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Frog Pond Wetland Preserve Enhancement and Erosion Control Plan

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Preface

This report was prepared for the Monterey Peninsula Regional Park District (MPRPD) between December 2012 and June 2014 to assess challenges in managing the Frog Pond Wetland Preserve (FPWP or preserve) and provide recommendations for the preserve's enhancement. The central feature of FPWP is a large pond (Frog Pond) that is fed by the Arroyo del Rey stream, South Boundary tributary, residential runoff, and spring water. The report focuses on erosion, restoration of the Arroyo del Rey stream, and the impacts that development in the South Boundary basin may have on Frog Pond.

First, we assess erosion within the watershed, with special consideration for how development may accelerate erosion and impact FPWP. Current and potential erosion features within FPWP are identified using GIS and photo documentation, and recommendations are based on successful restoration projects completed nearby on former Fort Ord.

We present 3 stream restoration designs for Arroyo del Rey that differ in the advantages they provide from a management perspective. The restoration plans utilize hydraulic modeling and Natural Channel Design methods.

Finally, we assess the role of the South Boundary tributary in the wetland preserve. Using hydrologic modeling, we estimate the effects that development on former Fort Ord in the South Boundary basin would have on Frog Pond.

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1 Introduction

1.1 Project Overview

This report is part of the larger Frog Pond Wetland Preserve Enhancement Plan developed in collaboration with Balance Hydrologics. The purpose of this report is to describe the current condition of the preserve, South Boundary tributary, and Arroyo del Rey in terms of erosion and hydrologic processes. We identify current management challenges as well as those posed by future development. FPWP is described within the context of the Canyon del Rey watershed, and recommendations are based on analysis at the local and watershed scale.

1.2 Goals

- Identify and describe management challenges
- Assess erosion and make recommendations for erosion control
- Develop alternative channel configurations for the Arroyo del Rey channel
- Determine the role of the South Boundary tributary and assess management options
- Make recommendations for enhancement of the preserve

1.3 Study Area

The Monterey Peninsula Regional Park District's 17-acre FPWP is located in Del Rey Oaks, California. Frog Pond is the central feature of the park. FPWP lies within the Canyon del Rey drainage system that begins in the coastal foothills at approximately 500 feet elevation and includes portions of the cities of Monterey, Del Rey Oaks, Seaside, and Sand City, California (MCFCWCD 1977). For the purposes of this study, the Canyon del Rey watershed was divided into three sub-basins: the upper and South Boundary basins drain towards FPWP, and the lower basin is downstream. The two parcels that comprise the preserve are shown in red in Figure 1.

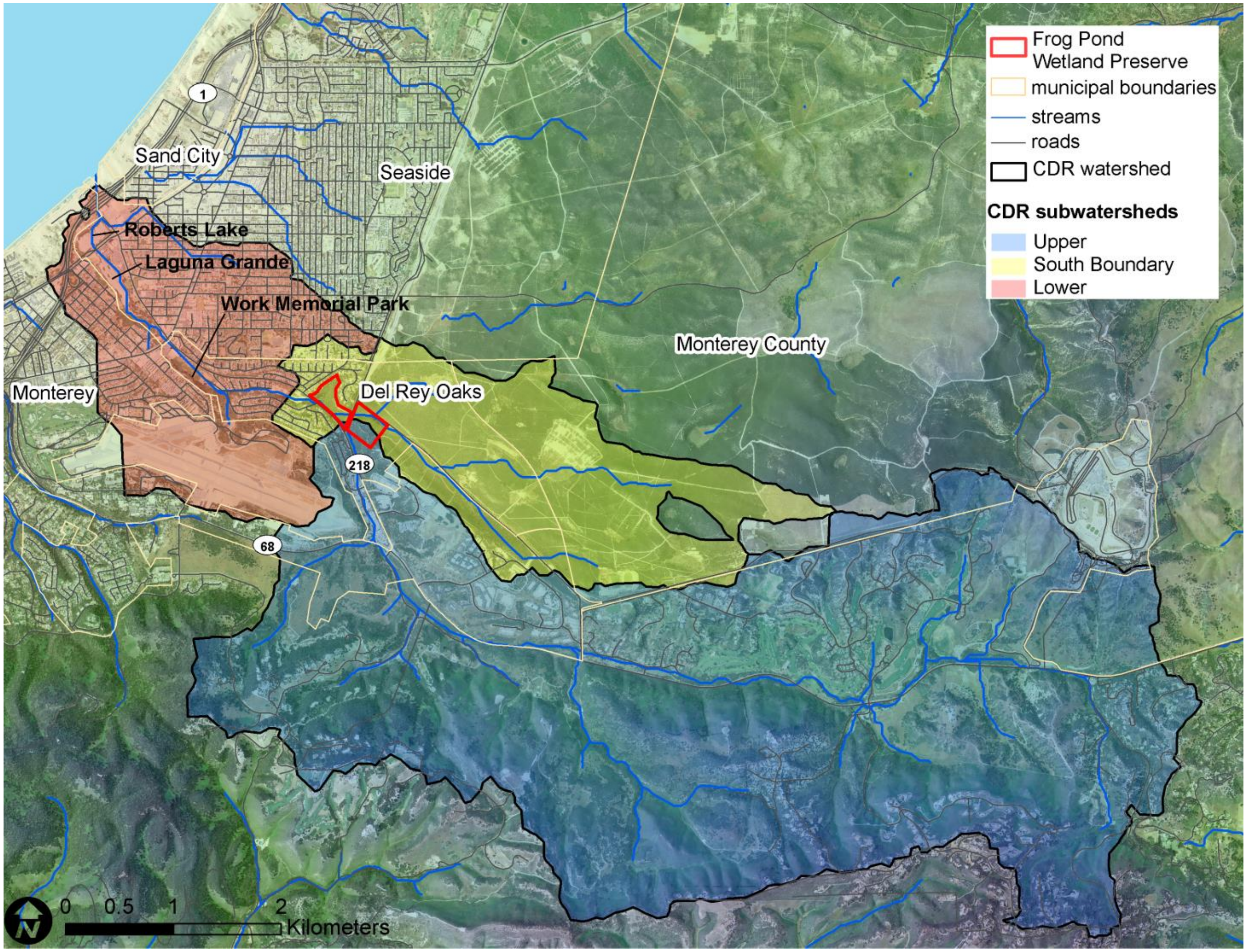
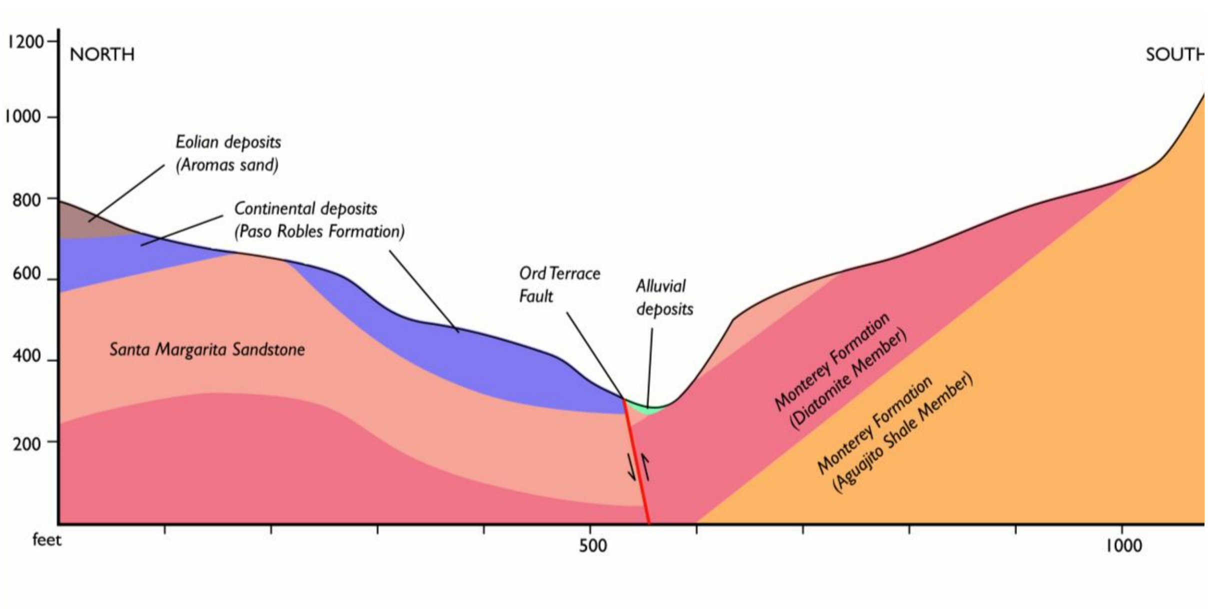


Figure 1 Location of the Frog Pond Wetland Preserve within the Canyon Del Rey (CDR) watershed in Monterey County.

Tributaries of the Canyon del Rey watershed feed the Arroyo del Rey channel, which flows along Highway 68, then Highway 218, in either incised or constructed channels. Downstream, Arroyo del Rey traverses Work Memorial Park before passing through a long culvert feeding the Laguna Grande and Roberts Lake system that drains to the Monterey Bay National Marine Sanctuary. FPWP is located approximately 2.2 river miles (3.5 km) upstream of Monterey Bay along Highway 218.

The geology of the upper Canyon del Rey sub-basin is roughly divided along Highway 68, with steep hillsides of Monterey Shale on the southern side, and highly pervious eolian and continental deposits (Paso Robles formation) underlain by and Santa Margarita Sandstone to the north (Figure 2; USGS 1997). Habitats range from oak woodland and pine forest, to maritime chaparral, and are interrupted by residential lots, commercial parks, and a golf course.

The South Boundary tributary drains toward Frog Pond through a culvert beneath General Jim Moore Blvd (Figure 3). The South Boundary drainage consists primarily of eolian deposits (USGS 1997) and sandy, highly pervious soils underlain by Aromas Sandstone and Paso Robles formation. Maritime



Generalized Cross-section of the Upper Canyon del Rey Watershed

Figure 2 Geology of the Upper Canyon Del Rey watershed (Underwood 2014).

chaparral and oak woodland dominate the landscape. The northeast portion of the South Boundary basin is an undeveloped region of the former Fort Ord army base. This area has potential to be developed once base re-use development plans are finalized. Increased urbanization in this region is likely to impact runoff and erosion within the South Boundary tributary. As such, development within the South Boundary tributary has potential impacts for FPWP.

From Highway 68 to Fremont Blvd., the Arroyo del Rey channel was straightened and deepened for stormwater conveyance. It is periodically devegetated to increase stormwater capacity. Describing the study area from upstream to downstream, the channel runs along an undeveloped parcel owned by the City of Del Rey Oaks (DRO parcel) that lies immediately upstream of General Jim Moore Blvd. For the purposes of this study, this section of the Arroyo del Rey will be referred to as the "upstream reach" (Figure 3). The road fill below General Jim Moore Blvd. has no functioning floodplain culverts, so the fill directs all out-of-bank flow of the upstream reach through a single concrete box culvert that carries the main channel of Arroyo del Rey. Downstream of the

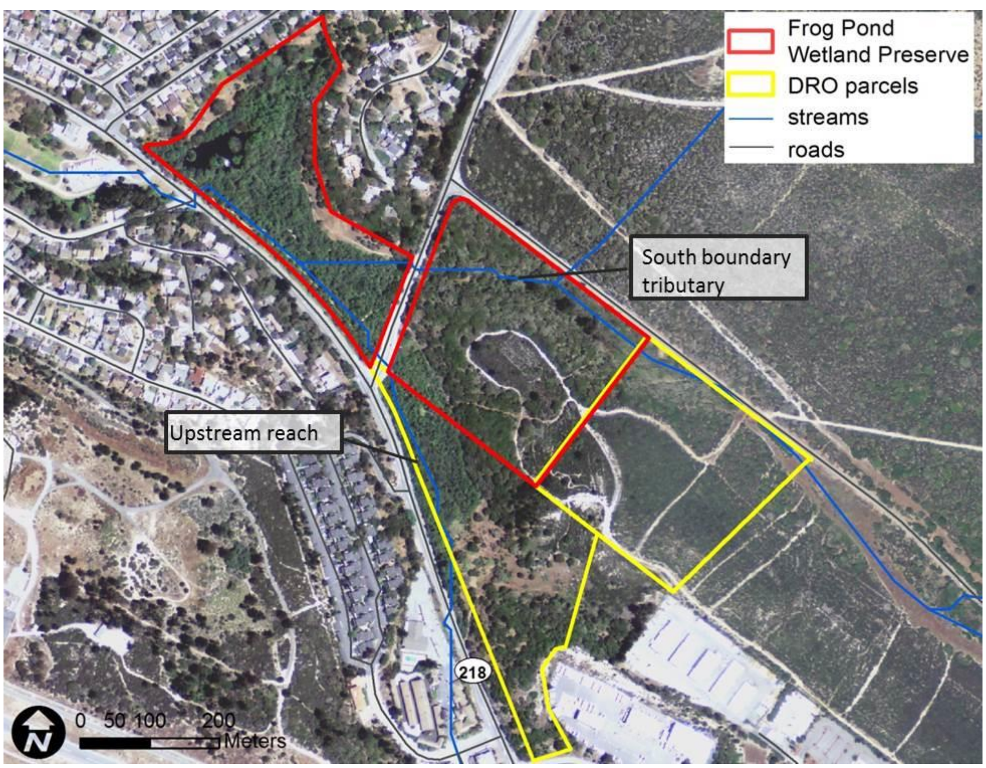


Figure 3 The South Boundary tributary and Arroyo del Rey upstream reach.

box culvert, Arroyo del Rey borders the southwest edge of FPWP, and is laterally connected to Frog Pond at higher flows across a concrete weir. The pond receives water from South Boundary Tributary, springs at the northern edge, and runoff from the residential neighborhoods along the northern border of the preserve (Figure 4). Frog Pond typically dries in mid to late summer, and refills after the first significant rains, whereas Arroyo del Rey maintains low baseflow throughout the summer, fed by return flow from residential and golf course irrigation.

