Section 1: Introduction

For the Introduction and background, refer to Section 1 of Planning Level TM No. 1.

1.1 Objectives

The purpose of TM No. 3 is to evaluate the options for systems and materials to be used in conveying wastewater to the SVCW treatment plant, and to identify the preferred tunnel excavation method for the proposed alignment.

1.2 Gravity Pipeline Description

As shown in Figure 1-1, the Proposed Gravity Pipeline, shown in green in the figure, connects to the recently constructed 48-inch force main project on Inner Bair Island and extends downstream to connect at the proposed Receiving Lift Station (RLS) at the SVCW wastewater treatment plant (WWTP). The currently proposed Gravity Pipeline consists of approximately 17,600 feet of 11-foot diameter wastewater gravity pipeline inside a 13-foot inside diameter tunnel with four shafts. The tunnel is to be constructed with its invert depth ranging between 35 and 65 feet in primarily firm to stiff clay soils.

Ideas under consideration by SVCW or that various PDB contractors have suggested to-date may change the basic Gravity Pipeline description. SVCW anticipates additional ideas coming out of the Progressive DB process. The ideas discussed to-date include the following.

- Multiple-layers of defense against corrosion including upstream dosing, enhanced air circulation, laminar flow, bacteria disruption and high performance precast concrete tunnel
segments with sacrificial thickness. This concept would eliminate the pipe in the tunnel and the related grout backfill of the annular space.

- Removal of the pipe in the tunnel, would allow SVCW to use the full inside diameter of the tunnel for equalization of dry and wet weather flows. This approach would also result in deferral of a concrete storage surface structure at the WWTP.

- Using Bair Island as the TBM launch location, resulting in elimination of the Airport Access Shaft. Recent input from contractors interested in proposing in response to SVCW's Progressive Design Build planned RFQ/RFP indicates interest in launching the TBM at Bair Island instead of the Airport Access Shaft. This would involve elimination of the Airport Access Shaft, partial realignment of the tunnel near the eliminated shaft and a larger construction footprint on Bair Island. If a selected PDB desires to pursue this alternative, the alternative would need to be described and reviewed under CEQA and permitted. Both appear to be challenging given the potential for public impacts and potential impacts on endangered species.

- Reconfiguration of the Receiving Lift Station that would modify the shape, size and configuration of the shafts at the WWTP.

These ideas are not addressed directly in TM No. 1, but are provided here for reference during the Progressive DB process.
1.3 Basic Approach

The approach for analyzing the alternatives for tunnel construction is to determine the following:

- Hydraulic requirements to handle design flows,
- Method of construction for the tunnel based on the soils information available to date, and
- The final lining materials for the tunnel/pipe system based on flow capacity and other design criteria.

Section 2 of this Tech Memo outlines the two types of tunnel systems, single pass and double pass, considered as part of this draft document. Table 2-1 outlines the major factors considered when screening alternative pipe materials for use on the Gravity Pipeline. These factors are later used as an evaluation tool.

Section 3 text provides a narrative description of single pass and double pass tunnel systems, as well as the range of materials that could be used for each system type. Table 3-1 narrows the list of materials considered for double pass systems based on commercial availability and ability to meet the hydraulic sizing requirements of the Gravity Pipeline. The remaining materials that meet these requirements were considered in further detail including the major factors outlined in Table 2-1,
to screen the most suitable materials for single pass and double pass tunnel systems. The advantages and disadvantages of the remaining materials were then fully evaluated, with the current recommendations summarized in Section 3.4.

Following preparation of the evaluation summarized in Section 3, SVCW authorized a follow-up evaluation effort, referenced as the Tunnel Interior Alternatives Analysis (Alternatives Analysis). This activity involved SVCW O&M, SVCW Engineering, the Gravity Pipeline team, Matt Fowler (Parsons Brinckerhoff -Gravity Pipeline Construction Peer Reviewers), Jim Joyce (corrosion specialist), Jose Pacheco (Portland Cement Association CTL – PCA research arm), Roya Joseph (SVCW CIP Program support), and the SVCW Construction Manager. This group conducted a review of the lining system alternatives and scored the alternatives in terms of the SVCW CIP Success Factors and Risk Factors. The Alternatives Analysis has been documented in Appendix A, summarizing the process, including screening and evaluation activities. The results of the Alternatives Analysis are included in Appendix A.

Additionally, Appendix Table A-1 provides a summary of the initial screening group discussions conducted during the Alternatives Analysis. An outcome of those group discussions was the inclusion for analysis of the proposed concept of multiple-layer defense (see Section 1.3), involving High-Performance Concrete (HPC) as a single pass alternative of interest to SVCW. This alternative was not considered in the original analysis documented in Planning Level TM No. 3, and it is presented here because of SVCW’s interest in further considering this concept.

Section 4 describes the tunnel excavation criteria used to evaluate the excavation method for the Gravity Pipeline.

Section 5 summarizes the tunneling process and major considerations, including soils characteristics, alignment, and the tunnel boring machine and excavation support recommended for the Gravity Pipeline. Constructability considerations and tunnel monitoring are also addressed in Section 5.
Section 2: Design Criteria

2.1 Overview

The proposed Gravity Pipeline represents the only means of conveyance of wastewater from the member agencies collection systems to the SVCW wastewater treatment plant. As such, the SVCW Gravity Pipeline will be a critical infrastructure element that, according to SVCW’s success factors, must provide the lowest practical capital and life cycle cost, be easy to operate, and minimize required maintenance. SVCW has identified the required service life of the proposed system at 100 years. Since wastewater conveyance is the primary function of the project, the approach to the Gravity Pipeline focuses on selecting the system for conveyance of wastewater that will provide a 100 year service life that has the highest likelihood of achieving the SVCW success factors. Once the Conveyance System alternative is selected, construction methods will be incorporated into the work conducted by the PDB. The Conveyance System will be installed by tunneling to mitigate disruption to residents and the general public and to minimize environmental impact.

There are two general methods for installation of the wastewater Conveyance System, single pass and double pass tunneling operations. A single pass tunnel support system consists of a support element, such as precast concrete segments and possibly a liner, which provides corrosion resistance. It is also possible for the support system to provide corrosion resistance as a part of its design and construction. Provision of corrosion resistance is necessary to prevent deterioration of the single pass support system by acid formed in the sanitary sewer.

The double pass method provides excavation support by using precast concrete segments (PCSL). Once the segments, and therefore the tunnel, are completed, a carrier pipe is installed within the tunnel to carry the wastewater flows.

There are emerging alternatives that add a corrosion barrier, sacrificial layer or segment design/construction process that offer support and corrosion resistance in a single pass tunnel. A number of emerging technologies, currently in various stages of development, may offer cost advantages, but have yet to establish their ability to offer the same durability as two pass systems. Areas of recent interest include:

- Adding corrosion resistant concrete liners to a concrete segment single pass tunnel support system,
- Adding corrosion resistant layers to a concrete segment single pass liner, constructed of an HDPE outer layer, overlying a sacrificial concrete inner layer,
- Stand alone, large diameter HDPE pipes installed inside of a single pass tunnel support system, and
- Design of a corrosion resistant concrete mix for use in construction of concrete segmental liners.
Research into the potential viability of these alternatives is beyond the scope of this Planning Level TM. Additional consideration of the most promising of these alternatives will be by the PDB for comparison to the described single and double pass tunnel support systems included in this document.

2.2 Criteria for Wastewater Conveyance

Multiple materials were considered for wastewater conveyance. These include petroleum-based composite materials and Portland cement-based composites. Each material provides various benefits and challenges, all of which were considered for their applicability to this project, given a preliminary understanding of the project constraints. The factors used to screen the material alternatives are summarized in Table 2-1 and are discussed below.

Table 2-1: Factors Considered During Alternative Pipe Materials Screening

<table>
<thead>
<tr>
<th>Factor</th>
<th>Key Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Characteristics</td>
<td>• Hydraulic design criteria and size compatibility&lt;br&gt;• Ability to handle external loads (including seismic)&lt;br&gt;• Corrosion resistance&lt;br&gt;• Weight of pipe</td>
</tr>
<tr>
<td>Fittings and Alignment</td>
<td>• Flexibility for alignment curvature&lt;br&gt;• Reliability of the joint connections (low leakage potential in gravity sewer use)&lt;br&gt;• Adaptability of pipe for special connections (e.g., manholes, unique fittings)</td>
</tr>
<tr>
<td>Constructability</td>
<td>• Ease of installation&lt;br&gt;• Compatibility with the means and methods for transferring each pipe section within the tunnel from portal to heading&lt;br&gt;• Resistance to damage during handling</td>
</tr>
<tr>
<td>Costs</td>
<td>• Material cost&lt;br&gt;• Construction costs&lt;br&gt;• Life cycle cost</td>
</tr>
<tr>
<td>Suitability</td>
<td>• History of manufacturer’s track record for delivery and support for tunnel construction&lt;br&gt;• Industry’s long term history of use in wastewater service (longevity)&lt;br&gt;• Affirmation of factory testing standards</td>
</tr>
</tbody>
</table>
2.3 Physical Characteristics

2.3.1 Hydraulic Design Criteria and Size Compatibility

The tunnel will be the only means of conveying wastewater to the SVCW WWTP. Flows entering the system from member agencies and hydraulic considerations will establish the proposed pipeline size and this size will be one discriminator that dictates the type of materials, which are available for use as the gravity pipeline.

The Gravity Pipeline should be designed to allow conveyance of the near term dry weather flows, future build-out dry weather flows, and wet weather flows [Flows used for the SVCW CIP are presented in Planning Level TM No. 1]. Uses of the Gravity Pipeline for diurnal and peak wet weather storage and ability to prevent grit build up must also be considered. A planning-level hydraulics evaluation by the Gravity Pipeline team provided input for initial flow parameters for the proposed wastewater Conveyance System. These hydraulic parameters will be further refined by the PDB. Based on the planning-level hydraulics evaluation, SVCW specified that the gravity pipeline should provide capacity for diurnal storage operations to assist with management of influent flows to the WWTP. An 11-foot diameter Gravity Pipeline was estimated during the planning stage to provide for the Gravity Pipeline operational requirements identified by SVCW. An inner tunnel bore diameter of 13 feet would offer capacity for improved operation during diurnal storage and wet weather operations.

2.3.2 Ability to Handle Applied Loads

The proposed wastewater Conveyance System should address the following applied loads:

1. Load during construction and installation (including grouting pressures if a two pass system is used).
2. Earth pressure and groundwater loading (without offsetting internal water pressure).
3. Earth pressure load with groundwater.
4. Minimum soil load with groundwater below the invert of the tunnel and with a maximum internal pressure.
5. Asymmetrical external loads due to gravity.

2.3.3 Corrosion Protection

Corrosion protection for the Gravity Pipeline is a two-part consideration. The first part is the external corrosion potential of the soils interacting with the tunnel excavation support system. The second part is the sewage acting within the interior of the carrier pipe or single pass tunnel liner system.
2.3.3.1  **External Corrosion Protection**

External corrosion protection should consider all corrosion-related issues associated with soils and Gravity Pipeline materials in contact with the soils. Soil pH can result in variable degrees of corrosivity to steel, cementitious compounds, or other construction materials.

**pH:**
- Generally, pH values less than 6.5 are considered acidic and are corrosive to steel and cementitious materials.
- Between pH 6.5 and 9.5, pH is not a significant factor in the corrosion of steel or cementitious materials.
- Above pH 9.5, corrosion rates continue to diminish on steel, cementitious materials are not attacked, and leaching of alkalinity from cementitious materials diminishes.

**Sulfates:**
Sulfate concentrations that are higher than 2,000 mg/kg are considered highly corrosive to hydrated cement in concrete.

**Chlorides:**
Studies have reported that corrosion of concrete-encased steel in soils will occur when chloride levels are greater than 300 mg/kg in the presence of oxygen.

The soil corrosivity testing that has been completed for the project, thus far, analyzes areas at the SVCW WWTP near the proposed RLS Shaft and along the tunnel alignment. A report of Soil corrosivity at the WWTP was prepared by Freyer & Laureta, Inc. entitled “Soil Corrosivity Evaluation”. The results of this report indicated a pH of 7.6, a sulfate level of 2,900 mg/kg, and a chloride level of 13,000 mg/kg. The findings of this report indicate that the soils at the site are highly corrosive to buried reinforced concrete. The soil corrosivity testing performed along the tunnel alignment by GTC confirms that the soils in this area are also highly corrosive. Based on this initial testing, the corrosivity of the soils along the tunnel alignment should be considered when selecting the final Gravity Pipeline material.

2.3.3.2  **Internal Corrosion**

Corrosion on the interior surface of the wastewater conveyance system can result from hydrogen sulfide (H₂S), which is produced in warm, slow moving wastewater where the dissolved oxygen content has been depleted. These conditions result in the production of hydrogen sulfide in the SVCW force mains that will feed into the Gravity Pipeline, as well as in the member agency collection systems that deliver wastewater to the Conveyance System. H₂S can also form in the Gravity Pipeline, however the higher velocities in the Gravity Pipeline when operating in free-flowing conditions are anticipated to result in lower residence times and may reduce the potential for generation of added hydrogen sulfide in the Gravity Pipeline. Bacteria on the damp upper surfaces of the Gravity Pipeline (exposed to air) convert the H₂S to sulfuric acid, which can attack the interior of the Gravity Pipeline, unless the interior is constructed to resist such corrosion.
2.3.4 **Weight of Pipe**

Where a pre-manufactured pipe is proposed as the Gravity Pipeline carrier pipe, the weight of pipe and distance from the point of manufacture are important issues to consider. Pipe weight contributes to time and expense of delivery and installation. Distance of delivery for large diameter pipe also equates to added cost and risk that the pipe will not reach the project site in good condition and in a timely manner.

2.4 **Fittings & Alignment**

Due to the proposed curvilinear alignment of the interceptor, pipe flexibility is another feature that was considered. All of the materials considered can be fabricated to spool lengths that provide flexibility at joints to accommodate alignment curvature. Similarly, leakage potential is also an important factor. SVCW has expressed concern for potential significant leakage in its force main system. Since the new tunnel would be a gravity system, leakage is not as great of a concern and, due to exterior hydrostatic head, will not leak to the groundwater, but should be considered. The specifications for the proposed project should include requirements for installation of the proposed materials and should address requirements for joint integrity and durability.

In addition, custom gravity pipeline tunnel fittings and connections should be required at each of the member agency connections.

2.5 **Constructability**

For double pass systems, the ease with which the carrier pipe can be installed within the tunnel excavation support system, and the ability to secure the carrier pipe at each joint, is critical for the SVCW Gravity Pipeline. Constructability also considers the ability of the material to handle the impacts of the construction process over the course of the project. The pipe installation methods for inserting pipe into the tunnel would include moving each pipe piece with a pipe carrier along tracks laid in the tunnel invert. Optimally, the pipe should be lightweight and easy to handle, while providing the required stiffness and strength to withstand construction applied loadings.

For single pass systems, constructability issues include preventing damage to concrete segments during their manufacture and installation, especially since they will have the added function of carrying wastewater to the WWTP from the member agencies.

2.6 **Gravity Pipeline / Liner Suitability**

Suitability of Gravity Pipeline carrier pipe/liner material is based its long-term durability. Each material should have a history of use in a wastewater environment as well as a tunnel system. As noted, SVCW has specified a required design life of 100 years for the Gravity Pipeline. Each material selected for use in the tunnel must meet rigorous industry standards for testing and verification (e.g., ASTM, AWWA, etc.), including affidavits that the material and its use in the system will meet specified requirements. This verification should include factory witness testing, so manufacturing in the United States would be desirable. The location of the Gravity Pipeline between two critical faults in the Bay Area makes the ability for the system to resist anticipated
seismic loads an important consideration. Final structural design of the system must meet the requirements for construction in the proposed soils, while meeting seismic design criteria for the Gravity Pipeline.

Section 3: Evaluation of Gravity Pipeline/Lining Systems

Two options that were evaluated within the stated scope of this Planning Level TM for evaluating wastewater conveyance within the Gravity Pipeline include: 1) providing a pre-manufactured pipe to function as the carrier pipe in the Gravity Pipeline; and 2) applying a liner or liners to the concrete segments which comprise the tunnel excavation support system. Gravity Pipeline carrier pipe and liner materials are evaluated in this section.

