LOS ANGELES COUNTY
DEPARTMENT OF PARKS & RECREATION
LAKE REHABILITATION ENVIRONMENTAL MANAGEMENT GROUP

A COMMUNITY APPROACH TO PUDDINGSTONE WATERSHED RESTORATION

CALIFORNIA POLYTECHNIC UNIVERSITY, POMONA
2020-2021

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TEAM ENTRY FORM

WEFTEC® 2021 STUDENT DESIGN COMPETITION

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ABSTRACT

Puddingstone Reservoir is in Frank G Bonelli Regional Park, San Dimas, California. This park is managed by the Los Angeles County Department of Parks and Recreation and provides the community with recreational activities including, fishing, swimming, and camping. Puddingstone Reservoir experiences excessive pollutant load, low dissolved oxygen, and high organic matter leading to algal blooms and pungent odors during the summer. These concentrations pose a health risk to the patrons of Puddingstone Reservoir and its ecosystem. As a result, the Environmental Protection Agency (EPA) designates Puddingstone Reservoir as an impaired water body.

While implementing a treatment plant to reduce these concentrations is ideal, it is costly and infeasible for the highly trafficked park. Therefore, a cost-effective approach is proposed to restore the watershed's natural processes. Strategic implementation of low impact development (LID) structures is proposed to reduce heavy metal contaminant load in sheet flow runoff. Furthermore, a wetland system enhanced by low intensity chemical dosing closer to the outlet of Live Oak Wash treats nitrogen, phosphorous, and methyl mercury. Utilizing HEC-RAS to model the watershed pre and post implementation, it was determined that contaminants would be decreased significantly, reducing Nitrogen (H) by 32%, Lead by 90%, and Cadmium by 13%.

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1.0 EXECUTIVE SUMMARY

The proposed project seeks to improve the water quality of Puddingstone Reservoir. Currently, the existing water quality of the Reservoir is a concern, due to the concentrations of phosphorus, chlorophyll, and mercury in the surface water coming from Live Oak Wash, and the presence of PCBs, Chlordane, Dieldrin, and DDT in the sediments (SWRCB, 2010). The presence of these contaminants at the concentrations reported are detrimental to surface water health. Furthermore, recurring large algal blooms due to an elevated level in phosphorus have forced reservoir closures and resulted in a reduction of dissolved oxygen in the water. The water conditions led to an increase in contaminants found in fish tissue, such as trout, caught and consumed by local fishermen. Our aim is to propose solutions that improve the overall health of the watershed, improve the water quality entering Puddingstone Reservoir (influent), and improve the overall aesthetics of Frank G. Bonelli Regional Park.

The project attempts to improve the water quality of the water flowing into the Reservoir from Live Oak Wash, in order to improve human health, reduce the risk of polluted groundwater infiltration, combat the negative effects of climate change, prevent legal actions and the decrease of land values, and address the problems resulting from local urbanization and wildfires. The objective will be achieved by the strategic implementation of low impact development retrofits, biofiltration located at Kuns Park and the La Verne Sports Park, and the construction of wetlands downstream close to the Reservoir. The implementation of these proposed solutions is estimated to be approximately $2.87 million dollars.

The proposed solutions propose the removal of the concentrations of contaminants entering the storm drain and pollutant reduction at the reservoir's inlet. This would result in improved water quality inflow which would eventually dilute the existing contaminants located in the surface water and improve the overall existing water quality of Puddingstone Reservoir, making the reservoir safe again for fishing and providing a healthier ecosystem, and a pleasant destination for the community. The chosen solution locations can be seen in the Figure A-1.

2.0 PROJECT SCOPE

Urbanization activities in the areas upstream to the reservoir, such as the city of La Verne, have led to an increasing demand for impervious surfaces in the form of parking lots, large streets for the purpose of transportation, as well as housing for a sprawling population. This change in land cover, with the addition of drainage design for flood prevention, has disrupted the natural hydrologic cycle by moving stormwater and the human-produced pollutants it picks up more quickly out of the watershed. Thus, the majority of contaminants flowing into Puddingstone Reservoir originate from non-point sources entering the storm drain system via sheet flow.

The challenge, then, is to improve storm water quality that discharges into the reservoir. To achieve this, the proposed project includes watershed restoration, to return the watershed hydrology to its original pre-development state, while minimizing disruption to current residents and the use of Low Impact Developments (LIDs). Strategically placed LID technologies would imitate natural processes by capturing stormwater runoff from a primarily impervious drainage area and treating before conveyance into the storm drain system.

Biofiltration LIDs were selected to remove heavy metals from stormwater before it is conveyed to the wetland treatment system (see section 5.0) via Live Oak Wash. A planning strategy was developed to determine the optimal sites for LID placement over time in order to gradually return the hydrological processes to their natural states. Two demonstration LID sites were selected using this methodology and designed to standards outlined in the Los Angeles County LID Standards Manual.

The goal is to provide Los Angeles County Parks and Recreation with cleaner water flowing into The Puddingstone Reservoir. In time with cleaner water flowing into the reservoir, the dilution will decrease DDT, PCB, and Mercury concentrations that would otherwise hinder wildlife and the fish population, as well as raise dissolved oxygen levels and decrease algal blooms.

3.0 SITE DESCRIPTION AND BACKGROUND

3.1 Puddingstone Reservoir

Puddingstone Reservoir is located in Frank G Bonelli Regional Park in San Dimas, California. The location of Puddingstone Reservoir can be seen in the Figure A-2. This park, managed by the Los Angeles County Department of Parks and Recreation, provides the surrounding area with recreational activities including, fishing, boating, swimming, camping, and hiking. Originally designed for flood control purposes, the reservoir was created upon the completion of the Puddingstone Dam in 1928 and has a surface area of 252 acres (based on Southern California Association of Governments [SCAG] 2005 land use), a total volume of 6,200 acre-feet (based on Los Angeles County Department of Public Works volume estimates from 2000 and 2001), and an average depth of 24.6 feet. Live Oak Wash is the major inflow to the reservoir, which discharges to Walnut Creek.

3.1.1 Water Quality

The team analyzed the water quality of the reservoir by its surface water and sediments separately. An overall surface water quality test was performed on the Puddingstone Reservoir on September 27th, 2019 by Aquatechnex, LLC. The four parameters shown on red (Free Reactive Phosphorus, Chlorophyll, Total Phosphorus, and Mercury) in the table in Table B-1 are the ones that the team is concerned about, as they do not meet EPA surface water standards. From the data, it can be seen that it is critical that solutions are implemented to improve the surface water quality of the reservoir.

In addition, according to a water quality study performed by the EPA, Puddingstone Reservoir is impaired by organic enrichment, low dissolved oxygen, chlordane, DDT, mercury, and PCBs. It is important to note that most of these impairing pollutants are found in the sediments due to historic loadings, meaning that these contaminants were released to the reservoir during the years where they were heavily used and manufactured (SWRCB, 2010). For example, the EPA study (EPA 2012) states that concentrations for PCBs: 4.99 µg/kg, Chlordane: 2.15 µg/kg, Dieldrin 1.32 µg/kg, and DDT 7.44 µg/kg have been measured in the sediments of the reservoir.

However, the EPA study from 2012 also shows that some of these contaminants are still detected in incoming upstream flows from the watershed, as shown in Figure A-3. The figure shows that the largest percentages and concentrations come from the La Verne sub watershed, while then concentrations gradually decrease as one moves up north to the LA County sub watershed.

3.2 The Puddingstone Reservoir Watershed

3.2.1 Community

The Cal Poly Pomona Senior Project Class of 2020 cold called several local companies and organizations to see how the quality of water in Puddingstone reservoir affected them. In addition, specific project issues were discussed and how the rehabilitation may aid the local businesses currently at the Puddingstone Reservoir. Table B-2 lists the stakeholders in the community that the team reached out to and their responses. The manager of Bonelli Bluffs RV Resort and Campground noted that during the summer, water quality is so low that it affects the local fishing scene and swimming areas in the reservoir need to be shut down.

3.2.2 Land Use

As shown in Figure A-4, the majority of the land use in the watershed corresponds to urban development. In urbanized areas, most land is covered in concrete or pavement which both have low infiltration rates. As a result, most of the storm water is directed to the reservoir through channels. When water travels from the furthest parts of the watershed, it picks up debris and contaminants along the way and carries them to Puddingstone Reservoir. Contaminants are consistently deposited in the reservoir, which is affecting the water quality.

3.2.3 Geology and Hydrology

The Puddingstone Reservoir Watershed deposits into an alluvial basin along the eastern San Gabriel Mountains, which include quaternary deposits of sand, gravel, and silt overlaying a metamorphic and plutonic bedrock (San Dimas SHZR). Figure A-5 shows the location of the geological units in the watershed. The extents of the watershed cover 7380.6 acres of area.

The Los Angeles County Public Works Hydrology Maps provide a more micro-scale understanding of the surface soils, numbered from 1-172. Table B-5 lists the common soils in the urbanized portion of the watershed.

Furthermore, the watershed is situated in a seismically active area, with the Indian Hill Fault and the Sierra Madre fault zone, extending east to west across and beyond the watershed. The greatest seismic risk comes from the Indian Hill fault that runs through the center of the watershed. It is capable of producing an earthquake with a magnitude of 6.6. (MACTEC Engineering and Consulting, Inc., 2011). Landslide risk is associated mainly with the sloped areas near Puddingstone Reservoir itself and in the foothills of the San Gabriel Mountains. When accessing the Sustainable Groundwater Management Act (SGMA) Data Viewer for the watershed, it is indicated that the groundwater table maintains an average historical depth of approximately 150 feet below the ground surface throughout.

4.0 HYDROLOGICAL ANALYSIS

An analysis of the hydrology of the Puddingstone Watershed was conducted to calculate time of concentration and flow volumes. The watershed is within Los Angeles county; as such, the methodology used to produce the hydrologic analysis was taken from the Los Angeles County Public Works Hydrology Manual.

Based upon the LA County Hydrology Manual, the appropriate method of runoff calculations in this case is the modified rational method. This method is appropriate for any size watershed, different combinations of developed and undeveloped drainage areas, and any combination of stream laterals. One limitation that this method has is that it can underestimate volumes in some rural areas. However, since most of the watershed in question is urbanized, we will assume that the error is negligible. Watershed characteristics are tabulated in the table in Appendix B-3. This data was collected through a surface generated in Civil 3D.

Since the watershed is of considerable size, it was split into 9 sub-basins to allow for more accurate flow calculations, as shown in Figure A-6. The flow rates were calculated using the rational method equation below:

$$Q = C_d * I_{T_C} * A$$

Q= Flow Rate (cfs)

I_{Tc} = Intensity at time of concentration

A= Area of sub-basin

C_d= Developed Runoff Coefficient, ratio of runoff rate to rainfall intensity (in/in)

Tables B-4 through B-8 show the 24-hour rainfall intensity in sub-basins, soil types to determine runoff coefficients, time of concentration, sub-basin lengths, slope, developed runoff coefficients, intensities, and areas used to calculate flows as well as the calculated flows.

The total flow at the outlet was calculated to be 6893.1 cfs after 6 hours and 36 minutes during a 50 year, 24-hour storm.

5.0 LOW IMPACT DEVELOPMENT

The current hydrological characteristics of the watershed informed the parameters for developing a low-impact restoration system. To imitate the theoretical upstream hydrology prior to the introduction of impervious surfaces by urban development, we propose introducing Low Impact Development (LID) retrofits.

5.1 Planning

Given the time constraint and a broad scope, it was not feasible to design LID elements throughout the entire watershed. Instead, we utilized ArcMap to determine the most suitable sites for mid-sized LIDs via geospatial analysis. The Los Angeles LID manual as well as the watershed management plan (WMP) produced by the cities of Pomona, Claremont, San Dimas, and La Verne, required compliance with specific standards, including:

Geology. Sites must have permeable sandy or loamy soil types identified via USGS San Dimas Quadrangle map.

Groundwater. Sites must than ten feet of separation between the surface of infiltration and the water table at its highest season, located via the San Dimas Quadrangle Seismic Hazard Zone Report (SHZR032).

Topography. LIDs may not be built on slopes steeper than 25% due to liquefaction risk. No sites in the urbanized area exceeded this maximum.

Land Use. Protected wilderness spaces are less preferable: however, most were outside our area of interest anyway. Underground utilities were avoided to prevent damage from potential increased stormwater volume. Furthermore, public land was preferred so that land would not have to be acquired from a private owner.

Environmental. Superfund sites and landfills, as well as areas of contaminated groundwater, were avoided. Sites were further preferred if they provided multiple environmental benefits, such as reducing the urban heat island effect or providing habitat.

Cost Effectiveness. Sites that maximized funding potential, such as in disadvantaged areas, were favored. Ease of implementation and constructability was heavily considered to reduce cost.

Stormwater Capture Goals. Sites with high capture volume potential were projected to have a higher impact on the overall quality of Puddingstone Reservoir and the watershed.

Through this process, we determined that public parks were most optimal for LID implementation, especially if they were downhill from particularly impervious areas. Ultimately, we selected La Verne Sports Park and Kuns Park for LID implementation (see Figures A-7 and A-8).

5.2 Selection

Several types of LIDs were considered for implementation (see Table B-9). Structural LIDs such as rain barrels and permeable pavement were eliminated due to their higher cost and a client preference for natural solutions. Furthermore, many of the structural LIDs are more equipped to collect rain as it falls instead of stormwater runoff. Re-grading towards a sidewalk is impractical because a heavy rain event could create an overflow effect and make the sidewalk impassable for pedestrians.

Among biological LIDs, a biofiltration method was preferred over bioretention. Though similar, bioretention LIDs are more typically selected with the intent to infiltrate stormwater into the groundwater (see Figure A-9). Because the scope of our project relies on maintaining inflow into Puddingstone to dilute the contaminants, and because field studies could not be performed to ensure safe infiltration, bioretention was eliminated and biofiltration ultimately selected.

5.3 Sizing

Once the LIDs were selected, they were then sized according to the LA LID manual. First, drainage area for each site was determined using a combination of topographic information from USGS and an understanding of drainage design in residential areas (see Figures A-10 and A-11).

Then, LA Public Works HydroCalc program was used to determine the flow volume during an 85th percentile rainfall event for each sub-area. Parameters included:

Area. Determined using spatial information.

Flow path length and slope. Determined using spatial information.

24-hour, 50-year rainfall depth (in). Retrieved from the LA County Hydrology Maps.

