

Application of Mixing Zone Modeling in Decision Making for CSO Tunnel Construction Water Discharge

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Narragansett Bay Commission (NBC), Rhode Island

- Two WWTFs
- 110 Miles of Interceptors
- 64 CSO Outfalls
- 3-mile CSO Tunnel
- 6 Pump Stations
- 10 Communities
(70,000 Customers)





NBC CSO Program

1992: Consent Agreement with RIDEM for CSO Controls

1996-1998: Program Reevaluation with Stakeholders Group Input

- 1994 EPA CSO Policy Change - Provide more flexibility
- Cost (capital and rate increase)
- Technical Concerns

1998: Defined a three-phase CSO Control Program

Program Goals:

- 98% reduction annual CSO volume
- 80% reduction in shellfish bed closures
- < 4 overflows per year

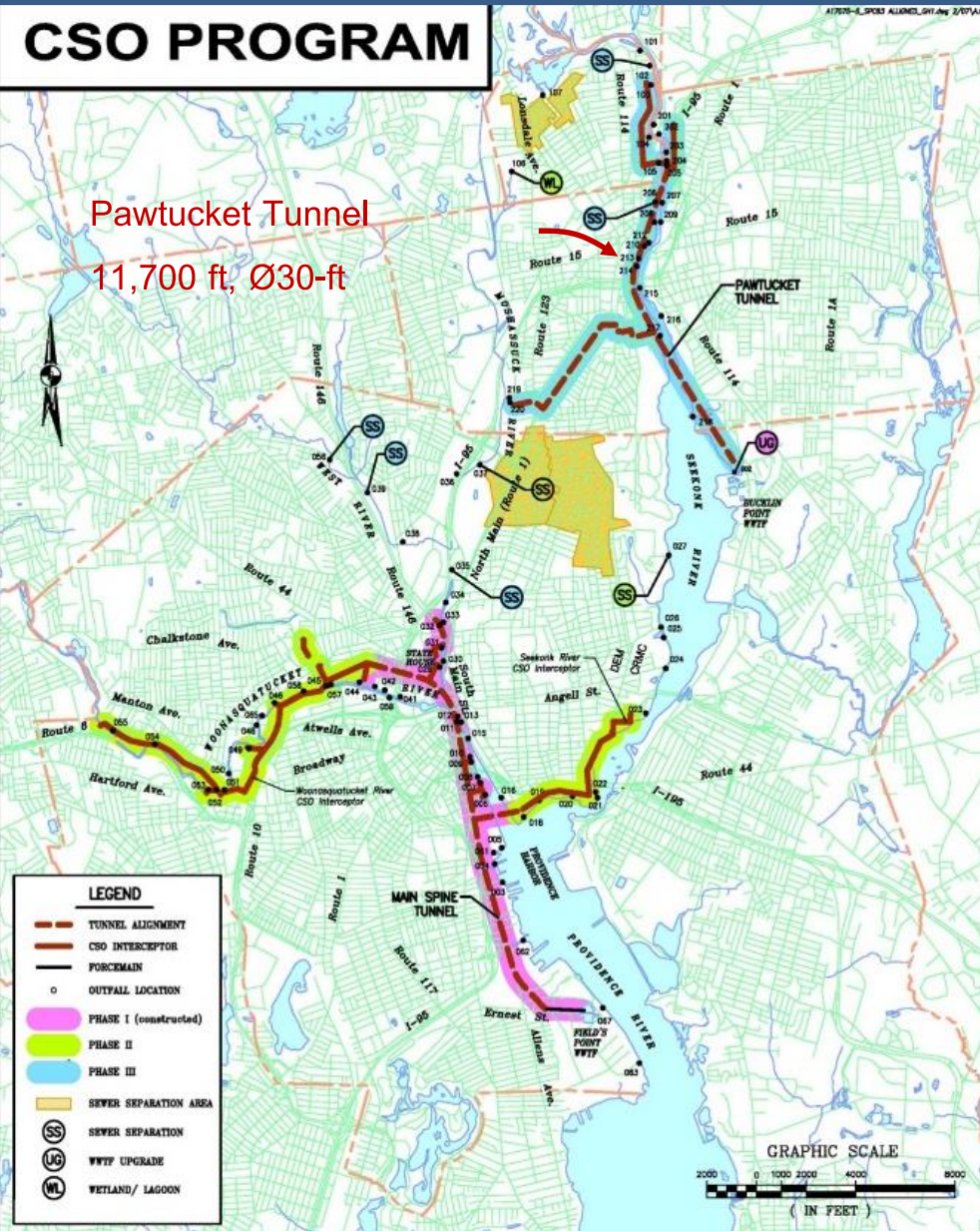




NBC CSO Program

CSO PROGRAM

Pawtucket Tunnel
11,700 ft, Ø30-ft



Phase I: 2001-2008

\$360M

Providence Tunnel (63 MG, Ø26-ft, 3-mile)

Addresses 40% CSO Volume

Phase II: 2011-2015

\$197M

CSO Interceptors

Sewer Separation

Storage/Wetlands Facility

Phase III: 2021-2041

\$1B

Pawtucket Tunnel (58.5 MG, Ø30-ft, 2.2-mile)

Bucklin Points WWTf Upgrades

Targeted Sewer Separation

Green Stormwater Infrastructure

What do we do
with the construction water during
tunnel mining?



Discharge Alternative & Summary

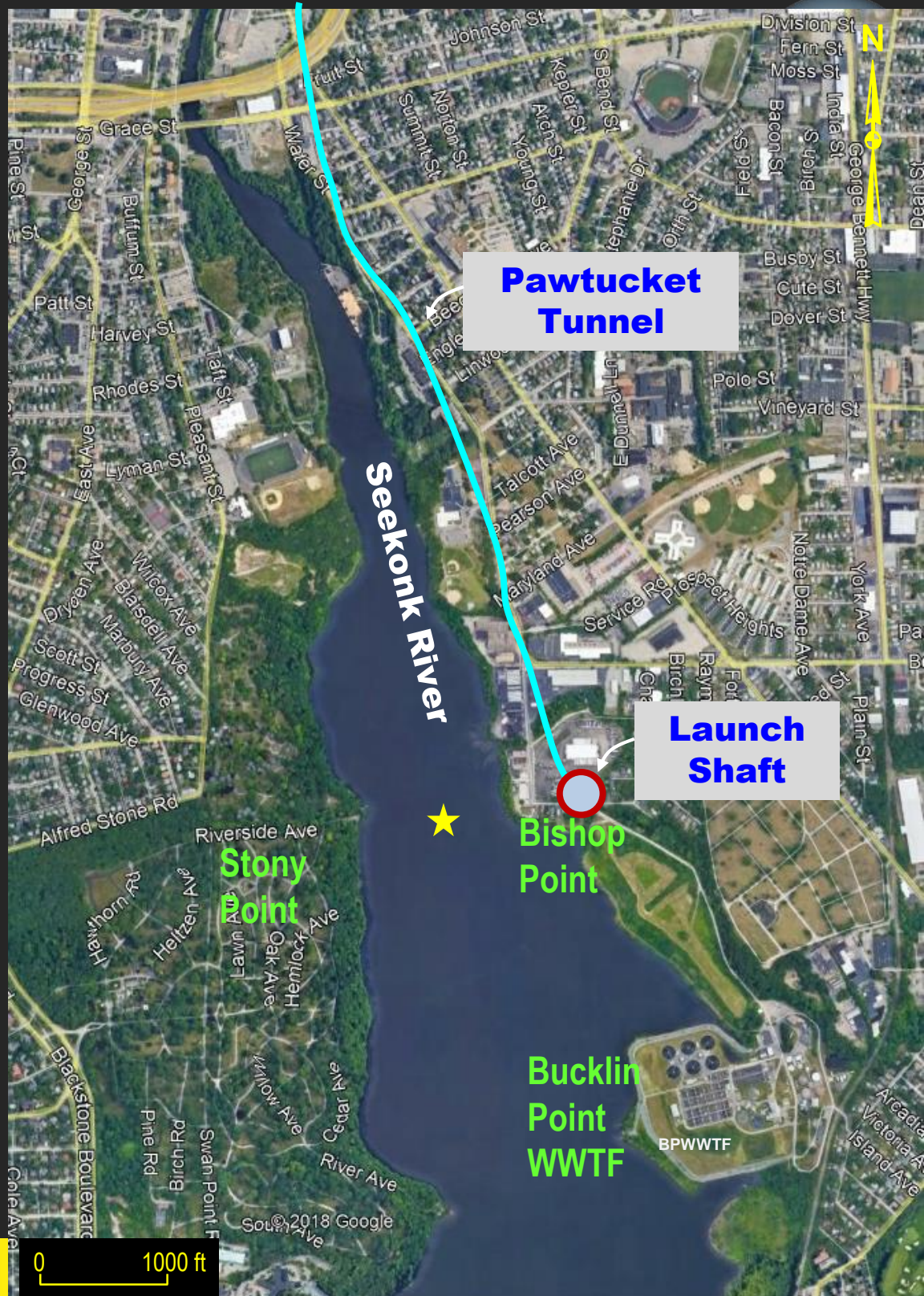
Alternative	Feasibility	Comments
1. No Build	Not feasible	<ul style="list-style-type: none"> NBC would violate the CA with RIDEM
2. Seekonk River In-channel Discharge	Feasible	<p>2. Seekonk River In-channel Discharge</p> <p>...ce ...to greatest extent possible through design</p>
3. Seekonk River Off-channel Discharge	Not feasible	<p>3. Seekonk River Off-channel Discharge</p> <p>...alternative viable. This degree of dredging is ...chedule constraints</p>
4. Subsurface Dispersal	Not feasible	<p>3. Seekonk River Off-channel Discharge</p> <p>...us of project site ...ot be constructible within allowable project schedule</p>
5. Discharge to Bucklin Brook	Not feasible	
6. Discharge to Bucklin Point WWTF	Not feasible	<p>...l sludge management ...arge permit</p>
7. Discharge to Ten Mile River	Not feasible	<ul style="list-style-type: none"> Challenging within allowable project schedule Technical constraints, such as crossing railroads and greenway/bike path Insufficient mixing and dilution

Seekonk River Discharge

- The Seekonk River has been identified as a Class SB receiving water by the Rhode Island Department of Environmental Management (RIDEM)

Permit Requirements

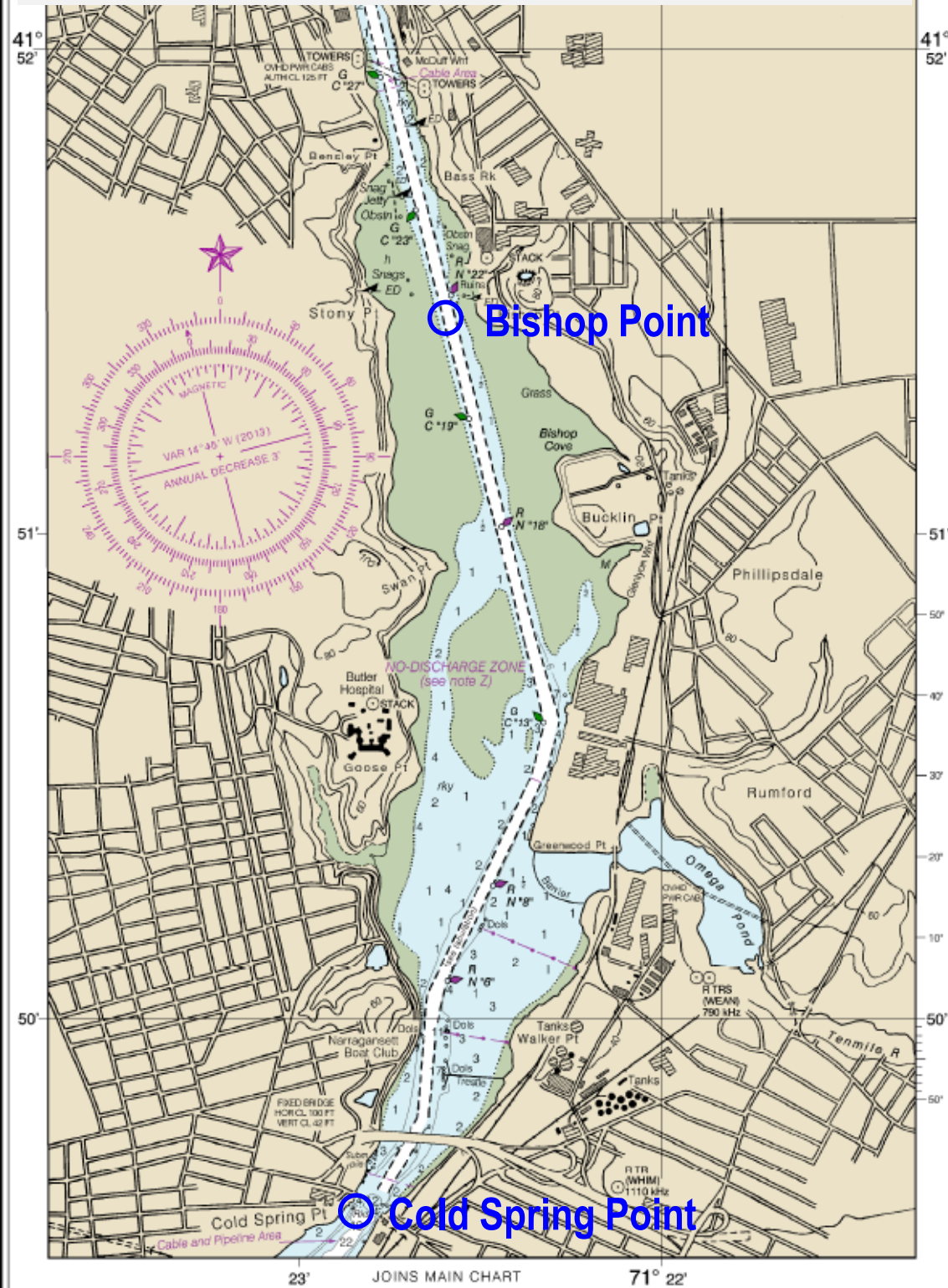
- Permits from RIDEM
- Permit from Rhode Island Coastal Resources Management Council (CRMC)
- Authorization from US Army Corps of Engineers (USACE)



Seekonk River Navigation Channel

- 3.4 mile-long
- 16 feet deep
- 100-230 feet wide (narrows to 60 feet upstream to the Division Street Bridge)

Reference: NOAA Chart of Providence River and Head of Narragansett Bay



CORMIX Model

- CORMIX is a USEPA-supported mixing zone model
- Decision support system for environmental impact assessment of mixing zones resulting from continuous point source discharges.
- The system emphasizes the role of boundary interaction to predict steady-state mixing behavior and plume geometry.
- The CORMIX methodology contains systems to model single-port, multiport diffuser discharges and surface discharge sources.

CORMIX model was used in this study to simulate mixing zone in the Seekonk River for estimating dilution factors.

CORMIX Input 1. Project Information

The screenshot displays the CORMIX v11.0.1.0 software interface. At the top, the title bar reads "CORMIX v11.0.1.0". Below it is a menu bar with options: Project, Pages, Pre-Processing Tools, Run, Output Data Reports, Post-Processing/Advanced, and Help. A toolbar contains various icons for file operations (Load, Clear, Save, Save As, Print) and simulation tools (SI-Units, CorHyd, CorSpy, Validate & Run, FC Tree, CorVue, CorJet, FFL, CorSens, User Manual, CorHelp). A tabbed interface below the toolbar shows "Project" as the active tab, with other tabs for Effluent, Ambient, Discharge, Mixing Zone, Output, and Processing. The "Project Legend/Identification" section contains the following fields:

- Project File Name: C:_YF\Project\RI_NBC Tunnel Discharge Pretreatment\CORMIX\CORMIX Model\Model 20200203\800_SinglePort_1HRbfHWS.cmx (with a Load... button)
- Design Case: 1 hr before HWS
- Site Name: Seekonk River (Tidal)
- Prepared By: Yuan Fang
- Date: 02/03/20 (with a Today button)

Below these fields is a "Project Notes" section with a text area containing the note: "800 gpm, Single Port discharge". At the bottom of the window, the status bar displays the file path and design case: "C:_YF\Project\RI_NBC Tunnel Discharge Pretreatment\CORMIX\CORMIX ModeModel 20200203\800_SinglePort_1HRbfHWS.cmx ; 1 hr before HWS".

