Predicting Riparian Vegetation Response to Water Released into an Arid Stream

Assessing Water Management Impacts & Alternatives

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This report is submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management from the Bren School of Environmental Science & Management at the University of California, Santa Barbara.

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As authors of this Group Project report, we are proud to archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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Explanation of Client Relationship

Boeing, the client of the project, is an aerospace company and manufacturer of commercial planes, defense and space systems. Boeing is a responsible party for the environmental clean-up at one of their properties in Ventura County, California. Boeing encountered environmental regulatory complications that have delayed one of their remediation projects at this location – groundwater treatment. This Bren Working Group has produced this report to support informed decision-making for progressing efforts to pump and treat the groundwater at Boeing's Santa Susana Field Laboratory property.

Abstract

Boeing must pump and treat the contaminated groundwater at the Santa Susana Field Laboratory (SSFL), a former rocket-testing site that is now 3,000 acres of wilderness in the hills near Simi Valley. This pump-and-treat project will keep groundwater below surface levels during heavy rainfall, preventing exposure to the contaminant in question, the industrial solvent trichloroethylene. After the groundwater is treated to the required standards of purity, Boeing would like to discharge the clean water into an arid creek on the SSFL site. This would increase the instream flow from ephemeral to perennial, potentially shifting riparian vegetation composition and allowing invasion of non-native vegetation. The Bren group analyzed these risks by first conducting physical and botanical surveys of the reach. Survey data were then used to predict flow depth, soil moisture, plant-available water, plant responses based on their water preferences, and differential native-invasive interactions following the groundwater release. Hydrophytic plants are likely to spread from their current locations in a naturally perennial wet zone, to dominate the bed of the channel. Drought-tolerant plants may remain primarily in the upland portions of the channel. Portions of the channel with low canopy and low diversity of shallow-rooted native species have higher non-native species cover and, in agreement with relevant literature on invasive species, perhaps have a lower resistance to invasion. A cost and benefit analysis was conducted over the minimum lifetime of the pump-and-treat project on two methods of water discharge (channel discharge and aquifer reinjection) to determine if a combination of these options could be used for water management. Channel discharge at multiple points and aquifer reinjection could be utilized during wet and dry months, respectively, to mimic a natural flow schedule and minimize the impacts to existing vegetation in any one location. Boeing should monitor areas with low resistance to invasion along the channel, especially after disturbances to the channel. If necessary, Boeing could remove existing non-native grasses, and supplement native shallow-rooted species and trees along areas identified as vulnerable to increase the channel's resistance to invasive species.

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Abbreviations

BCR	Benefit-Cost Ratio
CalEPA	California Environmental Protection Agency
CDFW	California Department of Fish and Wildlife
CNPS	California Native Plant Society
GETS	Groundwater Extraction Treatment System
GIS	Geographic Information System
LSAP	Lake and Streambed Alteration Program
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
PAW	Plant-Available Water
RCDSMM	The Resource Conservation District of the Santa Monica Mountains
SSFL	Santa Susana Field Laboratory
TCE	Trichloroethylene
ULARA	Upper Los Angeles River Area
WTP	Willingness to Pay

Executive Summary

The 2,850 acre Santa Susana Field Laboratory (SSFL) in Ventura County, California, once housed laboratories and testing facilities that developed technologies for U.S. space and energy programs from 1950 to 2006. These industrial activities led to the inadvertent contamination of groundwater by industrial cleaning solvents such as trichloroethylene (TCE). During early operations, these chemicals were often inappropriately stored in a manner that allowed them to infiltrate into soil and groundwater. Underneath SSFL, a sandstone bedrock formation serves as a fractured and porous aquifer for the site's groundwater—where much of these leaked contaminants remain today. The site is no longer a research facility, and many pollution remediation projects have been ongoing for the past two decades.

As part of the clean-up effort, Boeing, is required by the California Environmental Protection Agency (CalEPA) to start a project to pump and treat groundwater. Since the bulk of the TCE appears to adhere to particles in the sandstone aquifer, the plume of TCE has not travelled far. It extends beyond the property boundary in only one region. Still, groundwater levels could rise during rainstorms; there is a risk that water containing concentrations of TCE could emerge from springs on the site. CalEPA has directed that when groundwater levels rise, the groundwater in the aquifer shall be extracted and treated to remove the TCE and keep groundwater levels below the surface. The pumped groundwater at SSFL must then be treated to standards similar to state drinking water standards. Boeing has already built a system, the Groundwater Extraction and Treatment System (GETS), to pump and treat the groundwater to these standards of purity. This pump-and-treat process is expected to continue for decades.

Boeing's groundwater treatment project is not currently operating: The project has no approved plan to dispose of the treated water. Boeing planned to discharge the treated water into an ephemeral stream channel on the site, which connects downstream with tributaries of the Los Angeles River. However, this has been suspended by California Department of Fish and Wildlife (CDFW) over concerns of vegetation response from creating a perennial flow in the arid reach. Boeing's groundwater remediation project has been halted until a critical question can be answered: Will adding water to a stream channel that is dry for most of the year alter the riparian ecosystem in a way that allows non-native species to overwhelm the native vegetation? Concerns raised by CDFW are justified. A nearby steam with perennial flow, Malibu Creek, has about one-quarter of its riparian vegetation cover occupied by non-native plant species (Sikich et al. 2010). Some of the non-native species at Malibu Creek have already invaded other parts of SSFL. The concerns for discharging treated water at SSFL and creating a perennial flow in the disposal stream are mainly focused on the invasion of non-native plant species.

Without an approved way to discharge the treated water, Boeing cannot begin treating the contaminated groundwater. This report addresses CDFW's concerns about the ecological implications of the proposed water discharge. To analyze the extent of the introduced water, the Bren School Group Project working group surveyed the channel's physical characteristics and calculated the depth and velocity of the discharged water and the associated riparian water-table elevation and soil moisture levels. The working group then participated in a botanical survey and categorized the present riparian species according to their water tolerances and functional niches. These indicators were used to predict how native and non-native plants might colonize, grow, and interact along the riparian zones of the channel in response to the altered riparian moisture regime created by the treatment discharge activities. Alternative discharge strategies and schedules were considered, which might minimize the effects to native vegetation while maintaining the rate at which the groundwater needs to be treated.

The working group found that a continuous stream discharge will introduce wetland conditions along the ephemeral reach. In this new environment with added water, the probability of non-native species invasion could increase. Fortunately, there are characteristics of the existing riparian zone vegetation community that provide some resistance to invasion and decrease the abundance of non-native species: diversity of shallow-rooted species and canopy cover. The Bren working group recommends monitoring the channel while water is discharged, and possibly removing the current invasive species present. If invasive or non-native species are observed to increase, the working group recommends strategic restoration of riparian vegetation and an intermittent schedule of treated water release in order to minimize impacts on the vegetation community. Strategic restoration would include supplementing native plants and trees within the first 400 feet of the discharge location to increase community resistance to invasive species. Boeing could prioritize the establishment of shallow-rooted native species and species that quickly create canopy cover. In addition, removing existing smilo grass (*Stipa miliacea var. Miliacea*), ripgut brome (*Bromus diandrus*) and other non-native species along the reach would help reduce the likelihood of invasion. Finally, an intermittent discharge strategy that pauses stream discharge completely in the dry summer months, and allows the soil to dry between discrete discharge events during wet winter months could reduce the possibility of non-native species growth or invasion along the reach. Since this groundwater treatment project aims to reduce the groundwater level during rain events, a wet-season flow schedule is likely to be consistent with the project's treatment goals. Treated groundwater could be released into the stream only during the wet months, November to March at SSFL. An intermittent flow strategy would require cycling between channel discharge and some other discharge strategy, such as direct aquifer reinjection, to avoid shutting down the GETS. Additionally, the CDFW favors groundwater management actions that reduce environmental impacts. Cycling between discharge options could reduce riparian vegetation changes, increasing the probability of Boeing's implementing the proposed groundwater treatment project.

Project Context

The Santa Susana Field Laboratory (SSFL), purchased by Boeing in 1996, was a rocket engine testing site for several decades beginning in the 1950s. Trichloroethylene (TCE), a chlorinated solvent used to clean rocket engine parts, drained into the fractures and pores of the underlying sandstone aquifer, where most of it remains today. CalEPA has directed that Boeing pump-and-treat the groundwater in the aquifer to keep the TCE from being exposed at the surface when groundwater levels rise.

Boeing plans to meet CalEPA's mandate with the use of the Groundwater Extraction Treatment System (GETS). The GETS utilizes particulate filters, ion exchange vessels, an air stripper, liquid and vapor phase granular activated carbon, an ultraviolet and hydrogen peroxide system, and chemical dosing for pH and hardness adjustment to treat contaminated groundwater (Owens, 2015). The GETS will discharge water into a drainage at the southern edge of the site, a seasonal and ephemeral stream that connects to the Los Angeles River through a tributary called Bell Canyon Creek. This pump-and-treat operation is expected to continue for at least 10 to 25 years. After the cleanup is completed, Boeing intends to transition the site into open space with the North American Land Trust for wildlife conservation and possibly for recreational activities.

Boeing proposes an average discharge flow of 60 gallons per minute (gpm) of treated groundwater to the reach (Figure 1). Boeing cannot continue the groundwater treatment operation without a way to discharge treated water. Boeing plans to obtain a Lake and Streambed Alteration Program (LSAP) permit with approval from CDFW to discharge water into a channel reach after all contaminants are removed by the GETS. To receive the LSAP permit, Boeing is required by the CDFW to assess the potential changes to the vegetation in and around the stream after treated groundwater is released, which could convert the ephemeral reach into a perennial reach.

CDFW is concerned about non-native invasive species invasion along the reach following the increase in water along the reach. Non-native plants are species introduced to California after European contact and as a direct or indirect result of human activity (Cal-IPC, n.d.). According the CDFW, invasive species are organisms that are not native to an environment, quickly reproduce and spread, and cause harm to the environment, economy, or human health.

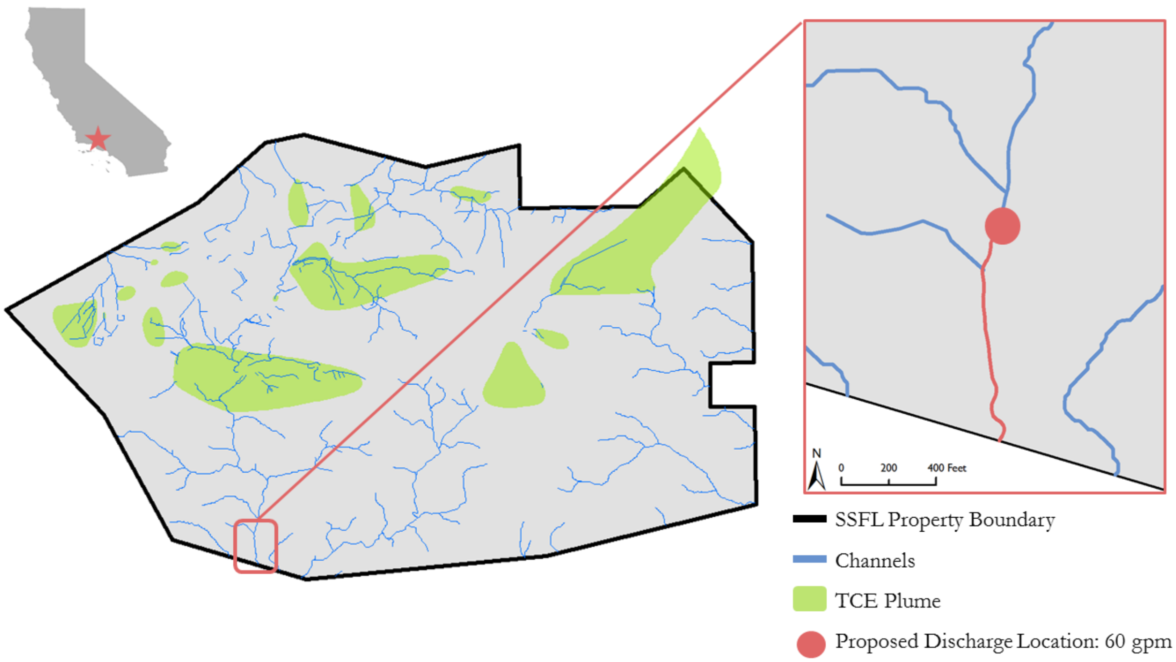

Figure 1. *Map of Santa Susana Field Laboratory in Ventura County, California, with trichloroethylene groundwater plumes (green), streams (blue), the proposed location for the discharge of 60 gallons per minute (gpm) of treated water (red dot) and on-site receiving reach (red line).*

Project Objectives

Boeing must receive a LSAP permit from CDFW to discharge water to a reach on the property. This activity would allow Boeing to move forward with groundwater treatment plans at SSFL. To address CDFW concerns regarding non-native species invasion, Boeing needs to determine how the riparian vegetation would respond when treated groundwater is released into the ephemeral reach. This project had the following objectives:

1. Predict changes to the composition of vegetation communities along the reach.

2. Assess the possibility that water discharge may increase non-native vegetation abundance or invasion along the reach.

3. Create monitoring and mitigation actions that could be taken to prevent environmental impacts, specifically the invasion of non-native vegetation.

Research Questions and Methodologies

To accomplish the objectives listed above, the Bren working group completed the following activities:

1. **Characterized the ephemeral reach, determined the current flow regime, and predicted the depth, velocity and escapement of the augmented flow.**
   Determined the channel's shape and soil types to identify how much water will flow downstream and how the proposed discharge will change the stream habitat.

2. **Analyzed how the increased instream flow will affect plant available water and current vegetation composition in the riparian zone.**
   Assessed how the added water will increase soil moisture levels for different soil types along the channel, since various soils retain different amount water. Increased soil moisture influences plant available water and can impact plant species along the channel based on their water preferences.

3. **Assessed the current vegetation composition along the channel and identified areas which were dominated by non-native species.**
   Identified existing areas dominated by native species and cross referenced these areas with zones of low non-native species to determine the environmental features that could account for this distribution. These features and analyses helped the working group recommend monitoring and conservation actions to reduce the risk of non-native invasion following treated groundwater release.

4. **Identified other groundwater management options with lower degrees of ecosystem alteration.**
   To increase the chance of obtaining a LSAP permit, the working group examined other management options that could be combined with the proposed channel discharge to reduce impacts to riparian vegetation. A cost and benefit analysis was utilized to determine the cost-effectiveness of the most feasible alternative over the expected lifetime of the project.

1 Physical Site Background

1.1 General Environmental Characteristics

The ephemeral reach of interest is located on the southern portion of the SSFL site. This reach is approximately 800 feet long within Boeing's property and then extends beyond the property boundary to connect with Bell Creek, a tributary to the Los Angeles River. The southern portion of the SSFL is largely undeveloped area located in Upper Bell Creek Watershed. The climate in the region is considered a Mediterranean dry-summer climate, which consists of cool, wet winters and warm, dry summers (RCDSMM, 2011). The study area is primarily composed of chaparral vegetation, a drought- resistant variety of vegetation that is dependent upon occasional wildfires that are expected in the Mediterranean climates of California. The site also contains oak woodland and coastal sage scrub habitat.

