ASCE-NH SECTION LUNCH & LEARN

A TUNNELLED SOLUTION FOR THE CEMETERY BROOK DRAIN TUNNEL PROJECT
Manchester, NH

Mahmood Khwaja, PE

National Discipline Leader

Tunnels

May 23, 2023

Agenda

- Tunnels for Stormwater Conveyance & Flood Control
- Overview of Tunneling
- Cemetery Brook Drain Tunnel Project

Tunnels for Stormwater Conveyance & Flood Control

Tunnels

- Underground horizontal excavation
- Excavated from a shaft, trench or portal
- Size (< 1 foot to 65 feet diameter)
- Water conveyance, mines, transportation, transit, utilities, and pedestrian

Why Tunnels

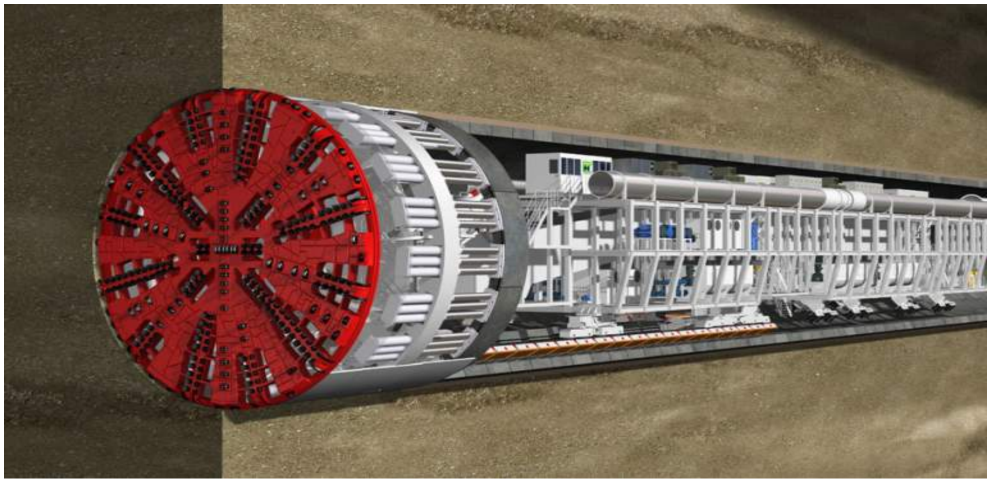
- Store & convey large volumes of stormwater
- Reduced construction related impacts
- Minimize real estate acquisitions
- Long-term and sustainable asset

Large Tunnel Projects

- Conceptual Planning
- Land Acquisition
- Program Controls and Reporting
- Permitting
- Engineering
- Initial technical investigations
- Delivery method analysis and selection
- Construction Procurement
- Project Administration
- Flexibility in reacting to external impacts
- Quality Control/Quality Assurance
- Commissioning and Closeout
- Secure financing and manage budget
- Interagency Coordination
- Construction Management and Support

Overview of Tunneling

Bored Tunnels



Soft Ground

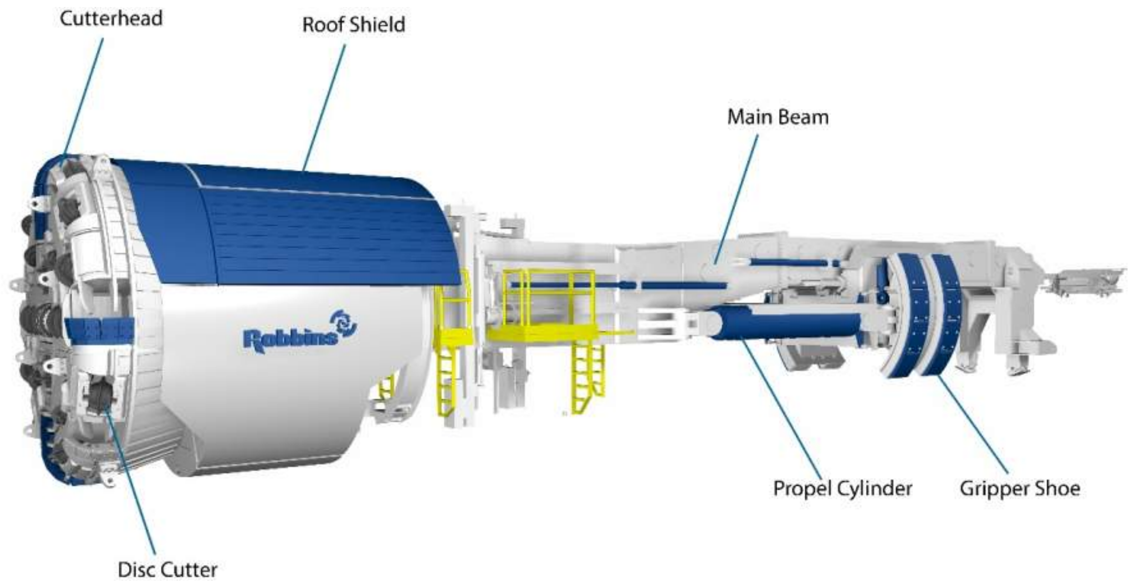
Mixed Face

Fractured Rock

Competent Rock

Bored Tunnels

Hard Rock TBM

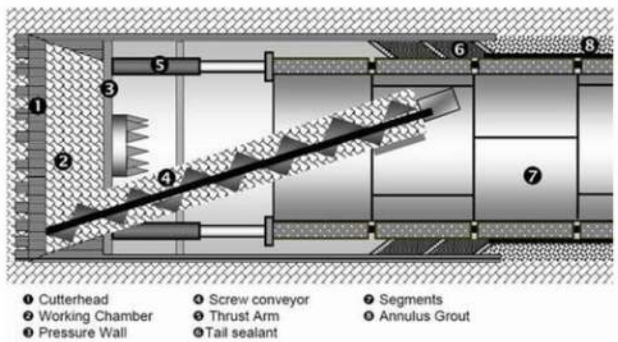


- Low permeability and good quality hard rock
- Relatively inexpensive
- Very efficient construction
- Cast-in-place lining
- Limited flexibility

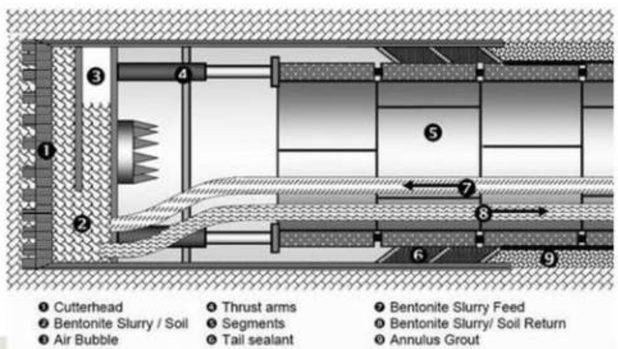
Bored Tunnels

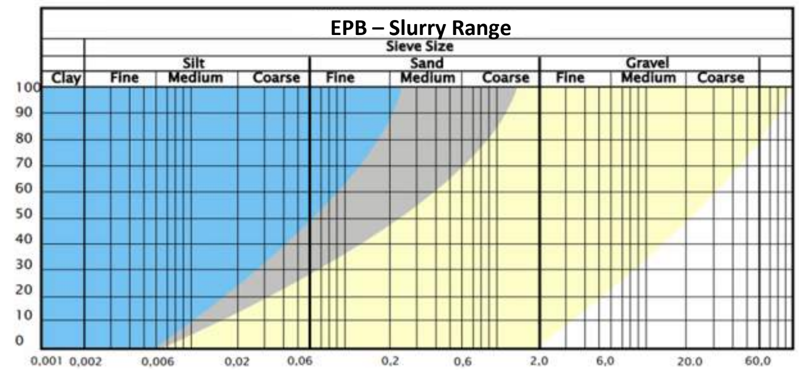
Soft Ground TBMs

- Earth Pressure Balance (EPB):
  - Mixes excavated soil, foaming agents, water and polymers in the working chamber behind cutter head. The muck pressure is controlled by the pressure wall.
  - Screw conveyor takes the mud out of the machine as the machine moves forward.



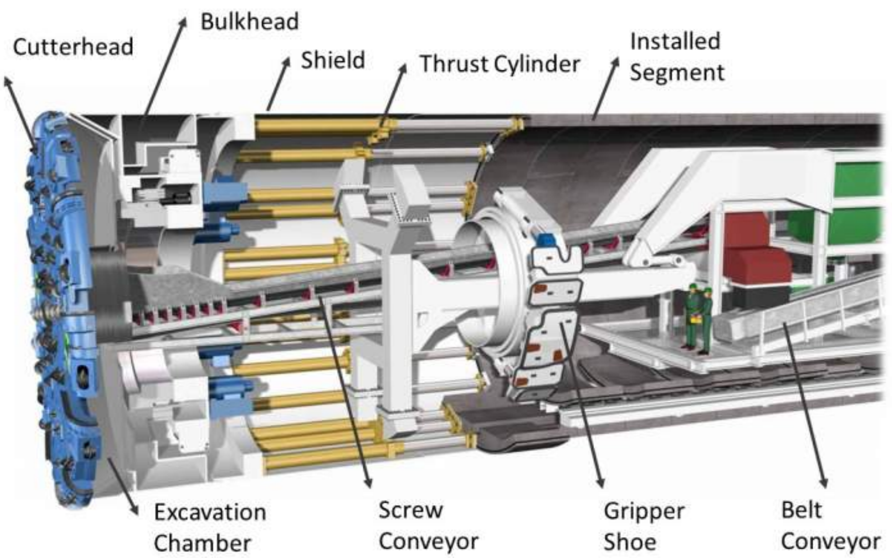
- Slurry Shield (SS):
  - The cutter head is balanced by bentonite slurry.
  - Screw conveyor is replaced by two pipes circulating the slurry in and out of the working chamber.

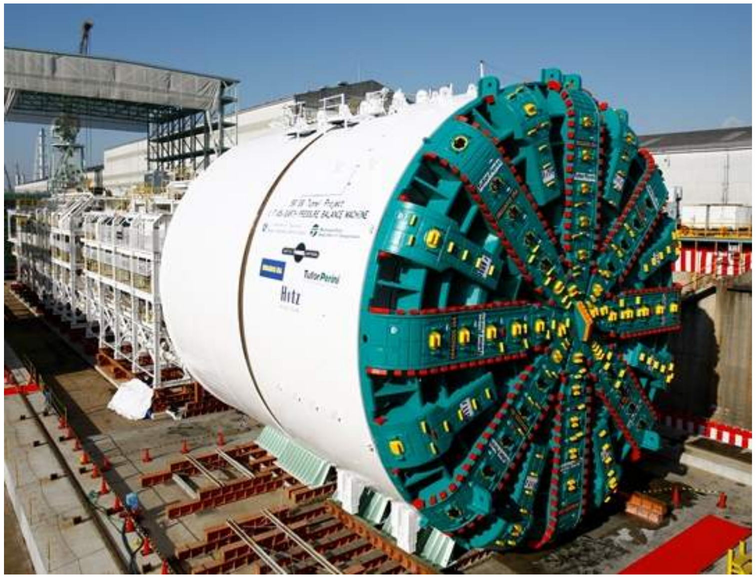




EPB → Slurry

Bored Tunnels





- Series of trailing gear modules
- 300 ft to 400 ft behind the shield

Bored Tunnels

- Sequence
  - Excavate launching/receiving shafts
  - Assemble and Launch TBM in launching shaft
  - Excavate tunnel / erect lining
  - Retrieve TBM from receiving shaft
  - Repurpose or backfill shafts
- Limits on alignment curvatures
- Cost effective for tunnels longer than 1 mile
- Fast construction
- Limited flexibility

Bored Tunnels

Mined Tunnels

- Often Used in combination with Bored Tunnels (adits and connections)
- Very flexible
- Cost effective for tunnel shorter than 1 mile
- Multiple headings to increase productivity
- Each heading requires a full crew
- Fast mobilization

Subsurface Investigation

- Phased Investigations Often Work the Best
- Project focused exploration/testing Program
  - Phase 1: Conceptual Stage
    - Desk study plus project specific field and lab investigation
    - Alignment and profile; Shaft locations
    - Method of construction
    - Geophysical Methods
    - Typical boring spacing 500 ft – 1000 ft
  - Phase 2: Preliminary Design
    - Boring spacing 100 ft – 300 ft
    - Ensure adequate coverage at shaft locations
    - Develop a more refined subsurface profile
    - Design development and manage project geotechnical risks
  - Phase 3: Final Design
    - Conducts select additional investigations
    - Prepare documents that convey the tunneling conditions fairly to all knowledgeable bidders (fill in the data gaps)

