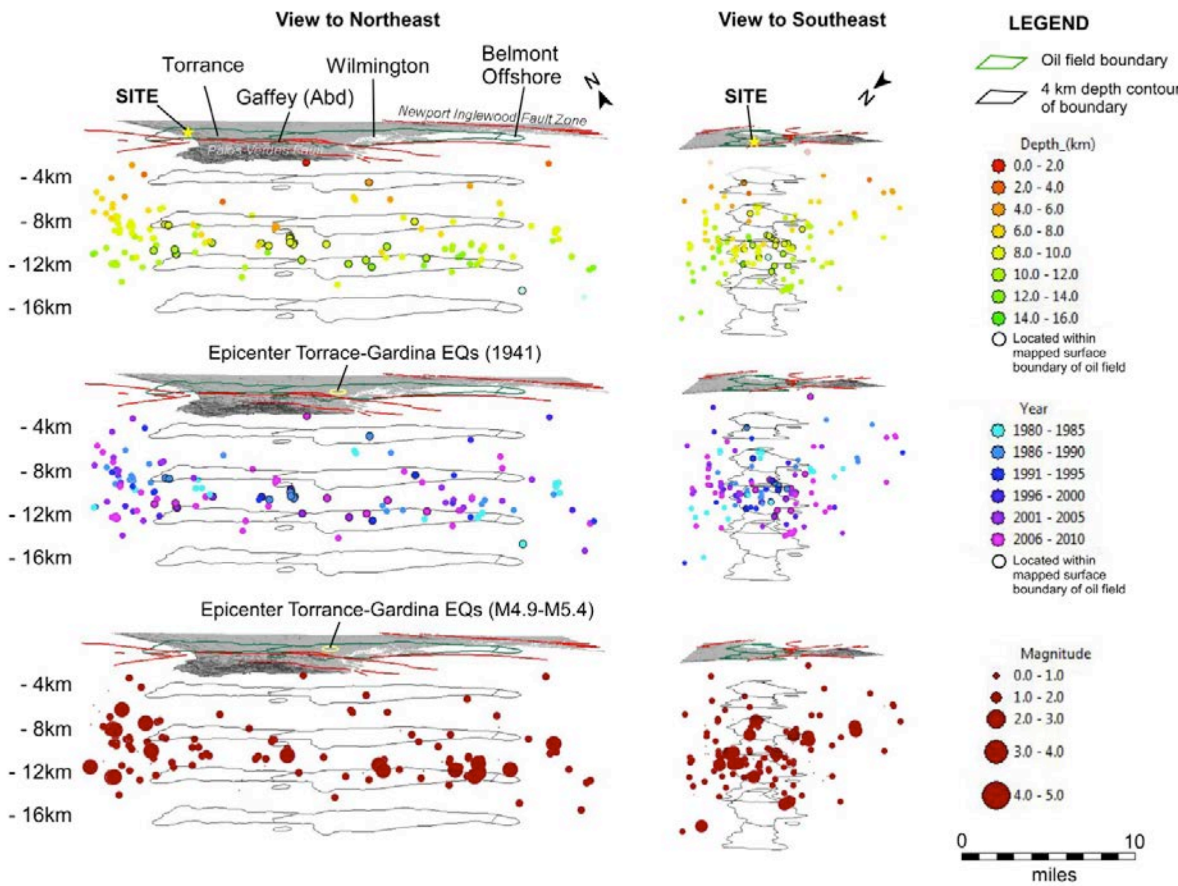

Figure 17. Depth, Timing, and Magnitude of Seismicity in the Area of the Wilmington-Torrance Anticline

The lack of shallow earthquakes during recent production in the Torrance Oil Field and the small numbers of shallow earthquakes that can even be possibly associated with oil field operations in the Wilmington Oil Field (one M2.2 earthquake) and the Venice Beach – Alondra trend (two small earthquakes) indicates that it is highly unlikely the

Hermosa Beach area will experience an increase in induced seismicity during oil extraction and associated activities such as water re-injection.

5.0 SUBSIDENCE AND INDUCED SEISMICITY DISCUSSION AND ANALYSIS

5.1 Subsidence

Significant land subsidence can occur in oil fields due to the lowering of reservoir pressures and the subsequent compaction of reservoir materials which is propagated to the land surface. When land subsidence occurs in oil fields it is often bowl-shaped in geometry with the largest amount of subsidence, or the base of the bowl, occurring over the area of oil field operations. Generally, damage to structures and underground utilities occurs only where a significant amount of subsidence occurs.

To estimate the potential for subsidence to occur in the Hermosa Beach area from the proposed oil field project, an evaluation of geology and historical subsidence was conducted for nearby oil fields. The nearby oil fields include the Wilmington Oil Field and the Torrance Oil Field. These fields occur along a similar structural setting – a northwest trending anticlinal structure. The Hermosa Beach project area is located in the northwest portion of the Torrance Oil Field which also includes the Redondo Beach oil field area (Figure 3).

As summarized in Section 4.3.3, historical subsidence due to oil field operations has occurred in the Wilmington Oil Field and the Torrance Oil Field, although the subsidence largely occurred before the understanding of the importance of water injection to control subsidence. A very significant amount of historical subsidence (29 feet) occurred in the Wilmington Oil Field in the 1940s through the 1960s and cracking of the land surface caused damage to structures and utilities including buildings, railroad tracks, roadways, pipelines and oil wells. However, a comparison of geology and proposed oil field management as part of this project indicates that this amount of subsidence would not occur in Hermosa Beach.

The oil reservoir materials in the Hermosa Beach area are much less susceptible to subsidence than the Wilmington Oil Field reservoir. Oil reservoir materials in the Hermosa Beach area are significantly finer-grained and more consolidated (i.e., cemented and compacted) than in the Wilmington area, and so compaction of the rock material due to stresses caused by oil extraction will be less. Reservoir materials in Hermosa Beach consist largely of interbedded thin sands and fractured shales; whereas, the main reservoir materials in Wilmington are thicker coarser sand units. The total thicknesses of sand materials that are most susceptible to subsidence are also significantly less in Hermosa Beach than the Wilmington area. Average net sand thickness in the Wilmington area has been estimated at approximately 800 to 1200 feet whereas compactible sands in the Redondo Beach and Hermosa Beach areas are more on the order of 100 to 150 feet thick (Mike Henry, personal communication, 2012). These differences in reservoir characteristics between Wilmington and Hermosa Beach coincide with the general regional geologic trends.

A smaller amount of subsidence, as much as 2 feet (0.6 m), has been measured in the Torrance Oil Field including the Redondo Beach area. No direct damage to building or underground utilities resulting from the subsidence was reported, although the U.S. Army Corp (1990) concluded that subsidence may have caused a lowering of the King Harbor breakwater and subsequent storm damage to commercial buildings in the harbor area during a large winter storm in 1988. A bowl-shaped subsidence area mapped by the CDOG (1974) in the oil field area clearly shows that the oil extraction produced some subsidence in the Torrance and Redondo Beach areas, although compaction of shallow lagoonal sediments beneath the King Harbor breakwater may have also contributed to the local subsidence (see Section 4.3.3).

The Redondo Beach Oil Field area is located directly adjacent to Hermosa Beach area. Both are located in the northwest portion of the Torrance Oil Field, and the geology and reservoir properties of the two areas are thought to be very similar. The main oil reservoirs beneath Redondo Beach and Hermosa Beach occur in the Puente Formation and the reservoir rocks are relatively fine-grained with net sand thickness estimated between 100 to 150 feet. Consequently, the Redondo Beach oil field area is a good geologic analog to the Hermosa Beach oil field area.

Based on a geologic analog comparison in the Torrance Oil Field, if left uncontrolled, as much as one to two feet of land subsidence could potentially occur in the Hermosa Beach area due to the proposed oil development project. However, it should be noted that re-injection of water in the Torrance Oil Field did not begin until 1970, approximately 50 years after oil extraction began in the area, and virtually no water injection occurred in the Redondo Beach area (CDOG, 1974, Wright, 1994, and Mike Henry, personal communication, 2012). Oil production, in combination with the lack of water injection operations, was likely responsible for most or all of the measured subsidence in the Torrance and Redondo Beach areas. The City of Torrance reported that recent surveys indicate that subsidence is no longer occurring or is occurring at substantially reduced rates (City of Torrance, 2009). As part of this evaluation for the proposed project, between the years 1992 and 1998, uplift was measured in the southeastern portions of the Torrance Oil Field (7 mm/yr) and small amount of subsidence was measured in the Redondo Beach area (4 mm/yr). As discussed below, re-injection of produced water is part of the E&B's proposed oil development project as well as a comprehensive subsidence monitoring plan with strict action levels (see Section 3.3.2).

Water produced during proposed oil operations will be re-injected below the oil water contacted within the producing zones. E&B estimates that the ratio of water injection volumes to total fluids produced will be less than one to one. Oil field operations in the Los Angeles Basin, where subsidence is a significant issue, include a water injection volume to total produced fluid ratio of 1:1 or slightly higher (i.e., 100% to 105% of the total fluid volumes produced are replaced). A 100% to 105% replacement of total fluid volumes produced has been shown to adequately control subsidence in the Wilmington-Long Beach area (Baqgdikian et. al., 2010). As discussed earlier, fluid reinjection in the Wilmington Oil Field was not initiated from the from the beginning of the project.

Because the project description calls for a less than 1:1 replacement of total produced fluids some subsidence cannot be precluded. Most of the initial water injection is planned for portions of reservoir zones located beneath on-shore areas; therefore, most of the subsidence, if it occurs, would likely take place in offshore areas. However, the oil development project includes a comprehensive subsidence monitoring plan for the Hermosa Beach area with strict action levels that will minimize or eliminate the potential for damaging amounts of subsidence to occur (see Section 3.3.2). In addition, DOGGR will review the proposed project operations including plans for fluid withdrawal, water re-injection and reservoir pressure maintenance. DOGGR maintains jurisdiction to arrest or ameliorate subsidence under Division 3, Chapter 1, Article 5.5 of the California Public Resources Code (beginning with Section 3315). The DOGGR requires development of field wide re-pressuring plan to abate potential subsidence due to fluid production and sand withdrawal. Furthermore, section 3319 (c) requires that "field wide re-pressuring plans be based upon a competent engineering study that includes re-pressuring operations designed to most effectively arrest or ameliorate subsidence." Consequently, oil field operations will be conducted under the oversight of DOGGR and will be designed to reduce potential subsidence as much as possible.

5.2 Induced Seismicity

Induced seismicity or human-generated earthquakes can cause damage to structures and create public annoyance. Significant increases and decreases in reservoir pressure may cause induced seismicity, but most often induced seismicity is associated with large increases in reservoir pressures that may result from injecting fluids back into the reservoir.

During oil field operations in Hermosa Beach, produced water is planned to be re-injected into the reservoir. Water re-injection is a common oil field operation in the Los Angeles Basin and reduces the potential for subsidence (see Section 5.1). Water re-injection in Hermosa Beach will occur at relatively low pressures, 900 to 1,100 psig, so as not to significantly increase reservoir pressures and cause damage to reservoir materials. As part of the project and as required under California regulations[5], re-injection pressures will be monitored and tested at the surface. The State of California (DOGGR) will oversee re-injection pressures and, in accordance with California regulations, maximum allowable injection pressures at the surface will be less than pressures that could cause fracturing in the subsurface reservoir. Consequently, the proposed project's plans for reservoir management should minimize or eliminate the potential for induced seismicity to occur.

It should also be noted that conventional hydro-fracking operations, where surface water is injected into large areas of the reservoir formation at relatively high rates, will not be utilized during the project. A completion method called High Rate Gravel Packing may be used.[6] As part of the High Rate Gravel Packing procedure, lithostatic pressures in the reservoir are slightly exceeded in a very limited area (radius of approximately 3-10 feet around the borehole target area). This method can cause limited fracturing in the area close to the well, but because of the limited formation intrusion associated with the method, the likelihood of induced seismicity is very low. A recent study by Cardno ENTRIX (2012) in the Inglewood Oil Field showed that the High Rate Gravel Packing completion method did not induce seismicity.

As part of this study, an evaluation of historical seismicity was conducted for nearby oil fields including the Wilmington Oil Field and the Torrance Oil Field. Results indicated that most of the recent seismicity (earthquakes occurring between 1981 and 2010) in the northwestern portion of the Los Angeles Basin occurred at depths below 8 km. These deeper seismic events are the result of natural tectonic stresses. Only a few shallow earthquakes between depths of 0-4 km with relatively low magnitude earthquakes were measured near oil field operations, and most of these shallow earthquakes occurred near oil fields located along the Newport-Inglewood fault zone which is generally considered

[5] California Code of Regulations Title 14, Division 2, Section 1724.10.

[6] High Rate Gravel Packing is a well completion method where a relatively small amount of uniform grain-size sand and water is pumped into the well after is perforated. The sand and water flow into the formation at a pressure that slightly exceeds the fracture gradient of the productive formation. The depth of sand penetration into the formation is minimal usually in the three to ten foot radius range. After the sand is displaced into the formation, the pressure is released in a controlled manner so that the sand is held in place. This method can greatly reduce the infiltration of reservoir sand into the wellbore. The industry term "Frac-Pac" is often used to describe this method and should not be confused with conventional hydraulic fracturing. Unlike conventional hydraulic fracturing, the process of High Rate Gravel Packing is not intended to fracture the formation in order to increase the permeability of producing formation, but rather is a method of placing sand and gravel in the well annulus (area close to the well bore) so as to limit the entry of formation sands into the wellbore. Injection rates used in the High Rate Gravel Packing method are much lower than in the conventional hydraulic fracturing methods.

a different structural setting than that which exists beneath Hermosa Beach. Except for one shallow, low magnitude earthquake (M2.2) west of the Wilmington Oil Field, no shallow earthquakes near oil field operations were recorded in the Wilmington Oil Field or the Torrance Oil Field including the Redondo Beach area. The relative lack of shallow earthquakes during recent production operations in these fields further suggests that the Hermosa Beach area should not experience an increase in seismicity during the proposed oil field operations.

6.0 POTENTIAL IMPACTS

E&B is proposing an oil development project for the Hermosa Beach that will utilize directional drilling to develop crude oil and gas reserves in onshore and offshore areas. Based on site and nearby geologic conditions, comparison to other oil fields, and analysis of project components (Section 5.0), the potential for the proposed oil development project to cause damaging land subsidence and induced seismicity was evaluated, and is summarized below.

The potential for damaging subsidence is considered less than significant for the following reasons:

- Oil operations will be planned and conducted under the oversight of the DOGGR.
- Oil field operations will include re-injection of produced water.
- The project includes a plan for monitoring potential subsidence with triggers (action levels) for operational review and changes should evidence of very small amounts of subsidence be observed. The plan is designed to detect subsidence in its earliest stages and action levels include shutdown of production should fractions of a foot of subsidence be observed.

The potential for induced seismicity which could cause damage to structures or annoy residents in the area is considered less than significant for the following reasons:

- Re-injection pressures will be overseen by the DOGGR and, generally, reservoir pressures will be maintained below the fracture pressure.
- Except for one shallow low magnitude earthquake near Wilmington, there has been a lack of recent earthquakes occurring near oil field operations in the Wilmington and Torrance Oil Field areas.
- The project includes a plan for monitoring seismic activity in the area during oil field operations, and modifying operations up to and including ceasing operations if overseeing agencies consider it necessary.

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APPENDIX A

Subsidence Monitoring Plan

Appendix A

Subsidence Monitoring Program

A.1 General

A Subsidence Monitoring Program was prepared for the E&B Project to measure ground movement (subsidence and uplift), if it occurs, within the region of the oil field area. The recommended Subsidence Monitoring Program is intended to meet the following objectives:

1. Measure subsidence (and uplift) accurately, if it occurs throughout the City of Hermosa Beach (City) and region;
2. Distinguish between any measurable subsidence caused by oil extraction operations and subsidence attributable to other human activity or natural processes (regional background);
3. Provide information on the relationship between oil field operations and any potential measurable subsidence patterns; and
4. Establish the action level requirements that will minimize or eliminate the potential for damaging subsidence.

To accomplish these objectives, the monitoring plan includes the following:

- Ground elevation survey methodologies with high vertical resolution;
- A network of survey or subsidence monitoring locations, including continuous GPS stations and GPS benchmarks, positioned within and outside the City that are sufficiently spaced to draw conclusions about subsidence within the City;
- Use of InSAR imagery technology to evaluate regional subsidence patterns both within and beyond the proposed oil field;
- Sufficient monitoring frequency to establish trends in subsidence in order to distinguish background ground movement from any subsidence caused by proposed oil field operations;
- Reservoir monitoring, including documentation of produced fluid volume (oil, gas and water) and reservoir pressures at similar frequency to ground elevation measurements;
- Reporting requirements; and
- Action levels.

The details of this plan are discussed in detail below.

