

Hazen *Technical Memorandum*

May 22, 2026

To: Ms. Marisol Bergstrom
From: Alex Biermann, Task Lead
Ryan Oberg, Technical Advisor
Aaron Duke, Project Manager

Bangor-Keyport Force Main Evaluation

Executive Summary

Hazen and Sawyer evaluated a proposed vertical realignment of the Bangor–Keyport Force Main (force main) at two proposed culvert crossings (Sites 16 and 17) to assess potential hydraulic and operational impacts. The analysis included a review of system characteristics, historical performance, and hydraulic modeling of the modified profile. The analysis provided the following results:

- Hydraulic modeling indicates the system can operate with the proposed vertical adjustments during periods of steady flow; however,
- The force main experiences significant grit and sediment accumulation and pumps at LS-17 operate intermittently, resulting in periods of low or no flow.

These conditions create ideal conditions for solids to settle, leading to increased risk of blockages and difficult cleaning and maintenance.

While the system is hydraulically capable, the proposed vertical alignment adjustments introduce significant operational and maintenance challenges driven by grit loading, intermittent pump operation, and accessibility, particularly at Site 16.

Introduction

At the request of Kitsap County (County), Hazen and Sawyer (Hazen) evaluated the existing Bangor-Keyport Force Main (force main) profile between Lift Station 17 (LS-17) and Lift Station 24 (LS-24) to assess the potential hydraulic and operational impacts associated with a proposed vertical realignment at two locations along the force main. These modifications have been requested to accommodate the construction of two fish passage culverts (Sites 16 and 17) as part of the Washington State Department of Transportation (WSDOT) Fish Barrier Removal Program.

The County has expressed concern that the proposed vertical alignment adjustments, particularly the introduction of deep low points, could increase the risk of increased sediment deposition, blockage, and increased operational challenges within the force main. These concerns are validated by documented sediment accumulation events and historical maintenance efforts and challenges within the existing system.

This technical memorandum (TM) presents a preliminary hydraulic evaluation, identifies key risks associated with the proposed profile changes, and provides engineering considerations regarding the feasibility of the proposed configurations.

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1. Existing System

The Bangor–Keyport Force Main (force main) conveys wastewater approximately 4 miles from Lift Station (LS)-17 to where it is combined with flows from LS-67 and ends at LS-24 before being pumped to the Central Kitsap Wastewater Treatment Plant (CKTP), for a total conveyance distance of approximately 6 miles. The force main was constructed in 2023, replacing the previous force main along this corridor. Nominal pipe diameters in this alignment vary from 20-inch to 30-inch and consist of both high-density polyethylene (HDPE) and lined ductile iron (DI) materials. At the two proposed crossings, the existing force main is 26” HDPE DR11 (Iron Pipe Size (IPS)). An existing sewer system map from BHC Consultants’ 2019 Technical Memorandum is provided in Appendix A.

As documented in the BHC Technical Memorandum, the system operates as a force main between LS-17 and Node PJ-32, where a sanitary sewer manhole is located directly west of the Hwy 3 crossing. Downstream of Node PJ-32, wastewater flows transition to a mix of gravity and pressurized flow to a point near the intersection of Hawk Avenue NE and NW Luoto Road (State Route 308), where it transitions to a constant pressurized full pipe flow. The force main from LS-17 connects via a wye connection to the force main from LS-67 at the intersection of NE Tagholm Road and Brownsville Highway NE. From this junction, the combined flows travel along Brownsville Highway NE to LS-24 and ultimately to the CKTP.

Two locations within the force main alignment were identified by the Washington State Department of Transportation (WSDOT) as sites that require a fish passage culvert. These two locations were evaluated to identify the potential impacts of modifying the vertical alignment of the force main, which is the approach proposed by WSDOT’s contractor constructing the culverts. The first location, referred to as Site 16, is located along State Route 308, approximately 580 linear feet east of the Silverdale Way NW intersection, at the Big Scandia Creek crossing. The second location, Site 17, is located along State Route 308, approximately 240 linear feet east of Daniels Creek Place NE, at an existing 24-inch concrete storm drain crossing. Additionally, Kitsap County has experienced, and continues to experience, significant grit accumulation within the force main, attributed to upstream conditions at LS-17. The presence of this sediment has raised concerns regarding the proposed fish passage culverts and is further evaluated in this TM.

To assist with the feasibility evaluation, the County provided flow data for LS-17 from 2021 through 2023 based on recorded flow meter data. During this period, pump station flow rates generally ranged from approximately 100 gallons per minute (gpm) to 500 gpm, representing the 5th and 95th percentile operating conditions, respectively. The average operating flow rate was approximately 250 gpm. The flow data is summarized in Table 1-1.

Table 1-1. PS-17 Flow Rates

Condition	Flowrate
Minimum	~100 gpm
Average	250 gpm
Maximum	500 gpm

2. Proposed Modifications

The alignment modifications proposed by the WSDOT contractor require a vertical realignment of the force main in the following locations:

- Site 16 includes an approximately 100-foot proposed vertical deflection to pass beneath the proposed fish passage culvert
- Site 17 includes an approximately 20-foot proposed vertical deflection to pass beneath the fish passage culvert.

The proposed profile modifications introduce deep inverted siphon-like conditions, with low points prone to increased sediment accumulation, and steep downhill and uphill segments promoting high flow velocities that can result in hydraulic jumps, air entrainment, and off gassing. A preliminary hydraulic profile comparison was performed between the existing and proposed modified conditions. This analysis utilized available system data and assumed that hydraulic behavior of the force main replaced in 2023 is comparable to historical observations of the previous force main operation Figure 2-1 and Figure 2-2 show the proposed WSDOT culvert crossings overlaid with the force main record drawings.

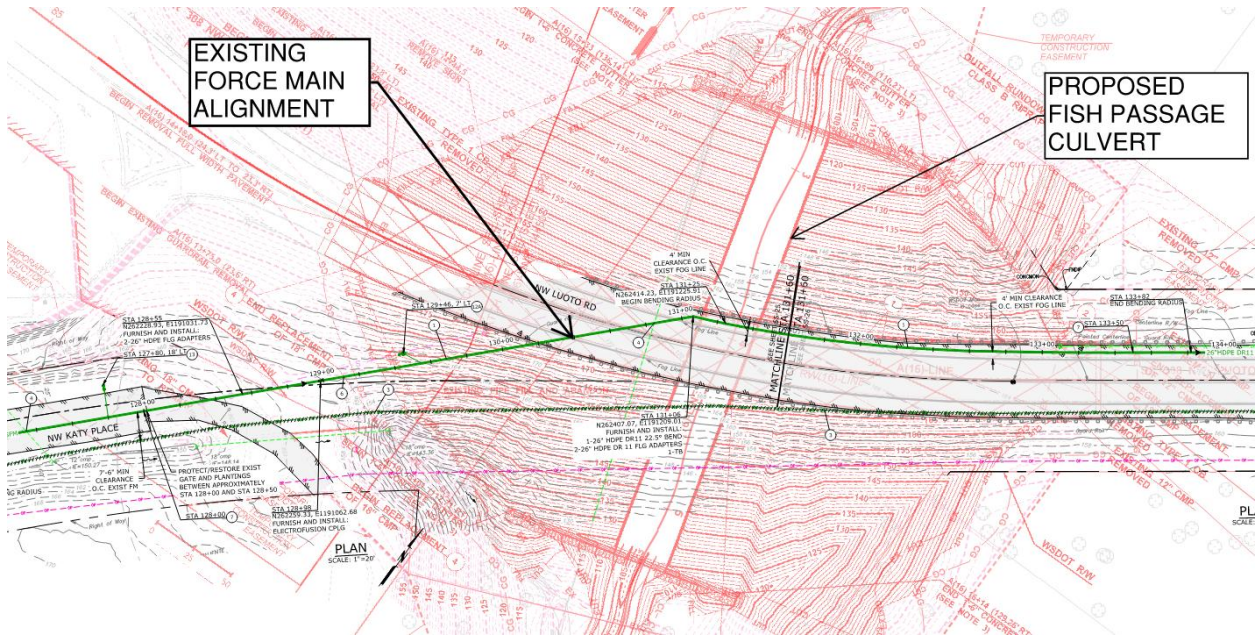


Figure 2-1. Site 16 Culvert Crossing

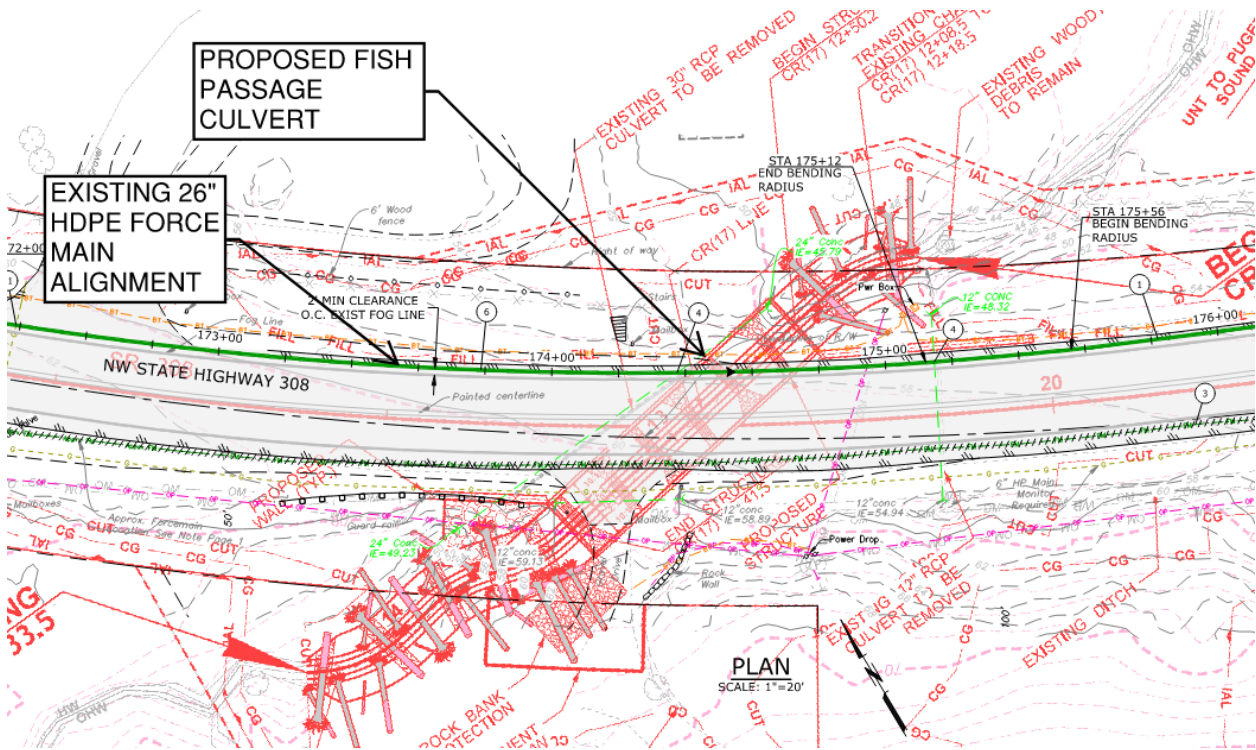


Figure 2-2. Site 17 Culvert Crossing

3. Hydraulic Analysis

To understand system flow rates under normal operations and with the fish passage culvert modifications, a model of the collection system in the vicinity of the proposed work was developed. This simplified model of the force main was developed in SewerGEMS to include LS-17 and LS-67 which combine and flow to a manhole upstream of LS-24, which functions as the hydraulic outlet. Table 3-1 provides the modeling assumptions used. The flow rates shown are the simulated results when the pumps are operating at 100% speed. The model calculates flow and TDH based on the LS-17 and LS-67 pump curves provided by the County. Furthermore, the proposed alignment modifications for the fish passage culverts were incorporated into the model. The model was run to determine the effects of the proposed pipe elevation modifications within the system at the maximum system operating condition.

Table 3-1. Hydraulic Model Assumptions

Item	Value
LS-17	3,600 gpm (2 duty @ 1,800 gpm & 63 feet TDH each)
LS-67	3,800 gpm (2 duty @ 1,900 gpm & 70 feet TDH each)
Roughness	Mannings n = 0.013; Hazen-Williams C=130
Diameter	Internal pipe diameters were used for HDPE DR 11 (IPS)

Figure 3-2 and Figure 3-3 show the modeled hydraulic and velocity profiles, respectively of the existing pipeline with the proposed modifications. Like BHC’s 2019 Technical Memorandum, which was discussed in Section 1, the model predicts that the force main is pressurized until the manhole located at a high point in the system at Node PJ-32. After this location, the force main transitions to gravity flow, fluctuating between partially full to full flow conditions depending on the slope. Both culvert sites are located at relatively low points within their respective alignments and hydraulically do not appear to impact the rest of the system’s operation. The proposed modifications are not expected to create operational issues for the existing LS-17 pumps. However, major operational considerations, including cleaning and pigging, are discussed further in this technical memorandum (TM). The velocities identified at each of the proposed fish passage culvert locations are approximately 3.4 feet per second (fps) at peak flow conditions, as shown in Figure 3-2. Velocities in the surrounding system are expected to be much higher and can range between 10 to 15 fps depending on the respective slopes.

While typically velocities greater than 3 fps are sufficient to suspend and maintain solids in suspension, this velocity is the highest identified at the proposed crossings. The modeled scenario accounts for the maximum system operating condition in which LS-17 and LS-67 are both pumping into the same force main. If flow from LS-17 is reduced or the pumps are off, the velocities in this section reduce below 3.4 fps and will reach 0 fps during times both lift stations are offline.

The flow meter data from the County indicated average flows of 250 gpm from the years 2021 to 2023. These flows are significantly lower than maximum operating conditions. When the model was re-run, assuming 250 gpm is pumped out of LS-17, the results indicated a velocity of 0.23 fps through the proposed modified sections, as shown in Figure 3-3. The resulting velocities below the maximum operating conditions listed in Table 3-1 will result in an increase in grit accumulation that has proven to be difficult to displace. Additionally, fluctuating flow regimes between full and partially full pipe flow

and abrupt changes in velocities due to varying slopes, even at maximum operating conditions, increase the uncertainty of predictable hydraulic behavior.