As noted, there are two basic systems being evaluated. The first is termed a single-pass system, where the wastewater conveyance system is integral to the tunnel excavation support system (i.e., a part of the segments). The second method is designated as a double-pass system. The double pass system is identified by the requirement to first construct the tunnel excavation support system, expected to be concrete segments, followed by installation of a second system to carry wastewater within the Gravity Pipeline. Typical materials for each of these systems are summarized below:

1. **Single Pass Tunnel System**: 11-foot inside diameter tunnel (A 13-foot inside diameter may be possible with a single pass system)
   a. Precast Concrete Segmental Liner with integrated HDPE liner
   b. Combisegments Type 1 – concrete segments with polydicyclopentadiene (pDCPD) internal lining
   c. Combisegments Type 2 – concrete segments with HDPE and pDCPD internal lining
   d. Polymer Concrete Segmental Liner

2. **Double Pass Tunnel System**: Concrete segmental liner with 11-foot inside diameter carrier pipe
   a. HDPE Liner – installed concurrently with a 6 to 10 inch concrete layer in the tunnel, as the liner to concrete segments
   b. HDPE Pipe – Smooth Wall and Profile Wall
   c. Polyvinyl Chloride (PVC) Pipe
   d. Fiberglass Reinforced Plastic (FRP) Pipe
   e. Reinforced Concrete Pipe (RCP), including T-Lock lined concrete pipe
   f. Polymer Concrete Pipe (PCP)
3.1 Single Pass Alternatives

A single pass tunnel can consist of a tunnel excavation support system (concrete segments) as a standalone solution. If an integral liner is attached to the concrete segments, a composite system is created. These systems are required to function both as the tunnel excavation support system and as a corrosion barrier. In a single pass system, the grade tolerances for the installation of the concrete segments must meet specified requirements, since a second and smaller carrier pipe that can be adjusted to a degree to account for misalignment is not provided. Providing added attention to maintaining grade for a single pass tunnel system in the expected tunnel-zone soils (referenced as upper layered sediments) may have an impact on the construction schedule and should be evaluated further by the PDB, should a single pass method be chosen. Three single pass systems were considered for use in the Gravity Pipeline, as noted below:

- Precast Concrete Segmental Liner with HDPE embedded sheeting
- Combisegments, a proprietary segmental liner system owned by Herrenknecht. Two systems are available, Type 1 and Type 2.
- Polymer Concrete Segmental Liner, a proprietary liner system owned by SolidCast Polymer Technology called QOR-TEQ.

A summary of these materials is presented below with reference to the screening criteria.

3.1.1 Precast Concrete-Segmental Liner with HDPE Sheeting (Single Pass System)

Where Precast Concrete Segmental Liners (PCSL) are used as the tunnel excavation support and final liner system, corrosion protection for the PCSL consists of HDPE sheeting (2.5 mm thickness). For a single pass system, the HDPE sheeting mechanically bonds the liner into the PCSL units during fabrication, creating a 360-degree HDPE surface around the interior surface of the PCSL.

Following the segment placement, all joints in the HDPE sheeting must be field welded to eliminate leakage and protect the concrete from corrosion. While mechanically bonding the HDPE sheeting to the PCSL fabrication provides potentially better quality control initially, there could be a potential for tears in the HDPE during construction. Tears would require repair and could introduce a point for future failure and potential corrosion. Additionally, field welding at each joint will require extensive quality control measures and requirements. Connection of the HDPE sheeting to the member agency connections would also require field welding. External corrosion protection for the concrete segments can be provided with appropriately designed concrete. Type V cement is used in high sulfate areas to resist deterioration of the concrete (all concrete in the SVCW area uses cement that meets the requirements for Type II and Type V cement). The long-term life expectancy of the integrated liner system is estimated in other projects to provide a 100 year service life, but further analysis to support this claim would be needed for the Gravity Pipeline. Due to the potential for failures of the field welds and tears in the liner during construction, there is concern for corrosion of the segments and overall longevity of the system.
3.1.2 Combi-segments

Herrenknecht has two PCSL systems, Type 1 and Type 2, that were evaluated for the tunnel excavation support system and final internal corrosion resistant liner of the Gravity Pipeline. These systems are trademarked and protected by a proprietary system under the name Combi-segments. With either of these options, no internal wastewater carrier pipeline is required. Furthermore, there is no annular space to fill between a carrier pipeline and the internal surface of the tunnel excavation support system. Since the single pass method does not require a carrier pipe, the diameter required for excavation can be reduced, or the inside diameter of the system can be increased to provide greater flexibility for use in flow equalization.

Combi-segments technology offers two differing approaches to providing a corrosion resistant lining for each segment, and uses an integral gasket seal along each segment edge. Combi-segments has not been used in the United States for tunneling applications. However, they were installed in Moscow, Russia. Documentation of the installation requirements, any quality concerns during construction, and current condition of the system would require further research. Each system is discussed below.

Type 1 design variant of the Combi-segment® lining panel combines a smooth chemical resistant liner and liner frame (one piece), the frame incorporates an EPDM sealing gasket for water tightness. A honeycombed structure made of polypropylene (PP) extends throughout the reverse surface of the main pDCPD liner and is used to lock the liner to the concrete segment. Type 1 uses a complete encapsulation of the exterior (inside faces) of the precast concrete segmental liner. The encapsulation material is pDCPD, which has been used in industry for such tough applications as auto and truck body parts. The issue with this system is the potentially weaker adhesion of the honeycombed polypropylene structure fused to the back of the pDCPD material, which could have limitations on hydrostatic groundwater loadings. If repairs to pDCPD are required in the field, they are expected to be a challenge. Based on the field conditions from the geotechnical testing to date, high groundwater is probable for the SVCW tunnel. Due to the expected difficulty of repairing pDCPD in the field and potential for groundwater to impact the bond on Type 1 Combi-segments, this product is not recommended for further consideration.

Type 2, also a design variant of a Combi-segments® lining panel, combines a smooth chemical resistant liner connected to a liner frame, which incorporates an EPDM sealing gasket for water tightness. Type 2 uses an HDPE sheet fused to the pDCPD frame. The HDPE sheeting is mechanically anchored into the PCSL and should have good adhesion properties. The quality of the fusion joint between the HDPE sheeting and the pDCPD frame is asserted by Herrenknecht to have a strength greater than the strength of the HDPE. The mechanical anchoring of the HDPE sheeting offered in the Type 2 system appears to be more robust than the Type 1 system and should be considered in further tunnel discussions. Type 2 Combi-segments have recently been used in tunnel construction in Canada as a test case and in the Middle East. Evaluation of Type 2 Combi-segments is summarized in Section 3.3 below.
3.1.3 Polymer Concrete Segments

The only polymer concrete segments considered for the Gravity Pipeline are identified under the name QOR-TEQ by SolidCast Polymer Technology. Solid Cast Polymer (SCP) concrete is a homogeneous mixture of chemically inert mineral fillers (aggregate), a thermosetting polymer resin, and reinforcement media (fiberglass fibers). Portland cement is not used in this mix. SCP resins are non-regulated, non-flammable and meet Occupational Safety and Health Administration (OSHA) Class 3B requirements. This means there are no volatile organic compounds (VOCs) or hazardous air pollutants (HAPs), resulting in an environmentally friendly product. Polymer concrete consists of high quality material and is suitable for wastewater collection applications based in large part on its corrosion resistant nature, which does not require a liner. Polymer concrete manholes have been used in various applications for tunneling throughout the United States. However, polymer concrete segments have not been used in the USA. Technologies used for sealing individual segments to each other, including gasket configurations, would need to be carefully evaluated for a polymer concrete option.

The QOR-TEQ product uses hollow core material in the segmental liner forms to reduce the amount of resin required, which effectively reduces the cost while still providing adequate strength for fabrication, handling, and tunnel support requirements. Since this product does not have a liner and the strength is provided by the polymer concrete, damage during shipping and tunneling operations is less likely.

The primary drawback in considering use of this new system is that it has not been used in a tunnel to date. Polymer concrete segment technology is summarized in Section 3.3 below.

3.2 Double Pass System

A double pass tunnel system consists of construction of a tunnel excavation support system followed by installation of a corrosion resistant carrier pipe, which functions to convey wastewater. The various pipe materials initially considered for use as a carrier pipe are as follows:

- Reinforced Concrete Pipe (RCP) – ASTM C76
- T-Lock Lined RCP – ASTM D412
- High Density Polyethylene (HDPE) Liner installed concurrently with a 6 to 10 inch concrete layer in the tunnel, as the liner to concrete segments
- HDPE Pipe – Smooth Wall and Profile Wall
- Polyvinyl Chloride (PVC) Pipe – ASTM F679
- Fiberglass Reinforced Plastic (FRP) Pipe – AWWA C950
- Polymer Concrete Pipe (PCP) – ASTM D6783
The first screening criteria evaluates whether the hydraulic criteria can be met by the availability of pipe in the required size. Each of these pipe materials are compared to the available commercial product sizes in Table 3-1 below.

### Table 3-1: Commercial Availability of Pipe

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Description</th>
<th>Size Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP with Liner</td>
<td>Reinforced Concrete Pipe, per ASTM C76 (with PVC liner)</td>
<td>144-inch</td>
</tr>
<tr>
<td>HDPE Liner</td>
<td>High Density Polyethylene Liner installed in the field</td>
<td>132-inch</td>
</tr>
<tr>
<td>HDPE – Smooth Wall</td>
<td>High Density Polyethylene Pipe, per AWWA C906</td>
<td>63-inch</td>
</tr>
<tr>
<td>HDPE – Profile Wall</td>
<td>High Density Polyethylene Pipe, per ASTM D3350</td>
<td>132-inch</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride Pipe, per ASTM F679</td>
<td>60-inch</td>
</tr>
<tr>
<td>FRP</td>
<td>Fiberglass Reinforced Plastic Pipe, per AWWA C950</td>
<td>156-inch</td>
</tr>
<tr>
<td>PCP</td>
<td>Polymer Concrete Pipe, per ASTM D6783</td>
<td>102-inch</td>
</tr>
</tbody>
</table>

Based on the availability of products for the proposed size of 132-inch or 11-feet, the pipe materials that could be considered further include: HDPE liner, HDPE – Profile Wall pipe, FRP, and RCP with a corrosion liner. PVC, HDPE – Smooth Wall, and PCP will be dropped from consideration since they are not available in the size needed for the carrier pipe. Table 3-1 narrows the list of materials considered for double pass systems based on commercial availability and ability to meet the hydraulic sizing requirements of the SVCW Gravity Pipeline.

The remaining materials that met the hydraulic sizing requirements were considered further, using the major factors outlined in Table 2-1 to screen the most suitable materials for single pass and double pass tunnel systems. The advantages and disadvantages of the remaining materials were further evaluated, and recommendations are summarized in Section 3.4.

### 3.2.1 Liner Systems

Corrosion resistance is a particularly important issue for wastewater collection pipelines. Portland cement-based materials used to construct pipelines are highly vulnerable to attack by sulfuric acid, which is created by aerobic bacteria attached to the pipe above the water surface. This bacteria converts H₂S gas in the air into sulfuric acid. Liner system such as T-Lock (PVC) or concrete pipe
with embedded HDPE sheeting have been used to protect the concrete pipe from corrosion. Although RCP with a PVC type liner (T-Lock) has been used in the wastewater industry for over 40 years and is available in the pipe sizes considered for the Gravity Pipeline, pipes installed within the past 10 to 20 years have faced issues with weld seam failures of the liner. These failures expose the RCP pipe to sulfuric acid attack above the waterline, causing the concrete to deteriorate and the PVC liner to delaminate from the concrete, ultimately leading to pipe failure. In these applications, the corrosive nature of the wastewater has caused failure of the gaskets, deterioration of the concrete, and exposed rebar materials to be visible during CCTV internal inspection. Many of these pipelines are now scheduled for rehabilitation or replacement. Additionally, the weight of RCP in large diameters poses a challenge for tunnel installations. As pipe lengths decrease due to weight limitations the handling time increases, efficiency of labor decreases, and the risk of misalignment increases. The 12-inch wall thickness of the RCP would also require a larger diameter tunnel. Due to previously documented quality issues on several tunnel projects in the United States lined with T-Lock RCP, as well as constructability concerns with RCP, this option was not considered further.

Similarly, HDPE sheeting can be added following placement of the precast concrete segment initial support system. This system requires a layer of concrete be placed against the concrete segments while HDPE sheeting with protruding feet forms the interior face of the lining system. The quality of this field placement is lower than the factory applied approach previously mentioned. Additionally, this sheeting is initially applied to 330 degrees of the tunnel to allow rails in the invert of the tunnel to be used to transport the tunnel formwork and concrete. Most systems using this method conclude that corrosion below the water surface is not an issue and do not take the extra step to line this portion with HDPE. One manufacturer also indicates that leaving the bottom of the liner open prevents the buildup of hydrostatic groundwater pressure behind the liner; the hydrostatic pressure would be a factor for the Gravity Pipeline, which will experience high groundwater hydrostatic loads. Since the sheeting is being installed in the field, quality control of the field welding would be critical to preventing corrosion. Each of the member agency connections would also require a design that accommodates the use of the HDPE liner or provides a method for connecting to the system. The longevity of the proposed liner system is unknown and may not meet the proposed requirement for a 100-year design life. It is possible to place a layer of concrete in the bottom of the tunnel, after removal of the rails. The strength of this concrete and the quality of its placement can also have an impact on longevity of this element, which is continuously subjected to bed load abrasion.

This proposed approach was used in the new Singapore Deep Tunnel Sewerage System.

### 3.2.2 High Density Polyethylene (HDPE) Pipe – Profile Wall

HDPE profile wall pipe is considered suitable for wastewater applications due to its corrosion resistance. Profile wall pipe is defined as “a pipe wall construction that presents a smooth interior wall in the waterway but includes ribs, corrugations, or other shapes, which can be either solid or hollow, that helps brace the pipe against diametrical deformation” (ASTM F2306/F2306M). These corrugations in the pipe wall help stiffen the pipe and allow larger load handling capabilities.
HDPE profile wall pipe is typically supplied with gasketed joints. HDPE is an advantageous alternative for several reasons including its lightweight construction and flexibility. The longevity of HDPE profile wall pipe does meet the criteria of an estimated design life of 100 years, and it has been used in sewer applications throughout the United States. Installation of HDPE in a double pass system would also allow for adjustments in line and grade after the completion of tunneling. However, HDPE profile wall pipe has not been used in a tunneling application of this size, and the required special connections for the Gravity Pipeline could make constructability an issue for member agency connections to the Gravity Pipeline.

3.2.3 Fiberglass Reinforced Plastic Pipe

Two currently available types of fiberglass reinforced plastic (FRP) pipe were considered: Hobas and Flowtite. Hobas is centrifugally cast FRP, while Flowtite is mandrel-wound FRP. Both are considered flexible pipe, suitable for a large diameter wastewater interceptor pipeline. They are designed and manufactured for project-specific external loading conditions. FRP pipe is supplied with bell and spigot joints and is typically available in 20-foot segments, but can be manufactured in smaller segments to achieve curves and radii that meet the manufacturer's requirements for joint deflection. FRP connections of various sizes and configurations can also be constructed in the field to meet the requirements for the member connections and would allow the most flexibility for design.

Both Hobas and Flowtite have been successfully used on similar double pass tunneling projects throughout the United States, and have experience with multiple project installations. Hobas and Flowtite are both available in the range of sizes that are being considered for the Gravity Pipeline and provide a smooth surface for conveyance of the wastewater. The interior surface of FRP is an extremely corrosion resistant, durable material with the ability to handle grit and sediment that may be present in the SVCW is tunnel. However, if the surface of the FRP pipe is damaged it would have to be repaired to prevent corrosion by the same sulfuric acid that attacks concrete. FRP is evaluated further in Section 3.3 below.

3.3 Evaluation

An initial screening was performed of the tunnel/pipeline construction approach and materials, which includes tunnel and pipe material properties and material costs, not including installation. Two alternatives do not meet the requirements for life expectancy or are considered not suitable for the Gravity Pipeline based on material limitations. Both Type 1 Combisegments and PCSL with T-lock lined RCP are not recommended for further evaluation due to product limitations.

The options remaining for further evaluation include the following:

- PCSL w/HDPE Liner – Single Pass System
- Combisegments (Type 2) – Single Pass System
- Polymer Concrete (SolidCast QOR-TEQ) – Single Pass System
- PCSL w/HDPE Liner – Double Pass System
Each of these options has been evaluated using the following evaluation criteria:

- Cost
- Constructability
- Longevity
- Schedule
- Seismic resiliency

The evaluation considers that: 1) Only a relative ranking based on limited data at this point in the conceptual design process is possible, 2) Cost information is limited to materials only and does not include installation or labor costs, 3) Constructability is based on the perceived ease of construction and the effort required for installation of the tunnel/pipe system and connection to member agency collection systems, 4) Longevity addresses only the ability to meet the 100-year design life, 5) Schedule considerations include the potential risks in schedule creep associated with delays in shipping, fabrication of materials, and/or installation, and 6) Seismic resiliency includes consideration of the tunnel/pipe/shaft response to the effects of an earthquake, and how well the tunnel system will respond to the seismic event.

