James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program

FUTURE PLANNING REPORT

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Future Planning

The report summarizes future planning efforts that were conducted by SFEI for the County of San Mateo as part of the Proposition 84-funded James V. Fitzgerald Area of Special Biological Significance Pollution Reduction Program (Project). The goal for the future planning task was to develop a plan for continuation of the Project. This Future Planning report is comprised of three tasks. Task 1 describes pollution load reduction forecasts generated from analyses developed by the San Francisco Estuary Institute (SFEI) that are based on potential low impact development (LID) and best management practices (BMP) implementation (Figure 1). These analyses included components of the Critical Coastal Area (CCA) Pilot Project (http://www.sfei.org/projects/critical-coastal-areas-0) – Phase 2 State Water Board grant agreement and were calibrated with flow and water quality data from the current study. As part of this effort, SFEI collected multiple water samples at nine LID sites to access effectiveness of LIDs and BMPs. Contaminant load reductions were calculated for the Project by assuming implementation of LIDs in all LID-suitable areas adjacent to transportation infrastructure. Furthermore, this Future Planning report also includes a prioritization of location for future LID implementation (Task 2), based on improved site locator tool outputs, using reasonable assumptions for the best placement of LID in the landscape in relation to transportation land use (Figure 1). Task 3 describes how potential pollutant mass reductions were calculated for the Project by assuming implementation of rain barrels in all suitable areas. Pollution load reduction forecasts were generated from hypothetical wide-spread rain barrel implementation combined with roof runoff pollutant data from the available literature. Rain barrel installation is an inexpensive but effective way to capture pollutants that originate from roof materials but also pollutants that originate from aerial deposition. Since the pollutant concentrations in roof runoff are much higher during the onset of storms, capturing that runoff will be highly beneficial to the Area of Special Biological Significance (ASBS) at the James V Fitzgerald Marine Reserve (Reserve).

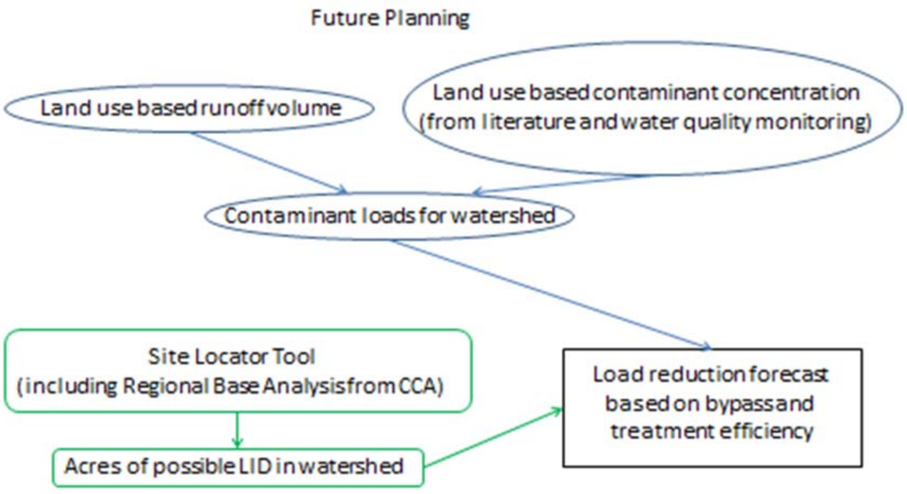

Figure 1. Flow chart for Future Planning

1. Pollution Reduction Forecast

1.2. Site Desciption

LID suitability was tested for the unincorporated communities of Moss Beach, Montara, and part of El Granada, including the surrounding areas in San Mateo County that constitute the larger Fitzgerald watershed area, in the San Francisco Bay Area (Figure 2). The coastal communities of Montara and Moss Beach border the Reserve and ASBS. Their population in the 2010 census was 2,909 and 3,103, respectively. El Granada is slightly bigger with a population of 5,467. The communities are situated approximately 20 miles (32 km) south of San Francisco and 50 miles (80 km) north of Santa Cruz. Montara and Moss Beach cover an area of 3.9 square miles (10.0 km^2) and 2.3 square miles (5.8 km^2), respectively. El Granada covers an area of 4.8 square miles (12.4 km^2). These communities are surrounded by rural land uses such as agriculture, ranching, equestrian facilities, and open space recreation. The area has mild weather throughout the year. January average maximum temperature (56.9°F or 13.8°C) and September average maximum temperature (73.1°F or 22.8°C) span a narrow range based on the long-term record (NOAA National Climatic Data Center, Station 43714). Typical of central California, most of the rainfall occurs from November through April, normally totaling more than 27 inches (69 cm).

The Fitzgerald watershed includes a little over three miles of shoreline, extending south from Point Montara to Pillar Point, including beaches, coastal bluffs, and the Pillar Point Marsh. The impervious area is estimated to be 9% of the total watershed area (California Coastal Commission 2008). Topographically the area is dominated by Montara Mountain at the western edge of the California Coast Ranges. Elevation ranges from sea level to 1,800 ft at the top of Montara Mountain. Marine terraces are dissected by streams that form coastal valleys and nearly level alluvial fans. Steep canyons in the upper watersheds change to broader lower valleys toward the ocean. The upper watershed includes unweathered igneous rock, volcanics, Mesozoic bedrock, and some Franciscan bedrock (USGS 2012, http://earthquake.usgs.gov/regional/nca/soiltype/). The valleys are filled with sediment (mud, sand silt, and gravel), sometimes to more than 100 feet above the canyon bottom (California Coastal Commission 2008). The unconsolidated deposits of the Pillar Point basin form the dominant aquifer of the region. The basin has accumulated decomposed granite from Montara Mountain deposited by the streams of the greater watershed area.

Slopes in the upper watersheds range from 5-50% (USDA 1991), and this area is predominantly not suitable for LID. The more gently sloped lower watersheds, with 0-10% slopes, include mudstone, sands, sandstone, limestone, and some Franciscan mélange and serpentinite (USGS 2012). Soil types in lower lying areas are mainly loamy sand and clay, resulting in imperfectly drained soil during storms.

Susceptibility to liquefaction is very low in the upper watersheds and moderate along the creeks. The susceptibility level is also moderate along parts of Highway 1 with larger alluvial fan deposits. The predominant stretch of the shoreline and bluff has a low level of susceptibility to liquefaction. Only the Pillar Point Marsh area has a high potential for liquefaction (USGS 2015, http://earthquake.usgs.gov/regional/nca/qmap/).

Taking all these factors into consideration is important when assessing site suitability for LID. Even though larger areas in this region are not suitable for LIDs due to the examined constraints (e.g., slope, soil type, susceptibility to liquefaction, etc.), the tool was still able to identify and rank 332 acres for potential LID implementation.

1.3. Estimation of Loads and Reductions

To increase the understanding of functionality and feasibility of different stormwater BMPs/LIDs and to demonstrate the beneficial value for water quality improvements in the ASBS watershed, the data obtained during the swale monitoring as part of this ASBS grant was integrated into future planning efforts and a simple model. For this, an estimate of loads for each pollutant (metals, organic contaminants, and nutrients) for each land use (agriculture, residential, transportation, etc.) based on a simple annual average time step model was developed. The model generated an estimate of runoff based on rainfall and runoff coefficients related to imperviousness for each land use, and additionally land use based estimates of event mean concentrations (EMCs) for each pollutant. The model was used to answer a series of very simple conceptual questions:

- If pollutant loads from transportation land use could be treated with 100% effectiveness, what percentage of load reduction would we see at the scale of the Reserve? The answer to this question gives us an estimate of the maximum potential for load reduction.
- Then, using reasonable assumptions about how a LID could be placed in the landscape in relation to transportation land use, the performance of the LID in relation to sources, and bypassing of the LID during larger rain events, what is the estimate of maximum potential load reduction in relation to applying LID to all transportation areas (including a 15 m buffer on each side) for each pollutant? Pollutants with greater EMCs associated with transportation land use should show a larger percent load reduction than pollutants with more ubiquitous EMCs across all land uses.
- For those pollutants with wide ranging concentrations among land use, how sensitive are the results to the choice of EMC central tendency? A sensitivity analysis was performed to determine confidence in percent load reductions in relation to the EMC parameter choices between minimum and maximum possible concentrations. This was

achieved by running the simple annual time step model and maximizing the EMCs for each pollutant for the land use of interest while minimizing the EMCs for the other land uses and vice versa.

