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Monitoring Trends of Regulated Outfall Water Quality over Twenty-Five Years in Response to Diverse Set of Site Management and Stormwater Controls at a Historical Industrial Site

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Abstract

The Santa Susana Field Laboratory (SSFL) occupies 1,153 ha (2,849 acres) in the Simi Hills of Ventura County, California, in the southern part of the state near Los Angeles. SSFL is a former rocket engine test and nuclear research facility. The site is jointly owned by the Boeing Company and the federal government. The National Aeronautics and Space Administration (NASA) administers the portion of the property owned by the federal government. The industrial activities at SSFL have ceased, and current activities include environmental monitoring and sampling, demolition, remediation, and ongoing remedial planning and activity. Undeveloped land and open space provide wildlife habitat and natural areas.

SSFL is currently the focus of a comprehensive environmental investigation and cleanup program, conducted by Boeing, the United States Department of Energy (DOE), and NASA, and is overseen by the California Department of Toxic Substances Control (DTSC) of the California Environmental Protection Agency (CalEPA). The DTSC is the lead regulatory agency overseeing the investigation and cleanup of contaminated soil and groundwater at SSFL. Final site soil cleanup will begin when the DTSC completes their site studies and sets the contaminated soil cleanup goals.

Stormwater discharges from SSFL are currently regulated by the Los Angeles Regional Water Quality Control Board (LARWQCB) under the *National Pollutant Discharge Elimination System (NPDES) Permit No. CA0001309*. The permit requires the Surface Water Expert Panel (SWEP) to provide input on annual reports that describe the previous year's monitoring results, evaluation of existing stormwater control performance, and a workplan that includes recommendations for modified and/or new stormwater controls and monitoring that addresses and numeric exceedances from the regulated outfalls.

Public interest and involvement with the regulatory process at SSFL are very high. This paper is intended to describe the site historical use and associated contamination, interim soil cleanup activities that have been approved by the regulatory agencies, and stormwater management and resulting runoff quality that have occurred before the final DTSC guidance is available.

More than 40,000 stormwater quality analyses have been conducted at SSFL during the past 25 years. About 35 to 50 constituents are analyzed at the 12 regulated outfalls for each runoff producing event. For this paper, these data were normalized to focus on the high concentrations by comparing them to the permit and benchmark numeric effluent limits (NELs) contained in the 2015 discharge permit. Complete data descriptions are contained in the monitoring reports submitted to the LARWQCB (https://www.boeing.com/principles/environment/santa-susana/monitoring-reports.page). The comparisons in this paper do not necessarily indicate permit limit exceedances as the NELs have changed with time and some analytes require additional evaluations. The numbers of observations greater than the 2015 NEL values were then compared as a time series over the complete 25-year monitoring period, focusing on comparisons for the early monitoring period (1998/99 to 2009/10 rain years) before the interim contaminated material removal activities and stormwater management at the site vs. the later monitoring period (2010/11 to 2022/23 rain years) since these site changes have occurred. Numerous graphical and statistical analyses were conducted indicating significant decreases in the number of concentration observations greater than the 2015 NELs since the interim contaminated material removal and stormwater management activities at SSFL.

Introduction and Site Description

The following sections describe the SSFL and industrial activities that have caused site contamination, and the interim soil cleanup activities that have been approved by the agencies (DTSC and LARWQCB). The sources of these descriptions are mostly from the DTSC, NASA, DOE, CalEPA, LARWQCB, and Boeing publicly accessible web sites, as listed in the references. This section is lightly edited from these official web sites to ensure accuracy.

History of Site Activities and Contamination at SSFL

Multiple state, federal and local government agencies are involved in the cleanup underway at SSFL (DTSC a). The investigation and cleanup activities include soils investigations and cleanup, groundwater cleanup and monitoring, hazardous materials and waste handling, air quality testing, and radiation cleanup programs.

Figure 1 is a map of SSFL showing the outfall locations along with the administrative Areas I through IV, plus the undeveloped buffer areas. The administrative and undeveloped buffer areas, along with their areas and historical industrial activities are:

- Area I consists of 272 ha (671 acres) owned by Boeing plus 17 ha (42 acres) in the northeast portion of the site administered by NASA. Area 1 contained administrative and laboratory facilities and was formerly used for rocket engine and component testing. Area I also included the former Area I Thermal Treatment Facility and three rocket engine test areas: the Bowl, Canyon, and Advanced Propulsion Test Facility areas. All test stands and administrative and laboratory facilities in Area I have been removed.

- Area II consists of 166 ha (410 acres) in the north-central portion of the site and is owned by the United States Government and is administered by NASA. Area II contained administrative and laboratory facilities, and four rocket test firing facilities: Alfa, Bravo, Coca, and Delta. NASA has removed the administrative and laboratory facilities and the Delta test area. The Bravo and Coca test areas are scheduled to be removed soon.

- Area III consists of 46 ha (114 acres) in the northwest portion of the site and is owned and operated by Boeing. Area III included the systems test area (STL-IV) and associated laboratories. All Boeing facilities in Area III have been removed.

- Area IV consists of 117 ha (290 acres) owned and operated by Boeing and 36 ha (90 acres) leased by DOE. DOE sponsored nuclear and non-nuclear energy research and development projects at the site. Nuclear energy research and handling of nuclear materials in Area IV ended by 1988. All DOE buildings in Area IV have been removed. There are five buildings that were operated by Boeing that remain within Area IV that will be removed.

- The northern and southern buffer areas consist of 71 and 461 ha (175 and 1,140 acres), respectively. Industrial activities have never occurred in these naturally vegetated areas.

Chemicals in SSFL soils and groundwater came from historical testing and maintenance activities. The primary chemical contaminants include a variety of solvents (primarily trichloroethylene), metals and petroleum hydrocarbons. Low-level radioactive contamination resulted from energy research operations. Solvents, containing volatile organic compounds, were used until the 1990s to clean rocket engine test equipment (Boeing a). These solvents were often disposed of onsite and seeped into soil, bedrock, and groundwater.

Much of the work conducted on behalf of the U.S. Department of Energy at the Energy Technology Engineering Center involved metallic sodium systems. The Sodium Reactor Experiment (SRE) suffered an accident in 1959 when overheating caused fuel damage in the reactor's core. During the accident, primary power and cooling were maintained, coolant continued to circulate throughout the reactor core and the reactor vessel remained intact, preventing a meltdown. Following the accident, the SRE was repaired, and operations continued until the end of the project in 1964. Most nuclear research related programs and operations at SSFL ended in 1988 (DOE). Beginning in the 1990s, activities in Area IV focused on decontamination and decommissioning of former nuclear facilities. In 1996, Rocketdyne merged into The Boeing Company in a corporate acquisition of the aerospace divisions of Rockwell International. In 2006 Rocketdyne was sold to Pratt-Whitney. The Boeing Company retained ownership and operations of Area IV.

The California Department of Toxic Substances Control (DTSC) is a department within California's Environmental Protection Agency. DTSC regulates the handling and cleanup of hazardous waste in California (DTSC a). At SSFL, DTSC directs and oversees the site investigation and cleanup being conducted by Boeing, NASA, and DOE. Boeing's cleanup can begin upon completion of the required environmental review process, and when DTSC makes the required findings, conducts a public process, and makes the remedy decision. Field sampling is complete. The investigation reports for soil and groundwater are in the review and approval process with DTSC project staff. Workplans and reports for evaluating potential cleanup technologies are being reviewed simultaneously. In September 2017, DTSC issued the draft Program Environmental Impact Report (PEIR) to evaluate impacts to the environment from SSFL cleanup activities and identified measures to address those impacts. DTSC is currently preparing responses to the comments on the draft report and preparing the final PEIR.

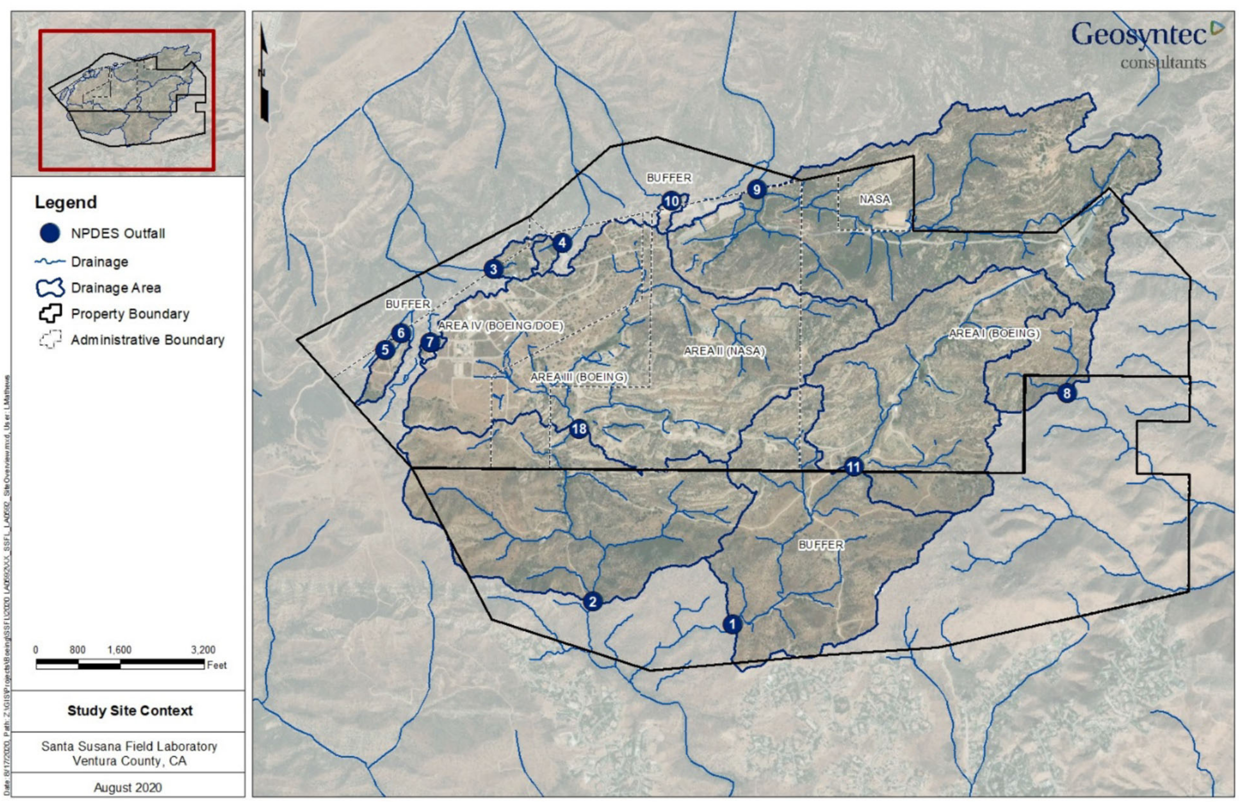


Figure 1. Stormwater outfall locations and administrative units at SSFL.

According to DTSC (a), SSFL is an ongoing cleanup project that will take years to complete. The site will continue to be monitored to ensure the safety of the community and the environment. While final cleanup has not yet begun, many interim actions have already been completed, including:

- Critical soil cleanups have been completed.
- A groundwater pump and treat system that removes contamination and stops groundwater migration is on-going.
- Stormwater treatment systems help prevent off-site releases of contaminated stormwater.
- The surface water discharge permit requires the continued use of distributed source area stormwater controls to reduce discharges of contaminated runoff. The permit also requires outfall compliance monitoring at all stormwater outfalls for every runoff producing rain.

An independent surface water expert panel was formed in response to the 2007 Cease and Desist Order from the Regional Water Quality Control Board (RWQCB): "…a panel to review site conditions, modeled flow, contaminants of concern, and evaluate the BMPs capable of providing the required treatment to meet the final effluent limits." The 2015 permit includes the ongoing charges for the expert panel:

- Review National Pollutant Discharge Elimination System (NPDES) compliance and stormwater control performance monitoring data.
- Investigate site-wide stormwater pollutant sources.
- Make recommendations for new stormwater controls or improvements to existing stormwater controls.
- Review stormwater Human Health Risk Assessment (HHRA).
- Conduct public outreach.
- Review site cleanup Stormwater Pollution Prevention Plans (SWPPPs).

There are therefore many challenges to implementing stormwater quality controls at SSFL, such as:

- steep topography, shallow bedrock (outcrops of Chatsworth Formation sandstone are ubiquitous, as readily apparent in aerial photographs),
- susceptibility to wildfire and the associated impacts of increased runoff and deteriorated water quality,
- susceptibility to extended drought which makes the establishment of vegetation to stabilize soils very challenging,
- occasional years of very high precipitation, such as 2022-23, which produce such large runoff volumes that all of the flow produced by the site cannot be treated to the desired level. Residential development is widespread immediately downhill from SSFL and the public can interact with the periodic stormflows generated on the site (see discussion of the Human Health Risk Assessment in this paper that was conducted to evaluate the interaction of the public with site stormwater runoff).

Adding to these technical challenges is the nature of the NPDES permit that governs stormwater discharges from SSFL and requires that very stringent numeric effluent limits be met for multiple contaminants at all of the outfalls for all rainfall events that produce runoff. The following sections of this paper address these topics and the resulting changes in site stormwater quality that have occurred over the years in response to interim contaminated material removal and stormwater management activities.

Interim Contaminated Material Removal and Stormwater Treatment at SSFL

The following section describes SSFL site activities that have involved removal of contaminated materials in critical areas as the final DTSC cleanup plans are being developed. This section also describes the stormwater treatment activities on SSFL. Table 1 lists, in chronological order, the interim contaminated material removal (yellow high-lighted), stormwater treatment installation (orange high-lighted), along with two wildfires that affected the site (red high-lighted). The dates for these activities are shown along with the locations affected (by NPDES outfall number). These activities are further described in the following subsections.

Table 1. Interim Contaminated Material Removal and Stormwater Treatment Activities at SSFL by Date.

Activity	Start/end dates	Locations
Sodium Disposal Facility (sodium burn pit) soil removal	2000	Outfalls 005, 006, and 007
Interim soil removal and perchlorate treatment	2003-2004	Building 359 Happy Valley Area 1, Outfalls 008 and 011
Topanga fire	October 2005	all
Northern Drainage debris removal	2007-2009	Liquid Oxygen (LOX) Plant and shooting range, Outfall 009
Distributed stormwater controls	2009-2019 installed	Outfalls 008 and 009
Interim/source removal actions (ISRA) at Outfall 008	2010	Outfall 008
Advanced stormwater treatment system at Outfall 018 in operation	2011, on-going	Outfalls 003, 004, 005, 006, 007, 010, 009 helipad paved area of 009, 018
Interim/source removal actions (ISRA) at Outfall 009	2013	Outfall 009
NASA demolition and contaminated material removal - structures removal	Phase 1, 2015 - 2016	Expendable Launch Vehicle (ELV) service area of northern portion of Area 2, Outfalls 018, 001, and 009
Boeing building demolition and asphalt removal	2015-2016	Area IV, Outfalls 005, 006, 007, 003, 004, and 018
NASA demolition and contaminated material removal - structures removal	Phase 2, 2017 - 2018	Skyline Tanks and Pipelines, the Alfa/Bravo and Coca/Delta Fuel Farms, the Sewage Treatment Plant, LOX Plant, and the former Delta Test Area, Outfalls 018 and 009
Woolsey fire	November 2018	Outfalls 001, 011, 002, 018, and 008
Treated wood pole barriers	2019 (area 2) and 2020 (southern buffer zone), on-going	Area 2 and southern buffer zone, Outfalls 018, 001, 009, and 002
NASA demolition and contaminated material removal - structures removal	Phase 3, 2019 - 2020	Alfa, Bravo, and Coca Test Areas, Outfall 018
NASA demolition and contaminated material removal - structures removal	Phase 4, 2021 - 2022	LOX area in NASA Area 1 and the Bravo Test Stand 3 area in NASA Area 2, Outfalls 018, 001, and 009
Advanced stormwater treatment system at Outfall 011 in operation	2021, on-going	Outfall 011
Utility pole removal	2022	Outfalls 011, 009, and 018
NASA demolition and contaminated material removal - structures removal	upcoming Phase 5, Spring 2023	Bravo Test Stands and control houses in NASA Area 2, Outfalls 018, 001, and 009
Imminent and Substantial Endangerment (ISE) Cleanup Shooting Range and Area 1 burn pit	upcoming 2013	Outfalls 009, 001, and 011

2 Yellow high-lighted: contaminated material removal
3 Orange high-lighted: stormwater treatment systems
4 Red high-lighted: wildfires on site

Interim Contaminated Soil and Materials Removal at SSFL

NASA (NASA a) has completed its soil investigation to understand the nature and extent of soil contamination in NASA administered areas at SSFL. This activity included sampling, laboratory analyses, treatability studies, and pilot testing in preparation for conducting a comprehensive soil cleanup effort. An example of an early interim soil cleanup activity included removing 2,300 m^3 (3,000 yd^3) of mercury contaminated material including several buildings and five underground storage tanks.

In 1999, the DTSC directed Boeing to remove soils contaminated with dioxin, PCBs, solvents, and other wastes at the former Sodium Disposal Facility (sodium burn pit) (DTSC b). The soil was a source for potential contamination to surrounding areas and to groundwater in the bedrock. In 2000, over 11,000 m^3 (14,000 yd^3) of contaminated soil down to bedrock were removed. Following removal of the soil, the exposed bedrock surfaces were swept and vacuumed and mapped for fractures. DTSC geologists collected samples to confirm that soil and bedrock were remediated to the required health-based cleanup levels prior to installation of a clay backfill cap. DTSC continues to monitor the cap's effectiveness.

The Happy Valley site at SSFL, located in Area I, was used for solid propellant research and testing, along with gun propellant testing, between the 1950s and 1993. The primary use of perchlorate at the Happy Valley site occurred in the 1960s in support of research, development, and production of flares for the military, as well as for rocket propellant research and testing activities during the 1970s through 1993. Additional perchlorate use occurred in the northern portion of Happy Valley, where turbine spinners were tested in the 1950s. A 2003 DTSC Interim Measure included: 1) removal and restoration of soil, sediment, and bedrock containing perchlorate, and in some cases, metals; and 2) biotreatment of the excavated soil containing perchlorate at the building 359 area. Excavation of soil that contained metals and perchlorate was completed in October 2003, re-contouring of soil, implementation of erosion control measures, and restoration of vegetation in the Happy Valley Drainage were completed in January 2004. The biotreatment of perchlorate in soil began in Fall 2004.

Northern Drainage Debris Removal

The Northern Drainage, the main drainage channel above Outfall 009, also had interim cleanup activities at the liquid oxygen (LOX) plant debris area and the adjacent shooting range/clay target debris area, targeting PAHs from clay targets and lead from the shot, along with other debris (Boeing b). About 1,900 m^3 (2,500 yd^3) of debris and soil were removed from an area of about 0.1 ha (0.3 acres) in the LOX debris area in 2007. The shooting range debris area removal activity in 2008 removed about 3,040 m^3 (3,970 yd^3) of sediment, soil, and debris. Additional clay target debris were also removed during 2009.

In addition to debris removal, sediment transport down the Northern Drainage channel is also of interest, particularly as related to pollutant transport. Fluvial morphologists from Geosyntec have evaluated the morphology and behavior of the channel on many occasions, including recommendations for bank and bottom stabilization measures in some key locations. Check dams, scour protection downstream from culverts and bridges, and bank stabilization measures have been implemented with success. These structures are monitored after large runoff events and are repaired as necessary.

NASA Demolition and Contaminated Material Removal

NASA is conducting demolition activities in NASA-administered areas at SSFL as part of its cleanup agreements and to prepare the site for final cleanup (NASA b). Demolition activities began in early 2015 and the first four phases have been completed by 2022, with Phase five demolition activities to begin in the Spring of 2023, as described below.

- Phase One: The ELV/Service Area is located in the northern portion of Area II. Structures removed in this area included former engineering offices, maintenance buildings, and the expendable launch vehicle (ELV) finally assembly building. In addition to above ground structures, utility poles, piping, concrete and roadways in this area were also removed.

- Phase Two: Phase 2 removal activities focused on areas outside of the historic areas where obsolete buildings and infrastructure were still in place. This included Skyline Tanks and Pipelines, the Alfa/Bravo and Coca/Delta Fuel Farms, the sewage treatment plant, the Liquid Oxygen (LOX) Plant, and the former Delta Test Area.

- Phase Three: Phase 3 focused on the removal of ancillary structures and buildings in the Alfa, Bravo, and Coca Test Areas. The six existing test stands and control houses were not demolished during Phase 3. Demolition in these areas involved obsolete structures such as inactive storage tanks, asphalt parking areas, and dormant office buildings.

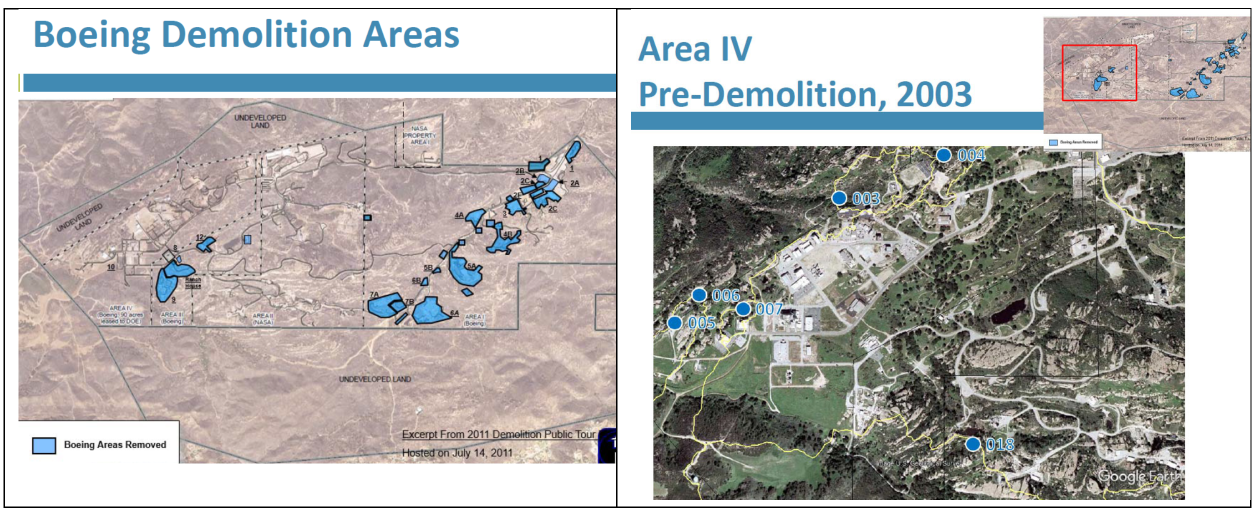
- Phase Four: Phase 4 demolition included approximately 80 ha (200 acres), involving the LOX area in NASA Area I and the Bravo Test Stand 3 area in NASA Area II. Phase 4 demolition focused on the removal of a subsurface concrete slab that remained in Area I LOX, as well as the retaining wall, concrete foundation, and spillway of the former Bravo Test Stand 3.