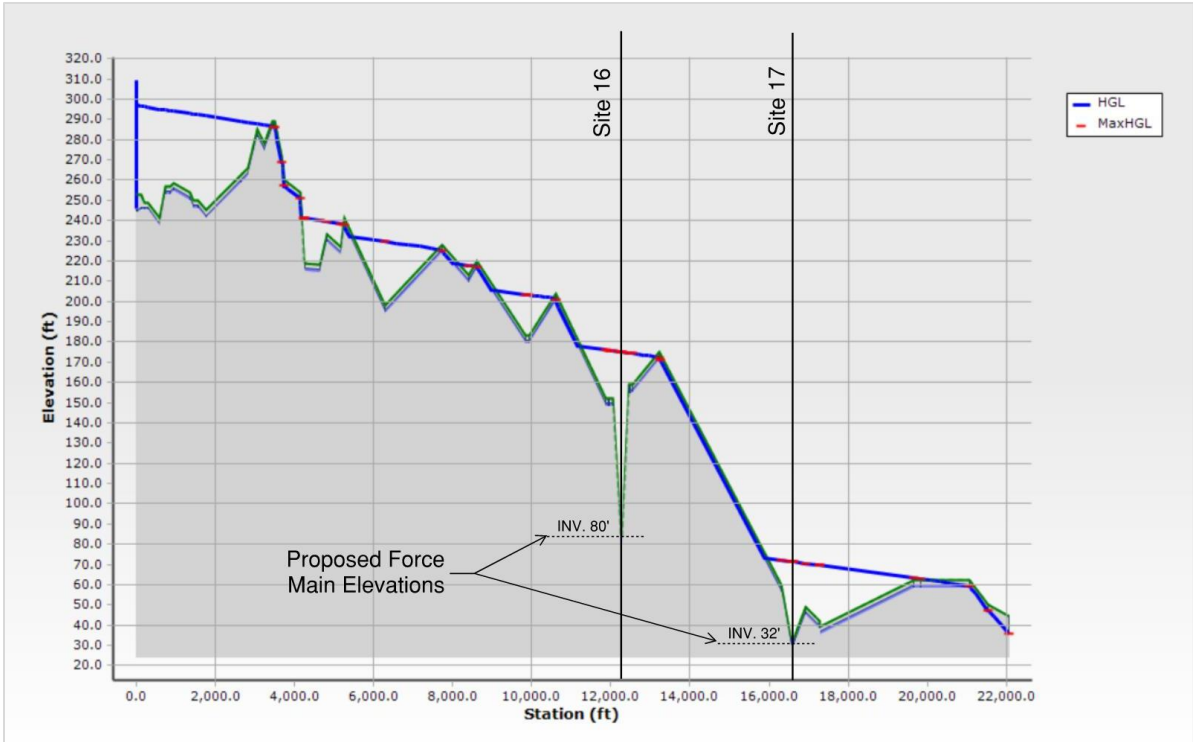


Figure 3-1: Modeled Hydraulic Profile of Proposed Force Main Profile

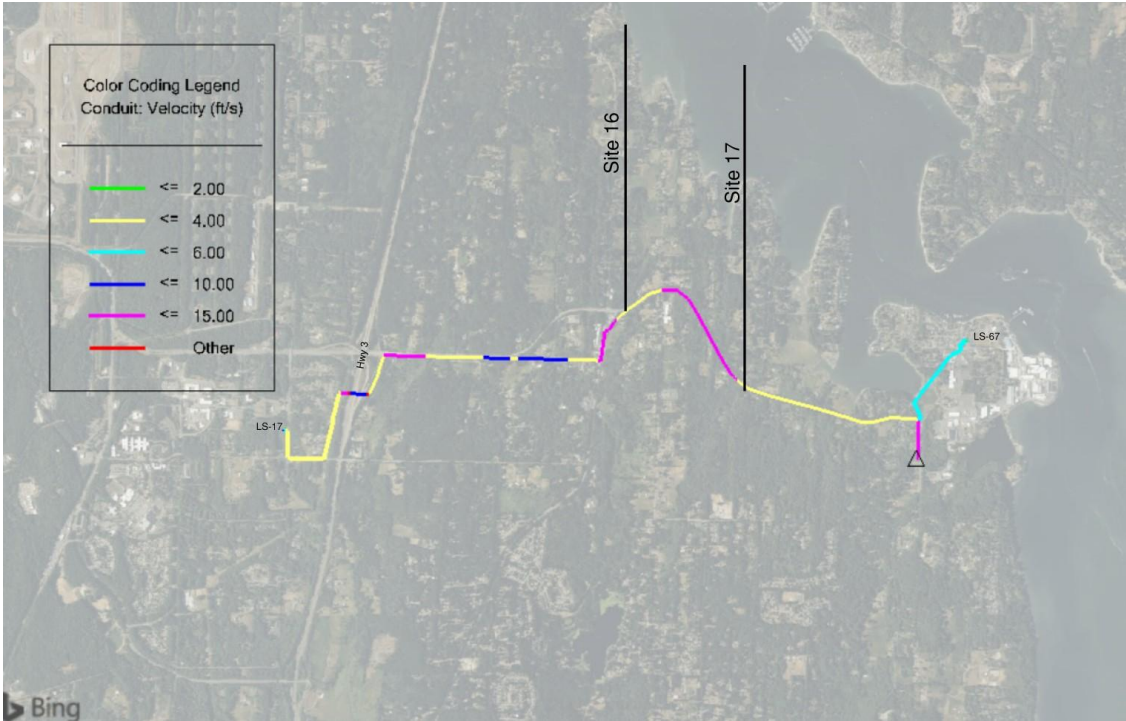


Figure 3-2: Modeled Velocity Profile of Proposed Force Main Profile (LS-17 @ 3,600 gpm)

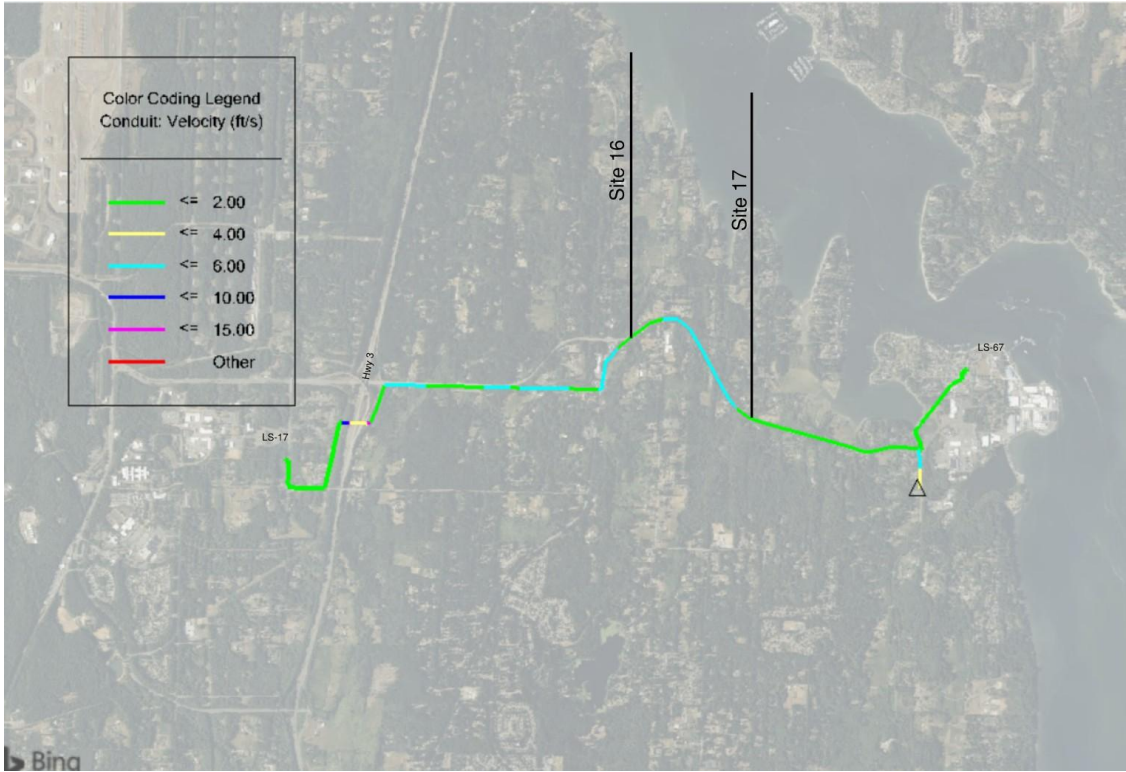


Figure 3-3: Modeled Velocity Profile of Proposed Force Main Profile (LS-17 @ 250 gpm)

4. Grit Analysis

4.1 Existing System

Kitsap County has experienced large volumes of grit accumulation within the Bangor-Keyport force main, primarily due to upstream conditions at LS-17. Existing sedimentation concerns are particularly important when evaluating the proposed fish passage culvert modifications. This is important because the revised vertical alignments introduce new low points that are substantially deeper than others within the current pipeline profile. These deeper sections are expected to increase both the frequency and volume of solids accumulation within the force main.

Periods of low flow or pump inactivity further increase the likelihood of grit deposition. Under these conditions, wastewater velocities decrease below the threshold necessary to maintain solids in suspension, allowing grit to settle within local low points of the pipeline. Over time, this accumulation increases the potential for flow restrictions, blockages, and difficult maintenance operations.

Field observations confirm the system's existing susceptibility to grit accumulation. Figure 4-1 shows grit deposits within a temporary bypass pipe after approximately 3.5 months of operation during construction of the Bangor–Keyport Force Main replacement project near the Highway 3 crossing. Figure 4-2 shows an opening cut into the previous force main prior to replacement, illustrating a more long-term grit accumulation within the pipeline under normal operating conditions.

The County also collected a grit sample from PS-17 and performed sieve analysis testing to characterize particle size distribution within the sample. The resulting data are presented in Figure 4-3. Using the sieve analysis results, settling and scouring velocities were estimated for each particle size range and are summarized in Table 4-1.



Figure 4-1. 18-inch Bypass Pipe



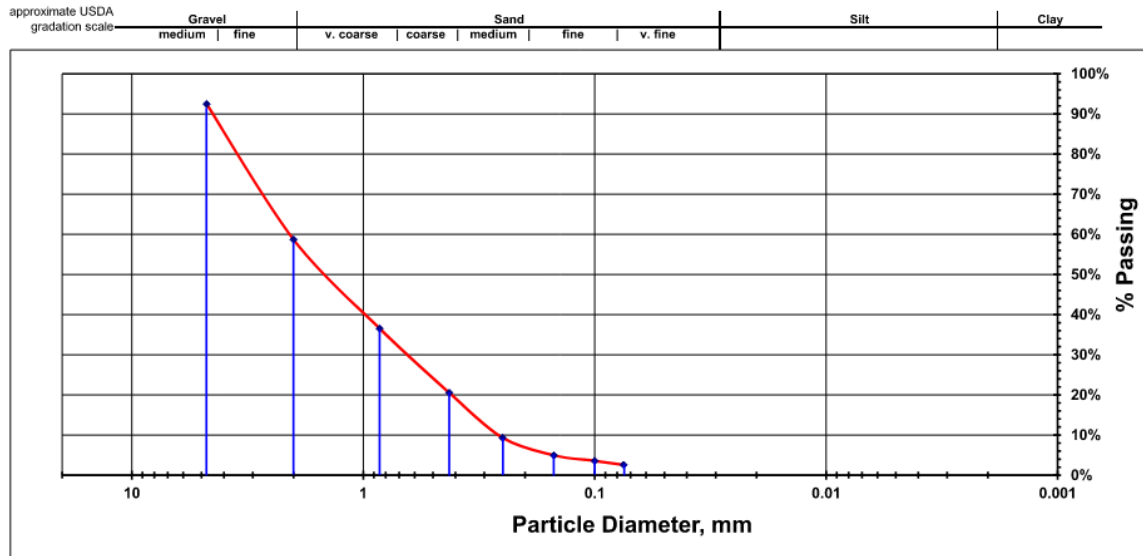
Figure 4-2. Old Force Main 75% Full

PARTICLE SIZE DISTRIBUTION REPORT

CLIENT: **Kitsap County Public Works**
 PROJECT: **S26-07094**
 Lab #

SAMPLE ID: **PS-17 Grit**

Date Received: **4/17/2026**
 Date Reported: **4/17/2026**
 Method: **ASTM D422**
 PO#: **402-155**
 Cost: **\$135**



description seive # diameter, mm	MedGr 1/2" 12.7	MedGr 3/8" 9.525	FIgr 4 4.75	vCoS 10 2.00	CoS 18 1.00	CoS 20 0.85	CoS 30 0.60	MedS 40 0.425	FIS 60 0.250	FIS 100 0.150	vFIS 140 0.100	vFIS 200 0.075	Silt 270 0.050	Sand Total	Gravel Total
Retained			7.5%	33.8%		22.1%		16.0%	11.2%	4.4%	1.4%	1.0%		56.1%	41.3%
Passing			92.5%	58.7%		36.5%		20.5%	9.3%	4.9%	3.6%	2.6%			

Graph Values	D ₁₀	2.10	Coefficient of Uniformity:	8.4
	D ₃₀	0.65	Coefficient of Gradation:	0.80
	D ₁₀	0.25		

Figure 4-3: Grit Sieve Data for PS-17

Table 4-1. Scouring Velocity by Grit Particle Size

Solids Diameter (mm)	Percent of Solids	Settling Velocity (ft/s)	Scouring Velocity (ft/s)
< 0.075	2.6%	0.013	1.3
0.075-0.1	1.0%	0.016	1.1
0.1-0.15	1.3%	0.030	0.8
0.15-0.25	4.4%	0.082	0.7
0.25-0.425	11.2%	0.115	0.7
0.425-0.85	16.0%	0.262	0.7
0.85-2.0	22.2%	0.492	1.1
2.0-4.75	33.8%	0.656	2.0
> 4.75	7.5%	0.820	2.3

The approximate location of the grit accumulation shown in Figure 4-1 is identified in Figure 4-4. The BHC modeling report of the pipeline prior to replacement indicates that this section of existing pipeline operates as a full-flowing 20-inch ductile iron force main. At the average system flow rate of approximately 250 gpm, the corresponding pipe velocity is approximately 0.2 feet per second (fps), which is substantially lower than the estimated scouring velocities for all measured grit particle sizes. Under these conditions, grit deposition is expected to occur continuously.

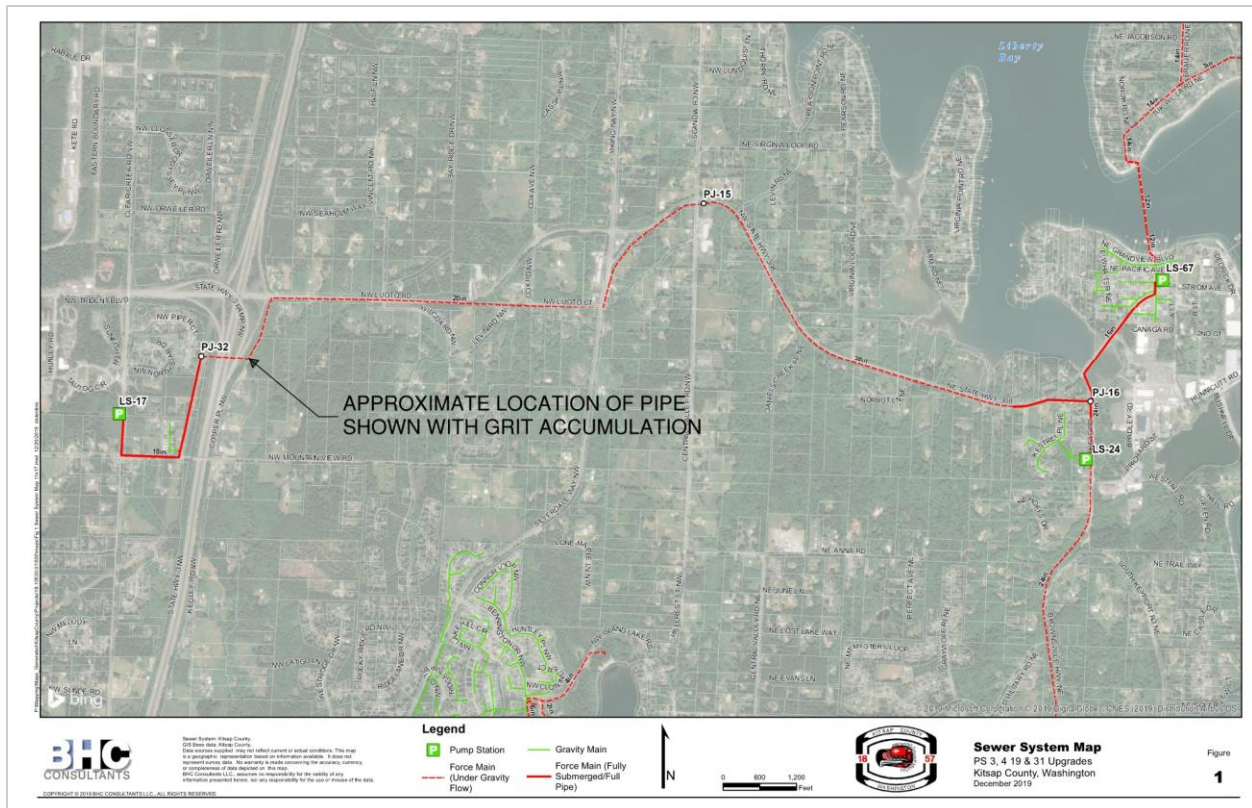


Figure 4-4. Grit Accumulation Example Location

As grit accumulates, the effective flow area within the pipe decreases, resulting in an increased velocity through the remaining open area. This continues to occur until the flow velocity approaches the scouring threshold for each particle size fraction. This reduced cross sectional flow condition represents the approximate steady-state accumulation condition within the given pipe section. To further explain this, the flow area required for each particle size band to equal the scouring velocity was calculated and a weighted average of the percent of pipe area filled with grit was calculated. For the pipe shown in Figure 4-2, approximately 80% of the pipe flow area would be full of grit at steady-state or a depth of 75% of the internal pipe diameter. This coincides with the field observations shown in Figure 4-2 and provides validation of the analytical approach.