A simple rainfall-runoff model was developed for the greater Fitzgerald watershed area (Figure 2) to estimate runoff volume by land use. The rainfall-runoff model assumes a linear relationship between annual stormwater volume and annual precipitation (Gunther et al. 1987; BCDC 1991; Maidment 1993; Davis et al. 2000), where a runoff coefficient related to general land use categories determines the fraction of the precipitation that becomes runoff. The latest revision of this simple annual rainfall-runoff model for the Bay Area is more advanced. In addition to land use, the model incorporates soil type and slope as factors for determining runoff coefficient, and the model was calibrated using 21 runoff gauges distributed across most of the nine counties of the Bay Area (Lent and McKee, 2011; Lent et al., 2012).

Figure 2. Map of watersheds draining into Area of Specific Biological Significance at James V. Fitzgerald Marine Reserve.

Runoff coefficients were developed using a calibrated range for runoff coefficients originating from Browne (Browne 1991). Some runoff coefficients were slightly modified to better represent local conditions after observed annual flow volumes were compared to simulated annual flow volumes. After average annual runoff was estimated in this manner for each land use polygon within the study area, stormwater contaminant loads were calculated by multiplying runoff volume (Table 1) by average concentrations of contaminants in stormwater runoff for each distinct land use type (ABAG 2005).

Table 1. Runoff volume (in acre feet) by land use for the Fitzgerald watershed.

Agriculture	Commercial	Industrial	Open	Residential	Transportation
715	128	7.99	3,460	490	1,640

Contaminant concentrations in stormwater runoff were compiled from the literature for each of the modeled land use categories. Specifically, EMCs were used, conceptually the best estimate of average annual concentrations for a watershed or area within a watershed of relatively homogeneous land use. Although our literature review included studies from other parts of the world, given the wealth of work completed by the Southern California Coastal Water Research Project (SCCWRP), the data are somewhat biased towards California near-coastal semiarid climatic conditions except for PAHs, pyrethriods, and nitrate. The concentrations were then checked against water quality data collected by SFEI during the Project and adjusted to ensure the concentrations for the modelling effort were close to the field observations thereby maintaining the relative nature between concentrations of different land use types in the process (Table 2). These contaminant concentrations were applied to six different land use types (agricultural, commercial, industrial, open, residential, and transportation) in the Fitzgerald watershed to generate baseline contaminant loads (Table 3).

Metals selected for this model were copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) because these metals cause the most concern for aquatic organisms and are commonly analyzed in monitoring programs (e.g., Marine Sanctuary Watersheds Monitoring Network), with a great amount of baseline data available. For the agricultural land use area, Ni and Zn originate predominantly from parent rock, while Cu and Pb sources are more related to anthropogenic activities (e.g., herbicides, pesticides, and fertilizer). Similarly, for the open space land use category, metal sources are mainly natural, while, some anthropogenic sources are related to vehicle use through atmospheric deposition, and discarding of metal parts as trash.

Organic contaminants that were monitored during the Project were polycyclic aromatic hydrocarbons (PAHs) and pyrethroid pesticides (of which only permethrin was detected). Nutrients that were monitored were nitrate and ammonium but only nitrate was included in the forecast prediction because ammonium often showed an increase in concentration within the LIDs, possibly due to pet activity after the compacted dirt shoulder was converted to a softer planted swale with grass or mulch cover. Only during very low intensity storms a slight reduction in ammonium was observed.

PAHs from urban and transportation land use areas include natural and man-made sources, such as, weathering pavement (asphalt), combustion (petroleum products, like oil and gasoline, coal, tar, etc.), and hazardous waste sites. Agricultural burning and wildfires can introduce PAHs to runoff from agricultural land use areas and open space. Permethrin is predominantly used in agriculture for insect control on crops and in the soil, but to a great extent, also in urban and residential areas for pest control and pest prevention. The main sources for nitrate is likely atmospheric deposition, pet waste, and synthetic and organic fertilizer from gardens and agriculture, but nitrate can also be formed from nitrogen oxide emissions from cars, trucks, and power plants and are often elevated along transportation corridors.

Table 2a. Concentration coefficients by land use for metals (µg/L).

Land Use	Cu	Ni	Pb	Zn
Agriculture	75	6.1	4.5	130
Commercial	34	10	5.0	120
Industrial	33	11	6.8	180
Open	11	2.9	0.61	12
Residential	19	5.5	3.4	54
Transportation	26	8.3	4.2	73

Table 2b. Concentration coefficients by land use for organic contaminants (PAH, permethrin), and nutrients (nitrate).

Land Use	PAH ng/L	Permethrin ng/L	Nitrate mg/L
Agriculture	9.5	2600	41
Commercial	300	4.0	180
Industrial	243	4.0	349
Open	2.3	0.0	160
Residential	300	4.0	270
Transportation	77	4.0	611

Table 3a. Fitzgerald land use area and metals baseline load calculated by combining the results of the rainfall runoff volume generation model with contaminant concentration distribution derived by a combination of literature review and local Fitzgerald watershed wet weather observations.

Land Use	Area km^2	% of total area	Cu (kg)	Ni (kg)	Pb (kg)	Zn (kg)
Agricultural	3.3	9.4	66	5.4	4.0	118
Commercial	0.39	1.1	5.4	1.6	0.79	20
Industrial	0.022	0.063	0.32	0.11	0.067	1.8
Open	24	69	47	12	2.6	51
Residential	3.5	10	12	3.3	2.1	33
Transportation	3.8	11	53	17	8.5	148
Total	35	100	183	39	18	371

Table 3b. Fitzgerald land use area and organic contaminants and nutrients baseline load calculated by combining the results of the rainfall runoff volume generation model with contaminant concentration distribution derived by a combination of literature review and local Fitzgerald watershed wet weather observations.

Land Use	Area km^2	% of total area	NO_3 (kg)	Permethrin (kg)	PAH (kg)
Agricultural	3.3	9.4	36	2.272	0.008
Commercial	0.39	1.1	29	0.001	0.047
Industrial	0.022	0.063	3	0.000	0.002
Open	24	69	683	0.000	0.010
Residential	3.5	10	163	0.002	0.181
Transportation	3.8	11	1234	0.008	0.155
Total	35	100	2148	2.283	0.404

Once the baseline loads for the watershed were estimated, the next step was to estimate the amount of load that could be potentially reduced if LID features were installed in the future to treat runoff generated from all transportation land uses in the watershed. Although this scenario is probably not plausible, at least in the immediate future due to costs and other unforeseen constraints, it does provide a planning level maximum implementation scenario to help inform management decisions.

Given that LID features placed adjacent to transportation land use could also be designed to capture runoff from nearby properties, for the purposes of this model we included the assumption that run-on from 15 m inside the local private property lines could potentially drain into the LID features. Such a run-on is expected from driveways and roof drains sloped to the curb-line. Although this assumption is not perfect, for planning level estimates of the potential for LID to reduce loads, it serves as a proxy for this run-on process. Using the information for LID site suitability based on the output of the site locator tool (please see Task 2 below for more information on site locator tool), and assuming a 15 m buffer adjacent to these suitable sites, the simple model was used to generate a set of land use related contaminant loads within this transportation-related layer (Table 4). This represents the treatable portion of the watershed contaminant load.

