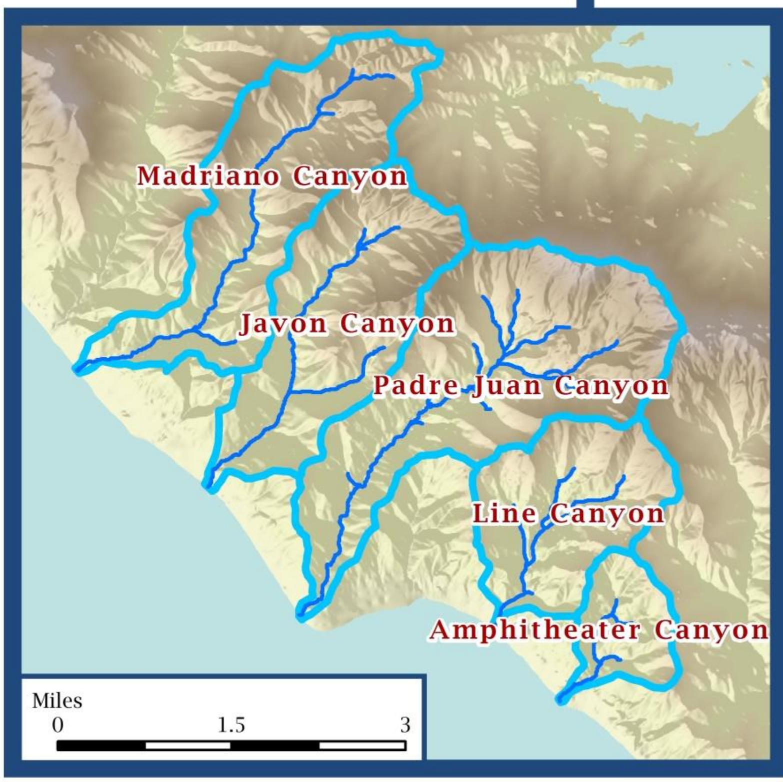
EXECUTIVE SUMMARY

NORTHERN VENTURA COUNTY COASTAL WATERSHED PROJECT

The Northern Ventura County Coastal Watershed Project (NVCCWP) assessed water quality and identified potential sources, pathways, receptors, and toxicity of pollutants detected in samples from Madriano, Javon, Padre Juan, Line, and Amphitheater Canyons. From October 2013 through April 2014, water and sediment samples were collected from each canyon to characterize water quality and inform strategies to mitigate impacts from pollutants being discharged from the watersheds.