CORMIX Input 2. Effluent Properties

The screenshot shows the CORMIX v11.0.1.0 software interface. The 'Effluent' tab is selected in the top navigation bar. The 'Effluent Characterization/Pollutant Type' section is active, with 'Conservative Pollutant' selected. A purple arrow points from the 'Flow Rate' dropdown menu in the 'Effluent Flow Rate/Velocity' section to the 'Flow Evaluated' list. The 'Flow Rate' is currently set to 800 GPM (US). The 'Effluent Density' section is also visible, with 'Fresh' selected and 'Temperature' set to 51 deg. F.

Flow Evaluated

- 400 gpm
- 800 gpm
- 1200 gpm
- 2400 gpm

The pollutant does NOT undergo chemical/biological decay/growth processes.

Discharge Concentration (Effluent): 100 %

Effluent Flow Rate/Velocity

Flow Rate: 800 GPM (US)

Effluent Density

Fresh Non-Fresh

Density Temperature

Temperature: 51 deg. F

CORMIX Input 3. Ambient Condition

CORMIX v11.0.1.0

Project Pages Pre-Processing Tools Run Output Data Reports Post-Processing/Advanced Help

Load Clear Save Save As Print lbs kg SI-Units CorHyd CorSpy Validate & Run FC Tree CorVue CorJet FFL CorSens User Manual CorHelp

Project Effluent **Ambient** Discharge Mixing Zone Output Processing

Ambient Page

1 Ambient Geometry/Flow Field Data

Average Depth: 11.17 ft
Depth at Discharge: 11.17 ft
Wind Speed: 2.1 m/s

Steady **Unsteady**

Period (hr): 12.4 12.4
Max Veloc: 0.49 m/s

Tidal Velocity: 0.039 m/s

At time (hr): 1 BEFORE slack. **Simulation**
 At slack - Delta Time (hr):
 At time (hr): AFTER slack.

Bounded Unbounded

Width: 200 ft

Simulations

- Slight Meander
- 1hr before LWS
- 1hr after LWS
- Manning's n: 0.028
- 1hr before HWS
- 1hr after HWS

2 Ambient Density Data

Fresh Water **Non-Fresh Water**

Uniform **Stratified** Type A Type B Type C

Linear Density Profile

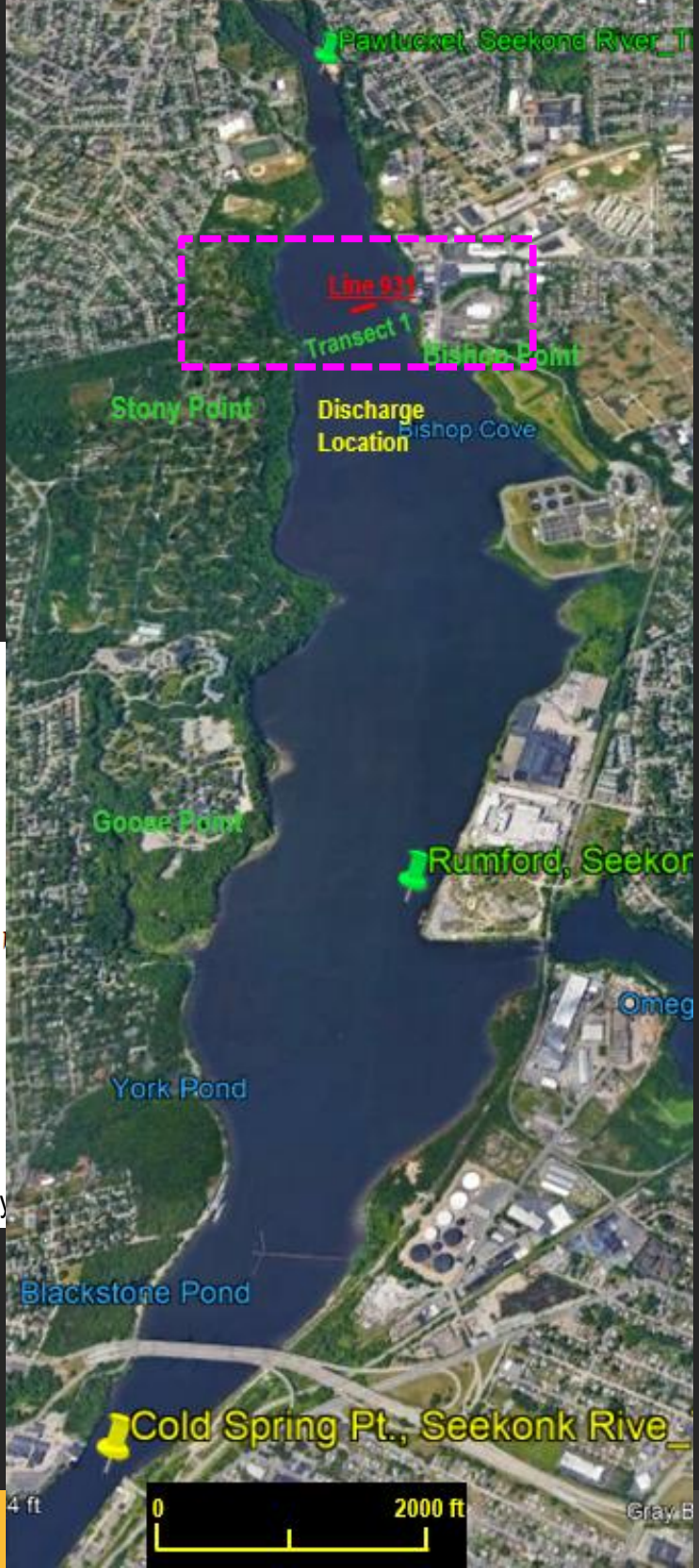
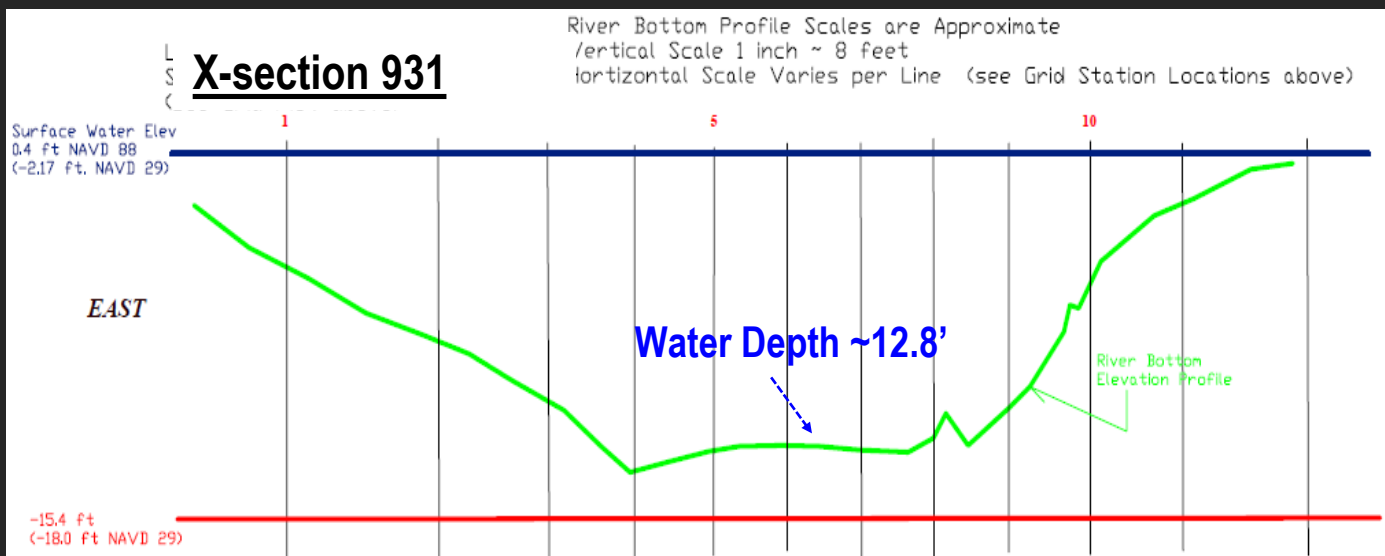
Density (kg/m3)

at Surface: 1006.6 Compute...
at Bottom: 1017.3 Compute...

C:\YF\Project\RI_NBC Tunnel Discharge Pretreatment\CORMIX\CORMIX Mode\Model 20200203\800_SinglePort_1HRbfHWS.cmx ; 1 hr before HWS

Reference 1: Pawtucket Geophysical Survey Profile

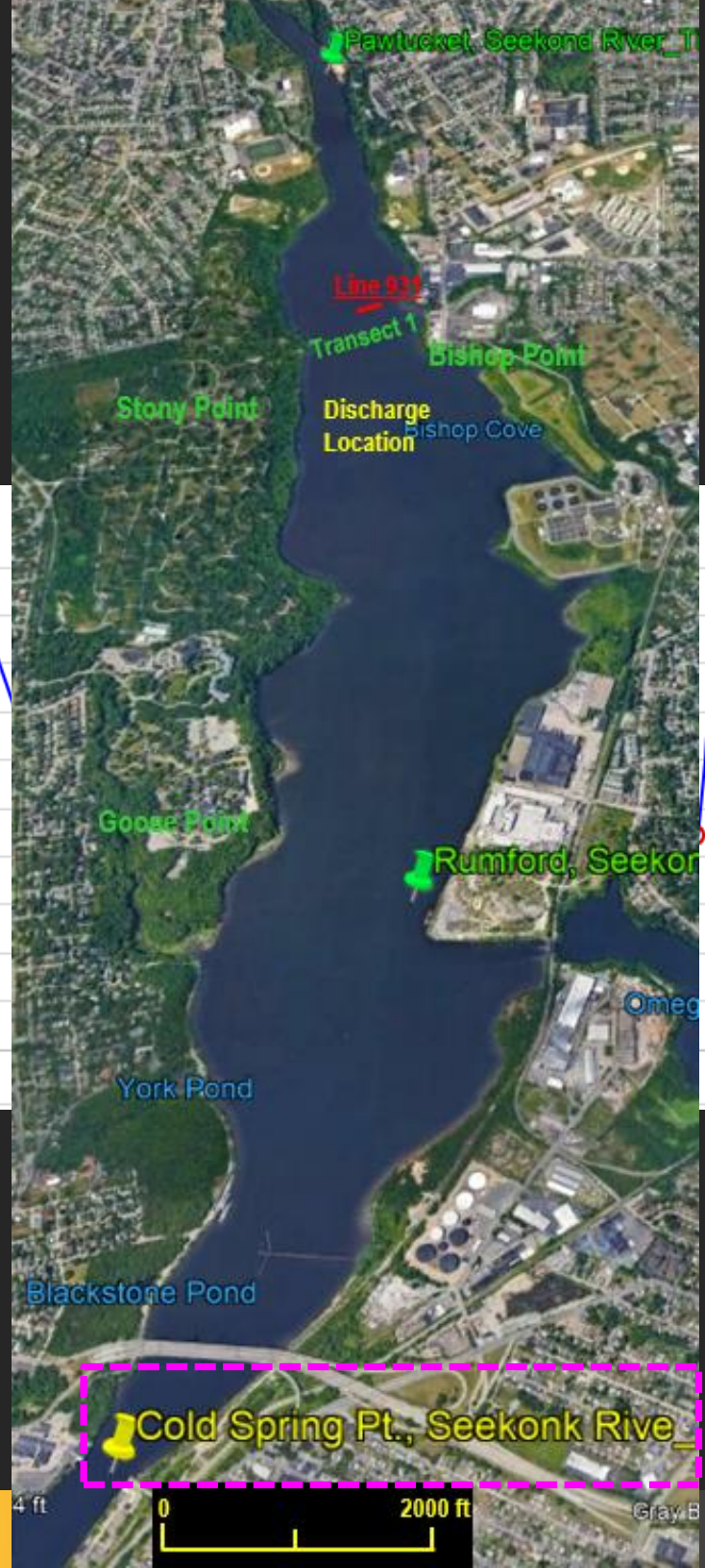
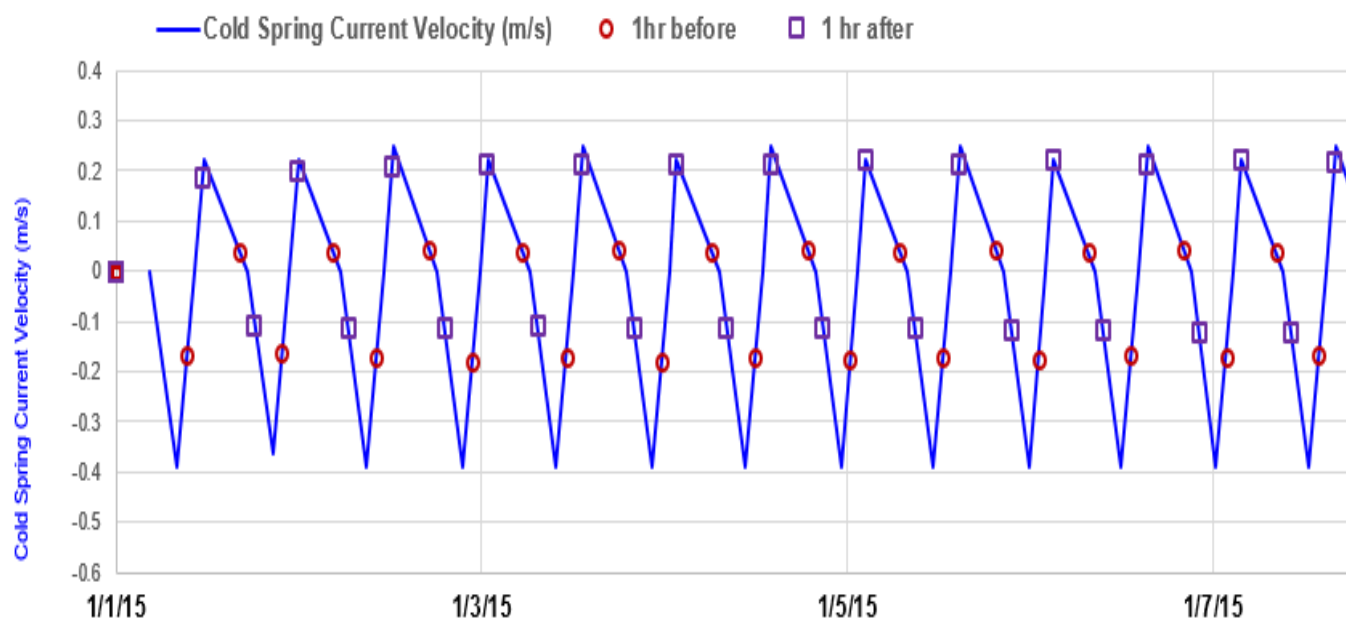
Seekonk River Channel Cross Section Profile



Note: The distance between two adjoining stations is 25ft based on survey document - Pawtucket Geophysical Survey Report, December 2017.