Table 4a. Fitzgerald land use related metal loads calculated by combining the results of the rainfall runoff volume generation model for areas likely to be suitable for LID implementation assuming a 15 m buffer.

Land Use	Area km^2	% of total area	Cu (kg)	Ni (kg)	Pb (kg)	Zn (kg)
Agricultural	0.03	9.4	0.46	0.04	0.03	0.82
Commercial	0.07	1.1	1.06	0.31	0.16	3.79
Industrial	0.01	0.1	0.11	0.04	0.02	0.61
Open	0.14	69	0.26	0.07	0.01	0.29
Residential	0.20	10	0.62	0.18	0.11	1.75
Transportation	0.60	11	7.63	2.43	1.23	21.41
Total	1.06	100	10.13	3.07	1.56	28.66

Table 4b. Fitzgerald land use related organic contaminant and nutrient loads calculated by combining the results of the rainfall runoff volume generation model for areas likely to be suitable for LID implementation assuming a 15 m buffer.

Land Use	Area km^2	% of total area	NO_3 (kg)	Permethrin (kg)	PAH (kg)
Agricultural	0.03	9.4	0.2	0.0157	0.00006
Commercial	0.07	1.1	5.6	0.0001	0.0093
Industrial	0.01	0.1	1.2	0.0000	0.00082
Open	0.14	69	3.9	0.0000	0.00006
Residential	0.20	10	8.7	0.0001	0.0097
Transportation	0.60	11	179.1	0.0012	0.022
Total	1.06	100	198.7	0.0172	0.042

The next step in the analysis was to determine the amount of load reduction that would be achieved by the installation of LID within these likely suitable transportation areas. There are two steps in this component of the analysis. The first is to estimate the amount of bypass that would likely occur under design conditions for LID, and the second is to estimate the amount of load reduction associated with the treatment process.

To estimate the percent of flow that would bypass the treatment systems, the percent of rainfall that would exceed the site design storm was estimated based on previous calculation for San Mateo County watersheds (David et al. 2011). For this purpose, a rainfall intensity cumulative distribution curve was developed based on an hourly precipitation record from San Francisco Airport (WY 1980-2007), a sufficiently long period to be climatically representative of the Bay Area conditions. This scaling is necessary because, unless monitoring is performed over a long time frame (i.e., decades), the monitoring period is generally not representative of long-term average climatic conditions. The ideal site design bypass threshold rate of 0.2 in/hr was applied to the rainfall intensity distribution to determine the long-term average bypass rate. The results indicated that the threshold rate was surpassed 7% of the time. A histogram of the hourly rainfall intensity was developed, and it was estimated that, over a decadal time scale, 28% of the total amount of rainfall (and the corresponding runoff) would bypass the treatment sites and therefore remain untreated. Table 5 shows both the ideal (no bypass) treatment efficiencies, which would apply in low rainfall intensity years, and the more realistic (some bypass) treatment efficiencies, which would apply in average rainfall intensity years.

The last step was to estimate the load reduction associated with LID treatment. For the applied treatment efficiency, the maximum reduction rate from all LID sites monitored for effectiveness by SFEI in this Project (David et al. 2015) was used to calculate the percentages that could be achieved with ideal site characteristics and design. For copper a treatment efficiency of 66% was used, for nickel 61%, for lead 76%, and for zinc 85% (Table 5a). Removal efficiency rates used for organic contaminants were 83% for PAHs and 92% for permethrin. Nitrate removal rates were observed at 76% in this Project (Table 5b).

Table 5a. Fitzgerald total transportation-related contaminant loads with applied contaminant concentration reductions for metals.

Contaminant	Total (kg) [with treatable fraction]	Load Reduction with 28% Bypass (%)	Load Reduction with no Bypass (%)
Cu	183 [10]	2.6	3.7
Ni	39 [3.1]	3.4	4.8
Pb	18 [1.2]	4.8	6.6
Zn	371 [29]	4.7	6.6

Table 5b. Fitzgerald total transportation-related contaminant loads with applied contaminant concentration reductions for organic contaminants and nutrients.

Contaminant	Total (kg) [with treatable fraction]	Load Reduction with 28% Bypass (%)	Load Reduction with no Bypass (%)
Nitrate	2148 [199]	5.0	7.0
Permethrin	2.28 [0.02]	0.5	0.7
PAH	0.40 [0.04]	6.3	8.6

One way to determine the accuracy for this simple model outcome is to perform a sensitivity analysis. Since the hydrology model is calibrated and we have field results for trace metal concentrations associated with mainly urban land-use, one of the weaknesses in our analysis is the lack of local knowledge about trace metal concentrations in relation to each of the other five land use categories. A sensitivity analysis provides a good control for the choice of concentrations relative to one another. To perform this analysis, we re-ran the simple model by systematically minimizing the concentrations associated with one land-use parameter while maximizing all concentrations for the other land uses and then conversely maximizing the concentrations for one land use parameter while minimizing all the others. This analysis was performed iteratively until loads were generated based on all parameters being both maximized and minimized.

The sensitivity analysis conducted showed that the great variability for the applied EMCs caused uncertainty in the output parameters of the model. For example, considering the minimum and maximum EMCs for copper, the total copper load can range anywhere between 36 kg and 605 kg for this watershed, but our best estimate is 183 kg. Based on that assumption, copper from agriculture land use can contribute anywhere between 4.9% and 93% to the total watershed copper load, but our best estimate is 36%. Furthermore, copper from transportation-related land use can contribute anywhere between 0.1% and 89% to the total watershed copper load, but our best estimate is 29%.

Additionally, permethrin concentrations in runoff published in peer-reviewed papers ranged from 0.5 to 110 ng/L, and in most studies were much higher than the observed concentrations during this Project. However, the study designs in the literature often included sample collection immediately adjacent to an application site (i.e., lawn or driveway), which caused the EMCs to be biased high for residential areas.

Since agriculture and transportation land use are the main contributors of the four metals, the organic contaminants and nitrate to the overall watershed load, the EMCs applied to these land uses are highly sensitive parameters. More robust estimates could be developed by an extended literature search to generate improved median concentrations that are used for the model. While outside the scope of this Project, the 10th and 90th percentile values (statistical reference values) could also be tested instead of the median literature values for land use specific EMCs. EMCs for industrial and commercial land uses exhibited the least sensitivity in this model reflecting that they contribute only small amounts of contaminants to the watershed load due to their small land use areas (0.02 and 0.4 km^2, respectively of the total 35 km^2).

The percent reduction numbers for metals and organic contaminants through LIDs (Table 5a & 5b) are relatively small (4 to 7% reduction of metal loads and 1 to 9% for organic contaminants and nitrate reduction) compared to the total watershed load. However, it has to be considered that only a small portion of the overall watershed load (between 6-8%) was designated treatable with LID placement for transportation land use. The main reason for this is the assumption (in this experimental analysis) that LIDs can only be placed along transportation infrastructure where the slope is not too steep and where it does not interfere with existing utilities, etc. If there was a way to include private land, for example a six-foot wide vegetated ditch at the lower lying edge of agricultural fields, the treatment area (and treatable load) could be increased. With this in mind, it would be helpful for the protection of the ASBS to maximize the areas for LID implementation because the treatment efficiency per LID unit is very promising in regard to particulate phase metals and organic contaminants. The results generated by this forecast model presented here may underestimate the achievable benefits if LIDs could be applied to other areas in addition to transportation land use.