A.**2 Continuous GPS Stations**

Description: GPS monitoring relies on satellites to precisely determine a particular location and elevation. Vertical elevations and horizontal positioning at monitoring sites can be measured to a fraction of an inch. Continuous GPS monitoring stations have been employed by the Houston Galveston Subsidence District and the City of Long Beach Gas and Oil Department since the late 1990s and early 2000s as part of a shift away from traditional spirit leveling. Figure A-1 shows an example from the City of Long Beach of a continuous GPS monitoring station. Permits and/or permission will likely be required from the cities or property owners where these stations are installed. Additionally, possible leasing of a footpad might be necessary. A continuous supply of electricity is required to run these stations, which is provided with solar panels.

***Figure A-1. Example of Continuous GPS Monitoring Station in the City of Long Beach*[1]**

[1] http://www.longbeach.gov/oil/subsidence/about_gps.asp

Purpose: Real-time GPS monitoring provides continuous elevation and horizontal positioning data that will serve to facilitate establishment of ground movement and subsidence trends over time. These trends can be used to augment interpretation of measurements at locations that are monitored with less frequency. Additionally, these stations will provide current information for locations, including critical structures that could present more significant impacts in the event of subsidence. In this way, if subsidence is measured at these locations between more comprehensive monitoring events, mitigating actions can be taken to avoid deleterious effects. Finally, permanent GPS stations increase the accuracy and efficiency of the benchmark surveys that are also proposed as part of this monitoring program (see below).[2]

Locations: At this time three (3) continuous GPS stations are proposed for this monitoring program. Additional continuous GPS stations may be required inland if the stations are to be used for vertical and horizontal control stations for the benchmark stations that will be surveyed using mobile equipment (see Section A.3). The 3 current proposed continuous GPS stations are:

- Hermosa Beach Pier. The pier will serve as the furthest offshore point in the monitoring program, and the closest to where the center of the subsidence bowl would be expected to occur. This location has an existing monitoring box operated by LA County. It is possible that shared use of this box could be coordinated for the purpose of installing subsidence monitoring equipment.
- Longfellow Outfall. The outfalls along the Hermosa Beach shoreline were carefully designed to divert a portion of storm flow into treatment facilities prior to being discharged into the ocean while also conveying peak flows to the ocean without causing flooding within Hermosa Beach. The Longfellow Outfall was selected for continuous monitoring because it is larger and more structurally stable than some of the other outfalls along the City's coast. This location does have a nearby monitoring box. It is possible that shared use of this box could be coordinated for the purposed of installing subsidence monitoring equipment.
- King Harbor Jetty. This location was selected to achieve a distribution of continuous monitoring points along the coast of Hermosa Beach. This will help provide a limited regional picture of the subsidence between survey events. There is no existing monitoring equipment in this location, so a monitoring station would have to be constructed from scratch.

Locations of the proposed continuous monitoring sites are shown in Figure A-2.

[2] Enhancements to GPS-Based Subsidence Monitoring at the Wilmington Oil Field, Baghdikian, et al. Society of Petroleum Engineers, 2010.

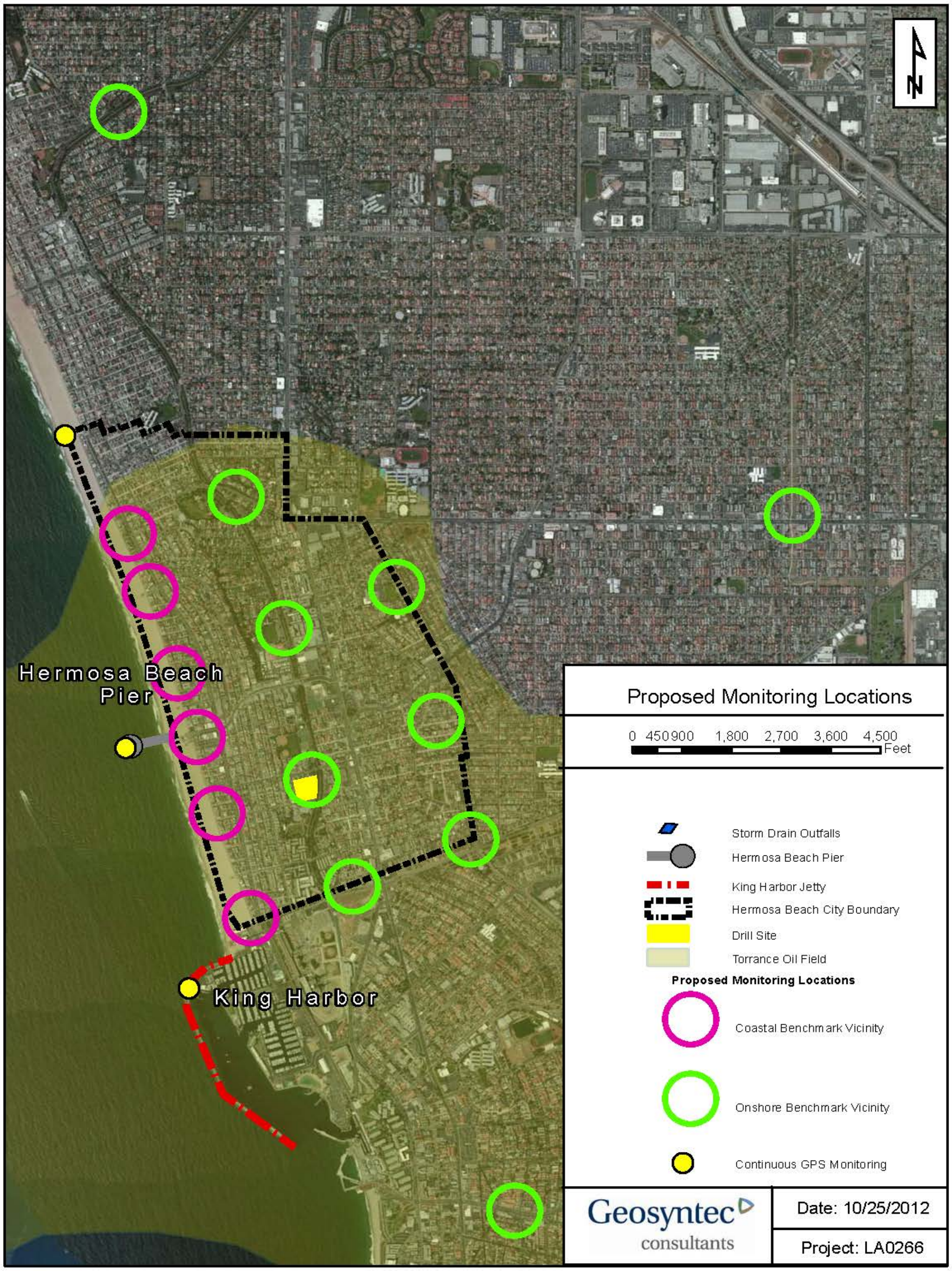

Figure A-2. Proposed Subsidence Monitoring Locations

A.3 GPS Surveys with Benchmark Stations

Description: GPS technology allows for large surveying projects to be completed efficiently and accurately. GPS technology is currently being used at the City of Long Beach to monitor subsidence. As part of the GPS monitoring plan, benchmarks must be selected for monitoring and the elevations of each of these points can be used to create a generalized picture of the topography of an area. Benchmarks do not take up space in the way that the continuous monitoring equipment does. Figure A-3 shows an example of a GPS benchmark installed in a local sidewalk and Figure A-4 shows the mobile equipment that is taken to each site during the survey. GPS technology allows the elevation at a site to be instantaneously pinpointed from a network of satellites. GPS units are highly accurate in both the vertical and horizontal direction. GPS technology can measure vertical elevation to a fraction of an inch. The Wilmington Oil Field monitoring program, which includes a similar program of GPS monitoring as this plan, is able to achieve an accuracy of 1.0 to 2.0 cm (0.033 to 0.066 feet).[3] GPS and InSAR imagery (discussed below), have been used concurrently with excellent results.[4]

Figure A-3. Example of Benchmark

[3] Enhancements to GPS-Based Subsidence Monitoring at the Wilmington Oil Field, Baghdikian, et al. Society of Petroleum Engineers, 2010.
[4] Mining Subsidence Monitoring Using the Combined InSAR and GPS Approach, Ge et al. 10th FIG International Symposium on Deformation Measurements, 2001.

Figure A-4. Benchmark Survey Equipment

Purpose: This network will be the basis for assessing the spatial distribution of subsidence. The regular spacing and high density of benchmarks within the limits of Hermosa Beach will provide a reliable estimate of subsidence within the City and selected locations outside of the City will establish a broader regional picture of subsidence.

Locations: Thirteen (13) benchmark locations were selected to provide a regional picture of subsidence patterns within the City of Hermosa and the Torrance oil field. The proposed locations are shown in **Error! Reference source not found.**. The areas shown are broad so that they can be adjusted slightly for accessibility. There is a higher density of benchmarks along the coastline, where there is a relatively higher potential for subsidence. In general, a grid pattern was followed with an approximately 0.4 km (0.25 mile) resolution within limits of the City. This density is similar to that of monitoring programs of the Chino Basin and Wilmington Oil Field.[5,6]

[5] Chino Basin Optimum Basin Management Program, Management Zone 1 Interim Monitoring Program. Wildermuth Environmental, 2006.

The GPS monuments will need to be constructed per the SCIGN/UNAVCO[7] design criteria to insure monument stability.

Additionally, three (3) locations outside of Hermosa Beach are proposed. The locations are positioned north, south and east of the Hermosa Beach oil field area. These locations will serve to provide information on ground movement outside the active oil field area.

Frequency: Because the ratio of fluid production volume to water injection volume will be highest in the first years of the project, a bi-annual GPS survey is proposed for the first 5 years of project operations. After five years, the monitoring program, including monitoring locations, methodology, and survey frequency, will be reevaluated based on the information collected (survey data, oil field operation information, analysis results, and trend evaluations). If oil production related subsidence is below the action levels outlined in the plan in the first five years (see below), the monitoring frequency for GPS surveying, and InSAR imagery analysis may be reduced to once per year, if there is sound rationale to support the reduced monitoring as long as oil operations remain consistent. If oil production related subsidence has been measured in the first five years, it is advisable to continue monitoring on a bi-annual basis, or more if it is deemed necessary. If a change in monitoring frequency is considered appropriate at any time, a revised monitoring program, that will include an evaluation of new monitoring methodologies and technologies, will be prepared by E&B. The revised monitoring plan would be submitted to the City and the overseeing agencies for review and approval. A similar reevaluation of the monitoring program will occur after ten years of operation or if any action levels are exceeded.

A.4 InSAR Imagery

Description: Synthetic Aperture Radar (SAR) is a radar imaging system that can provide very accurate measurements of ground movement over large regions. With InSAR techniques, using RADARSAT, ENVISAT and ERS satellite imagery, measurements of vertical ground movement on the millimeter scale have been demonstrated. A vertical resolution of 1 mm to 5 mm (approximately 0.003 to 0.016 feet) was achieved during this study using InSAR methodology. The resolution varies from 1-100 square meter pixels depending on the satellite and the quality of data requested.[8]

Purpose: InSAR imagery provides a broader regional picture than benchmark surveying. This regional information is useful in distinguishing between different subsidence areas and

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[6] Enhancements to GPS-Based Subsidence Monitoring at the Wilmington Oil Field, Baghdikian, et al. Society of Petroleum Engineers, 2010.
[7] Southern California Integrated GPS Network/University Navstar Consortium
[8] InSAR Applications for Highway Transportation Projects, Federal Highway Administration, 2006.

determining their cause. If data is shown to be dependable, and consistent with GPS data, this data could be used to justify reduced frequency of surveying in future.

Frequency: InSAR imagery will be acquired and analyzed such that the information will coincide with each GPS surveying event.

A.5 Oil Field Operation Information

Description: Monitoring oil fluid extraction volumes, water injection volumes, reservoir responses, and surface injection pressures is required for proper operation of any oil field. This information can provide critical information for preventing or controlling subsidence. This type of record keeping is generally kept during normal well operation. Measuring the reservoir pressure may require shutting down some wells for several days to measure pressures in the wells. This can also be accomplished when wells are down for maintenance. Details of the oil field reservoir record keeping and reservoir pressure monitoring will be provided by E&B and approved by the overseeing agencies, including DOGGR, before oil field operations are commenced.

Purpose: Oil field operation information will facilitate the evaluation of potential causes of ground movement in the area and provide information to help ameliorate or control any ground movement or subsidence, if it occurs.

Frequency: Continuous fluid extraction volumes and injection records must be kept throughout the life of the project. Reservoir pressure should be measured such that the data will coincide with each surveying event.

A.6 Reporting

A monitoring report will be prepared and submitted to the City and the overseeing agencies, such as DOGGR, after each monitoring event. This report will include an analysis of ground movement trends based on all data sources (GPS Survey and InSAR). Additionally, the report will present salient oil field operation data, including fluid production volumes, water injection volumes and pressures, and reservoir pressure data. This data will be compared with any ground movement trends to determine if any causative relationships exist.

A.7 Action Levels

Specific thresholds and action levels for subsidence have not been established by State or Federal agencies. For this specific project, the objectives of the action levels are to establish further safeguards to avoid subsidence that could potentially cause damage to property and the environment. The action levels will also provide an early warning system and sufficient time to implement mitigation activities or necessary modifications to oil field operations to minimize or eliminate the potential for damaging subsidence. More aggressive action may be required depending on the rate of subsidence. The action levels are as follows:

- If monitoring identifies a bowl-shaped subsidence feature with subsidence centered above the oil field greater than 0.05 feet (1.5 cm) above regional background levels at any one benchmark (GPS location) or area (InSar), the operator will: (a) immediately evaluate subsidence trends and geometry; (b) notify the City and overseeing agencies if evaluation indicates measured subsidence is associated with oil field operations (c) perform internal review of injection and reservoir re-pressurization programs and implement changes to oil field operations, if necessary; (d) increase monitoring frequency, if necessary .

- If monitoring identifies a bowl-shaped subsidence feature with subsidence centered above the oil field greater than 0.10 feet (3.0 cm) above regional background levels at any one benchmark (GPS location) or area (InSar), the operator will: a) immediately notify City and overseeing agencies, (b) immediately evaluate subsidence trends and geometry, (c) if evaluations indicate measured subsidence is associated with oil field operations, re-evaluate oil field operations including water injection and reservoir re-pressurization programs with overseeing agencies, (d) submit report with proposed modifications to oil field operations to overseeing agencies for approval, if necessary; and (e) implement approved modifications, if necessary. If projected trends in (b) indicate that subsidence greater than 0.3 feet will be reached during the lifetime of the project more aggressive action may be required.

- If monitoring identifies a bowl-shaped subsidence feature with subsidence centered above the oil field greater than 0.20 feet (6.1 cm) above regional background levels at any one benchmark (GPS location) or area (InSar) then the operator will: a) immediately notify City and overseeing agencies, b) appoint outside experts or panel to review data and oil field operations, including evaluation of subsidence trends and geometry, evaluation of effects on environment and critical structures, and review of water re-injection and re-pressurization programs; (c) provide results of analysis and expert recommendations to City and overseeing agencies including submittal of reports presenting the analyses and recommendations; (d) obtain approval from overseeing agencies for oil field operation modifications; and (e) implement approved modifications, if necessary. If projected trends in (b) indicate that subsidence greater than 0.3 feet will be reached during the lifetime of the project more aggressive action may be required.

- If monitoring identifies a bowl-shaped subsidence feature with subsidence centered above the oil field greater than 0.30 feet (9.1 cm) above regional background levels at any one benchmark (GPS location) or area (InSar) the operator will: (a) immediately notify City and overseeing agencies, (b) reduce or halt production from wells in subsidence zones at the direction of the overseeing agencies; (c) appoint outside experts or panel to review data and oil field operations, including evaluation of subsidence trends and geometry, evaluation of effects on environment and critical structures, and review of oil field operations including water re-injection and re-pressurization programs; (d) provide results of analysis to City and overseeing agencies, including submittal of reports, and obtain approval for any recommended modifications; and (e) if recommended modifications are not approved or modification are approved but found to be ineffective then the overseeing agencies have the prerogative of halting oil field operations. Monitoring of subsidence would continue past any halting of oil field operations.

APPENDIX B

ECI Report (InSAR and Seismic Activity Study)

November 6, 2012
Project No. 3215

To: **Geosyntec Consultants**
924 Anacapa Street, Suite 4A
Santa Barbara, CA 93101

Attention: **Mr. Mark Grivetti**

Subject: **Background Study for the Seismicity and Subsidence Sections of the Environmental Impact Assessment for a New Oil and Gas Production Facility Proposed by E&B Natural Resources in the City of Hermosa Beach, California**

Dear Mr. Grivetti

Introduction

In accordance with your request and authorization, Earth Consultants International (ECI) has completed this report to assist you in development of the Seismicity and Subsidence portions of the Environmental Impact Assessment for a proposed oil and gas production facility located on 1.3 acres in the City of Hermosa Beach. Geologically speaking, the project site is located in the northwesterly end of the Torrance-Wilmington Oil Field, in the western part of the Los Angeles Basin.

