Hydrology and Hydraulics Report

Final Design

Kennebunk/Kennebunkport, Route 9

WIN 22504.00

Northstar Hydro, Inc.

For **Stantec Consulting Services, Inc.** and **Maine Department of Transportation**

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STATE OF MAINE
ELLEN KNIGHT O'BRIEN
No. 7945
LICENSED
PROFESSIONAL ENGINEER

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Final Design
Kennebunk/Kennebunkport, Route 9

1.0 INTRODUCTION

A preliminary design report was issued in May of 2015 detailing hydrologic and hydraulic analyses for preliminary design bridge options. This report includes information related specifically to the selected bridge alternative. For additional information, refer to the preliminary design report.

This final design report includes results of analysis for the single span replacement option where the large center pier is removed to the river bed. Several additional data analyses have been added for the existing and proposed options, including 25-year storm data, and data for the 50-year storm surge including wave action and projected sea level rise.

The project location is shown in Figure 1.

Figure 1. Project Location

This bridge site is subject to flow in both directions as the tide causes the current to reverse twice each day. The bridge also conveys freshwater flows from the Kennebunk River basin. The existing bridge sits on granite stone abutments with a center granite stone pier and a small approach slab span on the Kennebunkport side. The abutments are founded on rock. The east side of the center pier appears to be founded on rock with the west side on or surrounded by timber cribworks. The west side of the pier had shown some evidence of scour under the timber cribbing in 2009, but is now filled in with mussels. The proposed bridge will eliminate the center pier.

Final design goals for the hydrologic and hydraulic analysis include:

- Compare projected flood elevations up- and down-stream of the bridge for existing and proposed conditions.
- Evaluate rate of flow through bridge under normal and flood tides and due to freshwater flows for existing and proposed conditions.
- Evaluate impact of bridge geometry on tidal flows from downstream to upstream and on freshwater flows with tidal influence from upstream to downstream for existing and proposed conditions.
- Evaluate scour potential for the proposed bridge based on velocity, bed material and bridge geometry.

The Maine Bridge Design Guide recommends evaluating the following conditions:

1. Typical tides with low upland flow to calibrate model
2. High Upland flows (Q50) with typical tides
3. Typical tide cycle with storm surge (50-year) superimposed at rising, mid and falling tides, with low upland flow (Q1.1)
4. Consider effects of waves and potential sea level rise

In this report, all elevations, unless otherwise noted, are relative to the North American Vertical Datum of 1988 (NAVD).

2.0 PRELIMINARY DESIGN SUMMARY

2.1 Existing Data Review and Compilation of GIS database

- ESRI's ArcMap was used to compile a GIS database of air photos, topographic maps, NOAA charts, Army Corps dredging data, LIDAR based 2' contour data and project survey.
- Data from the April, 2007 storm was gathered. This storm had an upland flow estimated as greater than a 500-year event and a tide level of about a 10-year frequency.

- Army Corps of Engineers Coastal Flood Profiles
- Flood Insurance Study data, including preliminary level restudy data and data related to a study appeal. The effective map for Kennebunk remains the 1983 FEMA map as of 2-5-2016. The preliminary level restudy map is shown below. The appeal of the study calculates a 100-year surge height with waves of 11.0' NAVD.

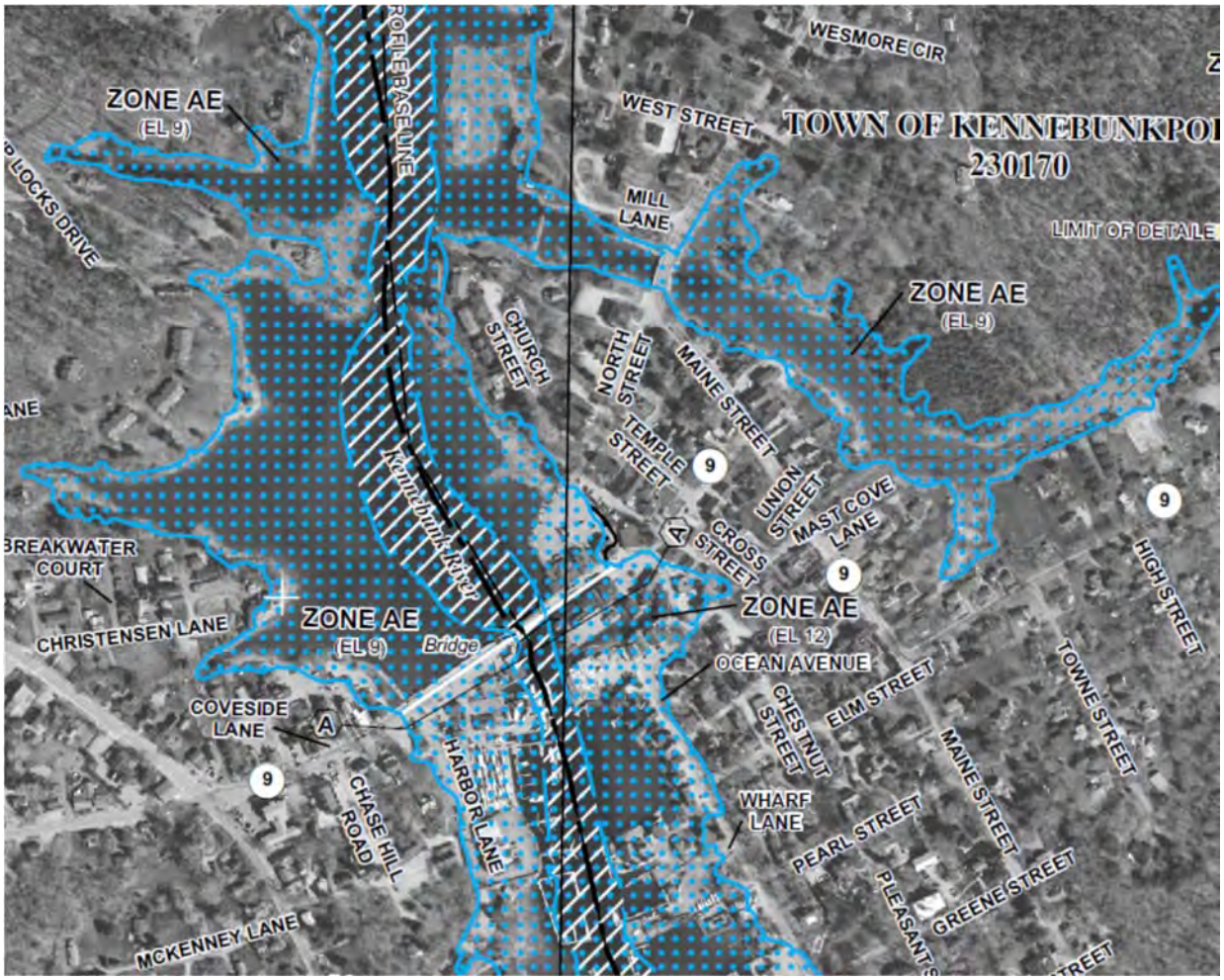

Figure 2. Preliminary Countywide Study Map, FEMA Flood Insurance Study for York County.

- Stantec provided preliminary design plans dated October 2015.
- National Oceanic and Atmospheric Administration (NOAA) tide data at Portland, Station Number 8418150 and tide predictions for the Kennebunk River at Kennebunkport, Station 8418911.
- NOAA coastal charts Number 13286, including data related to the November, 2011 dredging of the river channel.
- 2-foot contour data for Kennebunk and Kennebunkport from LIDAR surveys were downloaded from the Maine GIS (MEGIS) website.

- Sea level rise was predictions were based on NOAA's recommendation of 1.9 mm per year, or 0.62 feet per 100-years. http://www.co-ops.nos.noaa.gov/sltrends/sltrends.html

2.2 Inland Hydrology

Available data for upland flow for the Kennebunk River was gathered and evaluated in preliminary design, including calculated flows provided by Maine DOT, flows calculated for a bridge project near the Turnpike (I-95), the FEMA flood insurance study, and the USGS April 2007 storm report. The following flows were calculated by Maine DOT using the USGS Regional Regression Formula and were adopted for use in this study.

Drainage Area, Sq. mi.	56.4 square miles
Q25	2025 cfs
Design Discharge (Q50)	2316 cfs
Check Discharge (Q100)	2627 cfs
Scour Check Discharge (Q500)	3364 cfs
Ordinary High Water (Q1.1)	511 (est.) cfs
Flood of Record (>Q500)	April, 25-26, 2007 - 5730 cfs at Route 1.

Table 1. Summary of Design Hydrologic Data

2.3 Tidal Hydrology, Kennebunk River

- Measured Data: Tide data was collected on the Kennebunk River by Stantec using three pressure transducers installed in July, 2014, and recording until August 25, 2014. Data showed that the tide is delayed slightly from downstream to up on incoming tide and from upstream to down on an outgoing tide. The difference in elevation on a falling limb of the tide hydrograph is generally at a maximum mid tide and ranges up to 0.6' from K1 to K3. On a rising tide, the range is about 0.3' higher at K3 compared to K1. Through the bridge itself, the difference in elevation from upstream to down is generally not more than about 0.2' for typical daily tides. During the data collection period, the greatest difference occurs on August 14, when the Kennebunk River had upstream flow maximum of 850 cfs at the Turnpike, as shown in the following gage hydrograph.

- Daily and Storm Tides, gage data and predictions: Available data related to typical daily tides and storm tides was gathered from several sources including NOAA recording tide gage at Portland. Station Number 8418150, Portland, Maine.

Elevations, NAVD	Portland Recording Gage 8418150	Kennebunk River Predictive Gage 8418911
MHHW	4.65	4.50
MHW	4.21	4.08
NAVD	0.00	0.0
MSL	-0.32	-0.29
NGVD		-0.76
MLW	-4.91	-4.76
MLLW	-5.26	-5.10
Maximum 2/7/78	8.87	
10-year	7.93	
100-year	8.91	

Table 2. Summary of Tide Gage Levels

- Storm Surge Data: Data related to storm tide levels on the Kennebunk River were reviewed and compiled in the Preliminary Design phase of the project. Data reviewed included FEMA Surge Predictions and Ransom Engineering appeal of elevations, U.S. Army Corps of Engineers Tidal Flood Profiles, and Maine DOT recommended methodology for 50-year storm surge prediction.

- Sea Level Rise: NOAA suggests a 100-year predicted sea level rise of 0.62' based on trends observed in recorded tide data at Portland. Adding this to the ACOE 50-year surge yields 9.6. Adding a potential wave setup as modeled by Ransom adds 1.5' for a 50-year total of 11.1'.

	FEMA FIS					ACOE plus
Storm Frequency	Existing-1991	Preliminary - Under Review	Ransom review of FEMA	**Army COE 2012 profiles**	MDOT surge methodology	Add 1.5' of wave height and 0.6' of Sea Level Rise.
1.1-yr				**7.3**		
10-yr	7.4	7.9		**7.9**		**10.0**
50-yr	8	8.5		**9**	8.2	**11.1'**
100-yr	8.3	8.9		**9.5**	8.9	
100-yr plus wave setup		12	11			**11.0'**
100-year plus Sea Level Rise		9.5		**10.1**	9.5	**11.6'**
1978 Storm of Record, Portland				**9.9**		

Table 3. Summary of Storm Tide Levels. This project uses the Army Corps of Engineers Tidal Storm Profiles, with Ransom wave heights and NOAA Sea Level Rise

Note that FEMA flood elevations are still under review, so to provide a conservative set of design parameters, this study uses the Army Corps of Engineers Tidal Profiles for surge elevation, Ransom predictions of wave setup and NOAA recommendations for Sea Level Rise. (FEMA surge levels are lower than the Army COE Tidal Flood Profiles.)

3.0 HYDRAULIC MODEL

- Model choice: U.S. Army Corps of Engineers hydraulic model HECRAS was used to simulate tidal and upland flow in the Kennebunk River at the Route 9 Bridge and was run using the Beta version 5.0 in unsteady flow, 1-dimensional mode.
- River Geometric Model: Several data sources were used to compile the geometric model of the Kennebunk River. The data were meshed together to simulate the river channel and overbanks (cross sections) as well as additional overbank "storage" areas that are not within the channel but provide significant area for tidal inflow to spread out beyond the Kennebunk River Channel. Data included project survey by Maine DOT, Army Corps of Engineers channel dredging information from 2011, 2-foot contour interval LIDAR survey data for Kennebunk and Kennebunkport downloaded from State of Maine GIS website, and NOAA bathymetric map 13286 in digital format.
- Model Cross sections: Cross sections were compiled from project survey. Yellow sections are based on LIDAR data, NOAA map data and Corps of Engineers channel dredging data. Red sections are based on project survey.

Figure 3. Model cross sections downstream of Route 9 Bridge.

Figure 4. Kennebunk River model cross sections upstream of Route 9 Bridge.

- Storage: The selected channel cross sections do not account for some of the overbank storage. To account for that storage, the GIS model was used to measure overbank storage beyond the cross sections and add it to the HECRAS model as lateral structures connected to overbank areas.

4.0 Bridge Model

4.1 Existing Bridge

The existing bridge consists of three openings, with one massive granite pier and a narrower granite block pier separating the approach slab span in Kennebunkport.

The existing roadway approaches overtop at EL. 8.0' in Kennebunkport (east) and EL. 7.4' in Kennebunk (west), so there is some overtopping relief at the 10-year high tide and higher.

The low chord of the bridge is EL. 7.16' NAVD.

The MaineDOT Bridge Design Guide (BDG) indicates that freeboard should be 2'-0" over the 10-year surge including wave heights, and should take sea level rise (SLR) into account. 100-year SLR prediction by NOAA is 0.62' at Portland. Calculations for the 100-year surge by Ransom Engineering indicate that wave setup may be 1.5' in height above surge. While waves will not be generated within the Kennebunk River, the additional setup due to waves may be 1.5' above the surge level in a 100-year storm event. For a 10-year storm, this elevation could be 7.9' plus 1.5'of additional wave height = 9.4' NAVD. For a 50-year storm, surge elevation of 9.0', wave setup of 1.5' and SLR of 0.6' equals 11.1'. (Note that as discussed above, FEMA flood elevations are still under review, so to provide a conservative set of design parameters, this study uses the Army Corps of Engineers Tidal Profiles for surge elevation, Ransom predictions of wave setup and NOAA recommendations for Sea Level Rise. FEMA surge levels are lower than the Army COE Tidal Flood Elevations.)

The existing bridge profile has significant limitations for increasing freeboard. Many businesses and the adjacent roadway approaches are much lower than the 10-year high tide level. Freeboard considerations may include recreational boating safety.

4.2 Proposed Bridge

The commercial buildings adjacent to the existing bridge significantly limit the amount the bridge profile can be raised to increase freeboard. In addition, the roadway approach grade is lower than the existing bridge grade, so the benefit of raising bridge profile is limited because the approaches will flood before the bridge during a high flood event. The bridge is closed to commercial navigation, but freeboard considerations may include boating safety for small recreational boats.

The proposed bridge design includes retaining the existing abutments and construct a single span superstructure while also removing the existing mass granite block pier to the level of the river bed. Low chord ranges from 7.25' to 7.40'.

The hydraulic model considered the existing bridge and the proposed bridge under a variety of upland flow and tidal conditions.

5.0 FLOOD CONDITIONS

Flooding at the Route 9 Bridge results from freshwater flows from upland areas on the Kennebunk River, storm surge with potential wave setup, and potential sea level rise impacts.

The Maine Bridge Design Guide recommends evaluating the following conditions:

- Typical tides with low upland flow to calibrate model
- High Upland flows (Q50) with typical tides
- Typical tide cycle with storm surge (50-year) superimposed at rising, mid and falling tides, with low upland flow (Q1.1)
- Consideration of potential effects of wave setup and sea level rise

Because good records exist near this site that include actual storm data and because calibration data was collected at the site, model runs in preliminary design phase included a different but site appropriate set of storm data as described below. Additional tidal surge elevations were modeled in final design.

5.1 Tides

Based on available information, the following storm combinations were studied for final design.

Storm Tide Elevations in Feet (NAVD88)	
Annual High Tide (2014 highest)	6.7
1.1-year High Tide	7.3
10-year High Storm Surge +Tide	7.9
25-year High Storm Surge + Tide	8.5
50-year High Storm Surge + Tide	9.0
50-year High Storm Surge + Tide + Wave Setup Plus Sea Level Rise	9.0+1.5+0.6-= 11.1’
100-year High Storm Surge + Tide + Wave Setup	11.0 (9.5’ tide +surge + 1.5’ wave setup)
1978 Storm of Record	9.9’ at Portland Tide Gage
500-year High Storm Surge + Tide	11.0
100-year High Storm Surge + Tide + wave Setup + 100-year Sea Level Rise:	9.5+1.5+0.62 = 11.62’

Table 4. Summary of Theoretical Storm Tide Elevations

Specific data used for this location includes the following, note that all elevations referenced below are relative to NAVD:

- Annual Tide: Based on recorded high tides on January 28 to February 1, 2014. Tides ranged from a high of 6.7’ to a low of -7.7’.
- April 2007 Flood: The storm combined very high runoff (flood of record) with a substantial storm surge. Portland recorded a high tide of 8.1’ NGVD. This translates

to a high of about 7.7' NAVD on the Kennebunk River and a low tide of -5.7 NAVD at Kennebunk. This is close to a 10-year surge level.

- February 1978 Storm of Record: Portland recorded a high tide of 9.9' NAVD. This is greater than a 100-year level. This level was used in this study for the 100-year surge for both preliminary and final design.
- Calibration data from pressure transducers: For preliminary design, data from August 12 to August 15, 2014 was used for simulation run.
- The US Army Corps of Engineers 2012 Tidal Flood Profiles were used for the 25-, 50- and 500-year surge levels.
- NOAA sea level rise trend of 0.6'.
- Ransom Engineering estimated wave setup of 1.5

5.2 Upland Flows

The following riverine flows were used in model runs:

- 50-year upland flow, 2316
- 100-year upland flow, 2627 cfs (steady flow)
- 1-year flow, 511 cfs (steady flow) or 2-year flow at 929 cfs.
- Calibration flow, 11 cfs to 948 cfs (flow hydrograph)
- April, 2007 flow, 5730 peak cfs (flow hydrograph)

5.3 Modeled Conditions:

Table 5 summarizes selected combined flood conditions included in final design model runs.

Model	**Tide Range, feet NAVD88**	**Flow Range + type**	**Bridge models**	**Notes**
Calibration	+6.5 to -6.5	11.2-948 cfs, hydrograph	Existing and proposed	July/Aug 2014 field data
1978 Storm, 1-year upland	+9.9 to -5.5	929 cfs steady flow	Existing and proposed	Approx 100-year surge
April, 2007	+7.7 to -5.7	5730 cfs, peak, hydrograph	Existing and proposed	Q> 500-year Upstream elev >8.0'
Annual Tide, 50-year inland flow	+6.7 to -7.7	2317 cfs, steady flow	Existing and proposed	
Annual Tide, 100-year flow	+6.7 to -7.7	2630 cfs, steady flow	Existing and proposed	
50-year Surge, 1 –year inland flow	+9.0' to -5.5	929 cfs, steady flow	Existing and proposed	
50-year Surge plus wave setup plus Sea Level Rise, annual inland flow	+11.1 to -5.5	929 cfs, steady flow	Existing and proposed	

Table 5. Summary of Flood conditions evaluated

5.4 Model Results

Table 6 summarizes selected model results. Elevations and velocities for times of high tide, mid-falling tide, mid-rising tide and low tide are detailed for each flow/tide combination for existing and proposed bridges. Water surface profiles illustrating selected model results are included in the appendix, and also show up- and down-stream elevations for each tide/flow combination, for existing and proposed bridges.

Summary of Hydraulic Data Kennebunk/Kennebunkport Route 9 Bridge	Existing Bridge	Proposed Bridge Single span, Center pier eliminated
Low Chord, ft	7.16	7.25-7.4
Bridge Width at Q100, ft	81.5	90.9
Width at Banks, ft	81.5	90.9
Minimum Elevation of Road Profile – East/West Approaches, ft	7.4/8.0	7.4/8.0
Downstream Surge Level at 25-year storm surge	8.5	8.5
Headwater at Upstream face of existing bridge Q25, ft	6.9	6.9
Downstream Surge Level at 50-year storm surge	9.0	9.0
Headwater at 50-year inland flow	6.9	6.9
Downstream Surge Level at 100-year storm surge (1978 storm = approx. 100-year)	9.95’	9.95’
Headwater at Upstream face of bridge 100-year storm surge	9.95’	9.95’
Storm of Record, April, 2007 Headwater at U.S. face	8.1’	8.0’
Average Discharge Velocity at Q25, fps	7.3	7.1
Average Discharge Velocity at Q50, inland flow, fps	7.5	7.3
Average Discharge Velocity at Q100 year inland flow and 100-year tide, fps	7.8/5.0	7.5/5.4
Maximum Discharge Velocity at Q100, T1	10.2	9.7
Ordinary High Water Elevation (1.1-yr tide), ft	7.3	7.3
Average Discharge Velocity at 2-year flow, Calibration Tides (annual high)	5.0	4.6
Clearance @ Q25, ft	-1.4	-1.2
Max Discharge Velocity, Storm of Record, April 2007	9.7	11.3
Clearance @ 50-year tide	-1.8	-1.6
Clearance @ 100-year tide	-2.7	-2.55
Bridge Opening Area, ft^2	1232	1547
Flow Area at Q100, ft^2 (not including overtopping area)	1232	1547

Table 6. Summary of Hydraulic Data.