Percent imperviousness of the drainage area. Determined spatially and visually using satellite imagery from Google Earth and corresponding value in the LA County Hydrology Manual. The drainage area for Kuns Park mainly consists of single- and multi- family units, while the La Verne Sports Park area of focus consists of the parking lot, tennis courts, and sports fields.

Soil type. Retrieved from the LA County Hydrology Maps.

Design storm frequency. 85th percentile via the Los Angeles LID Standards Manual.

Fire Factor. Assumed to be 1.

The Design Flow (SWQDv) is derived from the volume calculations, and surface area is determined according to this number and the chosen design depth of 6 feet, well under the maximum depth constraint determined by infiltration rate.

$$d_{max} = \frac{f_{design}}{12} * t$$

$$A = \frac{SWQDv}{d_p}$$

Hydrocalc is used to determine hydrograph and runoff volumes for a drainage area. Final BMP sizes are summarized in Table B-10.

6.0 CONSTRUCTED WETLANDS

6.1 Site

Our proposed project location includes 2 acres of constructed wetlands near the northeast corner of the reservoir. The project area is situated right after the confluence of the two streams, Puddingstone Wash, and Live Oak Channel as shown in Figure A-12.

6.1.1 Site Description

Natural wetland systems have often been described as the "earth's kidneys" because they filter pollutants from water that flows through on its way to receiving lakes, streams, and oceans. These systems can improve water quality because of constructed systems that replicate the functions of natural wetlands. Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality.

A typical constructed wetland consists of several components, including berms to enclose the treatment cells, inlet structures that regulate and distribute influent water for optimum treatment, various combinations of open-water areas and fully vegetated surface areas, and outlet structures that allow adjustment of water levels within the treatment cell. Referring to Figure A-13, Zone 1, on the left, would contain the inlet and be fully vegetated with floating and emergent plants. Zone 2, in the middle, would be an open water surface zone with submerged plants and a greater depth, and Zone 3 on the right, would contain the outlet and again be fully vegetated with floating and emergent plants like Zone 1.

6.1.2 Design and Implementation

The wetlands were designed according to the EPA's Design Manual: Constructed Wetlands Treatment of Municipal Wastewater. The manual provides insight on utilizing constructed wetlands as a functional part of wastewater management.

Results

Calculations are done by using the equations from the EPA's Design Manual: Constructed Wetlands Treatment of Municipal Wastewater and they are summarized in Table B-11. The calculations themselves are located in Appendix C – Wetland Calculations.

The wetland site consists of 2 wetland treatment trains in parallel, having 3 cells in each train as shown in Figure A-14. We designed for the mean annual flow volume estimate of 2.31 cubic feet per second. Each of our wetland cells is about 0.69 acres and about 60 by 500 feet with an average depth of about 5 ft. These dimensions bring our length-to-width ratio to about 6:1, which is standard design for constructed free surface wetlands. Then, using our average flow and volume, we calculated our average hydraulic detention time for a single cell to be a little over 2 days.

Along with the wetland treatment system, polyaluminum chloride (PAC) can be used as a coagulant to further gather the suspended particulates. As a metalloid, Mercury is positively charged, and the suspended particles are typically negatively charged. From this, the mercury and suspended particles can become associated with one another and become suspended together in the water. Additionally, in systems with high concentrations of DOM, like the wetland treatment system, the DOM plays a significant role in Inorganic and Methylmercury concentrations. As such, mercury can be treated as a simple suspended particulate as it can flocculate. Through injection by a static inline mixer, sufficient blending can occur such that the flocculation process can occur within the constructed wetlands.

Operations and Maintenance

Following the construction of the wetland treatment cells with addition of the low intensity chemical dosing, operation and maintenance of the system must be kept in mind. Since the constructed wetlands are considered “natural” systems, the operations are mostly passive and require minimal operator intervention. Items that could require the operator’s attention are the maintenance of flow uniformity, management of vegetation, odor control, pest control, and maintenance of the berms or dikes. The low intensity chemical dosing would require the addition of coagulants as levels depleted from dosing the system.

7.0 COST AND FUNDING

The following section approximates the capital and annual expense for the three solution components, and then explore the opportunity for funding. The accuracy of the cost is constrained by the ability to estimate using several different sources and methods available through the Environmental Protection Agency, LA County, and the City of LA.

7.1 Capital Cost

The capital costs provided in Table B-12 are based on an average, including site preparation, physical construction, administrative expenses, and design. Ultimately, the most likely cost was determined to be around $2.8 Million. However, a capital cost between $1,870,000 and $3,820,000 can be reasonably expected based on the ranges of individual expenses provided in the literature.

The highest, and least predictable, associated capital expense is construction cost at $1.33 Million.

7.2 O&M Cost

It is vital to report an accurate annual cost for the low impact system to ensure the entity secures sufficient funding for the lifespan of the system and budgets enough for routine maintenance each year. Failure to maintain the integrity of the different components of the system on a regular basis can lead to more expensive failure, or even complete loss of function prior to the end of its expected lifespan.

Different EPA literature was used for estimating the annual cost of the LID structures and the artificial wetlands. The LIDs were calculated based on the estimated amount of hours and cost per acre of impervious surface provided by the EPA Opti-Tool. With an estimated commitment of 160 hours (or twenty 8-hour days) per year dedicated to maintenance of the landscape, and a developed location factor of 2, the minimum routine annual cost is around $29 thousand. Table B-13 summarizes these values.

The operation and maintenance of constructed wetland systems designed for wastewater treatment are relatively simple and require minimal time. Most of the operator’s time at a wetland treatment system is spent servicing pumps, headworks, disinfection, and other conventional components in the process. Animal (i.e., nutria, muskrats) control, vector (mosquitoes) control, and NPDES monitoring are probably the most time-consuming aspects of wetland operation and maintenance. At the FWS wetland system, the O&M requirements for the wetland are as follows: Remove sludge from inlet and outlets zones twice per week. Polyaluminum Chloride once per month. NPDES laboratory tests once per month. Wages once per month.

The annual cost for constructed wetlands was based on the lump sum methodology provided in an EPA fact sheet for artificial surface wetlands. The costs are summarized in Table B-14.

Therefore, the total maintenance cost of the proposed system is about $61 thousand per year. An additional budget of up to $50,000 may be necessary if worst-case scenario emergency maintenance is required. Therefore, annual maintenance cost may range between $61 thousand and $101 thousand.

7.3 Low Impact Approach Value

The cost per gallon of the low-impact treatment system was determined by calculating the maximum combined present value of the capital cost and operating cost over the next 20 years, which is the estimated life-span of the geotextile lining. The analysis in the previous Section 4.0 Hydrology was used to approximate the capacity of the low impact system. According to the EPA Free Water Surface Wetland Fact Sheet (2000) (see Table B-15), a conventional treatment system costs $3.20 at a 7% discount rate: therefore, the low impact method is significantly more cost-effective despite the high capital cost. It should be noted that this claim is constrained by the accuracy of the cost estimation in the section above.

7.4 Funding Opportunities

With the growing concern over maintaining an increasing population's access to water for many of its essential uses, there is a vast amount of funding available for water projects at the county level.

7.4.1 Measure W: The Safe Clean Water Act

Puddingstone Reservoir Watershed resides in LA County, and therefore our project may be eligible to access to the recent funding provided by Safe Clean Water Act (SCW), or Measure W, passed in 2018 to fund stormwater projects with a parcel tax on impervious surfaces. The entirety of the watershed restoration project takes place in the San Gabriel River region, which is allocated about $18.9 million dollars per year. This year, the steering group allocated the highest amount of SCW funding to Basset High School at $31.2 million over the next five years.

The regional steering committee selects projects each fiscal year depending on the success they will have reaching certain criteria. The indicators for wet weather LIDs include cost effectiveness, water quality benefit, life-cycle cost, water supply benefit, community investment, nature-based solutions, and cost sharing. The Community Approach to the Puddingstone Watershed Restoration must reach a minimum of 60 points to be considered, and may only be selected if it is among the highest scoring.

7.4.2. Proposition 1

The California State Water Resources Control Board was authorized to award $200 Million in grants to eligible projects starting in 2014 through the Storm Water Grant Program (SWGP) under Proposition 1. This project, implemented by Los Angeles County, may be eligible for funding for its multiple benefits, including improving the quality of an open space recreational area for residents, improving the water quality in the Puddingstone Reservoir, which infiltrates the groundwater, or eventually discharges into the ocean via the San Gabriel River. According to the most recent SWGP guidelines, the awardee will be selected based on its demonstration of longevity, outreach to the community, and meeting all permit requirements.

The same proposition also authorized the Department of Water Resources (DWR) to allocate $510 million through the Integrated Regional Water Management (IRWM) program. According to Water Code §79743, this project may be eligible for funding under the categories of watershed management, stormwater treatment, and multiple benefits.

8.0 PERMITS

Permitting regulates construction and property use to ensure safe, healthy, efficient, and accessible environments for human occupancy and habitation. California Code of Regulations, Title 24, Building Standards Code require that no building or structure may be erected, constructed, enlarged, altered, repaired, moved, improved, removed, converted or demolished unless a separate permit for each building or structure has been issued. In general, improvements, replacements, and repairs require permits. Exemptions from permitting are allowed for certain work, but vary for each jurisdiction. The projected necessary permits and cost of permits are summarized in Tables B-16 and B-17 respectively.

9.0 HYDRAULIC MODELING

To determine the effectiveness of the proposed solutions, a hydraulic model was created to show the water quality flowing into the reservoir before and after restoration efforts. Results were analyzed using a HEC-RAS model built for the main project stream. The model incorporates several portions of adjacent channels that flow into the main project stream to accurately capture waterflow. Figure A-15 shows the streams and junctions included in the model. The main project stream consists of Emerald Wash and the southern section of Live Oak Wash. It begins with the Emerald East Debris Basin (DB) Drain, connecting to Junction 1. Junction 1 connects to the adjacent Emerald DB to Live Oak Wash channel. The project stream then continues along the Emerald DB to Live Oak Wash channel through Junction 1 and connects to Junction 2. Adjacent to Junction 2 is a portion of the Live Oak Wash Channel that connects to the main project stream. The main project stream then continues through Junction 2 as the Live Oak Wash Channel and connects to Junction 3. Junction 3 also connects to a portion of the adjacent Marshall Canyon Channel. Finally, the main project stream continues past Junction 3 and the concrete channel gives way to natural channel that flows into Puddingstone Reservoir.

9.1 Model Surface Data

For the surface of the model, a digital elevation model (DEM) of the main project stream and the area surrounding the main project stream was created. The DEM was constructed on ArcMap with light detection and ranging (lidar) data from the United States Geological Survey (USGS). Figure A-16 shows the 20 parcels worth of point cloud data used, and the footprint of the final surface. The majority of the project stream flows through concrete channels. The created DEM was not able to capture the exact dimensions of the channels so cross sections were manually edited in HEC-RAS. The LA County Storm Drain Index was used to inform the placement and geometry of the concrete channels. The natural channel leading into Puddingstone Reservoir has cross sections placed as determined by Samuels Equation at 250ft between cross sections. Cross sections have been placed as close as possible upstream and downstream of junctions.

9.2 Steady Flow Analysis

Prior to conducting a water quality analysis, a steady flow analysis must be performed. The flow rate for a 2-year peak flood provided by stream stats was selected for use in the analysis to simulate a consistent flow rate for the main project stream. Cross sectional profiles of key points in the model are provided in Figure A-17. These key points include cross sections of the Marshall Canyon and Live Oak Wash channels connected to La Verne Sports Park and Kuns Park, cross sections set on points prior to and after the junction that leads into Puddingstone Reservoir, and the final cross section prior to Puddingstone Reservoir itself. Cross-sectional data at these locations allows for the collection of waterflow volume data that can later be used to calculate the dilution of pollutants as larger amounts of water flow is introduced at the junctions.

Table B-18 provides results from the key points in the steady flow simulation.

9.3 Water Quality Analysis

The main purpose of the HEC-RAS water quality analysis is to model a variety of organic nutrients often found in stream systems. However, arbitrary constituents can be added to the model to analyze the travel non-organic materials in the system. Such arbitrary constituents in this model include lead, cadmium, and several others.

In order to perform a water quality analysis, water temperature modeling and a meteorological time series must be set in place. It is preferable to have a set of data for the various parameters; however, it is possible to use constant temperature and meteorological conditions to perform a water quality analysis, as was done for this model. It should be noted that using constants does not allow for the analysis of seasonal variation.

Table 19 displays the results of the water quality analysis before and after the implementation of our solutions by showing the influents of total nitrogen and total phosphorus into Puddingstone Reservoir. As is, 558 μg/L of total phosphorus and 37.2 mg/L of total nitrogen are present in the inflow into the reservoir. After project implementation, concentrations in the inflow are reduced to 279 μg/L of total phosphorus and 1.22 mg/L of total nitrogen. Figure A-18, displays the focus of the treatment within the watershed.

From the table B-20, it is seen that total nitrogen and phosphorus compounds entering Puddingstone Reservoir have been reduced by the project solutions. The wetlands are responsible for the majority of the reduction in these compounds. Both nitrogen and phosphorous contribute to the growth of algae in Puddingstone Reservoir and their reduction from the stream flowing into Puddingstone will result in improved future health of the reservoir and reduced growth of algae. A significant reduction in both lead and cadmium is also seen and is largely due to the low impact developments implemented in Kuns Park and La Verne Sports Park. Overall, the combination of solutions successfully provides treatment to the watershed flowing into Puddingstone for a healthier community.

Mass Balancing

*Equations can be found in Appendix D – Mass Balancing Equations

Mass balancing is used calculate changes in concentration over time. It is used here to calculate the length of time it will take for contaminants in Puddingstone Reservoir to reach acceptable levels of concentration after project implementation. The mass balancing is also used to calculate the increase in contaminant concentration if the project site is left as is. The contaminants selected for mass balancing include total nitrogen and total phosphorus as they are largest contributor to algae growth in the reservoir.