Purpose

The objective of this report is 3-fold:

1. To provide a brief review of the structural geology of oil fields in the vicinity of the project.

2. To compile a seismicity catalog to evaluate background seismicity in the Hermosa Beach area. Patterns of seismic activity and quiescence identified in the vicinity of the proposed facility can be used as a baseline to monitor any changes in seismic activity during future oil field operations. A secondary goal is to evaluate the temporal and spatial patterns of seismicity in developed oil fields in the vicinity of the Hermosa Beach to look for evidence of seismicity that may be related to production.

3. To show that satellite-borne radar interferometry, InSAR, in conjunction with long-term GPS measurements, can be used to map and measure the magnitude of surface deformation of anthropogenic origin in Hermosa Beach and adjacent areas. Surface deformation occurs in most of the Los Angeles basin and the sources are both of natural and man-made origin. With the exception of earthquakes, extraction and injection of fluids in oil fields and aquifers are the most prominent sources of deformation in the Los Angeles basin. As the deformation can occur in a large area around the actual source, it is important to provide a baseline before

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extracting or injecting fluids into a prospective oil field or aquifer. Thus the second purpose of the InSAR study is to map the extent of the deformation from oil fields and water wells in areas adjacent to Hermosa Beach.

In line with the objectives above, the main text of the report is divided into three Sections: 1) An overview of the structural geology in the nearby region, 2) a discussion of the recent seismicity in the region, and 3) utilization of InSAR satellite imagery and GPS stations to evaluate ground surface deformation.

Scope of Work, Data Sources, and Methodology
For Section 1 we used numerous publications to briefly summarize the structural geology. A list of references is provided at the end of this report.

For Section 2, we compiled available seismicity data for the northwest Los Angeles Basin, entered the data into a GIS database, analyzed spatial and temporal patterns of seismicity relative to the Hermosa Beach area and nearby oil fields in 2-D and 3-D viewing environments, and produced this report with figures discussing our findings.

The data in our database are taken from three publicly available seismic catalogs:

1) Relocated Southern California Seismic Catalog (Yang et al., 2012): (http://web.gps.caltech.edu/~wenzheng/YHS_2011_focal_catalog.html)

2) The National Earthquake Information Center (NEIC) California Catalog (Real et al., 1978; Toppozada et al., 1984): http://earthquake.usgs.gov/earthquakes/eqarchives/epic/epic_rect.php)

3) The NEIC Preliminary Determination of Epicenters (PDE) Earthquake Catalog (various – follow link for full reference list): http://earthquake.usgs.gov/earthquakes/eqarchives/epic/epic_rect.php

All the catalogs include earthquake location (latitude/longitude), depth (if available), time and magnitude. Our study of baseline seismicity focuses primarily on the relocated Southern California Seismic Catalog, which includes earthquakes between 1981 and 2010 that have been reprocessed to greatly improve location accuracy, including focal depth. Earthquakes are relocated using waveform cross correlation to calculate differential travel times between earthquakes in the same vicinity (Yang et al., 2012). These travel times are combined with first motion P-wave picks to improve the relative location of clusters of events. Additionally this catalog contains strike, dip, and rake for earthquake focal mechanisms.

The NEIC California Catalog includes earthquakes between 1769 and 1974, although the oldest recorded earthquake within the southwest Los Angeles Basin dates to 1905. The NEIC PDE Earthquake Catalog contains data from 1973 to the present. For this last catalog we use only data from between 1974 and 1981 to bridge the data gap between the other two catalogs. Location uncertainty for earthquakes decreases towards the present due to densification of seismic networks, advances in earthquake detection technology, and updated crustal velocity models.

Seismicity data tables were saved as ASCII files and imported into ArcGIS 10. Datasets were trimmed to the northwest Los Angeles Basin. Each data point was coded by color or symbol for depth (if available), year, and magnitude. Coded seismicity data were imported into ArcScene 10 where spatial and temporal patterns of seismicity were analyzed in 3-D. Figures were generated in ArcGIS and ArcScene to highlight seismicity patterns in map view and orthogonal 3-D views. Base maps for the figures in this report consist of 10m digital elevation models generated using data from the USGS national elevation dataset (http://ned.usgs.gov/). Active faults shown in the figures are from the USGS Quaternary fault and Fold Database (http://earthquake.usgs.gov/hazards/qfaults/). Oil field boundaries are from the California Division of Oil Gas and Geothermal Resources 2010 District 1 Field Map. (ftp://ftp.consrv.ca.gov/pub/oil/maps/dist1/Dist1_fields.pdf)

For Section 3, two sets of interferograms were generated from historic data acquired by the ERS and ALOS satellite systems. These were then post processed and analyzed using MapInfo and Encamp Discover. Both interferograms reveal a number of sources of deformation in the area surrounding Hermosa Beach and the sources were determined by comparing the extent and magnitude of the areas showing deformation with the location of known wells and the extent of existing oilfields and aquifers. In addition, a comparison was made with long-term records from permanent GPS stations located in areas surrounding Hermosa Beach.

It has been interesting to work on these two analyses to determine if they are feasible for development into long-term oil field management tools. We believe that they are both viable for detection, management, and mitigation of potential well development or extraction-induced impacts to the surrounding community. These baseline data can be easily incorporated into an annual (or semi-annual) update program that will provide the operations group with advance warning of adverse impacts in their very early stages, and provide management options to modify operations as appropriate to mitigate those impacts.

To better improve the baseline data before the field begins production, it might be valuable to further integrate additional data within both analytical tools. The seismic analysis is as comprehensive as possible with the existing seismic data alone, but it might be instructive to integrate it with the detailed subsurface geology of the field as known today, and as it is developed by additional exploration. The subsidence analysis utilized a limited number of data sets, and there are additional InSAR data sets for additional years that could be incorporated into the baseline to provide additional control before field operations commence.

Thank you for the opportunity to assist you on this project. Should you have any questions regarding the information contained in our report, please do not hesitate to contact us.

Respectfully submitted,

EARTH CONSULTANTS INTERNATIONAL, INC.

Eldon Gath, PG 4140, CEG 1292
President

SECTION 1.
STRUCTURAL GEOLOGY – HERMOSA BEACH OIL RESERVOIRS IN THE TORRANCE OIL FIELD

1.1 Background

Oil from part of the Torrance Oil Field underlies Hermosa Beach, both onshore and in offshore tidelands (defined by law as within one mile of the shoreline). After discovery of the Torrance field in 1922, the City of Hermosa Beach in 1932 banned oilfield development, in contrast to Redondo Beach, adjacent to Hermosa Beach on the south, which permitted development wells both onshore and offshore. Because most of the well data are from Redondo Beach, this summary includes both Redondo Beach and Hermosa Beach, where new development by directional drilling from an onshore site is now proposed for the tidelands.

1.2 Tectonic Setting

Hermosa Beach and Redondo Beach are part of the Los Angeles Western Shelf, a less-deformed region between the Newport-Inglewood fault on the east and the Palos Verdes fault on the west (Figure 1-1). Both of these faults are predominantly right-lateral strike slip, and both show evidence of strain partitioning in that there is a significant component of dip-slip displacement (Yeats, 2012, p. 144-145). The Western Shelf is floored by Catalina Schist (Yeats, 1973), the predominant basement rock of the inner California Continental Borderland and the Palos Verdes Hills.

Oil production in the Western Shelf occurs in two west-northwest trends, the Schist Ridge trend on the north and the Torrance-Wilmington anticlinorium on the south. In that part of the Schist Ridge closest to Hermosa Beach, the Hyperion, El Segundo, Lawndale, and Alondra fields produce oil from Catalina Schist and an overlying transgressive sandstone and conglomerate of early late Miocene age deposited on an erosion surface of moderate relief (Schist-Conglomerate). To the northwest, the Schist Ridge continues as the Playa del Rey and Venice oil fields (Figure 1-1).

The southern trend is the broad Torrance-Wilmington anticline (Figure 1-2). Oil was discovered in the Torrance field in 1922 and in the Wilmington field in 1932 (Mayuga, 1970; Otott and Clarke, 2007). In contrast to the Schist Ridge, oil production is concentrated in deep-water sedimentary reservoirs of late Miocene (middle Mohnian) to early Pliocene (Repetto) age. The sedimentary section is thicker and contains a greater amount of sand in the Wilmington field as compared with the Torrance field (Figure 1-3) (Yeats and Beall, 1991, figure 2A; Wright, 1991, figure 31, longitudinal section). For this reason, the Wilmington field has at least ten times the oil as Torrance and is the third largest oil field in the United States. The question to be addressed here is: does the presence of subsidence at Wilmington require a search for evidence for subsidence at Torrance, and does the large amount of oil production and water flooding pose a subsidence or induced-seismicity hazard at Torrance?

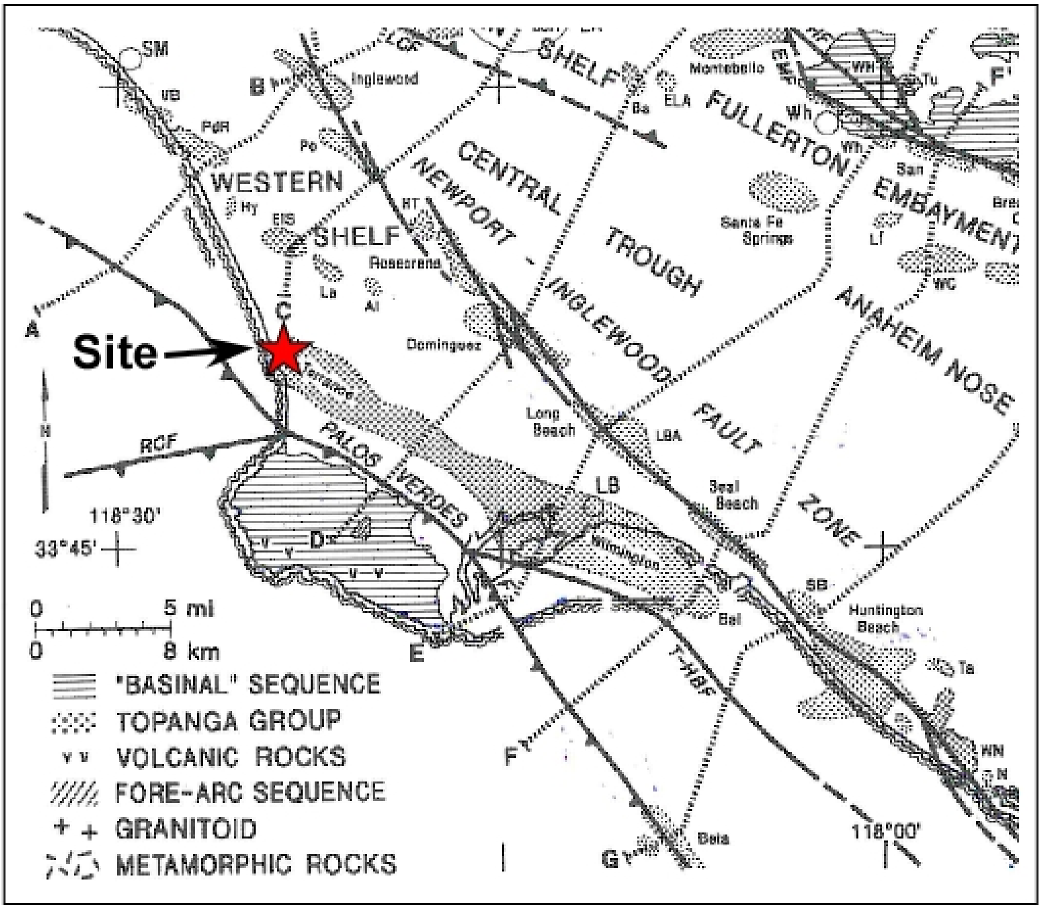

Figure 1-1. Index Map, Los Angeles Basin. The focus here is on the Western Shelf, the Newport-Inglewood fault on the east, and the Palos Verdes fault on the west. Oil fields are shown in dot pattern. The two productive trends in the Western Shelf are the Schist Ridge on the north, including the following oil fields, from NW to SE, Venice (VB), Playa del Rey (PdR), Hyperion (Hy), El Segundo (ElS), Lawndale (La), and Alondra (Al), and the Torrance-Wilmington anticlinorium on the south. The Newport-Inglewood trend includes the following oil fields of concern to this review: Inglewood, Potrero (Po), Howard Townsite (HT), Rosecrans, Dominguez, Long Beach, Long Beach Airport (LBA), and Seal Beach, The horizontal lined pattern marks the Palos Verdes Hills west of the Palos Verdes fault. (From Wright, 1991, Figure 7).

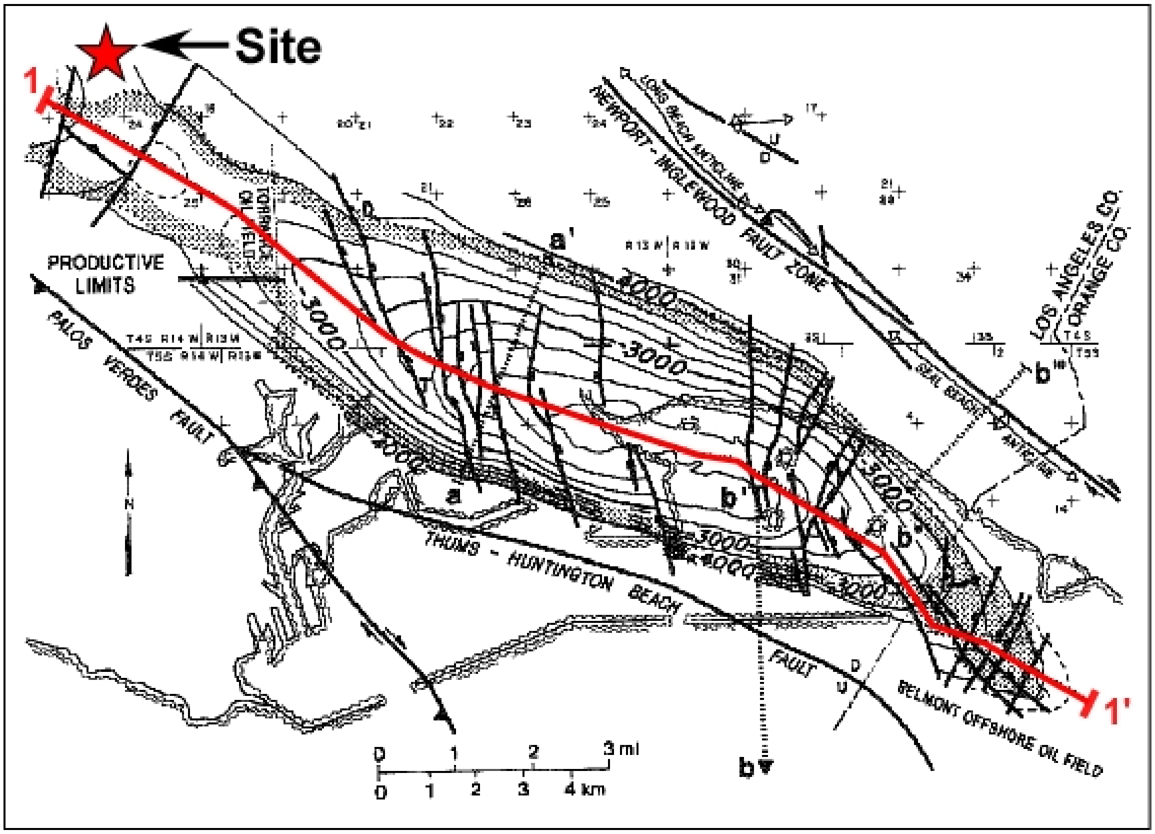

Figure1-2. Torrance and Wilmington Oil Fields. The boundary between the two fields is somewhat arbitrary but in general marks the structural saddle between Wilmington to the SE and Torrance to the NW. Both fields are cut by normal faults trending roughly N-S, oblique to the trend of the anticline. Dotted line l-l' is the line of cross section in Figure 1-3. (From Wright, 1991, Figure 30).