Geometry Files	Unsteady Flow Files	Plan combinations	
Kennebunk Existing.g04	Calibration.u02	Calibration EX bridge.p17	.p17
	April2007.u04	april 2007EX.p11	.p11
	50yearQ 1yrT.u06	50yr inland1-yrTide EX.p01	.p01
	100yearQ 1yrT.u03	100yearQ 1yrT.p03	.p03
	50yr surge 1yrQ.u01	Existing 50yr surge 1 yr Q.p22	.p22
	1978 100 yr tide 1yrQ.u07	1978 1-yr flow.p06	.p06
	11ft wavesetup Q1.u08	11ftwave Q1 EX.p02	.p02
	T50 plus waves SLR Q1.u05	T50 plus waves SLP Q1 existing.u05	.p31
	25yearQ T1.u09	25year inland T1 EX.p33	.p33
Kbunk-proposed single span-pier removed.g01	Calibration.u02	No pier calibration.p21	.p21
	April2007.u04	April 2007 no pier.p24	.p24
	50yearQ 1yrT.u06	50 inland 1-yr tide no pier.p25	.p25
	100yearQ 1yrT.u03	Q100 T1 no pier.p26	.p26
	50yr surge 1yrQ.u01	50-year tide Q1 no pier.p27	.p27
	1978 100 yr tide 1yrQ.u07	1978 tide 1-yr flow no pier.p28	.p28
	11ft wavesetup Q1.u08	T100 plus waves Q1 no pier.p29	.p29
	T50plus waves SLR Q1.u05	T50plus waves SLR Q1 no pier.p30	.p30
	25yearQ T1.u09	25inland Q1 no pier.p32	.p32

Table 7. Summary of HECRAS files

6.0 SCOUR CONSIDERATIONS

6.1 Geotechnical Data

Geotechnical data is included in the appendix. Maine DOT conducted a series of borings in and at the edges of abutments and the center pier. Drilling through the abutment was reported to be difficult. All foundations are on material that is either bedrock or relatively shallow to bedrock.

- East Abutment: Bedrock at -10’ to -11’ NAVD, streambed at -6’. Foundation base elevation unknown, but assumed to be founded on bedrock.
- West Abutment: Bedrock at -22.7’ downstream to -27.1’ upstream. Foundation appears to include a concrete seal to bedrock. Streambed at elevation -13’ +/-.
- East Side Center Pier: Bedrock at -8.4’ to -11.9’. Streambed at -7.0’ +/-. Foundation assumed to be on bedrock.
- West Side Center Pier: Bedrock at -17.7’ downstream to -20.5’ upstream. Foundation bearing unknown, but likely supported on timber cribworks. Streambed/timber cribbing elevation -8.0’ +/-. Loose fine sand is reported from streambed to rock.
- Center Channel is at elevation -17.0’ +/- from channel soundings.

6.2 Scour History and Concerns

Maine DOT inspection reports indicate some concern for undermining and scour at the westerly side of the granite block pier and timber cribbing at the base. Some stones are missing on the westerly side of the east abutment. Figure 16 is a sketch provided by Maine DOT as a result of a dive inspection in May of 2009.

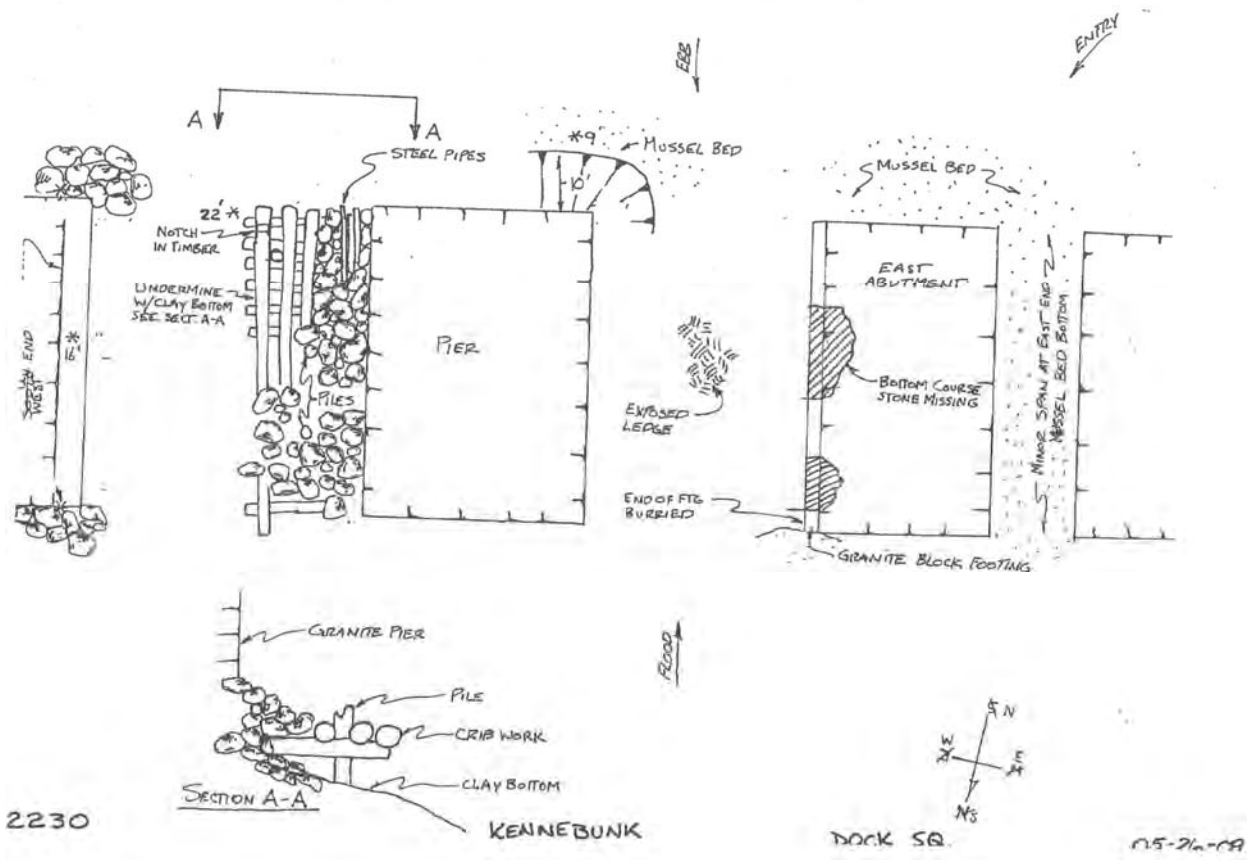

Figure 5. Sketch from May, 2009 Dive Inspection Report showing undermining of timber crib, ledge locations, and missing stones at east abutment.

2013 Underwater Inspection Report: "Some bottom course stones missing on E(aster)ly abut. Large voids, but no settling. Center pier stones in good cond., but larger timber grillage that extends out from W(ester)ly side of pier is severely undermined. 6' in. 2009: Dive out of routine cycle to check on undermined crib/grillage at pier. No major changes to undermining 6'+ in, 30" hi(gh) – Str(ea)mbed to bottom of grillage. Void goes back to stone pier shaft. 2013: Used ROV to conduct u/w insp. No major changes in condition. Undermined crib work is visible."

An additional underwater ROV inspection conducted on 1/6/2015. Minor undermining of the timber cribbing continued to be noted. However, the ROV inspection noted significant accumulations of mussels on the timber cribbing, to the point of filling the voids back in.

Additional field checks using waders and hand probe rods in December of 2014 indicate that the two abutments and the Kennebunkport (east) side of the mass pier are most likely founded on bedrock and should not have scour concerns. However, the Kennebunk (west) side of the pier seems to be founded on timber cribbing and may be susceptible to scour. As noted above, MaineDOT performed video investigation of the area in January to further investigate the scour and/or presence of ledge. Discussions included the options of

- For the proposed bridge, the center pier would not be used, but would be cut down and a single span bridge would be constructed. Since both abutments are founded on rock, scour is not a concern if abutments are located on competent rock.

Scour inspection reports are included in the appendix.

6.3 Scour Computations

For preliminary design, scour was not computed. For final design, scour was computed for the time during the 50-year tidal surge including waves when flow was computed to be at the highest rate through the bridge. A D50 of 0.1mm was used based on geotechnical reports of "fine sand". The computations show that scour could progress through the full sand layer to bedrock where overburden is present. Rock scour computations were not done for this project due to relatively low velocities and high water depths. However, it is recommended that foundations be set on competent rock and follow geotechnical engineering design recommendations due to potential scour to rock.

7.0 REFERENCE MATERIAL

- USGS Gaging data for Kennebunk River. Gage Number 01067950. http://waterdata.usgs.gov/nwis/uv/?site_no=01067950.
- USGS SIR Flood of April 2007 in Southern Maine.
    - USGS report The Patriot's Day Storm at Willard Beach.
    - Maine DOT provided flow calculations in accordance with the USGS Regional Formula Regression Equations.
    - U.S. Army Corps of Engineers provided storm surge levels for the New England Coast in a new report published in 2012.
    - Preliminary FEMA Flood Insurance Study of York County and July 1988 FEMA Flood Insurance Study of Kennebunkport. (https://msc.fema.gov/portal/availabilitySearch?addcommunity=230151&communityName=KENNEBUNK,TWN%20/%20YORK%20CO#searchresultsanchor (FEMA 1982))
    - Preliminary Countywide Study Map, FEMA Flood Insurance Study for York County. 23031CV001, 2, and 3A, Flood Insurance Study, York County, Maine, and digital DFIRM maps: 11/5/2013. Available through: https://msc.fema.gov/portal/advanceSearch.
    - Currently, the preliminary FEMA countywide study is under appeal. Ransom Engineering provided information related to the community appeals process. Ransom calculates the downstream 100-year level at 11' and the upstream level at 9'.
    - Stantec provided copies of Maine DOT bridge plans. Maine DOT Dock Square Bridge Between the Towns of Kennebunk and Kennebunkport, York County. January 18, 1930
    - Photos by Stantec
    - NOAA tide data: NOAA maintains a recording tide gage at Portland, Station Number 8418150, http://tidesandcurrents.noaa.gov/stationhome.html?id=8418150#tides.
    - NOAA also publishes tide predictions for the Kennebunk River at Kennebunkport, Station 8418911. http://tidesandcurrents.noaa.gov/stationhome.html?id=8418911#tides. These predictions do not apply to storm tides.
    - NOAA coastal charts. Navigation Chart Number 13286. The chart detail for the Kennebunk River provides data related to the November, 2011 dredging of the river channel.
    - Maine GIS website was used for download of 2' contour data for Kennebunk and Kennebunkport from LIDAR surveys. http://www.maine.gov/megis/catalog/
    - ESRI Arcview/ArcMap Version 9.3.1
    - USGS Topographic Maps, Kennebunk and Kennebunkport. GIS format.

Appendix

HECRAS water surface profiles and Velocity Distributions

Proposed Bridge, Single Span, Pier Removed
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  - Bridge Section with velocities — page 22
- 100-year Inland Flow, 1-year Tide