Furthermore, there are other LID techniques, which can be useful under different conditions; for example, permeable pavement could be used where space alongside the roadway is limited. The analytical framework provided here could be applied to a wider range of bioretention techniques and used to test which combinations of which LID techniques could be most advantageous and cost effective for local or regional scale application in San Mateo County.

2. Site Locator Tool

The GIS site locator tool is a flexible planning level tool to aid municipal planners with strategic LID implementation at the watershed scale. It is based on the Regional Base Analysis tool that was configured for the Critical Coastal Areas Project (http://www.sfei.org/projects/critical-coastal-areas-0). The tool can be used to create custom maps that identify and rank potential LID locations. The tool incorporates many regional, publicly available data layers and has built in flexibility to add local data layers to best identify suitable locations and rankings of LID. The site locator tool has end-user flexibility with access to the tool's engine resulting in an iterative tool that can be fine-tuned as additional local data, or data with better resolution, become available.

The GIS site locator tool allows the user to create custom outputs for their municipality and allows for multiple levels of refinement of outputs based on available local data. Local GIS data can be added to the tool to increase the tool's delivery of priority LID locations. The tool can create maps of suitable locations for different LID types. The GIS site locator tool allows for custom ranking of local and regional layers according to local priorities and municipal or county plans. Suitable LID locations are distinguished by both private and public designation. The tool also has flexibility to remove unsuitable areas for LID placement consideration, such as riparian or wetland areas, by adding exclusion buffers to the data layers.

For the LID site prioritization, similar areas to the LID storm drain retrofits that were implemented as part of the ASBS Program, specifically transportation-related land, were assessed for suitability for bioretention. Not all of the transportation land would be suitable for bioretention retrofits. The implementation is restricted by available space (that does not conflict with other uses such as utilities) and steepness of slope. Additionally, the site design is impacted by site topography (e.g., drainage paths and pooling points), soil type and stability, depth to impermeable layer, and depth to water table. Additionally, suitable locations are also limited because bioretention systems need to be at a low point of the curbline profile for them to capture runoff from most of the street. The areas meeting these basic bioretention site suitability criteria were identified using the previously developed site locator tool which systematizes the analysis of these constraints at a landscape scale (Kass et al. 2011). The transportation-related land included highways, streets, parking lots, and airports. Federal Aviation Administration regulations would have to be checked before implementation of bioretention systems near the airport to avoid a potential conflict with safety and navigation.

To further fine-tune the site suitability analysis, additional data layers and more detailed information for the Fitzgerald watershed area were included and helped to increase the understanding about the specific site characteristics. The goal was to maximize the confidence with which the site locator tool identified and prioritized suitable LID sites.

2.1 Improvements to LID site selection

This section outlines the efforts made to improve the site locator tool with additional localized GIS data for the Fitzgerald drainage area. In so doing, the feasibility and applicability of the resulting selected sites was increased. By adding additional information to the data layers, including more detailed land use information, county-owned land and roadway information, public land information, as well as private parking areas, the LID site selection was improved.

2.1.1. Adding new GIS layers and adjusting the ranking procedure

To improve the output from the site locator tool further, additional GIS data layers were added (Table 6). These included a more specific location layer that allowed for the separation of public right of way and actual street width and resulted in the output of unpaved shoulder areas available for LID on each side of the road (public right of way minus street width). Additionally, highways were separated from other roads and from parking lots to exactly map road locations. As a result of that potential LID locations improved in accuracy. Storm inlets and stormwater channels (storm mains) were added as favorable opportunities for LID, in addition to ditches with a slope of less than 2% and ditches that are inundated during a 10-year storm event. All these layers were used as positive weighting factors in the analysis.

In addition, a number of new negative weighting factors were added (Table 6). These included principal sewer lines (sewer mains), water mains, and hydrants (location map from Coastside Fire Protection District). All of these resulted in a lower ranking for LID suitability within determined buffers. Red-legged frog critical habitat (Data from US Fish and Wildlife 2010) was designated as a constraint for LIDs and thus was also negatively ranked by the tool. The area immediately adjacent to the coastal bluff was also ranked negatively due to the increased erosion risk. Furthermore, existing wetlands delineated by the California Aquatic Resource Inventory (CARI, for more information please go to http://www.sfei.org/cari) were designated unsuitable for LID, and existing LID and BMP sites were designated restricted due to prior implementation. Historical industrial information, e.g., an Ocean Shore Railroad layer, was considered but disregarded since the railroad was abandoned in 1920 and no tracks have been operated within the Fitzgerald watershed area for almost a century.

In locations where higher as well as lower rankings overlapped, the resulting positive and negative numbers canceled each other out, resulting in a neutral ranking. A neutral ranking differs from unranked locations, which included sites for which no ranking information was available and neither a positive or negative ranking could be applied. Unranked locations can be suitable for LID but they were not ranked due to a lacking of data.

Table 6. Fitzgerald watershed opportunities and constrains ranked positively or negatively by factor weight for LID.

Factor	Factor Weight	Layer Name	Layer Weight	Rank	Buffer (feet)
Base Analysis	0.273	RegionalBaseAnalysis	1	1	0
Erosion	0.273	Bluffs	1	-1	150
Conservation	0.091	CARI_wetlands	0.75	-1	160

Conservation	0.091	RedLeggedFrog_CritHab	0.25	-1	0
Infrastructure_Constraints	0.091	Hyrdants	0.25	-1	2
Infrastructure_Constraints	0.091	Waterlines	0.25	-1	20
Infrastructure_Constraints	0.091	Sewerlines_main	0.25	-1	50
Infrastructure_Constraints	0.091	Sewerlines_smaller	0.25	-1	50
Infrastructure_Opportunity	0.273	Storm_mains	0.15	1	10
Infrastructure_Opportunity	0.273	Storm_inlet	0.31	1	10
Infrastructure_Opportunity	0.273	DitchesLessThan2	0.23	1	25
Infrastructure_Opportunity	0.273	DitchesInnundated10year	0.31	1	25

With the additional GIS information, the site location analysis could now more accurately identify which sites are best suited for LID within the greater Fitzgerald watershed. The tool was run three times to identify the best suited locations for bioretention, vegetated swales, and pervious pavement. The final output of the tool identified suitable locations within these three categories at sizes of at least 1,000 sqft for vegetated swales and bioretention, and 5,000 sqft for pervious pavement. The area included in the tool and ranked for LID suitability within the Fitzgerald watershed included approximately 332 acres. This is the area predominantly associated with transportation infrastructure. The ranked area equals 0.5 mi^2 (1.3 km^2) or 3.7% of the entire Fitzgerald watershed. The entire watershed area is 13.5 mi^2 (35 km^2).

2.2 Site locator tool results

2.2.1 Site suitability for Bioretention

The tool run for suitable bioretention locations resulted in approximately 85 acres of higher ranked locations of which 72 acres are on public land and 13 acres are located on private properties (Figure 3). For more detailed section maps of all three LIDs and to access the map packages in ArcGIS please go to https://files.sfei.org/data/public/ff3cbd. The majority of locations suitable for bioretention fall along Highway 1 between the south end of Moss Beach and throughout El Granada. Slightly lower ranked sites, which include sites that have some restrictions for bioretention implementation, e.g., close vicinity to coastal bluff, narrow shoulder, slope more than 2%, etc., comprise 161 acres, 157 acres on public land and 4 acres on private land. The majority of lower ranked sites also fall along Highway 1, but north of Montara where the highway runs relatively close to the bluff.