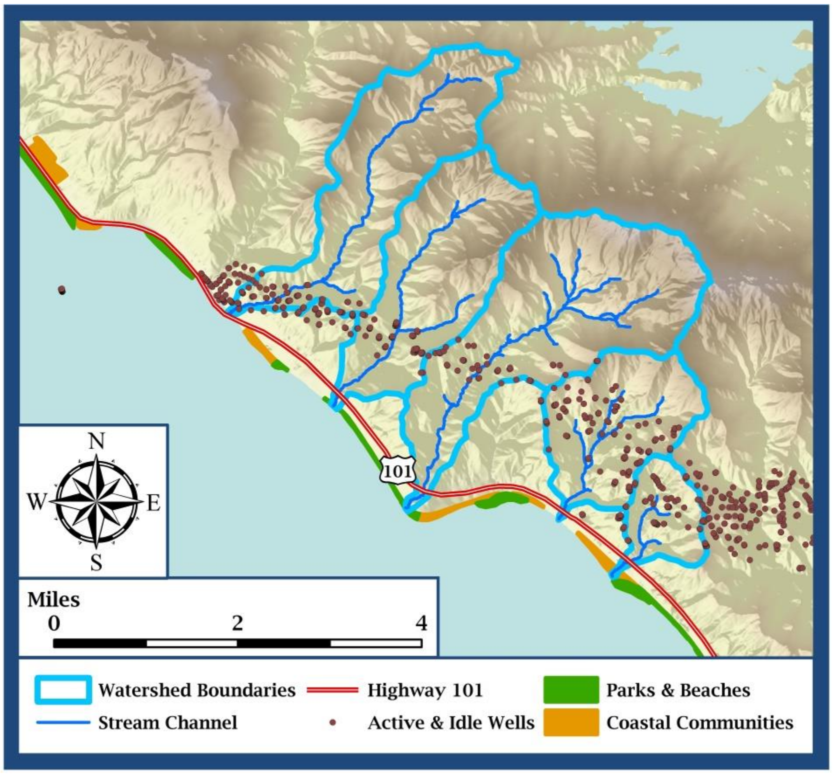
NVCCWP Watersheds

Located in northwestern Ventura County, California, the study watersheds are roughly 17 miles south of the city of Santa Barbara and 7 miles north of the city of Ventura, along Highway 101. Collectively, the watersheds span 9.5 square miles and the threatened California coastal scrub inhabits the majority of the area. These five watersheds drain the Rincon and San Miguelito oil fields, which are upstream of residential communities, popular beaches, and coastal habitat. Oil field infrastructure covers about 5% of the study area, and approximately 275 people live in three residential communities near the creeks. Each year, over 140,000 people visit campgrounds and 570,000 go to beaches downstream or adjacent to the watershed outlets. The watersheds discharge into coastal waters, which are home to kelp forests, marine mammals, fish, and bird species.



Oil Field Development and Production

The Rincon and San Miguelito oil fields have been in production since the early 20th century, and over 400 wells have been drilled in the watersheds. Oil field productivity has steadily declined since the late 1970's. Currently, over 90% of fluid extracted from the oil fields is produced water, which contains a complex mixture of organic and inorganic constituents with high levels of total dissolved solids (TDS).



As a result of declining productivity, enhanced oil recovery and well stimulation methods are used in the study watersheds. Hydraulic fracturing has been performed on at least 3 wells in Line Canyon, and roughly 9 million barrels (~380 million gallons) of produced water was injected into the oil fields in 2013 as part of water flood enhanced oil recovery projects.

Oil field development has led to large areas cleared for roads and well pads. This infrastructure covers about 11% of Line Canyon and 9% of Amphitheater Canyon. Roads, well pads, staging areas, and other cleared areas influence surface runoff and water quality, as unvegetated and compacted surfaces generate unnatural quantities of surface runoff and are sources of sediment and erosion.

Environmental Sampling

A total of 17 water samples and 10 sediment samples were collected from the study watersheds and tested for up to 68 constituents. Additionally, three samples were collected from the Line Canyon base flow, the only creek that flowed during dry periods. The 2014 water year was one of the driest on record in the study area, and only two rain events generated enough runoff for sampling (November 21, 2013 and February 27-March 1, 2014). Water and sediment samples were analyzed for a wide range of pollutants including metals, diesel and residual range organics (DRO & RRO), polycyclic aromatic hydrocarbons (PAHs), and other organic compounds and hydrocarbons. Pollutants were selected for analysis based on association with oil production operations and pollutants known to occur in hydraulic fracturing fluids, focusing on those that are of concern to public health and the environment.

Stormwater and Sediment Sample Results

Stormwater samples showed high levels of total suspended solids (TSS) and metals, most notably in Line and Amphitheater Canyons. Stormwater in Line and Amphitheater Canyons had the greatest concentration of TSS out of any project samples at 130,000 and 189,000 mg/L, respectively.

Samples of stormwater had high concentrations of total suspended and dissolved solids which were associated with high concentrations of metals. Stormwater in Amphitheater Canyon was found to contain 1790 mg/L of aluminum, 1.14 mg/L of arsenic, 14 mg/L of barium, 1.12 mg/L of lead, and 9.78 mg/L of zinc. The greatest TDS concentration in stormwater was detected in Line Canyon at 5,290 mg/L. The majority of the TDS can be accounted for by chloride, sulfate, sodium, calcium, and magnesium. The highest concentrations of PAHs were found in Line Canyon, which included 1.9 ug/L of naphthalene and several other PAHs, which were detected above reporting limits. DRO and RRO were detected in all canyons at concentrations above 0.5 mg/L, with the highest concentrations found in Madriano Canyon (5.9 mg/L of DRO and 4.1 mg/L of RRO).

