City of Tacoma
D-to-M Streets Track & Signal Project
Surface Water Hydraulic Analysis

Technical Memorandum
STORMWATER CONCEPTUAL DESIGN REPORT (FULL BUILDOUT)

FINAL | FEBRUARY 2019

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Section 1

OVERVIEW

The D-to-M Streets Track & Signal Project (Project) was completed by Sound Transit (ST) as part of a larger expansion of a regional rail line within Western Washington. This 19-acre portion of the expansion reconstructed City of Tacoma (City) streets from South 'D' Street to South 'M' Street and installed a new rail bed and regraded existing rail bed. The Project relocated over 4,000 linear feet of storm drainage pipe, replacing piping in the area with new pipes having diameters ranging in size from 12 inches to 72 inches. Figure 1 shows a map of the stormwater piping replacement Project vicinity.

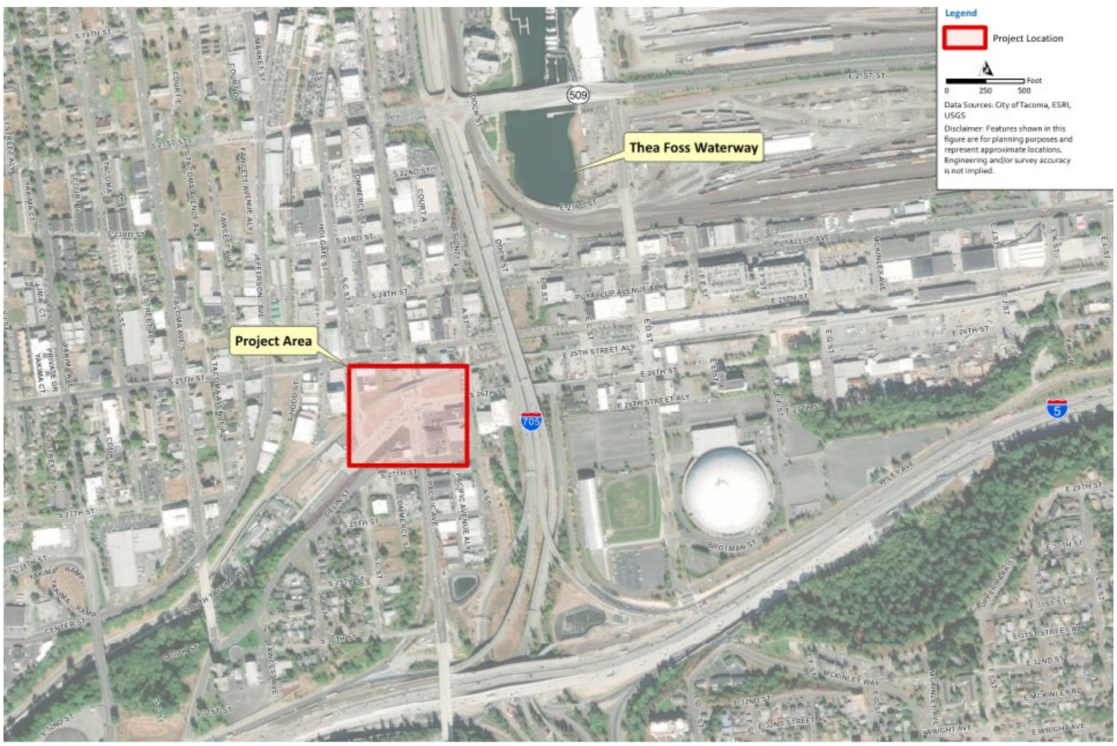


Figure 1 Project Location Map

1.1 Project Background

The Project's rail line alignment crossed numerous City roadways, including Pacific Avenue near the intersection with South 26th Street. To accommodate this crossing, a rail line bridge was constructed and the elevation of the Pacific Avenue and South 26th Street intersection grade surface was lowered to allow for adequate vehicle clearance as shown in Figure 2, with new storm drain manhole (SDMH) 681 at approximately the same location as pre-construction SDMH 9422. Lowering the intersection grade resulted in reconstructed SDMH and catch basin (CB) rims installed up to 18 feet below their pre-construction elevations.

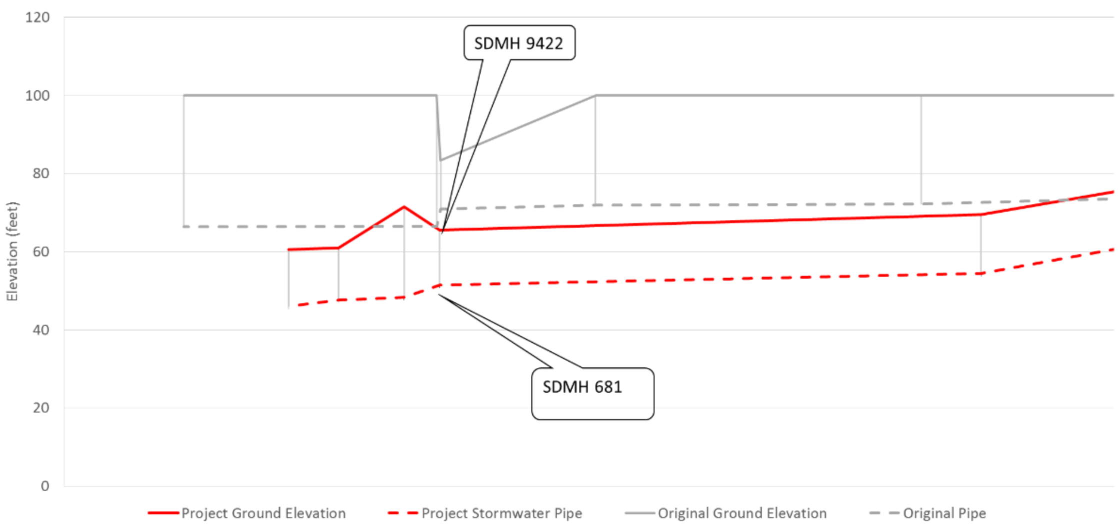


Figure 2 Grade and Pipe Profile Changes

Following construction, storm manholes (MHs) within the Project area have surcharged and flooded the lowered roadway during large storm events, particularly at the intersection of Pacific Avenue and South 26th Street.

The Project was located within the Thea Foss Waterway basin and therefore was subject to meeting the requirements of the City's 2008 Surface Water Management Manual (TSWMM)[1]. These included:

- Sites discharging to a pipe were required to complete a *quantitative* offsite analysis for capacity as part of the Stormwater Site Plan Report (TSWMM Vol. 1: 2.6.6.1).
- The *qualitative* analysis shall include the upstream system and downstream system to the receiving water or quarter mile, whichever is less. The City may require the longer distance. The City's GovMe site contained the basin information, contours and existing storm system information for developing the *qualitative* analysis. (TSWMM Vol. 1: 3.4.11.1).
- *Quantitative* analysis was required for all projects that creating more than 10,000 square feet of new impervious surface (TSWMM Vol. 1: 3.4.11.2).
- Some of the objectives of the *qualitative and quantitative* analysis were to evaluate drainage impacts that may be caused or aggravated by a project, such as localized flooding (TSWMM Vol. 1: 3.4.11.3).

1.2 Purpose

Carollo Engineers, Inc. (Carollo) previously conducted a conveyance capacity analysis of the stormwater system through the Project area[2] using the quantitative approaches prescribed in Volume 3, Chapter 3 of the TSWMM. The analysis included uniform flow and backwater analyses of the stormwater system in the Project area. The uniform flow analysis showed that some pipes in the Project stormwater system exceeded the depth to diameter ratio (d/D) of 0.9 required by the TSWMM design guidelines. The backwater analysis, using both industry accepted software

[1] Surface Water Management Manual, City of Tacoma, September 22, 2008.
[2] Stormwater Quantitative Analysis, City of Tacoma D-M Streets Track & Signal Project Surface Water Hydraulic Analysis, Carollo Engineers, February 2019.

(StormShed 3G) and a hand calculation (per TSWMM), for the 25-year design storm was completed for the Project stormwater system. The industry software was also used for backwater calculation of the 100-year storm. The backwater analysis showed the system did not meet the TSWMM conveyance requirements.

The purpose of this technical memorandum (TM) is to develop a conceptual design for piping improvements within the Project area that accommodates full buildout flow conditions in the Basin, as defined by the TSWMM and meets the City's 2008 conveyance design requirements. An opinion of construction cost to construct the conceptual design components for the system as it currently exists in 2019 was developed for the viable conceptual design.

Section 2

PIPING IMPROVEMENTS ANALYSIS

Several piping improvement strategies were screened to develop a viable conceptual design for stormwater trunk main piping improvements within the Project area that complies with the 2008 TSWMM *Quantitative* requirements for full buildout flows including:

- Option 1 - Replace some or all of existing pipe with new pipe of the same diameter at revised pipe slopes.
- Option 2 - Replace some or all of existing pipe with new larger diameter pipe at revised pipe slopes.
- Option 3 - Replace some of existing pipe with a box culvert.
- Option 4 - Replace existing pipe with a box culvert along the entire alignment.
- Option 5 - Keep existing pipe in service and install parallel pipe for all excess flow.

Development of these Options assumed:

- Ground surface could not be re-graded.
- Pipe crest could be installed as high as the existing grade (using a structural cover).
- Tail water elevation at the discharge point from the Project area to the downstream piping was at a d/D of 0.9, to simulate the downstream piping being in compliance with the TSWMM's quantitative analysis requirements.
- No potential hydraulic issues upstream or downstream of the Project area.
- The Project's as-built construction drawings (Sound Transit D-to-M Streets Track & Signal Project, Cosmopolitan Engineering Group, 2013) were used to determine the following:
  - Existing system configuration.
  - Invert elevations at upstream and downstream ends of the Project alignment.
  - Rim elevations for options with new MHs. New MHs assumed to be adjacent to existing MHs and have approximately the same rim elevations.
  - Pipe lengths were estimated based on geographic information system (GIS) measurements.
- MHs on the trunk line were assumed to be 96-inch channelized MHs.

2.1 Analysis Requirements

Carollo analyzed the adequacy of each trunk main option to meet the TSWMM criteria (Vol 3, Section 3.2 through Section 3.4). The four criteria that each option must meet are summarized as follows:

1. All pipe systems greater than or equal to 24 inches in diameter and all public pipe systems shall be designed to convey the 25-year, 24-hour peak flow rate without surcharging (i.e., the water depth in the pipe must not exceed 90 percent of the pipe diameter) (TSWMM Section 3.2).
2. For the 25-year event, there shall be a minimum of 0.5 feet of freeboard between the water surface and the top of any MH or CB (TSWMM Section 3.4.1.3).
3. For the 100-year event, overtopping of the pipe conveyance system may occur. However, the additional flow shall not extend beyond half the lane width of the outside lane of the traveled way and shall not exceed 4 inches in depth at its deepest point (TSWMM Section 3.4.1.3).
4. All conveyance systems shall be designed for fully developed conditions. The fully developed conditions for the Project site shall be derived from the percentages of proposed and existing impervious area (TSWMM Section 3.2.1).

The four requirements were then simplified to three pass/fail conditions to screen each Option:

- **Condition 1**: d/D < 0.9 during 25-year event uniform flow analysis.
- **Condition 2**: Hydraulic grade line (HGL) 0.5 feet or greater below rim elevations for 25-year backwater.
- **Condition 3**: HGL 4 inches above rim may be considered during 100-year backwater.

TSWMM Volume 3 provides equations and methods for hand and spreadsheet calculation of uniform and backwater flow conditions, and also allows for the use of stormwater modeling software to verify compliance with the requirements of the uniform flow and backwater analyses. StormShed 3G is a single event model accepted by the City and was utilized for this analysis.

2.2 Improvements Analysis Methodology

For ease of analysis and to better facility option comparisons, a fixed flow analysis was utilized based on the results from Carollo Stormwater Quantitative Analysis Memo, with key flows summarized in Appendix A. The peak flows for the 25-year and 100-year storms at the downstream end of the Project limits from the prior analysis were used (see Appendix A):

- 25-Year peak flow: 650 cubic feet per second (cfs).
- 100-Year peak flow: 800 cfs.