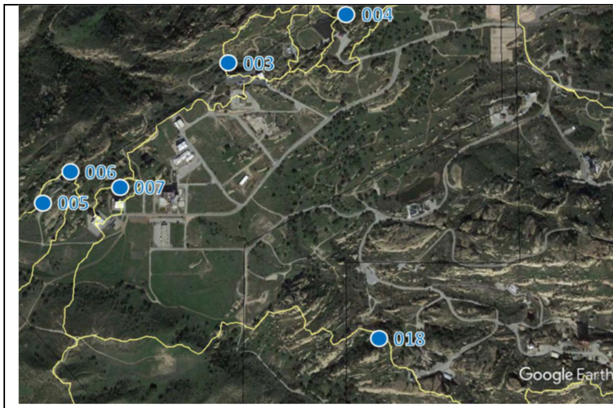
Figure 2. Photos of Phase 4 demolition from NASA website (NASA b)

Phase Five: This phase covers approximately 80 ha (200 acres), including the area of the Bravo Test Stands and control houses in NASA Area II. Phase 5 demolition includes the removal of the two remaining test stands and control house in the Bravo Test Area and is scheduled for the Spring of 2023.

Building and Asphalt Demolition on Boeing Property

The following map shows these demolition areas. Also shown on Figure 3 are pre- and post-demolition photographs at several of these locations.





After Demolition at Area (2016). Regulated stormwater outfalls shown.

Figure 3. Building and asphalt demolition on Boeing property.

Demolition Subarea Monitoring

Per a 2020 Storm Water Expert Panel (SWEP) recommendation to monitor stormwater near areas of demolition, subarea samples were collected to characterize runoff before reaching the Silvernale pond and the stormwater treatment system. Following the completion of demolition activities of the Sodium Pump Test Facility (SPTF), samples were collected and analyzed for metals, dioxins, radionuclides, and general water quality constituents. Concentrations in the stormwater sample collected at the SPTF demolition site were above Outfall 018 2015 Permit Limits in one or both samples for the following analytes: arsenic, cadmium, chromium VI, copper, lead, mercury, zinc, chronic toxicity, detergents (defined as methylene blue active substances, or MBAS), iron, manganese, and TCDD TEQ no DNQ. No radionuclides were detected above Outfall 018 2015 Permit Limits in any SPTF subarea sample. The runoff from this area is diverted to the Silvernale advanced stormwater treatment system for further treatment.

Non-Industrial Sources Special Study

Special studies were conducted to identify additional sources of contaminated materials for removal or treatment while waiting for final site cleanup guidance and permission from DTSC. The Surface Water Expert Panel and Geosyntec developed the *Special Monitoring Studies for the 009 Watershed* ("Special Study Work Plan") (Santa Susana Surface Water Expert Panel and Geosyntec Consultants, 2015b), in part to address periodic lead and dioxin exceedances despite the implementation of numerous stormwater controls targeting former operational areas in the upper Outfall 009 watershed area. Earlier findings from the stormwater treatment subarea monitoring at SSFL found that runoff from paved subareas had significantly higher concentrations of constituents of concern (COC) than from unpaved subareas, regardless of whether impacted soils were known to be present in the drainage areas. A technical paper describing the findings from this special sources study is currently being prepared for publication.

Besides the importance of pavement areas, treated utility poles and surrounding areas were found to have elevated dioxin concentrations. Therefore, utility poles at SSFL close to pavement or drainage areas were identified for special controls at the pole base. If poles were not in use (and belonging to Boeing or NASA), they were removed. Forty-two unused treated wood utility poles on Boeing property and 12 poles on NASA property were removed (mostly in the Outfall 009 and 011 watersheds), between April-June 2022, as shown in Figure 4.

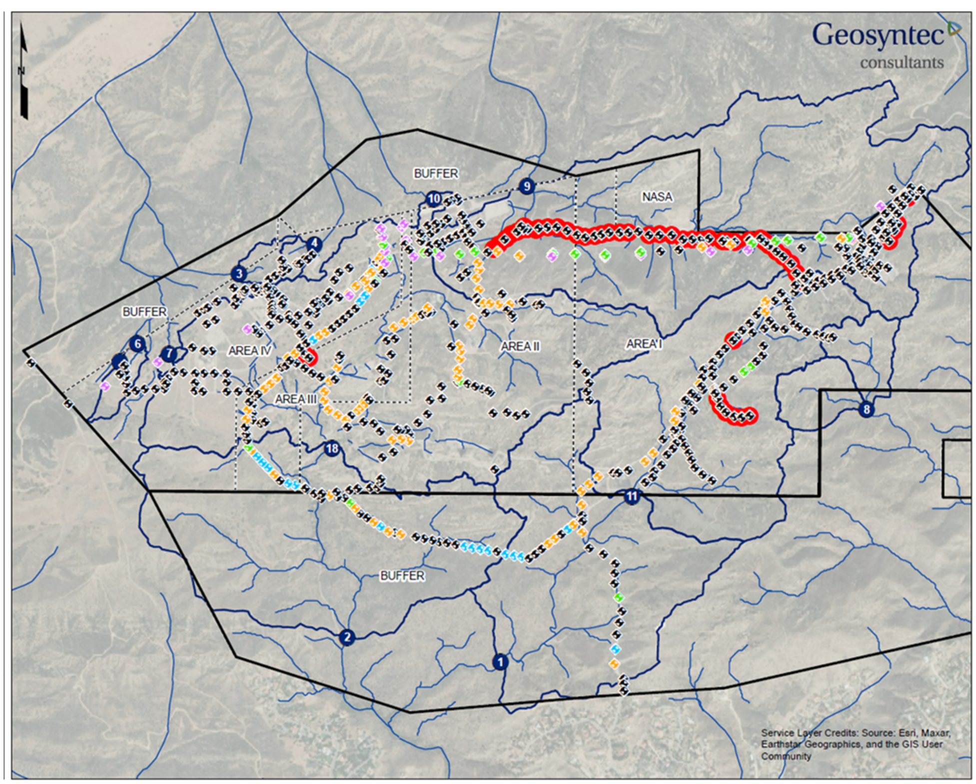


Figure 4. Utility Pole Locations and Materials (red high-lighted poles were removed)

Regional Water Quality Control Board Interim Source Removal Actions (ISRA)

The Los Angeles Regional Water Quality Control Board issued a 13304 Order on December 3, 2008, to require interim/source removal actions to remove wastes that are causing or contributing to violations of limitations contained in the NPDES Permit, Order No. R4-2004-0111, in the Outfalls 008 and 009 Drainage areas (Boeing c). Based on an evaluation of all stormwater samples collected at Outfalls 008 and 009 since August 2004, the following constituents of concern were identified for these outfalls; copper, lead, and dioxins at Outfall 008, and cadmium, copper, lead, mercury, and dioxins at Outfall 009.

ISRA activities were implemented in three phases between 2009 and 2013 and included the removal of approximately 19,622 m^3 (25,664 yd^3) from 36 ISRA areas. Restoration activities included backfilling the excavations using a local soil borrow source and/or gravel, re-contouring using adjacent soil, and/or installing erosion controls, including re-vegetation of the areas. Following the ISRA remedial activities, performance monitoring up- and downstream of completed ISRA areas was performed through two rainy seasons to ensure successful compliance with the restoration objectives.

Boeing photos of ISRA (Boeing d)

 2010: Outfall 008 Watershed ISRA Excavations	 2013: Outfall 009 Watershed ISRA Excavations

Figure 5. ISRA excavations and regrading.

Imminent and Substantial Endangerment (ISE) Cleanup Areas

Emergency provisions of the California Environmental Quality Act (CalEQA a) have allowed early cleanup of a former shooting range located adjacent to SSFL. Boeing will clean up the soil contaminated by lead from shot, skeet fragments, and clay pigeon target fragments left behind in a shooting range overshot area by a former gun club (Rocketdyne-Atomics International Rifle and Pistol Club) on property now owned by the Santa Monica Mountains Conservancy and operated as Sage Ranch Park by the Mountains Recreation Conservancy Authority (MRCA) (CalEQA a). This is a follow-up removal of contaminated material from this general area that occurred during 2007 to 2009 along the Northern Drainage, described previously. The purpose of this project is the removal of soil contaminated with the following hazardous substances: lead (the most frequently detected contaminant being addressed by this cleanup), polycyclic aromatic hydrocarbons (PAHs), antimony, and arsenic in an approximately 13 ha (31 acres) area, as shown on Figure 6.

The DTSC concluded that hazardous substances at the site pose a risk to human health and ecological receptors, and the DTSC and Boeing have agreed that removal actions are necessary to mitigate the release or threatened release of these substances from the site. Boeing's removal actions will bring site soil lead levels below the high toxicity reference ecological risk-based screening level for lead, which is significantly more protective than the human health criterion. The removal actions will also allow the MRCA to reopen closed portions of popular Sage Ranch Park trails to recreational users following DTSC review and approval of the cleanup. The cleanup is scheduled to begin in the spring of 2023.

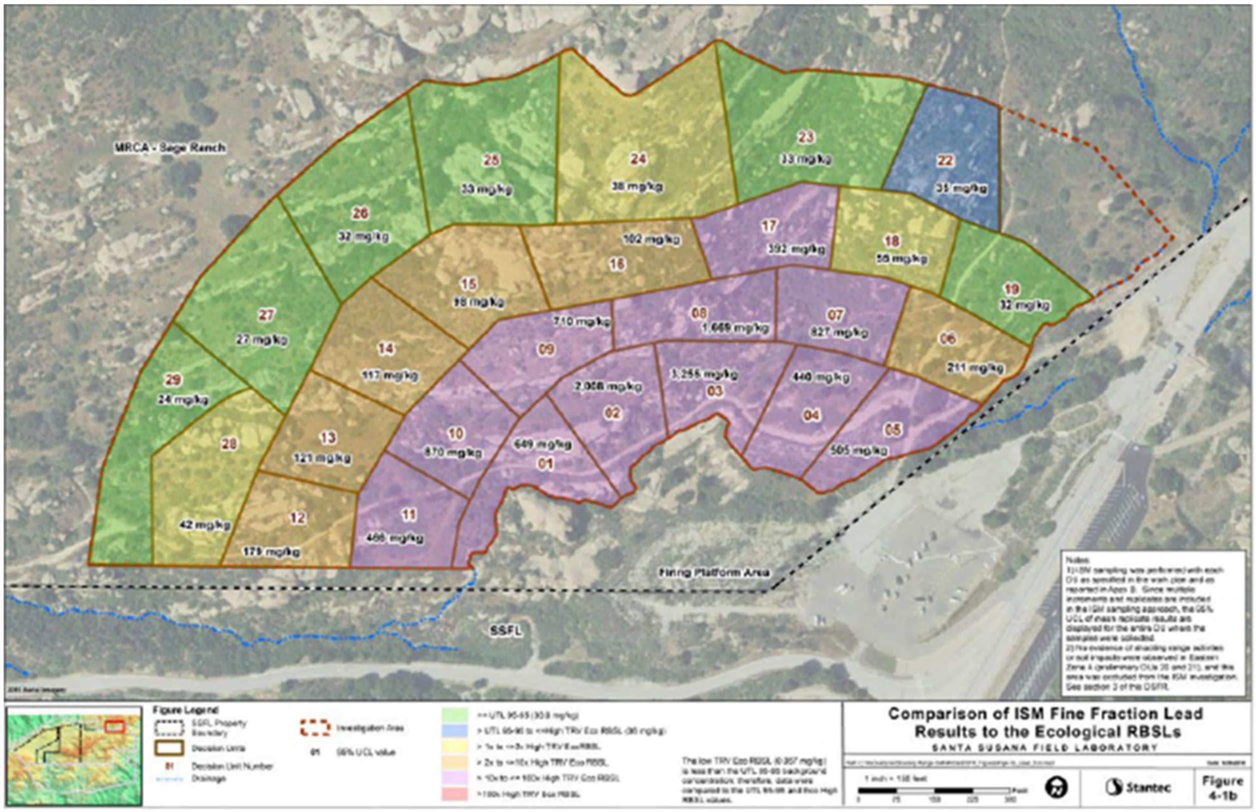


Figure 6. Former shooting range area soil lead contamination (Outfall 009 watershed).

The DTSC also issued a notice of exception concerning an ISE Determination and Consent Order for the Area 1 burn pit (CalEQA b). The purpose of this project is the removal of soil contaminated with hazardous substances, including cadmium, mercury, molybdenum, nickel, zinc, PCBs (Aroclor-1248 and Aroclor-1254), dioxins, pentachlorophenol, and trichloroethylene (TCE) in an approximately 2.3 ha (5.8 acres) site, as shown on Figure 7. The Area I Burn Pit area formerly consisted of two burn pits, three earthen ponds, three concrete-lined ponds, including an acid pit, a former Fire Department Demonstration Area, an entrance shack and related storage area, a control center, and two explosive storage sheds. The Area I Burn Pit area also contains levels of radionuclides above the January 30, 2013, Draft Provisional Radiological Lookup Table Values (LUTVs). The site currently uses a geotextile fabric cover to mitigate off-site migration. However, this cover is temporary, and the combination of time and severe weather is likely to cause contaminated runoff and migration of hazardous substances. The soil removal project at this location is scheduled for the summer of 2013.

Figure 7. Area 1 burn pit contaminated soil area (Outfall 011 and 001 watersheds).

Public Involvement

Numerous stakeholder groups and members of the public have expressed great concern about SSFL site contamination and potential exposure to community members, including stormwater transport of contaminants. These groups and individuals have therefore taken an active interest in stormwater topics at SSFL during past public engagements, including Regional Board hearings. The Surface Water Expert Panel has conducted approximately yearly public forum meetings and site tours since 2011, as noted on Table 2. These meetings have been used to provide progress updates on site conditions and stormwater quality, as well as to provide opportunities for feedback from the public. Project status reports and submittal documents have also been posted on the Boeing project website following completion of major project milestones and in advance of public outreach meetings, along with progress reports submitted to and posted by DTSC and the LARWQCB.

Table 2. Surface Water Expert Panel Public Involvement Activities, 2011-2023

Date	Activity
November 28, 2023 (tentatively scheduled)	Public meeting and SSFL tour
November 17, 2022	Public meeting and SSFL tour
August 19, 2021	Public meeting (virtual)
August 11, 2020	Public meeting (virtual)
July 17 2019	Public meeting and SSFL tour
May 9, 2019	Presentation to LARWQCB
May 25, 2018	Public meeting and SSFL tour
August 17, 2017	DIPCON LA Conference SSFL tour
March 21, 2017	Public meeting and SSFL tour
November 19, 2014	Community Action Group meeting
March 20, 2013	Public meeting and SSFL tour
October 6, 2013	Public meeting and SSFL tour
August 25, 2011	Public meeting
January 22, 2011	Public meeting and SSFL tour

Topics that the public has raised in meetings with the Panel include:

1) the relationship between health problems for residents who live downslope and in the vicinity of the site and contaminated site runoff;
2) continued NPDES permit exceedances despite the numerous facilities that have been implemented at the recommendation of the Panel to improve stormwater runoff quality;
3) the presence of seeps that are thought by some to be contaminated are located short distances downstream from Outfalls 001 and 002 and are therefore not being monitored at those locations; and
4) concerns that the stormwater storage ponds infiltrate water and therefore contaminate the groundwater.

Discussions and responses to these questions and concerns, and others, are available on SSFL FAQ web pages (such as at: https://dtsc.ca.gov/santa_susana_field_lab/santasusanafieldlabfaq/#easy-faq-379516, https://www.boeing.com/principles/environment/santa-susana/#/faq, https://ssfl.msfc.nasa.gov/about/faq, and https://www.waterboards.ca.gov/losangeles/santa_susana/Boeing%20SSFL%20FAQs%20for%20RB%20MOU%20with%20Boeing%205%205%2022%20(final%20on%20ltrhd)_ADAChecked.pdf).

The Surface Water Expert Panel has also often been asked questions by the public about groundwater contamination at SSFL. This is understandable given that releases of trichloroethylene and other chemicals to the groundwater beneath the site have been documented and described in numerous reports published by DTSC, DOE, NASA, Boeing, EPA, and other entities. However, the scope of evaluation for the Surface Water Panel has been limited to surface water and does not include groundwater. There is a Groundwater Advisory Panel that addresses this topic that was formed in 1997 and which has also hosted public meetings and prepared many reports to characterize groundwater contamination at SSFL.

Human Health Risk Assessment

In 2017, Geosyntec and the Expert Panel prepared the "Human Health Risk Assessment" (HHRA) report for SSFL, in accordance with California Water Code section 13383 Order (Order) from the Los Angeles Regional Water Quality Control Board (LARWQCB) dated June 24, 2015. The Order was proposed by the LARWQCB in response to health concerns expressed by members of the public regarding exposure to National Pollutant Discharge Elimination System (NPDES) discharges in the drainages near the SSFL. The HHRA Report provides a quantitative assessment of potential risks to downstream populations. In accordance with the Order, the analysis used conceptual exposure scenarios that are representative of realistic (but conservative) exposures that may occur immediately downstream of the SSFL property boundary over the long-term. The beneficial use designations set forth in the Los Angeles Water Quality Control Plan (Basin Plan) have been used to identify the surface water uses that may be relevant when establishing the HHRA exposure assumptions.

The HHRA evaluated exposure associated with non-swimming water contact recreational activities (hiking, rafting and other limited recreational uses that fall under the Basin Plan Limited Water Contact Recreation (LREC-1) designation). Direct exposures to surface water, i.e., incidental ingestion and dermal contact, were identified as the most likely potentially complete exposure pathways and were evaluated quantitatively in the HHRA. In addition, the inhalation pathway and the completeness of the aquatic plant and fish consumption pathways are evaluated. In addition, an evaluation was conducted to assess the completeness of the aquatic plant and fish consumption pathway.

The results of this HHRA indicate that potential recreational exposures to Constituents of Potential Concern (COPCs) in surface water runoff exiting the SSFL via Outfalls 001, 002, 008, 009, 011, 018, and 019 are below levels of concern as established by the California Environmental Protection Agency and the United States Environmental Protection Agency. This includes those COPCs that have had NPDES permit limit exceedances including lead and dioxins.

Stormwater Controls at SSFL

Stormwater discharges from SSFL are typically captured and treated at or upstream of outfalls up to a design storm size. Outfalls 011 and 018 have had advanced stormwater conveyance and active treatment systems since 2012 that use the natural storage provided by adjacent existing ponds, while Outfalls 008 and 009 use distributed source controls in lieu of the outfall-based treatment approach due to restrictive topography (tall dams would be necessary to store significant amounts of stormwater and such structures would not be feasible at those locations) and limited space near the outfalls. Discharges from Outfalls 001 and 002, located in the southern buffer zone, are comprised of runoff from undeveloped areas mixed with treated stormwater discharges from the Outfalls 011 and 018 advanced stormwater treatment systems. Interim Source Removal Action (ISRA) and distributed stormwater controls programs were implemented in the Outfall 008 and 009 watersheds beginning in 2009, with LARWQCB oversight and participation. This was to facilitate 2010 Permit compliance through a dual approach focusing on remediation of surface soils to thresholds defined for NPDES constituents of concern and implementation of distributed treatment controls for stormwater runoff from prioritized subareas. The 2010 BMP Plan (MWH et al., 2010) was developed under the oversight of the Surface Water Expert Panel for the Outfall 008 and 009 Watersheds.

Most of the distributed stormwater controls located throughout the Outfall 009 watershed use a filter media mix developed for SSFL consisting of sand, zeolite, and granulated activated carbon (GAC) and incorporate flow equalization, sedimentation, ion exchange, and sorption treatment processes (Pitt and Clark 2010). A variety of control types are used depending on available space and drainage areas, including:

- Culvert Modifications (CMs) and Media Filters
- Lower Lot Biofilter
- Detention Bioswales
- ELV Treatment Train

The advanced stormwater treatment systems for runoff from the Outfall 011 and 018 watersheds, pumped flows from the northern small watersheds, and a portion of the Outfall 009 area, use combinations of coagulation, sedimentation, sorption, and filtration unit processes. These measures were supplemented by intensive erosion control and revegetation as needed in the watersheds.

Advanced Stormwater Treatment Systems

Advanced stormwater treatment systems have been in place since 2012 at Outfalls 011 and 018. Figure 8 shows the Silvernale treatment system at Outfall 018, located adjacent to a pond for equalizing flow rates, pretreatment sedimentation, and storage of flows between periods of system operation. A similar treatment system is located at Outfall 011, also adjacent to a pond. The treatment systems utilize ActiFlow coagulation systems, along with bag and sand filters, granular activated carbon (GAC), and other processes. The ActiFlow system uses particulate and chemical additions to aid in coagulation of fine stormwater particulates. Chemical additions to aid the coagulation process include aluminum sulfate, sodium hydroxide (for pH adjustments), and polymers. The captured stormwater solids are concentrated and transported offsite for disposal. The sand and bag filters, followed by the GAC, are used to capture dissolved organic compounds from the stormwater. The treated stormwater is then discharged at the outfalls. The treatment systems operate periodically when the available storage in the ponds may not be sufficient to contain the runoff volumes from upcoming expected rains. The stormwater treatment performance of these advanced treatment systems is excellent, as described in later data discussions.

Besides the natural runoff in the watershed above Outfall 018, most of the stormwater from the small northern outfalls (003 through 007, and 010), along with runoff from a portion of the paved helipad above Outfall 009 (Figure 9), is pumped to the Silvernale pond and treatment system. Flows greater than the local storage and transfer capacity at the northern outfall locations are discharged at the northern outfalls, which also include media bed filters.

Figure 8. Outfall 018 Silvernale stormwater treatment system and adjacent storage pond completed in 2011.

Figure 9. Berms and pumps at helipad used to divert flows to Silvernale stormwater treatment system began in 2011.

Identification of Critical Subwatersheds and use of Distributed Stormwater Controls

One of the initial tasks of the SSFL stormwater expert panel was to identify stormwater controls that could be used in the Outfall 008 and 009 watersheds to minimize the discharge of critical constituents before the DTSC soil cleanup operations are completed. The approach recommended by the expert panel that has been used for several years is to rank monitoring locations at potential stormwater control subareas based on the results of water quality sample comparisons. The ranking methodology compares the observed stormwater concentrations to the permit limits or benchmarks, and the stormwater particulate strengths in affected vs. background areas. Particulate strengths are determined by taking the total concentrations of the constituent minus associated filtered concentrations, divided by the total suspended solids concentrations. This provides a measure of the mass of the particulate forms of the constituent per mass of suspended sediment. These values are useful in evaluating the relative strength of sediment-based pollutant sources in stormwater samples and assist in identifying potential sources of the particulate-bound constituents of concern.

Figure 10 is a map of the Outfall 008 and 009 watersheds showing the large number of subareas that have been monitored for constituents of concern to identify critical areas suitable for distributed stormwater controls. A total of 16 background sites (where no industrial activity was known to occur) and 68 potential distributed controls subareas were monitored and evaluated over several years.