PCSL with HDPE Liner – Single Pass System – An HDPE liner installed in the factory would potentially offer increased quality control and would provide a 360 degree corrosion barrier. A similar application using PVC T-Lock was installed in the Upper Northwest Interceptor in Sacramento, California and was the first application in the world to utilize this single pass cast-in-place liner attached to a PCSL. Other tunnels primarily in the Middle East have used a similar system with an internal HDPE liner. Due to the limited applications, this product was given an unfavorable rating for longevity.

Each segment would require field welds at joints, seams and connections to member agencies. Additionally, any damage to the liner during shipment and tunneling operations would require repairs. These concerns resulted in an unfavorable rating for constructability.

During a seismic event, there is a concern for the liner displacing from the PCSL. Due to lack of information about the performance of the single pass lining system in a seismic event, this was given an unfavorable rating.

Should this option be considered further, more information on the quality of the HDPE liner, construction installation experience, and installation cost would need to be developed.

Combisegments (Type 2) – Single Pass System – This tunnel construction method features a relatively unused product. Until very recently, only one project had been constructed using Combisegments and it was an earlier version of this corrosion resistant product. It is important to
note that the manufacturer indicated during a meeting with SVCW that a new generation of combisegments is in development that eliminates use of pDCPD. Based on these factors, the product was given an unfavorable ranking for longevity. With current generation Type 2 Combisegments, the connections to member agencies could produce a constructability issue and a point for a future failure. For this reason, Combisegments was given an unfavorable rating for constructability.

**Polymer Concrete (SolidCast QOR-TEQ) – Single Pass System** – Polymer concrete segments received a slightly higher ranking than the Combisegments system because the material longevity is assured due to the lack of lining system which could be compromised during construction activities. The schedule for polymer concrete segments was ranked higher because the product would be manufactured in the United States. However, it was ranked lower than the PCSL with FRP Pipe – Double Pass System due to cost of materials, limited seismic resiliency and single pass grade tolerance requirements during tunneling. Additionally, connections of polymer concrete segments to member agency connections could cause constructability issues.

**PCSL with HDPE Liner – Double Pass System** – PCSL with a HDPE Liner installed over shotcrete is less costly than both FRP and HDPE material costs. However, the installation time and potential quality control concerns associated with field welding of the liner resulted in an unfavorable constructability and schedule rating. Since this liner product is relatively new, with limited installations, the longevity and seismic resiliency of this product are unknown, also resulting in an unfavorable ranking. Hand placement of a concrete filler in the invert after the rails are removed is also viewed unfavorably. If SVCW determines that potential savings of initial capital cost merits further evaluation, a detailed analysis of the installed cost of this option should be conducted. More information on installed applications and current conditions of the system in operation should also be obtained.

**PCSL with FRP Pipe – Double Pass System** – FRP received a favorable ranking for longevity of this material for use in the wastewater industry, as the corrosion protection of the interior surface of the FRP is excellent. However, if the interior surface of the FRP is damaged, exposing the core of the FRP, the FRP is subject to corrosion from acids in the sewer. Care must be taken to avoid scratching the interior of the pipe during construction. If damage to the FRP inner surface gel coat occurs during installation, it should be repaired prior to final acceptance. This alternative had the same ranking for schedule as HDPE because they are both manufactured relatively locally and are readily available. Since FRP would be used for member agency connections, FRP is favorable for constructability. The double pass system is also able to address constructability issues with finished grade requirements for the pipe after the tunneling is complete. A two pass system, where the clearance between the inside of the concrete segments and the outside of a carrier pipe (such as Hobas), is minimal, and may not provide an advantage over a single pass system. There are advantages to having flexibility to adjust for grade control, and this aspect of the double-pass system should be reviewed further in Progressive DB. The initial material cost of this alternative is
higher than other alternatives and must be evaluated further to compare the overall installed cost of each alternative.

**PCSL with HDPE Profile Wall Pipe – Double Pass System** – The material cost for HDPE is less than FRP. With a lighter weight and flexible pipe material, profile wall HDPE would provide ease of installation within the tunnel. A double pass system also allows for adjustments to address constructability issues with finished grade requirements for the pipe after the tunneling is complete. On that basis, HDPE Profile Wall Pipe was given a favorable rating.

While HDPE has a long history of use in the wastewater industry, HDPE in this size range is not believed to have been used in a tunneling application. Thus, HDPE received a neutral rating for longevity. The schedule for HDPE is similar to FRP since the product is manufactured in the United States and would be installed in a double pass application, thereby receiving a neutral rating. The seismic resiliency is favorable for HDPE with the double pass system, as are methods of connection of the joints.

### 3.4 Recommendations

This initial conceptual analysis indicates that a double pass system with a carrier pipe appears to offer the best opportunity to meet the specified longevity requirement for the Gravity Pipeline.

In order to provide the hydraulic capacity required for meeting diurnal and wet weather storage requirements, the availability of carrier pipes is limited to RCP, HDPE Profile Wall and FRP. Due to previous issues with RCP pipe and T-lock lining in the industry, this pipe did not meet the initial screening criteria for corrosion. The only remaining product with a proven industry track record for manufacturing, installation within a tunnel, and product support in this diameter would be FRP (Hobas or Flowtite). FRP also provides integrity of joints and the ability to handle grit and abrasive materials that appears to be capable of meeting the specified 100-year design life. Due to the critical nature of the Gravity Pipeline as the only means to convey member agency wastewater to the WWTP, and the difficulty of by-pass pumping of this line for future maintenance or rehabilitation, the double pass system with a carrier pipe is recommended for further consideration.

Balancing the initial capital cost against the long term operation and maintenance cost for the Gravity Pipeline over the required 100-year life could allow for the investigation of other products with limited industry track records. Additional research would be required to adequately determine the installed cost for alternative materials, understand quality control requirements, and address constructability concerns.

Following completion of the above evaluation process, SVCW requested that additional analysis be performed for alternative tunnel lining systems, which might offer the potential to reduce cost. As noted in Section 1.4. Documentation of this analysis is included as Table A-1 in Appendix A. The analysis indicates that the so-called "Castle Approach", developed by SVCW Staff, using High Performance Concrete with upstream dosing as two of the multiple layers of defense against corrosion, should be considered during further design of the project.
Section 4: Tunnel Excavation Criteria

4.1 Structural Design Criteria

Structural design criteria for the tunnel elements should be developed based on the following considerations:

- Design life and durability of pipe and lining materials.
- Infiltration and exfiltration requirements.
- Seismic classification.
- Required hydraulic capacity.
- Allowable deformations, settlements, and impacts to adjacent structures.
- Excavation method selection and equipment performance requirements.

Single pass and double pass tunneling systems have been evaluated for the Gravity Pipeline. This section focuses on a double pass system, referenced in Section 3.4. Using a double pass tunneling procedure, a tunnel excavation support system (concrete segments) would be installed as the tunnel excavation progresses. After excavation and installation of the concrete segments to form the tunnel excavation support system, a second pass would be made in which an interior lining system (i.e., carrier pipe) would be placed and the annular space would be filled with grout. The carrier pipe would convey the wastewater. The conditions for the Gravity Pipeline include a high groundwater table (including slightly artesian conditions at the WWTP site). Loading conditions used for design should incorporate this hydrostatic pressure. The design approach should be further updated based on the identified seismic considerations and the information from the geotechnical investigation, as the project is developed by the PDB.

Temporary loads would consist of overburden, soil lateral pressures, and surcharge pressures, including construction loads, traffic surface loads, water pressure and seismic loads. The combination of the concrete segments and final lining should be designed to withstand grouting pressures during construction and permanent loads consisting of overburden, soil lateral pressure, surcharge pressures due to surface traffic loads, hydrostatic pressure, and seismic loads. Buoyancy of the tunnel should also be checked.

The Gravity Pipeline is located between two of the most active major faults in the San Francisco Bay Area, namely the San Andreas Fault to the west and the Hayward Fault to the east. The distance from the alignment to the San Andreas Fault varies from 4.2 miles to 6.8 miles and to the Hayward Fault, from 19.6 to 39.2 miles. Both faults are defined as type “A” by the California Geological Survey (CGS) with a 30-year probability of an earthquake with magnitude equal to or greater than 6.7.

The seismic design of the sewer system should be based on the intended operational performance level the system must achieve in a post-earthquake disaster situation. For the SVCW Gravity Pipeline, the seismic performance of the sewer system should be determined by the PDB and SVCW, and a seismic importance category should be defined for the design of the system.
The seismic analysis should be performed using analytical and numerical approaches. The dynamic site-specific response to the earthquake should be analyzed and the maximum acceleration profile determined for both the ground surface and at the depth of the tunnel (the effects of acceleration forces are expected to be much less at the depth of the tunnel than on the surface due to the confined nature of the ground at depth). The seismic analysis should be based on the soil-structure interaction, and both the transverse effects (tunnel ovaling) and the longitudinal effects (tunnel curvature bending) should be evaluated.

The ovaling response of tunnels would be analyzed using a pseudo-static approach. A 2D finite element continuum model would be generated using a finite element program such as Plaxis or Flac. The longitudinal response of tunnels would be evaluated analytically or numerically using a 3D finite element structural model such as SAP®.

4.2 Tunnel Excavation

As the tunnel concept was developed, an evaluation was conducted to determine the optimum tunnel excavation method as well as the optimum initial tunnel support system. One of the most commonly used soft ground tunneling methods is conventional tunneling. It involves the use of a tunnel shield or soft ground tunnel boring machine (TBM) to excavate the tunnel and to provide support to the ground during excavation, a safe place to erect the initial tunnel support system, and a means of controlling ground loss and associated surface settlement during tunneling operations. The shield or TBM is advanced with hydraulic jacks that push against the tunnel support (initial support system) that is erected at the back end of the shield or TBM. Typically, the tunnel shield is utilized for the excavation of short tunnels in soft ground with good standup time that is above the groundwater table. The excavation of the tunnel with a shield is done by hand labor or a basic mechanical excavator. For long tunnels excavated in soft ground with difficult conditions and/or presence of a high groundwater table, the use of TBM is advantageous. The TBM allows the excavation to be performed mechanically with significantly higher progress rate of excavation. For the SVCW project, a TBM machine has been identified to excavate the tunnel.

Conventional tunneling requires personnel to enter the tunnel to remove muck, operate the TBM, and to erect the tunnel support system. It will also require additional space in the tunnel to accommodate tunnel utilities required during construction such as ventilation ducts, water pipes, power lines and a muck conveyor. To accommodate the workers, tools and equipment, it has been determined that the minimum required inner diameter of the conventional tunnel is approximately 11 feet. However, the maximum size for the tunnel will be adjusted to accommodate the selected hydraulics requirements and the tunneling sewer/lining system selected.

Typically, the selection of a horizontal alignment should endeavor to provide a minimum 1,000-foot radius to promote efficient driving of the TBM during tunneling and facilitate initial support and final lining installations. Conventional tunneling systems can accommodate horizontal and vertical curves with a minimum radius of 500 feet or less in special cases. On this project, an 800-foot minimum radius is utilized. Drive lengths are typically only limited by the ability to efficiently
transport materials (including carrier pipe segments) and equipment to the face and convey muck out of the tunnel. For the Gravity Pipeline, two tunnel drive lengths are envisioned; approximately 12,500 feet long drive between the Airport Access Shaft and the RLS Shaft and approximately 5,200 feet long drive between the Airport Access Shaft and the Bair Island Inlet Structure.

Since the tunnel will be constructed in soft ground with a high groundwater table, a pressurized face TBM will be required. Pressurization of the face can be accomplished by either earth pressure balance (EPB) or slurry. Both EPB and Slurry types of TBM stabilize the face to prevent water infiltration into the tunnel and ground losses at the tunnel face during excavation. Selection of the TBM machine mainly depends on the anticipated soil conditions. For the SVCW project, it has been determined that EPB TBM is best suited for the project, since the soils mostly consist of firm to stiff clays with high groundwater table and artesian conditions at a few locations along the alignment.

### 4.2.1 Tunnel Excavation Support

For a TBM-mined tunnel, ribs with liner plates, timber lagging, or a precast reinforced concrete segmental lining are typical options for initial support that can withstand the forces during TBM advancement. However, timber lagging can only be used if the groundwater table is below the invert of the tunnel. Since this project has a high groundwater table, timber lagging will not be considered for use on this tunnel project. For the Gravity Pipeline, it has been determined that reinforced concrete segmental lining is best suited for the Gravity Pipeline. Additional discussions of the liner system are included below.

Precast concrete segmental tunnel lining will serve as the excavation support element that maintains a safe underground opening during the tunnel excavation and the installation of the initial or final liner. The segments will be gasketed to minimize groundwater infiltration to the tunnel. They will be designed and detailed to follow the curvature and configuration of the selected tunnel alignment. Since the concrete segmental lining derives its stability solely from the support provided by the surrounding ground, grout will be placed in the annulus between the outside of the concrete segments and the excavated ground surface created by the slightly larger diameter TBM shield. This is done, as the tunnel advances, to eliminate voids behind the concrete segments to ensure that the lining has support all around its perimeter and aid in developing uniform pressures.

The construction loads on the segmental lining consist of handling and erection loads, all loads due to jacking in advancing the TBM, and surcharge pressures due to construction equipment. The characteristics of the surrounding ground should be modeled as a modulus of subgrade reaction at supports in structural analysis models. Ground characteristics should also be simulated as soil parameters in models using an integrative soil-structure interaction computer analysis program.
Section 5: Tunnel Construction

5.1 Summary of Tunneling

5.1.1 Soils Characteristics
The general subsurface conditions along the Gravity Pipeline alignment, as presented in the Final Draft Geotechnical Data Report (GDR) prepared by Geotechnical Consultants, Inc., consist of four soil layers: Artificial Fill (AF), Young Bay Mud (YBM), Upper Layered Sediments (ULS) and Old Bay Deposits (OBD). Bedrock was not encountered within the proposed depths of excavation for tunnel or shafts. For more information on the subsurface conditions, please refer to the GDR.

5.1.2 Alignment
The recommended horizontal and vertical tunnel alignment is documented in Planning Level TM No. 2 – Tunnel Alignment and Shaft Siting.

The horizontal alignment of the tunnel generally follows the path of Redwood Shores Parkway. Based on this established alignment, the tunnel will be constructed in two separate sections. The first section will launch from the Airport Access Shaft, located just north of the intersection of Shoreway Road and Redwood Shores Parkway (Holly Street), and continue northeast towards the SVCW WWTP. This tunnel section will terminate at the proposed RLS Shaft for TBM retrieval, located on the west side of the plant at the future site of the RLS. The second tunnel section will also launch from the Airport Access Shaft and continue south towards Inner Bair Island, where it will terminate at the proposed Bair Island Inlet Structure (BIIS). The BIIS will serve as the TBM retrieval shaft for this section of the project as well as a connection to the recently completed 48-inch force main, which will convey wastewater flow from the Cities of Menlo Park and Redwood City to the proposed tunnel.

The tunnel vertical alignment will be finalized based on the geotechnical investigation program, which was recently completed in April 2016. Ultimately, the Tunnel Team's preference is to place the tunnel in the ULS stratum, which has been identified below the YBM layer extending along the entire length of the proposed alignment. Recommended separation distance between the crown of the tunnel excavation and the YBM/ULS interface is explored in Planning Level TM No. 2.

From a tunnel constructability perspective, placing the tunnel excavation in the ULS stratum would reduce the risk of surface subsidence by enabling excavation in stiffer soils with longer stand-up time. It would allow better control at the tunnel face during excavation and minimize the ground movement at the tunnel support system before an interaction is established between the tunnel lining and the surrounding soil.

The tunnel will be sloped to aid the installation of the final lining and to provide positive drainage for the raw wastewater conveyed through the system. The tunnel slope and vertical curvature are explored in greater detail in TM No. 2.
5.1.3 Tunnel Boring Machine (TBM)

For the SVCW project, it has been determined that an Earth Pressure Balancing Tunnel Boring Machine (EPB TBM) (refer to Figure 5-1) is best suited for the project, since the soils mostly consist of firm to stiff clays with high water table and slightly artesian conditions. The EPB TBM resists the earth and hydrostatic pressure at the face by keeping the interior of the EPBM's plenum or pressure chamber filled with a mixture of excavated earth and additives as required. Face stability is achieved by controlling earth pressure in the pressure chamber. This is accomplished by adjusting the rate of muck removal through the screw conveyor.

As the tunnel excavation progresses, the pressure at the heading is maintained by adjusting the speed of excavated material removal and the forward thrust of the machine. The EPBM will be equipped with a jack propulsion system located in the tail of the machine. Key operational factors are:

- The EPBM is advanced by pushing off the previously installed lining.
- To control the face stability, the pressure of the excavated ground and water mixture within the pressure chamber is maintained within the required range.
- The plasticity of the excavated material is controlled at all times (modified as needed with additives) such that the screw conveyor can be used to control the pressures within the EPBM’s face and maintain a balance with outside water pressures.
- The thrust force of the machine will vary according to the ground conditions encountered.
5.1.4 Initial Excavation Support

The tunnel excavation will be stabilized using precast segments that are gasketed, and may require bolts (this requirement should be determined in design). The segments will keep the tunnel essentially watertight. Typically, they will be fabricated in an offsite facility and shipped to the site for installation. The segmental lining would be transported by trucks and stored in the Contractor's staging area at the Airport Access Shaft construction site.