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1978 (100-year) Tide, 1-year Inland Flow
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Cross Section with Velocities at peak elevation page 27
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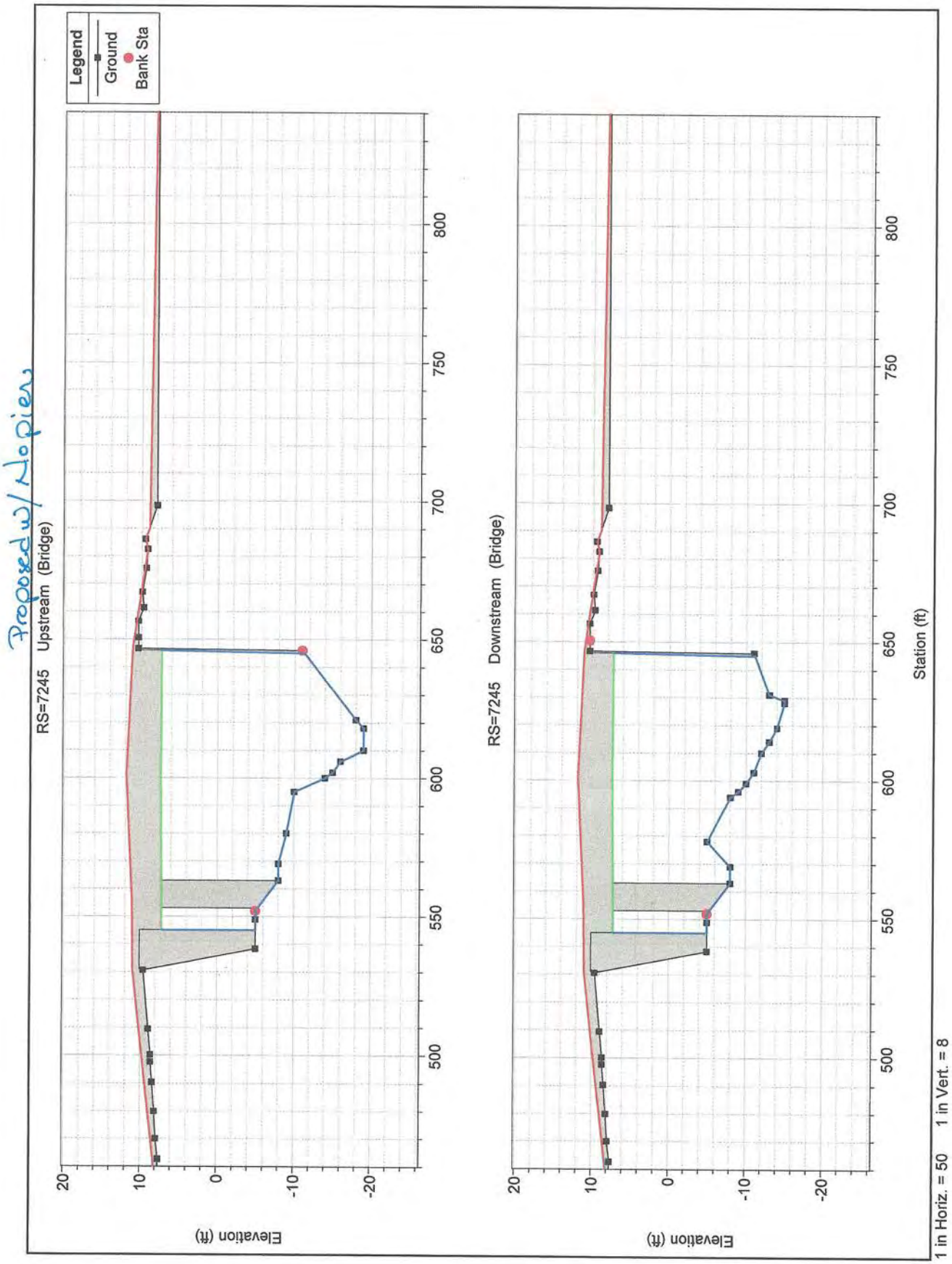
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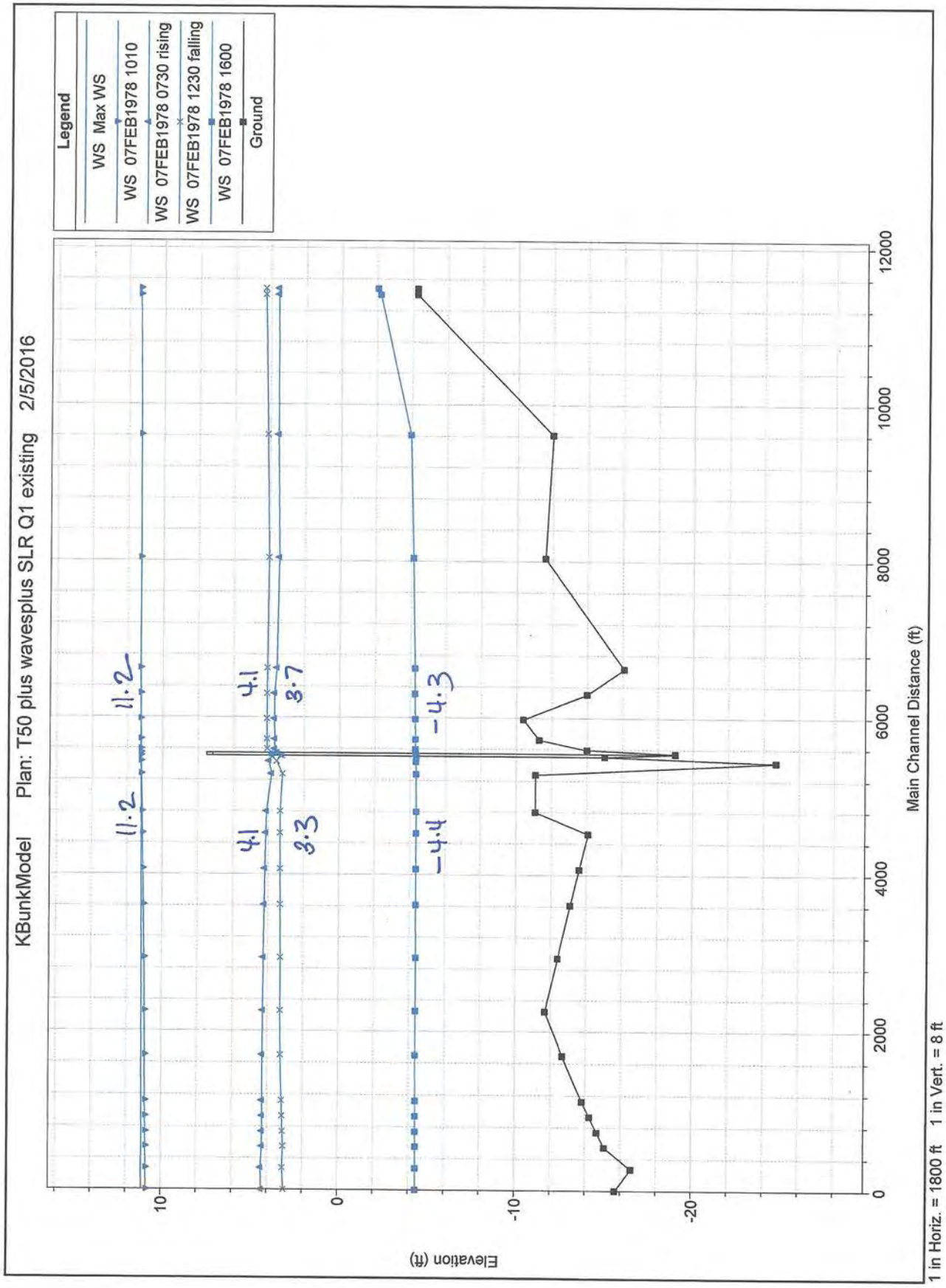
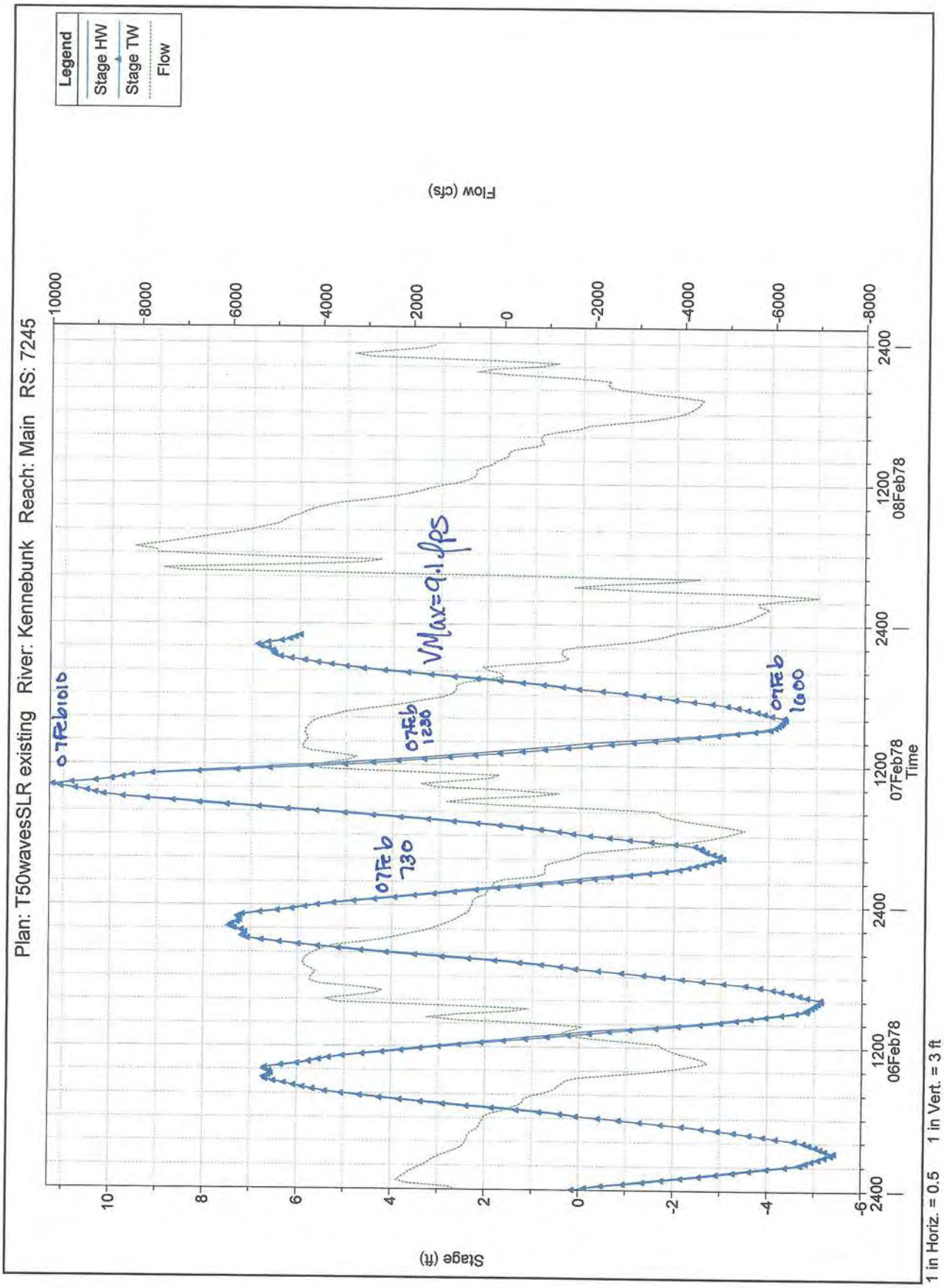
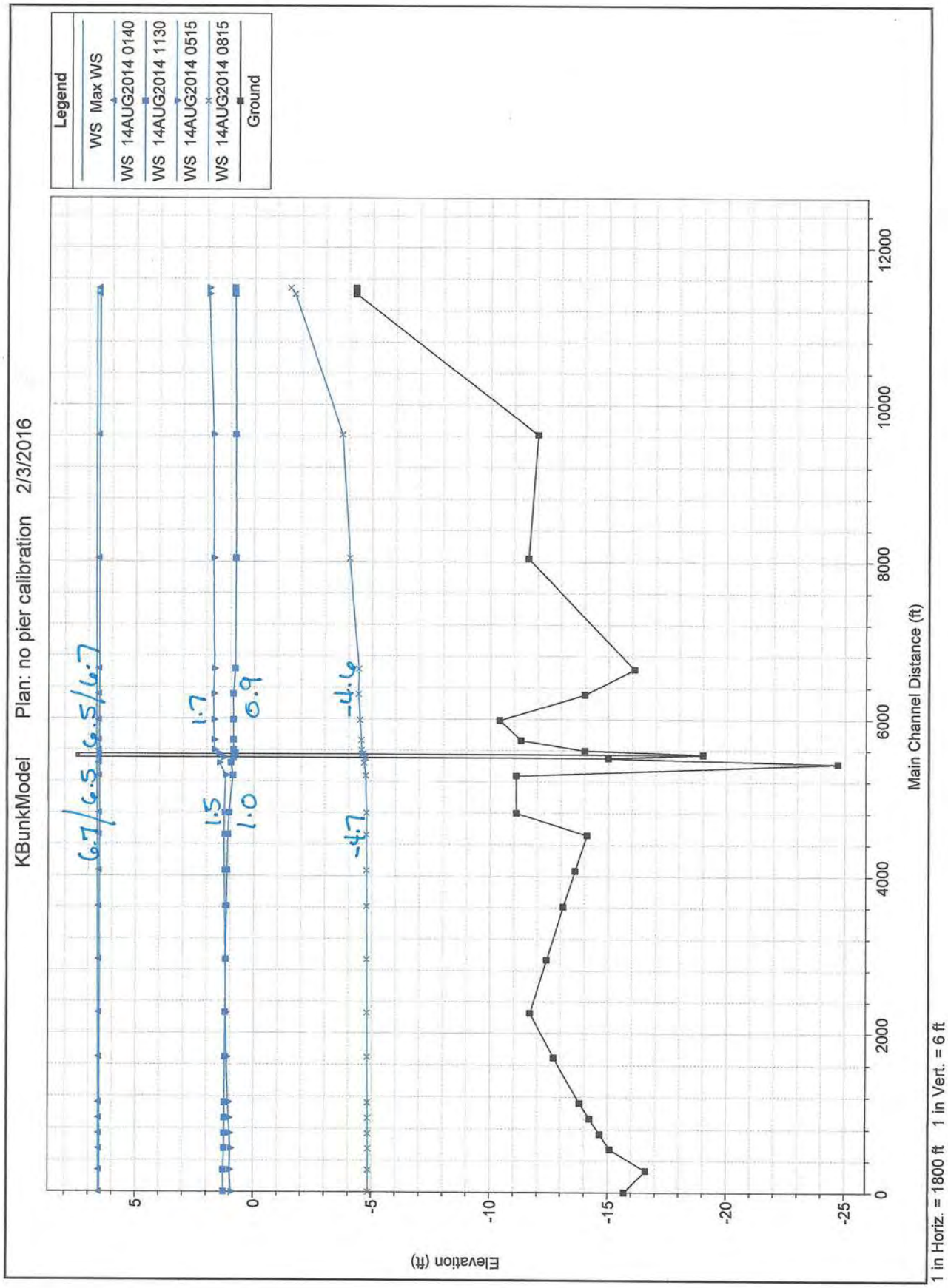
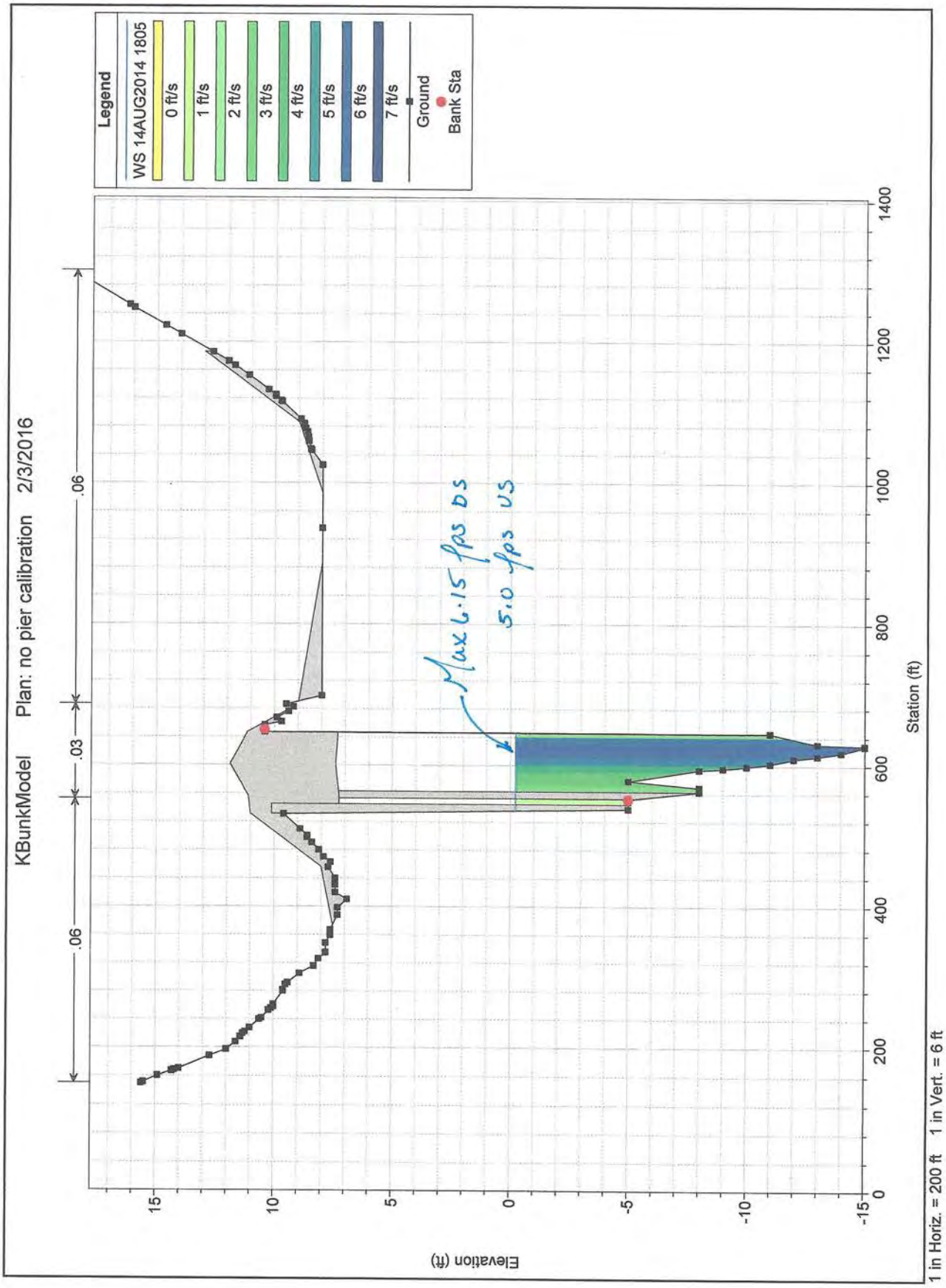
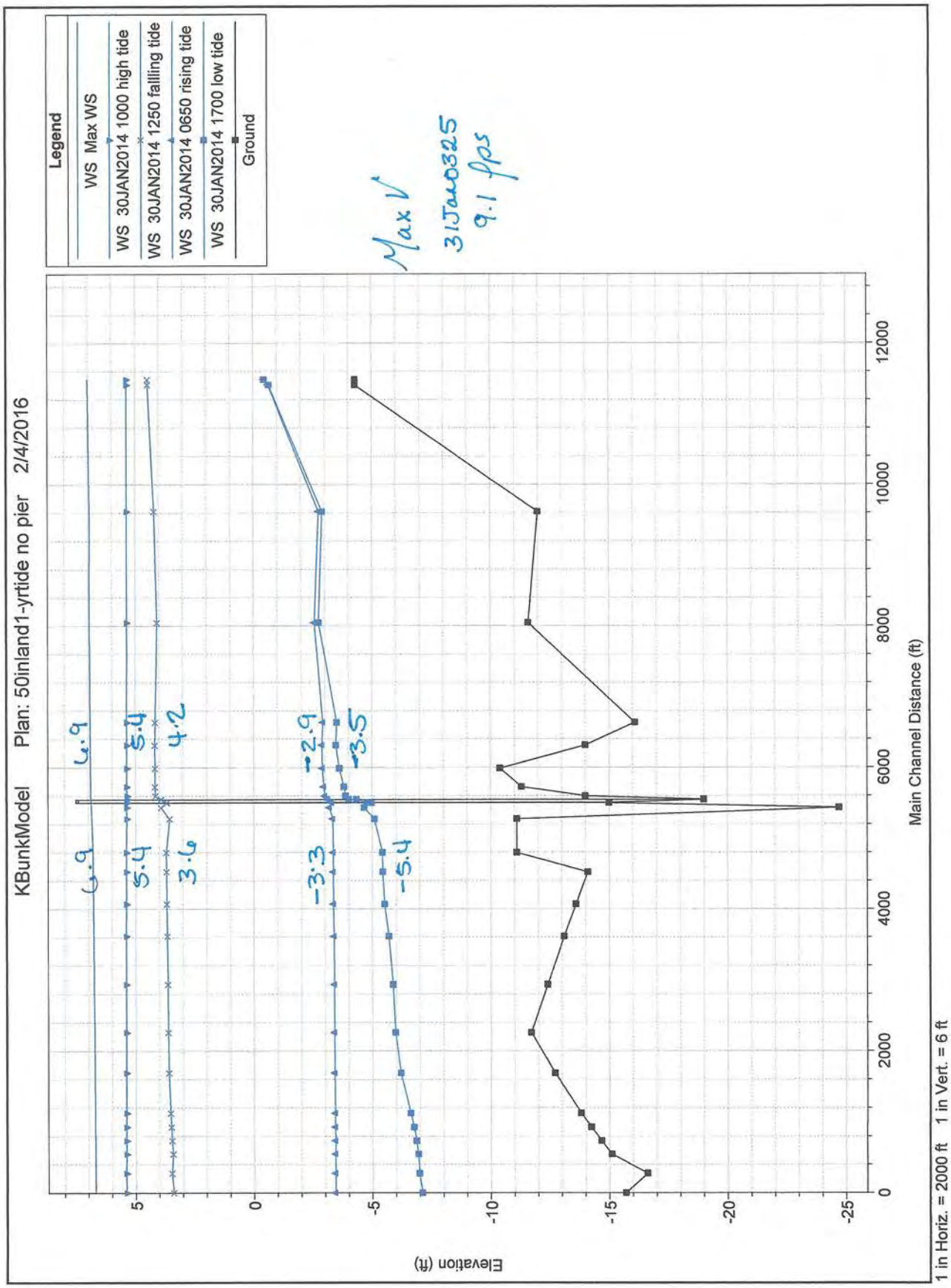
Ground
Bank Sta
RS=7245 Upstream (Bridge)
RS=7245 Downstream (Bridge)
Elevation (ft)
Station (ft)
20
10
0
-10
-20
500
550
600
650
700
750
800
1 in Horiz. = 50 1 in Vert. = 8

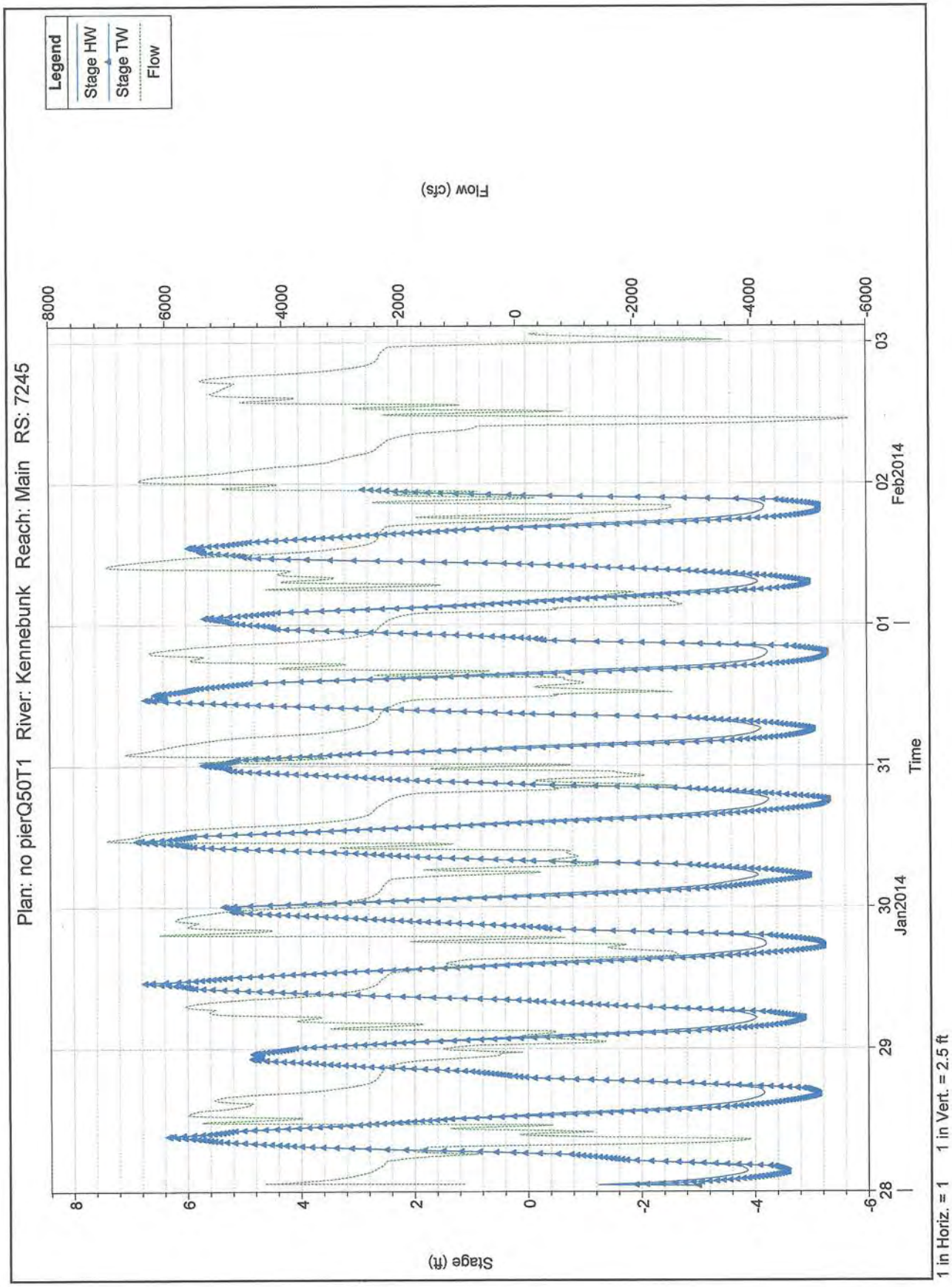

KBunkModel Plan: T50 plus wavesplus SLR Q1 existing 2/5/2016
Legend
WS Max WS
WS 07FEB1978 1010
WS 07FEB1978 0730 rising
WS 07FEB1978 1230 falling
WS 07FEB1978 1600
Ground
11.2
11.2
4.1
4.1
3.7
3.3
-4.3
-4.4
Elevation (ft)
10
0
-10
-20
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
1 in Horiz. = 1800 ft 1 in Vert. = 8 ft

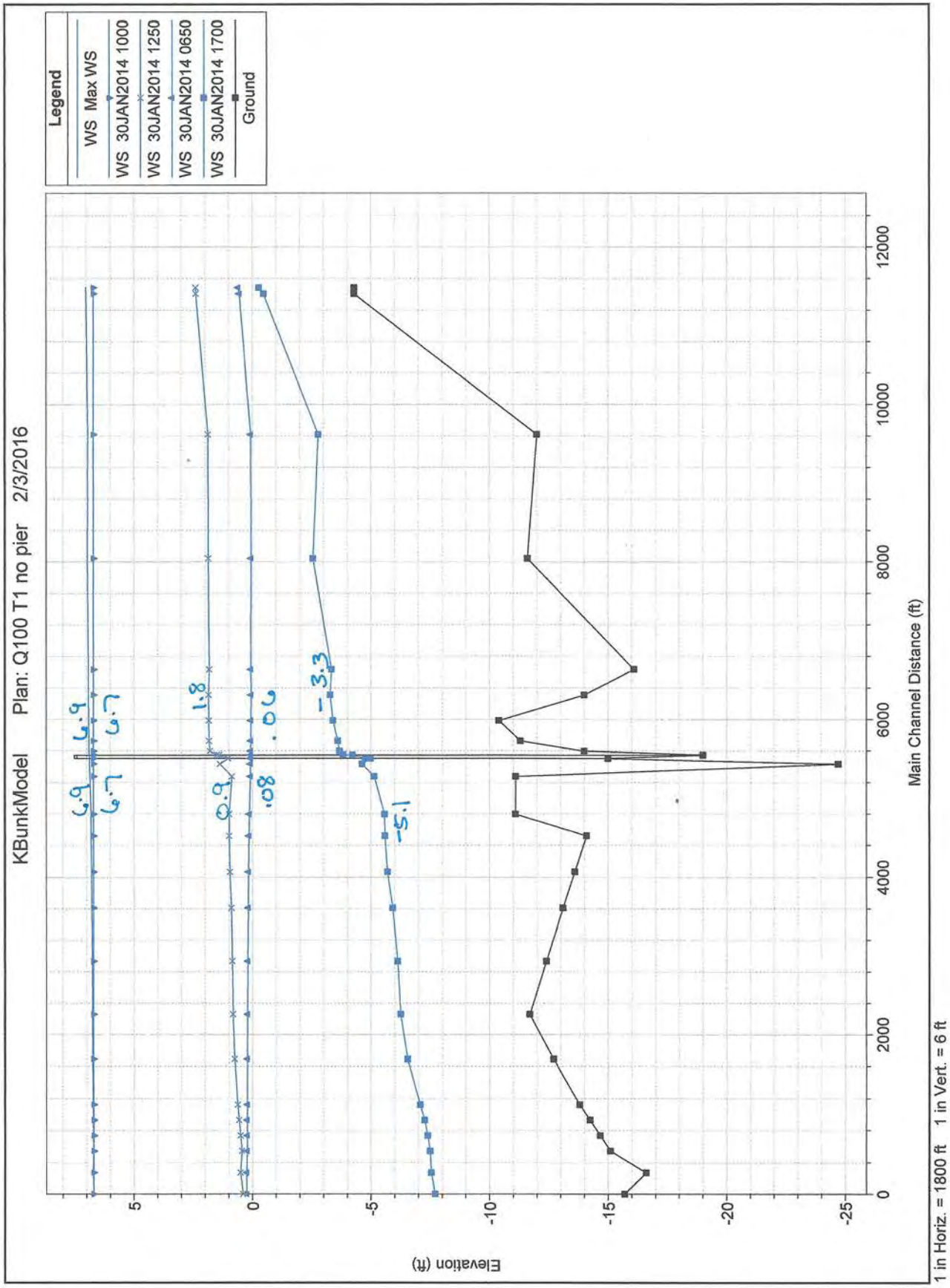

Plan: T50wavesSLR existing River: Kennebunk Reach: Main RS: 7245
Legend
Stage HW
Stage TW
Flow
Stage (ft)
Flow (cfs)
Time
06Feb78
07Feb78
08Feb78
07Feb1010
07Feb 730
07Feb 1230
VMax=9.1 fps
07Feb 1600
1 in Horiz. = 0.5 1 in Vert. = 3 ft