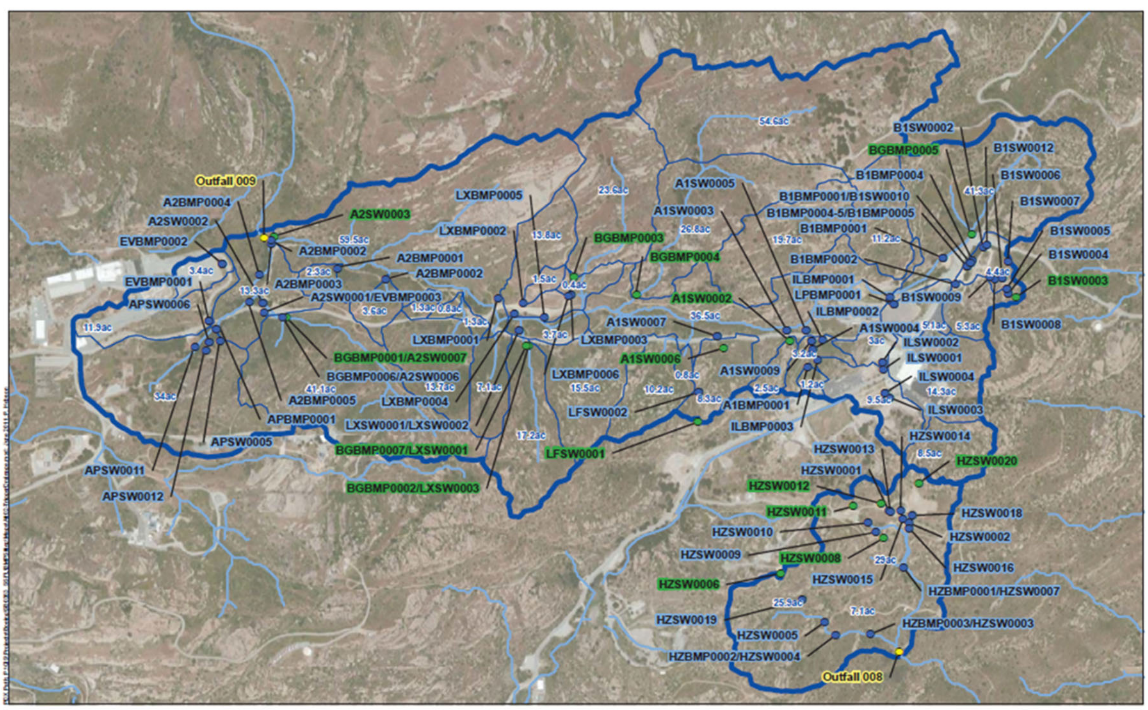


Figure 10. Outfall 008 and 009 watersheds showing monitoring locations for candidate distributed stormwater controls.

Figure 11 illustrates the basic approach for evaluating the subarea monitoring data to identify locations for distributed stormwater controls. Four priority categories are identified, with the highest priority having observed concentrations greater than both background concentrations and permit limits. Some constituents exceeded the permit limit but were generally lower than the background concentrations, falling into the second priority category. The third category included constituents that exceeded the background concentrations but were less than the permit limit, and the lowest priority category had concentrations below both the background and permit limit concentrations.

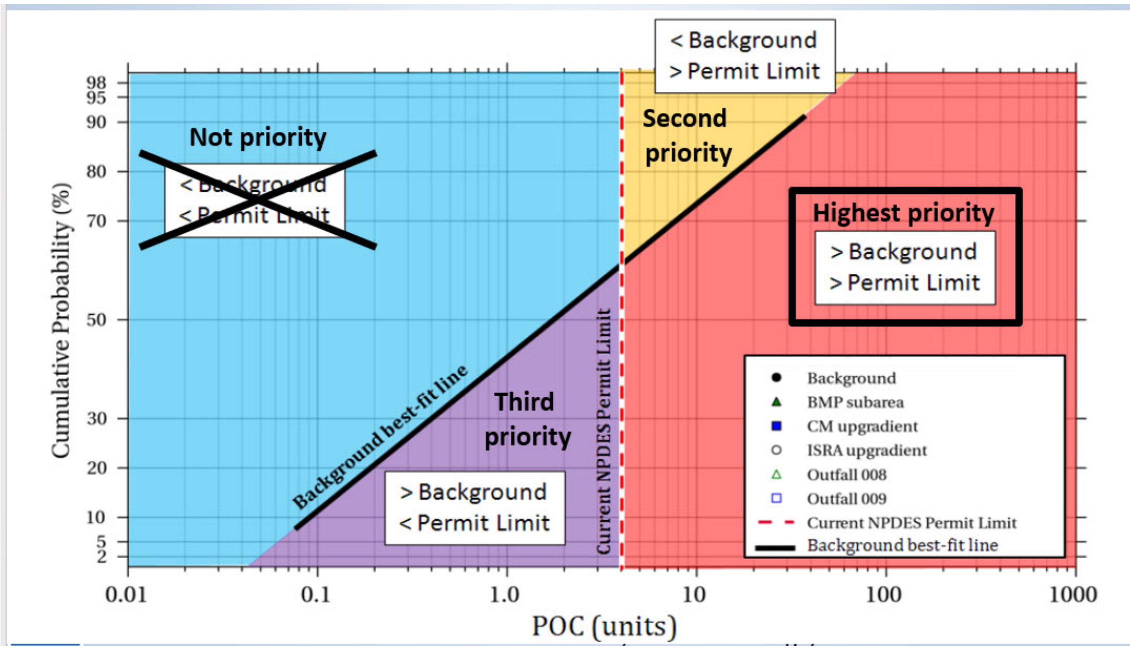
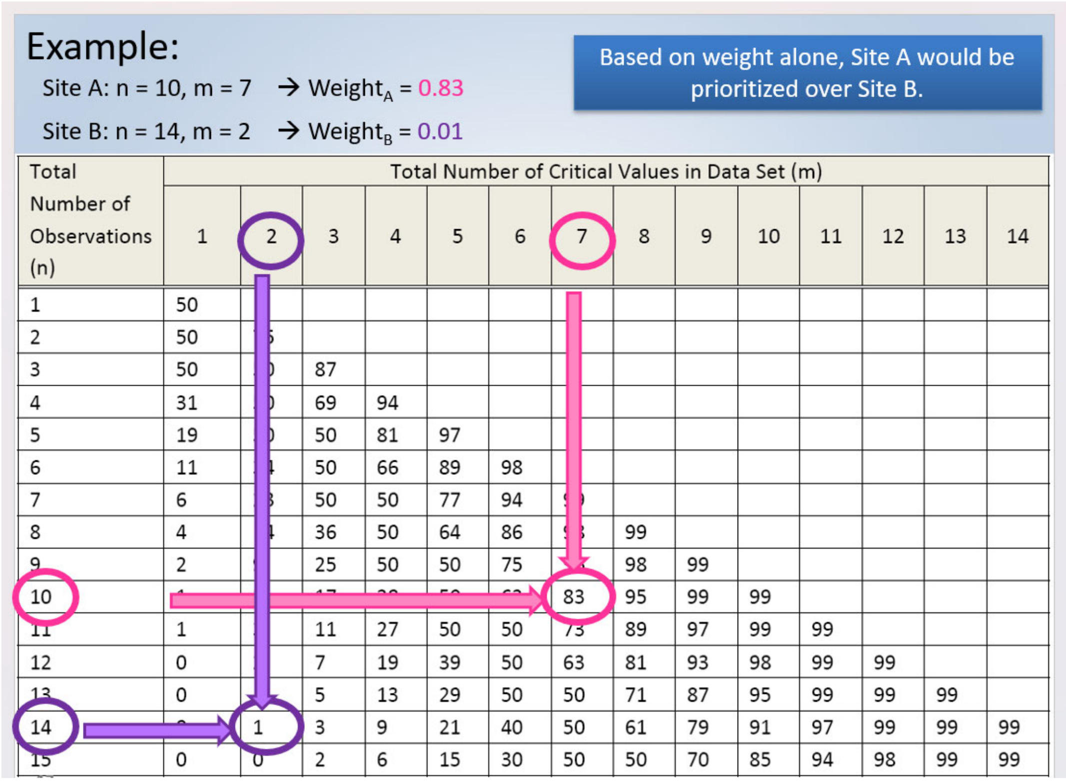


Figure 11. Example illustration of basic approach to identify priorities of pollutants of concern.

Over the years, additional sampling locations were added while others were removed, and not all locations had sampleable flows during most events. Therefore, a statistically based weighting method was used to adjust the ranking data based on the number of samples available and how they compared to the numeric limits. This methodology relies on "weighting factors" (based on the chi-square distribution corrected for small sample numbers) that are calculated for each constituent of concern for each subarea. The pollutant-specific weighting factors are ultimately summed to produce a multi-constituent score to allow relative ranking between the monitored locations, as illustrated in Figure 12. This methodology was previously published in *Stormwater Magazine* (Otto, et. al., 2013), and in *Water Resources Impact* (Costa, et al., 2016).



Total Number of Observations (n)	Total Number of Critical Values in Data Set (m)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	50													
2	50	[illegible]												
3	50	[illegible]	87											
4	31	[illegible]	69	94										
5	19	[illegible]	50	81	97									
6	11	[illegible]	50	66	89	98								
7	6	[illegible]	50	50	77	94	[illegible]							
8	4	[illegible]	36	50	64	86	[illegible]	99						
9	2	[illegible]	25	50	50	75	[illegible]	98	99					
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	95	99	99				
11	1	[illegible]	11	27	50	50	73	89	97	99	99			
12	0	[illegible]	7	19	39	50	63	81	93	98	99	99		
13	0	[illegible]	5	13	29	50	50	71	87	95	99	99	99	
14	[illegible]	1	3	9	21	40	50	61	79	91	97	99	99	99
15	0	0	2	6	15	30	50	50	70	85	94	98	99	99

Figure 12. Example weighting-factor calculations based on available data.

This process was repeated annually from 2010 through 2019 in these watersheds until no additional subwatershed areas were identified as being necessary for subarea distributed stormwater controls (when no consistent high priority locations were further identified). Figure 13 is an example ranking of control locations based on 2011/2012 monitoring data. Figure 14 shows the areas within Outfall 008 and 009 watersheds that are being treated by distributed stormwater controls using this selection methodology.

Rank from Average Weights	Potential BMP Subarea (Co-location(s))	Watershed	Description	Approx. Upstream DA (ac)	Events Sampled	Multi-constitue nt Score	Rank from Max Metal Weight	Rank from Max Dioxin Weight	Rank from TSS Weight
1	**EVBMP0003 (A2SW0001)[ab]**	Outfall 009	ELV road runoff/CM-1 upstream west	11.8	14	0.94	1	1	32
2	**B1BMP0004 (B1SW0015)[a]**	Outfall 009	B-1 media filter inlet north	3.7	2	0.72	9	5	74
3	**ILBMP0001[b]**	Outfall 009	Lower parking lot 24" stormdrain	23	10	0.68	14	4	39.5
4	**EVBMP0001-A[b]**	Outfall 009	ELV culvert inlet (helipad road and ELV ditch, composite)	2.5	5	0.67	16.5	3	15
5.5	**EVBMP0002[b]**	Outfall 009	Helipad (pre-sandbag berms)	4.1	6	0.66	15	6	31
5.5	**ILBMP0002[a]**	Outfall 009	Road runoff to CM-9	2.5	7	0.66	3	12	15
7	**A1SW0009-A**	Outfall 009	CM-9 downstream-underdrain outlet (post-building 1324 parking lot asphalt removal, pre-filter fabric over weir boards)	16.4	1	0.63	2	19.5	74
8	**APBMP0001**	Outfall 009	Ashpile culvert inlet / road runoff	34	2	0.60	4	19.5	74
9	**LPBMP0001-A[b]**	Outfall 009	Lower Parking Lot sheetflow (post-gravel bag berms)	5.1	6	0.52	30	2	27
12.5	LPBMP0001[b]	Outfall 009	Lower Parking Lot sheetflow (pre-gravel bag berms)	5.1	2	0.50	9	19.5	15
15.5	**A2SW0002-A**	Outfall 009	CM1 effluent (post-filter fabric over weir boards)	52.8	4	0.43	18.5	19.5	28.5
15.5	A1SW0009-B	Outfall 009	CM-9 downstream-underdrain outlet (post-filter fabric over weir boards, post-building 1324 parking lot asphalt removal)	16.4	4	0.43	18.5	19.5	15
17	**B1BMP0003 (B1BMP0002)**	Outfall 009	B-1 parking lot / road runoff to culvert inlet	5.2	12	0.43	38	7	33
27	B1SW0014-B	Outfall 009	B-1 media filter effluent (post-media filter reconstruction)	4.7	4	0.27	32.5	19.5	74
28	LXBMP0004[b]	Outfall 009	LOX southwest downstream of sandbag berm	10.6	5	0.26	9	40.5	1
34	EVBMP0001[b]	Outfall 009	ELV culvert inlet (helipad road gutter)	1.8	3	0.11	25	31.5	15
36	EVBMP0002-A[ab]	Outfall 009	Helipad (post-sandbag berms)	4.1	5	0.09	40	29.5	74

Notes
1) Potential BMP subareas sorted by multi-constituent score, computed as described in Section 5.
2) ([a]) These potential BMP subarea monitoring subareas are upstream of existing stormwater quality treatment controls.
3) ([b])These potential BMP subarea monitoring subareas have new planned (i.e., designed and ready for construction) stormwater quality treatment controls.
4) (**) NPDES outfalls are included for comparison and method testing purposes only, stormwater controls are not being contemplated at these locations.
5) The rounding of weights may account for similar weights being ranked differently
6) Approximate drainage areas based on the cumulative drainage area of the SWMM catchment in which the monitoring location is located (Geosyntec, 2011). At locations where the monitoring point is upstream of the catchment outfall a "<" sign is used.
7) Bolded locations indicate that both the NPDES permit limit and 95[th] percentile background particulate strength threshold were exceeded for any one COC

Figure 13. Example ranking of subareas for distributed stormwater controls.

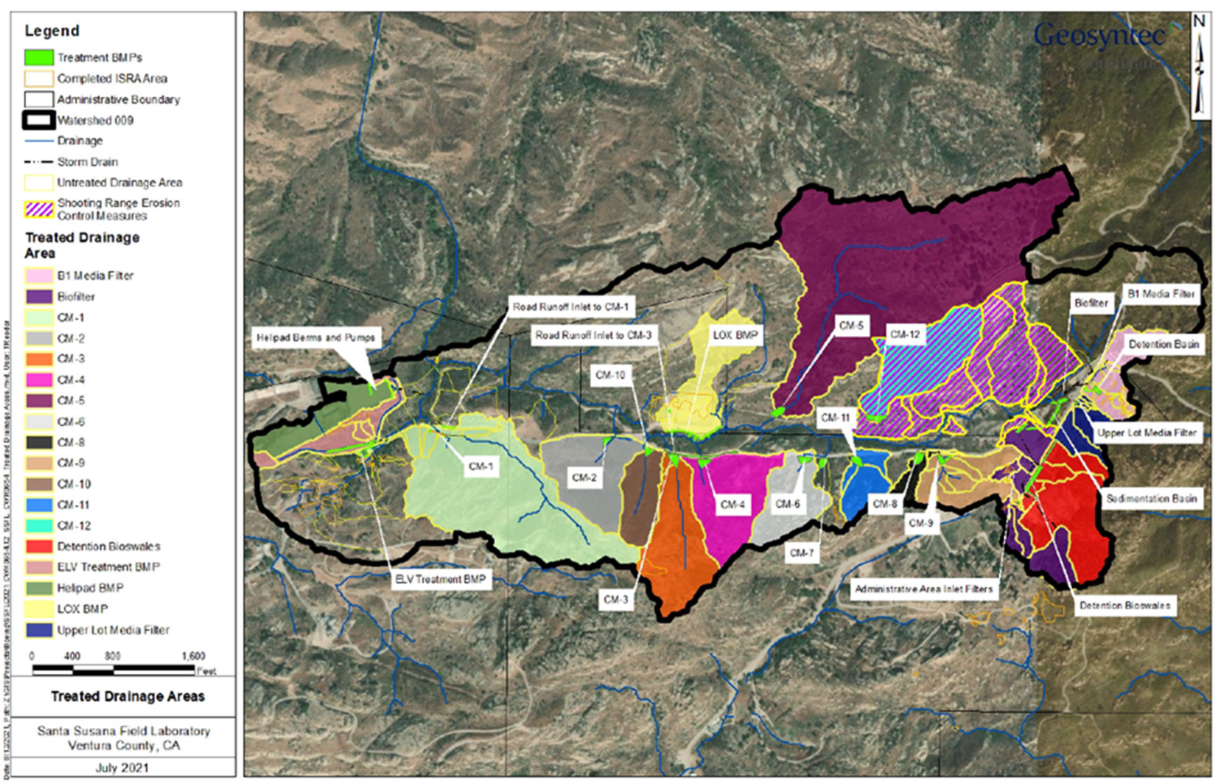


Figure 14. Outfall 008 and 009 watershed areas treated by distributed stormwater controls.

Subarea investigations were also extended into the Outfall 001 and 002 Watersheds (considered “buffer zone” watersheds) beginning in 2019/20 to characterize runoff from both natural background areas and potentially impacted areas to identify possible causes of repeated benchmark exceedances in these areas. Twelve samples were collected at six subarea sampling locations in these watersheds in 2021/22. Subarea samples were also collected in the Outfall 011 Watershed beginning in 2021/22 to characterize runoff from the Area 1 Burn Pit and other locations to inform investigations of possible causes of exceedances at Outfall 011. Six samples were collected at three subarea sampling locations near the burn pit in 2021/22.

Sources of Constituents of Concern

The next step after identifying critical subareas and implementing distributed stormwater controls was additional monitoring to examine sources of constituents of concern associated with widespread sources, such as atmospheric deposition, paved roads and parking areas, treated wood, and other potential sources. Appendix C of the 2022 SSFL Annual Report (*Exceeding Constituent Source Investigation*) submitted to the LARWQCB describes these special studies. A technical paper is currently being prepared that describes these source area analyses and outcomes, with a short summary included in the following subsection. Sources of permit limit and benchmark exceedances investigated through multiple data analyses provided independent lines of evidence (LOE) that when considered together provide a weight of evidence identifying one or more likely sources. The various LOEs considered were:

- spatial patterns
- particulate strengths
- metal ratio fingerprinting
- dioxin congener fingerprinting

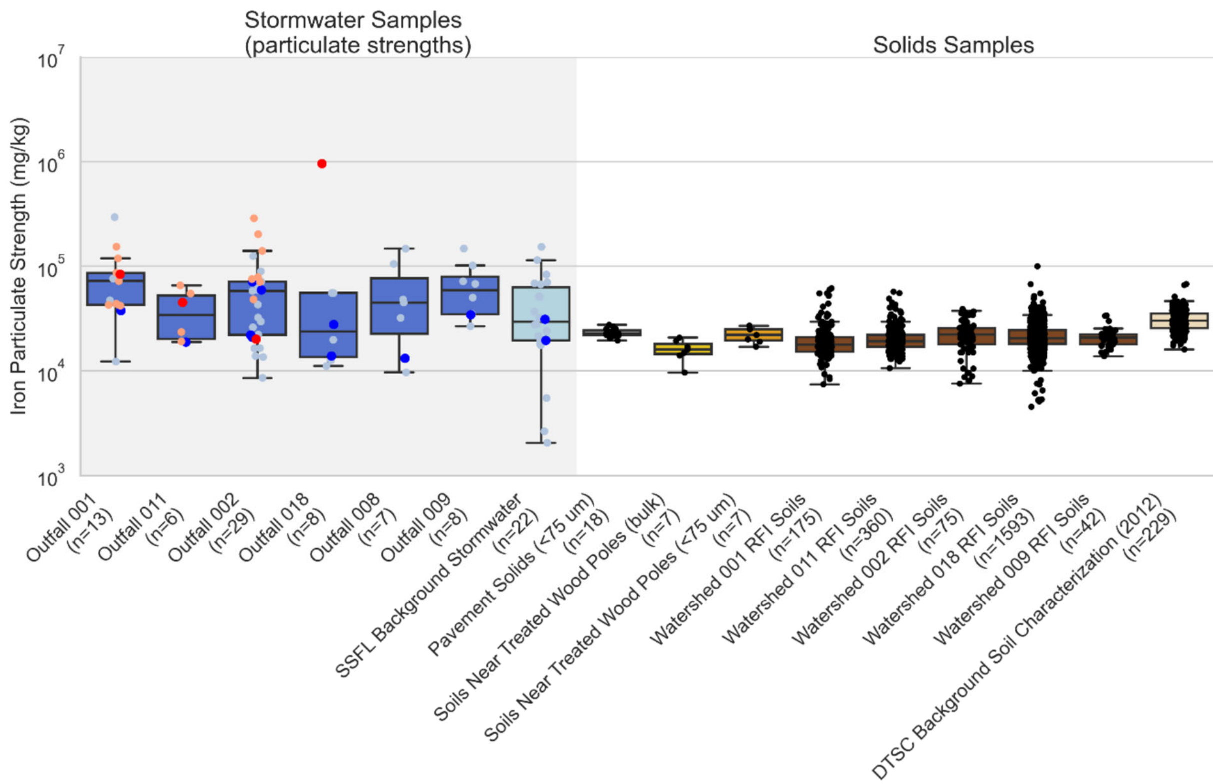
Potential sources evaluated included:

- Impacted Soils (referred to here as “RFI Soil”): Soils from areas potentially impacted by former operations were characterized for the Resource Conservation and Recovery Act (RCRA) program and other regulatory programs, including the RCRA Feasibility Investigations (RFI) conducted across the site.
- Background Soils: Natural background soils were evaluated using monitoring results from offsite soils evaluated in the California Department of Toxic Substances Control (DTSC) SSFL Background Soils Study (DTSC 2012).
- Pavement Solids: Particulates on pavements were collected quarterly from six sites throughout the Outfall 009 watershed between 2016-2017. The collected samples were sieved into three particle size fractions for analyses.
- Treated wood utility poles and adjacent soils: Treated wood utility poles and adjacent soils were evaluated by collecting samples of the treated wood utility pole material and the soil adjacent to treated wood at several locations.

• Utility Pole Wire Mesh: An intumescent-coated metal wire mesh was added to 12 poles in the Outfall 009 watershed in 2021 for fire protection. The mesh material was analyzed for constituents of concern that may leach during rains.

• Atmospheric Deposition Solids: Dry atmospheric deposition solid samples were collected monthly at the SSFL Fire Station and Helipad over the course of a year between 2016-2017.

Figure 15 shows example box and whisker plots comparing particulate strengths of iron and dioxin (measured as TCDD TEQ no DNQ) for potential sources, locations, and outfall samples.



Note: Red markers indicate PS values of outfall samples whose stormwater concentration exceeded an effluent limit or benchmark in the past year.
Blue markers signify stormwater samples that did not exceed an effluent limit or benchmark in the past year.
Orange markers indicate a previous exceedance in the past ten years. Light gray markers indicate a previous non-exceedance from the past ten years.
Black markers represent individual solid sample concentrations. Soils samples include top 6 inches only to reflect what is most likely to be mobilized in stormwater.