1.2 Description of Stream Receiving Discharged Water

The reach that would receive the discharged treated water from the GETS is dry year-round, except immediately after short water discharge events from stormwater storage ponds further upstream and infrequent winter rainstorms. A wetland area is located at the edge of the property where groundwater emerges from bedrock fractures and keeps a portion of the streambed perennially wet. The stream extends approximately 800 feet downstream of the proposed discharge location before reaching the SSFL property boundary, where Boeing's jurisdiction ends. Beyond this boundary lies a residential zone elevated high above the channel as it becomes more deeply incised in a bedrock gorge.

1.3 Precipitation Patterns and Stormwater at SSFL

Precipitation patterns influence instream flow, soil moisture levels and plant-available water. Additionally, precipitation patterns affect seasonal plant growth. A deviation from natural precipitation patterns and water availability can impact plant species that have developed certain evolutionary traits for surviving in arid environments, such as drought-tolerance traits.

Precipitation data from 1959 to 2016, measured by the Ventura County Watershed Protection District, demonstrated that the majority of rainfall events at the SSFL occurs during the winter months (Figure 2). Specifically, 90% of rainfall occurs between November and March. Minimal rainfall occurs during the summer months: The maximum precipitation during the summer months is less than 0.5 inch.

Stormwater at the SSFL is collected in storage ponds upstream from proposed treated water discharge location. Following rain events, stormwater in the storage ponds is treated and released into the stream between October and April, with flow lasting from a few hours to days. Stormwater is treated to concentration standards set by an NPDES permit. When released, treated stormwater flows downstream and through the proposed GETS discharge location.

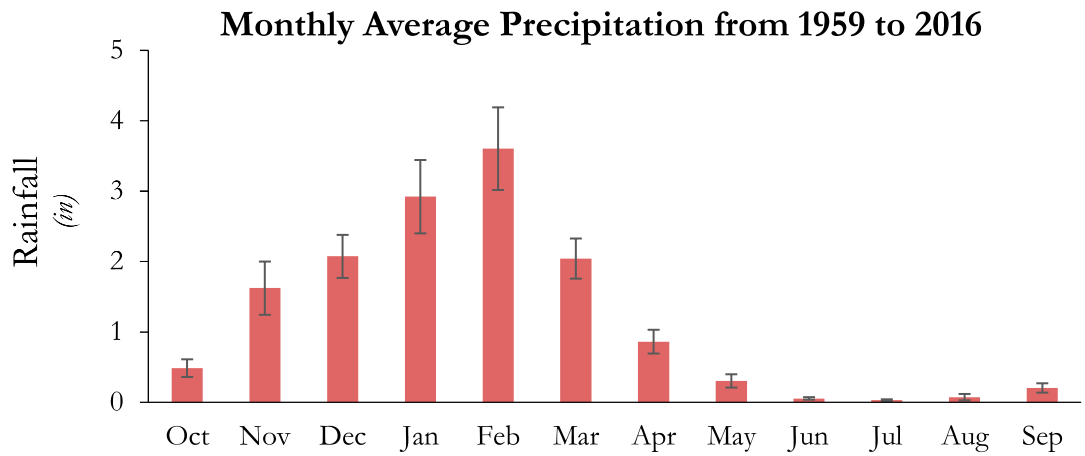

Figure 2. *SSFL's average monthly precipitation from 1959 to 2016 with standard errors.* Source: Ventura County Watershed Control Board.

2 Analysis of Proposed Discharge

Boeing proposes an average treated groundwater discharge of 60 gallons per minute (gpm) into an ephemeral reach (Figure 1.) The CDFW is concerned about the potential changes in riparian vegetation composition that this volume of water could create. Soil moisture influences plant available water along the reach, so first, the Bren working group gathered the necessary data. Physical characteristics of the reach and soil types present downstream of the proposed discharge point were surveyed by the Bren working group. These measurements allowed the working group to predict the extent of the water table and plant available water that would be created by the discharge.

2.1 Analysis of the Proposed Flow Rate

2.1.1 Survey 1: Channel Characteristics and Hydrological Survey

The ephemeral reach downstream of the discharge location was surveyed to calculate the depth and width of flow from the introduced water. The reach downstream of the discharge location currently lacks water except during precipitation events and occasional stormwater discharges from storage ponds upstream. These flows are short in duration, lasting no more than a few days. Based on field observations, the Bren working group concluded that there is negligible interaction between surface water in the channel and groundwater. One notable exception exists near the property boundary, where a groundwater seep from bedrock fractures provides moisture year-round.

2.1.2 Soils

Sediment depth and grain type in the channel bed and banks were recorded by the characterization survey. Sediments and soil grains form a single, shallow layer of soil, ranging from 5 cm to 35 cm in depth. The soil grain sizes vary from gravel and coarse sand, to silt-clay loam and silt loam. Coarse sand is predominant in the upper and middle parts of the channel. Bare bedrock occurs extensively in the upper part of the reach. Silts and fine sands are deposited along the banks of the downstream region of the channel. Near the SSFL property boundary, soils are composed mainly of fine sand and silt loam that retain moisture even in summer.

2.1.3 Physical Components and Geometry of the Drainage

The reach is a roughly trapezoidal open channel lined with dramatically tilted stratigraphy of fractured sandstone bedrock. No obvious fractures are visible in the bed. Twenty cross-sections of the reach were surveyed, with one survey cross-section approximately every 20 feet. See Appendix B for detailed survey methodology. The following physical and geometry components were measured for each cross-section:

- Depth of channel bed at the center, and on left and right bank
- The width of the bottom of the channel
- The width of the channel between the top of the banks

The working group applied these measurements to Manning's equation to calculate the perennial water flow depth that would result from a permanent water discharge. The stream has an average gradient of approximately 0.08 and the cross-sectional slopes range from 0.014 to 0.17, as determined by a post-hoc via GIS analysis of a digital topographic model of the site (USGS, 2103). The channel adopts a variety of irregular trapezoidal shapes along the reach: the narrowest cross-section is located 152 feet downstream of the proposed discharge location, with a maximum flow area of 1 square meter and wetted perimeter of 6 meters. Heading downstream to the SSFL property boundary, the channel broadens to form the widest cross-section with an area of 10 square meters and wetted perimeter of 18 meters.

2.1.4 Flow Alteration Calculations

The data collected by the Bren working group's hydrological survey was used to calculate the perennial flow regime that would result from a discharge of 60 gallons per minute, or gpm. The results from this calculation include the expected depth of water along the reach and water availability to plants in the channel bed and banks. This hydrological analysis was crucial for the final analysis – predicting how vegetation will respond to the introduced perennial flow.

Water Depth and Speed for Known Flow Volumes

To quantify the hydrological changes, the resulting flow from three different discharge scenarios was calculated. Figure 3 shows the two scenarios most pertinent to the GETS project. In the first scenario, a discharge of 400 gpm of treated stormwater was evaluated. This flow represented the maximum amount released to the stream from upstream storage ponds after rainfall events. The second scenario estimates the flow depth resulting from discharging 60 gpm of treated groundwater to the stream, as initially proposed by Boeing for the GETS discharge project. Finally, the third scenario quantifies the flow depth resulting from combining the previous two discharges, for a maximum possible flow of 460 gpm. The estimated water depth is the depth of flow that would occur if the discharges are locally uniform (See Appendix B for application of Manning's Equation). These results indicate that the maximum possible flow from simultaneous stormwater and treated groundwater discharge could exceed the banks in one location approximately 400 feet downstream of the discharge. The discharge rate from the GETS project alone never approaches the capacity of the banks.

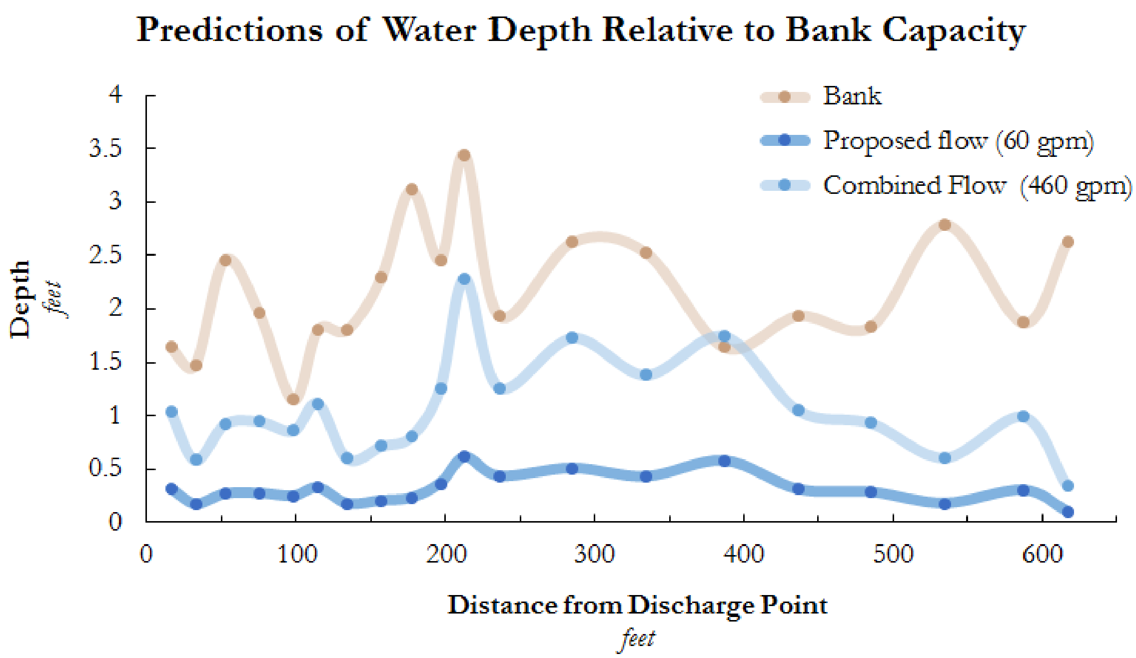

Figure 3. *Water depth predictions (feet) downstream from the proposed outfall location for 60 and 460 gallons per minute: the proposed discharge from groundwater treatment, and the combined depth of a high-volume storm water release and proposed GETS discharge. Markers denote data points taken from the working group's channel characterization, while approximations of the intermittent measurements are drawn as lines.*

Water exits the stream by four mechanisms: flowing downhill, evapotranspiration by vegetation, evaporation, and infiltration into the bed. Estimated rates of evapotranspiration, evaporation and infiltration relevant to the study area were applied across an approximation of the water surface area in the stream. The evaporation rate was taken from the 1979 report "Evaporation from Water Surfaces in California", the same value used in the 2011 analysis of the California State Water Project's efficiency. The regional average evapotranspiration rate used was the mean value between Ventura and Los Angeles County (Sanford and Selnick, 2013). Potential evapotranspiration was assumed to be 75% of the open water evaporation rate. Relevant infiltration rates were found in a 2011 study of aquifer recharge rates in a permeable sandstone aquifer (Heilweil & Watt, 2011). Heilwil and Watt's estimates of infiltration rates varied depending on the presence of fractures along the channel. Since the Bren working group's survey of the reach found no evidence of fractures up to the property boundary, the likely value for actual infiltration was taken from the low end of infiltration rate estimates. Rate estimates were transformed to flux values by using a conservative estimate of the full channel's surface area: the average distance between banks (4 ft) multiplied by the length of the channel (800 ft). The rates of mass transfer (Table 1) show that the channel flow flux dominates the other mechanisms of water escapement. This demonstrates that the flow of water is likely to reach the property boundary essentially undiminished.

Table 1. *Summary of water loss mechanisms from the drainage after flow is introduced.*

Water Escapement Route	**Rate** inch/sec	**Flux** gpm
Channel flow	--	60.00
Regional Average Evapotranspiration	5.1E-07	0.06
Potential Evapotranspiration	2.0E-06	0.23
Open Water Evaporation	2.6E-06	0.31
Min. Infiltration	1.8E-06	0.22

Plant-Available Water (PAW)

If Boeing proceeds to discharge clean groundwater into the reach, the critical change to the current moisture status would be the distribution of plant-available water in the riparian zone. Plant-available water (PAW) is the amount of water stored in the soil that plants have access to and varies between soil types (Table 2). The perennial water depth resulting from the discharge would create a water table in the riparian soil. This water table would support the permanent distribution of plant-available water in the unsaturated zone of the soil. Therefore, a plant would use water at the same rate regardless of soil texture because plan-available water would be permanently supplied by the water table that is maintained by the perennial flow. The working group estimated the soil moisture content and the plant-available water in the riparian soil, using water characteristic curves (Clapp & Hornberger, 1978) (Appendix C). From these estimates (Table 2, Appendix C), the distribution of plant-available water would be within the first 12-20 inches of unsaturated soil (Figure 4). The permanent distribution of PAW in the riparian zone could favor the colonization of plant species that have moderate to high water requirements. Hence, changes in the composition of plant species are expected as discussed in the vegetation response section.

***Table 2**. Plant-available water (PAW) for the different soils present downstream of the proposed discharge location.*

Soil type	**PAW (%)**
Fine Sand	16
Coarse Sand	11
Silt Loam	20
Silt Clay Loam	14

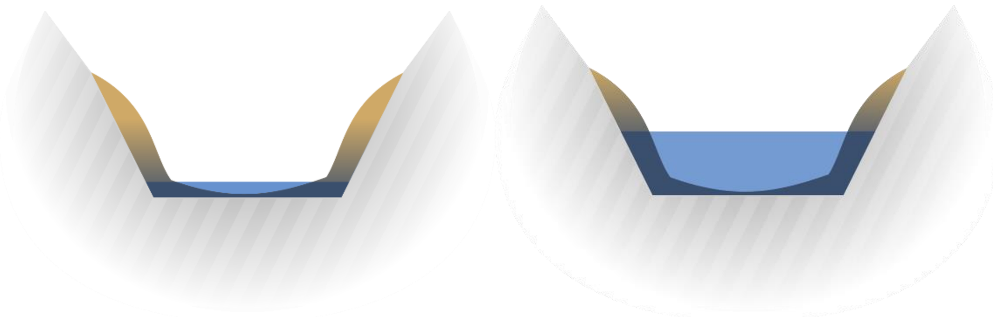

Figure 4. *Diagram of a simplified representative channel cross-section and soil layer with the shallowest (0.09 ft, left) and deepest (0.61 ft, right) expected water level from introduced flow and wetted soil.*

2.1.5 Discussion of Channel Characterization

A continuous flow of 60 gpm would result in a perennial flow depth that varies along the reach from 1.2 to 7 inches. Physical impacts of this flow are not likely to exceed that of the 400 gpm maximum discharged by the occasional stormwater release events. The physical impacts of the 400 gpm release were considered by the NPDES permit granted for stormwater release. If the continuous 60 gpm discharge occurred concurrently with a 400 gpm stormwater release event, the channel's capacity would be approached, and exceeded in one section of the reach. The perennial flow from the groundwater project alone would not exceed the capacity of the reach, and water would flow downhill beyond the property boundary. However, the critical change to the current flow regime would be the presence of permanent plant-available water in the riparian zone. The perennial flow depth would create a water table in the saturated zone that would support the distribution of plant-available water in the unsaturated areas along the stream banks of approximately 12-20 in. of soil. The volume of plant-available water held in soil would vary between soil texture types, but plants growing on all soils with PAW would be in permanent contact with this water. Since there would be permanent wet conditions along the bed and banks of the entire reach, the working group evaluated the potential vegetation responses to this new moisture regime.