The tunnel excavation support system (concrete segments) will consist of a universal ring (refer to Figure 5-2) with a key segment. The universal ring configuration is designed to satisfy project curvatures both horizontal and vertical (refer to Figure 5-3). The rings have two types of joints: circumferential and radial. The radial joints are connected with bolts or pins (refer to Figure 5-4) and the circumferential joints – with dowels (refer to Figure 5-5) The segments will be gasketed all around to keep the tunnel watertight.
Figure 5-1: Universal Ring – Section

Figure 5-2: Universal Ring - Isometric

Figure 5-3: Radial Joint
During the installation of each ring, guide rods (refer to Figure 5-4) are used between segments to aid in aligning them into position. They are placed in the guide rod slots (refer to Figure 5-6) at the radial joints of each precast segment. Often bolts are used, but in a sewer tunnel, elimination of bolts and use of pins could be desirable, if such elimination can be accommodated in the design. This is a topic for further review by the PDB.

As the tunnel advances, grout will be injected into the annular space between the outside of the concrete segments and the excavated ground surface. Grouting will be performed by injecting two part grout at the rear of the TBM shield to ensure continuous contact between the segmental lining and the surrounding ground. To minimize settlement, the pressures at the TBM face and around the shield are closely watched along with the quantity of muck removed compared to the diameter of the concrete segments and annular grout used. Probes (extensometers) just above the tunnel excavation are used to monitor settlement. Using these and other tunneling practices, settlement on the surface above the tunnel is expected, based on the information currently available, to be negligible.

**Figure 5-4: Circumferential Joint**
5.2 Constructability

5.2.1 Mobilization and Site Access
Construction will be staged at the Airport Access Shaft area. Construction trailers, security fencing and gates will already be on site from the shaft construction. The Airport Access Shaft will serve as an access point to place the tunnel TBM, tunnel liner installation entry point and backfill and contact grouting entry point. Electrical power for the tunnel construction activities will be provided by Pacific Gas and Electric Company (PG&E) through an electrical drop from overhead wires near the site.

A plan will be developed for the construction site to include egress/ingress, circulation, access management, emergency vehicles access, on-site parking and access to roadways. The shaft area will support material and muck storage and muck removal.

5.2.2 Tunnel Utility Operations
The utilities in the tunnel mainly consist of power cables to provide electricity to the TBM and for tunnel illumination, ventilation ducts, air and water pipes, and dewatering system. A compressed air system and lighting will be located along the tunnel walls.

It is estimated that the site will require approximately 2,950 KW of power. This value represents power requirements for the TBM, tunnel and site illumination, tunnel ventilation, dewatering
pumps, air compressor and muck conveyor, etc. The source for the electricity will be the local power company, PG&E. This will require building a medium-voltage drop from a PG&E line located at the job site.

Discussions with the PG&E Power Company indicate that sufficient power is available from the power lines running through the Airport Access Shaft site. A power drop will be made available during construction. The contractor will provide the necessary transformers for their equipment.

The tunnel ventilation system will consist of ventilation ducts and fans designed according to the standards for underground construction (29 CFR 1926.800) by the OSHA. The direction of mechanical air flow will be reversible.

5.2.3 Muck Handling Operations
The EPBM maintains face pressure by holding tunnel muck in a chamber and withdrawing the muck at a controlled rate using a fully encased screw auger called a screw conveyer. The mucking is realized through a screw conveyer; this essential component facilitates the mucking operation. A conveyer system within the TBM transports the excavated material from the screw conveyer to the rear of the TBM and then into muck cars or a belt conveyer. Muck cars would travel on rails from the TBM to the Airport Access Shaft, where the excavated material would be transported to the surface. If a belt conveyer is selected for the project, it would be supported on the top or side wall of the tunnel. As the tunnel excavation progresses, subsequent sections of the belt conveyer would be attached to the conveyer at the muck receiving station to accommodate increased length of tunnel. Description of muck handling operations at the surface is further discussed in TM No.4 – Shaft Construction.
Tunnel muck disposal site is selected at the Airport Access Shaft. This area will provide the launching point for the TBM and the location from where muck will be removed from the tunnel and construction materials will enter. The Airport Access Shaft work area will provide sufficient
space for mucking and equipment operations, muck storage, drying of wet muck before hauling off the site, material storage, and treatment of construction discharge water.

Drive lengths are typically only limited by the ability to efficiently transport materials and equipment to the face and convey muck out of the tunnel. The lengths on this project of approximately 12,500 feet between the Airport Access Shaft and the RLS Shaft and approximately 5,200 feet between the Airport Access Shaft and the Bair Island Inlet Structure are within the limits of typical constructions methods.

### 5.2.4 Tunnel Cleanup

Prior to the final liner pipe installation, all debris in the tunnel, fans, ventilation ducts, water lines and power and light wiring will be removed. The tunnel will be prepared for the carrier pipe. Depending on the installation method chosen by the PDB, the rail tracks may be left in place for installation of the carrier pipe.

### 5.2.5 Pipe Placement

If a double pass tunneling system is chosen for the final Gravity Pipeline configuration, then a carrier pipe will need to be placed into the tunnel for flow conveyance. The final lining pipe will be lowered down the Airport Access Shaft onto a transporter positioned at the bottom of the shaft and then transported to the RLS Shaft end and, in a separate operation, towards the Bair Island Inlet Structure. The pipe carrier will be used to align the pipe to its final position. For each reach, the pipe will be installed sequentially along the alignment until the Airport Access Shaft is reached.

In general, 10 to 20 foot sections of pipe will be installed. Shorter sections may be utilized within curves to prevent angular joint deflections in excess of manufacturer’s guidelines. The installation of the pipe will be performed according to a prepared pipe laying schedule to ensure that the alignment radii and required spacing of grout holes is maintained. Methods of following line and grade will be implemented to verify that the alignment and elevation of the pipe are within the applicable tolerances.

At the ends of each pipe section, supports will be placed at several points around the circumference, including the invert and a few other locations as determined by analysis (for pipe grouting operations), to block the pipe in place. Adjustable supports above the pipe, such as wooden blocking, will also be installed before coupling to stabilize the pipe during grout placement, prevent floatation, and maintain grade control. For the section between the Airport Access Shaft and the RLS Shaft, bulkheads may be utilized during backfill grouting for each reach or the pumps may be moved along the section.

After installation of pipe supports, a pipe pusher will be used in order to join the pipe and couplings together. During connecting of the pipe sections, point loading of the pipe and the couplings will be avoided. After placement, and where applicable, each joint of the carrier pipe will be pressure
tested for leakage before proceeding to the next joint. For joint testing equipment, refer to Figure 5-9 below.

![Figure 5-8: Final Lining Joint Testing](image)

5.2.6 Annular Space Grouting

Assuming a double pass system will be chosen for the tunnel, grouting behind the carrier pipe will be necessary. Since the carrier pipe derives its stability entirely from the support provided by the surrounding medium, low density cellular grout backfill will be placed in the annulus between the initial support and the final lining (carrier pipe). Backfill grouting will be placed from the interior of the pipe through grout plugs in order to fill the void behind the final lining pipe and ensure that the pipe maintains support around its entire perimeter.

After each section of the final lining pipe is installed in the tunnel and stabilized with blocking or other methods, the annulus between the initial support and the final lining will be grouted with low density cellular concrete backfill. Bulkheads will be constructed for the section of tunnel between the Airport Access Shaft and the RLS Shaft at each reach of pipe being backfilled.

The low density cellular concrete backfill will consist of cement, cement-silica, cement-pozzolan, lime-silica or mixes containing all these ingredients with a foaming agent. The grouting will be placed in several lifts, as determined by analysis of the pipe-in–tunnel in order not to produce excessive stresses and/or deformations in the pipe.
5.2.7 Monitoring Program

Operating the TBM with the correct parameters, settlement monitoring and mitigation plans are critical in minimizing and/or preventing settlements at the surface. To ensure the success of tunnel excavation, real time monitoring of the TBM and surface geotechnical monitoring program will be used.

The EPBM provides positive control of the tunnel face and thus reduces the risk associated with ground settlement. Even so, if the tunnel envelope is over excavated for any reason, a void may form behind the tunnel shield. Settlement can occur if the void travels to the ground surface. Therefore, over excavation of the tunnel will be avoided, and grouting of the void behind the precast concrete segments will be conducted as the segments emerge from the TBM to further reduce risk of surface settlement.

Other potential conditions that could produce one or more settlements at the ground surface are loss of face stability and ineffective grouting of the annular space excavated by the TBM. These potential settlements are generally caused by insufficient control of soil and groundwater pressures, over excavation of the soil materials and/or poor workmanship, as further indicated below:

- Face loss due to stress relief at the tunnel face resulting in the soil either moving towards or away from the cutterhead.
- Overcutting of the opening at the edge of the EPBM shield to reduce frictional forces on the machine.
- Closure of the tail void gap in soils that have insufficient "stand up" time before the gap can be grouted.
- Consolidation of relatively soft soils due to changes in total stress and pore water pressures that may occur during tunneling operations.

EPBM related settlements can be mitigated by proper control of the face pressure and pressure in the shield area, balance of tunnel advance and excavated muck volume rates, use of two part grouts at the rear of the TBM shield and proper design and use of soil conditioners.

Tunneling related settlements in soft ground are usually expressed at the ground surface by a settlement trough, which extends perpendicular to the tunnel alignment centerline. The settlement trough generally extends along both sides of the tunneling operations an equal distance from the centerline and the distance that the trough extends is related to the diameter of tunnel excavation and depth of the tunnel spring line below the ground surface.

Within the extent of the settlement trough, building structures, bridge foundations, paved surfaces (roadways and sidewalks), concrete curbs and individual utility poles can be affected by settlement resulting from tunneling activities. In addition, underground pipelines and conduits located within the extent of the trough can also be affected by settlement.
In order to minimize the potential settlement related to tunneling activities, various control and monitoring actions will be implemented during tunneling operations. Control and monitoring for tunnel excavation involves measuring of several operational parameters. Some of these parameters include:

- The volume of muck removed via the screw conveyor at the TBM head,
- The volume of additives (considering their effect on the volume of muck),
- The volume of grout placed to fill the annular space behind the segments, and
- The rate of advancement of the TBM.
- Pressure at the TBM face
- Pressure around the TBM shield

Careful operation of the excavation equipment and monitoring for a proper balance of the monitoring parameters will result in a successful project. Control and monitoring will be done in real time by operators in the tunnel, where adjustments can be made rapidly. Using these and other good tunnel practices, settlement on the surface above the tunnel is expected to be negligible, based on currently available information.

Secondary monitoring will be performed from the ground surface to confirm that settlements are negligible. It is prudent to perform monitoring of structures and paved areas within the settlement trough extent that could be damaged from settlement.

The geotechnical monitoring program will be designed to monitor ground behavior during the excavation and construction of the tunnel and associated structures. The program will provide timely warning before surface movements occur in connection with tunnel excavation activities of any type. If movements are recorded, the Contractor will stop his operations and modify his methods and procedures of construction to avoid unacceptable ground movements.

Regular periodic recording of instrument readings and data review/evaluation will be specified to assess ground behavior near the tunnel and along the anticipated settlement trough. The program for this project would include instruments to measure vertical ground movements along the sewer alignment, settlement/tilting of structures and utilities, tilting of utility poles and groundwater fluctuations throughout the tunnel alignment. Specifically, the type of instruments required for the project will include:

- Surface Settlement Markers installed on building walls and foundations to measure vertical displacement.
- Subsurface Shallow Settlement Indicators installed adjacent to foundations and over underground utilities to measure settlement or installed in pavement/ground to measure settlement near the ground surface.
- Deep Settlement Indicators installed at intervals just above the tunnel excavation for early indications of any soil settlements.
• Tiltmeters to measure rotational movement of vertical walls and utility poles.
• Crackmeters to determine if existing cracks in structures are progressively widening.
• Control observation wells installed adjacent to shafts to measure groundwater levels.

Prior to commencement of work, a pre-construction survey will be implemented to document the existing conditions of all structures located entirely or partially within the tunnel influence zone. The pre-construction survey will document interior and exterior condition of all structures within the width of the calculated settlement trough to provide a baseline of data for evaluating construction claims.
REFERENCES


Appendix A
Gravity Pipeline Interior Alternatives Evaluation

PURPOSE
As Silicon Valley Clean Water (SVCW) moves the Gravity Pipeline forward to design and construction, CIP budget constraints have necessitated development of alternatives to significantly reduce the Gravity Pipeline cost. Alternative solutions to protect the inside of the gravity pipeline from corrosion over 100 years offer a possibility for significantly reducing the project cost. This evaluation explores various alternatives, including installing a pipe in the tunnel, lining the tunnel, and using multiple layers of defense to protect an unlined concrete tunnel from corrosion. Costs, opportunities, and risks associated with the alternatives have been reviewed as part of the evaluation to provide decision makers with preliminary information that could be used to support selection of one or more alternatives for further evaluation during the upcoming Progressive DB process.

BACKGROUND
Silicon Valley Clean Water (SVCW) is undertaking improvements to the reliability of its wastewater conveyance system serving the cities of Belmont, Redwood City, and San Carlos, and the West Bay Sanitary District. SVCW’s Conveyance system has reached the end of its useful life and needs to be replaced. A Conveyance System Master Plan was issued in 2011. The Master Plan included replacing the existing 48-inch and 54-inch sections of the SVCW Influent Force Main with a new high-density polyethylene (HDPE) pipeline and replacing or rehabilitating the four pump stations. Replacing the 54-inch section would involve open trench construction through Redwood Shores Parkway, a residential area, or complex construction along and in the toe of a FEMA protective levy. Many members of the public and the City of Redwood City indicated that either of these proposed projects would cause significant disruption and inconvenience to Redwood Shores’ residents or potentially place their protective levy at risk. In response SVCW decided to evaluate alternative alignments and construction methods.

The conveyance system alternatives analysis identified over 140 pipeline alignments. These alignments included different routes, construction methods, and modes of operation (e.g., gravity and pressurized transmission pipelines). Each alignment affected the scope, cost, and operation of the other nine projects in the CSMP. Variations included eliminating some pump stations, changing the capacity of the headworks, operating the pipelines in a gravity mode versus a force main mode, and adding flow equalization capability at the WWTP. Based on a feasibility assessment, these 140 alternatives were reduced to 15 feasible alternatives.

A “success factor” based alternative analysis was developed and executed by the SVCW’s Conveyance System Planning Group to evaluate the top 15 alternatives. Success was defined by
SVCW in terms of costs, operations, maintenance, safety, schedule, and stakeholder impacts. An evaluation process was built around these success factors and used for an alternatives analysis. This extensive evaluation process resulted in the recommended alternative for the Wastewater Conveyance System Reliability Improvement Project. This alternative analysis began in October 2014, and was completed in March 2015. The recommended alternative, referenced during the analysis period as Alternative 4BE, is now referred to as the Gravity Pipeline, and includes use of a tunnel boring machine to install a gravity pipeline, three low-head pump stations, flow diversion, a receiving lift station, odor control, headworks, and influent connector pipeline.

Between August and October, 2016, SVCW initiated a supplemental study to evaluate a set of alternatives for the interior of the Gravity Pipeline, focusing on the approach for protecting the inside of the Gravity Pipeline from corrosion.

This Appendix presents a summary of the evaluation of alternative approaches to Gravity Pipeline interior materials. The evaluation considered construction and operational strategies for the proposed Gravity Pipeline related to protection of the interior of the gravity pipeline from corrosion.

ALTERNATIVES EVALUATION APPROACH

The evaluation of Gravity Pipeline interior materials involved a group process, based on methodology similar to the approach taken for identifying the Gravity Pipeline alignment. This approach involved a meetings-based approach to share information, discuss technical questions, and to conduct the scoring for each alternative. The process was led by SVCW, and facilitated by Kennedy/Jenks.

Team

The team included SVCW internal and external technical resources.