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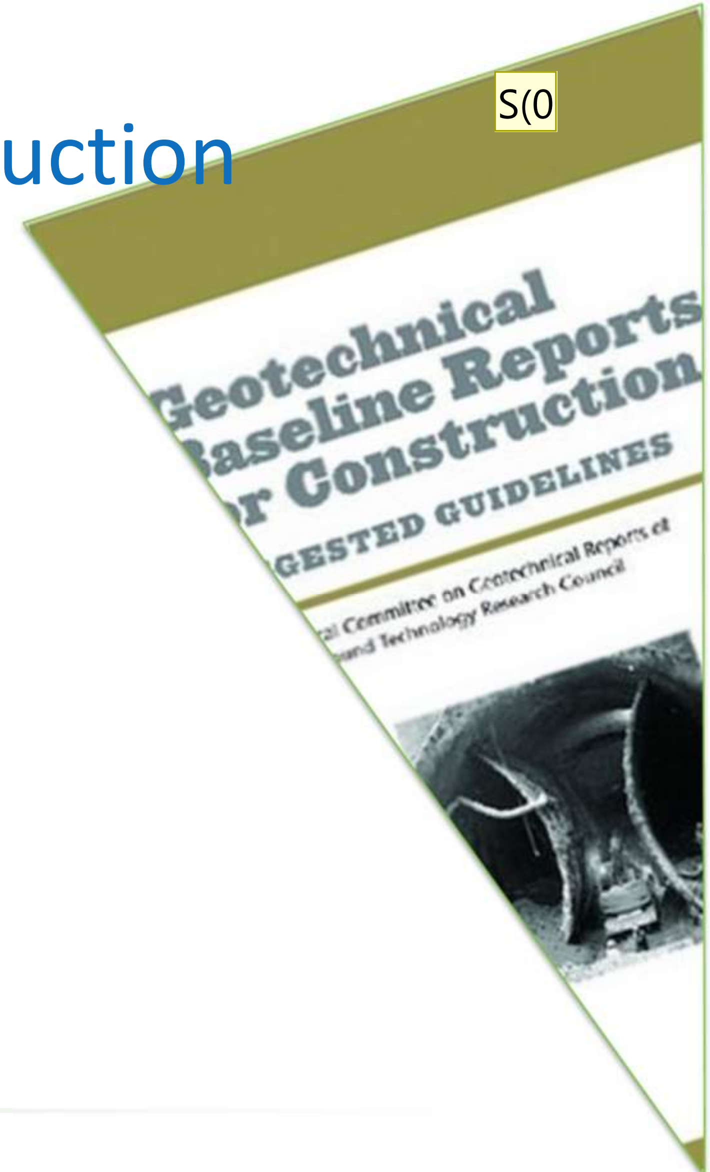
Contracting for Underground Construction



Geotechnical Data Report (GDR)

- Presents all subsurface data
- Just the facts

Geotechnical Baseline Report (GBR)

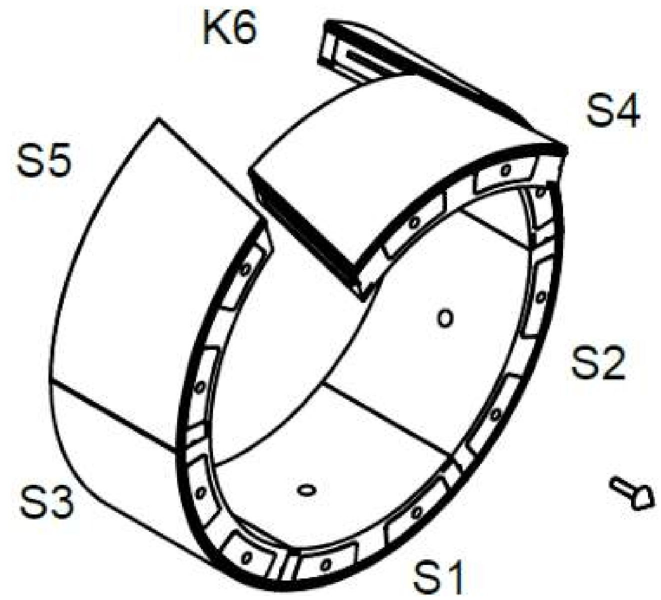
- “Levels the playing field” for bids
- Interpretation of the conditions
- Baseline for change condition claims

Differing Site Conditions (DSC)

- Clause needs to be added to contract documents.

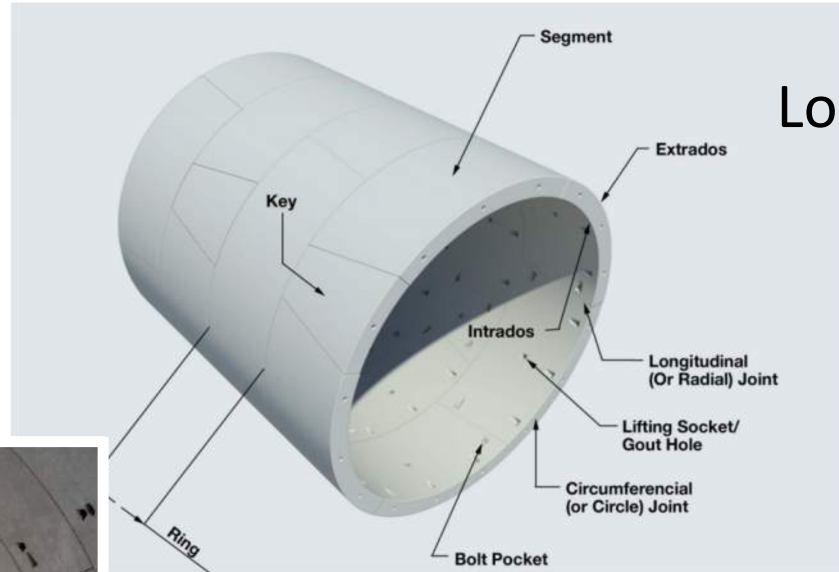
Tunnel Lining

- Purpose
- Initial / Final
- One-Pass / Two-Pass
- Dependent on tunneling method and tunnel use



Tunnel Lining

Precast Segmental



Load considerations

- Ground
- Groundwater
- Seismic
- Interior
- Installation
  - Jacking
  - Grouting
  - Deformation
- Stacking and handling
- Transportation

Tunnel Lining

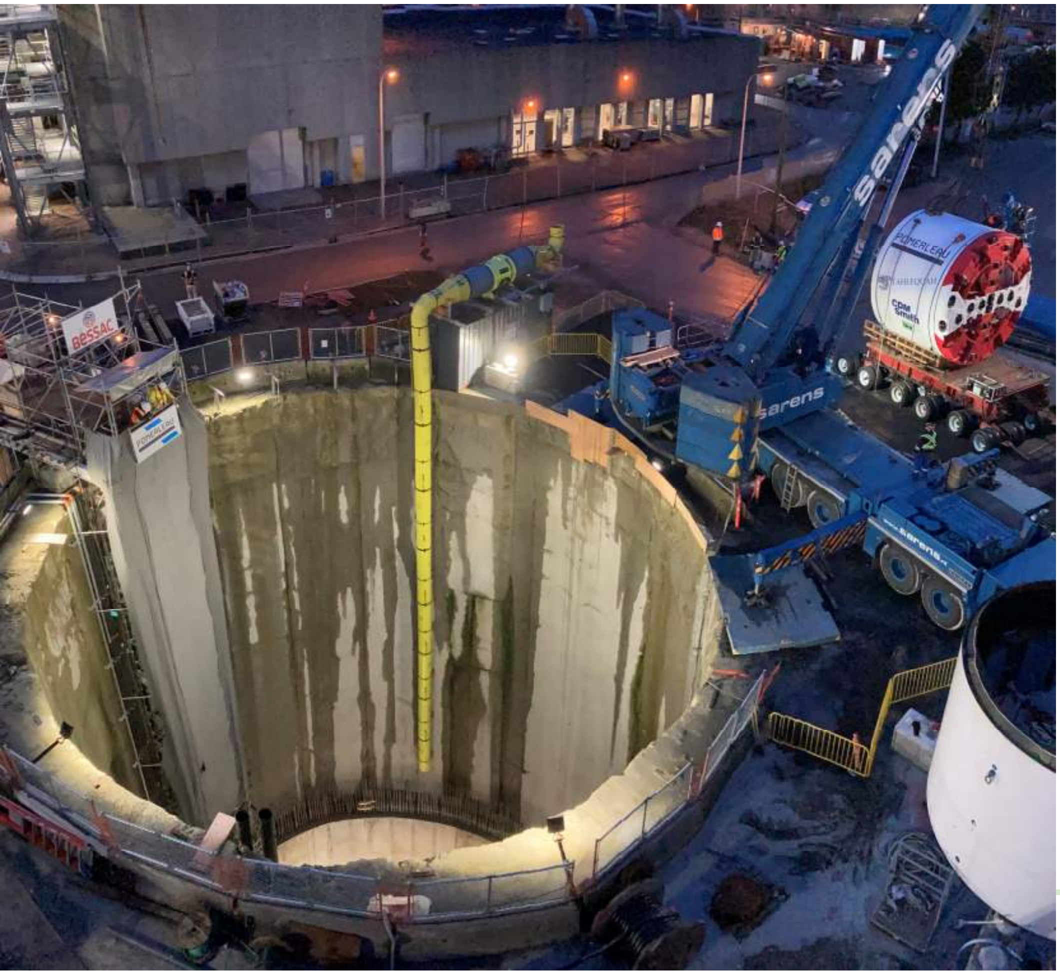
- Structural design requirements
  - Project specific
    - ACI
    - AASHTO
    - AREMA
    - Waterproofing
    - Other

Tunnel Lining

- Reinforcement
  - Unreinforced
  - Deformed bar/wire mesh
  - Fiber Reinforced

Working Shafts & Drop Shafts

Working Shafts

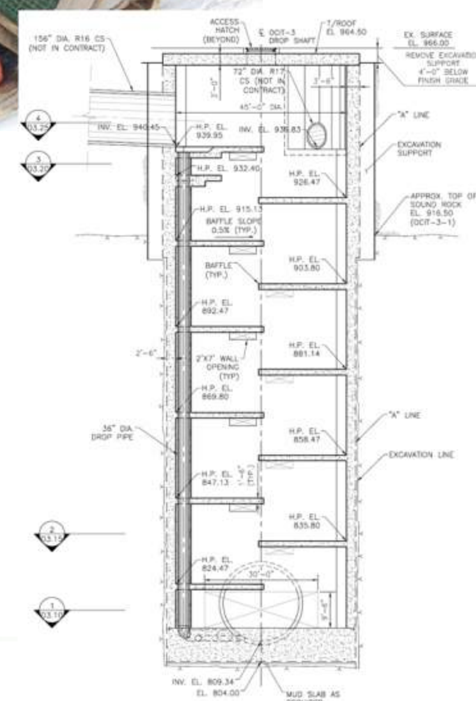


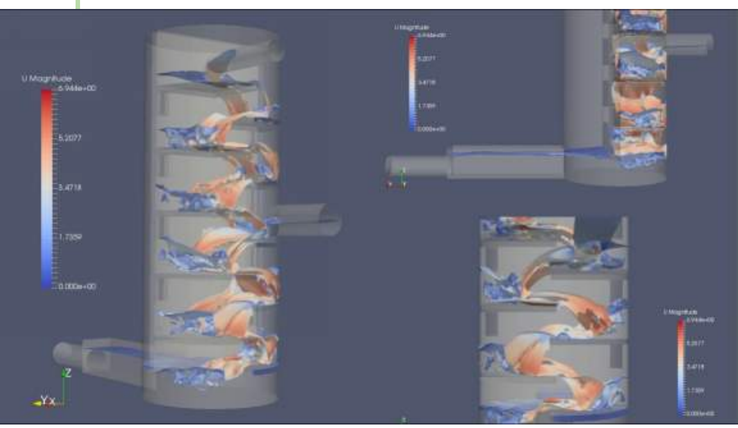
Vortex Drop Shaft

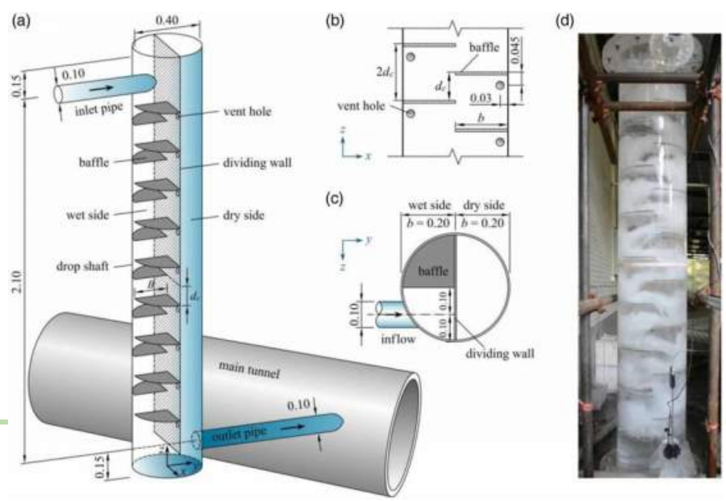
- Anacostia River Tunnel Project
  - Launch shaft
  - Final large-scale vortex drop shaft

Baffle Drop Shaft

- Stormwater cascades down baffle
- Into deaeration chamber / Adit
- Feeds into the main tunnel







CEMETERY BROOK DRAIN TUNNEL PROJECT

Alternative evaluation ● Preliminary engineering

Open-cut ● Tunnel ● Trenchless technologies

12,000-ft ● 12-ft ID

Soft ground ● Mixed face ● Rock

Environmental assessment ● Permitting ● Traffic management

Hydraulics engineering ● Ground investigation ● Community outreach

Structural engineering ● Traffic management

CITY OF MANCHESTER

MANCHESTER, NH

Cemetery Brook Drain Tunnel Discussion

- **Program Background & Importance**
- **Alternatives**
- **Design and Construction Considerations**
- **Hydraulic Modelling**
- **Project Status**