Sediment samples collected early in the study showed the highest concentration of oil and grease in Madriano and Line Canyons at 1,740 and 1,610 mg/kg, respectively. DRO was also detected in all of the first sediment samples, with the highest concentration being 200 mg/kg in the Madriano Canyon sample. The first sediment samples detected bis(2-ethylhexyl)phthalate in all creeks, except Madriano Canyon, with the highest concentration found in Line Canyon at 0.17 mg/kg. Several of the metals were detected at relatively high concentrations, indicating how rich the local geology is in these naturally occurring metals.

Line Canyon Base Flow

Streams in the study watersheds have been classified historically as ephemeral or intermittent. However, the Line Canyon base flow exhibited perennial characteristics over the duration of the project, despite extreme drought conditions, and was measured at 0.03 to 0.04 cfs (0.85 to 1.1 L/s). This base flow had concentrations of DRO and RRO up to 2.3 and 1.5 mg/L, respectively.

Conductivity of the base flow was measured in field tests and lab samples, and ranged between 14,000 and 16,000 µS/cm. The high conductivity in the base flow was due to high TDS concentrations, which were measured at between 9,450 and 10,500 mg/L (roughly 1/3 the concentration of seawater). Chloride, sodium, and sulfate constitute the majority of this TDS (approximately 39% Cl^-, 29% Na^+, 21% SO_4^{2-}). The greatest difference between levels of metals in Line Canyon base flow and stormwater runoff was boron, which was detected at a much higher concentration (20.4 mg/L) in the base flow. Although the Line Canyon base flow discharge rate was very small compared to the stormwater discharges, the DRO and RRO can add up to annual loads of 66 and 36 kilograms (assuming constant flow at 0.04 cfs).

Pollutant Loading Rates in Stormwater

The loading rates from Line Canyon on February 27, 2014 at the time of sampling included 390 kg/hr of aluminum, over 0.2 kg/hr of both arsenic and lead, 2 kg/hr of zinc, 0.380 kg/hr of DRO, 0.400 kg/hr of RRO, 0.0023 kg/hr of bis(2-ethylhexyl) phthalate, and many PAHs in the range of 10's of milligrams per hour (mg/hr).

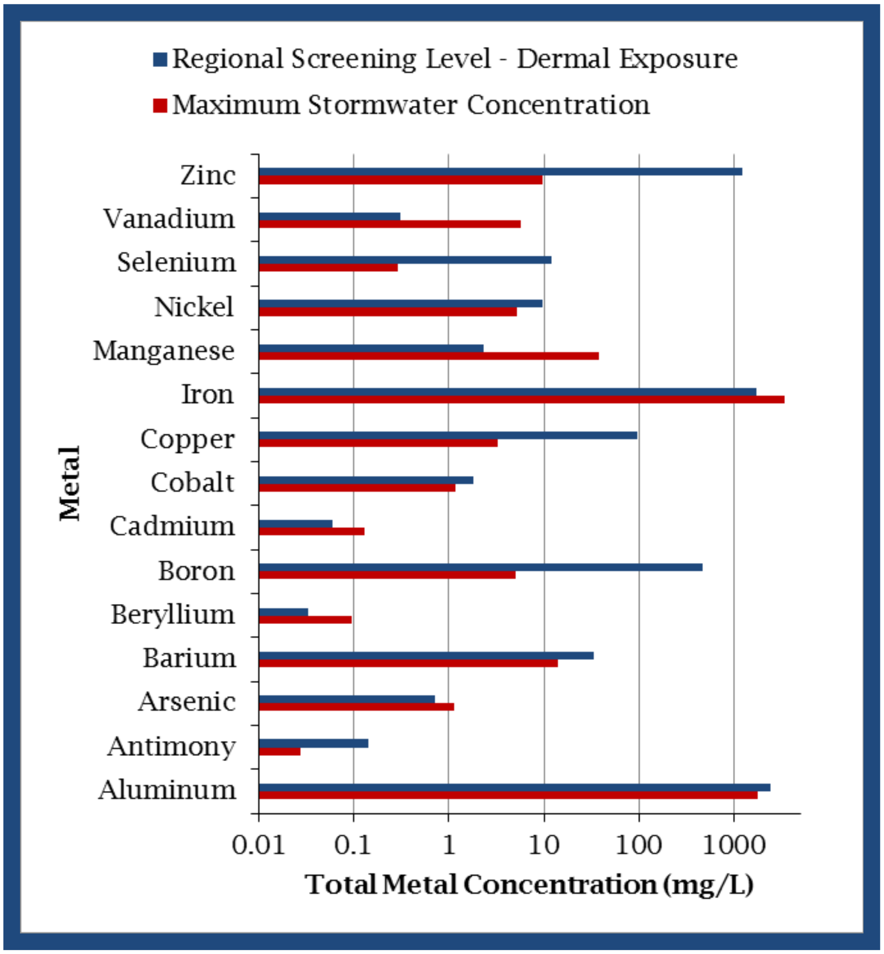
The picture to the left shows the discharge from the Line Canyon outlet during the storm on February 28, 2014.