These flows were assumed to enter the Project area at the upstream limits of the Project area and include the calculated inflows along the reach. This slightly conservative assumption was made to simply analysis, particularly for cases with grade changes. The inflows along the pipe were from onsite drainage areas and smaller sub-basins entering the trunk main within the Project limits, contributing up to 13 cfs during a 25-year event and 19 cfs during a 100-year event, or 2 percent of the total peak flow for both scenarios.

2.2.1 Uniform Flow Analysis

Based on available pipe information (length, slope, diameter, etc.), StormShed 3G was used to determine a pipe capacity for each pipe within each conceptual design option and compared with the appropriate TSWMM criteria conditions.

2.2.2 Backwater Analysis

StormShed 3G was also used for backwater analysis to determine if the HGL met TSWMM design criteria. The peak flows were used to determine the HGL at each pipe's upstream structure, starting at the downstream Project limits – the existing stormwater vault, working upstream. The starting tailwater depth at downstream stormwater vault discharge point was set at +4.5 feet, which represents a d/D of 0.9 in the existing 60-inch pipe downstream of the vault. The calculation assumes the downstream piping is in compliance with the backwater depth requirements of the TSWMM.

The 25-year and 100-year peak flows were modeled for each conceptual design option to determine if these requirements were met.

Section 3
RESULTS

Table 1 summarizes the modeled configuration along with a description of which pass/fail conditions could be met for each option.

Table 1 Options Evaluated and Results

Option #	Configuration	Description	Notes	Condition 1	Condition 2	Condition 3	Pass/Fail Result
1	Replace portions or all of existing pipe with new pipe of the same diameter laid at revised pipe slopes	Assumes same alignment as existing pipe. Existing system (same diameters) with the slopes of the four most downstream pipe sections revised. Slopes at the lowest pipe sections were increased to increase capacity through the intersection of Pacific Avenue and South 26th Street. Slopes at the two pipe sections prior to the intersection were lowered to reduce flow momentum prior to the flatter pipe sections at the intersection.	Conditions 1, 2, and 3 are not met. All MHs overtopping during 25-year and 100-year storm.	Fail	Fail	Fail	**Fail**
2	Replace portions or all of existing pipe with new larger diameter pipe laid at revised pipe slopes	Assumes same alignment as existing pipe. Same configuration as Option #1 but with increased diameters for increased capacity. The five upstream pipe sections were increased to a 96-inch diameter. The remaining three downstream pipes were increased to a 120-inch diameter. These are the largest pipe sizes possible without the pipe top extending above the existing grade.	Conditions 1, 2, and 3 are not met. Most MHs overtopping during 25-year storm and all MHs overtopping for 100-year storm.	Fail	Fail	Fail	**Fail**
3	Replace portions of existing pipe with a box culvert	Assumes same alignment as existing pipe. Same pipe slopes as Option #1. The four downstream pipes were revised to an 8-foot (rise) x 12-foot (span) box culvert. The remaining upstream pipes were increased to a 96-diameter pipe (largest pipe possible without the pipe top extending above the existing grade).	Condition 1 is met. Conditions 2 and 3 are not met. Three MHs overtopping during 25-year storm. Four MHs overtopping for the 100-year storm.	Pass	Fail	Fail	**Fail**

Option #	Configuration	Description	Notes	Condition 1	Condition 2	Condition 3	Pass/Fail Result
4	Replace existing pipe with a box culvert along the entire alignment	Assumes same alignment as existing pipe. Same slopes as Option #1. Revised all pipes along alignment to an 8-foot (rise) x 18-foot (span) box culvert. This is the largest box culvert possible without the culvert top extending above the existing grade.	Conditions 1 and 3 are met. Condition 2 is not met due to one MH overtopping during 25-year storm.	Pass	Fail	Pass	**Fail**
5	Keep existing pipe in service and install parallel pipe for all excess flow	Modelled existing pipe and ran iterations to determine the maximum flow the pipe can accommodate without overtopping (365 cfs). This maximum flow was then subtracted from the systems 25-year and 100-year peak storms, as determined by the existing pipe model, to determine applicable flows for the new pipe (285 cfs for 25-year flow and 435 cfs for the 100-year flow). Iterations were then run to size the pipe to meet all conditions for these flows. A 72-inch parallel pipe was required to meet all conditions.	Conditions 1, 2, and 3 are met.	Pass	Pass	Pass	**Pass**

3.1 Viable Option

Only one option met all three pass/fail conditions in the Project area. Option 5 included installation of a parallel pipe for flows exceeding the existing pipe's capacity. For this option, a model of the existing storm line was also evaluated to determine the maximum flow it could convey within compliance of the TSWMM requirements for a 25-year storm. The parallel pipe was sized to meet the 25 and 100-year flows based on the capacity of the existing line.

Stormshed 3G results for this model are presented in Appendix B. For the 25-year event, the HGL was at or below the MH and CB rims. For the 100-year storm, the HGL analysis showed that the HGL would be slightly above the rim as MHs #1 and #3. While the overtopping expected at MH #3 meets the requirements of Condition 3, the overtopping shown at MH #1 may slightly exceed the 4-inch depth requirement of Condition 3. This was acceptable for this phase due to uncertainty associated with the proposed MH #7's rim elevation and the existing roadway slope in the area, the issue would be fully addressed during a more detailed evaluation that would occur through Project design.

Figures 3 and 4 illustrate the proposed layout for Option 5. The option consists of the installation of a parallel pipeline approximately matching the grade of the existing storm pipe with large vaults at the upstream and downstream ends of the new pipe's alignment to split and then combine flow, respectively. In general, the parallel pipe would be installed within grassy areas, but crosses an active railroad track and several City roadways. Major components include:

- Approximately 1,100 feet of 72-inch diameter reinforced concrete pipe (RCP) in an urban environment.
- Extension of two vaults for splitting and combining flows.
- Six new 96-inch MHs, installed adjacent to the existing pipe's MHs.
- Trenchless pipe installation (pipe ramming) of approximately 60-linear feet of 96-inch steel casing to cross under the railroad, including associated access pits, material, and equipment (detailed in Figure 4).
- Management of several utility conflicts.