Program Background & Importance

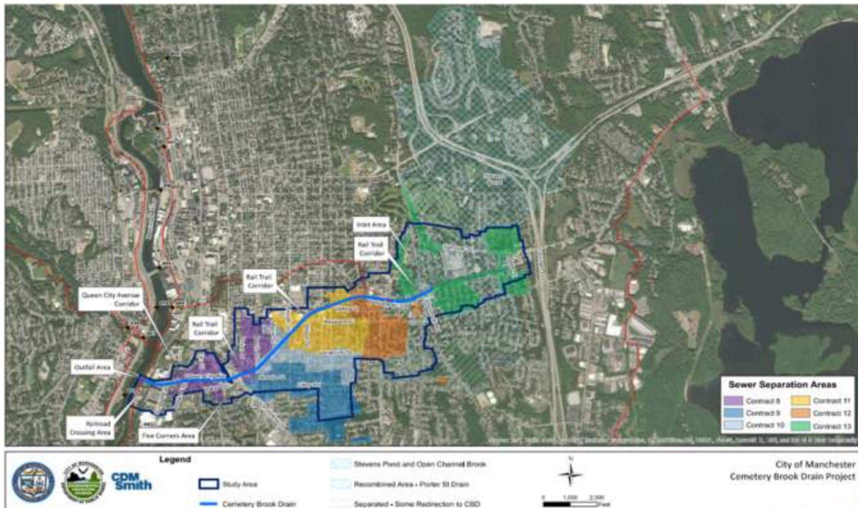
Program Background & Importance

- City of Manchester committed to solving CSO Issues
- 1995 LTCP agreement US EPA/NHDES/City
- Phase I Combined Sewer Overflow (CSO) Abatement Program
- 2010 LTCP updated
- Phase II Combined Sewer Overflow (CSO) Program

Program Background & Importance

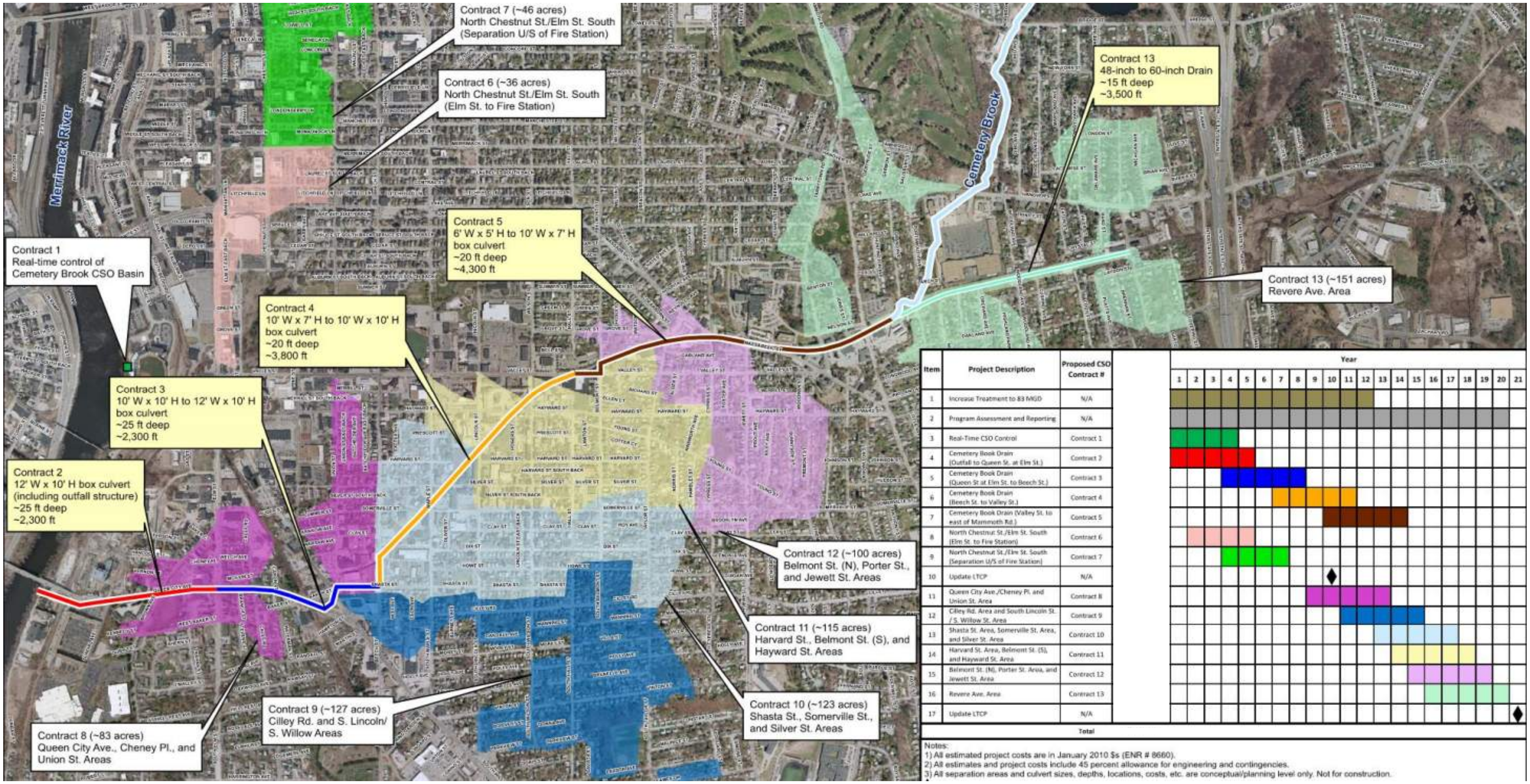
- Wastewater Treatment Plan improvements
- System optimization
- Brook removal
- Sewer separation

Location



- Manchester, NH
- ~ 115,000 population
- Proximity to Boston, MA

Program Components



Item	Project Description	Proposed CSO Contract #	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Increase Treatment to 83 MGD	N/A	■	■	■	■	■	■	■	■	■	■	■	■									
2	Program Assessment and Reporting	N/A	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
3	Real-Time CSO Control	Contract 1	■	■	■	■																	
4	Cemetery Book Drain (Outfall to Queen St. at Elm St.)	Contract 2	■	■	■	■	■																
5	Cemetery Book Drain (Queen St at Elm St. to Beech St.)	Contract 3				■	■	■	■	■													
6	Cemetery Book Drain (Beech St. to Valley St.)	Contract 4							■	■	■	■	■										
7	Cemetery Book Drain (Valley St. to east of Mammoth Rd.)	Contract 5										■	■	■	■	■							
8	North Chestnut St./Elm St. South (Elm St. to Fire Station)	Contract 6		■	■	■	■																
9	North Chestnut St./Elm St. South (Separation U/S of Fire Station)	Contract 7				■	■	■	■														
10	Update LTCP	N/A										◆											
11	Queen City Ave./Cheney Pl. and Union St. Area	Contract 8									■	■	■	■	■								
12	Cilley Rd. Area and South Lincoln St. / S. Willow St. Area	Contract 9											■	■	■	■	■						
13	Shasta St. Area, Somerville St. Area, and Silver St. Area	Contract 10													■	■	■	■	■				
14	Harvard St. Area, Belmont St. (S), and Hayward St. Area	Contract 11														■	■	■	■	■			
15	Belmont St. (N), Porter St. Area, and Jewett St. Area	Contract 12															■	■	■	■	■		
16	Revere Ave. Area	Contract 13																■	■	■	■	■	
17	Update LTCP	N/A																					◆
		Total																					

Notes:
1) All estimated project costs are in January 2010 $s (ENR # 8660).
2) All estimates and project costs include 45 percent allowance for engineering and contingencies.
3) All separation areas and culvert sizes, depths, locations, costs, etc. are conceptual/planning level only. Not for construction.