On March 1, 2014 Line Canyon was sampled while discharging 1,300 L/s (45 cfs). This resulted in a sediment loading rate of 560,000 kg/hr (1.2 million lbs/hr), which (with an assumed sediment density of 2,500 kg/m^3) yields a loading rate of about 220 m^3 of sediment per hour. Amphitheater Canyon had higher TSS concentrations measured in samples and a much higher discharge rate that, at peak flow, was estimated to be discharging over 2,000 m^3/hr.

Toxicity of Pollutants

Various beneficial uses are designated for the watersheds, including the potential to be used for municipal and domestic water supply. Children live adjacent to (and play in) these stream channels, and during the study people were observed swimming in the effluent from the watersheds and walking barefoot up the creeks. Exposure to pollutants through dermal contact, ingestion, or inhalation can increase the likelihood of adverse health effects including cancer. The Line Canyon base flow had the greatest potential human toxicity of all water samples for dissolved metals and salts.

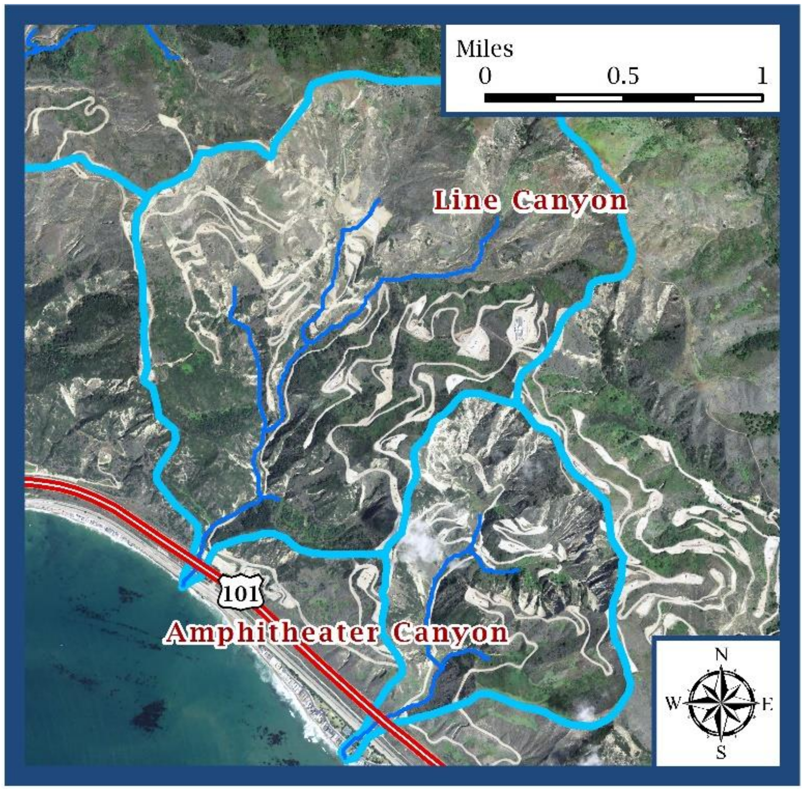
Maximum Stormwater Total Metal Concentrations



Arsenic was detected at relatively high concentrations in sediments and stormwater samples from all five canyons. Arsenic was found to have the maximum increased carcinogenic risk through residential soil exposure pathways of 18 in one million from a sediment sample collected in Javon Canyon, and 25,000 in a million for chronic dermal exposure from a water sample collected in Amphitheater Canyon. Based on EPA Regional Screening Levels (RSLs), these high concentrations of total metals (excluding arsenic) in stormwater samples are 19 and 44 times greater than what would be expected to cause no observable adverse effect from chronic dermal exposure to Line and Amphitheater Canyon stormwater, respectively. These metals are shown in the graph above with the maximum concentration detected in water samples and the RSLs for dermal exposure to tap water.