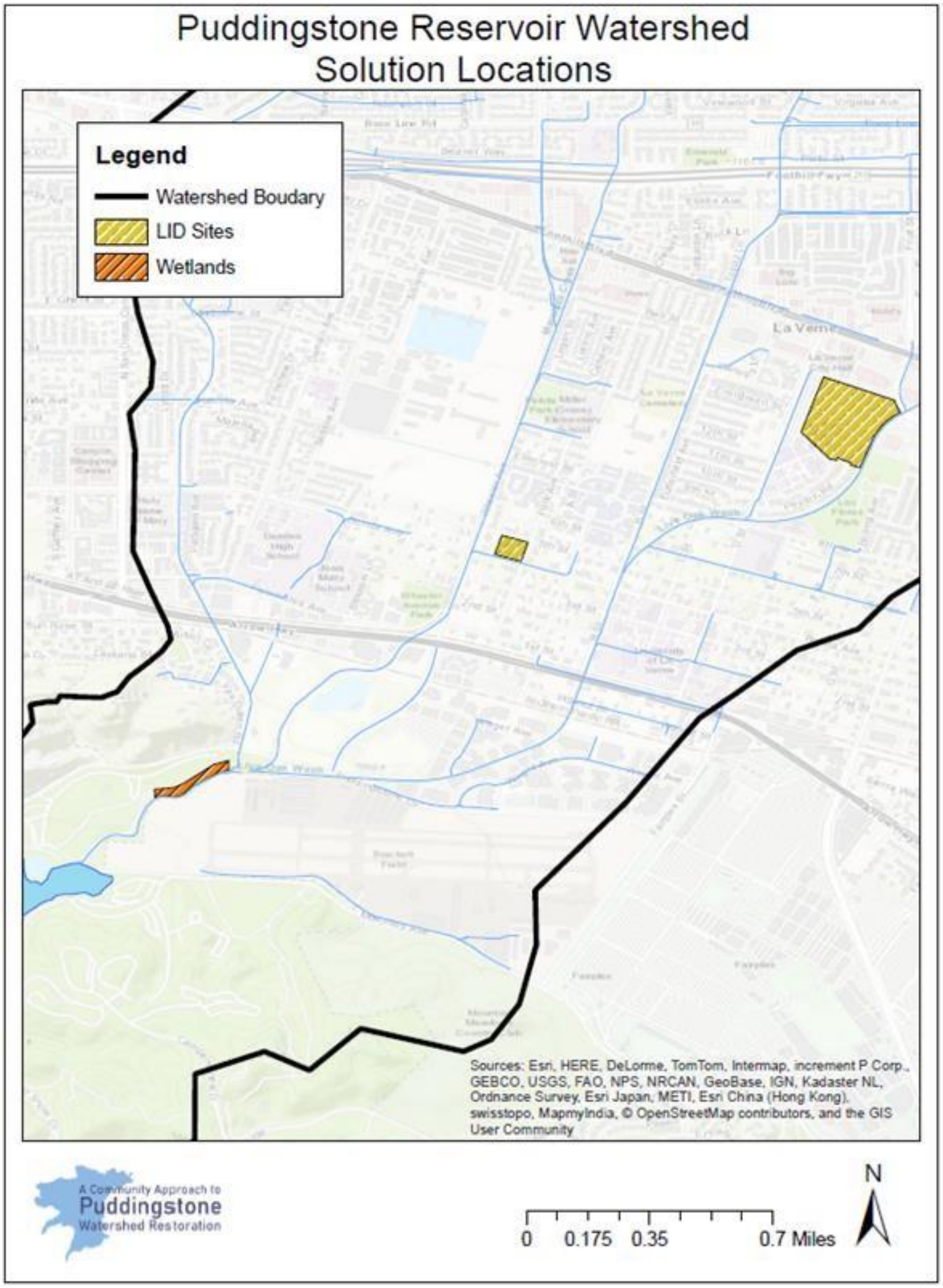
The current total nitrogen concentration in Puddingstone Reservoir already meets the goal of 1 $\frac{\mathrm{m}g}{L}$ or less at 0.5 $\frac{\mathrm{m}g}{L}$ however, if the inflow were left untreated the nitrogen concentration would increase to 1 $\frac{\mathrm{m}g}{L}$ in the span of 29 years. Given more time and the total nitrogen will exceed the concentration goal of 1 $\frac{\mathrm{m}g}{L}$ and promote the growth of algae in the reservoir.

It will take 6.34 years for the concentration of total phosphorus in Puddingstone Reservoir to reach the intended concentration goal of 12 $\frac{\mu g}{L}$. If the inflow is left untreated the concentration of total phosphorus would increase to 140 $\frac{\mu g}{L}$ in the same time frame of 6.34 years. The increased phosphorus would encourage algae growth and reduce the water quality of the reservoir.

The water quality of the water if left untreated is summarized in Table B-21.

APPENDIX A – FIGURES AND TABLES

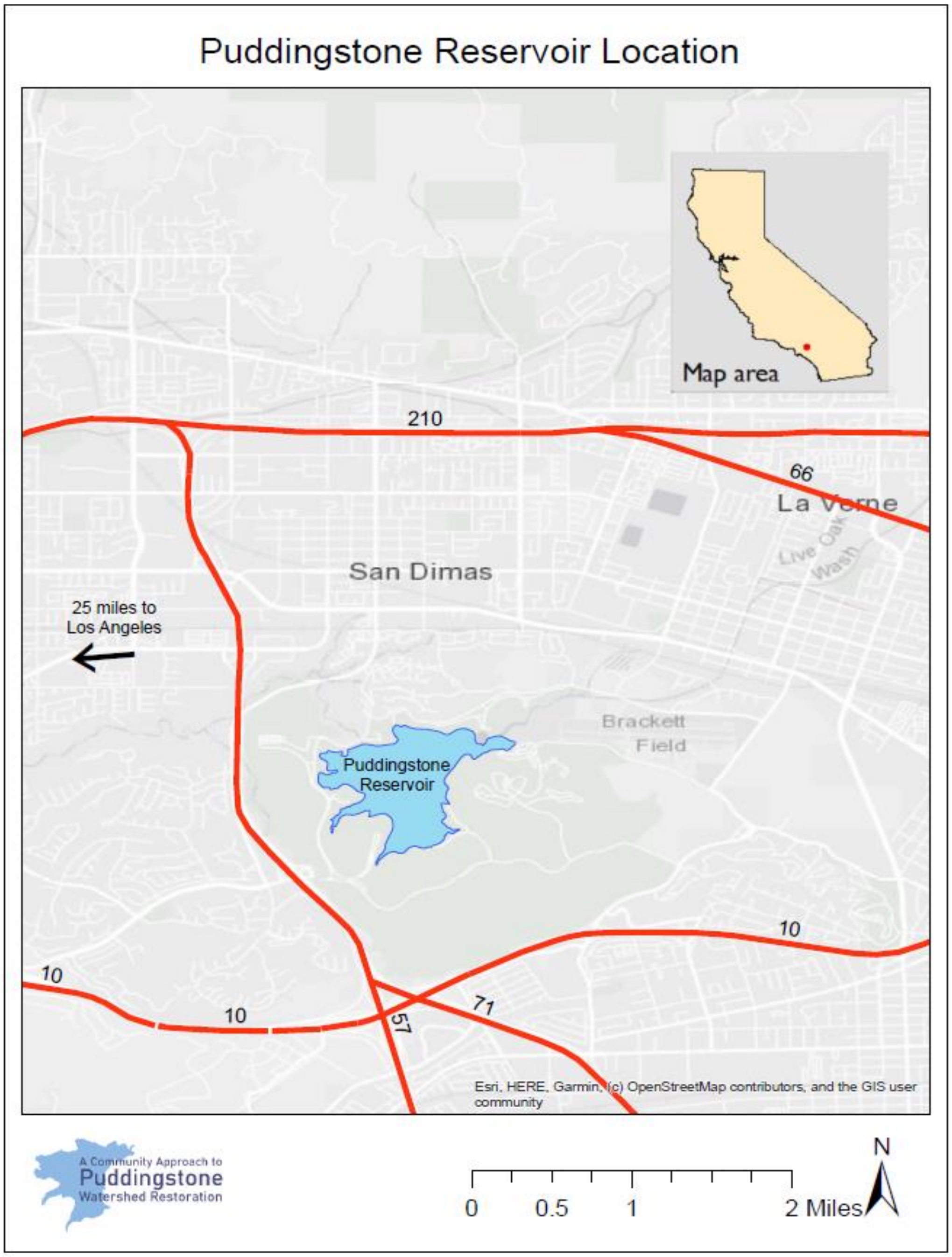
A-1: Puddingstone Watershed Solution Locations



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

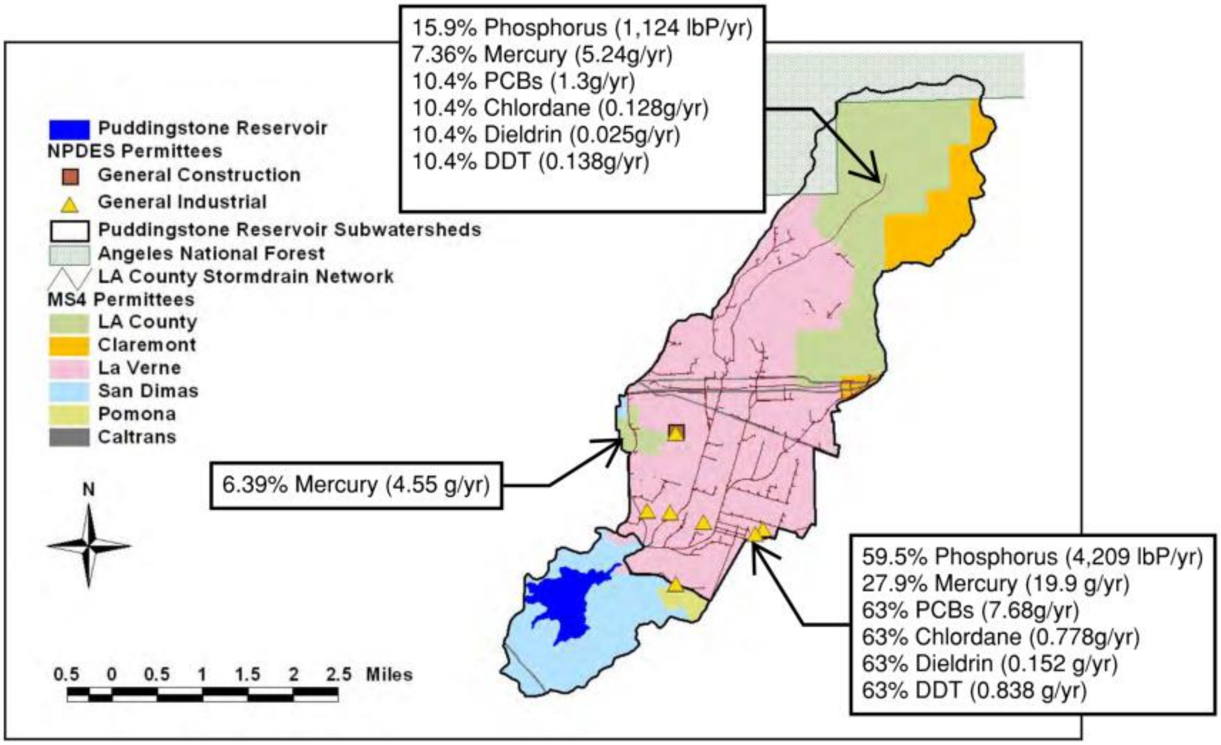
Puddingstone Watershed Solution Locations.

A-2: Puddingstone Reservoir and Site Key Features.



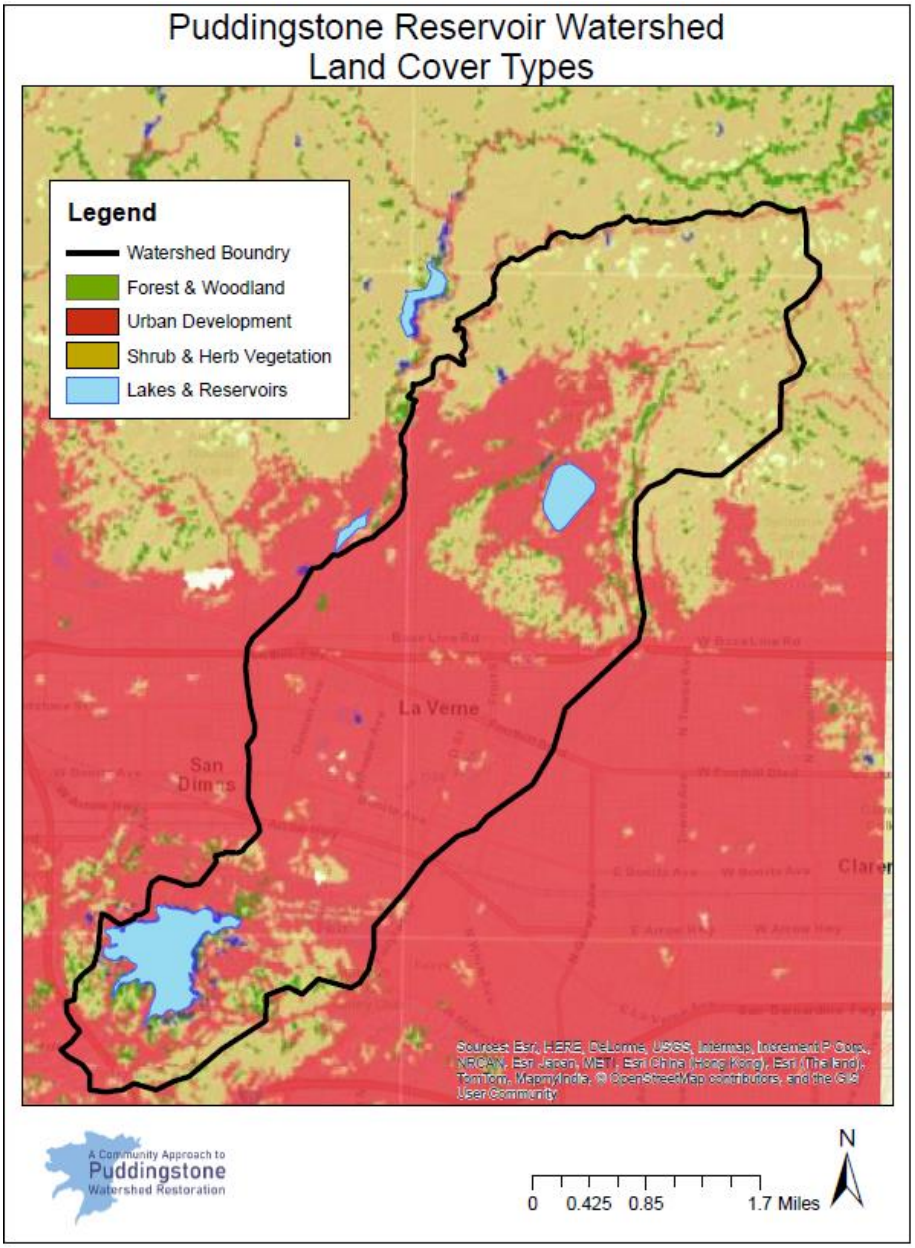
Puddingstone Reservoir and Site Key Features. Source: Garmin, OpenSteetMap.