Project Goals and Objectives

Brook removal

Sewer separation

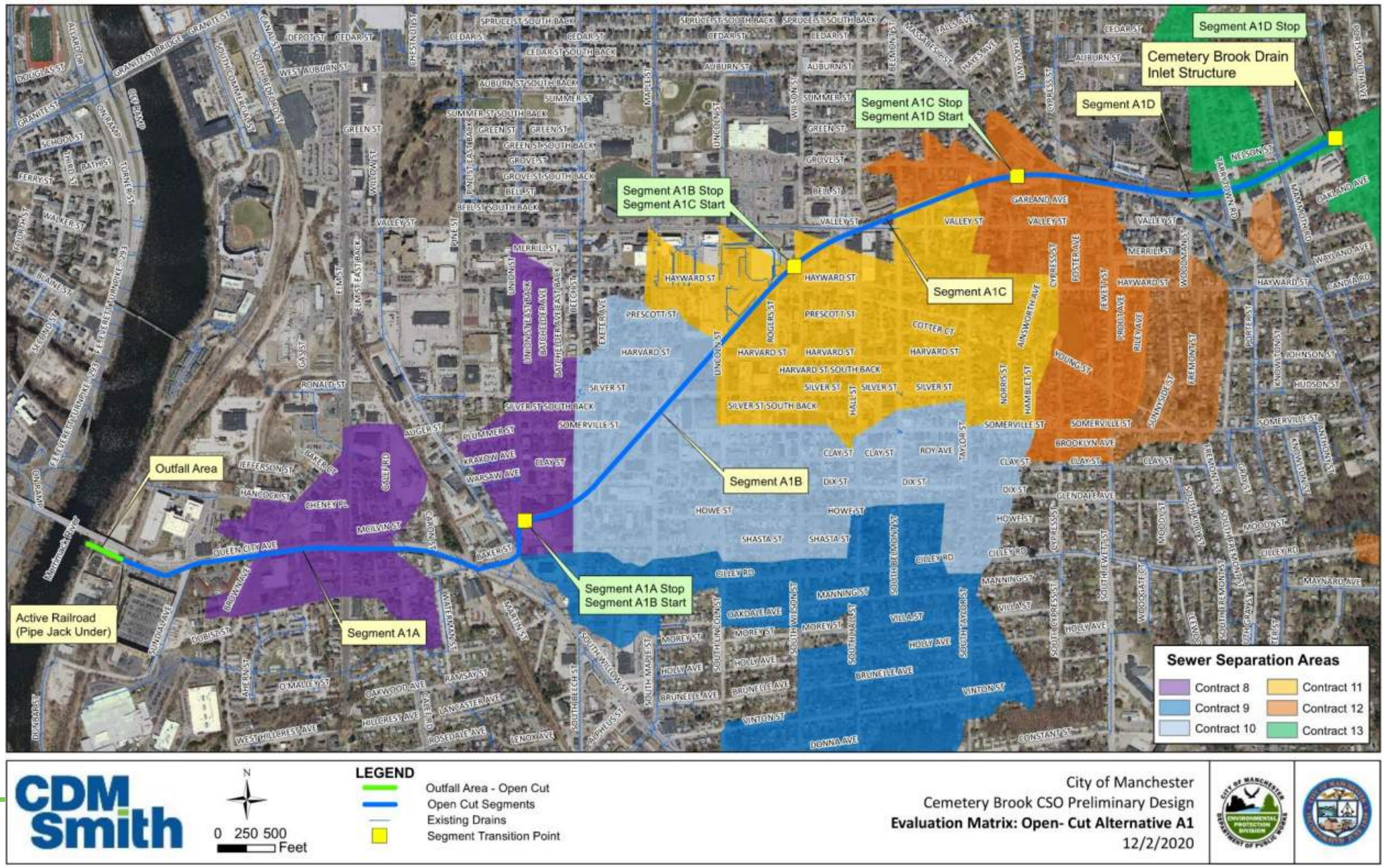
System capacity

Street flooding

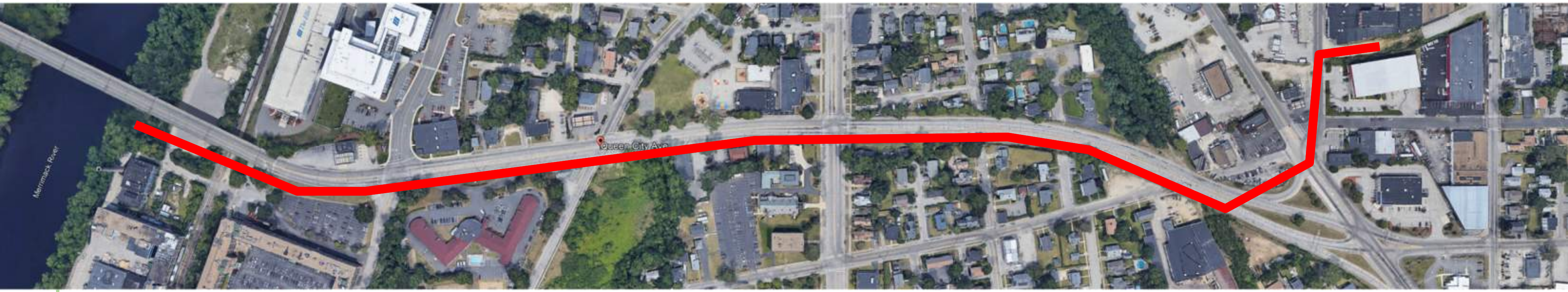
CSO discharge

Alternatives

Open Cut Alternative Alignment



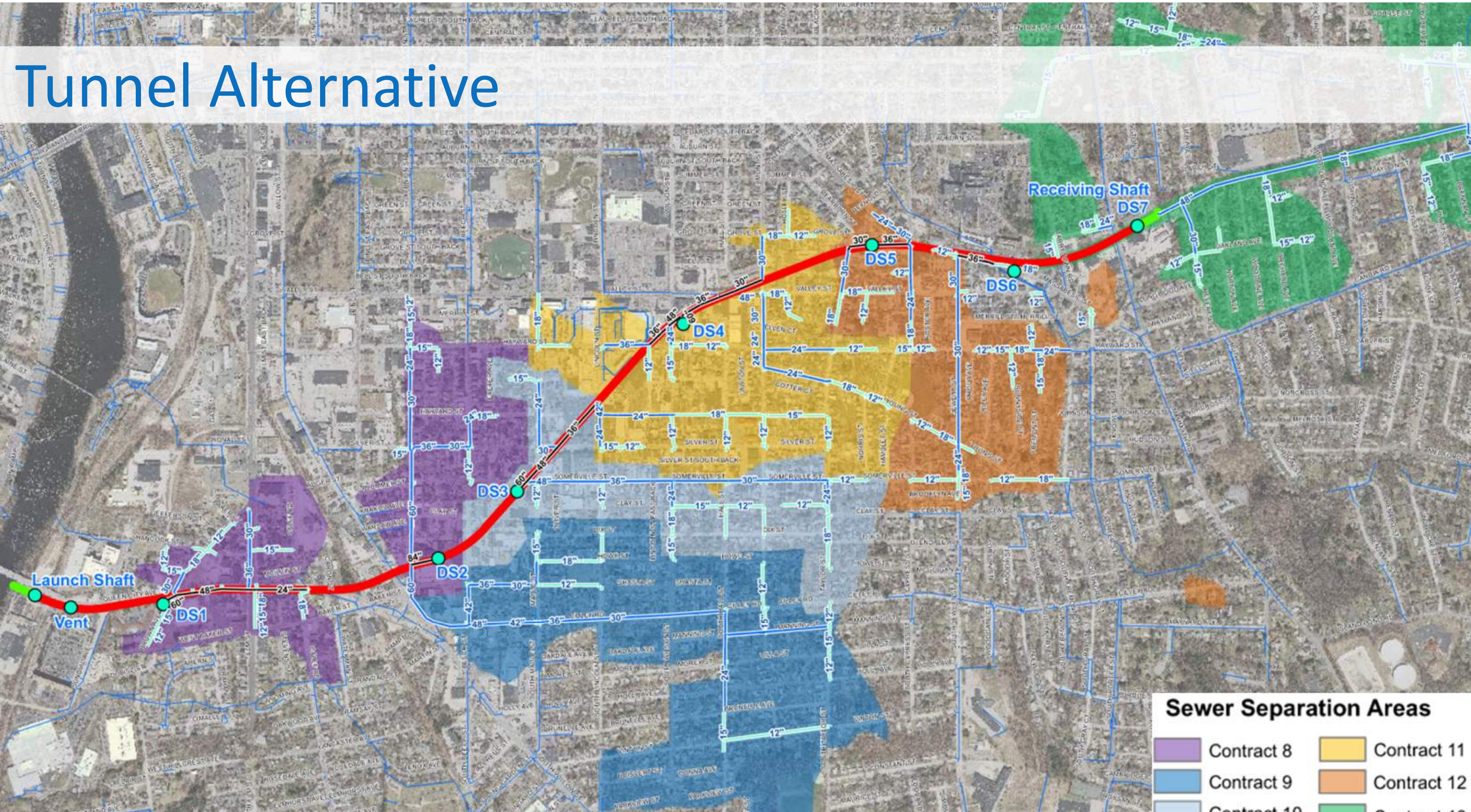
Alignment – Queen City Avenue



Alignment – Rail Trail Corridor

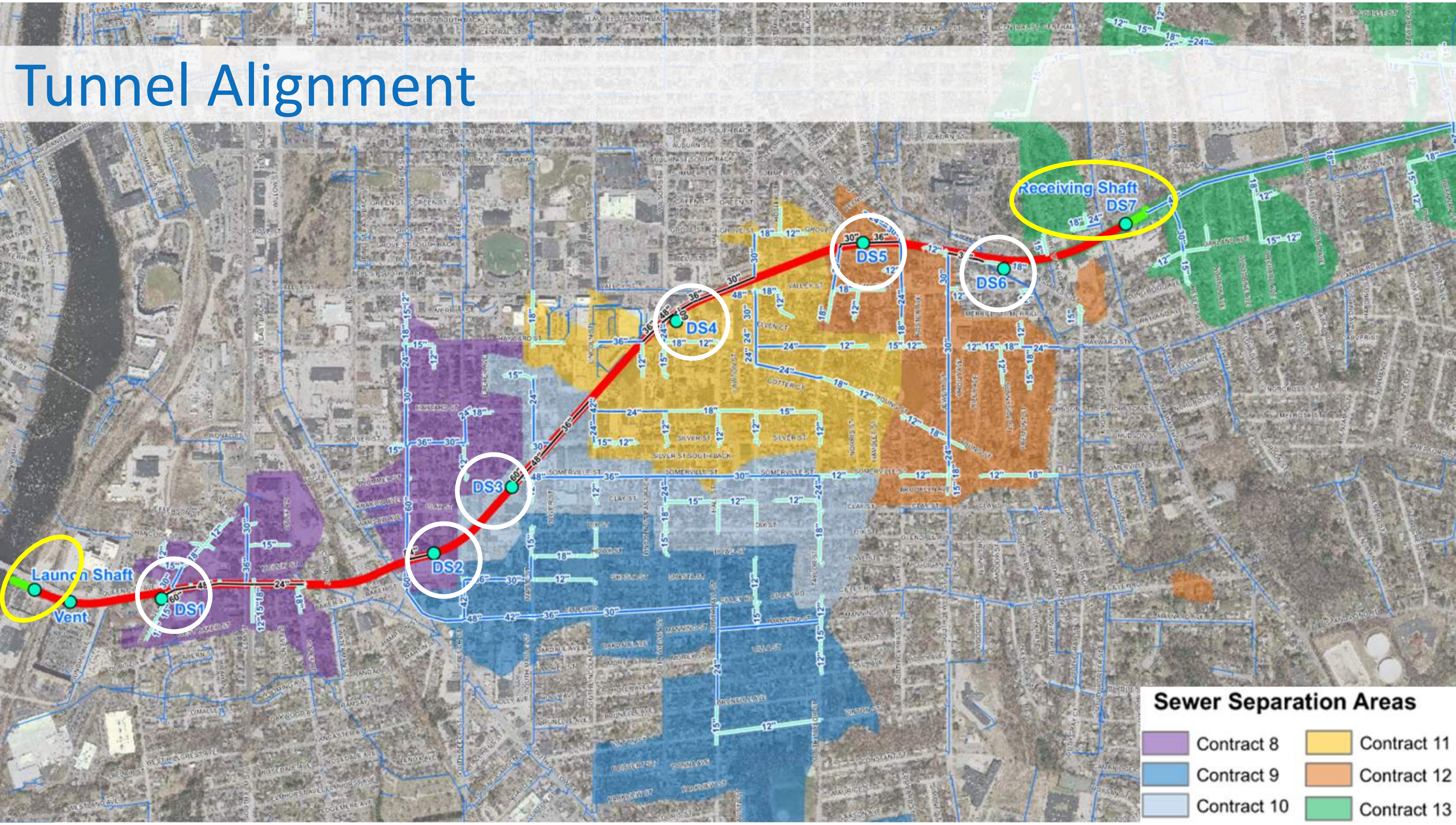
Alignment – Massabesic Avenue & Elliot Hospital

Tunnel Alternative

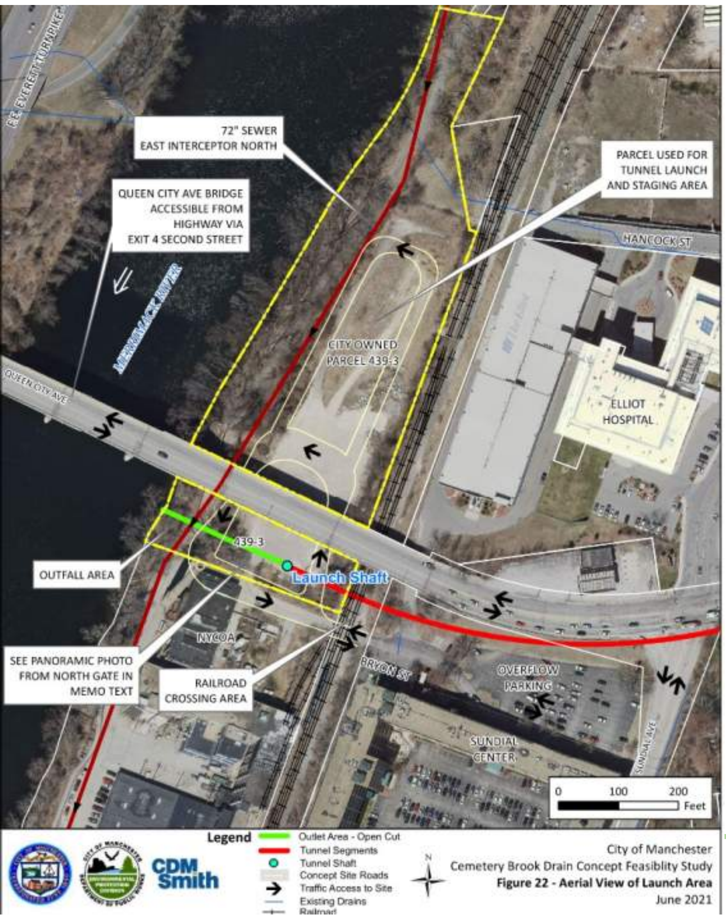


Design and Construction Considerations

Tunnel Alignment



TBM Launching and Main Construction Staging Area



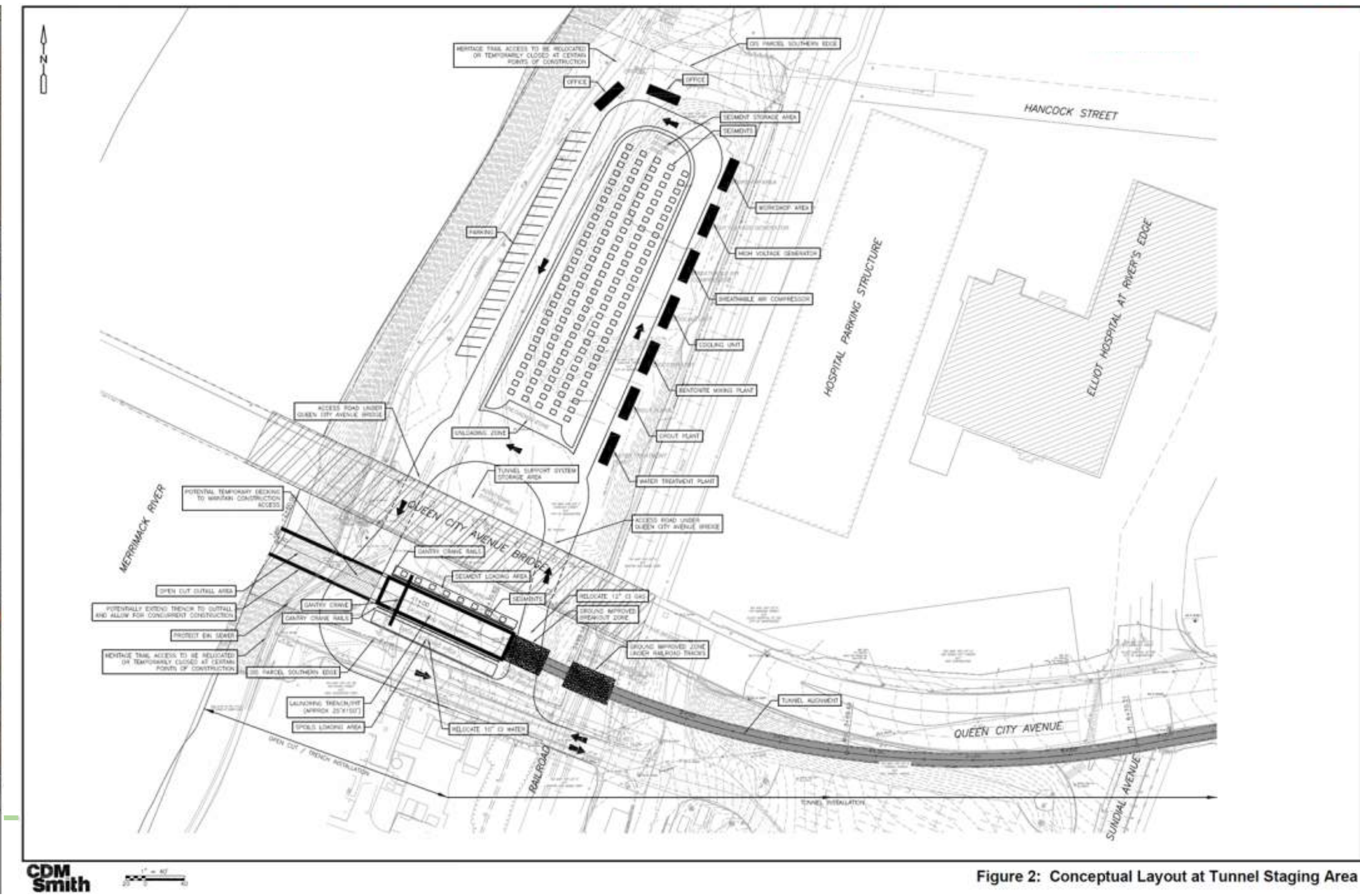
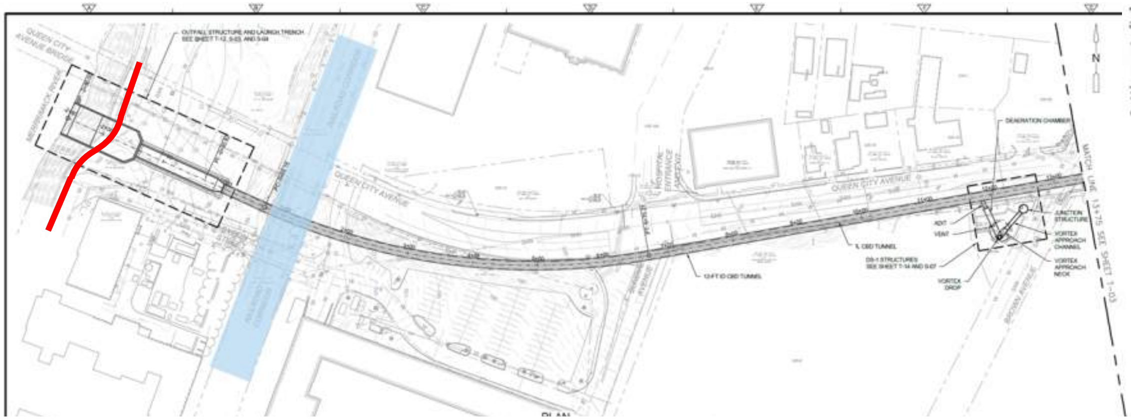
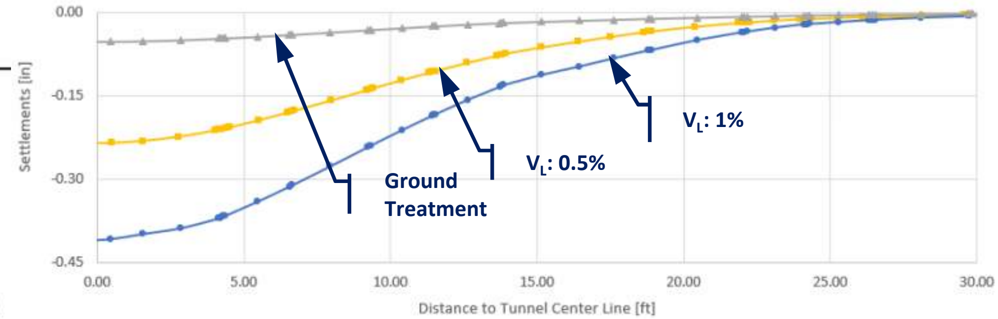