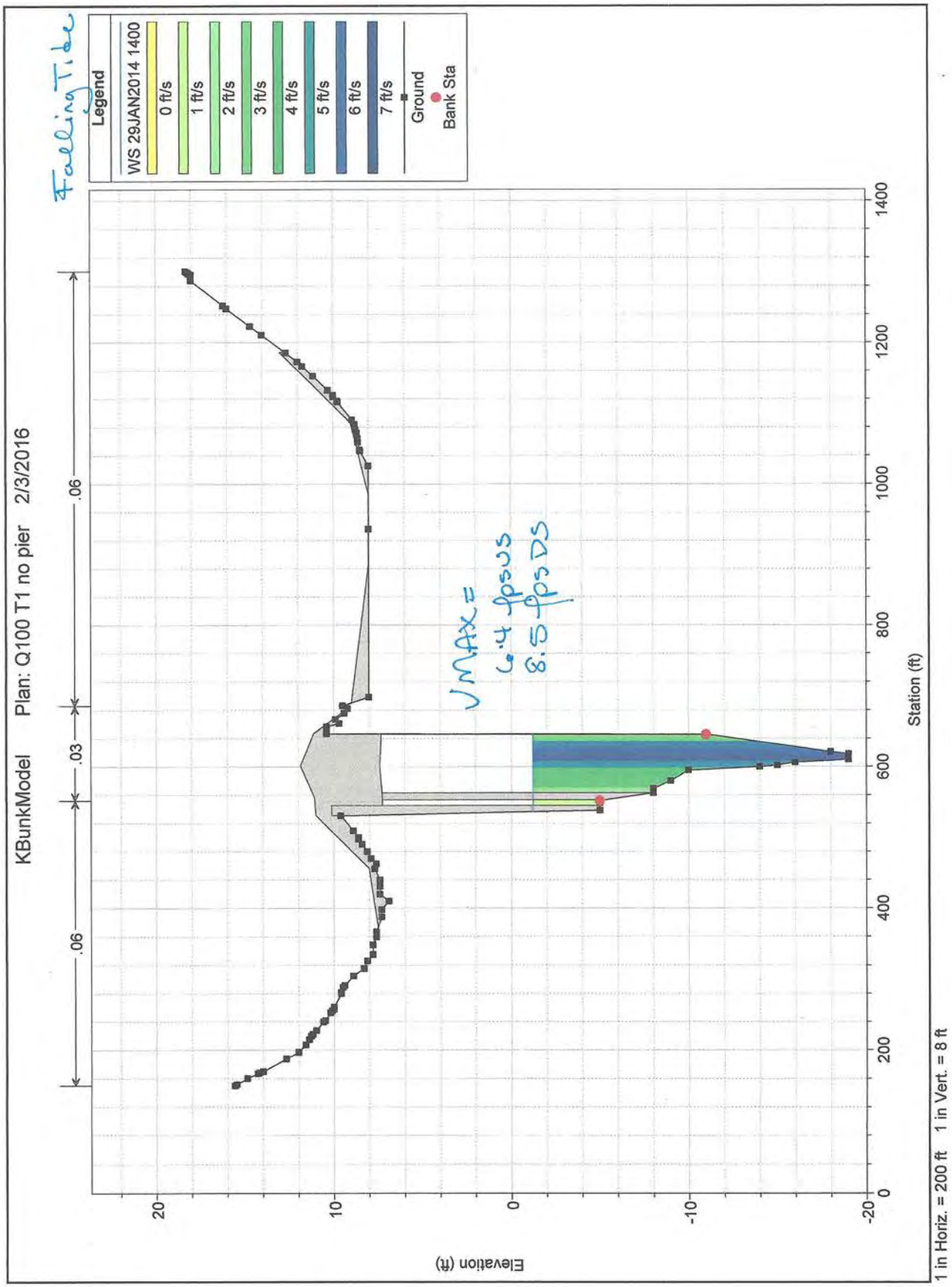

KBunkModel Plan: no pier calibration 2/3/2016
Legend
WS Max WS
WS 14AUG2014 0140
WS 14AUG2014 1130
WS 14AUG2014 0515
WS 14AUG2014 0815
Ground
6.7
6.5
6.5
6.7
1.7
0.9
1.5
1.0
-4.6
-4.7
Elevation (ft)
5
0
-5
-10
-15
-20
-25
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
1 in Horiz. = 1800 ft 1 in Vert. = 6 ft

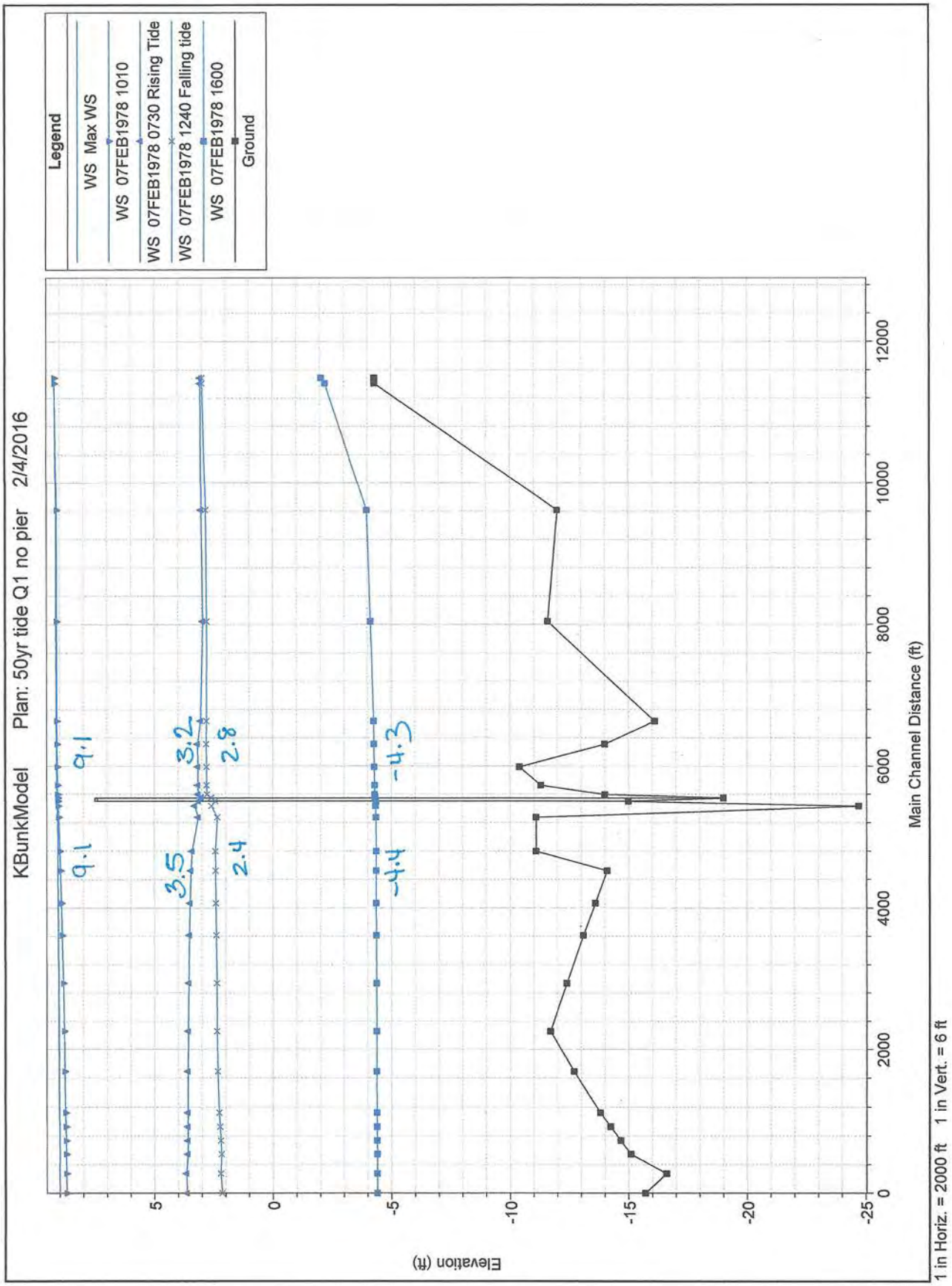

KBunkModel Plan: no pier calibration 2/3/2016
Legend
WS 14AUG2014 1805
0 ft/s
1 ft/s
2 ft/s
3 ft/s
4 ft/s
5 ft/s
6 ft/s
7 ft/s
Ground
Bank Sta
.06
.03
.06
Max 6.15 fps DS
5.0 fps US
Elevation (ft)
15
10
5
0
-5
-10
-15
Station (ft)
0
200
400
600
800
1000
1200
1400
1 in Horiz. = 200 ft 1 in Vert. = 6 ft

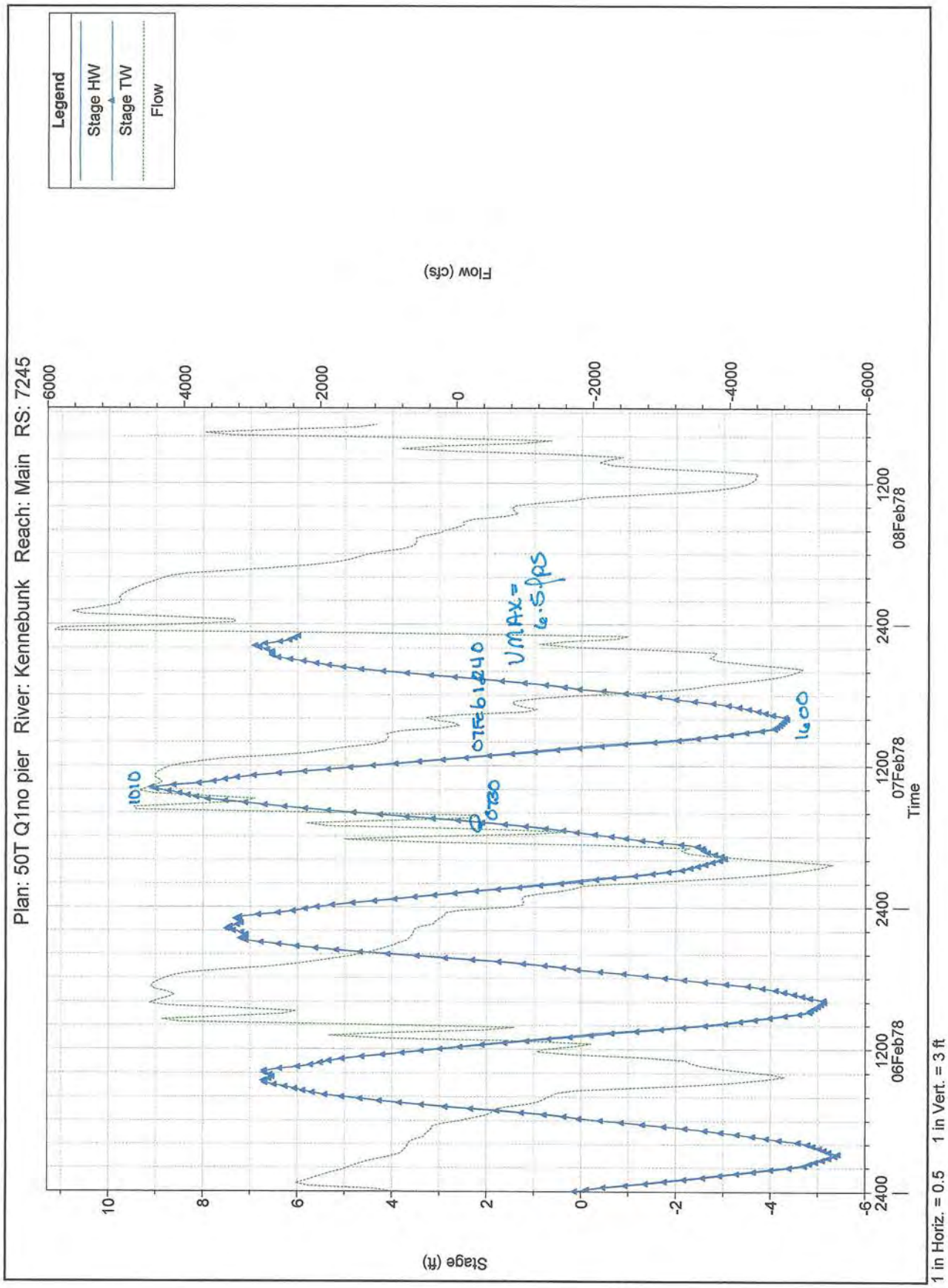

KBunkModel Plan: 50inland1-yrtide no pier 2/4/2016
Legend
WS Max WS
WS 30JAN2014 1000 high tide
WS 30JAN2014 1250 falling tide
WS 30JAN2014 0650 rising tide
WS 30JAN2014 1700 low tide
Ground
Elevation (ft)
Main Channel Distance (ft)
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft
Max V
31Jan0325
9.1 fps
6.9
6.9
5.4
5.4
4.2
3.6
-2.9
-3.5
-3.3
-5.4

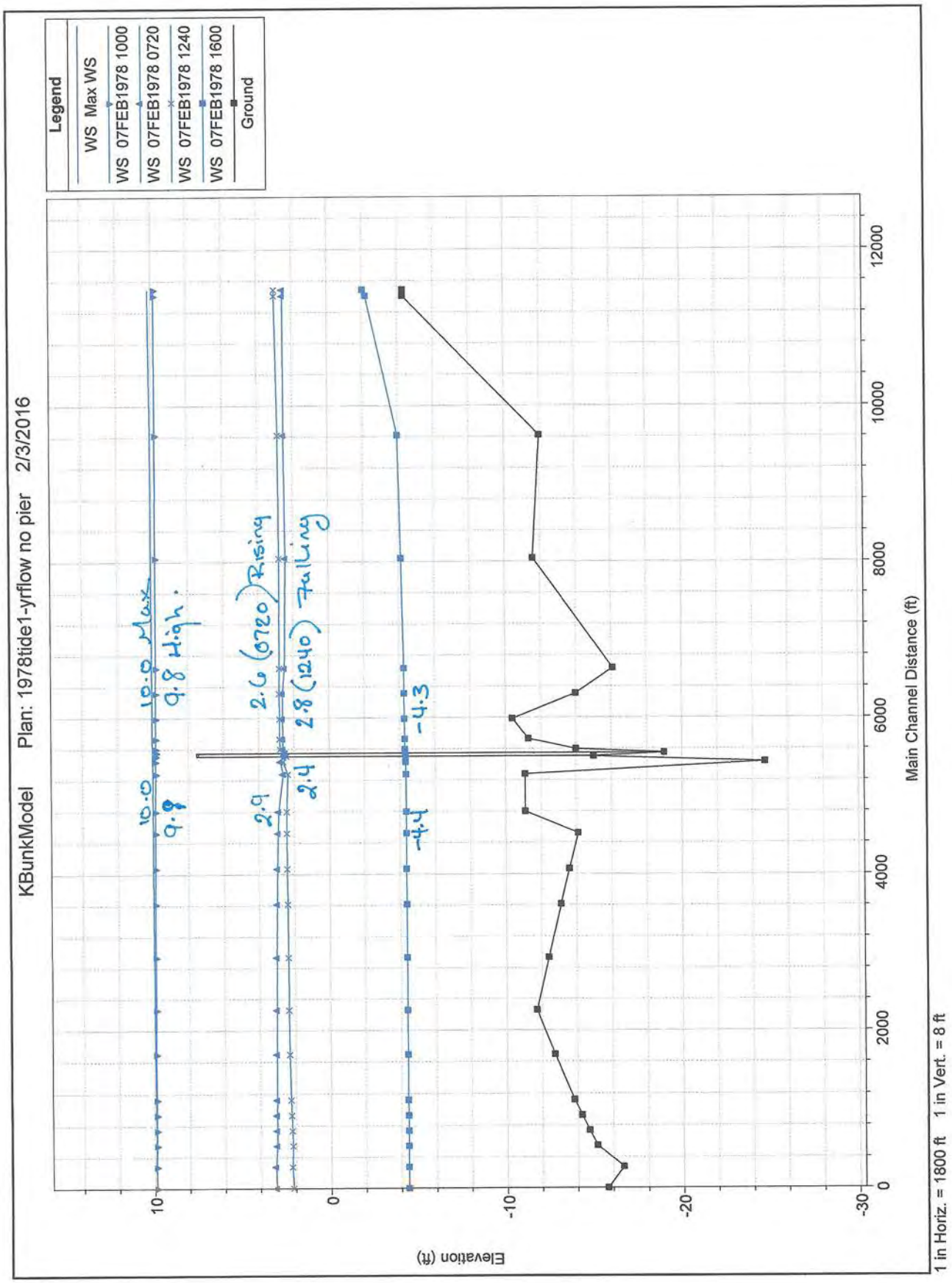

Plan: no pierQ50T1 River: Kennebunk Reach: Main RS: 7245
Legend
Stage HW
Stage TW
Flow
Stage (ft)
Flow (cfs)
Time
28
29
30
Jan2014
31
01
02
Feb2014
03
8
6
4
2
0
-2
-4
-6
8000
6000
4000
2000
0
-2000
-4000
-6000
1 in Horiz. = 1
1 in Vert. = 2.5 ft

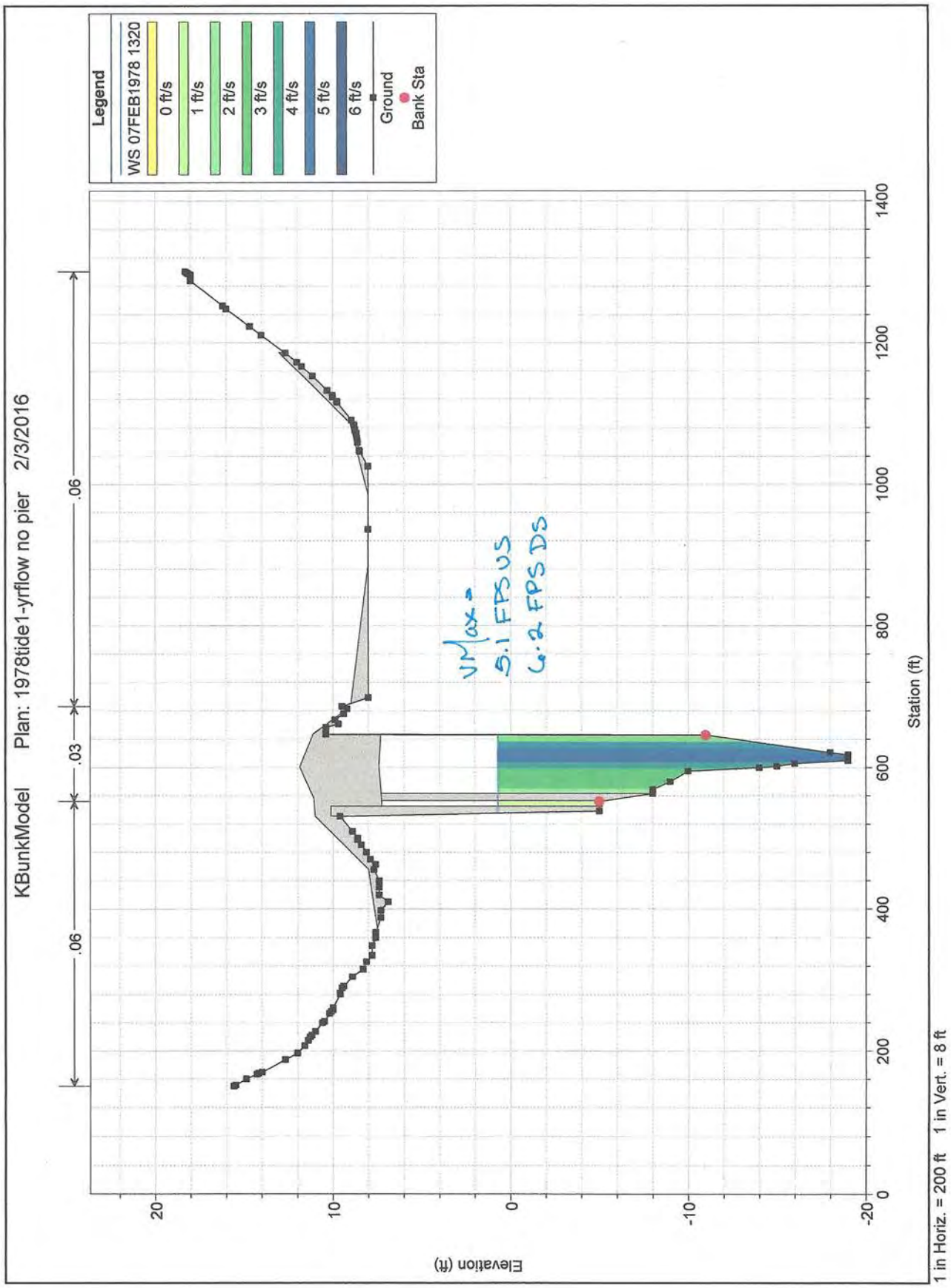

KBunkModel Plan: Q100 T1 no pier 2/3/2016
Legend
WS Max WS
WS 30JAN2014 1000
WS 30JAN2014 1250
WS 30JAN2014 0650
WS 30JAN2014 1700
Ground
Elevation (ft)
Main Channel Distance (ft)
1 in Horiz. = 1800 ft 1 in Vert. = 6 ft
6.9
6.9
6.7
6.7
1.8
0.9
.06
.08
-3.3
-5.1