A-3: Annual Impairment Concentrations for the Puddingstone Reservoir Watershed



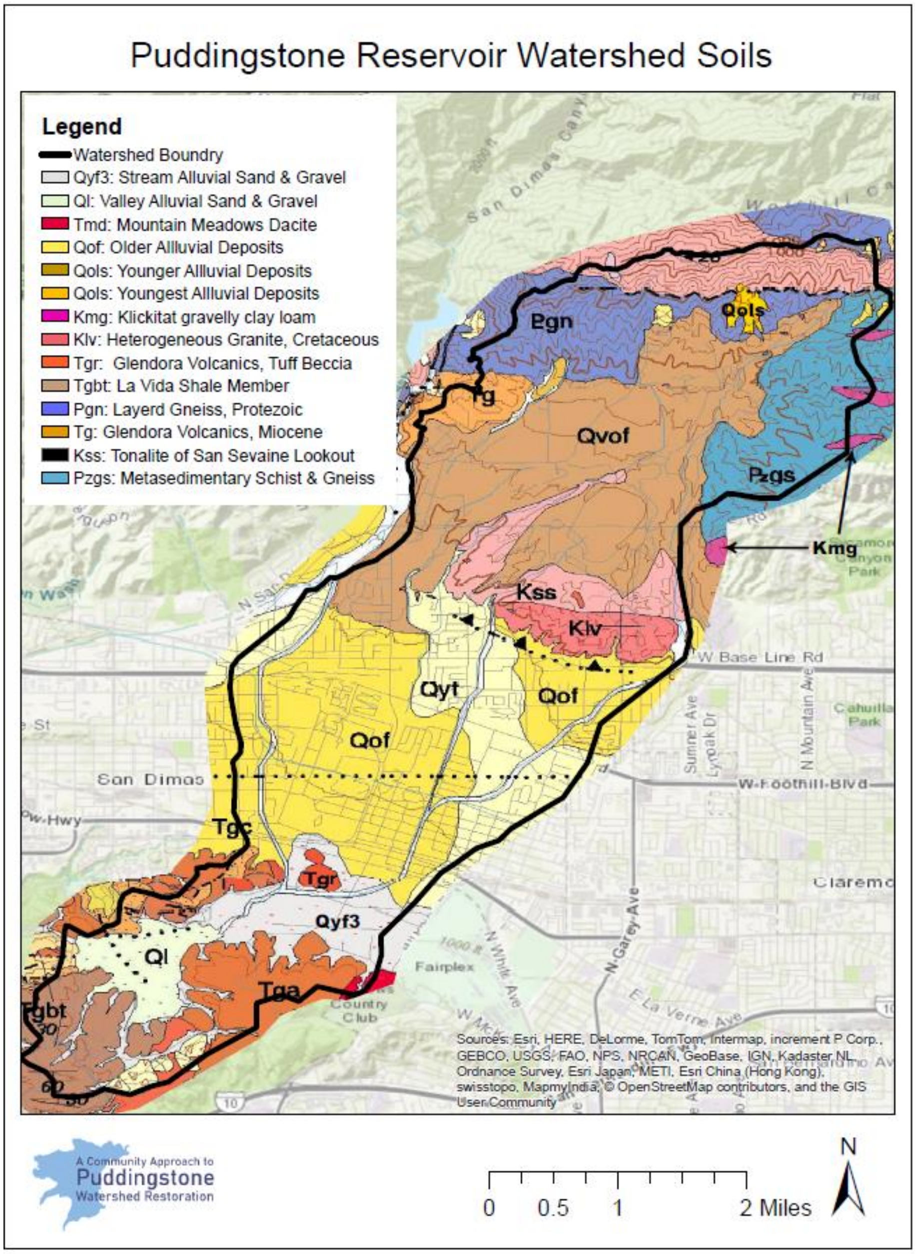
Annual Impairment Concentrations for the Puddingstone Reservoir Watershed. Source: Environmental Protection Agency. Los Angeles Area Lakes Total Maximum Daily Loads for Nitrogen, Phosphorus, Mercury, Trash, Organochlorine Pesticides and PCBs. March 2012.

A-4: Puddingstone Reservoir Watershed Land Cover



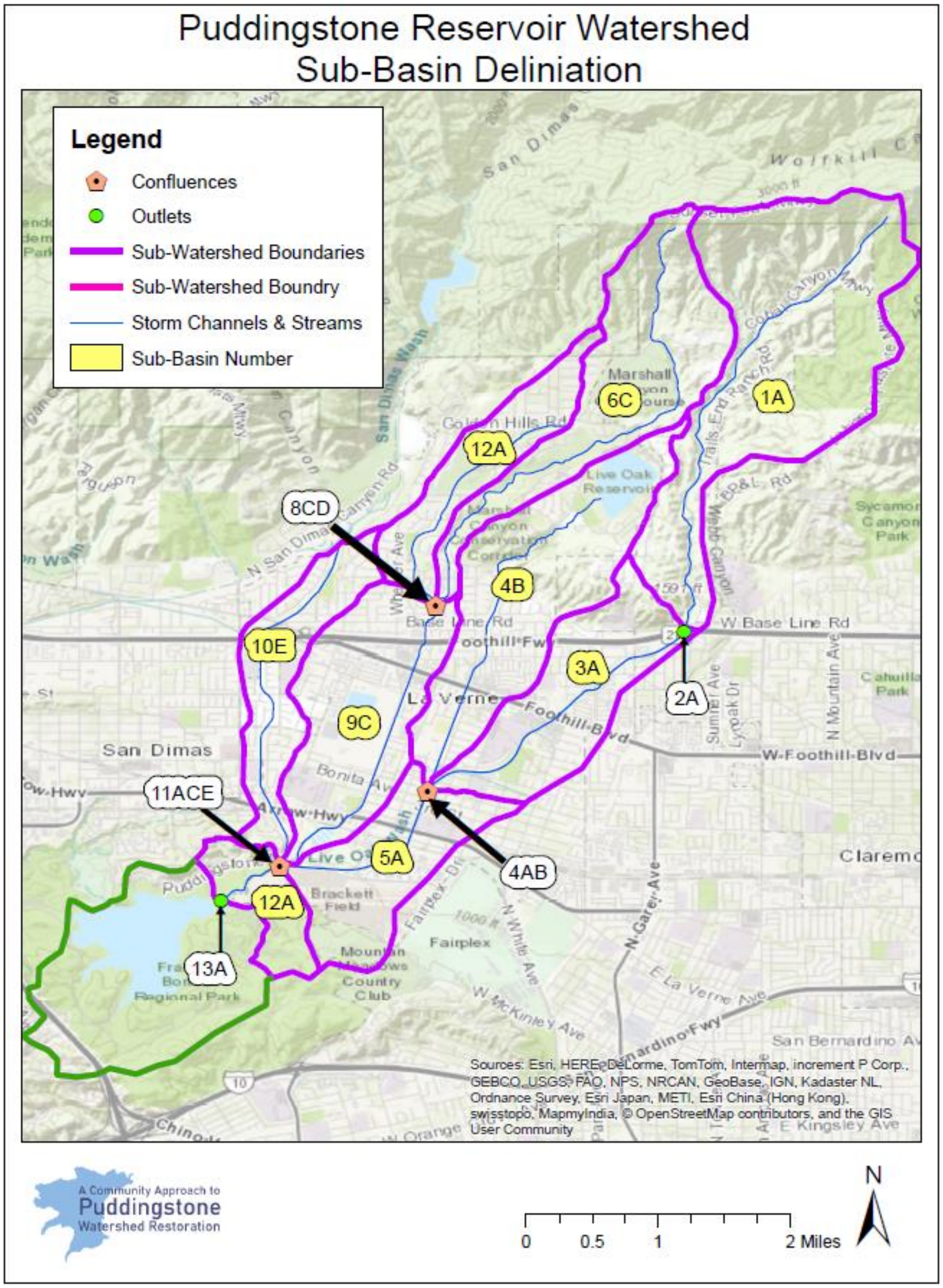
Puddingstone Reservoir Watershed Land Cover
https://www.usgs.gov/centers/eros/science/national-land-cover-database, 2016

A-5: Puddingstone Watershed Soils



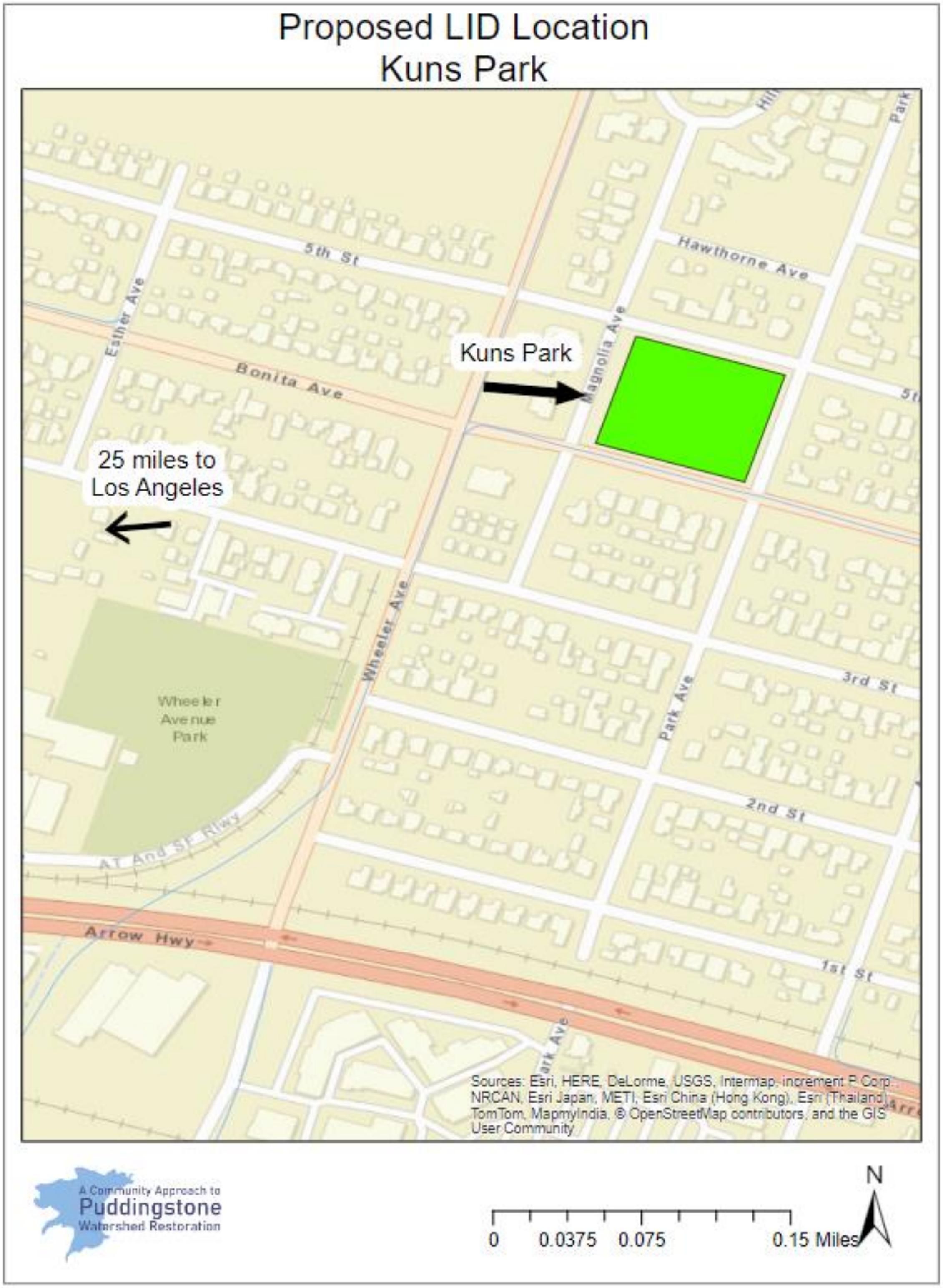
Puddingstone Watershed Soils. Source: USGS GEOLOGIC MAP OF THE SAN BERNARDINO AND SANTA ANA 30’ X 60’ QUADRANGLES, CALIFORNIA, 2006

A-6: Sub-Basin Delineation



Sub-Basin Delineation

A-7: Kuns Park Vicinity Map



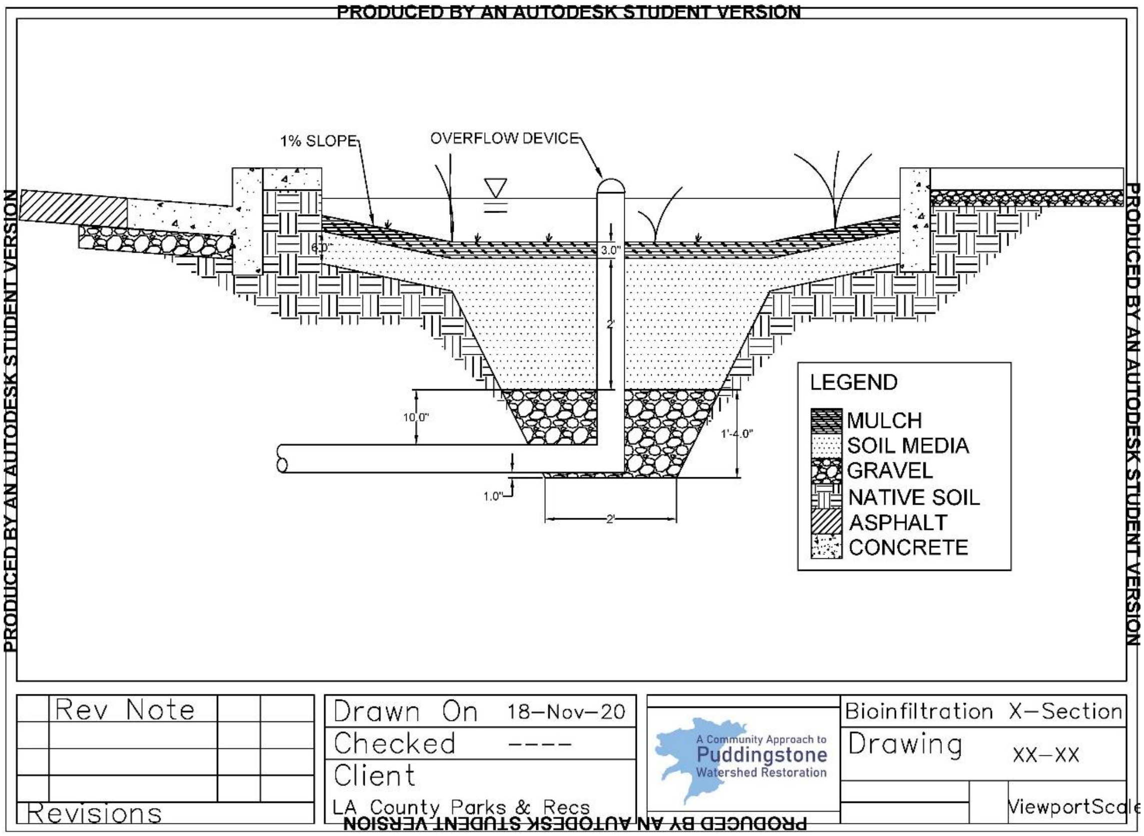
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Kuns Park Vicinity Map