4.2 Proposed System

The proposed fish passage culvert modifications would deepen the existing low points within the force main by approximately 80 feet at Site 16 and approximately 20 feet at Site 17. Because both locations are already situated at local hydraulic low points within the system, some degree of grit accumulation would be expected under existing conditions. However, the increased depth and revised vertical profile are expected to significantly increase the potential for sediment deposition and long-term accumulation.

Steady State Conditions

At both proposed crossing locations, the force main consists of 26-inch HDPE pipe with an internal diameter of approximately 21 inches. Hydraulic modeling discussed in Section 3 indicates that both crossing segments will operate under full pipe flow conditions. Given the average discharge rate from PS-17 of approximately 250 gpm, the resulting flow velocity within these pipe segments will also be approximately 0.2 fps, like the existing condition evaluated in Section 4.1. This velocity remains well below the required scouring velocities for all measured grit particle sizes and will therefore result in continued net deposition of solids within the proposed sections.

Applying the same analytical methodology applied in Section 4.1, the estimated steady-state condition at 250 gpm results in approximately 80% of the pipe cross-sectional area becoming occupied by grit deposits, equivalent to roughly 75% of the pipe diameter. However, system flows frequently decrease below average operating conditions and have shown to approach approximately 100 gpm. Under these lower flow conditions, the steady-state open flow area reduces to approximately 7% of the pipe cross section, resulting in approximately 93% of the pipe filled with grit.

At this level of deposition, the remaining flow opening becomes highly vulnerable to obstruction from rags, grease, and other debris commonly present in wastewater systems. With 7% of the pipe flow area open, relatively small obstructions could bridge the remaining opening, trap additional solids, and rapidly develop into a complete blockage.

Cleaning Cycles

One potential operational strategy for limiting grit accumulation would involve periodically cycling the pumps to generate short-duration, high-velocity flushing events capable of mobilizing deposited solids. Current PS-17 operating conditions generally exhibit limited cycling behavior, and observed system performance more closely resembles the steady-state accumulation conditions described previously. Furthermore, there are a couple of potential concerns with running the pump station with periodic cycles to generate short-duration, high velocity flushing events. First, the combined influent flow and wet well storage would need to be large enough to be able to produce and sustain high flowrates for long enough to suspend settle grit. Second, flushing cycling would increase the number of pump starts and would decrease pump runtime and increase no-flow time in the force main. Flushing time would need to offset increased grit settlement during no-flow times for this approach to be effective.

To achieve scouring velocities sufficient to mobilize the full range of grit particle sizes identified in the sieve analysis, a flow rate of approximately 2,400 gpm will be required. Based on the pump flowrate data analysis provided in Section 1, these flow conditions occur infrequently in the system. Furthermore, based

on available wet well storage volume and drawdown testing, LS-17 could only sustain this flow rate for approximately 5 to 8 minutes before pump operating conditions are jeopardized. This duration is insufficient to effectively scour and transport accumulated grit throughout the approximately 22,000-foot force main system.

In addition, increased pump cycling may unintentionally exacerbate grit accumulation at the proposed fish passage locations during no-flow conditions. Because both crossings are located at low points in the system, solids suspended within adjacent upstream and downstream pipeline segments would tend to settle toward these locations whenever pumps are offline. Based on the estimated settling velocities summarized in Table 4-1, most grit particles will settle from suspension within approximately 10 minutes after flow is stopped.

As a result, grit deposition will be exacerbated in the immediate sections beneath the culverts as solids from longer segments of the force main between adjacent local high points will progressively migrate and accumulate within the proposed low sections. For both crossings, the contributing pipeline length extends several thousand feet, as illustrated in Figure 4-5.

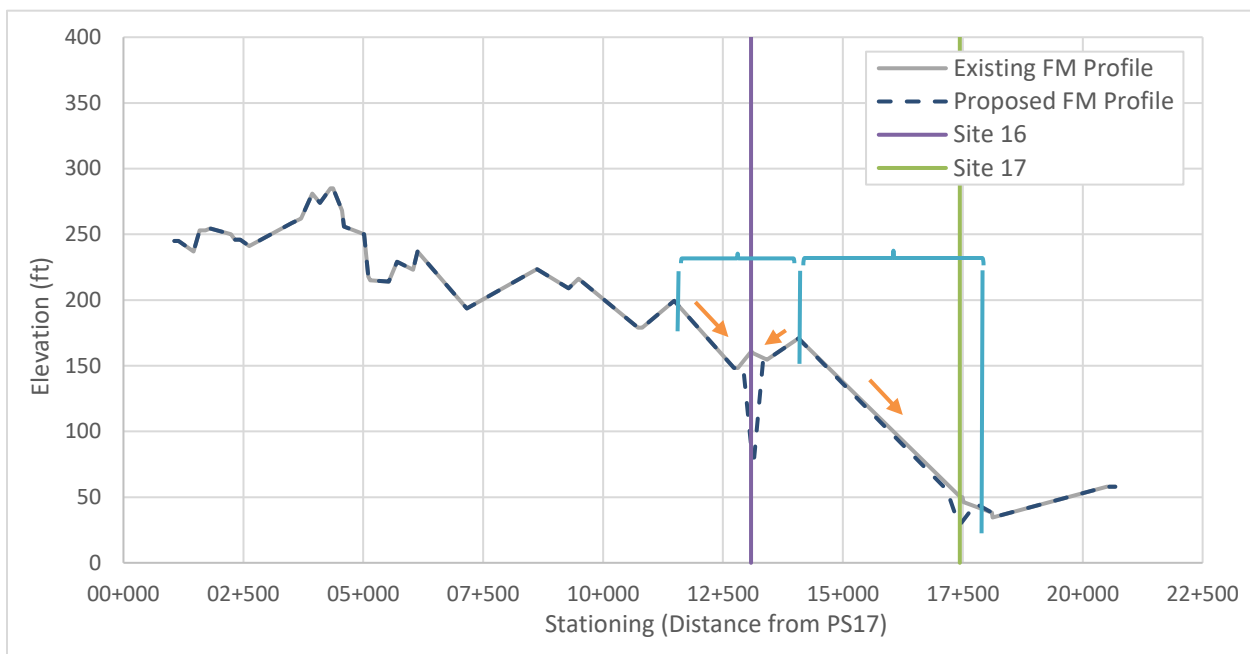


Figure 4-5. On/Off Cycling Grit Accumulation in Fish Passages

Consequently, based on historical operating data, drawdown testing, and settling behavior analysis, modifications to pump operating cycles are not considered a practical or reliable long-term solution for controlling grit accumulation within the proposed fish passage alignments. For LS-17, which typically has low-flow conditions and limited storage, increased pump cycling would likely cause a net increase in grit accumulation in the proposed fish passage sections compared to typical operations.

Pigging

An alternative method for removing grit accumulated within the force main is pigging. The County currently maintains a pig launching station at LS-17. Under the proposed vertical alignment modifications at Site 16, a sufficient pressure head will be required to propel the pig through the accumulated grit and transport the material out of the proposed 100-foot section.

Based on the grit accumulation analysis presented in Appendix B, approximately 215 feet of head will be required to mobilize and remove the estimated 20 ft³ at Site 16 of accumulated grit. The available system head upstream of Site 16 is approximately 137 feet resulting in a driving head deficit of 78 feet. Additional details regarding the pigging and required driving head calculations are provided in Appendix C.

The driving head deficit indicates that the system is not configured to provide sufficient hydraulic head to effectively perform pigging operations at Site 16. As a result, the proposed vertical alignment modifications will introduce a significant long-term maintenance challenge.

5. Considerations

The proposed vertical realignments introduce several hydraulic reliability uncertainties and challenges. Vertical alignments within a gravity pipeline promote operational conditions that are prone to flow regime transitions. This is particularly applicable along steep vertical drop segments where turbulence, air entrainment, surge, and off gassing are critical design elements. Vertical drops and rises within a pipeline alignment also present challenges with operational efficiencies and reliability resulting from sedimentation and solids accumulation.

Given that this system has historically been challenged with abnormally high grit concentrations and flow restrictions, maintaining and cleaning efforts have been cumbersome and time consuming. Deep vertical drops present additional maintenance challenges and difficulties that often result in outages, emergency bypasses, and sometimes pipeline replacement. Additional maintenance challenges with gravity flow pipelines include the need for pigging or other solids accumulation extraction, access, inspection and monitoring.

The proposed crossing at Site 16 incorporates what will be the deepest and steepest change in vertical alignment within the system. This configuration lends itself to increased system operational uncertainties, poor efficiencies, and long-term reliability challenges. Because of the issues and challenges with heavy grit accumulation experienced within the existing system, and their exacerbation by installing a new piping segment in a deep, inaccessible alignment below the proposed culvert, designing a bypass to also serve as a permanent relocation solution would need to be strongly considered. A bypass system is required for any scenario considered to construct the culvert, therefore installing the new pipeline in as close to the same location, and more importantly depth to the existing line will avoid intensifying the grit accumulation challenges. This approach maintains accessibility for crews to address problems that may necessitate quick access to the pipeline. There is a high risk the pipeline will become clogged and pigging or flushing will prove to be ineffective, requiring a bypass system and constructing a new pipeline segment above the proposed culvert. This will further impede traffic while the road is removed to address.

Since this is likely to occur in short order upon returning the pipeline to service (based on historical grit accumulation discussed in Section 4), construction activities associated with the proposed culvert will also be impacted.

The proposed crossing at Site 17 results in a vertical alignment shift like those within the existing alignment. While it is not anticipated that the revised alignment will result in a significant increase in grit accumulation and maintenance challenges, it will increase within the specific segment. Additionally, consideration should be given to address the increased air entrainment and off gassing that will result.

The proposed vertical alignment modifications at Site 16 and Site 17 each present their own challenges to the effective and efficient operation of the conveyance system. The following elements are of particular concern:

1. Site 16 Crossing:
 - a. Increase in grit and solids accumulation.
 - b. Insufficient driving head for pigging and cleaning.
 - c. Vacuum truck lift limitations.
 - d. Increase in gas and air entrainment and accumulation beyond design criteria.
 - e. Deep subsurface and below structure accessibility.
 - f. Increased potential for system surge and pressure fluctuations.
 - g. Potential for line failure and washout of crossing.
 - h. Inspection equipment access and entrapment.
2. Site 17:
 - a. Increase in gas and air entrainment and accumulation beyond design criteria.
 - b. Increase in grit and solids accumulation within the specific pipe segment.
 - c. Insufficient driving head for pigging and cleaning.
 - d. Potential for line failure and washout of crossing.
 - e. Deep subsurface and below structure challenges and accessibility.

6. Recommendations

The preferred solution is one that minimizes solids deposition potential and eliminates the potential for maintenance-intensive operations to remove accumulated grit. To help mitigate the challenges associated with the proposed alignment modifications, the following recommendations should be considered for further evaluation:

1. Site 16:
 - a. Maintain a bypass system during culvert construction and replace the force main as construction is progressed to the backfill phases to return the piping to its existing

alignment, avoiding the significant vertical drop and the associated challenges. A phased construction approach may help reduce bypass duration.

- b. Reconfigure the horizontal piping alignment around this location and maintain pipe elevations to closely match existing conditions.
2. Site 17:
- a. Incorporate the use of a pipe bridge along the downstream side of the proposed culvert to maintain existing pipe vertical alignment.
 - b. Incorporate the use of pipe hangers or supports along the downstream culvert headwall to suspend the pipe along its existing vertical alignment.
 - c. Reconfigure the horizontal piping alignment around this location and maintain pipe elevations to closely match existing conditions.

Appendix A: BHS Consultant's 2019 Technical Memorandum



TECHNICAL MEMORANDUM

Date: December 20, 2019
To: Barbara Zaroff
From: Tony Fisher
CC: Stella Vakarcs
Subject: Lift Station 17 Force Main Sizing/HGL
Project No: 10530.01

At the request of Kitsap County (County), BHC Consultants, LLC (BHC) reviewed the profile of the sewer system between Lift Station 17 and Lift Station 24 to determine the sections of pipe that remain full under the modeled flow conditions. The County also asked BHC to investigate whether decreasing the size of the piping would provide additional protection from corrosion by extending the length of pipe that is typically submerged and flowing full.

A review of the sanitary sewer system between Lift Station 17 and Lift Station 24 indicates that the system acts as a force main between Lift Station 17 and Node PJ-32. Downstream of Node PJ-32, the sewage flows by gravity to Lift Station 24 where it is subsequently pumped to the Central Kitsap Wastewater Treatment Plant (CKTP) for treatment. The 24-inch pipe between Lift Station 24 and Node PJ-16, which has a length of about 1000 feet, remains fully submerged at all times as Node PJ-16 is located at a lower elevation than the invert into Lift Station 24. The hydraulic grade line in this segment of pipe is driven by pumped flows from Lift Station 67 combined with the Lift Station 17 pumped flows and creates a backwater affect in the 20-inch pipe between Node PS-16 and Node PJ-15. The backwater extends west into the 20-inch pipe for about 1,300 feet. Figure 1 depicts the sanitary sewer system between Lift Station 17, Lift Station 67, and Lift Station 24.