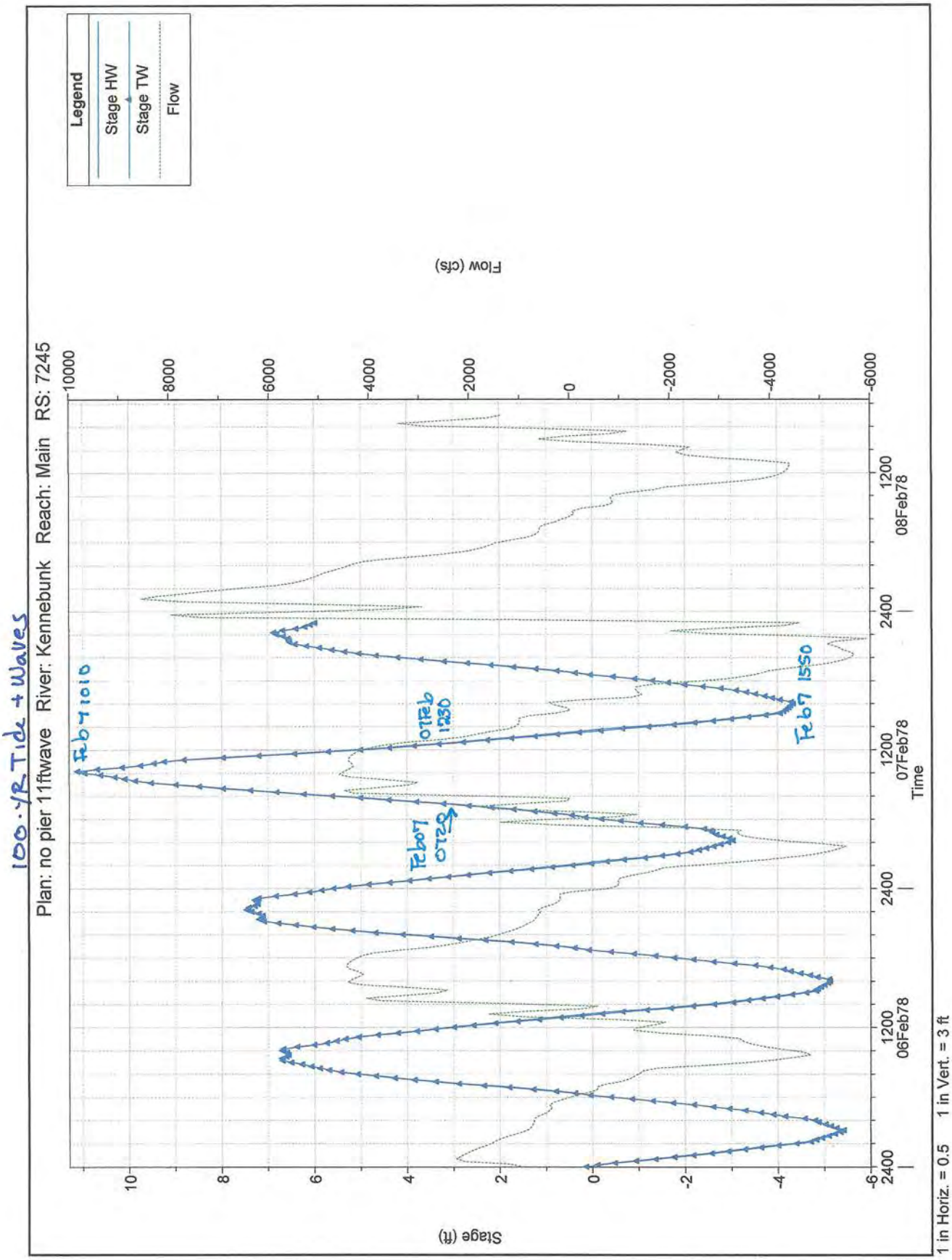

KBunkModel Plan: Q100 T1 no pier 2/3/2016
Falling Tide
Legend
WS 29JAN2014 1400
0 ft/s
1 ft/s
2 ft/s
3 ft/s
4 ft/s
5 ft/s
6 ft/s
7 ft/s
Ground
Bank Sta
.06
.03
.06
VMAX =
6.4 fps US
8.5 fps DS
Elevation (ft)
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 8 ft

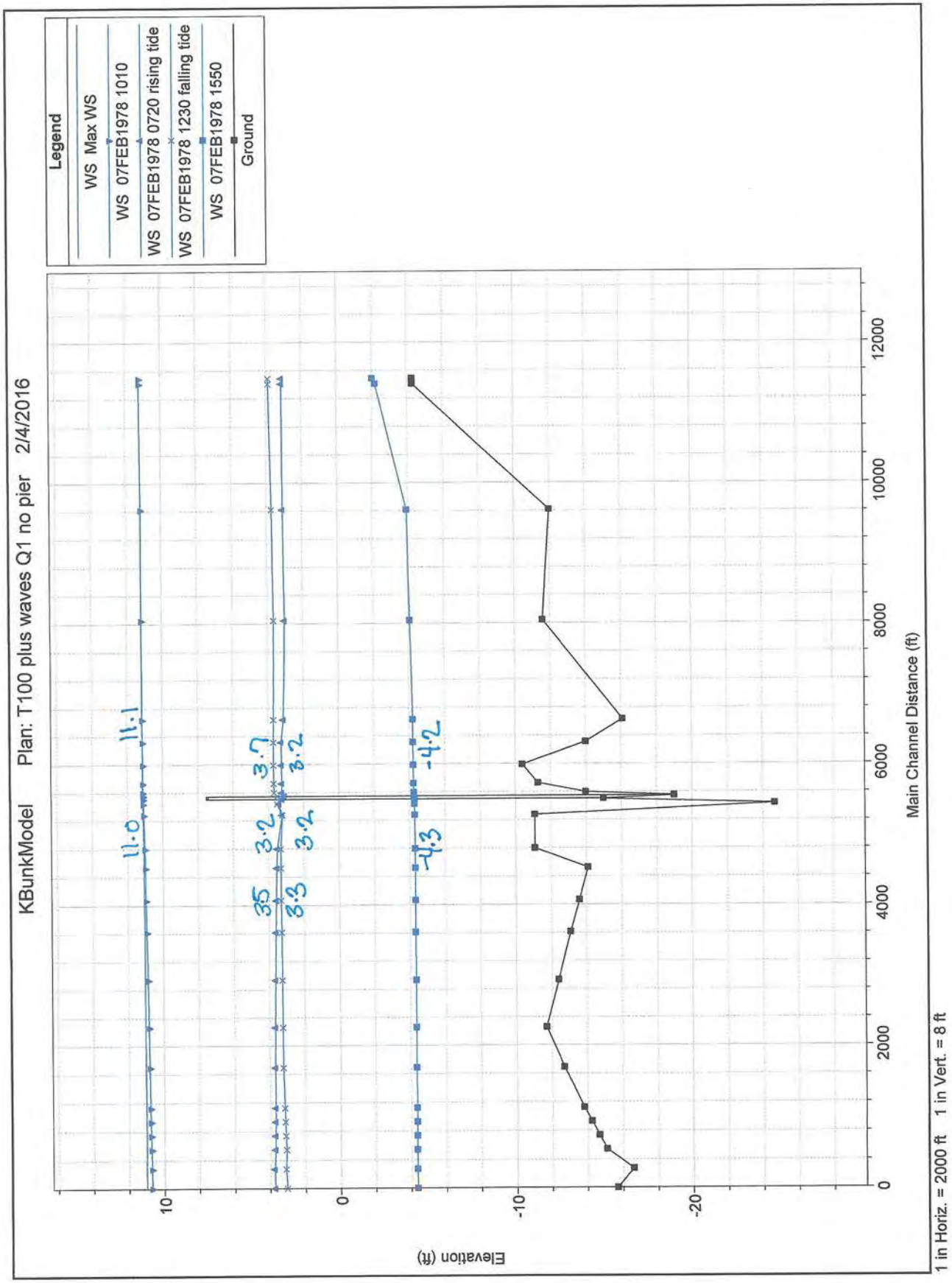

KBunkModel Plan: 50yr tide Q1 no pier 2/4/2016
Legend
WS Max WS
WS 07FEB1978 1010
WS 07FEB1978 0730 Rising Tide
WS 07FEB1978 1240 Falling tide
WS 07FEB1978 1600
Ground
9.1
9.1
3.5
3.2
2.4
2.8
-4.4
-4.3
Elevation (ft)
5
0
-5
-10
-15
-20
-25
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft

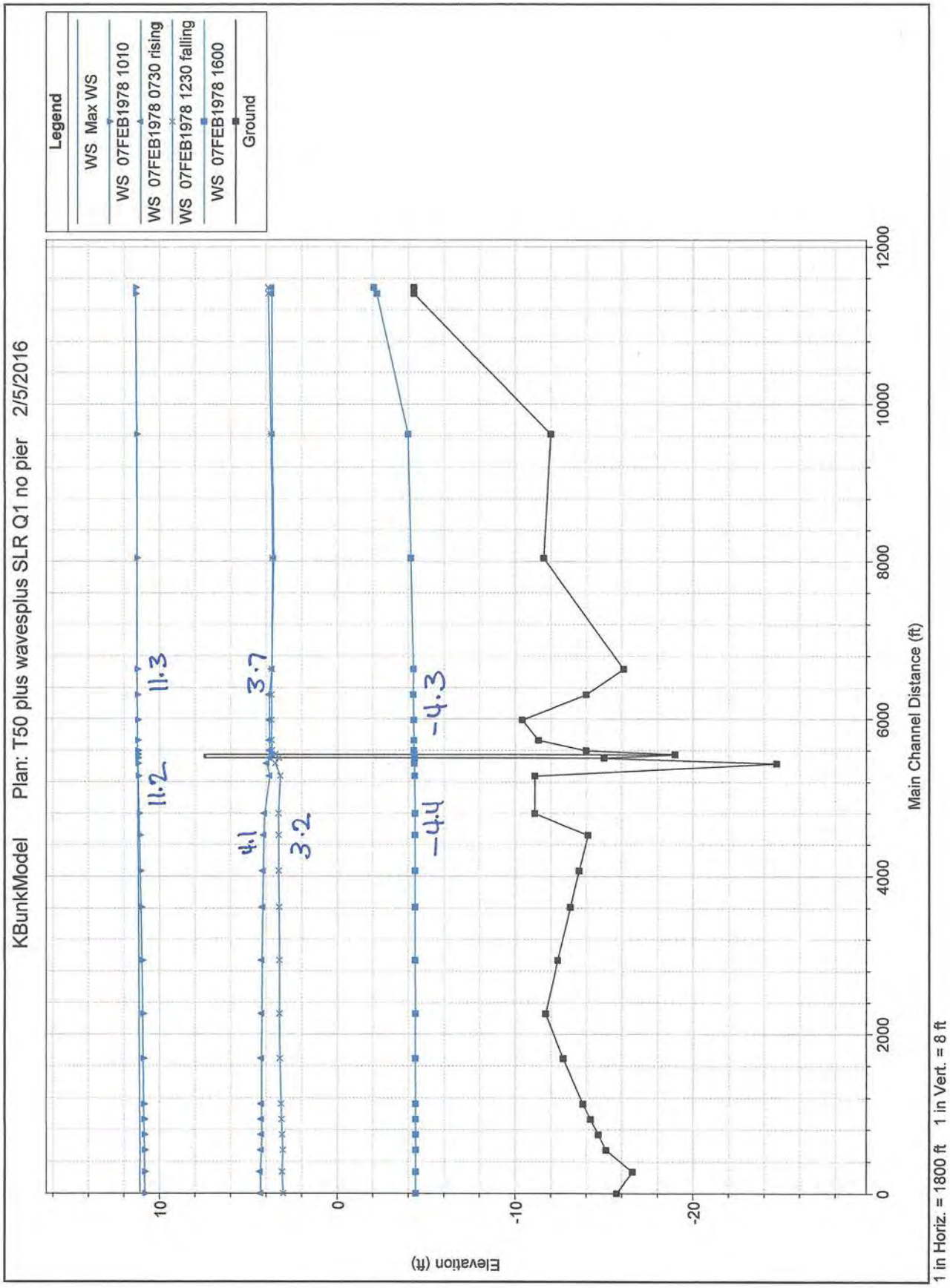

Plan: 50T Q1no pier River: Kennebunk Reach: Main RS: 7245
Legend
Stage HW
Stage TW
Flow
Stage (ft)
Flow (cfs)
Time
06Feb78
07Feb78
08Feb78
1010
0730
07Feb1240
VMAX=
6.5fps
1600
1 in Horiz. = 0.5 1 in Vert. = 3 ft

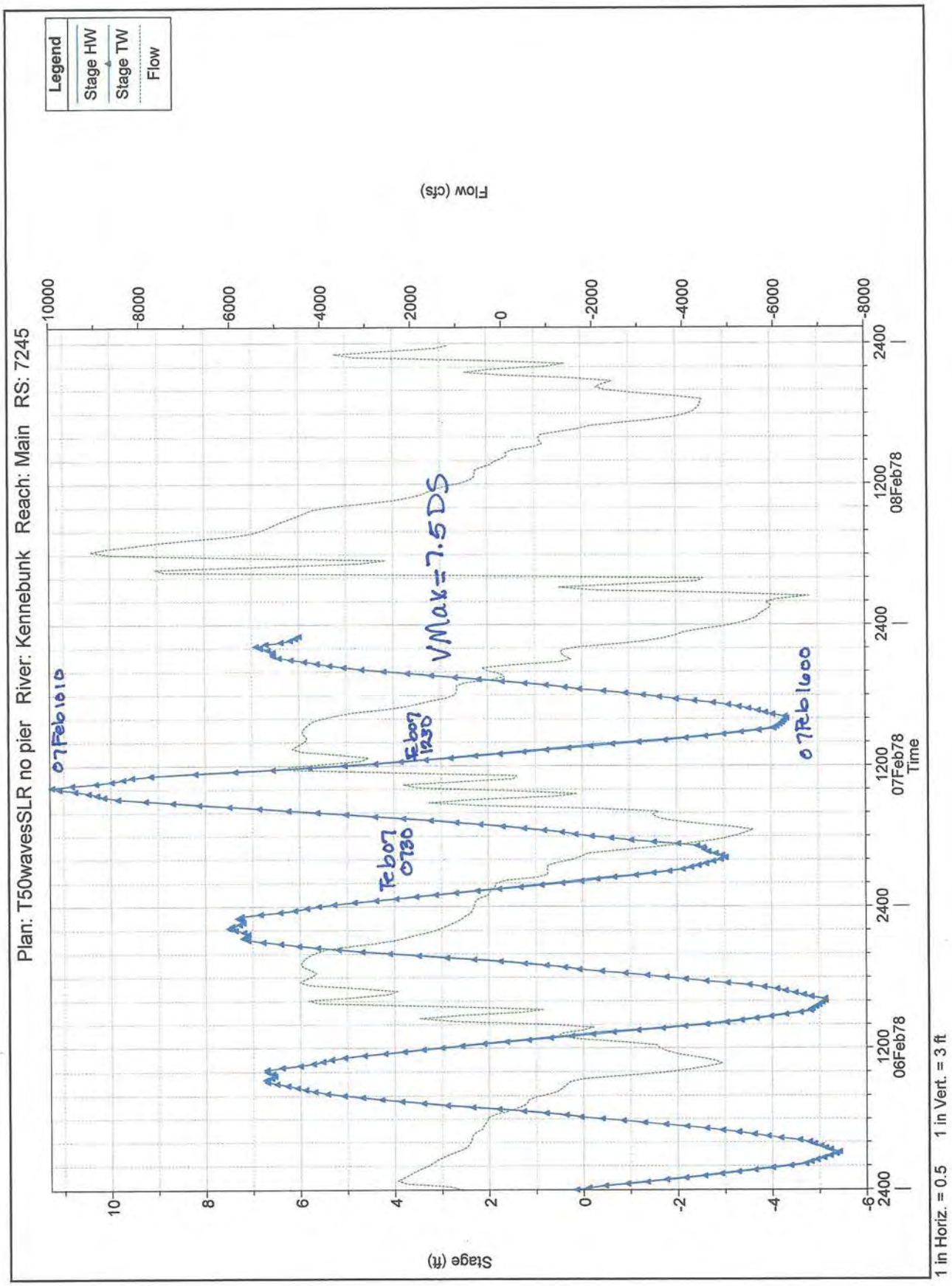

KBunkModel Plan: 1978tide1-yrflow no pier 2/3/2016
Legend
WS Max WS
WS 07FEB1978 1000
WS 07FEB1978 0720
WS 07FEB1978 1240
WS 07FEB1978 1600
Ground
10.0 Max
9.8 High
10.0
9.8
2.6 (0720) Rising
2.8 (1240) Falling
2.9
2.4
-4.3
-4.4
Elevation (ft)
10
0
-10
-20
-30
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
1 in Horiz. = 1800 ft 1 in Vert. = 8 ft

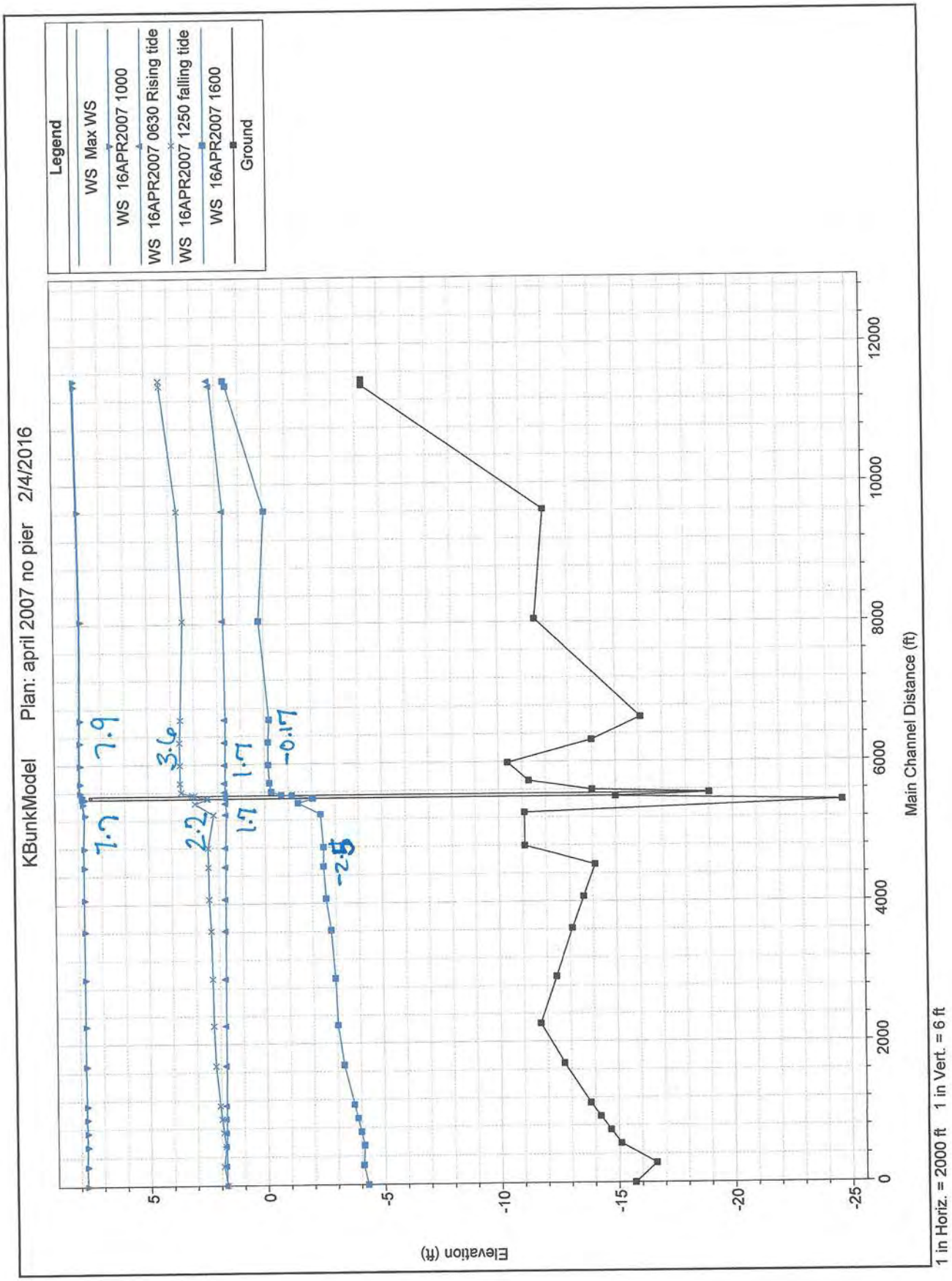

KBunkModel Plan: 1978tide1-yrflow no pier 2/3/2016
Legend
WS 07FEB1978 1320
0 ft/s
1 ft/s
2 ft/s
3 ft/s
4 ft/s
5 ft/s
6 ft/s
Ground
Bank Sta
.06
.03
.06
Vmax =
5.1 FPS US
6.2 FPS DS
Elevation (ft)
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 8 ft

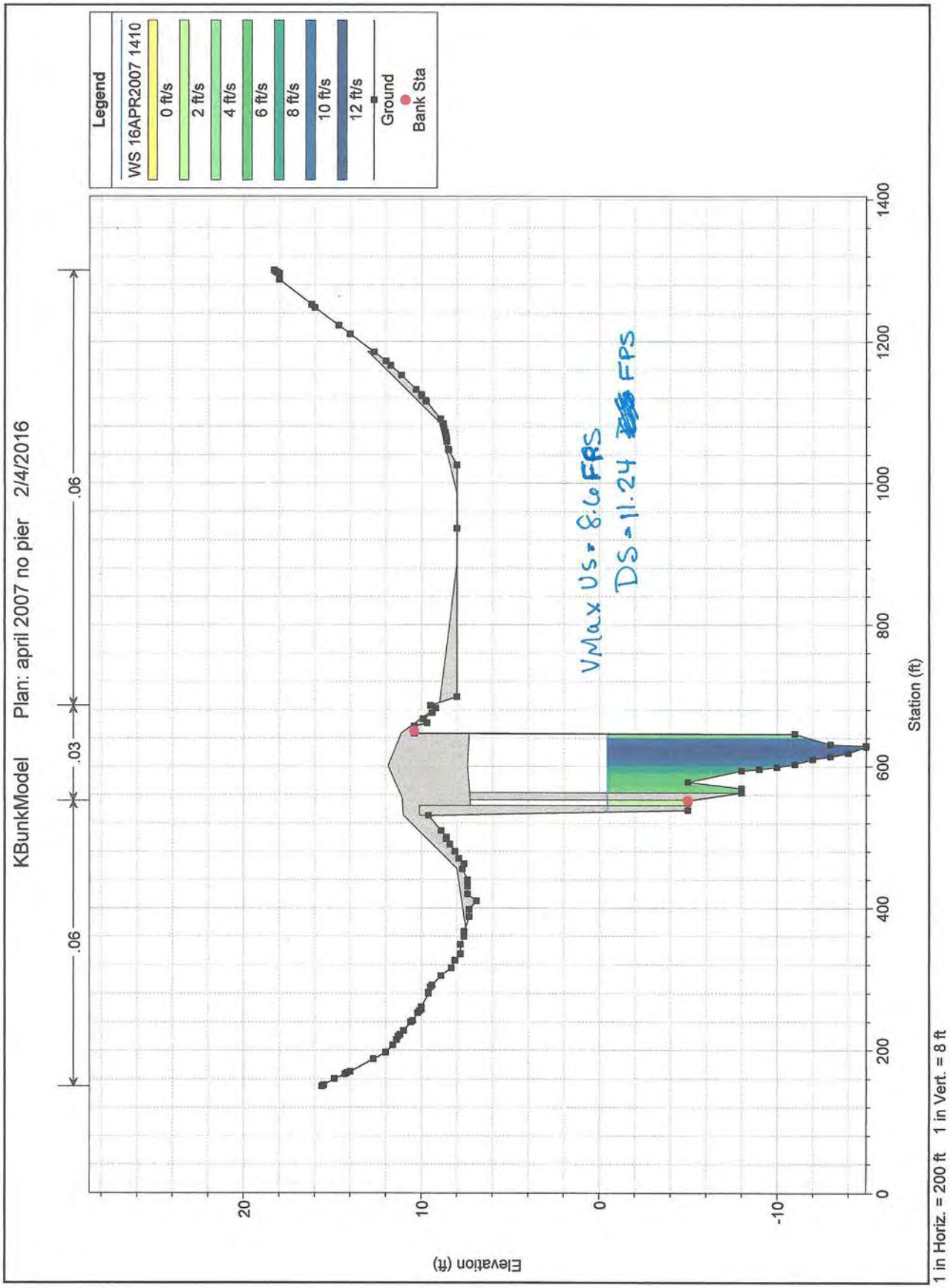

100-YR Tide + Waves
Plan: no pier 11ftwave River: Kennebunk Reach: Main RS: 7245
Legend
Stage HW
Stage TW
Flow
Stage (ft)
Flow (cfs)
Time
06Feb78
07Feb78
08Feb78
Feb7 1010
Feb7 0720
07Feb 1230
Feb7 1550
1 in Horiz. = 0.5 1 in Vert. = 3 ft

