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Regional Wastewater Facility Systems Design

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I HEREBY RECOMMEND THAT THE THESIS PREPARED
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ENTITLED

Regional Wastewater Facility Systems Design

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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1. INTRODUCTION

1.1 - Project History

The San José-Santa Clara Regional Wastewater Facility (RWF) was constructed in 1956 as a primary water treatment plant. Secondary treatment facilities were constructed in 1964 in response to a growing population and economy along with state regulations. The RWF expanded to tertiary treatment in 1979 to meet Clean Water Act regulations. A wet weather headworks facility was commissioned in 2008, and in 2011 the gaseous chlorine/sulfur dioxide system for disinfection was converted to a sodium hypochlorite/sodium bisulfate system in 2011 (RWF 2015). The RWF launched a Capital Improvement Program (CIP) in 2014, identifying 33 capital projects. The Facility Wide Water Systems package (package PF-06) in the CIP served as the inspiration of the Regional Wastewater Facility Systems Design project.

Figure 1: Aerial photograph of the Regional Wastewater Facility

Package PF-06 states that the RWF has four water systems in need of rehabilitation and upgrade: 1W (potable water), 2W (groundwater), 3W (process water) and 4W (fire protection water). Due to age, condition, and change in water demands over time, the RWF requested an updated hydraulic model and assessment of current and future water demands for a proper redesign of each system. The Hydraulic Engineering and Design (HEAD) team has decided to redesign the RWF's 1W and 2W systems for this capstone project.

1.2 - Project Need

This infrastructural project originates from a regulatory need to replace or upgrade existing systems to meet growing water demands. Current hydraulic models will soon lose validity as demand for water increases with population, creating the need for systems to be upgraded to a capacity that satisfies future demands. This project will secure RWF systems' distribution reliability, which in turn benefits the public by providing a dependable discharge outlet for wastewater and satisfying the community need for water utilities. Completing this project will also result in fewer machinery/equipment problems during plant operations due to a more appropriate selection of pipe materials.

1.3 - General Description & Site Details

The RWF has a daily wastewater treatment capacity of 167 million gallons per day (MGD) during dry weather flow and 217 MGD during wet weather flow. It treats a daily average of 110 MGD. The 1W system is supplied by the San José Municipal Water System while 2W system is supplied from two wells located at the RWF. The 3W and 4W systems are both supplied from the final effluent of the RWF (RWF, 2015). Table 1 identifies the cities and districts within the RWF service area while Figures 2 and 3 identify them geographically.

Table 1: Cities and Districts Serviced by the RWF

City	District
City of San José	Cupertino Sanitary District
City of Santa Clara	West Valley Sanitation District
City of Milpitas	County Sanitation Districts 2-3
	Burbank Sanitary District

Figure2: Aerial view of Regional Wastewater Facility Tributary Service Area

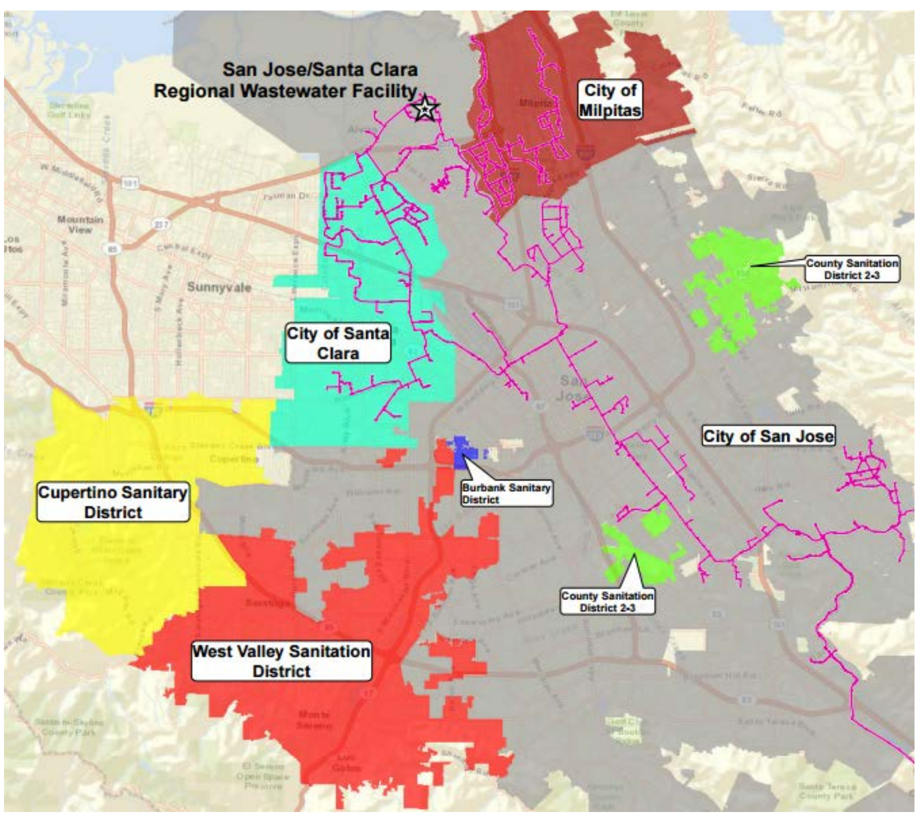


Figure 3: Aerial view of cities and districts under RWF service

1.4 - Project Objective

The project aims to create a flexible and sustainable design of the RWF's 1W and 2W systems that meets dynamic future demands and falls within social, economic and environmental constraints. This thesis includes design criteria and standards, an analysis of alternatives, a description of the redesigned systems, a cost estimate and a life-cycle analysis (LCA). The final product is a proposal of the redesign of the RWF 1W and 2W systems that includes plans, details, specifications, cost estimations, and a LCA.

1.5 - Scope of Work

Table 2 provides the scope of work followed by the HEAD team. Figure 4 provides a visual timeline of the scope of work. Existing conditions of the 1W and 2W systems were determined through direct inspection and research of the age, size and material of each element. Future system limitations were predicted based on information deduced from the condition assessment and engineering judgement. The hydraulic models were built and calibrated using Bentley's WaterGEMS platform and physical system attributes. Modeling was done in conjunction with condition assessments of the existing 1W and 2W systems (shown in Figures 5 and 6), and was followed by building alternative design models, evaluating those models and selecting the optimal alternative for each system using an economic feasibility analysis and a LCA.

Table 2: Scheduled deadlines for Regional Wastewater Facility Systems Design Project

Task Name	Duration	Start	Finish
Condition Assessment of 1W and 2W Systems	46 days	Mon 11/30/15	Sun 1/31/16
Hydraulic Modeling of Existing 1W and 2W Systems	46 days	Mon 12/14/15	Sun 2/14/16
Build Alternative Design Models for Proposed 1W and 2W Systems	31 days	Mon 2/15/16	Mon 3/28/16
Evaluate Design Alternatives for Proposed 1W and 2W Systems	20 days	Tue 3/29/16	Sun 4/24/16
Choose Optimal Designs for 1W and 2W Systems	10 days	Mon 4/25/16	Fri 5/6/16

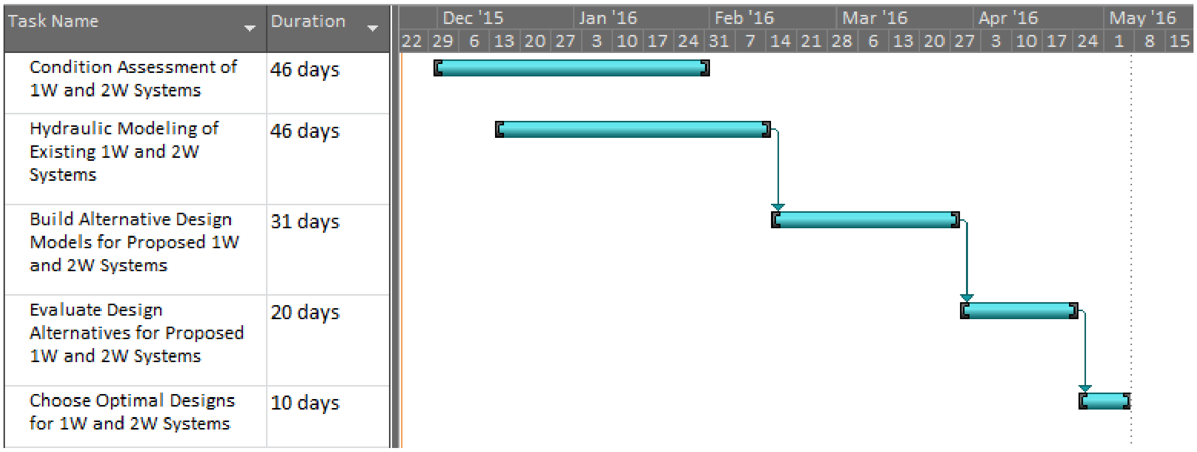


Figure 4: Gantt Chart of Proposed Schedule for Facility Wide Water Systems Project

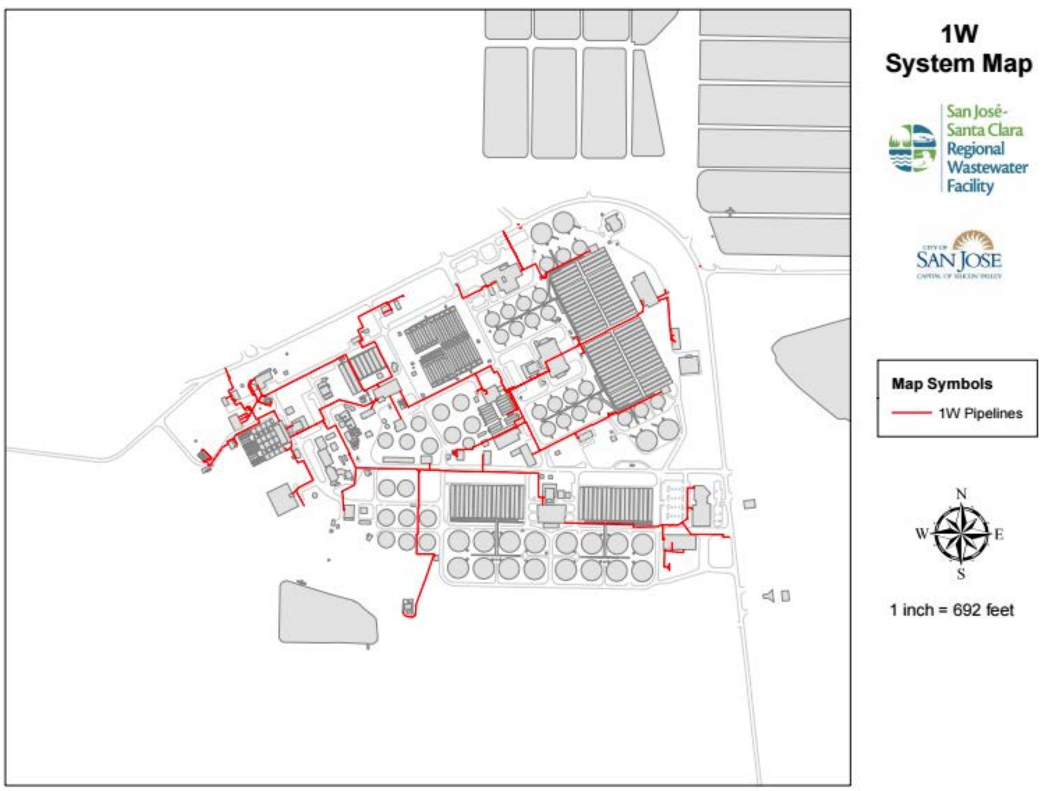


Figure 5: 1W Existing System Aerial Layout

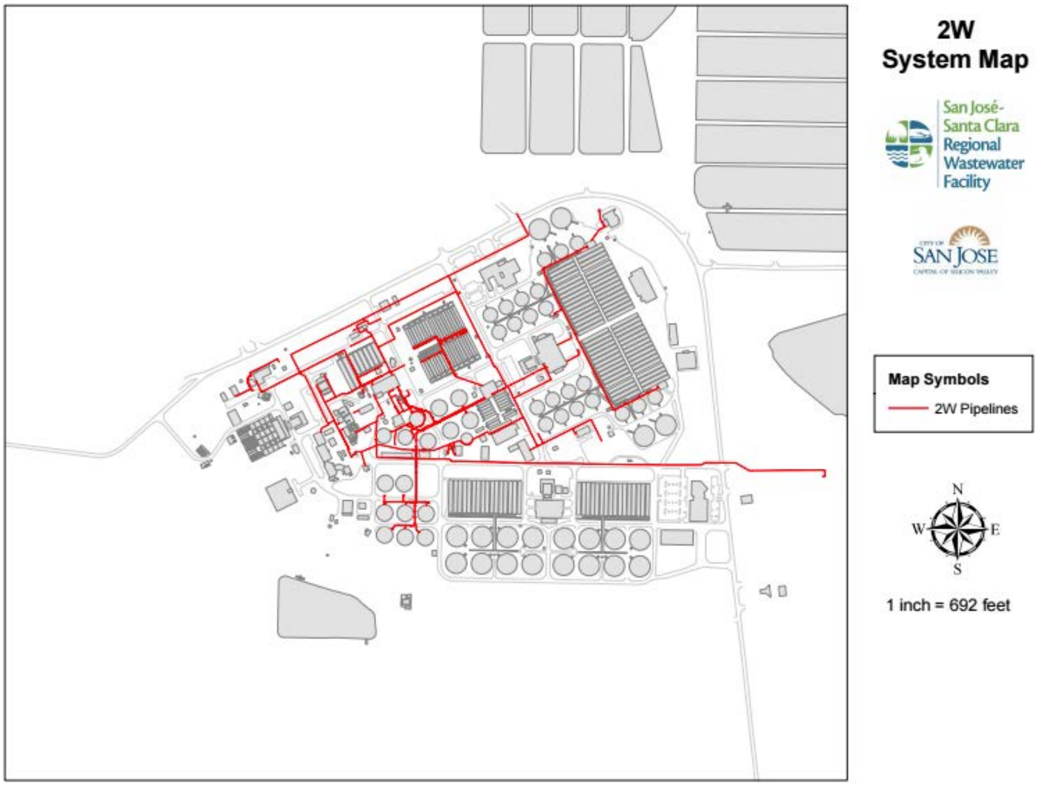


Figure 6: 2W Existing System Aerial Layout

2. DESIGN CRITERIA & STANDARDS

2.1 - Ideal Velocity and Operating Pressure Range

The redesign of both the 1W and 2W systems required operation within an acceptable range of pressures and distribution velocities. Typical government standards for minimum pressure in a water system design are 20 psi (138 kPa) at ground level across the whole distribution system, and between 35 psi (241 kPa) and 60 psi (414 kPa) for operating pressures (GLUMB 1992). The criteria for the permissible velocity in a water distribution network was established based on research performed by Walski (1983), who showed that the optimal velocity range should be between 3 to 10 ft/s. It should be noted that because velocity is an indirect limiting factor for pipe redesign, it was only considered as a design parameter used to verify the validity of proposed design alternatives, not for determining the solution to a design alternative.