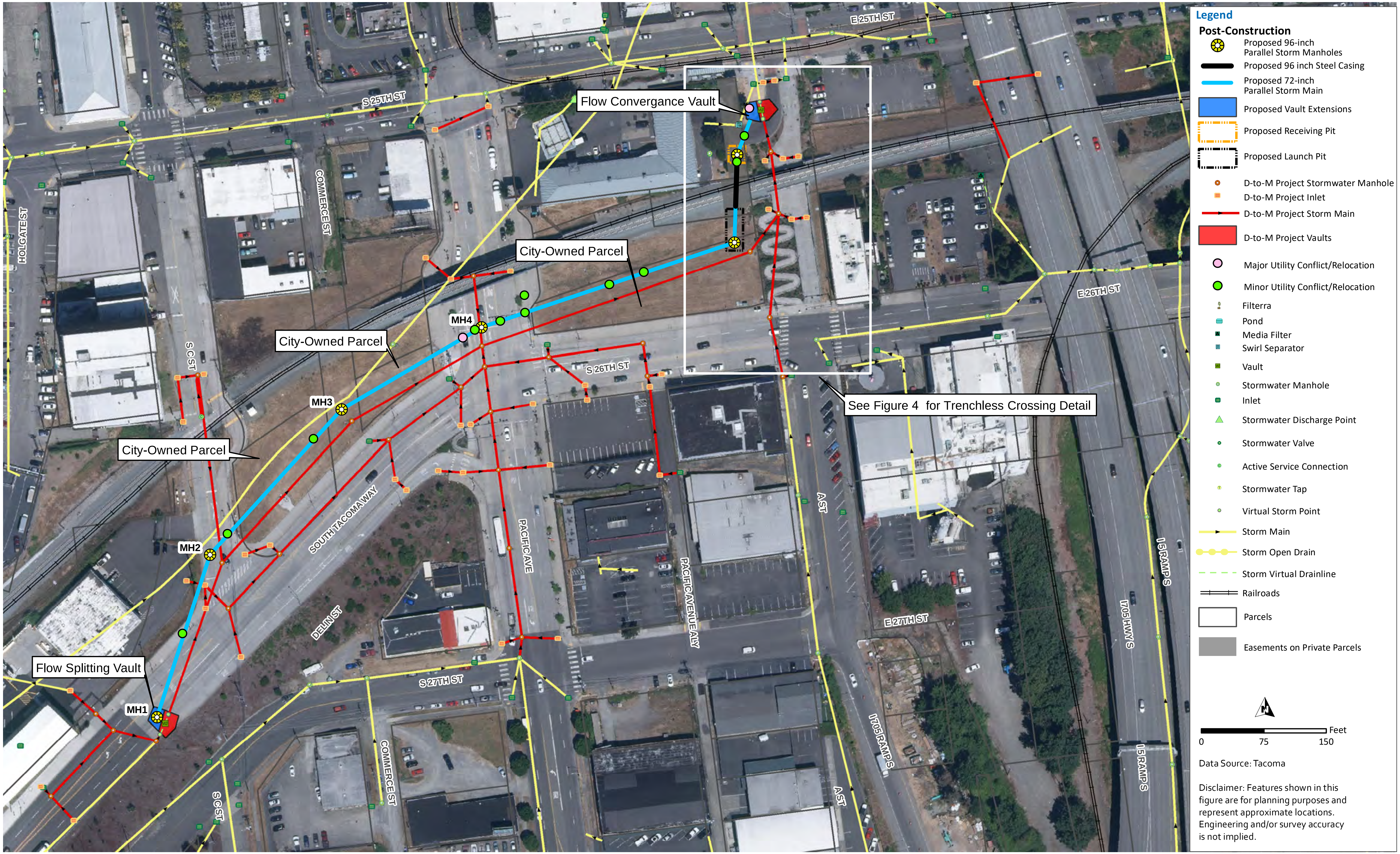


Figure 3 Parallel Pipe Alternative

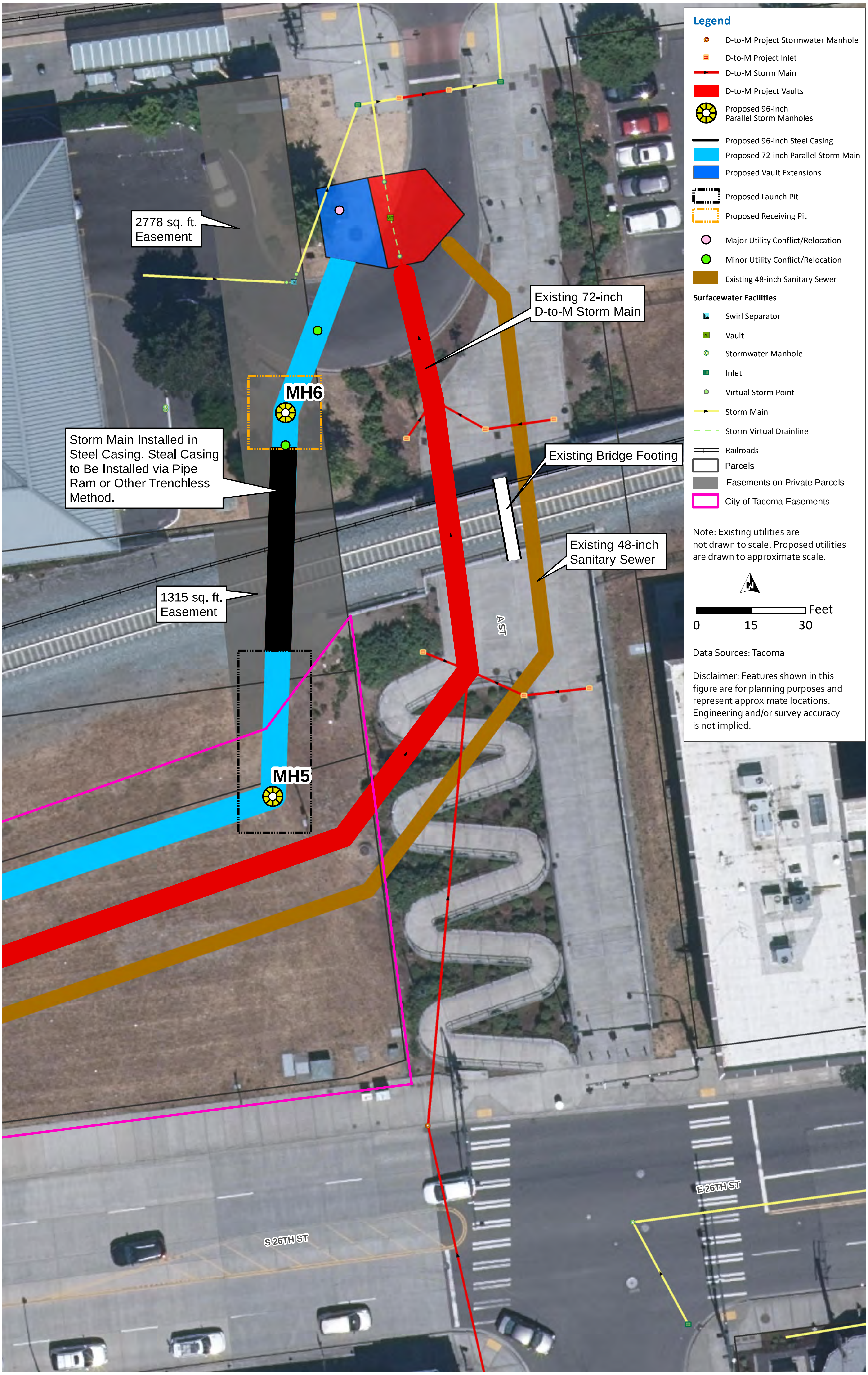


Figure 4 Potential Trenchless Crossing

3.2 Model Limitations

The StormShed model was based on a conceptual design and provides a high-level conservative analysis. A more detailed model should be employed for Project design, such Mike Urban 1D that is more capable of managing momentum transfer through MHs, as well as other minor losses such as bend losses.

Section 4

CONCEPTUAL DESIGN COST ESTIMATE

The cost opinion was prepared for Option 5. The expected level of accuracy for this cost opinion follows the Recommended Practice 18R-97 Cost Estimate Classification System for the Process Industries (Association for the Advancement of Cost Engineering [AACE], 1998) designation as a "Class 4" estimate with an expected level of accuracy of -30 percent to +50 percent of the cost presented. Estimated Project costs are in December 2019 dollars, consistent with the Seattle Engineering News-Record (ENR) value of 12112. As the Project design matures, cost estimates are subject to change, and the cost of labor, materials, and equipment may vary. Because the Project timeline is unknown, costs were not adjusted to the mid-point of construction. The conceptual design estimate costs are presented below in Table 2.

Table 2 Conceptual Design Estimated Costs

Cost Type (2019 $'s)	Lower Range (-30%)	Upper Range (+50%)
Construction Cost	$3,200,000	$6,700,000
Project Cost	$4,600,000	$9,700,000

The basis of estimate (BOE) explaining the estimate components, assumptions, and methodology can be found in Appendix C and the corresponding cost opinion details can be found in Appendix D.

Appendix A
STORMSHED 3G INPUTS

Node & Invert Report

Alternative #5 Node and Inverts

Node and Reach invert report				
Node	MH1		Out ie	86.30 ft
	Reach	P1	I.E. Out	86.30 ft
Node	MH2		Out ie	73.70 ft
	Reach	P1	I.E. In	73.70 ft
	Reach	P2	I.E. Out	73.70 ft
Node	MH3		Out ie	58.68 ft
	Reach	P2	I.E. In	58.68 ft
	Reach	P3	I.E. Out	58.68 ft
Node	MH4		Out ie	54.71 ft
	Reach	P3	I.E. In	54.71 ft
	Reach	P4	I.E. Out	54.71 ft
Node	MH5		Out ie	49.05 ft
	Reach	P4	I.E. In	49.05 ft
	Reach	P5	I.E. Out	49.05 ft
Node	MH6		Out ie	47.68 ft
	Reach	P5	I.E. In	47.68 ft
	Reach	P6	I.E. Out	47.68 ft

Node & Invert Report

Ex. System Node and Inverts

Node and Reach invert report				
Node	SWFA-1000543		Out ie	86.30 ft
	Reach	3569	I.E. Out	86.30 ft
Node	682		Out ie	72.40 ft
	Reach	3569	I.E. In	72.40 ft
	Reach	3568	I.E. Out	72.40 ft
Node	2917		Out ie	54.40 ft
	Reach	3568	I.E. In	54.40 ft
	Reach	12133	I.E. Out	54.40 ft
Node	681		Out ie	51.40 ft
	Reach	12133	I.E. In	51.40 ft
	Reach	3567	I.E. Out	51.40 ft
Node	2916		Out ie	48.28 ft
	Reach	3567	I.E. In	48.28 ft
	Reach	12132	I.E. Out	48.28 ft
Node	12704		Out ie	47.68 ft
	Reach	12132	I.E. In	47.68 ft
	Reach	3566	I.E. Out	47.68 ft

Analysis conducted with previous report: Stormwater Quantitative Analysis, City of Tacoma D-M Streets Track & Signal Project Surface Water Hydraulic Analysis, Carollo Engineers, February 2019.

Ex. Stormwater System 25-Year Pipe Capacity Analysis

D-to-M Streets Track & Signal Project

Stormwater Quantitative Analysis

Reach ID	Area (ac)	Flow (cfs)	Full Q (cfs)	Full ratio	nDepth (ft)	Depth ratio	Size	nVel (ft/s)	fVel (ft/s)	CBasin / Hyd
8225	0.2247	0.1781	5.7468	0.031	0.1209	0.1209	12 in Diam	3.3007	7.317	39B
8227	0.0565	0.0419	5.2941	0.0079	0.0629	0.0629	12 in Diam	2.0271	6.7407	40B
8226	0.1258	0.0829	5.8213	0.0142	0.0837	0.0837	12 in Diam	2.6371	7.412	36B
8293	0.0757	0.06	5.4365	0.011	0.0738	0.0738	12 in Diam	2.2973	6.922	37B
8229	0.1702	0.1308	5.3412	0.0245	0.1081	0.1081	12 in Diam	2.8551	6.8006	38B
8228	0.1448	0.0989	9.4561	0.0105	0.0718	0.0718	12 in Diam	3.9432	12.0399	35B
8210	0.6548	0.4054	15.1221	0.0268	0.1129	0.1129	12 in Diam	8.3079	19.254	19B
8211	0.0963	0.0763	13.2653	0.0058	0.0542	0.0542	12 in Diam	4.6139	16.8899	20B
8044	0.4394	0.2543	11.8445	0.0215	0.1014	0.1014	12 in Diam	6.0986	15.0809	14B
8043	0.728	0.4831	11.3703	0.0425	0.1407	0.1407	12 in Diam	7.1779	14.4771	13B
8052	0.4042	0.2083	13.3807	0.0156	0.0871	0.0871	12 in Diam	6.2427	17.0368	15B
8119	0.7297	0.5785	20.8891	0.0277	0.1146	0.1146	12 in Diam	11.5947	26.5968	6B
8055	0.3589	0.2845	10.8152	0.0263	0.1119	0.1119	12 in Diam	5.9052	13.7704	4B
8054	1.2	0.9514	5.0295	0.1892	0.2948	0.2948	12 in Diam	4.9196	6.4037	8B
8120	0.632	0.4116	12.7821	0.0322	0.123	0.123	12 in Diam	7.4386	16.2747	5B
8053	1.832	1.363	41.6646	0.0327	0.1858	0.1239	18 in Diam	10.8334	23.5774	
8041	0.3257	0.2332	15.5661	0.015	0.0856	0.0856	12 in Diam	7.1728	19.8194	9B
8040	0.4924	0.3069	8.4001	0.0365	0.1305	0.1305	12 in Diam	5.0875	10.6953	12B
8039	2.3244	1.6699	35.6795	0.0468	0.2206	0.1471	18 in Diam	10.3366	20.1904	
8042	3.4566	2.3613	15.8836	0.1487	0.3897	0.2598	18 in Diam	6.4738	8.9883	
8207A	4.2077	2.8431	3.5058	0.811	1.0253	0.6835	18 in Diam	2.209	1.9839	
8212	0.1004	0.0796	13.017	0.0061	0.0558	0.0558	12 in Diam	4.6071	16.5738	21B
8209	0.4628	0.3669	9.6675	0.038	0.1329	0.1329	12 in Diam	5.9192	12.309	26B
3454	0.2083	0.1307	4.9851	0.0262	0.1117	0.1117	12 in Diam	2.7185	6.3472	16B
8215	0.718	0.5275	5.5772	0.0946	0.2078	0.2078	12 in Diam	4.4667	7.1012	17B
8214	0.602	0.4773	11.3331	0.0421	0.1401	0.1401	12 in Diam	7.132	14.4298	29B
8217	0.3682	0.2919	14.7664	0.0198	0.0974	0.0974	12 in Diam	7.4235	18.8012	18B
8218	0.4934	0.3912	15.5062	0.0252	0.1097	0.1097	12 in Diam	8.3513	19.743	30B
8220	35.2	18.446	71.9253	0.2565	0.518	0.3453	18 in Diam	34.0868	40.7014	FS_08A
8219	36.0616	19.1291	50.3116	0.3802	0.6417	0.4278	18 in Diam	26.5086	28.4705	
8216	36.0616	19.1291	48.0861	0.3978	0.6584	0.439	18 in Diam	25.6223	27.2112	
8213	37.3816	20.1339	34.2114	0.5885	0.8276	0.5518	18 in Diam	20.1375	19.3597	
8208	37.9448	20.5804	25.3377	0.8122	1.0265	0.6843	18 in Diam	15.9697	14.3382	
8036	0.9519	0.5142	8.6653	0.0593	0.1652	0.1652	12 in Diam	6.0532	11.033	25B
8038	0.2407	0.1908	14.6257	0.013	0.0806	0.0806	12 in Diam	6.4172	18.6221	28B
8037	0.3364	0.2667	5.7692	0.0462	0.1462	0.1462	12 in Diam	3.7459	7.3456	27B
8033	0.188	0.149	17.8379	0.0084	0.0645	0.0645	12 in Diam	6.9616	22.7119	33B
7968	0.4459	0.3535	20.3613	0.0174	0.0916	0.0916	12 in Diam	9.8343	25.9247	31B
8034	0.8699	0.6897	20.1839	0.0342	0.1264	0.1264	12 in Diam	11.9765	25.699	32B
7969	1.0579	0.8387	21.2416	0.0395	0.2034	0.1356	18 in Diam	5.8431	12.0203	
8035	1.0579	0.8387	18.9239	0.0443	0.2151	0.1434	18 in Diam	5.3863	10.7087	
8142	2.3462	1.6196	16.315	0.0993	0.3189	0.2126	18 in Diam	5.8981	9.2324	
8206	44.4987	25.0431	157.27	0.1592	0.5396	0.2698	24 in Diam	36.6331	50.0609	
79818	0.1612	0.1278	8.5287	0.015	0.0856	0.0856	12 in Diam	3.9306	10.8591	23B
8139	0.3055	0.2133	11.5153	0.0185	0.0944	0.0944	12 in Diam	5.6781	14.6617	22B
8127	0.6349	0.4327	9.5008	0.0455	0.1452	0.1452	12 in Diam	6.1394	12.0968	24B
8138	0.9404	0.646	3.9298	0.1644	0.2739	0.2739	12 in Diam	3.7	5.0036	
7967	0.386	0.2374	4.4619	0.0532	0.1566	0.1566	12 in Diam	3.0197	5.6811	7B
7965	0.5446	0.3632	15.4423	0.0235	0.1059	0.1059	12 in Diam	8.1649	19.6618	10B
7964	0.1719	0.1363	28.7165	0.0047	0.0497	0.0497	12 in Diam	9.379	36.5629	11B
7963	0.7165	0.4995	30.5414	0.0164	0.1337	0.0891	18 in Diam	6.4301	17.2829	
8122	0.696	0.4403	8.5778	0.0513	0.1025	0.1538	8 in Diam	12.9345	24.5785	3B
8121	0.696	0.4403	19.1829	0.023	0.1047	0.1047	12 in Diam	10.0737	24.4244	
8125	0.599	0.4044	4.3173	0.0937	0.2068	0.2068	12 in Diam	3.4482	5.4969	1B
8126	0.9317	0.6656	7.2459	0.0919	0.2048	0.2048	12 in Diam	5.7556	9.2257	2B
8124	1.5307	1.0699	12.0717	0.0886	0.2012	0.2012	12 in Diam	9.4892	15.3702	
8123	2.2267	1.5102	10.6253	0.1421	0.2543	0.2543	12 in Diam	9.6006	13.5286	
16573	2624.027	636.23	794.67	0.8006	3.3854	0.6771	60 in Diam	44.9626	40.4722	FS_01;FS_02;FS_03;FS_04;FS_08;FS_09
3569	2624.027	636.23	1338.85	0.4752	2.913	0.4855	72 in Diam	46.7293	47.3521	
3568	2624.743	636.42	1397.11	0.4555	2.8421	0.4737	72 in Diam	48.2488	49.4127	
12133	2624.743	636.42	636.79	0.9994	4.9151	0.8192	72 in Diam	25.6715	22.5217	
3567	2670.182	647.56	471.51	1.3734	-----	na	72 in Diam	22.9027	16.6761	
12132	2670.182	647.56	468.1	1.3834	-----	na	72 in Diam	22.9027	16.5557	
8295	8.6134	3.8108	17.2876	0.2204	0.4789	0.3193	18 in Diam	7.8418	9.7828	34B;FS_08B
8294	8.6134	3.8108	45.4889	0.0838	0.2931	0.1954	18 in Diam	15.6559	25.7415	
3566	2679.111	649.6	764.41	0.8498	4.2543	0.709	72 in Diam	30.3018	27.0353	
3565	2679.461	649.71	792.52	0.8198	4.1342	0.689	72 in Diam	31.2709	28.0297	
18804	2679.461	649.71	476.12	1.3646	-----	na	60 in Diam	33.0894	24.2487	
23037	2679.461	649.71	717.18	0.9059	3.7322	0.7464	60 in Diam	41.3325	36.5256	
22412	2679.461	649.71	576.59	1.1268	-----	na	72 in Diam	22.9788	20.3927	
~~14491/21749~~	~~2833.261~~	~~711~~	~~1746.11~~	~~0.4072~~	~~3.5565~~	~~0.4446~~	~~96 in Diam~~	~~32.9292~~	~~34.7377~~	~~FS_07~~