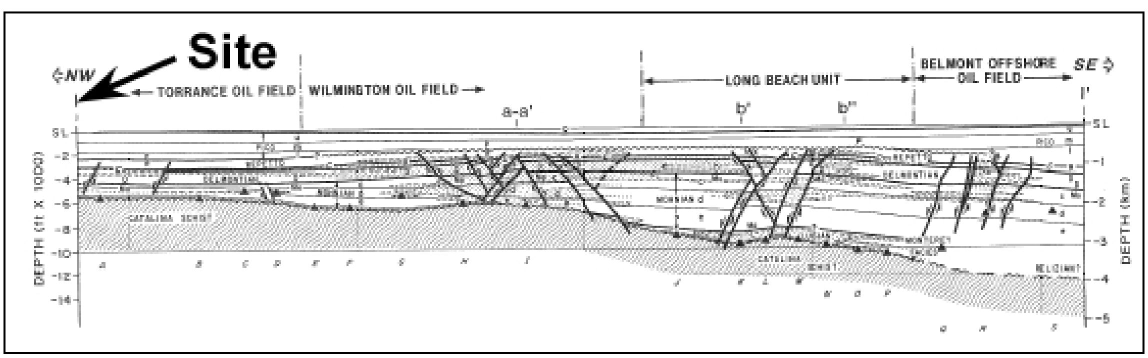

Figure 1-3. Cross-Section Following the Crests of the Torrance and Wilmington Anticlines. The normal faults are largely pre-Pico Formation (late Pliocene), although the base of the Pico is broadly warped. Letters identify control wells (filled triangles locate total depth of wells) that are identified on p. 134 of Wright (1991). The stratigraphic section, especially pre-Repetto formations, becomes thinner northwestward, largely due to the increase in missing section northwestward due to unconformities. The project site lies just off the NW end of the section. (From Wright, 1991, Figure 31).

The basal transgressive Schist-Conglomerate at Torrance is overlain by Mohnian and Delmontian mudstone, including the lower Mohnian (Division E) Nodular Shale. West from Wilmington through Torrance and offshore at the base of the Repetto, Pico, and Pleistocene Lomita-Timms Point formations, unconformities increase in magnitude and the percentage of sandstone decreases. Mohnian and younger strata show evidence of anticlinal growth of the southeast-plunging Torrance anticline (Yeats and Beall, 1991). The top of the section is San Pedro Formation, including coarse clastic deposits that are potential aquifers. A set of normal faults at Wilmington strikes approximately north-south, oblique to the trend of the Wilmington anticline; the faults do not appear to cut the Pico (upper Pliocene) or San Pedro. There are, in addition, three normal faults in the Torrance field (Figure 1-2) that, as at Wilmington, do not cut the Pico. Wright (1991) also maps the west-striking Redondo Canyon reverse fault that intersects the Palos Verdes fault on the east and bounds the Palos Verdes Hills on the north. This fault may control the trend of the west-southwest-trending Redondo submarine canyon.

The Western Shelf terminates westward against the Palos Verdes fault. This is predominantly a right-lateral strike-slip fault, but uplift of the Palos Verdes Hills is evidence of subordinate dip slip. Uplift of a flight of terraces surrounding the Palos Verdes Hills is evidence of an oblique-slip rate of 3.0-3.7 mm/yr (Ward and Valensise, 1994). Southeast of San Pedro, the channel of the Los Angeles River is offset at a rate of 2.5-3.8 mm/yr, predominantly by strike slip (Stephenson et al., 1995). An early Holocene channel in Los Angeles Harbor has been offset at a rate of 2.7 mm/yr, with the ratio of horizontal to vertical slip 7:1 to 8:1 (McNeilan et al., 1996). Brankman and Shaw (2009) summarized previous estimates of slip and calculated a long-term slip rate of 4 mm/yr. They divide the Palos Verdes fault into a southwest-dipping oblique reverse-right slip segment opposite the Palos Verdes Hills and a northeast-dipping oblique normal-right slip segment offshore to the southeast, near Lasuen Knoll.

The Palos Verdes fault is clearly visible in side-scan sonar on the sea floor southeast of the Palos Verdes Hills, but not northwest. Yeats and Beall (1991) map the changes of stratigraphy along the Torrance anticline westward, including six core holes west of the Palos Verdes fault (offshore Redondo Beach core holes 9-27 to 9-32) (Figure 1-4). They found no evidence of offset on the Palos Verdes fault younger than Miocene, although such offset might not show in their sections if it were pure strike slip. Farther northwest in the offshore, the Palos Verdes fault does not continue northward to intersect the Malibu Coast fault (Nardin and Henyey, 1978).

The eastern boundary of the Western Shelf is the Newport-Inglewood fault zone, which includes, from NW to SE, the Inglewood, Potrero, Howard Townsite, Rosecrans, Dominguez, Long Beach, Long Beach Airport, Seal Beach, Sunset Beach, Huntington Beach, and West Newport oil fields (Harding, 1973, Yeats, 1973; Barrows, 1974).

The zone may be divided into a northern section between Inglewood and Dominguez, where strike-slip faults are discontinuous, and earthquake focal mechanisms include both strike slip and reverse slip (Hauksson, 1987). Surface faults flanking the main strike-slip fault are predominantly normal, although the deep Sentous fault is reverse with an east-west strike (Elliott et al., 2009).

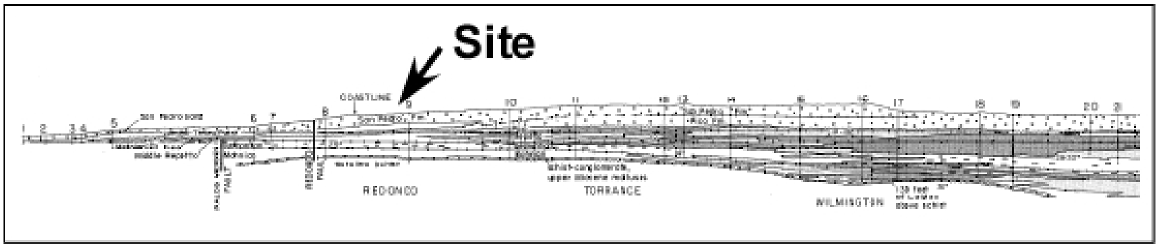

Figure 1-4. Stratigraphic Changes Along Crests of the Torrance and Wilmington Anticlines. Section constructed such that Repettian-Delmontian boundary is a horizontal line. Coarse dots at base of the stratigraphic section are basal transgressive sandstone and conglomerate (Schist-Conglomerate), which is not productive in this trend although it is productive on the Schist Ridge. Unfilled dots mark the upper shallow-marine San Pedro and part of the Pico formations. Fine dot pattern is predominantly deep-water sandstone, with oil-bearing zones marked in heavier pattern. (From Yeats and Beall, 1991, Figure 2A).

The Dominguez field to the south (McMurdie, 1973) trends east-west, oblique to the regional Newport-Inglewood trend, and the field is dominated by reverse faults (Harding, 1973; Yeats, 1973). The strike-slip faults occur along the axis of a broad anticline called the Central Uplift. Recent work by ECI (Yeats and Verdugo, 2011) has shown that the Compton-Los Alamitos reverse fault east of the Central Uplift is related to transpression along the Newport-Inglewood trend rather than a separate fault related to shortening along the central Los Angeles trough. Hills related to the Inglewood and Dominguez oil fields are also related to transpression.

The central section is dominated by the Long Beach and Seal Beach oil fields with the throughgoing Cherry-Hill and Seal Beach right-lateral faults, respectively. The famous Signal Hill, however, owes its presence to the hanging wall of the NE-striking Pickler reverse fault. Evidence for transpression from the 1933 "Long Beach" earthquake east of the surface strike-slip fault was found by Gilluly and Grant (1949; cf. Barrows, 1974 and Yeats and Verdugo, 2011). The southern section includes the Sunset Beach, Huntington Beach, and West Newport oil fields, marked by strike-slip faults and normal faults that strike more northerly than the Newport-Inglewood fault. These different styles of faulting were explained by Yeats (1973) as related to a broad zone of deformation in which basement anisotropy has resulted in WNW- to W-striking reverse faulting, NW-striking right-lateral faulting, and N-striking normal faulting. Hauksson (1987) reported more strike-slip faulting in the southern section and a combination of strike-slip and reverse faulting in the northern section.

1.3 Torrance Oil Field

The Torrance oil field is west of a structural saddle between Torrance and Wilmington oil field (Crowder, 1957). After the discovery of the Torrance field in 1922, a town-lot drilling boom ensued in the Main zone, principally in the central part of the field. In 1936, the deeper Del Amo zone was discovered and developed over the next three years. Development of the western end was prohibited by the City of Redondo Beach until 1943, when wells were directionally drilled offshore from an onshore surface location. In 1956, the City permitted additional offshore wells drilled from an onshore surface location (Figure 1-4). Because this area is on an eastward-plunging anticline, the offshore area is not considered as developed, particularly to the north in the City of Hermosa Beach, where drilling had previously not been approved.

Numerous wells were drilled into the Schist-Conglomerate and Catalina Schist basement, but these were not found to be oil-productive, in contrast to the Schist Ridge to the north, where the basement and Schist-Conglomerate are the main reservoirs. The Schist-Conglomerate is overlain by the Nodular Shale, widespread throughout the Western Shelf. The deepest producing zone is the Del Amo Zone in the Puente Formation with Mohnian microfossils. Production is limited mainly to the central part of the field. The most important producing zone is the Main Zone in the Puente Formation, productive throughout the field. The API gravity in the Main zone is 12 to 28 degrees. The shallowest zone is the Ranger Zone in the lower Pliocene Repetto Formation; this is not productive in the western part of the field.

1.4 Potential Geologic Hazards at Hermosa Beach

The main hazard that must be considered is the subsidence problem encountered in the Wilmington field to the southeast. Net sand thickness at Wilmington averages 800-1200 feet (Mike Henry, Personal Comm. 2012) but may be up to 2000 feet in some areas (Wright, 1991). In contrast, net sand thickness at Torrance averages 210 feet, with the result that the ultimate oil recovery at Wilmington is more than ten times that at Torrance.

The high volume of oil and water withdrawn from Wilmington reservoirs led to land subsidence by the early 1940s, with up to 29 feet maximum at Terminal Island (Poland and Davis, 1969; Colazas et al., 1993; mechanics described by Doornhof et al., 2006). From 1951 to 1952, the subsidence bowl was sinking at a rate of 2.4 feet/yr. A water injection program was started in 1952 and was found to stabilize subsidence and enhance oil production. This led to expansion of the water flooding program to the area offshore Long Beach. Additional problems that might arise are bending moment faulting and fracturing across formations undergoing subsidence or recovery and seismicity induced by pressure changes due to oil recovery or water injection. There is no evidence of increased seismicity at Wilmington.

Although the formations and structure are similar at Torrance and Wilmington, the sands apparently fine northwesterly, and the greatly reduced volume of the reservoir make subsidence much less likely. However, development at the Torrance field should be accompanied by monitoring of possible surface deformation, which is expected to be small, but possibly measurable.

The second hazard was experienced in the Inglewood Oil Field on December 14, 1963 (Meehan and Hamilton, 1971; Jansen, 1988). A water reservoir had been constructed at the top of an uplifted anticline called Baldwin Hills, taking advantage of the hydraulic head above the residential areas of Inglewood to be served. Subsurface fluid withdrawal produced subsidence up to ten feet by 1964. Waterflooding was begun in 1954 and expanded in 1955 and 1961, causing an increase in pore pressure beneath the reservoir. This led to fault creep that caused failure of the reservoir liner and catastrophic release of stored water. Fault creep was not accompanied by seismicity; this was not caused by seismicity induced by the higher pore pressure. This hazard is not one that would be expected at Torrance because Torrance is not overlain by tectonically elevated hills; the anticline is largely inactive.

Another hazard at Inglewood is illustrated by an earthquake of M_w 4.6-4.7 on May 18, 2009 (Luo et al., 2010). This earthquake is close to an earlier earthquake of the same magnitude in 1920. The 2009 earthquake had an oblique-slip fault-plane solution, with a dominant NW-trending right-lateral component and a secondary SW-dipping reverse component, with the result that aftershocks lined up along a NW-striking plane SW of the surface trace of the Newport-Inglewood fault (Luo et al., 2010). An earlier earthquake of M_w 3.8 on October 28, 2001 southeast of the 2009 event had a reverse-fault plane solution with fault strike NW-SE, consistent with the distribution of earthquakes reported by Hauksson (1987) and with the strain partitioning model of Yeats (2012).

SECTION 2.
RECENT SEISMICITY OF THE NORTHWESTERN LOS ANGELES BASIN

2.1 Background

Seismicity in the earth's crust is typically localized along active faults or near volcanic sources. Stress changes caused by the redistribution of mass near the surface can also produce seismicity, even in areas without active faulting. For example, recently de-glaciated areas often experience seismicity due to isostatic rebound of the earth's crust following the retreat of heavy ice masses. Anthropogenic causes for redistribution of mass include impoundment of water behind dams, mining, and injection and extraction of fluids.

The Los Angeles Basin is a tectonically active region with many active faults and related zones of seismicity at depth. In the northwest part of the basin, oil fields are in close proximity, or even on top of these faults (Figure 2-1). Spatial and temporal patterns of seismicity documented in earthquake catalogs can be used to evaluate whether seismicity in an area is more likely related to tectonics, or to oil extraction. Seismicity in the vicinity of active faults, especially at seismogenic depths of 12-14 km, where temperature and

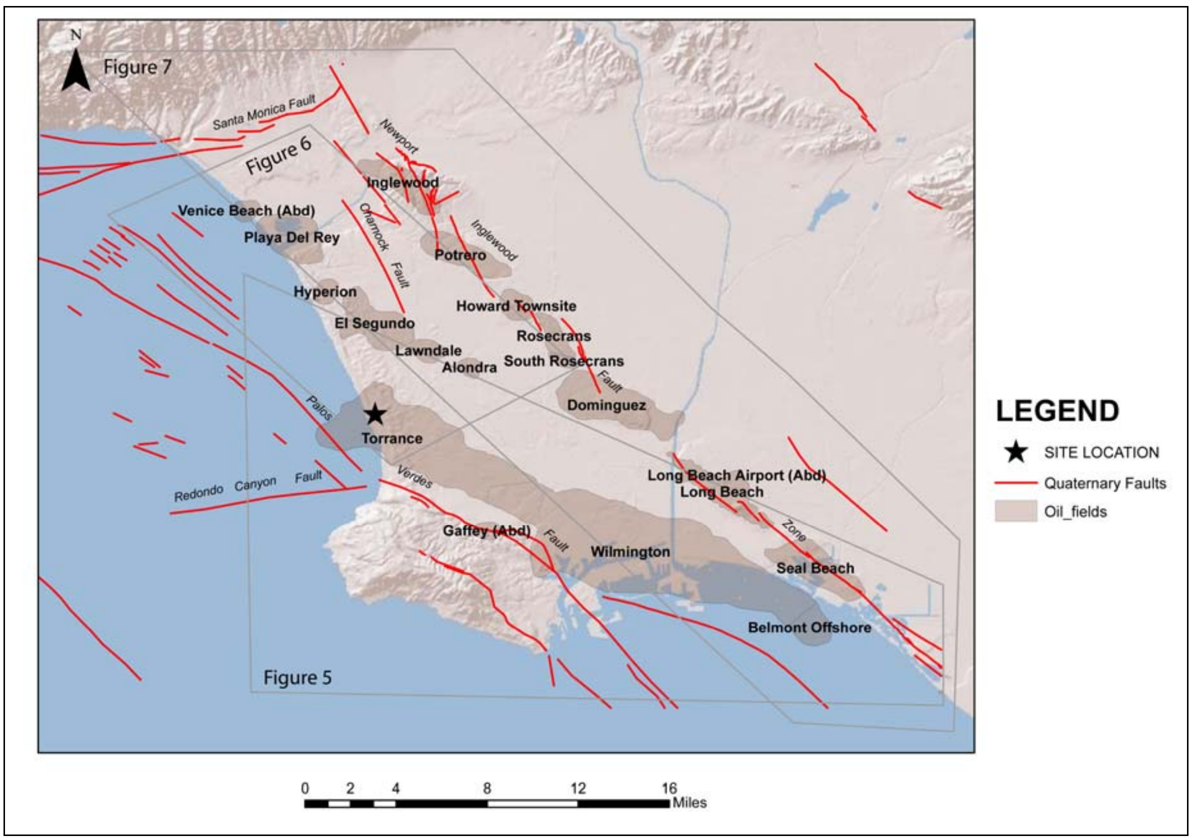

Figure 2-1. Relationship between oil fields and active faults in the northwest Los Angeles Basin. The project site location is marked by a star at the northwest end of the Torrance Oil Field. Boxes indicate areas shown in figures 2-5 through 2-7.

pressure conditions favor earthquake nucleation, are more likely due to tectonic stresses, and can be considered part of the natural background seismicity. Shallow seismicity in the vicinity of oil fields, especially small earthquakes above depths of 4 km, suggests a possible relation to extraction activities, although shallow earthquakes do also occur naturally from tectonic forces. For example, a series of shallow earthquakes between 1947 and 1961 in the Wilmington oilfield are attributed to stress changes in the upper crust caused by the extreme subsidence that was occurring from the oil extraction (Kovach, 1974). Fluids were eventually pumped back into the oil reservoir to mitigate subsistence, and the earthquakes stopped.