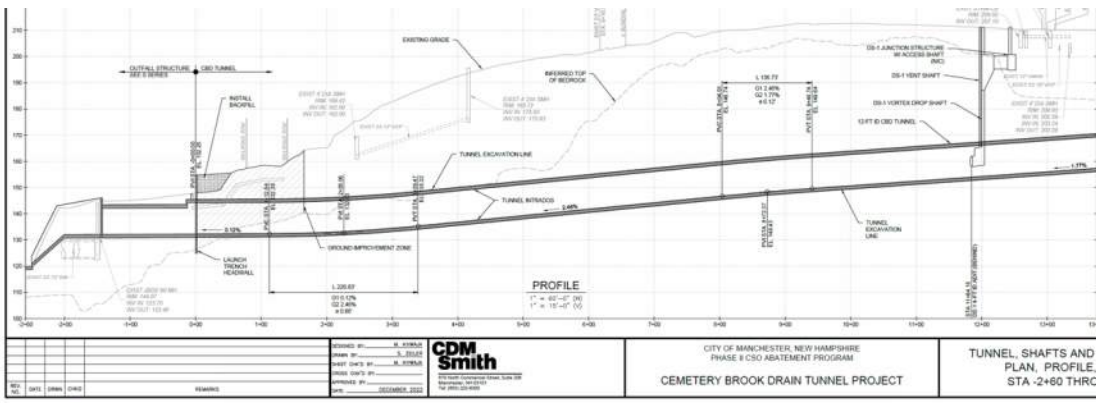
Figure 2: Conceptual Layout at Tunnel Staging Area

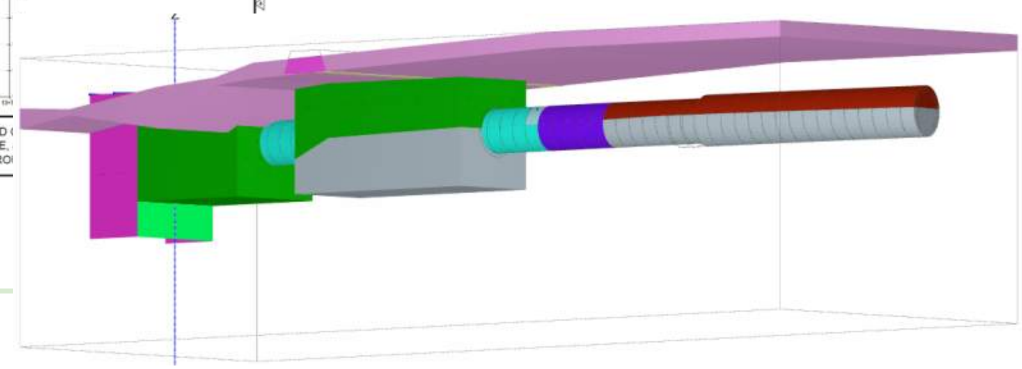
TBM Receiving Area

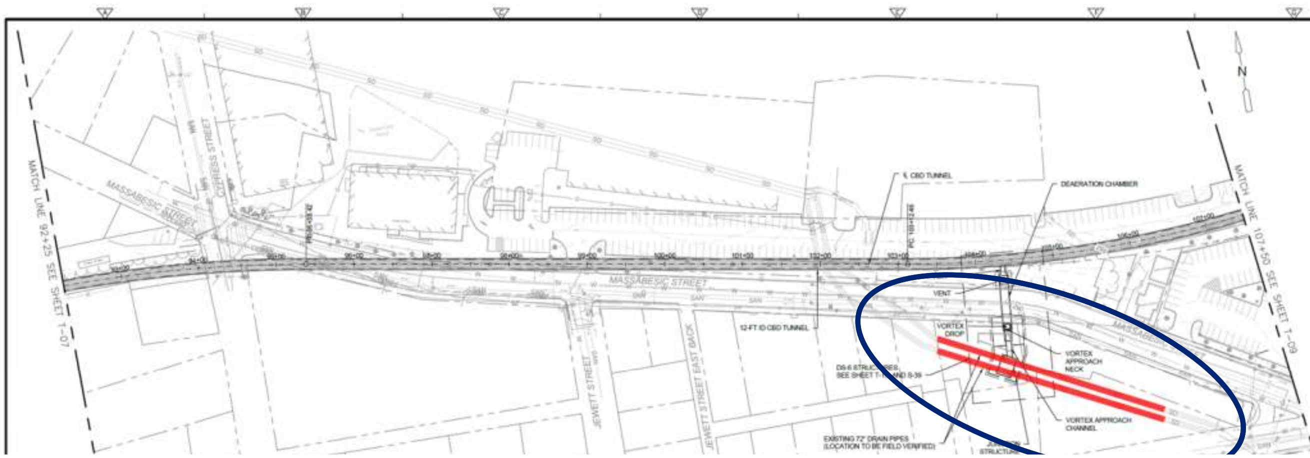
Outfall Structures / Existing EIN / CSX Crossing