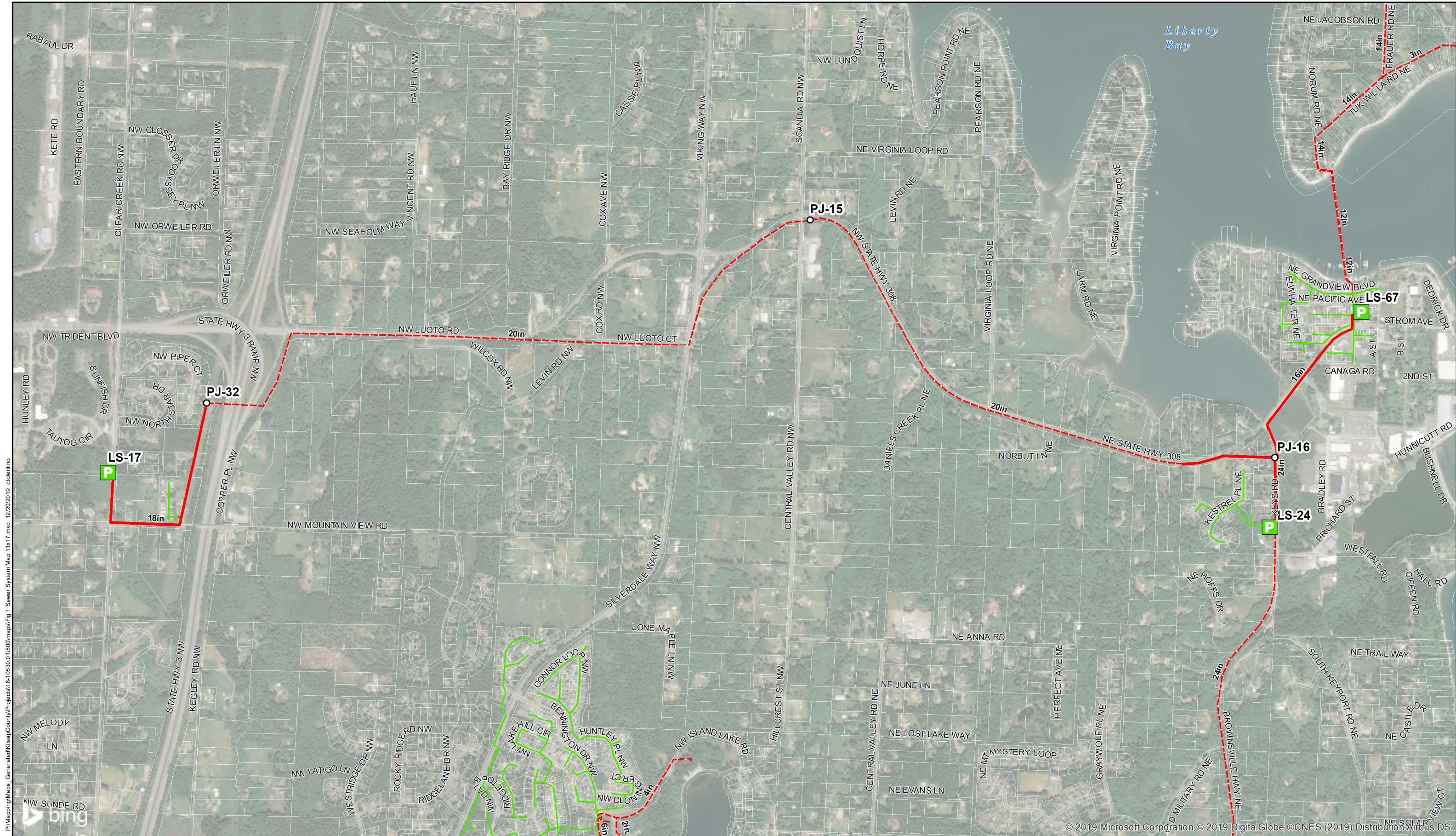
The 20-inch pipe between Node PJ-32 and Node PJ-16 appears to have sufficient capacity to convey the current, future (2038), and buildout flows (See appendix for model results) and may even be slightly oversized. However, this main is experiencing corrosion issues and needs to



be replaced. As previously mentioned, corrosion in pipelines typically occurs at the water surface line where hydrogen sulfide in the sewage reacts with moisture in the air to make sulfuric acid. One means of minimizing the amount of pipe that is subject to this corrosion is to submerge more of the pipe. However, the pipeline grades would require the pipes to be substantially deeper to significantly increase the amount of submerged pipe and that is not practical.

Another means of increasing the length of submerged pipe is to decrease the diameter of the pipe, resulting in more frictional head loss and a higher hydraulic grade line. Increasing the hydraulic grade line in the pipe between Lift Station 24 and Node PJ-16 would directly impact the pumping capacity at Lift Station 67 and is not recommended as that could trigger an upgrade to the station. Decreasing the diameter of the pipe between Node PJ-16 and Node PJ-32, while physically possible, would provide little benefit as the minimum amount of submerged pipe would be dictated by the lowest flows, which occurs when the pumps at Lift Station 67 and Lift Station 17 are off. This condition would essentially result in a relatively flat hydraulic grade line that is set by the invert elevation of the pipe entering Lift Station 24. Decreasing the diameter of the pipe between Node PJ-16 and PJ-32 would not significantly change that elevation. Decreasing the diameter of the pipe between those two nodes would increase the hydraulic grade line in that segment of the system when the pumps at Lift Station 17 are operating but would have little to no benefit at low flows.

Lowering the pipe or decreasing its diameter would require the pipe to be replaced. When the pipe is replaced, PVC or HDPE should be used for the pipe material as either option is more resistant to corrosion and is less expensive than ductile iron or steel pipe. Since the pipe would need to be replaced anyway, decreasing the diameter or increasing the depth of the pipe would offer little benefit and could potentially create a future bottleneck at full buildout flows, depending on how growth occurs and whether any contributing areas undergo zoning changes. Therefore, the recommendation is to maintain the existing grade and diameter of this pipe when it is replaced, while using corrosion resistant materials such as HDPE or PVC pipe.



P:\Mapping\Maps_Generated\KitsapCounty\Projects\18-10530_01\500\maps\Fig 1 Sewer System Map 11x17.mxd 12/20/2019 cblentini

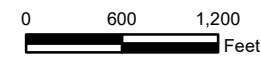
© 2019 Microsoft Corporation © 2019 DigitalGlobe © CNES (2019) Distribution Airbus DS



Sewer System: Kitsap County.
 GIS Base data: Kitsap County.
 Data sources supplied may not reflect current or actual conditions. This map is a geographic representation based on information available. It does not represent survey data. No warranty is made concerning the accuracy, currency, or completeness of data depicted on this map.
 BHC Consultants LLC., assumes no responsibility for the validity of any information presented herein, nor any responsibility for the use or misuse of the data.

Legend

- P Pump Station
- Gravity Main
- Force Main (Under Gravity Flow)
- Force Main (Fully Submerged/Full Pipe)



Sewer System Map
 PS 3, 4 19 & 31 Upgrades
 Kitsap County, Washington
 December 2019



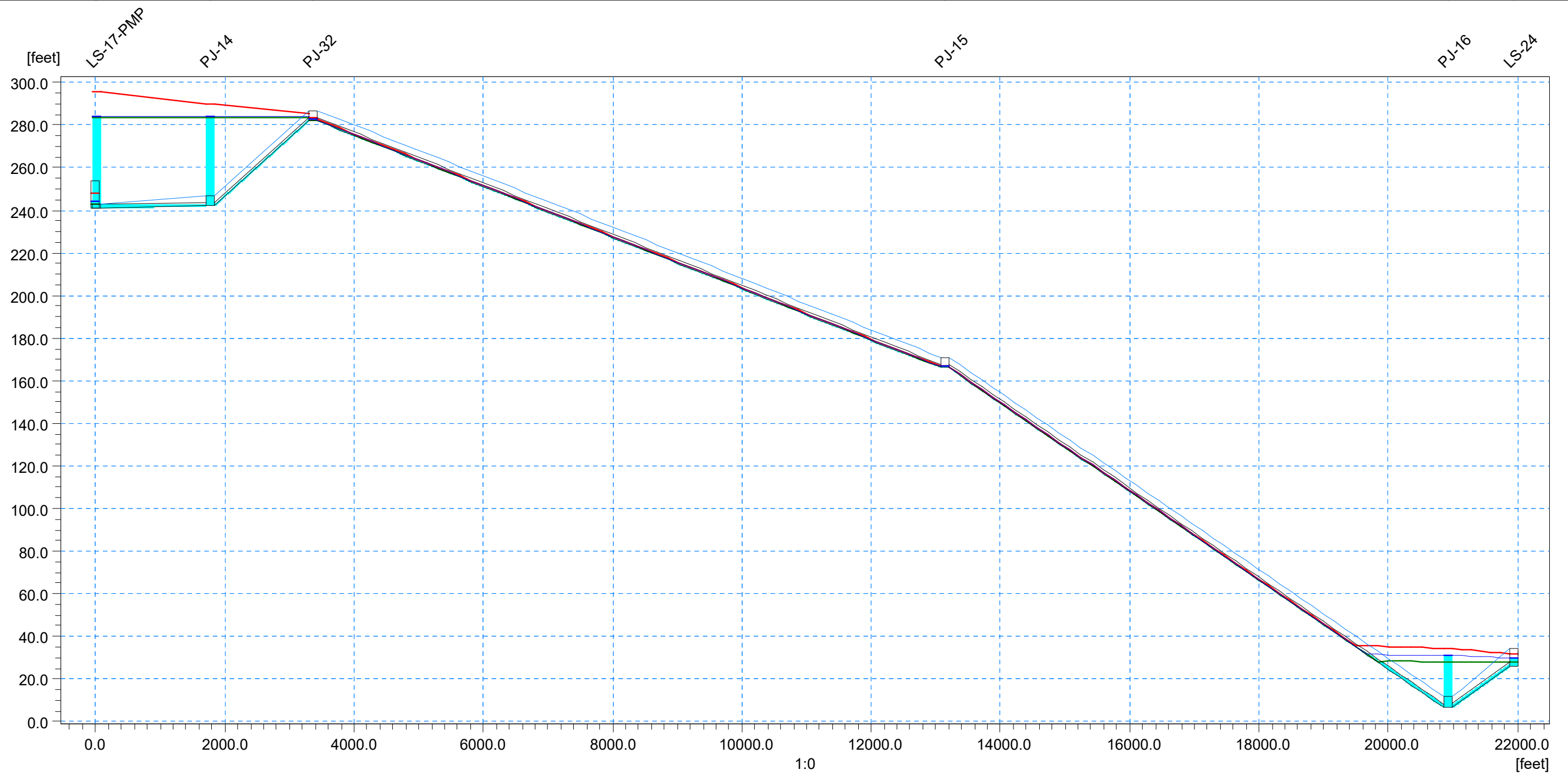
APPENDIX – MODEL RESULTS

LS17 to LS 24

2017 PEAK FLOW CONDITIONS
PRE CIP

Link Water Level - 1-1-2007 00:00:00 2017_Peak_FINAL2017_Peak.PRF

Discharge	-0.000	-0.000	1.398	3.026	7.129	cfs
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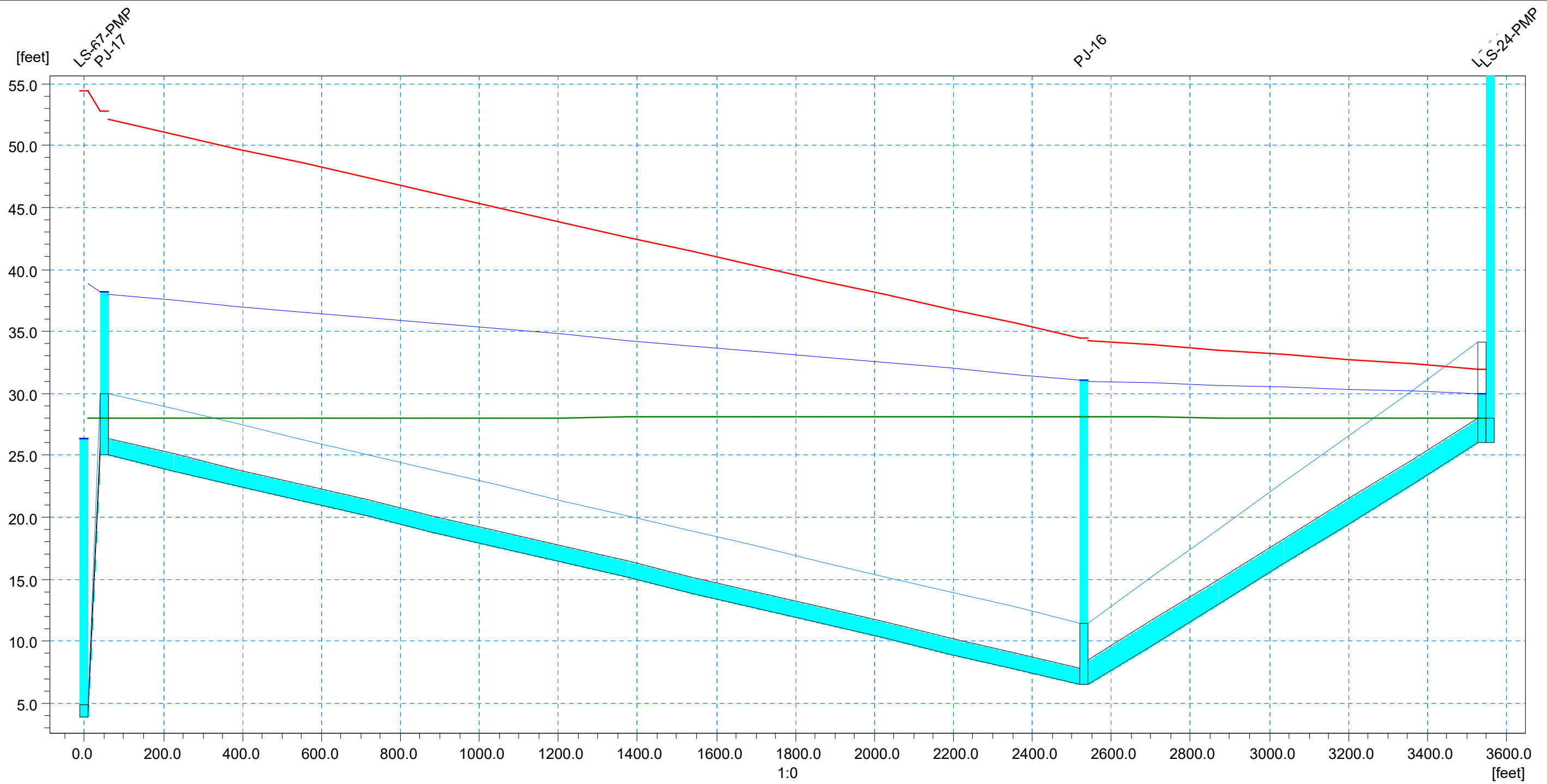
Ground Lev.	241.20	253.70	242.00	247.00	282.00	287.00	166.00	171.00	11.50	[m]
Invert lev.	241.20	253.70	242.00	247.00	282.00	287.00	166.00	171.00	6.50	[m]
Length	1762.35	1589.08	9779.49	7780.43	1008.00	[m]				
Diameter	1.50	1.50	1.67	1.67	2.00	[m]				
Slope o/oo	0.45	25.17	11.86	20.50	19.35					