Reference 2: Narragansett Bay Tidal Current

Cold Spring Pt., 2015 Tidal Current Predictions



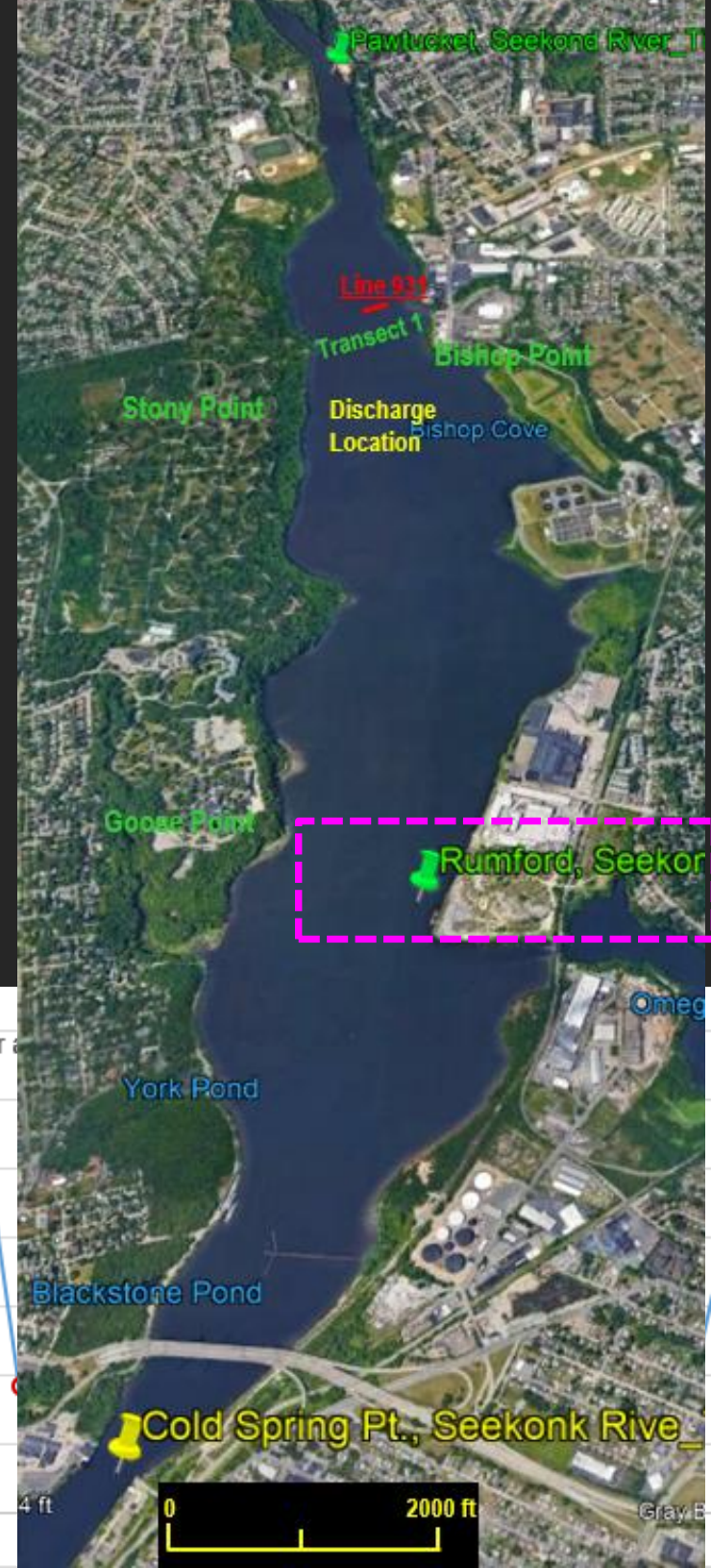
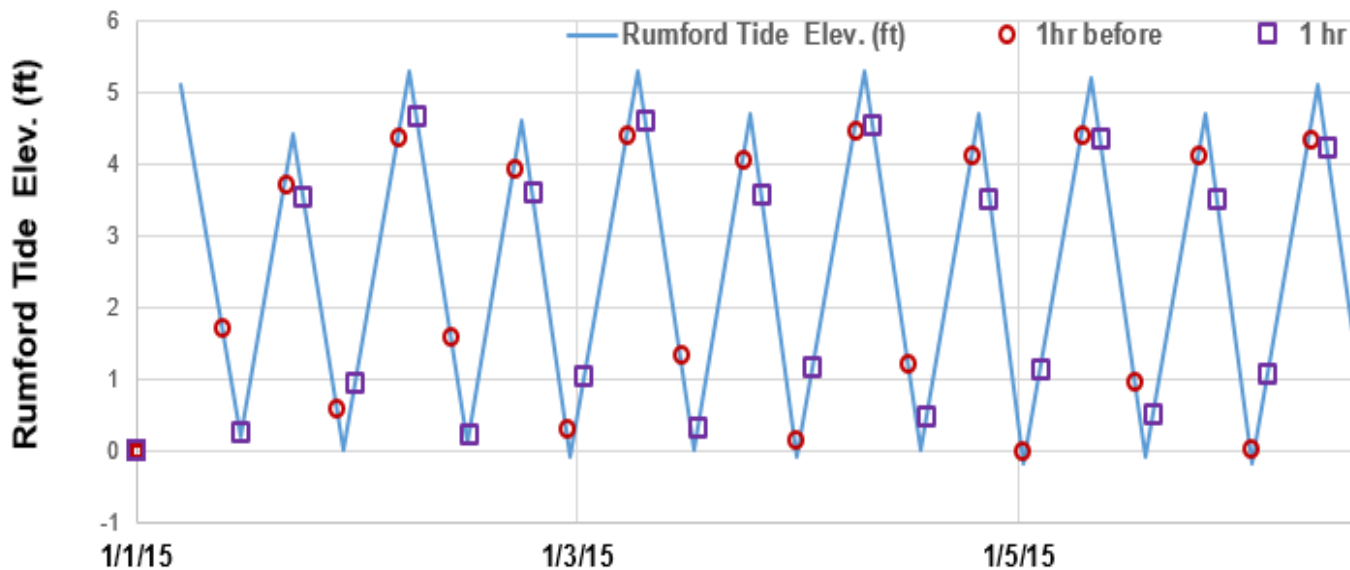
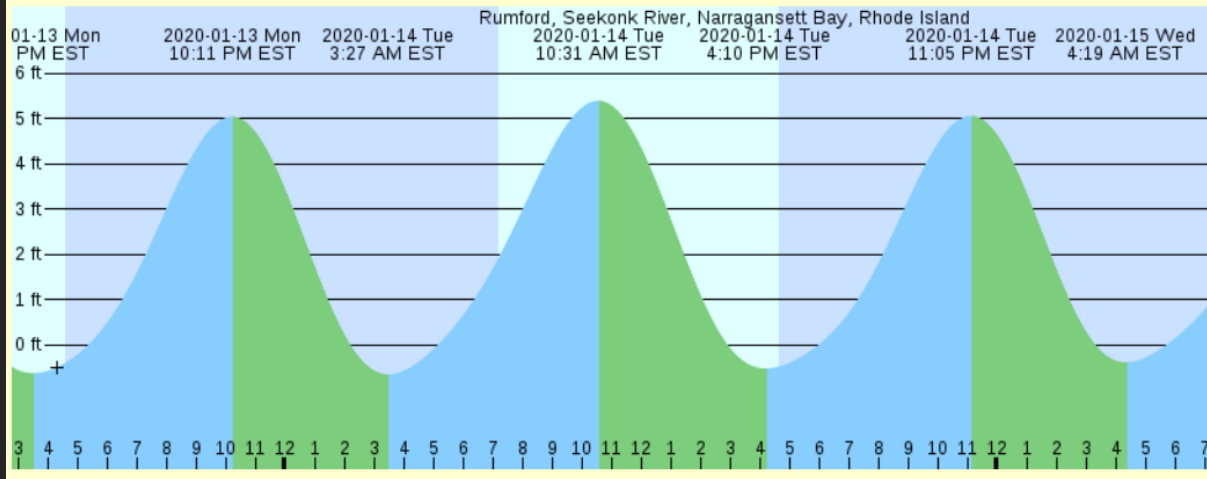
Reference 3: Narragansett Bay Tidal Chart

Rumford, Seekonk River Tidal Chart, 2015

Rumford, Seekonk River, Narragansett Bay, Rhode Island Tide Chart

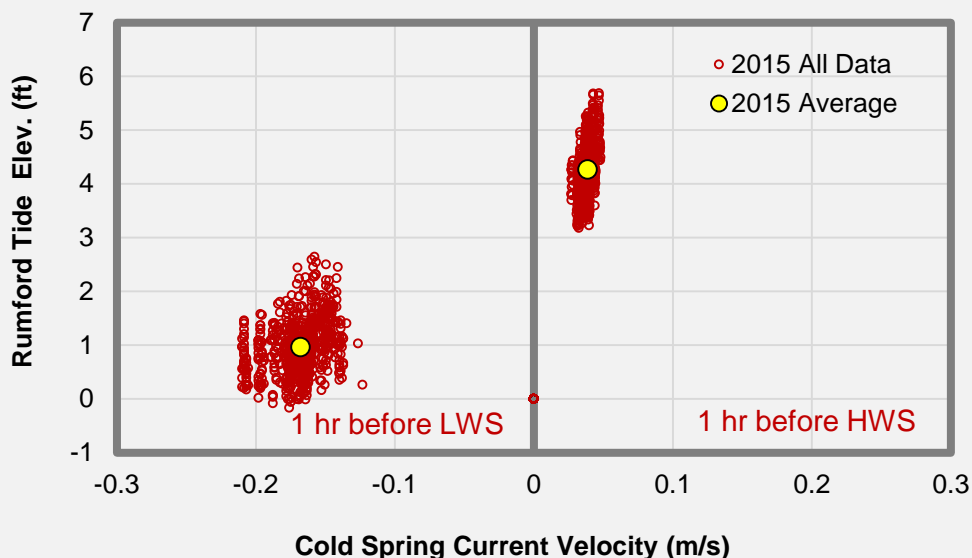
Not the place you expected to see? Try <https://tideslegacy.mobilegeographics.com>.

Local time: 2020-01-13 Mon 4:16 PM EST

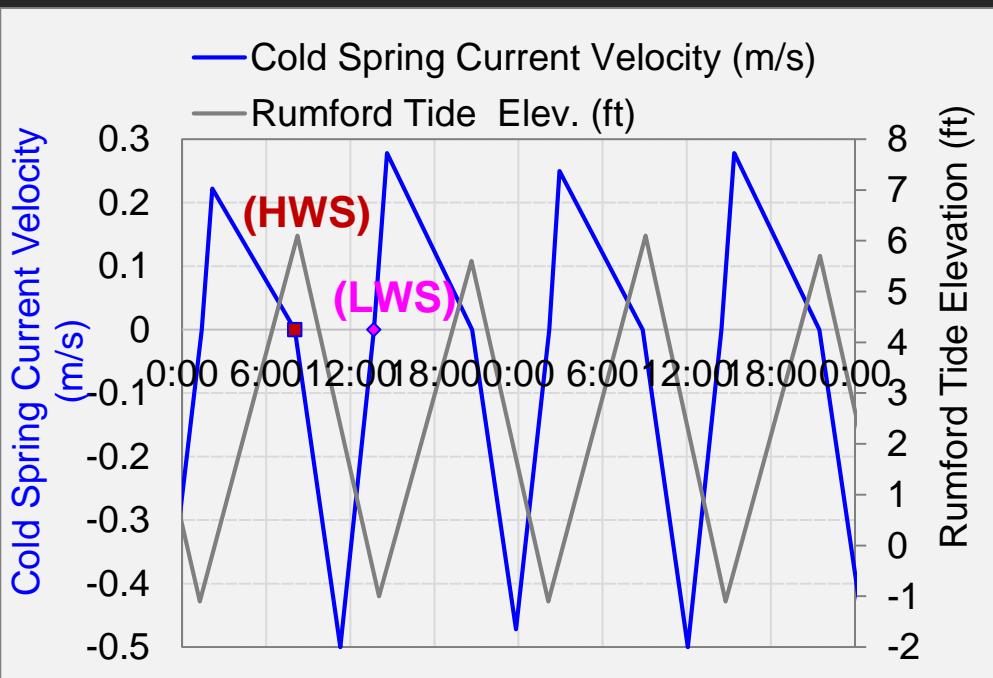
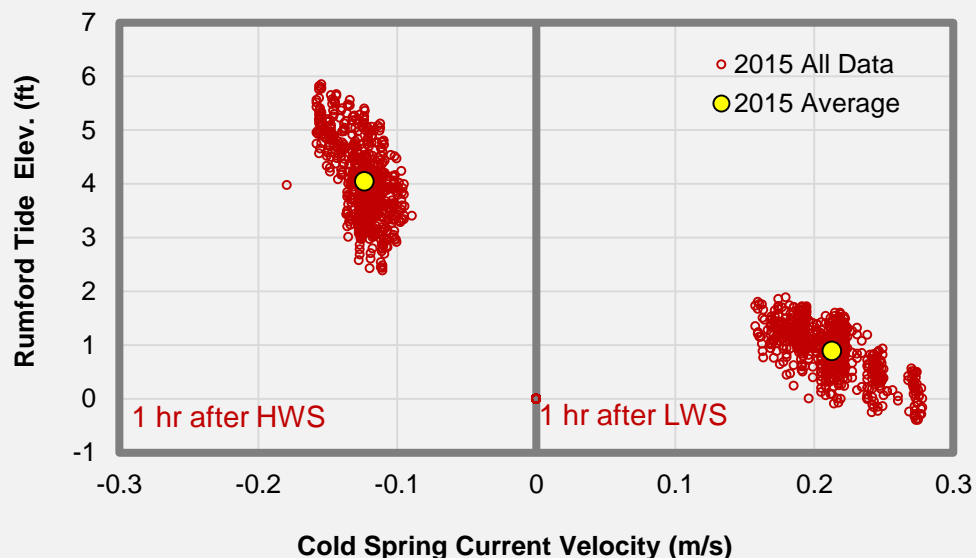


Tide Elevation vs. Current Velocity at Four Tidal Intervals

Tide Elevation vs. Current Velocity, 1 hr before Slack

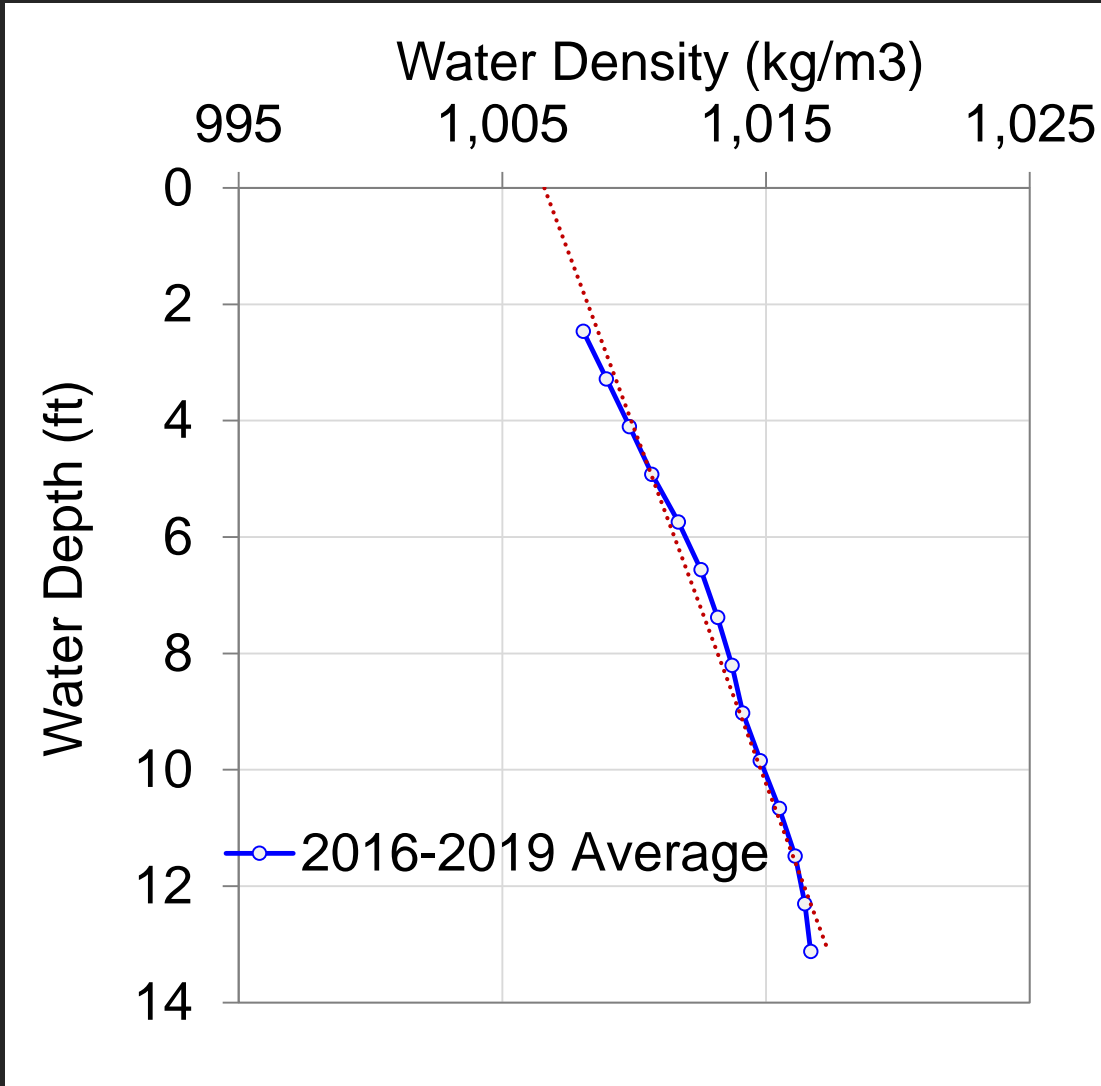


Tide Elevation vs. Current Velocity, 1 hr after Slack



Simulation Time	Current Velocity (m/s)	Tide Elevation (ft)	Average Depth at Discharge (ft)
1hr before LWS	-0.168	0.97	8.38
1hr after LWS	0.213	0.90	8.38
1hr before HWS	0.039	4.27	11.17
1hr after HWS	-0.124	4.05	11.57