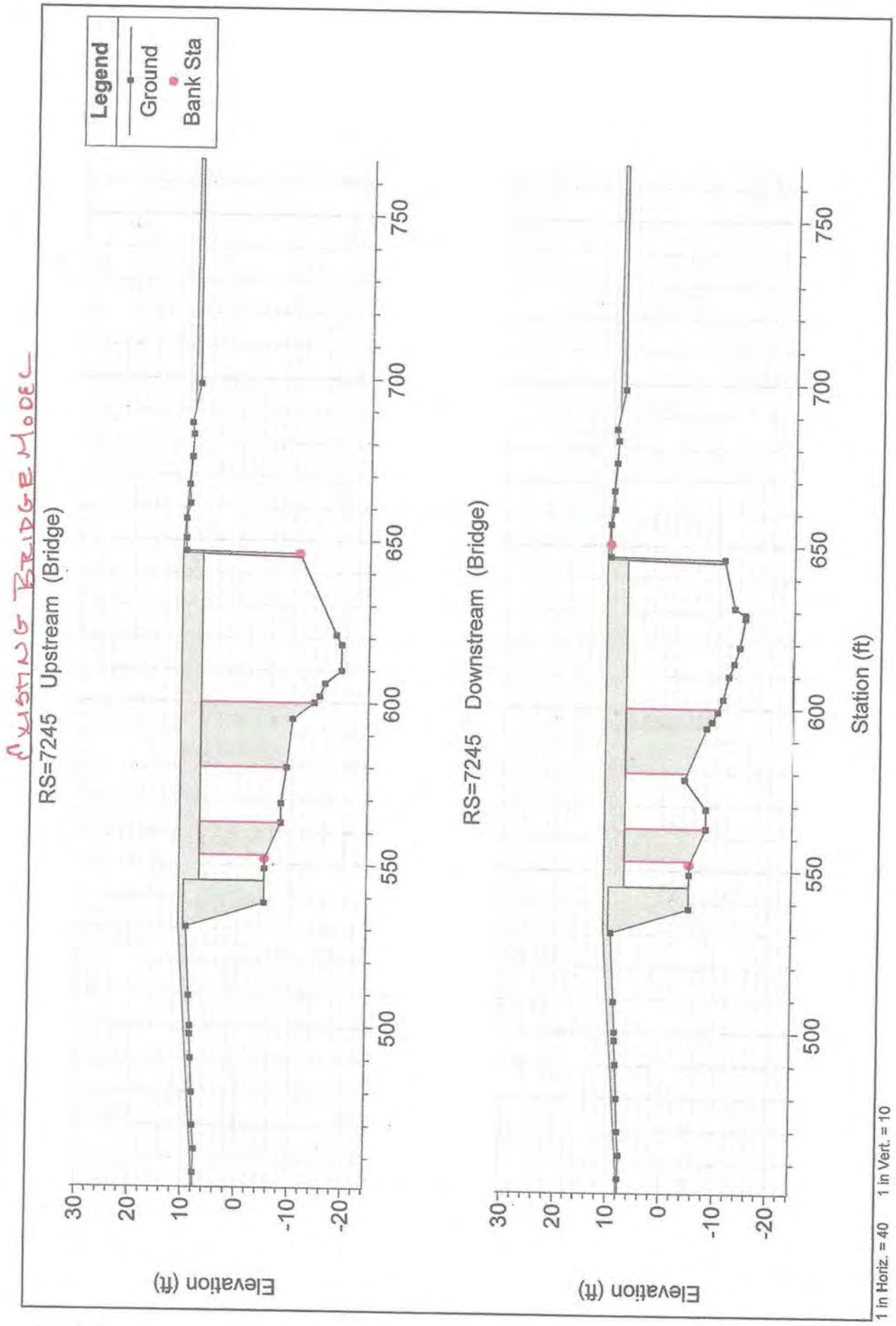

KBunkModel Plan: T100 plus waves Q1 no pier 2/4/2016
Legend
WS Max WS
WS 07FEB1978 1010
WS 07FEB1978 0720 rising tide
WS 07FEB1978 1230 falling tide
WS 07FEB1978 1550
Ground
Elevation (ft)
Main Channel Distance (ft)
1 in Horiz. = 2000 ft 1 in Vert. = 8 ft
11.0
11.1
3.5
3.2
3.3
3.2
3.7
3.2
-4.3
-4.2

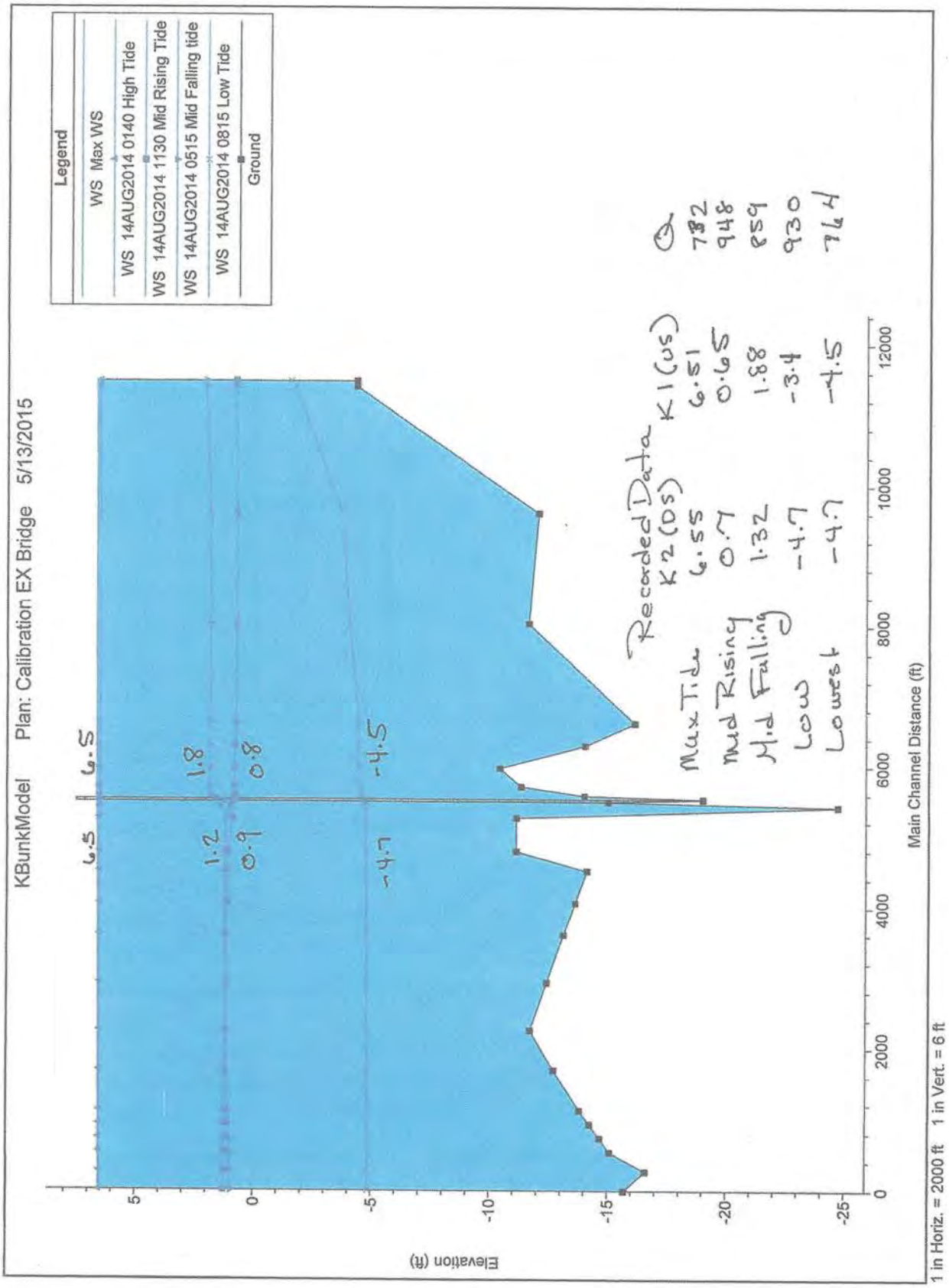

KBunkModel Plan: T50 plus wavesplus SLR Q1 no pier 2/5/2016
Legend
WS Max WS
WS 07FEB1978 1010
WS 07FEB1978 0730 rising
WS 07FEB1978 1230 falling
WS 07FEB1978 1600
Ground
11.2
11.3
3.7
4.1
3.2
-4.3
-4.4
Elevation (ft)
10
0
-10
-20
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
1 in Horiz. = 1800 ft 1 in Vert. = 8 ft

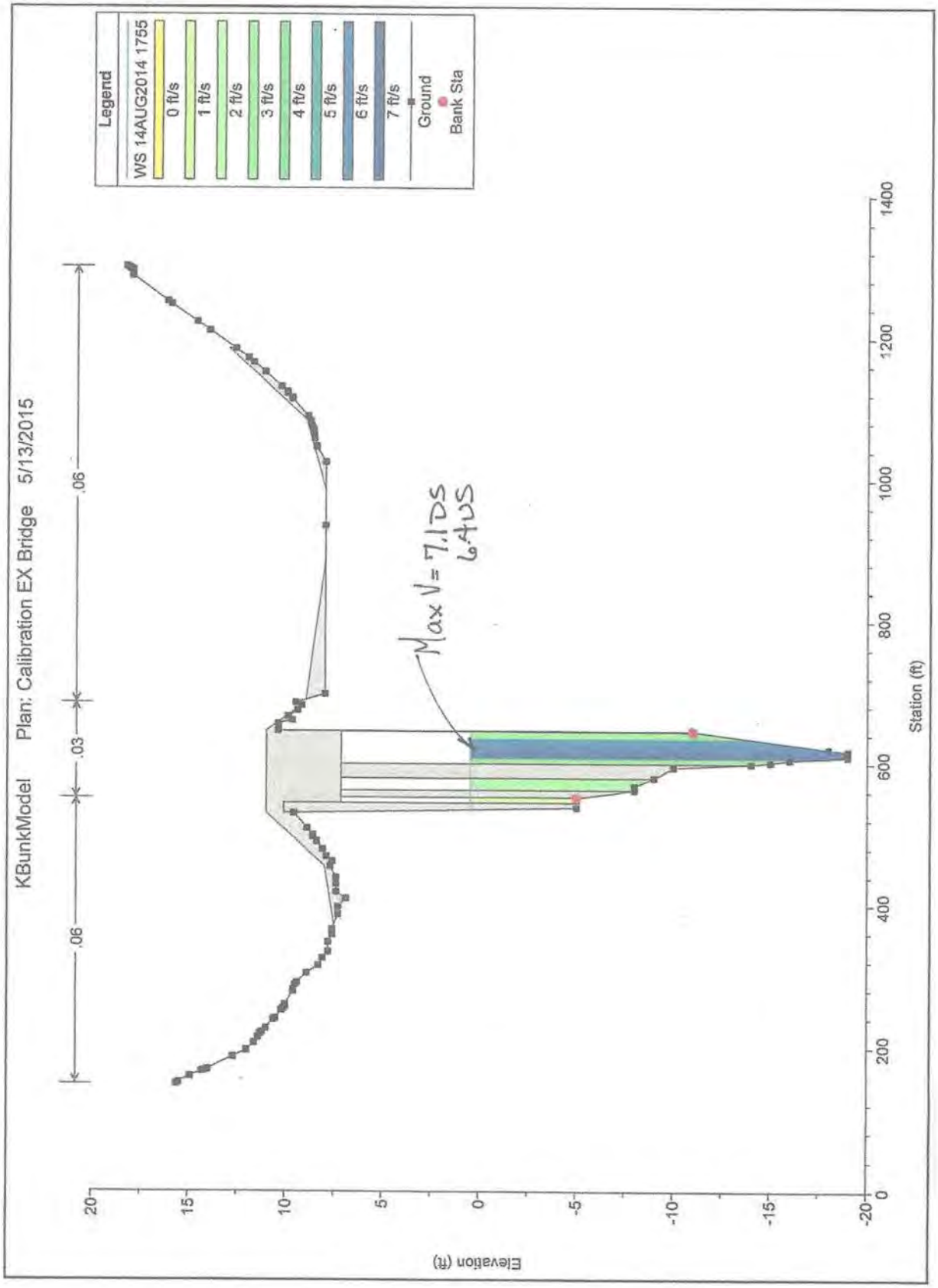

Plan: T50wavesSLR no pier River: Kennebunk Reach: Main RS: 7245
Legend
Stage HW
Stage TW
Flow
Stage (ft)
Flow (cfs)
Time
06Feb78
07Feb78
08Feb78
07Feb1615
Feb07 0730
Feb07 1230
07Feb1600
VMax=7.5DS
1 in Horiz. = 0.5 1 in Vert. = 3 ft

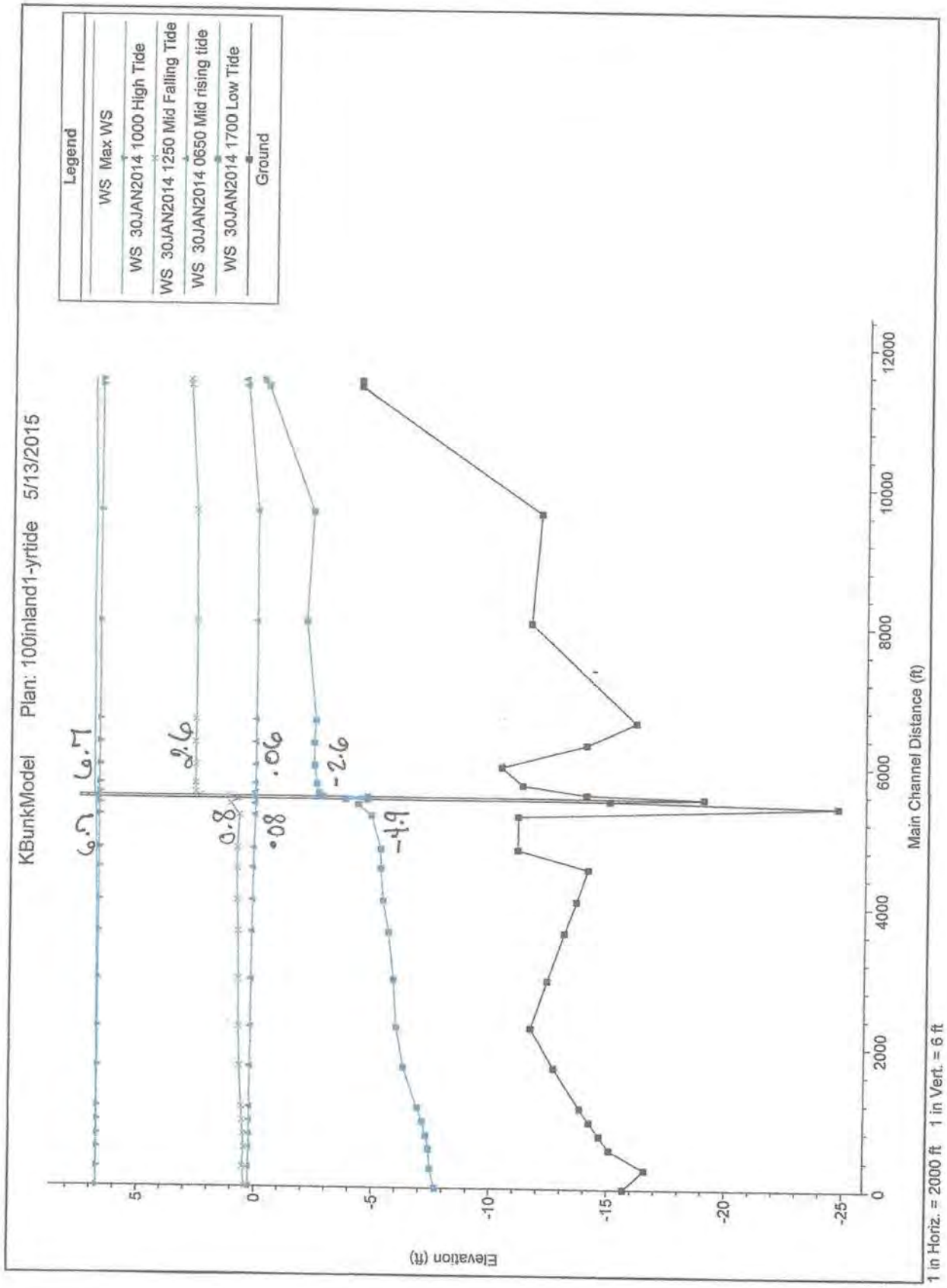

KBunkModel Plan: april 2007 no pier 2/4/2016
Legend
WS Max WS
WS 16APR2007 1000
WS 16APR2007 0630 Rising tide
WS 16APR2007 1250 falling tide
WS 16APR2007 1600
Ground
Elevation (ft)
Main Channel Distance (ft)
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft
7.9
7.7
3.6
2.2
1.7
1.7
-0.17
-2.5

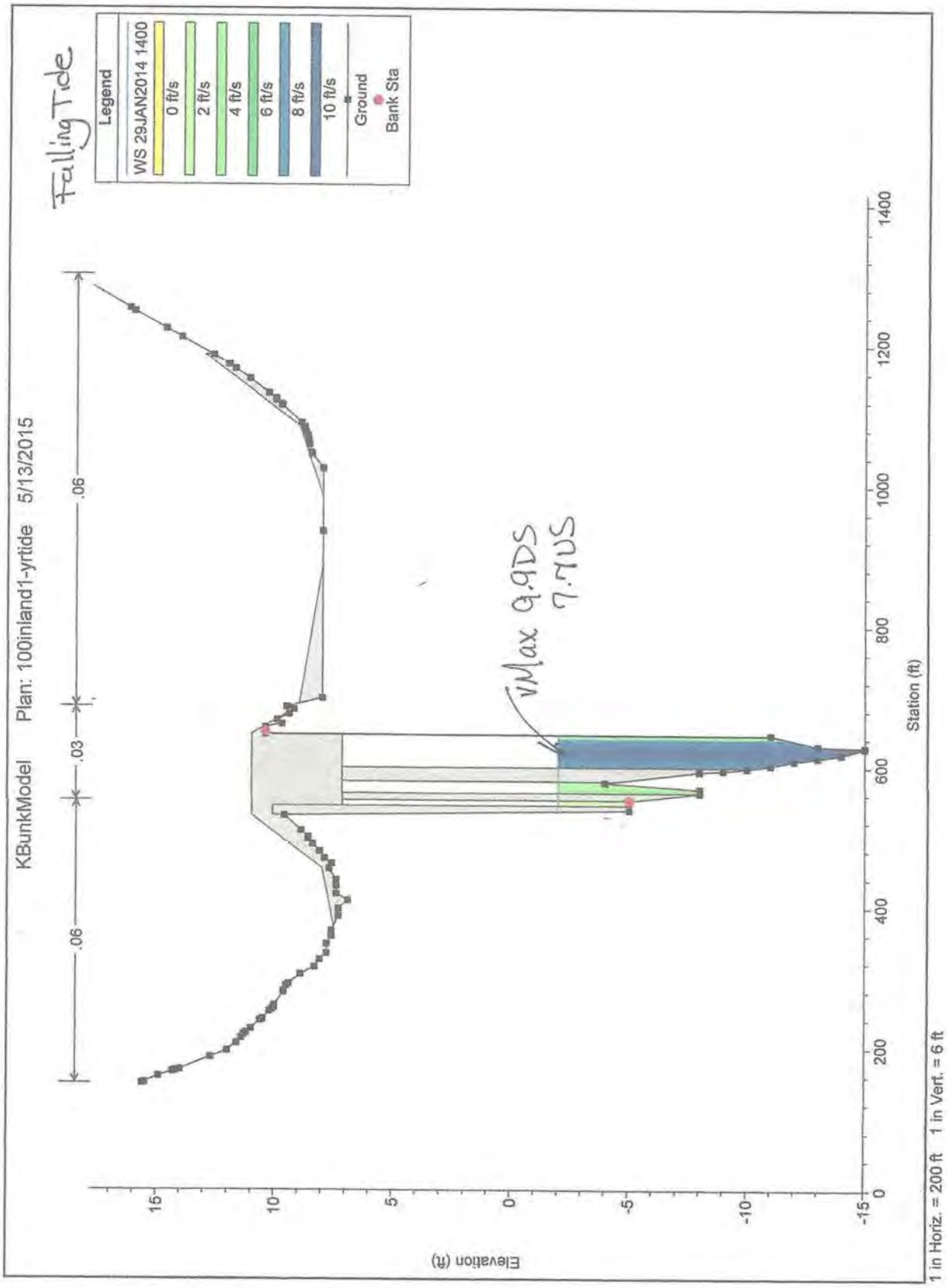

KBunkModel Plan: april 2007 no pier 2/4/2016
Legend
WS 16APR2007 1410
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
Ground
Bank Sta
.06
.03
.06
VMax US = 8.6 FPS
DS = 11.24 FPS
Elevation (ft)
Station (ft)
20
10
0
-10
0
200
400
600
800
1000
1200
1400
1 in Horiz. = 200 ft 1 in Vert. = 8 ft