The SVCW technical team included:

- SVCW Engineering Department: Bruce Burnworth (Gravity Pipeline PM), Kim Hackett
- SVCW Operations and Maintenance: Bob Huffstutler, Rosendo Gallegos
- SVCW Gravity Sewer construction Peer reviewers: Matt Fowler (Parsons Brinckerhoff)
- SVCW-contracted specialty consultants: Jim Joyce (corrosion), Jose Pacheco (CTL - research arm of Portland Cement Association)
- Construction Management – Joe Covello, Mike Jaeger (Tanner Pacific)
- CIP Program support – Roya Joseph (WBA)

The Kennedy/Jenks team involved in this effort included:

- Kennedy/Jenks: Al Shewey, Xiangquan Li, Theresa Pedrazas, Mark Minkowski, Kathy Fretwell, Bob Ryder, Mark Nelson
- COWI North America: Tom Kwiatkowski, Ivona Tarchala
Initial Review of Alternatives

As part of preparation for the project kick-off, the team received Table A-1, which combined information prepared by the SVCW Project Manager with information compiled by Kennedy/Jenks. Table A-1 (included in this Appendix) provides a summary of alternative lining materials that were brought to the evaluation process for consideration. All but one of these materials was described in the main text of Planning Level TM No. 3. Subsequent to the preparation of TM No. 3, another alternative was identified and brought to the group for consideration by the SVCW Project Manager. This alternative is included in Table A-1 as the “multi-strategy” alternative. The other alternatives in Table A-1 include variations on placing a pipe inside the tunnel and variations of lining the tunnel (one pass or two pass).

Description of Multiple Layers of Defense Alternative

The Multiple Layers of Defense against Corrosion Alternative (also referenced herein as the multi-strategy alternative) was developed by SVCW for comparison to other Gravity Pipeline construction alternatives that have already been considered at the concept level (See main text of Planning Level TM No. 3). In general, the multi-strategy alternative incorporates multiple layers of defense that address each of the steps involved in corrosion related to sewage. Microbially Induced Corrosion (MIC) includes four basic steps:

1) Solids in sewage provide a food source for bacteria that create H₂S if there are no oxygen or nitrate molecules available.
2) H₂S in solution comes out of solution into the air in the sewer if the pH is low and with turbulence.
3) H₂S in the air is converted by bacteria on the moist surface of the pipe to create H₂SO₄
4) H₂SO₄ eats away at cement paste in concrete

The Multiple Layers of Defense against Corrosion Alternative features multiple material and operation strategies with the goal to provide a 100 year-plus service life for the Gravity Pipeline. This approach includes four main parts to address the four main steps in MIC:

1) Continuation of upstream Bioxide dosing to reduce H₂S formation in the wastewater,
2) Adjustments to pH and laminar flow to reduce the movement of H₂S from water to air,
3) Enhanced air movement and biocide to reduce conversion of H₂S to H₂SO₄, and
4) Acid resistant precast concrete tunnel segments with sacrificial thickness to provide for extended useful life of the concrete structure in an acid environment.

The latest description of the Multiple Layers of Defense against Corrosion Alternative, compiled by the SVCW Project Manager, is included in this Appendix. This latest version is a more concise description of the alternative than was available at the time the alternatives analysis was performed.
EVALUATION OF ALTERNATIVES

The evaluation of alternatives was conducted in a series of meetings.

- Kickoff – Review and screening of alternatives
- Review and definition of evaluation criteria and risk issues
- Evaluation meeting – scoring of alternatives
- Workshop – review and discussion of alternative scores
- Department Head Presentation – summary and recommendation

Review and screening of alternatives (Kickoff)

As noted, prior to the kick-off meeting, a summary of the multi-strategy alternative was circulated to the team. The review provided an opportunity to learn the conceptual details of the alternative and to identify potential fatal flaws, if any.

The review of alternatives, discussion of fatal flaws, and initial screening of alternative were conducted in an initial team kick-off meeting and conference call involving the SVCW technical and Kennedy/Jenks teams. Meeting minutes from the 23 August 2016 meeting to document the discussion are included in this Appendix.

As summarized in Table A-1, the list of alternatives that passed the screening review for further evaluation are (Alternative numbers presented here correspond to final evaluation tables):

- Alternative 1A – HDPE Liner on segments
- Alternative 1B – PVC Liner on segments
- Alternative 1C – Telene Gasket Connection (Combisegments Type 2)
- Alternative 2 – Multi-Strategy Alternative
- Alternative 3A – FRP Pipe (double-pass)
- Alternative 3B – HDPE Profile Wall (double-pass)

Evaluation Criteria and Risk Issues – Review of Criteria and Risks

With the list of remaining alternatives resulting from the screening process, the next step in the evaluation process involved a review of the criteria to be used for the evaluation and also the key issues to be considered for the risk analysis. The evaluation criteria were based on the SVCW Conveyance Program success factors, and the risk issues were specific to the interior alternatives; the risk analysis involved assessing probability and consequence of the occurrence of specific issues, and identifying potential mitigations.

The criteria and risk issues were reviewed and modified as appropriate in a single small-group meeting between the SVCW Project Manager and the Kennedy/Jenks team, consisting of staff...
and subconsultants. Results of this activity involved a list of criteria and risk issues for use in the evaluation of alternatives; the list from the 30 August 2016 meeting is included in this Appendix.

**Evaluation Meeting - Scoring of Alternatives**

Using the criteria and risk information compiled from the initial small-group meeting, the same group (consisting of the SVCW Project Manager and Kennedy/Jenks team) scored the alternatives. The scoring exercise involved two parts:

- Scoring the alternatives in terms of the criteria related to Program success factors
- Scoring the alternatives in terms of the risk probability and consequence of the different risk issues identified during the previous meeting.

Using the scoring information, Kennedy/Jenks collected and summarized the criteria scores and risk ratings from the Evaluation Meeting in tabular form, using the format used for the previously completed alignment alternatives analysis. A similar activity was conducted to compile the success-factor scores and risk rating scores into a similar graphical quadrant scoring chart used to show relative rankings in terms of success and risk for the alignment alternatives.

**Workshop**

The tabulated criteria and scores were presented to the larger technical group (see “Team” above) in a workshop format on 14 September 2016. This meeting followed the format of the currently-suspended Tunnel Design Team meetings, and included soliciting commentary on all facets of the process. The summary table, and graphical comparison of success vs risk, were provided to the meeting attendees before the Workshop to allow time for review and development of questions and input. The format of the meeting involved review of each of the “small-group” scores for commentary by the larger group. Each score for the success factors and risk criteria was reviewed and modifications from the “small-group” scores were recorded in the table.

Kennedy/Jenks prepared meeting minutes to document action items and any changes to the evaluation results coming from the workshop discussion. The minutes, and the summary tables are included in this Appendix.

**Conveyance System Department Head Meeting Presentation**

Using the results of the larger team workshop, a presentation was made at a Department Head meeting on 22 September 2016. Minutes from that meeting are included in this Appendix.

**Additional Work Needed to Evaluate the Multiple layers of defense alternative.**

There is early promise that the Multiple Layers of Defense against Corrosion Alternative may offer a solution that is cost effective and could provide a 100 year life. Additional work should be conducted by SVCW and the PDB to further develop and evaluate this alternative.
The strength of the Multiple Layers of Defense Alternative lies in the number of ways that a concrete pipeline, to be used as a wastewater carrier pipe, can be protected from corrosion. Both the number of protection methods (Layers) and the value of each merits further development. As an example, the use of chemicals to inhibit formation of H₂S and therefore H₂SO₄ is well established and has a long history of use. High Performance Concrete and sacrificial thickness also have a long history of use to resist corrosion and protect against its effects. Bacteria disruptors are also familiar in the industry for reducing bacterial activity. Air movement in sewers and laminar liquid flow have a long history of use in reducing corrosion and odors in sewer pipes. Less is known about the combined use of these layers of defense as described in this Appendix. Also recent advances in each of these areas warrant additional investigation.

To add strength to the Multiple Layer of Defense Alternative all layers should receive further development and evaluation as to their compatibility, costs and benefits. This should include collecting additional sewer system characteristics especially during warmer summer months to better understand the level of H₂S that is and will be produced and the amount of upstream dosing that may be required to minimize concrete mass loss due to corrosion. Further research into biocides is needed to confirm compatibility with specific concrete mixes and determine if the benefits are worth the added costs. Some layers such as concrete mix enhancements and sacrificial concrete thickness, once implemented, may provide protection of the tunnel without need for future commitment to layers of defense that require operational continuity and expenses (upstream dosing, and air movement). High and low value layers of defense in the Multiple Layers of Defense approach need to be identified so that more effort and resources can be focused on the high value layers.

One part of the path to accomplishing this goal is a robust and defensible research and testing program, which will require SVCW funding and time allowance to complete. It is the success of this testing effort that will provide clearer insight into this concept for SVCW.
<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
<th>Min. Tunnel Diameter (ID – ft)</th>
<th>Corrosion Control</th>
<th>Interceptor ID (ft)</th>
<th>PCSL Weight Per Foot (lbs)</th>
<th>Corrosion Protection Weight Per Foot (lbs)</th>
<th>Installed PCSL Base Const. Cost Per Foot</th>
<th>Additional Const. Cost for Corrosion Protection per foot</th>
<th>Total Const. Cost per foot</th>
<th>Expected System Life per manufacturer (yrs.)</th>
<th>Concerns</th>
<th>Suitable for further Consideration in SVCW Tunnel (Yes/No)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PCSL with HDPE Liner</td>
<td>Precast Concrete Segments with an embedded HDPE Liner (field welded joints)</td>
<td>13</td>
<td></td>
<td>13</td>
<td>4,900 (assumes 9-inch thick segments)</td>
<td>Negligible</td>
<td>$5,100</td>
<td>$300</td>
<td>$5,400</td>
<td>100+</td>
<td>Field welds at each joint higher risk due to quality control and seismic limitations, concrete corrosion potential at liner holes</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Type 1</td>
<td>Type I, a design variant of a Combisegments®, lining panel, combines a smooth chemical resistant liner and liner frame (one piece), The frame incorporates an EPDM sealing gasket for water tightness. Includes a honeycombed structure made of polypropylene (PP) throughout the reverse surface of the main pDCPD liner.</td>
<td>13</td>
<td></td>
<td>13</td>
<td>4,900 (assumes 9-inch thick segments)</td>
<td>Negligible</td>
<td>$5,100</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Not currently being promoted by manufacturer, honeycomb liner bond may fail under hydrostatic groundwater pressure, no positive (embedded) anchor system used</td>
<td>No</td>
</tr>
<tr>
<td>3. Type 2</td>
<td>Type II, most recent design variant of a Combisegments®, each PCSL individually lined, HDPE liner connected to a Telene®-pDCPD liner frame using Reaction Injection Molding (RIM) Technology, with EPDM gasket.</td>
<td>13</td>
<td></td>
<td>13</td>
<td>4,900 (assumes 9-inch thick segments)</td>
<td>Negligible</td>
<td>$5,100</td>
<td>$400</td>
<td>$5,500</td>
<td>100+</td>
<td>System has not been installed anywhere, gaskets at joints may have seismic limitations, unknown longevity EPDM/HDPE joints, concrete corrosion potential at liner holes, cost may increase after first installation</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Polymer Concrete</td>
<td>Proprietary product from “SolidCast Polymer Technology” called QOR-TEQ. This product is a FRP reinforced polymer concrete segmental liner using internal cores to reduce weight, while still retaining strength and reducing cost.</td>
<td>13</td>
<td></td>
<td>13</td>
<td>2,200 (assumes 7-inch thick segments with constructed voids)</td>
<td>NA</td>
<td>Unknown</td>
<td>NA</td>
<td>Unknown</td>
<td>100+</td>
<td>System has not been installed anywhere, gasket joints may have seismic limitations</td>
<td>No</td>
</tr>
<tr>
<td>5. HDPE Liner in cast-in-place Concrete</td>
<td>Precast Concrete Segmental Liners with an HDPE liner (mechanically anchored) installed into a 9-inch thick cast-in-place liner system, after the segments have been installed.</td>
<td>13</td>
<td></td>
<td>11.5</td>
<td>4,900 (assumes 9-inch thick segments)</td>
<td>4,300 (assumes 9-inch thick poured in place concrete)</td>
<td>$5,100</td>
<td>$1,500 (ballpark est.)</td>
<td>$6,600</td>
<td>100+</td>
<td>Field welds at joints have higher risk due to quality control, concrete corrosion potential at liner holes, const. schedule</td>
<td>Yes</td>
</tr>
<tr>
<td>6. FRP Pipe</td>
<td>Precast Concrete Segmental Liner with FRP carrier pipe. Both Hobas and Flowlite have indicated that an 11-foot diameter (132-inch) pipe can be supplied.</td>
<td>13</td>
<td></td>
<td>11</td>
<td>4,900 (assumes 9-inch thick segments)</td>
<td>1,300</td>
<td>$5,100</td>
<td>$3,600</td>
<td>$8,700</td>
<td>1,000+</td>
<td>High cost, const. schedule, construction issues due to small annular space (9”), gasket joints may have seismic limitations</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Planning Level TM No.</td>
<td>Description</td>
<td>No.</td>
<td>Notes</td>
<td>Initial Cost</td>
<td>Materials Costs</td>
<td>Replacement Costs</td>
<td>Notes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----</td>
<td>-----------------------------------------------------------------------</td>
<td>--------------</td>
<td>-----------------</td>
<td>--------------------</td>
<td>---------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>RCP Pipe</td>
<td>Precast Concrete Segmental Liner with RCP-T-Lock (PVC) lined concrete carrier pipe.</td>
<td>15</td>
<td>RCP – 12” thick wall, T-Lock lined pipe - welded along all seams with gasketed joints</td>
<td>11 (12-inch thick wall)</td>
<td>5,100 (assumes 9-inch thick segments)</td>
<td>6,000</td>
<td>High cost, const. schedule, larger tunnel required, construction issues due to small annular space, gasket joints may have seismic limitations, bond may fail under hydrostatic groundwater pressure, concrete corrosion potential at liner holes</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Profile Wall HDPE Pipe</td>
<td>Precast Concrete Segmental Liner with Profile wall HDPE carrier pipe. Requires grouting of annulus between the HDPE pipe and the PCSL.</td>
<td>13</td>
<td>HDPE pipe with gasketed joints</td>
<td>11 (7-inch thick wall)</td>
<td>4,900 (assumes 9-inch thick segments)</td>
<td>400</td>
<td>Largest installation to date in a tunnel is 66-inch diameter, gasket joints may have seismic limitations, construction issues due to small annular space, high cost, const. schedule, coating of crown of tunnel may be needed in 40 or 50 years</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Multi-Strategy</td>
<td>Continued chemical dosing to control sulfides, Precast Concrete Tunnel Segments with High Performance Concrete and biocide</td>
<td>13</td>
<td>Control of sulfides in sewer, High Performance Concrete, biocide</td>
<td>13</td>
<td>5,000</td>
<td>Negligible</td>
<td>If continued chemical dosing is not done, coating of crown of tunnel may be needed in 40 or 50 years</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**
Planning Level TM No. 3 is subject to comment from SVCW.

**ABBREVIATIONS:**
- HDPE: High Density Polyethylene
- PCSL: Precast Concrete Segmental Liner
- PVC: Polyvinyl Chloride
- SFRC: Steel Fiber Reinforced Concrete
- pDCPD: Polydicyclopentadiene
- HPC: High Performance Concrete
CASTLE APPROACH
ALTERNATIVE
Multiple Layer Defense against Corrosion
Unlined Tunnels Conveying Sewage

Understanding the Attackers:
What are the sewage and tunnel characteristics that induce corrosion?

Microbially Induced Corrosion involves multiple steps:
1. Solids in sewage converted to dissolved H₂S gas in absence of oxygen,
2. H₂S gas coming out of solution into the pipe airspace,
3. Concentration of H₂S in the airspace,
4. H₂S gas in the airspace being converted by bacteria on moist surface to H₂SO₄,
   and
5. H₂SO₄ destroying the concrete surface and corroding steel rebar

MIC attacks increase in ferocity as temperatures rise, detention times increase,
dissolved oxygen is not available, air flow slows, concrete is easily penetrated by
acids allowing steel rebar to corrode and concrete spall.

Corrosion varies dramatically with these variables. Understanding how these
variables affect MIC for a specific section of sewer is critical to an appropriate
design that defends against MIC attack at every process step.

The Pantheon's dome, built 2000 years ago, is still the world's largest unreinforced concrete dome.
CASTLE APPROACH
ALTERNATIVE
Multiple Layer Defense against Corrosion
Unlined Tunnels Conveying Sewage

Goal: Achieve a 100 year sewer life using precast High Performance Concrete tunnel segments without the high cost and potential failure of a liner.