An understanding of the timing, distribution and depth of past seismicity in the Hermosa Beach area is necessary to evaluate the possible causes of future seismicity in the vicinity of the E&B Natural Resources proposed oil field project.

2.2 Structural Setting

The proposed project is located in the northwest Los Angeles Basin. The Newport Inglewood fault zone and the Palos Verdes fault are the primary active surface faults that transect this part of the basin (Figure 2-1). The northwest-striking Newport Inglewood fault is a right-lateral wrench system defined by a series of discontinuous left-stepping en-echelon faults and folds (Wright, 1991). To the southwest, the high-angle, west-dipping Palos Verdes fault exhibits northeast-vergent right lateral oblique slip. The Newport-Inglewood fault zone defines the boundary between sediments of the Los Angeles Basin to the northeast east and basement to the west, defined through the study area by a schist ridge.

Oil fields in the northwest Los Angeles Basin form three northwest-trending linear alignments that parallel the structural grain. An alignment containing the Torrance, Wilmington, Gaffey and Belmont Offshore fields is coincident with a broad anticline between the Palos Verdes and Newport-Inglewood fault zone. To the northwest, an alignment of several fields bounded by the Venice Beach field to the northwest and Alondra field to the southeast is coincident with the onlap of basin sediments on the northeast against the schist ridge to the southwest. A third alignment follows structural traps along the Newport-Inglewood fault zone. The relationship of the oil fields to the geologic structure in the northwest Los Angeles Basin is discussed in more detail in Section 1 of this report.

2.3 Seismicity

Seismicity between 1981 and 2010 in the southwest edge of the northwest Los Angeles Basin is characterized by two distinct linear trends (Figures 2-2 and 2-3). Along the eastern trend, seismicity is generally coincident with the Newport-Inglewood fault zone, although clusters of seismicity typically occur to the west or east of the mapped surface trace of the fault. The other seismic trend occurs to the west between the Newport-Inglewood fault zone and the Venice Beach - Alondra oil field alignment. The orientation of this seismic trend is not coincident with any surface faults, and obliquely crosses the Charnock fault.

More diffuse zones of seismicity occur to the southwest and northeast of the study region, offshore, and in the Los Angles basin, respectively (Figures 2-2 and 2-3). This seismicity is coincident with offshore faults and blind thrust faults within the basin. The Torrance and

Wilmington fields are notable for their relative paucity of recent seismicity in the last few decades, although the Wilmington area experienced notable earthquakes, between 1941 and 1961 (Figure 2-3). The pattern of pre-1981 seismicity is less clustered and distributed more evenly throughout northwest Los Angeles Basin than the relocated earthquakes, but this dfference is likely due to poor location accuracy than any actual change in the seismicity (Figure 2-3).

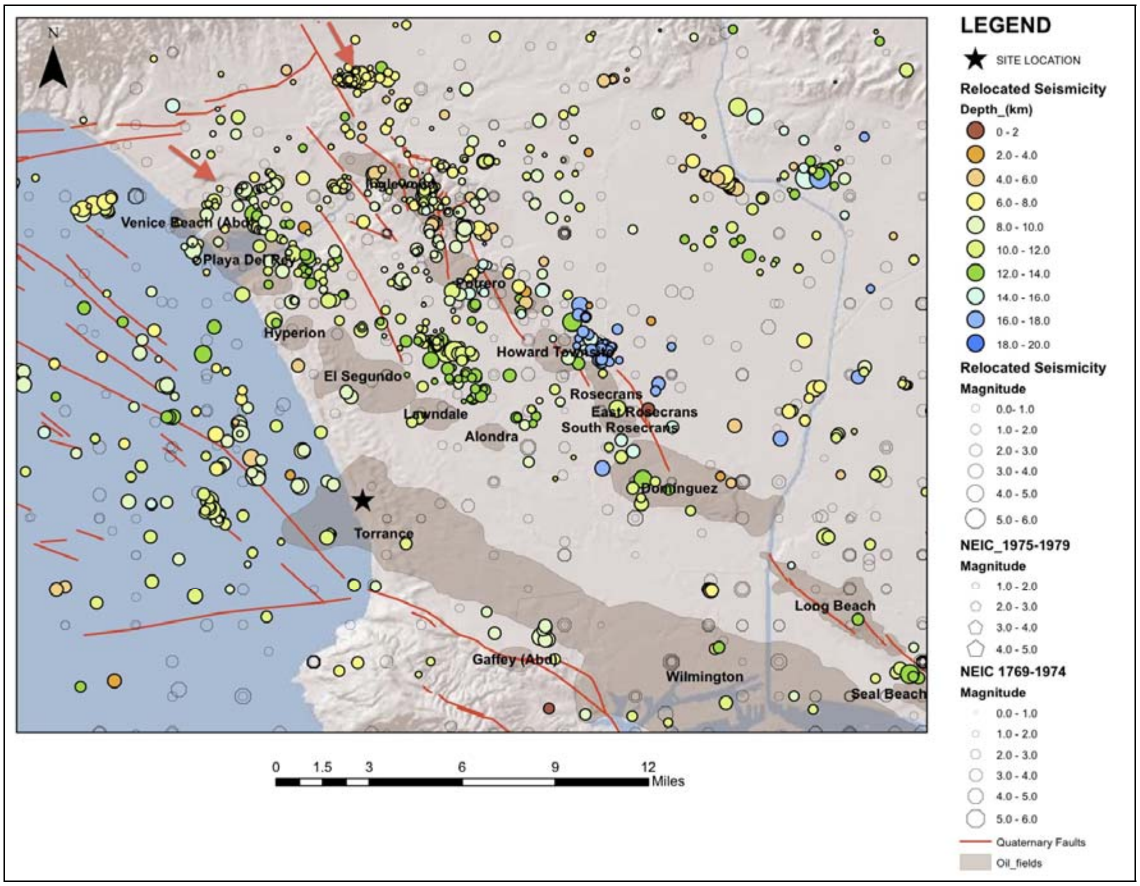

Figure 2-2. Distribution and depth of earthquakes in the Los Angeles Basin. Colored symbols mark relocated earthquakes from Yang et al. (2012). Open symbols mark seismicity from National Earthquake Information Center catalogs that have not been relocated. Red arrows highlight linear seismic trends.

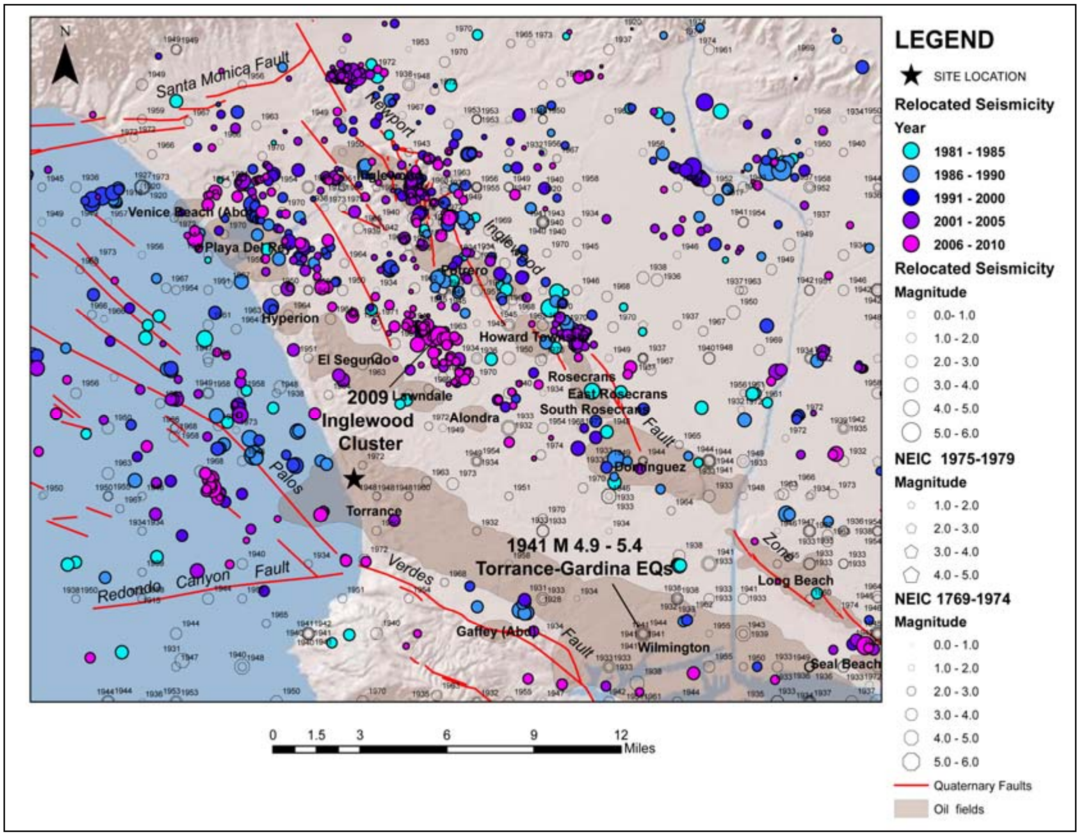

Figure 2-3. Distribution and timing of earthquakes in the northwest Los Angeles Basin. Colored symbols mark relocated earthquakes from Yang et al. (2012). Open symbols mark seismicity from National Earthquake Information Center catalogs that have not been relocated.

The majority of recent seismicity in the region occurs between depths of 8 and 14 km (Figure 2-4), although shallower and deeper earthquakes occur locally, primarily along the Newport Inglewood fault zone, as discussed below.

2.3.1 Torrance – Belmont Offshore Alignment

The project will be located at the northern edge of the Torrance Oil Field as shown in Figures 2-2 and 2-3. At the surface, the Palos Verdes fault is located about a mile southwest of the onshore section of the Torrance field, and crosses the western corner of the offshore section of the field. In the vicinity of the field, seismicity is somewhat diffuse, but generally parallels the Palos Verdes fault (Figure 2-2). No shallow seismicity has been recorded in the mapped boundary of the field. Earthquakes within the boundary occur at depths of 8-12 km, with most magnitudes between 0 and 2 (Figure 2-5).

Northwest of the Torrance Oil Field, seismicity increases notably along the offshore extension of the Palos Verdes fault. Seismicity in this region occurs primarily between 4-12 km, with a few earthquakes extending up to within a few kilometers of the surface. Earthquakes in this area are more frequent than to the southeast. While most earthquakes have magnitudes of between 1 and 2, five earthquakes have magnitudes between 2 and 3.

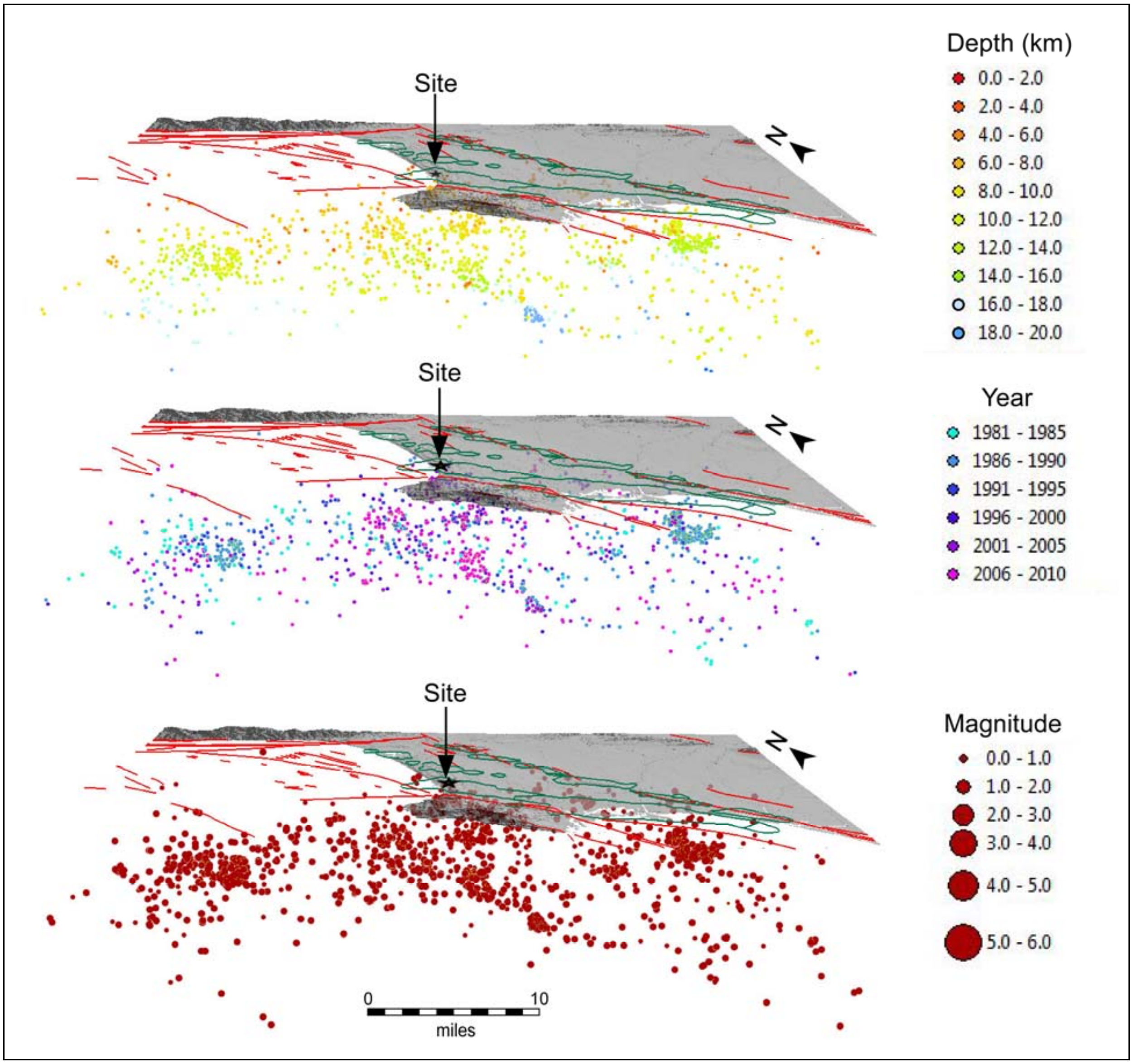

Figure 2-4. Distribution of seismicity with depth in the northwest Los Angeles Basin between 1981 and 2010.

To the southeast of the Torrance field, the majority of seismicity in the Wilmington Oil Field occurs between 8-12 km, with several earthquakes extending up to within 4 km of the surface. The distribution of earthquakes is focused near the Palos Verdes fault near the northern part of the field, and extends away from the fault near the southwest end of the field. The magnitude of earthquakes in this area ranges from 0-3. In 2006, a magnitude 2.2 earthquake, with a depth of less than 2 km occurred less than a mile west of the Wilmington field, and 0.3 miles from the nearest oil well. Although unconfirmed, the shallow depth of this earthquake suggests a possible anthropogenic cause.