The organic pollutants detected in sediments and waters were detected at low enough concentrations that they did not have an appreciably high risk with respect to RSLs, except for the propargyl alcohol detected in one water sample from Padre Juan Canyon, which could be harmful when chronic ingestion is considered. 1,2,4- trimethylbenzene and propargyl alcohol were found to be the organics with the highest non-carcinogenic risk. The California Toxics Rule criteria identified several PAHs and bis(2-ethylhexyl)phthalate as potential pollutants of concern, most of them found in Line Canyon.

Sources of Pollutants



The primary sources of sediment, metals, and salts found in stormwater runoff are upstream geology and soils. The watersheds are in one of the most tectonically active areas on earth, and the soils are highly erosive. Oil field roads and clearings exacerbate erosion of sediment that is rich in heavy metals, increasing the transport of these metals along with carcinogenic organic compounds onto the beaches and into coastal waters.

The persistent Line Canyon base flow exhibits characteristics of a deep ground water source, and potentially originates from thousands of feet deep. The base flow may originate from or be mixed with produced water that is being injected into the oil fields as part of the water flooding enhanced oil recovery projects. Fractures and faults in the study watersheds may be providing pathways for deep groundwater or injected water that surfaces as a spring and sustains this base flow.

DRO, RRO, and PAHs were detected in the base flow, and the volume of produced water and the hazardous chemicals that are being injected into deep geologic formations pose a potential risk of deep springs being hydraulically connected to the petroleum source formations and returning these pollutants to the surface.

Project Recommendations

Recommendations have been developed for the study area based on the research and analysis presented in the four project elements: Watershed Assessment, Environmental Sampling, Toxicity Analysis, and Source Assessment.

The primary mitigation strategies focus on controlling erosion in the study watersheds, which has been linked to the mobilization and transport of toxic heavy metals that are naturally occurring in the geology of the area, and the transport of organic compounds and PAHs originating from well pads and oil field operations.

Environmental sampling, and surveys of habitat and species, should be conducted in the oil fields. Continued monitoring in the study watersheds and investigation of the Line Canyon base flow is needed for a more thorough assessment of the risks posed to people and habitats. Designated beneficial uses and environmentally sensitive areas should be reevaluated to protect human uses and receiving ecosystems. The hydraulic fracturing of wells and water flood projects used in the study area should be studied further, considering the local geology, to assess the risk of these fluids reaching the surface.

Recommendations & Mitigation Strategies

- Erosion Control
- Hazard Signage and Education
- Base Flow Investigation & Tracer Test
- Continued Monitoring
- Watershed and Erosion Modelling
- Reevaluating Beneficial Uses and Environmentally Sensitive Areas
- Environmental Sampling within Study Watersheds
- Investigate Potential Hydraulic Fracturing and Water Injection Effects in the Geologic Environment

NVCCWP Summary

The primary objectives of this project were to examine water quality in the study watersheds and test for a wide range of constituents that are known to occur in hydraulic fracturing fluids and other oil field operations. The study was exploratory in nature, and sought to assess the toxicity and identify sources of detected pollutants. The study indicates impacts to water quality from various upstream oil production operations.

Oil field roads and clearings increase the suspended sediment and metal concentrations found in stormwater, which poses a risk to people and other organisms. The Line Canyon base flow may be hydraulically connected to formations which are drilled or injected with produced water. These creeks are pathways for pollutants originating from upstream land uses and mitigation strategies should be implemented to protect human and environmental health along the coast.

Recommendations & Mitigation Strategies

Recommendations have been developed for the study area of the Northern Ventura County Coastal Watershed Project (NVCCWP) based on the research and analysis presented in the four project elements: Watershed Assessment, Environmental Sampling, Toxicity Analysis, and Source Assessment.

The primary mitigation strategies focus on erosion control in the study watersheds, which has been linked to the mobilization and transport of toxic heavy metals that are naturally occurring in the geology of the area, and the transport of organic compounds and PAHs likely originating from well pads and oil field operations. These include specific Best Management Practices (BMPs) for stream rehabilitations, on-the-ground investigation of road erosion and sediment sources, permitting of large oil field construction activities, and other BMPs that should be incorporated into the Storm Water Pollution Prevention Plan (SWPPP) for the oil fields.