FPWP provides habitat for a variety of species including migratory birds, deer and frogs. Species of special concern have not been documented at the preserve; however, habitat has been identified as suitable for California Red-legged Frog *(Rana draytonii)*, a species listed as threatened under the Endangered Species Act (Anderson 2013). Willow-rich riparian vegetation is the predominant habitat surrounding Frog Pond, followed by grassland, oak woodland, scattered pine trees, and a pocket of planted mature redwood trees. A hiking trail is maintained along the perimeter of the pond.

Figure 4 Sources of inflow to Frog Pond.

2 Management Challenges

There are current and future concerns for preservation of FPWP and the species it supports. Current management challenges include upland erosion, gradual siltation of the pond, and the condition of the Arroyo del Rey channel. Future concerns center around the effects that further urban development of the watershed will have on FPWP. Development typically expands impervious cover and causes increased runoff. The erosional features that exist upstream of FPWP will likely intensify, with impacts to water quality, and landscape, stream and pond morphology. These challenges are assessed in the following sections.

3 Erosion

3.1 Introduction

Erosion caused by water occurs when rainfall, runoff, or springs detach and transport soil across the land (Houghton and Charman 1986). Erosion potential refers to qualities of the land itself that make erosion likely, such as climate, landform, slope, land use, and soil type (Charman 1986). In the context of land management, erosion poses an immediate threat to soil resources and a secondary threat to aquatic habitat.

The Frog Pond lotic ecosystem would be compromised by infilling with sediment transported from the upper watershed as army base redevelopment alters the infiltration and storm runoff processes (CDWR 2013). Sediment from Arroyo del Rey or eroded from local hills surrounding the Preserve would deposit in Frog Pond. As pond siltation is a serious management concern, this section of the report identifies current erosion sites and future erosion risk at Frog Pond, and identifies restoration opportunities. Analysis is broken into two subsections. First there is a broad overview of sediment sources in the upper watershed, and second there is a more detailed review of erosion in the local slopes feeding Frog Pond, which includes the South Boundary basin and the upstream reach of Arroyo del Rey.

3.2 Upper Watershed Erosion and Sediment Sources

Sediment sources in the upper Canyon del Rey watershed were identified using aerial imagery, site visits, and review of the soils and geology of the region. In general, erosion occurs on the north side of Highway 68 near developed areas. Soil types in this area are predominantly Arnold-Santa Ynez complex, and Santa Ynez fine sandy loam, which are highly erodible soils (USDA 1978). These are underlain by continental deposits, undifferentiated coastal terrace, and older eolian deposits (USGS 1997). It is commonly noted that these deposits lie unconformably over the Paso Robles formation (USGS 1997; Kingsley & Associates 1980). In contrast, erosion appears to be minimal on the southern side of the valley. The hillsides south of Highway 68 are primarily steep, densely vegetated, and undeveloped. Santa Lucia Reliz-Association, and Santa Lucia shaly clay loam soils overlie the Monterey formation and some continental deposits (USGS 1997).

Sediment sources, erosion features, and stream channel aggradation or incision were noted between the intersection of Laureles Grade/Highway 68 and FPWP (Figure 5, location 1 and 8). Arroyo del Rey has aggrading sections and deeply incised sections, depending on management. Aside from sediment aggradation between Laureles Grade and the Laguna Seca Raceway entrance, and upstream of Monterra Rd., the channel is deeply incised and unstable, and

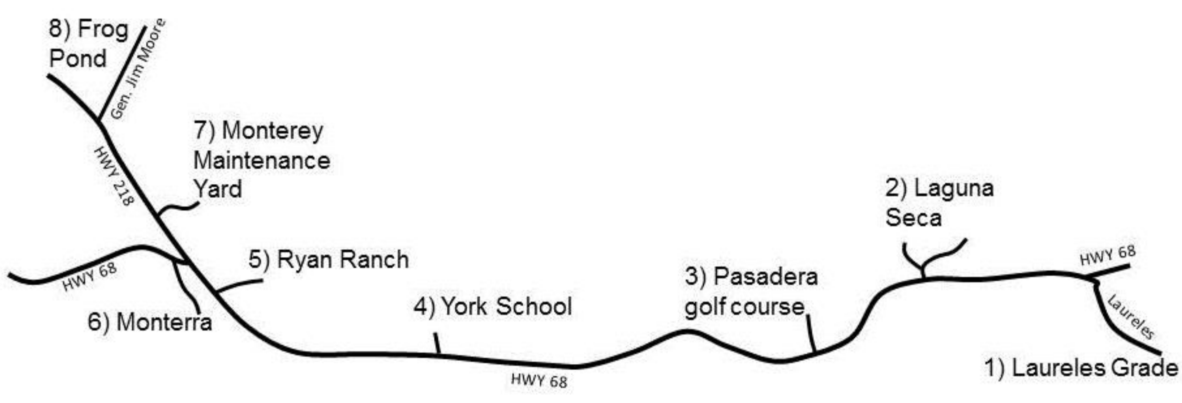


Figure 5 Locations of identifying features within the Upper Canyon Del Rey watershed.

becomes shallower near Frog Pond.

From Laureles Grade to the Laguna Seca entrance off of Highway 68 (across from Monterey County SPCA), the stream channel is narrow and shallow, with sparse vegetation on the banks. Some gullying and erosion below the Raceway and entrance roads are visible from aerial imagery and from Highway 68. Erosion of the channel edges is a significant sediment source near the entrance to Laguna Seca (Figure 6).

Sediment accumulates behind several concrete V-notched weirs in this section of the Arroyo del Rey. After passing through a culvert beneath the Raceway entrance road, there is a four foot drop to a channel incised 12 ft. below the valley bottom (Figure 7). Immediately downstream from the Laguna Seca entrance the channel enters a broad wetland that efficiently traps all bedload carried by the channel. Suspended load is probably trapped as well, except

Figure 6 Erosion of channel edges near Laguna Seca.

Figure 7 Upstream aggradation and downstream incision in the Arroyo del Rey channel at the Laguna Seca Raceway entrance.

during significant runoff events. The wetland is present because water and sediment is impounded behind a culverted 20 ft. tall concrete dam.

The reach between the wetland dam at Laguna Seca and Pasadera golf course is deeply incised and heavily vegetated with willows, except for a couple of small wetland areas. Runoff from the roads and golf course irrigation creates ravines leading into the stream bed. Arroyo del Rey crosses to the south side of Highway 68 towards the middle of the golf course and widens slightly in an undeveloped area next to the steep mountainside. Near York School (Figure 5, location 4) the stream is again on the north side of the road, in a 10-15 foot incised channel with unstable banks (Figure 8). Homes built along the creek approximately 100 m upstream from location 4 are threatened by channel widening.

Arroyo del Rey crosses the road again near Ryan Ranch and flows along Highway 68 beside a large floodplain that is part of the Monterra property (Figure5, Location 6). The floodplain is an area of sediment deposition that is vegetated with grasses, cattails, and mature riparian forest. There is no evidence of bedload in the channel immediately downstream from the Monterra Road culvert, indicating that the Monterra wetland is effectively trapping all the bedload delivered to the property. After crossing under Highway 68, the

Figure 8 Steep erodible stream banks Arroyo del Rey near York School.

channel receives a modest supply of bedload eroded from the Paso Robles formation (visible near the Highway 68 and Highway 218 intersection). Between this intersection and Frog Pond, Arroyo del Rey is a deep, narrow excavated stormwater ditch with an average depth of 10 feet until it reaches FPWP. Sediment sources for the channel as it enters FPWP include sloughing of fines and pebbles of Monterey Shale from steep channel sides, riprap that has fallen in from road revetments, and erosion of the Paso Robles formation outcrops alongside highway 218 (Figure 9).

Figure 9 Erosion in the Paso Robles formation along Highway 68

3.3 FPWP Erosion and Sediment Sources

Analysis of erosion at Frog Pond and in the FPWP uplands included site visits to areas of concern, literature review, the creation of an erosion risk map, and a tour of similar BLM erosion sites that have been restored. After identifying erosional areas using the risk map generated in ArcGIS, we provide descriptions of the current state of the FPWP uplands, which include the Del Rey Oaks parcels, Arroyo Del Rey upstream reach, the South Boundary basin, and Frog Pond itself. Erosion control recommendations (Section 3.4) are based on successful BLM restoration methods used at sites with similar physical characteristics to FPWP uplands.

3.3.1 Erosion Risk Map Overview

We developed an erosion risk map that encompasses FPWP, the South Boundary basin, and Arroyo del Rey upstream reach. The purpose of this map is to identify potential areas for restoration. Identifying the spatial distribution of erosion risk is an essential first step in conserving soil resources and limiting the downstream effects of erosion (Kheir 2005).

Qualitative approaches to erosion risk analysis commonly employ the Universal Soil Loss Equation (USLE) or the similar Rapid USLE (RUSLE) which define erosion risk as the product of soil erodibility, slope steepness and length, land cover/management, rainfall erosivity and conservation practices (Boggs 2001; Aksoy and Kavvas 2005). Some of these factors may be excluded from the equation if they are uniform across the study site (Boggs 2001). A simplified approach to erosion risk analysis, appropriate for conservation planning purposes, focuses on three of the factors identified in USLE: soil erodibility, slope, and rainfall (Wells 2001). Specifically, this method combines slope gradient and soil erodibility data, including soil resistance to detachment and soil infiltration potential, into a classification system for identifying areas of highest risk (Wells 2001). This methodology was used to assess erosion at FPWP, in the South Boundary basin, and in the Arroyo del Rey upstream reach.

3.3.2 Erosion Risk Map Methods

The erosion risk map was created in ArcMap (ESRI 2010) using soil type, precipitation, and slope as indicators of erosion potential. Risk classifications were assigned using literature values of erodibility, and the reclassification and raster addition tools in ArcMap (see Appendix for flow chart). Data sources included:

- Soil-type - Source: Soil Survey Geographic Database (SSURGO 2.2). Soil Survey Spatial and Tabular Data for Monterey County. Downloaded from the Geospatial Data Gateway (USDA/FSA).

- Precipitation - Source: The PRISM Climate Group at Oregon State University. July 7, 2012.

- Slope - Digital Elevation Model (DEM) - Source: United States Geological Survey, National Elevation Dataset (NED). 2009. 1/3 arc second (~10m). Downloaded from The National Map Viewer (USGS) February 2013.

Slopes within the study area were calculated from the DEM and then reclassified according to literature values for breaks in slope steepness (Table 1).
The soil-type raster was reclassified according to soil erodibility values obtained from the USDA Soil Survey for Monterey County (USDA 1978). Soil type, erodibility, runoff rate, and slopes were extracted from the survey in order to create a reclassification scheme specific to FPWP (Table 2).

Table 1. FPWP slopes classified by steepness.

Slope Type	Slope (%)	Reclass #
Steep - Very steep	>30	1
Moderately steep	20-30	2
Moderately inclined	10-20	3
Gentle	3-10	4
Level - Very gentle	0-3	5

Table 2. Soil types of FPWP, classified by erodibility.

Soil	Type	Erodibility	Runoff rate	Slope (%)	Reclass #
Df	Dune land	high–very high	very slow–slow	2–50	1
AkF	Arnold loamy sand	high	rapid	15–50	2
ShE	Santa Ynez fine sandy loam	high	rapid	15–30	2
Ar	Arnold–Santa Ynez Complex	moderate–high	medium–rapid	9–30	3
Akd	Arnold loamy sand	moderate	medium	9–15	4
NcC	Narlon loamy fine sand	moderate	slow–medium	2–9	4
Bbc	Baywood sand	slight–moderate	slow–medium	2–15	5
Oad	Oceano loamy sand	slight–moderate	slow–medium	2–15	5
Rb	Rindge muck	none	very slow	< 1	6

The reclassified slope, soil type, and precipitation rasters were added using Raster Calculator to create a map of erosion risk based on these characteristics. Vegetation cover was not taken into account.

3.3.3 Erosion Risk Map Results

Evaluation of the precipitation raster (Figure 10) showed rainfall is uniform across the study site (average15.9 in/yr). The reclassified soil-type raster showed soils with moderate to high erodibility in the South Boundary basin and the hillside adjacent to the Arroyo del Rey upstream reach, while the reclassified slope raster indicated these same locations have the highest potential for erosion due to their steep slopes (Figures 11 & 12).

The final erosion risk map combined just the reclassified soils and slope rasters since precipitation was uniform throughout the study area. Both the Frog Pond uplands and the area across the road from the south-west edge of the preserve exhibited high erosion sensitivity (Figure 13). Many of these areas have high oak woodland cover, which would be expected to mitigate the erosion risk.