2.2 - Applicable Codes and Standards

Designing was done within the legal confines laid out in the RWF's Request for Qualifications, Master Consultant Agreement and other guidance criterion. Applicable code sections include the Political Reform Act (Government Code Section 81000), title violation policy (Government Code Section 83116), indemnity (California Civil Code Section 2778), non-discrimination requirements for contracts (San Jose Municipal Code Section 4.08.020), prohibition of gifts (San Jose Municipal Code Section 12.08), the San Jose City Environmentally Preferable Procurement Policy, and water main installation and separation standards (Title 22 California Code of Regulations, Chapter 16, Sections 64630 & 64572). Earthwork calculations as a result of design abided by the City of San Jose Standard Specifications Section 1301 - Trench Excavation, Bedding and Backfill. Section 1303-3.2 requires a 12-inch minimum cover and at least a 4-inch lateral clearance between the pipe and trench walls for the pipe sizes used in the design. Figure D.2 of Appendix D shows a code-compliant trench cross-section. All directly and indirectly applicable standards and limitations can be accessed in Appendix C.

2.3 - Design Approach

The design approach used for the redesign of the RWF's 1W and 2W systems is summarized in Figure 7. Once the models of the existing systems were created and calibrated to standard, models of the systems running under a variety of conditions (average demands, peak demands, 24-hour simulations) were analyzed in order to check for problems, such as, low velocity and inadequate pressures. If pipes in the system were not functioning to the design criteria, they became candidates for resizing. The diameters of these pipes were then adjusted until the models of the systems were operating to acceptable standards. Once a redesign had been found that met the desired design criteria, a cost estimate was created for the redesign so that a lowest-cost alternative could be determined.

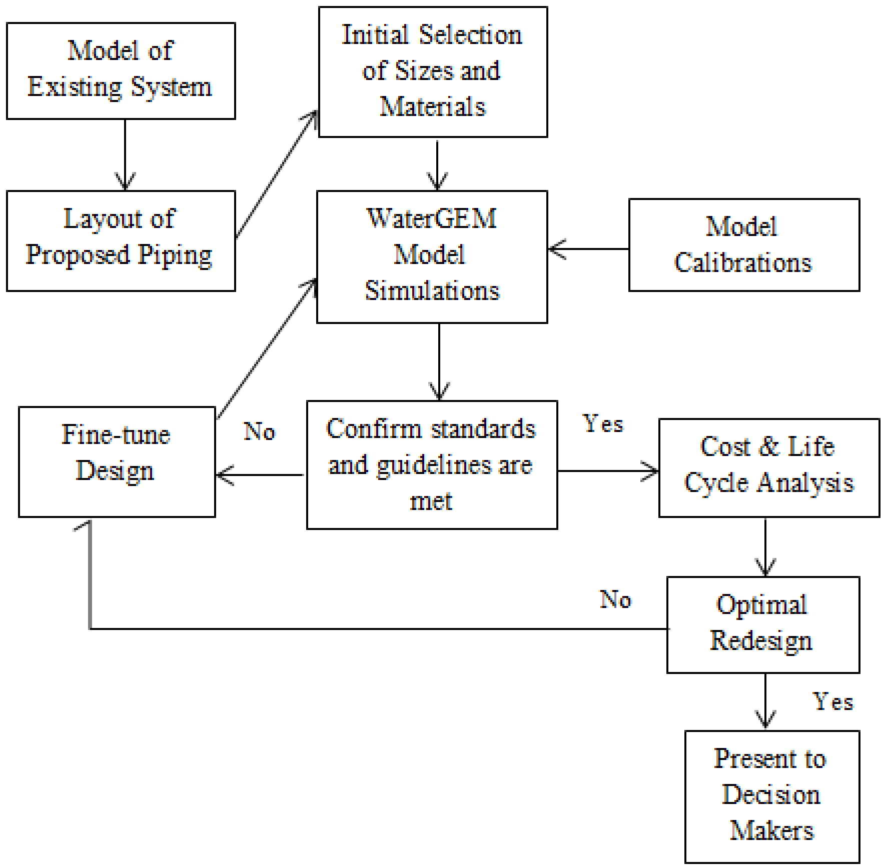


Figure 7: Flow Chart of the key steps within the project

2.4 - Design Assumptions

Not all of the information required for building an existing model was obtained in the condition assessment phase: Figures 8 and 9 show the pipes with no record of installation date. Various pipes had no record of size, age or material. Unspecified pipe attributes such as material, pipe diameter, and installation year had to be interpolated based on the assumptions from known characteristics and functions of existing pipes within the vicinity of the pipe with unidentified attributes.

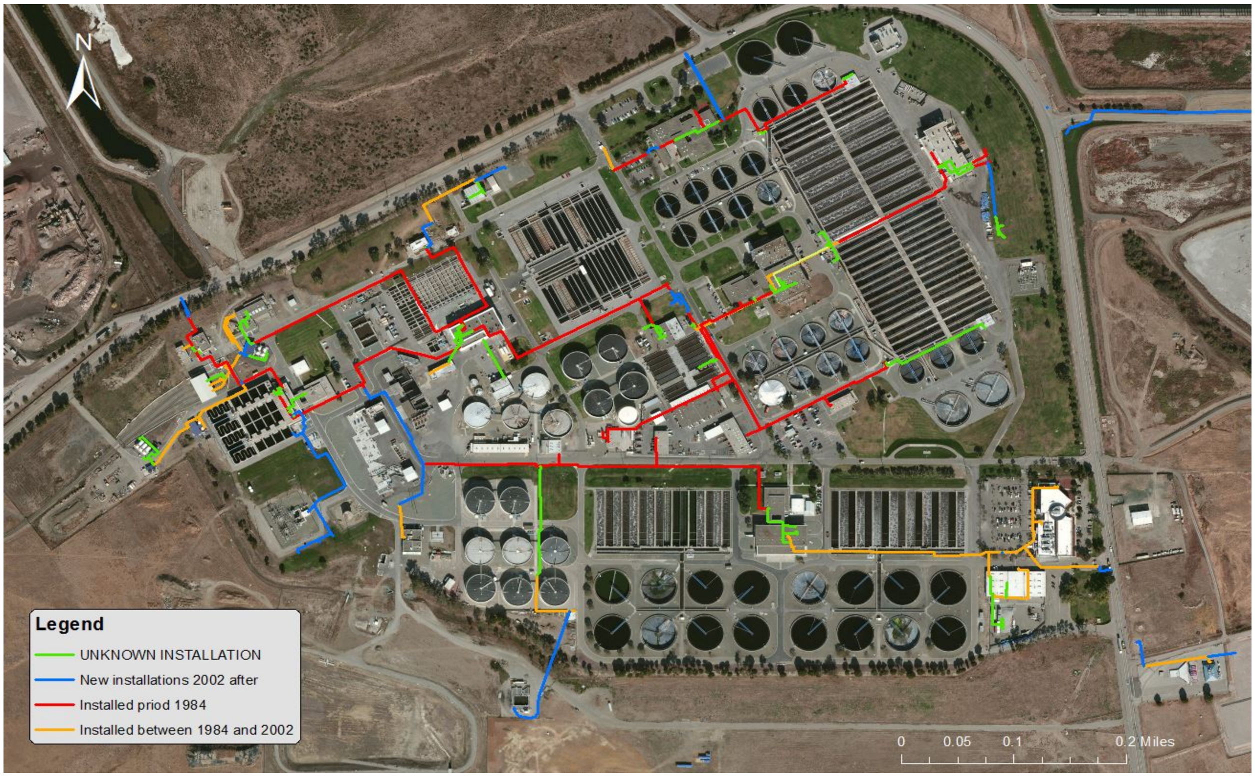


Figure 8: 1W ArcMap projection of pipe age color-coded by year of pipe installation

Figure 9: 2W ArcMap projection of pipe age color-coded by year of pipe installation

Hourly flow data for the 2W system was missing, which led to an extrapolation of hourly flow using hourly pressure data. The graphs that contain pressure calibration data can be referenced from Appendix A in figures A.1-A.6.

Without elevation data of the existing systems, the excavation area for the proposed designs and earthwork calculations was assumed to be a depth of 12-inches above the pipe with a 4-inch bottom clearance and a 5-inch lateral clearance on each side of the pipe. Assumptions also had to be made for pipe roughness during model calibration.

Once the representative models for both water distribution systems were created and calibrated, the models were skeletonized to remove pipes that had insignificant results on the models' hourly behavior, as shown in Figures 10 and 11. The results of the skeletonized models were compared to that of the un-skeletonized models in order to assess the validity of the skeletonization. Skeletonization of both models was implemented in order to simplify the managing, using, and troubleshooting of the models. Since the redesign process for both systems focused on important pipes (e.g. points of known conditions, large diameter pipes, and loop competing pipes), skeletonization of the models ensured the redesign systems focused exclusively on the main pipes vital to the functional integrity of the system (Eggener 1976).

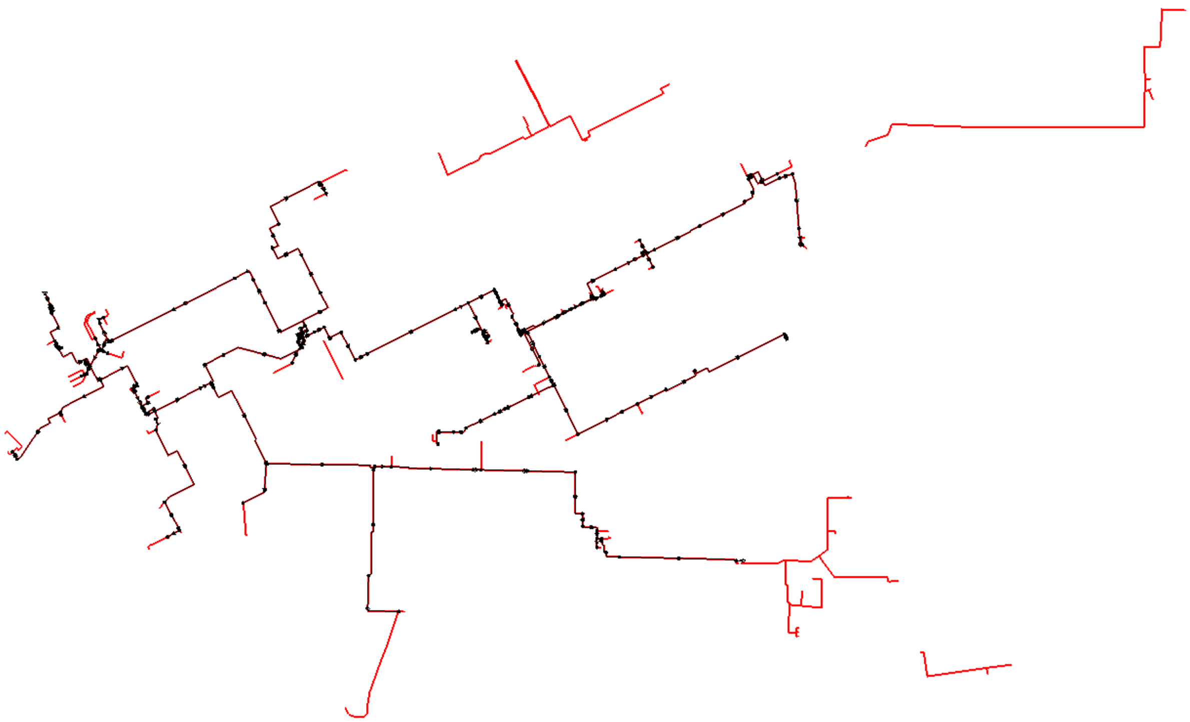


Figure 10: Skeletonization of the 1W system; pipes that have been skeletonized shown in red.

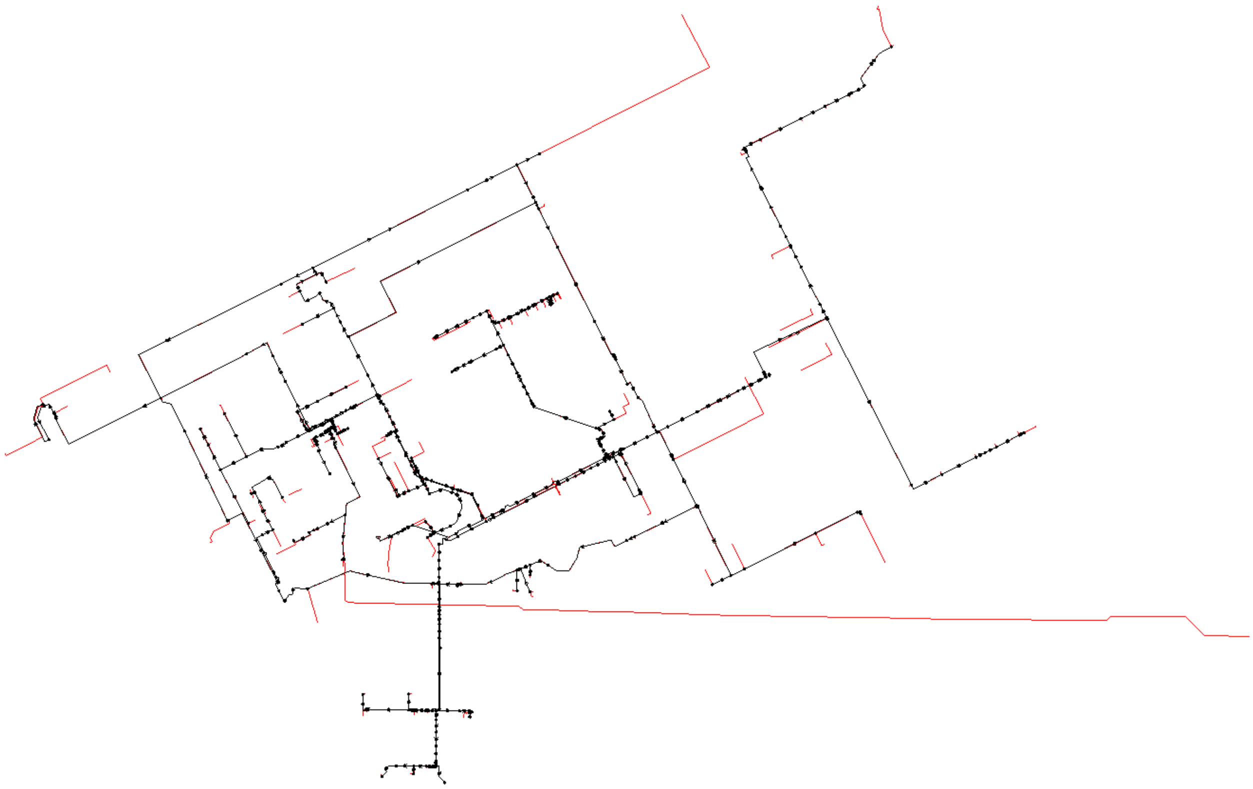


Figure 11: Skeletonization of the 2W system; pipes that have been skeletonized shown in red.

3. ANALYSIS OF ALTERNATIVES

3.1 - Description of Design Alternatives

The WaterGEMS software tool, Darwin Designer, was utilized to run five hundred thousand extended period simulations for each of the four proposed alternatives. Through the simulations, the project team selected the four redesigns (two alternatives for each system) that were deemed the most appropriate final alternatives for the 1W and 2W systems. Both distribution system redesigns were proposed to be either an all Polyvinyl Chloride (PVC) pipe system or a PVC and steel pipe composite system. PVC and steel were chosen as the ideal materials for four reasons: cost efficiency (as listed in RSMeans catalog of construction costs), light weight (steel piping only used for smaller sized diameters), performance longevity, and simplified installation. The redesigns for the 1W system included a connection to the Environmental Services Building to serve as an alternate path in the case of a failure in the main line. A detail of a typical pipe connection is shown in Figure D.1 of Appendix D.1. The redesigns for the 2W system included a proposed looped path for alternate travel in the case of main line failure. These four alternative solutions were analyzed for economic feasibility and environmental impact.