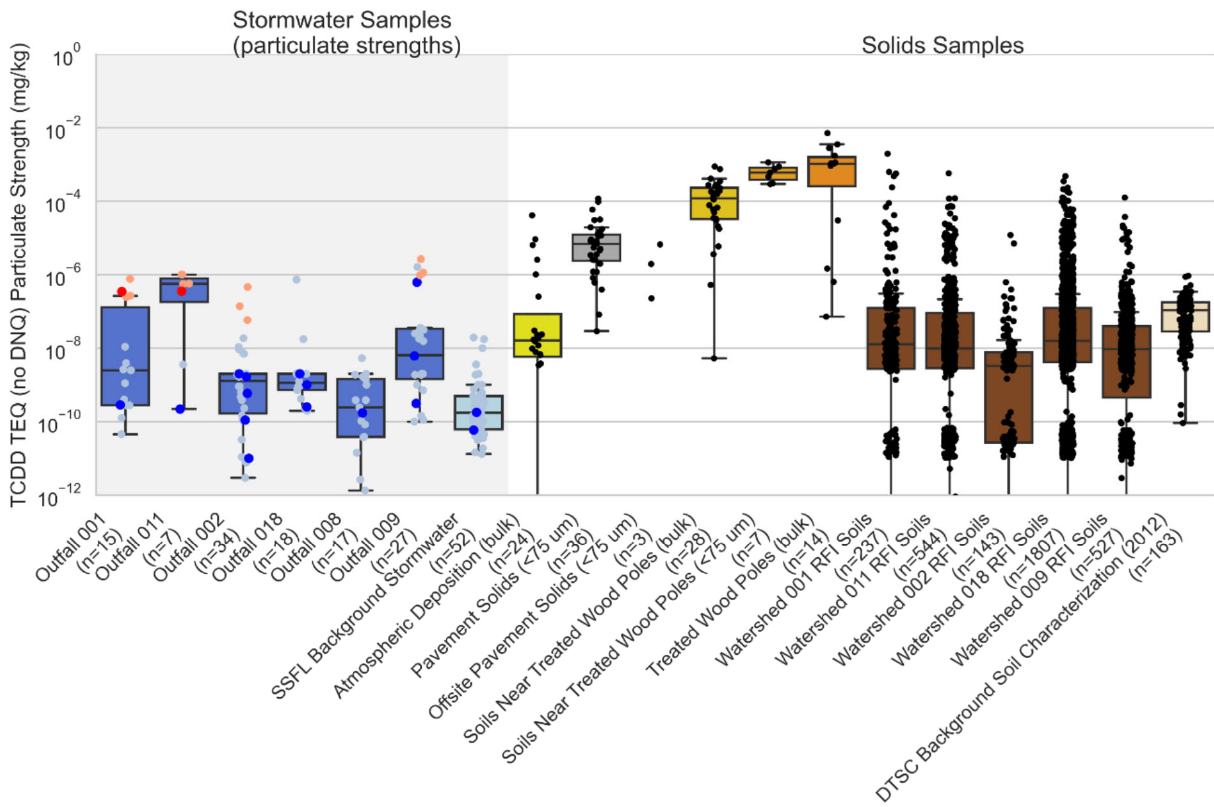


Figure 15. Particulate strengths of stormwater and potential sources of iron and TCDD TEQ (no DNQ) (source: 2022 SSFL Annual Report)

The analyses and evaluations indicated that the elevated iron and manganese concentrations were likely due to natural soils present throughout SSFL, while elevated TCDD TEQ (no DNQ) results were likely affected by contributions from localized sources. TCDD TEQ (no DNQ) exceedances were likely primarily from natural background soils with smaller but more concentrated contributions from impacted soils (RFI Soils), treated wood poles and adjacent soils, and pavement solids. In contrast, the iron example shows very similar particulate strength values for all of the sample locations. These results lead to the focus of stormwater controls (or removal) of paved areas and the treated wood poles on the site. The removal of contaminated soil will occur with the future guidance and approval of the DTSC after their studies and analyses are completed.

Description of Distributed Stormwater Controls

Distributed stormwater controls have been implemented mainly in the Outfall 008 and 009 watersheds to treat stormwater prior to discharge. Extensive erosion and sediment controls, revegetation, stabilization of repaved roads, and other soil stabilization activities have been implemented in all areas of the site, as needed based on frequent inspections. Impervious surfaces such as buildings and parking lots have also been removed and disconnected from the drainage systems by reintroducing vegetation and open space, effectively restoring many areas of the site to natural conditions.

Major structural distributed stormwater controls are described in the *ISRA Performance Monitoring and BMP Monitoring for the Outfalls 008 and 009 Watersheds, 2014/2015 Rainy Season* (“2015 Annual Report for Outfalls 008 and 009”) (MWH *et al.*, 2015), the 2015 BMP Plan (Haley & Aldrich, 2015), and later Annual Reports. Major structural distributed controls in the Outfall 008 and 009 watersheds include the following, listed by implementation date, which were located based on the subarea monitoring to identify critical source areas as previously described:

- 2009: Outfall 009 Culvert Modifications (CMs)
- 2010: Outfall 008 ISRA Excavations
- 2011: Outfall 009 Helipad Berms and Pumps to divert flows to the Silvernale Advanced Stormwater System at Outfall 018
- 2012: Outfall 009 B-1 Sedimentation Basin and Media Filter
- 2012: Outfall 009 Northern Drainage Restoration Measures
- 2012: Outfall 009 CM-9 Additional Improvements
- 2013: Outfall 009 Lower Parking Lot Sedimentation Basin and Biofilter
- 2013: Outfall 009 ISRA Excavations
- 2013: Outfall 009 ELV Treatment BMP
- 2013: Outfall 009 LOX Sandbag Berms and Slope Drains
- 2015: Outfall 009 B1436 Detention Bioswales
- 2017: Outfall 009 Wattles added around Poles along Roads
- 2017: Outfall 009 Upper Parking Lot Media Filter
- 2017: Outfall 009 Roadway Diversion to CM-3
- 2017: Outfall 009 Administration Area Inlet Filters
- 2017: Outfall 009 Enhanced Erosion Controls in the Former Shooting Range Area
- 2017: Outfall 009 Roadway Diversion to CM-1
- 2018: Outfall 009 CM-1 Reconstruction
- 2019: Outfall 009 Mulch Sack Curb Extension in Lower Parking Lot
- 2020: Outfall 009 ELV and Biofilter Cistern Generators Added
- 2020: Outfall 009 CM-3 Check Dams Added and Media Filter Reconstruction
- 2021: Outfall 009 ELV Treatment System Media Filter Underdrain Layer Reconstruction

The following briefly describes several of these distributed stormwater control categories.

Culvert Modifications

“Culvert modifications” (CMs) were installed early in the process in 2009 and 2010 as these could be installed quickly. The CMs are retrofits of the existing culverts and include headwalls with weir boards that span the entrance to each culvert that divert stormwater through treatment media (mixture of GAC, zeolite, and sand). Twelve culvert modification systems have been installed at SSFL.

Figure 16. Culvert modifications installed in 2009.

B1 Media Filter and Detention Basin

Upstream of an existing culvert, a media filter with sediment forebays was installed in 2012 to capture stormwater from the adjacent hillside and roadway. The media filter consists of a 10 cm (4 in) layer of gravel on the surface, underlaid by a 45 cm (18 in) layer of filter media (sand, GAC, zeolite), which are on top of a 10 cm (4 in) perforated pipe surrounded by gravel. The underdrain conveys the treated stormwater to a riser overflow structure where it is discharged to the Northern Drainage. A detention basin was also installed upstream to provide flow equalization along with additional settling and pretreatment of hillside flows before the media bed.

Figure 17. B-1 Sedimentation basin and media filter installed in 2012.

Lower Lot Sediment Pond and Biofilter

This system was constructed in 2013 and consists of a collection trench drain that conveys stormwater from the lower paved lot to an 85 m^3 (3,000 ft^3) cistern, where it is then pumped to a 650 m^3 (23,000 ft^3) dry sediment basin. The sediment basin drains to a biofilter, which discharges the treated stormwater to the Northern Drainage. The sediment basin drains half the volume in 12 hours and the remaining volume in 28 hours. The biofilter provides a minimum media contact time of 2.1 hours. The biofilter consists of a 10 cm (4 in) layer topsoil/compost vegetative support layer, 45 cm (18 in) layer of treatment media (fine filter sand, GAC, zeolite), 30 cm (12in) gravel layer and a 20 cm (8 in) underdrain. A plant growth pilot study identified native plants that could grow in the treatment media and survive alternating submerged and long-duration dry conditions.

Figure 18. Lower parking lot sedimentation basin and biofilter installed in 2013.

NASA ELV Stormwater Treatment Train

The ELV (historical NASA extended launch vehicle research area) treatment train was constructed in 2013. The stormwater captured in the sump is pumped into two open top portable sediment tanks having floating tube settlers. The sediment tanks drain by gravity to an additional open top portable media filter tank, which percolates stormwater through 45 cm (18 in) of treatment media (mixture of sand, zeolite, and GAC) before discharge through an underdrain pipe.

Figure 19. ELV treatment train installed in 2013.

Detention Bioswales

Two detention bioswales were constructed in 2014 consisting of vegetated swales with subsurface storage chambers (Contech ChamberMaxx®), backfilled with 2 cm (0.8 in) stone bedding material. No specialized treatment media are used at these facilities as they were designed as flow detention controls before the lower lot biofilter system (which contains the specialized treatment media) after the initial lower lot flows are treated. Excess water that cannot be further treated by the biofilter (during periods of high flows and when the treatment system capacity if full) is directly discharged to the Northern Drainage. Each detention bioswale drains through an outlet pipe, controlled by two orifices sized to drain the system within 72 hours.

Figure 20. Detention bioswales installed in 2015.

Performance of Distributed Stormwater Controls

Water quality samples have been collected at inlets and outlets at many of the distributed stormwater controls in the Outfall 009 watershed. Pitt, et al. (2022a and 2022b) describe six to nine years of monitoring results at these controls and found no degradation in performance or unusual maintenance requirements. Average and maximum effluent concentrations for the constituents of concern (COC) are generally lower than the corresponding influent values. Overall, constituent loads are being reduced due to concentrations reductions, and because runoff volumes are also being reduced by pavement and building removals accompanied by revegetation.

Figures 21 and 22 are example summaries of influent and effluent monitoring results for dioxins and lead by stormwater treatment category. The Outfall 009 2015 permit limits are shown for reference only as it is not applicable at these internal monitoring locations. These plots allow a quick assessment of the performance of the various distributed stormwater controls used at SSFL for different constituents. For example, the dioxin performance plot shows that the detention bioswales and lower lot biofilter resulted in the largest reductions in the effluent concentrations, with most of the effluent values below the NELs, while the influent values were mostly greater than the NELs. In contrast, the administration area inlet filter also had high influent concentrations, but the effluent concentrations do not indicate any reductions (the increases shown are likely due to typical sampling and analytical variability). The lead plots show that most of the influent concentrations were relatively low and did not exceed the 2015 lead NEL. The culvert modifications are shown to have the highest influent concentrations, with moderate effluent concentration reductions. The ELV treatment train had relatively low influent lead concentrations, but the effluent concentrations were further reduced to all below the NELs. Again, the recent papers by Pitt, et al. (2022a and 2022b) describe the performance trends for all locations and constituents in detail.

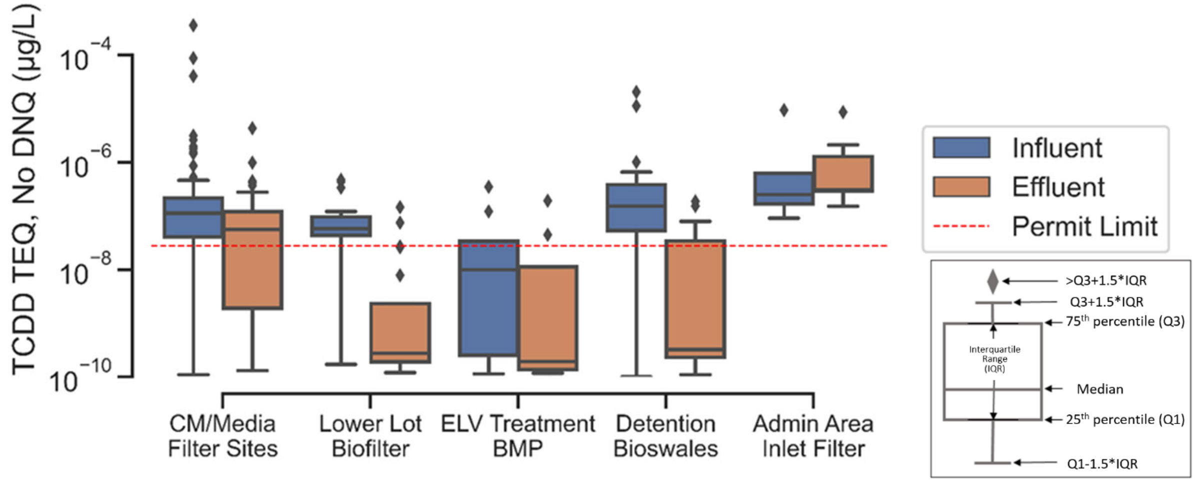


Figure 21. Stormwater control performance – Influent/effluent box plot for dioxins, 2009-2022.

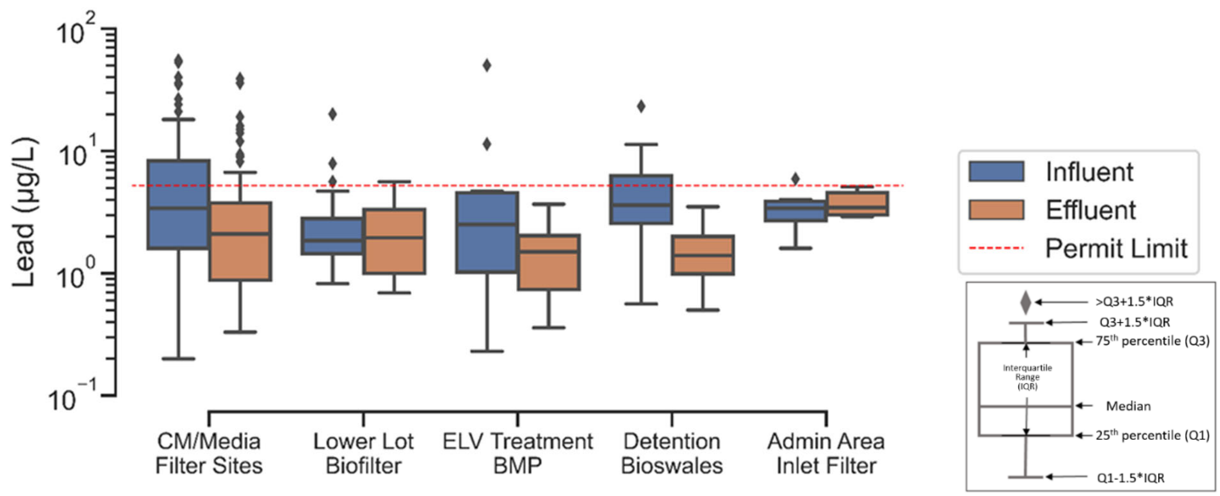


Figure 22. Stormwater control performance – Influent/effluent box plot for lead, 2009-2022.

Performance of Active Stormwater Treatment Systems (SWTSs)

The two active SWTSs are performing well, as evidenced by compliance results at Outfalls 011 and 018, as well as reductions in concentration observed between untreated SWTS influent and treated Outfall discharge samples. Untreated stormwater runoff entering the SWTSs was sampled once each at the Outfall 011 and 018 SWTSs and analyzed for the full monitoring suite required at the corresponding NPDES Outfall. Influent sampling at both SWTS is planned to continue in 2022/23 as required in the pending NPDES Permit. Most of the parameter concentrations in the untreated influent samples were below the Permit Limits applicable at the corresponding NPDES Outfall. A summary of SWTS influent results is as follows:

- Oil and grease, mercury, iron, manganese, and TCDD TEQ (no DNQ) were detected above the Permit Limit in the influent samples at one or both SWTS.
- Most radionuclides (Gross Alpha, Gross Beta, Combined Radium-226 & Radium-228, Strontium-90, Tritium, Cesium-137, Uranium, and Potassium-40) were not detected and those detected were well below Permit Limits.
- No analytes were detected above CA Primary MCLs in the untreated influent samples.

Effluent concentrations as measured in discharge at Outfall 011 and 018 indicated reductions from influent concentrations, as shown in Table 3 for a subset of analytes.

Table 3. SWTS Influent and Effluent Comparison

Analyte	Units	Daily Maximum Permit Limit	Outfall 018 SWTS Influent Sample 12/25/2021	Outfall 018 Discharge Sample 12/26/2021	Outfall 011 SWTS Influent Sample 1/10/2022	Outfall 011 Discharge Sample 1/18/2022
Oil & Grease	mg/L	15	0.74 J	ND < 0.54	710	ND < 0.53
Mercury	µg/L	0.1	0.11 J	ND < 0.12	ND < 0.12	ND < 0.12
Lead	µg/L	5.2	3.2	ND < 0.5	0.87	ND < 0.5
Iron	mg/L	0.3	2.2	ND < 0.05	1.2	0.092
Manganese	µg/L	50	77	15	19 J	25
Perchlorate	µg/L	6.0	ND < 9.1	ND < 0.91	3.9	ND < 0.95
Trichloroethene (TCE)	µg/L	5	ND < 0.17	ND < 0.17	ND < 0.17	ND < 0.17
Gross Alpha	pCi/L	15	4.46+/-2.73	2.1+/-1.82	1.92+/-1.27	0.55+/-1.39
Gross Beta	pCi/L	50	4.17+/-1.75	4.07+/-1.12	3.68+/-0.904	2.81+/-1.01
TCDD TEQ (no DNQ)	µg/L	2.8E-08	6.1E-08	ND	1.3E-08	ND

Note: J indicates the analyte concentration was detected but not quantified due to being between the method detection limit and reporting limit levels. ND indicates the analyte was not detected above the method detection limit.

Regulated Outfall Monitoring Programs

Stormwater discharges from SSFL are currently regulated by an individual discharge permit from the Los Angeles Regional Water Quality Control Board (LARWQCB) under the *National Pollutant Discharge Elimination System (NPDES) Permit No. CA0001309 for the Boeing Company, SSFL, Canoga Park, CA,* Order No. R4-2015-0033 (“2015 Permit”) (LARWQCB 2015). This permit requires composite sampling at the 12 surface water outfalls during every storm that produces runoff. Table 4 lists the numeric effluent limits (NELs) for each outfall, while Table 5 lists some of the permit criteria listed for protection of human health and aquatic life, or as listed in the regional Basin Plan. Table 6 lists the number of concentration observations recorded as required by this permit. About 43,000 concentration values were recorded over the 25 years at the 12 outfalls, or an average of about 150 observations per outfall per year. Table 6 also shows the number of events that were associated with these observations. Besides the constituents having NELs, many others are also routinely monitored as required by the discharge permit, including more than 250 constituents that are analyzed at every outfall at least once annually.

Table 4. Numeric Effluent Limits (NELs) in 2015 SSFL NPDES Discharge Permit (all Permit Limits except for Outfalls 001 and 002 that are Benchmarks) (LARWQCB 2015)

analyte	units	OF03, 05, 07, 10	OF04, 06	OF08	OF09	OF11, 01, 18, 02
pH (field) (upper limit)	SU	n/a	8.5	8.5	8.5	8.5
Temperature	°F	n/a	86	86	86	86
Total Dissolved Solids	mg/L	850	850	950	850	950
Chloride	mg/L	150	150	150	150	150
Biochemical Oxygen Demand (BOD)	mg/L	n/a	n/a	n/a	n/a	30
Total Residual Chlorine	mg/L	n/a	n/a	n/a	n/a	0.1
Oil & Grease	mg/L	15	15	15	15	15
Sulfate	mg/L	250	250	300	250	300
Fluoride	mg/L	n/a	n/a	1.6	1.6	1.6
Surfactants (MBAS)	mg/L	n/a	n/a	n/a	n/a	0.5
Chronic Toxicity, Selenastrum	%	n/a	50	50	50	50
Ammonia as Nitrogen (N)	mg/L	n/a	n/a	10.1	n/a	10.1
Nitrate + Nitrite as Nitrogen (N)	mg/L	10	10	8	10	8
Nitrate as Nitrogen (N)	mg/L	n/a	n/a	8	n/a	8
Nitrite as Nitrogen (N)	mg/L	n/a	n/a	1	n/a	1
Combined Radium-226 and Radium-228	pCi/L	5	5	5	5	5
Gross Alpha	pCi/L	15	15	15	15	15
Gross Beta	pCi/L	50	50	50	50	50
Strontium-90	pCi/L	8	8	8	8	8
Tritium	pCi/L	20000	20000	20000	20000	20000
Antimony	µg/L	6	6	6	6	n/a
Arsenic	µg/L	n/a	n/a	n/a	n/a	10
Barium	mg/L	n/a	n/a	1	1	1
Beryllium	µg/L	n/a	n/a	n/a	n/a	4
Cadmium	µg/L	4	4	3.1	4	3.1
Chromium VI	µg/L	n/a	n/a	n/a	n/a	16
Copper	µg/L	13	13	14	13	14
Iron	mg/L	n/a	n/a	n/a	n/a	0.3

Cyanide	µg/L	9.5	9.5	9.5	9.5	8.5
Lead	µg/L	5.2	5.2	5.2	5.2	5.2
Manganese	µg/L	n/a	n/a	n/a	n/a	50
Mercury	µg/L	0.13	0.13	0.13	0.13	0.1
Nickel	µg/L	86	86	86	86	n/a
Selenium	µg/L	n/a	n/a	5	n/a	8.2
Thallium	µg/L	2	2	2	2	n/a
Zinc	µg/L	120	120	120	120	119
1,1-Dichloroethene	µg/L	n/a	n/a	n/a	n/a	6
1,2-Dichloroethane	µg/L	n/a	n/a	n/a	n/a	0.5
2,4-Dinitrotoluene	µg/L	n/a	n/a	n/a	n/a	18
2,4,6-Trichlorophenol	µg/L	n/a	n/a	n/a	n/a	13
alpha-BHC	µg/L	n/a	n/a	n/a	n/a	0.03
bis (2-ethylhexyl) Phthalate	µg/L	n/a	n/a	n/a	n/a	4
n-Nitrosodimethylamine	µg/L	n/a	n/a	n/a	n/a	16
Pentachlorophenol	µg/L	n/a	n/a	n/a	n/a	16.5
Perchlorate	µg/L	6	6	6	6	6
TCDD TEQ No DNQ	µg/L	$2.8X10^{-08}$	$2.8X10^{-08}$	$2.8X10^{-08}$	$2.8X10^{-08}$	$2.8X10^{-08}$
Trichloroethene	µg/L	n/a	n/a	n/a	n/a	5

Note that some limits are not simple comparisons against the concentration observations. As example:

1. If hexavalent chromium is analyzed along with total chromium, the limit is only applied to hexavalent chromium and not to total chromium.
2. For gross alpha, the limit is compared against the calendar year average. These results may also trigger speciation analyses that are performed for individual samples to identify anthropogenic vs. natural sources of the alpha emitters.
3. Chronic toxicity is reported as pass/fail and percent effect. An exceedance requires both a “fail” and % effect greater than 50%.