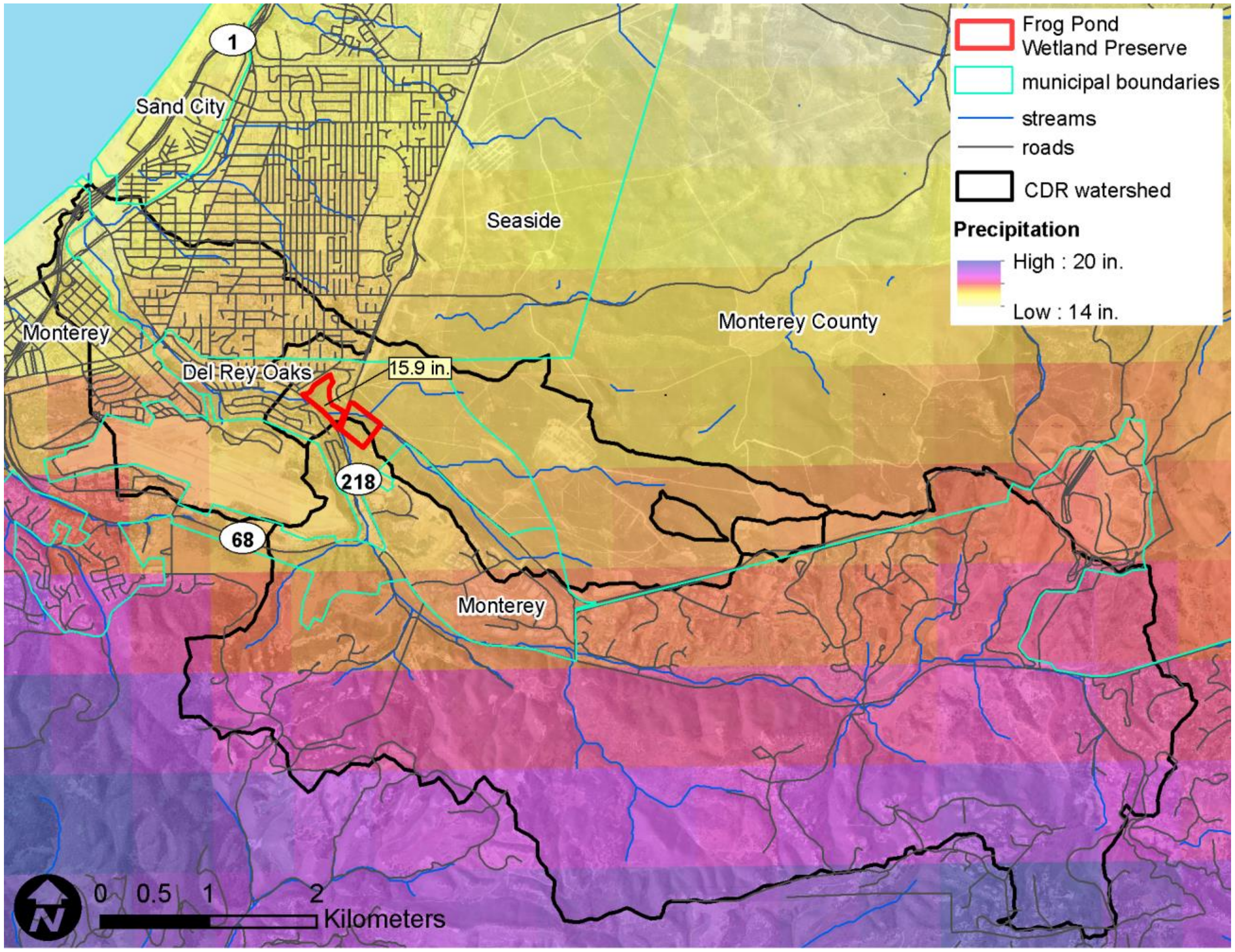


Figure 10 Average yearly precipitation in the Canyon Del Rey Watershed.

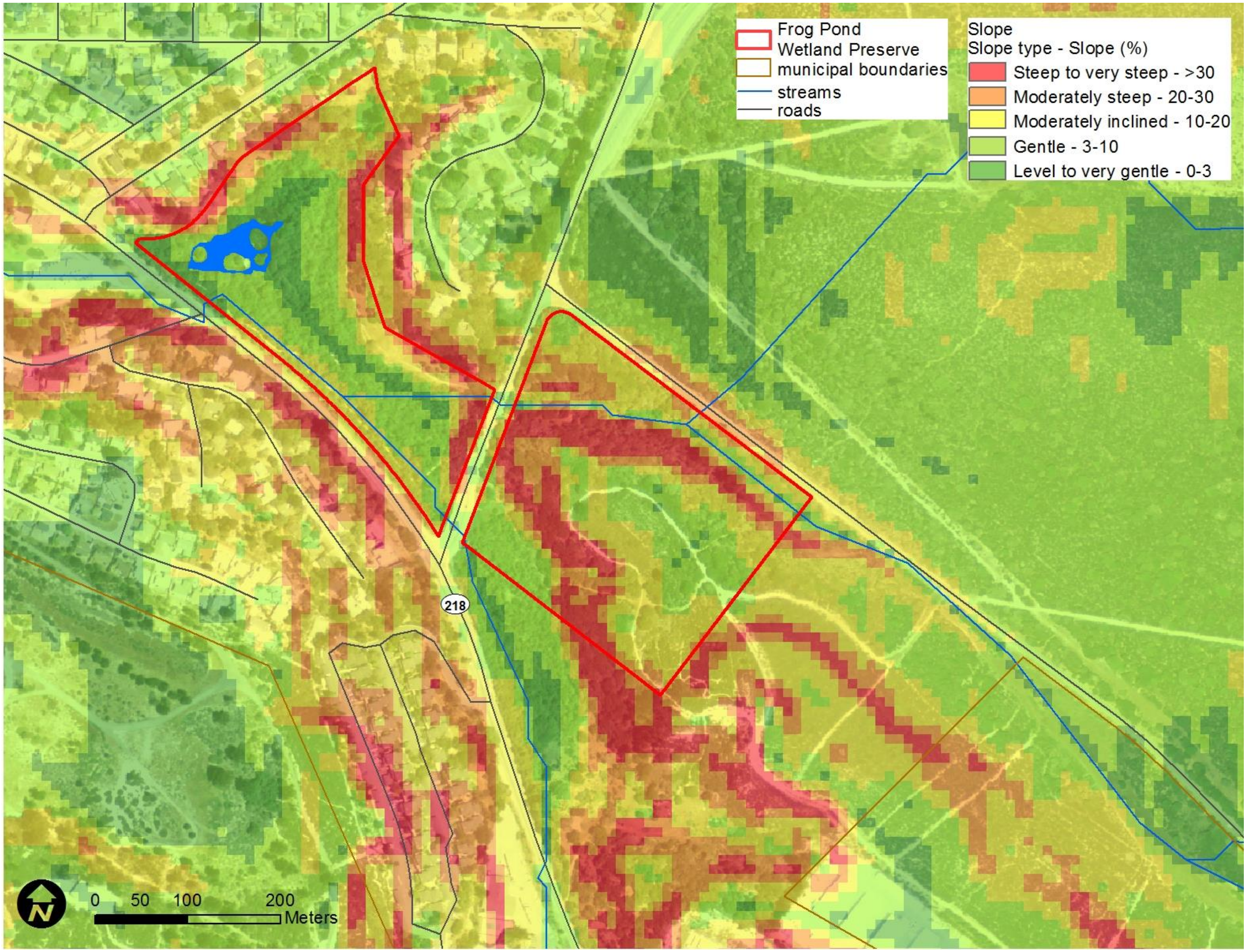


Figure 11 FPWP slopes classified by erodibility.

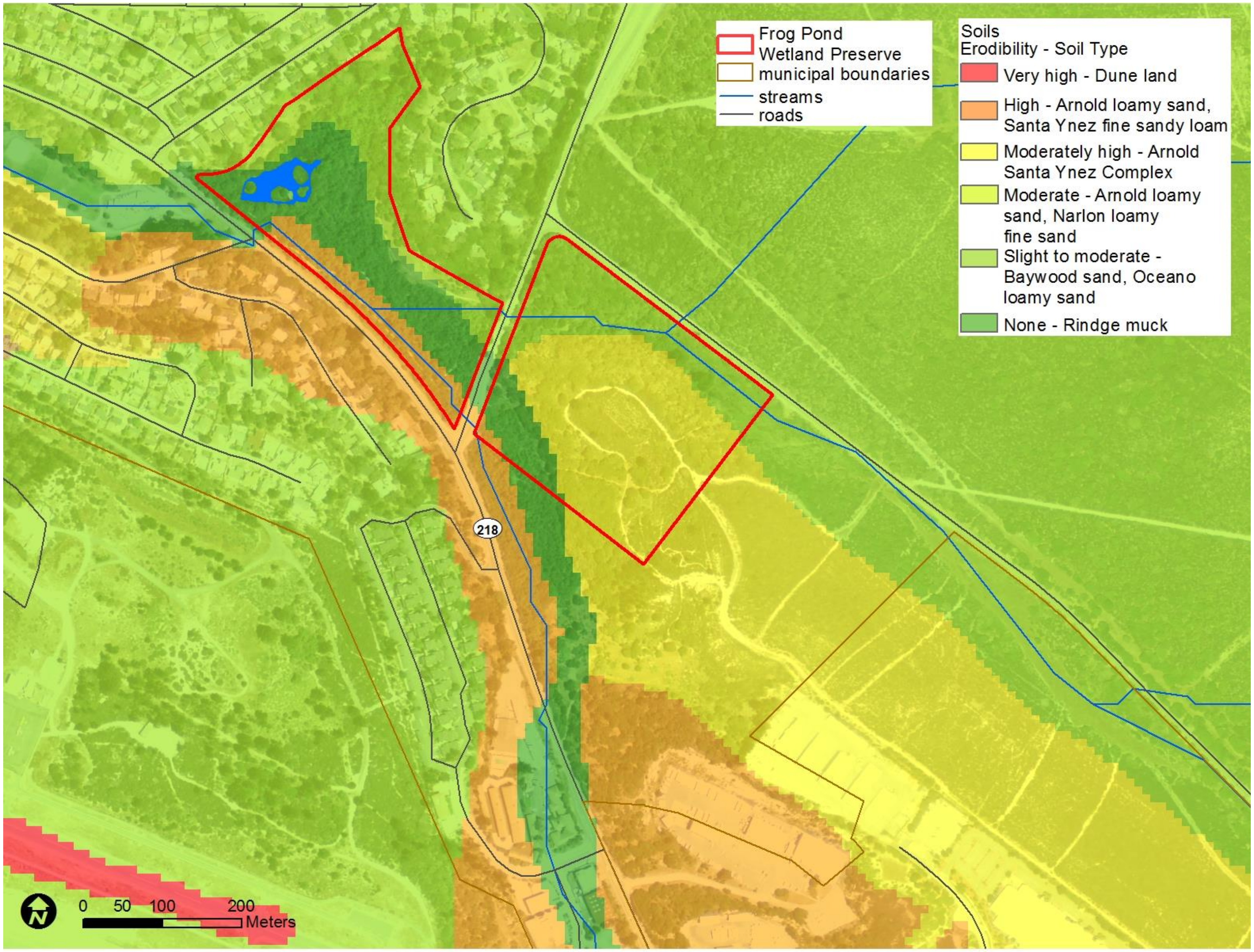


Figure 12 FPWP soils classified by erodibility.

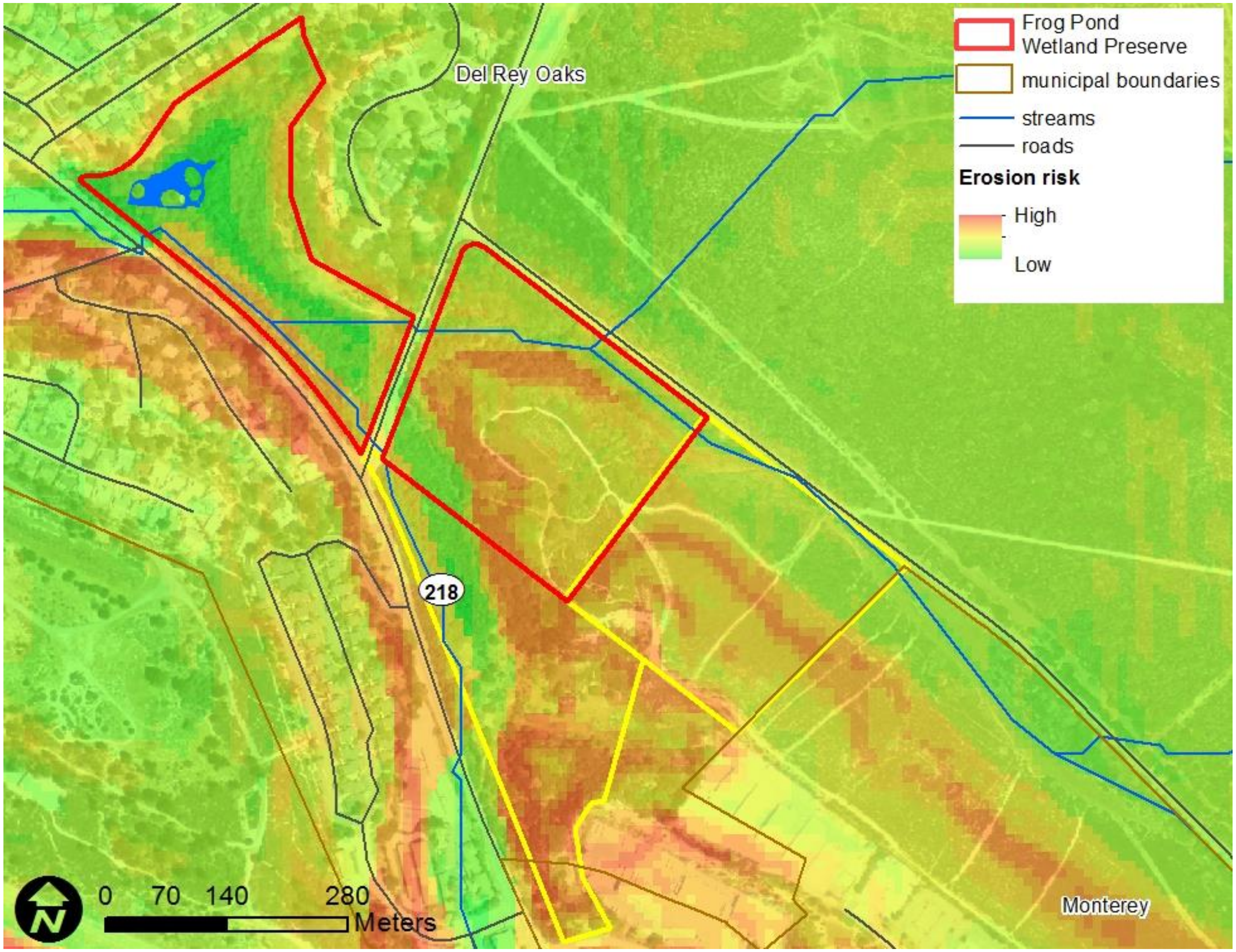


Figure 13 FPWP erosion risk map (not accounting for current vegetation cover).

3.3.4 Del Rey Oaks Parcel and Arroyo del Rey Upstream Reach

The Arroyo del Rey upstream reach extends from General Jim Moore Blvd to approximately 985 feet (300 meters) upstream on the DRO parcel. The upstream reach is an incised channel parallel to Highway 218, with a willow-dominated floodplain to the north. The floodplain is on average 250 feet wide and terminates against highly erodible hillsides that rise approximately 150 feet above the stream channel. At the southeast end of the parcel lies the City of Monterey Public Works Vehicle Maintenance Yard. An east/west valley begins next to the Maintenance Yard, and slopes down into the northeast end of the floodplain. In a 1980 geologic study, Kingsley and Associates noted the valley lacked an erosional channel and that water was likely draining subsurface. This theory was supported by the appearance of sinkholes in the valley in 1979 and 1980. The valley has not developed a defined channel as of 2014 (Figure 14).