3.2 - Feasibility of System Construction

Incorporating either all PVC or PVC and steel redesigns allow each system to be constructed using materials that are widely available, and keep some uniformity across each system. PVC and steel piping are commonly used pipe materials, especially in small water distribution systems such as this. Also the RWF has installed predominantly PVC and steel piping over recent years. To accommodate this trend, the design team decided that PVC and steel would be the sole material types used in analysis for both redesigns.

4. COST ESTIMATION

4.1 - Opinion of Probable Cost

When estimating the total cost of construction for each alternative redesign, all direct costs associated with the construction of each system were taken into account. A standard breakdown of material costs, installation/labor costs, and earthwork costs was used for quantity take-offs and estimation. These factors encapsulate all significant costs the RWF would incur by implementing the proposed redesigns.

4.2 - Cost Indexing Assumptions

In the original CIP package description laid out by the RWF, the entire project's estimated cost was 12.6 million dollars (Kvasnicka 2014). This lump sum reflected costs for the redesign of all four water distribution systems including 3W (Process) and 4W (Fire). A more detailed cost estimation breakdown estimated the redesigns of both 1W and 2W systems at 1 million dollars each. The design team decided to use this initial estimation as a representative budget to stay within.

Majority of the unit prices used in the economic analysis came from the RSMeans 2016 Building Construction Cost Data Book (The Guardian Group 2016) including pipe costs, earthwork costs, and labor rates. RSMeans publishes prices based on a national average, to account for regional differences; location factors for the San Jose area were applied to materials and installation rates. With the inclusion of the location factor, and conversion of older prices into present value dollars, the prices were assumed to be close to market value for a contractor in the San Jose Area.

Pipe costs were in dollars per linear foot of piping based on size and material. With certain pipe diameters being excluded in the RSMeans cost data manual, the missing values were assumed through a linear interpolation of documented prices. It should be noted that the linear regression used for interpolation accounted for 98% of the variation shown in the existing prices. The same process was used for determining the labor and equipment costs, as well as trenching and backfill costs, which were also provided in dollars per linear foot. Both linear regressions accounted for at least 99% of the variation shown in the existing prices.

Pricing for isolation valves were not provided in the RSMeans manual. Publically published prices from a manufacturing company of AWWA C515 Gate Valves were used in estimation. Certain pipe size diameters were excluded in documentation by the manufacturers, so a polynomial interpolation of missing diameter pricing was used to determine the unit costs for all isolation valves.

4.3 - Labor and Equipment Cost Calculations

The RSMeans construction data manual was utilized to determine a pricing index for labor and equipment costs in terms of cost per linear foot. Based on whether the material was PVC or steel and the sizing of the pipes, the prices varied between $10.50~$27.20 of labor and equipment cost per linear foot for all four redesigns. RSMeans calculates installation costs according to the crew required to install the materials in question. According to RSMeans the installation of all pipes could be accomplished with a two man crew, on plumber and one plumber-apprentice. Note that this crew is only for installation and does not take into account the crew required for excavation and backfill. Locations factors were also taken into consideration by applying the San Jose regional material location factor of 1.039 and installation location factor of 1.369 (The Guardian Group 2016).

4.4 - Variation in Material Costs

The material cost criteria had the largest variation, at 29~36%, in terms of the proportion of total costs. This relatively large variation was a direct result of the pipe materials and diameters selected for each alternative. For the 1W system, the PVC & Steel upgrade required $186,480 which was less than the material cost for the $210,763 all PVC upgrade because the system performance requirements allowed for implementation of smaller sized steel pipes (between 0.5~4 inch diameters), while the all PVC upgrade required larger pipe diameters (up to 6 inches) to satisfy the same performance requirements. For the 2W system, the $311,547 PVC & Steel material cost was higher than the $295,343 all PVC material cost and this was because a higher quantity of steel pipes with relatively larger diameters were implemented to meet the higher demand patterns for the 2W system in general.

4.5 - Total Cost of Design Alternatives

The cost associated with each alternative was broken down into three components: material cost, labor and equipment cost, and earthwork cost. The total cost of each alternative, as shown in Figure 12, is $723,172 for 1W All PVC, $675,101 for 1W PVC & Steel, $887,362 for 2W All PVC, and $864,300 for 2W PVC & Steel. As shown in Figure 13, approximately 52~58% of the total investment for each alternatives went into labor and equipment cost, whereas earthwork cost accounted for a less substantial 12~14% of the total costs. An example of a cost calculation can be accessed in Table A.1 in Appendix A.

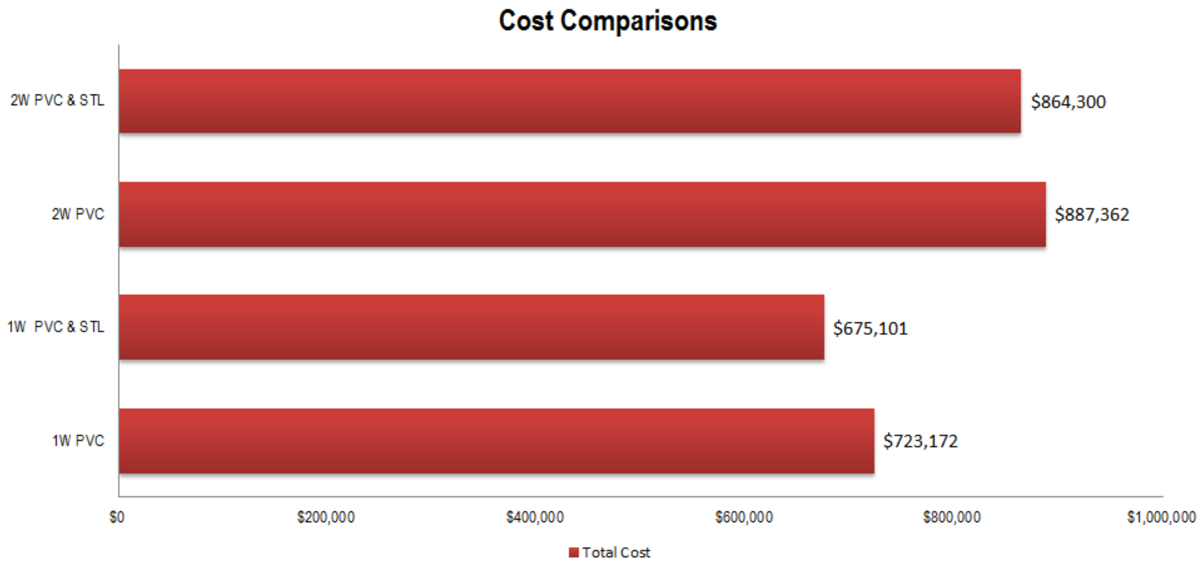


Figure 12: Total cost breakdown of design alternatives

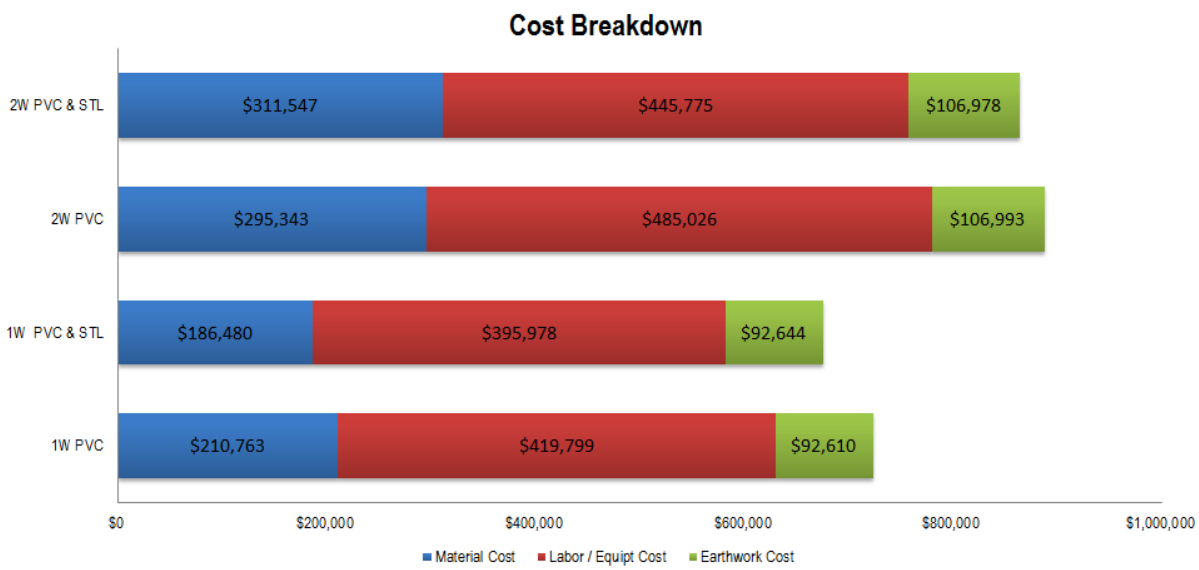


Figure 13: Cost breakdown of alternatives separated by material, installation, and earthwork costs.

4.6 - Earthwork Cost Calculations

Trenching and backfill costs for all four redesigns were calculated using the RSMeans construction data manual. Appropriate trenching and backfill volumes were determined according to pipe diameters and the minimum cover depth required according to the City of San Jose's design specifications. Installation costs for trenching and backfill were determined according to the crew specified by RSMeans required to accomplish the task. For both the trenching and backfill processes this amounted to one equipment operator, one laborer, and the associated equipment required for earthwork (The Guardian Group 2016).

5. LIFE CYCLE ANALYSIS OF DESIGN ALTERNATIVES

5.1 - Scope of Life Cycle Analysis

The LCA for each distribution system analyzed the embodied carbon associated with the different phases constructing the proposed system would go through. The phases were broken down as follows: 1) Production 2) Transportation 3) Installation. Normally a fourth phase of "Useful Life" would be included (Du 2013). However, due to lack of documentation on pipe characteristics, the team decided to exclude this step from analysis. It was decided that accuracy with a less inclusive scope was preferred over inaccuracy with a greater scope. It should be noted that each redesign operated under the same parameters. Thus, the likelihood of possessing a similar carbon footprint during the useful life of each system is high. Since the redesigns are only being compared to each other, a small difference in embodied carbon relative to the preceding phases can be thought of as negligible.

Figure 14 shows the contribution as a percentage from each phase of the total embodied carbon for each redesign. As shown in the graph, production of materials was the most carbon intensive process contributing about 94%-95% of the embodied carbon in each system alternative. Transportation had an extremely low contribution to the total embodied carbon due to the fact that the water distribution systems are very lightweight (pipe diameters from 0.5 - 12 in) and the short distance needed to transport the materials from the contractor's manufacturer (about 10 miles round trip).

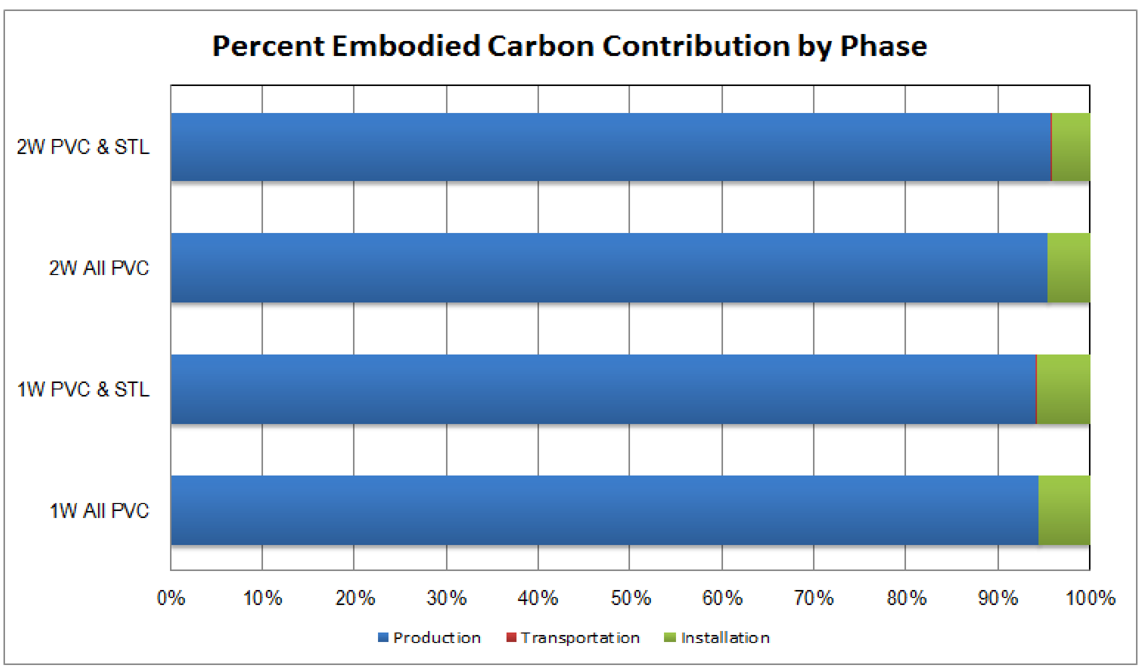


Figure 14: Embodied carbon contribution by LCA phase

5.2 - LCA Step 1: Production

When comparing the embodied energy (EE) related to the redesigns of each system (shown in Figure 15), the weight of all piping was found for each redesign based off of the pipe length, size (diameter), and material. Each pipe weight ("PVC and CPVC Pipes" n.d.) was then multiplied by an EE factor accounting for size and material. It should be noted that the EE factor for PVC was based off of size and material while the EE factor for steel was a function of material only (Hendrickson 2014). The EE factors were provided in MJ/kg, which was then converted to Mega joules and summed up for each redesign. Similarly, when calculating the embodied carbon associated with the material manufacturing, an embodied carbon factor was applied to the pipe weight. This factor was a function of material only, and thus could be applied to the total weight of each redesign (Hammond 2008). Kilograms of Carbon dioxide were summed up and compared between redesigns (shown in Figure 16). For both systems, the all PVC redesigns had higher embodied energy totals when compared to the PVC and steel systems. When comparing the embodied carbon of each redesign, the all PVC redesign for the 1W system had a greater amount of embodied carbon than the composite counterpart, however for the 2W system, the PVC and steel redesign was calculated to have a greater embodied carbon content than the all PVC redesign. This was due to the PVC and steel being about 60% heavier with a significant amount of steel being required. The 1W composite system had less steel compared to the 2W system, which drove the total weight of the system down enough to produce less CO_2 than the all PVC redesign. An example of an EE calculation is shown in Table A.2 of Appendix A.