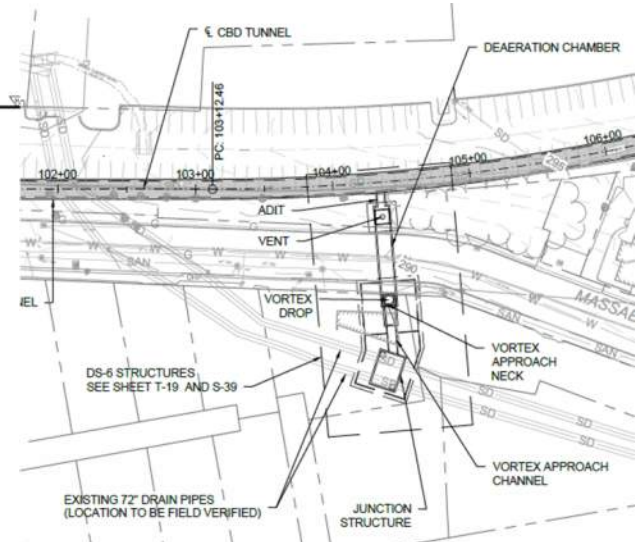




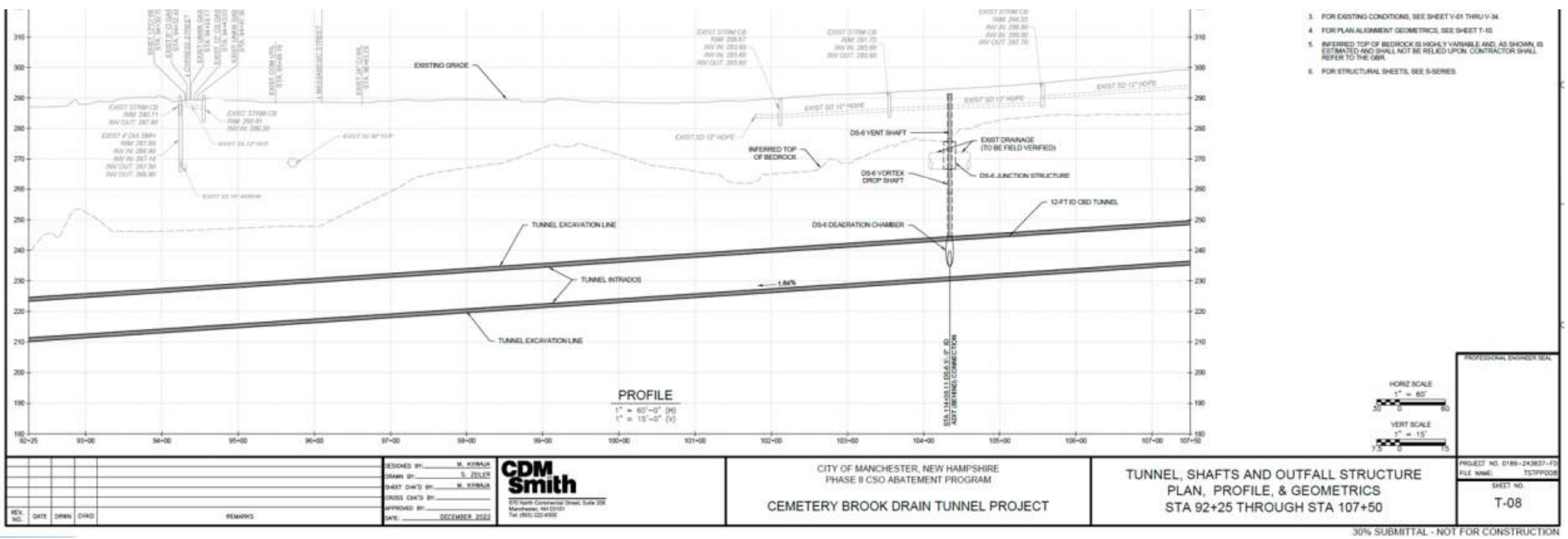


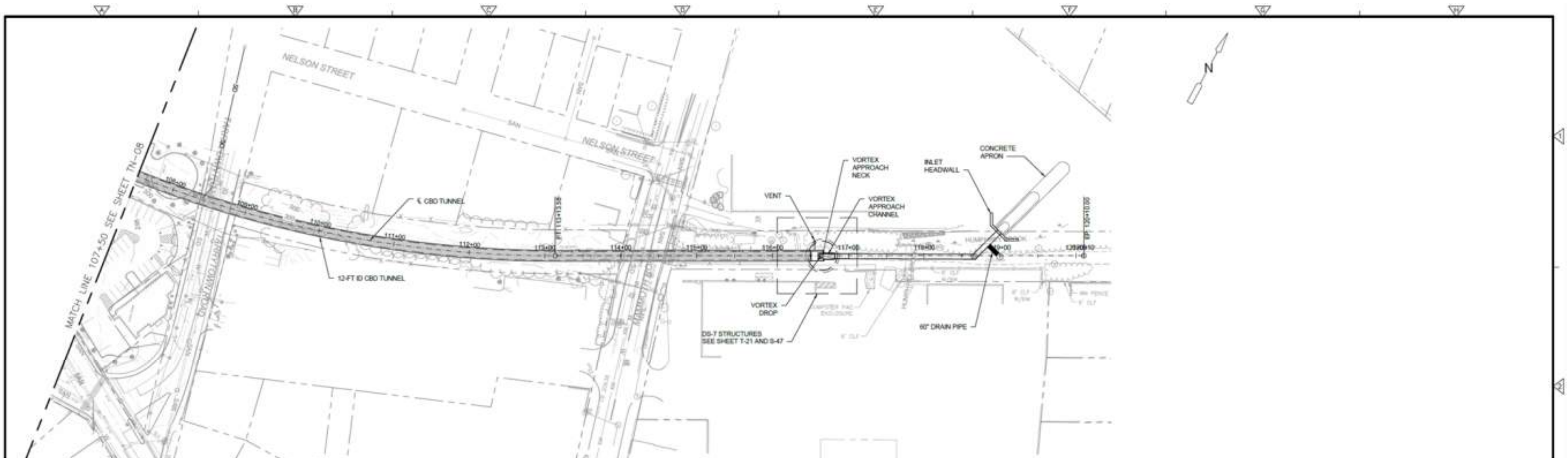




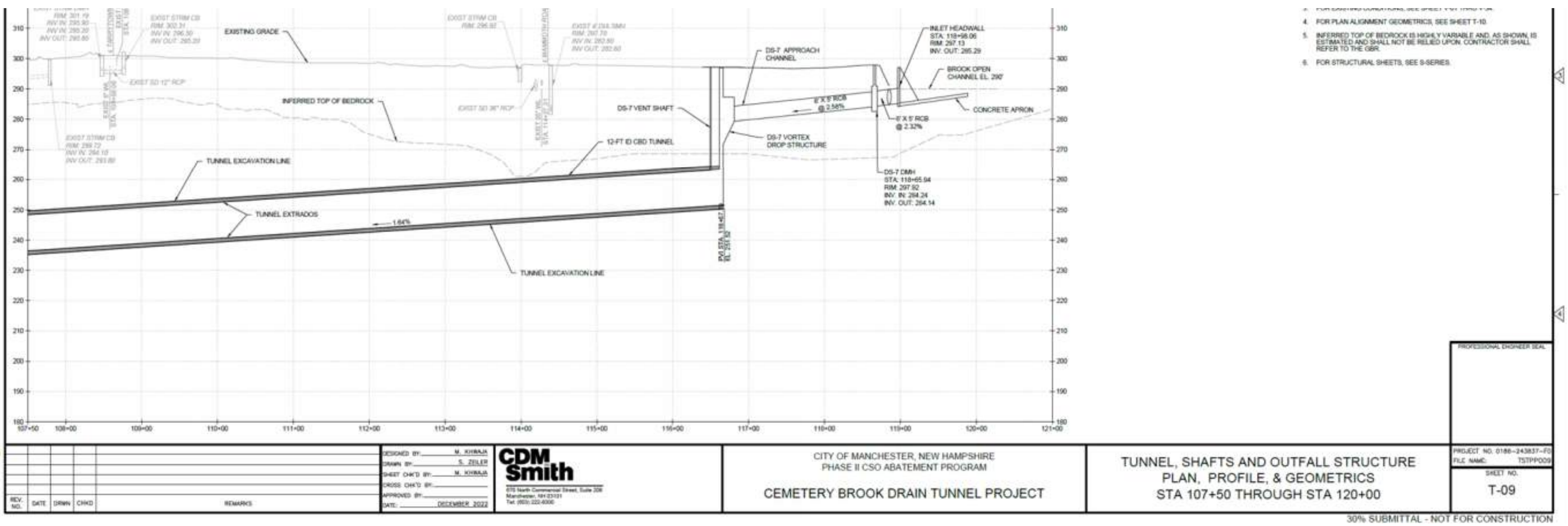


Drop Shaft 6 / Existing Storm Drain Intercept

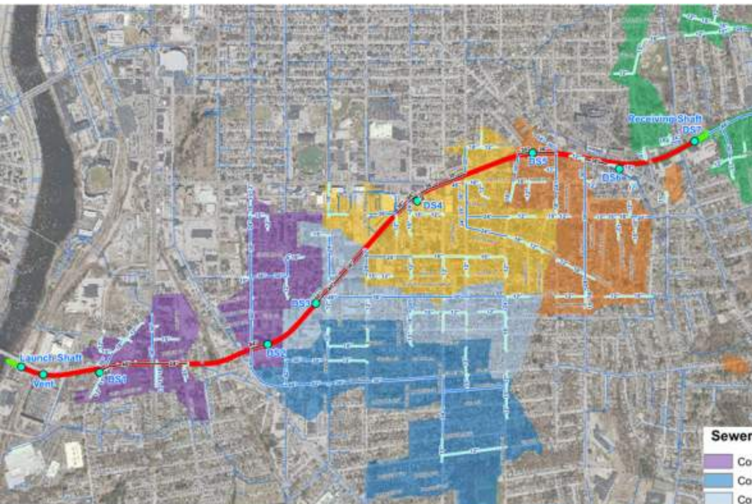


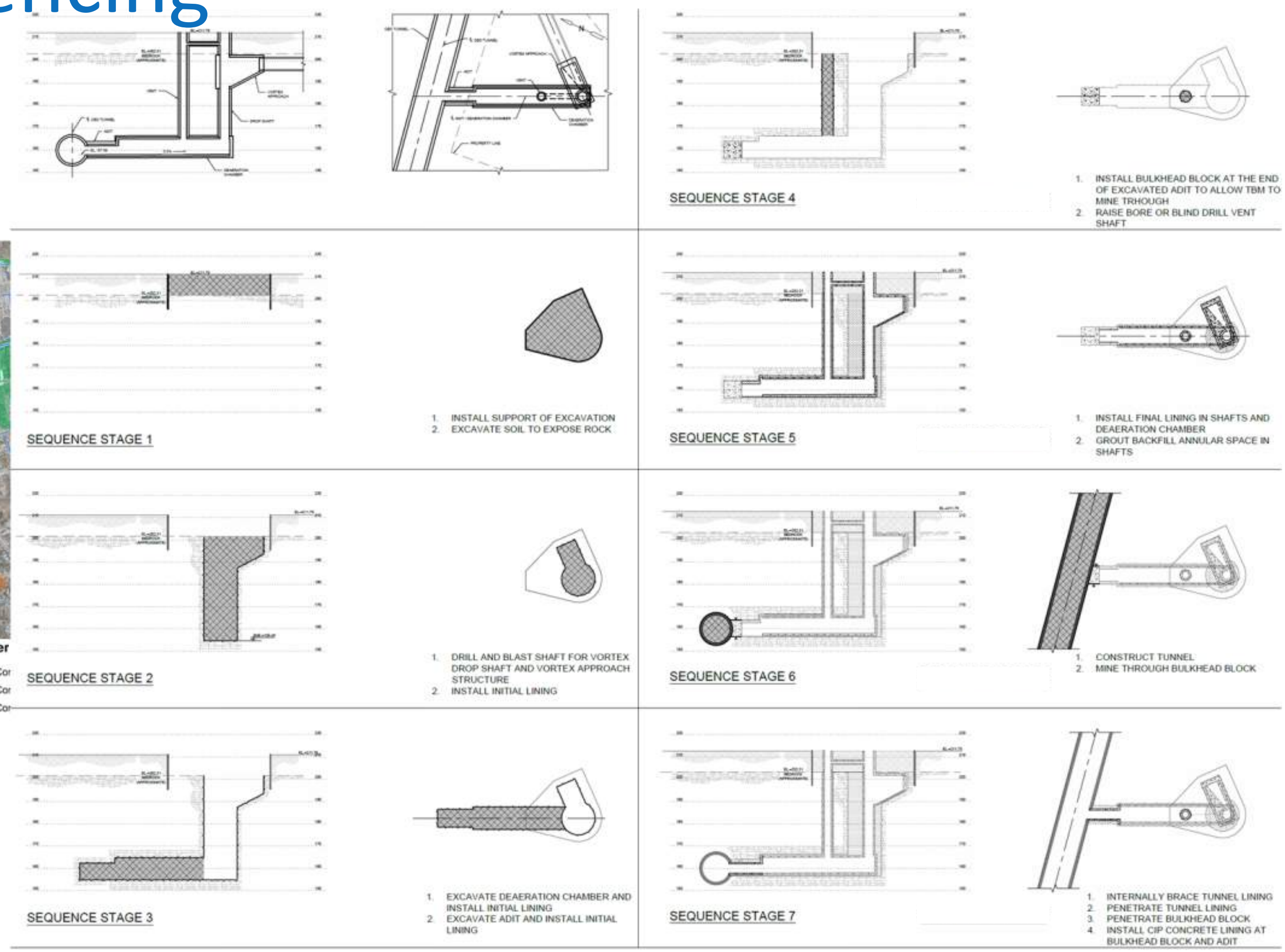


Cemetery Brook Inlet



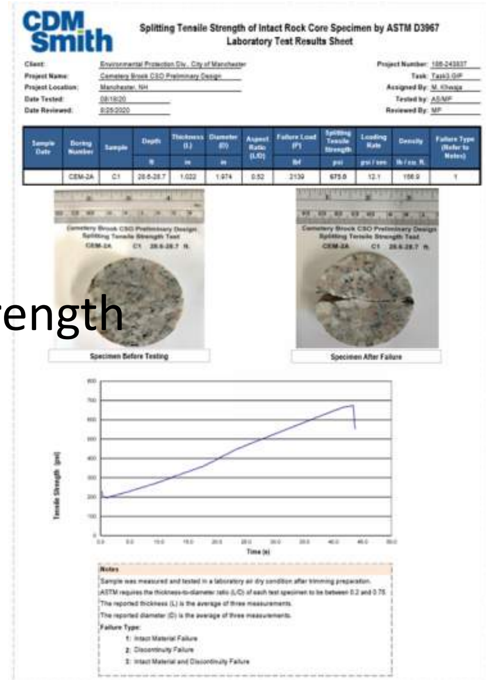
Construction Sequencing





Ground Investigation Program (GIP) Overview

- Field Activities
  - Soil Boring
  - Rock Coring
  - Packer Tests
  - Geophysical Survey
    - ATV/OTV Televiewer Logging
    - Seismic Refraction
- Laboratory Testing
  - Soil
    - Index Testing
  - Rock
    - Uniaxial Compressive Strength
    - Tensile Strength
    - Point Load
    - CERCHAR
    - Drillability Index
    - Petrographic Analysis


Splitting Tensile Strength of Intact Rock Core Specimen by ASTM D3967
Laboratory Test Results Sheet

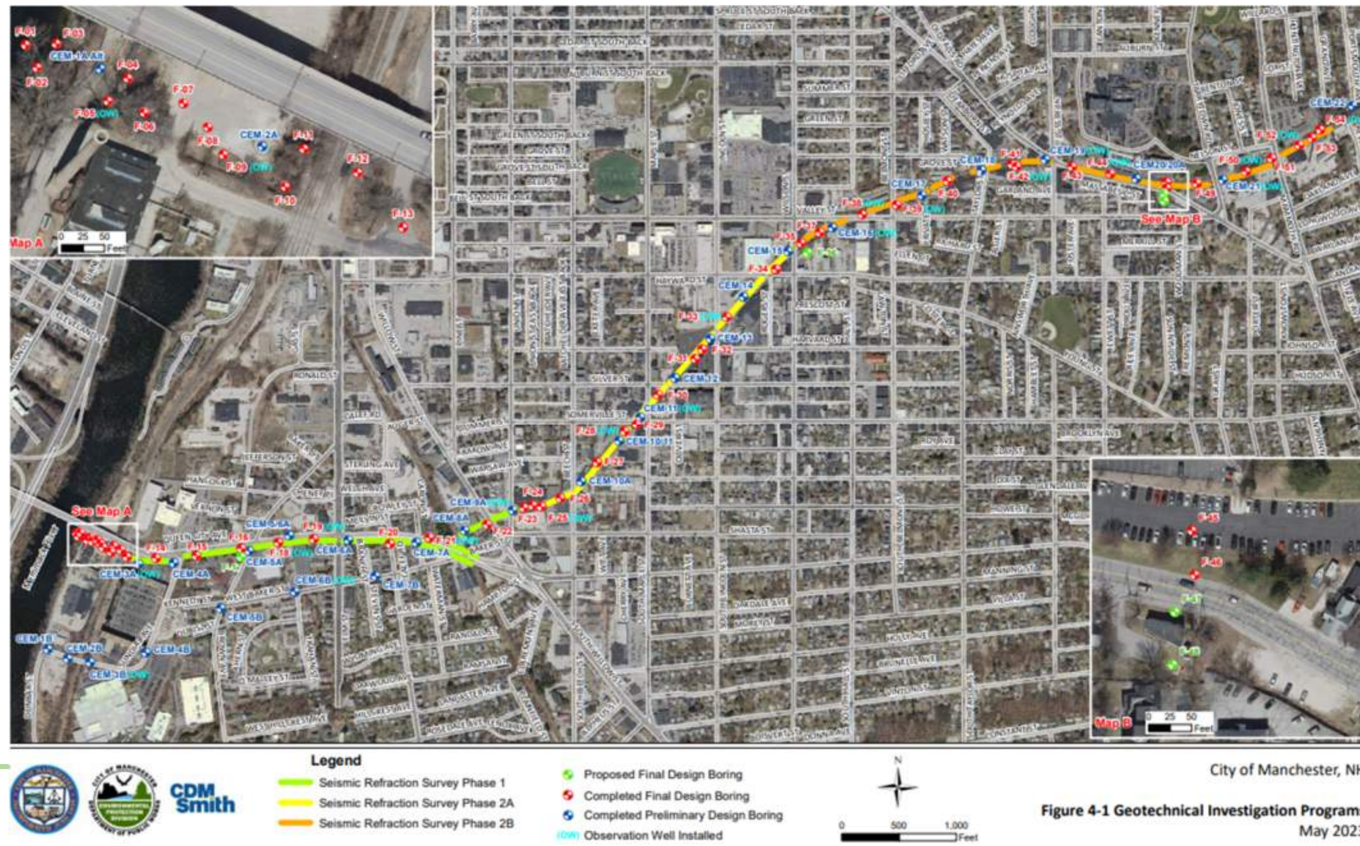
Client: Environmental Protection Div., City of Manchester
Project Name: Cemetery Brook CSO Preliminary Design
Project Location: Manchester, NH
Date Tested: 08/18/20
Date Reviewed: 8/25/2020
Project Number: 106-243837
Task: Task3 GIP
Assigned By: M. Khwaja
Tested by: AS/MF
Reviewed By: MF

Sample Date	Boring Number	Sample	Depth (ft)	Thickness (L) (in)	Diameter (D) (in)	Aspect Ratio (L/D)	Failure Load (P) (lbf)	Splitting Tensile Strength (psi)	Loading Rate (psi / sec)	Density (lb / cu. ft.)	Failure Type (Refer to Notes)
	CEM-2A	C1	28.6-28.7	1.022	1.974	0.52	2139	675.8	12.1	166.9	1

Cemetery Brook CSO Preliminary Design
Splitting Tensile Strength Test
CEM-2A C1 28.6-28.7 ft.