1. Upstream dosing to control $H_2S$ formation in sewage (Calcium Nitrate available in water avoids production of $H_2S$) . . . needed for odor control regardless

2. Upstream dosing to control the release of $H_2S$ from sewage (pH adjustment)

3. Design for laminar (smooth) flow to minimize release of $H_2S$ from water

4. Enhanced air movement in tunnel to minimize concentrations of $H_2S$ and reduce moisture level required for bacterial growth

5. Biocide in concrete to reduce bacterial action turning $H_2S$ into $H_2SO_4$

6. High Performance Concrete precast segments (specific concrete design to resist $H_2SO_4$ attack . . . e.g., dense concrete with steel fibers) . . . needed for corrosive soils outside regardless
   a. Dense concrete to reduce acid penetration into concrete
      i. Low water to binder ratio
      ii. High binder content (50/50 Type II/V cement, slag, fly ash, silica fume)
      iii. Superplasticizers to make mix workable
   b. Steel fiber instead of rebar to reduce failure due to steel corrosion and related concrete spalling
   c. Calcareous aggregate (limestone) to provide broader base for $H_2SO_4$ to act on rather than concentrating just on cement paste
   d. Plastic dowels and pins instead of steel bolts
   e. Sacrificial concrete thickness making use of difference between concrete thickness for temporary and permanent loads (e.g., 12” design for TBM ram resistance and 6” design for permanent loads provides 6” of sacrificial concrete without compromising structure)
   f. Double gaskets (front and back of segment thickness) in association with double thickness of sacrificial concrete

7. Eliminate surfaces where acid producing bacteria can grow . . . all surfaces biocide infused concrete

8. Monitoring to confirm performance
   a. Real time monitoring of sewage constituents from member agencies and at tunnel entrances (e.g., temperature, dissolved oxygen, dissolved $H_2S$, pH)
   b. Annual inspections at inlets
   c. 10 year robotic inspections of tunnel
CASTLE APPROACH
Multiple Layer Defense against Corrosion

Multiple layers of defense were used in medieval castles and are now used in modern electronics systems.

The “Layers of Defense” concept is used extensively in protecting electronic/industrial data and in home security.

ESRI, Microsoft, RedHat, SimpliSafe (home security), HIPAA (health care), Siemens AG (oil and gas) and others all rely heavily on a layered approach to protect critical assets.

http://simplisafe.com/resource/layered-defense/
CASTLE APPROACH
ALTERNATIVE
Multiple Layer Defense against Corrosion

Next Steps in Determining Applicability to SVCW

To determine applicability to SVCW’s Gravity Pipeline several areas require further investigation
including characteristics of the sewage entering SVCW’s system and confirmation of concrete
segment design concepts. These analyses and others will help SVCW determine during final design
which layers of defense are cost effective and appropriate for inclusion in the final design.

Characteristics of the sewage entering SVCW’s system

Why: The extent of Microbial Induced Corrosion (MIC) and the amount of upstream dosing needed
to control MIC are largely a function of the characteristics of the sewage entering the system and
design parameters that affect the sewage once in the system. The design parameters affecting MIC
can be addressed during design if we have a good understanding of the sewage characteristics
entering the system. MIC has less of an impact on pipelines when the temperature of the sewage is
low and dissolved oxygen levels are high. Dissolved oxygen levels can be monitored and controlled
and are a function of many other sewage characteristics that can also be monitored and controlled
(e.g., detention time [http://www.lgam.info/detention-time], Biological Oxygen Demand, pH).

Needed: Survey of sewage characteristics entering the SVCW system including temperature, DO,
BOD, pH, Dissolved H₂S, H₂S, air flow, detention time. Having this information as it varies by season
and time of day would be useful in estimating the level of expected MIC as well as the amount of
upstream dosing needed to control MIC in SVCW’s proposed gravity pipeline.

Then during design calculations can be performed estimating the amount of upstream dosing
required to control MIC. The life of the proposed gravity pipeline can then be estimated if un-lined
concrete segments are used both with and without upstream dosing.

Confirmation of concrete segment design concepts

Why: Substantial project cost savings ($50m to $60m) can be realized if a fiberglass reinforced pipe
(FRP) does not need to be placed inside the excavated tunnel with concrete segments. Eliminating
the FRP requires that the concrete segments not only need to resist corrosion from the exterior soils
but also the MIC inside the pipe. Many factors affect the ability of High Performance Concrete
segments to resist MIC including: use of steel fibers vs. steel rebar, type of binders used, binder to
water ratios, excess thickness of concrete segments for construction loads compared to permanent
loads, use of plastic pins to allow elimination of steel bolts, addition of biocide to the concrete,
aggregate size, type of aggregate, and use of double gaskets. The confidence associated with
combining these various concrete segments together to address SVCW’s specific needs would be
enhanced by sample production and testing. This sample production and testing will take months of
effort and starting prior to selection of a contractor for progressive design-build would benefit the
overall project schedule.

Needed: Define various concrete segment samples to be produced and tested. Arrange to have the
samples produced at various precast concrete segment plants (Traylor, CSI, Precast Management).
Arrange to have the samples tested for effectiveness.

Then during design project calculations can be performed for SVCW’s project based on the samples
produced and tested.
SVCW Gravity Pipeline Component – Interior Alternatives Evaluation Kick-Off Meeting
Minutes – 23 August 2016, 1:30PM to 3:00PM PST
Meeting Location: SVCW Fishbowl Conference Room, Conference Call

Attendees:

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim Hackett</td>
<td>SVCW</td>
</tr>
<tr>
<td>Bruce Burnworth</td>
<td>SVCW</td>
</tr>
<tr>
<td>Bob Huffstutler</td>
<td>SVCW</td>
</tr>
<tr>
<td>Rosendo Gallegos</td>
<td>SVCW</td>
</tr>
<tr>
<td>Mark Minkowski</td>
<td>K/J</td>
</tr>
<tr>
<td>Al Shewey</td>
<td>K/J</td>
</tr>
<tr>
<td>Theresa Pedrazas</td>
<td>K/J</td>
</tr>
<tr>
<td>Xiangquan Li</td>
<td>K/J</td>
</tr>
<tr>
<td>Bob Ryder</td>
<td>K/J</td>
</tr>
<tr>
<td>Kathy Fretwell</td>
<td>K/J</td>
</tr>
<tr>
<td>Mark Nelson</td>
<td>K/J</td>
</tr>
<tr>
<td>Tom Kwiatkowski</td>
<td>COWI</td>
</tr>
<tr>
<td>Ivona Tarchala</td>
<td>COWI</td>
</tr>
<tr>
<td>Brad Moore</td>
<td>STC</td>
</tr>
<tr>
<td>Bob Donaldson</td>
<td>CSC</td>
</tr>
<tr>
<td>Matt Fowler</td>
<td>PB</td>
</tr>
<tr>
<td>Joe Covello</td>
<td>COV</td>
</tr>
<tr>
<td>Mike Jaeger</td>
<td>TPI</td>
</tr>
<tr>
<td>Jim Joyce</td>
<td>CTL</td>
</tr>
<tr>
<td>Jose Pacheco</td>
<td>CTL</td>
</tr>
<tr>
<td>John Roller</td>
<td>CTL</td>
</tr>
<tr>
<td>John Gida</td>
<td>CTL</td>
</tr>
<tr>
<td>Roya Joseph</td>
<td>WBA</td>
</tr>
</tbody>
</table>

I. Introductions
   a. Review meeting objectives and format
   b. Objective: to define gravity pipeline interior alternatives to consider in pre-design and design
      i. Goal of this meeting is for group members to understand the alternatives and come up with a short list of alternatives to be considered further (process of elimination from the current list and potentially add alternatives).
   c. Format:
      i. SVCW PM and Kennedy/Jenks team will use outcome from 8/23 meeting, to adapt the success factor scoring criteria, then develop scoring in "small group" format.
      ii. During 9/14 workshop, large group will review and modify small group entries; this is a comparative analysis of alternatives, identifying which should be ranked higher/lower.
      iii. Results will be taken to 9/22 SVCW CIP Department Head (DH) meeting attended by technical, CM, legal, permitting, CEQA, discipline leads to get their input.
      iv. Information from DH meeting will be taken to SVCW executive management, which will convene a separate meeting to make decision on which interior alternative(s) to carry forward to preliminary design.

II. Review Evaluation Process
   a. Today’s meeting: review alternatives to be considered
      1. Group considered questions and additions to the alternatives presented in the pre-meeting version of Table 1 (on Dropbox) summarizing a wide spectrum of options. Group assignment during this meeting was to discuss alternatives and recommend whether to carry forward for further analysis.
      2. Group discussion:
         a. PVC T-Lock identified as additional option. T-Lock has mixed record, generally not favorable for durability so was not identified for further study. However, recommendation from Jim Joyce to retain this alternative for comparison to HDPE liner applied to segments.
         b. CIPP identified as added option. CIPP reviewed with limitations for this application in diameter and required installation coverage distance between access points. Added to Table 1 and identified not to carry forward.
         c. Option added by CTL representatives: Stirling Lloyd’s Integritank spray-on lining system as an option to multi-strategy use of biocide. Discussion of uncertainty regarding durability of adhesion to inside surface of tunnel excavation support ring segments. Full suits and respiratory equipment required for installation. Added to Table 1 and identified not to carry forward.
d. Upstream chemical addition: discussion of anticipated approach to use, including dosing point and frequency. Review of current SVCW practice of using calcium nitrate (Bioxide) dosed at the San Carlos PS (annual operational costs estimated at $300,000).
   i. SVCW anticipates future use at this frequency, with dosing moved upstream to the RWC PS.
   ii. Group review of requirements for 100-year service life, including continued availability and use of chemical addition. Chemical addition to remain part of the multi-strategy approach.

e. Sampling program: SVCW will be getting dissolved sulfide and oxygen and BOD in the upstream member agency systems to record dissolved H2S concentrations.

f. Discussion of conveyance system without liner pipe. For segmented systems installed in soft ground, questions about allowable inflow rates, success rates for removing water, and water pressure behind a lining system (if any).

g. Discussion with COWI regarding segments and water infiltration: 1) the joint systems of the segments, if properly designed and installed, can be essentially water tight with little to no infiltration, 2) the segments themselves (concrete) are not impermeable, and water will penetrate segments and usually evaporate before anything occurs.

h. Review of air sparging systems that, if installed inside the tunnel, would require access to maintain. SVCW will not install components or systems in the tunnel that are less durable than the segments. No process or mechanical systems will be installed in the gravity tunnel that require regular staff maintenance.

i. Discussion of constructability of installing a pipe in the tunnel with limited annular space. Question whether there would be value in increasing the diameter of the tunnel bore to accommodate, possibly by an aggregate of 1 foot in additional diameter.

III. Questions and comments regarding alternatives

a. Reviewed Draft Comparison Table and Multi-Strategy Alternative description

b. Discussion of alternatives in the meeting version of Table 1 (on Dropbox) to identify fatal flaws and recommendation for further study:
   i. Item 1: HDPE Liner. No need for welding in tunnel after segments installed, similar to Combi Type II. Quality assurance is the fatal flaw per CTL input. Limited installations (Agru makes the liner among others). Segment lining system to be included for further study.
   ii. Item 1A: T-Lock (PVC liner). Included for comparison to Item 1, included for further study.
   iii. Item 3: Combi Type I. Apparently no longer supported by Herenknecht, with no known installations. Not recommended for further study.
   iv. Item 4: Combi Type II. Prior use limited, with in-progress projects, not yet completed. Lining systems to be evaluated; included for further study.
   v. Item 5: Polymer Concrete. No evidence concrete segments have been fabricated from this material. Pipe is manufactured in this material. High cost with limited to no track record compared to other alternatives. Not recommended for further study.
   vi. Item 6: Separate HDPE liner grout base layer that contacts inner wall surface of segment concrete (example: Singapore project). Requires second pass to install liner and grout layer. Manufacturer not responsive for providing a cost or timeframe. Jim Joyce and CTL referenced concerns that, under diurnal storage conditions, force of releasing flow could cause the liner to pull away. Not recommended for further study.
   vii. Item 7: FRP with pipe. Considered a standard approach for mitigating potential corrosion for large diameter tunnels that carry raw wastewater. Has high cost compared to other alternatives. Included for further study.
   viii. Item 8: RCP. Not considered feasible for this application and removed from consideration.
### Criteria Notes

<table>
<thead>
<tr>
<th></th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alternative lasts a minimum of 100-years without rehabilitation or replacement.</td>
</tr>
<tr>
<td>2</td>
<td>What is the R&amp;D Premium?: cost related to being first (also relates to risk eval)</td>
</tr>
<tr>
<td>3</td>
<td>What is requirement for Line &amp; grade control; set criteria for acceptable deviation prior to pre-design?</td>
</tr>
<tr>
<td>4</td>
<td>Alternative has a barrier to internal corrosion that is either part of the wastewater carrier pipe system or segments in combination with protective operational strategies (including chemical and/or O2 addition)?</td>
</tr>
<tr>
<td>5</td>
<td>Conformance to original goal of SVCW to limit number of joints in the conveyance pipeline.</td>
</tr>
<tr>
<td>6</td>
<td>What is impact of joint seal performance?: hydraulic performance when the segmental liner stones are not flush across the joint.</td>
</tr>
<tr>
<td>7</td>
<td>Gasket connection surfaces - what level of protection from corrosion to prevent loss of gasket integrity?</td>
</tr>
<tr>
<td>8</td>
<td>System meets seismic requirements with appropriate redundancy.</td>
</tr>
<tr>
<td>9</td>
<td>If the soil in which the tunnel will be constructed continue to settle, with the potential to settle differentially, what impact on seismic and water resistance performance? (Checking with Neel on this scenario)</td>
</tr>
</tbody>
</table>

### Comments

- Addressed in success and risk tables.
- Addressed in risk tables.
- "Bellies" in pipe: how many acceptable, how much deviation from centerline. Clearance for pipe installation acceptable? (During predesign, talk to COWI and PB re: tolerance “circle” criteria from other projects) What impact on production rate? What impact on hydraulic performance?
- Sacrificial scenario is not acceptable; avoid segment wall section deterioration. Prevent corrosion. Segment design for handling loads (critical design case): thickness based on this, which is likely greater than permanent in-place loads. SVCW guidance/policy. Risk of system failure (addressed).
- Addressed in production rate risk and quality control.
- Risk of this occurring addressed in tables: system failure, risk of rehab. In design for any system, can design to respond to seismic with adequate safety factor. Connections to shafts will be key design area.
- Consider in pre-design phase. Differentiator? Gasketed pipe in compressible soils that could cause problems?
ix. Item 9: Profile Wall HDPE pipe, similar to FRP pipe. Largest known installation is 66” diameter. Jim Joyce reported seeing 120” just not in tunnel. Diameter of tunnel would be larger than that for FRP equivalent, due to large HDPE pipe wall thickness. However, material and technology considered potentially feasible; included for further study.

x. Item 10: Multi Strategy Concept to manage potential for corrosion. Combines operational requirements with dense high-performance concrete, and biocide additive. Included for further study.

xi. Item 11: CIPP - See discussion Section II. Not recommended for further study.

xii. Item 12: Integritank – See discussion Section II. Not recommended for further study.

IV. Additional Alternatives (reviewed in Sections I and II)

V. Alternatives to be considered further in alternatives review process: short list

a. List comes from updated Table 1
   i. HDPE Liner (cast with segment)
   ii. T-Lock (PVC liner).
   iii. Herrenknecht Combi Type II.
   iv. FRP pipe in tunnel.
   v. Profile Wall HDPE
   vi. Multi-Strategy
**SVCW Gravity Pipeline Component Project – Alternative Materials Evaluation**

Large Group Meeting - Minutes  
Minutes – 14 September 2016, 11:00am to 2:00pm  
Meeting Location: SVCW Pelican Room

Attendees:

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
<th>Name</th>
<th>Company</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim Hackett</td>
<td>SVCW</td>
<td>Al Shewey</td>
<td>K/J</td>
<td></td>
</tr>
<tr>
<td>Bob Huffstutler</td>
<td>SVCW</td>
<td>Mark Minkowski</td>
<td>K/J</td>
<td></td>
</tr>
<tr>
<td>Rosendo Gallegos</td>
<td>SVCW</td>
<td>Theresa Pedrazas</td>
<td>K/J</td>
<td></td>
</tr>
<tr>
<td>Bruce Burnworth</td>
<td>SVCW</td>
<td>Mike Jaeger</td>
<td>TP</td>
<td></td>
</tr>
<tr>
<td>Matt Fowler</td>
<td>PB</td>
<td>Xiangquan Li</td>
<td>K/J</td>
<td></td>
</tr>
<tr>
<td>Joe Covello</td>
<td>COV</td>
<td>Tom Kwiatkowski</td>
<td>COWI</td>
<td></td>
</tr>
<tr>
<td>Jim Joyce</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brad Moore</td>
<td>STC</td>
<td>Roya Joseph</td>
<td>WBA</td>
<td></td>
</tr>
<tr>
<td>Jose Pacheco</td>
<td>CTL Group</td>
<td>John Gajda</td>
<td>CTL Group</td>
<td></td>
</tr>
</tbody>
</table>

*Unfortunately due to a family emergency Jim Joyce was unable to participate in the meeting.*

Note that some of the comments and scoring described below was modified during the Department Head meeting on September 22.