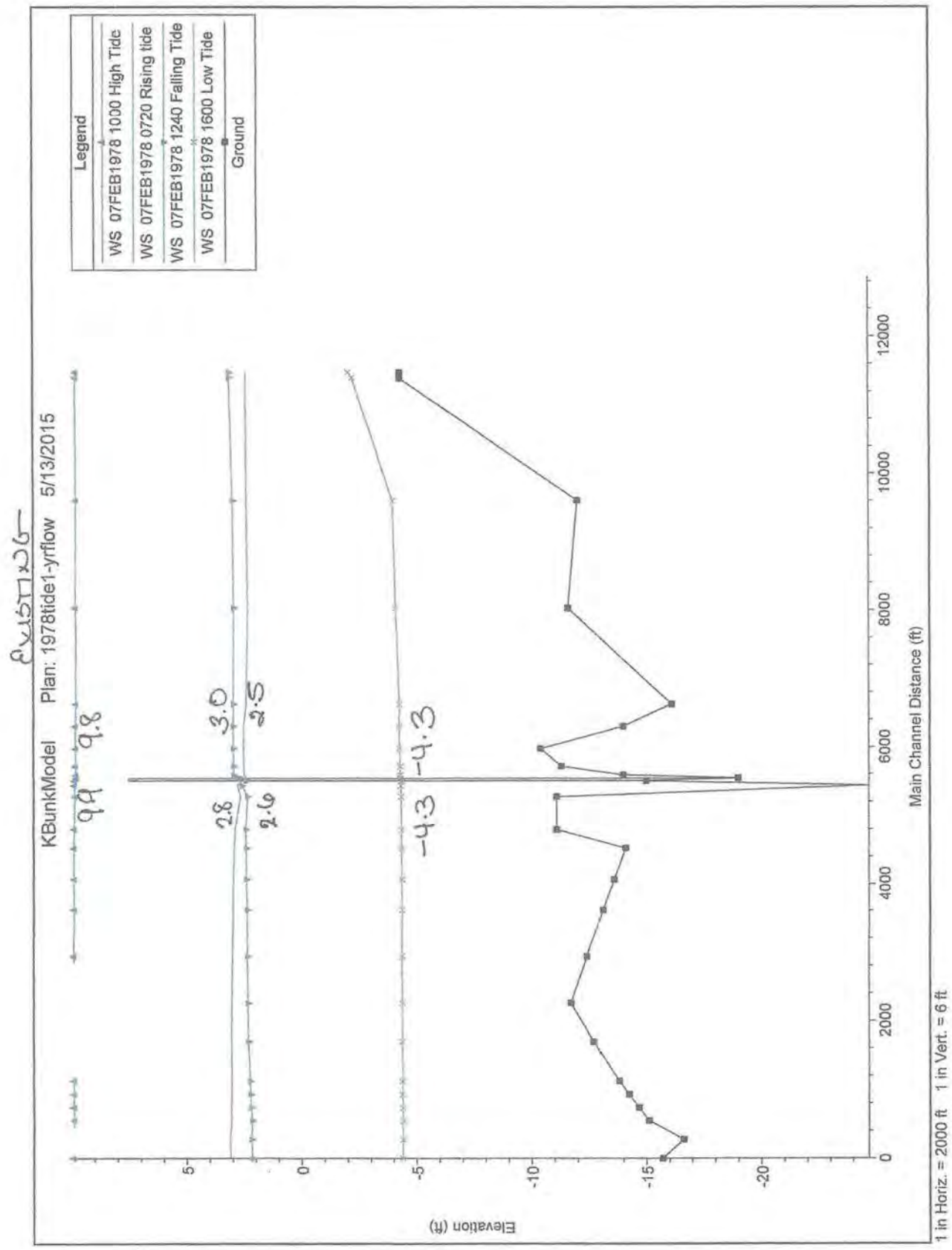

EXISTING BRIDGE MODEL
Legend
Ground
Bank Sta
RS=7245 Upstream (Bridge)
RS=7245 Downstream (Bridge)
Elevation (ft)
Station (ft)
30
20
10
0
-10
-20
500
550
600
650
700
750
1 in Horiz. = 40
1 in Vert. = 10

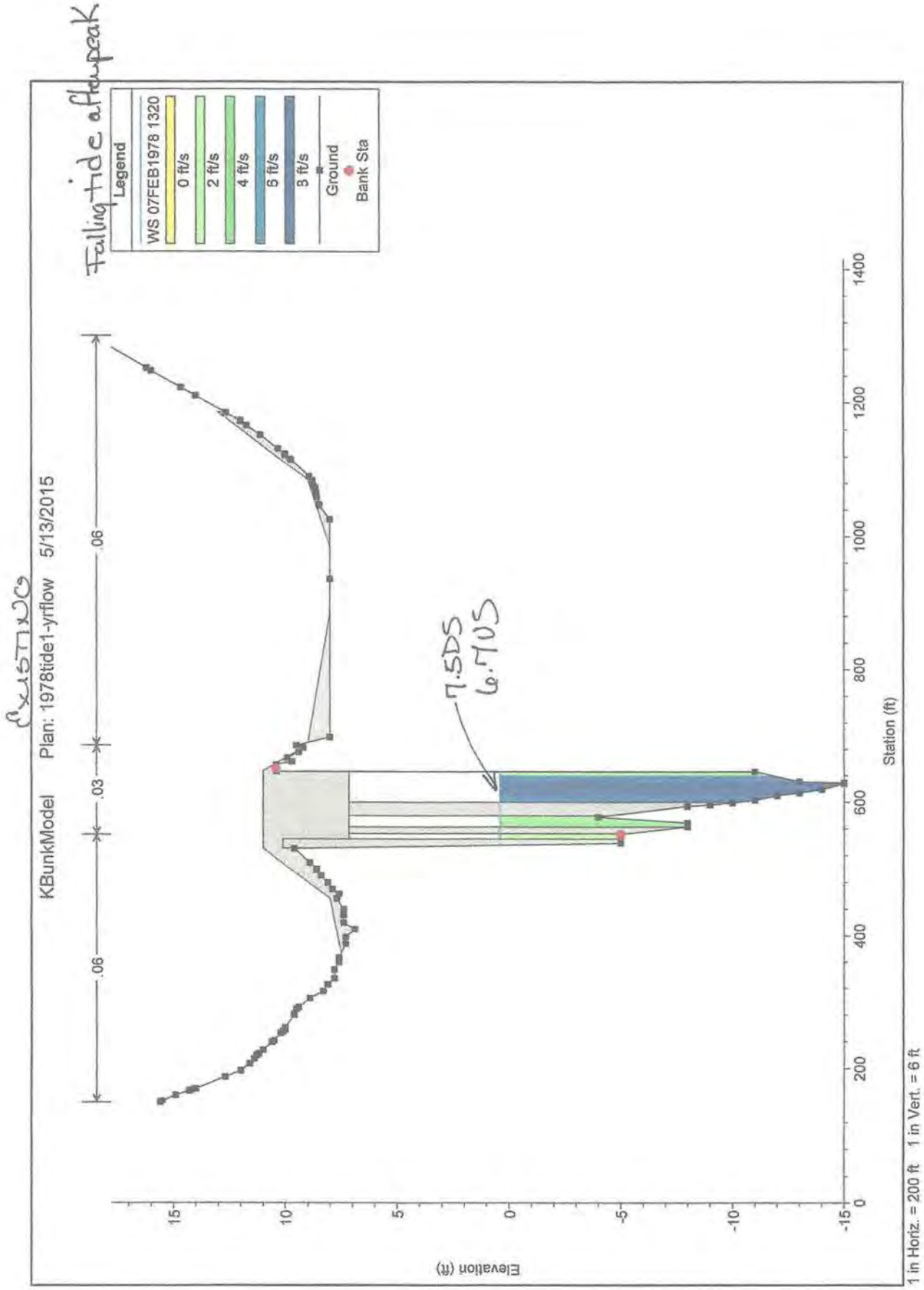

KBunkModel Plan: Calibration EX Bridge 5/13/2015
Legend
WS Max WS
WS 14AUG2014 0140 High Tide
WS 14AUG2014 1130 Mid Rising Tide
WS 14AUG2014 0515 Mid Falling tide
WS 14AUG2014 0815 Low Tide
Ground
6.5
6.5
1.8
1.2
0.8
0.9
-4.5
-4.7
Recorded Data
K2 (DS) K1 (US) Q
Max Tide 6.55 6.51 782
Mid Rising 0.7 0.65 948
Mid Falling 1.32 1.88 859
Low -4.7 -3.4 930
Lowest -4.7 -4.5 764
Elevation (ft)
5
0
-5
-10
-15
-20
-25
0
2000
4000
6000
8000
10000
12000
Main Channel Distance (ft)
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft

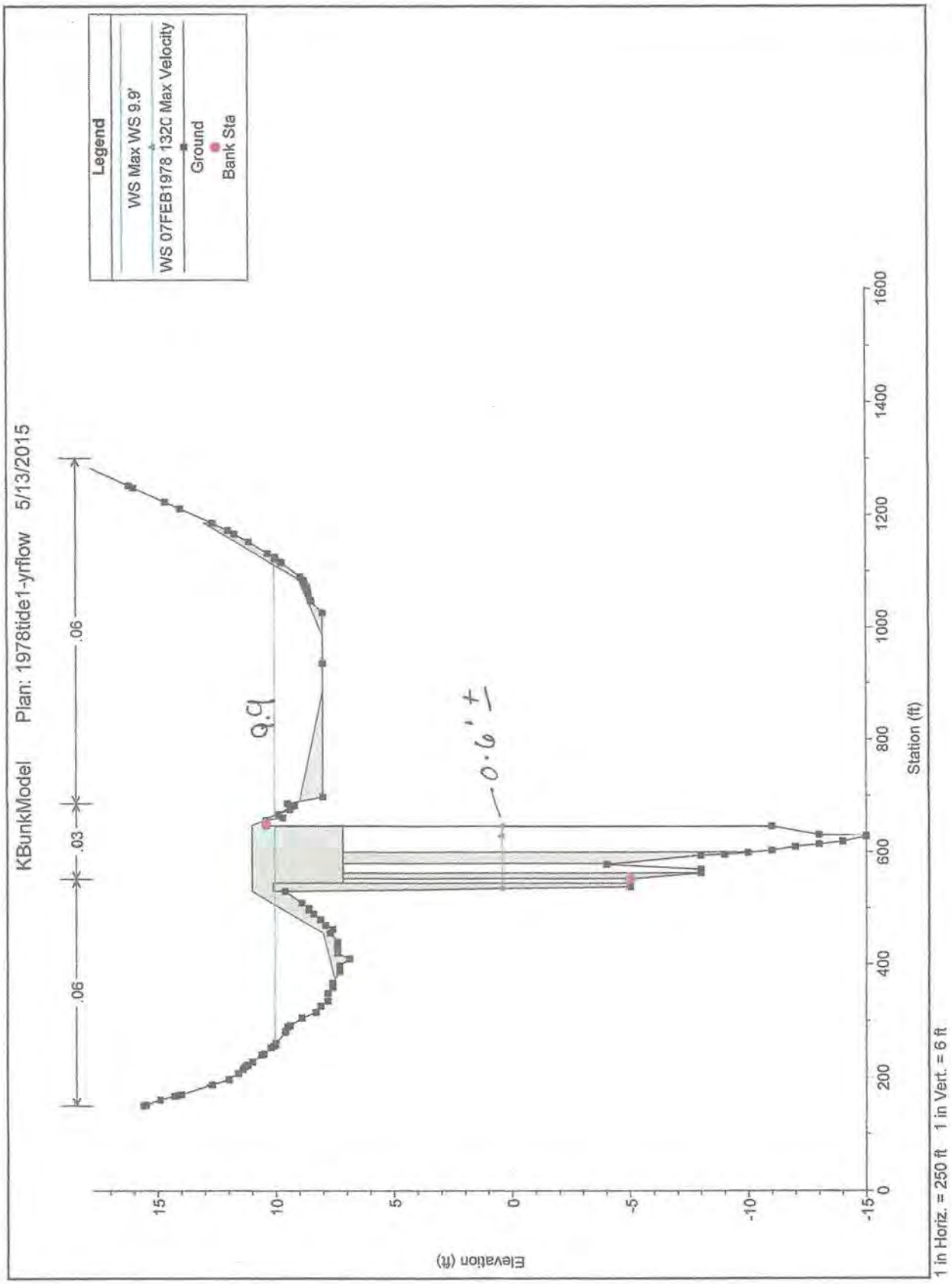

KBunkModel Plan: Calibration EX Bridge 5/13/2015
Legend
WS 14AUG2014 1755
0 ft/s
1 ft/s
2 ft/s
3 ft/s
4 ft/s
5 ft/s
6 ft/s
7 ft/s
Ground
Bank Sta
.06
.03
.06
Max V = 7.1 DS
6.4 US
Elevation (ft)
Station (ft)
20
15
10
5
0
-5
-10
-15
-20
0
200
400
600
800
1000
1200
1400

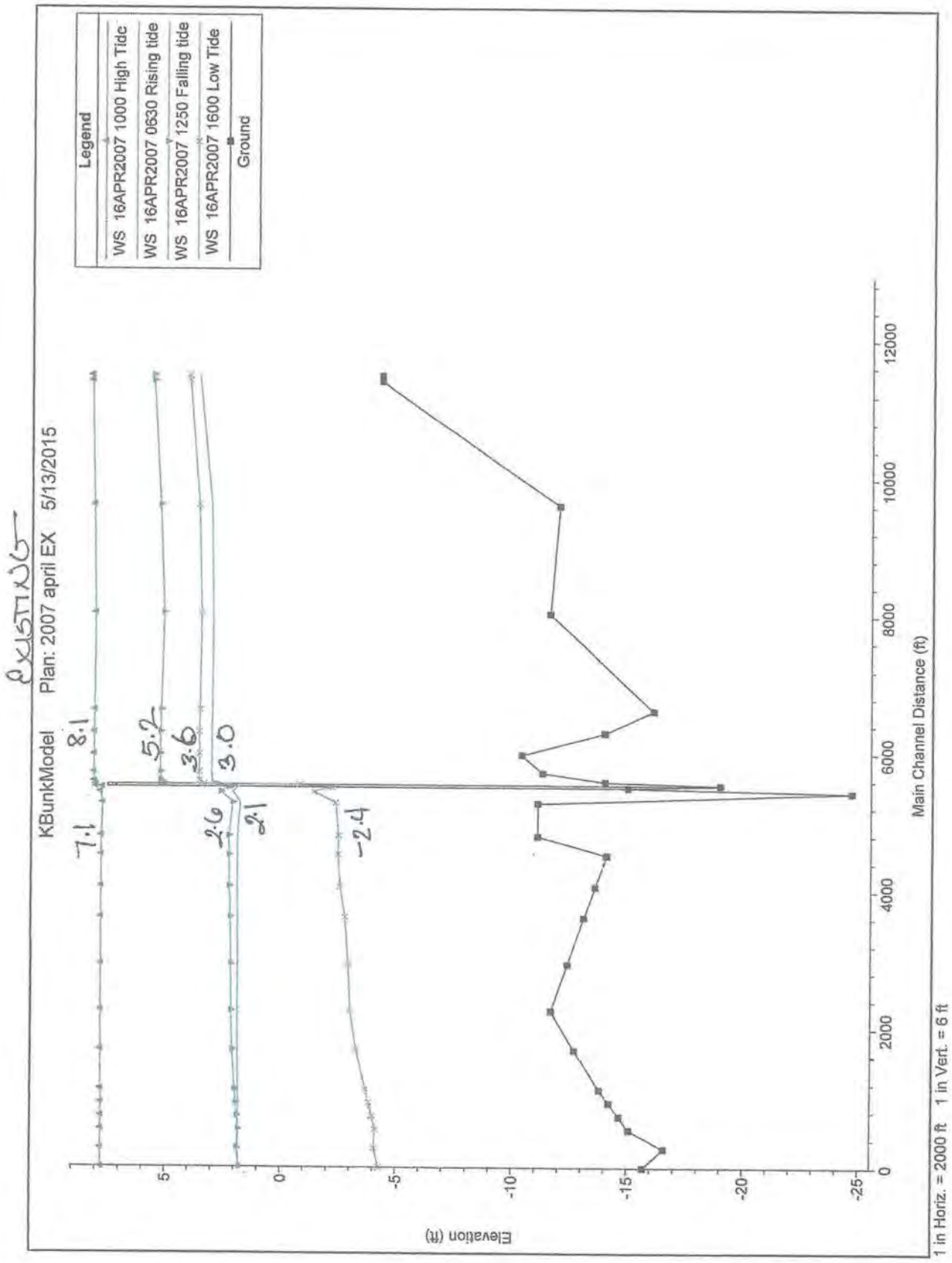

KBunkModel Plan: 100inland1-yrtide 5/13/2015
Legend
WS Max WS
WS 30JAN2014 1000 High Tide
WS 30JAN2014 1250 Mid Falling Tide
WS 30JAN2014 0650 Mid rising tide
WS 30JAN2014 1700 Low Tide
Ground
Elevation (ft)
Main Channel Distance (ft)
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft

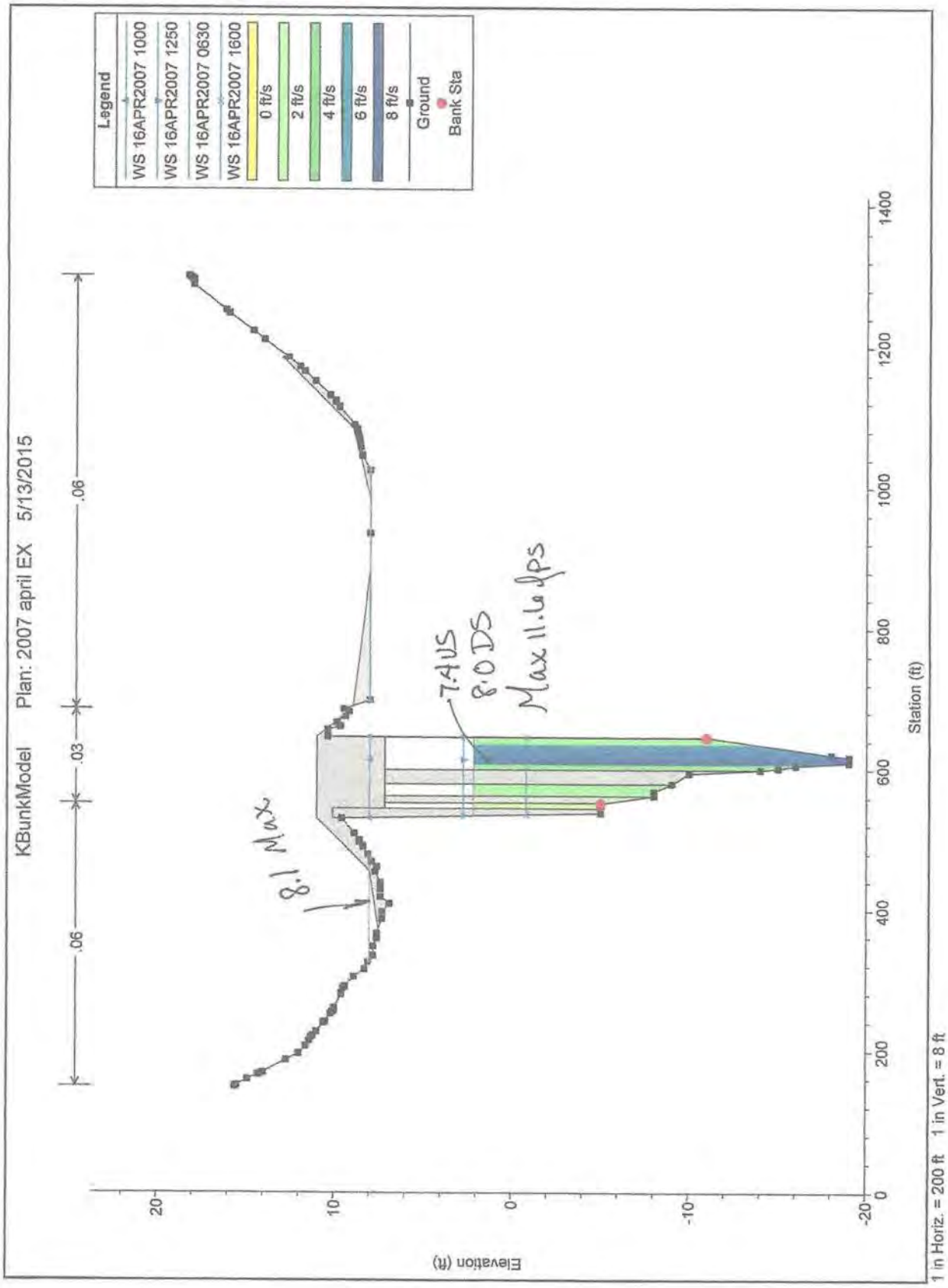

KBunkModel Plan: 100inland1-yrtide 5/13/2015
Falling Tide
Legend
WS 29JAN2014 1400
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
Ground
Bank Sta
.06
.03
.06
VMax 9.9DS
7.7US
Elevation (ft)
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 6 ft