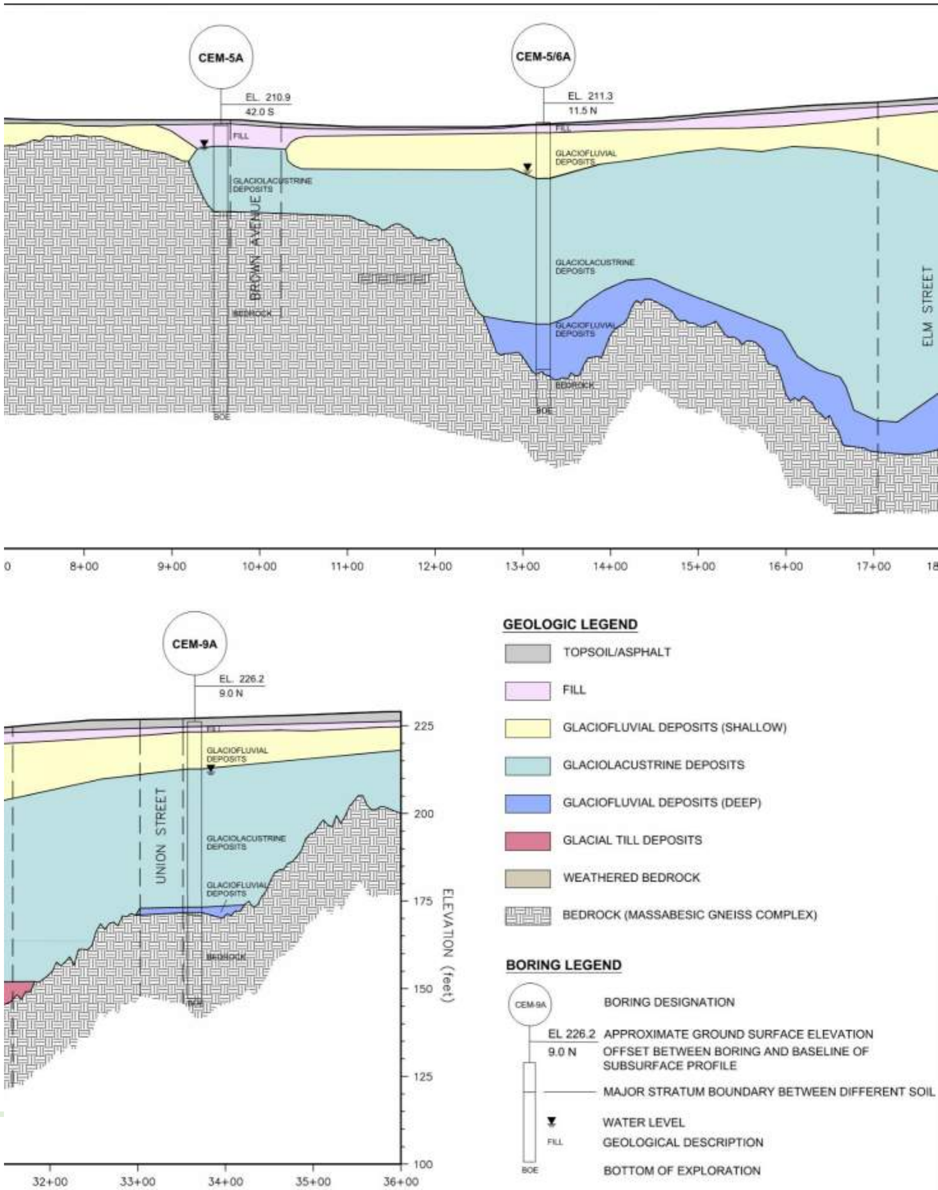
Geotechnical Investigation (GIP) Program Overview

- Seismic refraction preceded borings
- 88 borings
  - 50/80-ft deep
  - 24 Monitoring Wells
  - Packer tests
- Geophysical Survey
  - 11000-ft
- GIP Phase 2



GIP Findings

- Subsurface strata
  - Fill
  - Glaciofluvial deposits
  - Glaciolacustrine deposits
  - Glacial till
  - Bedrock
- Groundwater varies – 6 ft to 20+ ft bgs
- Bedrock: 10-ft to 110 ft bgs



Laboratory Test Results - Rock

- Tensile Strength
  - 524 psi → 1,836 psi
- UCS/Elastic Modulus
  - UCS: 1,000 psi → 32,000 psi; Average 13.6 ksi
  - EM: 1,485 ksi → 9,687 ksi
- CERCHAR (Abrasiveness)
  - Very → Extreme
- Point Load Test (Correlated UCS)
  - 2,900 ksi → 23,300 ksi

CDM Smith

Splitting Tensile Strength of Intact Rock Core Specimens by ASTM D3967

Laboratory Test results Summary Sheet

Client: City of Manchester
Project Name: Cemetery Brook CSO Preliminary Design
Project Location: Manchester, NH
Project Number: 186-243837
Task: Task3.GIP
Assigned By: M. Khwaja

Date Tested: 7/29/2020
Date Reviewed: 8/27/2020
Tested by: MP
Reviewed By: AS

Boring Number	Sample ID	Depth	Preparation	Density	Failure Load	Splitting Tensile Strength	Failure Type
		ft		lb / cu. ft.	lbf	psi	
CEM-2A	C1	28.1-28.6	Saw Cut	156.9	2139	**675.0**	1
CEM-3A	C2	42.5-42.8	Saw Cut	182.3	2511	**821.6**	1
CEM-4A	C5	44.1-49.1	Saw Cut	178.4	3455	**1163.5**	1
CEM-5A	C9	70.7-71.1	Saw Cut	183.0	1858	**687.4**	1
CEM-5/6A	C1	75.3-75.8	Saw Cut	174.4	3880	**1266.5**	1
CEM-8A	C1	82.0-82.3	Saw Cut	137.2	3197	**862.9**	1
CEM-9A	C2	65.6-66.9	Saw Cut	163.0	4138	**1304.2**	1
CEM-1B	C1	42.2-44.5	Saw Cut	165.1	5943	**1835.9**	1
CEM-2B	C2	31.4-31.9	Saw Cut	192.6	1453	**524.0**	4
CEM-3B	C3	34.1-34.9	Saw Cut	152.5	2291	**702.9**	1
CEM-4B	C3	29.6-30.4	Saw Cut	204.7	2298	**879.7**	1
CEM-5B	C3	27.6-28.0	Saw Cut	161.2	3186	**1006.0**	1
CEM-7B	C1	68.1-68.5	Saw Cut	170.7	3337	**1135.2**	1

Notes

Sample was measured and tested in a laboratory air dry condition after trimming preparation.
ASTM requires the thickness-to-diameter ratio (L/D) of each test specimen to be between 0.2 and 0.75.
The reported thickness (L) is the average of three measurements.
The reported diameter (D) is the average of three measurements.

Failure Type:

1: Intact Material Failure
2: Discontinuity Failure
3: Intact Material and Discontinuity Failure
4: No visible failure planes. Sample compressed into foliations

Rock Drillability Tests (1) (2)

Test Results:

Brittleness Value S_{20}, (%)	Flakiness, (f)	Compaction Index	Density, (g/cm^3)	Sievers J-Value, (0.1 mm)	Abrasion Value, (mg)	Abrasion Value Steel Cutters, (mg)
40.33	1.33	2	2.71	13.73	4.05	43.75
Low	---	---	---	**Medium**	**Low**	**Very High**

Calculated Indices:

	Drilling Rate Index	Bit Wear Index	Cutter Life Index
Assessed value	44	32	8.9
Classification Category	**Medium**	**Medium**	**Medium**

Rock Quality

- High Rock Quality Designation (RQD)
- Low number of Joints & discontinuities
- Low permeability
- High strength
- Extremely abrasive

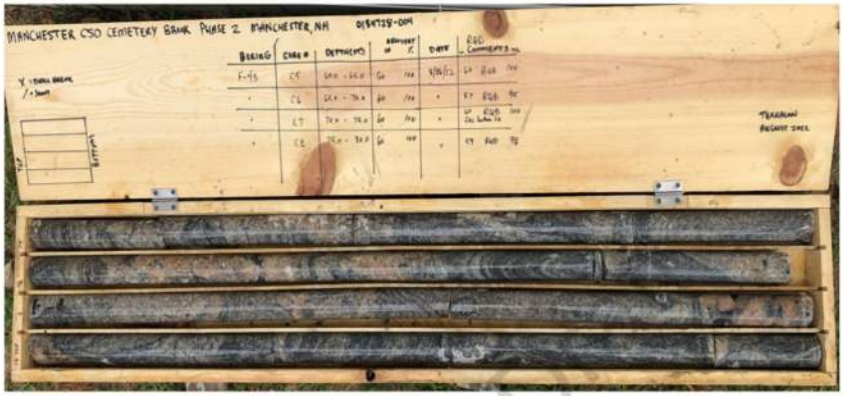
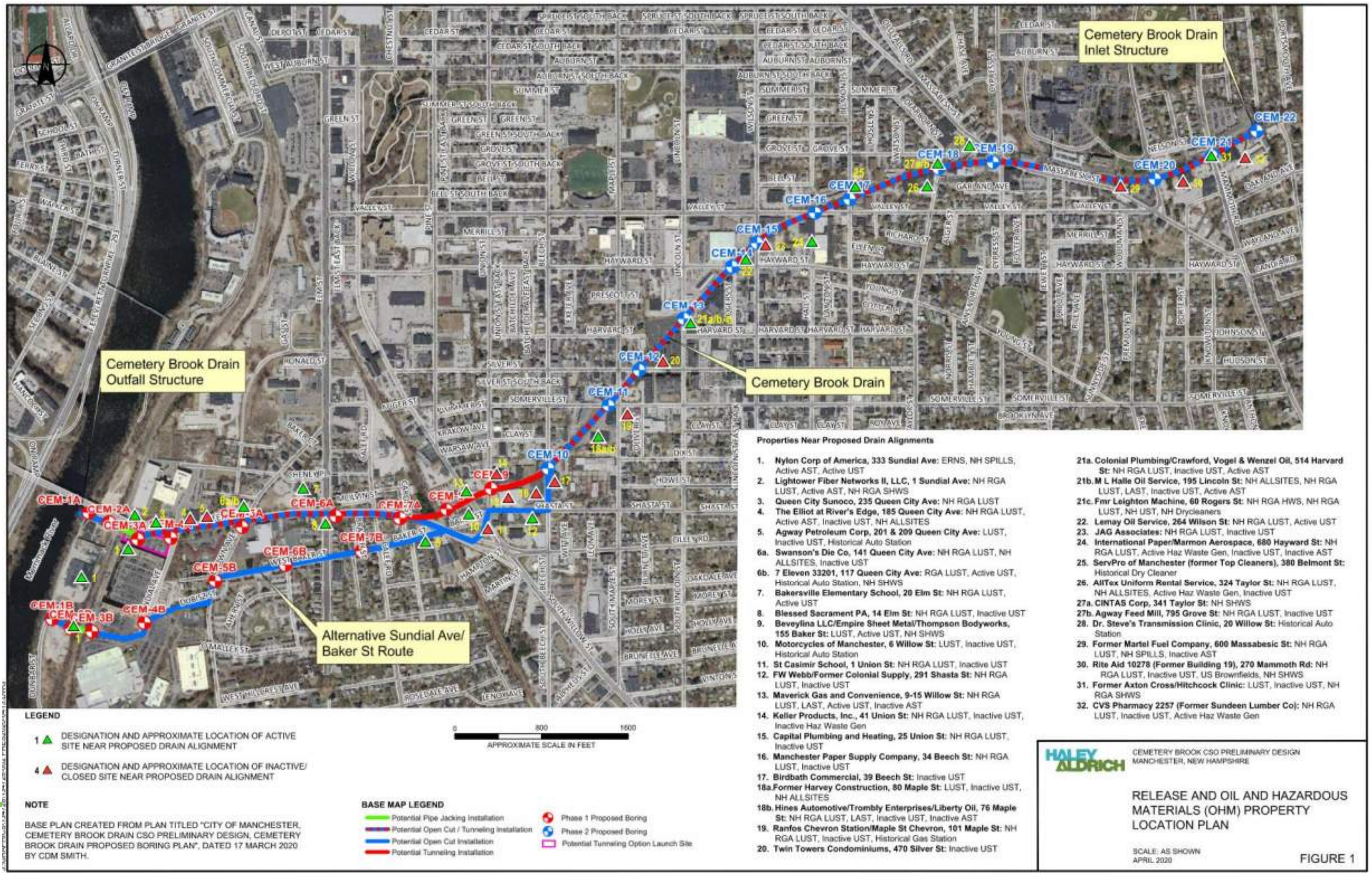