Note: DS of Project Limits

PEAK 25-YEAR FLOW IN PROJECT TRUNK MAIN (~650 cfs)

Analysis conducted with previous report: Stormwater Quantitative Analysis, City of Tacoma D-M Streets Track & Signal Project Surface Water Hydraulic Analysis, Carollo Engineers, February 2019.

Ex. Stormwater System 100-Year Pipe Capacity Analysis

D-to-M Streets Track & Signal Project

Stormwater Quantitative Analysis

Reach ID	Area (ac)	Flow (cfs)	Full Q (cfs)	Full ratio	nDepth (ft)	Depth ratio	Size	nVel (ft/s)	fVel (ft/s)	Infil Vol (cf)	CBasin / Hyd
8225	0.2247	0.2097	5.7468	0.0365	0.1304	0.1304	12 in Diam	3.4789	7.317	0	39B
8227	0.0565	0.05	5.2941	0.0094	0.0683	0.0683	12 in Diam	2.1472	6.7407	0	40B
8226	0.1258	0.1012	5.8213	0.0174	0.0917	0.0917	12 in Diam	2.8125	7.412	0	36B
8293	0.0757	0.0706	5.4365	0.013	0.0804	0.0804	12 in Diam	2.3815	6.922	0	37B
8229	0.1702	0.155	5.3412	0.029	0.1172	0.1172	12 in Diam	3.0072	6.8006	0	38B
8228	0.1448	0.1201	9.4561	0.0127	0.0795	0.0795	12 in Diam	4.1147	12.0399	0	35B
8210	0.6548	0.5011	15.1221	0.0331	0.1246	0.1246	12 in Diam	8.8848	19.254	0	19B
8211	0.0963	0.0899	13.2653	0.0068	0.0587	0.0587	12 in Diam	4.8205	16.8899	0	20B
8044	0.4394	0.3181	11.8445	0.0269	0.1129	0.1129	12 in Diam	6.5107	15.0809	0	14B
8043	0.728	0.5874	11.3703	0.0517	0.1543	0.1543	12 in Diam	7.6325	14.4771	0	13B
8052	0.4042	0.2656	13.3807	0.0199	0.0976	0.0976	12 in Diam	6.7348	17.0368	0	15B
8119	0.7297	0.6809	20.8891	0.0326	0.1237	0.1237	12 in Diam	12.2061	26.5968	0	6B
8055	0.3589	0.3349	10.8152	0.031	0.1208	0.1208	12 in Diam	6.2094	13.7704	0	4B
8054	1.2	1.1197	5.0295	0.2226	0.3208	0.3208	12 in Diam	5.1491	6.4037	0	8B
8120	0.632	0.5042	12.7821	0.0394	0.1355	0.1355	12 in Diam	7.909	16.2747	0	5B
8053	1.832	1.6239	41.6646	0.039	0.2021	0.1347	18 in Diam	11.4211	23.5774	0	
8041	0.3257	0.2805	15.5661	0.018	0.0932	0.0932	12 in Diam	7.6097	19.8194	0	9B
8040	0.4924	0.377	8.4001	0.0449	0.1442	0.1442	12 in Diam	5.4021	10.6953	0	12B
8039	2.3244	2.0009	35.6795	0.0561	0.2412	0.1608	18 in Diam	10.8868	20.1904	0	
8042	3.4566	2.8539	15.8836	0.1797	0.4303	0.2869	18 in Diam	6.8118	8.9883	0	
8207A	4.2077	3.4449	3.5058	0.9826	1.2072	0.8048	18 in Diam	2.2602	1.9839	0	
8212	0.1004	0.0937	13.017	0.0072	0.0605	0.0605	12 in Diam	4.8122	16.5738	0	21B
8209	0.4628	0.4318	9.6675	0.0447	0.1439	0.1439	12 in Diam	6.2074	12.309	0	26B
3454	0.2083	0.1611	4.9851	0.0323	0.1232	0.1232	12 in Diam	2.9047	6.3472	0	16B
8215	0.718	0.6302	5.5772	0.113	0.2274	0.2274	12 in Diam	4.6937	7.1012	0	17B
8214	0.602	0.5617	11.3331	0.0496	0.1512	0.1512	12 in Diam	7.5175	14.4298	0	29B
8217	0.3682	0.3436	14.7664	0.0233	0.1054	0.1054	12 in Diam	7.7843	18.8012	0	18B
8218	0.4934	0.4604	15.5062	0.0297	0.1185	0.1185	12 in Diam	8.7878	19.743	0	30B
8220	35.2	23.0948	71.9253	0.3211	0.5806	0.387	18 in Diam	36.5651	40.7014	0	FS_08A
8219	36.0616	23.8987	50.3116	0.475	0.7281	0.4854	18 in Diam	28.0931	28.4705	0	
8216	36.0616	23.8987	48.0861	0.497	0.7475	0.4983	18 in Diam	27.1643	27.2112	0	
8213	37.3816	25.0906	34.2114	0.7334	0.9552	0.6368	18 in Diam	21.1299	19.3597	0	
8208	37.9448	25.6161	25.3377	1.011	1.2451	0.83	18 in Diam	16.3368	14.3382	0	
8036	0.9519	0.6507	8.6653	0.0751	0.1852	0.1852	12 in Diam	6.4969	11.033	0	25B
8038	0.2407	0.2246	14.6257	0.0154	0.0866	0.0866	12 in Diam	6.7944	18.6221	0	28B
8037	0.3364	0.3139	5.7692	0.0544	0.1584	0.1584	12 in Diam	3.9275	7.3456	0	27B
8033	0.188	0.1754	17.8379	0.0098	0.0696	0.0696	12 in Diam	7.318	22.7119	0	33B
7968	0.4459	0.4161	20.3613	0.0204	0.099	0.099	12 in Diam	10.3313	25.9247	0	31B
8034	0.8699	0.8117	20.1839	0.0402	0.1369	0.1369	12 in Diam	12.5527	25.699	0	32B
7969	1.0579	0.9871	21.2416	0.0465	0.2199	0.1466	18 in Diam	6.14	12.0203	0	
8035	1.0579	0.9871	18.9239	0.0522	0.2326	0.155	18 in Diam	5.661	10.7087	0	
8142	2.3462	1.9517	16.315	0.1196	0.3509	0.234	18 in Diam	6.2044	9.2324	0	
8206	44.4987	31.0127	157.27	0.1972	0.6023	0.3012	24 in Diam	38.9161	50.0609	0	
79818	0.1612	0.1504	8.5287	0.0176	0.0923	0.0923	12 in Diam	4.1406	10.8591	0	23B
8139	0.3055	0.2569	11.5153	0.0223	0.1032	0.1032	12 in Diam	5.9977	14.6617	0	22B
8127	0.6349	0.5256	9.5008	0.0553	0.1597	0.1597	12 in Diam	6.4957	12.0968	0	24B
8138	0.9404	0.7825	3.9298	0.1991	0.3026	0.3026	12 in Diam	3.9006	5.0036	0	
7967	0.386	0.2938	4.4619	0.0659	0.1739	0.1739	12 in Diam	3.2132	5.6811	0	7B
7965	0.5446	0.4418	15.4423	0.0286	0.1164	0.1164	12 in Diam	8.6571	19.6618	0	10B
7964	0.1719	0.1604	28.7165	0.0056	0.0534	0.0534	12 in Diam	9.8974	36.5629	0	11B
7963	0.7165	0.6022	30.5414	0.0197	0.1459	0.0973	18 in Diam	6.819	17.2829	0	
8122	0.696	0.5421	8.5778	0.0632	0.1136	0.1704	8 in Diam	13.732	24.5785	0	3B
8121	0.696	0.5421	19.1829	0.0283	0.1157	0.1157	12 in Diam	10.7142	24.4244	0	
8125	0.599	0.492	4.3173	0.114	0.2285	0.2285	12 in Diam	3.6381	5.4969	0	1B
8126	0.9317	0.8011	7.2459	0.1106	0.2245	0.2245	12 in Diam	6.0771	9.2257	0	2B
8124	1.5307	1.2931	12.0717	0.1071	0.2203	0.2203	12 in Diam	10.0715	15.3702	0	
8123	2.2267	1.8352	10.6253	0.1727	0.2807	0.2807	12 in Diam	10.1605	13.5286	0	
16573	2624.027	779.68	794.67	0.9811	4.0176	0.8035	60 in Diam	46.1084	40.4722	0	FS_01;FS_02;FS_03; FS_04;FS_08;FS_09
3569	2624.027	779.68	1338.85	0.5823	3.2888	0.5481	72 in Diam	49.1376	47.3521	0	
3568	2624.743	779.9	1397.11	0.5582	3.2062	0.5344	72 in Diam	50.7302	49.4127	0	
12133	2624.743	779.9	636.79	1.2247	-----	na	72 in Diam	27.5832	22.5217	0	
3567	2670.182	795.31	471.51	1.6867	-----	na	72 in Diam	28.1284	16.6761	0	
12132	2670.182	795.31	468.1	1.699	-----	na	72 in Diam	28.1284	16.5557	0	
8295	8.6134	4.8984	17.2876	0.2834	0.5464	0.3643	18 in Diam	8.4173	9.7828	0	34B;FS_08B
8294	8.6134	4.8984	45.4889	0.1077	0.3315	0.221	18 in Diam	16.8826	25.7415	0	
3566	2679.111	798.3	764.41	1.0443	5.1977	0.8663	72 in Diam	30.676	27.0353	0	
3565	2679.461	798.44	792.52	1.0075	4.9602	0.8267	72 in Diam	31.9406	28.0297	0	
18804	2679.461	798.44	476.12	1.677	-----	na	60 in Diam	40.6641	24.2487	0	
23037	2679.461	798.44	717.18	1.1133	-----	na	60 in Diam	40.6641	36.5256	0	
22412	2679.461	**798.44**	576.59	1.3848	-----	na	72 in Diam	28.239	20.3927	0	
~~14491/21749~~	~~2833.261~~	~~871.77~~	~~1746.11~~	~~0.4993~~	~~3.9972~~	~~0.4996~~	~~96 in Diam~~	~~34.7177~~	~~34.7377~~	~~0~~	~~FS_07~~