2.2 Native and Invasive Riparian Vegetation

An assessment of the current riparian vegetation is important to determine the water preferences of the current native and non-native plant species along the proposed discharge reach. The Bren working group participated in a survey of the vegetation in the reach and conducted a literature review about how the region's vegetation interacts with water as a limiting resource. Using these data, the working group analyzed how different species would likely respond to the added water and the distribution of resistance to invasion along the reach. The results of this analysis identified areas of low environmental resistance to invasion by non-native plants existing in the region as well as options for management responses to mitigate the invasion of the unwanted non-native plant species. The working group provided management options for Boeing to reduce the likelihood for non-native species invasion and growth.

2.2.1 Survey 2: Existing Vegetation Communities in the Reach

Two members of the Bren working group participated in a biological survey specific to the reach. The species identification survey was performed by biologists Chris Dunn and Zach Abbey of Padre Consulting with the assistance of Lina Barbosa and Elise Wall. The survey began at the location of proposed treated water discharge and extended to the property boundary, with species observations occurring every 100 feet. Observations were made by identifying plant species within sight of the center of the steam. These observations were used to identify sequential plant community types along the stream, from the point of proposed treated water discharge to the SSFL property boundary.

This survey revealed a trend of four vegetation communities arranged in a downstream direction along the reach. These habitat types are chaparral, mulefat scrub, Coast Live Oak riparian woodland and a wetland vegetation community. There was an observed general trend in species composition along the reach's riparian zone, with sparse grasses and shrubs in the upper and middle of portions of the reach and denser trees and wetland vegetation in the lower portion. The generally increasing biomass and height of vegetation are likely favored by the increasing moisture conditions at the lower end of the reach. This trend provides progressively more shade to the soil surface when moving downstream from the proposed discharge location – open at the top of the reach and shaded by oaks and denser vegetation at the bottom.

Chaparral community covers approximately 6% of the reach and is located in the vicinity of proposed water discharge at the beginning of the stream survey area. Chaparral habitat is a dense assemblage of broad-leaved, woody, sclerophyll – woody plants with evergreen leaves that are tough and thick in order to reduce water loss. This vegetation consists primarily of deep rooted shrubs, with many species being adapted to fire (Holland, 1986). The chaparral species found in this area included black sage (*Salvia mellifera*), toyon (*Heteromeles arbutifolia*), and poison oak (*Toxicodendron diversilobum*), species all commonly found in chaparral communities (England, n.d.). The chaparral in this area also has scattered arroyo willow (*Salix lasiolepis*) and western sycamore (*Platanus racemosa*), trees often found in riparian or wetland areas. The upper region of the reach, with bare ground and bedrock material, has mostly scattered deep-rooted plants such as trees and shrubs.

Mulefat scrub vegetation occupies the next 300 feet downstream from the water discharge location and approximately 38% of the observed stream length, from the discharge location to the property boundary. Mulefat scrub habitat, a coastal scrub plant community, is similar to chaparral in species composition and characterization but is dominated by mule fat (*Baccharis salicifolia*) in creek beds and margins (Dunn, 2016). Some chaparral species intermixed with mulefat included hairy ceanothus (*Ceanothus oliganthus*), black sage (*Salvia mellifera*) and California rose (*Rosa californica*). A single Santa Susana tarplant (*Deinandra minthornii*) is located in this area. The downstream portion of the mulefat scrub zone is a transitional zone of a coast live oak community.

The coast live oak vegetation community comprises the remaining portion of the stream to the property boundary, about 450 feet long and 56% of the study area. Coast Live Oak riparian wetland is characterized by prevalence of coast live oak (*Quercus agrifolia*) intermixed with other riparian trees and an understory of shrubs and herbaceous plants, usually surrounded and interwoven by chaparral species (Dunn, 2016). Coast live oak riparian habitat in Southern California tends to have more herbaceous plants than shrubs compared to the Northern and Central California complements, though it is still an evergreen riparian woodland (Holland, 1986). Intermixed with the oaks are other riparian trees, such as arroyo willow and western sycamore, and a sparse understory of chaparral species, including coyote brush (*Baccharis pilularis*), black sage and toyon.

An assemblage of southern cattail (*Typha domingensis*) and nutsedge (*Cyperus eragrostis*) were observed in the final portion of the study area near the property boundary for approximately 100 feet of the creek bed. The presence of cattails and nutsedge in this location also occurred where the survey team observed water seeping from the bedrock in the channel bed. These species are usually found in perennially wet environments in California and are an indicator of a wetland.

One special status species was found in the study area – a single Santa Susana tarplant. Santa Susana tarplant is listed by the California Native Plant Society (CNPS) in their Inventory of Rare and Endangered Plants on list 1B.2 - rare, threatened, or endangered in California and elsewhere. Santa Susana tarplant was not usually found or expected to grow in drainage areas of SSFL and is most often found near sandstone outcrops at other, drier locations on the property (Dunn, 2016). Like many plants that prefer dry environments, the drought in California has expanded the microclimates in which this species can thrive.

Two non-native species were found in the reach, both shallow-rooted grasses. Smilo grass (*Stipa miliacea var. Miliacea,* a perennial grass species) and Ripgut Brome (*Bromus diandrus*, an annual grass). Smilo grass occupies a large portion of the plant assemblages at the upstream portions of the study area, about the first 400 feet downstream of the proposed discharge location. Ripgut brome is also abundant in the upper portion of the study area but had a smaller extent. Non-native plants were not observed in the lower, downstream portions of the study area where the vegetation created more dense shade and was representative of coast live oak riparian woodland. The establishment of grasses and shrubs seemed to favor areas along the banks that had deposits of silts and fine sands and less shade due to the sparser tree canopy.

2.2.2 Understanding Native Vegetation's Interaction with Water

Plant roots are specialized features that extract water. The plant communities that exist at the SSFL can be categorized into two different functional types that define how they distribute their roots for the purpose of absorbing water (Appendix D):

1. Deep-rooted woody plants
2. Shallow-rooted herbaceous plants

As their names suggest, these two classes of plants have different root lengths that determine the depth at which they can absorb water. For instance, a herbaceous species found at SSFL, Coyote brush, typically has a root depth of approximately 0.5 meters (Callaway, 1990). Deep-rooted plants, such as Chamise (*Adenostoma fasciculatum*) with a root length averaging 7.6 meters, can utilize water much deeper in the soil (Callaway, 1990). The definition is drawn at a depth of two meters: shallow rooted plants have roots less than two meters long, and deep rooted plants have roots longer than two meters (Hellmers et al., 1955). A database of the characteristics and categories of plants observed in the stream was assembled (Appendix D). Separating plants based on these functional characteristics made it possible to predict their possible response from increasing plant-available water in the reach.

Deep-rooted plants, such as the coast live oak and sycamore, take up water from deep soil layers where soil moisture are less likely to be depleted by evaporation or by shallow-rooted competitors (Chesson et al., 2004; Chambers et al. 2016; Breshears et al., 1999). The resource partition between shallow- and deep-rooted plants influences the plant composition of a riparian habitat. The vertical heterogeneity of root depths typically defines separate niches, allowing the two functional groups to co-exist in the same areas in systems where the soil is deep enough to allow for a two-layer model of the soil. Herbaceous plants have a much denser root distribution in the upper layer compared to woody plants, making them much more efficient at extracting available water in the shallower soil compartment (Walter, 1971 & 1973). Even though the reach in question at SSFL had only a shallow layer of soil, these characteristics of root systems are important to consider when predicting which plants will extract water most efficiently at shallow depths.

2.2.3 Non-native Grasses and Water

The working group next explored if non-native invasive species gain a competitive advantage from increasing plant-available water in the arid reach. A recent study found that increased rainfall alone was not enough to give invasive species an advantage (Eskelinen and Harrison, 2014). Nutrient limitations and native competitors were found to be highly effective in curtailing the added effects of heightened precipitation – added water is more likely to have a drastic effect on nutrient rich, disturbed conditions where invasive species are already present (Eskelinen and Harrison, 2014). A similar study found that undisturbed native habitats of coastal sage scrub were able to resist invasion under multiple conditions, including heightened water availability at multiple depths, but the most conclusive indicator of invasive success was habitat disturbance, or other mechanism inducing resource fluctuation (Goldstein and Suding, 2014). These studies demonstrate that an increase in water alone in the ephemeral stream at the SFFL is not necessarily favorable to non-native species invasion and that other factors, such as nutrients or disturbance, play an important part in a community's vulnerability to vegetation invasion.

Disturbances such as fire can increase invasive species' competition against native shrubs if resources are limited. For instance, decreases in water input following a fire can slow the recovery of native scrub and increase invasive vegetation cover (Kimball et al., 2014). In fact, increases in water input have been shown to help the recovery of these shrubs and reduce non-native grass cover (Kimball et al., 2014). A case study demonstrated that four years after a fire event, the average native shrub cover in a California coastal sage scrub community varied based more on nitrogen addition compared to water addition. The authors posit that this was due to fast growing grasses taking advantage of a slow shrub recovery and suppressing new shrub seedlings. The invasive *Bromus* species studied struggled the most in plots where water was added and nitrogen was unaltered. Native shrubs in these plots showed a rapid growth rate and the highest native shrub coverage. Kimball et al 2014 concluded that changes in the balance of native and non-native vegetation is mostly caused by nitrogen addition in combination with fire, drought, or other disturbance event that creates open space for invasive grasses to colonize.

Similar studies supported these results and have demonstrated that shrub recruitment in post-fire coastal sage scrub and chaparral were positively correlated with increased precipitation or water input (Keeley et al., 1981 & 2006). Invasive grass cover is lower when the recovery of native scrub is supported after disturbance.

If disturbance is the main facilitator of vegetation invasion, the seeds present after disturbance play a key role in how the vegetation community will return. Decreasing or increasing the native plant and invasive species cover at one point in time is likely to shift the plant cover composition for multiple years. Coastal scrub and chaparral plant seeds often lie dormant for long periods of time; for many of these seeds, the cues for germination are fire: heat, scorching, or smoke. (Keeley and Fortheringham, 2000; van Staden et al., 2000). Since widespread germination of chaparral and coastal scrub follows fire events, changes in the seed bank composition can have a dramatic effect on the landscape and ecosystem following a fire disturbance. Factors that are known to affect plant cover such as water and recruitment play an important factor in the maintenance of the native cover. Drought conditions have been shown to lower germination rates of seeds (Ochoa-Hueso and Manrique, 2010). Water input can ensure efficient soil moisture levels during severe drought conditions, and may be beneficial to native shrubs to ensure recruitment of native scrub following high heat or fire conditions (Kimball et al., 2014; Ochoa-Hueso and Manrique, 2010).

2.2.4 Non-Native Species Interactions and Resistance to Invasion

Considering the studies reviewed above, disturbance events favor invasion by non-native plants. The ability of an ecosystem to rebuff invading species can be impacted by altering historical disturbance regimes (Brooks et al., 2016). In addition, changes in water regimes are not common mechanisms of disturbance (Brooks et al., 2016). Instead, grazing and clearcutting are the typical routes cited as making ecosystems more vulnerable to invasion. Neither of these activities are of concern in the proposed discharge reach – the largest disturbances that the reach experienced were the periodic high-volume flow from storm water release. While this disturbance regime has been mildly intensified by stormwater released from storage ponds at SSFL in recent history, the new water discharge regime will follow these disturbances with longer periods of plant-available water. This has the potential to support pioneer species that have higher water requirements than the *Bromus* and *Stipia* species that currently occur in portions of the channel bed. This is the main risk for new invasion or for currently present invasive species to propagate farther along the channel. Fortunately, chaparral ecosystems have natural resistance mechanism for species invasions, and these features are present in the discharge reach.

Since growth patterns of non-native vegetation is highly species-specific, the first priority of the working group was to determine which non-native species are already present in the reach. There was little information in the current literature regarding the invasive characteristics of the grass *Stipa miliacea*, but information is available on the other non-native species present in the reach: the *Bromus* species. Ripgut Brome (currently present in the reach) and Red Brome (present in other areas of SSFL) are the two dominant species of Brome in California's Mediterranean coastal climate (Brooks et al., 2016). These species of *Bromus* have rapid growth rates that allow them to utilize scare resources more effectively that native species (Chambers et al., 2016), underlining the importance of understanding how the abundance of these species will change when the ecosystems is altered by increasing water availability.

California ecosystems resist *Bromus* and similar non-native grasses with differing levels of success. Sage scrub in California's Mediterranean climates has a very low resistance to these two species (Brooks et al., 2016). Oak woodlands are slightly more resilient in the absence of grazing or if fire frequency is low. Of all California ecosystems, chaparral is the most resilient due to shrub canopy cover – shrub canopy is in fact the best way to discourage *Bromus* (Brooks et al., 2016). *Bromus* still has the potential to exist in ecosystems with higher water content if competition from native species is not sufficient to suppress its growth (Brooks et al., 2016). Nutrient addition or ecosystem stress has the capacity to reduce this resistance in all of these habitats: nitrogen fertilization has been shown to have conflicting effects on early growth in *Stipa* and *Bromus* species, showing a strong influence in *Bromus* and none on *Stipa*. (Tulloss and Cadenasso, 2016; Valliere and Allen, n.d.). The key mechanisms of resisting the growth of non-native grasses in the vegetation community are avoiding nutrient addition, avoiding ecosystem disturbance, and established canopy cover. Nutrient addition is unlikely to be an issue so long as the concentration limits on nitrogen compounds in the NPDES permit are not exceeded. The current distribution of tree species along the reach aligns with literature's assertion that canopy cover discourages the growth of invasive grasses (Figure 5). This may be explained by the reduced solar radiation on surface areas where higher leaves shade the ground; reduced solar radiation provides less sunlight resources for grasses that require direct sunlight.