Many neutrally ranked locations were identified along streets in Montara, Moss Beach, and El Granada where the potential for bioretention installation is neither favorable nor restricted. Because of the lack of sidewalks and curbs in this area, road runoff drains directly to the dirt shoulder and most streets would be suited for smaller bioretention systems where the street slope is not too steep and allows for reduction in runoff velocity within an LID. Streets running in north-south direction in Montara and Moss Beach are usually less steep and better suited, e.g., Le Conte, Acacia, Cedar, and Birch Street in Montara and Stetson, Sierra, Kelmore, Buena Vista, and Tierra Alta Street in Moss Beach. California Avenue and other streets in east-west direction are generally steeper and would likely have higher velocity flows, which make filtration challenging.

2.2.2. Site suitability for Vegetated Swales

The tool run for suitable locations for vegetated swales produced a total of 186 acres of higher ranked sites (Figure 4) (https://files.sfei.org/data/public/ff3cbd). Vegetated swales had the highest output of suitable area, which is mainly attributable to the fact that vegetated swales are shallower than bioretention systems and easier to install on top of existing water and sewer lines. Also, other restrictions, like depth to impermeable layer and vicinity to stormdrains can be less prohibitive for vegetated swales than for biorentention because of the different design of these two feature types.

Out of the 186 acres suitable for vegetated swales, 163 acres were located on public land while 23 acres were location on private land. Similar to bioretention, the majority of suitable sites for vegetated swales were located along Highway 1, but in the extended area from north of Montara all the way through El Granada and additionally along Airport Boulevard in Moss Beach. Also, several streets in Montara are suitable locations, with higher ranking for the north-south facing streets like Cedar, Acacia, Le Conte, and Birch Street. Good potential LID sites were also identified by the tool for the west side of Highway 1 in Moss Beach and in the Pillar Ridge mobile home park, as well as in the entire community of Princeton.

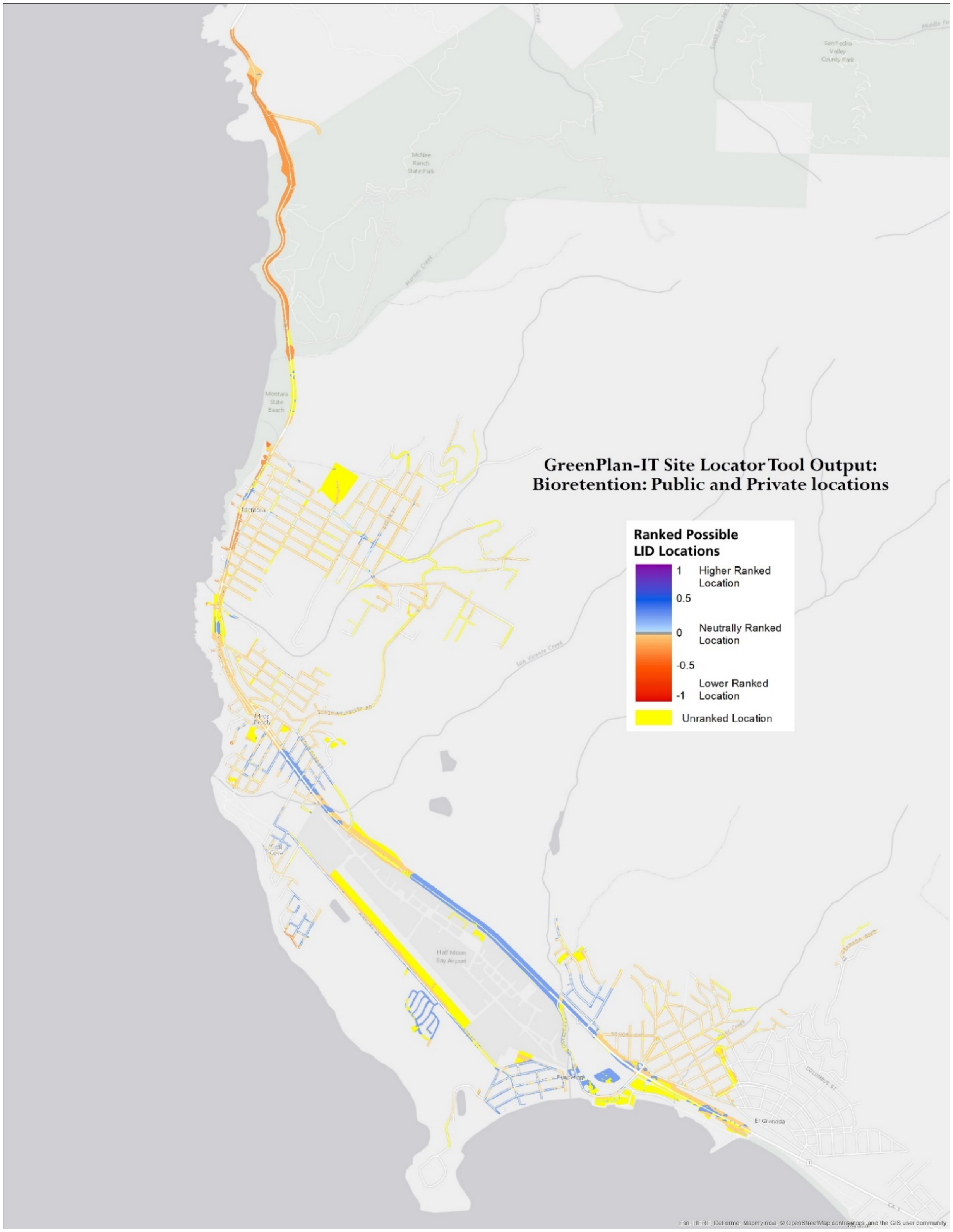

Figure 3. GreenPlan-IT Site Locator Tool output locations: Bioretention: public and private locations in the greater Fitzgerald watershed area. For more detailed section maps please go to https://files.sfei.org/data/public/ff3cbd to download the map packages in ArcGIS.