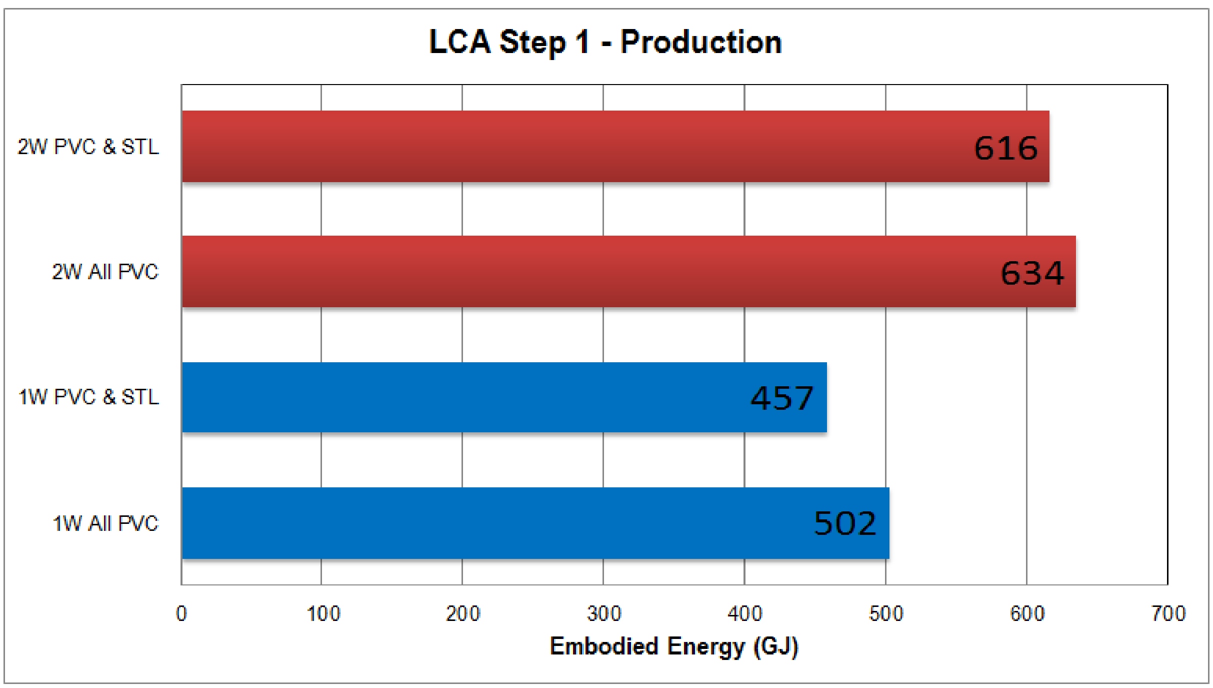


Figure 15: Embodied energy from production results for design alternatives

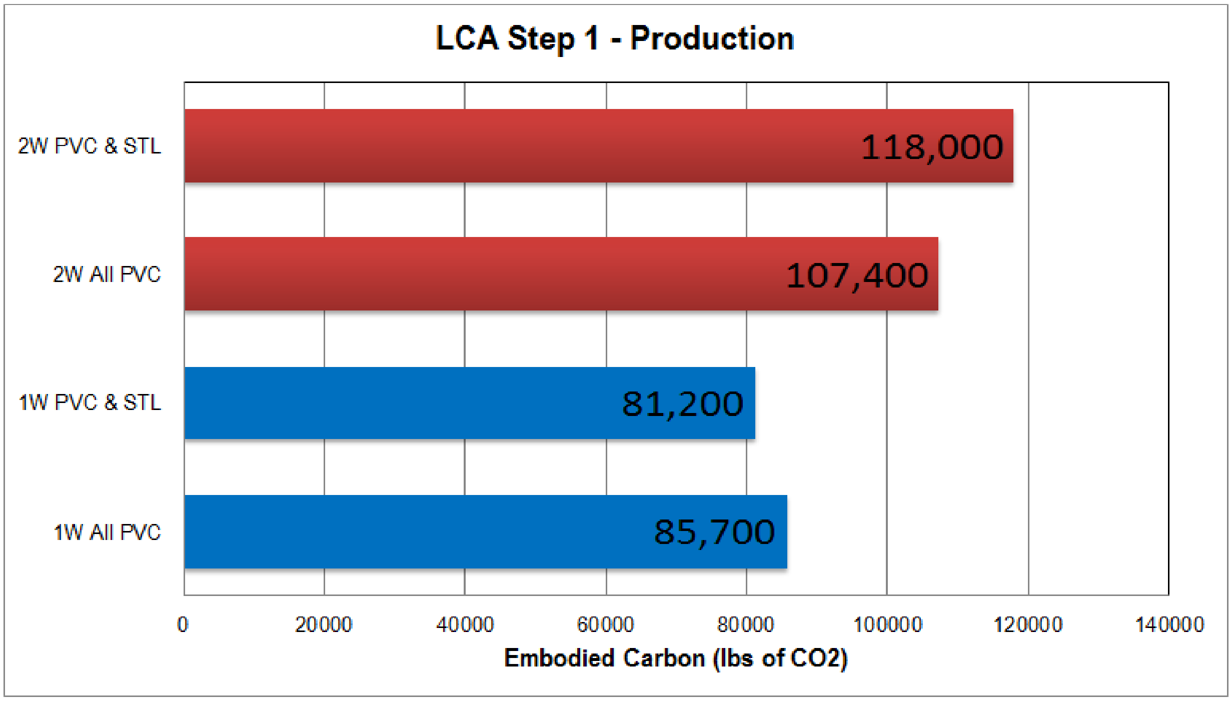


Figure 16: Embodied carbon from production results for design alternatives

5.3 - LCA Step 2: Transportation

Transportation emissions from the vehicles used in delivering the materials was a function of distance and number of vehicles needed to transport the entire system. The CO_2 conversion factor used in calculation was found in an online Environmental Protection Agency (EPA) database, and specified to use units of kg of CO_2/vehicle-mile (EPA 2015). By taking the number of vehicles used in transportation and multiplying the distance in miles each vehicle would have to travel, a lump sum value can be applied to this conversion factor to determine the amount of carbon that would be emitted during this process. To estimate the number of vehicles required for transportation, the loading capacity of a Class 7 (medium-heavy duty) truck was used for calculation (DOE 2010). This classification seemed most appropriate given the lightweight and small size of the pipe systems. In order to find the minimum number of vehicles needed, the total weight of each redesign (found in the production phase) was divided by the loading capacity of the truck based on its vehicle specifications and California vehicle weight regulations (DOT 2016). Any decimal result was rounded up to a whole integer. The distance of transportation was determined by mapping a logical route from the contractor's manufacturing site to the RWF. This was found to be a little less than 5 miles one way, 10 miles round trip which was the number used for calculation. As shown in Figure 17, the redesigns for the 1W system possessed the same embodied carbon content due to the equal number of vehicles required to transport the entire weight of each system. While distance and carbon factors remained constant, the number of vehicles was the sole driver of embodied carbon. For the 2W system, the composite redesign having significantly more weight required one more truck to fully transport the pipes. An example of a transportation embodied carbon calculation is shown in Table A.3 of Appendix A.

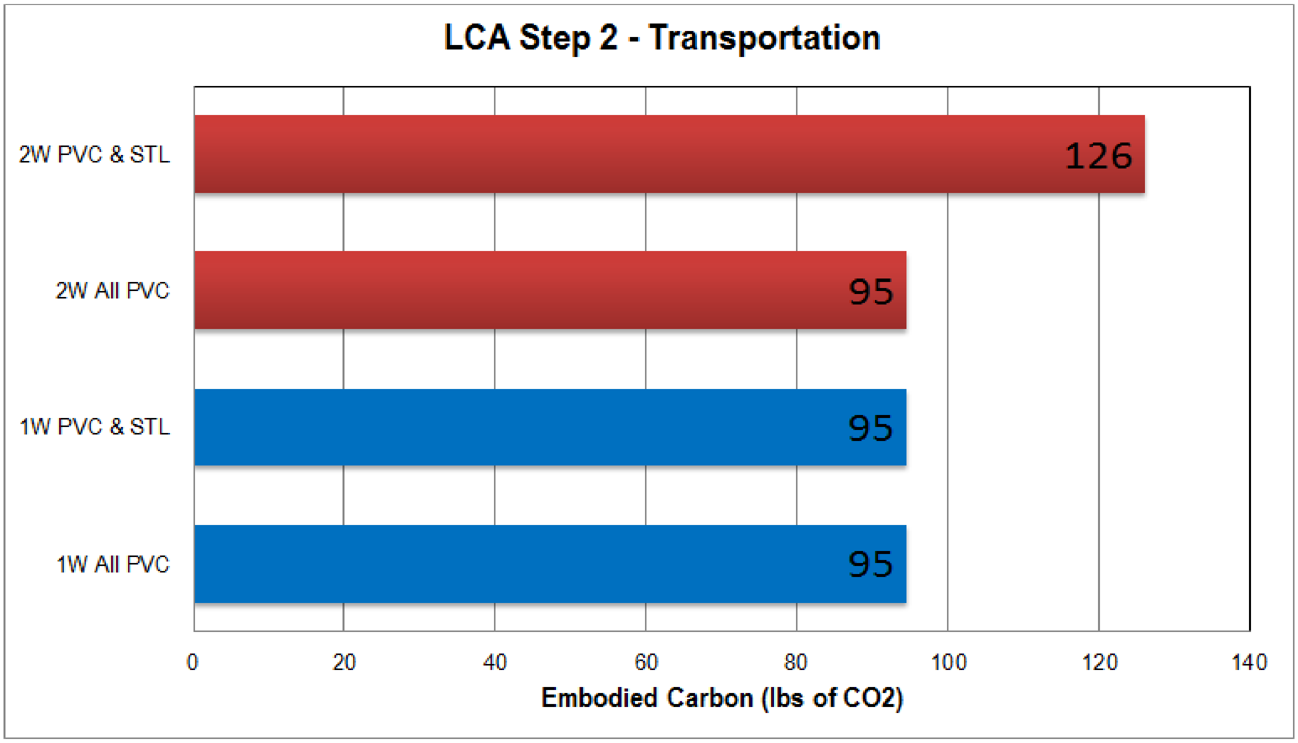


Figure 17: Embodied carbon from transportation results for design alternatives

5.4 - LCA Step 3: Installation

The embodied carbon associated with installing each redesign involved looking at emission rates for excavation and backfilling. This required assuming a specific excavator model to draw data from. The Holt Cat 304 CR series model (Holt Cat 2011) was decided to be appropriate for the trench dimensions needed for the piping. By analyzing the excavator's excavation rate (Super User 2012) with the amount of trenching required, a total trenching time was found. Paired with the vehicle's specific fuel consumption rate (Holt Cat 2011) and carbon emission rate (EPA 2005), a total carbon emission value was produced. The earthwork involved with excavation and backfill were the sole components analyzed for the installation phase. The replacement of existing pipes was assumed to be done in parallel with the new pipes. Thus, all processes were consolidated into one excavation and backfill rate. As shown in Figure 18, the all PVC redesigns for both systems were determined to produce more carbon during installation. This was largely due to the piping in the all PVC redesigns requiring larger diameter pipes which require larger trenches, eventually leading to more fuel being consumed and CO_2 emissions produced. An example of an installation embodied carbon calculation is shown in Table A.4 of Appendix A.

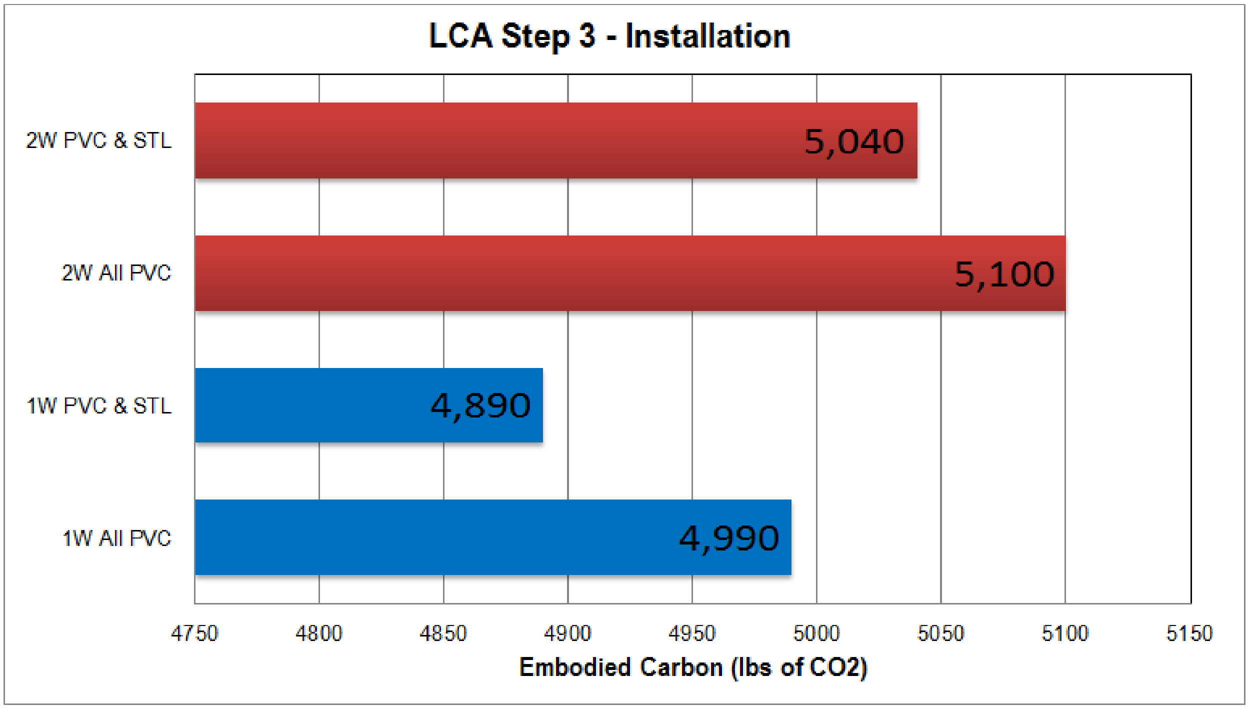


Figure 18: Embodied carbon from installation results for design alternatives

6. DESIGN ALTERNATIVE SELECTIONS

6.1 - Comparison of Design Alternatives

The best redesigns for each respective water distribution system were chosen using a decision matrix (Table 3) that weighed the impact each alternative would have in five specific categories including the three steps involved in the life cycle analysis (production CO_2 emissions/ embodied energy, transportation CO_2 emissions, installation CO_2 emissions), and the overall cost of each alternative. With the 1W potable water system, the proposed 1W PVC & steel redesign had advantages in four of the five categories. It had less carbon emissions and embodied energy from production, less carbon emissions from installation, and was more cost efficient overall, whereas the proposed 1W all PVC redesign had no distinct advantages other than a draw in the transportation CO_2 emissions category. With the 2W groundwater system, the proposed 2W PVC & steel redesign had less carbon emissions from production and installation, and also the lower cost, whereas the proposed 2W all PVC redesign had less production embodied energy and less transportation carbon emissions category. With the five decision categories taken into account for comparison between all four redesigns, the PVC & steel alternatives ruled out to be the better option for both the 1W and 2W distribution systems. It is for these reasons that the PVC & steel option was the best solution for both the 1W and 2W distribution systems. The quantities of piping and isolation valves in each alternative are shown in Appendix B.

Table 3: Decision Matrix

Alternatives	1W all PVC	1W PVC & STL	2W all PVC	2W PVC & STL
Production CO_2		X		X
Production EE		X	X	
Transportation CO_2	X	X	X	
Installation CO_2		X		X
Cost		X		X
Decision		X		X

6.2 - Improved Velocity

Model results of the redesigned 1W system composed of PVC and steel showed an improvement to average velocity of 54% (from 0.37 ft/s to 0.69 ft/s) across the entire system at peak operating hours. Results for the redesigned 2W system show an average improvement of 57% (from 0.36 ft/s to 0.63 ft/s) to velocity at peak operation hours. Improvements to the average velocity of both systems should result in reduced probability of material build up occurring within pipes, which leads to periodic spikes in water turbidity and coliform bacteria growth (RWF 2015). Also reduction in material build up within pipes will result in prolonged useful life for the redesigned systems. Relative velocity differences between the existing and proposed 1W system are shown in Figures 19 and 20, respectively. Relative velocity differences between the existing and proposed 2W system are shown in Figures 21 and 22, respectively.