Note: DS of Project Limits

PEAK 100-YEAR FLOW IN PROJECT TRUNK MAIN (~800 cfs)

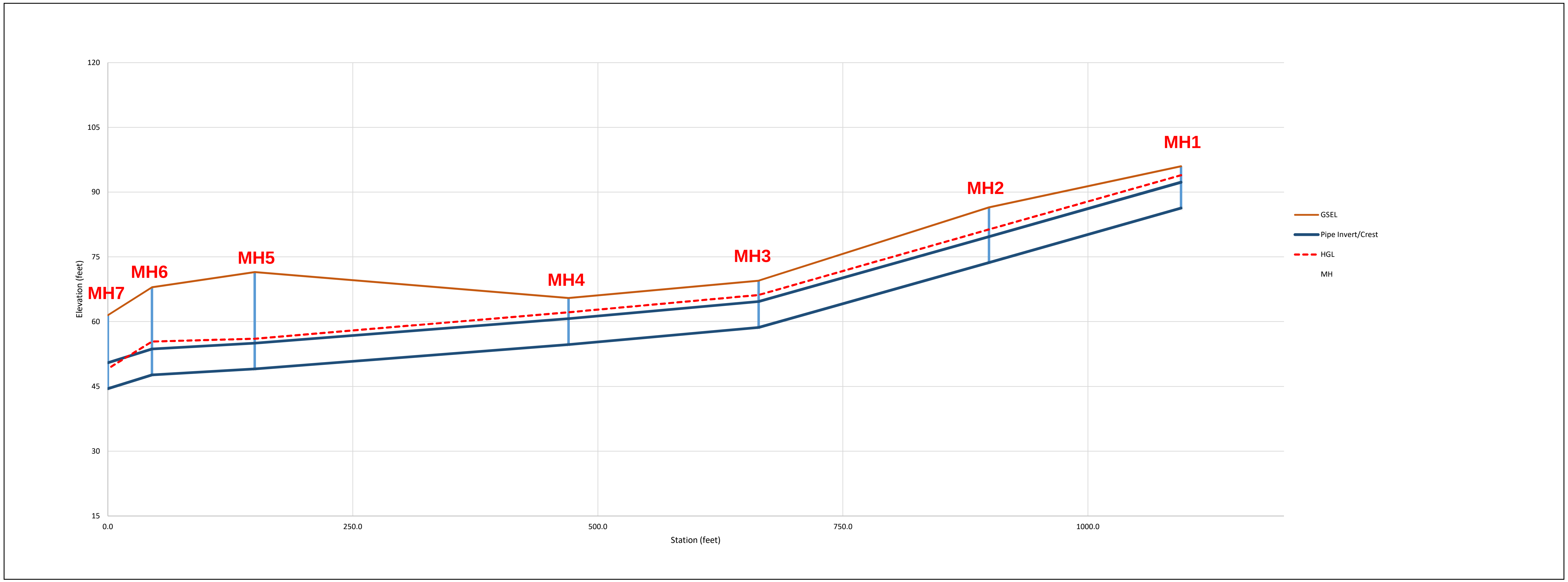
Appendix B

STORMSHED 3G RESULTS

Full Buildout - 25 Year (Parallel Pipe)

	Label	Length (ft)	Distance (STA)	Ground Elev	Invert Elev	Pipe Diam	Crown Elev	HGL	Manhole Depth	Depth %	Height from Rim	Cover
Upstream	MH1	196	1095.0	96	**86.3**	6	92.3	93.93	9.7	127.2%	2.07	3.70
	MH2	235	899.0	86.5	73.7	6	79.7	81.38	12.8	128.0%	5.12	6.80
	MH3	194	664.0	69.5	58.68	6	64.68	66.18	10.82	125.0%	3.32	4.82
	MH4	320	470.0	65.50	54.71	6	60.71	62.20	10.79	124.8%	3.30	4.79
	MH5	105	150.0	71.50	49.05	6	55.05	56.06	22.45	116.8%	15.44	16.45
	MH6	45	45.0	68.00	47.68	6	53.68	55.39	20.32	128.5%	12.61	14.32
	MH7		0.0	61.5	**44.5**	6	50.5	49.12	17	77.0%	12.38	11.00
		1095					w/ TW of 4.5' (elev. 49)					

Pipe Label	Avg. Manhole Depth	
	12.54131	
P1		
P2		9.7
P3		12.8
P4		10.79
P5		10.82
P6		22.45
		20.32
		17



Modeled Flow
650 cfs (Ex. System 25-year Peak)
- 365 cfs (Ex. System Capacity)
= 285 cfs

Parallel Pipe 25-Year Results

Gravity Analysis using fixed flowrates

Reach ID	Flow (cfs)	Full Q (cfs)	Full ratio	nDepth (ft)	Size	nVel (ft/s)	fVel (ft/s)	CFlow
P1	285	1272.582	0.224	1.9305	72 in Diam	36.2656	45.0084	285
P2	285	1268.617	0.2247	1.9333	72 in Diam	36.1922	44.8682	0
P3	285	718.5501	0.3966	2.6293	72 in Diam	23.9124	25.4135	0
P4	285	667.6775	0.4269	2.7389	72 in Diam	22.6682	23.6143	0
P5	285	572.2052	0.4981	2.9937	72 in Diam	20.2138	20.2376	0
P6	285	1334.412	0.2136	1.8835	72 in Diam	37.5179	47.1952	0

HGL Analysis

From Node	To Node	HG El (ft)	App (ft)	Bend (ft)	Junct Loss (ft)	Adjusted HG El (ft)	Max El (ft)
							49.1202
MH6	MH7	55.3837	------	0.0061	------	55.3898	68
MH5	MH6	57.6265	1.5777	0.0077	------	56.0566	71.5
MH4	MH5	62.1911	------	0.0077	------	62.1989	65.5
MH3	MH4	66.1729	------	0.008	------	66.1809	69.5
MH2	MH3	81.3752	------	0.006	------	81.3812	86.5
MH1	MH2	93.9309	------	------	------	93.9309	96

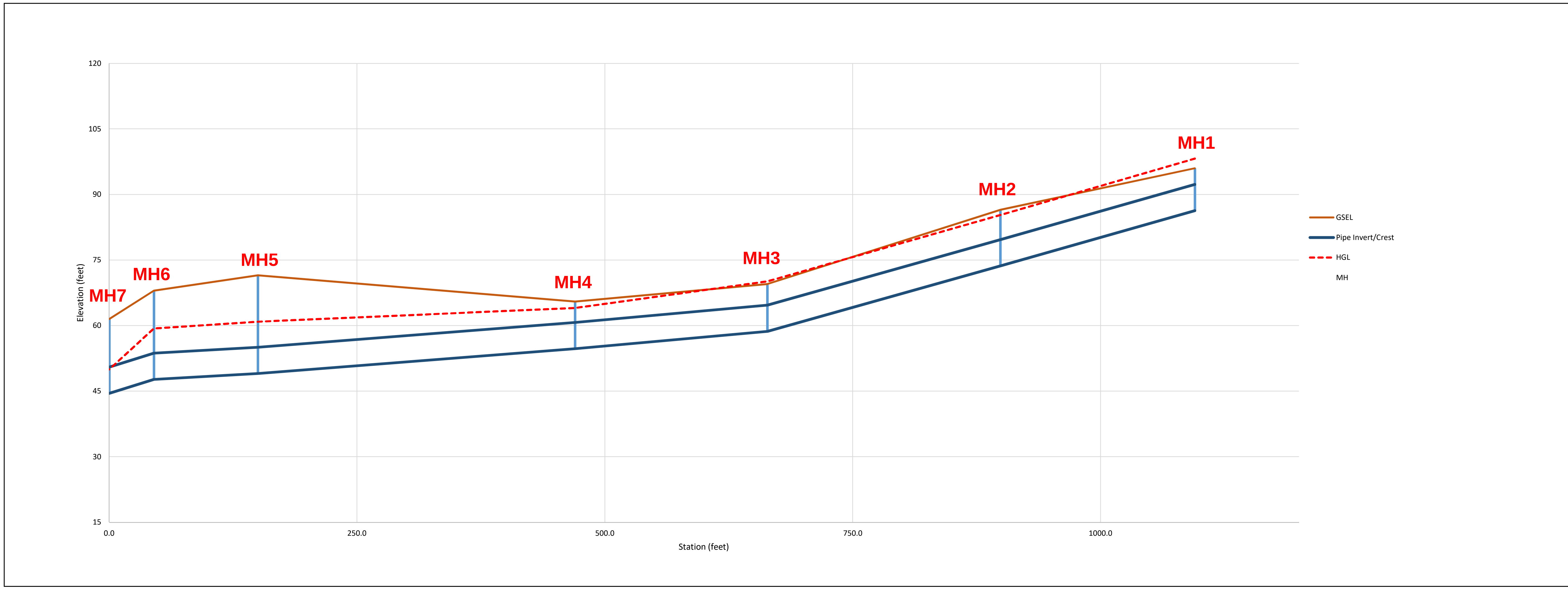
Conduit Notes

Reach	HW Depth (ft)	HW/D ratio	Q (cfs)	TW Depth (ft)	Dc (ft)	Dn (ft)	Comment
P6	7.7037	1.284	285	4.6202	4.6202	1.8835	SuperCrit flow, Inlet end controls
P5	9.9415	1.6569	285	7.7098	4.6202	2.9937	Outlet Control
P4	7.4811	1.2469	285	7.0066	4.6202	2.7389	SuperCrit flow, Inlet end controls
P3	7.4929	1.2488	285	7.4889	4.6202	2.6293	SuperCrit flow, Inlet end controls
P2	7.6752	1.2792	285	7.5009	4.6202	1.9333	SuperCrit flow, Inlet end controls
P1	7.6309	1.2718	285	7.6812	4.6202	1.9305	SuperCrit flow, Inlet end controls

Full Buildout - 100 Year (Parallel Pipe)

	Label	Length (ft)	Distance (STA)	Ground Elev	Invert Elev	Pipe Diam	Crown Elev	HGL	Manhole Depth	Depth %	Height from Rim	Cover
Upstream	MH1	196	1095.0	96	**86.3**	6	92.3	98.21	9.7	198.5%	-2.21	3.70
	MH2	235	899.0	86.5	73.7	6	79.7	85.33	12.8	193.8%	1.17	6.80
	MH3	194	664.0	69.5	58.68	6	64.68	70.14	10.82	191.0%	-0.64	4.82
	MH4	320	470.0	65.50	54.71	6	60.71	64.04	10.79	155.5%	1.46	4.79
	MH5	105	150.0	71.50	49.05	6	55.05	60.89	22.45	197.3%	10.61	16.45
	MH6	45	45.0	68.00	47.68	6	53.68	59.34	20.32	194.3%	8.66	14.32
	MH7		0.0	61.5	**44.5**	6	50.5	49.98	17	91.3%	11.52	11.00
		1095					w/ TW of 4.5' (elev. 49)					