A-8: La Verne Sports Park Vicinity Map

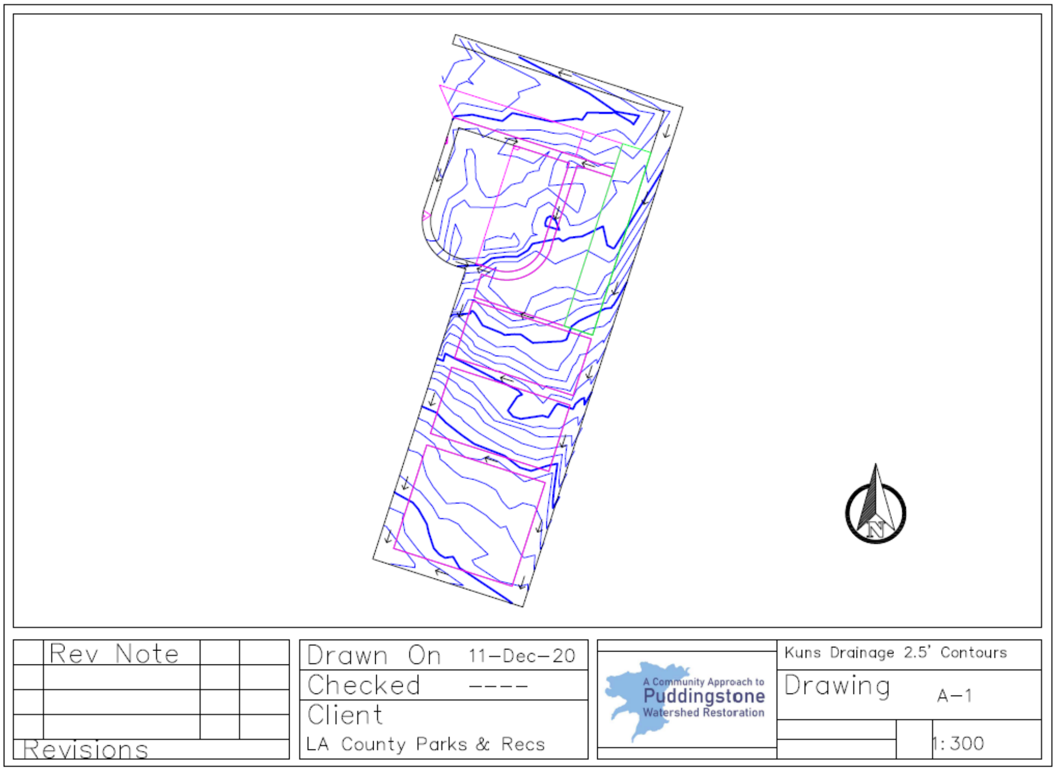
La Verne Sports Park Vicinity Map

A-9: Biofiltration Cross-Sections



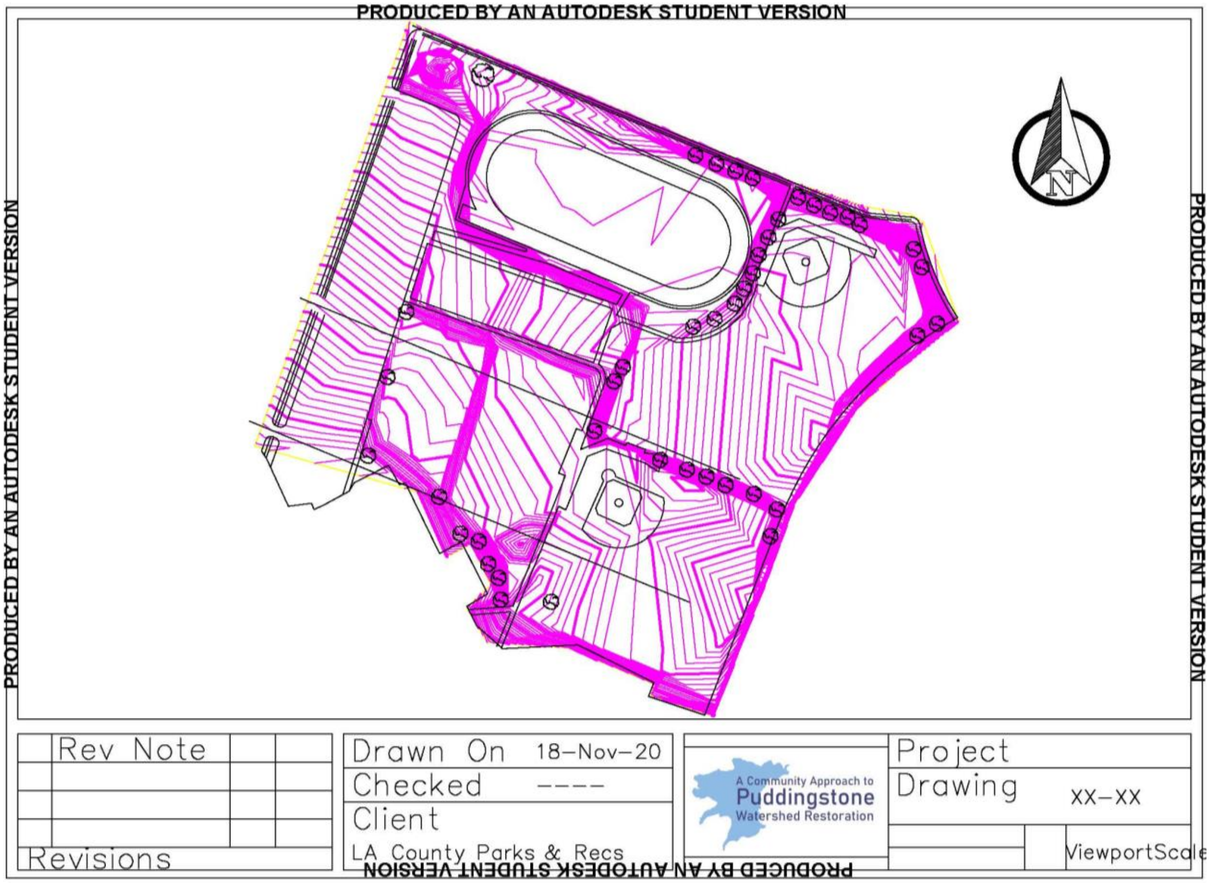
Biofiltration Cross-Sections

A-10: Kuns Park Drainage Area



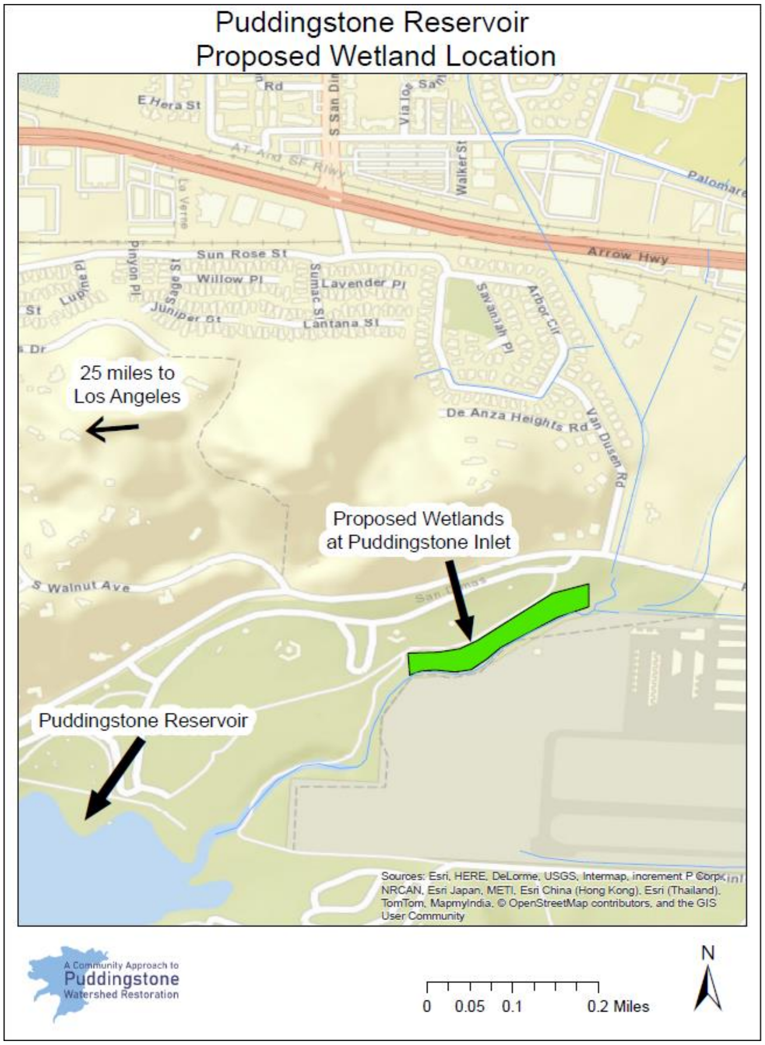
Kuns Park Drainage Area

A-11 : La Verne Sports Park Drainage Area



La Verne Sports Park Drainage Area

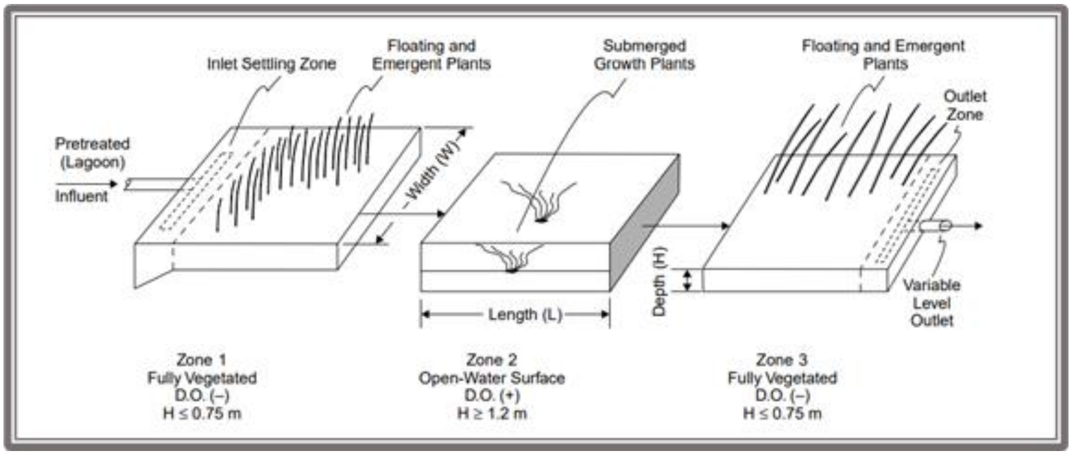
A-12: Proposed Wetland Location on Northeast corner of Puddingstone Reservoir



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

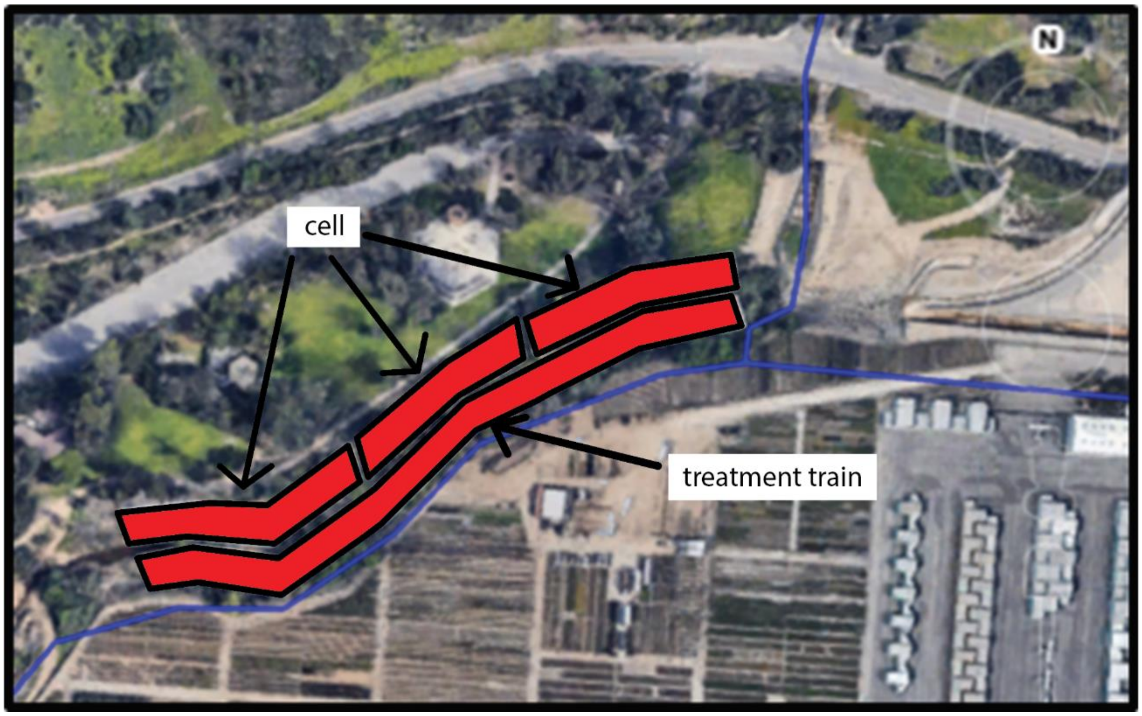
Proposed Wetland Location on Northeast corner of Puddingstone Reservoir