Regulatory exceedances are only applied to the permit limits and not to the benchmarks at Outfalls 001 and 002. High benchmark values are also reported, including discussions on possible sources and responses (as with the permit limits), but fines are not imposed.

Table 5. Example Criteria Rational Provided in 2015 SSFL NPDES Discharge Permit (LARWQCB 2015)

analyte	units	Freshwater aquatic life (most metal criteria are calculated as a function of hardness)	Human Health	Basin Plan
Antimony	µg/L	none	14	6
Arsenic	µg/L	150	none	10
Beryllium	µg/L	none	narrative	4
Cadmium	µg/L	2.5	narrative	5
Copper	µg/L	9.3	1300	

Lead	µg/L	3.2	narrative	
Mercury	µg/L	reserved	0.05	2
Nickel	µg/L	52	610	100
Selenium	µg/L	5	narrative	50
Thallium	µg/L	none	1.7	2
Zinc	µg/L	120	none	
TCDD TEQ No DNQ	µg/L		$1.30X10^{-08}$	0.00003
Trichloroethene	µg/L	none	2.7	5

Table 6. Numbers of Concentration Observations and Events Recorded per SSFL Outfall Location since the 1998 Discharge Permit

Outfall	Number of total observations	Approximate number of total events
001	5,083	107
002	9,056	222
003	2,457	67
004	2,883	85
005	2,693	88
006	3,426	98
007	1,538	53
008	2,902	83
009	4,299	137
010	1,542	43
011	3,272	46
018	3,755	80
total	42,906	222

Trends of High Outfall Stormwater Concentrations with Time and Site Activities

As described in the preceding sections of this paper, many site activities and stormwater treatment efforts have occurred on SSFL over many years to reduce the stormwater discharge of constituents of concern, while waiting final site cleanup direction from the DTSC. This section describes how the stormwater discharge quality at the regulated outfalls responded to these efforts. Table 7 illustrates the timeline of interim contaminated material removal, stormwater controls, and wildfires affecting the outfall drainage areas, while Figure 23 shows the changes in the number of outfall permit limit and benchmark exceedances since 1998.

Table 7. Site Contaminated Material Removal, Advanced Stormwater Treatment Systems, Distributed Stormwater Controls, and Site Wildfires Timeline for SSFL Outfall Drainage Areas

	Northern Outfalls								Below OF011		Below OF018	
Site Activity	OF003	OF004	OF005	OF006	OF007	OF010	OF008	OF009	OF001	OF011	OF002	OF018
Sodium Disposal Facility (burn pit) soil removal			2000	2000	2000							
Interim soil removal and perchlorate treatment							2003			2003		
Topanga fire	2005	2005	2005	2005	2005	2005	2005	2005	2005	2005	2005	2005
Northern Drainage debris removal								2007				
Distributed stormwater controls							2009	2009				
Interim/source removal actions (ISRA) at OF008							2010					
Advanced stormwater treatment system at OF018 in operation	2011	2011	2011	2011	2011	2011		2011*				2011
Interim/source removal actions (ISRA) at OF009								2013				
NASA demolition and contaminated material removal - structures removal								2015	2015			2015
Boeing building demolition and asphalt removal	2015	2015	2015	2015	2015	2015						2015
NASA demolition and contaminated material removal - structures removal								2017				2017
Woolsey fire							2018		2018	2018	2018	2018
Treated wood pole barriers								2019	2020		2020	2019
NASA demolition and contaminated material removal - structures removal												2019
NASA demolition and contaminated material removal - structures removal								2019	2021			2021
Advanced stormwater treatment system at OF011 in operation**										2021		
Utility pole removal								2022		2022		2022

*a portion of the paved helipad area above Outfall 009 was diverted to the Silvernale advanced stormwater treatment system, starting in 2011.

**the advanced stormwater treatment system at Outfall 011 was constructed in 2011 but was not put in operation until 2021 due to low flows.

Yellow high-lighted: contaminated material removal

Orange high-lighted: stormwater treatment systems

Red high-lighted: wildfires on site

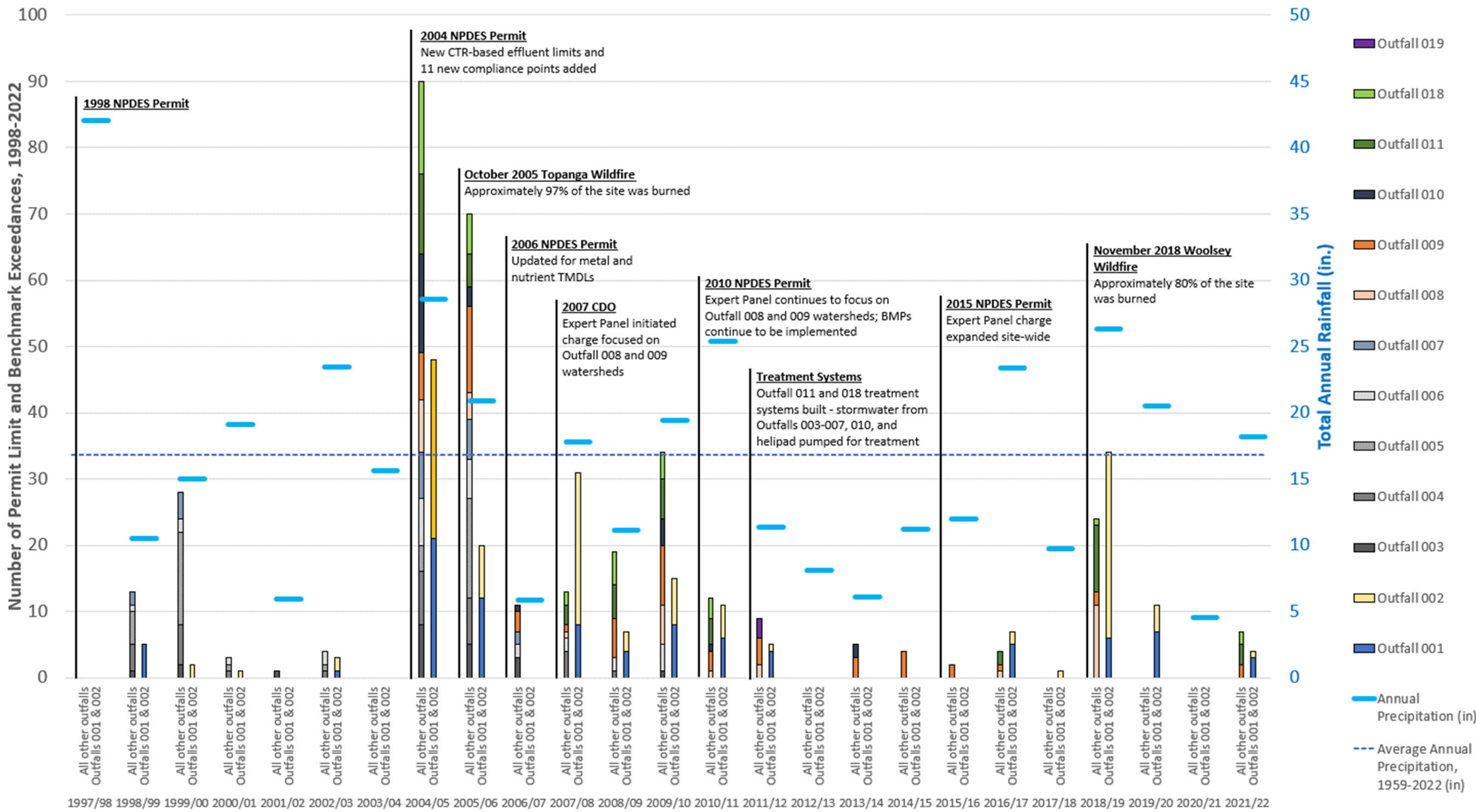


Figure 23. Summary of SSFL Permits, Surface Water Expert Panel Involvement, and Water Quality Compared to 2015 Permit Limits, 1998-2022

(Note: Benchmarks apply at Outfalls 001 and 002; effluent limits apply at all other outfalls)

Notable milestones on the Figure 23 time series plot includes:

- **1998 NPDES Permit:** NPDES Permit No. CA0001309 was issued to regulate wastewater and stormwater discharged from SSFL.
- **2004 NPDES Permit:** The 2004 Permit included new California Toxics Rule (CTR)-based effluent limits and added 11 new compliance monitoring locations.
- **2005 Topanga wildfire**: Approximately 97% of SSFL burned.
- **2006 NPDES Permit:** The 2004 Permit was revised to include the waste load allocations (WLAs) specified by applicable TMDLs of downstream waterbodies.
- **2007 Cease and Desist Order (CDO):** In the CDO, the RWQCB required the "assembly of a panel to review site conditions, modeled flow, contaminants of concern, and evaluate the BMPs capable of providing treatment to meet the final effluent limits." The CDO also required stormwater control planning, performance evaluation, and reporting requirements.
- **2010 NPDES Permit:** No major changes to the Permit. The Expert Panel continued to make data-informed recommendations for stormwater controls in the Outfall 008 and 009 Watersheds, which were then implemented at the Site.
- In **2011**, following the construction of the Outfall 018 advanced stormwater treatment system, stormwater from Outfalls 003 through 007 and Outfall 010 was retained in storage tanks and then transferred to Silvernale Pond before being treated by the advanced stormwater treatment system. Paved helipad areas at Outfall 009 are also diverted to the Silvernale advanced treatment system.
- **2015 NPDES Permit:** Permit expanded the Expert Panel's charge to all regulated SSFL Outfalls. In response, the Panel continues to review Permit Limits and Benchmark exceedances at all Outfalls, making data-driven stormwater control recommendations on a site-wide basis.
- **2018 Woolsey wildfire:** Approximately 80% of SSFL was impacted by the wildfire, and the site received above-average rainfall in 2018/19. Because of the post-fire hydrophobicity of the soil and loss of vegetative cover, rain events following the fire produced significantly greater runoff volumes as well as an increase in the number of permit limit and benchmark exceedances compared to rain events of similar size during non-fire years. Stormwater runoff volumes and water quality across the SSFL site returned to typically observed conditions the following year.
- **2022/2023 record rains:** The 2022/23 rain year had a total of 1,120 mm (44.4 inches) of rainfall, a record compared to the 57 year rain monitoring period. The long-term average rainfall at SSFL is 434 mm (17.1 inches). Fourteen exceedances were recorded during this period (12 were for aesthetic-based permit limits and benchmarks for Fe and Mn, while 2 were for TCDD TEQ no DNQ).

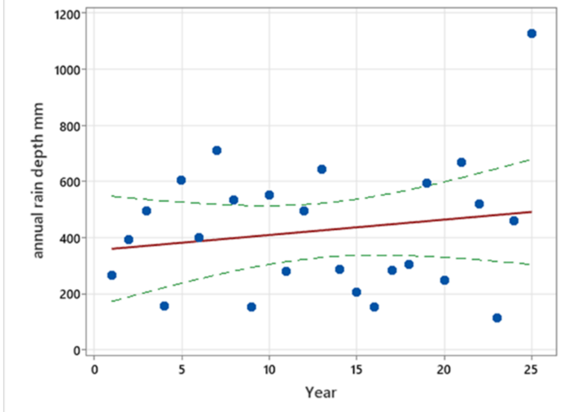
Outfall Trends Associated with Rains

The annual rain totals during the 25-year period shown on Figure 23 ranged from about 114 to 1,130 mm (4.49 to 44.5 inches). The following analyses focus on the comparison of numbers of concentration observations greater than the 2015 NELs (as a normalizing method) with site conditions (removal of contaminated materials) and the use of stormwater management practices. Most of these site changes have occurred since the 2010/11 rain year. Therefore, basic analyses compare the observed stormwater quality from 1998/99 to 2009/10 as the early period before site changes occurred vs. from 2010/11 to 2022/23 as the later period after the site changes occurred.

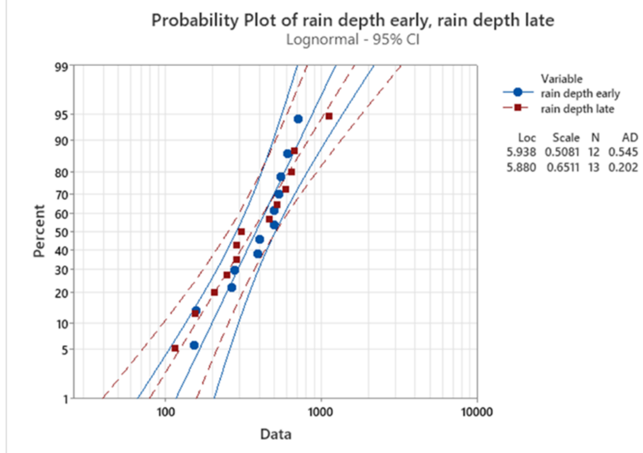
It is possible that any changes in site rainfall conditions during these two periods may also affect stormwater runoff quality. Therefore, the rainfall during these two periods is described and compared in Table 8 and Figure 24. These data indicate that the annual rainfall amounts were very similar during these two periods, as shown by no apparent or statistically significant ($p = 0.41$) changes in the regression slope term of rainfall amount vs. time since the monitoring started, and by overlapping probability plots of the rainfall amounts in the two periods. Nonparametric Mann-Whitney statistical comparison tests also found no significant differences ($p = 0.87$) in the rainfall amounts for these two periods.

Table 8. Annual Rainfall Characteristics at SSFL before and after Interim Contaminated Material Removal and Stormwater Management

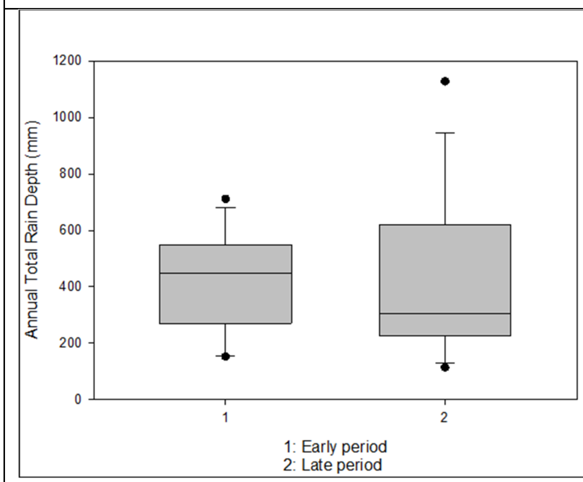
Annual rainfall depths (mm and inches)	Early rain period (1998/99 to 2009/10)	Late rain period (2010/11 to 2022/23)
minimum	152 (5.98)	114 (4.49)
maximum	711 (28.0)	1128 (44.41)
median	448 (17.6)	305 (12.0)
average	420 (16.5)	432 (17.0)
standard deviation	177 (7.0)	280 (11.0)
coefficient of variation (COV)	0.42	0.65
Rain depth during years of Topanga (early period) and Woolsey (late period) fires	533 (21.0)	668 (26.3)



Time series plot of annual rain



Probability plots of annual rain for early vs. late monitoring periods



Box and whisker plots of annual rain for early and late monitoring periods

Annual rainfall trends

Slope coefficient p = 0.41

Comparison of early vs. late monitoring period annual rainfall

Mann-Whitney Rank Sum test p = 0.87

Figure 24. Time series, probability, and box and whisker plots of annual rainfall amounts before and after interim contaminated material removal and stormwater management at SSFL.

Figure 25 shows scatterplots of the numbers of concentration observations that were greater than the 2015 NELs per year vs. annual rainfall, excluding the two years having large fires. Both plots show significant relationships with increasing observations greater than the 2015 NEL values with increasing annual rain amounts (p of the regression slopes were both <0.02, with insignificant intercept terms). However, the early period before the interim contaminated material removal and stormwater management at the site had an average slope coefficient more than eight times greater than the slope coefficient during the later period (early period slope term: 0.14 relative slope with a 95% confidence interval of 0.03 to 0.26, and later period slope term: 0.016 relative slope with a 95% confidence interval of 0.007 to 0.025).

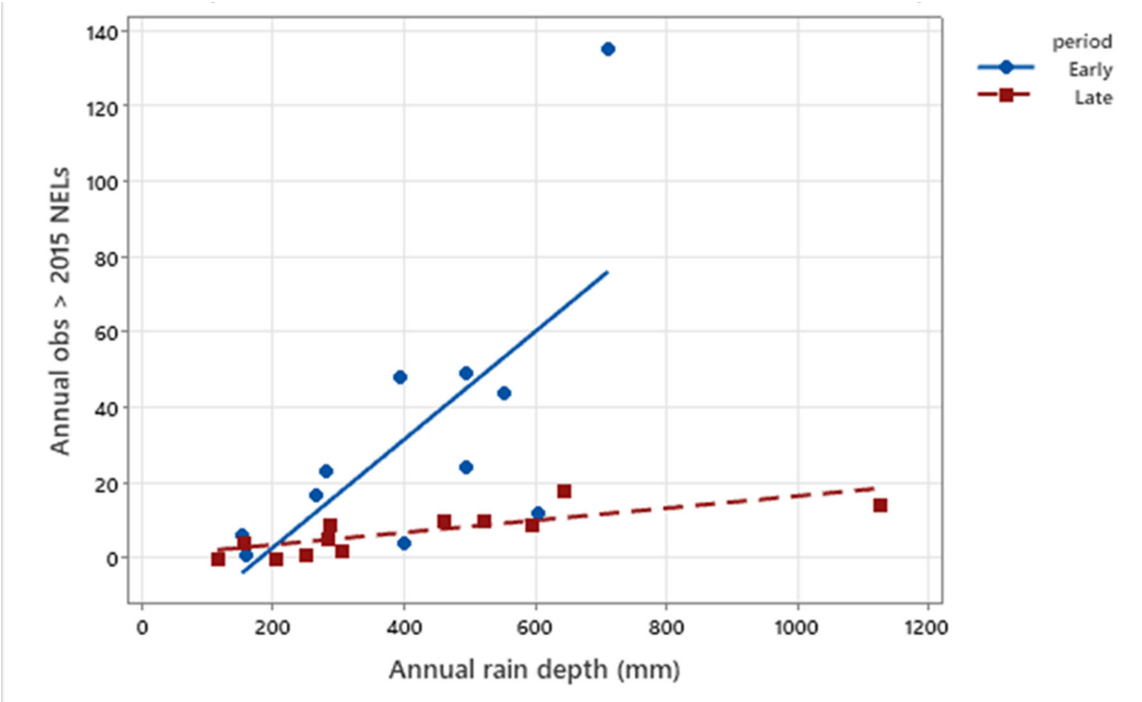


Figure 25. Annual sum of observations greater than the 2015 NELs compared to annual rain depth (mm) before and after interim contaminated material removal and stormwater management at SSFL, excluding two years with fires.

The rain year including the Topanga fire in 2005 had 533 mm (21.0 in) of rainfall and resulted in 92 concentration observations greater than the 2015 NELs, while the previous rain year had the largest number of observations greater than the 2015 NELs during the early monitoring period (135). The rain year with the Woolsey fire in 2018 had 668 mm (26.3 in) of rainfall with 59 concentration observations greater than the 2015 NELs which was the largest number during the later monitoring period. Therefore, the two fires resulted in high counts of high concentrations with similar rainfall totals, but the early Topanga fire larger number of high concentrations was exceeded by another year. In contrast, the rain year with the Woolsey fire was associated with unusually large counts of high concentrations compared to other years in the later monitoring period (more than three times greater than the other rain years in the later rain period) but was substantially less than the number of high concentrations during the earlier Topanga fire year.

Figure 25 also shows that the largest rainfall on record (1,128 mm, 44.4 in, during the 2022/23 rain year) did not have an unusual number of high concentration observations compared to the relatively flat trend line plotted for the late monitoring period. Figure 26 shows the number of qualifying rain events per year during the later rain period, as defined in the 2015 permit for the events requiring compliance monitoring. There is no obvious (or statistically relevant) trend in this plot. During this period, there were 4 to 14 (average of 9.5) qualifying rain events per year associated with 114 to 1,130 mm (4.5 to 44.4 in) of rain per year. The record 2022/23 rain year did not have an unusual number of qualifying rain events (10 events compared to the average of 9.5), but most of the individual rain events occurring during that year were unusually large.

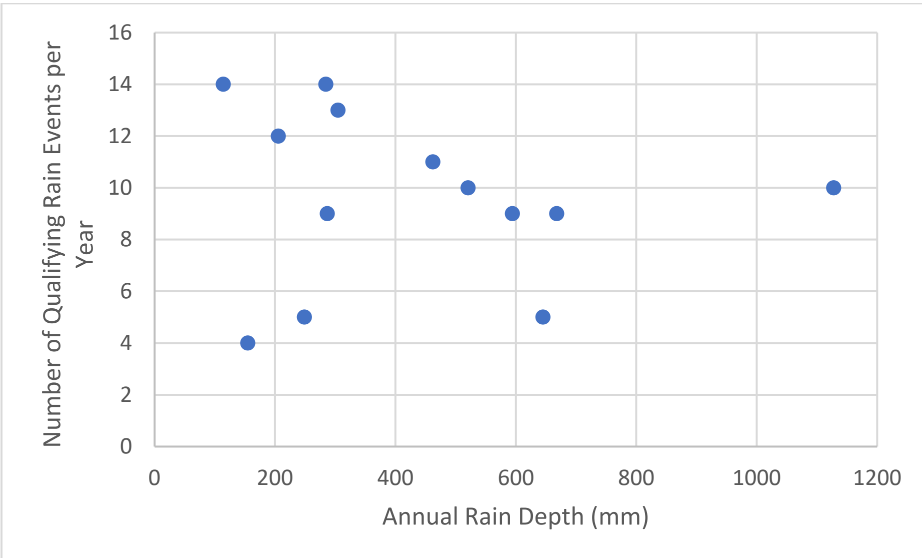


Figure 26. Number of qualifying rain events vs. total annual rain depth (later rain period).

Similar evaluations were conducted comparing relationships of high stormwater concentrations with recurrent interval storms. Generally, the highest SSFL stormwater concentrations were associated with intermediate sized events having recurrent intervals of about 1 or 2 years, with more frequent and less frequent events having lower concentrations. The SSFL site is routinely inspected and any locations with potential high erosion losses are quickly stabilized, which was especially important during the very large rains occurring during the 2022/23 rain year.