LS67 to LS 24

2017 PEAK FLOW
CONDITIONS
PRE CIP

Link Water Level - 1-1-2007 00:00:00 2017_Peak_FINAL2017_Peak.PRF

Discharge		4.023		7.129		cfs
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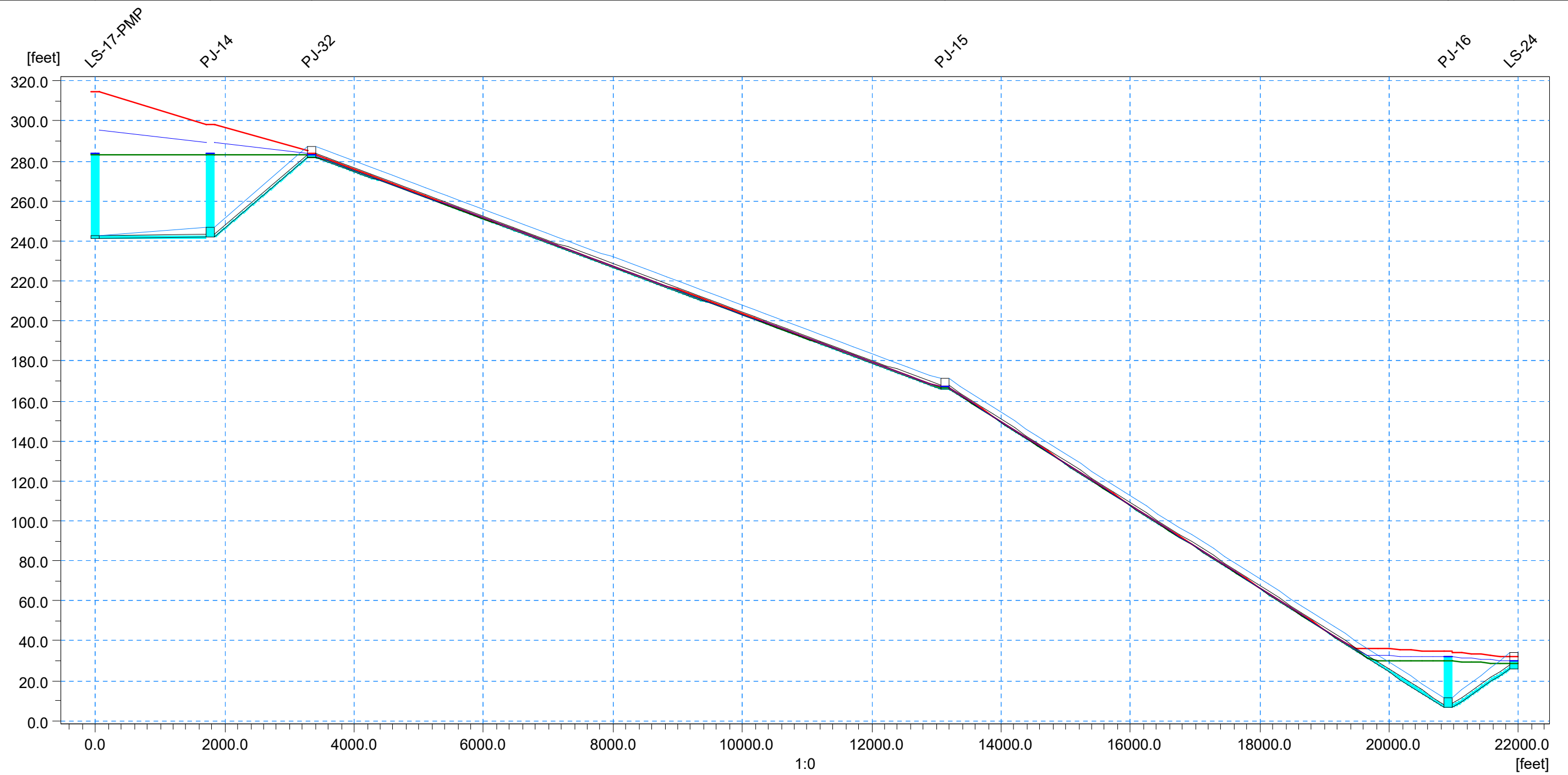
Ground Lev.	4.90					[m]
Invert lev.	3.90			6.50	26.00	[m]
Length		2481.16		1008.00		[m]
Diameter		1.33		2.00		[m]
Slope o/oo		7.46		19.35		

LS17 to LS 24

2038 PEAK FLOW CONDITIONS
PRE CIP

Link Water Level - 1-1-2007 00:00:00 2038_PEAk2038_Peak.PRF

Discharge	6.238	6.238	6.232	3.884	9.414	cfs
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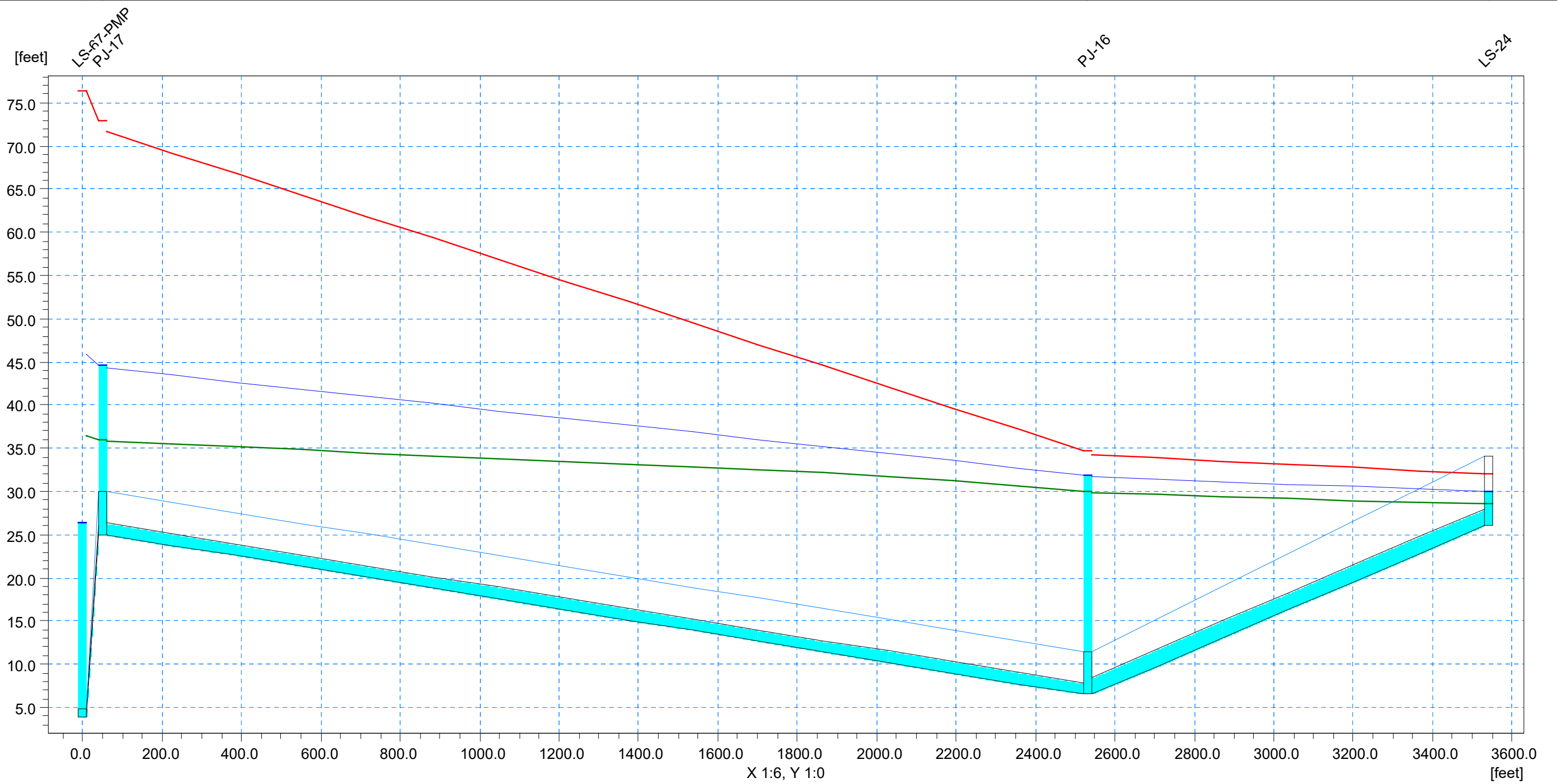
Ground Lev.	241.20	242.70	247.00	282.00	287.00	166.00	171.00	11.50	[m]
Invert lev.	241.20	242.00	247.00	282.00	287.00	166.00	171.00	6.50	[m]
Length	1762.35	1589.08	9779.49	7780.43	1008.00				[m]
Diameter	1.50	1.50	1.67	1.67	2.00				[m]
Slope o/oo	0.45	25.17	11.86	20.50	19.35				

LS67 to LS 24

2038 PEAK FLOW CONDITIONS
PRE CIP

Link Water Level - 1-1-2007 00:00:00 2038_PEAKE2038_Peak.PRF

Discharge	5.420	9.414	cfs
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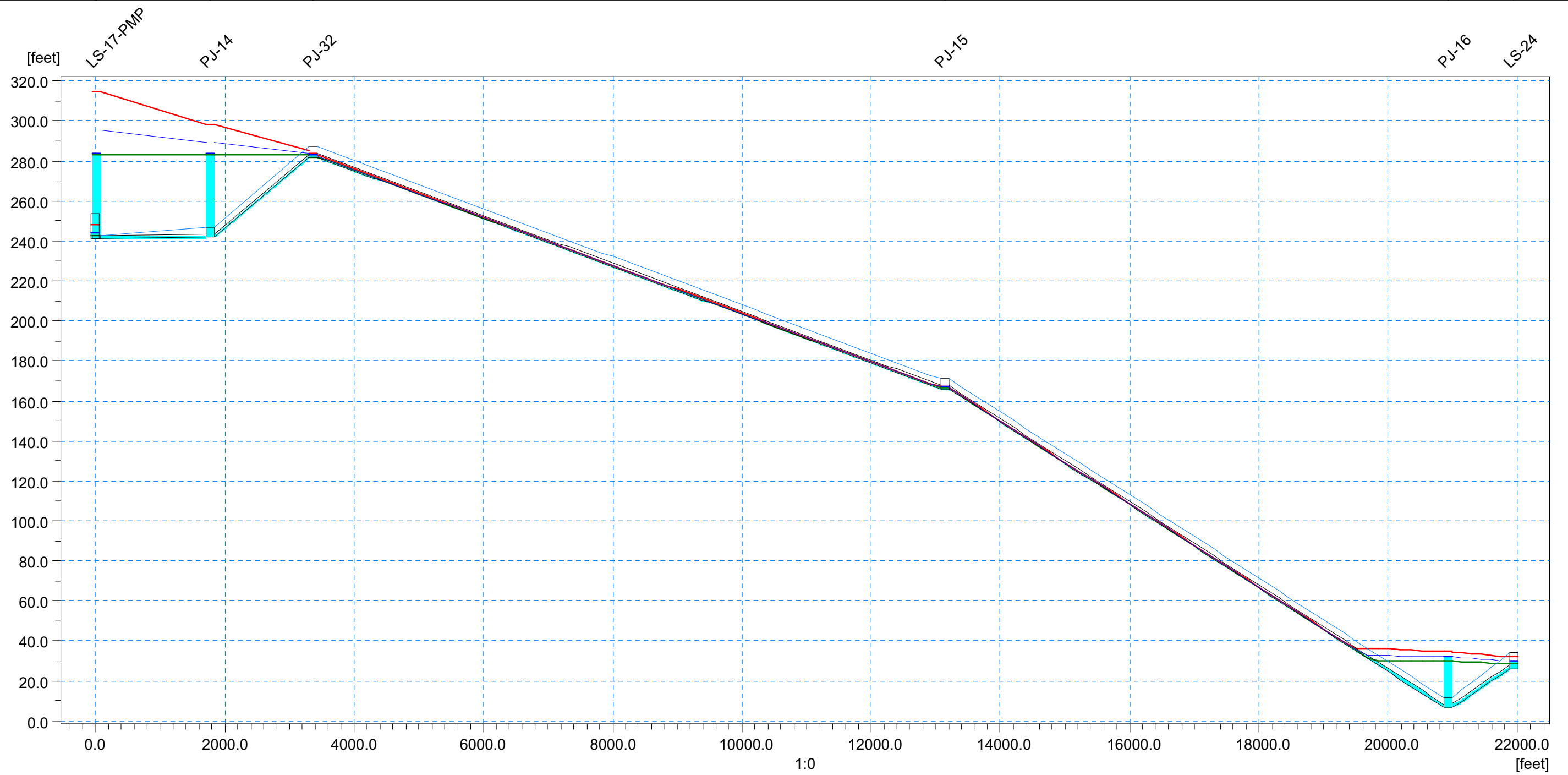
Ground Lev.	4.90			[m]
Invert lev.	3.90			[m]
Length		2481.16	1008.00	[m]
Diameter		1.33	2.00	[m]
Slope o/oo		7.46	19.35	

LS17 to LS 24

BUILDOUT PEAK FLOW CONDITIONS
PRE CIP

Link Water Level - 1-1-2007 00:00:00 Buildout_PEAKBuildout_Peak.PRF

Discharge	6.238	6.238	6.232	3.884	9.414	cfs
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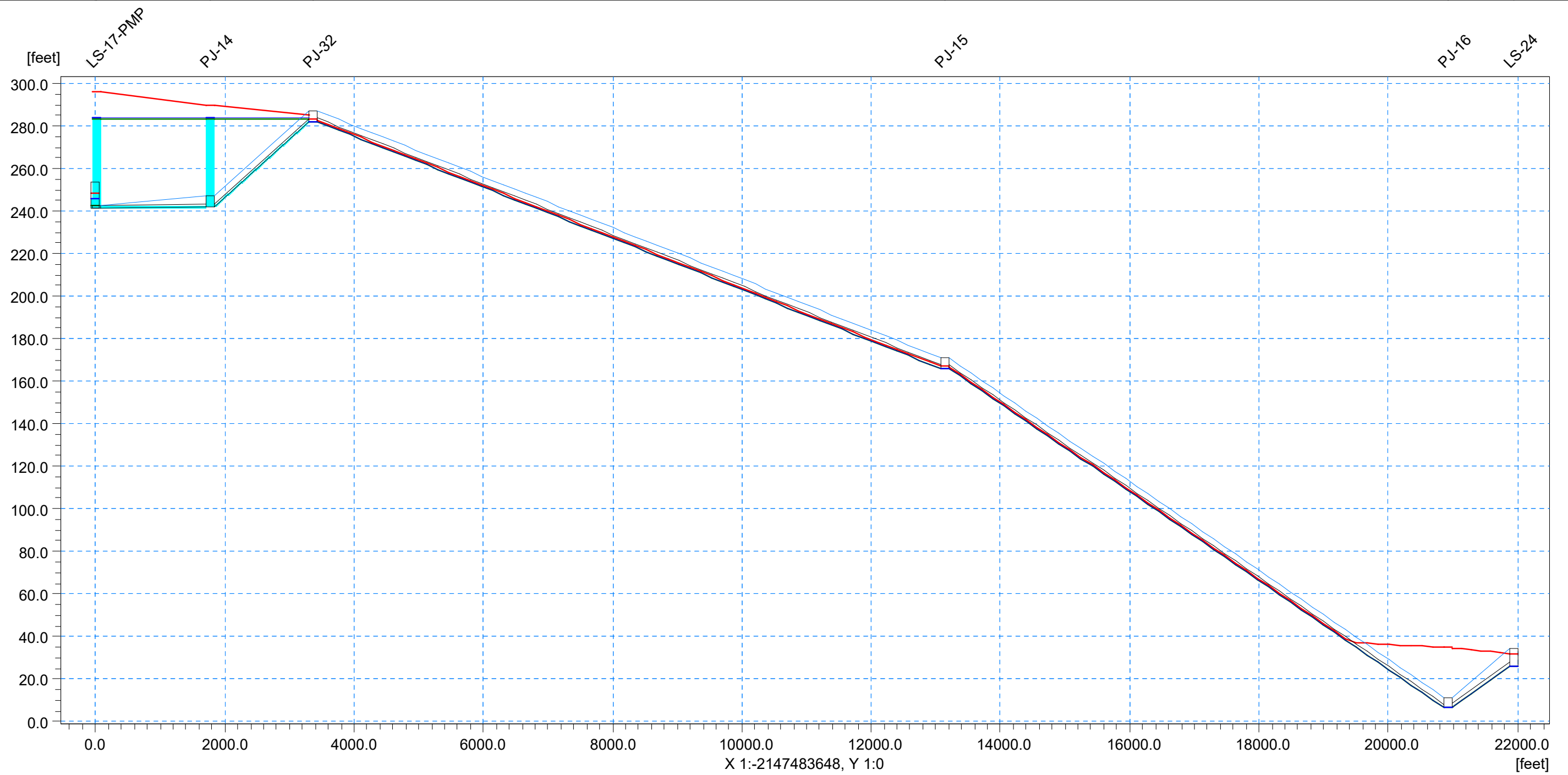
Ground Lev.	241.20	253.70	242.00	247.00	282.00	287.00	166.00	171.00	6.50	11.50	[m]
Invert lev.	241.20	253.70	242.00	247.00	282.00	287.00	166.00	171.00	6.50	11.50	[m]
Length	1762.35	1589.08	9779.49	7780.43	1008.00	[m]					
Diameter	1.50	1.50	1.67	1.67	2.00	[m]					
Slope o/oo	0.45	25.17	11.86	20.50	19.35						