A-13: Elements of a Free Water Surface (FWS) Constructed Wetland



Elements of a free water surface (FWS) constructed wetland. Source: Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment

A-14: Proposed Wetland Location Showing The 3 Cells in Each of the 2 Trains

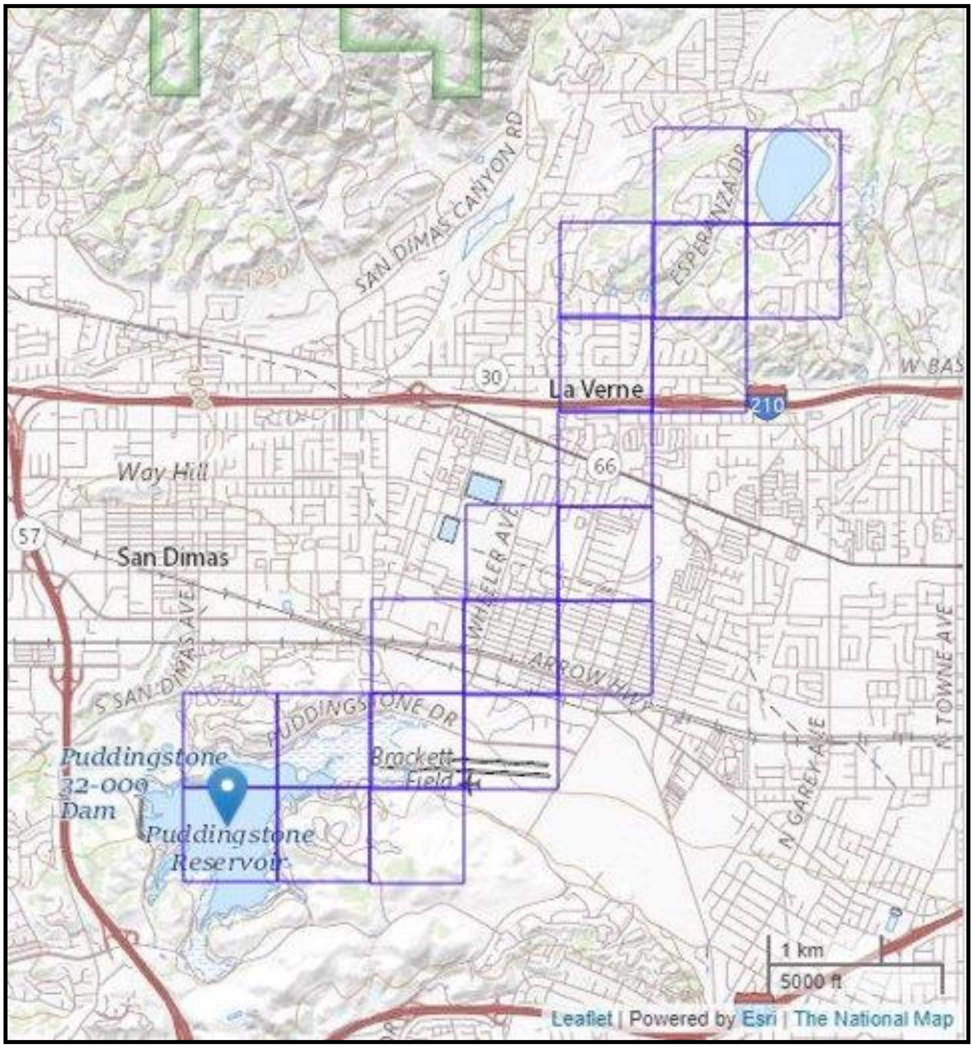


Proposed Wetland Location Showing The 3 Cells in Each of the 2 Trains

A-15: Model Streams and Junctions Map

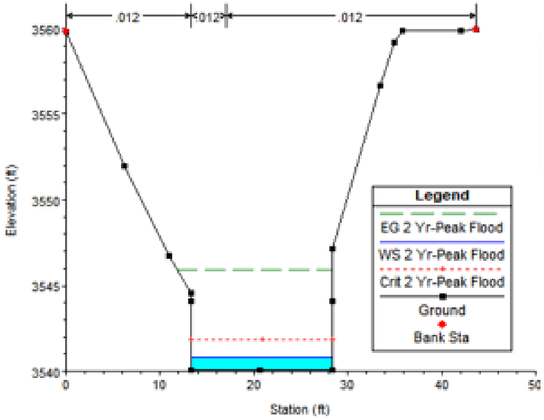
Model Streams and Junctions Map

A-16: Footprint of USGS Lidar Point Cloud Data Used

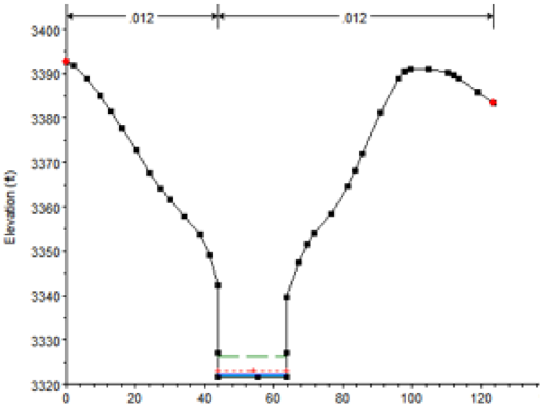


Footprint of USGS Lidar Point Cloud Data Used   Source: U.S. Geological Survey: The National Map

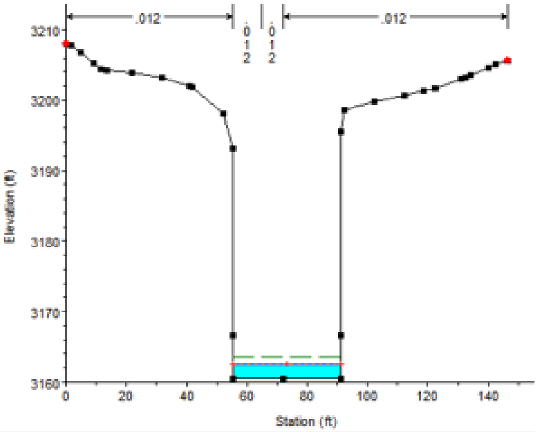
A-17: HEC-RAS Typical Cross Sections



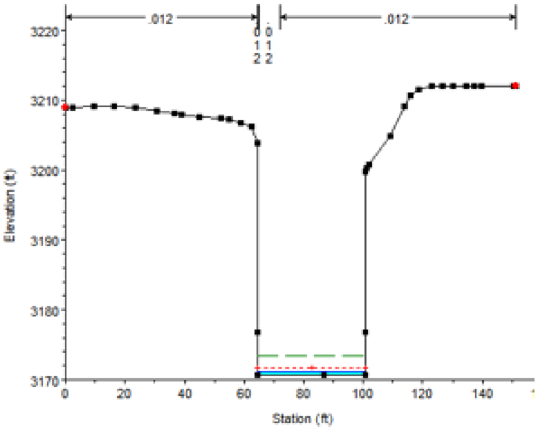
a) Live Oak Wash: River Sta. 2876



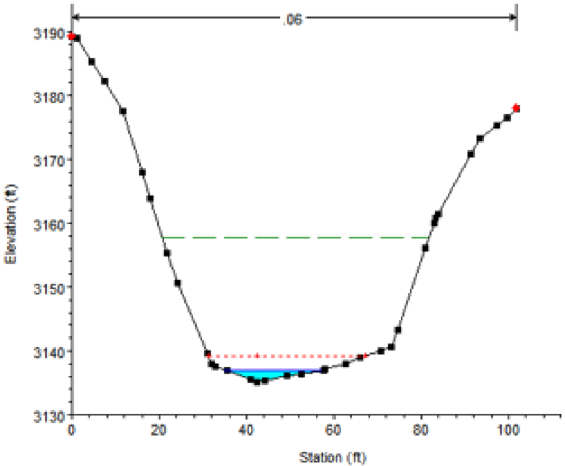
b) Marshall Canyon: River Sta. 3587



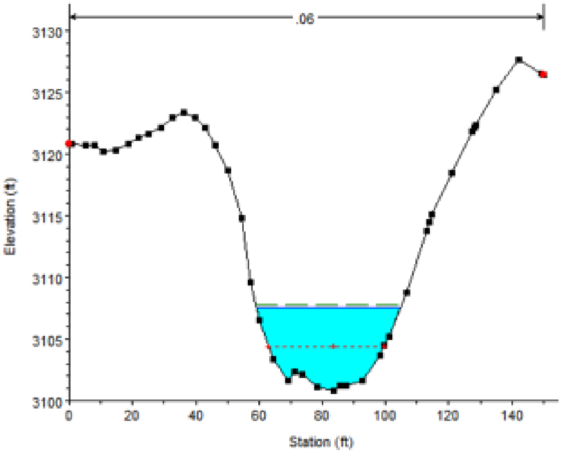
c) Project Stream: River Sta. 3229



d) Marshall Canyon: River Sta. 400

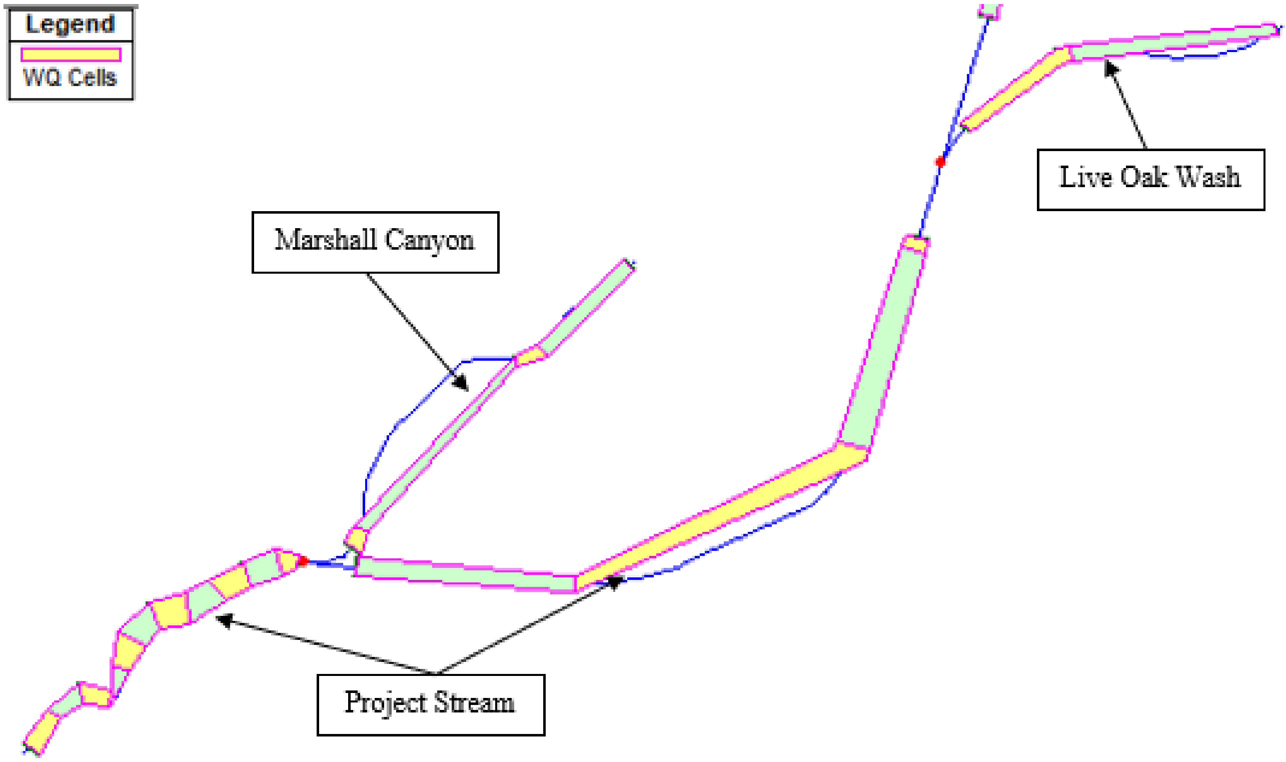


e) Project Stream: River Sta. 2794



g) Project Stream: River Sta. 97

A-18: HEC-RAS Water Quality Focus



HEC-RAS Water Quality Focus

APPENDIX B – TABLES

B-1: Water Quality Test at Puddingstone Reservoir

Table 1: Water Quality Test at Puddingstone Reservoir. Sampling Date: 9/27/2019. Red font representative of conditions that do not meet EPA Surface Water Standards.