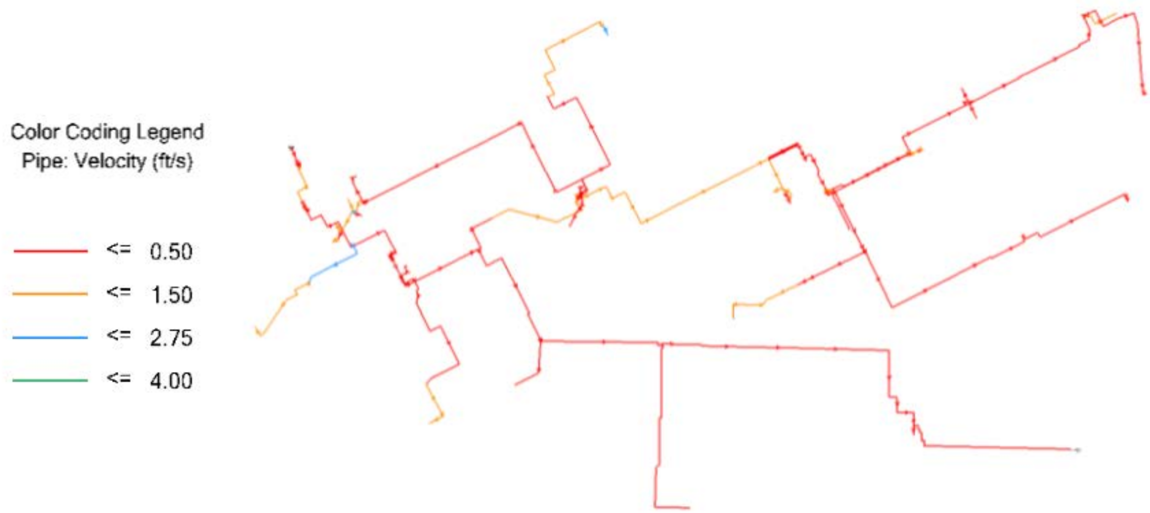


Figure 19: 1W existing velocities during peak operating hours

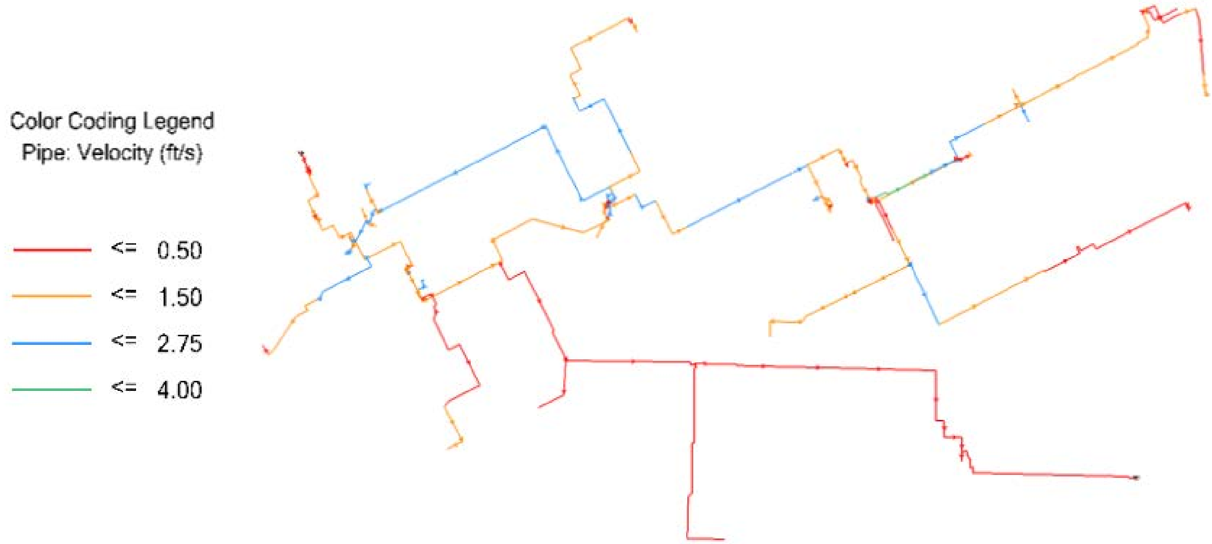


Figure 20: 1W PVC and steel velocities during peak operating hours

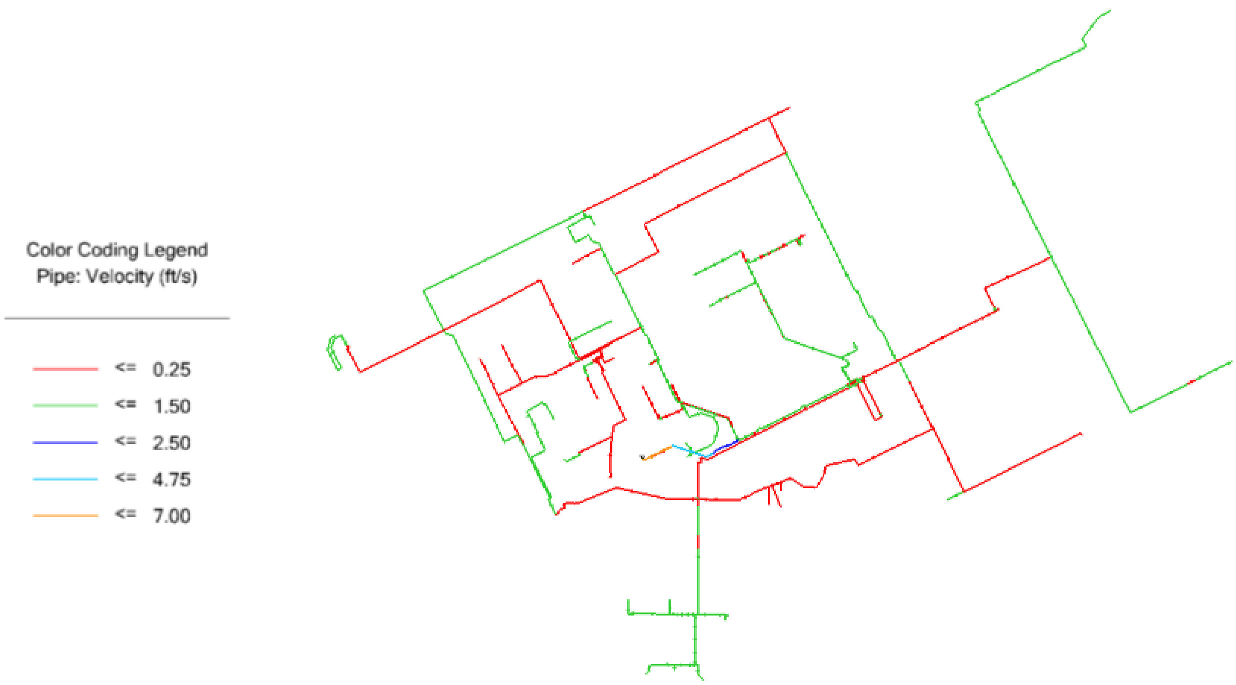


Figure 21: 2W existing velocity during peak operating hours

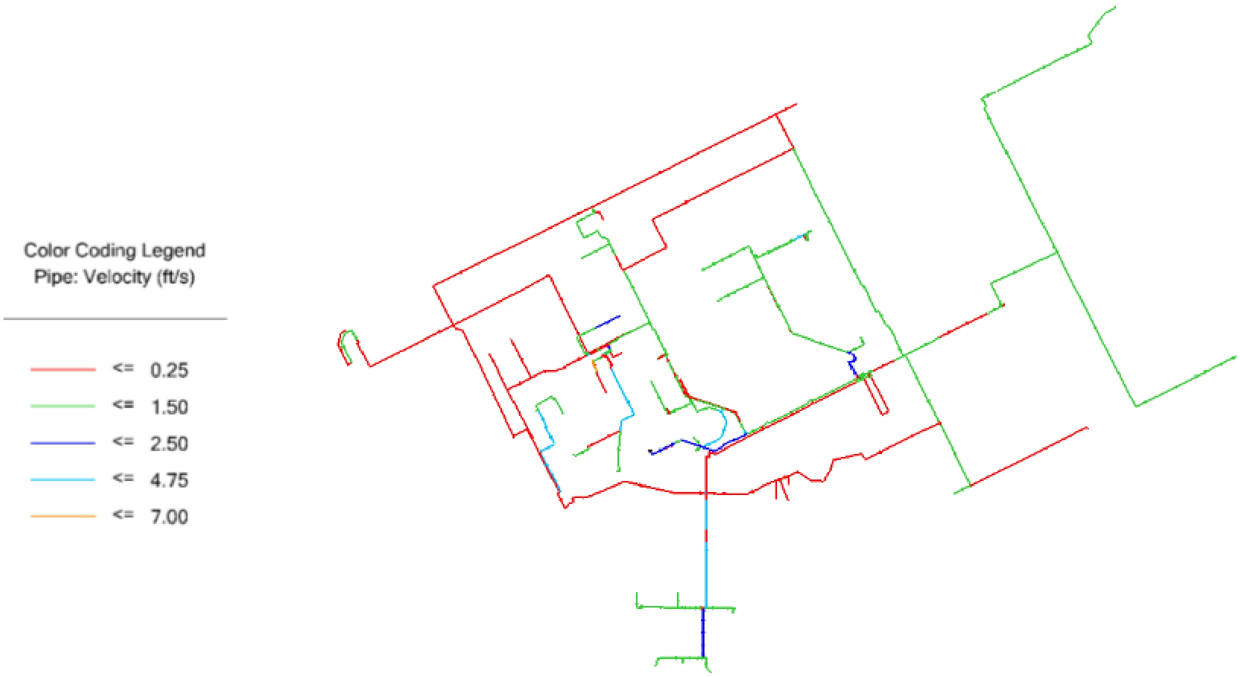


Figure 22: 2W PVC & steel velocity during peak operating hours

6.3 - Consistent Operating Pressures

Increasing the velocities of each system may result in a drop in operating pressures. Each redesign was tested and confirmed through extended period simulation modeling that all pipes are within ideal operating pressures while maintaining an increased average velocity throughout the system. Pressure readings of the redesigned 1W and 2W systems can be viewed in Figures 23 and 24, respectively. Note the minimum pressures of the 1W and 2W systems are 58 psi and 55 psi, respectively.

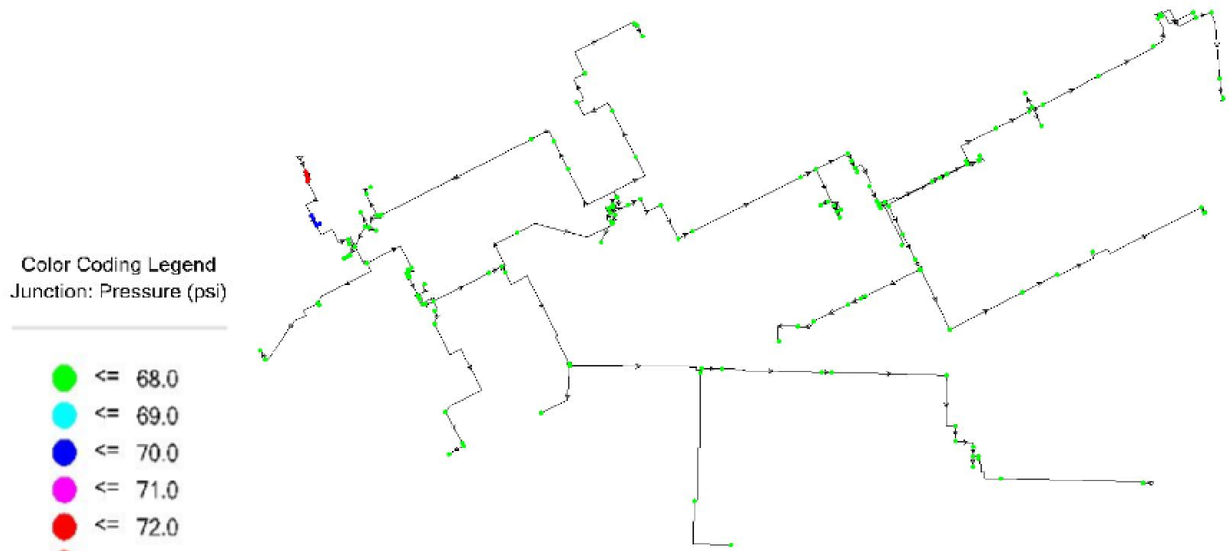


Figure 23: 1W PVC and steel pressure readings during peak operating hours

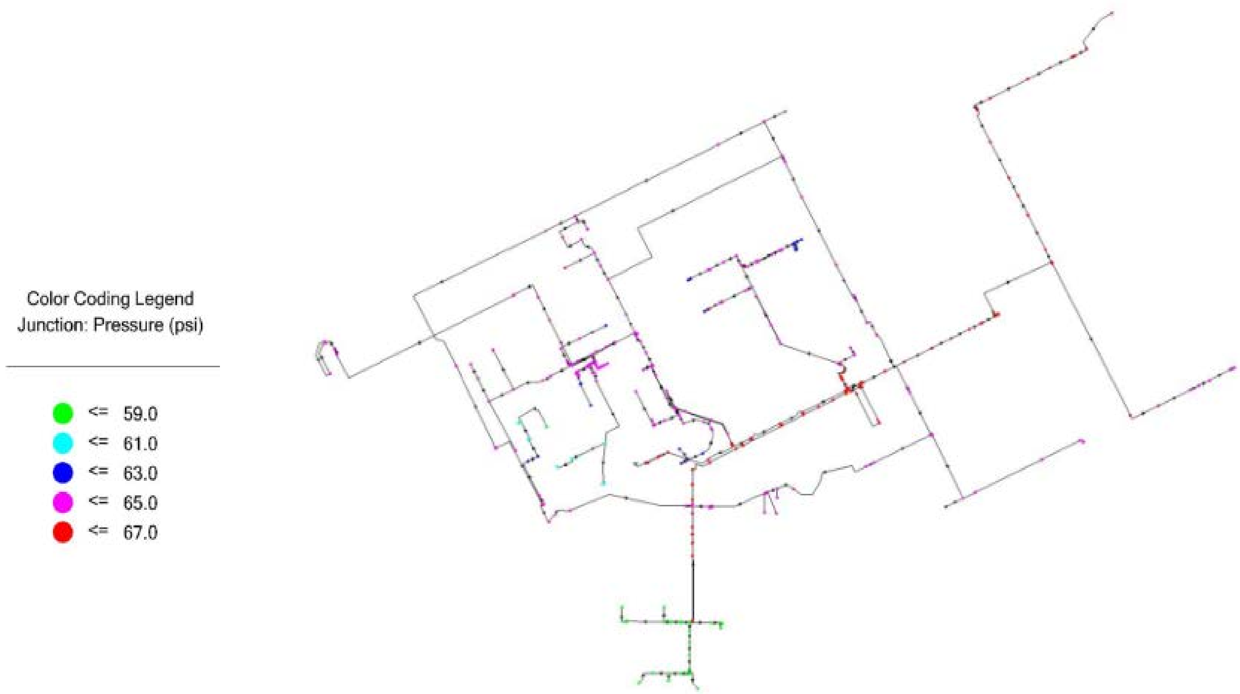


Figure 24: 2W PVC & steel pressure readings during peak operating hours

6.4 - Improved Pipe Material Selection

The buildup of material under low flow conditions was addressed through increasing (and thus improving) average velocities in each system and by selecting materials which will perform over a longer period of time while having a high Hazen-Williams friction coefficient. PVC and steel piping have Hazen Williams coefficient values of approximately 140 and 120, respectively.