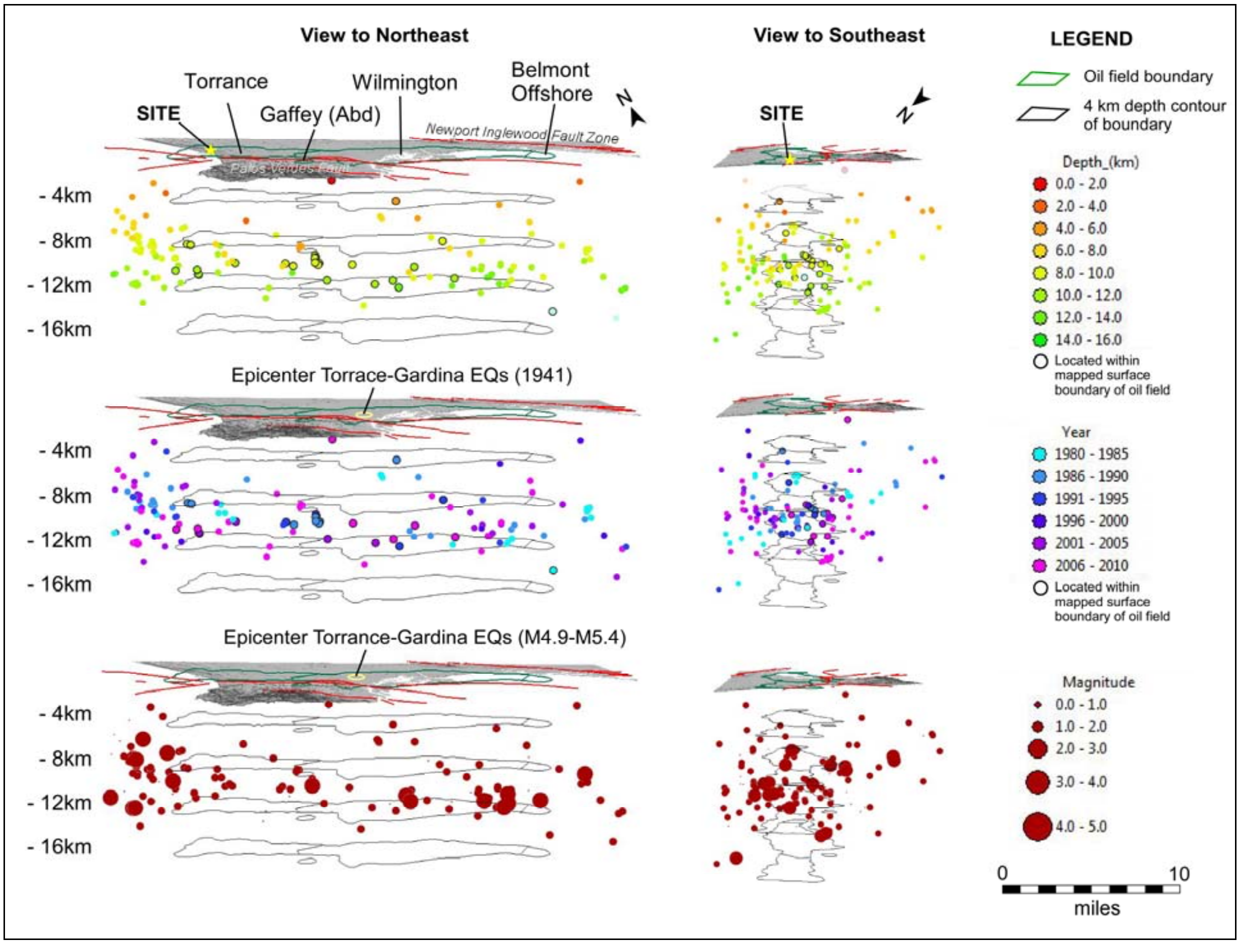

Figure 2-5. Depth, timing and magnitude of seismicity beneath the Torrance, Gaffey, Wilmington and Belmont Offshore oil fields. The view to the northwest is normal to the trend of the oil fields, and the view to the southeast looks down the axis of the fields, and is parallel to the Palos Verdes fault. Earthquakes that occurred within the boundary of the field defined at the surface are highlighted with a black ring.

The Wilmington area is notable for the damaging 1941 M4.9 Torrance, and M5.4 Torrance-Gardena earthquakes (Figures 2-3 and 2-5). Further to the southwest, smaller earthquakes between M2.4 and 3.3 in 1947, 1949, 1951, 1954, 1955, and 1961 are attributed to stress changes from the extreme subsidence (29 feet) due to oil extraction from the Wilmington oil field (Kovach, 1974; Figure 3). The earthquakes occurred on sub-horizontal shear planes within 0.5 km of the surface, and produced seismic waves that were distinct from tectonic earthquakes (Kovach, 1974). Fluid injection efforts eventually mitigated some of the subsidence, and no more earthquakes were recorded at such shallow depths. Between 1981 and 2010 no earthquakes were recorded above 4 km in this area.

2.3.2 Venice Beach – Alondra Alignment

Seismicity in the vicinity of the Venice Beach – Alondra oilfield alignment occurs primarily northeast of the oil fields, in two distinct linear clusters east and west of the Charnock fault. Exceptions are the Playa Del Ray and El Segunda oil fields, which have had several earthquakes within their boundaries since 1990. The linearity of the 2009 Inglewood cluster, suggests that these earthquakes are occurring on a fault at depth rather than in response to near-surface drilling or field operation activities (Figures 2-2 and 2-3). Furthermore the size of the first earthquake in the sequence and subsequent decay of seismicity is also consistent with a tectonic origin for this earthquake sequence.

Seismicity near the Venice Beach – Alondra alignment primarily occurs between depths of 8-12 km, with the exception of an earthquake east of the Playa Del Ray field and an earthquake west of the El Segundo field that occur within 4 km of the surface (Figure 2-6). The majority of earthquakes are magnitude 2-3, with several M3-4 and a couple M4-5 earthquakes. The largest earthquakes are part of the Inglewood cluster.

2.3.3 Newport Inglewood Alignment

The Newport Inglewood fault zone is characterized by abundant small magnitude earthquakes (<M3), especially near the northwest end of the fault. Seismicity extends east and west of the main fault, likely occurring on blind thrusts that splay off of the main fault. The seismicity near the northwest end of the fault extends from depths of 16 km to within a kilometer beneath the surface.

Six earthquakes in the upper 4 km occur along the Newport Inglewood fault between 1981 and 2010. The most shallow earthquakes to occur beneath oil fields along the Newport Inglewood fault include a M2.2 earthquake 3.3 km beneath the Potrero field, a M2.0 earthquake 3.1 km beneath the Dominguez field, and M2.5 earthquake at a depth of 0.5 km and less than a tenth of a mile outside the boundary of the East Rosecrans field (Figure 2-7). These shallow earthquakes, especially the earthquake in the vicinity of the East Rosecrans field, could be consistent with seismicity induced by drilling or field operations, although earthquakes do also occur naturally at these shallow depths. More detailed correlation between the timing of these earthquakes and extraction activities and the spatial proximity of the earthquakes to active wells would be required to better establish whether any causative relationship exists.

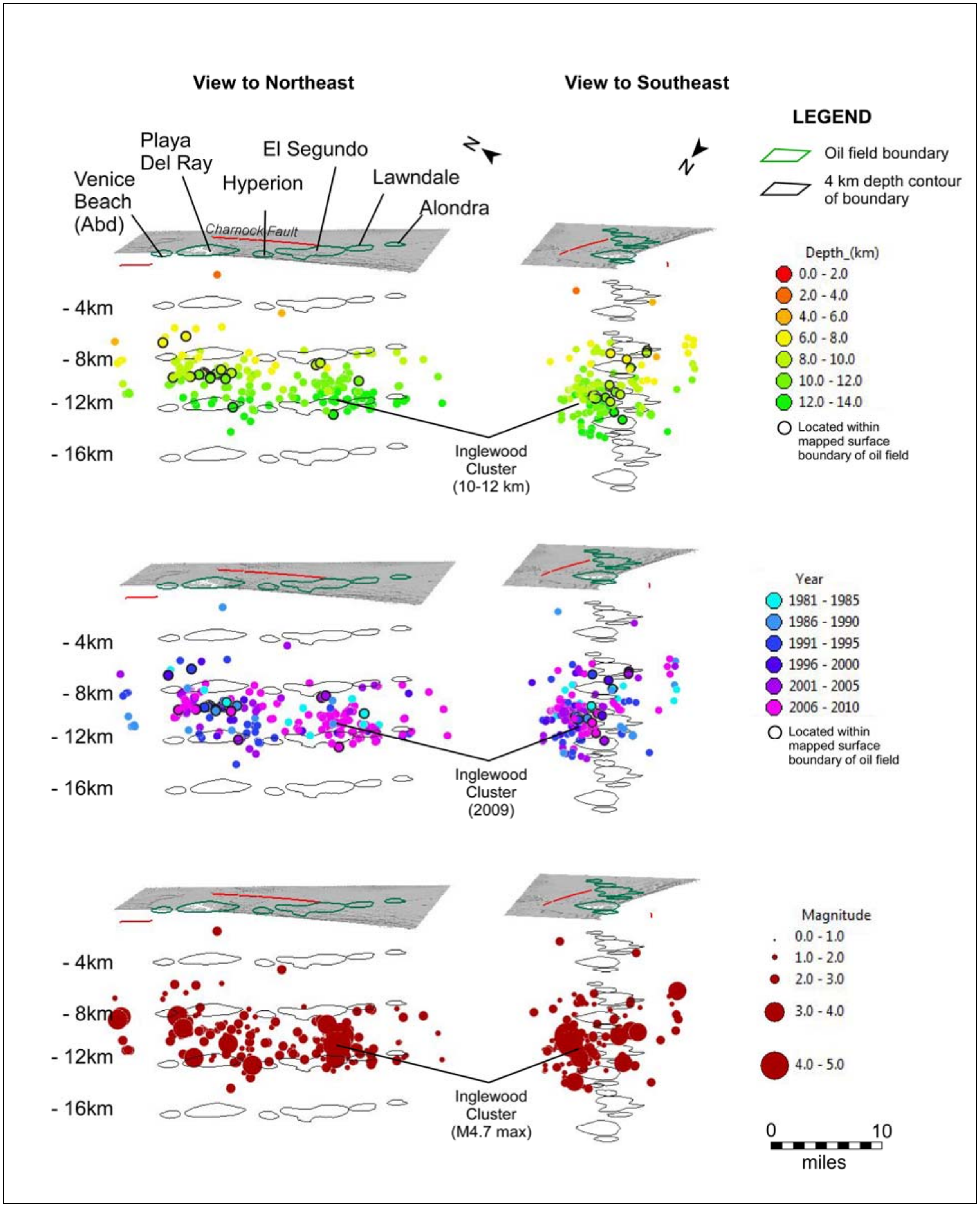

Figure 2-6. Depth, timing and magnitude of seismicity beneath the Venice Beach – Alondra oilfield alignment. The view to the northwest is normal to the trend of the oil fields, and the view to the southeast looks down the axis of the fields.

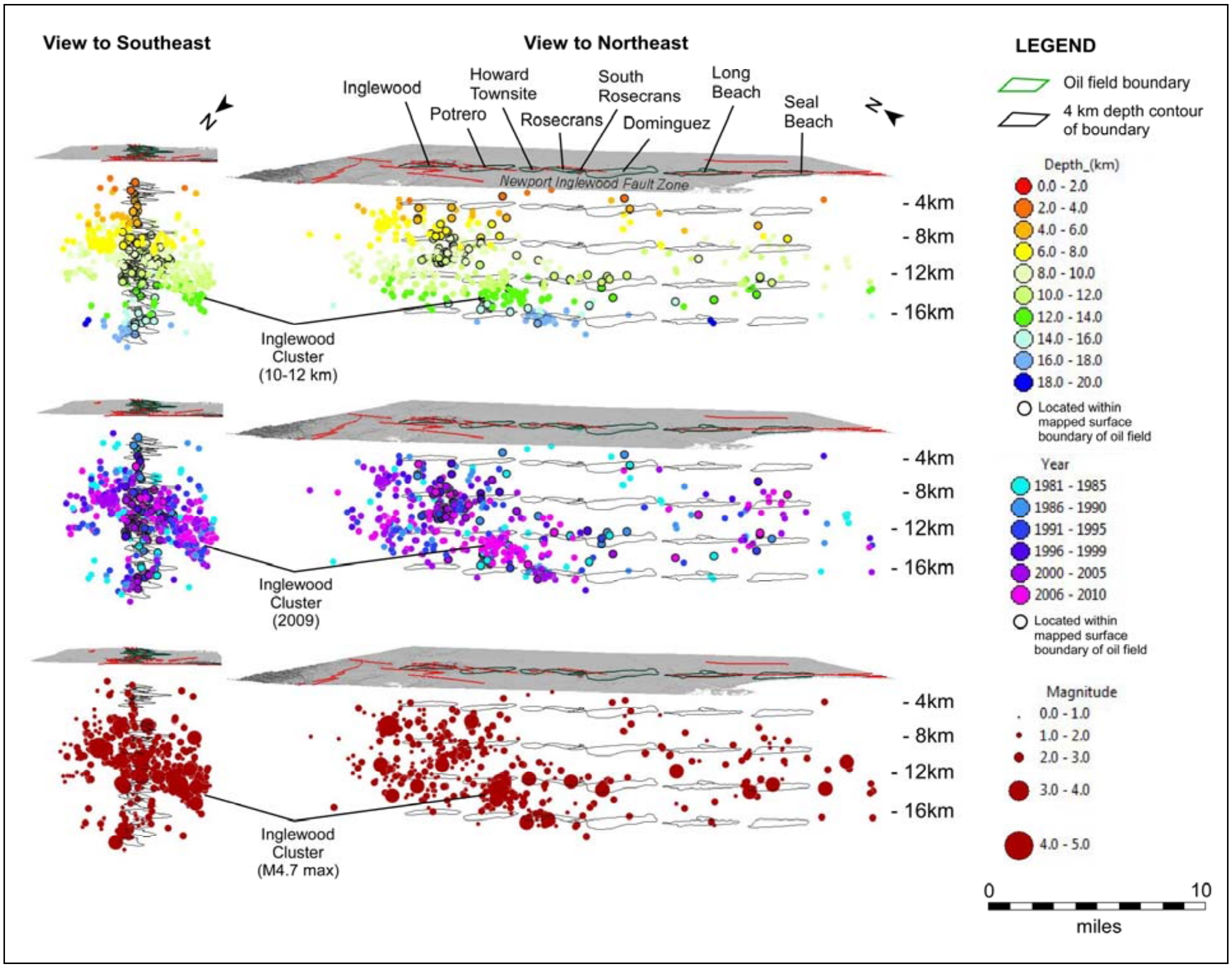

Figure 2-7. Depth, timing and magnitude of seismicity beneath the Newport-Inglewood Oilfield alignment. The view to the northeast is normal to the trend of the oil fields, and the view to the southeast looks down the axis of the fields, parallel to the strike of the fault.

2.4 Discussion

No shallow earthquakes have been identified in the Hermosa Beach and Redondo Beach areas between 1981 and 2010. In addition, with the exception of one shallow earthquake west of the Wilmington Oil Field, two earthquakes in the vicinity of the Venice Beach – Alondra alignment, and six earthquakes in fields along the Newport Inglewood fault, no earthquakes between 1981 and 2010 are shallow enough to be associated with oil field operations. But earthquakes occur naturally at shallow depths even outside of oil extraction areas, so even these events could be naturally occurring tectonic events, unrelated to oil activities. Considering how few events there are, it would be difficult to specifically identify whether any of them were directly induced by oil operations unless the precise well activities were known at the time of the event. Earthquakes up to M5.4 are however, directly attributed to the extreme subsidence in the Wilmington field between 1947 and 1961. These earthquakes occurred prior to the establishment of fluid replacement techniques to mitigate subsidence in oil fields that has now become the standard of practice. The cause of a shallow (<2km) M2.2 earthquake in 2006 west of the Wilmington oil field, but within 0.3 miles of a well, and within a mile of the Palos Verdes fault is unknown, but seems to be the only one that could have an anthropogenic cause. Linear (map view) and planar (3-D) clustering of most earthquakes at seismogenic depths, far below the oil fields suggests that the majority of earthquakes in the catalog are on faults and likely caused by tectonic stresses unrelated to human activities.

The Wilmington field and fields along the Venice Beach - Alondra trend are in a similar structural setting as the proposed oil and gas facility. The relative lack of shallow earthquakes during recent production in these fields suggests that the proposed Hermosa field should not experience an increase in seismicity during production and associated activities, such as reinjection.

The historical record lacks previous earthquakes occurring at shallow depths (in the upper 8 km) in the immediate vicinity of the proposed facility. Therefore, should shallow earthquakes occur in the future during oil field operations, it is likely that they would be attributed to oil field activities.

2.5 Seismicity Conclusions

- The earthquake catalog presented herein provides a good baseline for recent background seismicity in the vicinity of the proposed oil and gas facility.

- There are no shallow earthquakes in the immediate vicinity of the proposed oil and gas facility between 1981 and 2010.

- Between 1981 and 2010, no shallow earthquakes occurred within the Torrance Oil Field, including the Redondo Beach area that could be associated with oil field operations. Furthermore, with the exception of a few shallow earthquakes in other oil fields in the vicinity of Hermosa Beach, the depth and proximity of seismicity in the catalog appears consistent with tectonic stresses and not with oil field operations.

- Comparison of seismicity (if any) during development of the proposed oil and gas facility can be compared to this seismic catalog to evaluate potential earthquake sources.

SECTION 3.
SATELLITE INTERFEROMETRY (InSAR) AND PERMAMENT GPS STUDY OF SURFACE DEFORMATION AT HERMOSA BEACH AND ADJACENT OIL FIELDS

3.1 Processing of SAR and GPS Data

Interferometric images generated from Synthetic Aperture Radar (SAR) data, generally known as InSAR, has recently been developed into an efficient way to map and monitor deformation occurring over large areas. As a rule of thumb the lower detection limit is 1-5 mm depending on the wavelength of the radar system used. Together with long-term GPS measurements from permanent stations it is widely recognized as one of the best ways of mapping and quantifying surface deformation both by natural causes as well as extraction of oil, gas and water (Dornhoof et al., 2006).