Figure 14 East/west valley leading into the Arroyo del Rey floodplain upstream of General Jim Moore Blvd (Facing Hwy 218).

The ridge extending to the northwest from the Maintenance Yard divides the Arroyo del Rey upstream reach from the South Boundary basin, and here there is evidence of erosion. The ridge is supported by Aromas Sandstone outcrops at the highest elevations, and at lower elevations there are gullies in the Paso Robles formation that extend toward the Arroyo del Rey floodplain (Figure 15). The hillsides are vegetated with chaparral and oaks; however an old army road and gullies branching off of un-managed trails are sources of sediment to the floodplain below. Valley slopes are steep, often exceeding 30 %, and eroded banks reveal underlying compacted sandy alluvium or sandstone. The predominant soil type is Arnold-Santa Ynez complex, which the Soil Conservation Service defines as 40 % Arnold soils, 20 % Santa Ynez soils, and the remainder of Elkhorn soils or other loamy sands (USDA 1978). The soils are highly permeable, consisting primarily of unconsolidated loamy sands. They have an available water capacity between 2-5 inches, and medium to rapid runoff rates (USDA 1978). A geologic cross section is available in the Appendix.

The stream banks in the upper reach and within FPWP are steep and unstable, composed of unconsolidated sediments and sections of placed granitic rip-rap. The southern bank descends into the stream channel within a meter or two of

Figure 15 Outcrop of Aromas Sandstone (left), and a gully in the Paso Robles formation (right). Both are located on the hill above the Arroyo del Rey floodplain upstream of General Jim Moore Blvd.

Highway 218, and decomposed granite along the shoulder of the road spills into the stream. During rainstorms rivulets run off the pavement and cause erosion of the stream bank. The banks are typically vegetated with cattails, stinging nettle, horsetail, grasses, and berry bushes. Aquatic vegetation flourishes in the stream bed from late spring and through the summer, to the extent that much of the stream bed becomes choked with vegetation. In winter, flood management activities take place and include the denuding of stream banks, cutting of willows that line the northern stream bank, and removal of emergent vegetation from the stream bed (Figure 16).

When vegetation is cleared, the channel sides slough sediment into the channel and the disturbed stream bed transports more sediment. Sections of gravel may become exposed in one storm event and are covered by 2 – 3 inches of fine sediment in the next event (Figure 17). Sediment obtained in bedload samples

Figure 16 Excessive vegetation growth in the Arroyo del Rey in summer, and the same reach after de-vegetation for flood control.

Figure 17 The Arroyo del Rey streambed shortly after a rain storm, and the same section approximately one month later. The presence of sediment ripples in the streambed indicates sediment transport.

was primarily fine to medium grain sand with some larger shale pieces up to 9 mm in size. During the highest flow measurement of the study period (10 cfs), bedload rate was 1.29 g/s.

In general, the various wetlands located throughout the watershed upstream of Monterra Road trap all the bedload derived from the upper watershed. The amount of sediment passing through the channel near FPWP is diminutive, given the size of the watershed. All the bedload in the channel is derived as described above from a few sources downstream of Highway 68. Sediment transport within the Arroyo del Rey may impact Frog Pond under future management scenarios. Potential impacts are discussed in section 4.

3.3.5 South Boundary Basin

Much of the South Boundary drainage appears to be in a state of equilibrium; however there is some significant evidence of anthropogenic disturbance.

Habitat is primarily oak woodland, with small marsh sections in the valley floor. The lack of a distinct channel indicates water movement is primarily subsurface; however the presence of some aquatic plants in broad, flat areas of fine, soft sediments suggests deposition from valley slopes occurs, and standing water may be present during some periods (Figure 18). Upstream there are scattered pine trees in the valley floor (Figure 19). Toward the southwest ridge, chaparral becomes the predominant vegetation type.

Soils of this region are similar to those described in the uplands of the Arroyo del Rey upstream reach. They are highly permeable, and consist primarily of unconsolidated loamy sands. They have an available water capacity between 2-5 inches, and medium to rapid runoff rates (USDA 1978). The predominant soil type on the southwest side of the valley is Arnold-Santa Ynez complex. On the northeast side of the South Boundary valley the soils are Oceano loamy sand and Baywood sand (USDA 1978).

Figure 18 Dry marsh in the South Boundary basin.

Figure 19 Pine tree grove in the South Boundary basin.

Erosion within the South Boundary drainage occurs near un-managed trails on the upstream ridges, and also along an old army road (Figure 20). On the opposite side of the valley, a deep ravine (approximately 10 feet) has formed beneath an outfall pipe that extends into the valley at the edge of South Boundary Road (Figure 21). This erosion feature is particularly interesting because it shows significant potential for erosion within the South Boundary basin. Possible impacts of future development in this region are explored in Section 5.

Figure 20 Erosion on an old army road within the South Boundary basin.

Figure 21 Outfall pipe extending from beneath South Boundary Road into the South Boundary basin. A deep ravine has formed beneath the pipe.

3.3.6 Frog Pond

Ponds and wetlands form in a watershed where the valley bottom slope is very low; they are therefore natural areas of sediment accumulation over time. Frog Pond is an area of sediment accumulation within the Canyon del Rey watershed. Sediment is carried by runoff from the roads, Arroyo del Rey (if it is overtopping the weir), and potentially from the South Boundary tributary. During the period of this study the Arroyo del Rey was not observed flowing over the weir into the pond. Evaluation of the connection between the South Boundary basin and the pond indicated minimal erosion and sediment transport, but potential for future sediment movement.

A cement box culvert connects the South Boundary basin to FPWP. The cement culvert is entirely filled with sediment at the downstream end, and only contributing water subsurface; however a round, plastic culvert stacked on top of the South Boundary culvert carries flow and minimal sediments off of General Jim Moore Blvd (Figure 22). While minimal sediment has been observed coming from the road, fresh deposits of sediment in a small, defined channel beneath the culvert indicate some erosion is occurring within FPWP on the slope beneath General Jim Moore Blvd. (Figure 23). Sediment samples collected to a depth of 4 feet using a hand auger revealed fine to coarse sand and organics in the first half foot, a mix of sand and gravel from here to 1.5 feet, occasional clay interspersed to 3.5 feet, and black, odorous clayey sand at 4 feet depth (see Appendix for boring log). Increased runoff from the road or South Boundary tributary would affect the sediment transport and morphology of this small channel.

Figure 22 Square, concrete culverts connect the South Boundary basin to Frog Pond. The culvert is filled with sediment at the downstream end. The black, circular culverts drain runoff from General Jim Moore Blvd.

Figure 23 Fresh sediment deposits in the channel downstream of the South Boundary and General Jim Moore Blvd. culverts.

3.4 Erosion Restoration Recommendations

The previous sections identified erosion sites within FPWP boundaries using an erosion risk map and photo documentation. Here we review successful erosion restoration projects carried out by the Bureau of Land Management (BLM) on former Fort Ord lands, and use this framework for restoration recommendations for the Frog Pond. Smith et al. (2002) identified over 100 significant erosion sites on Fort Ord BLM property. Since that time BLM resource managers have been developing the best strategies to successfully restore stable slopes and vegetative ecosystems. BLM's restoration projects offer valuable methodology because the sites have similar geologic history and habitat to the Frog Pond's uplands. A tour of FPWP and upland erosion sites took place on July 18 and 22, 2013. BLM Botanist Bruce Delgado, who implements restoration projects on former Fort Ord, identified erosion sites at Frog Pond that had potential for restoration using BLM methodology. In general, it was confirmed that erosion is occurring in the regions indicated on the erosion risk map. The main areas of concern were gullies in the slopes lying below un-managed hiking trails that line the upland ridges, and along an old army road. We toured successful BLM restoration sites of similar size and slope to those observed near FPWP (Figure 24). BLM restoration reports were obtained for further analysis of proven methods for this terrain.

We recommend gully restoration in the Frog Pond uplands because the natural evolution of these erosion features poses a threat to the lotic environment downstream. The formation of gullies typically begins when intense winter storms cause concentrated flow in an area where the landscape has been altered (Smith et al. 2002). A long evolutionary cycle of gradual filling and then rapid, storm-driven emptying of sediments ensues. A gully may widen and stabilize in 10 - 30 years, but infilling with sediments can take hundreds of years (Smith et al. 2002). During this time gullies may grow larger and encompass more of the watershed, increasing the amount of barren land, and transporting abnormally large volumes of water and sediment during storms.

Figure 24 Erosion restoration plans for the Frog Pond Wetland Preserve's upland area were based on the BLM's restoration of similar sites located on former Fort Ord.

Restoring gullies in the FPWP uplands will increase native habitat and reduce the risk of sediment transport into the pond.

The desired future condition of the upland restoration areas is maritime chaparral and oak woodland. Following BLM methods, the general procedure for restoration includes:

1) Site Preparation: To prepare the site for restoration, the first step is to stabilize eroding banks and loosen compacted soils. This will create a suitable environment for planting by allowing for improved root penetration through the soil. Use heavy equipment to disturb compacted soil, fill gullies, and achieve desired slope. Soil from the edges of the site may be used to fill in and recontour the land. The formation of water bars is recommended as it is effective in slowing runoff and allowing for infiltration near the roots of plants (Figure 25). Cover the site with barley seed (Hordium vulgare) and certified weed free rice straw to protect against erosion before planting occurs. Barley is effective at minimizing erosion in the first 2-3 years while native vegetation becomes established (BLM 2012).

Figure 25 Water bars are created to allow for runoff accumulation near the roots of plants (Photo taken on BLM land in former Fort Ord).

2) Vegetation Restoration: Plant in January or February after the site has been prepared. If water bars were formed in the project area, it is recommended to plant on top of the berms so that water accumulates just below the seedlings at the root level. Seedling stage plants (3-4 months old) are appropriate, however larger plants may be used as well. Species that have been most successful at BLM restoration sites include coyote bush, black sage, blue wildrye, horkelia, deer weed, white yarrow, rush rose, and sticky monkey flower (Table 3).

3) Restoration Monitoring: The first monitoring should occur in summer, and be repeated on a yearly basis until vegetation is mature. Transect studies are an appropriate monitoring method for obtaining general percent cover figures for the restoration site. Use the point-intercept method at half meter intervals, crossing the length of the project area. At each half meter, record the presence or absence of any plant species

Table 3. Typical plants used in restoration of Fort Ord lands (adapted from BLM Report).

Common Name	Latin Name	Common Name	Latin Name
Black Sage	*Salvia mellifera*	Deerweed	*Lotus scoparius*
Blue Blossum Ceanothus	*Ceanothus thyrsiflorus*	Golden Yarrow	*Eriophyllum confertiflorum*
Blue Wild Rye	*Elymus glaucus*	Gooseberry	*Ribes speciosum*
Branching Aster	*Corethrogyne leucophylla*	Horkelia	*Horkelia cuneata*
California Sage	*Artemisia californica*	Naked Buckwheat	*Eriogonum nudum*
California brome	*Bromus carinatus*	Needlegrass	*Nassella pulchra*
Coast Live Oak	*Quercus agrifolia*	Pitcher Sage	*Lepechinia calycina*
Coast Whitethorn	*Ceanothus incanus*	Rush Rose	*Helianthemum scoparium*
Coffeeberry	*Rhamnus californica*	Sticky Monkey Flower	*Mimulus aurantiacus*
Common Yarrow	*Achillea millefolium*	Yellow Bush Lupine	*Lupinus arboreus*
Coyote Bush	*Baccharis pilularis*		

within the following categories: above 2 meters (tree layer), between 0.5 – 2 meters (shrub layer), below 0.5 meters (herb layer), and ground cover or bare ground (ground layer) (BLM 2012). As vegetation matures, it may be appropriate to measure percent cover using aerial imagery (if recent imagery is available) and ArcGIS. Polygons can be manually "drawn" around vegetation in an aerial image, or the Image Classification Tool (within the Spatial Analyst Extension) can be used to identify habitat types.

The costs of erosion restoration in the FPWP uplands will vary depending on the size of the erosion feature to be restored, source of plants (grown from seedlings collected by MPRPD, or bought), and labor costs (volunteer, salaried employee, or contractors).

4 Arroyo del Rey Channel Design

4.1 Introduction

This section of the report describes stream restoration opportunities at FPWP. Arroyo del Rey currently flows in a manmade, earthen canal along the Del Rey Oaks parcel and alongside the preserve. Lateral erosion threatens Canyon Del Rey Blvd, so riprap has been used to repair erosion sites, and the debris are sporadically removed. General Jim Moore Blvd (GJM) blocks the stream's natural floodplain. There are plans under consideration that would elevate GJM, and a causeway beneath the road would reconnect the floodplain. As a result Frog Pond would become a catchment for additional flood water and sediment. With a more direct link between Frog Pond and Arroyo del Rey, the condition of the stream becomes increasingly significant as it could affect the pond's morphology, water quality, and aquatic habitat. If GJM is not elevated, there is still an opportunity to restore a more natural stream on the Del Rey Oaks parcel. The general benefits would be improved biological function, improved water quality, and reduced erosion risk to Del Rey Oaks Blvd.

Arroyo del Rey within the study area (see section 3.3.2) is regularly maintained by heavy equipment that removes sediment and flow-impeding vegetation. The straight alignment, and periodic disturbance reduce habitat value. Rosgen (1997) explains that streams in "dynamic equilibrium" have the ability to transport flow and sediment while maintaining their average dimension, pattern, and profile without long-term aggradation (filling) or degradation (incising). Arroyo del Rey can be restored to an equilibrium state using Natural Channel Design (NCD) methodology. NCD methods draw upon channel dimensions and shapes of naturally stable streams in the design of restoration projects (Rosgen 1997). The objective is to restore degraded river reaches by mimicking river reaches that have reasonably frequent flooding and that can transport the sediment supplied to them.