LS17 to LS 24

2038 PEAK FLOW CONDITIONS
POST CIP

Link Water Level - 1-1-2007 00:00:00 2038_PEAK_CIPedits.PRF

Discharge	0.000	0.000	0.001	0.001	-0.001	cfs
-----------	-------	-------	-------	-------	--------	-----

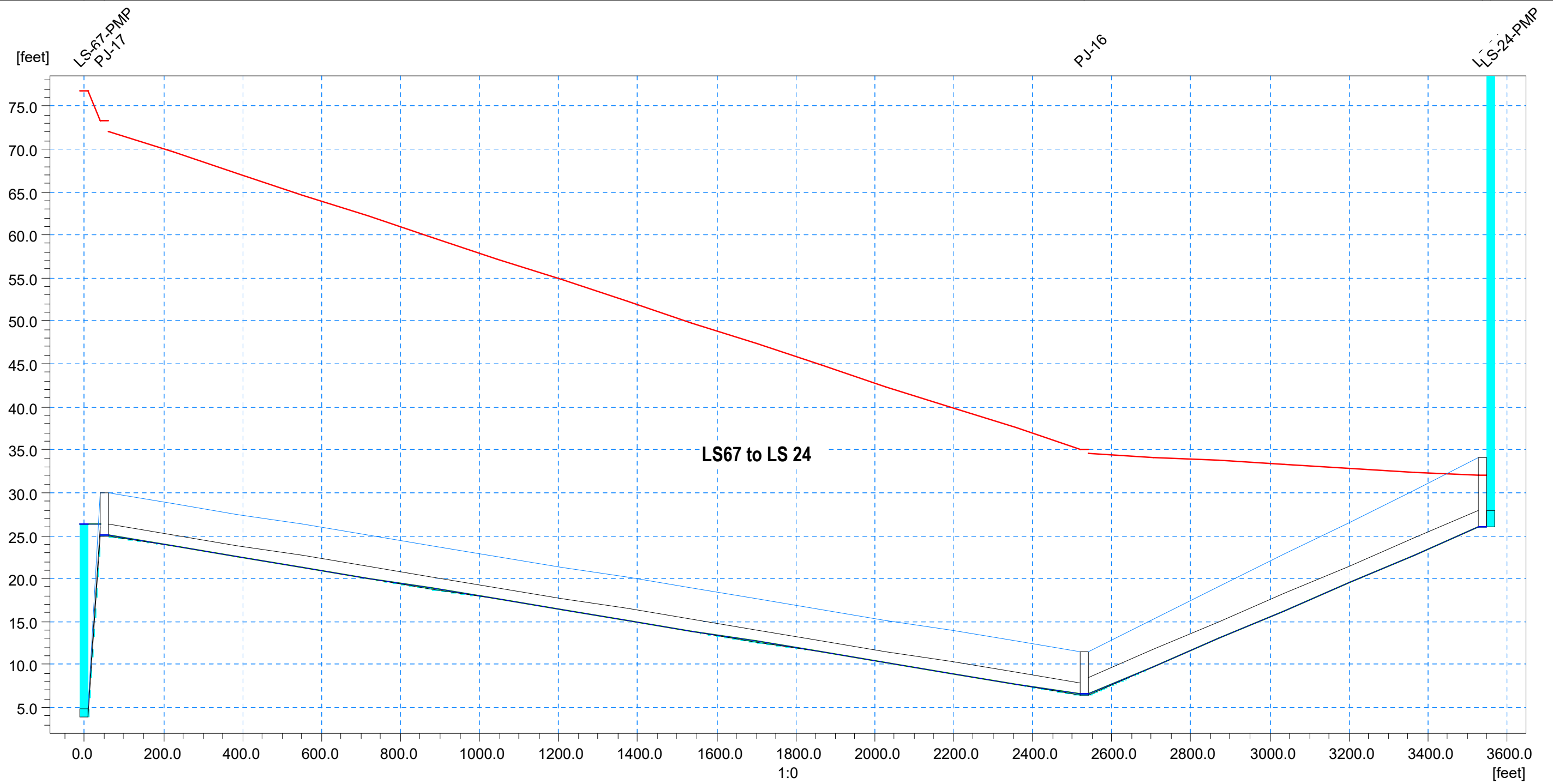


Ground Lev.	241.20	253.70	242.00	247.00	282.00	287.00	166.00	171.00	11.50	[m]
Invert lev.	241.20	247.00	242.00	247.00	282.00	287.00	166.00	171.00	6.50	[m]
Length	1762.35	1589.08	9779.49	7780.43	1008.00	[m]				
Diameter	1.50	1.50	1.67	1.67	2.00	[m]				
Slope o/oo	0.45	25.17	11.86	20.50	19.35					

Link Water Level - 1-1-2007 00:00:00 2038_PEAK_CIPedits.PRF

2038 PEAK FLOW CONDITIONS
POST CIP

Discharge		0.000		-0.001		cfs
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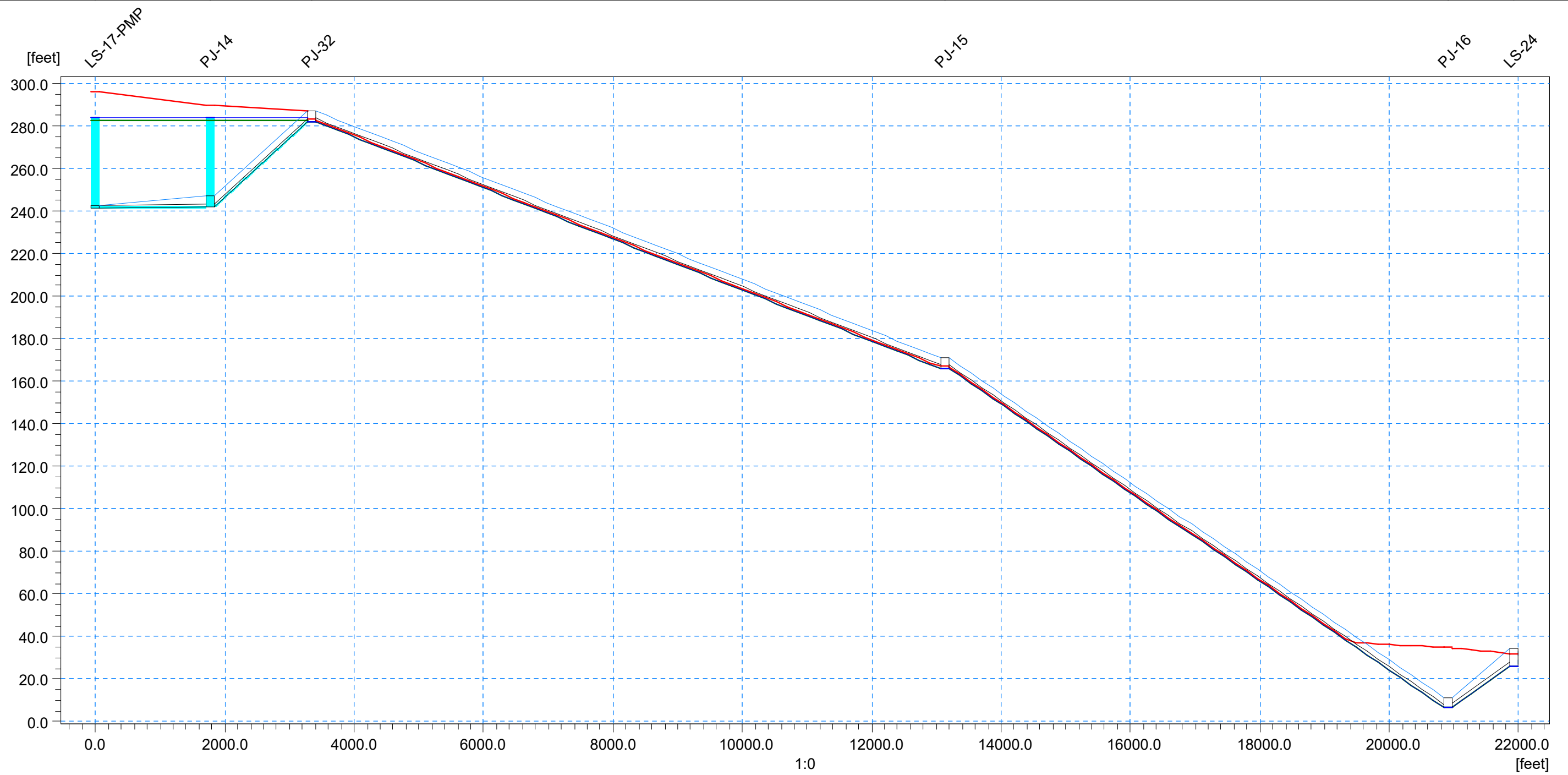
Ground Lev.	4.90			11.50		34.10	[m]
Invert lev.	3.90			6.50		26.00	[m]
Length		2481.16			1008.00		[m]
Diameter		1.33			2.00		[m]
Slope o/oo		7.46			19.35		

LS17 to LS 24

**BUILDOUT PEAK FLOW CONDITIONS
POST CIP**

Link Water Level - 1-1-2007 00:00:00 Buildout_Peak_CIPedits.PRF

Discharge	0.000	0.000	0.001	0.001	-0.001	cfs
-----------	-------	-------	-------	-------	--------	-----



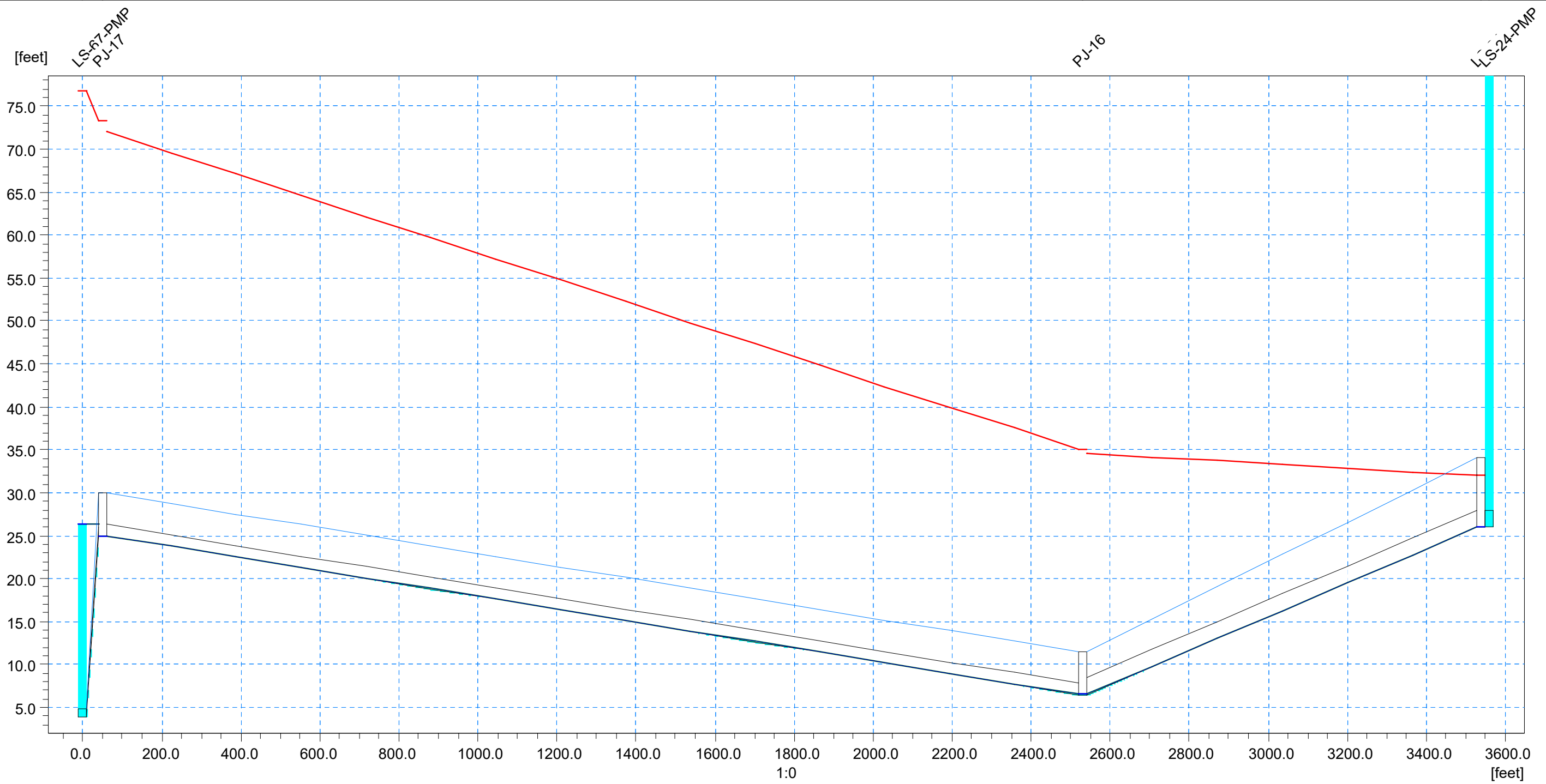
Ground Lev.	241.20	242.70	242.00	247.00	282.00	287.00	166.00	171.00	11.50	[m]
Invert lev.	241.20	242.00	242.00	247.00	282.00	287.00	166.00	171.00	6.50	[m]
Length	1762.35	1589.08	9779.49	7780.43	1008.00	[m]				
Diameter	1.50	1.50	1.67	1.67	2.00	[m]				
Slope o/oo	0.45	25.17	11.86	20.50	19.35					

LS67 to LS 24

Link Water Level - 1-1-2007 00:00:00 Buildout_Peak_CIPedits.PRF

**BUILDOUT PEAK FLOW CONDITIONS
POST CIP**

Discharge	0.000	-0.001	cfs
-----------	-------	--------	-----



Ground Lev.	4.90		11.50	34.10	[m]
Invert lev.	3.90		6.50	26.00	[m]
Length		2481.16		1008.00	[m]
Diameter		1.33		2.00	[m]
Slope o/oo		7.46		19.35	

Appendix B: Grit Settling Calculations

Hazen *Calculations*

Client **Kitsap County Public Works**
 Project **Integrated Design, Engineering, and Analysis Services**

Sheet 1 of 7

Description **Grit Settling Analysis**

Job No. 80029-001

Discipline Conveyance

Revisoning					
Rev.	Date	Description	By	Checked By	Check Date
0	4/23/26	Initial calculation	Ana Haines		
Calculation Folder Location and Methods					
PDF and electronic copies of these calculations are located in the project folder; see link below.					
Calculation Method(s) and Software					
1	MS Excel				
Table of Contents					
					Page #
Cover Sheet					1
Calculations (Attachments)					
1	References page with links				2
2	Forcemain analysis with flow data, distances, and elevations				3
3	Particle settling velocity calcs determined by particle size				4
4	Settled solids volume calcs determined by elevation and settling velocity				5
5	Settled solids volume calcs determined by horizontal velocity and settling velocity				6
6	Calculations to determine required pipe blockage for scouring to occur				7
Objective					
The purpose of this calculation is to determine the volume of solids settled in the forcemain under pump on and off conditions.					
Design Basis					
The settled solids volume is based on forcemain data and seive data provided by Kitsap County Public Works.					
Calculations (Attachments)					
See list of Calculations (Attachments) in Table of Contents above.					