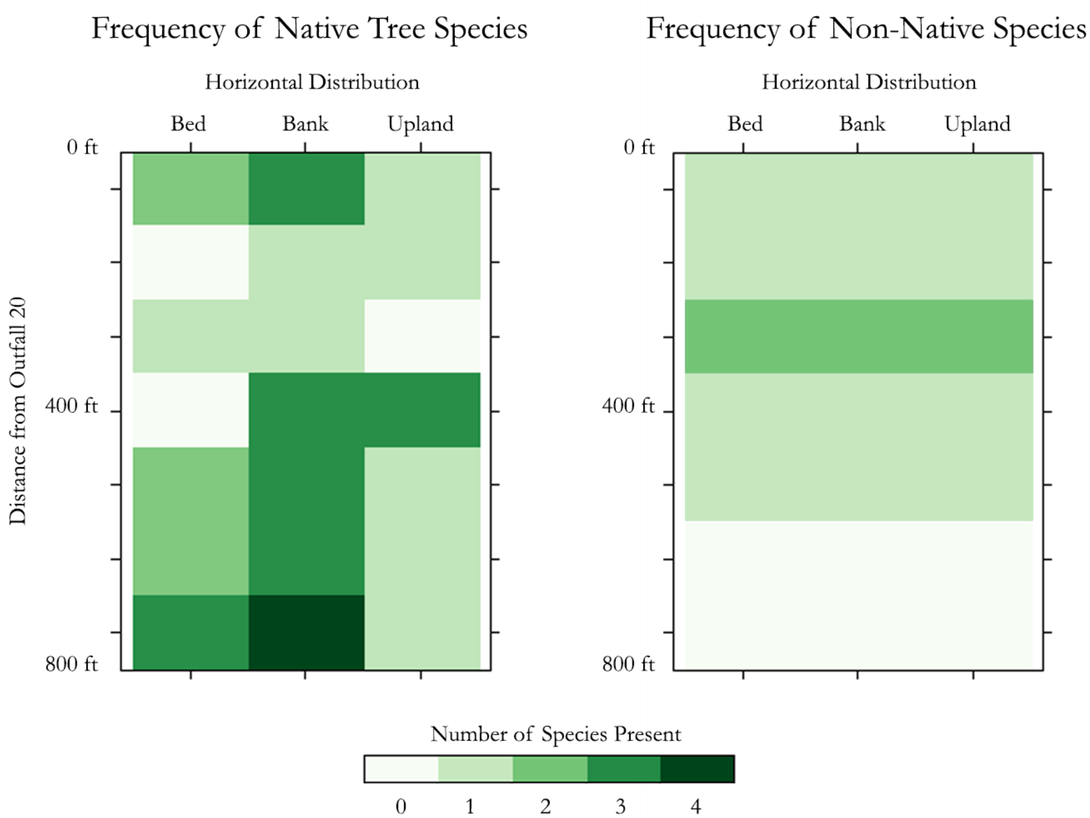

Figure 5. *Canopy cover in the reach and the loose affiliation between current invasive species and frequency of species giving canopy cover.*

The hot, dry summers of the SSFL introduce another mechanism by which native plants compete with non-native species: outlasting them during dry periods. The plant communities on the site efficiently utilize a notable limiting resource of the region – water (Redtfelt, 1996). These native scrub species have seasonal dimorphism adaptations, traits that are triggered in the dry season to help them survive periods of low water availability. When precipitation events are spaced farther apart, annual grasses (like the invasive species present in the reach) have weaker competitive effects on the native shrub seedlings (Goldstein and Suding, 2014). Furthermore, mature shrubs compete most effectively with grasses under periods of infrequent rainfall where the shallow layer of soil has less plant available water (Goldstein and Suding, 2014). While these results are predicated on an ecosystem with both shallow and deep soil, the conclusions regarding competition between shallow-rooted species still apply to the single shallow layer of soil found at the SSFL reach in question.

The seasonal timing of precipitation is critical to the interactions between native chaparral species and non-native invaders (Eskelinen and Harrison, 2014). Invasive competitiveness is weakest when water is introduced during historical wet seasons (Eskelinen and Harrison, 2014). Therefore, dry season flow in the reach could benefit non-natives plants. When water is not the limiting resource, species that have not spent resources on drought-tolerant traits (i.e. non-native plants) are likely to have a competitive advantage.

Even these well adapted native plants can sustain serious injury to their root structure during frequent, severe, or long-lasting droughts. For example, drought-induced xylem cavitation can cause severe embolism formation in the xylem vessels blocking water transport and cause shoot dieback (Kolb et al., 1994). In arid or semi-arid ecosystems, any decrease in effective precipitation – the portion of precipitation that is stored in the soil – can lower the native plant community resistance to non-native grasses (Chambers et al., 2016). The California drought, affecting the study area since approximately 2014, has likely put this region under a similar stress. Woody tree seedlings with shallow roots can directly compete with native shrubs and invasive grasses. Altered water input and regime can shift the competitive advantage of certain species that can change the overall plant composition. However, the effect of herbaceous competition on woody seedling growth remains constant with both increasing water and nutrient availability (Van Der Walls et al., 2009). The main driver that can shift the competitive dynamic among herbaceous plant and woody seedlings is prolonged wet-season drought, which until recently affected the SSFL (Ochoa-Hueso and Manrique, 2010; Luebehusen, 2017). Minimizing the length of severe water-limited periods can favor the survival of woody seedlings since they are intolerant of wet-season droughts and successful recruitment of young seedlings is dependent on continuous water supply (Ochoa-Hueso and Manrique, 2010).

There is a subtle distinction between understanding how the native vegetation might out-compete the existing non-native species and understanding how the existing vegetation community can resist the invasion of new non-native species. To address the latter topic, new species invasion, the Bren working group examined two invasive species in similar channels on the SSFL that have high potential to colonize: Stinkwort (*Dittrichia graveolens,* a shallow rooted annual herb) and summer mustard (*Hirschfeldia incana,* a shallow rooted perennial herb). Bolstering the native competition in that niche is a simple mechanism to increase the competition facing species attempting invasion of a shallow-rooted niche. *D. graveolens* seedlings emerge from Fall through Spring following rain events (Brownsey et al., 2013), and would therefore be likely to sprout even if the proposed discharge was limited to the winter season. Since the viability of *D. graveolens* seeds can be up to three years in length, the most effective deterrent of persistent *D. graveolens* presence is removing early pioneers before they can complete seed production (Brownsey et al., 2013). Fortunately, *D. graveolens* may be less competitive for soil moisture than other early season annuals (Brownsey et al., 2013). *H. Incana* is also likely to persist during long periods of drought and produce viable seeds (Marushia et al., 2012). For dry ecosystems, management strategies that stop the plants before seed production are generally recommended (Marushia et al., 2012).

To identify where native shallow-rooted communities are the most diverse, the current distribution of shallow-rooted native invasion species in the discharge reach was plotted using data from the working group's vegetation survey (Figure 6). Again, we see a lack of resistance from 100 to 400 feet from the proposed discharge location.

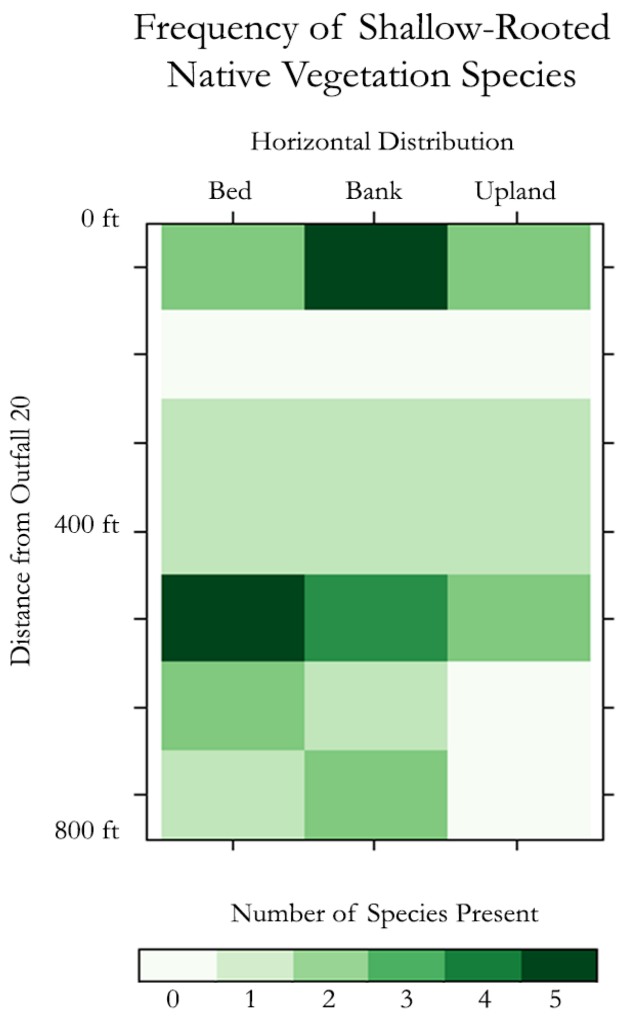

Figure 6. *Distribution of shallow-rooted native species in the discharge channel reach. Areas of higher diversity are colored with a darker green and areas of low diversity are light or white colored.*

Canopy cover and diverse shallow-rooted chaparral community are important for deterring both the growth of the current non-native species of the reach and for deterring the invasion of new non-native species into the new niches that will be created by the introduced flow. Native species' resistance to invasion and non-native species is balanced between having long periods of dryness. The nutrient levels in the introduced flow must be low to avoid supplementing the nutrient content of the soil. Many species of chaparral native to the region are nitrogen fixers, and can tolerate low nitrogen levels better than invasive grasses.

A critical eye by SSFL managers for events that may disturb the reach will be essential, as these events will increase the chance of invasion by destabilizing existing native communities. A long discharge event following such a disturbance will create a hospitable niche for any seedlings in the bed and banks. Seasonal fires can occur in the area, but they are fairly rare. One regular and important disturbance event identified by the Bren working group is the occasional high-volume flows released from stormwater storage ponds further upstream. It is possible that these flows have uprooted susceptible plants growing in the stream bed, creating periodic open soil allowing invasive grasses to pioneer as seen in the first 400 feet from the discharge location. Adding water to the channel via the proposed treated water discharge may allow plants to establish themselves strongly enough to more successfully withstand these high flow storm water discharge events.

2.2.5 Species Distribution in the Reach

Having identified possible plant-interaction mechanisms that resist species invasion, the working group next determined if the riparian habitat downstream of the proposed discharge location exhibits the characteristics of invasive resistance described above. The working group used spatial analysis to identify where there is the lowest resistance to the growth of existing non-native species or the invasion of new non-native plant species.

The distribution of plants was identified for the current water regime. The species list provided by Padre Consulting and the working group's biological survey (Dunn, 2016) had seven observation points, one observation point for every 100 feet along the channel. This information was compiled into a database drawing additional information from the Army Corps of Engineers Arid West 2016 Regional Wetland Plant List.

The Army Corps of Engineer's Arid West 2016 Regional Wetland Plant List is a database that describes the water tolerances of plants inhabiting California. This database organizes plants into categories based on their probability of occurring in wetlands – Obligate almost always occur in wetlands, with a greater than 99% probability. The 'facultative' qualifier means that a species has flexible water requirements, occurring in and outside of wetlands to varying degrees. The Bren working group considered all plants with an obligate rating, a wetland facultative, or an upland facultative rating to be likely to respond well to a continuous water supply. These species were labeled as "hydrophytic" by the Bren working group.

The working group's hydrological assessment demonstrated that the introduced flow will create a significant change to the current moisture status of the bed and banks of the channel. The plant species observations from a 2016 Padre Consulting report did not differentiate between plants in the bed, banks, or uplands of the reach. Chris Dunn, a veteran biologist at the site, separately provided his expert opinion on which plants were likely to be found along the reach, giving this analysis a clearer picture of which species are present in the bed and banks, and therefore which species could be directly exposed to the water in the bed and banks of the reach.

Next, the Bren working group laid out the plants in the reach by their water preferences (Figure 7). The pattern by which plant species have distributed themselves in the current water regime was determined by sorting the reach vegetation database into bins tallying the number of species in each area (bed, bank, or upland) at each observation location. This species count contains all plants likely to be present in each compartment. By taking the ratio of hydrophytic species to the total number of species in that compartment, it was discerned whether plants that prefer water or plants that prefer dry environments dominate the spatial bin (Equation 1). The Bren working group called this value the Water Preference Indicator of the bin (WPI). Since wetland obligate species are likely to thrive particularly well under a continual water discharge, their presence was noted in addition to the WPI, with white stripes. Figure 8 shows these values plotted on a scale of blue, where hydrophytic species dominate, to red, where dry-loving species dominate.

$$WPI = \frac{\sum Hydrophytic\ \ species}{\sum Species\ present\ in\ compartment}$$

WPI = 0, Compartment is dominated by upland plants.
WPI = 1, Compartment is dominated by plants likely to respond well to water influx.

Equation 1. *Calculation of Water Preference Index (WPI) parameter used in Figures 8 and 9. Hydrophytic classifications are obligate, facultative wetland and facultative upland under the Army Corp's definition.*

The area of the reach leading up to the observed groundwater seep is dominated with water-loving plants, while the 200-500 feet area is dominated by drought-tolerant species (Figure 8). Since the water requirements of successful plants in equilibrium are non-uniform, the channel currently likely has a non-uniform distribution of plant-available water. This would change when treated groundwater is discharged into the reach. However, the treated groundwater release would likely create a uniform plant-available water throughout the reach.

The reach has been under the stress of drought for the last few years; it is not surprising that upland plants have colonized so extensively in the drier regions of the channel bed. Water discharge may change how these plants are distributed in the channel, but the habitat has been under extreme drought for many years. The current distribution of species may reflect this; upland plants that succeed when their roots remain drier would have been able to thrive nearer to the center of the dry channel than in non-drought years.

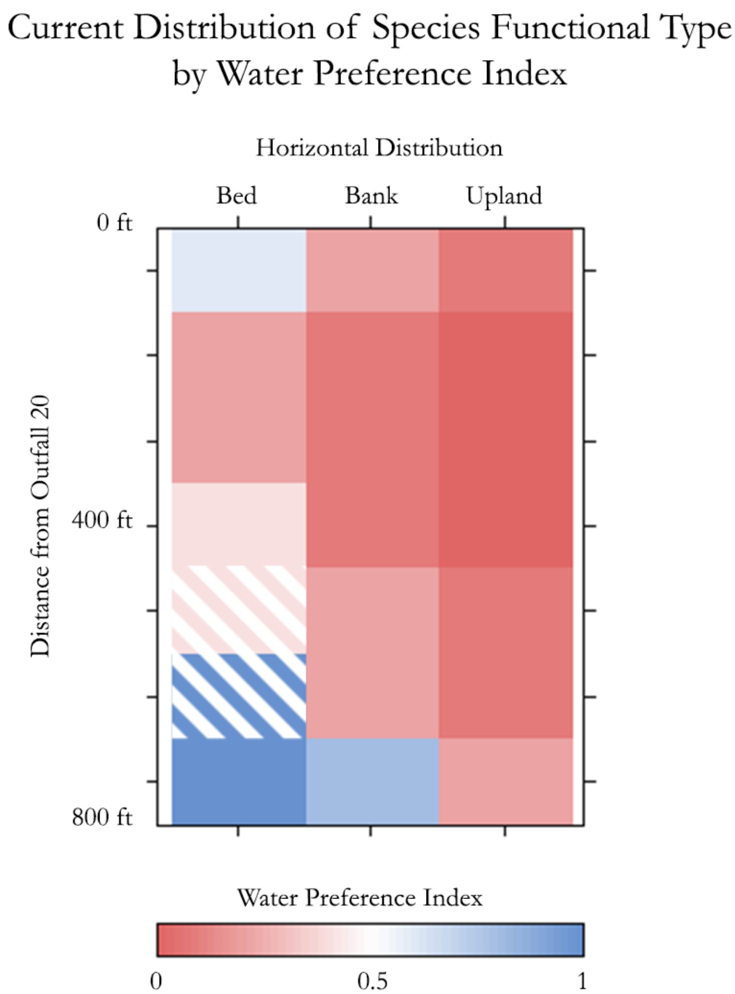

Figure 7. *The distribution of categorical dominance: blue indicated hydrophytic species dominate the space, while read indicated drought-tolerant species dominate. White stripes indicate wetland-obligate species in that location, a sign of existing persistent soil moisture.*

2.2.5 Discussion and Predictions of Impacts to Vegetation

Discharging water into the stream would create a perennial flow maintaining a saturated zone in the channel bed with a water table at the elevation of the stream flow surface in the adjacent stream bank. This would support a permanent column of unsaturated plant-available water in soils distributed along the riparian zone. Permanent wet conditions along the stream would favor a more uniform distribution of plants with high water requirements, specifically hydrophytic plants (Figure 8). The Bren working group considered it likely that the dominance of hydrophytic plants would spread in the channel bed and facultative species, such as invasive grasses, would exist in the stream banks. The obligate plants established near the property boundary groundwater seep would likely spread up the channel. Facultative plants currently in the bed and bank would remain primarily in the bank, an area between the saturated zone and dry soil, due to their flexibility in wet and dry environments. Upland species have low water preference and would be present at the upland portions of the channel, far from the water table.