Using field measurements, gage hydrology, NCD, hydraulic modeling, and GIS mapping we assessed 4 potential channel configurations for Arroyo del Rey: 1) leaving the stream channel "as-is", 2) creating a meandering channel that reconnects with the current canal upstream of GJM, 3) creating a meandering channel that continues downstream of GJM and connects with the current canal 50 m before the pond, and 4) creating a meandering channel that enters the pond. The advantages of a meandering channel as opposed to the current, straight canal include:

a. Increased linear channel length that would provide additional habitat for wetland species.

b. Improved water quality leaving the restored reach (sediment trapping, and potential nutrient reduction may aid in NPDES compliance for cities downstream).

c. Increased infiltration (would reduce runoff and increase groundwater replenishment).

d. Sediment retention (lessen the need for dredging of Frog Pond.

e. Increased recreational value (i.e. room for additional trails, improved birding, etc.).

f. Reduced erosion risk for Canyon Del Rey Blvd.

4.2 Overarching Goals

Stream restoration can take many forms. The design approach can be driven by the specific goals (e.g., wetland maintenance and sediment transport), available data (e.g., hydrology and presence of reference reaches), and external physical setting (e.g. floodplain geometry and bedload delivery rate). For Frog pond, we sought to design a channel and floodplain system that floods frequently (to support wetland species), transports bedload (for physical stability), and that maintains physical integrity (does not rapidly erode its banks). The externalities of the stream design are shown in Table 4.

We first analyzed the present configuration of the canal and culvert beneath General Jim, Moore, then began calculating the parameters for a restoration design.

Table 4 Arroyo del Rey restoration design considerations and externalities.

Variable	Desired Outcome	Data	Opportunities/Constraints
Flood Frequency	Approximately annual flooding to maintain riparian wetlands	11 years of stream gage data near the site	
Bedload Sediment Transport	Transport the bedload supplied from upstream without long-term net aggradation, degradation, or rapid bank erosion	Current stormwater canal adequately transports the sediment. Exit from GJM culvert has central bar. Laguna Grande does not receive large bedload supply. All bedload is supplied to the site from local streambank and small local bedrock outcrops.	Low bedload supply allows a design that has relatively low shear stress, and lower risk of bank erosion. Current canal channel shape offers one "solution" to bedload transport considerations.
Channel dimension	Geomorphically stable design that is in steady-state equilibrium with watershed sediment supply over the scale of decades, and in the context of El Nino events.	Existing valley slope. A channel segment in Monterra wetland of questionable design value. Discharge data for flows with near-annual recurrence interval (partial duration series). Typical dimensionless ratios for channel design.	No high-value local examples to use as reference reaches. No "regional curves" of bankfull geometry. Broad unobstructed floodplain for a meandering channel. No significant challenges from bedload supply. High water table maintained by perennial baseflow from upstream

4.3 Methods

We used the Hydrologic Engineering Center's River Analysis System (HEC-RAS 2011) to develop two one-dimensional hydraulic models: one of the "current" Arroyo del Rey channel, and the other a "restored" stream channel. We collected stream flow, sediment transport, and cross-sectional survey data of Arroyo del Rey between December 2012 and April 2014 to create the current model. NCD methodology was used to design a Priority I restoration channel, which re-establishes the channel on to its original floodplain (Rosgen 1997).

The current model was calibrated by adjusting the roughness coefficient, Manning's n, which represents the resistance to flows in the channel. We determined Manning's n using multiple approaches. First, we adjusted the n values in the model until simulated flow and stage (water elevation) matched those measured in the field. Another approach was to calculate Manning's n based on the USGS guide for selecting roughness coefficients (Arcement & Schneider 1989). Using this method, a base value of n was selected based on the channel's stability, bed composition and form. Adjustment factors such as in-stream vegetation increased the value of n. Finally, we modeled stream flow over a range of possible n values, and determined what values were required to result in the field-verified stream competence (the size of bedload particles moved by the stream). The best estimate of channel roughness was selected by comparing these three methods.

Shear stress was derived from the current model at channel-full flow. This value describes the amount of energy available to transport sediment. The shear stress of the current model was compared with that of the restored model to ensure that the restored channel would transport the sediment supplied to the stream.

We developed the HEC-RAS model of the restored channel using an iterative process informed by flood frequency analysis and review of a potential reference reach. Using 11 years of stream discharge data from the Monterey Peninsula Water Management District, we approximated the recurrence interval and frequency of channel-full flows. Partial duration series analysis was used rather than Log Pearson Type III analysis so that true frequencies of low magnitude flows could be calculated (e.g., Smith et al, 2009), and because of the limited number of years for the annual maximum series from the gage.

The NCD approach to stream channel/floodplain design usually relies on local examples of geomorphically-appropriate (for example, not incised or rapidly changing) streams that are effectively processing sediment. There are no clear examples of functioning streams to draw upon in this watershed. While not in an ideal setting, we identified a potential reference reach upstream of FPWP on the Monterra Property as an initial guide for channel dimensions. The channel is not incised, but it also does not have any bedload transport requirements, being at the downstream end of a wetland. Rough measurements were made of the channel at Monterra and were used in the initial iterations of potential restoration designs. Given the paucity of reference streams, and very limited bedload transport requirements, our design was strongly influenced on a choice of flooding frequency (described below).

Based on dimensions of the design channel that met the competence, capacity, and flood frequency requirements of the current Arroyo del Rey system, we created a visual representation of a restored, sinuous channel in ArcGIS. Three alternative end points of the restored channel were developed for consideration.

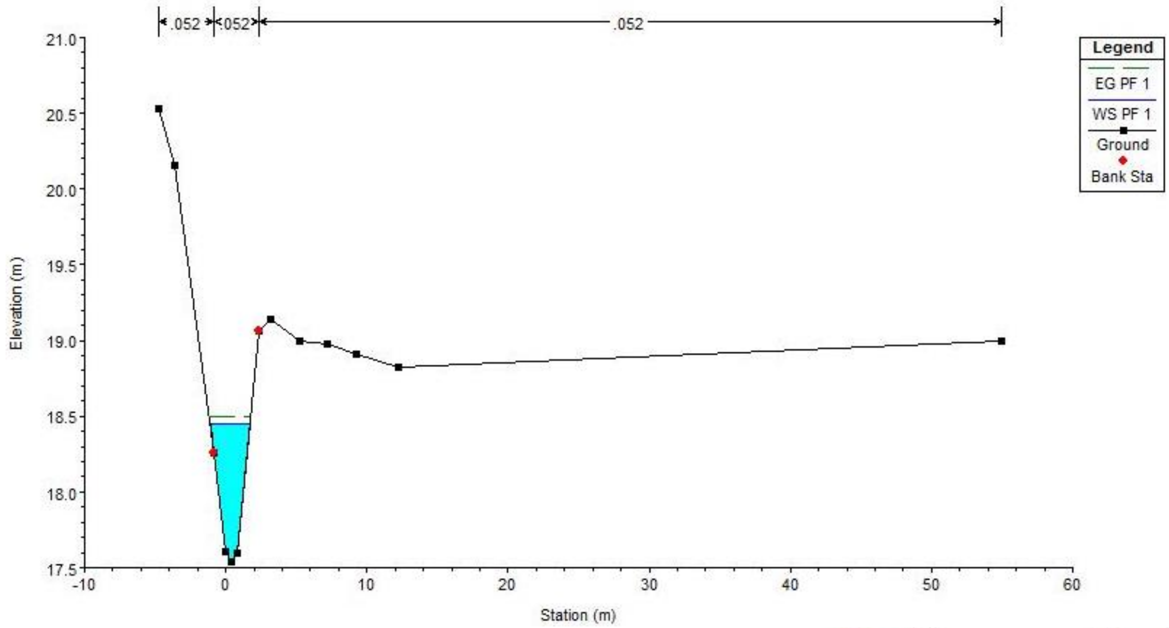
4.4 Results

4.4.1 Current (As-Is) Arroyo del Rey HEC-RAS model

We created the current Arroyo del Rey HEC-RAS model using channel dimensions obtained in cross sectional surveys in summer 2013. The box culvert that Arroyo del Rey flows through beneath GJM was included in the model as it can cause backwater during flooding flows. Ineffective flow areas were input on both sides of the culvert (Figure 26).

Once existing geometric data were input to a HEC RAS model, the model was calibrated by adjusting Manning's roughness coefficient (n) until the model flow elevation matched the observed flow elevation at the staff plate of our gage. Given the low flow conditions that prevailed during the study period, we calibrated the low flow data, but then made two independent estimates of manning's n for higher flows, near channel full. The two high-flow estimates for n, described below, converged on an n value near 0.04.

Calibration of the current model using field measurements of stage and flow led to a high roughness value (n = 0.085). Due to the dry and critically dry years during which flow data was collected, this method of calibration was appropriate for low flows only. It is assumed that the channel behaves differently during higher flows. The high n-value reflected the frictional impact



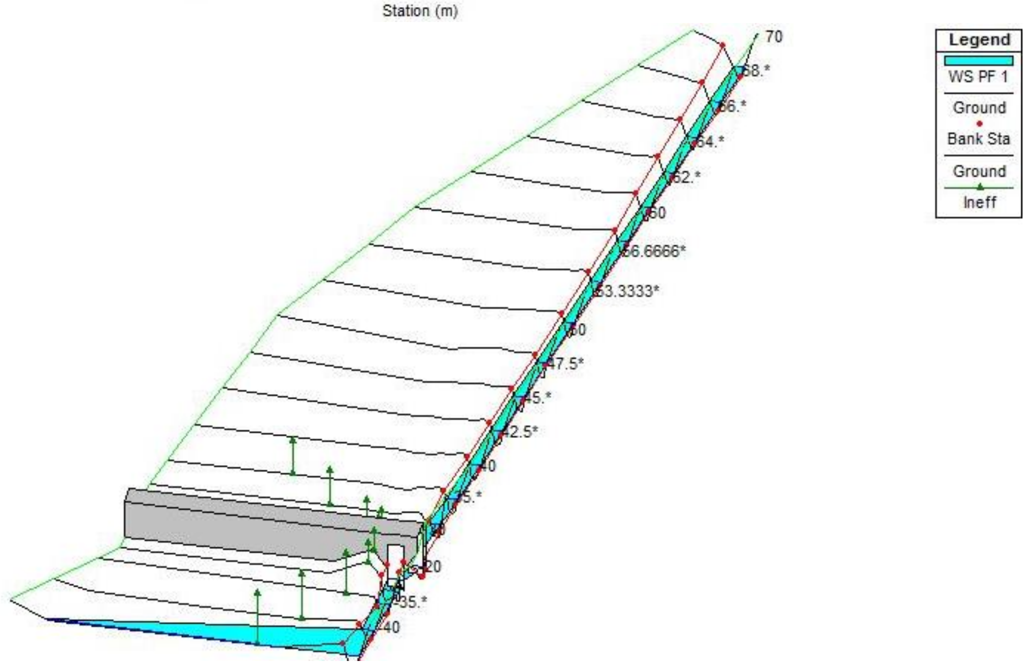


Figure 26 Cross-section and oblique planform view of the current-conditions Arroyo del Rey HEC-RAS model. View is upstream. Grey block is General Jim Moore road grade and culvert. Modeled flow is 35 cfs. Cross section is station 60.

of dense aquatic vegetation in the channel during low flows. The high value is less appropriate for high flows that drown small bed roughness elements and that contact relatively bare upper stream banks.

To calibrate the deeper flows, we calculated a composite n value of 0.045 using the approach detailed in Arcement & Schneider 1989. Lastly we calibrated the deep-water n value of the current model using bedload competence (largest particle moved) obtained at a flow of 10 cfs, the highest flow that was sampled during the study period. The largest particle from that sample also approximated the largest particles in the bed material in the channel as well (ignoring riprap that is not transported by the channel). We modeled channel-full flow over a range of n-values to find a coefficient that generated enough shear stress to transport the large particles in the channel (Table 5). We determined that n = 0.04 produced adequate shear stress (τ) to transport the typical large particles present in the channel. This calibrated model may be considered the "as-is" channel for comparison to the models of the channel realignment management option.

Table 5. Shear stress (τ) of the current Arroyo del Rey model with varying roughness coefficients (Manning's n). A is cross sectional area, W is top width of water, d is A/W, dmax is maximum water depth, and w/d is the width to depth ratio. di is the largest bed particle that can be moved by the flow assuming a value of 0.05 for dimensionless critical shear.

	Channel dimensions						max grain size
n	A (m^2)	w (m)	d (m)	dmax (m)	w/d	τ (N/m^2)	di (m)
0.025	0.91	2.18	0.42	0.66	5.19	21.12	0.028
0.03	1.05	2.32	0.45	0.72	5.16	22.46	0.029
0.035	1.17	2.46	0.52	0.77	4.73	25.19	0.033
0.04	1.29	2.58	0.58	0.82	4.45	27.76	0.036
0.045	1.41	2.69	0.63	0.86	4.27	30.09	0.039
0.05	1.53	2.80	0.68	0.90	4.12	32.26	0.042
0.055	1.64	2.90	0.73	0.94	3.97	34.27	0.045
0.06	1.75	3.00	0.78	0.98	3.85	36.16	0.047
0.065	1.86	3.09	0.83	1.02	3.72	37.95	0.050
0.07	1.96	3.18	0.87	1.05	3.66	39.65	0.052
0.075	2.07	3.26	0.90	1.08	3.62	41.28	0.054
0.08	2.18	3.35	0.95	1.11	3.53	42.87	0.056

4.4.2 Flood frequency analysis

Channel design incorporates a “design flood frequency.” In this regard, a channel can be designed to have any flood frequency desired for ecological considerations, if the channel were fully armored. As this will be an alluvial channel, free to adjust to changing conditions, the size must also approximate the dimensions of a channel that would form in this setting under natural conditions. To satisfy the requirement for frequent flooding, eleven years of 15-minute stream gage data were used in our partial duration series analysis.

It is commonly cited that bankfull flow in natural streams has an exceedance recurrence interval near 1.5 yrs., using the annual maximum series (Dunne and Leopold 1977). While typical analysis (Log-Pearson III) of the annual maximum series is appropriate for modeling rare, high-magnitude annual floods, it grossly underestimates the true frequency of frequent flows (e.g., Smith et al. 2009). When more accurate frequencies are obtained through partial duration series, streams are found to flood approximately annually.