Several of the recommendations are aimed at generating data and information on the study area, and increasing protection of beneficial uses and water quality. It is recommended that monitoring and sampling of the creeks continue, including stormwater and channel sediment sampling. Future monitoring and sampling efforts could be improved by sampling within the oil fields, testing well pad runoff and sediments for the organics, metals and salts that were found to be of concern in this study. Coastal areas and their beneficial uses would benefit from increased protection through designation as an Area of Special Biological Significance (ASBS).

To better assess risk of the potential pollutants of concern identified in the Toxicity Analysis coastal marine waters could be sampled near the watershed outlets during large discharge events. Based on the current study it is believed that educating the public about potential pollution hazards and the placement of hazard warning signs are justified, and continued monitoring will help better evaluate the potential risk to people and species from exposure of pollutants.

Recommendations are organized with supporting evidence and justification, which is derived directly from the four project elements, followed by specific recommendations. For additional information, support, or justification for these recommendations refer to the four project elements.

1.0 Erosion Control

Erosion, a natural mechanism accelerated from the presence of oil field infrastructure and activity, is a dominant driver of water quality in the study watersheds. The natural geology and soils are known to be highly erosive and sensitive to disturbance. Oil field roads and clearings, which disturb and compact native soils, and change hydrologic flow paths and response (hydro-modification), can have drastic effects on the erosion rates of the small study watersheds. The greater sensitivity of the study area to erosion (from the naturally sensitive geology and soils) warrants greater erosion mitigation measures compared to less erodible landscapes. These practices are necessary to limit the impact to downstream ecosystems and coastal environments from oil field operations. As noted in the watershed assessment there have been large scale (>50,000 m^2) land clearing and excavation activities in the oil fields in the recent past, which undoubtedly have large sedimentation impacts downstream and in the coastal environment. The following recommendations include strategies to mitigate erosion and sediment transport from oil field roads and clearings. The majority of the BMPs are derived from the USDA National Core BMP Technical Guide and the EPA National Management Measures to Control Nonpoint Source Pollution from Forestry; refer to these documents for details on unpaved-road placement, construction, and maintenance BMPs.

Recommendations

1.1 Specific road and staging area construction BMPs should be integrated into the Storm Water Pollution Prevention Plan (SWPPP) for the oil fields that include specific actions and structures such as those listed below:

- **1.1A** Use water bars, rolling dips, or inlaid open top box culverts to divert water off roads and from road ditches at a minimum of every 300-500 feet for road grades between 2-5 percent and every 300-100 feet for slopes between 6-15 percent
- **1.1B** These diversions should have adequately sized energy dissipation structures and rip rap to prevent hill slope erosion where water leaves the road surface
- **1.1C** Create out-sloped roads and limit the use of inboard ditches that can accumulate water. If inboard ditches must be used, divert water from ditch using the same spacing as above to limit water accumulation and increasing erosive power of flow
- **1.1D** Gravel roads that are not paved. This will maintain infiltration but decrease the availability of fine sediment. Gravel is preferred over paving because impervious pavement creates greater hydro-modification and flow energy that can impact highly erosive soils and slopes
- **1.1E** Minimize driving on unpaved roads during and after rain while roads are still wet
- **1.1F** Decommission and re-vegetate well pads and roads that are no longer in use

1.1G Minimize the grading of well pads and road surfaces, where possible, to the minimum needed for operation

1.1H Re-vegetate exposed and disturbed slopes using native vegetation

1.2 Perform on the ground investigation of oil fields and road network to assess erosion sources, and quantify erosion from road surfaces and well pads, and to assess shortcomings and improvements that could be made to road networks and clearings

1.3 Remove sediment settling ponds and restore stream channel to its natural grade to reestablish aquatic organism passage. Downstream sediment basins are ineffective because they cannot trap silt sized sediment given the flow regimes (Amphitheater Canyon would require a basin in excess of 400 km^2 to trap silt in a 250 cfs flow). Sediment and erosion control should be placed upstream closer to sources and not focused on downstream point source control

1.4 Require permits for dredging and filling through the CWA and permitted by the U.S. Army Corps of Engineers and follow permit guidelines during large construction and development of the oil field