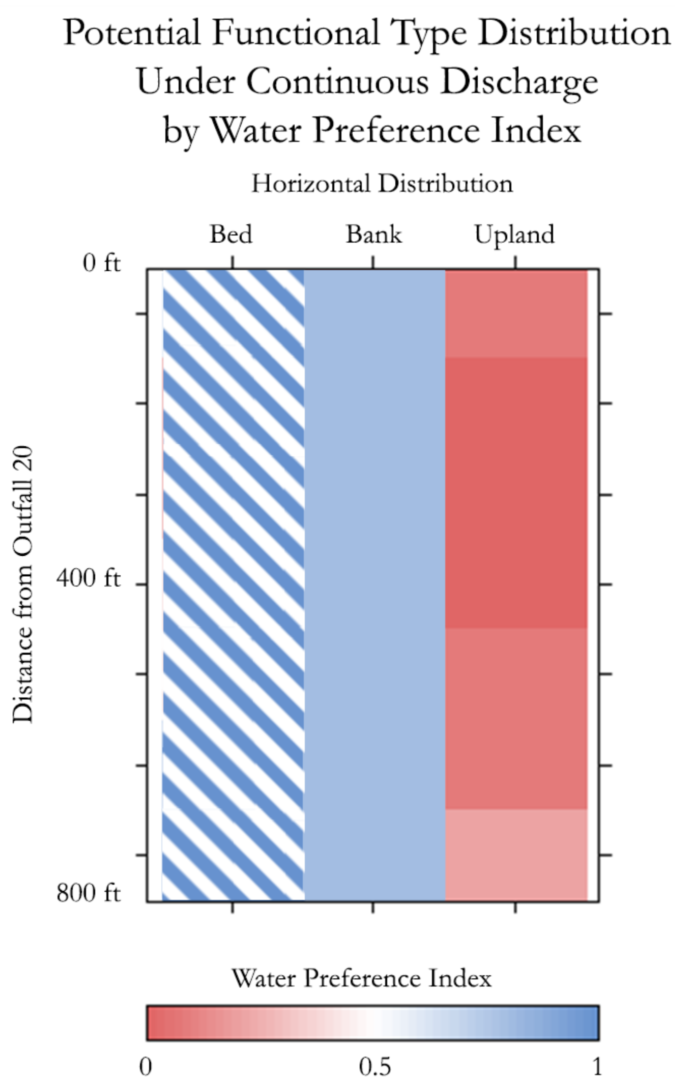

Figure 8. *Expected distribution of obligate or water-loving (dashed blue), facultative (blue), and upland or drought-tolerant (red) plant species found in the outfall reach after treated water discharge occurs.*

In the first stage of the channel's response to water discharge, species with the ability to adapt quickly to water (e.g. facultative wetland status and wetland obligate species) would have the potential to rapidly colonize areas in the stream bed and banks in response to increased water availability. This remains true for non-native grasses and native shallow-rooted species that generally require more water throughout the year. Bare areas with low vegetation density could be potential hotspots for shallow-rooted species, such as invasive grasses, to colonize, resulting in the subsequent reduction of bare soil patches (Chesson et al., 2004). Tree density will remain constant at the beginning of discharge into the stream, though there will probably be a rapid response in canopy density and leaf area index, providing increased shading. However, after this initial response stage, assuming that trees and shrubs are successfully established in areas with low canopy and native diversity cover, there will be an overall increase in plant biomass, including canopy cover along the banks.

Management Strategies to Mitigate Invasions

Given the research and analysis described above, it was determined that non-native species invasion could occur in this new moisture regime established by the water discharge. However, the literature review discussed above revealed no definitive outcome of invasion increasing with water addition. There are adaptive management methods that Boeing could implement to monitor the situation and, if necessary, discourage non-native species while strengthening the existing ecosystem against additional species invasion. The Bren working group has identified methods which could help mitigate the chance of species invasion.

Strategy 1: Decrease Non-Native Presence

Boeing could remove non-native plants from the reach prior to and after channel discharge operations begin. Removal could be achieved by hand-weeding or herbicide application. If herbicide is used, we recommend one that lacks a surfactant (often glyphosate) to better preserve the wetland health of aquatic organisms. Grazing is another technique for plant removal but is not recommend for SSFL. Problems with grazing include water quality issues from ruminant waste, natives will also be consumed and grazing has the potential to favor non-natives by creating a disturbed environment (Gornish, 2016).

Strategy 2: Increase Native Plant Diversity and Canopy Cover

Habitats with high shallow-rooted plant diversity and canopy cover are potentially more resilient to non-native species invasion than habitats without these characteristics (Brooks et al., 2016). Boeing could supplement the reach's vegetation with shallow-rooted native species, or native species that quickly establish canopy cover. This action would increase shallow-rooted species diversity with the goal of adding more plants that could outcompete non-native grasses for water or habitable space. In conjunction with increasing native shallow-rooted diversity, native trees and shrubs could also be planted to increase canopy cover with the goal of shading out non-natives. Native plantings for these projects could include native grasses, shrubs and trees already found in the reach and throughout SSFL. These efforts would be most beneficial in areas identified as being susceptible to invasion in Figures 5 and 6.

Strategy 3: Intermittent Discharge Schedule

If native plants are unable to outcompete non-native species invasion, Boeing could use an irregular discharge schedule as opposed to continuous discharge into the reach. This method would cycle discharge to create dry and wet periods. Native, drought-tolerant plants have deep, extensive root systems that can access water during dry times, while non-natives with a less extensive root system do not succeed as well during dry periods. An intermittent flow schedule will release water into the stream only during wet seasons, which is between November and March at SSFL. The strategy here is to introduce a stressful environment that will disfavor non-native plant invasion for the lifespan of the project. This method would take advantage of native plants' natural ability to survive drought, hopefully reducing invasion or preventing the spread of non-native species invasion along the channel.

The intermittent flow strategy may work in synergy with Boeing's goal of keeping the water table below the surface to prevent possible exposure to contaminants. Since the water table level is likely to only increase during seasons of high precipitation, there may be no need to pump groundwater during the summer because the water table will remain stable in the absence of precipitation.

For an irregular discharge schedule to be implemented, Boeing would need an alternative discharge option to manage treated water during the dry, summer months. The Bren working group next investigated alternative discharge options that Boeing could focus their attention to complement channel discharge and be able to deploy an irregular discharge schedule.

2.3 Analysis of Discharge Management Options

In addition to providing Boeing with an analysis of stream flow effects, the Bren working group also performed an analysis of other discharge management options to determine a cost effective alternative to stream discharge. An alternative to stream discharge also needed to be identified to manage the treated water during the summer months for the intermittent flow schedule strategy to be implemented. Additionally, a viable discharge alternative could be used as part of a suite of management options to increase the likelihood of the LSA permit approval from CDFW.

One of Boeing's consultants on this project, MWH Consulting, conducted an analysis of costs associated with various options for management of the treated groundwater in a 2016 technical memorandum to Boeing. The Bren working group expanded on the MWH analysis by estimating the net present value of the project, including the benefits associated with treating the water. Additionally, other management options not analyzed by MWH were identified and analyzed by the working group.

This study also investigated two ways to quantify indirect benefits beyond the Boeing's bottom line. First, a method was created to determine the influence of the instream flow that would be created by the proposed discharge on the surrounding property values, known as a hedonic study or an *Instream Flow Property Valuation.* Second, an analysis was conducted to determine the benefits to the public from transferring the SSFL into an open space or recreational area, called a *Preliminary Valuation of Remediated Site to Open Space*.

2.3.1 Discharge Alternatives

Five alternatives for the management of the treated groundwater were analyzed: 1) Boeing's proposed Channel Discharge; 2) Direct Reinjection; 3) Discharge to a Nearby Sewer System; 4) Discharge to Chatsworth Reservoir, a nearby wetland in need of habitat rehabilitation; and 5) Water Markets, transferring the water to companies or organizations that may want to purchase it. A preliminary analysis of construction costs, permitting processes, and legality revealed that Alternatives 3, 4, and 5 are not viable due to high costs, intricate permitting procedures, and nebulous groundwater rights. Implementing any one of these strategies would open Boeing to potential litigation over water rights. A cost and permitting analysis of Alternatives 1, 2, and 3 was conducted by MWH Consulting; Alternatives 4 and 5 were analyzed by the Bren working group. Additional information on Alternatives 3, 4, and 5 can be found in Appendix A.

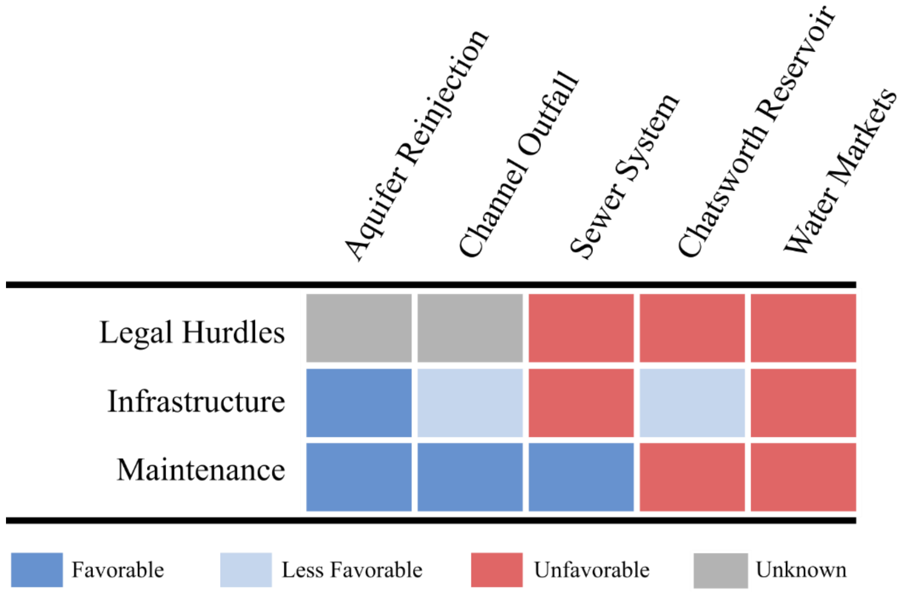

Figure 9. *Summary of the results from the feasibility assessment of treated water discharge options.*

Alternative 1: Proposed Channel Discharge

Boeing intends to discharge treated groundwater in a reach located at the southern portion of the SSFL (Figure 1). This discharge location is downhill of the GETS; water would flow by gravity to a point of discharge in the reach for 800 ft. before it reaches Boeing's property boundary. The stream receiving the discharge of treated water connects to the Bell Canyon Creek, which flows into the Los Angeles River.

The *Analysis of Proposed Discharge* section of this report investigated the vegetation impacts of this alternative; however, for the purpose of analyzing the cost and benefit of this management option, this section of the report assumed that there are no negative environmental repercussions from introducing additional water.

Alternative 2: Direct Reinjection

Treated groundwater could be piped to an onsite well for reinjection into the Chatsworth Formation. Moving water offsite could result in litigation against Boeing, since groundwater rights are not well defined in this basin and are typically clarified by lawsuit. Reinjecting the treated groundwater into an onsite reinjection well will keep the treated groundwater on site and avoid potential litigation. Similar to Alternative 1, this section of this report assumed that there are no negative environmental impacts resulting from this alternative.

2.3.2 Project Lifetime Valuation

The benefits for either of these alternatives were considered to be the avoided non-compliance fine of $10,000 per day that could be imposed by regulators if groundwater treatment does not move forward. The costs are Boeing's direct financial burdens from the construction and operation of the water discharge projects. A discount rate of 9.5%, which is a typical project discount rate for Boeing, was applied to the benefit and costs to determine the net present values (NPV) and benefit-cost ratios (BCR) associated with each management option. The NPV and BCR were conducted for Alternatives 1 and 2 based on lower construction costs and legal requirements such as permitting. Boeing intends to revisit the selected discharge option in 10 or 25 years to evaluate the effectiveness of removing the contaminants from the groundwater. NPV and BCR for 10- and 25-year operation for the alternatives helped to determine which treated groundwater management options are financially beneficial. Additional costs and calculations for this analysis can be found in Appendix A.

Alternative 1: Proposed Channel Discharge

New construction for discharging treated water into an onsite stream would be required; a piping system would be installed above-ground from the GETS to the discharge location (Andrachek et al., 2016). Additionally, two permits are required for this alternative: 1) National Pollutant Discharge Elimination System (NPDES) from the Los Angeles Regional Water Quality Control Board (CWB); and 2) Lake and Streambed Alteration (LSA) from the California Department of Fish and Wildlife (CDFW). The CWB issued Boeing the NPDES permit with a 5-year expiration; however, the LSA has not yet been issued by the CDFW. In addition to the construction and permits costs, the Upper Los Angeles River Area (ULARA) Wastewater fees for extracting groundwater of $0.90 per 100 gallons would be required. (Present Values of costs for Alternative 1 are summarized in Appendix A, Table 2A)

Alternative 2: Reinjection

Infrastructure construction for direct reinjection will require a booster pump system since the reinjection well is located uphill of the GETS (Andrachek et al., 2016). Treated groundwater storage tanks, transfer pump, and level controls would be installed next to the GETS (Andrachek et al., 2016). Due to the relatively short distance from the GETS to the reinjection well, construction necessary for this alternative would only require a small crew working approximately for five working days (Andrachek et al., 2016). Permits and ULARA wastewater discharge fees would not be required for Alternative 2 since treated water will remain onsite. (Present Values of costs for Alternative 1 are summarized in Appendix A, Table 2A)

NPV and BCR

Directly injecting the treated water into the aquifer (Alternative 2) had the highest Benefit-Cost Ratio (BCR) and Net Present Value (NPV) in both 10-year and 25-year project lifetimes (Table 3). The NPV of both alternatives was extremely high due to the costly consequences of taking no action which was a non-compliance fine of $10,000 per year.