Pipe Label	Avg. Manhole Depth	
P1	12.54131	
P2		9.7
P3		12.8
P4		10.82
P5		10.79
P6		22.45
		20.32
		17



Modeled Flow
800 cfs (Ex. System 100-year Peak)
- 365 cfs (Ex. System Capacity)
= 435 cfs

Parallel Pipe 100-Year Results

Gravity Analysis using fixed flowrates

Reach ID	Flow (cfs)	Full Q (cfs)	Full ratio	nDepth (ft)	Size	nVel (ft/s)	fVel (ft/s)	CFlow
P1	435	1272.582	0.3418	2.4185	72 in Diam	40.7679	45.0084	435
P2	435	1268.617	0.3429	2.4225	72 in Diam	40.6783	44.8682	0
P3	435	718.5501	0.6054	3.3697	72 in Diam	26.6058	25.4135	0
P4	435	667.6775	0.6515	3.5285	72 in Diam	25.1564	23.6143	0
P5	435	572.2052	0.7602	3.9141	72 in Diam	22.2672	20.2376	0
P6	435	1334.412	0.326	2.3364	72 in Diam	42.6972	47.1952	0

HGL Analysis

From Node	To Node	HG El (ft)	App (ft)	Bend (ft)	Junct Loss (ft)	Adjusted HG El (ft)	Max El (ft)
							49.9794
MH6	MH7	59.3285	------	0.0141	------	59.3426	68
MH5	MH6	64.5468	3.6754	0.018	------	60.8894	71.5
MH4	MH5	67.6994	3.6754	0.018	------	64.042	65.5
MH3	MH4	70.1177	------	0.0185	------	69.6	69.5
MH2	MH3	85.3199	------	0.014	------	85.3339	86.5
MH1	MH2	98.2134	------	------	------	96.1	96

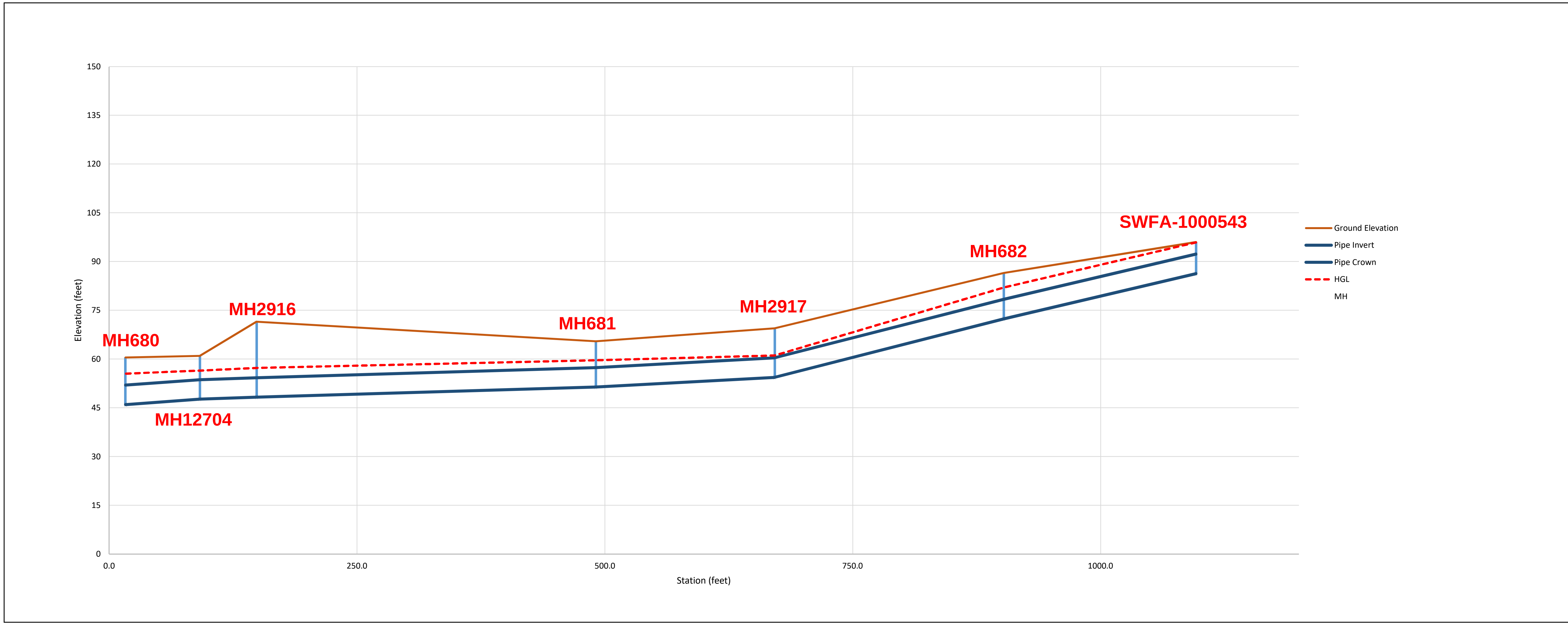
Conduit Notes

Reach	HW Depth (ft)	HW/D ratio	Q (cfs)	TW Depth (ft)	Dc (ft)	Dn (ft)	Comment
P6	11.6485	1.9414	435	5.4794	5.4794	2.3364	SuperCrit flow, Inlet end controls
P5	16.8618	2.8103	435	11.6626	5.4794	3.9141	Outlet Control
P4	18.6534	3.1089	435	11.8394	5.4794	3.5285	Outlet Control
P3	11.4377	1.9063	435	9.332	5.4794	3.3697	SuperCrit flow, Inlet end controls
P2	11.6199	1.9367	435	11.4562	5.4794	2.4225	SuperCrit flow, Inlet end controls
P1	11.9134	1.9856	435	11.6339	5.4794	2.4185	SuperCrit flow, Inlet end controls

Full Buildout_Ex Pipe_365 cfs

	Label	Length	Distance (STA)	Ground Elev	Invert Elev	Pipe Diam	Crown Elev	HGL	Manhole Depth	Depth %	Height from Rim
Upstream											
	SWFA-1000543	193.9	1096.2	96	86.3	6	92.3	95.91	9.7	160.2%	0.09
	682	231	902.3	86.5	72.4	6	78.4	82.05	14.1	160.8%	4.45
	2917	180.5	671.3	69.5	54.4	6	60.4	61.10	15.1	111.7%	8.40
	681	342.12	490.8	65.50	51.4	6	57.4	59.61	14.1	136.8%	5.89
	2916	57.16	148.7	71.50	48.28	6	54.28	57.27	23.22	149.8%	14.23
	12704	75	91.5	61.00	47.68	6	53.68	56.44	13.32	146.0%	4.56
	680	16.5	16.5	60.50	46.01	6	52.01	55.52	14.49	158.5%	4.98
	SWFA-1000547		0.0	61.5				49.66			11.84
							w/ TW of 4.5' (elev. 49)				

Pipe Label	
16573	
3569	9.7
3568	14.1
12133	15.1
3567	14.1
12132	23.22
3566	13.32
8226	14.49
	61.5



Existing Pipe Maximum Capacity Results

Gravity Analysis using fixed flowrates

Reach ID	Flow (cfs)	Full Q (cfs)	Full ratio	nDepth (ft)	Size	nVel (ft/s)	fVel (ft/s)	CFlow
3569	365	1343.816	0.2716	2.1362	72 in Diam	40.4334	47.5278	365
3568	365	1400.712	0.2606	2.0894	72 in Diam	41.6742	49.5401	0
12133	365	646.5977	0.5645	3.2268	72 in Diam	23.5536	22.8687	0
3567	365	478.7412	0.7624	3.9225	72 in Diam	18.6382	16.932	0
12132	365	514.2506	0.7098	3.735	72 in Diam	19.7269	18.1879	0
3566	365	749.4326	0.487	2.9547	72 in Diam	26.3241	26.5058	0
3565	365	978.6215	0.373	2.539	72 in Diam	32.0682	34.6117	0

HGL Analysis

From Node	To Node	HG El (ft)	App (ft)	Bend (ft)	Junct Loss (ft)	Adjusted HG El (ft)	Max El (ft)
							49.6564
680	SWFA-1000547	55.5058	------	0.0096	------	55.5155	60.5
12704	680	59.0148	2.5877	0.0096	------	56.4368	61
2916	12704	59.8441	2.5877	0.0121	------	57.2685	71.5
681	2916	62.1897	2.5877	0.0121	------	59.6141	65.5
2917	681	63.6776	2.5877	0.0075	------	61.0974	69.5
682	2917	82.0333	------	0.0146	------	82.0479	86.5
SWFA-1000543	682	95.9073	------	------	------	95.9073	95.99

Conduit Notes

Reach	HW Depth (ft)	HW/D ratio	Q (cfs)	TW Depth (ft)	Dc (ft)	Dn (ft)	Comment
3565	9.4658	1.5776	365	5.1564	5.1564	2.539	SuperCrit flow, Inlet end controls
3566	13.0073	2.1679	365	9.5055	5.1564	2.9547	Outlet Control
12132	12.1643	2.0274	365	8.7568	5.1564	3.735	Outlet Control
3567	13.903	2.3172	365	8.9885	5.1564	3.9225	Outlet Control
12133	12.2739	2.0456	365	8.2141	5.1564	3.2268	Outlet Control
3568	9.6333	1.6056	365	6.6974	5.1564	2.0894	SuperCrit flow, Inlet end controls
3569	9.6073	1.6012	365	9.6479	5.1564	2.1362	SuperCrit flow, Inlet end controls

Appendix C

VIABLE OPTION BASIS OF COST ESTIMATE (BOE)

PROJECT MEMORANDUM

D-TO-M STREETS TRACK & SIGNAL PROJECT SURFACE WATER HYDRAULIC ANALYSIS

Date: February 10, 2020
Project No.: 10964A00

City of Tacoma

Prepared By:	Brian Sliger, PE
Reviewed By:	Erik Waligorski, PE & Susanna Leung, PE
Subject:	Task 6.1: Basis of AACE Class 4 Cost Estimate for Full Buildout Conceptual Design

Background and Purpose

The D-to-M Streets Track & Signal Project (Project) was completed by Sound Transit (ST) as part of a larger expansion of a regional rail line within Western Washington. This 19-acre portion of the expansion reconstructed City of Tacoma (City) streets from South 'D' Street to South 'M' Street, installed a new rail bed, and regraded an existing rail bed. The Project relocated over 4,000 linear feet of storm drainage pipe, replacing piping in the area with new pipes having diameters ranging in size from 12 inches to 72 inches. These relocations were performed to allow for the lowering of the roadway grade and the installation of a railway bridge over the roadway. Following construction, multiple storm manholes within the Project area have surcharged and flooded the lowered roadway during large storm events.

The Project was located within the Thea Foss Waterway basin (Basin) and therefore was subject to meeting the requirements of the City's 2008 Surface Water Management Manual (TSWMM). Carollo Engineers, Inc. (Carollo) has independently completed an alternatives analysis to identify a viable solution that complies with the TSWMM requirements within the Project area. The alternatives analysis and cost opinion are provided in separate, accompanying documents. The purpose of this project memorandum is to summarize the basis of cost opinion for the identified viable solution that:

- Meets City's 2008 conveyance design requirements (TSWMM) within the Project area.
- Accommodates full buildout flow conditions within the Basin.
- Retrofits the storm system as it currently exists (Year 2019).

The cost opinion prepared reflects the installation of a parallel pipeline matching the grade of the existing storm pipe with large vaults at the upstream and downstream ends of the new pipe's alignment to split and then combine flow, respectively. In general, the parallel pipe would be installed within grassy areas, but crosses an active railroad track and several City roadways. Major components include:

- Approximately 1,100 feet of 72-inch diameter reinforced concrete pipe (RCP) in an urban environment.
- Extension of two (2) vaults for splitting and combining flows.
- Six (6) new 96-inch manholes.
- Trenchless pipe installation (pipe ramming) of approximately 60-linear feet of 96-inch steel casing to cross under the railroad, including associated access pits, material, and equipment.