7. DESCRIPTION OF DESIGNED FACILITY

7.1 - Looped System Design

There was a conscious effort to implement a looped systems design for both the 1W and 2W distribution systems (shown in Figures 25 and 26). In order to facilitate this effort, certain pipe diameters were increased to match surrounding pipe diameters for emergency functional needs in the case that primary distribution failure would require pipes that are not normally used for emergency purposes to be able to accommodate those needs.

Figure 25: ArcMap rendition of the redesigned 1W system

Figure 26: ArcMap rendition of the 2W system with color coding depicting looped pattern

7.2 - Life Cycle Analysis (LCA)

In an attempt to provide an optimal redesign which encompassed a broader range of concerns than standard economics, both alternatives incorporated the LCA along with the cost estimate to quantitatively present a solution which encapsulated both economic and environmental interests. With a growing emphasis on environmental sustainability taking root in the design and construction industries, both proposed alternative systems were determined to not only be the more cost efficient alternatives, but also produced the smallest carbon footprints. Carbon emissions are one of the main contributors to global warming and climate change; as such the team decided this would be the most appropriate unit of measurement to quantify environmental impact.

7.3 - Site-specific Problems - Troubleshooting & Solutions

Upon receiving all pipe documentation for the 1W and 2W systems from the RWF, there was a significant amount of piping which did not include certain attributes such as material type and year of installation. To account for the missing pipe attributes in the WaterGEMS model, assumptions for pipe material and installation years had to be made. These were determined by analyzing the element (pipe segment) in question and assigning pipe attributes which were consistent with the surrounding/connecting elements. Each pipe that had missing data was looked at individually, with elements that possessed the most existing data to base an assumption on first. By consecutively assigning attributes to the more obvious pipe segments followed by the least obvious ones, the model was built in an incremental, logical fashion.

7.4 - Pressure Readings & Calibration

Another piece of missing information that was needed for the model was hourly flow data for the 2w system, instead only a monthly flow was provided. Without hourly flows, the model of the 2W system could not be calibrated to behave like the actual system. To generate hourly flow data, a baseline (average) hourly flow was calculated from the monthly flow, which then needed a demand pattern to be applied to accurately mimic the existing systems. Pressure gauges were placed throughout each system (shown in Figure 27) which produced hourly pressure data to be used in determining the demand pattern. The pressure readings were graphed over a 24 hour time span, and the inverse of this graph was taken as the flow pattern of the system (since pressure and velocity are inversely related). The friction factors for certain sections of piping in the model were adjusted so that the baseline flow would mimic the behavior of the measured flow pattern for a 24 hour time interval. After calibrating the model, the demand pattern established came within a 10% deviation from the observed demand pattern.

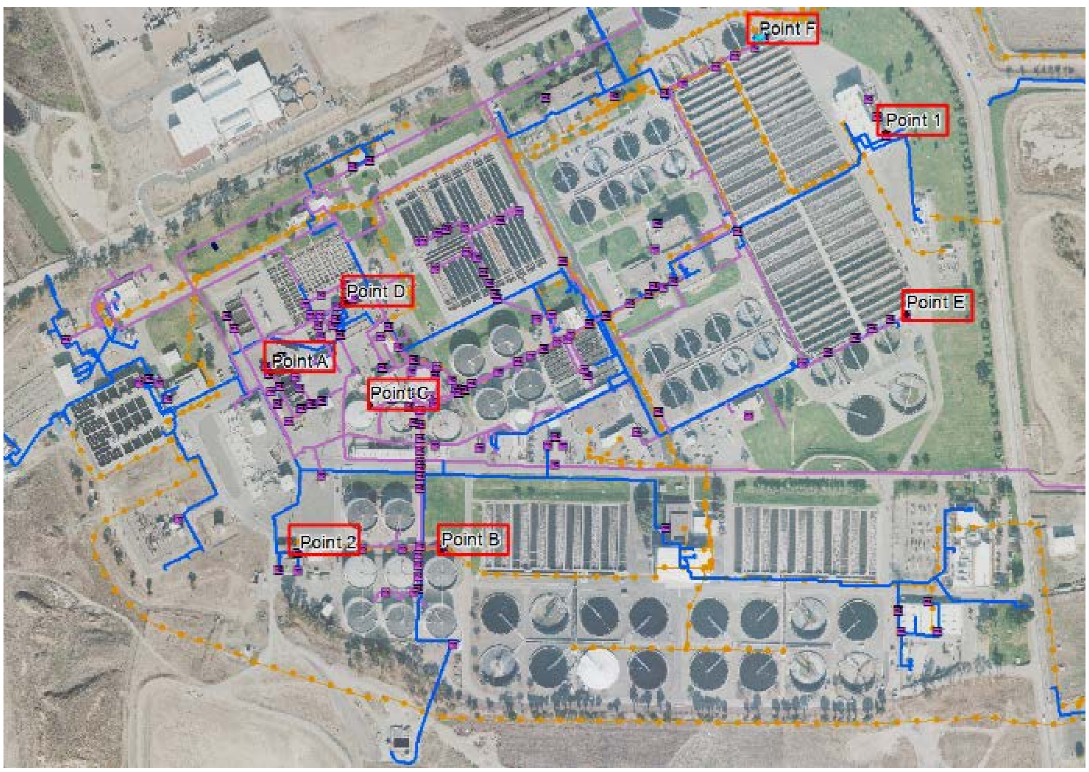


Figure 27: Aerial photograph showing locations of pressure loggers used for model calibration

7.5 - Connection to Environmental Services Building

For the 1W potable water system, there was a crucial design variable that was taken into consideration. The piping connection that links the main facility to the Environmental Services Building (ESB) located towards the southeast junction of the facility (shown in Figure 28) has a jumper that allows for discontinuation / recirculation of water supplies depending on whether or not the primary distribution undergoes failure. The team was left to decide whether to leave the jumper at the connection in order to maintain a looped design or to disconnect it to prevent potential risks for backwash and cross contamination of the potable water supply to the ESB. The ultimate decision was to open the jumper to allow for an alternate supply point for the 1W system while the main line is being replaced. By utilizing the Environmental Sciences Building as a supply for the main 1W system the need for additional pipes to be laid before the primary lines of the 1W system were replaced was eliminated. The risk of backwash and cross-contamination was resolved by picking the appropriate pipe sizing to yield higher velocities. Having a higher velocity at the connection prevents stagnation and buildup of harmful coliform bacteria.

Figure 28: Aerial rendition of the 1W system connection to the Environmental Services Building

7.6 - Non-technical Issues

The political climate surrounding the RWF in terms of proposal approval, funding, and implementation should not significantly affect the project. The RWF has included the upgrade/rehabilitation of these water distribution systems into their CIP which plans and carries out projects from the 2013 Plant Master Plan. $2 billion has been invested in the Plant Master Plan which will be distributed amongst the CIP packages that are selected. According to the project package, the Facility Wide Water Systems project is estimated to cost $12.5 million. Long term operation of the RWF will continue to be jointly ran by the cities of San Jose and Santa Clara's Environmental Service Department. The RWF is subject to strict regulatory requirements in order ensure the health and safety of the public from discharged wastewater and air emissions, as well as, those who use the plant's products (bio solids and recycled water).

Regulations can be divided into the six categories: treated wastewater discharged to the South San Francisco Bay, use of recycled water, disposal or reuse of bio solids, air emissions from Plant processes and engines, safety requirements to protect Plant workers, and land use controls.

Under the scope of services for the project, it is stated that when developing the conceptual design, documents required by the California Environmental Quality Act (CEQA) must be prepared for the review and approval process. The City's Planning Department will conduct the necessary public outreach and make the final CEQA determination. The Regional Wastewater Facility is operated under a National Pollutant Discharge System permit issued by the San Francisco Bay Regional Wastewater Quality Control Board to comply with the federal Clean Water Act and the California Porter-Cologne Water Quality Control Act. The current standards set by the permit include rated capacity of 167 MGD average dry weather flows and peak wet weather flows capacity of 271 MGD. The final product should, at a minimum, be appropriately sized for these capacities. Table 4 lists effluent standards set by the permit.

Table 4: NPDES Permit Effluent Requirements (Dunlavey & Ervin 2014)

Constituent	Units	Monthly Average	Daily Maximum	Instantaneous Maximum	Total Monthly	Range
Carbonaceous Biochemical Oxygen Demand (CBOD)	mg/L	10	30	–	–	–
Ammonia-Nitrogen	mg/L	3	8	–	–	–
Total Suspended Solids (TSS)	mg/L	10	20	–	–	–
Oil and Grease	mg/L	5	10	–	–	–
Settleable Matter	mg/L-hr	0.1	0.2	–	–	–
Turbidity	NTU	–	–	10	–	–
Chlorine Residual	mg/L	–	–	0.0(1)	–	–
pH	-	–	–	–	–	6.5 8.5
Copper	mg/L	12	18	–	–	–
Mercury(2)	mg/L	0.012	2.1	–	–	–
Mercury	kg/ month				0.231(3)	
Nickel	mg/L	25	34	–	–	–
4,4-DDE(2)	mg/L	–	0.05	–	–	–
Dieldrin(2)	mg/L	–	0.01	–	–	–
Heptachlor Epoxide(2)	mg/L	–	0.01	–	–	–
Benzo(b)Fluoranthene(2)	mg/L	–	10.0	–	–	–
Indeno(1,2,3-cd)Pyrene(2)	mg/L	–	0.05	–	–	–
Enterococcus	Colonies /100 mL	35	–	276	–	–

Notes:

(1) Requirement defined as below the limit of detection in standard test methods defined in the latest EPA approved edition of Standard Methods for the Examination of Water and Wastewater.

(2) Interim Limits, valid until October 31, 2008, or until the RWQCB amends the limitations based on additional data, site-specific objective, or the waste load allocation in respective TMDLs.

(3) Dry weather months (May through October), the total mercury mass load shall not exceed the mercury mass emission limitation of 0.231 kilogram per month (kg/month).

The RWF must also follow air quality permits issued by the Bay Area Air Quality Management District such as “Authority to Construct (A/C) or “Permit to Operate (P/O). These permits regulate the air quality emissions that are released as a result of a project’s construction/ operation to minimize adverse effects felt by the public. The RWF participates in the San Francisco Estuary Institute and the Aquatic Center’s (SFEI) Regional Monitoring Program (RMP) which provides water quality regulators w/ information that will assist in managing the Estuary effectively. The RMP produces an Annual Monitoring Report that documents the activities of the program each year which can be used to track facility efficiency and to verify that code requirements are met. As a part of the Water Pollution Control Program (WPCP), the RWF must comply with a variety of regulations at the federal, state, and regional level to limit environmental impact. A list of regulations applicable to the RWF is shown in Appendix C.

The implementation of the project will not require the seizure of private property as all upgrades and rehabilitation will be constrained to the RWF’s existing property lines. Ethical dilemmas related to economic/cost considerations regarding alternative designs will be resolved using the “triple bottom line plus” business case analysis approach developed for the CIP. If an alternative design is appropriate, the alternative shall be documented and submitted to the RWF for review.

8. CONCLUSION

The creation of the hydraulic models for the 1W and 2W systems will allow the RWF to execute performance analyses on their existing systems. This was one of the first deliverables specified in the CIP summary. Both models run with decent accuracy to actual system behavior given the available information. Utilizing these models, the future operation and maintenance of the 1W and 2W systems should become more streamlined and efficient as piping with higher risks of failure can be pinpointed quickly.

The two proposed redesigns have proven to increase each system's average velocity so the pipes will be used to a fuller capacity. With increased velocities, each system will run more efficiently while providing adequate service to meet current demands. An information systems specialist at the RWF informed the team that there has been a trend of decreasing demands in recent years, likely due to increasing environmental awareness and activism. The design team assumed this trend would either continue or flat-line, making the proposed redesigns sufficient to handle both current and future demands.

Another dimension of the redesigns which takes into account future operations is the proposed PVC and steel composite system. The many pipes in the existing systems made of cast-iron or ductile iron that were installed decades ago are likely degraded to the point of impaired functionality or possible buildup of material. The proposal for only PVC and steel piping ensures the use of pipe materials that have been proven to perform for over a long period of time. Many studies on PVC piping estimate its useful life to exceed 100 years, with steel piping having a useful life around 50 years.

On top of all functional goals that were set for the redesigns, both proposed redesigns were within the RWF's estimated 1 million dollar project cost, with allowed room for contingencies.

9. APPENDICES

Appendix A - Supporting Calculations and Model Results

Table A.1: Cost Estimate Calculation Example

Pipe Size	Material	Total Length	Pipe Material Cost		Install Rate	Labor & Equipment Cost		Earthwork Cost		Total Installed Cost		Isolation Valves Cost		
(IN)		(LF)	($/LF)	(Total $)	(LF/day)	($/LF)	(Total $)	($/LF)	(Total $)	($/LF)	(Total $)	($/in)	Quantity	(Total $)
0.5	PVC	884	$4.65	$4,271	(NA)	$10.55	$12,768	$3.15	$3,297	$23.00	$20,335	$83	4	$391
0.75	PVC	953	$4.83	$4,783	(NA)	$11.20	$14,612	$3.24	$3,656	$24.19	$23,051	$114	17	$2,288
1	PVC	1,771	$5.00	$9,200	(NA)	$11.85	$28,730	$3.33	$6,983	$25.36	$44,913	$134	14	$2,224
1.5	PVC	3,175	$5.35	$17,649	36	$13.15	$57,157	$3.51	$13,195	$27.72	$88,001	$180	26	$5,546
2	PVC	1,219	$5.70	$7,219	59	$14.45	$24,114	$3.68	$5,311	$30.06	$36,645	$247	8	$2,340
2.5	PVC	249	$6.05	$1,565	(NA)	$15.75	$5,369	$3.86	$1,138	$32.42	$8,072	$268	6	$1,904
3	PVC	938	$8.20	$7,992	53	$16.10	$20,674	$4.04	$4,487	$35.34	$33,153	$339	6	$2,408
4	PVC	888	$10.25	$9,457	48	$17.75	$21,578	$4.49	$4,721	$40.27	$35,756	$450	12	$6,394
5	PVC	8,835	$12.30	$112,909	(NA)	$19.40	$234,645	$4.76	$49,793	$44.97	$397,347	$590	16	$11,177
6	PVC	5	$16.90	$88	39	$22.00	$151	$5.15	$30	$53.77	$269	$810	1	$959
			Total	$175,132		Total	$419,799	Total	$92,610	Total	$687,541		Total	$35,631
													$723,172	