***Table 3**. Benefit cost ratio (BCR) and net present value (NPV) for Alternative 1 and Alternative 2 for 10- and 25-year operation with a discount rate of 9.5%.*

Project Lifetime	Scenario	BCR	NPV
10 Years	1: Channel Discharge	2.64	$16,496,218
	2: Direct Reinjection	3.56	$19,104,002
25 Years	1: Channel Discharge	2.55	$23,177,668
	2: Direct Reinjection	3.56	$26,985,158

2.3.3 Preliminary Valuation of Remediated Site as Open Space

Boeing intends to re-evaluate the effectiveness of its groundwater treatment process after 10 or 25 years. If the analysis of the groundwater treatment processes are effective, Boeing intends to transfer the SSFL into an open space or a recreational site to be managed by a state or local park service. Introducing a new recreational site in a predominantly metropolitan area like the County of Los Angeles and Ventura increases environmental amenities and provides benefits to the public in the region. This analysis utilized the California State Parks' (CSP) 2010 *California Outdoor Recreation Economic Study: Statewide Contributions and Benefits* to quantify the benefit of transferring the SSFL into a recreational site. Individual benefit or consumer surplus – the difference between an individuals' willingness-to-pay (WTP) to attend a recreational site and the amount that they actually paid – was extracted from the CSP study and applied to the total visitations of a similar site to obtain the total benefit to the public from transferring the SSFL into a recreational site.

Data Acquisition

The CSP study quantified the contribution to the California economy from expenditures on outdoor recreation and the economic benefits that Californians receive from participating in outdoor recreation. This analysis focused on the latter part of the CSP study – the economic benefits that Californians received from a recreational site. The economic benefits were examined for different regions of California and for different types of parks and facilities such as federally-managed, state-managed parks, and local or regional parks. Data used to quantify economic benefits to Californians in the CSP study was from 2,780 responses on a 2008 Survey of Public Opinions and Attitudes on Outdoor Recreation (SPOA). 1,227 of the participants subsequently completed more detailed mail surveys. The participants were surveyed on their WTP and their average expenditures to attend recreational sites.

The CSP utilized the value of participation (per visitor, per day) by facility types in different regions of California. This analysis extracted the benefits to individuals that attend local parks in the Los Angeles region from the CSP study. This region includes the Los Angeles County and the Ventura County; the SSL is located within the border of Los Angeles and Ventura County. Total annual benefits and total consumer surplus to residents for attending local and regional parks is $1,501 million per year with an average visit of 26 times per year for an average adult in the Los Angeles region (Table 4). To determine the individual consumer surplus per visit per year, total adult populations from Ventura and Los Angeles Counties was obtained from the US Census Data (Table 5). The total annual consumer surplus for the Los Angeles region was divided by the regional adult population and number of visits per adult to obtain the individual benefit per visit per year, which was $6.76 (Table 4).

Table 4. *The economic benefit or consumer surplus of regional and local parks to Californians and the average number of visits for an adult in the Los Angeles region.* Source: CSP 2010 study and US Census Data.

Total Annual Benefits	Regional Adult Population	Number of Visits per Adult	Individual Benefit per Visit
$1,501,000,000	8,540,255*	26	$ 6.76

* Regional adult population is the sum of the US Census Data's projected adult populations in Ventura and Los Angeles Counties in 2015.

Table 5. *The projected populations for the Los Angeles and Ventura Counties in 2015.* Source: US Census Data.

County	Total Population	Under 18 Population	Adult Population
Los Angeles	10,170,292	2,278,145*	7,892,147
Ventura	850,536	202,428**	648,108

*22.4% of the total Los Angeles County's population is under the age of 18.
**23.8% of the total Ventura County's population is under the age of 18.

Due to the its proximity to the SSFL site, Tapo Canyon Park was utilized as a proxy to determine the visitation rate for SSFL site. Tapo Canyon Park's annual visitations from 2011 to 2015 were obtained from the Ventura County Parks Department (Table 6). Tapo Canyon Park is located approximately 6 miles away from the SSFL with similar climate and topography to those of the SSFL. The CSP study concluded that regional and local parks tend to be visited by residents that are within approximately 15-mile radius to the sites. The individual consumer surplus per visit per year, $6.76, was predominantly influenced by local residents' recreational behavior (CSP, 2010). Tapon Canyon Park is within a 15-mile radius from the SSFL (Figure 11). This analysis assumed that the same populations or demographics that visit Tapo Canyon Park would also visit the SSFL recreational site due to the close proximity and similar climate and topography.

Table 6. *Annual visitations of Tapo Canyon Park from 2011 to 2015. Each total consumer surplus or total economic benefit for the public within 15-mile radius of the SSFL is the product of visitation and individual benefit per visit per year, $6.76.* Source: Ventura County Parks Department and CSP 2010 Study.

Year	Annual Visits	Total Consumer Surplus
2011	7,001	$47,327
2012	7,407	$50,071
2013	8,997	$60,820
2014	8,721	$58,954
2015	11,813	$79,856

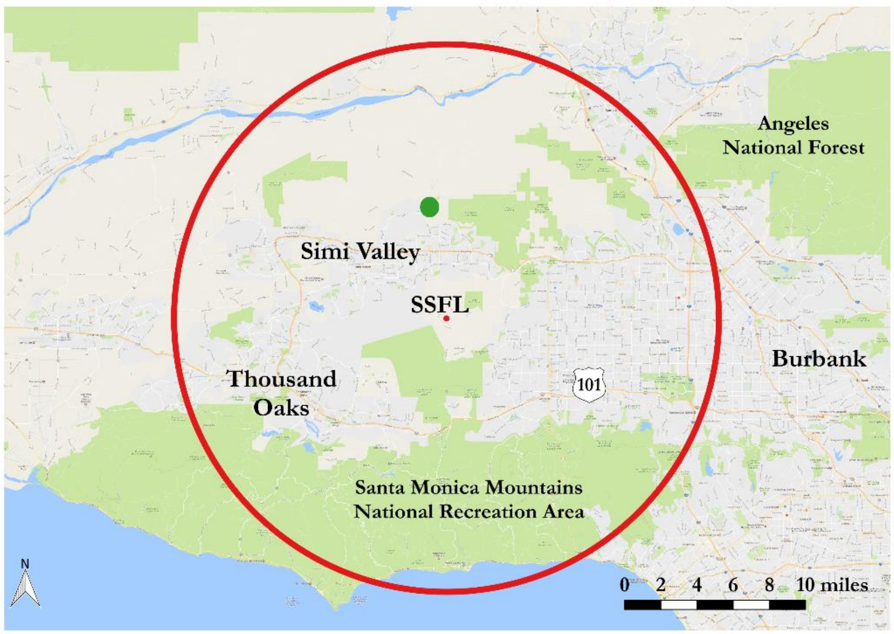

Figure 10. *15-mile radius of the SSFL site (red). The Tapo Canyon Park (green) is within the 15-mile radius of the SSFL site and can be assumed to be visited by the same populations and demographics as those of the Tapo Canyon Park. Source:* CSP 2010 study and Google.

2.3.4 Discussion

Project Lifetime Valuation

Based on the net present values (NPVs) and benefit-cost ratios (BCRs) for the 10- and 25-year projection, direct reinjection was more financially beneficial to implement. However, this analysis was completed prior to LARWQCB permit – which allows reinjection on site – decision on Boeing permit application. Prior to the formal LARWQCB's decision, reinjection option seemed to be favored by the agency. However, LARWQCB permit was denied for the SSFL site. Thus, despite lower NPVs and BCRs, the proposed channel discharge option remains relevant to Boeing's management options of the treated groundwater. It may also be beneficial for

Boeing to employ both management option in order to minimize changes in riparian vegetation response to the proposed channel discharge.

Preliminary Valuation of Remediated Site as Open Space

Individual consumer surplus per visit per year is multiplied by the annual visitation to determine the total benefit to the public from transferring the SSFL site into a recreational site (Table 6). Demand for recreational sites is consistently increasing in the SSFL's surrounding communities where total benefits to the public per year increased from $47,327 to $79,856 in 2011 to 2015 respectively. Projected total consumer surplus seemed to increase based on the current visitation growth rate (Figure 11). Based on this projection, if the park is opened at the end of the 10-year study period, the total consumer surplus provided by SSFL was projected to be $165,661 with a visitation of 24,506 by the year 2027 (Figure 11).

The demand for recreational sites was increasing in the region, demonstrating that transferring the SSFL site into an open space could provide more environmental amenities to the surrounding communities. Additionally, as Tapo Canyon Park becomes more crowded as the demand increases, the park becomes less desirable and its economic benefits to visitors may decrease. Thus, the SSFL site will not compete with Tapo Canyon Park and split visitation; instead, the SSFL site could potentially ensure that the benefit to visitors remain relatively constant by ensuring that over-crowdedness does not reduce the park's economic benefits to visitors.

Instream Flow Property Valuation

Indirect benefits from Alternative 1, discharging water to a dry tributary of Bell Creek, could be measured using a hedonics study to determine the aggregated increase in property values along the creek due to increased channel flow. Unfortunately, neither the LA River Restoration Project nor the LA Department of Water and Power records water flows in Bell Canyon, so an analysis could not be completed. This study designed a methodology for such a hedonics study in case data is available in the future. In order to push Alternative 1's NPV above Alternative 2, this hedonic benefit would need to add at least $2,607,784 to Alternative 1's 10 year NPV, or $3,807,490 to its 25 year NPV.

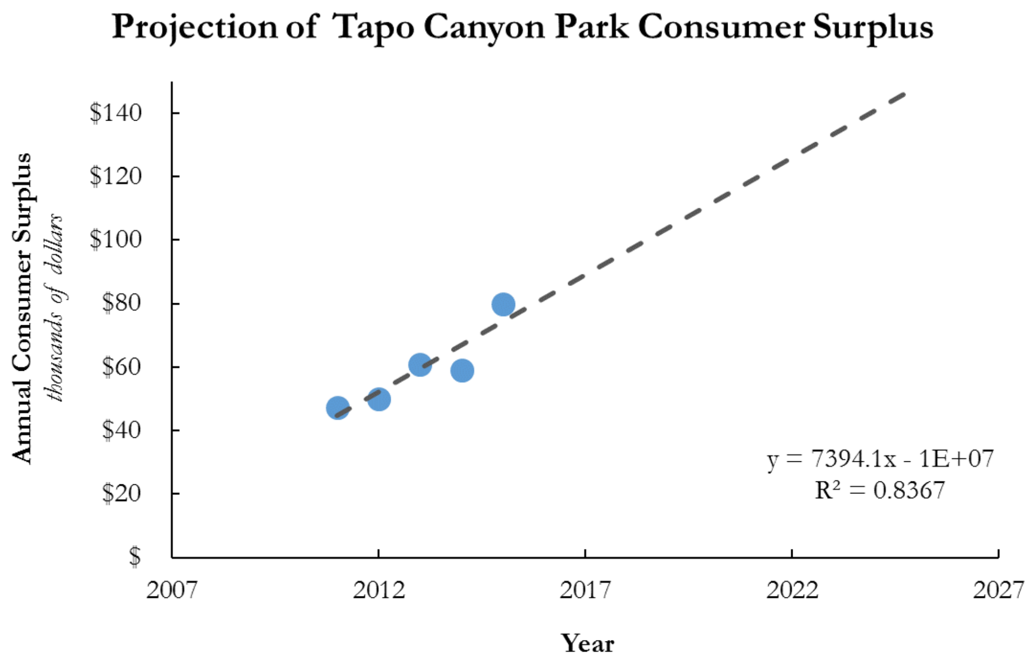

Figure 11. *Consumer surplus of Tapo Canyon Park calculated based on CSP 2010 estimates and Ventura County Parks Department visitation data. Trendline estimates 10 years of similar growth.*

2.3.5 Limitations and Next Steps

Due to the lack of instream flow data for the Bell Canyon tributaries, this analysis did not quantify the impact of introducing water to the Bell Canyon Creeks for the surrounding property values. However, if instream flow data becomes available in the future, the working group can utilize the data to generate the results that can further assist the Boeing Company in determining which Alternative is the appropriate management option. Detailed methodology for the *Instream Flow Property Valuation* can be found in Appendix A.

The recreational visitation estimate was limited by the assumption of independent visitation between Tapo Canyon and SSFL. However, even if this assumption was violated, SSFL would still provide value to the public by decreasing visitation density, preventing degradation of existing park facilities from those visitors. Future studies could attempt to quantify this effect.

Visitation data from other parks would increase the accuracy of the visitation rate forecast. Tapo Canyon is not a perfect proxy; it is only 210 acres compared to SSFL and provides amenities that SSFL is not likely to install, such as 16 RV hook-ups. However, other potential proxy parks in the region do not track visitation rates. Furthermore, majority of the park managers that were contacted for data were not responsive to data requests.

Future studies may consider a more precise assessment of the park's value as additional recreation space. This will require better data on park visitation, scaled for park size relative to SSFL and adjusted for additional amenities. Visitation rates of nearby parks are steadily increasing, which has been shown to degrade environmental amenities. Studies expanding on this work could put a dollar value on how SSFL as an open recreational site may reduce strain on existing parks.

3 Summary and Conclusions

3.1 Hydrology

The Bren working group analyzed different stormwater and groundwater discharge scenarios: 1) 60 gpm of treated groundwater; and 2) 460 gpm of combined stormwater and treated groundwater. Combining this analysis with the geometry of the drainage, the working group concluded that water would only overflow the channel banks in one location under the combined discharge scenario (Figure 2). For the 60 gpm scenario, flow depth would vary along the channel from 1.2 to 7 inches, and would never overflow the channel banks. This revealed that the proposed channel discharge would cause a permanent water table, creating plant-available water in the bed and banks of the reach. Additionally, calculations of the evapotranspiration, evaporation, and infiltration demonstrated that these rates of water escapement are insignificant compared to the flux of groundwater release (Table 1). Water would flow downstream beyond Boeing's property boundary before dissipating.

3.2 Vegetation

3.2.1 Native Plants and Flow Schedule

Current native vegetation composition along the reach is composed of chaparral, mulefat scrub, coast live oak riparian woodland, and grassland. These vegetation communities are relatively drought-tolerant; however, drought during historically wet months – November to March – can impact native species, making them vulnerable to invasion. The added water from treated groundwater discharge could increase productivity of the native plant community during their growing seasons. Therefore, if historically wet months continue to experience drought conditions in southern California, the added water may provide ecosystem resilience in this area.

Native plants at the SSFL have traits that reduce their water loss during dry months while non-native plants at the SSFL lack many of those drought-tolerant traits. A discharge scenario that creates intermittent dry periods would allow the native plants to utilize their drought-tolerant traits to better compete with non-native plants. In contrast, a discharge scenario that created a continuous flow in historically dry seasons may favor non-native plants.