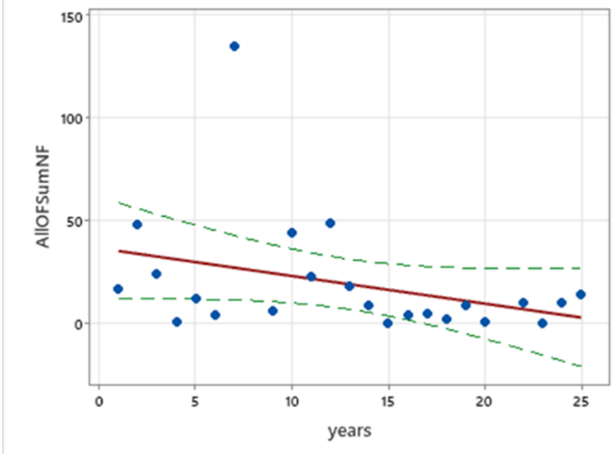
Therefore, it is apparent that the number of concentration observations greater than the 2015 NELs were significantly greater during the early period before interim contaminated material removal and stormwater management at SSFL compared to the later period. These differences were not associated with differences in the annual rain depths or the number of qualifying rain events for monitoring. The two fires on SSFL both resulted in large numbers of concentration observations greater than the 2015 NELs. Another rain year during the early period had more concentration observations (135 high observations) than the 2015 NELs compared to the rain year after the Topanga fire result (92 high observations). However, the rain year following the later 2018 Woolsey fire resulted in the largest number of concentration observations greater than the 2015 NELs during the later period (59 high observations). In addition, the record 2022/23 rain year did not result in an unusual number of high concentrations (14) when compared to the trend of high observations vs. rainfall for the later monitoring period.

Topanga and Woolsey Fires

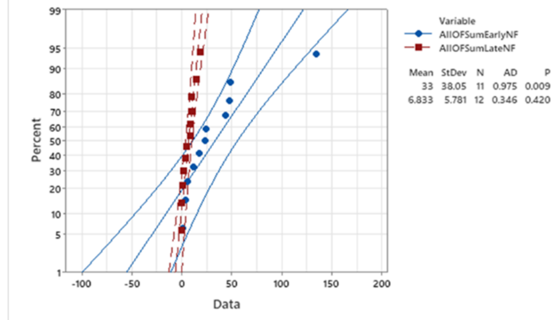
The Topanga fire started on September 28 and was fully contained on October 6, 2005. It burned 9,783 ha (24,175 acres), including almost all of SSFL. The Woolsey fire started on November 8 and was fully contained on November 21, 2018, after burning 39,234 ha (96,949 acres). About 80 percent of SSFL was directly affected by the Woolsey fire (watersheds above Outfalls 001, 002, 008, 011, and 018, plus a small portion of the watershed above Outfall 009). The northern outfall watersheds (above Outfalls 003 through 007 and 010) were not directly affected by the fire. Increased occurrences of high concentrations above the 2015 NELs in the stormwater were observed for the remainder of the rain year having these fall season fires, with typical stormwater conditions observed during the following rain year. During the early monitoring period, the Topanga fire caused the largest increases in high concentrations for copper, strontium-90, lead, and TCDD (TEQ no DNQ). The watersheds were all about evenly affected after the Topanga fire. During the late monitoring period, the Woolsey fire caused the largest increases in high concentrations for mercury, gross alpha, copper, and lead. As noted, not all of the SSFL watersheds were directly affected by the Woolsey fire. The watersheds above Outfalls 008 and 002 had the largest increases in high stormwater concentrations above the 2015 NELs after the Woolsey fire, with fewer increases in the Outfall 011 and 001 watershed areas, and no reported increases in the Outfall 018 watershed stormwater associated with the Woolsey fire.

Trends Associated with All Outfalls Combined

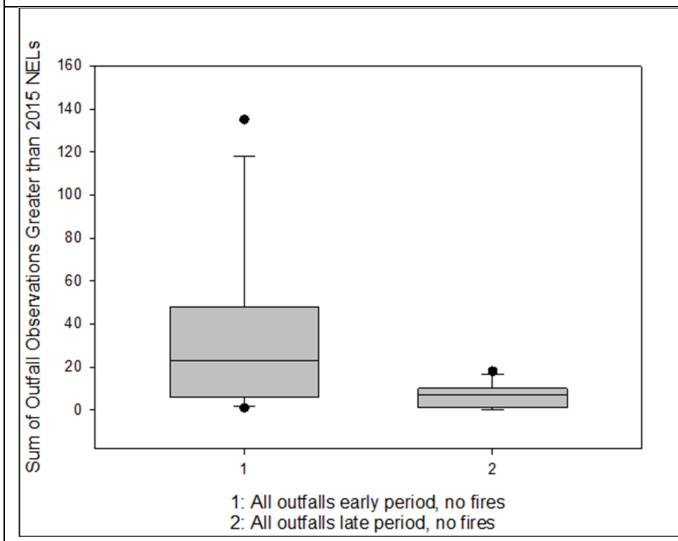
The following discussion summarizes the trends of the high concentration observations for the different groups of outfalls. Figure 27 presents trends with time and other comparisons of concentration observations greater than the 2015 NELs for all site outfall data combined, excluding the two years with the Topanga and Woolsey fires. The regression slope term is not significant ($p = 0.11$) but shows apparent decreasing observations greater than the 2015 NELs with time, although with a large amount of data scatter. The probability plots show overlapping confidence intervals for years having small numbers of observations greater than the 2015 NELs but are widely separated for the years with larger numbers of high concentration observations. The box and whisker plots show large differences in the numbers of observations greater than the 2015 NELs for the two monitoring periods, with a corresponding significant Mann-Whitney Rank Sum test p value for years without the fires ($p=0.014$), and also when the fire years are considered ($p=0.022$). An additional check calculated the paired t-tests of early vs. late monitoring periods of each outfall, which also resulted in a significant p value (<0.001). The slope and rank sum comparison p values are shown for the years without the fires and also for the years including the fires. Overall, decreasing observations greater than the 2015 NELs with time indicate improving conditions with the stormwater management and interim contaminated material removal during the later monitoring period.



Time series plot of numbers of concentrations per year greater than 2015 NELs for all outfalls combined



Probability plots of numbers of concentrations per year greater than 2015 NELs for all outfalls combined for early vs. late monitoring periods



Box and whisker plots of annual observations greater than the 2015 NELs for all outfalls combined

All Outfalls Combined:

Trends slope coefficient p = 0.11

Trends slope coefficient p = 0.16 (including years with fires)

Comparison of early vs. late monitoring period annual observations greater than 2015 NELs

Mann-Whitney Rank Sum test p = 0.014

Mann-Whitney Rank Sum test p = 0.022

(including years with fires)

Figure 27. Trends of the numbers of concentration observations greater than the 2015 NELs for all outfalls combined.

The following discussions show similar plots and data for the individual outfalls. They are shown without the two years with fires to better focus on changes associated with the interim contaminated material removal and stormwater management activities, although the slope and rank sum comparison p values are shown for both with and without the fire years.

Northern Outfalls (Outfalls 003, 004, 005, 006, 007, and 010 combined)

The northern outfall drainage areas (Outfalls 003 through 007 and 010) are all small but had many administrative and energy research activities overseen by the USDOE located in their watershed areas.

Interim contaminated material and soil removal activities have occurred in these areas. The Topanga fire affected most of SSFL in 2005, including these areas, but the 2018 Woolsey fire did not directly affect these drainage areas. Since 2012, stormwater runoff from these northern areas has been transferred to the Silvernale Pond for treatment at an advanced stormwater treatment system prior to discharge at Outfall 018. The advanced stormwater treatment facility includes stormwater ponds that provide flow equalization and pretreatment by sedimentation followed by ActiFlo coagulation and associated filtration systems. The Silvernale treatment system was not operated during the 2018/19 rain year due to damage from the Woolsey fire. Runoff quantities greater than the capacity of the storage and transfer systems at the northern outfalls are discharged at Outfalls 003 through 007 and at Outfall 010 which have media bed filters. Only infrequent discharges occur at these northern outfalls after the diversion facilities were installed in 2012.

Table 9 shows the 2015 numeric effluent limits that were used to normalize the counts of high constituent observations with time, and the threshold type (permit limit or benchmark). The ratios shown are the observed concentrations compared to the 2015 numeric effluent limit (NEL) threshold, although many of the permit limits have changed with time. These 2015 limits are used to examine the concentration trends of these potentially problematic constituents. The maximum observed ratios (observed concentration compared to the 2015 NEL threshold limits) are shown along with the total count of ratios greater than 1.0, along with counts of high ratios before vs. during and after the 2010/11 rain year.

Constituents with concentrations that were never observed to be greater than the 2015 NELs are not listed on these tables. Mercury, lead, copper, and dioxin (measured as TCDD TEQ No DNQ) had the largest number of high ratios at these northern outfalls, almost all occurring in the early data set.

The numbers of observed concentrations that were greater than the 2015 permit limits are seen to significantly decrease with time, as seen on the time series, probability, and box and whisker plots on Figure 28. The probability plots compare early with later rain period total numbers of these high observations and are also seen to be very distinct, with the later period rain years having close to zero observations greater than the 2015 NELs. The significance of the slope term when these numbers of observations are regressed with time are all significant (all outfalls having P=0.038 without fire years and p=0.027 when the fire years are considered). In addition, the nonparametric Mann Whitney Rank Sum test compared the concentration observation counts greater than the 2015 NELs for the period before 2011 compared to later data also indicated significant differences (P=0.001) with and without considering the years with the fires.

Table 9. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Northern Outfalls

	Total Dissolved Solids	**Chloride**	**Nitrate + Nitrite as Nitrogen (N)**	**Oil & Grease**	**Gross Beta**	**Strontium-90**	**Antimony**	**Cadmium**
threshold maximum 2015 (NEL)	850 mg/L	150 mg/L	10 mg/L	15 mg/L	50 pCi/L	8 pCi/L	6 µg/L	4 µg/L
threshold type 2015 NEL	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit
max observed ratio OF003	1.00	<1	<1	<1	1.13	1.35	5.83	<1
count >2015 NEL	1	0	0	0	1	2	1	0
count before 2010-2011 rain year	1	0	0	0	1	2	1	0
count during Topanga fire year	1	0	0	0	0	1	1	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF004	<1	<1	<1	<1	1.25	<1	<1	<1
count >2015 NEL	0	0	0	0	1	0	0	0
count before 2010-2011 rain year	0	0	0	0	1	0	0	0
count during Topanga fire year	0	0	0	0	0	0	0	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF005	1.15	1.07	5.10	<1	<1	<1	1.33	<1
count >2015 NEL	1	1	7	0	0	0	4	0
count before 2010-2011 rain year	1	1	7	0	0	0	4	0
count during Topanga fire year	1	1	6	0	0	0	0	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 9. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Northern Outfalls (cont.)

	Total Dissolved Solids	Chloride	Nitrate + Nitrite as Nitrogen (N)	Oil & Grease	Gross Beta	Strontium-90	Antimony	Cadmium
threshold maximum 2015 (NEL)	850 mg/L	150 mg/L	10 mg/L	15 mg/L	50 pCi/L	8 pCi/L	6 µg/L	4 µg/L
threshold type 2015 NEL	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit
max observed ratio OF006	<1	1.40	1.30	2.03	1.28	<1	<1	<1
count >2015 NEL	0	2	1	1	1	0	0	0
count before 2010-2011 rain year	0	2	1	1	1	0	0	0
count during Topanga fire year	0	0	0	0	0	0	0	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF007	<1	<1	<1	<1	5.88	<1	1.83	1.00
count >2015 NEL	0	0	0	0	2	0	4	1
count before 2010-2011 rain year	0	0	0	0	2	0	4	1
count during Topanga fire year	0	0	0	0	0	0	1	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF010	<1	1.00	<1	<1	<1	<1	3.33	<1
count >2015 NEL	0	1	0	0	0	0	1	0
count before 2010-2011 rain year	0	1	0	0	0	0	1	0
count during Topanga fire year	0	0	0	0	0	0	1	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio 003 to 007 plus 010	1.15	1.40	5.10	2.03	5.88	1.35	5.83	1.00
count >2015 NEL	2	4	8	1	5	2	10	1
count before 2010-2011 rain year	2	4	8	1	5	2	10	1
count during Topanga fire year	2	1	6	0	0	1	3	0

count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* the Woolesy fire did not directly impact the northern outfall watershed areas

Table 9. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Northern Outfalls (cont.)

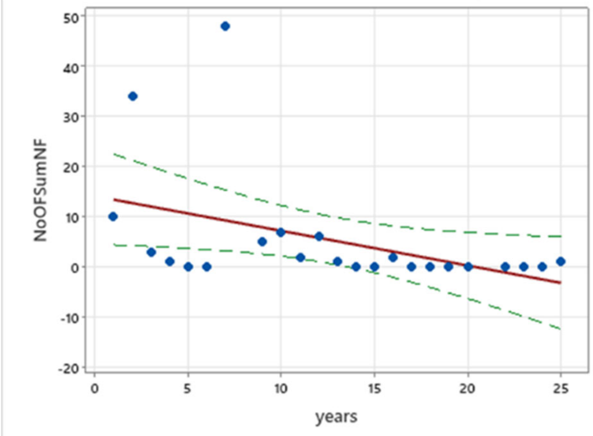
	Copper	**Cyanide**	**Lead**	**Mercury**	**Thallium**	**Zinc**	**TCDD TEQ No DNQ**	**Total**
threshold maximum 2015 (NEL)	13 µg/L	9.5 µg/L	5.2 µg/L	0.13 µg/L	2 µg/L	120 µg/L	$2.8X10^{-8}$ µg/L	
threshold type 2015 NEL	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	
max observed ratio OF003	1.31	<1	2.12	1.54	<1	<1	13.47	
count >2015 NEL	2	0	1	7	0	0	1	16
count before 2010-2011 rain year	2	0	1	6	0	0	1	15
count during Topanga fire year	1	0	1	0	0	0	0	5
count during and after 2010-2011 rain year	0	0	0	1	0	0	0	1
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF004	1.15	<1	<1	24.62	<1	<1	157.82	
count >2015 NEL	1	0	0	20	0	0	9	31
count before 2010-2011 rain year	1	0	0	20	0	0	9	31
count during Topanga fire year	0	0	0	2	0	0	5	7
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF005	2.31	<1	6.54	61.85	1.55	<1	171.43	
count >2015 NEL	3	0	3	18	1	0	4	42
count before 2010-2011 rain year	3	0	3	18	1	0	4	42
count during Topanga fire year	2	0	2	1	0	0	2	15
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 9. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Northern Outfalls (cont.)

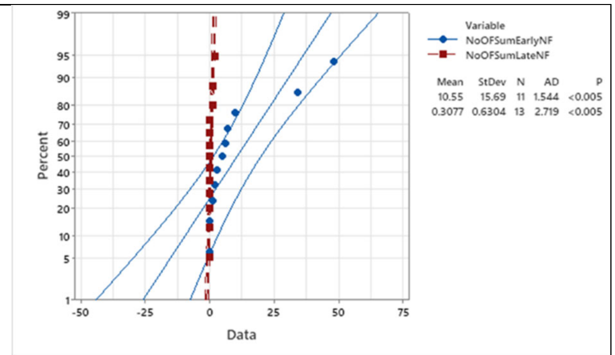
	Copper	**Cyanide**	**Lead**	**Mercury**	**Thallium**	**Zinc**	**TCDD TEQ No DNQ**	**Total**
threshold maximum 2015 (NEL)	13 µg/L	9.5 µg/L	5.2 µg/L	0.13 µg/L	2 µg/L	120 µg/L	$2.8X10^{-8}$ µg/L	
threshold type 2015 NEL	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	
max observed ratio OF006	2.62	1.01	5.58	6.85	<1	<1	2048.26	
count >2015 NEL	2	1	2	10	0	0	3	23
count before 2010-2011 rain year	2	1	2	10	0	0	3	23
count during Topanga fire year	2	0	2	2	0	0	1	7
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF007	1.92	<1	3.85	4.08	<1	<1	1.26	
count >2015 NEL	4	0	3	8	0	0	2	24
count before 2010-2011 rain year	4	0	3	8	0	0	2	24
count during Topanga fire year	2	0	2	0	0	0	1	6
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio OF010	1.62	<1	15.19	2.77	<1	1.34	9.28	
count >2015 NEL	2	0	6	5	0	1	12	28
count before 2010-2011 rain year	2	0	5	5	0	0	11	25
count during Topanga fire year	1	0	1	0	0	0	2	5
count during and after 2010-2011 rain year	0	0	1	0	0	1	1	3
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
max observed ratio 003 to 007 plus 010	2.62	1.01	15.19	61.85	1.55	1.34	2048.26	
count >2015 NEL	14	1	15	68	1	1	31	164
count before 2010-2011 rain year	14	1	14	67	1	0	30	160

count during Topanga fire year	8	0	8	5	0	0	11	45
count during and after 2010-2011 rain year	0	0	1	1	0	1	1	4
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

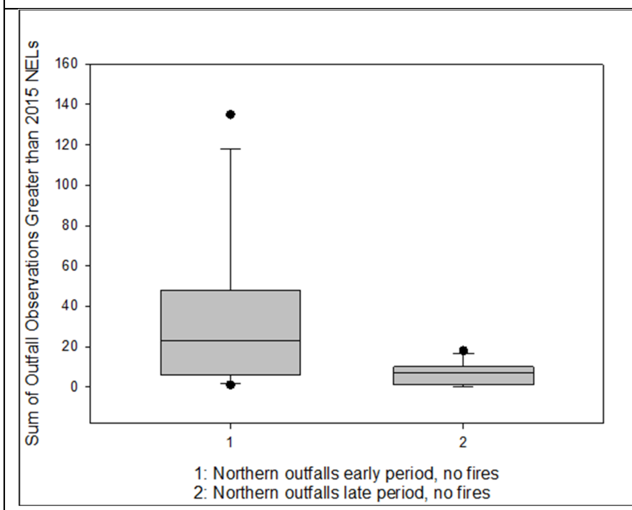
* the Woolesy fire did not directly impact the northern outfall watershed areas



Time series plot of numbers of concentrations per year greater than 2015 NELs for all Northern Outfalls combined



Probability plots of numbers of concentrations per year greater than 2015 NELs for all Northern Outfalls combined for early vs. late monitoring periods



Box and whisker plots of annual observations greater than the 2015 NELs for all Northern Outfalls combined

All Northern Outfalls Combined:

Trends slope coefficient p = 0.038
Trends slope coefficient p = 0.027 (including years with fires)

Comparison of early vs. late monitoring period annual observations greater than 2015 NELs

Mann-Whitney Rank Sum test p = 0.001
Mann-Whitney Rank Sum test p <0.001 (including years with fires)

Figure 28. Time series and probability plots for numbers of high concentrations per year at SSFL Northern Outfalls.

Outfalls 008 and 009

When the Surface Water Expert Panel began its work at the site in 2007, their efforts focused on the Outfall 008 and 009 watersheds, as per the directive of the cease-and-desist order that created the panel. Specifically, because these watersheds are steep and rugged, they did not lend themselves to the construction of new storage facilities coupled with large, advanced treatment systems like those at Outfalls 011 and 018. The panel initially evaluated the feasibility of building dams to store stormwater and found these to be infeasible due to their required size (dam heights of 12m, or 40 ft, or more would be necessary to provide adequate storage given the steep watersheds), spillway requirements, environmental impacts to construct and safety concerns with residential neighborhoods immediately downslope from SSFL. This prompted the need for widely distributed and smaller stormwater quality control practices in the Outfall 008 and 009 watersheds. These were referred to as “Engineered Natural Treatment Systems” or “ENTS” in the Cease-and-Desist Order. Working closely with Geosyntec, the panel developed conceptual designs for multiple ENTS facilities, such as for the liquid oxygen (LOX) plant area in the Outfall 009 watershed and located in and adjacent to the Northern Drainage. These original ENTS designs evolved into the ISRA cleanup program, and the distributed controls currently used in these watersheds, and the term ENTS was dropped from further use by the panel and other groups involved with stormwater management at the site.

Stormwater runoff from the Outfall 008 and 009 watersheds is therefore not captured and treated by a central stormwater treatment system (except for a portion of the paved helipad area in Area II in the Outfall 009 watershed which is pumped to the Silvernale Pond and treated by the Outfall 018 advanced treatment system). Distributed stormwater treatment and an iterative, adaptive management-based approach has therefore been used within both the Outfall 008 and 009 watersheds, as described previously.

Stormwater from Happy Valley in the Outfall 008 watershed flows via Dayton Canyon Creek to Chatsworth Creek, which flows south to join Bell Creek southwest of the intersection of Shoup Avenue and Sherman Way. Bell Creek then continues southeast toward its confluence with the Los Angeles River. The Outfall 008 watershed had industrial activity, mainly in the Happy Valley area. This area had an interim soil removal and perchlorate treatment effort in 2003. This area was also affected by the Topanga fire in 2005. Distributed controls (mainly erosion control and dirt road stabilization) and interim source removal as part of the ISRA activities occurred in this area between 2009 and 2012. The Woolsey fire also affected this watershed in 2018. Limited runoff has been discharged at Outfall 008 since the 2012 completion of ISRA activities that included interim identification, evaluation, remediation or stabilization, and restoration of areas containing soil contaminated with COCs. Installation of new erosion and sediment controls, revegetation, and unpaved road stabilization also took place in 2012.

Table 10 shows that the constituents measured at Outfall 008 that had the greatest number of concentration observations larger than the 2015 NELs were lead, copper, and mercury. The Figure 29 time series of concentration observations greater than the 2015 NELs show obvious decreases with time. The trend of the concentration counts greater than the 2015 NELs was significant during years without and including fires ($p = 0.015$ and 0.004). The probability plots of the early and later time periods show minor overlap associated with years having zero values, resulting in a significant comparison result in years without fires ($p = 0.042$), but not significant for years with fires ($p = 0.06$).

Stormwater runoff that discharges at Outfall 009 naturally flows to Arroyo Simi and then to Calleguas Creek. The Outfall 009 watershed had a variety of administrative and rocket engine test activities. The area was affected by the 2005 Topanga fire, but only a small portion of the Outfall 009 watershed area was directly affected by the 2018 Woolsey fire. The Northern Drainage, which flows through the Outfall

009 watershed, undergoes annual inspections to identify and correct any unstable areas. Debris removal, especially near the LOX and shooting range areas, occurred in 2007. Distributed stormwater controls were installed in this watershed starting in 2010/11 and proceeded for several years as critical subareas were identified. Runoff from portions of the paved helipad area were diverted to the Silvernale advanced stormwater treatment system beginning in 2012. Interim source removal actions (ISRA) to remove contaminated material was conducted in 2013, and NASA conducted demolition and contaminated material removal at test sites in 2015 through 2019. Barriers were also installed around critical treated wood utility poles in 2019, and utility poles no longer needed were removed in 2022.

Table 10 summarizes the concentration observations that were above the 2015 NELs at Outfall 009 for the period before the 2010/11 rain year and for the period during and after the 2010/11 rain year, corresponding to the period before and after interim removal of contaminated materials and stormwater management in the Outfall 009 watershed. Figure 29 shows the time series of the high concentrations and a grouped probability plot contrasting the numbers of the high concentrations for these two periods. The trend of the high observations is shown to significantly decrease during years without the fires and with the fires (regression slope $p = 0.0036$ and 0.001) with time, and the probability plots also show that the early period had significantly higher numbers of high concentrations per year compared to the later period during years without the fires and including the fires ($p = 0.023$ and 0.009 using the Mann Whitney Rank Sum test).

The most common constituents having high concentrations at Outfall 009 were dioxin, TCDD TEQ no DNQ (14 during the early period and 10 during the later period) and lead (13 during early period and 7 during later period). Other constituents included mercury (5 all during the early period), copper (3 with 2 during the early period) and seven other constituents having one or two high observations during the 25-year period.