- Utility relocations required along the new alignment.
- Traffic control associated with the trenching of the pipe through major intersections.

Cost Basis

The expected level of accuracy for this cost estimate follows the Recommended Practice 18R-97 Cost Estimate Classification System for the Process Industries (Association for the Advancement of Cost Engineering [AACE], 1998) designation as a "Class 4" estimate with an expected level of accuracy of -30 percent to +50 percent of the cost presented. Estimated project costs are in December 2019 dollars, consistent with the Seattle Engineering News-Record (ENR) value of 12112. As the project design matures, cost estimates are subject to change, and the cost of labor, materials, and equipment may vary. Because the project timeline is unknown, costs were not adjusted to the mid-point of construction.

Carollo's Conceptual Pipeline Model for cost estimating was utilized to prepare the cost opinion. This model compiles historical cost data for various project items to produce a unit cost representative of the costs expected to be encountered during the construction bidding process. This planning approach uses both major-item quantity estimates and percentage allowances based on experience with similar projects. The following narrative compliments the assumptions listed in the cost opinion worksheet.

General:

- Costs included in the estimate reflect the best understanding of planning level requirements, as they existed at the time the estimate was prepared. Any modifications to the present scope and/or alignment may have substantial cost impacts.
- Existing civil site conditions reflect the piping and paving/grading as depicted in the D-to-M Project as-built drawings. [1]
- Construction activities and sequencing are not hampered by constrained site conditions (no reduced productivity). Work can be sequenced to minimize service and community interruptions.
- Pipe installation and trenching is completed within a single dry season.
- Groundwater table remains generally below the bottom of the trench during the dry season. Trench dewatering is limited to sump pumps.
- All shoring is driven steel sheet piles with internal bracing.

Pipe Trench:

- Excavation depth of the parallel pipe is based on the weighted average invert depth along the entire alignment (approximately 12-feet).
- Pipe zone bedding and backfill between the pipe zone and the bottom of the pavement section is installed with imported structural material.
- The existing roadway in the Project area is reinforced concrete. Approximately 420-feet of the 1,100 feet of installed pipe will be trenched through existing roadways, but the affected size of the existing concrete panels along the pipe alignment is unknown. The assumed square footage of concrete pavement replacement is therefore assumed to be the total pipe length (1,100 feet) multiplied by the top trench width (+1 foot on either side of the trench). The pavement is assumed to be 8-inch thick reinforced concrete.

Rammed Pipe and Pipe:

- Geotechnical conditions encountered at the proposed pipe ram location are adequate for the proposed method.
- Insertion pit accommodates the ramming machine, casings, and pipe:
  - Ramming machine was assumed to be an Grundoram Apollo Pneumatic Pipe Ramming System as manufactured by TT Technologies.[3]
  - Typical casing and pipe lengths of 20-feet.

- A concrete platform is required for the ramming system. Preliminarily sizing per manufacturer guidelines.
- Receiving pit sized to allow for a sufficient work area within the pit including the installation of a 96-inch manhole and manhole connection following the pipe ram.
- Insertion and receiving pits are to both be 25 feet deep, based on ground surface elevations from the record drawings and the proposed invert elevations.
- Insertion and receiving pits are assumed to both be backfilled with imported structural backfill, due to their proximity to the railroad.
- Pipe ramming equipment and labor costs were assumed to be 30 percent of the sum of all other pipe ram costs (including pipe ram earthwork costs).
- The parallel pipe material is RCP:
  - This pipe material remains more readily available and less expensive than other types of pipe that are suitable for an installation of this size and type.
  - Class III RCP Pipe using American Concrete Pipe Association standards[2], assuming a fill height of 15 feet and a Type 2 installation type.

Miscellaneous:

- New 96-inch diameter precast manholes are assumed to accommodate the proposed 72-inch pipe and match the existing manholes.
- Minor utility conflicts are assumed to include utility pole relocations and short distances of small diameter storm drain, sewer, and conduit relocations.
- Major utility conflicts are assumed to include utility vault relocations, grade sensitive storm drain, sewer, and conduit relocations (longer distances) and traffic control electrical cabinet/wiring relocations. The cost assumed for these major conflicts was assumed to be four times that of a minor conflict.
- Flow vaults were originally constructed at the upstream and downstream end of the existing 72-inch stormwater pipe to assist with construction staging, bypass, and the connection of the newly installed 72-inch pipe to the existing pipes. For the installation of the new parallel pipe, extensions to these vaults will be required to split flows between the two 72-inch pipes (upstream end) then combine them again (downstream end). Assumptions utilized while estimating the cost of these structures are as follows:
  - Extensions to these existing vaults will be constructed to allow for flow splitting and convergence.
  - These extensions are assumed to require demolition of a portion of the existing vaults.
  - Concrete thickness and reinforcement was assumed to be equal to that of the existing vaults.
  - Assumed vault extension dimensions were minimized while allowing for adequate space to provide the required flow characteristics.
- Traffic control was assumed to be higher percentage than a typical project due to the urban nature of the area and the required trenching of piping through a major intersection (15 percent of total direct cost).

Exclusions

All potential items of cost which might be associated with the project but for which no costs have been included are listed below:

- Costs for unusual site conditions not currently identified within this memorandum.
- Costs for community impacts (e.g. disruption to surrounding businesses).
- Costs for temporary staging easements beyond the City's existing easements.

- Estimating allowances for City's indirect costs not specifically listed, including bid market, construction management and inspection, permitting, operations support, community outreach, environmental impacts, real estate acquisition and easements, and mitigation.
- Costs for any potential construction delays due to external interferences such as weather conditions, union strikes, or emergency services.
- Costs for unknown or changing site conditions including, but not limited to, ground improvements and site developments beyond existing site conditions reflected in the D-to-M Project as-built drawings[1].
- Costs for additional scope beyond that as detailed in the current scope of work.

References

1. As-Built Drawings, Sound Transit D-to-M Streets Track & Signal Project, Sound Transit, April 2013.
2. American Concrete Pipe Association – LRFD Fill Height Tables for Concrete Pipe: https://www.concretepipe.org/wp-content/uploads/FillHeightTables-1.pdf
3. TT Technologies - Trenchless Equipment Specifications: https://www.tttechnologies.com/download/literature/grundoram-lit.pdf
4. Carollo Cost Estimating Manual
5. Carollo Conceptual Pipeline Model for Confined/Urban Setting
6. Sounder Commuter Rail, D-to-M Streets, Track & Signal Project Specifications, Appendix F, Vol. 2, Book 3 of 4, April 12, 2010 (Well Logs)
7. Department of Ecology, Resource Protection Well Reports, Various Locations in Project Vicinity, https://appswr.ecology.wa.gov/wellconstruction/map/WCLSWebMap/default.aspx

Prepared by:

Brian Sliger

Brian Sliger, PE

BAS:sm

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Appendix D
VIABLE OPTION COST ESTIMATE

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CONCEPTUAL PIPELINE MODEL - TYPE "1" TRENCH - CONFINED / URBAN

Version 2.0-4

This template calculates the excavation and backfill volumes for, what we refer to, as **TYPE 1 TRENCHES**, that are either, 1) a totally full height vertical trench, or, 2) a trench with a "vertical pit" (max depth = 4') plus equal unsupported side slopes to the surface. Type 1 Trenchs are usually considered more for "***Urban***" locations because of restricted access and excavation configuration considerations.

The text and numbers in **RED** are the variables to change to fit your project. These are the **ONLY** inputs that need to be changed. All of the other values shown are based on formulas. By using the side slope of: 1 Vert.to **0 Horiz**, a **vertical trench** is obtained. (Refer to Operation Note #4, for complete instructions.). Calculated values appear in the highlighted box with **bold** lettering. These values can be transferred to your estimate worksheet.

Note: All earthwork quantities are "Bank Measure" volumes without any shrink/swell factors. Operational Notes provided at approximately cell P46.

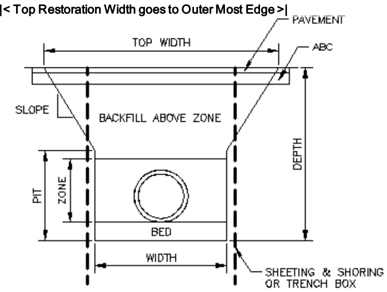
QUANTITY CALCULATIONS:

TYPE 1 TRENCH

Proj Name/No: **D-to-M**
Item: **72" RCP Storm Sewer**
Notes: **Incls. Pipe Ram Segment**

Date: **1/29/2020**
Proj Mgr:: **S. Leung**
Prepared by: **B. Sliger**

|< Top Restoration Width goes to Outer Most Edge >|



DESCRIPTION	**INPUT**	
Pipe Diameter (Nom.)	72	inches
Average **Total** Exc **Depth**	13	feet (Include Bed Thickness)
Length	1,100	feet
Trench Slope: 1 Vert. to	0	Horiz.
Pavement Thickness:	8	inches
ABC Depth:	6	inches
No.of Pavement Cuts	2	Each

Calculated Values

8.0	ft	= Top Trench Width
10.0	ft	= Top Restoration Width

CALCULATED QUANTITIES for ESTIMATE			
Pavement Cutting (per Inch Depth x Length)	=	**17,600**	**ln ft**
Pavement Removal	=	**11,000**	**sq ft**
Trench Excavation	=	**4,237**	**cu yd**
Bed + Zone fill (Excludes Pipe Volume)	=	**1,130**	**cu yd**
Zone Only Fill (Excludes Pipe Volume)	=	**967**	**cu yd**
Bed Only Fill	=	**163**	**cu yd**
Backfill Above Zone	=	**1,956**	**cu yd**
Waste if Import Bed, Zone	=	**2,281**	**cu yd**
~~**Waste if Native Bed, Zone**~~	=	~~**1,152**~~	~~**cu yd**~~
Surface Restoration Area	=	**11,000**	**sq ft**
Shoring Area (Optional): Trench Shored Area	=	**28,600**	**sq ft**
Shoring Area (Optional): With 30% Toe-In	=	**38,038**	**sq ft**

= For driven solid shoring

INPUT VARIABLES

Bed Depth =	**6.0**	in	Default = 6"
Zone Depth Above Pipe =	**6.0**	in	Default = 6"
Min. Width =	**36.0**	in	Indicate Practical Bucket Width
Side Width (per side x 2) =	**24.0**	in	Default @ 12" per side
Pit Depth =	**13.0**	ft	See Note #2, #3 and #4
	1.0	ft	Add'l **allowance** for surface restoration per side **(see Note #5)**

ESTIMATED COSTS:

DESCRIPTION	QTY	UNIT	$/UNIT	TOTAL	$/LF	COMMENTS
Pipe Trench Earthwork	(Important Note: Not all of the quantities generated above will be used in your estimate. See "Example".)					
Pavement Cutting	17,600	in FT	$0.41	$7,298	$7	AC Thickness = 8 in
Pavement Removal	11,000	SF	$1.37	$15,115	$14	
Disposal Haul	272	CY	$8.26	$2,245	$2	Assumed haul distance is: 10 CY Dump Truck, 10 Miles/Round Trip
Trench Excavation	4,237	CY	$3.00	$12,712	$12	Assumed excavator used is: Cat 225 Trackhoe, 1-1/2CY Bucket, Class B (Medium Digging), 0-16' D
Bed + Zone fill	1,130	CY	$34.71	$39,212	$36	Imported confined material used: Imported Trench Backfill/Unconfined Struct. BF, Class B Material
Backfill Above Zone	1,956	CY	$34.71	$67,886	$62	Imported confined material used: Imported Trench Backfill/Unconfined Struct. BF, Class B Material
Waste if Import Bed, Zone	2,281	CY	$8.26	$18,855	$17	Assumed haul distance is: 10 CY Dump Truck, 10 Miles/Round Trip
Surface Restoration Area	11,000	SF	$5.76	$63,384	$58	Pavement replacement is assumed to be: 8" REINFORCED CONCRETE PAVING
Shoring Area	38,038	SF	$15.48	$588,869	$535	Shoring is Sheet Piling, 27#/SF To 20' Deep, Pull & Salvage (Trenches Only)
Dewatering Allowance	1	LS	$100,000	$100,000	$91	
Pipe Ram Earthwork						
Trench Excavation	1,111	CY	$3	$3,334	$3	Assumed excavator used is: Cat 225 Trackhoe, 1-1/2CY Bucket, Class B (Medium Digging), 0-16' D
Backfill	818	CY	$34.71	$28,393	$26	Imported confined material used: Imported Trench Backfill/Unconfined Struct. BF, Class B Material
Shoring Area	6,650	SF	$31.46	$209,182	$190	Shoring is Sheet Piling, 38#/SF To 25' Deep, Pulled & Salvaged (Pits Only)
Earthwork Subtotal				$1,156,484	$1,051	
Pipe						
72-inch Diam. RCP	1,100	LF	$190.02	$209,023	$190	72" Astm C-76 Class III Rcp In Open Trench
Pipe Subtotal				$209,023	$190	
Pipe Ram Misc.						
96-inch Diam. Steel Casing	60	LF	$635	$38,100	$35	96" C200 1/4" Wall Wld Cs Pipe In Open Trench
Concrete Slab for Ram Equipment	1	LS	$12,000	$12,000	$11	Refer to Misc. Item Estimate for additional detail.
Pipe Void Fill	105	CY	$93	$9,765	$9	Refer to Misc. Item Estimate for additional detail.
Pipe Ramming (Equip & Labor)	1	LS	$91,000	$91,000	$83	Assumed to be 30% of all other pipe ram costs (incl. earthwork)
Miscellaneous						
96-inch Manhole	6	EA	$7,658	$45,948	$42	84" X 8' Deep Precast Manhole, No Ring & Cover, No Earthwork + 4-feet (84" Precast Manhole, Xtra Depth Over 8') +10% adder for 96-inch
MH Frame and Cover	8	EA	$1,421	$11,368	$10	36" Dia. X 1150 LB Heavy Traffic Manhole Frame & Cover
Utility Relocation (Minor)	11	EA	$10,000	$110,000	$100	Assumed $10,000 EA
Utility Relocation (Major)	2	EA	$40,000	$80,000	$73	Assumed x4 minor utility conflict
Flow Splitter Vault Extension	1	LS	$80,000	$80,000	$73	Refer to Misc. Item Estimate for additional detail.
Flow Convergence Vault Extension	1	LS	$100,000	$100,000	$91	Refer to Misc. Item Estimate for additional detail.
Traffic Control	1	LS	$300,000	$300,000	$798	15% of Total Direct Cost (less Traffic Control)
Miscellaneous Subtotal				$878,181	$798	

ESTIMATED COSTS:

DESCRIPTION	QTY	UNIT	$/UNIT	TOTAL	$/LF	COMMENTS
TOTAL DIRECT COST:				$2,243,689	*$2,040*	
Indirect Costs						
General Conditions			15.0%	$336,553	*$306*	
Subtotal				**$2,580,242**	***$2,346***	
Design Contingency			30.0%	$774,073	*$704*	
Subtotal				**$3,354,314**	***$3,049***	
General Contractor Overhead, Profit & Risk			20.0%	$670,863	*$610*	
Subtotal				**$4,025,177**	***$3,659***	
Escalation to Mid-Point			0.0%	$0	*$0*	
Subtotal				**$4,025,177**	***$3,659***	
Sales Tax (Based on Tacoma, WA)			10.2%	$410,568	*$373*	
Subtotal				**$4,435,745**	***$4,032***	
Bid Market Allowance			0.0%	$0	*$0*	
TOTAL INDIRECT COST:				$2,192,057	*$1,993*	
TOTAL ESTIMATED CONSTRUCTION COST				$4,435,745	*$4,032*	
Engineering, Legal & Administration Fees			25.0%	$1,108,936	*$1,008*	
Owner's Reserve for Change Orders			20.0%	$887,149	*$806*	
TOTAL ESTIMATED PROJECT COST				$6,431,831	*$5,847*	

AACE Class 4 Accuracy Range

-30%	to	50%	Cost (2019$)
$3,200,000		**$6,700,000**	**Construction Cost**
$4,600,000		**$9,700,000**	**Project Cost**

A. Assumptions, Qualifications, Clarifications:
See separate Basis of Estimate Document (BOE)

B. Supplemental Quantity Calculations (if needed):
Refer to Miscellaneous Item Estimate for additional detail.

Disclaimer: The calculated **quantities** represent "reasonable quantities to perform the work" in Bank Measure. They are not intended to provide "absolute" or "exact" volumes. The execution of earthwork is highly variable due to the unknowns of soil conditions and contractors procedures. The calculated quantities are intended to be used as a general guide ONLY for the basis of the scope of work under consideration. The **cost estimate** herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Carollo Engineers have no control over variances in the cost of labor, materials, equipment; nor services provided by others, contractor's means and methods of executing the work or of determining prices, competitive bidding or market conditions, practices or bidding strategies. Carollo Engineers cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented as shown.

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QUANTITY TAKEOFF WORKSHEET

Project: D-to-M
Client: City of Tacoma
Location: Tacoma, WA
Zip Code: 98402
Element 01 Cost Resources

Date: January 29, 2020
By : BAS
Reviewed: SL
Format: MASTER FORMAT 50

MF50 / SPEC NO.	DRAWING # / DESCRIPTION	# of PLACES	Resulting UNIT	LENGTH in Feet	WIDTH, HEIGHT or DEPTH	THICKNESS in Feet	DIAMETER in Feet	LBS per LF	TOTAL QTY	NOTES	Item No. (Carollo Code)
	(Leave this row blank)										
Flow Splitter Vault											
03_30_00 / 03300	30" Structural Flat Mat On Grade	1	CY	17.5	17	2.5			27.55 CY	Opposing sides averaged for length/width number.	0330030058
03_30_00 / 03300	30" Edge Forms, Slab On Grade, Add	1	LF	69					69 LF		0330030059
03_30_00 / 03300	18" Straight Wall >8' High	1	CY	69	2	1.5			7.67 CY		0330040050
03_30_00 / 03300	18" Straight Wall, To 8' High	1	CY	69	8	1.5			30.67 CY		0330040049
03_30_00 / 03300	12" Elevated Slab To 20'	1	CY	17.5	17	2			22.04 CY	Opposing sides averaged for length/width number.	0330050041
33_05_13 / 02580	36" Dia. X 1150 Lb Heavy Traffic Manhole Frame & Cover	2	EA						2 EA		0258013065
33_05_13 / 02580	Concrete Manhole Invert, Triple Channel	1	EA						1 EA		0258013074
02_41_00 / 02220	Demo Concrete Walls, Heavy Rebar, 12"	1	SF	21	10	1.5			210 SF		0222012022
Flow Convergance Vault											
03_30_00 / 03300	30" Structural Flat Mat On Grade	1	CY	16	21.5	2.5			31.85 CY	Opposing sides averaged for length/width number.	0330030058
03_30_00 / 03300	30" Edge Forms, Slab On Grade, Add	1	LF	75					75 LF		0330030059
03_30_00 / 03300	18" Straight Wall >8' High	1	CY	75	5	1.5			20.83 CY		0330040050
03_30_00 / 03300	18" Straight Wall, To 8' High	1	CY	75	8	1.5			33.33 CY		0330040049
03_30_00 / 03300	12" Elevated Slab To 20'	1	CY	16	21.5	2.5			31.85 CY	Opposing sides averaged for length/width number.	0330050041
33_05_13 / 02580	36" Dia. X 1150 Lb Heavy Traffic Manhole Frame & Cover	2	EA						2 EA		0258013065
33_05_13 / 02580	Concrete Manhole Invert, Triple Channel	1	EA						1 EA		0258013074
02_41_00 / 02220	Demo Concrete Walls, Heavy Rebar, 12"	1	SF	24	13	1.5			312 SF		0222012022
Concrete Slab for Ram Equip.											
03_30_00 / 03300	30" Structural Flat Mat On Grade	1.00	CY	20.00	10.00	2.50			18.52 CY		0330030058
03_30_00 / 03300	30" Edge Forms, Slab On Grade, Add	1.00	LF	60.00					60.00 LF		0330030059
Pipe Void Fill											
31_00_00 / 02300	Controlled Density Fill (Cdf)	1.00	CY						104.72 CY		0230025073
	Pipe Volume			60.00			8.00		446.80 CY		
	Casing Volume			60.00			7.00		342.08 CY		
	Net								104.72		
96-inch Diam. Steel Casing											
40_05_24 / 15270	96" C200 1/4" Wall Wld Cs Pipe In Open Trench	1.00	LF	60.00					60.00 LF		1525214069

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DETAILED COST ESTIMATE

For Allowances, make sure "Spec No." is entered as TEXT.

Project: D-to-M
Client: City of Tacoma
Location: Tacoma, WA
Element: 01 Cost Resources

Format: MASTER FORMAT 50
Date : January 29, 2020
By : BAS
Reviewed: SL

SPEC. NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL	TOTAL	COMMENTS	ITEM NO (Carollo Code)
Flow Splitter Vault								
03_30_00 / 03300	30" Edge Forms, Slab On Grade, Add	69	LF	$32.55	$2,246			0330030059
03_30_00 / 03300	30" Structural Flat Mat On Grade	27.55	CY	$540.09	$14,879			0330030058
03_30_00 / 03300	18" Straight Wall >8' High	7.67	CY	$724.49	$5,557			0330040050
03_30_00 / 03300	18" Straight Wall, To 8' High	30.67	CY	$976.09	$29,937			0330040049
03_30_00 / 03300	12" Elevated Slab To 20'	22.04	CY	$443.74	$9,780			0330050041
33_05_13 / 02580	36" Dia. X 1150 Lb Heavy Traffic Manhole Frame & Cover	2	EA	$1,420.80	$2,842			0258013065
33_05_13 / 02580	Concrete Manhole Invert, Triple Channel	1	EA	$619.40	$619			0258013074
02_41_00 / 02220	Demo Concrete Walls, Heavy Rebar, 12"	210	SF	$24.07	$5,054			0222012022
					$70,914	**$80,000**	Round-up	
Flow Convergance Vault								
03_30_00 / 03300	30" Edge Forms, Slab On Grade, Add	75	LF	$32.55	$2,442			0330030059
03_30_00 / 03300	30" Structural Flat Mat On Grade	31.85	CY	$540.09	$17,202			0330030058
03_30_00 / 03300	18" Straight Wall >8' High	20.83	CY	$724.49	$15,091			0330040050
03_30_00 / 03300	18" Straight Wall, To 8' High	33.33	CY	$976.09	$32,533			0330040049
03_30_00 / 03300	12" Elevated Slab To 20'	31.85	CY	$443.74	$14,133			0330050041
33_05_13 / 02580	36" Dia. X 1150 Lb Heavy Traffic Manhole Frame & Cover	2	EA	$1,420.80	$2,842			0258013065
33_05_13 / 02580	Concrete Manhole Invert, Triple Channel	1	EA	$619.40	$619			0258013074
02_41_00 / 02220	Demo Concrete Walls, Heavy Rebar, 12"	312	SF	$24.07	$7,508			0222012022
					$92,370	**$100,000**	Round-up	
Concrete Slab for Ram Equip.								
03_30_00 / 03300	30" Edge Forms, Slab On Grade, Add	60.00	LF	$32.55	$1,953			0330030059
03_30_00 / 03300	30" Structural Flat Mat On Grade	18.52	CY	$540.09	$10,002			0330030058
					$11,956	**$12,000**	Round-up	
Pipe Void Fill								
31_00_00 / 02300	Controlled Density Fill (Cdf)	104.72	CY	$92.79	$9,717	**$10,000**	Round-up	0230025073
96-inch Diam. Steel Casing								
40_05_24 / 15270	96" C200 1/4" Wall Wld Cs Pipe In Open Trench	60.00	LF	$633.52	$38,011			1525214069