The purpose of the proposed groundwater discharge is to reduce exposure to TCE. Currently, the majority of the TCE is in the bedrock fractures; heavy rainfall causes the water table to rise which can push the TCE to the surface. To this end, it is possible that little to no pumping of groundwater will be necessary during dry summers. A discharge schedule releasing water during only historically wet months (November to March) would allow Boeing to maintain the groundwater table at an appropriate level, while also accomplishing two goals for native plants: 1) Allowing native plants to retain and use their drought-tolerant traits as a competitive advantage against non-native species, and 2) Boosting the productivity of native plants in their growing season.

3.2.2 Native and Non-Native Species Interactions

Plant communities along the reach consist of shallow- and deep-rooted plants. Shallow-rooted plants extract more water from the shallow soil compartments. Since the reach is a bedrock lined channel with no deep soil compartment, the short-term response of the vegetation would consist of shallow-rooted, herbaceous species increasing in biomass proportional to deep-rooted species. In the long-term, water could enter bedrock fractures that may be created by deep-rooted species that previously existed along the reach. This, in turn, could increase the proportional biomass of the deep-rooted species that already exist along the reach.

An analysis of the water tolerance of current species along the reach demonstrated that within the channel bed obligate and facultative plants dominate the lowermost 200 feet of the study area. The presence of a groundwater seep at the end of the reach creates a wet area that can support water-tolerant and water-loving plants, like southern cattail (*Typha domingensis*). Facultative plants dominate the banks of the reach, even in the last 100 feet of the channel near the groundwater seep. In the upland portion of the entire reach, drought-tolerant plants dominate along the reach.

The current distribution of plants based on the current plant-available water served as a baseline estimate of how different plants could respond to a continual release of treated groundwater. As treated groundwater is released, the soil along the channel bed would become saturated, creating a favorable condition for obligate and facultative species to spread from the bottom of the reach. Due to the high water-tolerance of obligate species, obligate species could dominate regions of the channel bed where facultative species currently dominate. Along the channel banks, the majority of the plants would be facultative due to lower soil moisture level compared to the channel bed. The few drought-tolerant species that currently exist in the channel bed and banks, due to the increase in soil moisture level, could be forced away from the channel bed and banks, only dominating the upland region.

The Bren working group found that areas with the lowest resistance to the invasion of non-native vegetation are areas with low diversity of shallow-rooted and canopy species. Two non-native grasses, smilo grass and ripgut brome, are present along stretches of the reach. Their absence is notable in the last 200 feet of reach (Figure 4). This last portion of the reach has a higher diversity of native shallow-rooted species and species providing canopy cover (Figure 4). Conversely, areas with the lowest native species diversity and canopy species have the most non-native grass species. Two factors may have contributed to the resistance of non-native plant invasion in these areas. First, native shallow-rooted species with high water-requirements extract water and nutrients from the same soil compartments as shallow-rooted non-native grasses. This interaction may impede where non-native plants can grow. Second, trees provide canopy cover, shading out solar radiation that non-native plants utilize.

There are occasional releases of stormwater that has been collected in ponds upstream from the proposed point of discharge. These events create short durations of high flow during wet months. Some plants in the bed of the reach may periodically be scoured out, only to recolonize the area later. This disturbance may have presented a previous opportunity for the invasion of non-native species, allowing the current non-native grasses to invade the channel. These events may continue to present a vulnerability to invasion under groundwater project discharge conditions. The stormwater flows under the new conditions will create a disturbance, followed by longer periods of abundant plant-available water. This has the potential to support pioneer species that have higher water requirements than the *Bromus* and *Stipia* species that are currently present in the bed of the channel. This could be the main risk for new invasion. Furthermore, this additional amount of water could allow the currently present non-native species to propagate farther.

3.3 Cost and Benefit Analysis

3.3.1 Net Present Values and Benefit Cost Ratio

Direct reinjection has higher net present values (NPVs) and benefit cost ratios (BCRs) for the projected 10- and 25-year projects, demonstrating that direct reinjection is a more cost-effective treated groundwater management option for Boeing. The benefits associated with the proposed channel discharge and direct reinjection is the avoided non-compliance fee of $10,000 per day. Construction costs for direct reinjection are lower than those of the proposed channel discharge. Benefit and costs were discounted over time at Boeing's internal project discount rate of 9.5%. Value added by preventing exposure to TCE was considered to be accounted for in the non-compliance fine.

3.3.2 Instream Flow Property Valuation

A methodology to analyze the influence of water discharge on the surrounding property values – a hedonic study – with the addition of treated groundwater flow to the onsite stream (Alternative 1) was created. However, due to the lack of historic instream flow data for this reach in Bell Canyon, an analysis could not be completed. If historic instream flow data becomes available in the future, the methodology that was created by this study could be utilized to determine channel discharge's added value to properties bordering the reach. This hedonic study would need to add at least $2,607,784 to the 10-year NPV, or $3,807,490 to the 25-year NPV, of the channel discharge project in order to make channel discharge a more cost-effective option than direct reinjection. This of course would not be not value added directly to The Boeing Company, but the public value of the project.

3.3.3 Valuing the Remediated Site as an Open Space

The Santa Susana Field Laboratory (SSFL) is located in a predominantly metropolitan area. An analysis of visitation rates of Tapo Canyon Park – approximately 6 miles away from the SSFL – demonstrated that demand for open spaces and recreation areas has been steadily increasing in this region (Figure 9). According to the California State Park (CSP), regional and local parks tend to be visited by residents that are within approximately 15-miles radius to the site. Since Tapo Canyon Park is within a 15-mile radius from SSFL, this analysis assumed that the same demographics that visit Tapo Canyon Park will also visit the SSFL recreational site due to the close proximity and similarities in climate and topography. Individual consumer surplus for visitation to a local park was provided by CSP and US Census Data for the region, $6.76 per person per visit.

Demand for open spaces was projected for 10 years based on historic visitation rate at Tapo Canyon park. Based on this projection and the individual consumer surplus rate, if SSFL is transferred into an open space in 10 years, the total consumer surplus provided by SSFL is projected to be $165,661 with a visitation of 24,506 by the year 2027 (Figure 10).

4 Recommendations

The working group recommends that Boeing monitor for new invasion and the spread of existing non-native species. If monitoring of the reach demonstrates that non-native plants are increasing, Boeing can take action by actively restoring riparian vegetation and discharging the treated groundwater on an intermittent schedule.

4.1 Monitoring of Non-Native Species

- Actively monitor the first 400 feet of the proposed discharge location to track the growth of the existing non-native grasses, smilo grass and ripgut brome, as well as new invading non-native species.
- If non-native species are increasing in relative abundance along the reach, conduct active restoration of the riparian vegetation.

4.2 Active Restoration of Riparian Vegetation

- Remove smilo grass and ripgut brome from the proposed discharge location
- Supplement native plants and trees within the first 400 feet of the discharge location to increase environmental resistance to non-native species along this portion of the reach. Prioritize shallow-rooted native species and species that quickly establish canopy cover.

4.3 Treated Groundwater Release Schedule

- Treated groundwater could be released into the stream only from November to March to mimic historical precipitation events. Cycling between other discharge methods, such as direct reinjection, would allow the channel to periodically dry without pausing the treatment project. This could be utilized during dry months and during the wet season to allow native plants to use their drought-tolerant adaptations to compete with non-native species. Utilizing additional outfall locations would also allow for non-continuous flow in a channel while groundwater treatment continues without interruption.

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Appendix A: Additional Information on Discharge Management Options

There are several methods available for the discharge of treated water from water treatment projects. The Bren working group researched and analyzed the feasibility of five options for treated water management. The purpose of this analysis was to explore and assess the feasibility of alternatives for channel discharge. In addition, this analysis helped to identify a discharge option for the dry, summer months so that the Irregular Discharge Schedule could be implemented. The management options the working group explored were:

1. Channel Discharge
2. Reinjection
3. Discharge to Sewer
4. Rehabilitation of Chatsworth Reservoir
5. Water Markets

Channel Discharge

The channel discharge option would release treated water from the GETS into a natural drainage on-site at SSFL. The costs associated with option include the construction, maintenance and permitting for approximately 8,000 feet of piping to connect the GETS to the drainage. Discharge from this system would have a target of 49 gpm and a maximum discharge of 60 gpm (Andrachek, 2016). Permits and approval from the Los Angeles Regional Water Quality Control Board, California Department of Fish and Wildlife and United States Army Corps of Engineers would be required (Andrachek, 2016). Total costs for implementing and operating for 10 years is estimated to be $15.8 million (Andrachek, 2016). The potential impacts of this activity was the primary focus of our research and was described in detail above.

Reinjection

This option uses pumps to return treated water from the GETS back to the Chatsworth Formation – the groundwater aquifer under SSFL. The maximum flow from the reinjection system to the groundwater is expected to be 49 gallons per minute. Reinjection costs are pumps, approximately 500 feet of pipes, permitting, maintenance and operational costs. Capital costs are expected to be $210,000 with an additional 10-year operating expense of $11.6 million (Andrachek, 2016). Boeing has already pursued this option but has been blocked by regulators during the permitting process. Reinjection was further analyzed in the Cost-Benefit Analysis described above.

Table 1A. *Upfront and annual costs for Channel Discharge and Reinjection used the Cost-Benefit Analysis*

	Upfront Costs		Annual Costs	
Channel Discharge	Pre-construction	$50,000	NPDES Permit	$800
	Construction	$221,750	URLARA Watermaster Fee	$10,000
	Construction allowances	$71,834	Monitoring of ecological impacts	$4,800
	Owner allowances	$69,000	Annual GETS Maintenance and Operation	$744,000
	Project allowances	$21,805	Annual GETS Treatment Media OPEX Costs	$686,000
	Fish and Wildlife Permit	$307		
	TOTAL	$434,696		$1,969,496
Reinjection	Pre-Construction	$62,400	Utilities	$1,000
	Construction	$67,550	Reinjection Well replacement	$40,000
	Construction allowances	$29,010	Reinjection Well rehabilitation	$12,000
	Owner allowances	$28,000	GETS Maintenance and Operation	$744,000
	Project allowances	$8,743	GETS Treatment Media OPEX Costs	$358,000
	TOTAL	$195,703	**TOTAL**	$1,155,000

Table 2A. *Results from Net Present Value calculation for the direct costs and benefits for Channel Discharge and Reinjection using a 10-year timeframe of operation*

	Net Present Value										
Alternative 1: Channel Discharge	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
NPDES Permit	$800	$731	$667	$609	$556	$508	$464	$424	$387	$353	$323
URLARA Watermaster Fee	$10,000	$9,132	$8,340	$7,617	$6,956	$6,352	$5,801	$5,298	$4,838	$4,418	$4,035
Monitoring of ecological impacts	$4,800	$4,384	$4,003	$3,656	$3,339	$3,049	$2,785	$2,543	$2,322	$2,121	$1,937
Annual GETS Maintenance and Operation	$744,000	$679,452	$620,504	$566,670	$517,507	$472,609	$431,607	$394,161	$359,965	$328,735	$300,215
Annual GETS Treatment Media OPEX Costs	$686,000	$626,484	$572,132	$522,495	$477,164	$435,766	$397,960	$363,434	$331,903	$303,108	$276,811
TOTAL	$1,969,496	$1,320,183	$1,205,646	$1,101,047	$1,005,522	$918,285	$838,617	$765,860	$699,415	$638,736	$583,320
Alternative 2: Reinjection											
Utilities	$1,000	$913.24	$834.01	$761.65	$695.57	$635.23	$580.12	$529.79	$483.82	$441.85	$403.51
Reinjection Well replacement	$40,000	$36,529.68	$33,360.44	$30,466.15	$27,822.97	$25,409.11	$23,204.66	$21,191.47	$19,352.94	$17,673.92	$16,140.57
Reinjection Well rehabilitation	$12,000	$10,958.90	$10,008.13	$9,139.85	$8,346.89	$7,622.73	$6,961.40	$6,357.44	$5,805.88	$5,302.18	$4,842.17
GETS Maintenance and Operation	$744,000	$679,452.05	$620,504.16	$566,670.47	$517,507.27	$472,609.38	$431,606.74	$394,161.41	$359,964.76	$328,734.94	$300,214.55
GETS Treatment Media OPEX Costs	$358,000	$326,940.64	$298,575.93	$272,672.08	$249,015.60	$227,411.50	$207,681.74	$189,663.69	$173,208.85	$158,181.60	$144,458.08
TOTAL	$1,155,000	$1,054,794.52	$963,282.67	$879,710.20	$803,388.31	$733,687.95	$670,034.66	$611,903.80	$558,816.26	$510,334.48	$466,058.89
Benefits											
Avoided Penalty	$3,650,000	$3,333,333	$3,044,140	$2,780,037	$2,538,846	$2,318,581	$2,117,426	$1,933,722	$1,765,956	$1,612,745	$1,472,827

Discharge to Local Sewer System
Treated water from the GETS could be released directly into the Simi Valley or Ventura Regional sanitary sewer system. This option would require the installation of pumps and pipes to connect the GETS to the sanitary sewer manholes (Andrachek, 2016). Permits for grading and property encroachment would need to be obtained, in addition to permits and fess from the sanitary districts to receive the water (Andrachek, 2016). The Simi Valley option would require the construction of 21,700 feet of pipes while the Ventura Regional option would utilize existing pipes with an additional 1,000 feet added to complete a connection to the sewer manhole (Andrachek, 2016). The Ventura Regional water sanitation managers have already denied requests to accept treated water from SSFL, while Simi Valley managers were more open to accepting SSFL treated water pending a plan review (Andrachek, 2016). Both of these sewer discharge options would have large environmental impacts from physical disturbance, vehicle and equipment emissions, and require more fuel and construction materials than most other alternatives considered (Andrachek, 2016). Net costs for this alternative (capital and 10-year operational costs) are estimated to be $15.6 million for the Simi Valley option and $12.8 million for the Ventura Regional option (Andrachek, 2016).

Rehabilitation of Chatsworth Reservoir
Water from treatment projects can also be used to rehabilitate local wetlands. Our group identified the Chatsworth Ecology Pond at Chatsworth Reservoir as a candidate for wetland rehabilitation. This wetland is about four miles from SSFL and has been heavily impacted from the prolonged drought in California. The Ecology Pond is approximately 7 acres in size and can hold 95,000 cubic feet of water (LADWP, 2016). The discharge of treated water from SSFL, at 49 gpm, would fill the Ecology Pond in about 10 days, much shorter than the dry season and required time necessary to be a feasible alternative to Channel Discharge. The Ecology Pond's wide and shallow composition make it prone to quick evaporation (DWP, 2016). However, water loss from evaporation will most likely not result in dramatically increasing the number of days the Ecology Pond could be used to receive treated water from SSFL. Construction, permitting and other legal issues are expected to be larger than most other alternatives, especially on-site management options of treated water discharge.