Table 10. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Outfalls 008 and 009

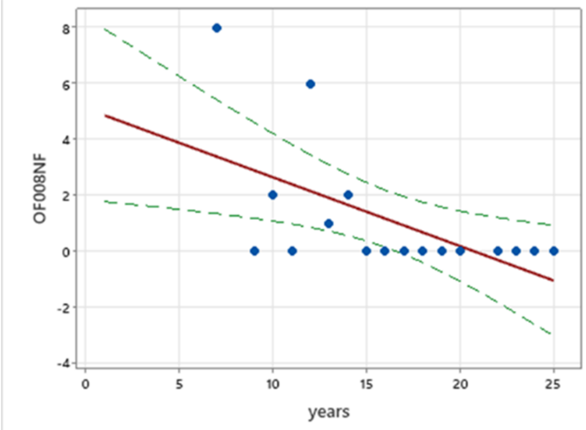
	pH (field)	**Oil & Grease**	**Nitrate + Nitrite as Nitrogen (N)**	**Nitrate as Nitrogen (N)**	**Gross Alpha**	**Cadmium**	**Copper**	**Cyanide**	**Lead**
threshold maximum 2015 (NEL)	8.5	15 mg/L	8 mg/L	8 mg/L	15 pCi/L	4 µg/L	14 µg/L	9.5 µg/L	5.2 µg/L
threshold type 2015 NEL	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit
max observed ratio OF008	<1	<1	1.08	1.08	1.72	<1	1.29	1.58	23.08
count >2015 NEL	0	0	2	2	3	0	5	1	16
count before 2010-2011 rain year	0	0	0	0	2	0	2	0	11
count during Topanga fire year	0	0	0	0	0	0	1	0	3
count during and after 2010-2011 rain year	0	0	2	2	1	0	3	1	5
count during Woolsey fire year	0	0	2	2	1	0	2	1	3
max observed ratio OF009	1.04	1.07	<1	<1	<1	2.30	3.00	<1	50.00
count >2015 NEL	1	1	0	0	0	1	3	0	20
count before 2010-2011 rain year	1	1	0	0	1	1	2	0	13
count during Topanga fire year	1	0	0	0	1	1	2	0	3
count during and after 2010-2011 rain year	0	0	0	0	0	0	1	0	7
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

* the Woolesy fire only impacted a small portion of the OF009 watershed area

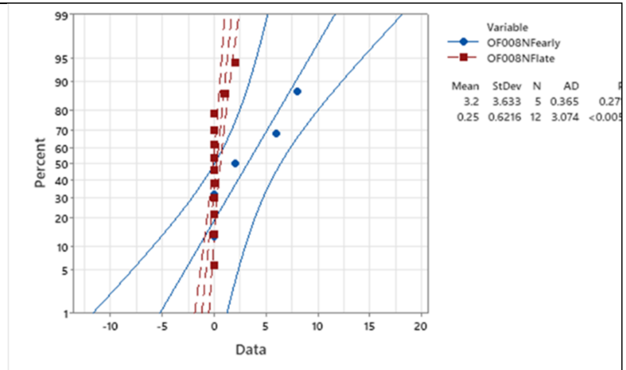
Table 10. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Outfalls 008 and 009 (cont.).

	Mercury	**Nickel**	**Selenium**	**Thallium**	**Zinc**	**TCDD TEQ No DNQ**	**Chronic Toxicity, Selenastrum**	**total**
threshold maximum 2015 (NEL)	0.13 µg/L	86 µg/L	5 µg/L	2 µg/L	120 µg/L	$2.8X10^{-8}$ µg/L	50%	
threshold type 2015 NEL	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	NPDES Permit Limit	
max observed ratio OF008	1.31	<1	1.60	<1	1.00	3.13	<1	
count >2015 NEL	4	0	2	0	1	1	0	37
count before 2010-2011 rain year	4	0	2	0	0	1	0	22
count during Topanga fire year	1	0	1	0	0	0	0	6
count during and after 2010-2011 rain year	0	0	0	0	1	0	0	15
count during Woolsey fire year	0	0	0	0	1	0	0	12
max observed ratio OF009	1.62	1.98	<1	3.50	<1	20346.55	1.15	
count >2015 NEL	5	1	0	2	0	24	1	60
count before 2010-2011 rain year	5	0	0	2	0	14	0	40
count during Topanga fire year	1	0	0	1	0	3	0	13
count during and after 2010-2011 rain year	0	1	0	0	0	10	1	20
count during Woolsey fire year*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

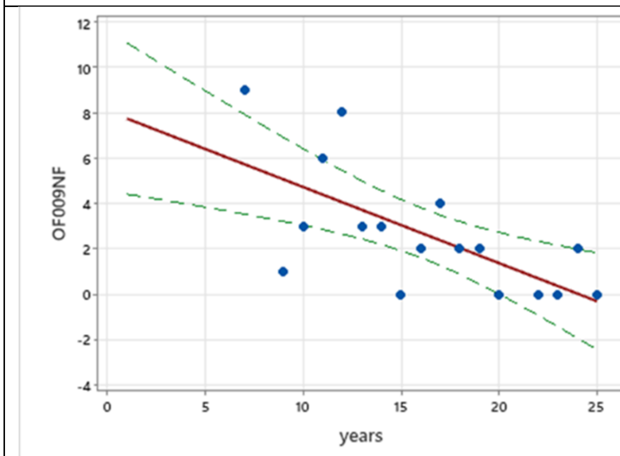
* the Woolesy fire only impacted a small portion of the OF009 watershed area



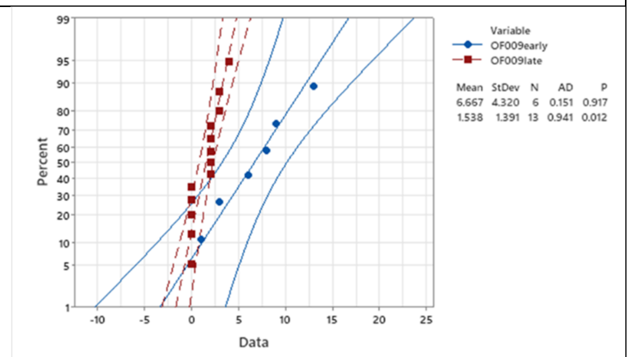
Time series plot of numbers of concentrations per year greater than 2015 NELs for Outfall 008



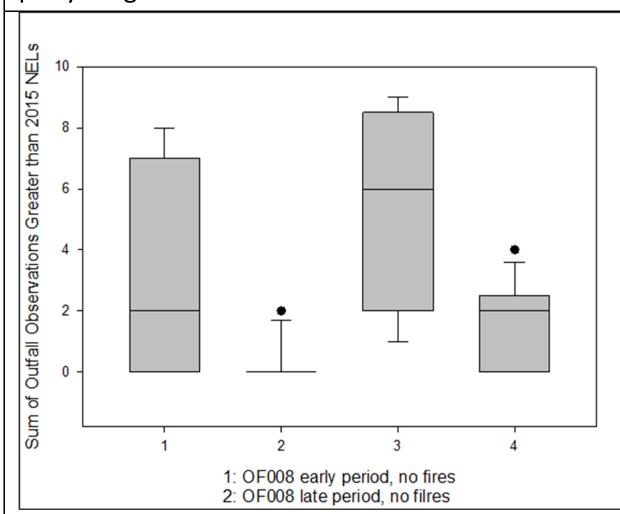
Probability plots of numbers of concentrations per year greater than 2015 NELs for Outfall 008 for early vs. late monitoring periods



Time series plot of numbers of concentrations per year greater than 2015 NELs for Outfall 009



Probability plots of numbers of concentrations per year greater than 2015 NELs for Outfall 009 for early vs. late monitoring periods



Box and whisker plots of annual observations greater than the 2015 NELs for Outfalls 008 and 009

Outfalls 008 and 009

Trends slope coefficient p = 0.015 and 0.0036
Trends slope coefficient p = 0.22 and 0.001 (including years with fires)

Comparison of early vs. late monitoring period annual observations greater than 2015 NELs

Mann-Whitney Rank Sum test p = 0.042 and 0.023
Mann-Whitney Rank Sum test p = 0.061 and 0.009 (including years with fires)

Figure 29. Time series of concentration observations greater than the 2015 NELs at Outfalls 008 and 009.

Outfall 011/001

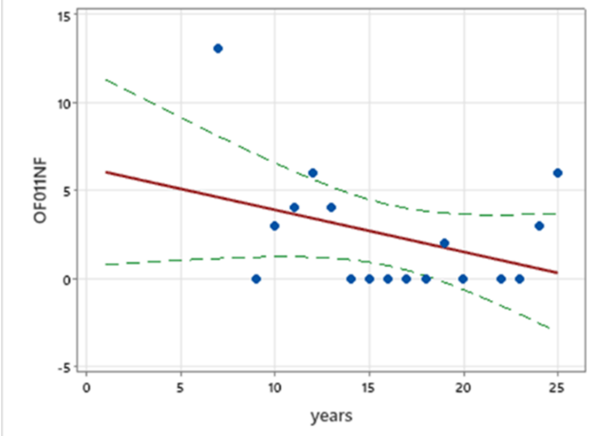
Outfall 011 drains an area that had various historical industrial activities. It is located above the southern buffer zone that has Outfall 001 located near the SSFL property boundary, but also includes the discharges from Outfall 011. Therefore, the NELs at Outfall 011 are permit limits, while the NELs at Outfall 001 are benchmarks. Interim soil removal and perchlorate treatment occurred in the Outfall 011 watershed area in 2003. The Topanga fire affected both Outfall 011 and 001 watershed areas in 2005 and the Woolsey fire also affected both of the watershed areas in 2018. NASA demolition of rocket engine test structures and removal of contaminated materials from the Outfall 001 watershed area were carried out in 2015 and in 2021. Treated wood pole barriers were installed at critical locations in 2020 and unused treated wood poles were removed in 2022. The advanced stormwater treatment system was installed at Outfall 011 in 2011 but was not extensively used beyond the storage ponds until 2021 due to low flows at that location.

Table 11 shows the number of concentration observations greater than the 2015 NELs at Outfalls 011 and 001 for the different periods corresponding to before and after interim contaminated material removal and stormwater management activities, while Figure 30 shows the time series, probability, and box and whisker plots of these high stormwater concentrations. The downgradient Outfall 001 data does not indicate a significant downward trend with time for years without fires and including fires (regression slope terms $p = 0.39$ and 0.37). Significant differences for the counts of high concentration observations for the two time periods using the Mann Whitney Rank Sum were not found for years without or including fires ($p = 0.11$ and 0.10). Similar plots for Outfall 011 observations also did not indicate significant trends for years without or including fires ($p = 0.14$ and 0.29) for the slope terms, but the Mann Whitney Rank Sum test did indicate significant differences between the high concentration counts for the two monitoring periods for years without or including fires ($p = 0.045$ and 0.01).

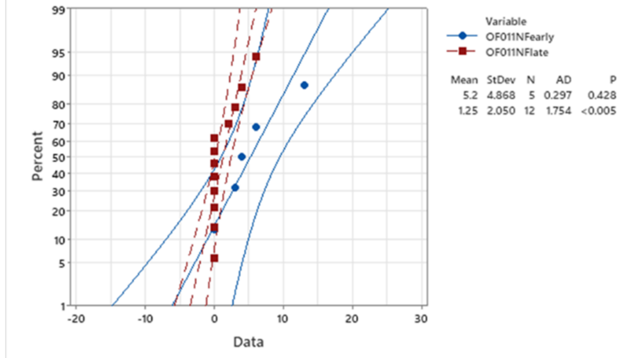
The constituents with the largest numbers of high concentration observations at Outfall 011 were iron (14 in the early period and 7 in the later period), mercury (3 in the early period and none in the later period), manganese (6 in the early period and 5 in the later period), TCDD (3 in the early period and 5 in the later period), and lead (4 in the early period and 1 in the later period). Similar constituents were also noted to be greater than the 2015 NELs at Outfall 001 (iron, manganese, TCDD, and mercury). The numbers of high concentrations at Outfall 001 were greater than at Outfall 011, reflecting contributions of critical contaminants from the intermediate buffer area between these two outfall monitoring locations.

Table 11. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Outfalls 011 and 001

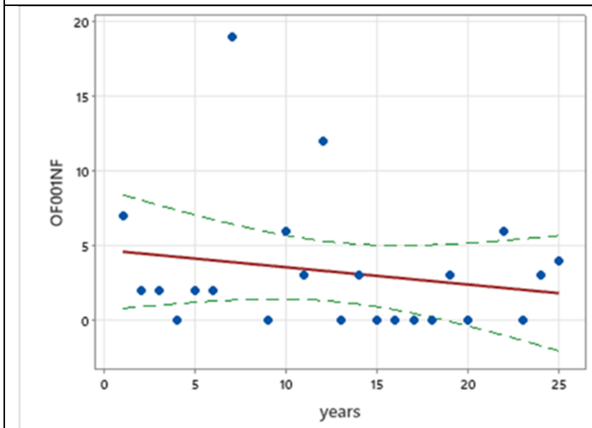
	Total Residual Chlorine	**Gross Alpha**	**Arsenic**	**Copper**	**Iron**	**Lead**	**Manganese**	**Mercury**	**TCDD TEQ No DNQ**	**total**
threshold maximum 2015 (NEL)	0.1 mg/L	15 pCi/L	10 µg/L	14 µg/L	0.3 mg/L	5.2 µg/L	50 µg/L	0.1 µg/L	$2.8X10^{-8}$ µg/L	
threshold type 2015 NEL	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	Benchmark for OF001 Permit Limit for OF011	
max observed ratio OF011	1.50	<1	1.10	<1	36.67	1.69	3.40	1.60	6.12	
count >2015 NEL	1	0	1	0	21	5	11	3	8	50
count before 2010-2011 rain year	1	0	0	0	14	4	6	3	3	31
count during Topanga fire year	0	0	0	0	1	2	1	0	1	5
count during and after 2010-2011 rain year	0	0	1	0	7	1	5	0	5	19
count during Woolsey fire year	0	0	1	0	3	1	2	0	3	10
max observed ratio OF001	1.70	1.15	<1	3.93	306.67	<1	8.00	2.60	6.80	
count >2015 NEL	1	2	0	2	33	0	21	9	16	84
count before 2010-2011 rain year	1	1	0	1	18	0	11	9	10	51
count during Topanga fire year	0	0	0	1	6	0	1	1	1	10
count during and after 2010-2011 rain year	0	1	0	1	15	0	10	0	6	33
count during Woolsey fire year	0	0	0	0	4	0	2	0	0	6



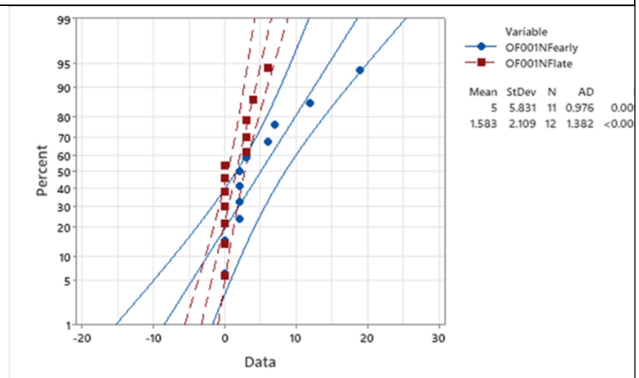
Time series plot of numbers of concentrations per year greater than 2015 NELs for Outfall 011



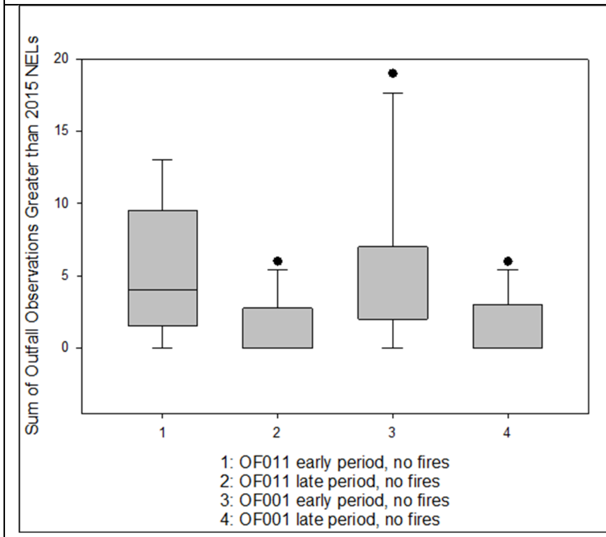
Probability plots of numbers of concentrations per year greater than 2015 NELs for Outfall 011 for early vs. late monitoring periods (including 2 fire years)



Time series plot of numbers of concentrations per year greater than 2015 NELs for Outfall 001



Probability plots of numbers of concentrations per year greater than 2015 NELs for Outfall 001 for early vs. late monitoring periods (including 2 fire years)



Outfalls 011 and 001:

Trends slope coefficient p = 0.14 and 0.39
Trends slope coefficient p = 0.29 and 0.37 (including years with fires)

Comparison of early vs. late monitoring period annual observations greater than 2015 NELs

Mann-Whitney Rank Sum test p = 0.045 and 0.11
Mann-Whitney Rank Sum test p = 0.057 and 0.099 (including years with fires)

Box and whisker plots of annual observations greater than the 2015 NELs for Outfalls 011 and 001	

Figure 30. Time series and probability plots of high stormwater concentrations at Outfalls 011 and 001.

Outfall 018/002

Outfall 018 is located at the downgradient edge of an area that had industrial activity while Outfall 002 is located further downstream below the southern buffer zone near the SSFL property boundary, similar to Outfalls 011 and 001. The Topanga Fire in 2005 and the Woolsey Fire in 2018 both affected these watershed areas. The Woolsey Fire caused damage to the Silvernale advanced stormwater treatment system which was repaired and operational by the following rain year. The Silvernale treatment system was initially in operation in 2012 and received runoff from the Outfall 018 watershed, along with pumped stormwater from the small northern outfall watershed areas (Outfalls 003 through 007, and 010) and from some paved helipad areas in the Outfall 009 watershed area. Treated wood pole barriers were placed in 2020 in the Outfall 002 watershed area. Interim contaminated material removal, including building and asphalt removal, occurred in the Outfall 018 watershed from 2015 to 2022.

Table 12 summarizes the observed outfall concentrations that were greater than the 2015 NELs (Outfall 018 has permit limits, while Outfall 002 has benchmarks). Figure 31 shows time series, probability, and box and whisker plots of the observations of concentrations greater than the 2015 NELs. The Outfall 002 time series of high concentrations had significant downward trends with time during years without the fires (regression slope term $p = 0.04$), but was not statistically significant when the fire years were considered ($p=0.27$). The Outfall 018 trends were significant without and with the fire years ($p = 0.01$ and 0.002). Both of the probability plots show substantial overlaps in the confidence intervals for the lower high concentration counts and were distinctly separated during years with more frequent high concentration observations. The Mann Whitney Rank Sum tests indicated significant differences based on the number of samples comparing the early to late monitoring period for Outfall 018 for years without and with fire years ($p = 0.008$ and 0.002) but was not significant for the Outfall 002 comparisons ($p = 0.06$ and 0.1).

The constituents having the largest number of high concentrations were mercury (total of 5 at OF018 and 13 at OF002), lead (2 and 10), iron (9 and 30), manganese (6 and 10), and TCDD (TEQ no DNQ) (9 and 9). High counts of pentachlorophenol (0 and 12) and bis (2-ethylhexyl) phthalate (0 and 16) were also observed, but only during the early years at Outfall 002.

Table 12. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Outfalls 018 and 002

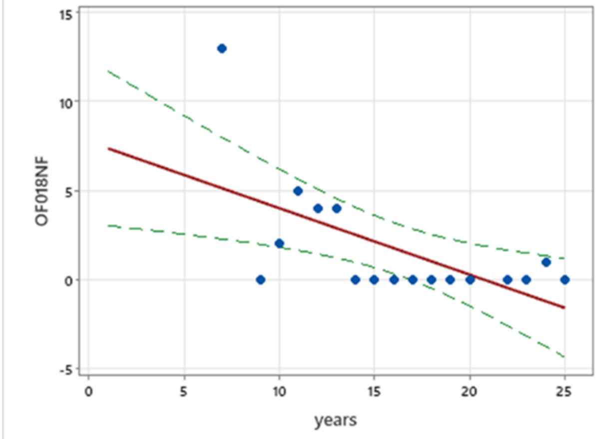
	Total Dissolved Solids	**Total Residual Chlorine**	**Biochemical Oxygen Demand (BOD)**	**Oil & Grease**	**Nitrate + Nitrite as Nitrogen (N)**	**Sulfate**	**Gross Alpha**	**Gross Beta**	**Combined Radium-226 and Radium-229**
threshold maximum 2015 (NEL)	950 mg/L	0.1 mg/L	30 mg/L	15 mg/L	8 mg/L	300 mg/L	15 pCi/L	50 pCi/L	5 pCi/L
threshold type 2015 NEL	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018
max observed ratio OF018	<1	1.40	<1	1.13	<1	<1	<1	<1	<1
count >2015 NEL	0	1	0	1	0	0	0	0	0
count before 2010-2011 rain year	0	1	0	1	0	0	0	0	0
count during Topanga fire year	0	0	0	0	0	0	0	0	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0	0
count during Woolsey fire year	0	0	0	0	0	0	0	0	0
max observed ratio OF002	1.05	1.40	1.10	<1	1.25	2.57	46.73	8.52	3.40
count >2015 NEL	1	1	1	0	1	9	4	1	1
count before 2010-2011 rain year	1	1	1	0	1	8	1	1	1
count during Topanga fire year	0	0	1	0	1	0	0	0	0
count during and after 2010-2011 rain year	0	0	0	0	0	1	3	0	0
count during Woolsey fire year	0	0	0	0	0	1	3	0	0

Table 12. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Outfalls 018 and 002 (cont.)