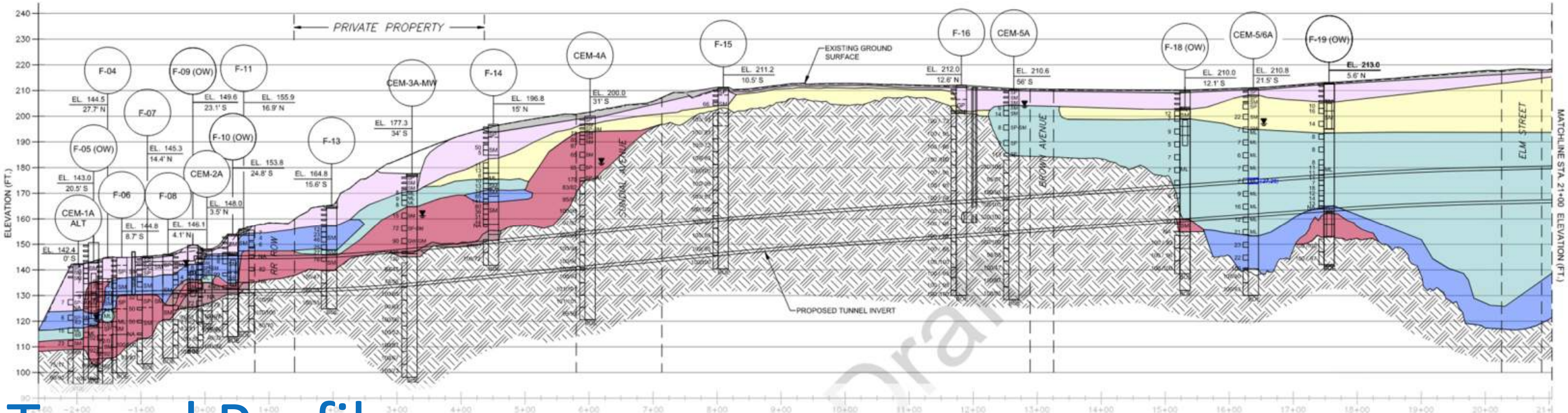
Photo 65: F-43 C5-C8

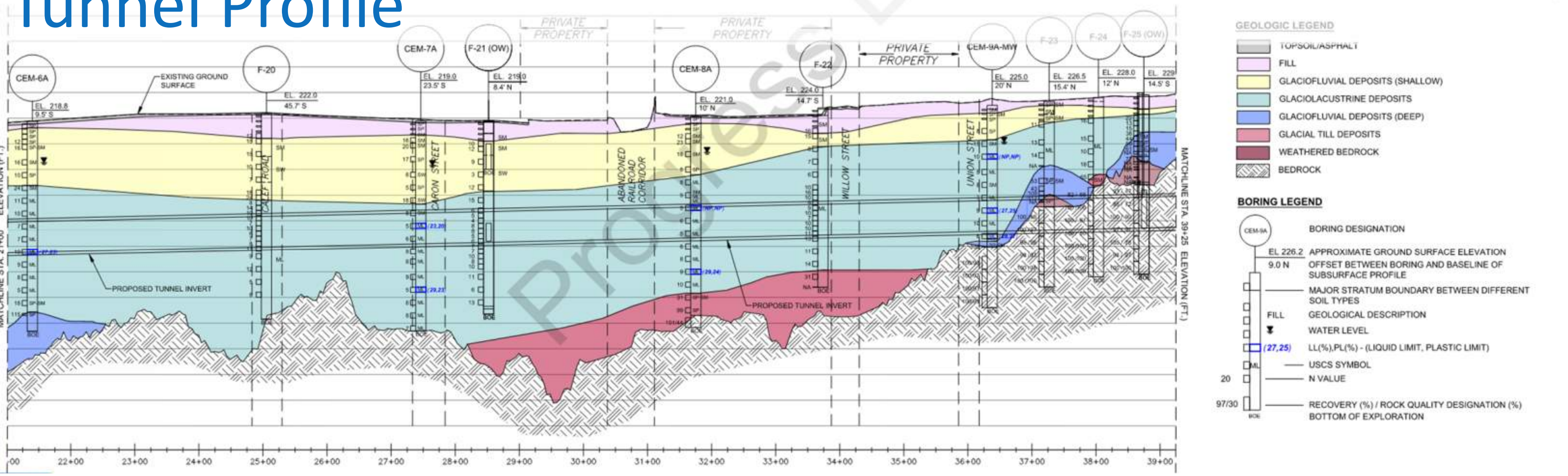
Photo 66: F-43 C9-C10

GIP Phase 1 Environmental Testing – Group 1

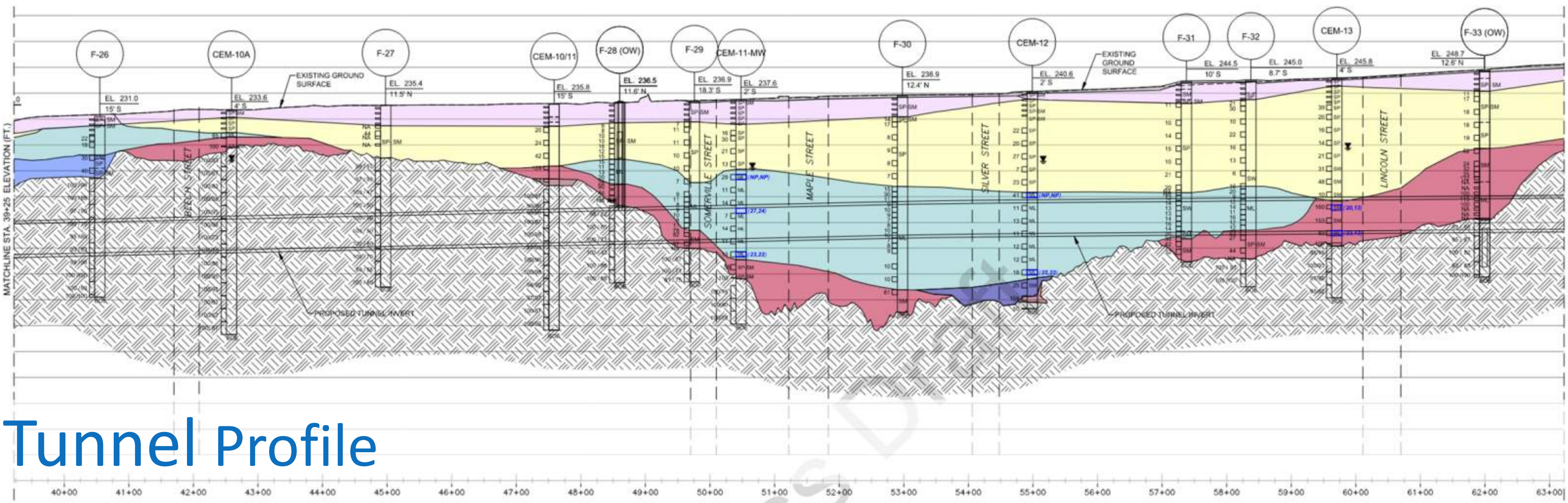


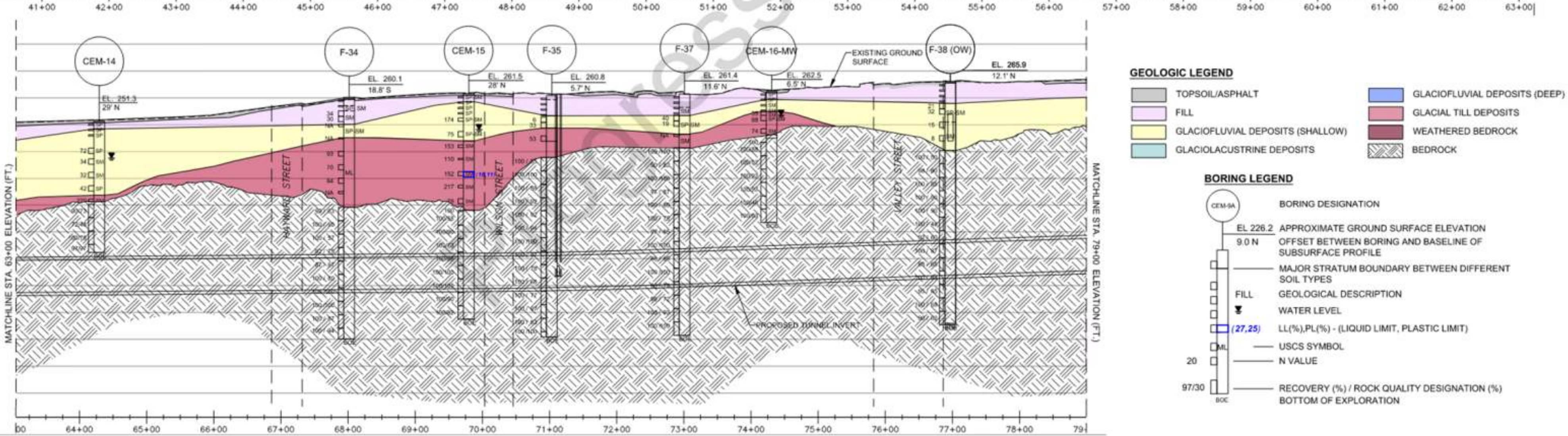
Tunnel Profile





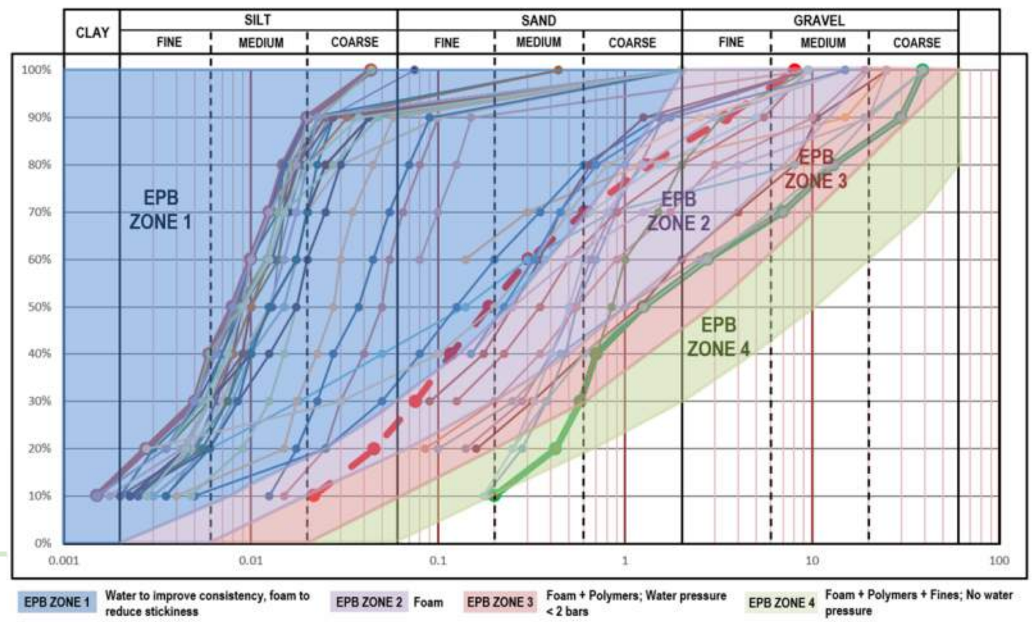
Tunnel Profile





Machine Type

- Grain size distribution
- Pressurized face
- Soft ground / rock
- Segmental lining



Hydraulic Physical Model

Hydraulic Physical Scaled Model

- Evaluate design elements
  - Air movement
  - Venting
  - Connection criteria
- Two types of drop shafts
  - In-line drop shaft
  - Off-line drop shaft
- Outfall structures
  - Transition
  - Energy dissipation/Apron

Tunnel and Outfall Structures

Project Status

CEMETERY BROOK DRAIN TUNNEL PROJECT

Preliminary/Final engineering

12,000-ft ● 12-ft ID ● Segmentally lined tunnel

Design through Q2 2024

Bid late Q3 2024 (tentative)