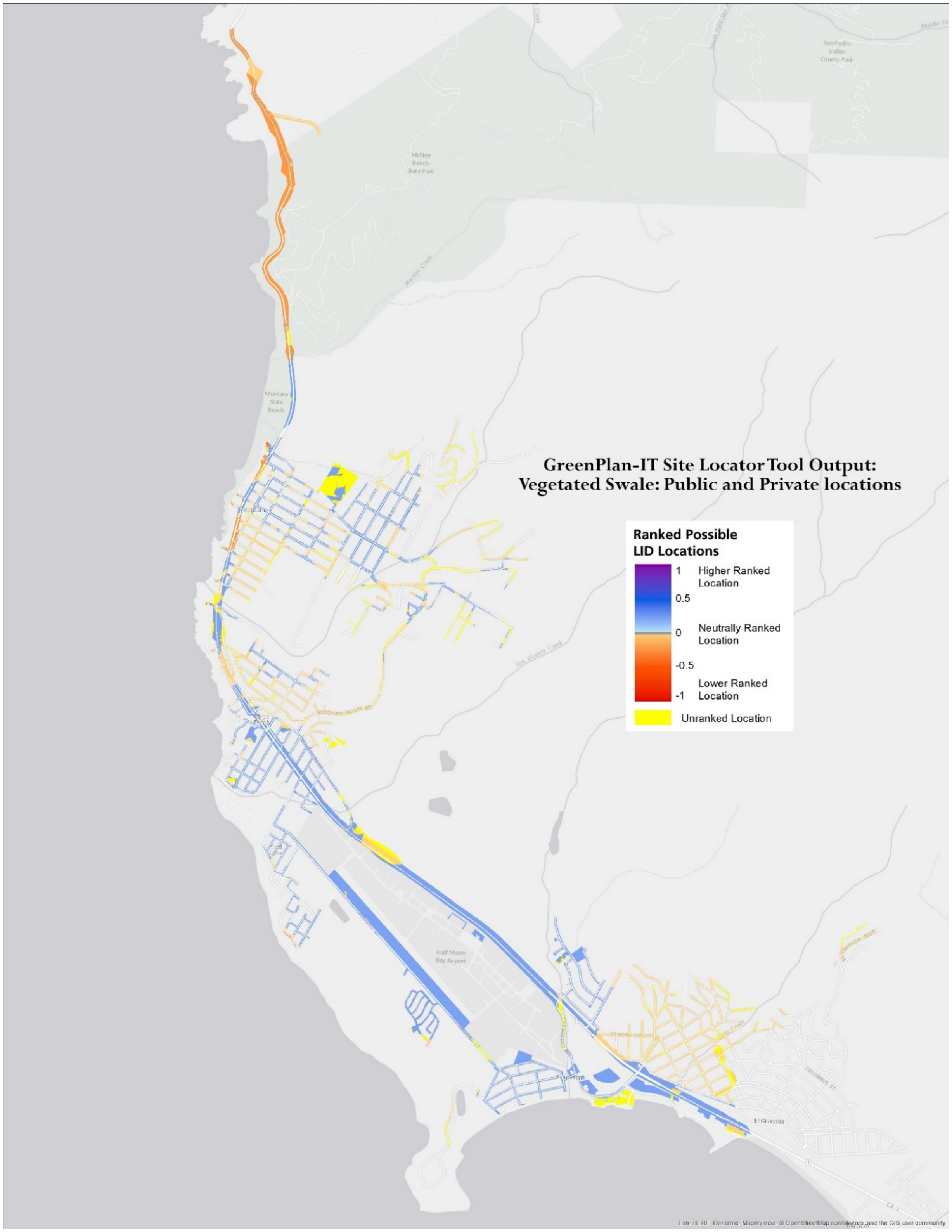

Figure 4. GreenPlan-IT Site Locator Tool output locations: Vegetated Swales: public and private locations in the greater Fitzgerald watershed area. For more detailed section maps please go to https://files.sfei.org/data/public/ff3cbd to download the map packages in ArcGIS.

The tool output for lower ranked suitability for vegetated swales, in which some restrictions applied for this type of LID, resulted in 104 acres. Again similar to bioretention, vegetated swales have some restriction along Highway 1 where the road is close to the coastal bluff. Out of the 104 acres with lower ranking for vegetated swales, 102 acres were on public land and only two acres were identified on private property.

2.2.3. Site suitability for Pervious Pavement

Suitable areas for this LID type were more restricted because the tool was set up to identify sites with a minimum of 5,000 sq ft of available space for pervious pavement. If the size requirement was lowered to 800-1,000 sq ft private driveways would also show in the tool output. Even though the County does not have access to private driveways this opportunity could possibly be considered for further public outreach and education purposes since many remodeled driveways together could significantly reduce the water flow and contaminant input into the Fitzgerald ASBS if pervious pavement would be installed.

Higher ranked suitable sites resulted in a total of 68 acres for pervious pavement (Figure 5) (https://files.sfei.org/data/public/ff3cbd). Fifty-eight acres were on public land and 10 acres on private property. Most suitable sites were located between the south end of Moss Beach and the north end of El Granada, along Highway 1. Additionally, the parking lot at the Oceana Hotel in Princeton, as well as Pillar Ridge (a mobile home park) and Seal Cove (a residential area near the secluded Seal Cove Beach, also called Cypress Cove Beach) in Moss Beach provide more opportunities for pervious pavement.

Neutrally ranked sites were identified along streets in Montara, streets on the east side of Highway 1 in Moss Beach, and in El Granada. Additionally, a narrow area on the east side of Airport Boulevard was identified as neutrally ranked. These sites had neither advantages nor disadvantages for LID implementation, according to the criteria applied by the tool.

Lower ranking areas added up to 171 acres for this LID type. Of those 171 acres, 167 were on public land and only four acres were located on private property. Most of the lower ranking sites were located in the communities of Montara, Moss Beach, and El Granada with some restrictions that applied for pervious pavement. As in all other LID types, the coastal bluff was deemed not suitable for pervious pavement since erosion would likely increase the deterioration and shorten the lifetime of such LID implementation.

The acreage output ranked for permeable pavement is likely biased high. It has to be considered that some sites suggested by the tool for pervious pavement are currently dirt shoulders or grassy shoulders. The currently utilized location layers for the tool could not differentiate paved on-street parking from unpaved, dirt or grassy shoulders also in the public right of way. Implementation of permeable pavement as an LID would only have an advantage if it replaced impermeable pavement and not an already more porous substrate. For example, dirt shoulders that are subject to damage from rill erosion from concentrated water flow or damage from parked cars could be repaired and protected through the installation of pervious pavement. In such cases installing pervious pavement could be beneficial. However, in most other cases a healthy grassy strip will likely be more porous and slow down and filter stormwater more effectively than pervious pavement.

A remaining weakness in the current tool is the above described lack of GIS data to support the analysis of management options for unpaved shoulders. It would require a more substantial effort to manually remove the standard width of the sides of the streets where that particular area is unpaved and to then re-run the tool for impervious pavement only to account for the difference that currently creates a bias in the results for pervious pavement. Since this effort would require more time, the authors suggest that the output for pervious pavement be interpreted carefully and to consider site specific conditions of road shoulders when using the results of this LID location planning tool. Best professional judgement will be required during any subsequent site reconnaissance to assess specific conditions where the accuracy of the tool is inadequate to yield detailed location information.

Overall a total of 775 acres have been identified as feasible for different LID implementation. However, some of the resulting suitable sites may be appropriate locations for two or all three LID types meaning some site acreage has been counted twice or three-times in this total output number. Out of the total 775 acres, 339 acres had a higher ranking for LID, and 436 acres had a lower ranking for LID implementation. Out of the total acreage, seven percent of the suitable locations were determined to be on private property and 93% on public land.

Private property LIDs have been explored and implemented by the San Mateo County Resources Conservation District (RCD). They include pervious pavement in remodeled driveways, rain barrels and raingardens (discussed further below).