The method relies on raw SAR images storing information about both Phase and Amplitude. By subtracting the phase information stored in two raw SAR files it is possible to generate an image representing the range-change that occurred between the satellite and different areas of the target in the time period between the acquisitions of the data. For the Hermosa Beach area we relied on two sources of satellite-borne SAR data, the European ERS-1 and -2 satellites for the image pair acquired between 1990-2000 and the Japanese ALOS satellite for the period between 2000-2010. As the satellites have a finite lifetime it is generally rare to find image pairs acquired more than 8-10 years apart for any given satellite system. We generated two interferograms for the target area, the first for the 5.6 year period between June 17th 1992 and January 31st 1998 and the second for the 2.5 year period between January 20th 2008 and July 28th 2010. To provide further data for comparison we also conducted a literature study and a study of the vertical component of the long-term velocity vectors of five permanent GPS stations in the target area.

3.2 Satellite Interferometry (InSAR)

Synthetic Aperture Radar, or SAR, is a satellite or airborne radar system that generates high-resolution remote sensing imagery using a system that stores the phase and amplitude of the received signals over successive pulses from a 'synthetic aperture' antenna, sometimes consisting of hundreds of smaller antenna elements. The phase information of an image pixel represents the complex vector sum of the radar echoes from each scattering element within the corresponding resolution cell on the ground, covering an area of 20 x 5 meters for ERS-1 and 2 and 50 x 50 meters for the ALOS/PALSAR satellite(s). The return phase of the signal from each scattering center has its phase determined by the two-way range to the satellite and this will vary by several hundred wavelengths (ERS-1 and -2, 56.66 mm and for ALOS 236.06 mm) across a typical resolution cell. The phase of an image pixel by itself is, thus, a random and not very meaningful parameter. There is however, a correlation between the phase information in corresponding pixels in scenes covering the same area and any movements that has occurred between the acquisitions of the scenes will be represented by a phase shift. For this assumption to be valid the satellite needs to be located very precisely over the target area and any difference in the repeat orbits introduces phase shifts that need to be removed mathematically. Depending on the intended use of the interferograms, detection of surface deformation or the generation of Digital Elevation Models (DEMs), the maximum allowable offsets in the orbits differ. For DEM generation, a maximum value of the perpendicular offset (offset between orbits) is around 1100 meters, whereas a value of less than 250 meters is needed for precise measurements of surface deformation. A high degree of control over the satellite's orbits is imperative if the SAR images are to be used for interferometric purposes.

In addition to problems with phase shift introduced by offsets in the orbits, other problems can occur. Examples are: loss of coherence caused by differences in the viewing geometry, ambiguities caused by the relief giving false signals in the interferogram, and phase shift caused by an elevation dependent change in the air moisture content. With these restrictions only a small number of the acquired scenes will be suitable for the generation of interferograms and sometimes it can be difficult to find pairs of scenes suitable for the task at hand. The interference pattern is a function of the geometries of the orbits as well as the topography of the target area. By analyzing the interference patterns knowing the precise orbits, the topography can be calculated and, if the topography also is known, any elevation changes in the surface can be calculated from the interferogram by removing the topographic effects using an existing DEM. The difference in phase between the SAR images is usually represented by colors in such a way that a movement corresponding to half the wavelength of the radar is shown as a complete color cycle in a color band (Figure 3-1). As this representation sometimes can make the deformation rate difficult to interpret we decided to use contour lines with an equidistance of 1 mm/year for this study.

Apart from phase information, the quality of the correlation, (the 'coherence') between two SAR images can also be determined. Such coherence values are related to the nature of the ground surface. Any chaotic movements of the scatterers in the target area between the acquisitions will cause the coherence to be low. Open water and active agricultural areas are usually totally decorrelated, whereas urban areas and areas free of vegetation are more likely to have a high coherence over extended periods of time. Low coherence makes it impossible to calculate the phase shift, and thus a high degree of coherence is imperative in the areas of interest. Fortunately, the coherence in most parts of the greater Los Angeles area is excellent, and coverage in the whole area surrounding Hermosa Beach was close to 100%.

Regardless of the type of the final product, processing the raw SAR data is a multi-step operation involving highly complex mathematics, not just in the creation of the actual interferogram, but also during the initial steps when the pixels of the images are matched against each other to line them up, and when the resolution of the images is enhanced by software focusing.

The resolution or detection level of ground deformation by InSAR is dependent on the wavelength of the radar and the angle of line of sight. It is also dependent on the direction of the deformation. Horizontal deformation can only be detected if there is sufficient relief in the area to cause movements along the line of sight and thus the resolution can vary across the target area. As a rule of thumb the detection level is around 1 mm for vertical measurements, but the limit is not as well defined for horizontal measurements. Sometimes stacking of several interferograms is needed for the measurements to yield conclusive results but the number of interferograms and the success rate is extremely hard to predict in those cases. As other parts of this study covers surface deformation of tectonic origin, stacking of interferograms are only of theoretical interest and are only mentioned here for the completeness of the description of InSAR and its capabilities.

Historically InSAR has been used successfully to map and monitor deformation related to extraction of oil and gas at a number of places. Nederlandse Aardolie Maatschappij B.V. (NAM) in used the method at the Groningen gas field in the Netherlands between 1993 and 2003 (Ketelaar et al., 2005). It has also been used successfully for detecting subsidence due to groundwater extraction in Antelope Valley (Galloway et.al, 1998).

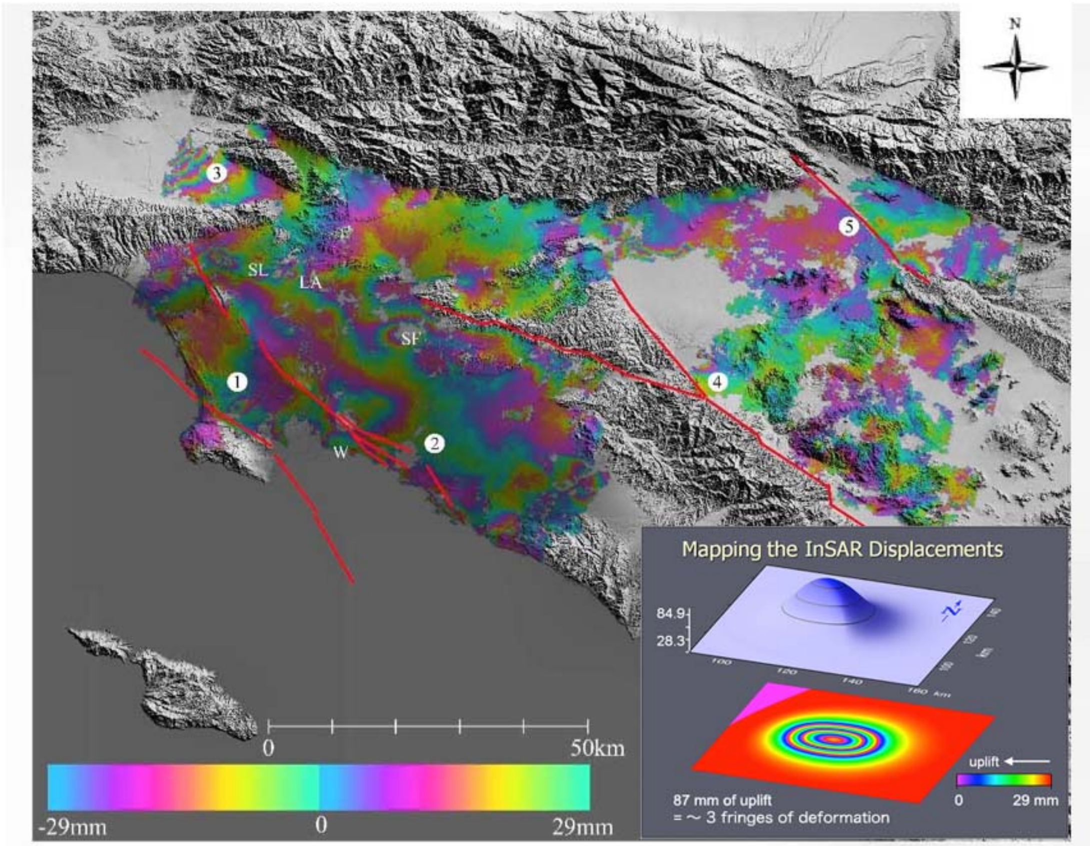

Figure 3-1 Long-term interferogram (1992-06-17 to 1998-01-31) showing different types of strain in the LA-Basin. The incidence angle of the ERS satellites is 23° off vertical, thus the interferogram is most sensitive to vertical motion. Raw data were acquired from the European Space Agency ERS-1 and ERS-2 satellites: track 170, frame 2925 and the National Elevation Dataset (NED). The interferogram (in color) is draped over a hill-shaded gray-scale version of the NED. At '1' there is an area showing long-term uplift within a subsiding area in the Torrance oil field (+38mm). At '2' there is a large area with long-term subsidence in the Santa Ana basin due to pumping of groundwater (-35mm). '3' shows an area of uplift related to the 1994 Northridge earthquake (146mm). At '4', near the junction between the Whittier and Chino faults there is a small area showing subsidence related to ground water extraction (-4mm). The San Jacinto fault, '5', seems to act as a barrier for ground water resulting in differential subsidence across the fault. All of the SL, Salt Lake; LA, Los Angeles; SF, Santa Fe Springs and W, Wilmington oil fields also show significant deformation. It is also interesting to note that the faults and folds to a large extent control the extent of the areas showing subsidence to pumping of oil and groundwater. The color bands wrap around and are repeated as the measurements are made at the radar wavelength used. By counting the number of repeats it is easy to get a quick estimate of the amount of deformation without making detailed measurements, something which would be impossible if the color band was spread out between the min and max values.

3.3 Literature Study – Sources of deformation in the Western LA Basin

A literature study was done to find more information about the sources and mechanisms behind the surface deformation that occurs in the greater Los Angeles area. Though there are a number of man made sources of surface deformation including those this study is addressing, there are also a few natural sources that potentially can be picked up by the interferograms or permanent GPS stations. Due to its size and the amount of periodic uplift and subsidence, the largest source of deformation is caused by the seasonal pumping of groundwater from the approximately 20km x 40 km Santa Ana aquifer though other smaller aquifers contribute to the seasonal deformation. On an annual basis the oscillations of the surface over the Santa Ana aquifer amounts to 50mm of uplift during the refill-phase in late fall through to mid-spring, followed by a period of 60mm subsidence when groundwater water is withdrawn at a higher rate during the hot summer months (Bawden et al., 2001). Due to compaction of the strata in the aquifer there is also a net subsidence in the area of approximately 10-15 mm/year. Though the Santa Ana basin is located well outside the target area, the deformation is still detectable in an area 10 km or more from the edges of the actual aquifer, something that was very obvious when studying the data collected by the Southern California Integrated GPS Network (SCIGN) stations within the target area surrounding Hermosa Beach. Bawden et al (2001) noticed it in their study and the results were reproduced by our GPS study as well. Bawden's paper also describes local subsidence and uplift in the Wilmington, Santa Fe Springs, Salt Lake and Baldwin Hills oil fields (Bawden et al., 2001), (Figure 3-1). The results for the parts of the Wilmington Oil Field where water injection has been used to manage subsidence (Strehle, 2007), matches the deformation rates found in the interferograms created by us as well as by Bawden et al (2001). It is also clear that it is possible to overinflate by injecting too much water and steam into an oil field or aquifer. The surface at both the Santa Fe Springs and parts of the Baldwin Hills oil field were experiencing an uplift of 5-9 mm/year (Bawden et al., 2001) at the time of their study.

3.4 1992-1998 Interferogram

The first interferogram was created from a pair of SAR images acquired by the European ERS satellites in June 17th 1992 and January 31st 1998, and with data from the National Elevation Dataset (NED). Processing of the data was done with the software package GMTSAR published by Scripps Institution of Oceanography at UCSD. As the SAR system on board the ERS satellites operated at a wavelength of 56.66 mm the vertical resolution of the interferogram is approximately 1 mm and the spatial resolution 20 x 5 m. As the coherence in the target area was close to 100 % the resulting interferogram was of high quality and a large number of sources of deformation could be observed. The subsidence caused by the Santa Ana aquifer can clearly be seen on a regional scale (numbering from Hermosa Beach and east, Figure 3-2). Also an area with rapid uplift (A, Figure 3-2) presumably caused by injection of water into the Torrance Oil Field area along with minor subsidence (B, Figure 3-2), in the Redondo Beach area. Approximately 4 mm/yr and 1 mm/yr of subsidence in the Redondo Beach Area and Hermosa Beach areas, respectively, is estimated (Figure 3-2).

To correlate this information with the location of active oil- and injection wells we acquired a copy of the current well database from the Department of Conservation and plotted it on top of the interferogram. Most of the wells that were in production in the

Torrance oil field at the time of the acquisition of the SAR data are no longer active and this might explain why the surface has stabilized since the 1990's.

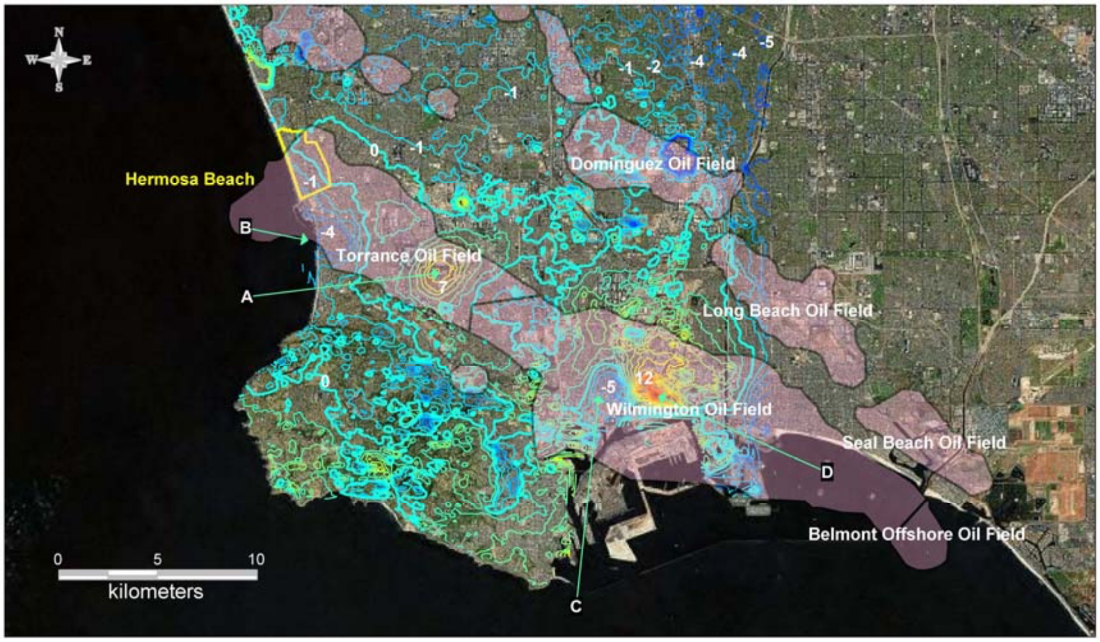

Figure 3-2. Interferogram with contour lines, each representing a 1-mm/year displacement. Blue-Green is 0; Blue represents subsidence and Green-Yellow-Red uplift. At A and D there are areas with rapid uplift and at B and C areas with subsidence.

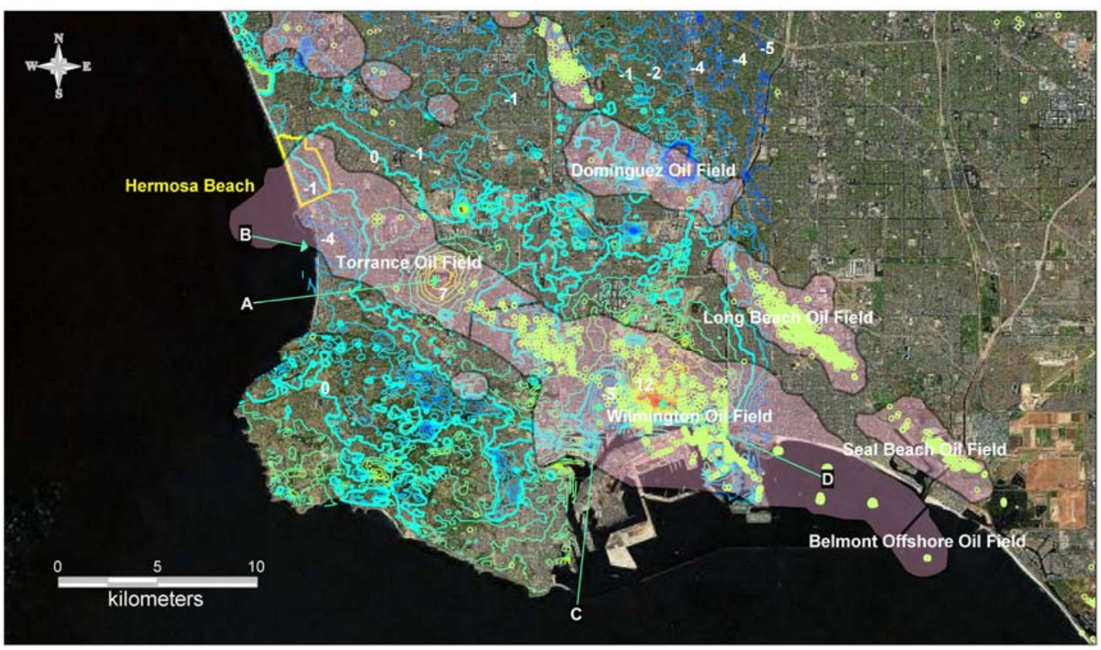

Figure 3-3. Same interferogram as in previous figure but with currently active wells as green dots. Notice the relative absence of active wells in the A and B areas in the Torrance oil field. Production in the Torrance oil field seems to have ceased since 1998.