A typical annual hydrograph is shown in Figure 27. Visually, a flow of 50 cfs occurred twice that year. Using partial duration analysis with 11 years of data, 50 cfs has a recurrence interval of 1 year. The same data indicate that 65 cfs corresponds to a 1.5 year recurrence interval, and 80 cfs has a 2 year recurrence interval. We sought to create a restored channel that floods approximately annually to support a wetland ecosystem on the floodplain, so for the purposes of this study the design bankfull flow was chosen to be approximately 50 cfs.

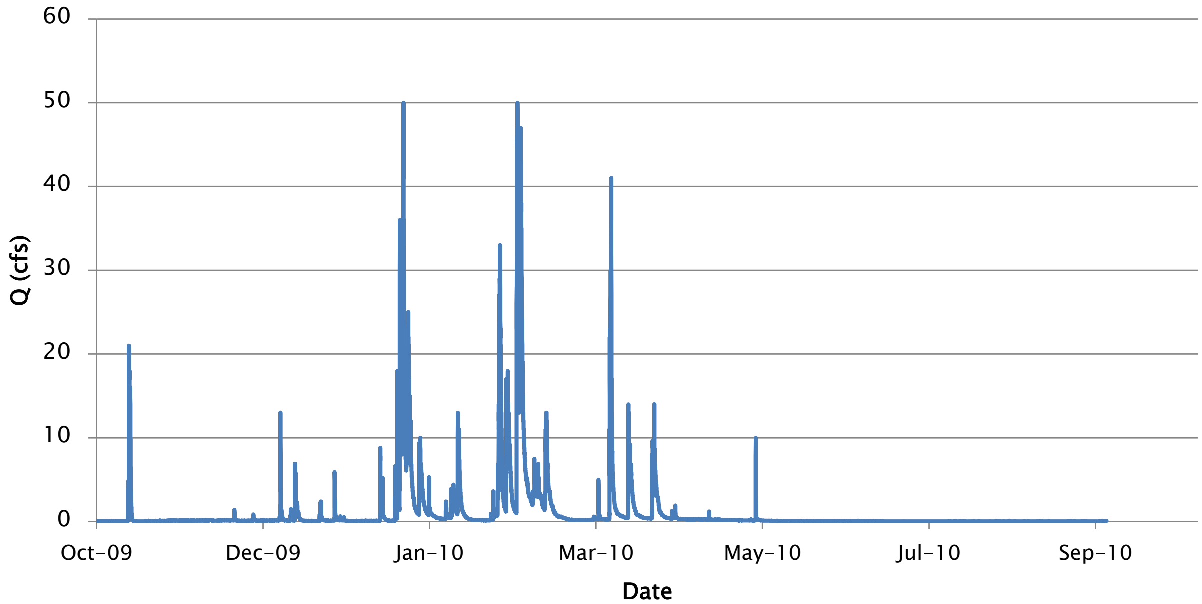


Figure 27 A typical annual hydrograph for Arroyo del Rey.

4.4.3 Monterra as a potential reference reach

The physical dimensions of the channel were developed through an iterative approach that required a channel capacity to carry approximately 50 cfs before incipient flooding. Efforts to find a reference reach for Arroyo del Rey were limited by the high level of disturbance in the watershed. Reconnaissance of the wetland area upstream of Monterra Road showed that Arroyo del Rey flows in a dominant, continuous channel parallel to Highway 68 (Figure 28), and in discontinuous, anastomosing channels on a broad floodplain. Stable islands vegetated with dense willows defined the boundaries of small channels, and sedge meadow filled the remainder of the floodplain. We observed small channels filled with flattened sedges and areas of standing water in the floodplain, indicating flow across the floodplain was recent and occurs frequently even in dry years (Figure 28). The valley floor and stream beds were composed of mud and clay, suggesting bedload is trapped in upstream reaches of the wetland. When high flows occur, the broad, densely vegetated floodplain presumably slows the water and filters suspended sediments.

Figure 28 Arroyo del Rey channel and wetlands at Monterra.

At the downstream end of this reach two defined channels drain through 5 culverts under the Monterra entrance road: a channel running parallel to Highway 68, and a more sinuous channel that meanders through the floodplain. The sinuous channel appeared to have the most natural and stable form (Figures 29 & 30). The channel was approximately 3 m wide and 0.35 – 0.4 m deep. While not a perfect reference reach, similar dimensions were explored for the Arroyo del Rey restoration design.

From a broader perspective, it is feasible and worth considering a similar system as Monterra for the floodplain upstream of General Jim Moore. Additionally, we'd like to note that Monterra is likely trapping the majority of sediment from the upper watershed and is a valuable feature for the preservation of the aquatic systems (and future restored channels) downstream of Monterra Road.

Figure 29 Potential reference reach at Monterra.

Figure 30 Potential reference reach at Monterra.

4.4.4 *Arroyo del Rey restoration model*

The conditions at the restoration site are ideal for restoration (low bedload supply, broad floodplain, high water table, and dense riparian vegetation), so there are fewer than usual constraints on channel design. The options include steep, low sinuosity channels, as is currently present, to more sinuous, wide and shallow channels. The sinuous channels fit within stream types C and E of the Rosgen stream classification system (Rosgen 1997). After comparing channels of varying dimension, we developed a restoration model that fits the E classification to maximize water depth (to optimize aquatic habitat) at low discharge conditions that are present all year long. The design channel is 3.5 m wide, 0.75 m deep at the deepest point, and has greater sinuosity and a gentler slope than the current channel (Table 6). When this channel is constructed, the existing canal would be filled to above floodplain elevation, thereby protecting Del Rey Oaks Blvd from erosion or flooding.

A HEC-RAS model of the restored channel was developed using the new channel dimensions (Table 6) and Manning's n = 0.04, as determined from the bedload transport analysis (Figure 31). The modeled channel length was increased to provide a channel with a moderate sinuosity (k) of 1.3 and a channel slope appropriate to transport sediment.

Table 6. Arroyo del Rey restoration design parameters.

Design Parameters	m or m²	Design Parameters	m or m
Area (Abkfl)	1.50	Channel slope (Sc)	0.00
Width (wbkfl)	3.50	Sinuosity (k)	1.
Depth (dbkfl)	0.43	Radius of curvature (Rc)	9.
Max depth (dmax)	0.75	Meander length (Lm)	42.
w/d	8.17	Belt width (wb)	20.
Side slope	2.00	**Dimensionless Ratios**	
Wetted perimeter (WP)	3.85	Rc/wbkfl	2.
Hydraulic radius (R)	0.39	Lm/wbkfl	12.
Valley slope (Sv)	0.0075	Wb/wbkfl	5.

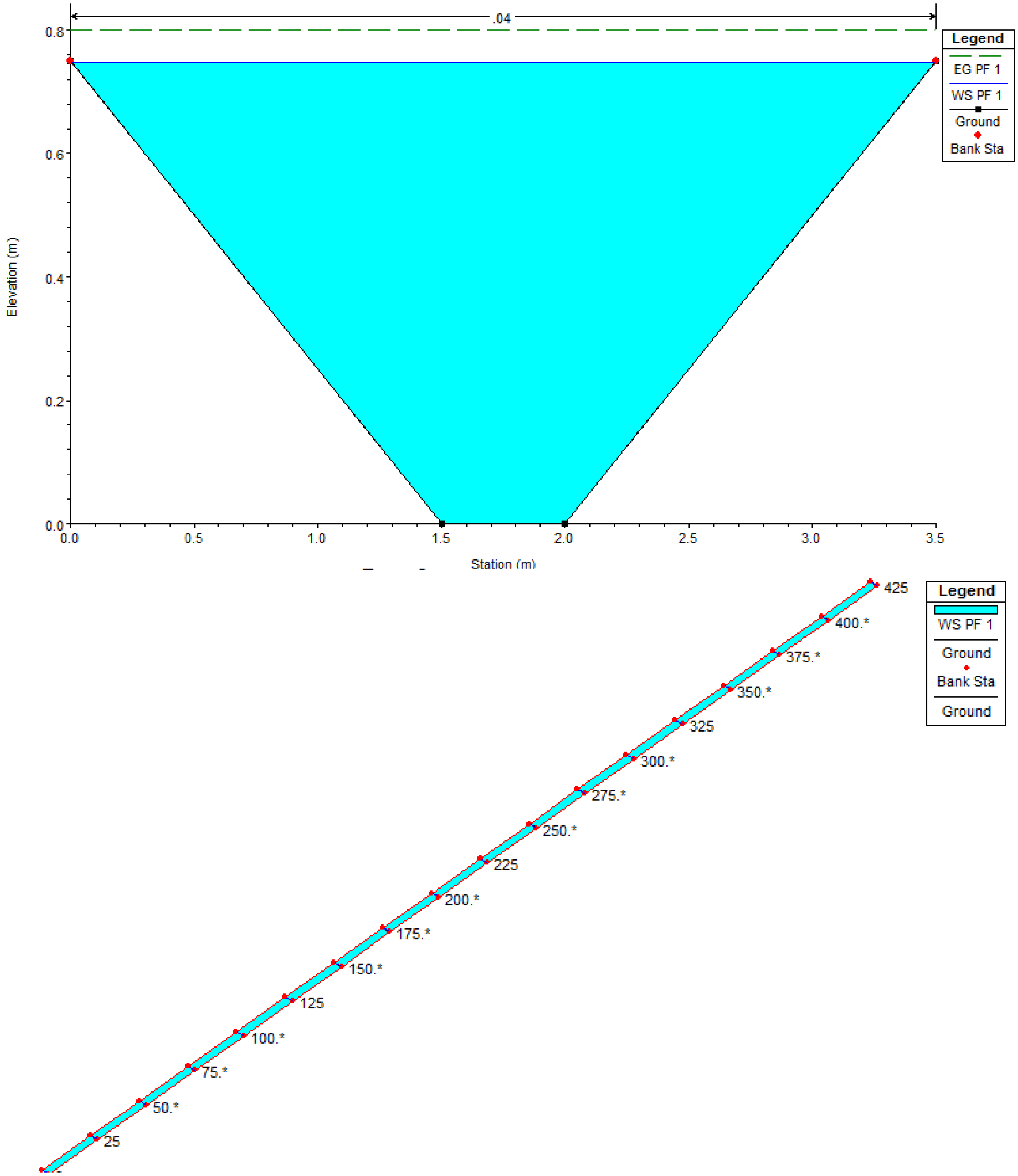


Figure 31 Cross-sectional and long view of the HEC-RAS restoration model.

The modeled channel reaches channel-full flow at 50 cfs (1.41 m^2/s), and generates shear stress similar to the current model ($\tau = 22$ N/m^2). Of note, the minimal sediment transport requirements of this system make it feasible to create a channel with reduced shear stress. This is desirable as it would lower the velocity of flow, and produce less stress on the stream banks. A reduction in shear stress could be achieved by creating a more meandering or wider, shallower channel.

4.4.5 Restoration planform parameters

Based on the dimensions of the restored model, we calculated the map-view "planform" parameters of the design to show what the channel would look like on the parcel. We calculated meander length (Lm) and radius of curvature (Rc) according to Rosgen's dimensionless ratios (Rosgen 1997). Belt width (wb) was based on the size suggested by Williams (1986), but then modestly increased to reach the desired sinuosity.

A digital elevation model (USDA 2009) was used to draw a line along the fall-line of the valley, where the channel centerline should run. Meander length and other planform parameters were drawn as shapefiles on the map (Figure 32). These parameters guided the drawing of 3 alternative restoration channels. Recall that 3 endpoints for the restored channel are possible. The channel can reconnect with the current canal upstream of GJM, extend downstream of GJM and connect with the current canal 50 m before the pond, or enter the pond directly (Figures 33, 34, 35). The design that brings the channel close to, but not into, Frog Pond would include a low protective terrace to guide floodwaters back to the existing canal 50 m upstream of the pond in order to protect the pond from flood waters and sediment. In each design, excavated material from the restored channel could be used to fill the current channel and would protect from further erosion along the road. Channel length and valley length of each design were measured and resulted in the expected final sinuosity (approximately $k = 1.3$).