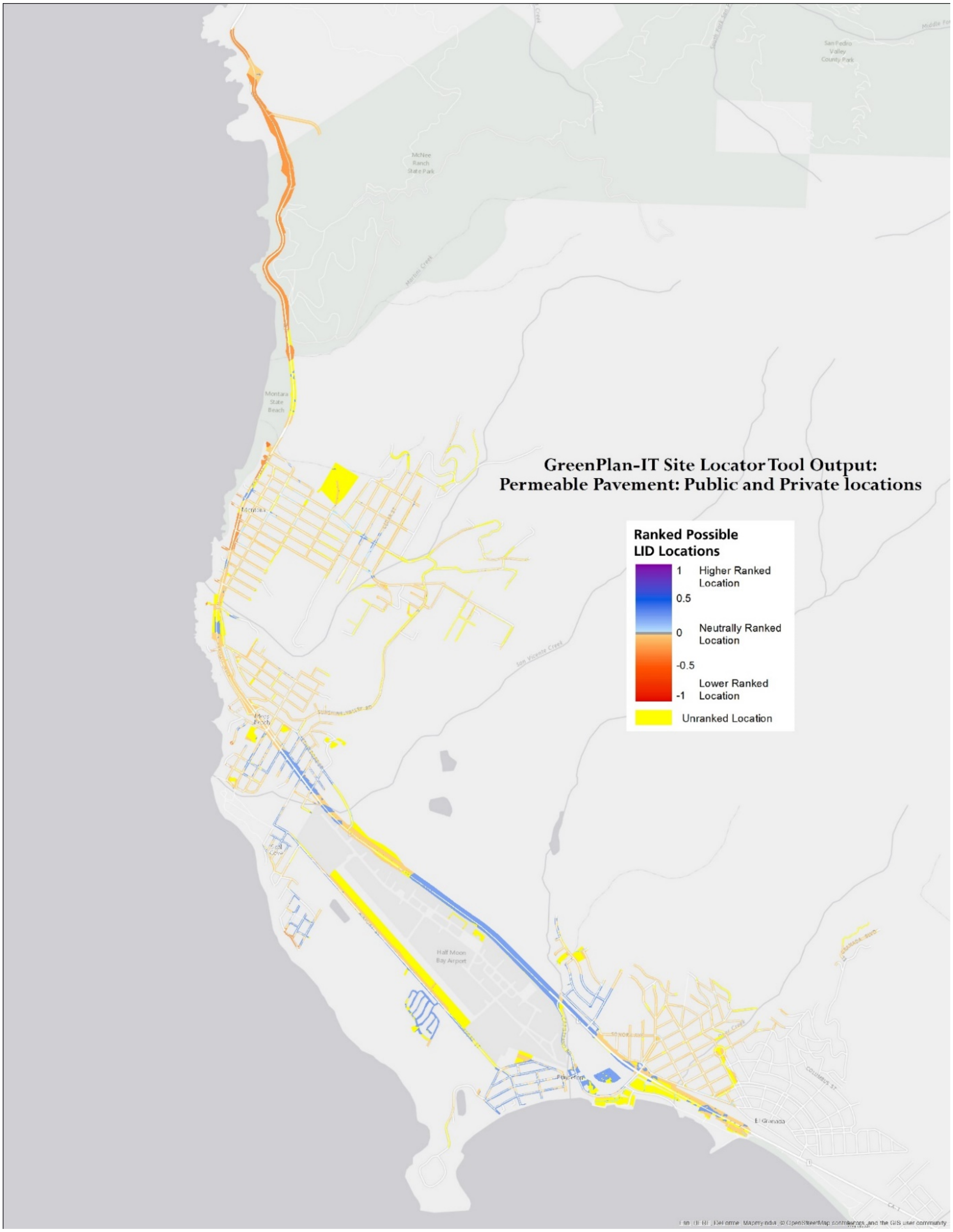

Figure 5. GreenPlan-IT Site Locator Tool Output Locations: Pervious Pavement: Public and Private Locations in the greater Fitzgerald watershed area. For more detailed section maps please go to https://files.sfei.org/data/public/ff3cbd to download the map packages in ArcGIS.

3. Modeling Water Quality Improvements associated with Rain Barrels

Water conservation efforts in San Mateo County have resulted in the installation of many rain barrels throughout the county, including some in the greater Fitzgerald watershed. As part of this Project, the RCD started construction on seven residential properties to implement rain barrel and cistern projects and to have them serve as demonstration gardens for the community. Rain barrels collect the roof runoff and release excess water through an overflow hose when the barrel is filled. Harvested rainwater often contains metals, hydrocarbons, and other contaminants and exceeds US Environmental Protection Agency (EPA) surface water quality objectives (US EPA, http://water.epa.gov/scitech/swguidance/standards/ and Chang and Crowley 1993). Collecting roof runoff and using it for landscape watering reduces the amount of contaminants in stormwater runoff that reaches storm drains, creeks, and the ocean. An associated benefit is that the collection of rainwater also reduces the peak hydrograph for the watershed by delaying the contribution of roof runoff. The objective of this section is to report on estimates of volume and potential contamination reduction for residential stormwater management practices in relation to the first flush rain event.

In the United States, fiberglass-based asphalt shingles also called composite shingles are by far the most common roofing material used for residential roofing applications. They account for roughly 87% of the market share (Cullen 1992). Asphalt shingles contain recycled plastic for the backing and the top layer of the shingle. The protective nature of fiberglass asphalt shingles primarily comes from the polycyclic aromatic hydrocarbons (PAHs) and other long-chain petroleum hydrocarbons. Over time, the shingles weather and the hydrocarbons soften. They are gradually washed out of the shingles, especially during high intensity rainfall, but the pH of rainfall also plays a role in the release of these contaminants (Yaziz et al. 1989; Van Metre and Mahler 2003). Since shingles have a lifetime of 20+ years, past recycling practices may have included source material that contained PCBs, metals and other toxics, e.g., asbestos (Mowat et al. 2007) also adding to the potential for ongoing pollution from the breakdown of the plastic backing.

Additionally, studies have shown that roof runoff contamination can be affected by metals like copper and zinc from gutters and downspouts (Chang et al. 2004). The concentrations of contaminants in harvested roof runoff vary with length of time between rain events, land use and particle deposition, sunlight, and wind direction. Since rain barrels are a great water conservation effort that has been supported by the Water Pollution Protection Program (SMCWPPP) through a county-wide rebate program (http://www.flowstobay.org/rainbarrel), here we estimate additional benefits for contaminant reduction potential through harvested roof runoff.

County-wide more than 500 rain barrels have been installed through the rebate program while in the unincorporated areas of Montara, Moss Beach, and El Granada numbers are relatively low (below 10 barrels installed) (Bay Area Water Supply and Conservation Agency (BAWSCA)). The numbers seem to be heavily influenced by the rebate amount, about twice as many barrels were installed in areas where the water agencies match the SMCWPPP rebates ($100 rebate if matched). If education and outreach efforts could be maximized and rain barrel use increased, the hypothetical benefits from treated roof area (see Table 7 for demographics and number of household) and reductions in contaminant loads to the creeks and ocean could be wide-spread.

Table 7. Demographics for unincorporated areas in greater Fitzgerald watershed.

Unincorporated Area	**Montara**	**Moss Beach**	**El Granada ***
Square miles	3.9	2.3	4.8
Population**	2,909	3,103	5,467
Households	1,109	1,062	2,098
% of roofs with composite shingles	95	95	95

*Not all of El Granada lies within the greater Fitzgerald watershed area; only approximately 40%.

** Data from 2010 census

A conservative estimate of 1,500 sq ft of roof area per home (including garage space) would provide a treatable surface area of 1,663,500 sq ft (or 38.2 acres) for Montara, 1,593,000 sq ft (or 36.6 acres) for Moss Beach, and 1,258,800 sq ft (or 28.9 acres) for 40% of El Granada (the part that falls within the greater Fitzgerald watershed area), if all downspouts were connected to rain barrels.

If each home (3,010 homes total) had an average of five downspouts with an empty standard barrel of a 60-gallon capacity connected to each downspout, 903,000 gallons of roof water could be collected during the first flush and kept from reaching streams and the ocean. This volume equals 3,418 m^3 (which equals 902,940 gal or 3,418,000 L). This captured volume divided by the capture area of 103.7 acres (1 acre = 43,560 ft^2) or 419,659 m^2 (1 m^2 = 10.76 ft^2) equals the amount of rainfall that could be collected, which equals the first 0.0061 m (6.1 mm) or 0.24 inches of rain falling on the roofs.

In a previous study, Mendez et al. (2010) analyzed contaminants in the first flush of roof runoff (first 0.027 inches, only 11.3 % of our estimated capture volume) and measured concentrations of 338.6 µg/L for copper and 112.6 µg/L for zinc (Table 8). Using these concentrations as examples, a mass of 1.16 kg for copper and 0.39 kg for zinc could be collected in rain barrels in this area if residential roof water would be collected in rain barrels and used for irrigation. With a 100 % capture effort during the onset of a storm, this amount could be subtracted from the overall metal loads draining into the Reserve. This is less pollutant mass reduction than is achieved through the installation of vegetated swales (determined by effectiveness data from water quality monitoring for this Project), but could impact the pollutant load into the ASBS when added to the overall effort of LID installation.

Table 8a. Concentrations of pollutants measured in roof runoff.