Water Column Profile Data 2016-2019



CORMIX Input 4. Discharge Properties

CORMIX v11.0.1.0

Project Pages Pre-Processing Tools Run Output Data Reports Post-Processing/Advanced Help

Load Clear Save Save As Print lbs kg SI-Units CorHyd CorSpy Validate & Run FC Tree CorVue CorJet FFL CorSens User Manual CorHelp

Project Effluent Ambient **Discharge** Mixing Zone Output Processing

Discharge Page

CORMIX1 Single Port CORMIX2 Multiport CORMIX3 Surface

Single Port
 Single Multiport
 Perpendicular
 Parallel

Nearest bank is on the:

Distance to nearest bank:

Vertical Angle THETA: degrees

Horizontal Angle ALPHA: degrees

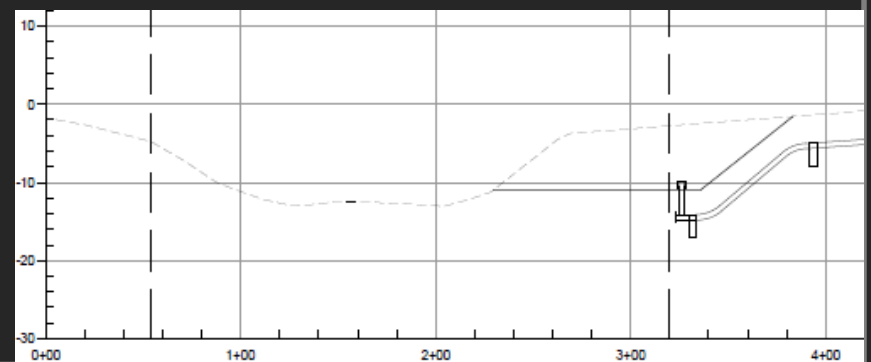
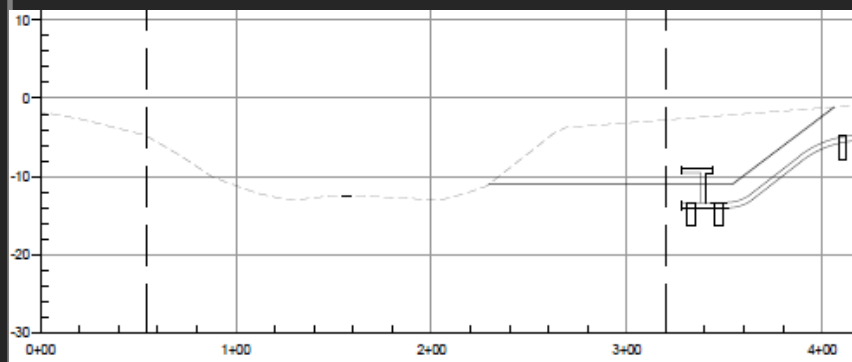
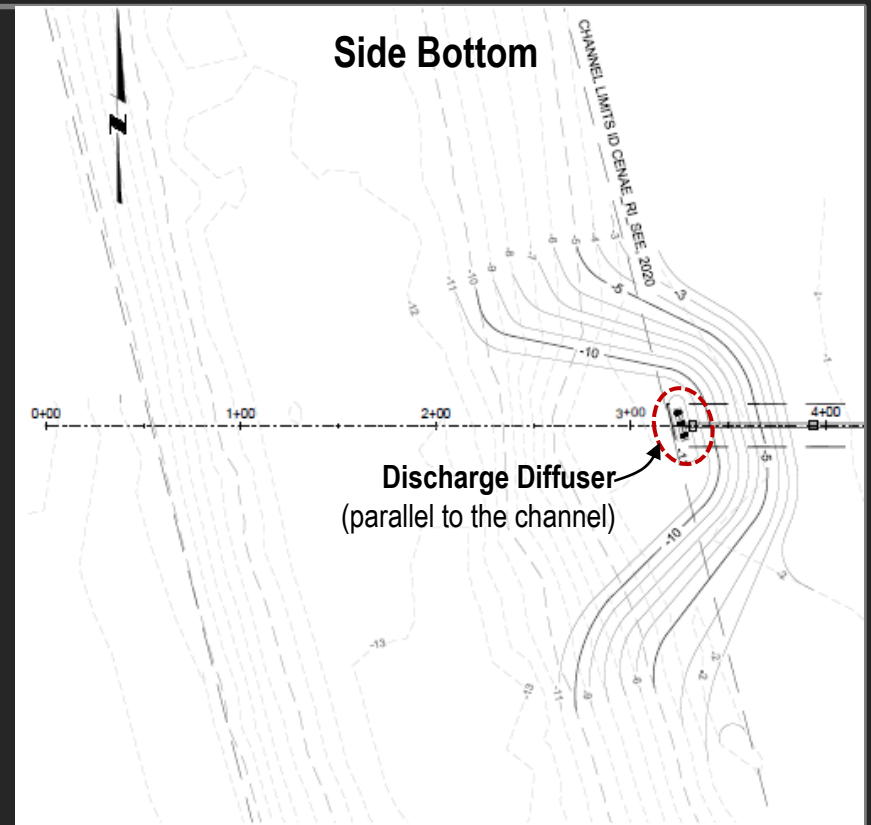
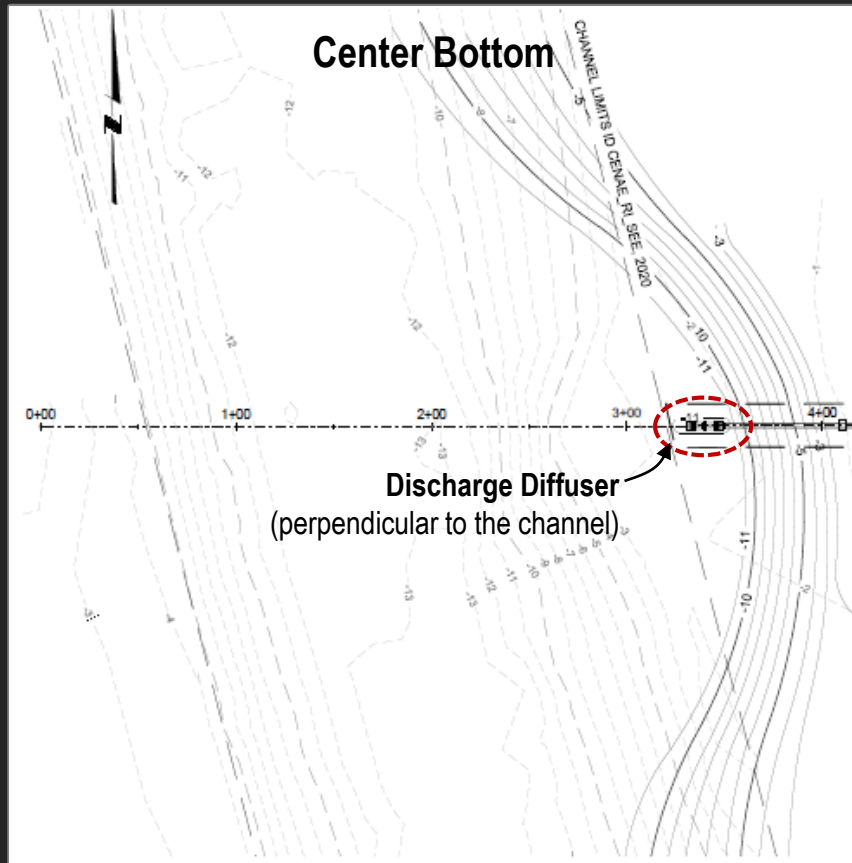
In Channel
 Off Channel
 Inside limit
 Outside of limit

Cross - Section

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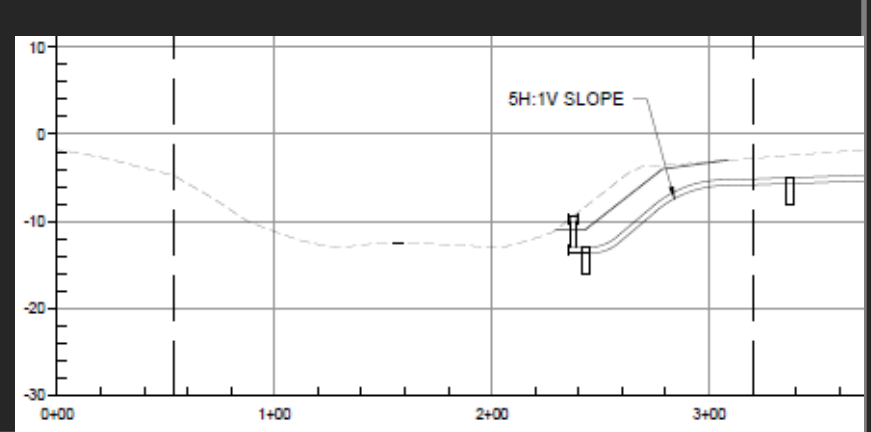
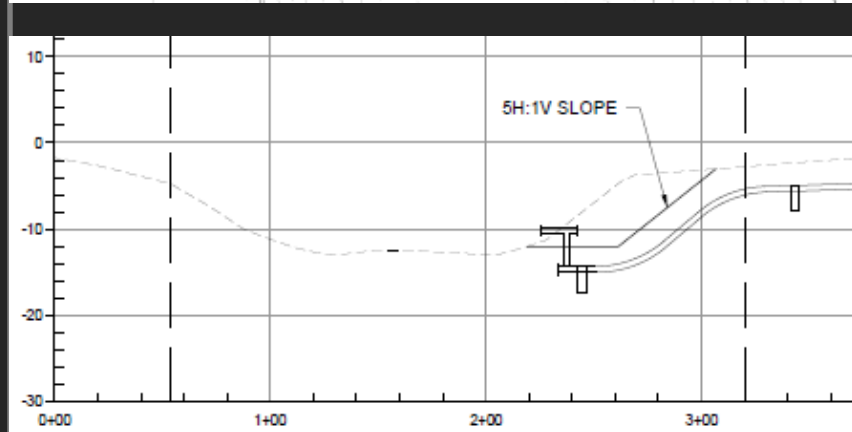
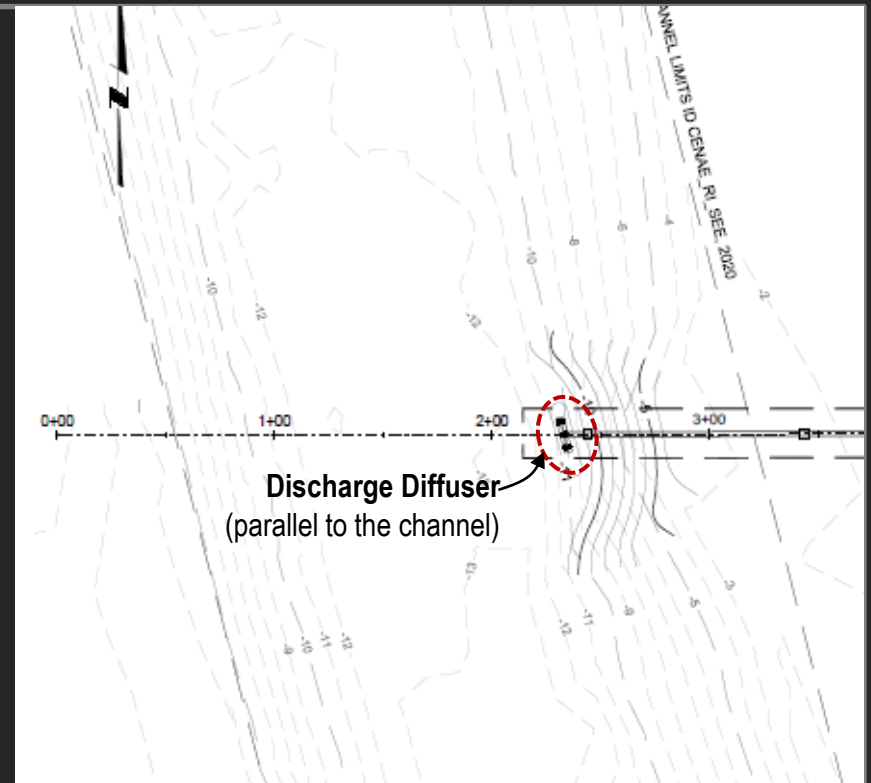
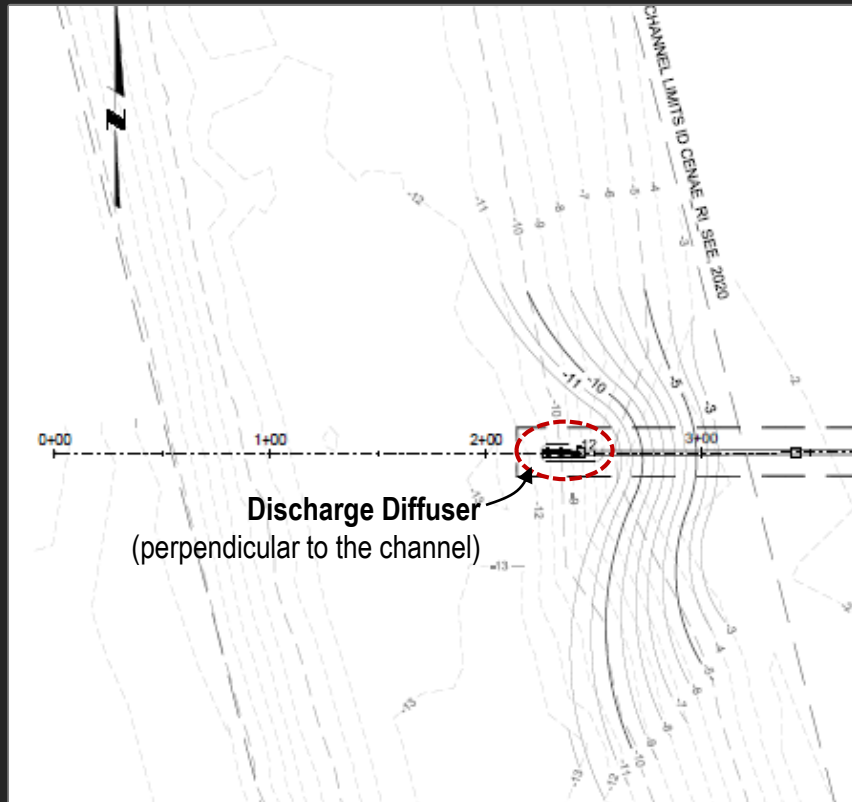
Tunnel Construction Water Discharge Options