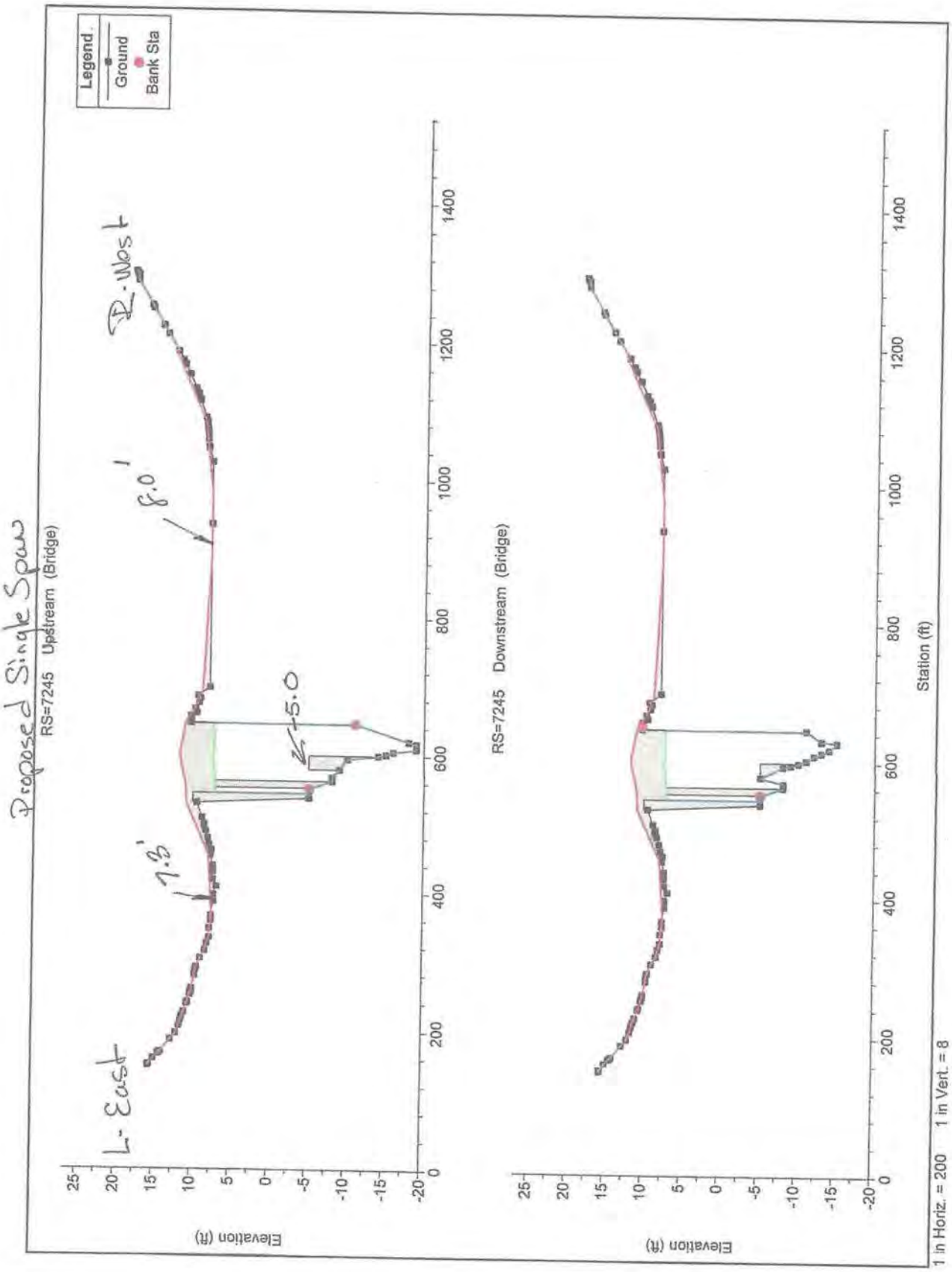

KBunkModel Plan: 1978tide1-yrflow 5/13/2015
Legend
WS 07FEB1978 1000 High Tide
WS 07FEB1978 0720 Rising tide
WS 07FEB1978 1240 Falling Tide
WS 07FEB1978 1600 Low Tide
Ground
Elevation (ft)
Main Channel Distance (ft)
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft
9.9
9.8
3.0
2.5
2.8
2.6
-4.3
-4.3


Falling tide after peak
Legend
WS 07FEB1978 1320
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
Ground
Bank Sta
Existing
KBunkModel Plan: 1978tide1-yrflow 5/13/2015
.06
.03
.06
7.5DS
6.7US
Elevation (ft)
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 6 ft


KBunkModel Plan: 1978tide1-yrflow 5/13/2015
Legend
WS Max WS 9.9'
WS 07FEB1978 132C Max Velocity
Ground
Bank Sta
.06
.03
.06
Q.C
0.6' +
Elevation (ft)
Station (ft)
1 in Horiz. = 250 ft 1 in Vert. = 6 ft


Existing
KBunkModel Plan: 2007 april EX 5/13/2015
Legend
WS 16APR2007 1000 High Tide
WS 16APR2007 0630 Rising tide
WS 16APR2007 1250 Falling tide
WS 16APR2007 1600 Low Tide
Ground
8.1
7.1
5.2
3.6
3.0
2.6
2.1
-2.4
Elevation (ft)
5
0
-5
-10
-15
-20
-25
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
1 in Horiz. = 2000 ft 1 in Vert. = 6 ft


KBunkModel Plan: 2007 april EX 5/13/2015
Legend
WS 16APR2007 1000
WS 16APR2007 1250
WS 16APR2007 0630
WS 16APR2007 1600
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
Ground
Bank Sta
.06
.03
.06
8.1 Max
7.4US
8.0DS
Max 11.6 fps
Elevation (ft)
Station (ft)
1 in Horiz. = 200 ft 1 in Vert. = 8 ft


Proposed Single Span
RS=7245 Upstream (Bridge)
RS=7245 Downstream (Bridge)
Legend
Ground
Bank Sta
L- East
R- West
7.3'
8.0'
5.0
Elevation (ft)
Station (ft)
1 in Horiz. = 200 1 in Vert. = 8

Kennebunk Route 9 Feb 07, 1978 1130 Am outgoing hydrograph

Contraction Scour

	Left	Channel	Right
Input Data			
Average Depth (ft):	1.96	12.10	1.73
Approach Velocity (ft/s):	0.15	1.02	0.13
Br Average Depth (ft):	6.01		
BR Opening Flow (cfs):	127.83	8952.86	
BR Top WD (ft):	14.33		
Grain Size D50 (mm):	0.10	0.10	0.10
Approach Flow (cfs):	3.29	7740.72	4.62
Approach Top WD (ft):	11.45	626.64	19.78
K1 Coefficient:	0.690	0.690	0.640
Results			
Scour Depth Ys (ft):	1.54		
Critical Velocity (ft/s):	0.86		
Equation:	Clear		

Pier Scour

All piers have the same scour depth

Input Data	
Pier Shape:	Round nose
Pier Width (ft):	10.00
Grain Size D50 (mm):	0.10000
Depth Upstream (ft):	26.46
Velocity Upstream (ft/s):	7.02
K1 Nose Shape:	1.00
Pier Angle:	
Pier Length (ft):	44.00
K2 Angle Coef:	
K3 Bed Cond Coef:	1.10
Grain Size D90 (mm):	
K4 Armouring Coef:	1.00
Set K1 value to 1.0 because angle > 5 degrees	
Results	
Scour Depth Ys (ft):	
Froude #:	
Equation:	CSU equation

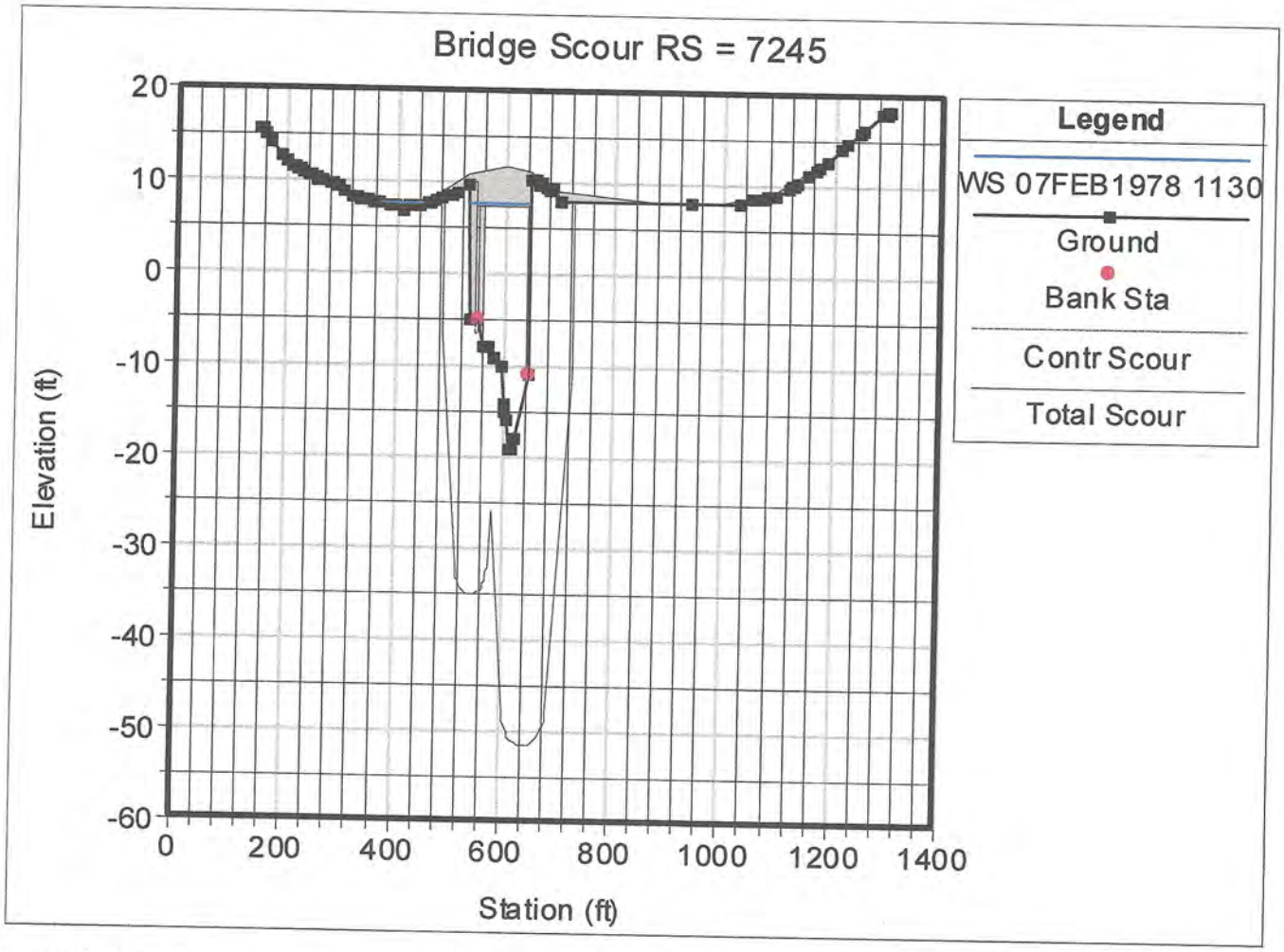
Abutment Scour

	Left	Right
Input Data		
Station at Toe (ft):	545.00	645.00
Toe Sta at appr (ft):	453.05	1049.98
Abutment Length (ft):	300.00	400.00
Depth at Toe (ft):	12.56	18.84
K1 Shape Coef:	1.00 - Vertical abutment	
Degree of Skew (degrees):	90.00	90.00
K2 Skew Coef:	1.00	1.00
Projected Length L' (ft):	300.00	400.00
Avg Depth Obstructed Ya (ft):	11.63	19.00
Flow Obstructed Qe (cfs):	3040	4500
Area Obstructed Ae (sq ft):	3240	4960
Results		
Scour Depth Ys (ft):	28.49	40.29

Qe/Ae = Ve:	0.94	0.91
Froude #:	0.05	0.04
Equation:	Froehlich	Froehlich

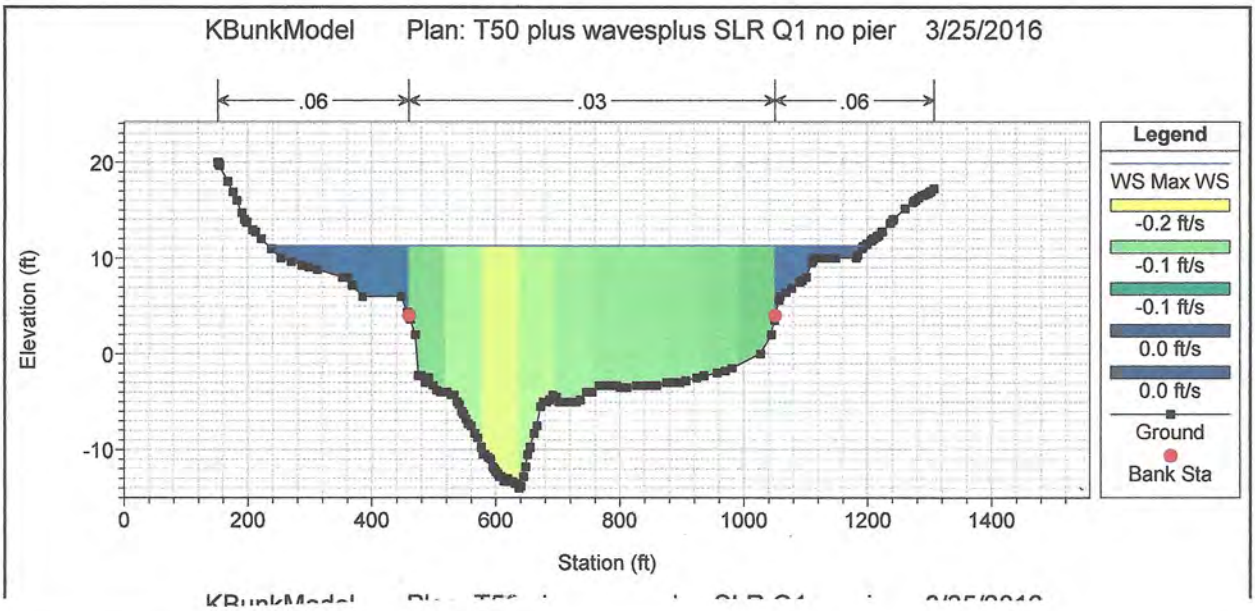
Combined Scour Depths

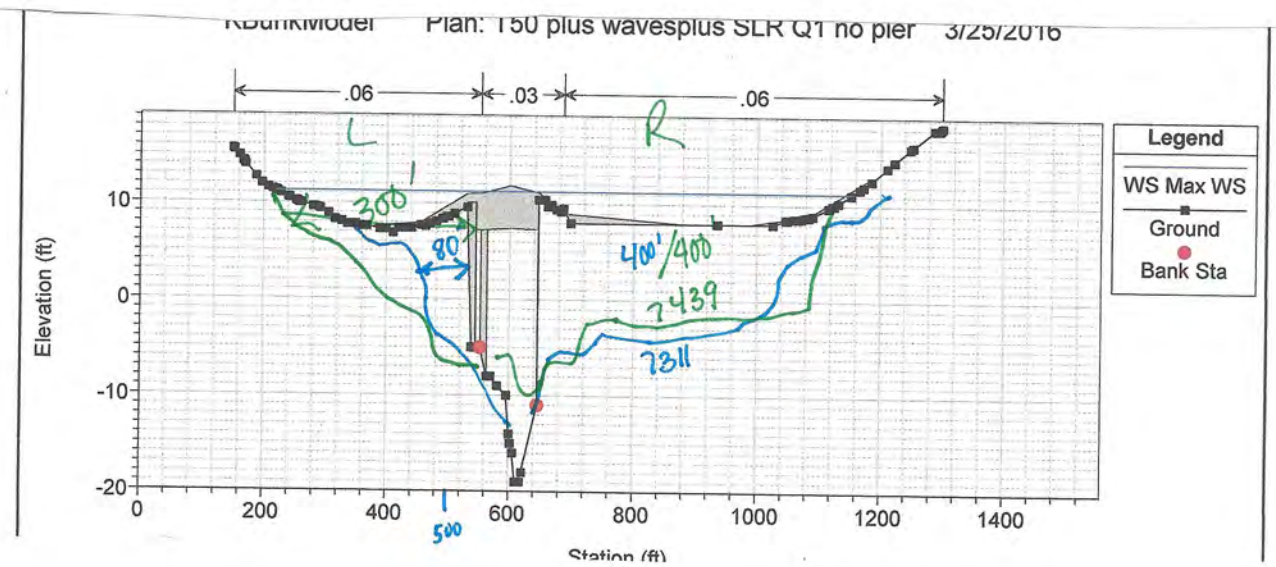
Pier Scour + Contraction Scour (ft):	
	Channel:
Left abutment scour + contraction scour (ft):	30.02
Right abutment scour + contraction scour (ft):	40.29



Route 9, Kennebunk

Potential Scour prism assuming unlimited overburden of fine sand.


KBunkModel Plan: T50 plus wavesplus SLR Q1 no pier 3/25/2016
.06
.03
.06
Elevation (ft)
Station (ft)
Legend
WS Max WS
-0.2 ft/s
-0.1 ft/s
-0.1 ft/s
0.0 ft/s
0.0 ft/s
Ground
Bank Sta


KBunkModel Plan: T50 plus wavesplus SLR Q1 no pier 3/25/2016
.06
.03
.06
L
R
300'
80
400'/400
7439
7311
500
Elevation (ft)
Station (ft)
Legend
WS Max WS
Ground
Bank Sta

3040 3240

Plan: T50wavesSLR no pier Kennebunk Main RS: 7439 Profile: 07FEB1978 1130

	Pos	Left Sta	Right Sta	Flow	Area	W.P.	Percent	Hydr	Velocity	Shear	Power
		(ft)	(ft)	(cfs)	(sq ft)	(ft)	Conv	Depth(ft)	(ft/s)	(lb/sq ft)	(lb/ft s)
1	LOB	142.03	189.37	4.71	50.95	45.27	0.06	1.13	0.09	0.00	0.00
2	LOB	189.37	236.72	19.49	121.64	47.40	0.24	2.57	0.16	0.00	0.00
3	Chan	236.72	309.56	380.28	550.16	73.18	4.62	7.55	0.69	0.01	0.00
4	Chan	309.56	382.40	731.09	815.03	73.33	8.88	11.19	0.90	0.01	0.01
5	Chan	382.40	455.23	1218.53	1104.75	72.90	14.80	15.17	1.10	0.01	0.01
6	Chan	455.23	528.07	1372.93	1191.34	73.61	16.67	16.36	1.15	0.01	0.02
7	Chan	528.07	600.91	1178.18	1084.09	73.14	14.31	14.88	1.09	0.01	0.01
8	Chan	600.91	673.75	732.44	813.99	72.90	8.89	11.18	0.90	0.01	0.01
9	Chan	673.75	746.59	759.51	831.83	72.88	9.22	11.42	0.91	0.01	0.01
10	Chan	746.59	819.43	670.54	771.78	72.85	8.14	10.60	0.87	0.01	0.01
11	Chan	819.43	892.27	647.35	755.67	72.85	7.86	10.37	0.86	0.01	0.01
12	Chan	892.27	965.11	514.59	662.31	73.92	6.25	9.09	0.78	0.01	0.01
13	ROB	965.11	1084.49	5.02	41.41	27.64	0.06	1.52	0.12	0.00	0.00

490 abut.
CL @ 504
abut 521
1/2
4500 4960

Plan: T50wavesSLR no pier Kennebunk Main RS: 7245 BR D Profile: 07FEB1978 1130

	Pos	Left Sta	Right Sta	Flow	Area	W.P.	Percent	Hydr	Velocity	Shear	Power
		(ft)	(ft)	(cfs)	(sq ft)	(ft)	Conv	Depth(ft)	(ft/s)	(lb/sq ft)	(lb/ft s)
1	LOB	471.60	552.00	127.37	86.20	26.25	1.40	12.31	1.48	0.15	0.22
2	Chan	552.00	561.85	11.45	12.45	14.56	0.13	12.45	0.92	0.04	0.04
3	Chan	561.85	571.70	342.65	132.02	32.82	3.77	15.17	2.60	0.19	0.48
4	Chan	571.70	581.55	592.66	129.09	13.69	6.53	13.11	4.59	0.44	2.01
5	Chan	581.55	591.40	805.53	136.94	10.02	8.87	13.90	5.88	0.63	3.72
6	Chan	591.40	601.25	1029.93	160.84	10.36	11.34	16.33	6.40	0.72	4.61
7	Chan	601.25	611.10	1328.10	184.76	10.01	14.63	18.76	7.19	0.86	6.15
8	Chan	611.10	620.95	1558.40	203.70	10.05	17.16	20.68	7.65	0.94	7.18
9	Chan	620.95	630.80	1646.83	215.41	10.64	18.14	21.87	7.65	0.94	7.17
10	Chan	630.80	640.65	1438.45	193.90	10.02	15.84	19.69	7.42	0.90	6.65
11	Chan	640.65	650.50	199.29	89.42	28.06	2.19	17.14	2.23	0.15	0.33

538.3
90'
CL @ 628
17' 645.

5680 channel
9000 cfs total