Pollutant	**Minimum** (µg/L)	**Maximum** (µg/L)	**Mean** (µg/L)	**Rainfall** (in)	**Reference**
Copper		338.6		0.03	Mendez et al. 2010
Zinc		112.6		0.03	Mendez et al. 2010
PAH	1.9	6.2	3.9	0.1	Van Metre and Mahler 2003
Lead		1.5		NA	Davis et al. 2001
Lead	14.0	154	68.0	0.1	Van Metre and Mahler 2003
Cadmium		0.12		NA	Davis et al. 2001
Copper		7.5		NA	Davis et al. 2001
Zinc		100		NA	Davis et al. 2001

Table 8b. Runoff rates for pollutants measured in roof runoff.

Pollutant	**Minimum** (mg/m$^{2/}$y)	**Maximum** (mg/m$^{2/}$y)	**Mean** (mg/m$^{2/}$y)	**Rainfall** (in/y)	**Ref**
Copper		1,300		21	He et al. 2001
Zinc		3,100		21	He et al. 2001
PAH*	1.2	4.2	2.6	32	Van Metre and Mahler 2003

*Biased high because only the beginning of rainfall events (first 0.1 inches of rain) was sampled and analyzed.

Table 8c. Estimated contaminant mass reduction if 100% of the roof water could be captured in rain barrels during the onset of a storm.

Pollutant	**Mass reduction through rain barrel capture (kg)**	**Mass estimated from residential land use (kg)** (this report)	**Pollutant reduction through rain barrels (%)**	**Pollutant reduction through vegetated swales (%)**
Copper (kg)	1.2	12	9.7	34
Zinc (kg)	0.39	33	11	33
Lead (kg)	0.23	2.1	1.2	64
PAH (kg)	0.013	0.18	7.2	38

Another study (Davis et al. 2001) measured lower concentrations for zinc (11% lower than in Mendez study) and copper (98% lower than in Mendez study) in roof runoff. Accordingly, the mass removed would be lower if these concentrations would be used for the contaminant reduction estimate. The vicinity to high traffic areas and industrial complexes plays a role in regard to the concentration of heavy metals in runoff. In general, metal concentrations from residential roofs are relatively low. However, concentrations from commercial and industrial buildings can be significantly higher (Davis et al. 2001).

PAH concentrations from shingle roofs were measured by Van Metre and Mahler (2003). Mean concentrations were measured at 3.9 µg/L. If the estimated capture volume in the rain barrels would reduce the total flow volume into the ASBS, the reduction would equal a mass of 0.013 kg for PAHs that would be collected during the onset of the first storm when the rain barrels are empty.

A more successful reduction in contaminant mass to the ASBS could be achieved by installing more complex roof runoff capture systems, like the one displayed in Figure 6. This RCD-led effort provides a valuable demonstration and education tool for the community. Six rain barrels with a capture volume of 205 gallons per barrel were combined with two smaller rain gardens. Three barrels and one rain garden are connected to the downspout in the front of the house and an additional three barrels with a slightly larger garden are connected to the downspout in the back. Once the three barrels, that were installed in line, are filled, roof runoff ponds in the rain garden and filters through the ground. Overflow drains prevent water from topping over the rain garden borders and prevent flooding of adjacent areas.

The total capture volume of the barrels is 1,230 gallons. Furthermore, the ponds can store and filter approximately an additional 600 gallons for a total of 1,830 gallons of roof water that is retained on this private property during the first flush. Efforts like this one in Moss Beach can make a difference in helping reduce contaminants reaching the ASBS and will also provide enough water to maintain a native plant garden throughout the summer months without additional water usage. Native plants need very little additional water but do benefit from slight irrigation, especially during drought years.

Figure 6. Examples of rain barrels installed in the vicinity of the James V Fitzgerald Marine Reserve. A) Private rain barrel and rain garden system in Moss Beach, CA; B) and C) Front yard rain barrels with rain garden; D) and E) Back yard rain garden and rain barrels connected to down spout.

This more complex system can capture approximately six times the volume of roof runoff than was calculated in the first example of five 60-gallon rain barrels at each downspout per household. Considering that the highest contaminant concentrations were measured in roof runoff at the very beginning of the storm and the initial 0.03 inches of rain the higher capture volume will likely not result in an exponential reduction of contaminants but will still contribute further to the improvement of water quality of stormwater runoff. Especially on properties in close vicinity to Highway 1 with increased traffic and higher metals concentrations in areal deposition, the additional storing capacity of the Moss Beach system and treatment through soil filtration within the rain gardens will allow for a more significant mass reduction of contaminants draining to the ASBS.

4. Recommendations

In an ongoing effort to reduce pollution to the ASBS and to receiving waters in general, new LIDs and existing LID combinations will receive more and more attention. Additionally, numerical goals, total maximum daily loads (TMDLs), and antidegradation requirements are creating even more emphasis on stormwater treatment practices. To meet these requirements in the years to come, low cost, low maintenance, high performance, and extended usable life are important factors to consider when planning LIDs.

The outputs from the site locator tool are helping prioritize suitable sites and, in addition with site reconnaissance, are helping maximize the usable space in the Fitzgerald watershed for stormwater treatment. Private property owners can likely contribute more significantly to this effort than they would expect and the example of the wide-spread rain barrel installation could be used as an example for outreach and education.

Especially since more recent studies discovered that methylmercury concentrations in fog can be 19 times higher than in rain (Weiss-Penzias et al. 2012), treatment of roof water originating from aerial deposition and very low flow road runoff filtering through rain gardens and swales may be much more effective than previously predicted. The collection of samples is not possible during those low flow conditions, however, the installed LIDs may show a much larger benefit to the ASBS than originally measured during monitored rainfall events that were part of the effectiveness monitoring for this Project. The same applies to stormwater treatment through pervious pavement, especially if more private driveways could be included in future LID implementation.

A recommendation for future efforts would include site reconnaissance in accordance with the high ranking site identification that resulted from the site locator tool output. Verifying the ranked output from the tool is an important validation exercise of the planning process of LID implementation. Criteria that would be emphasized and evaluated would include:

- Public safety, roadway safety, and safety of adjacent structures, considering ponding depth, width, and duration of ponding.
- All impacts should be restrained to the road right of way
- The shorter the flow path of water into a filter strip or swale is the better. The flow path for runoff should not exceed 75 feet before it reaches the treatment system.
- Site designs must allow for providing safe conveyance of the 100-year rain event.
- Presence of animal species should be assessed during site visits, especially for garter snakes and red-legged frogs.

Another recommendation would be to consider the design of the LIDs, where possible, to increase capacity for runoff and infiltration, adjust the sizing ratio, and to provide more freeboard to avoid bypass of LID systems by stormwater. Additionally, maintenance should be a factor that is accounted for in the planning phase to strategically clear away trash or vegetative debris, especially in the earlier part of the winter when leaf fall is at a maximum.

Regarding the pollution reduction forecast, the data that were included from the literature for EMC development for the load reduction forecast model had some weaknesses. Study designs and sample collection efforts varied significantly in the literature, and data were not always comparable to this Project. EMCs could be improved by additional literature review and a more tailored approach. For example, the residential land use category included studies from highly urbanized areas in Southern California that in comparison to the Fitzgerald watershed’s urban land use likely yielded higher contaminant loads. At the same time, different study designs may have biased the data low when samples were collected in tributaries to rivers or bays with more dilution in the receiving water body than we would expect for the swales in this Project.

Another potential bias could have been introduced to the load reduction forecast by comparing studies that used the parameter total PAHs. This sum is often calculated differently, including different PAH compounds, and may not have been derived from the same 13 PAH compounds that were used in the Ocean Plan and this Project. A more thorough literature review, which in some cases would entail contacting authors of papers, could identify a narrowed down and more compatible approach for the development of the EMC.

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