Diffuser located outside of the Federal Channel Limits

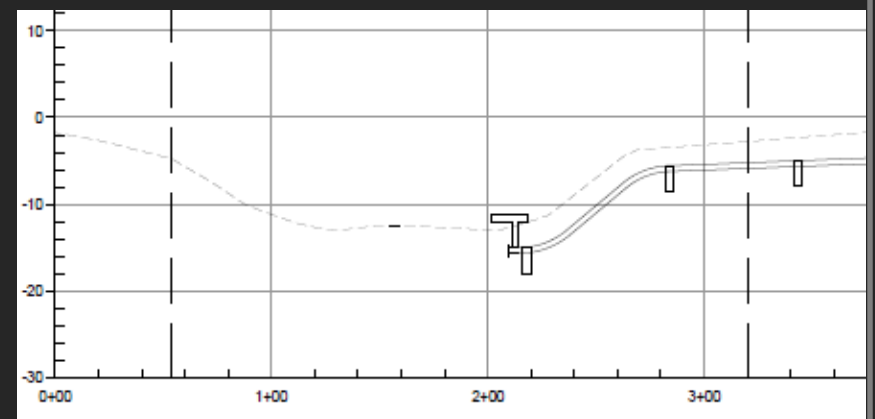
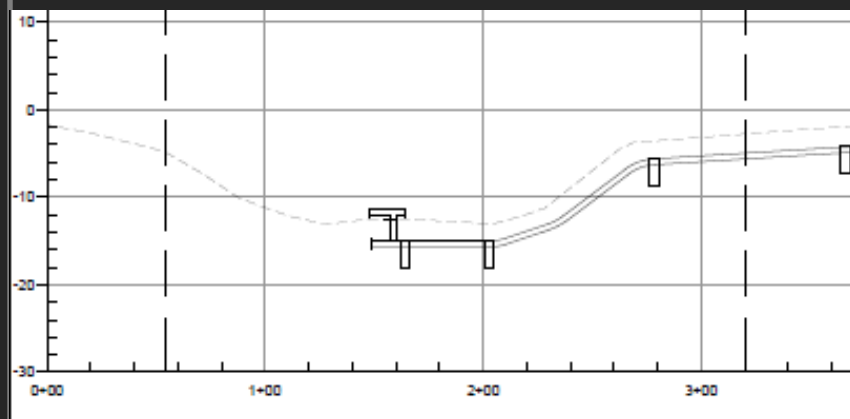
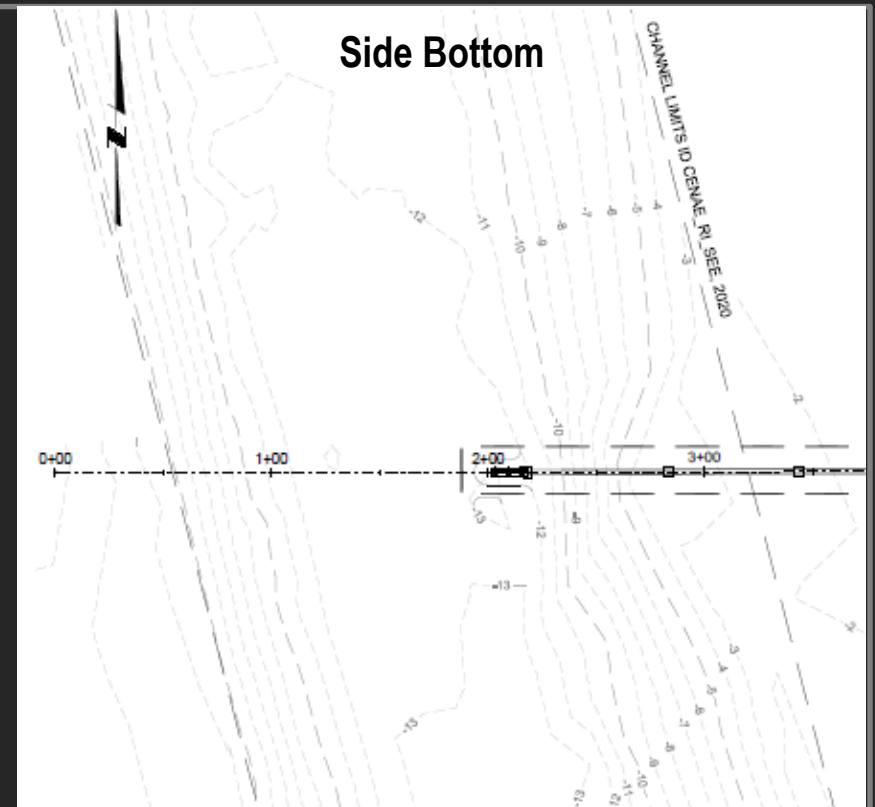
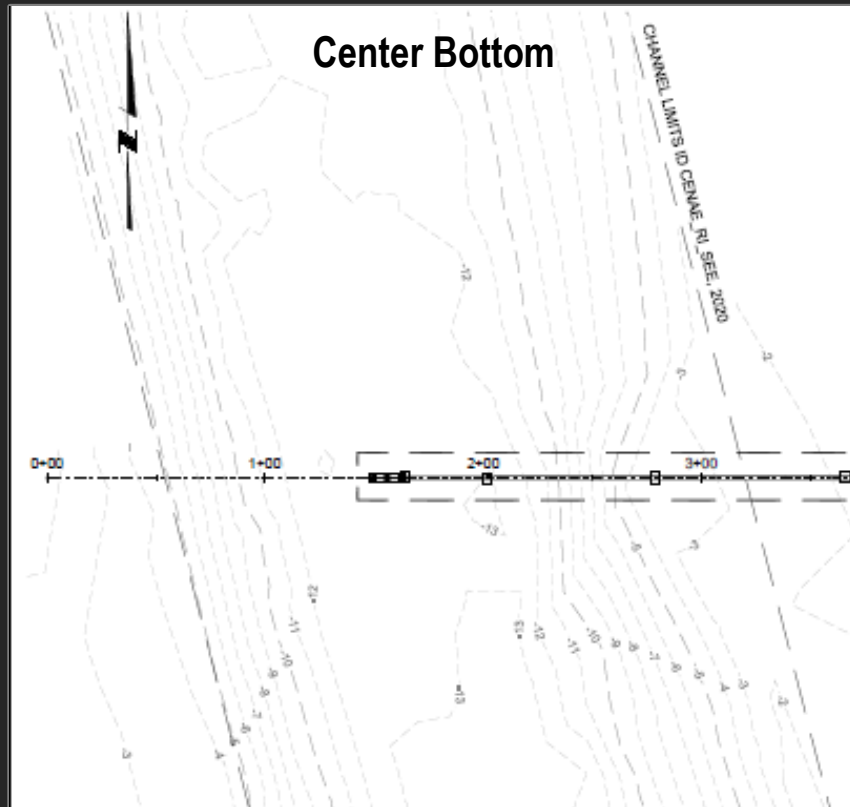


Tunnel Construction Water Discharge Options

Inside of the Federal Channel Limits but outside of the deep channel



Tunnel Construction Water Discharge Options In Channel Discharge

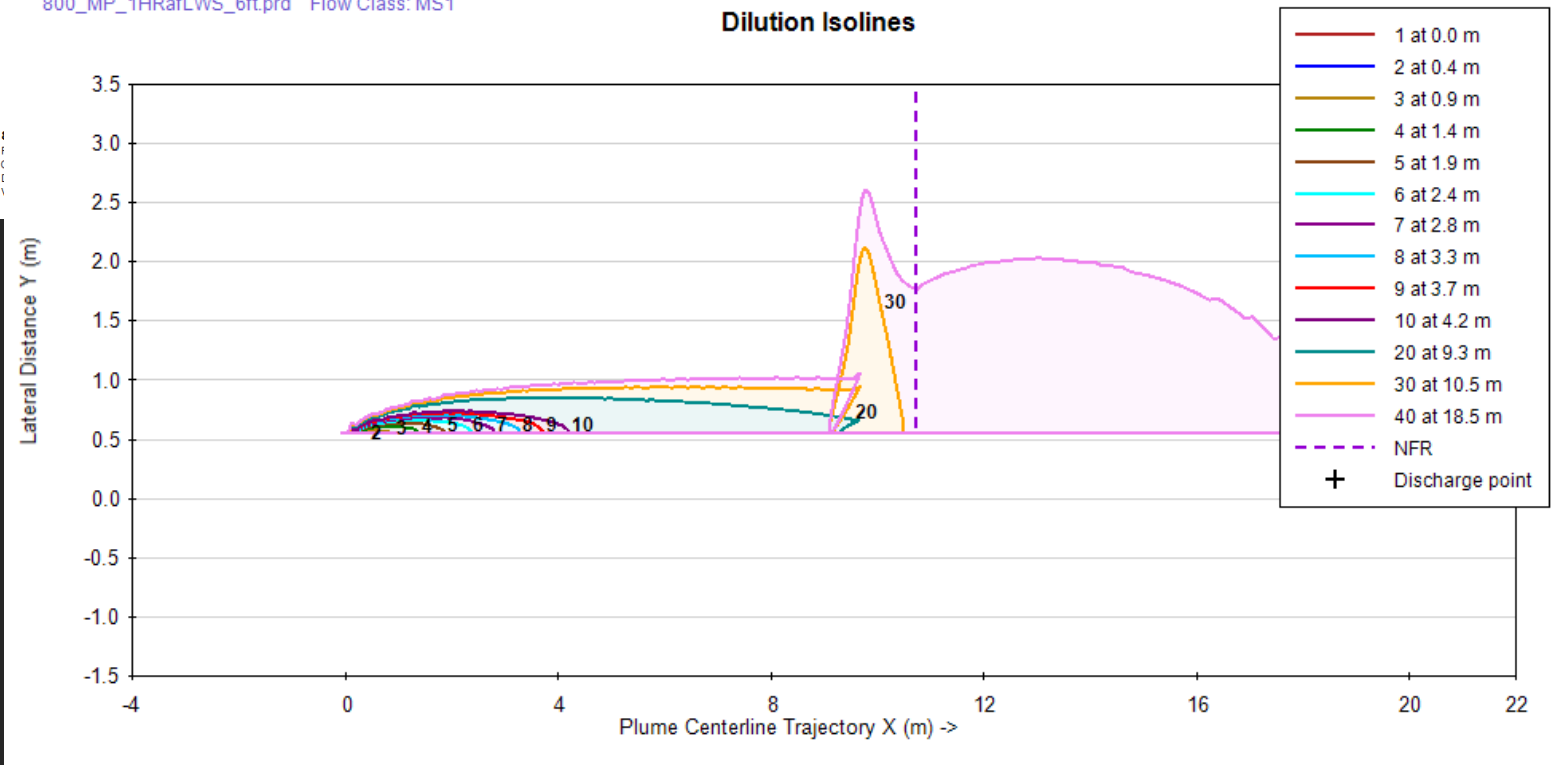
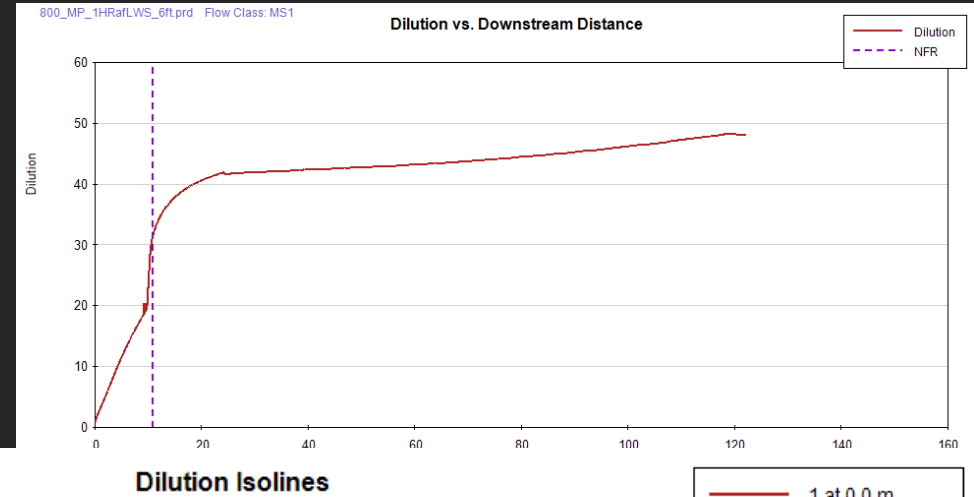
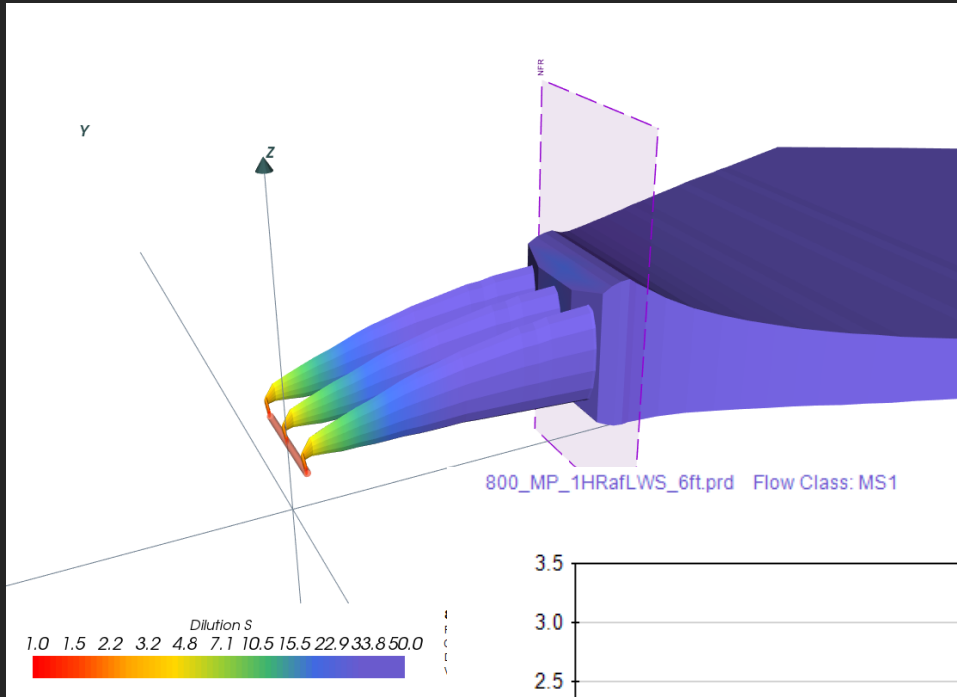


CORMIX Model Scenario Examples

Modeling Scenario	Discharge Flow (GPM)	Simulation Time	Single / Multiple Port
400_SinglePort_1HRbfLWS	400	1hr before LWS	Single Port
400_SinglePort_1HRafLWS	400	1hr after LWS	
400_SinglePort_1HRbfHWS	400	1hr before HWS	
400_SinglePort_1HRafHWS	400	1hr after HWS	
800_SinglePort_1HRbfLWS	800	1hr before LWS	Single Port
800_SinglePort_1HRafLWS	800	1hr after LWS	
800_SinglePort_1HRbfHWS	800	1hr before HWS	
800_SinglePort_1HRafHWS	800	1hr after HWS	
1200_SinglePort_1HRbfLWS	1200	1hr before LWS	Single Port
1200_SinglePort_1HRafLWS	1200	1hr after LWS	
1200_SinglePort_1HRbfHWS	1200	1hr before HWS	
1200_SinglePort_1HRafHWS	1200	1hr after HWS	
1200_MultiPort_1HRbfLWS	1200	1hr before LWS	Multiple Port
1200_MultiPort_1HRafLWS	1200	1hr after LWS	
1200_MultiPort_1HRbfHWS	1200	1hr before HWS	
1200_MultiPort_1HRafHWS	1200	1hr after HWS	
2400_MultiPort_1HRbfLWS	2400	1hr before LWS	Multiple Port
2400_MultiPort_1HRafLWS	2400	1hr after LWS	
2400_MultiPort_1HRbfHWS	2400	1hr before HWS	
2400_MultiPort_1HRafHWS	2400	1hr after HWS	