Water Markets
Boeing could sell treated water from the GETS through water markets. For example, treated water could be sold for irrigation of a nearby golf course or for non-potable reuse by a local municipality. Water is sold in California's water market through leases and permanent sales of water rights (PPIC, 2012). California's water market, which began in the early 1980's, accounts for about 3% of all water used in the state, with most water sales coming from the farming sector – farmers selling water to cities (PPIC, 2012). However, trading is complicated by oversight from multiple agencies and a fragmented and inconsistent transfer approval process (PPIC, 2012). The situation at SSFL is further complicated because the groundwater basin boundary was not designated under the Sustainable Groundwater Management Act of 2014. Without this designation, water rights at SSFL are undetermined and transferability of SSFL groundwater would be contentious.

Management Options and Alternatives Conclusion
Research revealed that any option that transports water off-site will be obstructed from legal and water rights issues, mostly caused by SSFL groundwater being in an unadjudicated water basin. Therefore, treated water should be managed on-site. The next best method for Boeing, besides channel discharge, is groundwater reinjection. Although reinjection and channel discharge has been blocked by regulators, it's possible that a synergistic water management plan, with two options for discharge water (channel discharge and reinjection) coupled with a water release plan the favors native plants (our proposed release schedule), may be approved.

Indirect Benefits: Revealed Preference Methodology:
The receiving channel for treated groundwater discharge, a tributary of Bell Canyon Creek, is an ephemeral stream that is dry for the majority of the year. An increase in streamflow at this location is likely to increase downstream Bell Canyon property values since property values can be positively affected by surface water (Streiner and Loomis, 1995). Downstream from the Outfall channels, more tributaries contribute to the instream flow of Bell Canyon. The environmental benefits of increasing flow in the channel could be quantified by isolating the effect of instream flow on the price of houses adjacent to Bell Canyon – a hedonic study. The goal of a hedonic study is to isolate the value of an environmental amenity, streamflow in this case, from other house attributes. This is done via a multilinear regression, producing an estimate of how much of a home's price can be associated with each marginal unit of the increased streamflow. Then, take the value per unit streamflow and aggregate the results over all house lots within the study boundary. The study boundary encompasses all houses whose lots share a border with the Bell Canyon channel, up to the confluence with the Arroyo Calabasas that forms the LA River (Figure 1A) This begins in Ventura County (BOOK number 850) and continues into LA County.

As one might expect, there are many variables that affect house price – to control for all these variables, you must collect data in as many of these categories as possible. In order to control for all potential variables affecting property values in the area, we would include a set of variables that describe: 1) physical attributes of the property, 2) Neighborhood characteristics, 3) Aspect related to the environmental amenity, in this case, instream water. Housing price data for Ventura and LA Countries can be acquired from the respective County Assessors Office. These prices are not necessarily indicative of the house's current value, and may need to be adjusted by a local or national residential price index to give a prices for a normalized base year (Streiner and Loomis, 1995). The next step is to collect data on the physical attributes for each house that might have bearing on it's value. Year built, lot size, number of bed/bathrooms, and square footage are all available from the County Assessor's Office. Distance to freeway or grocery store can be determined for each parcel using GIS techniques. Information on neighborhood crime rates can be obtained from the County Sheriff's Office. School district quality should also be considered, potentially in the form of student/teacher ratios at nearby schools. Finally, the most important type of data for each house would be how many days per year the creek stretch is wetted. We have spoken to the LA County Department of Public Works Department of Public Works Watershed Management Division, who has informed us that they do not track flow in the headwaters of the LA River. Since this data was not available, we were not able to run the analysis. Table 3A shows how this data would be organized.

We searched for existing hedonic studies that might give a loose estimate of how much this water could affect housing prices, and discovered a 1995 study by Carol Streiner and John Loomis, Estimating the Benefits of Urban Stream Restoration Using the Hedonic Price Method. They found that restored streams increased home values by 3 to 13% of the mean property price. This increase was not just for water -- it includes the benefits of stabilized streambanks and acquiring land for education trails. Whatever the value of the instream flow, this value can make its way to the communities -- the increased price of homes will increase how much property tax is paid on the home, giving a cash influx into the community.

Multilinear Regression Methodology

Test Assumptions

Does each dataset meet assumptions of Linearity, Independence, Homoscedasticity, or Normality? If linearity is violated, you might apply a nonlinear transformation. Explore multi/collinearity among candidate variables through regression analysis, and select the final variables for the regression carefully to minimize effects of multicollinearity, and document your reasoning. For example, square-footage is likely to scale with number of bedrooms. You may choose to keep both variables, but consider introducing an interaction term to make the relationship explicit.

Multilinear Regression

This can be done easily in R Statistical Software. Before the regression is run, set confidence intervals for p-values: 0.05 and 0.10 are common limits.

a. Report correlation coefficients, (ask: set a cutoff for unacceptable?) Property and demographic characteristics are likely to be highly correlated. Choose variables to minimize the effects of multicollinearity.
b. Conduct regression analysis on groups of independent variables, calculate partial R^2 values. Boeing would want to use variables within the three groups (listed above) with low partial R^2s. Select these as candidate representative variables.
c. Test for heteroskedasticity.

Report Results of Multiple Regression

d. Assess p-values and R^2 values.
e. The coefficients of the different variables give you the incremental change in house value for an increase/decrease in the variable.
f. Expected signs of variable coefficients:

Table 3A. Regression parameters and expected coefficient signs for the hedonic study

Parameter	Expected Coefficient Sign
Lot Size	+
House Sq. Footage	+
Number of Bedrooms	+
Student/Teacher Ratio	-
Neighborhood Crime Rate	-
Fraction of Year Channel is Wetted	+

Figure 1A. *Bell Canyon Creek Study Area Downstream of the proposed treated groundwater discharge location to the confluence with the LA River.*

Table 4A. *Example Layout of Hedonics Regression Data*

House ID	*Price ($ in Base year)*	*Student/Teacher Ratio*	*Fraction of year channel is wetted*	*# of Bedrooms*	*Sq. ft.*
1	500,000	20	0.2	3	2,000
2	350,000	30	0.15	3	1,500

Appendix B: Channel Characterization Methodology and Flow Depth Calculations

Channel Characterization
The channel located at the proposed treated water discharge location was considered as an open trapezoidal channel. It was divided into 20 cross-sections separated 20 feet apart from each other. For each cross-section, the following geometry and physical components were measured:

1. Distance from the previous cross-section. The reference point was the bridge located at the beginning of the channel. The first cross-section was located at 13 feet and 4 inches from the bridge (160 in).
2. Channel width and geometry, four measurements were taken: Lout (starting point at the left bank of the channel), Lin, Rout (total width of the channel), Rin. See Figure 1 below.
3. Sediment grain type, size and depth
4. Vegetation description and other observations

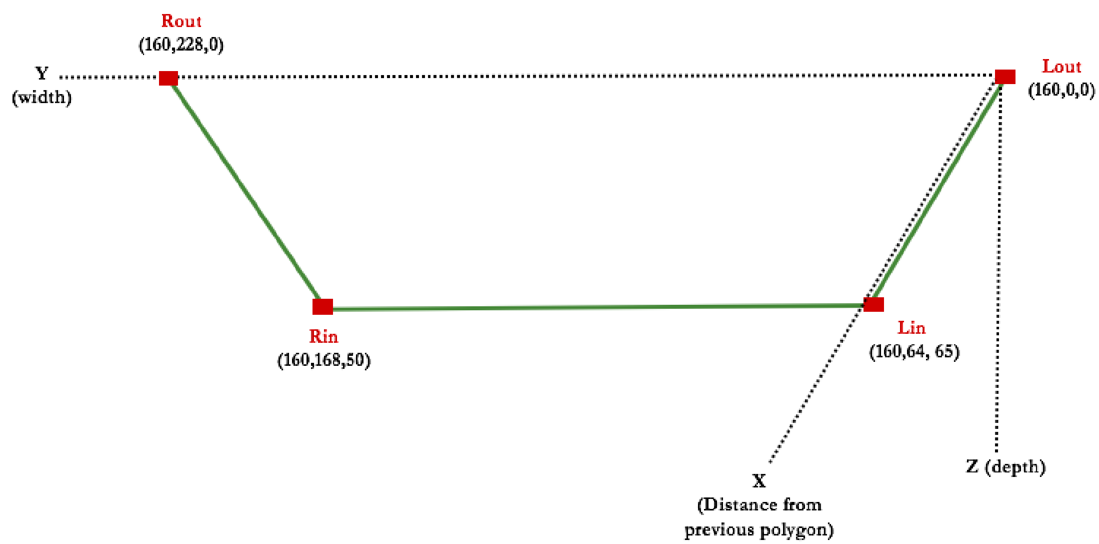

Figure 1B. *Cross section 1 (rough representation). Each position (Rout, Rin, Lout, Rin) has X, Y and Z coordinates. X, Y (inches) Z (cm). (In the R code all X, Y and Z values are converted to cm.) All positions from each cross section has the same X coordinate because they are located at the same distance from the previous cross section.*

Channel Geometry: Calculating area and perimeter

Area of an open trapezoidal channel

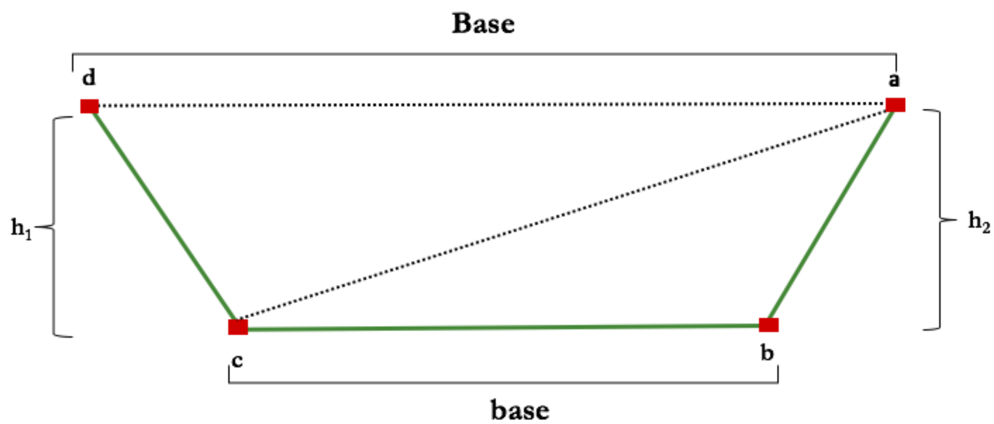

Figure 2B. *Notations used to calculate the area of each cross section.*

$$abc\Delta = \frac{base * h_1}{2} = \frac{[(c-b)*(h_1)]}{2}$$

$$acd\Delta = \frac{Base * h_2}{2} = \frac{[(d-a)*(h_2)]}{2}$$

$$Area = abc\Delta + acd\Delta$$

Equation 1B. Area of an open trapezoidal channel

Perimeter of a trapezoid

$$\sum L_i = \sqrt{(a_Y - b_Y)^2 + (a_z - b_z)^2}$$

Equation 2B. Perimeter and distances between each point.

Calculating water flow depth from known discharge

Discharge (Q): The *volume of water per unit time* that passes a specified point on a stream. Discharge is conventionally measured in cubic feet per second (ft^3/s) or cubic meters per second (m^3/sec or cms). Equation 3 described below was used to estimate the water flow depth (m) that would result from a perennial flow of 60 gpm.

Q= AV

Where,
Q = Flow Rate, (ft^3/s)
v = Velocity, (ft/s)
A = Flow Area, (ft^2)
Re-writing this expression using the Manning's equation,

$$Q=\frac{1}{n}*\left[\frac{\frac{y}{2}(b+(b+y(z_1+z_2)\right)^{5/3}}{b+y\left[\sqrt{1+z_1{}^2}+\sqrt{1+z_2{}^2}\right]^{2/3}}\right]*S^{1/2}$$

Equation 3B. Manning's Equation to estimate flow (ft^3/s)

Where,
n = Manning's Roughness Coefficient
R = Hydraulic Radius, (ft)
Z= Trapezoidal Side slopes
S = Channel Slope, (ft/ft)
Y= Water flow depth (ft or m)

Appendix C: Plant available water calculations

Soil moisture content and plant available water were estimated using Clapp and Hornberger model equation. This model contain shape parameters known as hydraulic parameters. The hydraulic parameters listed below were taken from Clapp and Hornberger (1978). Soil hydraulic parameters are traditionally obtained by curve-fitting the water retention functions using experimental data.

$$\theta = n\left(\frac{|\psi s|}{|\psi_a|}\right)^{-(1/b)}$$

Equation 1C. Clapp and Hornberger model to calculate soil water content

Where,

$$\theta = \text{Soil water content} = \frac{\text{Volume of water}}{\text{total volume}}$$

ψ_a = Air-entry tension

ψ_s = Suction head

b= pore-size distribution index

n= porosity

Applying equation 4 with the correspondent hydraulic parameters for each soil type present at the outfall channel, was possible to determine soil moisture curves and plant available water.

Appendix D: Riparian Vegetation and Classification Criteria

Riparian vegetation species present at reach were classified into two functional types: shallow-rooted and deep-rooted species. The water preference indicator was created based on data collected about species annual water requirement and wetland status.[1, 2]

Table 1D. *Shallow-rooted species list, water preference indicators and habitat type.*

Scientific Name	Common Name	Annual Water Requirement	Wetland Status	Habitat type
Ambrosia psilostachya	Western ragweed	Moderate	Facultative	Perennial Herb
Baccharis pilularis	Coyote brush	Low	Upland	Shrub
Bromus diandrus	Ripgut brome	-	Upland	Annual Grass
Cyperus eragrostis	Nutsedge	High	Facultative	Perennial Herb
Deinandra minthornii	Santa Susana tarplant	Moderate	Upland	Shrub
Juncus patens	Spreading rush	High	Facultative	Perennial Herb
Rosa californica	California rose	High	Facultative	Shrub
Salix laevigata	Red willow	High	Facultative	Tree
Salix lasiolepis	Arroyo willow	High	Facultative	Tree
Stipa miliacea	Smilo grass	-	Upland	Perennial Grass
Toxicodendron diversilobum	Poison oak	Low	Facultative	Shrub
Typha domingensis	Southern cattail	High	Obligate	Shrub

Table 2D. *Deep-rooted species list, water preference indicators and habitat type.*

Scientific Name	Common Name	Annual Water Requirement	Wetland Status	Habitat type
Adenostoma fasciculatum	Chamise	Low	Upland	Shrub
Baccharis salicifolia	Mulefat	Low	Facultative	Shrub
Ceanothus oliganthus	Hairy ceanothus	Low	Upland	Shrub
Heteromeles arbutifolia	Toyon	Low	Upland	Tree
Malosma laurina	Laurel sumac	Low	Upland	Perennial Vine
Platanus racemosa	Western sycamore	High	Facultative	Tree
Quercus agrifolia	Coast live oak	Low	Upland	Tree
Salvia mellifera	Black sage	Low	Upland	Shrub

[1] Water Requirement is a measure of how much moisture a plant requires assuming it is planted in its natural range
[2] The wetland status refers to the probability of a species being present in wetlands