I. **Summary of Progress To Date**

a. **Scoring tables** – results are included in the attached summary table and chart.
   i. In the criteria scoring meeting on September 7, the smaller group including K/J, COWI, STC, Bruce, and Joe Covello, discussed the alternatives and prepared draft criteria and risk scores. The results from this meeting were distributed to the larger group last week in advance of this meeting. All information is available on Dropbox.
   ii. The alternatives and their traits were summarized again for the group. One-pass alternatives include HDPE with Field Welding (Alternative 1A), PVC with Field Welding (1B), Telene Connecting Gasket to HDPE such as Combi-segments Type II (1C), and high-performance concrete (HPC) with upstream dosing for corrosion control (2). Two-pass systems include FRP pipe-in-tunnel such as Hobas or Flowtite (3A) and HDPE Profile pipe (3B).
   1. All alternatives anticipate the use of chemical dosing for odor and/or corrosion control.
   2. Discussion of using concrete resistive to corrosion. The soils within the project vicinity are corrosive, so exterior soil corrosivity will need to be factored into the design of the construction materials.

b. **Discussion of multi-layered defense approach (Bruce)**
   i. Bruce provided a brief presentation inspired by an IT-related presentation about the Defense concept multiple layers of protection.
   ii. Summary of the HPC defense approach (Alternative 2) with upstream dosing and additional (multiple) layers of protection from corrosion. No tunnel lining would be included for this option. Construction materials and techniques such as biocide concrete additive, Type II/V cement, other admixtures, steam curing to avoid micro-cracking, as well as thicker concrete than needed for permanent loads and enhanced air circulation could be used as a multi-layer defense system against MIC.
   iii. Inclusion of all defense layer options in the multi-layer concept to be considered when evaluating this alternative further in pre-design.
c. Discussion of concrete thickness and joint integrity.
   i. Review of wall thickness assumption, which will be developed during design stage and
      will be based on loads anticipated for transportation and handling of the segments,
      which may be higher than the in-place loads the segments will see after installation.
   
   ii. Discussion of joints between segments as a source of leakage and potential risk for
      water infiltration related to Alternative 2 (i.e., no interior lining system). One approach
      reviewed: if leakage has been a significant issue in other tunnels, double gaskets have
      been used toward both the inside and outside surfaces of the segment wall section.
      This information was reported based on discussions with precast segment
      manufacturers and tunnel designers, including Traylor Bros (the precast concrete
      segmental liner manufacturer in Stockton, CA). See III.b.ii.2 below for discussion of
      leakage.

d. Development of Capital and Life Cycle Costs
   i. The capital cost values do not include soft costs; they are considered construction cost
      estimates (summary scoring table column headings were adjusted to reference these
      costs as Construction Costs vs Capital Costs).
   
   ii. Cost for alternative 3A is based on COWI construction cost developed during the Project
      Development phase. This alternative estimate has the highest degree of confidence for
      accuracy and is the most detailed cost estimate developed to date.
   
   iii. The other alternative estimates start with the estimate for Alternative 3A, and create
      estimates for other alternatives based on appropriate subtractions and additions from
      this base alternative.
   
   iv. Discussion that Alternative 2 (no interior liner) may have a higher design cost as a
      percentage of construction costs compared to the lower design cost for FRP (Alt 3A);
      anticipate there should not be a high cost of designing a pipe inside a tunnel.
   
   v. Discussion regarding the weighting of cost Alt 3A versus estimates for the other
      alternatives, particularly related to life cycle costs (LCC).
      1. Discussion that the LCCs, as currently calculated, do not address the risk associated
         with long-term maintenance cost for some alternatives compared to others. The risks
         associated with the potential cost of rehab, if needed, are addressed in the success
         and risk factor evaluations.

II. Lunch Break)

III. Review of Scores
   a. Criteria Scores (attached table)
      i. At the time of the meeting, SVCW management had not yet discussed the weighting of
         criteria.
      
      ii. Criteria scoring evaluation for 100-year service life assumes good quality construction
          for all alternatives.
      
      iii. The Cost category success factor evaluation (first five factors) assumes dosing will be
          needed for odor and corrosion control on all alternatives.
      
      iv. Discussion of the risk that future Operations staff will discontinue upstream dosing at
          one or more points during the 100-year service life. Risks of potential cost impacts for
          not dosing upstream are addressed in scoring of multiple success and risk factors.
v. Discussion whether all alternatives should be judged based on the assumption that with good quality construction and good O&M practices, all the alternatives are likely to have a 100 year service life.

vi. The greater potential for joint issues for an alternative with more linear footage of joints was discussed as was the potential need for repair as part of the clean up at the conclusion of initial construction. The repair of joints in segments is typically accomplished through the use of chemical grout injection to stop the leak. Durability of the injected grout was discussed.

vii. Discussion of leaks included highlighting that criteria should not require each alternative to be completely leak-free for 100 years, but criteria should establish a requirement that leaks do not undermine the integrity of the gravity pipeline system. See III.b.ii.2 below for discussion of leakage.

viii. Debate conducted regarding durability of the high-performance concrete segments if upstream chemical dosing is discontinued at one or more points during the 100-year service life. Question whether significant concrete rehab work would be required at some point during the 100 year service period. Discussion of multi-strategy concept, which was developed to provide redundant protections for the concrete such that, should one of the protective elements be degraded or discontinued, the combination of the other elements would provide continuing protection.

1. Example of multi-strategy protection provided from Jim Joyce (via report of conversation with SVCW) that biocide would not be needed to achieve a 100 year service life if appropriate upstream dosing is consistently preformed.

ix. Discussion of limited industry experience high-performance concrete (as defined in the multi-strategy approach description) with biocide tunnels and/or pipes conveying raw wastewater. Discussion included reference to common practice of using concrete in raw wastewater sewers for many years, including SVCW conveyance piping. Without special provisions for protection, concrete use for sewer interceptors has typically resulted in corrosion issues. Multi-strategy concept has been developed to address the main agents that promote corrosion. The dosing, biocide additive, and thicker HPC of this alternative must be designed for the specific sewage and environmental characteristics (e.g., detention time and temperature) that impact MIC rates. SVCW is planning to collect the needed information over the coming months.

x. Discussion of different scales used for success factor criteria scoring. Some criteria are scored on a scale of 1 to 3 and some scored on basis of 1 to 4. Discussion about standardizing the scoring range. This topic to be addressed with SVCW Management and addressed separately.

xi. Review of assumptions for inspections of conditions inside the tunnel and shafts. Inspections are assumed to involve full-length of the tunnel and are to be completed once every 10 years for each alternative.

1. Discussion regarding applicability of inspections for all alternatives.

2. Variation in the need for inspections across the different alternatives is addressed in the success and risk factors (e.g., “Location & Ease of more frequent supplemental inspections (<10yrs)”)

xii. Group review resulted in the addition of a fine criteria item to be scored for long-term water tightness. See III.b.ii.2 below for discussion of leakage.

xiii. Stakeholder Impacts category was scored the same for all alternatives. These criteria were scored to provide completeness to the evaluation.
b. Risk Scores - results are included in the summary table and chart.
   i. Discussion of use of biocide.
      1. Clarification that biocide would be included as part of the precast concrete segment manufacture process, and is not applied on-site.)
      2. Comments that concrete used in the SF-Oakland Bay Bridge used a similar HPC concrete mix (without biocide) with chloride penetration resistance. Mix referenced in the discussion as a “bridge concrete mix”.
      3. One biocide manufacturer, BASF, was contacted prior to the meeting and was reported to have stated that their biocide admixture is compatible with all BASF concrete additives and has no negative affect on HPC performance.
      4. Discussion of use of fiber-reinforcement in segment concrete mix. This approach to reinforcing is rapidly becoming more common in segment mix design. The supplemental use of conventional reinforcing in a portion or all of a specific segment section was indicated as depending on the anticipated loads, and the need would be clarified during a future design process.
      5. Biocide questions
         a. Question whether steam curing during segment manufacturing might affect biocide effectiveness. Report from early contact with BASF: they indicate biocide would still be effective after steam curing.
         b. Question whether biocide will impact strength properties of fibers or wire cage. Recommendation from CTL for testing of the biocide in the mix design to evaluate performance.
   ii. Updates to risk scoring based on team discussion
      1. Updated probability and consequence ratings for risk related to conventionality of the proposed construction techniques for each alternative.
      2. Updated ratings for risk of future environmental damage from groundwater leakage into the conveyance system through joints in conveyance carrier piping. The leakage concern relates to groundwater that has elevated salinity: what is the potential impact on WWTP process of saline groundwater entering the tunnel?
         a. Discussion whether groundwater salinity and volume of inflow would result in a major impact to the WWTP process. SVCW Operations staff indicated no expectation of impacts and no difference was reflected in the risk scores.
         b. Updated scores for all alternatives to reflect this discussion.
      3. Updated ratings for risk of upstream dosing not continuing during service life of the alternatives.
      4. Added a risk criterion concerning risk of biocide in concrete mix being ineffective coupled with stoppage of upstream dosing.
      5. Updated ratings for risk that maintenance rehab will be needed within 100 years.

IV. Next Steps
   a. Present recommendations at Department Head meeting, September 22
   b. SVCW Management actions
      i. Apply weights to scores in success factor and risk score tables
      ii. Decision on which interior material alternative(s) to carry forward to pre-design
Silicon Valley Clean Water  
Gravity Pipeline  
Interior Alternatives Analysis  
**Cost Estimate Table**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Construction Cost (millions)</th>
<th>Project Cost (1.58 X Const. Cost) (millions)</th>
<th>Total Life Cycle Cost for 50 Years of Beneficial Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A. HDPE Field Welding</td>
<td>$117</td>
<td>$185</td>
<td>$213 (millions) $220 (Base) $241 (High)</td>
</tr>
<tr>
<td>1B. PVC Field Welding</td>
<td>$115</td>
<td>$182</td>
<td>$210 (millions) $216 (Base) $236 (High)</td>
</tr>
<tr>
<td>1C. Telene Connecting Gasket to HDPE</td>
<td>$119</td>
<td>$188</td>
<td>$217 (millions) $224 (Base) $245 (High)</td>
</tr>
<tr>
<td>2. HPC Segments with Upstream Dosing</td>
<td>$107</td>
<td>$169</td>
<td>$195 (millions) $201 (Base) $220 (High)</td>
</tr>
<tr>
<td>3A. Hobas or Flowtite</td>
<td>$163</td>
<td>$258</td>
<td>$296 (millions) $306 (Base) $334 (High)</td>
</tr>
<tr>
<td>3B. HDPE Profile</td>
<td>$164</td>
<td>$259</td>
<td>$298 (millions) $308 (Base) $337 (High)</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Alternatives 1A, 1B, 1C, 2, and 3B are approximate costs based on the March 2016 cost prepared by the Kennedy/Jenks Team for pipe-in-tunnel with Hobas or Flowtite (Alternative 3A).

2. Alternative 1A. HDPE Field Welding capital cost based on adjustment to cost of Alternative 1C (Combisegments). Subtracted $2M from Alternative 1C.

3. Alternative 1B. PVC Field Welding capital cost based on adjustment to cost of Alternative 1A. Subtracted $2M from Alternative 1A.

4. Alternative 1C Telene Connecting Gasket to HDPE cost based on quote from Herrenknecht for Combisegments Type II.

5. Alternative 2 HPC Segments with Upstream Dosing cost based on subtraction of $62M for March 2016 planning level costs for pipe-in-tunnel, and addition of $6M to account for Biocide and markups.

6. All life cycle cost (LCC) estimates are based on sewer inspections once every 10 years.

7. Assume upstream dosing to prevent corrosion will be similar to odor control dosing, which is needed for all alternatives. Alternative 2 will have similar exterior corrosion protection to all other alternatives. Added risk for Alternative 2 is embedded in the risk score evaluation.
### Success Factor Evaluation

**Gravity Pipeline Interior Alternatives Analysis**

<table>
<thead>
<tr>
<th>Metric</th>
<th>LA, TEPE - Field Welding</th>
<th>1B, PVC - Field Welding</th>
<th>1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting</th>
<th>3B, Tunnel of Pipeline</th>
<th>3C, TEPE Field</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>$117</td>
<td>$115</td>
<td>$119</td>
<td>$107</td>
<td>$163</td>
<td>164</td>
</tr>
</tbody>
</table>

**Initial Costs**

- **Construction Cost of Tunnel**: $Million (2015)**
  - **LA, TEPE - Field Welding**: $117
  - **1B, PVC - Field Welding**: $115
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: $119
  - **3B, Tunnel of Pipeline**: $107
  - **3C, TEPE Field**: $163

**Long Term Costs**

- **LA, TEPE - Field Welding**: $Million (2015)**
  - **LA, TEPE - Field Welding**: $117
  - **1B, PVC - Field Welding**: $115
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: $119
  - **3B, Tunnel of Pipeline**: $107
  - **3C, TEPE Field**: $163

**Long Term Factors**

- **Life Cycle Costs of Tunnel**: $Million (2015)**
  - **LA, TEPE - Field Welding**: $117
  - **1B, PVC - Field Welding**: $115
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: $119
  - **3B, Tunnel of Pipeline**: $107
  - **3C, TEPE Field**: $163

**Operational**

- **Location & Ease of Main Frequent Supplemental Inspections (>12/mo)**
  - **LA, TEPE - Field Welding**: 1.0
  - **1B, PVC - Field Welding**: 1.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 2.0
  - **3B, Tunnel of Pipeline**: 2.0
  - **3C, TEPE Field**: 3.0

- **Point for Accessing of Steel and Concrete (Granite & Concrete, LANB, AGS, 3A, Ribs, Tunnel Limiting)**
  - **LA, TEPE - Field Welding**: 3.0
  - **1B, PVC - Field Welding**: 3.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 3.0
  - **3B, Tunnel of Pipeline**: 3.0
  - **3C, TEPE Field**: 3.0

- **Flow Equalization & Flexibility in Operations**
  - **LA, TEPE - Field Welding**: 3.0
  - **1B, PVC - Field Welding**: 3.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 3.0
  - **3B, Tunnel of Pipeline**: 3.0
  - **3C, TEPE Field**: 3.0

**Maintenance**

- **Long Term Water Tightness (No Test Proofs)**
  - **LA, TEPE - Field Welding**: 1.0
  - **1B, PVC - Field Welding**: 1.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 1.0
  - **3B, Tunnel of Pipeline**: 1.0
  - **3C, TEPE Field**: 1.0

- **Insulation of Interiors**
  - **LA, TEPE - Field Welding**: 1.0
  - **1B, PVC - Field Welding**: 1.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 1.0
  - **3B, Tunnel of Pipeline**: 1.0
  - **3C, TEPE Field**: 1.0

- **Cement of Interior**
  - **LA, TEPE - Field Welding**: 1.0
  - **1B, PVC - Field Welding**: 1.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 1.0
  - **3B, Tunnel of Pipeline**: 1.0
  - **3C, TEPE Field**: 1.0

- **Need for Annual Coating (Liner) on Gravity Pipeline Interior (wk’s, months, years)**
  - **LA, TEPE - Field Welding**: 3.0
  - **1B, PVC - Field Welding**: 3.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 3.0
  - **3B, Tunnel of Pipeline**: 3.0
  - **3C, TEPE Field**: 3.0

**Future Rehabilitation**

- **Number of Required Plant Operations (Maintenance)**
  - **LA, TEPE - Field Welding**: 3.0
  - **1B, PVC - Field Welding**: 3.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 3.0
  - **3B, Tunnel of Pipeline**: 3.0
  - **3C, TEPE Field**: 3.0

**Ease of Maintenance**

- **No special means required for routine maintenance or PM activities**
  - **LA, TEPE - Field Welding**: 1.0
  - **1B, PVC - Field Welding**: 1.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 1.0
  - **3B, Tunnel of Pipeline**: 1.0
  - **3C, TEPE Field**: 1.0

**Design Elements that Affect Maintenance**

- **Shafts easy to maintain**
  - **LA, TEPE - Field Welding**: 1.0
  - **1B, PVC - Field Welding**: 1.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 1.0
  - **3B, Tunnel of Pipeline**: 1.0
  - **3C, TEPE Field**: 1.0

**Gravity Pipeline**

- **One year or two year construction**
  - **LA, TEPE - Field Welding**: 3.0
  - **1B, PVC - Field Welding**: 3.0
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: 3.0
  - **3B, Tunnel of Pipeline**: 3.0
  - **3C, TEPE Field**: 1.0

---

**Notes:**

- Assumptions: good construction quality and regular inspections + dosing (if required).
- **Score** indicates level of satisfaction:
  - **1.0**: Excellent
  - **2.0**: Good
  - **3.0**: Fairly Good
  - **4.0**: Poor
  - **5.0**: Very Poor

**Comments:**

- **LA, TEPE - Field Welding**: $213 to $241
  - **1B, PVC - Field Welding**: $210 to $236
  - **1C, Tunnel (Pumping Station in 1B), 3A, Ribs and Tunnel Limiting**: $217 to $245
  - **3B, Tunnel of Pipeline**: $195 to $236
  - **3C, TEPE Field**: $298 to $337

- Assumes inspections frequency and costs are the same for all alternatives. Assumes no rehabilitation in 50 year life cycle period.