CORMIX Model Result Examples

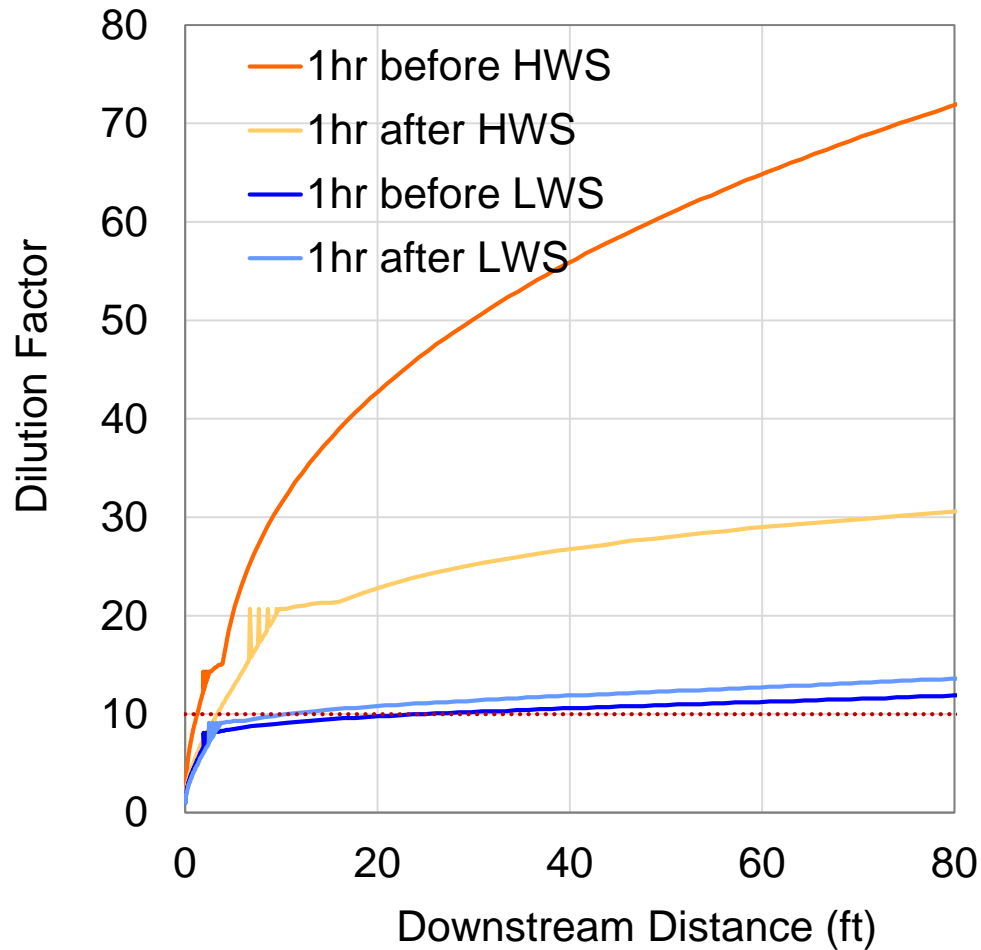
800gpm, 1HR after LWS, multiport



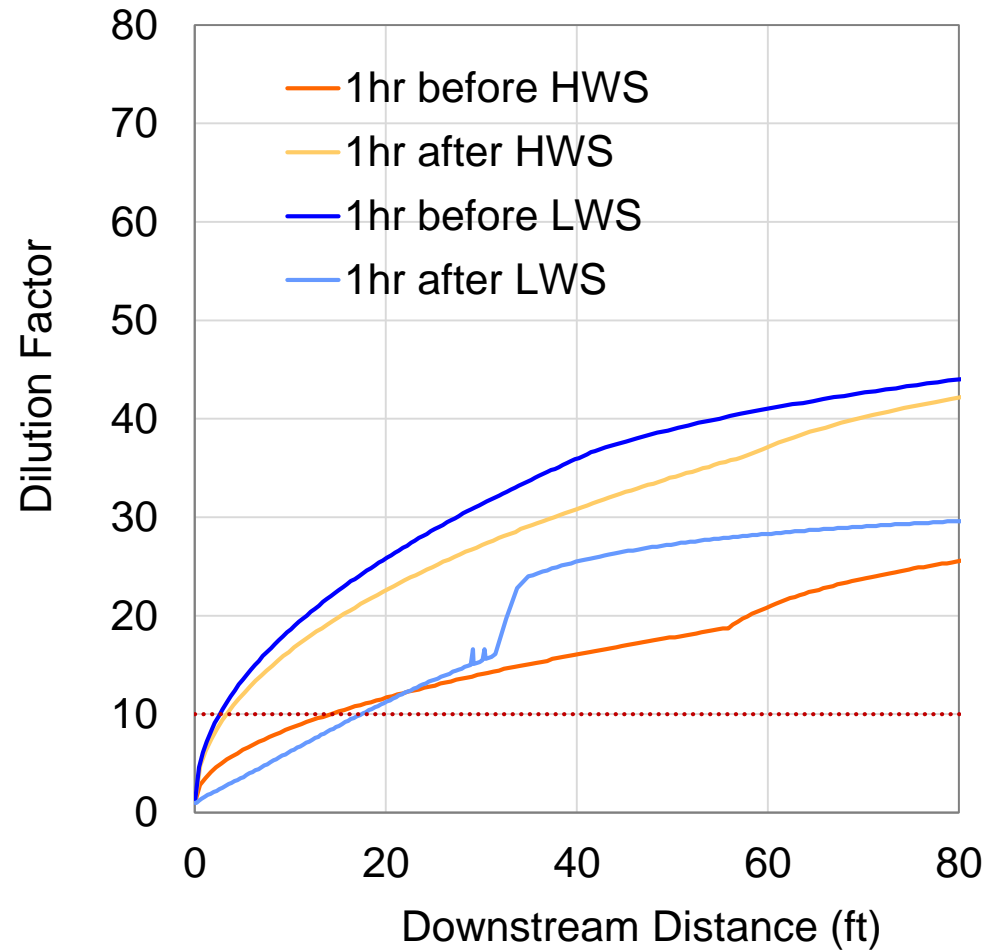
CORMIX Model Result Examples

1200gpm, Single Port vs. Multiport

Discharge Flow 1200 GPM, Single Port

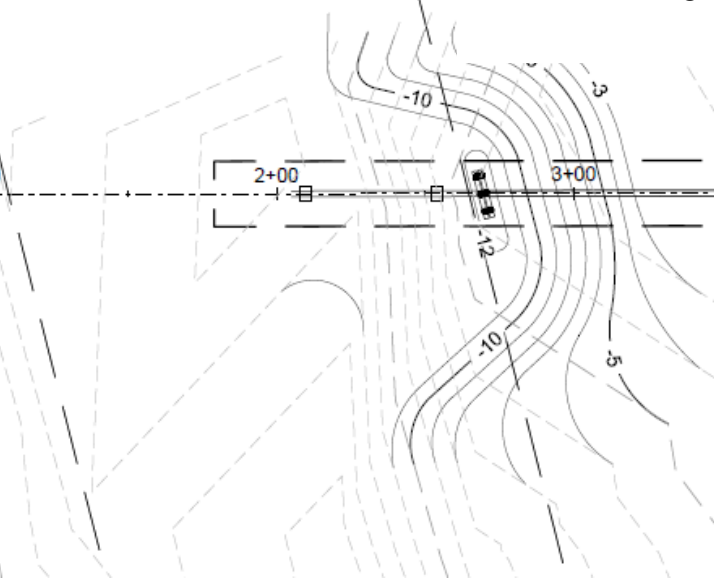
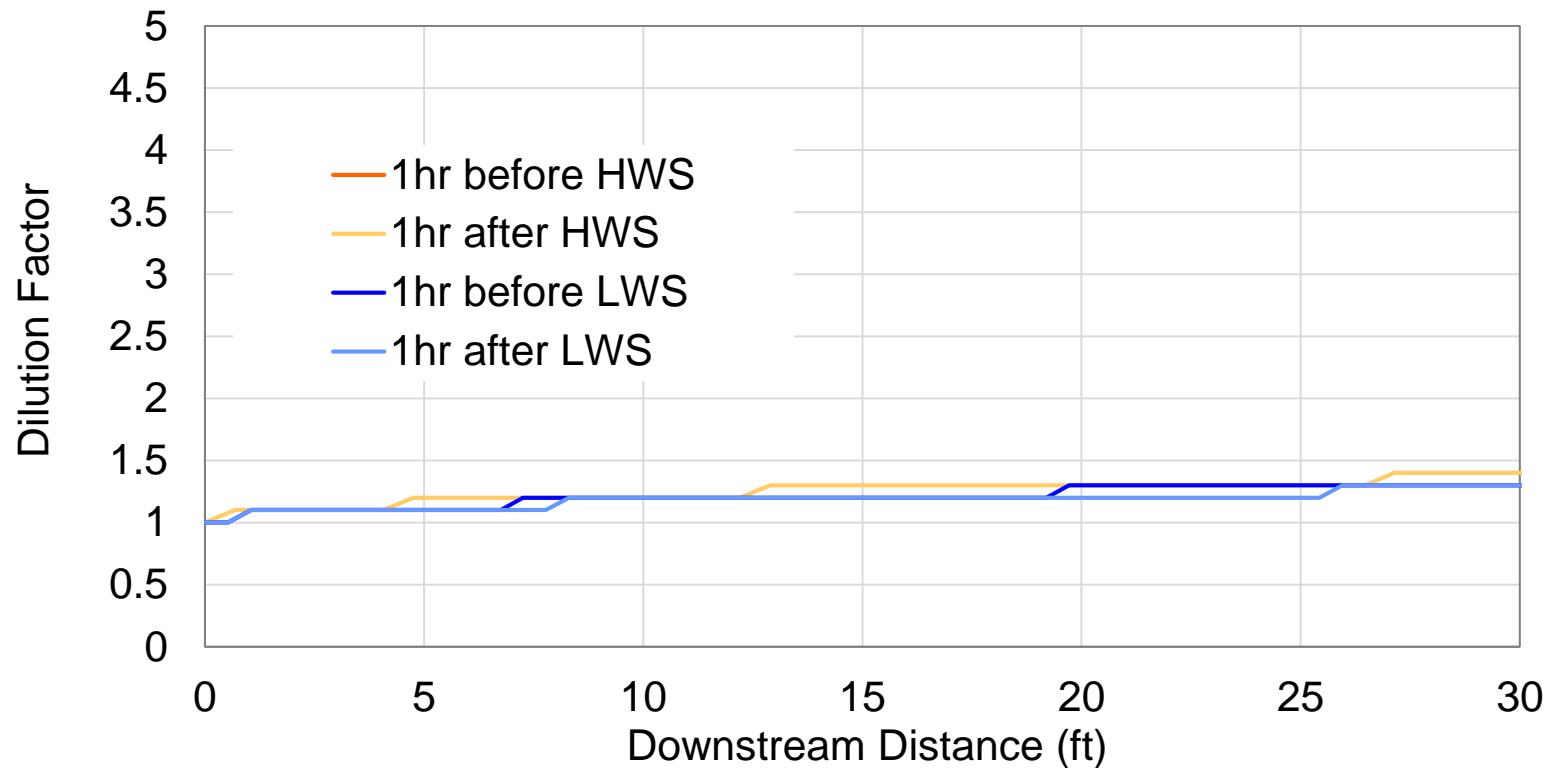


Discharge Flow 1200 GPM, Multiport



CORMIX Model Result Examples

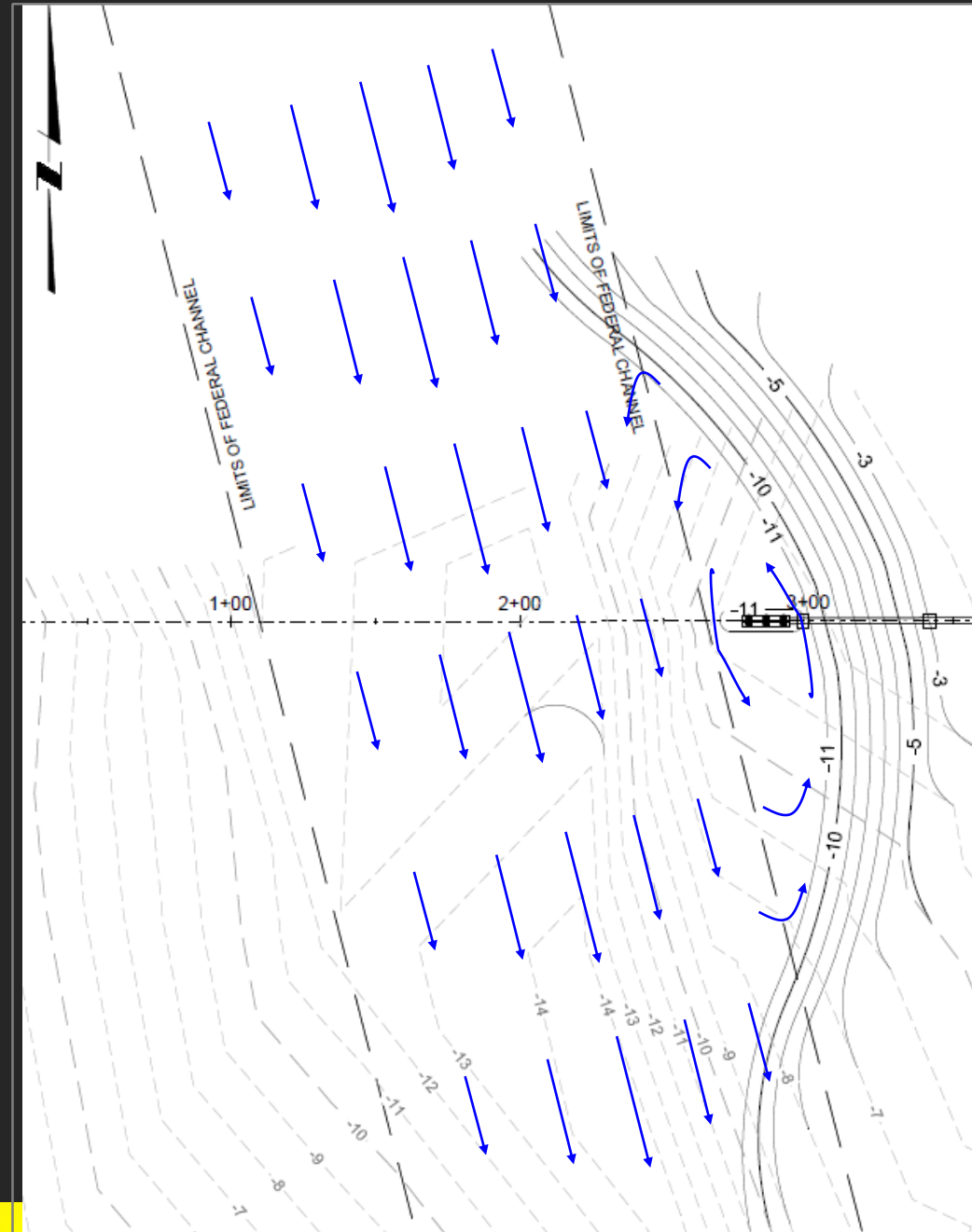
2400gpm, Multiport Diffuser Parallel to Flow