Table A.2: LCA Calculation Example - Production

Pipe ID	Material	Diameter D (in)	Length L (ft)	Length L (m)	Density d (kg/m)	Mass (kg)	EE (MJ/kg)	Total EE (MJ) = L*d*EE	EC (Kg CO2)
464	PVC	8.00	0.7	0	9.980	2	21.62	45	5
464	PVC	8.00	1	0	9.980	4	21.62	78	9
464	PVC	8.00	4	1	9.980	13	21.62	285	33
464	PVC	8.00	12	4	9.980	37	21.62	798	92
465	PVC	8.00	2	1	9.980	6	21.62	135	16
4149	PVC	8.00	1	0	9.980	3	21.62	66	8
	Totals:		**23,830**			**19,505**		**634,799**	**48,763**

Table A.3: LCA Calculation Example - Transportation

Pipe weight (kg)	Pipe weight (lbs)	# of vehicles	Distance (miles)	Truck emission rate (kg/veh-mile)	Total CO2 (kg)	Total CO2 (ton)
23.372064	38,379	3.0	10	1.43	42.9	0.047

Table A.4 - LCA Calculation Example - Installation

Pipe ID	Diameter D (in)	Length L (ft)	Trench Vol. (ft^3)	Trench Vol. (m^3)	Trenching time (hrs)	Fuel consumed (gal)	CO2 emission (tons CO2)
60521	0.5	271	326	9.23	1.51	1.94	0.022
69346	2	16	24	0.68	0.11	0.14	0.002
70151	1.5	11	15	0.44	0.07	0.09	0.001
70152	1.5	56	78	2.22	0.36	0.47	0.005
						Total:	**2.494**