Test	Unit	Concentration	Conclusion	EPA Goal
Turbidity	NTU	2.6	Typical for fresh waters	<10
Conductivity	µS/cm	472.0	Typical for fresh waters	50-1500
Free Reactive Phosphorus	µg/L	5.0	Contributes to algae growth	N/A
Dissolved Oxygen	mg/L	8.6	Able to support most fish	>6
Chlorophyll a	µg/L	<10	Mesotrophic	0-2.6
Total Phosphorus	µg/L	31	Eutrophic waters	<12
Alkalinity	mg/L as $CaCO_3$	111.6	Buffered	>101
Total Hardness	mg/L as $CaCO_3$	36	Soft	0-60

Total Nitrate	mg/L	<0.02	Typical for fresh waters	<1
Nitrite	mg/L	<0.02	Typical for fresh waters	<1
Nitrate	mg/L	<0.02	Typical for fresh waters	<1
Total Kjeldahl Nitrogen	mg/L	0.5	Typical for fresh waters	<1
Total Nitrogen	mg/L	0.5	Typical for fresh waters	<1
pH	N/A	7.4	Typical for fresh waters	6-9
Mercury in Fish Tissue	ppm	0.686	High Concentrations	0.22

Source: Aquatechnex LLC, Laboratory Report, September 2019

B-2: Community Outreach and Responses

Table 2: Community Outreach and Responses

Company/ Organization	Contact	How much does Puddingstone reservoir affect the organization?	Has the organization been affected by poor water quality or pollutants in the reservoir?	Any suggestions on how to improve the park?
Raging Waters LA	(909)-802-2200	No Answer. Closed due to COVID-19		
Mountain Meadows Golf Course	(909)-623-3704	Waiting for manager approval for answering questions		
Bonelli Bluffs	(909)-599-8355	Affects us because we are right on the reservoir when they let too much water out it becomes too shallow then there's stagnant water. When the water is full, and guests like it because they can do fishing and the waterfall in the area. It is nice when there's not enough water	Only when the water level is very shallow when they let too much water out. especially in the summer months because the magnesium is too high fishing is catch and release instead of taking it home swimming because the water quality is so poor, they close the swimming area	The park itself one is the trails need to be cleaned up a bit, dead brush in the reservoir needs to be removed. Signage, new trail signs should be put up because things have deteriorated over the years and have never been replaced. lots of vandalism needs to be repaired. that would be a big improvement. as far as putting things in I would suggest a dog park to be put in and putting more outdoor fitness machines would be a big draw, tickle ball for seniors would bring people out to the park. Key things to increase and make it more enjoyable, shade structures should be replaced
San Gabriel Mountain Regional Conservancy	glcroissant@cpp.edu			Work with the natural processes, not against it

B-3: Puddingstone Watershed Characteristics

Table 3: Puddingstone Watershed Characteristics

Watershed Length (ft)	39,700
Emerald Wash/ Lower Live Oak Wash Stream Length (ft)	23,800
Watershed Area (ft^2)	321,498,936
Watershed Area (Acres)	7380.6
Highest Elevation (ft)	3,584
Lowest Elevation (ft)	944
Watershed Relief (ft)	2,640
Overall Slope (%)	6.6
Highest Elevation of Stream (ft)	1536
Lowest Elevation of Stream (ft)	944
Stream Relief(ft)	592
Stream Slope (%)	2.5

B-4: 24 Hour Rainfall Intensity in sub-basins

Table 4: 24 Hour Rainfall Intensity in sub-basins

Basin No.	**I_{1440} (in/hr)**
1A	0.3968
3A	0.2957
4B	0.3172
5A	0.2875
6C	0.3786
7D	0.3486
9C	0.2966
10E	0.3027
12A	0.2879

B-5: Soil Types. Source: Los Angeles County Hydrology Maps

Table 5:Soil Types. Source: Los Angeles County Hydrology Maps.

Number	**Name**	**Runoff Coefficient Cu at 1-inch in depth**
002	ALTAMONT CLAY LOAM	0.73
003	CHINO SILT LOAM	0.12
006	HANFORD FINE SANDY LOAM	0.59
007	HANFORD GRAVELLY SANDY LOAM	0.26
011	PLACENTIA LOAM	0.58
012	RAMONA CLAY LOAM	0.82
013	RAMONA LOAM	0.45
016	YOLO LOAM	0.54
017	YOLO CLAY LOAM	0.70
088	UPPER SAN GABRIEL RIVER	0.24

B-6: Sub-basin length, slope, developed runoff coefficient, and time of concentrations

Table 6: Sub-basin length, slope, developed runoff coefficient, and time of concentrations

Basin No.	**Length (ft)**	**Slope (ft/ft)**	**Cd**	**Tc (min)**
1A	20033	0.113	0.273	77
3A	11902	0.0226	0.772	44
4B	14350	0.034	0.673	48
5A	6700	0.013	0.776	34
6C	20717	0.099	0.380	66
7D	10100	0.0355	0.678	36
9C	12212	0.017	0.824	45
10E	14397	0.013	0.884	49
12A	2806	0.004	0.198	61

B-7: Watershed Time of Concentration

Table 7: Watershed Time of Concentration

Basin 1A T_c (min)	77
Basin 3A T_c (min)	44
Basin 5A T_c (min)	34
Basin 12A T_c (min)	61
Watershed T_c (min)	216

B-8: Flow Calculations

Table 8: Flow Calculations

Basin No.	**C_d**	**I_{Tc} (in/hr)**	**A (acres)**	**Q(cfs)**
1A	0.24	1.57	1658.9	625.7
3A	0.84	1.52	712.3	907.3
4B	0.67	1.65	1111.5	1235.8
5A	0.78	1.67	609.4	790.7
6C	0.38	1.61	951.6	582.9
7D	0.68	1.96	461.3	612.6
9C	0.84	1.51	1069.6	1361.8
10E	0.88	1.48	541.5	709.7
12A	0.20	1.27	264.5	66.6
			Total Q (cfs)	6893.1

B-9: Structural Low Impact Development Stormwater Infrastructure Considered

Table 9: Structural Low Impact Development Stormwater Infrastructure Considered. Source: Los Angeles LID Manual Appendix E.

LID Infrastructure	Explanation	Advantages	Disadvantages
Infiltration Trench	Narrow trench designed for retraining and infiltrating stormwater runoff.	Groundwater recharge, small footprint, no irrigation necessary	Native soil must be optimal, cannot be used in contaminated areas or high sediment loads, may result in standing water
Permeable Pavement	Permeable interlocking pavers, pervious concrete, or porous asphalt atop sand and gravel sublayers.	Aesthetics, reduced heat island, dual use	Cannot be used in contaminated areas, vulnerable to high truck loads, uneven driving surfaces, frequent maintenance required to prevent clogging
Dry Wells	Bored, drilled, or driven shaft or hole filled with aggregate to store and infiltrate runoff.	Small footprint, low installation cost, groundwater recharge, good for small storm events	Native soil must be optimal, cannot be used in contaminated areas, cannot receive untreated stormwater runoff, failed drywells require complete reconstruction
Sand Filter	Constructed sand bed with underdrain system.	Small footprint, potential underground placement, suitable for most soil conditions	Requires flat surface, does not reduce volume of runoff, expensive construction
Rain Barrels	Containers that collect and store precipitation from rooftops.	Low installation cost, small footprint, irrigation uses, easy to maintain	Limited storage volume, not suitable for consumption, aesthetics, standing water, individual responsibility for maintenance

B-10: Final BMP sizes

Table 10: Final BMP sizes

Inlet	Total Flow (cu-ft)	SWQDv[1] (cu-ft)	Infiltration (in/hr)	Max Depth (ft)	Design Depth (ft)	Area (sq-ft)
Kuns SW	16000	24000	2.5	20	6	4000
Kuns SE	3303	4954.5	2.5	20	6	825.75
La Verne Sports	20569	30853.5	2.5	20	6	5150

B-11: Calculations of a Single Cell and Entire Wetland

Table 11: Calculations of a Single Cell and Entire Wetland

	Cell 1	**Cell 2**	**Cell 3**	**Entire Wetland**
Volume of a FWS wetland; V_w	4,244 m^3	4,244 m^3	4,244 m^3	12,732 m^3
Average Wastewater Flow; Q_{ave}	$0.048\ \mathrm{m}^3/s$	$0.0243\mathrm{m}^3/s$	$0.0120\mathrm{m}^3/s$	$0.0843\mathrm{m}^3/s$
Hydraulic Retention Time; t	24.6 hours	48.5 hours	98.2 hours	171.3 hours
Hydraulic Loading Rate; q	$1.53 \times 10^{-5}\ \mathrm{m/s}$	$0.76 \times 10^{-5}\ \mathrm{m/s}$	$0.38 \times 10^{-5}\ \mathrm{m/s}$	$2.67 \times 10^{-5}\ \mathrm{m/s}$
Average Flow Velocity; v	$1.72 \times 10^{-5}\ \mathrm{m/s}$	$0.87 \times 10^{-3}\ \mathrm{m/s}$	$0.43 \times 10^{-3}\ \mathrm{m/s}$	$3.02 \times 10^{-3}\ \mathrm{m/s}$
Hydraulic Gradient in the FWS Constructed Wetland; S	$15.2 \times 10^{-8}\ \mathrm{m/m}$	$3.9 \times 10^{-8}\ \mathrm{m/m}$	$1.0 \times 10^{-8}\ \mathrm{m/m}$	$20.1 \times 10^{-8}\ \mathrm{m/m}$

B-12: Capital Cost

Capital Cost. Source: City of Los Angeles

	Unit	Quantity	Price	Item Total
GENERAL PREPARATION				
Mobilization	LS	3	$30,000	$90,000
Traffic Control	LS	3	$10,000	$30,000
Clearing and Grubbing	LS	3	$60,000	$180,000
SUBTOTAL 1				**$300,000**
CONSTRUCTION				
Wetlands				
Excavation/Compaction	CF	37083.92174	$1.12	$41,595.70
Media	CF	37083.92038	$10.85	$402,393.17
Geosynthetic Clay Layer	SF	22538.6659	$2.50	$56,332.24
Plants	EA	11303.17708	$0.96	$10,851.05
Plolyaluminum Chloride	ML	100	$43.30	$4,330.00
Plumbing	LS			$12,000.00
Control Structures	LS			$11,200.00
Other	LS			$16,000.00
Vegetated Swale (Prep and Vegetation Inclusive)	CF	1500	$18.67[1]	$28,005.00
Bioretention (Prep and Vegetation Inclusive)	CF	40900	$15.97[1]	$653,173.00
Retrofit Current Irrigation Systems	LS			$3,350.00
30mil Geomembrane Liner	SF	94140	$0.54	$50,835.60
Trash Can	EA	3	$750.00	$2,250.00
Educational Signage	LS			$20,000.00
Chain Link Fencing	LF	700	$25.00	$17,500.00
Unperforated 6" Pipe	LF	500	$1.49	$745.00
Perforated 6" Pipe	LF	2000	$1.79	$3,580.00
SUBTOTAL 2				**$1,334,140.76**
TOTAL CONSTRUCTION COST				**$1,334,140.76**
PERMITS AND CONTINGENCY				
Permits (3% CC)	LS	3%	$1,334,140.76	$40,024.22

Allowances (5% CC)	LS	5%	$1,334,140.76	$66,707.04
Estimating Contingency (25% CC)	LS	25%	$1,334,140.76	$333,535.19
Construction Contingency (20% CC)	LS	20%	$1,334,140.76	$266,828.15
Cost Escalation (5% CC)	LS	5%	$1,334,140.76	$66,707.04
SUBTOTAL 3				**$773,801.64**
Community Outreach (1% CC)	LS	1%	$1,334,140.76	**$13,341.41**
Pre-Design and Design (22% CC)	LS	22%	$1,334,140.76	**$293,510.97**
Construction and Post-Construction Mgnt (12% CC)	LS	12%	$1,334,140.76	**$160,096.89**
GRAND TOTAL				**$2,874,892**

[1] Los Angeles Sustainable Water Project: Ballona Creek Watershed.

B-13: Routine LID Operations and Maintenance Cost

Table 13: Routine LID Operations and Maintenance Cost

Site	Subarea	Drainage Area	% Impervious	Annual Cost/acre IC[1]	Hours[1]	Adjustment Factor[1]	Total Cost
Kuns	**SW1**	0.87	0.55	$1,890.00	9.90495	2	$1,808.73
	SW2	0.64	0.55	$1,890.00	7.2864	2	$1,330.56
	SW3	1.19	0.55	$1,890.00	13.54815	2	$2,474.01
	SW4	2.64	0.55	$1,890.00	30.0564	2	$5,488.56
	SW5	2.17	0.42	$1,890.00	18.86598	2	$3,445.09
	KUNS	1.68	0.55	$1,890.00	19.1268	2	$3,492.72
	SE1	3.34	0.1	$1,890.00	6.9138	2	$1,262.52
La Verne Sports Park	**Subarea 3**	4.88	0.53	$1,890.00	53.53848	2	$9,776.59
				Tot Hours/yr	**159.24096**	Tot Cost/yr	**$29,078.78**

[1] EPA Methodology for developing cost estimates for Opti-Tool.

B-14: Constructed Wetlands Annual Operations and Maintenance Cost

Table 9: Constructed Wetlands Annual Operations and Maintenance Cost. Source: EPA Wastewater Technology Fact Sheet: Free Water Surface Wetlands

	Cost ($)	Percent of Total (%)
Sludge removal and disposal	2560.00	8.1
Polyaluminum Chloride	2400.00	7.6
NPDES laboratory tests	5760.00	18.3
Wages	20793.60	66.0
Total	31513.60	100.0

B-15: Present Value Cost Analysis

Table 10: Present Value Cost Analysis. Source: EPA Wastewater Technology Fact Sheet: Free Water Surface Wetlands

	Low Impact: Worst Case	Low Impact: Likely Case	Traditional
Capital Cost	$3,820,000	$2,866,535	$1,104,500
Annual Operations Cost	$137,000.00	$87,000.00	106600
Lifespan (yrs)	20	20	20
Discount Rate	0%	7%	7%
Present Value	$6,560,000	$3,788,214	$2,233,400.00
Gallons treated over lifespan	10,993,230,336	10,993,230,336	729,869,281
price/1000 Gal	**$0.60**	**$0.34**	**$3.06**

B-16: Projected Necessary Permits

Table 11: Projected Necessary Permits

Permit Name	Jurisdiction	Reason
Encroachment	City of La Verne	Construction
Encroachment	City of La Verne	Construction
Heavy Haul	City of San Dimas	Construction
Heavy Haul	City of San Dimas	Construction
NPDES	County of Los Angeles	Operation
Flood Construction	County of Los Angeles	Construction
Incidental Take	US Fish and Wildlife	Construction
Enhancement of Survival	US Fish and Wildlife	Operation
Migratory Birds Permit	US Fish and Wildlife	Operation

B-17: Cost of Permits

Table 17: Cost of Permits

Permit Name	Estimated Fee
Encroachment	$82 Per Hour
Heavy Haul	$90 Annual
NPDES	Category 2 - $9,786
Flood Construction	Excavations: $686 Major Revisions: $750 Inspection of Construction: $686
Incidental Take	$100
Enhancement of Survival	$50
Migratory Birds Permit	$100

B-18: Steady flow Results at Key Cross Sections

Table 18: Steady flow Results at Key Cross Sections

Cross Section Locations	Q (CFS)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq. ft)
Live Oak Wash: River Sta. 2876	198.00	0.037646	18.22	10.87
Marshall Canyon: River Sta. 3587	198.00	0.034016	15.96	12.41
Project Stream: River Sta. 3229	594.00	0.001927	8.12	73.15
Marshall Canyon: River Sta. 400	198.00	0.026553	11.88	16.67
Project Stream: River Sta. 2794	792.00	2.342199	36.61	21.63
Project Steam: River Sta. 97	792.00	0.002872	3.60	219.91

B-19: Water Quality Influent Before and After

Table 19: Water Quality Influent Before and After

Constituent	**Before**	**After**
Total Phosphorous (µg/L)	558	279
Total Nitrogen (mg/L)	57.2	1.22
Arbitrary Constituent		
Lead (mg/L)	$1.58* 10^{-3}$	$0.16* 10^{-3}$
Cadmium (mg/L)	$0.04* 10^{-3}$	$0.35* 10^{-3}$