2.0 Hazard Signage and Education

The toxicity analysis indicates potential hazards from bathing and chronic exposure to runoff and sediments from the watersheds. The greatest risk comes from carcinogenic arsenic, which occurs naturally in the geology. Propargyl alcohol, a toxic unnatural organic pollutant which is known to be used as a corrosion inhibitor in the oil fields, was also detected in one sample of runoff from Padre Juan Canyon (which discharges to the coast adjacent to Faria County Park and Rincon Parkway). During sampling activities and site visits performed through this study, several people were observed swimming in the ocean directly in front of the stormwater discharge, children and families from the residential communities were observed playing in and around the Amphitheater Canyon stream channel, and foot prints were observed from people walking barefoot in stream channel sediments. As documented in the Watershed Assessment, the coastal area adjacent to the watershed outlets is home to three residential communities and is a popular tourist and local recreational area. Signage and education measures are recommended to prevent people from exposing themselves to potentially hazardous pollutants.

Recommendations

2.1 Educate local communities of the potential hazard from frequent contact with water and sediments directly discharged from the watersheds, specifically Line and Amphitheater Canyons

2.2 Place hazard warning signs next to stream outlets that have the highest potential risk to people being exposed to carcinogenic compounds and other potentially hazardous pollutants

2.3 If through further monitoring and testing of stormwater runoff, propargyl alcohol continues to be detected, and other organics are detected at or near chronic toxicity levels, signs should include warnings for specific hazardous organics originating from the oil fields

3.0 Base Flow Investigation and Tracer Test

From October 2013 through April 2014 sampling and field tests at the stream in Line Canyon revealed a persistent perennial base flow of 0.85 to 1.1 L/s (0.03 to 0.04 cfs) despite a prolonged drought. None of the other study watersheds exhibited any base flow, intermittently or perennially. The base flow was consistently measured to have between 9,000 and 10,000 mg/L total dissolved solids (TDS) consisting mostly of chloride, sulfate, sodium, magnesium, calcium, potassium, and boron. Due to these factors and the lack of surficial sedimentary deposits sufficient for groundwater storage, it is likely this base flow is originating from either a very deep ground water source (potentially thousands of feet), or from produced water improperly reinjected for disposal or water flooding enhanced oil recovery. The study area contains fractures and faults caused by the tectonic activity in the region, and these faults may be providing pathways for deep springs. Diesel range organics (DRO), residual range organics (RRO) and PAHs were detected in samples of the base flow. The volume of produced water and the hazardous chemicals that are being injected into deep geologic formations and the potential risk of this deep spring to be hydraulically connected to these formations warrant further investigation and monitoring.

Recommendations

3.1 Perform a tracer test analysis on the base flow coming from Line Canyon to determine if there is any connectivity between the base flow and the injection wells in the oil field

3.2 Collect water samples from the spring source where the base flow originates and test for organics and metals

3.3 Sample the base flow spring source for radioactivity (i.e. radon) known to naturally occur in the subsurface and oil reservoirs

4.0 Continued Monitoring

The study area has been found to have complex and potentially hazardous water and sediment quality and attracts visitors that frequently come in contact with these waters and sediments. The small watershed size and high density of oil wells and infrastructure may result in large fluctuations in water quality that would be revealed through a more continuous monitoring program over multiple years. This study tested for many constituents that should continue to be tested for in future samples. Additionally, there may be many other organics present in runoff from the oil fields that were not tested for that, if sampled, could provide a better characterization of downstream risk and impact.

Recommendations

4.1 Continue stormwater monitoring of runoff from the coastal watersheds

4.2 Research and add other potential pollutants of concern that may be originating from oil field operations

4.3 Continue to sample stream sediments, particularly from creeks with a high level of nearby residential and recreational activity

4.4 Sample coastal marine waters directly below stream outlets during large stormwater events to assess arsenic levels and other pollutants in coastal waters during discharge events

4.5 Sample fish tissue from fish caught near the watershed outlets to assess for possible bioaccumulating pollutants originating from the study watersheds

5.0 Watershed and Erosion Modelling

It is clear from the extent of oil field infrastructure found in Line and Amphitheater Canyons (about 11% and 9%) that these operations are having an influence on the hydrology and erosion rates of these watersheds. However, the exact size of the effect is unknown. While there is a difference in the hydrologic response and sediment yield between the five study watersheds, the differences between the driving factors are unknown. Modelling the coastal study watersheds would allow for a better understanding of the hydro-modification caused by land use and help identify the areas with the greatest need for mitigation and erosion control. Spatially modelling erosion from the watersheds would allow for the generation of a sediment budget based on natural characteristics.