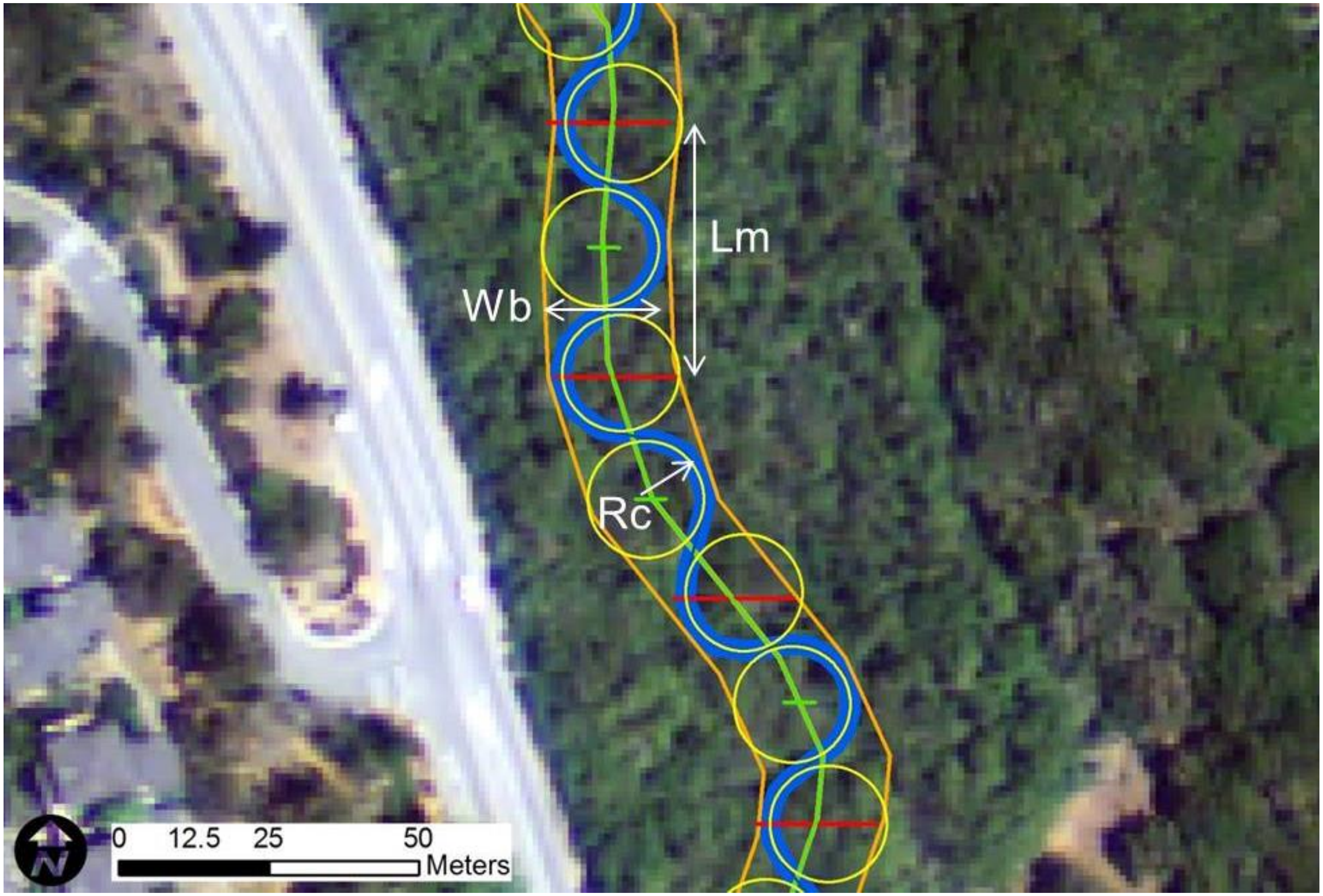


Figure 32 Design parameters used to draw the Arroyo del Rey restoration channel.

Figure 33 Arroyo del Rey restoration design 1.

Figure 34 Arroyo del Rey restoration design 2.

Figure 35 Arroyo del Rey restoration design 3.

Any of the three restoration designs will increase channel length which will effectively slow floodwaters, allow for increased infiltration, and provide additional habitat. If General Jim Moore is not elevated in the future, restoration design 1 offers restoration benefits on the DRO parcel. If the road is elevated, design 2 provides increased channel length and the pond will be unaffected. In design 3, the pond will accumulate sediment over time and likely require dredging.

5 South Boundary Tributary Management Challenges

5.1 Introduction

This section of the report describes management challenges related to the South Boundary tributary in the context of future development. As described earlier in this report, much of the South Boundary drainage appears to be a relatively stable, well-vegetated landscape, though some unmanaged trails on highly erodible soils are rapidly eroding into gully systems. Urban development is likely to occur on former Fort Ord lands in the upper area of the South Boundary basin. Development could lead to increased runoff and erosion if projects do not include appropriate stormwater management systems. An increase in runoff and sediment would impact Frog Pond's morphology, water quality, and habitat.

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is an effective tool for predicting the hydrologic effects of watershed alterations. We developed a coarse HEC-HMS model of the Canyon del Rey watershed to estimate the effects of urban development in the South Boundary basin. We created a model of the current hydrologic system, and then increased impervious cover in the model to determine how runoff might change. The amount of impervious area added to the model (100 acres) was loosely based on a formerly proposed development for the City of Del Rey Oaks. While the actual amount of imperious cover generated by future develoment may vary, the predictions generated by the model can provide a general appreciation of how increased impervious cover will alter the hydrology in this specific watershed setting (drainage area, soils, relief, slopes, etc.). This information can inform stormwater runoff planning for future development, aid in the management of FPWP, and perhaps the design of other downstream features such as detention ponds. Further calibration of the model would make it an effective tool in peak flow predictions,

5.2 Methods

We developed a watershed model using HEC-HMS modeling software, data from two stream flow gages, a precipitation gage located in the watershed, and in-field flow measurements. We calibrated the model by adjusting hydrologic parameters such as baseflow, impervious runoff, and groundwater retention until an accurate hydrograph of observed versus predicted flows was developed. We modeled expected future flows under two scenarios, one with a detention pond to capture impervious flow, and the other with unimpaired flow.

The following data were used to delineate the Canyon del Rey watershed in ArcMap, and to determine HEC-HMS model parameters:

Spatial data

- Orthoimagery – Original Source: National Agriculture Imagery Program. 2011. One meter resolution. Downloaded from the Geospatial Data Gateway (USDA/FSA) February 2013.

- Canopy – Source: National Land Cover Database (NLCD). 2001. One Arc Second (~30 meter). Downloaded from the USGS National Map Viewer February 2013.

- Digital Elevation Model – Source: United States Geological Survey, National Elevation Dataset (NED). 2009. 1/3 arc second (~10m). Downloaded from The National Map Viewer (USGS) February 2013.

- Impervious area: Source: National Land Cover Database (NLCD). 2006. One Arc Second (~30 meter). Downloaded from the USGS National Map Viewer February 2013.

- Precipitation map – Source: The PRISM Climate Group at Oregon State University. July 7, 2012. Downloaded February 2013.

- Resort at Del Rey Oaks – Source: Dahlin Architecture Planning Group. August 7, 2007. Downloaded February 2013.

Time series data – precipitation and discharge

- Precipitation – Source: California Irrigation Management Information System (CIMIS). Hourly data from Laguna Seca CIMIS station (# 229). Downloaded February 2013.

- Arroyo Del Rey Discharge adjacent to Frog Pond Wetland Preserve – Source: California State University Monterey Bay (CSUMB)/Watershed Institute unpublished stream gage data. 10 minute interval data. Received February 2013.

- Arroyo Del Rey Discharge downstream of Frog Pond Wetland Preserve – Source: Monterey Peninsula Water Management District (MPWMD) gage data. 15 minute interval data. Received February 2013.

The land cover, geology, and topology of the watershed were reflected in the loss methods and parameters we set for each sub-basin. The model functions by simulating the capture of rainfall by the canopy or soil surface, the transformation of water to stream flow, water infiltration into groundwater storage, and lateral flow into the stream or percolation into deeper groundwater storage. Within HEC-HMS we specified the following loss methods which simulate the movement of water through the watershed:

- Simple Canopy: A canopy storage capacity is set, and only when filled will precipitation fall to the surface and be reflected in the soil components of the model.

- Simple Surface: Rainfall that reaches the surface and cannot infiltrate (due to either soil saturation or exceedance of maximum possible infiltration rate) is captured in a specified soil storage component. Once this storage is full, surface runoff occurs.

- Soil Moisture Accounting (SMA) Loss: This method models the movement of water through the ground through the incorporation of soil, upper groundwater, and lower groundwater storage layers. The soil layer is divided into water tension and gravity storage, and the groundwater layers reflect lateral flows.

- Clark Unit Hydrograph Transform: This method represents water lost directly to the stream as runoff. A hydrograph using a time and area relationship (rating curve) is applied to precipitation events (HEC-HMS 2010).

- Linear Reservoir Baseflow: This loss method simulates the linear movement and recession of water as baseflow. It was used to move water from the SMA component into the stream; however the time-coefficient was set to a very low value and essentially passed water immediately into the stream. Baseflow dynamics were modeled through the groundwater parameters of SMA (HEC-HMS 2010).

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These loss methods were specified across the watershed by sub-basin. The upper, South Boundary, and lower sub-basins are delineated based on natural boundaries and the locations of the CSUMB and MPWMD stream gages. This allows for separate analyses of how the upper basin and South Boundary basin affect runoff and stream flow. Each basin was further divided for modeling purposes to represent the varying surfaces and runoff patterns that exist within each sub-basin. The upper and South Boundary basins were given moist, impervious with no detention basin (ImpFree), and impervious with a detention basin (ImpDet) subcategories and their parameters were adjusted separately (Figure 36). Detention basins (detpond) were created with 2 acre-ft. storage capacity and a discharge rate of 1 cfs before spilling. The effects of both detention basins were explored, however for the purposes of this study we will only discuss the impacts of a detention basin in the South Boundary basin.

The moist sub-basins were designed to reflect areas of steeper hillsides, less pervious soils, and higher canopy cover, and precipitation reaching the soil surface was directly connected to stream flow. The impervious sub-basins were

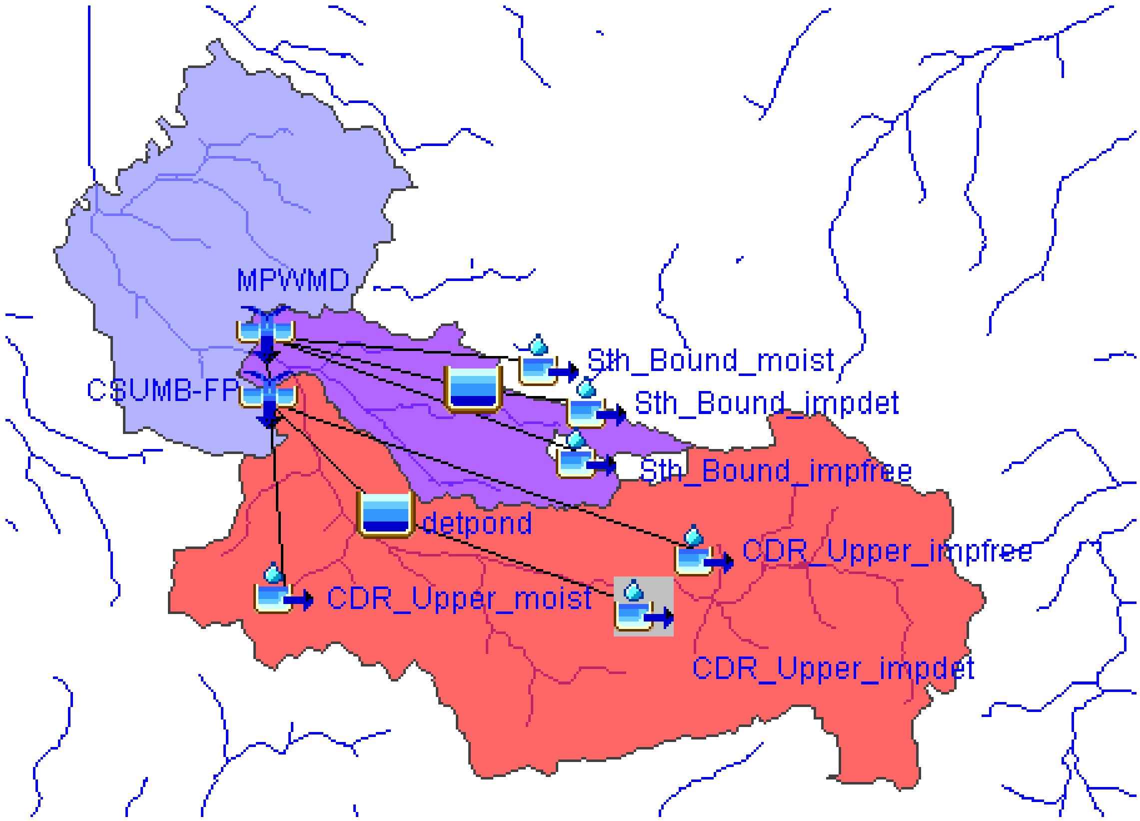

Figure 36 HECHMS model structure representing the Canyon del Rey watershed.

characterized by sandy soils with high percolation rates so that all modeled runoff was a result of impervious land cover, such as roads, residential areas, and commercial parks. Comprehensive parameter specifications are shown in Table 7. The model was simulated from December 15, 2012 to January 10, 2013, and incorporated 8 precipitation events. The model utilized hourly precipitation data, stream gage data from CSUMB at 10 minute intervals, and stream gage data from MPWMD at 15 minute intervals.

Some critical assumptions were made in the selection of model parameters, including the size of groundwater, canopy, and surface storage, and the geologic influence on water movement. In addition, the HEC-HMS model was calibrated in part by using a rating curve (graph of stream flow versus stage) for Arroyo del Rey which was assumed to be accurate although it was created with limited flow measurements.

Table 7. HEC-HMS model parameters for the Upper and South Boundary (S.B.) sub-basins. The sub-basins are divided as moist or impervious (Imp.), and the inclusion of detention ponds (Det.) are noted. GW denotes groundwater.