4.4: Terminal Settling Velocity Equations



Sape A. Medema
Delft University of Technology via TU Delft Open Textbooks

Stokes, Budryck and Rittinger used these drag coefficients to calculate settling velocities for laminar settling (Stokes), a transition zone (Budryck) and turbulent settling (Rittinger) of real sand grains. This gives the following equations for the settling velocity:

Laminar flow, $d < 0.1$ mm, according to Stokes:

$$v_s = 424 \cdot R_{sd} \cdot d^2 \tag{4.4.1}$$

Transition zone, $d = 0.1$ mm and $d < 1$ mm, according to Budryck:

$$v_s = 8.925 \cdot \frac{(\sqrt{(1 + 95 \cdot R_{sd} \cdot d^3)} - 1)}{d} \tag{4.4.2}$$

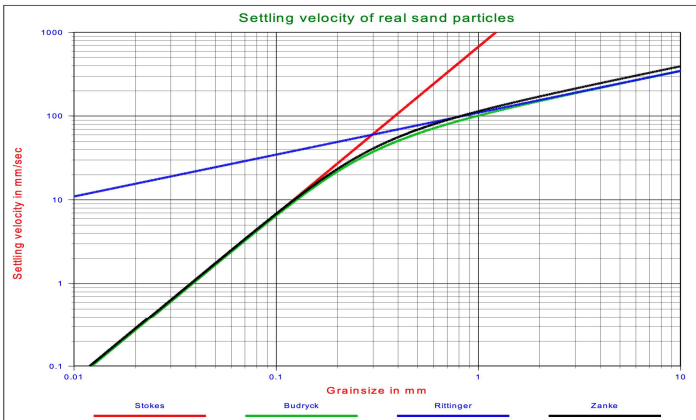
Turbulent flow, $d > 1$ mm, according to Rittinger:

$$v_s = 87 \cdot \sqrt{R_{sd} \cdot d} \tag{4.4.3}$$

With the relative submerged density R_{sd} defined as:

$$R_{sd} = \frac{\rho_s - \rho_l}{\rho_l} \tag{4.4.4}$$

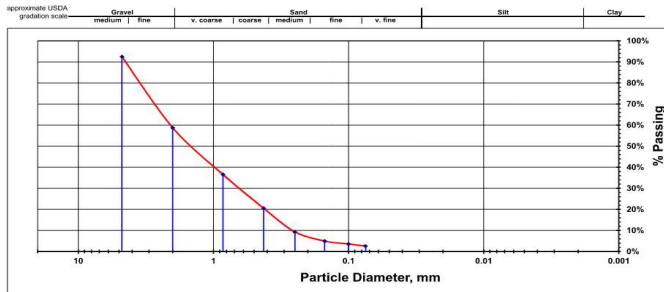
In these equations the grain diameter is in mm and the settling velocity in mm/sec. Since the equations were derived for sand grains, the shape factor for sand grains is included for determining the constants in these equations.



Kitsap Provided Particle Size Distribution

PARTICLE SIZE DISTRIBUTION REPORT

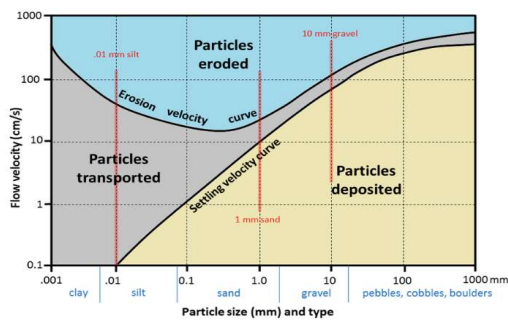
CLIENT: Kitsap County Public Works
 PROJECT: Lab # S28-07094
 SAMPLE ID: PS-17 Grit
 Date Received: 4/17/2026
 Date Reported: 4/17/2026
 Method: ASTM D422
 PDI# 402-155
 Cost: \$135



description	MedGr		FG	VCuS	CuS	CuS	CuS	MeS	FS	FS	VF	VF	Silt	Sand	Gravel
	75	250	4.75	75	150	250	300	425	600	1000	2000	4750	75	Total	Total
Retained			7.5%	33.8%		22.1%		16.0%	11.2%	4.4%	1.4%	1.0%		56.1%	41.3%
Passing			92.5%	58.7%		36.5%		20.5%	9.3%	4.9%	3.6%	2.6%			

Stat Values	D ₁₀ : 2.10	Coefficient of Uniformity: 8.4
	D ₅₀ : 0.85	Coefficient of Gradation: 8.89
	D ₉₀ : 0.25	

The Hjulström-Sundborg Diagram



S. Earle, 2014

Figure A5.1. The Hjulström-Sundborg diagram (Earle, 2014).

New Proposed System with Fish Passage Crossings

Pump Requirements	Total Flow	Pump Low	Pump High
Flow per Pump	250 gpm	250	1800
No of Duty Pumps	0.56 cfs		01+377
Total Dynamic Head			

Segment ID	End Station	Length	Slope	Diameter	Inner Diameter	Invert Elev. @ End Sta.	Crown Elev. @ End Sta.	Manning n	Flow	Qfull	Q/Qfull	Est. % Full	Flow Area	Velocity	Velocity Head	Froude #	Flow Regime	Headloss	Downstream EGL	Downstream HGL	Upstream Invert	Upstream Crown	Upstream EGL	Upstream HGL	Pressure	Status
	ft	ft	ft/ft	ft	in	ft	ft		cfs	cfs			ft^2	ft/s	ft			ft	ft	ft	ft	ft	ft	psi		
S1	01+060	1060	0.0010	2.00	19.40	245.00	247.00	0.012	0.56	7.75	0.072	18.1%	0.388	1.44	0.03	0.50	#VALUE!	0.42	368.56	368.53	245.42	247.42	368.98	368.95	52.69	OK
S2	01+148	88	0.0001	2.00	19.40	245.00	247.00	0.012	0.56	2.45	0.227	32.4%	0.882	0.63	0.01	0.16	Subcritical	0.00	368.56	368.55	245.00	247.00	368.56	368.55	52.70	OK
S3	01+460	312	0.0256	2.00	19.40	237.00	239.00	0.012	0.56	39.24	0.014	8.3%	0.124	4.48	0.31	2.35	Supercritical	3.20	365.36	365.04	240.20	242.20	368.56	368.25	54.65	OK
S4	01+589	129	0.1240	2.00	19.40	253.00	255.00	0.012	0.56	86.31	0.006	5.7%	0.071	7.81	0.95	4.96	Uphill	6.52	358.83	357.89	259.52	261.52	365.36	364.41	44.61	OK
S5	01+707	118	0.0001	2.00	19.40	253.00	255.00	0.012	0.56	2.45	0.227	32.4%	0.882	0.63	0.01	0.16	Subcritical	0.00	358.83	358.82	255.00	255.00	358.83	358.83	45.01	OK
S6	01+810	103	0.0146	2.00	19.40	254.50	256.50	0.012	0.56	29.58	0.019	9.5%	0.152	3.67	0.21	1.80	Uphill	0.60	358.23	358.02	255.10	257.10	358.83	358.62	44.01	OK
S7	02+240	430	0.0105	2.00	19.40	250.00	252.00	0.012	0.56	25.07	0.022	10.3%	0.171	3.26	0.17	1.53	Supercritical	1.78	356.46	356.29	251.78	253.78	358.07	358.07	45.21	OK
S8	02+325	85	0.0471	2.00	19.40	246.00	248.00	0.012	0.56	53.16	0.010	7.2%	0.101	5.53	0.47	3.12	Supercritical	1.59	354.86	354.39	247.59	249.59	356.46	355.98	46.12	OK
S9	02+435	110	0.0001	2.00	19.40	246.00	248.00	0.012	0.56	2.45	0.227	32.4%	0.882	0.63	0.01	0.16	Subcritical	0.00	354.86	354.85	246.00	248.00	354.86	354.86	46.32	OK
S10	02+620	185	0.0270	2.00	19.40	241.00	243.00	0.012	0.56	40.29	0.014	8.2%	0.122	4.56	0.32	2.41	Supercritical	2.00	352.86	352.54	243.00	245.00	354.86	354.54	47.49	OK
S11	03+509	889	0.0197	2.00	19.40	258.50	260.50	0.012	0.56	34.38	0.016	8.8%	0.135	4.11	0.26	2.10	Uphill	7.12	345.74	345.48	265.62	267.62	352.86	352.60	36.84	OK
S12	03+705	196	0.0179	2.00	19.40	262.00	264.00	0.012	0.56	32.75	0.017	9.0%	0.140	3.98	0.25	2.00	Uphill	1.43	344.31	344.06	263.43	265.43	345.74	345.49	34.71	OK
S13	03+940	235	0.0809	2.00	19.40	281.00	283.00	0.012	0.56	69.69	0.008	6.3%	0.083	6.73	0.70	4.07	Uphill	7.76	336.55	335.85	288.76	290.76	344.31	343.61	22.91	OK
S14	04+100	160	0.0438	2.00	19.40	274.00	276.00	0.012	0.56	51.26	0.011	7.3%	0.103	5.42	0.46	3.04	Supercritical	2.83	333.72	333.27	276.83	278.83	336.55	336.09	24.83	OK
S15	04+320	220	0.0500	2.00	19.40	285.00	287.00	0.012	0.56	54.80	0.010	7.1%	0.099	5.64	0.49	3.21	Uphill	4.37	329.35	328.86	289.37	291.37	333.72	333.23	18.15	OK
S16	04+352	32	0.0001	1.67	16.00	285.00	286.67	0.012	0.56	1.51	0.370	42.0%	0.870	0.64	0.01	0.16	Subcritical	0.00	329.35	329.34	285.00	286.67	329.35	329.35	18.50	OK
S17	04+368	16	0.0001	1.67	16.00	285.00	286.67	0.012	0.56	1.51	0.370	42.0%	0.870	0.64	0.01	0.16	Subcritical	0.00	329.35	329.34	285.00	286.67	329.35	329.34	18.50	OK
S18	04+560	192	0.0885	1.67	16.00	268.00	269.67	0.012	0.56	44.85	0.012	7.8%	0.079	7.07	0.78	4.20	Supercritical	6.77	322.58	321.80	274.77	276.44	329.35	328.57	22.60	OK
S19	04+600	40	0.3000	1.67	16.00	256.00	257.67	0.012	0.56	82.55	0.007	5.8%	0.051	10.96	1.87	7.56	Hydraulic Jump	4.97	317.61	315.75	260.97	262.63	322.58	320.71	25.18	OK
S20	05+020	420	0.0143	1.67	16.00	250.00	251.67	0.012	0.56	18.01	0.031	12.0%	0.148	3.76	0.22	1.79	Supercritical	2.42	314.97	314.97	252.42	254.09	317.61	317.39	27.44	OK
S21	05+105	85	0.3765	1.67	16.00	218.00	219.67	0.012	0.56	92.47	0.006	5.5%	0.047	11.86	2.18	8.40	Hydraulic Jump	13.23	301.96	299.77	231.23	232.90	315.19	313.01	34.73	OK
S22	05+115	10	0.1000	1.67	16.00	217.00	219.17	0.012	0.56	95.94	0.006	5.4%	0.077	7.21	0.81	4.52	Supercritical	0.42	301.54	300.73	217.42	219.58	301.96	301.15	35.36	OK
S23	05+142	27	0.0741	2.17	21.00	215.00	217.17	0.012	0.56	82.57	0.007	5.8%	0.086	6.48	0.65	3.92	Subcritical	0.83	300.71	300.06	215.83	217.99	300.71	300.89	35.94	OK
S24	05+530	388	0.0026	2.17	21.00	214.00	216.17	0.012	0.56	15.40	0.036	13.0%	0.282	1.98	0.06	0.79	Subcritical	0.40	300.32	300.26	214.40	216.56	300.71	300.65	36.46	OK
S25	05+707	177	0.0847	2.17	21.00	229.00	231.17	0.012	0.56	88.32	0.006	5.6%	0.082	6.83	0.72	4.21	Uphill	6.30	294.02	293.30	235.30	237.46	300.32	299.59	26.94	OK
S26	06+040	333	0.0180	2.17	21.00	223.00	225.17	0.012	0.56	40.72	0.014	8.1%	0.141	3.96	0.24	2.02	Supercritical	2.47	291.55	291.31	225.47	227.64	294.02	293.78	28.67	OK
S27	06+134	94	0.1489	2.17	21.00	237.00	239.17	0.012	0.56	117.08	0.005	4.9%	0.067	8.33	1.08	5.49	Uphill	5.91	285.64	284.56	242.91	245.08	291.55	290.47	19.68	OK
S28	07+160	1026	0.0424	2.17	21.00	193.50	195.67	0.012	0.56	62.47	0.009	6.6%	0.104	5.36	0.45	3.04	Supercritical	18.14	267.50	267.05	211.64	213.81	267.50	265.19	30.95	OK
S29	08+620	1460	0.0205	2.17	21.00	223.50	225.67	0.012	0.56	43.49	0.013	7.9%	0.136	4.11	0.26	2.12	Uphill	12.04	255.46	255.19	235.54	237.71	267.50	267.24	12.80	OK
S30	09+280	660	0.0220	2.17	21.00	209.00	211.17	0.012	0.56	44.97	0.012	7.8%	0.133	4.18	0.27	2.18	Supercritical	5.75	249.71	249.44	214.75	216.91	255.46	255.18	16.59	OK
S31	09+490	210	0.0348	2.17	21.00	216.30	218.47	0.012	0.56	56.57	0.010	7.0%	0.113	4.91	0.37	2.70	Uphill	2.89	246.82	246.44	219.19	221.36	249.71	249.34	12.13	OK
S32	10+730	1240	0.0301	2.17	21.00	179.00	181.17	0.012	0.56	52.62	0.011	7.2%	0.118	4.71	0.34	2.55	Supercritical	15.15	231.66	231.32	194.15	196.32	246.82	246.47	21.74	OK
S33	10+818	88	0.0001	2.17	21.00	179.00	181.17	0.012	0.56	3.03	0.184	29.0%	0.887	0.63	0.01	0.16	Subcritical	0.00	231.66	231.65	179.00	181.17	231.66	231.66	21.89	OK
S34	11+480	663	0.0309	2.17	21.00	199.50	201.67	0.012	0.56	53.37	0.010	7.2%	0.118	4.71	0.34	2.55	Uphill	8.10	223.57	223.22	207.60	209.76	231.66	231.32	9.34	OK
S35	12+733	1253	0.0409	1.75	21.00	148.30	150.05	0.012	0.56	34.70	0.016	8.8%	0.104	5.37	0.45	2.93	Supercritical	20.47	203.10	202.65	168.77	170.52	223.57	223.12	22.80	OK
S36	12+812	79	0.0001	1.75	21.00	148.30	150.05	0.012	0.56	1.72	0.324	39.1%	0.871	0.64	0.01	0.16	Subcritical	0.00	203.10	203.09	148.30	150.05	203.10	203.09	22.99	OK
FP1	12+924	112	0.0001	1.75	21.00	148.30	150.05	0.012	0.56	1.72	0.324	39.1%	0.871	0.64	0.01	0.16	Subcritical	0.00	203.09	203.08	148.30	150.05	203.10	203.09	22.99	OK
FP1	13+113	189	0.3614	1.75	21.00	80.00	81.75	0.012	0.56	103.19	0.005	5.2%	0.048	11.69	2.12	8.32	Hydraulic Jump	28.81	174.28	172.16	108.81	110.56	203.09	200.97	39.19	OK
FP1	13+133	20	0.0001	1.75	21.00	80.00	81.75	0.012	0.56	1.72	0.324	39.1%	0.871	0.64	0.01	0.16	Subcritical	0.00	174.28	174.27	80.00	81.75	174.28	174.27	40.11	OK
FP1	13+153	20	0.0001	1.75	21.00	80.00	81.75	0.012	0.56	1.72	0.324	39.1%	0.871	0.64	0.01	0.16	Subcritical	0.00	174.28	174.27	80.00	81.75	174.28	174.27	40.11	OK
FP1	13+339	186	0.4005	1.75	21.00	154.50	156.25	0.012	0.56	108.64	0.005	5.1%	0.046	12.03	2.25	8.64	Uphill	30.81	143.47	154.59	185.31	187.06	174.28	185.39	OK	OK
S38	13+420	81	0.0001	1.75	21.00	154.50	156.25	0.012	0.56	1.72	0.324	39.1%	0.871	0.64	0.01	0.16	Subcritical	0.00	143.47	155.18	154.50	156.25	143.47	155.19	OK	OK
S39	14+080	660	0.0250	1.75	21.00	171.00	172.75	0.012	0.56	27.14	0.021	9.9%	0.123	4.52	0.32	2.32	Uphill	6.56	136.90	171.17	177.56	179.31	143.47	177.74	OK	OK
S40	14+110	30	0.0500	1.75	21.00	169.50	171.25	0.012	0.56	38.38	0.015	8.4%	0.097	5.75	0.51	3.21	Supercritical	0.60	136.31	169.65	170.10	171.85	136.90	170.24	OK	OK