Recommendations

5.1 Model hydrology of the coastal watersheds using impervious surfaces and or factors to represent the oil field development, and calibrate using field flow measurements. Then rerun the model without development to assess the size of the effect land use is having

5.2 Spatially model erosion to identify significant natural source areas and compare the expected natural erosion rates to measured rates

6.0 Reevaluating Beneficial Uses and Environmentally Sensitive Areas

The study area has a large amount of coastal habitat and sensitive ecosystems that are important for local fisheries and recreationalists. There are unique terrestrial and marine ecosystems located along the northern Ventura coastline that would greatly benefit from increased protection, such as the California coastal scrub in the watersheds and kelp forests along the coast. The beaches and coastal waters near the outlets of the study watersheds are frequently visited by people participating in a variety of beach and coastal activities including fishing and wildlife viewing. The coastal areas are habitat for numerous marine mammals and fish, and the near coastal zone provides rocky hard-bottom habitat. The section of coastline adjacent to the study area is threatened by pollution from the oil fields, roads and highways, agricultural practices, and leaky sewer systems.

Recommendations

6.1 Consider designating the coastline from the Rincon Creek outlet to the Ventura River outlet an Area of Special Biological Significance (ASBS), to provide additional protection to water quality, coastal ecosystems, and beneficial uses of the coastline

6.2 Reevaluate the beneficial uses designated to the canyons and coastline to develop site specific uses and water quality objectives for the northern Ventura county coastal streams based on background water quality

6.3 Study coastal kelp forests and potential impacts from sedimentation from the watersheds, comparing the extent of kelp forests over time to periods of intense oil field development (such as that mentioned in the watershed assessment between 2010 and 2012 when >50,000 m^2 were cleared)

6.4 Perform vegetation, endangered species, and other biological surveys within the study watersheds. If surveys reveal extensive California coastal scrub habitat and or other endangered habitat and species additional conservation of the inland watershed should be considered.

7.0 Environmental Sampling within the Study Watersheds

Well pads are the most likely source of organic pollutants detected downstream, and due to the large amount of dilution and volatilization that would be expected for most compounds, the detections downstream indicate either wide spread low level contamination or small areas of high level contamination. The greatest impacts to ecosystems are likely occurring upstream of the sampling locations used in this study. Testing of well pad soils and stormwater runoff, as well as the runoff from undisturbed hill slopes above the oil fields, would allow for better assessment of sources of organics and total and dissolved metals.

Recommendations

7.1 Sample well pad soils and runoff for pollutants detected downstream

7.2 Sample above and below areas that drain oil field infrastructure to better understand impacts from this land use

7.3 Consider other pollutants that were not tested for in the NVCCWP that may impact downstream water quality and coastal environments

8.0 Investigate Potential Hydraulic Fracturing and Water Injection Effects in the Geologic Environment

The study area is within one of the most tectonically active regions in the world with active faults traversing the watersheds. Hydraulic fracturing is used to purposefully fracture the bedrock to increase permeability and connectivity for better producing oil wells. But in an already highly fractured environment fractures may have unanticipated effects creating connectivity with faults and waters that discharge to the surface. Such influence on natural seeps and springs from oil wells and production is known to occur and is plausible in such a tectonically active region. Historic gas injection tests in the oil field proved that there was large connectivity and quick depressurizing of the injection zone.

Recommendations

8.1 Detailed geophysical mapping to identify fault planes and fractures capable of allowing migration of hydrocarbons and produced water from oil producing zones to the surface

8.2 Develop Ventura County hydraulic fracturing policies and regulations aimed at preventing adverse effects and near surface contamination in this highly faulted and tectonically active region

8.3 Evaluate potential contamination scenarios based on detailed fault plane mapping. Based on whether there is an appreciable risk, develop containment strategies such as plugging springs and fractures, stopping injection operations, or depressurizing oil reservoirs that may be allowing contaminated fluids to migrate upward towards the surface