B-20: Treated Reservoir Water Quality Change

Table 20: Treated Reservoir Water Quality Change

Contaminant	Unit	Current Concentration	Concentration Change (yr)	Time to reach goal (yr)	Goal
Total Nitrogen (TN)	mg/L	0.5	-0.246	N/A	<1
Total Phosphorus (TP)	µg/L	31	-2.99	6.34	<12

B-21: Untreated Reservoir Water Quality Change

Table 21: Untreated Reservoir Water Quality Change

Contaminant	Unit	Current Concentration	Concentration Change (yr)	Time past goal (yr)	Goal
Total Nitrogen (TN)	mg/L	0.5	0.0172	29	<1
Total Phosphorus (TP)	μg/L	31	17.2	N/A	<12

APPENDIX C – WETLAND CALCULATIONS

Treatment Cell One

Volume of FWS wetland; V_w

Area = A_w = 0.69 acres = 2792 m^2

Water depth = h = 5 ft = 1.52 m

$$\mathbf{V_w} = (A_w)(h) = (2792)(1.52\text{ m}) = \mathbf{4244\ m^3}$$

Average Wastewater Flow; Q_{ave}

FWS influent flow rate = Q_o = 2.31 cfs = 0.065 m^3/s

FWS effluent flow rate = Q_e = 1.15 cfs = 0.032 m^3/s

$$\mathbf{Q_{ave}} = \frac{Q_o + Q_e}{2} = \frac{(2.31\text{ cfs}) + (\ 2\text{ cfs})}{2} = \mathbf{1.73\ cfs = 0.048\frac{m^3}{\mathit{s}}}$$

Hydraulic Retention Time; t

Volume of FWS wetland V_w = 4244 m^3

Average porosity value = ϵ = 1.0

Average Flow Rate = Q_{ave} = 0.037 m^3/s

$$\mathbf{t} = \frac{(V_w)(\epsilon)}{Q_{ave}} = \frac{(4244\text{ m}^3)(1.0)}{0.048\ m^3/s} = \mathbf{24.6\ hours = 1.02\ days}$$

Hydraulic Loading Rate; q

FWS influent flow rate = Q_o = 0.065 m^3/s

Area = A_w = 4244 m^2

$$\mathbf{q} = \frac{Q_o}{A_w} = \frac{0.065\frac{m^3}{s}}{4244\text{ m}^2} = \mathbf{1.53 \times 10^{-5}\ \frac{m}{s}}$$

Average Flow Velocity; v

Average Wastewater Flow = Q_{ave} = 0.048 m^3/s

Average cross-sectional area = A_v = 1.52 m x 18.29 m = 27.80 m^2

Average porosity value = ϵ = 1.0

$$\mathbf{v} = \frac{Q_{ave}}{(A_v)(\epsilon)} = \frac{\left(0.048\,\frac{m^3}{s}\right)}{(27.80\,m^2)(1.0)} = \mathbf{1.72 \times 10^{-3}\,\frac{m}{s}}$$

Hydraulic Gradient in the FWS Constructed Wetland; S

Average flow velocity = v = 1.72 x 10^{-3} m/s

Water depth = h = 1.52 m

Manning's resistance coefficient = n = 0.3 s/$m^{1/3}$

$$\mathbf{S^{\frac{1}{2}}} = \frac{v}{\left(\frac{1}{n}\right)\left(h^{\frac{2}{3}}\right)} = \frac{(1.72 \times 10^{-3}\ m/s)}{\left(\frac{1}{0.3\ s/m^{\frac{1}{3}}}\right)\left((1.52\ m)^{\frac{2}{3}}\right)} = 3.90 \times 10^{-4}$$

$$\mathbf{S} = (3.90 \times 10^{-4})^2 = \mathbf{15.2 \times 10^{-8}\,\frac{m}{m}}$$

<u>Treatment Cell Two</u>

Volume of a FWS wetland; V_w

Area = A_w = 0.69 acres = 2792 m^2

Water depth = h = 5 ft = 1.52 m

$$\mathbf{V_w} = (A_w)(h) = (2792)(1.52\ m) = \mathbf{4244\ m^3}$$

Average Wastewater Flow; Q_{ave}

FWS influent flow rate = Q_o = 1.15 cfs = 0.0326 m^3/s

FWS effluent flow rate = Q_e = 0.57 cfs =0.016 m^3/s

$$\mathbf{Q_{ave}} = \frac{Q_o + Q_e}{2} = \frac{(1.15cfs) + (\ 0.57\ cfs)}{2} = \mathbf{0.86cfs = 0.0243\,\frac{m^3}{s}}$$

Hydraulic Retention Time; t

Volume of FWS wetland V_w = 4244 m^3

Average porosity value = ϵ = 1.0

Average Flow Rate = Q_{ave} = 0.0243 m^3/s

$$\mathbf{t} = \frac{(V_w)(\epsilon)}{Q_{ave}} = \frac{(4244\ m^3)(1.0)}{0.0243\ m^3/s} = \mathbf{48.5\ hours = 0.81days}$$

Hydraulic Loading Rate; q

FWS influent flow rate = Q_o = 0.0326 m^3/s

Area = A_w = 4244 m^2

$$\mathbf{q} = \frac{\mathrm{Q_o}}{\mathrm{A_w}} = \frac{0.0326\,\frac{\mathrm{m}^3}{\mathrm{s}}}{4244\ \mathrm{m}^2} = \mathbf{0.768143 \times 10^{-5}\,\frac{m}{s}}$$

Average Flow Velocity; v

Average Wastewater Flow = Q_{ave} = 0.0243 m^3/s

Average cross-sectional area = A_v = 1.52 m x 18.29 m = 27.80 m^2

Average porosity value = ϵ = 1.0

$$\mathbf{v} = \frac{\mathrm{Q_{ave}}}{(\mathrm{A_v})(\epsilon)} = \frac{\left(0.0243\,\frac{m^3}{s}\right)}{(27.80\ m^2)(1.0)} = \mathbf{8.74 \times 10^{-4}\,\frac{m}{s}}$$

Hydraulic Gradient in the FWS Constructed Wetland; S

Average flow velocity = v = 8.74 x 10^{-4} m/s

Water depth = h = 1.52 m

Manning’s resistance coefficient = n = 0.3 $s/m^{1/3}$

$$\mathbf{S^{\frac{1}{2}}} = \frac{\mathrm{v}}{\left(\frac{1}{\mathrm{n}}\right)\left(\mathrm{h}^{\frac{2}{3}}\right)} = \frac{(8.74 \times 10^{-4}\ \mathrm{m/s})}{\left(\frac{1}{0.3\ \mathrm{s/m^{\frac{1}{3}}}}\right)\left((1.52\ \mathrm{m})^{\frac{2}{3}}\right)} = 1.983 \times 10^{-4}$$

$$\mathbf{S} = (1.983 \times 10^{-4})^2 = \mathbf{3.9 \times 10^{-8}\,\frac{m}{m}}$$

Treatment Cell Three

Volume of a FWS wetland; V_w

Area = A_w = 0.69 acres = 2792 m^2

Water depth = h = 5 ft = 1.52 m

$$\mathbf{V_w} = (\mathrm{A_w})(\mathrm{h}) = (2792)(1.52\ \mathrm{m}) = \mathbf{4244\ m^3}$$

Average Wastewater Flow; Q_{ave}

FWS influent flow rate = Q_o = 0.57 cfs = 0.0161 $\frac{\mathbf{m^3}}{\boldsymbol{s}}$

FWS effluent flow rate = Q_e = 0.28 cfs = 0.0793 $\frac{\mathbf{m^3}}{\boldsymbol{s}}$

$$\mathbf{Q_{ave}} = \frac{\mathrm{Q_o} + \mathrm{Q_e}}{2} = \frac{(0.57\ \mathrm{cfs}) + (\ 0.28\ \mathrm{cfs})}{2} = \mathbf{0.425\ cfs = 0.0120\,\frac{m^3}{\boldsymbol{s}}}$$

Hydraulic Retention Time; t

Volume of FWS wetland V_w = 4244 m^3

Average porosity value = ϵ = 1.0

Average Flow Rate = Q_{ave} = 0.0120 $\frac{\mathbf{m^3}}{\boldsymbol{s}}$

$$\mathbf{t} = \frac{(\mathrm{V_w})(\epsilon)}{\mathrm{Q_{ave}}} = \frac{(4244\ \mathrm{m}^3)(1.0)}{0.0120\ m^3/s} = \mathbf{98.24\ hours = 4.09\ days}$$

Hydraulic Loading Rate; q

FWS influent flow rate = Q_o = 0.0161 m^3/s

Area = A_w = 4244 m^2

$$\mathbf{q} = \frac{\mathrm{Q_o}}{\mathrm{A_w}} = \frac{0.0161\,\frac{\mathrm{m}^3}{\mathrm{s}}}{4244\ \mathrm{m}^2} = \mathbf{0.38 \times 10^{-5}\,\frac{m}{s}}$$

Average Flow Velocity; v

Average Wastewater Flow = Q_{ave} = 0.0120 m^3/s

Average cross-sectional area = A_v = 1.52 m x 18.29 m = 27.80 m^2

Average porosity value = ϵ = 1.0

$$\mathbf{v} = \frac{\mathrm{Q_{ave}}}{(\mathrm{A_v})(\epsilon)} = \frac{\left(0.0161\,\frac{m^3}{s}\right)}{(27.80\ m^2)(1.0)} = \mathbf{0.431 \times 10^{-3}\,\frac{m}{s}}$$

Hydraulic Gradient in the FWS Constructed Wetland; S

Average flow velocity = v = 0.431 x 10^{-3} m/s

Water depth = h = 1.52 m

Manning's resistance coefficient = n = 0.3 $s/m^{1/3}$

$$\mathbf{S^{\frac{1}{2}}} = \frac{\mathrm{v}}{\left(\frac{1}{\mathrm{n}}\right)\left(\mathrm{h}^{\frac{2}{3}}\right)} = \frac{\left(1.27 \times 10^{-3}\,\frac{\mathrm{m}}{\mathrm{s}}\right)}{\left(\frac{1}{0.3\,\frac{\mathrm{s}}{\mathrm{m}^{\frac{1}{3}}}}\right)\left((1.52\ \mathrm{m})^{\frac{2}{3}}\right)} = 0.98 \times 10^{-4}$$

APPENDIX D – MASS BALANCING EQUATIONS

Assumptions made for these equations include equal inflow and outflow volumes over the course of a year and constant concentrations.

Total Nitrogen

Untreated concentration change rate per year:

$$(V_L)(TN_{LC}) = (V_{yr})(TN_{IC}) - (V_{yr})(TN_{OC})$$
$$(7.64 * 10^9 L)(TN_{LC}) = (574 * 10^7 L_{yr})\left(0.523\frac{mg}{L}\right) - (574 * 10^7 L_{yr})\left(0.5\frac{mg}{L}\right)$$
$$TN_{LC} = 0.0172\ \frac{mg}{L_{yr}}$$

Treated concentration change rate per year:

$$(V_L)(TN_{LT}) = (V_{yr})(TN_{IT}) - (V_{yr})(TN_{OC})$$
$$(7.64 * 10^9 L)(TN_{LT}) = (574 * 10^7 L_{yr})\left(0.172\frac{mg}{L}\right) - (574 * 10^7 L_{yr})\left(0.5\frac{mg}{L}\right)$$
$$TN_{LT} = -0.246\ \frac{mg}{L_{yr}}$$

Total Phosphorus

untreated concentration change rate per year:

$$(V_L)(TP_{LC}) = (V_{yr})(TP_{IC}) - (V_{yr})(TP_{OC})$$
$$(7.64 * 10^9 L)(TP_{LC}) = (574 * 10^7 L_{yr})\left(54\frac{\mu g}{L}\right) - (574 * 10^7 L_{yr})\left(31\frac{\mu g}{L}\right)$$
$$TP_{LC} = 17.2\frac{\mu g}{L_{yr}}$$

Treated concentration change rate per year:

$$(V_L)(TP_{LT}) = (V_{yr})(TP_{IT}) - (V_{yr})(TP_{OC})$$
$$(7.64 * 10^9 L)(TP_{LT}) = (574 * 10^7 L_{yr})\left(27\frac{\mu g}{L}\right) - (574 * 10^7 L_{yr})\left(31\frac{\mu g}{L}\right)$$
$$TP_{LT} = -2.99\frac{\mu g}{L_{yr}}$$

Time to Achieve Concentration Goals

Total Nitrogen

$$(TN_{LG}) = (TN_L) + (TN_{LC})(t)$$

$$1\,\frac{\mathrm{m}g}{L} = 0.5\,\frac{\mathrm{m}g}{L} + 0.0172\,\frac{\mathrm{m}g}{L} * t$$

$t = 29.0$ yrs

Total Phosphorus

$$(TP_{LG}) = (TP_L) - (t)(TP_{LT})$$

$$12\,\frac{\mu g}{L} = 31\,\frac{\mu g}{L} - (t) * 2.99\,\frac{\mu g}{L_{yr}}$$

$t = 6.34$ yr

$$(TP) = (TP_L) + (t)(TP_{LC})$$

$$(TP) = 31\,\frac{\mu g}{L} + 6.34\,yr * 17.2\,\frac{\mu g}{L}$$

$$(TP) = 140\,\frac{\mu g}{L}$$

Glossary

V_L = Volume of Lake
V_{yr} = Volume of Inflow/Outflow Per Year
t = Time in Years

TN_L = Current Total Nitrogen Concentration in Lake
TN_{LC} = Total Nitrogen Concentration in Contaminated Lake
TN_{LT} = Total Nitrogen Concentration in Treated Lake
TN_{IC} = Total Nitrogen Concentration in Contaminated Inflow
TN_{IT} = Total Nitrogen Concentration in Treated Inflow
TN_{OC} = Total Nitrogen Concentration in Outflow
TN_{LG} = Total Nitrogen Lake Concentration Goal

TP_L = Current Total Phosphorus Concentration in Lake
TP_{LC} = Total Phosphorus Concentration in Contaminated Lake
TP_{LT} = Total Phosphorus Concentration in Treated Lake
TP_{IC} = Total Phosphorus Concentration in Contaminated Inflow
TP_{IT} = Total Phosphorus Concentration in Treated Inflow
TP_{OC} = Total Phosphorus Concentration in Outflow
TP_{LG} = Total Phosphorus Lake Concentration Goal

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