Method	Sub-Method	Parameters	Sub-Basins					
			Upper Imp.+Det.	Upper Imp.	Upper Moist	S.B. Imp.+ Det.	S.B. Imp.	S.B. Moist
Canopy		Initial Storage (%)	0	0	0	0	0	0
		Max Storage (in)	0	0	0.1	0	0	0.1
Surface		Initial Storage (%)	0	0	0	0	0	0
		Max Storage (in)	0.01	0.05	0.05	0.01	0.05	0.05
Transform		Time of Concen. (hr)	5	2	5	5	2	5
		Storage Coeff. (hr)	5	2	5	5	2	5
Loss	Impervious	Area (%)	1	0.5	0	1/7*	0.5/7*	0
	Soil	Initial Storage (%)	30	30	45	30	30	45
		Storage (in)	1	1	3	1	1	3
		Max Infiltration (in/hr)	9	3	3	9	3	3
		Tension Storage (in)	0.5	0.5	1.5	0.5	0.5	1.5
		Perc. (in/hr)	9	3	0.5	9	3	0.5
	GW1	Initial Storage (%)	0	0	0	0	0	0
		Storage (in)	2	3	6	2	3	6
		Perc. (in/hr)	9	3	0.03	9	3	0.03
		Coeff. (hrs)	0.5	100	40	0.5	100	40
	GW 2	Initial Storage (%)	1	1	4	1	1	4
		Storage (in)	3	6	6	3	6	6
		Perc. (in/hr)	9	3	0	9	3	0
		Coeff. (hrs)	1000	1000	200	1000	1000	200
Baseflow	GW 1	Initial (cfs/mi²)	off	off	off	off	off	off
		Initial (cfs)	off	0	0	off	0	0
		Coeff. (hr)	off	0.001	0.001	off	0.001	0.001
		Reservoirs	off	1	1	off	1	1
	GW 2	Initial (cfs/mi²)	off	off	off	off	off	off
		Initial (cfs)	off	off	0	off	off	0
		Coeff. (hr)	off	off	0.001	off	off	0.001
		Reservoirs	off	1	2	off	1	2

Note: Shaded cells represent parameters with little effect on modeled discharge
* Adjusted parameter values that reflect development in upper watershed

5.3 Results

A calibrated model of the Canyon del Rey watershed was created. As seen in the hydrograph of modeled versus observed flows (Fig. 37), the model was fairly accurate in demonstrating peak flows in storm events. The modeled flows show slightly higher peak flows, indicating that impervious runoff values may have been too high, or that greater infiltration into the aquifer occurs. Recession times appear slightly inaccurate; however they are sometimes ahead of the observed recession, and sometimes after. Further adjustment of the groundwater coefficients may improve the fit. In fine-tuning the model, we

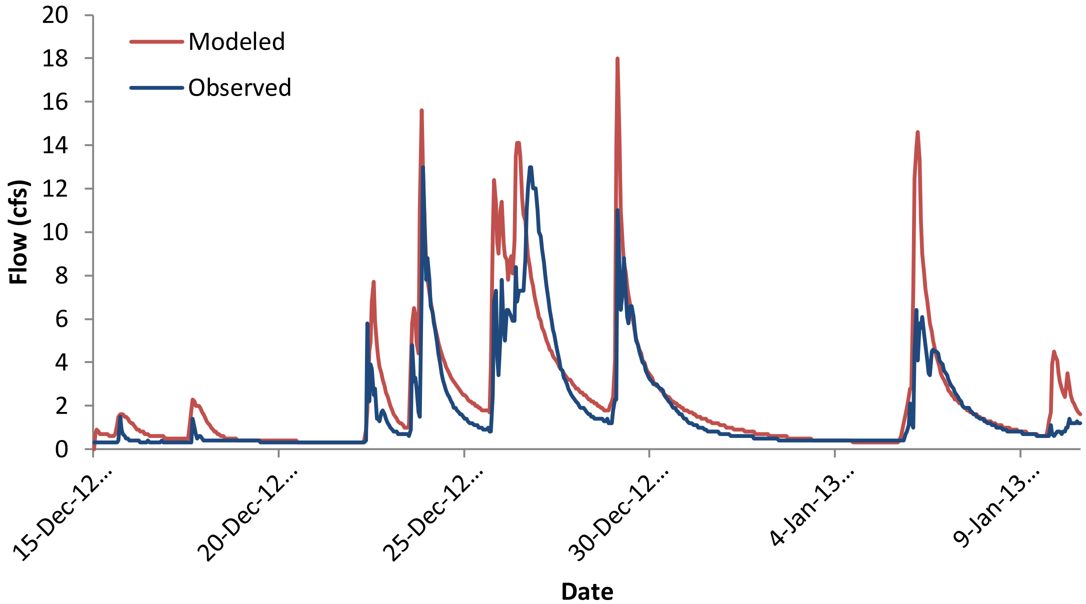

Figure 37 Graph of modeled versus observed flow in the CDR watershed.

determined that certain parameters were especially sensitive, such as canopy storage in the moist sub-basins, and the amount of groundwater already stored in the system before precipitation events. The poor fit of the model to the January precipitation events as compared to the December events may have been caused by significant vegetation growth in the channel affecting the accuracy of the rating curve.

The calibrated model was used to assess hydrologic change associated with potential development in the South Boundary portion of the watershed. We ran the model with additional 100 acres of impervious added to the South Boundary basin, and observed the change in peak flows. Over the course of 8 peak flow events between December 15, 2012 and January 10, 2013, the model indicated the increased impervious cover would result in flow magnitudes approximately 2 – 8 cfs higher than the current peak flows which ranged from 2 – 18 cfs (Fig.38, Table 8).

To evaluate the effects of a detention basin, we added 100 acres of impervious cover to the South Boundary sub-basin designed to hold 2 acre-feet of water before spilling (ImpDet). A smaller increase in peak flows was observed (Fig. 38

Table 8). The results indicated that the inclusion of a detention pond would reduce the degree to which flows are increased by approximately 12 – 58 % depending on the size of the storm and amount of moisture already present in the system.

Table 8. HEC-HMS modeled results of current and future peak storm flows in the Canyon Del Rey watershed, with and without detention pond (Det).

Date of Peak Flow	Current (cfs)	Future No Det (cfs)	Future with Det (cfs)	Diff (No Det - Det) (cfs)	Increase in flow without Det (%)	Decrease in flow by Det (%)
15-Dec-12	1.6	3.7	1.8	1.9	131.3	51.4
17-Dec-12	2.3	6.2	2.6	3.6	169.6	58.1
22-Dec-12	7.7	11.9	9.4	2.5	54.5	21.0
23-Dec-12	15.6	21.1	17.1	4	35.3	19.0
25-Dec-12	12.4	18.2	12.8	5.4	46.8	29.7
26-Dec-12	14.1	18.3	16.1	2.2	29.8	12.0
29-Dec-12	18	25.9	18.9	7	43.9	27.0
6-Jan-13	14.6	21.2	17.3	3.9	45.2	18.4
9-Jan-13	4.5	8.0	5.2	2.8	77.8	35.0

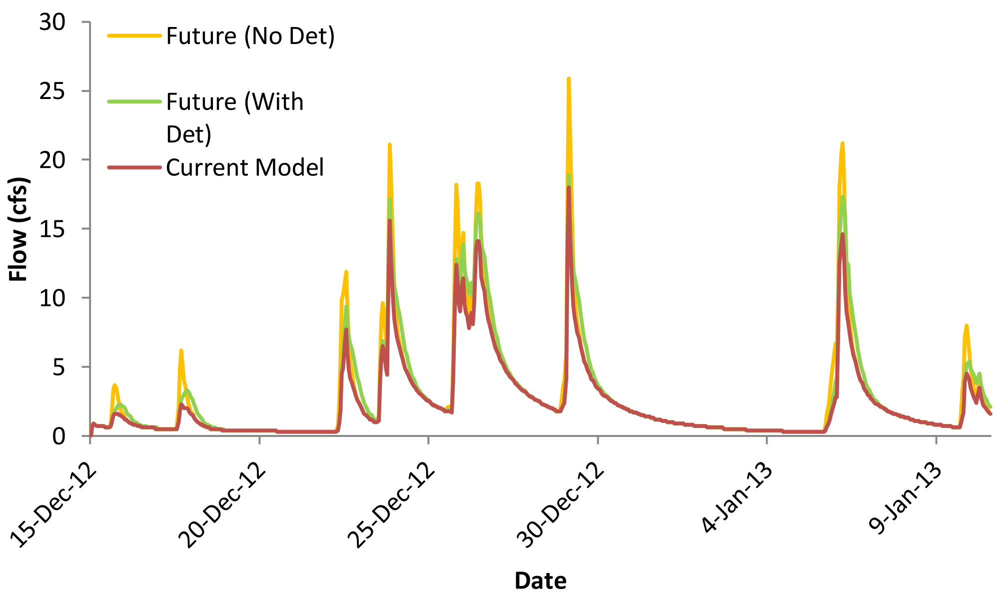

Figure 38 Graph comparing current modeled flows to predicted future flows without a detention pond, and future flows with a detention pond in the South Boundary basin.

6 Summary and Recommendations

Management challenges at FPWP can be addressed by protecting slopes that are well-vegetated, and restoring areas where erosion is occurring. We recommend restoration of erosional features in the Frog Pond uplands following methods proved by BLM projects on former Fort Ord land. In addition, management of the trails, and other areas where runoff is concentrated, will limit additional gully formation.

Arroyo del Rey was observed to be in a state of disequilibrium at FPWP and in much of the watershed. Three channel restoration designs were developed to improve the reach of the stream within the study area. The benefits of this restoration project include increased channel length which provides additional habitat and range for aquatic species, and infiltration benefits. Downstream, Frog Pond and ultimately the Monterey Bay National Marine Sanctuary would benefit from improved water quality.

The South Boundary tributary deserves special consideration in the context of development, as it may pose significant threat to the water quality entering FPWP. Our HEC-HMS model predicted that the addition of 100 acres of impervious cover to the upper Canyon Del Rey watershed would lead to a 30 – 170% increase in peak stream flow above current peak flows. Specifically, peak flows ranging from 2 – 18 cfs would increase by approximately 2 – 8 cfs. The addition of a detention basin could reduce that increase by up to 58 %. These findings should be considered in stormwater runoff planning for future development in the watershed. We suggest further study focus on building hydrologic models with greater accuracy in order to confidently quantify flow changes.

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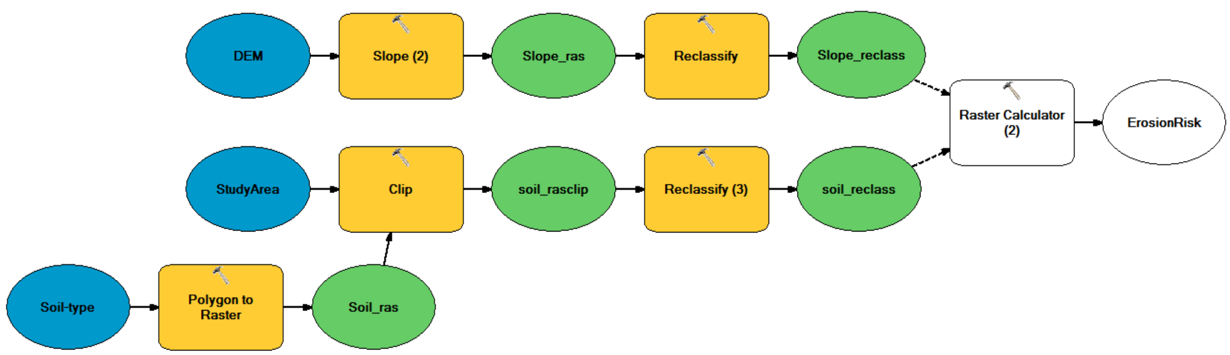
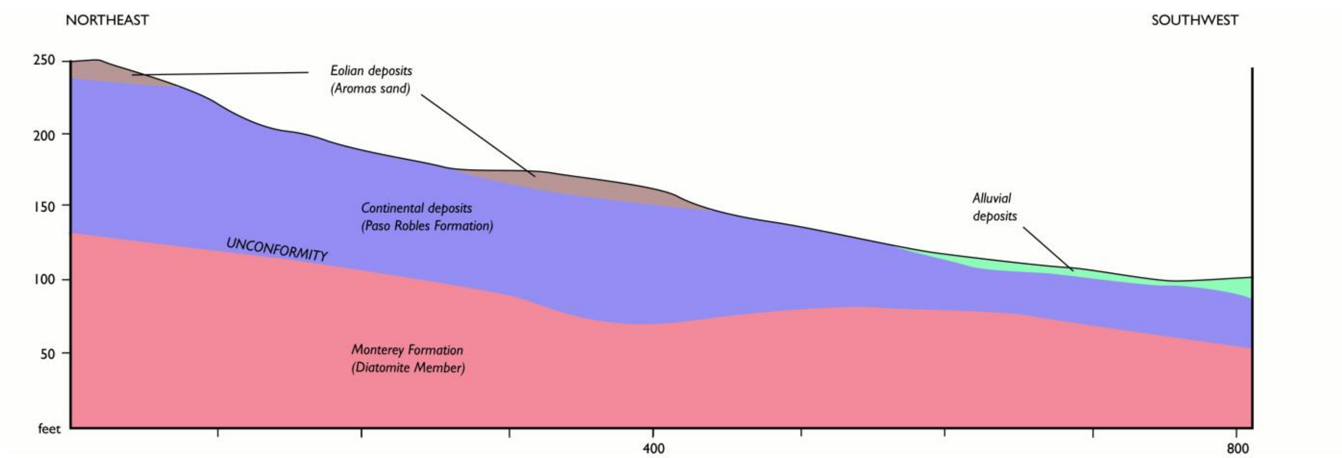
Appendix:

Flow chart for creation of the erosion sensitivity map:



Geologic cross section of the Del Rey Oaks parcel and upstream reach area (Underwood 2014):



Generalized Cross-section of the Lower Canyon del Rey Watershed

Project: Frog Pond Preserve	Boring Number FP-1	Date Completed March 18, 2014
Logged By: Alex Snyder	**Client** Monterey Peninsula Regional Park District	
Drill Crew: Alex Snyder/Elizabeth Geisler	**Method** 3.25" Hand Auger	
Location 36.592260°, -121.832104°	**Depth to Groundwater During Drilling** N/A	

Lithology

Soil Group Name: grain size, color, moisture, sorting, angularity, other descriptors, composition.

Sample Type

Described Sample

Preserved Sample

Depth (feet)	Sample Type	Graphic Log	USCS	Lithology
0 – 0.25	Described Sample		SP	SAND: fine- to coarse-grained, tan, dry, angular to subrounded, moderately graded, leaves/sticks present (0,0,100,0).
0.25 – 0.5	Described Sample		SP	SAND: fine- to coarse-grained, tan, moist, angular to subrounded, moderately graded, with gravel. leaves/roots present (0,0,100,10).
0.5 – 0.75 – 1 – 1.25 – 1.5	Described Sample		SP	SAND with Gravel: fine- to coarse grained, tan, moist, subangular to subrounded, moderately graded, trace silt, occ. Cobble, roots present(0,5,80,20) .
1.5 – 1.75 – 2 – 2.25 – 2.5	Described Sample		SW	SAND with fines: fine- to medium-grained, light tan, wet, sub-rounded, well sorted, roots present, fines present in clumps of silt and clay (10,10,80,0)
2.5 – 2.75 – 3 – 3.25 – 3.5	Described Sample		SW	SAND with fines: fine- to medium-grained, light rust color, wet, sub-rounded, well sorted, roots present, fines present in clumps of silt and clay (10,10,80,0) Same, occational gravel present.
3.5 – 3.75	Described Sample		SC	Clayey SAND with silt: very fine- to medium-grained, black, wet, subrounded, moderately sorted, low plasticity in fines (30,10,60,0)