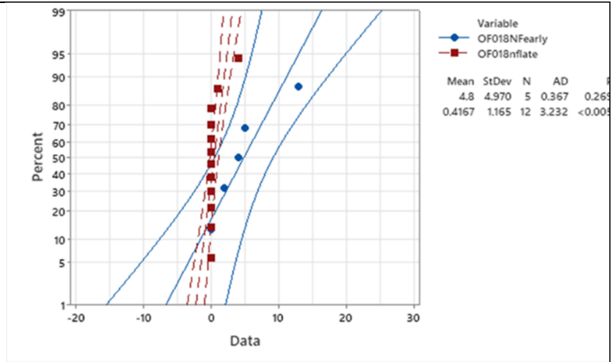
	Arsenic	**Barium**	**Beryllium**	**Cadmium**	**Copper**	**Cyanide**	**Iron**	**Lead**	**Manganese**	**Mercury**
threshold maximum 2015 (NEL)	10 µg/L	1 µg/L	4 µg/L	3.1 µg/L	14 µg/L	8.5 µg/L	0.3 mg/L	5.2 µg/L	50 µg/L	0.1 µg/L
threshold type 2015 NEL	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018
max observed ratio OF018	<1	<1	<1	<1	<1	<1	40.00	1.58	4.20	2.60
count >2015 NEL	0	0	0	0	0	0	9	2	6	5
count before 2010-2011 rain year	0	0	0	0	0	0	5	2	5	5
count during Topanga fire year	0	0	0	0	0	0	1	0	1	0
count during and after 2010-2011 rain year	0	0	0	0	0	0	4	0	1	0
count during Woolsey fire year	0	0	0	0	0	0	0	0	0	0
max observed ratio OF002	3.50	2.30	2.75	2.23	7.14	2.12	326.67	59.62	220.00	3.20
count >2015 NEL	4	1	1	1	5	2	30	10	10	13
count before 2010-2011 rain year	3	1	1	1	2	2	9	6	4	12
count during Topanga fire year	0	0	0	0	0	1	2	2	0	0
count during and after 2010-2011 rain year	1	0	0	0	3	0	21	4	6	1
count during Woolsey fire year	1	0	0	0	3	0	6	4	4	1

Table 12. Concentration Observations Greater than the 2015 NELs Before and After Interim Contaminated Material Removal and Stormwater Management at SSFL Outfalls 018 and 002 (cont.)

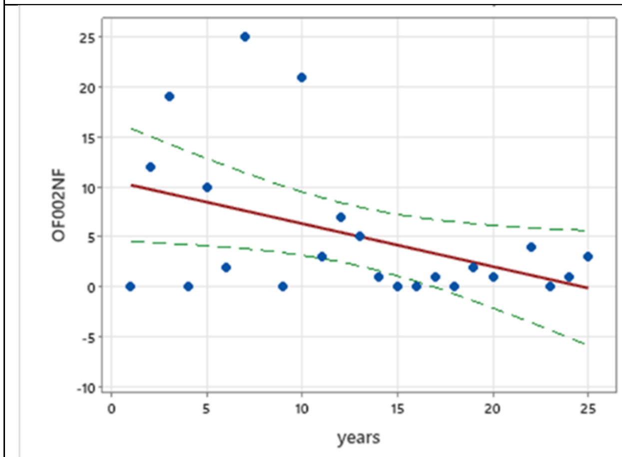
	Selenium	**Zinc**	**1,2-Dichloroethane**	**alpha-BHC**	**bis (2-ethylhexyl) Phthalate**	**n-Nitroso-dimethylamine**	**Penta-chlorophenol**	**TCDD TEQ No DNQ**	**Chronic Toxicity, Selenastrum**	**total**
threshold maximum 2015 (NEL)	8.2 µg/L	119 µg/L	0.5 µg/L	0.03 µg/L	4 µg/L	16 µg/L	16.5 µg/L	$2.8X10^{-8}$ µg/L	50%	
threshold type 2015 NEL	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	Benchmark for OF002 Permit Limit for OF018	
max observed ratio OF018	<1	2.27	4.80	<1	<1	<1	<1	3.88	<1	
count >2015 NEL	0	1	1	0	0	0	0	9	0	35
count before 2010-2011 rain year	0	1	1	0	0	0	0	9	0	30
count during Topanga fire year	0	1	0	0	0	0	0	3	0	6
count during and after 2010-2011 rain year	0	0	0	0	0	0	0	0	0	5
count during Woolsey fire year	0	0	0	0	0	0	0	0	0	0
max observed ratio OF002	1.34	6.64	<1	3.33	25.00	1.25	3.03	1276.38	1.11	
count >2015 NEL	1	4	0	7	16	5	12	9	1	151
count before 2010-2011 rain year	0	1	0	7	16	5	12	3	0	100
count during Topanga fire year	0	0	0	0	0	0	0	1	0	8
count during and after 2010-2011 rain year	1	3	0	0	0	0	0	6	1	51
count during Woolsey fire year	1	3	0	0	0	0	0	2	0	29



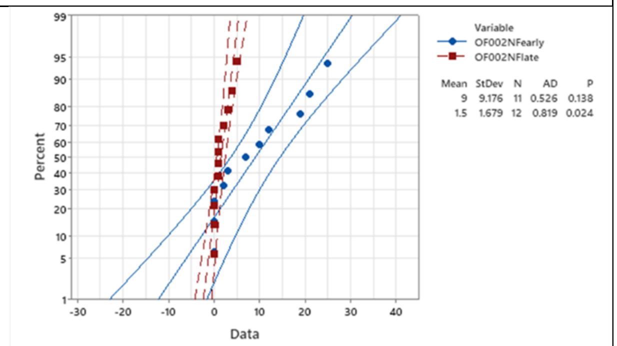
Time series plot of numbers of concentrations per year greater than 2015 NELs for Outfall 018



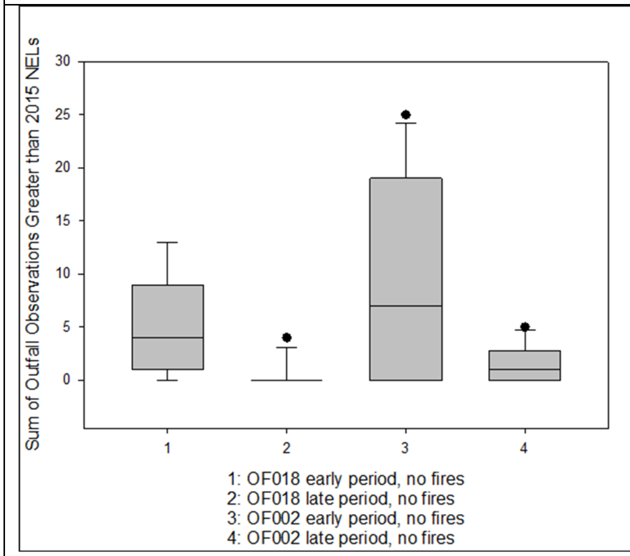
Probability plots of numbers of concentrations per year greater than 2015 NELs for Outfall 018 for early vs. late monitoring periods



Time series plot of numbers of concentrations per year greater than 2015 NELs for Outfall 002



Probability plots of numbers of concentrations per year greater than 2015 NELs for Outfall 002 for early vs. late monitoring periods



Outfalls 018 and 002:

Trends slope coefficient p = 0.01 and 0.04
Trends slope coefficient p = 0.002 and 0.27 (including years with fires)

Comparison of early vs. late monitoring period annual observations greater than 2015 NELs

Mann-Whitney Rank Sum test p = 0.008 and 0.060
Mann-Whitney Rank Sum test p = 0.002 and 0.098 (including years with fires)

Box and whisker plots of annual observations greater than the 2015 NELs for Outfalls 018 and 002	

Figure 31. Time series and probability plots of high concentrations at Outfalls 002 and 018.

Summary, Conclusions, and Future Activities

The past aerospace and energy research activities at SSFL have ceased. SSFL is currently the focus of a comprehensive environmental investigation and cleanup program, conducted by Boeing, DOE, and NASA, which is overseen by the DTSC. Final site contaminated soil cleanup will begin when the DTSC completes their site studies and sets the contaminated soil cleanup goals. This paper summarizes the history of the industrial activities on the site, interim contaminated material removal, and stormwater management activities. Stormwater discharges from SSFL are currently regulated by the Los Angeles Regional Water Quality Control Board. Twenty-five years of monitoring data are examined in this paper to identify the trends in the outfall stormwater quality in response to these interim contaminated material removal and stormwater management activities.

The stormwater trend analyses focus on the comparison of numbers of concentration observations greater than the 2015 NELs (as a normalizing procedure due to changing NELs with earlier permits) with interim removal of contaminated materials, and the use of stormwater management practices. Most of the site changes have occurred since the 2010/11 rain year. Therefore, the basic analyses compare the observed stormwater quality for the rain years from 1998/99 to 2009/10 as the early period before site changes vs. from 2010/11 to 2022/23 as the later period after the site changes.

The number of concentration observations greater than the 2015 NELs were significantly greater during the early period before interim contaminated material removal and stormwater management at SSFL compared to the later period, as shown on Table 13. Any changes in site rainfall conditions during these two periods may also affect stormwater runoff quality, but there were no significant differences associated with the annual rain depths or the number of qualifying rain events for monitoring during these two periods when the rain data were examined. The two fires on SSFL both resulted in large numbers of concentration observations greater than the 2015 NELs during the rain year containing the fire. The rain year prior to the Topanga fire had a larger number of concentration observations greater than the 2015 NELs compared to the rain year with the Topanga fire result (88 high observations). However, the rain year including the 2018 Woolsey fire, resulted in the largest number of concentration observations greater than the 2015 NELs during the later period (56 high observations). In addition, the record 2022/23 rain year did not result in an unusual number of high concentrations compared to the trend of concentration observations greater than the 2015 NELs vs. rainfall amount.

Table 13. Number of all Constituent Concentration Observations greater than the 2015 NEL for Outfalls during Early and Late Monitoring Periods, without Fires (except as noted)

Outfall Location	early monitoring period	late monitoring period
Outfall 003	10	0
Outfall 004	23	0
Outfall 005	24	0
Outfall 006	17	0
Outfall 007	18	0
Outfall 010	18	3
Outfall 008	17	2
Outfall 009	31	16
Outfall 018	27	2
Outfall 002	85	14
Outfall 011	29	11
Outfall 001	50	22
All outfalls combined without fire years	349	70
All outfalls combined with fire years	437	126

The major factors found to affect the number of concentration observations greater than the 2015 NELs included:

- Diversion of northern outfall stormwater to the Silvernale advanced stormwater treatment facility resulted in almost complete elimination of stormwater discharges and high concentrations from and at these outfalls.
- The advanced stormwater treatment systems at Outfalls 011 and 018 resulted in decreased numbers of high concentration discharges from these outfalls, even considering the increased diverted flows from the northern outfalls (and a portion of the helipad above Outfall 009) to the Outfall 018 Silvernale advanced stormwater treatment system.
- The Topanga fire in 2005 and the Woolsey fire in 2018 resulted in large increases in the numbers of high concentrations greater than the 2015 NELs during the rain year with the fires compared to other rain years in the monitoring periods. The early monitoring period had one year with a greater number of high concentrations than the year of the Topanga fire, but the Woolsey fire rain year had the largest number of high concentrations for any of the rain years during the later monitoring period. The stormwater characteristics during the rain years following the fires were similar to typical conditions.
- The distributed stormwater controls and interim contaminated soil removal activities resulted in large decreases in the numbers of high stormwater concentrations at Outfalls 008 and 009.

The constituents comprising about 90% of the high concentrations greater than the 2015 NELs during the early monitoring period without the Topanga fire were relatively diverse, including (in order of abundance): mercury (28%), iron (16%, TCDD (TEQ no DNQ) (14%), lead (9.5%), manganese (8.6%), pentachlorophenol (3.4%), sulfate (2.6%), bis (2-ethylhexyl) phthalate (2.6%), copper (2.3%), gross beta

(1.7%), and antimony (1.7%). After the interim contaminated material removal and use of stormwater controls, the numbers of high concentrations greater than the 2015 NELs were greatly reduced, and the number of constituents comprising about 90% of these high concentrations were also greatly reduced (for years without the Woolsey fire): iron (40%), TCDD (TEQ no DNQ) (26%), lead (14%), and manganese (10%). The following are general observations associated with constituents of most interest in SSFL stormwater.

Gross alpha and gross beta high concentration occurrences are summarized on Table 14 and strontium-90 conditions are summarized on Table 15. These constituents represented few of the total observations greater than the 2015 NELs, but are of great interest to the stakeholders. These radioactive constituents had a total of 13 values greater than the 2015 NELs during the early monitoring period which decreased to three values (all gross alpha) greater than the 2015 NELs during the late monitoring period.

Table 14. Number of Gross Alpha and Gross Beta Values >2015 NELs, without Fires

Outfall Location	early monitoring period gross alpha (1.1% of total)	late monitoring period gross alpha (1.4 % of total)	early monitoring period for gross beta (1.7% of total)	late monitoring period for gross beta (<0.1% of total)
Outfall 003	0	0	1	0
Outfall 004	0	0	1	0
Outfall 005	0	0	0	0
Outfall 006	0	0	1	0
Outfall 007	0	0	2	0
Outfall 010	0	0	0	0
Outfall 008	2	0	0	0
Outfall 009	0	0	0	0
Outfall 018	0	0	0	0
Outfall 002	1	0	1	0
Outfall 011	0	0	0	0
Outfall 001	1	1	0	0
All outfalls combined	4	1	6	0
All outfalls combined with fire years	5	3	6	0

Table 15. Number of Strontium-90 Values >2015 NELs, without Fires

Outfall Location	early monitoring period (0.3% of total)	late monitoring period (<0.1% of total)
Outfall 003	1	0
Outfall 004	0	0

Outfall 005	0	0
Outfall 006	0	0
Outfall 007	0	0
Outfall 010	0	0
Outfall 008	0	0
Outfall 009	0	0
Outfall 018	0	0
Outfall 002	0	0
Outfall 011	0	0
Outfall 001	0	0
All outfalls combined	1	0
All outfalls combined with fire years	2	0

Few of these values exceeded the specific permit limits as the regulated permit limits are calculated based on long term averages and not single events, and they also need supporting isotope and related analyses to identify anthropogenic vs. natural sources. During the late monitoring period, no gross beta or strontium-90 concentrations greater than the 2015 NELs were detected, even during the Woolsey fire year. One high gross alpha value was detected during the late non-fire monitoring period, and two high values were detected during the year of the Woolsey fire. The observations of high concentrations for these constituents were greater during the early monitoring period and were reduced after the interim contaminated material removal and stormwater management, as reflected in the late monitoring period data.

Table 16 summarizes the dioxin (TCDD TEQ no DNQ) observations greater than the 2015 NELs by outfall and monitoring period. Most of the high values were associated with the northern outfalls combined (Outfalls 003 through 007 plus 010) and Outfall 009 during the early period (31 out of 50). After the interim contaminated material removal and after stormwater from the northern outfalls were diverted to the Silvernale advanced treatment system at Outfall 018, the high dioxin observations from these northern areas were eliminated at those locations, except for 2 at Outfall 010. The Outfall 018 discharges (after the Silvernale advanced stormwater treatment) had no high dioxin discharges, even with the additional diverted flows from the northern outfalls and the paved portion of the helipad in the Outfall 009 watershed. The 15 Outfall 009 high dioxin observations during the early monitoring period were reduced to eight high dioxin observations during the late monitoring period after the distributed stormwater controls were installed and after the helipad flow diversions to the Silvernale treatment plant. The year with the Topanga fire had 18 high dioxin concentration observations and the year with the Woolsey fire had five high dioxin concentration observations. Dioxin high concentrations also made up about 14% of the total non-fire early monitoring period high concentration observations (3^{rd} most abundant) and about 26% of the total non-fire late monitoring period concentration observations (2^{nd} most abundant).

Table 16. Number of TCDD TEQ No DNQ Concentration Observations >2015 NEL, without Fires

Outfall Location	early monitoring period (14% of total)	late monitoring period (26% of total)
Outfall 003	1	0
Outfall 004	3	0
Outfall 005	2	0
Outfall 006	2	0
Outfall 007	1	0
Outfall 010	7	2
Outfall 008	1	0
Outfall 009	15	8
Outfall 018	6	0
Outfall 002	6	1
Outfall 011	2	3
Outfall 001	4	4
All outfalls combined	50	18
All outfalls combined with fire years	68	23

Table 17 shows the numbers of high concentration observations greater than the 2015 NELs for lead for non-fire conditions. Lead was the fourth most abundant constituent having high concentration observations during the early monitoring period (about 10% of the total) and was the third most abundant constituent having high concentrations greater than the 2015 NELs during the later monitoring period (about 14% of the total). Most of the high lead concentrations occurred at Outfalls 008 and 009 (9 and 10 respectively out of 33) which were significantly reduced during the later monitoring period after the interim contaminated material removal and the use of the distributed controls in those areas (1 and 5 respectively out of 10). Large numbers of high lead concentrations were also observed during the two years with fires, 18 during the early Topanga fire year and nine during the later Woolsey fire year. The Imminent and Substantial Endangerment (ISE) Cleanup at the historical shooting range in the Outfall 009 watershed scheduled for the summer of 2023 is expected to further reduce the number of lead concentration observations greater than the 2015 NEL in that area.

Table 17. Number of Lead Concentration Observations >2015 NEL, without Fires

Outfall Location	early monitoring period (9.5% of total)	late monitoring period (14% of total)
Outfall 003	0	0
Outfall 004	0	0

Outfall 005	0	0
Outfall 006	0	0
Outfall 007	1	0
Outfall 010	3	1
Outfall 008	9	1
Outfall 009	10	5
Outfall 018	2	0
Outfall 002	2	0
Outfall 011	2	0
Outfall 001	4	3
All outfalls combined	33	10
All outfalls combined with fire years	51	19

Table 18 summarizes the high copper concentration observations greater than the 2015 NELs for the years without fires during the early and late monitoring periods. Copper accounted for about 2% of the total early monitoring period high concentration observations and about 3% of the total late monitoring period high concentration observations. Individual outfalls had 0, 1 or 2 high copper concentration observations during either the early or late monitoring periods. Five high copper observations (out of the eight total) occurred at the northern outfalls combined (Outfalls 003 through 007 plus 010) during the early monitoring period and were reduced to zero during the late monitoring period after their diversions to the Silvernale stormwater treatment plant at Outfall 018. Outfall 018 had zero high copper concentration observations during both the early and late monitoring periods, even after the increased flows diverted from the northern outfalls during the late monitoring period. The numbers of high copper concentration observations increased substantially during the fire years, with ten during the year of the Topanga fire and five during the year of the Woolsey fire.

Table 18. Number of Copper Concentration Observations >2015 NEL, without Fires

Outfall Location	early monitoring period (2.3% of total)	late monitoring period (2.9% of total)
Outfall 003	0	0
Outfall 004	1	0
Outfall 005	1	0
Outfall 006	0	0
Outfall 007	2	0
Outfall 010	1	0
Outfall 008	1	1
Outfall 009	0	1
Outfall 018	0	0

Outfall 002	2	0
Outfall 011	0	0
Outfall 001	0	0
All outfalls combined	8	2
All outfalls combined with fire years	18	7

Table 19 shows that the early period northern outfalls had the greatest numbers of concentration observations greater than the 2015 NEL for mercury (62 of the 97 high mercury observations). Mercury accounted for most of the high concentration observations greater than the 2015 NELs during the early monitoring period (about 28%). Outfall 002 also had a large number of high mercury observations during the early monitoring period (12). There were no high mercury concentration observations during the late monitoring period, after the interim contaminated material removal and use of stormwater controls. Eight high mercury concentrations were observed during the year of the Topanga fire while one high mercury concentration was observed during the year of the Woolsey fire.

Table 19. Number of Mercury Concentration Observations >2015 NEL, without Fires

Outfall Location	early monitoring period (28% of total)	late monitoring period (<0.1% of total)
Outfall 003	7	0
Outfall 004	18	0
Outfall 005	16	0
Outfall 006	8	0
Outfall 007	8	0
Outfall 010	5	0
Outfall 008	3	0
Outfall 009	4	0
Outfall 018	5	0
Outfall 002	12	0
Outfall 011	3	0
Outfall 001	8	0
All outfalls combined	97	0
All outfalls combined with fire years	105	1

Table 20 shows the data for iron and manganese. These constituents are only monitored at Outfalls 001, 002, 011, and 018 per the NPDES discharge permit monitoring requirements. Iron was the second most abundant constituent having high concentration observations during the early monitoring period (about

16% of the total) and was the most abundant constituent having high concentrations during the late monitoring period (about 40%), even considering their reduced number of monitoring locations. A total of 55 high iron concentrations were observed during the early monitoring period, which was reduced to 28 during the late monitoring period. Ten high iron concentrations were observed during the year of the Topanga fire and 13 high iron concentrations were observed during the year of the Woolsey fire.

Manganese accounted for about 9% of the total high concentration observations during the early monitoring period (ranked fifth) and accounted for about 10% of the total high concentration observations during the later monitoring period (ranked fourth). During the non-fire early monitoring years, 33 high manganese concentrations were observed, which were reduced to seven during the late monitoring period. Three high manganese concentrations were observed during the year of the Topanga fire and eight were observed during the year of the Woolsey fire. Based on the source investigations and supporting evaluations, these two constituents, which account for about half of the total current concentration observations greater than the 2015 NELs, are expected to be from background soil sources and not from any historical or current SSFL site activities.

Table 20. Number of Iron and Manganese Concentration Observations >2015 NELs, without Fires

Outfall Location*	early monitoring period iron (16% of total)	late monitoring period iron (40% of total)	early monitoring period for manganese (8.6% of total)	late monitoring period for manganese (10% of total)
Outfall 018	7	1	4	0
Outfall 002	15	12	6	0
Outfall 011	16	5	5	3
Outfall 001	17	10	15	4
All outfalls combined	55	28	30	7
All outfalls combined with fire years	65	41	33	15

*Iron and manganese NELs are only monitored at Outfalls 018/002 and 011/001

Paired t-Tests were used to calculate the significance of the differences between the early and late monitoring period numbers of high concentration observations greater than the 2015 NELs during the non-fire years for all of the outfalls, reflecting the benefits of the interim contaminated soil removal and use of the stormwater controls. Constituents with sufficient data and having significant ($p \leq 0.05$) decreases when early vs. late monitoring period data were compared included: gross beta, copper, lead, iron, manganese, mercury, TCDD TEQ no DNQ, and for all constituents combined. Similar tests were also conducted to compare the annual average number of high constituent observations during the early and late monitoring period vs. the years of the Topanga and Woolsey fires. Fewer data were available for these analyses considering the decreased areas affected by the Woolsey fire. The following constituents have sufficient data and have significant ($p \leq 0.05$) increases in the numbers of high concentrations during the fire years compared to average non-fire years: iron (late), copper (early), lead (early and late), TCDD TEQ no DNQ (early), and for all constituents combined (early and late).

In August 2022, a Memorandum of Understanding (MOU) was adopted as part of a comprehensive framework that establishes specific cleanup protocols and timelines for Boeing, and also involves an agreement between Boeing and the Department of Toxic Substances Control (DTSC). The MOU outlines additional responsibilities for the Surface Water Expert Panel including modeling stormwater quality at SSFL outfalls that Boeing cleanup areas drain to, establishing background stormwater concentration thresholds, and designing a post-cleanup stormwater monitoring plan within Boeing areas of SSFL. The panel's focus regarding control measures as the site moves into full scale remediation will focus more on erosion and sediment controls and keeping soil onsite.

This paper included descriptions of the historical site activities potentially affecting stormwater quality along with the interim contaminated material removal and stormwater management that have occurred on the site. Twenty-five years of monitoring data, about evenly divided into early and late monitoring periods before and after these interim material removal activities and the use of stormwater controls, have shown consistent improvements in stormwater quality, as indicated by data for a broad range of constituents when compared to the 2015 permit numeric effluent limits. On-going site interim controls and stormwater management, along with potential additional activities as indicated by site data or directed by the regulatory agencies, will continue. Final site cleanup activities will be determined by the DTSC based on their site studies when they set the contaminated soil cleanup goals, with significant input from the stakeholders.

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