- Assumes repair rear and 6% of total.
### Silicon Valley Clean Water

#### Gravity Pipeline Interior Alternatives Analysis

#### Success Factor Evaluation

<table>
<thead>
<tr>
<th>Category</th>
<th>Green Criteria</th>
<th>Fine Criteria</th>
<th>Quantifying Criteria for Each Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Interior pipe and constr. Pipeline</td>
<td>Low (11-100 FT wide, 100+ FT long)</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Need for repairs</td>
<td>Likely along entire length 1.0, avoid but have some damage along length 1.0, many over 100%</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Scars welding required in underground locations</td>
<td>Scars welding in tunnel (1), no welding (8)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Operations Safety</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Constr./Schedule</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity Pipeline constr. schedule &amp; maintenance</td>
<td>Current schedule (1), &amp; months less (2), one year less (3)</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>General Impacts</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sum of Score:** 55 54 57 59 63 63

*HPF Bus 366 yr life provided other ongoing resource calculations.*
<table>
<thead>
<tr>
<th>Category</th>
<th>Risk issue</th>
<th>Weighting</th>
<th>Probability</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Construction cost escalation risk (Cost increase if escalation per year is 3% instead of 4%)</td>
<td>2</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Risk related to how conventional is the proposed construction techniques (impacts to use of bid well for SV/CW)</td>
<td>3</td>
<td>4</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Risk of cost of future environmental damage assessments from leaks</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Risk of production rate lower than planned</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Operation</td>
<td>Risk of system failure</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Risk of spills</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Risk that upstream dosing not continued (Bioxide, O2 or functional equivalent)*</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Risk that both Bioxide in concrete mix ineffective &amp; upstream dosing stopped</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Risk items that could affect</td>
<td>Risk that maintenance rehab will be needed within 100 years</td>
<td>4</td>
<td>3</td>
<td>48</td>
</tr>
<tr>
<td>safety</td>
<td>Risk of future environmental damage</td>
<td>5</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Risk of injury inside tunnel (initial construction)</td>
<td>5</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Risk items that could affect</td>
<td>Risk of injury inside tunnel (operations)</td>
<td>5</td>
<td>2.0</td>
<td>50</td>
</tr>
<tr>
<td>schedule</td>
<td>Potential for schedule delays due to production</td>
<td>NDD</td>
<td>NDD</td>
<td>NDD</td>
</tr>
<tr>
<td></td>
<td>Potential for schedule delays due to installation</td>
<td>NDD</td>
<td>NDD</td>
<td>NDD</td>
</tr>
<tr>
<td>Risk items that could affect</td>
<td>Potential for schedule delays due to repairs and testing</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>stakeholder impacts</td>
<td></td>
<td>NDD</td>
<td>NDD</td>
<td>NDD</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Probability and Consequences for Each Alternative</th>
<th>1A. HDPE - Field Welding</th>
<th>1B. PVC - Field Welding</th>
<th>1C. Telene Connecting Gasket to HDPE</th>
<th>2. HPC Segments with Upstream Dosing</th>
<th>3A. Hobas or Flowtite</th>
<th>3B. HDPE Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Consequence</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

**For Each Alternative and Each issue**

Rate Probability: 1 very unlikely to 5 very likely
Rate Consequence: 1 lowest to 5 highest

**Risk Probability and Consequences**

**Sum of Scores**

- 283
- 271
- 295
- 299
- 211
- 232
Gravity Pipeline

Interior Alternatives Analysis

Summary of Weighted Scores for Each Alternative and Each Category

<table>
<thead>
<tr>
<th>Success Factor Categories</th>
<th>1A. HDPE - Field Welding</th>
<th>1B. PVC - Field Welding</th>
<th>1C. Telene Connecting Gasket to HDPE</th>
<th>2. HPC Segments with Upstream Dosing</th>
<th>3A. Hobas or Flowtile</th>
<th>3B. HDPE Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost (M)</td>
<td>$117</td>
<td>$115</td>
<td>$119</td>
<td>$107</td>
<td>$163</td>
<td>$164</td>
</tr>
<tr>
<td>Life Cycle Cost (M)</td>
<td>$213 to $241</td>
<td>$210 to $236</td>
<td>$217 to $245</td>
<td>$195 to $220</td>
<td>$296 to $334</td>
<td>$298 to $337</td>
</tr>
<tr>
<td>Cost (other factors)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Operations</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>15</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Maintenance</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Schedule</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Stakeholder Impact</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td><strong>Success Score, weighted</strong></td>
<td><strong>55</strong></td>
<td><strong>54</strong></td>
<td><strong>57</strong></td>
<td><strong>59</strong></td>
<td><strong>63</strong></td>
<td><strong>63</strong></td>
</tr>
<tr>
<td>Cost</td>
<td>93</td>
<td>81</td>
<td>105</td>
<td>72</td>
<td>78</td>
<td>99</td>
</tr>
<tr>
<td>Operations</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>67</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Maintenance</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Safety</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Schedule</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Stakeholder Impact</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td><strong>Risk Score, weighted</strong></td>
<td><strong>283</strong></td>
<td><strong>271</strong></td>
<td><strong>295</strong></td>
<td><strong>299</strong></td>
<td><strong>211</strong></td>
<td><strong>232</strong></td>
</tr>
</tbody>
</table>

The Higher the number the better for Success Factors

Higher the Risk number the more risk
Gravity Pipeline Interior Alternatives Analysis: Risk vs. Scores (Weighted)

Showing Construction Costs (Project Costs 58% more)
Silicon Valley Clean Water
Conveyance System Program Planning Group

Monthly Department Head Meeting #23

September 22, 2016
1:30 to 3:30
Pelican Board Room

Minutes

Attended:  Bob Allen, Bill Bryan, Bruce Burnworth, Jill Chamberlain, Joe Covello, Bob Donaldson, Christine Fitzgerald, Kim Hackett, Eric Hansen, Teresa Herrera, Mike Jaeger, Charlie Joyce, Rich Laureta, Mark Minkowski, Roanne Ross, John Schwarz, Justin Semion, Al Shewey

Phone:  Akoni Danielsen, Duane Sandul

Notes by:  Roanne Ross (see Dropbox for visuals used during meeting)

Introductions

- August 25 DH #22 minutes – Will be finalized shortly and put on Dropbox.

Part 1 – Program Updates - Kim

1. Report from the Sept. 8 SVCW Commission Meeting
   - The predesign task orders were on the September 8 Commission agenda and failed to receive approval. WBSD voted no and said their position will hold until April.
   - Dan, Teresa and Matt attended the WBSD Board meeting on September 14 to hear Board’s discussion on the SVCW conveyance system. At their meeting a joint meeting between the Commission and their Boards was proposed. Kim said this may or may not happen.
   - Joe shared that from his experience being on the DSRSD Board, they benefited from joint board meetings that included all the boards of the LAVWMA JPA.

2. Revisit the alternative cost comparison graph
   Kim reviewed the outcome of the alternative selection process. The claim that to address Redwood Shores’ concerns about traffic disturbance a more expensive alternative was selected is not supported. The proposed alternative (Alt 4BE) costs were very close to the lowest cost alternative (Alt 7). Cost was just one of our selection criteria and when all criteria were taken into consideration 4BE was superior to 7.
3. Next Steps
We are moving forward on EIR, environmental permitting, and will be draining the ponding this winter. Kim remains optimistic.

4. Report from Sept. 22 Technical Committee meetings
Staff reported on what the conveyance system program is currently working on. There was not much discussion on the conveyance system, just few questions.

5. Quarterly Review Success Factors
Kim likes to walk through the success factors on a quarterly basis to keep them in everyone’s mind, and inform new team members of their existence. Later in the meeting Bruce will be presenting the gravity sewer construction alternatives evaluation process. That evaluation used the success factors.

<table>
<thead>
<tr>
<th>SVCW Conveyance Planning Groups Success Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category</strong></td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Operations</td>
</tr>
<tr>
<td>Maintenance</td>
</tr>
<tr>
<td>Safety</td>
</tr>
<tr>
<td>Schedule</td>
</tr>
<tr>
<td>Stakeholder Impacts</td>
</tr>
</tbody>
</table>

6. SRF Technical Package
- The SRF application includes a technical report that describes the project. The initial assumption was that there would be predesign reports that would be referenced in the SRF technical report. Now that predesign reports will not be prepared during the SRF application timeline Kim is proposing to Matt, Teresa and Anita an alternative to the predesign reports. She would like the design teams to prepare a conceptual design report that summarizes where we are right now.
- SVCW’s SRF planning loan has a deliverable of 30% predesign reports. SVCW is meeting with the SRF staff on Sept. 26 to see if these conceptual design reports would be acceptable in place of the 30% reports.
- Kim will provide the design teams more direction after a decision has been made on the conceptual design scopes.

**Part 2 - Program Schedule – Version 16 - Roanne**

7. Three variations of the schedule can be found on Dropbox (full, grid, condensed)
8. See report attached to minutes for Highlights of Changes from Previous Version Discussion:

**Compared to Exponent schedule:**
- Version 16 moves the predesign task order approval to April 2016 and these results in a delay of about nine months to the final completion of all the projects.
- It was pointed out that the Exponent report showed that the delay in the predesign task orders to April resulted in a 16 months completion delay. Why the difference?
- The Exponent schedule factored in risks of delay, Version 16 is “risk free.”

**Critical Path:**
- Version 16 does not show the EIR on the critical path – why not?
- The predesign task orders have not been linked to the EIR completion.
- Discussed if the predesign TO should now be linked to the EIR. Concluded that if WBSD says their approval of the TO will come after the EIR we should link them. This change will be made on Version 17.
- Roanne pointed out that the dates on Version 16 will not change because both the certification of the EIR and the approval of TOs are both set on the April 2017 Commission date (April 13) in Version 16.

9. Four month look ahead (based on Version 16)
- Comments on Version #16 due to Roanne by Oct. 14
- Roanne requested PMs look at the completion percentage on the schedule and provide updates if there have been progress.
- Christine was asked to provide new completion dates for the Redwood City acquisition tasks.

Part 3 – Project Spotlight

- Gravity Sewer Construction Alternatives Evaluation Process – Bruce
- The full presentation is on Dropbox. Bruce passed out a 4 page handout with costs, success factor evaluation and risk evaluation spreadsheets (copy on Dropbox).
- Bruce explained the overall process of developing the criteria and then doing the evaluation. They started with a long list of alternatives which they shortened to the following six alternatives.

**Summary Descriptions of Alternative Gravity Pipeline Interiors to be Evaluated Further**

<table>
<thead>
<tr>
<th>Common Features</th>
<th>All Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Precast Concrete Segments</td>
</tr>
<tr>
<td></td>
<td>o Segments carry all earth loads</td>
</tr>
<tr>
<td></td>
<td>o Withstand corrosion from outside tunnel</td>
</tr>
<tr>
<td></td>
<td>o HPC with steel fiber reinforcement, Fly Ash/ Slag,</td>
</tr>
</tbody>
</table>
Silica Fume (fill voids), Nano Silica (for density), Low b/w ratio, High binder content, Small aggregate, type 2/5 cement, High strength  
- Upstream dosing to control odors

## Single Pass Alternatives

### Alternative 1 – Lined Tunnel Segments

| Common Features | • Each concrete tunnel segment lined with lining attached to concrete  
• Connections use same lining material |
| Variations | • Lining material  
• Method of joining lining at segment edge |
| 1A. HDPE – Field Welding | • HDPE butt welded after installation in tunnel  
• Signal layer available  
• Middle east installations |
| 1B. PVC – Field Welding | • PVC (T-Lock) lapped and welded after installation in tunnel  
• Sacramento Regional installation |
| 1C. – Telene connecting gasket to HDPE | • Herrenknecht Type 2 CombiSegment  
• Signal layer available  
• Installation in progress near Niagara Falls |

### Alternative 2 – HPC with Chemical Dosing

2. HPC Segments with Upstream Dosing  
- High Performance Concrete with Biocide (for MIC control)  
- HPC thickness above required for permanent loads  
- Upstream dosing to include Biodox or Oxygen at MPPS, RWCPs, Belmont PS and possibly add lime upstream of SCPS  
- Connections use similar HPC  
- Numerous sewer installations – concrete sewer pipe installs.

## Double Pass Alternatives

### Alternative 3 – Pipe inside Tunnel

| Common Features | • Pipe pieces joined by gaskets  
• Annular space filled with lightweight flowable grout  
• Special pipe fittings at connections |
| Variations | • Materials and Cross Section |
| 3A. Hobas or Flowtite | • Fiberglass reinforced pipe  
• Inside surface layer resistant to chemical corrosion  
• Core subject to corrosion  
• ~3” Thick  
• 10’ ID installed in Hawaii inside 15’ ID tunnel |
| 3B. HDPE Profile | • Profile HDPE pipe  
• Not subject to corrosion |
- Relatively thin inside wall (not solid wall)
- ~11” Thick wall section.
- Installations this large (not in tunnels)

- All alternatives will have upstream dosing for odor control. Some alternative will have more dosing for corrosion protection.
- We have corrosive soils so need to protect the exteriors of all the pipe alternatives.
- The first four alternatives (single pass) do not have a pipe in the tunnel, that last two (double pass) do. There is no grout in the single pass alternatives.
- The four alternatives without a pipe have multiple lines of defense – their variations are in how this defense is provided.
- Alternative 3A has a Hobas pipe, and 3B has an HDPE pipe that is 11-inches thick and will require a tunnel larger in diameter than the other five alternatives.

**Cost Estimates** – They are Relative to each other
- A detailed planning level cost estimate had been prepared previously for Alternative 3A, as this alternative is the gravity pipeline included in the recommended project Alt. 4BE.
- Bruce explained that the cost estimates for the other alternatives built on the 3A costs and we should consider these as ranges and relative costs.
- He also pointed out that the cost of 3A is higher than the cost used in the selection process that chose 4BE (and Kim spoke about earlier in this meeting.)

**Success Factor Criteria:**
- A small group developed fine criteria for the various success factors that the large group then reviewed and modified. The large group discussion focused on the scoring.

**Risk Evaluation:**
- Ndd = no detectable difference for the stakeholders.
- The large group had a lengthy discussion on rehab and maintenance requirements over the 100 years and how it would be accomplished. The tunnel between the airport shaft and the WWTP is 14,000 ft. and it can’t be by passed.

**Solicited Input from the Non-Engineers**
Bruce wanted to know from Christine, John, Justin and Akoni if there were any concerns or items related to permitting, CEQA or acquisitions that should be factored into the evaluation.

Justin: no permitting issues.
Environmental;
- Discussed truck trips. The EIR reflects the worst case, so any change that lessons the impact will not make a difference to the EIR.
- Discussed the biocide that would be in the high performance concrete (Alt 2)
- The biocide is mixed in the liquid concrete and embedded in the concrete – it will not leach into the environment. The biocide is part of the casting process which is done offsite at the concrete pipe manufacturing site.
**Additional Discussion at the Department Head Meeting:**

*Biocide*
- Cannot confirm that the biocide would be effective the full 100 year design life of the tunnel.
- The maximum length of time a project with the biocide has existed is 15 years.
- Three firms make the biocide; none have been approved by California yet.

*Stakeholder Impacts.*
Alternatives construction duration times varies with some taking a year less than the others. This means there would be a year less of traffic impacts on stakeholders. It does not change impact to residential areas, but it could to local businesses. Lines 42, 45 and 50 from the spreadsheet will be refined to show a distinction.

**Next Step - Weighting Factors:**
Dan, Teresa and Monte to prepare the weighting factors in the near future. They said they will put more focus on the risk rather than the success factor criteria.

**Part 4 – Design Team Reports**

10. Design Flow Table – Revised (Charlie)
   - A revised design flow table dated Sept 20, 2016 was sent with agenda and is on Dropbox.
   - These are the flows all the design teams are supposed to use.
   - Someone from SVCW will need to provide information on the average annual flow.
   - If you have comments or if you need another flow category added let Charlie know.

11. Hydraulic Modeling – Results (Charlie)
   The hydraulic model was based on October 2015 plant data. Charlie reported that the hydraulic model showed that a 13-ft ID pipe can be operated to provide storage to equalize dry weather flow and maintain good air flow ($d/D > 0.7$). There is an approximate 5 ft. variation on the water surface over the course of a day. He showed a visual (video) of the dynamic model, it is on Dropbox.

**Part 5 - Department Reports** *(note: time was short so reports were brief)*

12. Financing – Kim
   Teresa, Matt, Kim, Anita, and Justin are going to Sacramento on Monday, Sept. 26, to meet with the SRF staff to discuss the planning loan, the construction loan application and the wildlife consultations.

13. Public Information – Duane
   Did not send any information to the public related to the recent SVCW Commission or WBSD Board activities or decisions.