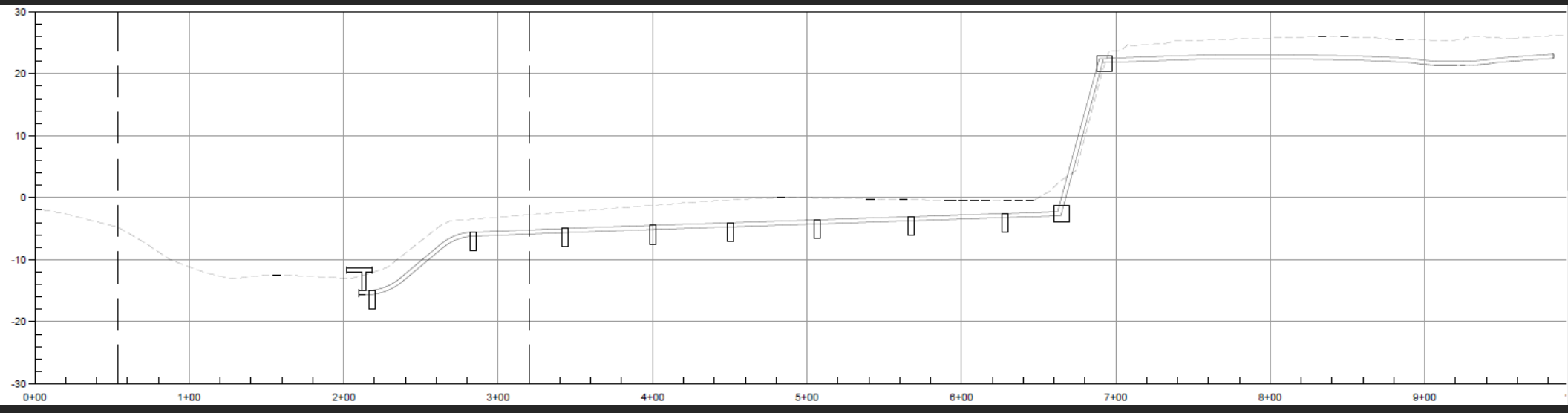
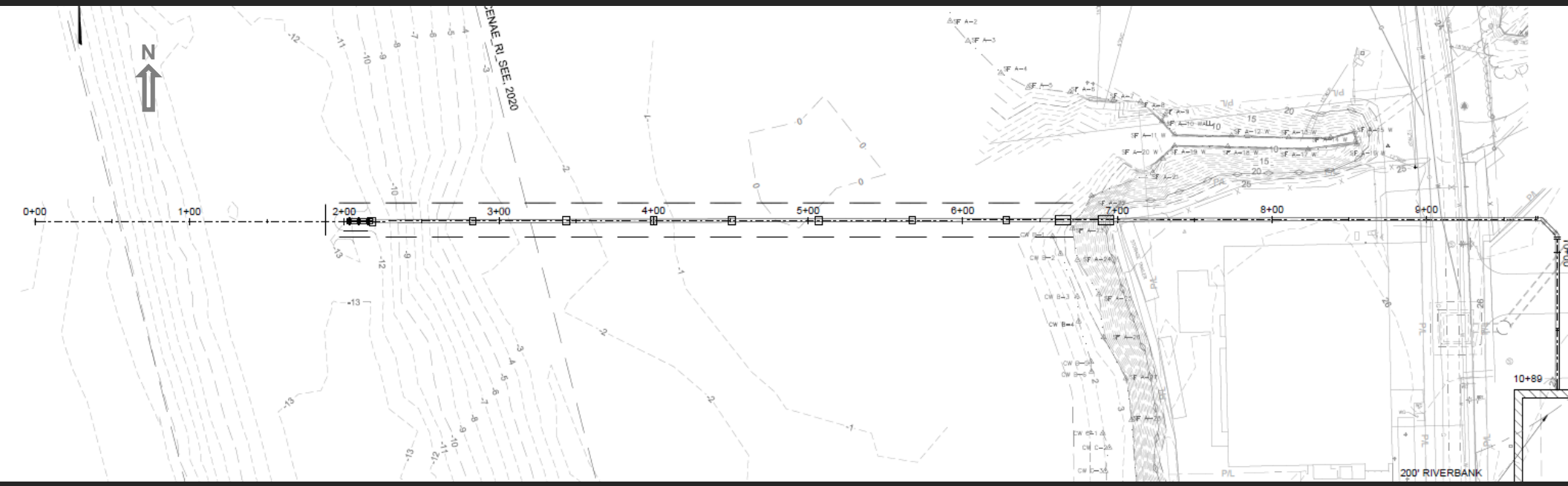
CORMIX Model Result Examples

Multiport Diffuser off Channel Limit

- Depending on bank curvature, surface roughness and flow regime, **flow detachment and eddy** may form within the dredged section outside of the channel
- Discharge in the curved section **will not have sufficient ambient flow and velocity** to for effective mixing
- In long term, the pollutant from the discharge will accumulate in the curved section to **high concentration levels**

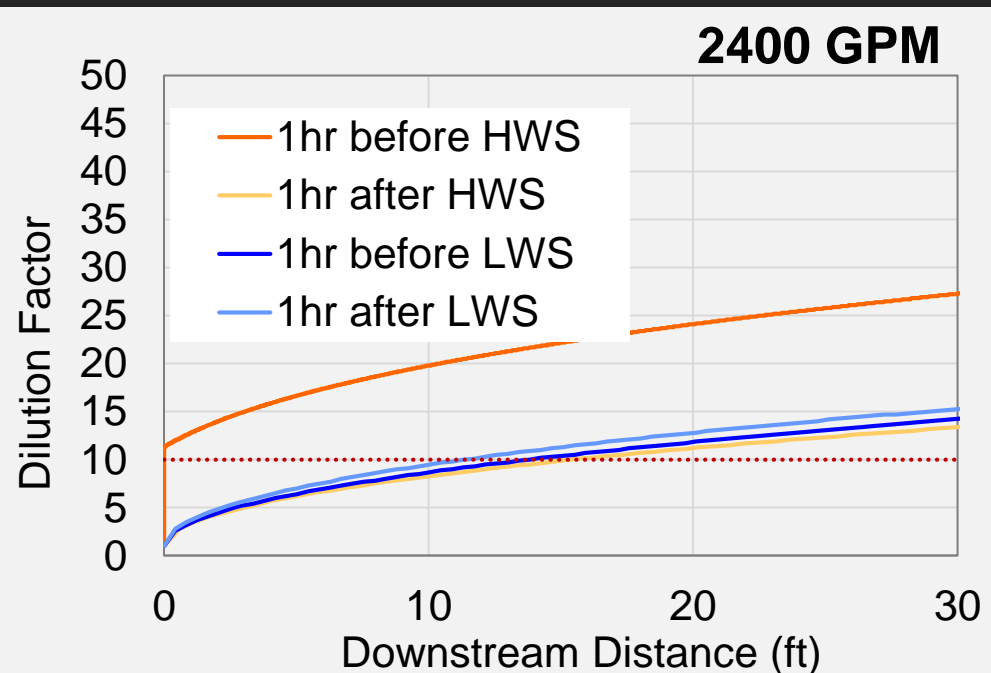
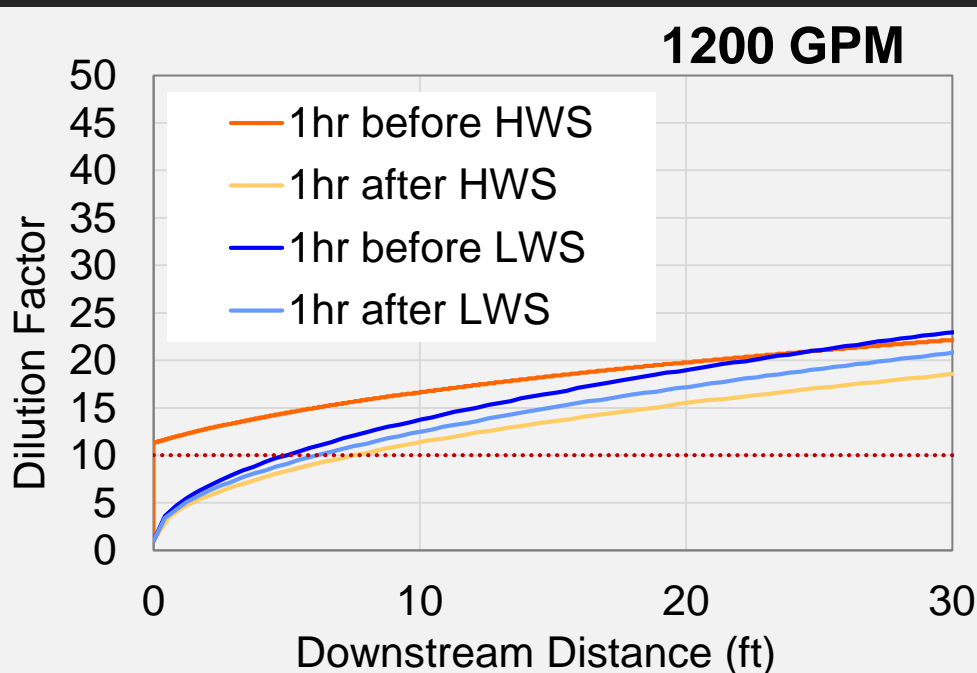
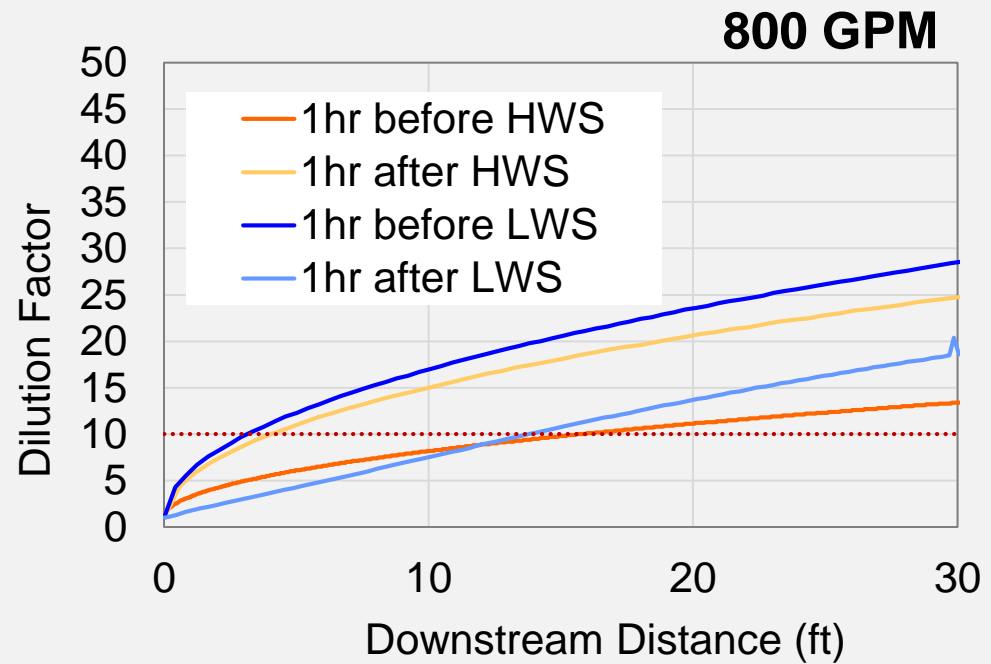
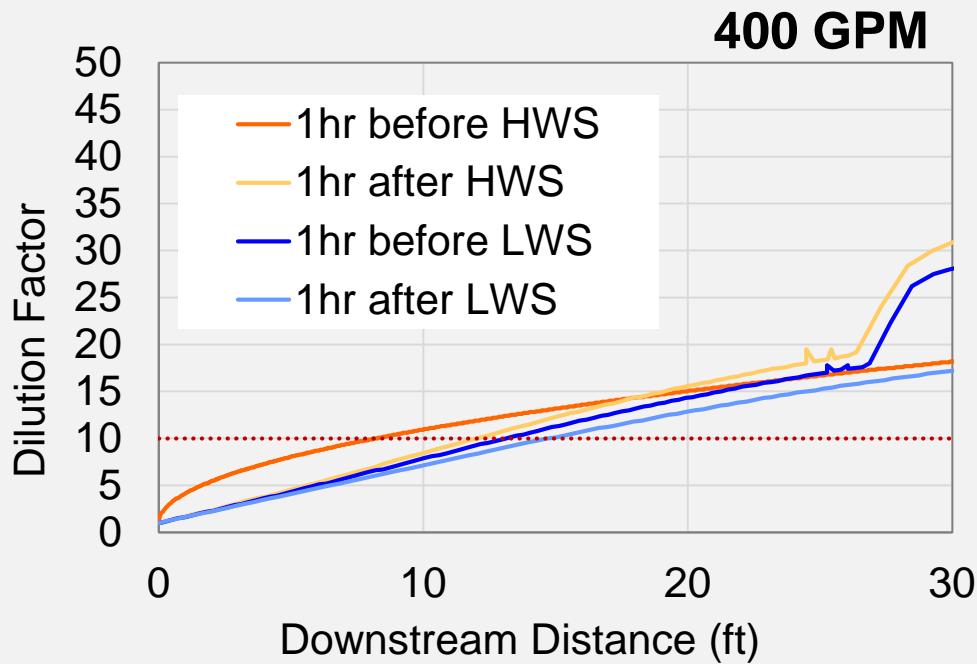


Pawtucket Tunnel Construction Water Effluent Pipe and Discharge Diffuser Proposed Plan and Profile View



CORMIX Model Result Examples

Multiport Diffuser, three 4" ports @6ft apart



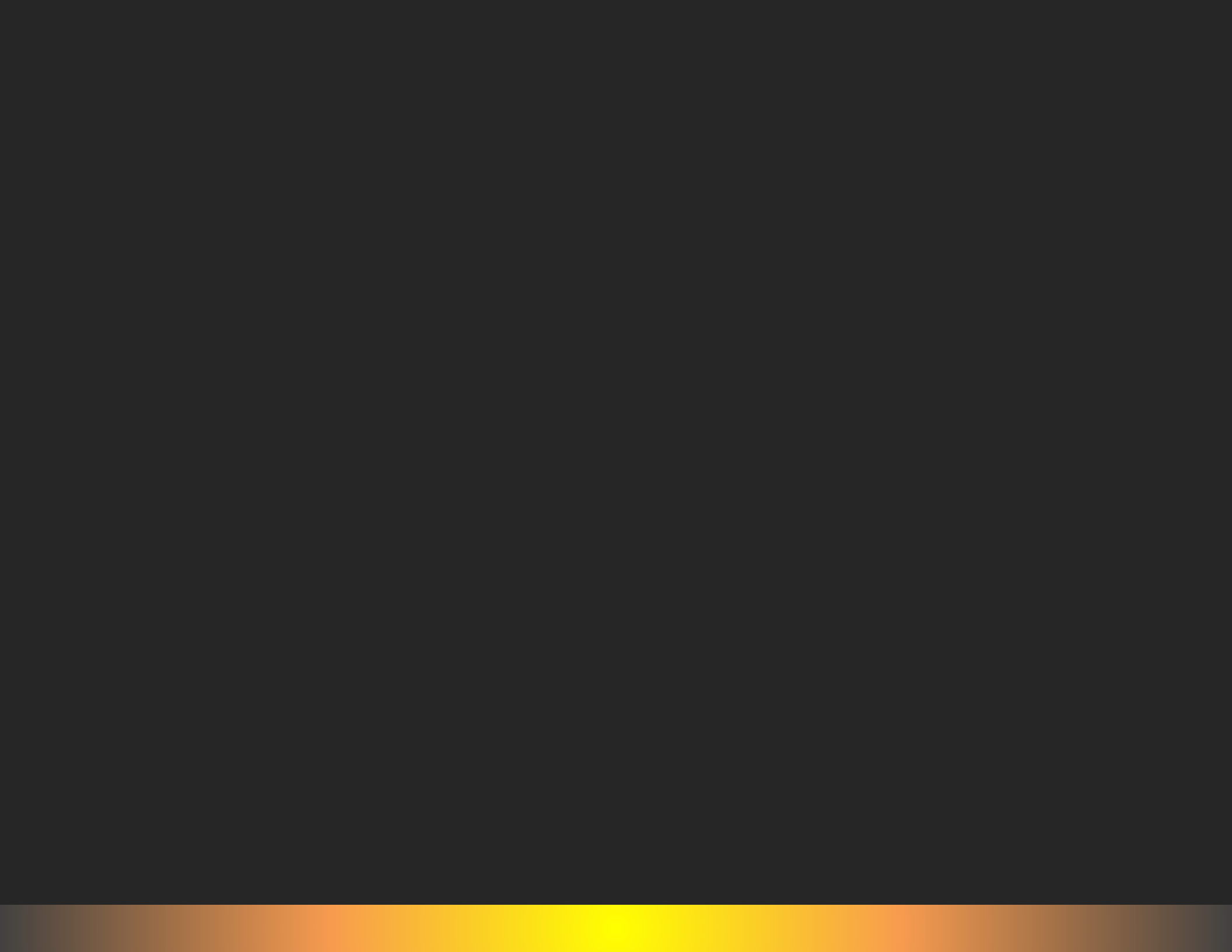
Take-away Message

- CORMIX Modeling is a useful tool to simulate mixing zone around the discharge to estimate dilution factors
- Dredging and expanding river channel for an off-channel discharge would not provide sufficient ambient flow to mix and dilute the discharged stream.
- Positioning multiport diffuser parallel to the channel will reduce intrusion to the channel, however, it would provide insufficient dilution.
- **Recommended Alternative:** multiport diffuser in the channel perpendicular to the flow. Achieve a dilution factor of 10 within 20 feet downstream of the discharging point.