3.5 2008-2010 Interferogram

The second interferogram was created from a pair of SAR images acquired by the Japanese ALOS/PALSAR satellite in January 20th 2008 and July 28th 2010, together with data from the National Elevation Dataset (NED). Processing of the data was yet again done with the software package GMTSAR published by Scripps Institution of Oceanography at UCSD. As the SAR system on board the ERS satellites operates at a wavelength of 236.06 mm the vertical resolution of the interferogram is approximately 5 mm and the spatial resolution 50 x 50 m. As the coherence in the target area was close to 100%, the resulting interferogram was of high quality. But due to an error in the processing software we were unable to get absolute numbers on the deformation in the target area. However, by studying one of the intermediate files containing an image representing the phase-shift, we can draw the conclusion that the deformation that occurred in the Redondo Beach region of the Torrance oil field in the 1990's has ended and that any source of anthropogenic surface deformation in the Hermosa Beach area must be smaller than 1 mm/year, if it exists at all.

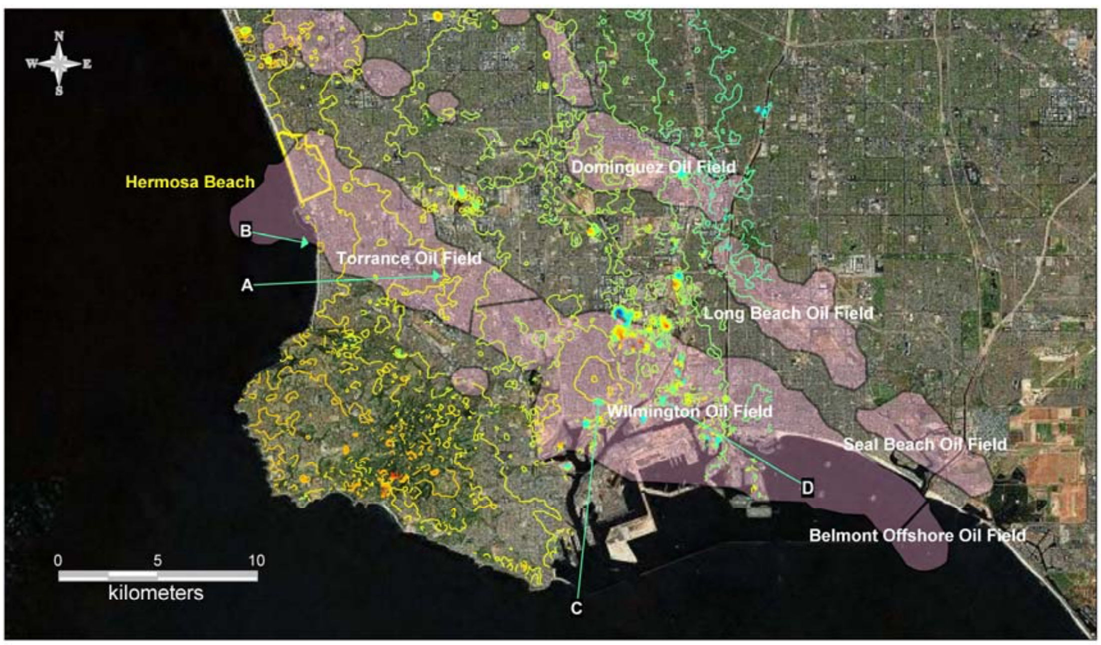

Figure 3-4. Interferogram generated from ALOS-PALSAR data acquired on January 20th 2008 and July 28th 2010. The range-change between the contour lines is approximately 16 mm/year as the phase shift is π radians across the area (see figures 3-5 and 3-6). Note that the areas with subsidence and uplift in the central parts of the Wilmington oil field still is present (C and D) but that the strong surface deformation that was present at A and B in the previous interferogram is gone.

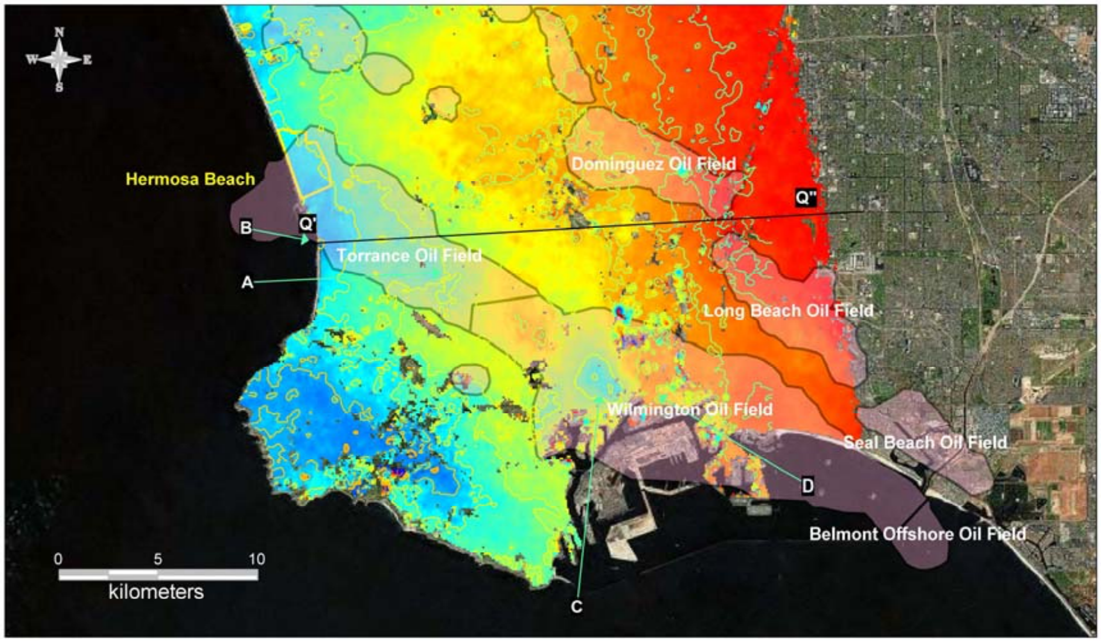

Figure 3-5. A false-color representation of the previous interferogram draped over a map of the project area. The profile Q′-Q″ can be seen in Figure 3-6 which illustrates the phase-shift caused by deformation mainly caused by the pumping of groundwater in the Santa Ana aquifer. The phase shift is π radians, which at the ALOS wavelength equals a range-change of 118.03 mm. The increase in phase shift (and range-change) from Q′ to Q″ is caused by the target moving away from the satellite, thus being caused by subsidence in the eastern area.

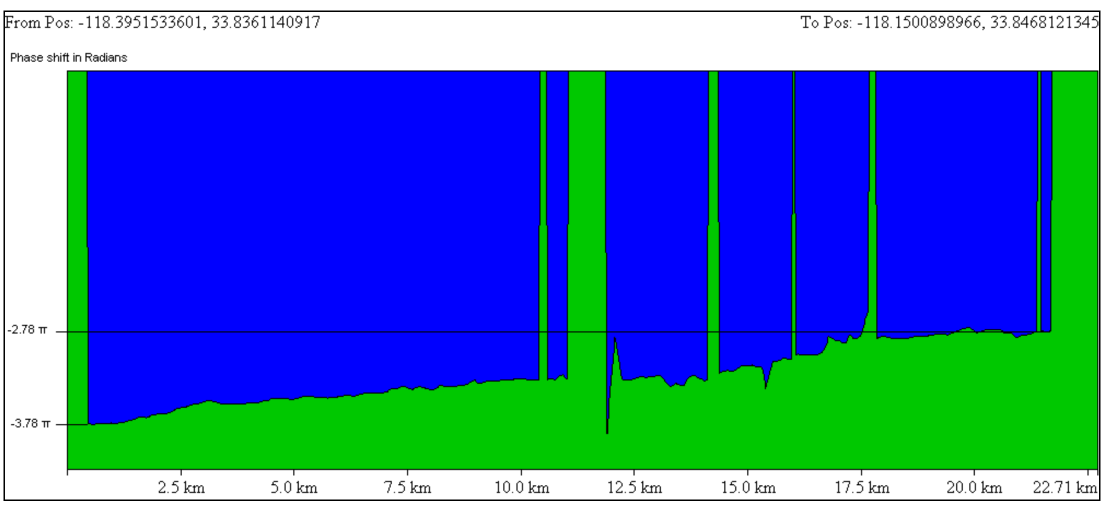

Figure 3-6. The phase shift across the profile Q′-Q″ is 1 x π radians which equals a range of 118.03 mm at a wavelength of 236.06 mm.

3.6 GPS Study

We used the Southern California Integrated GPS Network (SCIGN) data portal to select six permanent GPS stations in the area southward and eastward of Hermosa Beach (Figure 3-7). The stations were VTIS (Marine Exchange, San Pedro), TORP (Torrance Airport), CRHS (Carson High School), PVE3 (Palos Verdes), CSDH (CSU Dominguez) and HBCO (Harbor College, Wilmington). The vertical velocity vectors of all stations show a net uplift of between 2.10 mm/year and 2.91 mm/year with an oscillation with the amplitude of 5-10 mm superimposed over it (Figure 3-8). This oscillation seems to be caused by deformation related to the cycles of depletion and refill of the Santa Ana aquifer (and possibly other aquifers in the area too). Though it is difficult to get a perfect match between the GPS data and the interferograms due to the difference between the time series, it is still interesting to note that the two datasets do not contradict each other and that the uplift detected by the GPS stations in stable areas match the 1992-1998 interferogram enough to be well within the detection limits of the method.

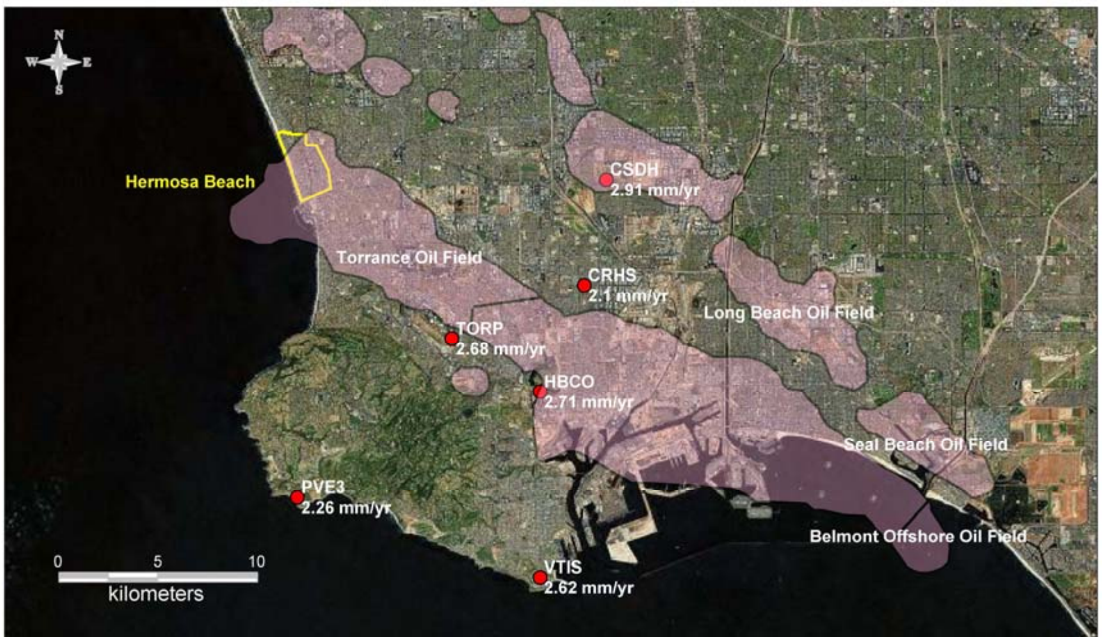

Figure 3-7. Map showing the locations and vertical velocity vectors of the permanent GPS stations in the area belonging to the SCIGN network.

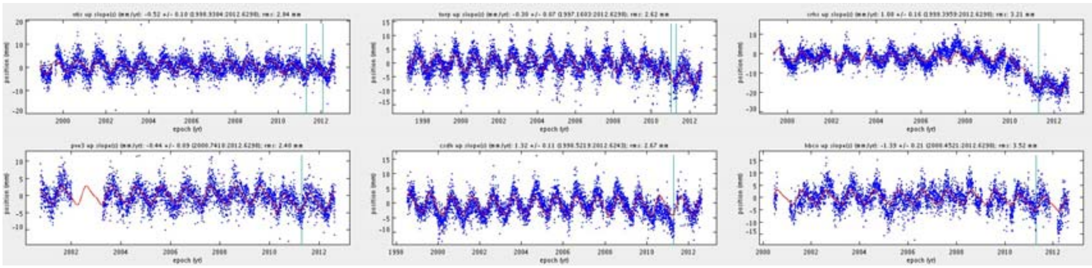

Figure 3-8. Graphs of the velocity vectors for the six GPS stations. All show an annual uplift-subsidence cycle. The station located at Carson High School (CRHS) is also showing a trend of subsidence between 2008-2012 (-10 mm). The cause is unknown and does not correlate with the interferograms. The amount of noise in the signal is also somewhat higher than at the other stations, possibly indicating poor stability of the antenna mount.

3.7 Results

Due to limitations in the SAR processing software, absolute numbers on the deformation rates occurring after January 2008 could not be obtained, but we can still draw several conclusions for the Hermosa Beach target area for that time period as relative changes in elevation are visible on the mm-scale. The permanent GPS stations are recording a long-term uplift of 2-3 mm/year for the whole area. On a local scale the interferograms reveal that in the 1990's there was a lot of surface deformation occurring on a regional scale, most of which may be related to oil extraction and water injection in the nearby Torrance Oil Field. For the target area the deformation manifested itself as subsidence of approximately 1mm/year relative to surrounding areas east and north of Hermosa Beach. The second interferogram (2008 to 2010) shows little or no deformation (<1mm/year) in the target area besides the regional heave and subsidence caused by the annual depletion and refill of nearby aquifers, with the Santa Ana aquifer being the largest source (Bawden et al., 2001). With this study we have provided a baseline for surface deformation occurring in Hermosa Beach and also shown that satellite interferometry (possibly linked to a number of permanent GPS stations) is a suitable method to map and quantify potential surface deformation related to future oil field activity in the Hermosa Beach area.

Though the scope of this InSAR and GPS study of the Hermosa Beach area is somewhat limited the results still shows that the methods work reliably in the area. The coverage of the SAR data with high coherence is nearly 100% and the quality of the interferograms is high. As the main goal of the study was to determine the feasibility of the use of InSAR and GPS measurements in mapping and monitoring of surface deformation in the Hermosa Beach area, the results must be considered a success even though limitations in the SAR processing software prevented full use of the second interferogram. The limitations have been reported to the software developers at UCSD-Scripps and should not be considered a problem for future use of InSAR and the GMTSAR processing software.

The second goal of the study was for the results to act as a baseline when comparing future deformation maps in the Hermosa Beach target area. Historically a deformation rate of approximately 1 mm/year in Hermosa Beach was apparently caused by extraction of oil in the adjacent Torrance oil field as was seen in the 1992-1998 interferogram. Currently no major sources of man-made deformation can be detected in the Hermosa Beach area including nearby parts of the Torrance oil field (Redondo Beach area) and any ongoing deformation must occur at a rate of less than 1 mm/year. With a combination of satellite interferometry and a set of permanent GPS stations it is our opinion that such a system could provide the means for monitoring the surface deformation associated with proposed oil field operations in the Hermosa Beach area.

2.5 Subsidence Conclusions

- InSAR successfully captured and quantified the background surface movements in the project area.
- Approximately 1 mm/yr of subsidence was occurring within Hermosa Beach, near the project area, during field operations at the Torrance Field (1992-1998).
- Approximately 2-3 mm/yr of uplift is now occurring within the inland portions of the Torrance Field but this is not reflected north into Hermosa Beach.
- Calibration with the SCIGN GPS Network significantly improves the InSAR results.
- Future long-term monitoring is feasible with the combined data sets.

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