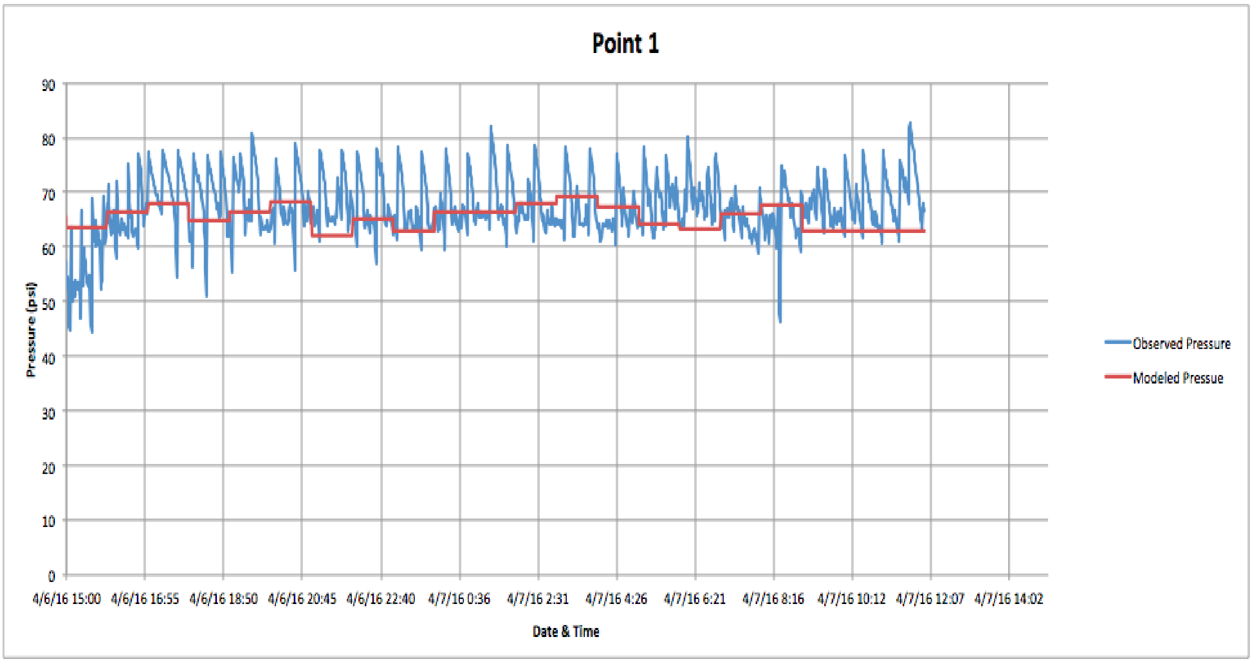


Figure A.1: Graph of observed and modeled pressures for 1W point 1

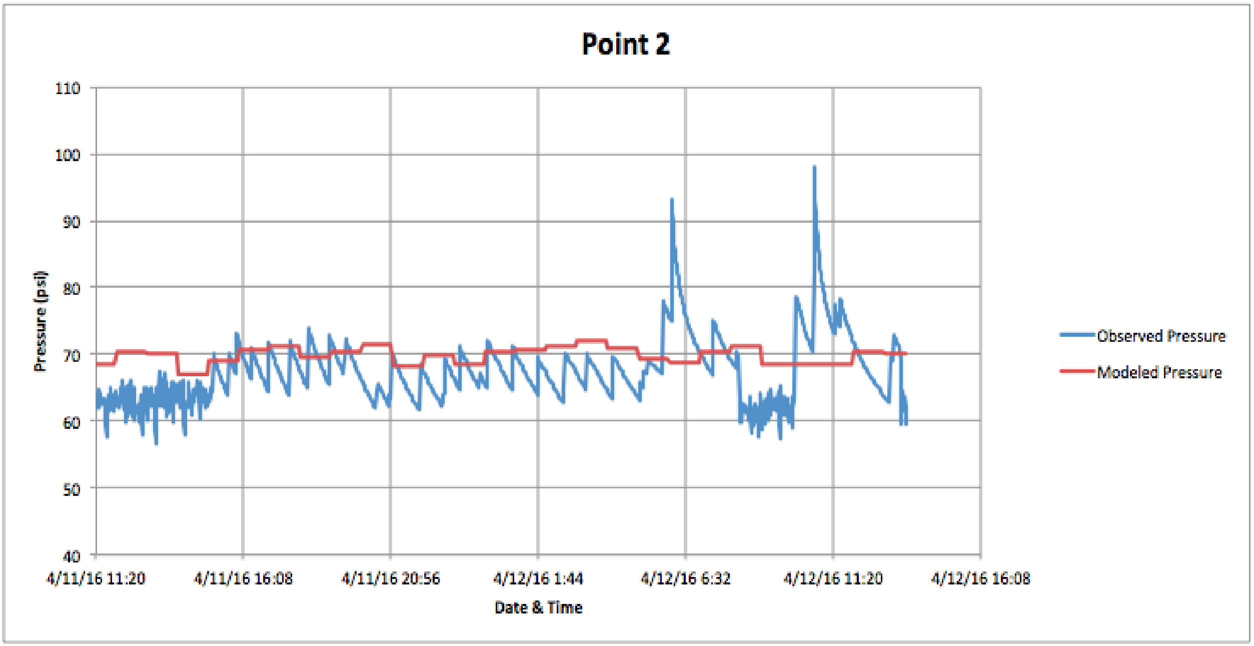


Figure A.2: Graph of observed and modeled pressures for 1W point 2

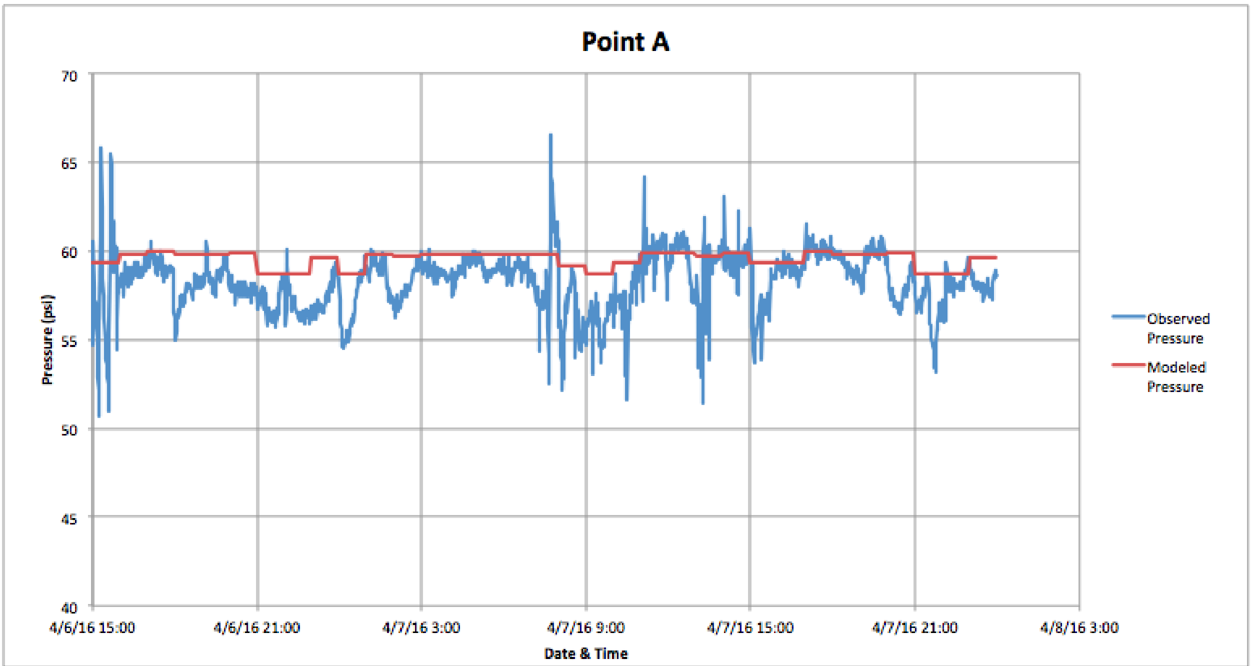


Figure A.3: Graph of observed and modeled pressures for 2W point A

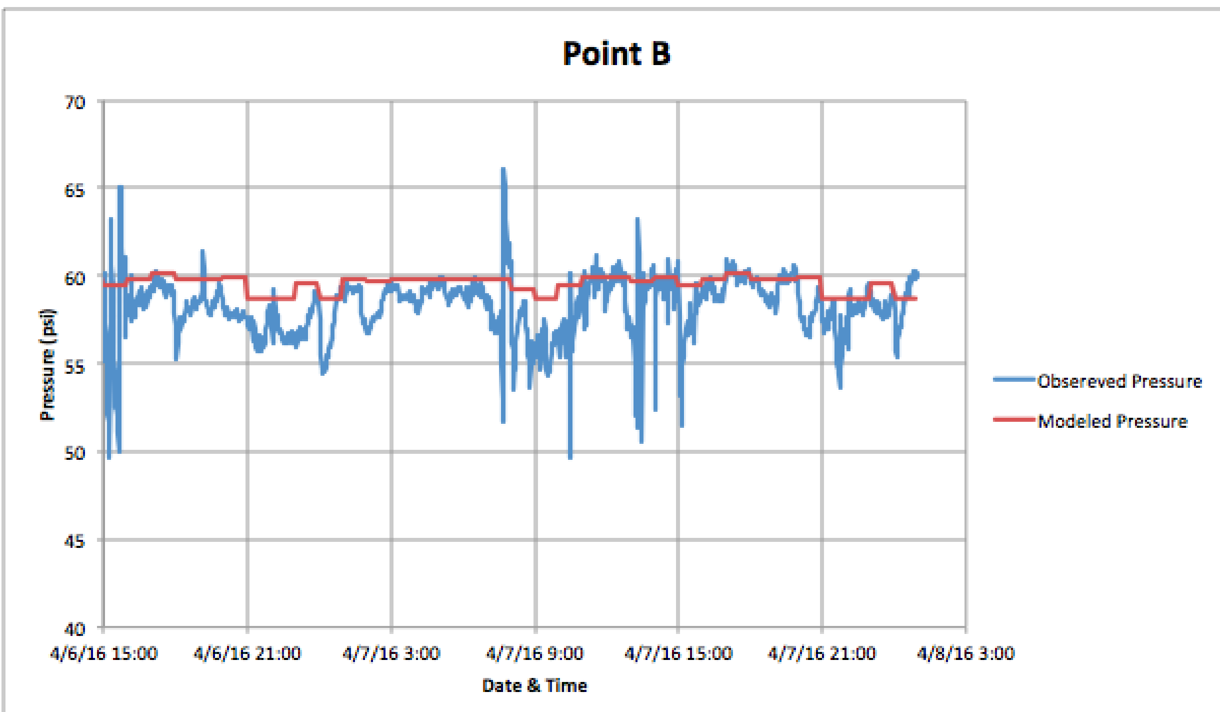


Figure A.4: Graph of observed and modeled pressures for 2W point B

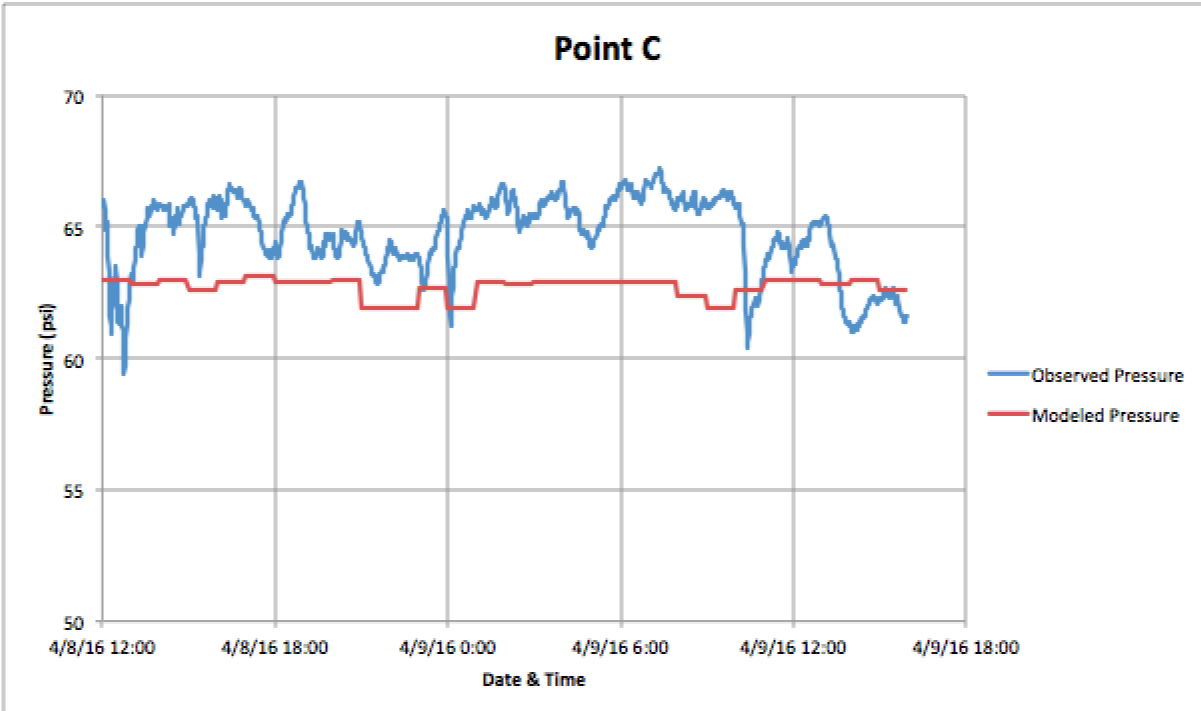


Figure A.5: Graph of observed and modeled pressures for 2W point C

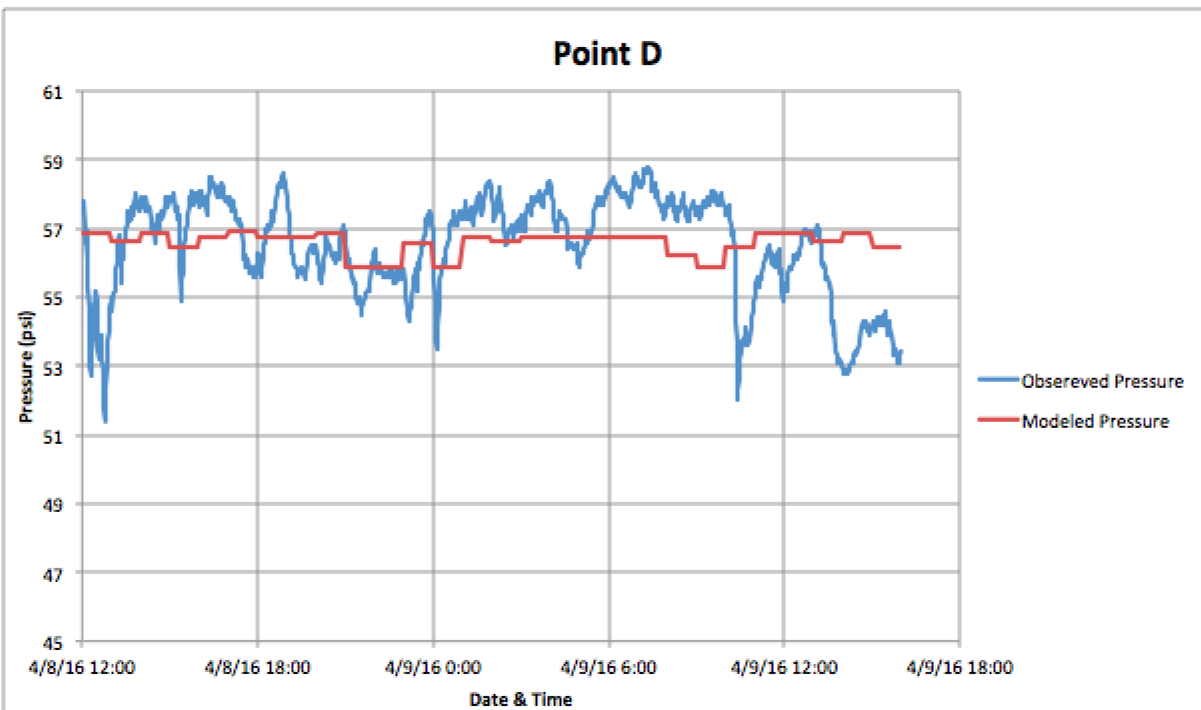


Figure A.6: Graph of observed and modeled pressures for 2W point D

Appendix B - System Element Quantity Catalog

Table B.1: 1W All PVC Alternative

Pipe Size (in)	Material	Total Length (ft)	Isolation Valve (Quantity)
0.5	PVC	884	4
0.75	PVC	953	17
1	PVC	1,771	14
1.5	PVC	3,175	26
2	PVC	1,219	8
2.5	PVC	249	6
3	PVC	938	6
4	PVC	888	12
5	PVC	8,835	16
6	PVC	5	1
	Total:	**18,917**	**110**

Table B.2: 1W PVC & Steel Alternative

Pipe Size (in)	Material	Total Length (ft)	Isolation Valve (Quantity)
0.5	STL	877	5
1	STL	179	6
1.5	STL	4,403	33
2	STL	882	11
2.5	STL	83	8
3	STL	56	3
4	STL	18	0
1.5	PVC	205	0
4	PVC	12,214	0
	Total:	**18,917**	**66**

Table B.3: 2W All PVC Alternative

Pipe Size (in)	Material	Total Length (ft)	Isolation Valve (Quantity)
0.5	PVC	384	9
0.75	PVC	362	13
1	PVC	2,543	43
1.5	PVC	5,927	37
2	PVC	3,836	91
2.5	PVC	697	9
3	PVC	2,328	19
4	PVC	830	10
5	PVC	4,962	26
6	PVC	403	5
8	PVC	528	15
	Total:	**22,800**	**277**

Table B.4: 2W PVC & Steel Alternative

Pipe Size (in)	Material	Total Length (ft)	Isolation Valve (Quantity)
0.5	STL	269	9
0.75	STL	294	8
1	STL	6,888	69
1.5	STL	3,283	54
2	STL	2,735	45
2.5	STL	199	4
3	STL	1,186	23
4	STL	655	7
3	PVC	142	0
4	PVC	434	0
5	PVC	6,284	47
6	PVC	158	5
8	PVC	391	9
	Total:	**22,918**	**280**

Appendix C - Relevant Legal Constraints

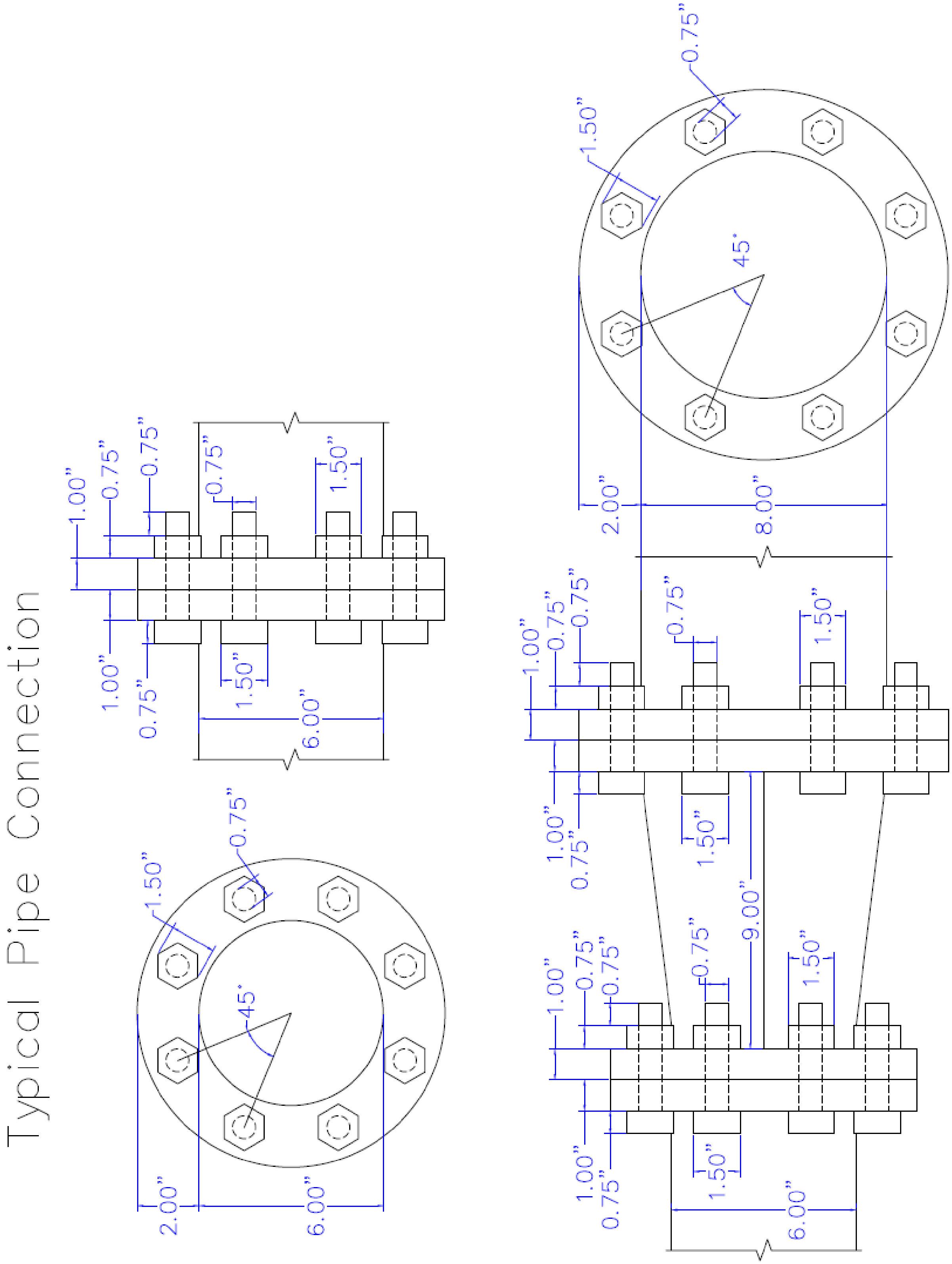
- Government Code Sections 83111-83116 (Political Reform Act) :
- Government Code Section 81000
- California Civil Code Sections 2778 / 2782.8
- San Jose Municipal Code Sections 4.08.020 / 12.08
- City Council Policy 4-6 (Environmentally Preferable Procurement Policy)
- Title 22 CA Code of Regulations, Chapter 16, Sections 64630 & 64572

Table C.1: Summary of Federal, State and Regional Regulations Applicable to WPCP

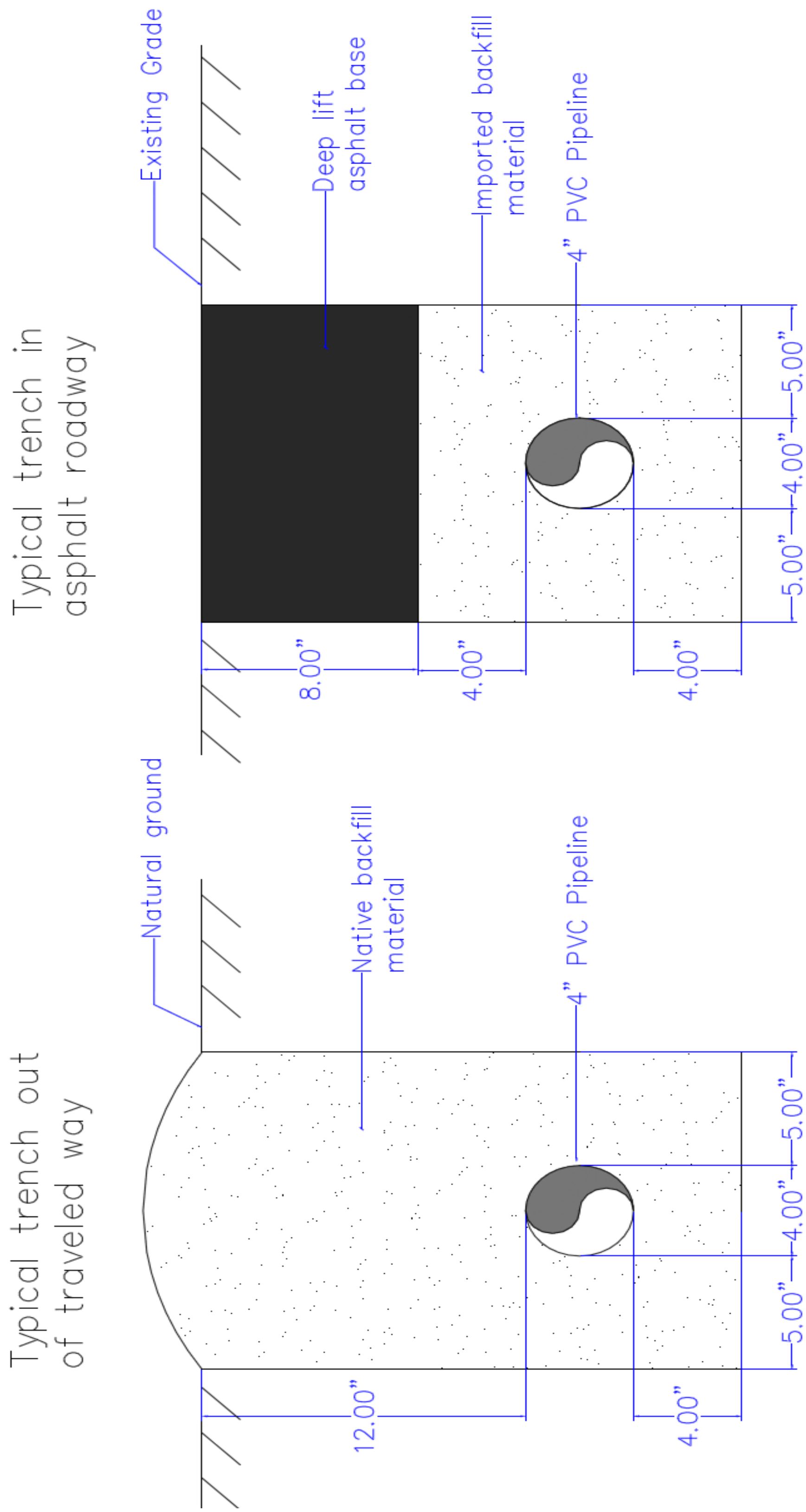
Discharge to Receiving Water	Discharge to Land	Air Emissions
Federal		
• Clean Water Act (CWA) of 1972 • National Pollutant Discharge Elimination System (NPDES) (40 CFR 122) • Water Quality Standards (40 CFR 131)	• Sewage Sludge Regulation (40 CFR Part 503) • Landfill Requirements (40 CFR Parts 257 and 258) • Clean Air Act (CAA) of 1970 (amendments in 1977 and 1990) • Resource Conservation and Recovery Act (RCRA) of 1976 (amended in 1984 and 1986) • Clean Water Act (CWA) of 1972 • 40 CFR Part 761 (promulgated under Toxic Substances Control Act) • Federal Endangered Species Act of 1973	• Clean Air Act (CAA) and National Ambient Air Quality Standards (NAAQS) of 1970 (amendments in 1977 and 1990) • National Emission Standards for Hazardous Air Pollutants (NESHAPS) (40 CFR 61) • Sewage Sludge Regulation (40 CFR Part 503) • Occupational Safety and Health Administration (OSHA) (29 CFR 1910)
State		
• Porter-Cologne Act of 1969 • Reclaimed Water Requirements (CCR Title 22) • Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California, 2005 (SIP) • Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays And Estuaries Of California, 1998 (California Thermal Plan)	• CCR Title 23, Chapter 3, Chapter 15 • CCR Title 22, Article 3 • Toxic Pit Clean Up Act of 1984 (Katz Bill AB 3566/3121) • Porter-Cologne Act of 1969 • General Waste Discharge Requirements (GWDR) for Discharge of Biosolids to Land for Use as a Soil Amendment in Agriculture, Silviculture, Horticulture, and Land Reclamation Activities	• CARB State Implementation Plan, 2007 (SIP) • CARB Air Toxic Pollutant Program (Tanner Bill AB 1807) • Air Toxics "Hot Spots" Information and Assessment Act of 1987 (Connelly/ Stirling Bill AB 2588) • California Clean Air Act of 1988
Regional		
• San Francisco Bay Basin Water Quality Control Plan, 2007 (Basin Plan) • Whole Effluent Toxicity Characterization Program		• Bay Area Air Quality Management District (BAAQMD) Rules and Regulations • Santa Clara County Toxic Gas Ordinance, 1990 (TGO)

Notes:
CARB = California Air Resources Board.
CCR = California Code of Regulations.
CFR = Code of Federal Regulations.

Appendix D - Detailed Drawings



Detail D.1



Typical trench in
asphalt roadway
Existing Grade
Deep lift
asphalt base
Imported backfill
material
4" PVC Pipeline
8.00"
4.00"
4.00"
5.00"
4.00"
5.00"
Typical trench out
of traveled way
Natural ground
Native backfill
material
4" PVC Pipeline
12.00"
4.00"
5.00"
4.00"
5.00"

Detail D.2

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