Happy New Year of the Rabbit!





Construction Pictures



Construction Pictures



Construction Pictures



Construction Pictures



Construction Pictures



Construction Pictures



Construction Pictures

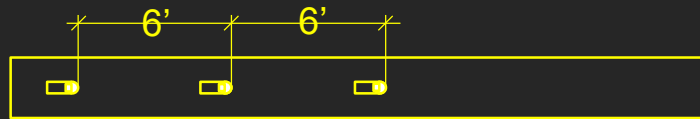


Construction Pictures

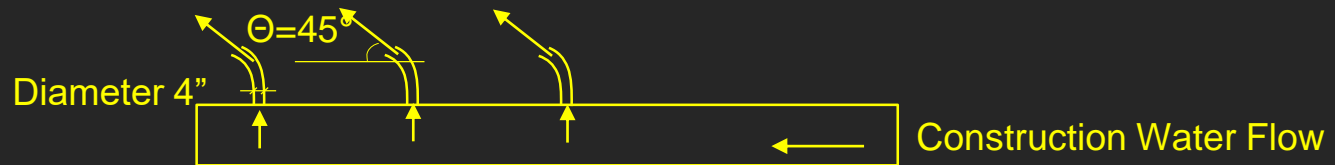


Multiport Diffuser Simulated in the Model

- Port Number: 3
- Port Diameter: 4 inch
- Distance between continuous port: minimum 6 ft
- Orientation of Nozzles
 - Vertical: 45 degrees
 - Horizontal: parallel to the diffuser (length)



Top View



Side View

CALCULATION OF WATER QUALITY BASED SALTWATER DISCHARGE LIMITS

FACILITY NAME: **NBC Pawtucket Tunnel Construction Dewatering (DF=10)** RIPDES PERMIT #:

CHEMICAL NAME	CAS#	DAILY MAX LIMIT (ug/L)	MONTHLY AVE LIMIT (ug/L)	CHEMICAL NAME	CAS#	DAILY MAX LIMIT (ug/L)	MONTHLY AVE LIMIT (ug/L)
PRIORITY POLLUTANTS:				TETRACHLOROETHYLENE	127184	No Criteria	264.00
TOXIC METALS AND CYANIDE				TOLUENE	108883	No Criteria	120000.00
ANTIMONY	7440360	No Criteria	5120.00	1,2TRANSDICHLOROETHYLENE	156605	No Criteria	80000.00
ARSENIC, TOTAL	7440382	611.64	3.24	1,1,1TRICHLOROETHANE	71556	No Criteria	No Criteria
ASBESTOS	1332214	No Criteria	No Criteria	1,1,2TRICHLOROETHANE	79005	No Criteria	1280.00
BERYLLIUM	7440417	No Criteria	No Criteria	TRICHLOROETHYLENE	79016	No Criteria	2400.00
CADMIUM, TOTAL	7440439	377.82	82.86	VINYL CHLORIDE	75014	No Criteria	19.20
CHROMIUM III, TOTAL	16065831	No Criteria	No Criteria	ACID ORGANIC COMPOUNDS			
CHROMIUM VI, TOTAL	18540299	9967.32	450.71	2CHLOROPHENOL	95578	No Criteria	1200.00
COPPER, TOTAL	7440508	59.31	36.47	2,4DICHLOROPHENOL	120832	No Criteria	2320.00
CYANIDE	57125	8.00	8.00	2,4DIMETHYLPHENOL	105679	No Criteria	6800.00
LEAD, TOTAL	7439921	13690.50	523.11	4,6DINITRO2METHYL PHENOL	534521	No Criteria	2240.00
MERCURY, TOTAL	7439976	19.05	1.34	2,4DINITROPHENOL	51285	No Criteria	42400.00
NICKEL, TOTAL	7440020	698.76	73.42	4NITROPHENOL	88755	No Criteria	No Criteria
SELENIUM, TOTAL	7782492	2614.60	639.65	PENTACHLOROPHENOL	87865	104.00	63.20
SILVER, TOTAL	7440224	34.55	No Criteria	PHENOL	108952	No Criteria	13600000.00
THALLIUM	7440280	No Criteria	3.76	2,4,6TRICHLOROPHENOL	88062	No Criteria	192.00
ZINC, TOTAL	7440666	843.58	757.96	BASE NEUTRAL COMPUNDS			
VOLATILE ORGANIC COMPOUNDS				ACENAPHTHENE	83329	No Criteria	7920.00
ACROLEIN	107028	No Criteria	2320.00	ANTHRACENE	120127	No Criteria	320000.00
ACRYLONITRILE	107131	No Criteria	20.00	BENZIDINE	92875	No Criteria	0.02
BENZENE	71432	No Criteria	4080.00	PAHs		No Criteria	1.44
BROMOFORM	75252	No Criteria	11200.00	BIS(2CHLOROETHYL)ETHER	111444	No Criteria	42.40
CARBON TETRACHLORIDE	56235	No Criteria	128.00		108601	No Criteria	520000.00
CHLOROBENZENE	108907	No Criteria	12800.00	BIS(2ETHYLHEXYL)PHTHALATE	117817	No Criteria	176.00
CHLORODIBROMOMETHANE	124481	No Criteria	1040.00	BUTYL BENZYL PHTHALATE	85687	No Criteria	15200.00
CHLOROFORM	67663	No Criteria	37600.00	2CHLORONAPHTHALENE	91587	No Criteria	12800.00
DICHLOROBROMOMETHANE	75274	No Criteria	1360.00	1,2DICHLOROBENZENE	95501	No Criteria	10400.00
1,2DICHLOROETHANE	107062	No Criteria	2960.00	1,3DICHLOROBENZENE	541731	No Criteria	7680.00
1,1DICHLOROETHYLENE	75354	No Criteria	56800.00	1,4DICHLOROBENZENE	106467	No Criteria	1520.00
1,2DICHLOROPROPANE	78875	No Criteria	1200.00	3,3DICHLOROBENZIDENE	91941	No Criteria	2.24
1,3DICHLOROPROPYLENE	542756	No Criteria	168.00	DIETHYL PHTHALATE	84662	No Criteria	352000.00
ETHYLBENZENE	100414	No Criteria	16800.00	DIMETHYL PHTHALATE	131113	No Criteria	8800000.00
BROMOMETHANE (methyl bromide)	74839	No Criteria	12000.00	DI-n-BUTYL PHTHALATE	84742	No Criteria	36000.00
CHLOROMETHANE (methyl chloride)	74873	No Criteria	No Criteria	2,4DINITROTOLUENE	121142	No Criteria	272.00

Parameter	Unit	South Hartford Conveyance Tunnel Construction Dewatering Samples ¹								RIPDES GP G	
										DF=10 ³	
		INF 1	INF 3	INF 4	INF 6	Influent Average	EFF 3	EFF 6	Effluent Average	Maximum Daily	Average Monthly
Antimony	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	56	56
Arsenic	µg/L	6	4	ND	ND	3.5	ND	ND	ND	552	11
Cadmium	µg/L	1	1	ND	ND	1	ND	ND	ND	102	71
Chromium	µg/L	29	40	16	21	26.5	9	7	8	3,230	1,000
Copper	µg/L	19.5	22.5	6.5	6.4	13.7	3.1	2.7	2.9	46	30
Cyanide	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	8	8
Lead	µg/L	13	17	4	10	11	ND	ND	ND	1,600	68
Mercury	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	17	1
Nickel	µg/L	31	36	11	16	23.5	3	3	3	598	66
pH (S.U.)		9.65	11.09	10.63	10.62	10.5	7.51	6.71	7.1		
Selenium	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	2,325	569
Silver	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	18	18
Zinc	µg/L	136	194	43	89	115.5	15	16	15.5	761	685
TSS	mg/L	280	970	6300	1200	860 ²	75	77	104 ²	300	
Iron	mg/L	29.6	33.6	11.3	14.5	22.3	2.59	2.82	2.7	10	

Parameter	Unit	South Hartford Conveyance Tunnel Construction Dewatering Samples ¹								RIPDES GP G	
										No Dilution (DF=1)	
		INF 1	INF 3	INF 4	INF 6	Influent Average	EFF 3	EFF 6	Effluent Average	Maximum Daily	Average Monthly
Antimony	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	5.6	5.6
Arsenic	µg/L	6	4	ND	ND	3.5	ND	ND	ND	55.2	1.12
Cadmium	µg/L	1	1	ND	ND	1	ND	ND	ND	10.2	7.08
Chromium	µg/L	29	40	16	21	26.5	9	7	8	323	100
Copper	µg/L	19.5	22.5	6.5	6.4	13.7	3.1	2.7	2.9	4.62	2.98
Cyanide	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	0.8	0.8
Lead	µg/L	13	17	4	10	11	ND	ND	ND	160	6.81
Mercury	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	1.69	0.12
Nickel	µg/L	31	36	11	16	23.5	3	3	3	59.79	6.62
pH (S.U.)		9.6	11.1	10.6	10.6	10.5	7.5	6.7	7.1	5.0-11.0	
Selenium	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	232.46	56.91
Silver	µg/L	ND	ND	ND	ND	ND	ND	ND	ND	1.78	1.78
Zinc	µg/L	136	194	43	89	116	15	16	15.5	76.11	68.5
TSS	mg/L	280	970	6300	1200	860 ²	75	77	104 ²	30	
Iron	mg/L	29.6	33.6	11.3	14.5	22.3	2.59	2.82	2.7	1	

Parameter ¹	Unit	Providence Tunnel		Foundry		Seekonk CSO Interceptor		RIPDES GP G DF=10 ²	
		Mean	95% CI	Mean	95% CI	Mean	95% CI	Maximum Daily	Average Monthly
Antimony	µg/L	1	NA	NA	NA	NA	NA	56	56
Arsenic	µg/L	NA	NA	NA	NA	NA	NA	552	11
Cadmium	µg/L	6.2	14	8.5	41.9	5.5	18.8	102	71
Chromium	µg/L	27.9	67	31.6	60	11.9	75	3,230	1,000
Copper	µg/L	36.8	50	41.5	50	21.5	40	46	30
Cyanide	µg/L	NA	NA	NA	NA	NA	NA	8	8
Lead	µg/L	41.9	80	43.3	87	10.9	63.5	1,600	68
Mercury	µg/L	NA	NA	NA	NA	NA	NA	17	1
Nickel	µg/L	25.3	50	23	58	8.5	44	598	66
pH (S.U.)	µg/L	NA	NA	NA	NA	NA	NA	ND	17
Selenium	µg/L	NA	NA	NA	NA	NA	NA	2,325	569
Silver	µg/L	19.4	20	19.6	20	7.4	23.8	18	18
Zinc	µg/L	57.7	150	51	91	23.8	60	761	685
TSS	mg/L	NA	NA	NA	NA	NA	NA	300	18
Iron	mg/L	NA	NA	NA	NA	NA	NA	10	761

Reference 4: Hydrographic Surveys on the Providence and Seekonk Rivers, December 2001

Circuit 2 & Circuit 3 (mid & late ebb) velocity contours

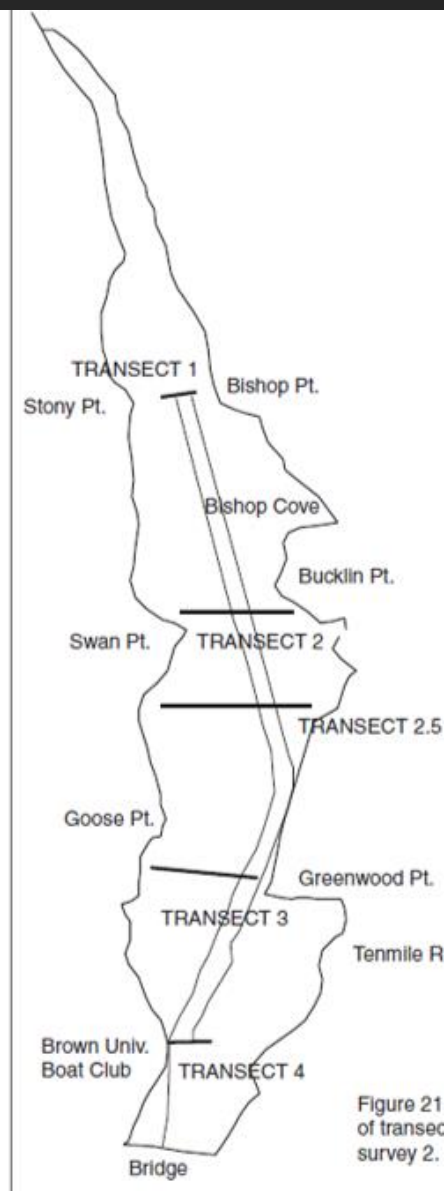
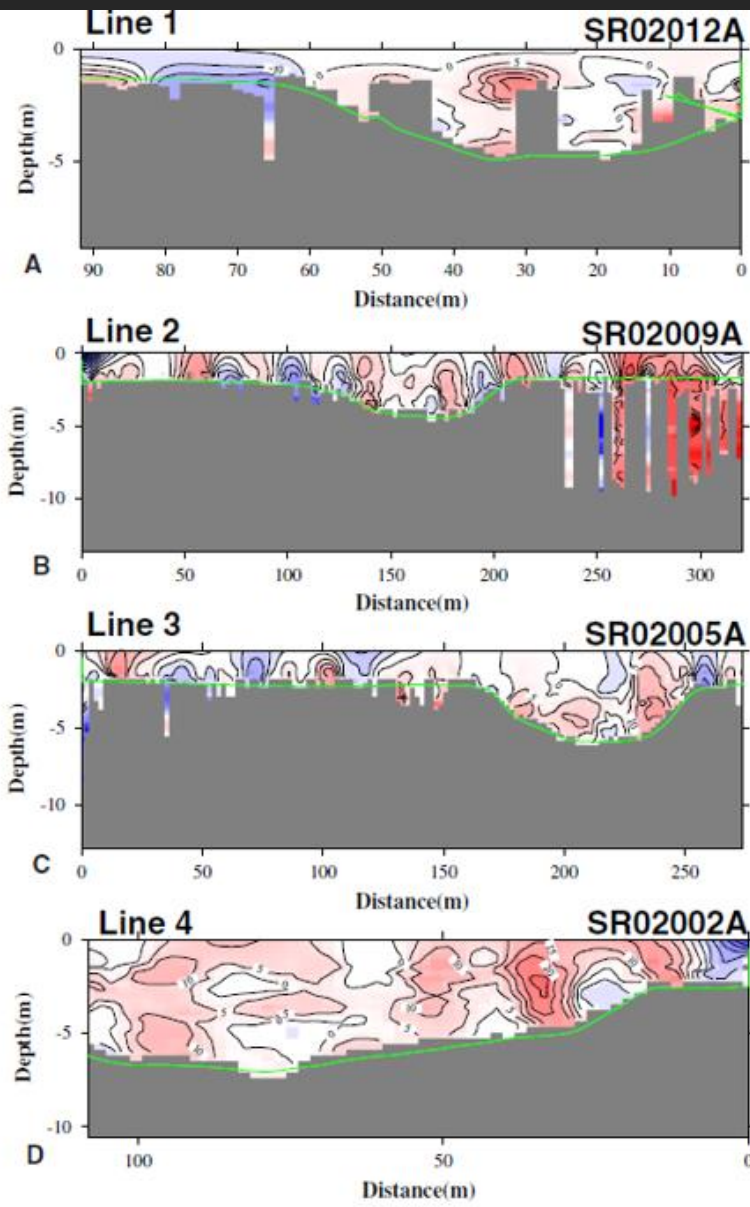


Figure 21 of transect survey 2.