Particle Size Settling Velocity

Solids Diameter (mm)	Approx. Diameter (mm)	Percent Solids	Settling Velocity from Graph (mm/s)	Settling Velocity (ft/s)	Distance Settled in 15 Min (ft)
< 0.075	0.075	2.6%	4	0.013	11.81
0.075-0.1	0.0875	1.0%	5	0.016	14.76
0.1-0.15	0.125	1.3%	9	0.030	26.57
0.15-0.25	0.2	4.4%	25	0.082	73.82
0.25-0.425	0.3375	11.2%	35	0.115	103.35
0.425-0.85	0.6375	16.0%	80	0.262	236.22
0.85-2.0	1.425	22.2%	150	0.492	442.91
2.0-4.75	3.375	33.8%	200	0.656	590.55
> 4.75	5	7.5%	250	0.820	738.19

Unit of Time
 15 Min ← select

Pipes (Sta 11+480 to Sta 13+153)

Pipe Segment	Pipe Segment Vol. (cf)	Pipe Solids Vol. (cf)	Assumed Distance to Settle (ft)	% of Solids Settled per 15 Min (cf)	Vol of Solids Settled per 15 Min (cf)
S35 (sta 11+480 to sta 12+733)	1390	5.56	46.95	95%	5.29
S36 (sta 12+733 to sta 12+812)	292	1.17	34.15	95%	1.11
FP1 (sta 12+812 to sta 12+924)	414	1.66	34.15	95%	1.58
FP1 (sta 12+924 to sta 13+113)	122	0.49	17.08	96%	0.47
FP1 (sta 13+113 to sta 13+133)	74	0.30	0.00	100%	0.30
FP1 (sta 13+133 to sta 13+153)	74	0.30	0.00	100%	0.30

% solids
0.4%

<- per WEF MOP -
Chapter 11, 4.2.1, 0.5 to 20 cu ft/mil gal

"Low Point"

Pipes (Sta 13+153 to Sta 14+110)

Pipe Segment	Pipe Segment Vol. (cf)	Pipe Solids Vol. (cf)	Assumed Distance to Settle (ft)	% of Solids Settled per 15 Min (cf)	Vol of Solids Settled per 15 Min (cf)
FP1 (sta 13+153 to sta 13+339)	116	0.5	18.63	96%	0.45
S38 (sta 13+339 to sta 13+420)	300	1.2	37.25	95%	1.14
S39 (sta 14+080 to sta 14+110)	2441	9.8	41.38	95%	9.29
S40 (sta 14+110 to sta 17+165)	111	0.4	45.13	95%	0.42

Total Solids Settled in 15 Min (cf) 20.33

Low Point Pipe Filling

Vol. of piping at low point (cf)	% of pipe vol. at low point filled per 15 Min pump off time	% of pipe vol. at low point filled per month
148	14%	825%

on/off cycles
per day
2

← change

Pipes (Sta 11+480 to Sta 13+153)

Pipe Segment	Pipe Segment Volume (cf)	Pipe Solids Vol. (cf)	Assumed Distance to Settle (ft)	% of Solids Settled per 15 Min (cf)	Horizontal Velocity (ft/s)	Horizontal Velocity (cm/s)	Does the sediment settle? (MANUAL INPUT)	Vol of Solids Settled per 15 Min (cf)
S35 (sta 11+480 to sta 12+733)	1390	5.56	46.95	95%	5.37	163.7	no	0.0
S36 (sta 12+733 to sta 12+812)	292	1.17	34.15	95%	0.64	19.5	yes	1.1
FP1 (sta 12+812 to sta 12+924)	414	1.66	34.15	95%	0.64	19.5	yes	1.6
FP1 (sta 12+924 to sta 13+113)	122	0.49	17.08	96%	11.69	356.2	no	0.0
FP1 (sta 13+113 to sta 13+133)	74	0.30	0.00	100%	0.64	19.5	yes	0.3
FP1 (sta 13+133 to sta 13+153)	74	0.30	0.00	100%	0.64	19.5	yes	0.3

% solids
0.4% ← select

"Low Point"

Pipes (Sta 13+153 to Sta 14+110)

Pipe Segment	Pipe Segment Volume (cf)	Pipe Solids Vol. (cf)	Assumed Distance to Settle (ft)	% of Solids Settled per 15 Min (cf)	Horizontal Velocity (ft/s)	Horizontal Velocity (cm/s)	Does the sediment settle? (MANUAL INPUT)	Vol of Solids Settled per 15 Min (cf)
FP1 (sta 13+153 to sta 13+339)	116	0.5	18.63	96%	12.03	366.7	no	0.0
S38 (sta 13+339 to sta 13+420)	300	1.2	37.25	95%	0.64	19.5	yes	1.1
S39 (sta 14+080 to sta 14+110)	2441	9.8	41.38	95%	4.52	137.6	no	0.0
S40 (sta 14+110 to sta 17+165)	111	0.4	45.13	95%	5.75	175.3	no	0.0

Total Solids Settled (cf) 4.42

Low Point Pipe Filling

Vol. of piping at low point (cf)	% of pipe vol. at low point filled per 15 Min pump off time	% of pipe vol. at low point filled per month
148	3%	179%

on/off cycles per day
2 ← select

Scouring Evaluation

Solids Diameter (mm)	Approx. Diameter (mm)	Percent Solids	Scour Velocity from Graph (cm/s)	Scour Velocity from Graph (ft/s)	Pipe Area to Achieve Scour Velocity (sf)	Pipe Velocity (fps)	Settle or Scour?	% Pipe Area Open to Scour	Open Area (square inches)	Critical Flow to Scour (full area) (gpm)	Settling Efficiency	cf/day	days until scour velocity reached
< 0.075	0.075	3%	40	1.3	2.5	1.4	Scour	100%	18.6	1,415	0.03	3.75	0.0
0.075-0.1	0.0875	1%	35	1.1	2.9	1.4	Scour	100%	18.6	1,238	0.01	1.44	0.0
0.1-0.15	0.125	1%	25	0.8	4.1	1.4	Scour	100%	18.6	885	0.01	1.88	0.0
0.15-0.25	0.2	4%	20	0.7	5.1	1.4	Scour	100%	18.6	708	0.04	6.35	0.0
0.25-0.425	0.3375	11%	20	0.7	5.1	1.4	Scour	100%	18.6	708	0.11	16.17	0.0
0.425-0.85	0.6375	16%	20	0.7	5.1	1.4	Scour	100%	18.6	708	0.16	23.10	0.0
0.85-2.0	1.425	22%	35	1.1	2.9	1.4	Scour	100%	18.6	1,238	0.22	32.05	0.0
2.0-4.75	3.375	34%	60	2.0	1.7	1.4	Settle	62%	14.6	2,123	0.34	48.80	0.8
> 4.75	5.0	8%	70	2.3	1.5	1.4	Settle	53%	13.5	2,477	0.08	10.83	4.2

Reference Values

Flow (gpm)	Flow (cfs)	Pipe Internal Diameter (ft)
1,500	3.34	1.75

% solids
0.05%

← select

Appendix C: Pigging Calculations

Pipe Friction Calculations

Governing Equations

$$H_{\text{Total}} = H_{\text{Static}} + H_{\text{PipeFriction}} + H_{\text{Pig}} + H_{\text{Grit}} + H_{\text{Slope}}$$

Solved Parameters	Value	Unit
H_Static	92.00	Ft
H_PipeFriction	0.19	Ft
H_Pig	34.65	Ft
H_Grit	6.10	Ft
H_Slope	11.543	Ft

Total Pressure Head Required to Push Pig	144.486	Ft
Factor of Safety	1.5	
Total Pressure Head Required to Push Pig	216.73	Ft

MH invert elevation (ft)= 292.6
 Tie-In Elevation (ft)= 155
 Available Head (ft)= 137.6

Static Head Calculations

Governing Equations	
$H_{\text{Static}} = Z_{\text{out}} - Z_{\text{in}}$	

Known Parameters	Value	Unit
Z_out	155.000	ft
Z_in	247.000	ft

Solved Parameters	Value	Unit
H_Static	92.00	ft

Pipe Friction Head Loss Calculations

Hazen-Williams formula

$$h_f = \frac{10.44 \cdot L \cdot Q^{1.85}}{C^{1.85} \cdot d^{4.8655}}$$

Where: h_f = head loss due to friction (ft)
 L = length of pipe (ft)
 Q = flow rate of water (gpm)
 C = Hazen-Williams constant
 d = diameter of the pipe (in.)

Known Parameters	24"	20"	26"	Unit
L	3293	762	8224	ft
Q	258	258	258	gpm
C	140	140	140	
D	19.37	16.15	20.99	in

Solved Parameters	Value			Unit
H _f	0.06	0.03	0.10	ft

Total H _f =	0.19
------------------------	------

Pigging Differential Calculations

PIPE I.D.	TYPICAL DIFFERENTIAL PRESSURE IN PSI		LIQUID FLOW GPM		GASEOUS FLOW SCFM	
	FOR LAUNCHING	FOR RUNNING	3 FPS	5 FPS	5 FPS	10 FPS
2"	100-200	40-100	30	50	21	98
3"	100-150	35-85	70	100	46	172
4"	75-125	30-80	120	200	70	273
6"	50-100	30-75	250	450	134	498
8"	30-80	25-70	450	800	238	749
10"	30-60	25-50	750	1,250	317	957
12"	30-50	20-45	1,000	1,800	458	1,223
14"	20-50	15-40	1,400	2,500	518	1,665
16"	15-45	10-40	1,800	3,000	540	1,901
18"	15-40	10-30	2,000	4,000	683	2,406
20"	10-25	5-20	2,800	5,000	843	2,542
24"	10-25	5-20	4,000	7,000	1,214	3,661
30"	10-20	5-15	7,000	11,000	1,897	4,757

Condition	Typical ΔP
Clean force main	5–15 psi
Moderate solids	15–30 psi
Heavy grit deposits	30–80+ psi
Partial blockage/stall	> 100 psi possible

Solved Parameters

Feet of Water = PSI x 2.31

ΔP = 15 psi (15 psi used for heavier grit deposits in the line)

ΔP = 34.65 ft

Grit Friction Head Loss Calculations

$$W_{grit} = V_{grit} \gamma_{grit}$$

$$F_{grit} = \mu_g W_{grit}$$

$$H_{grit} = \frac{F_{grit}}{\gamma A}$$

Known Parameters	Value	Unit
Volume_grit	20.330	ft ³
γ_grit	100.000	lbs/ft ³
μ_grit	0.450	
Area	2.402	ft ²
γ_water	62.400	lbs/ft ³

Solved Parameters	Value	Unit
W_grit	2033.00	lbs
F_grit	914.85	lbs
H_grit	6.104263	ft

Condition	Suggested μ
Loose/mobile grit	0.2–0.3
Typical sewer grit	0.4–0.5
Heavy consolidated deposits	0.6–0.8

$$F_{slope} = W_{grit} \sin \theta$$

Known Parameters	Value	Unit
θ	45.000	degrees
W_{grit}	2033.000	lbs/ft ³

Solved Parameters	Value	Unit
F_{Slope}	1729.89	lbs
H_{slope}	11.54253153	ft

Static Head Calculations

Governing Equations	
$H_{\text{Static}} = Z_{\text{out}} - Z_{\text{in}}$	

Known Parameters	Value	Unit
Z_out	155.000	ft
Z_in	247.000	ft

Solved Parameters	Value	Unit
H_Static	92.00	ft

Pipe Friction Head Loss Calculations

Hazen-Williams formula

$$h_f = \frac{10.44 \cdot L \cdot Q^{1.85}}{C^{1.85} \cdot d^{4.8655}}$$

Where: h_f = head loss due to friction (ft)
 L = length of pipe (ft)
 Q = flow rate of water (gpm)
 C = Hazen-Williams constant
 d = diameter of the pipe (in.)

Known Parameters	24"	20"	26"	Unit
L	3293	762	8224	ft
Q	258	258	258	gpm
C	140	140	140	
D	19.37	16.15	20.99	in

Solved Parameters	Value			Unit
H _f	0.06	0.03	0.10	ft

Total H_f= 0.19

Pigging Differential Calculations

PIPE I.D.	TYPICAL DIFFERENTIAL PRESSURE IN PSI		LIQUID FLOW GPM		GASEOUS FLOW SCFM	
	FOR LAUNCHING	FOR RUNNING	3 FPS	5 FPS	5 FPS	10 FPS
2"	100-200	40-100	30	50	21	98
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4"	75-125	30-80	120	200	70	273
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16"	15-45	10-40	1,800	3,000	540	1,901
18"	15-40	10-30	2,000	4,000	683	2,406
20"	10-25	5-20	2,800	5,000	843	2,542
24"	10-25	5-20	4,000	7,000	1,214	3,661
30"	10-20	5-15	7,000	11,000	1,897	4,757

Condition	Typical ΔP
Clean force main	5–15 psi
Moderate solids	15–30 psi
Heavy grit deposits	30–80+ psi
Partial blockage/stall	> 100 psi possible

Solved Parameters

Feet of Water = PSI x 2.31

ΔP = 15 psi (15 psi used for heavier grit deposits in the line)

ΔP = 34.65 ft

Grit Friction Head Loss Calculations

$$W_{grit} = V_{grit} \gamma_{grit}$$

$$F_{grit} = \mu_g W_{grit}$$

$$H_{grit} = \frac{F_{grit}}{\gamma A}$$

Known Parameters	Value	Unit
Volume_grit	20.330	ft ³
γ_grit	100.000	lbs/ft ³
μ_grit	0.450	
Area	2.402	ft ²
γ_water	62.400	lbs/ft ³

Solved Parameters	Value	Unit
W_grit	2033.00	lbs
F_grit	914.85	lbs
H_grit	6.104263	ft

Condition	Suggested μ
Loose/mobile grit	0.2–0.3
Typical sewer grit	0.4–0.5
Heavy consolidated deposits	0.6–0.8

$$F_{slope} = W_{grit} \sin \theta$$

Known Parameters	Value	Unit
θ	45.000	degrees
W_{grit}	2033.000	lbs/ft ³

Solved Parameters	Value	Unit
F_Slope	1729.89	lbs
H_slope	11.54253153	ft