CFD HYDRAULIC MODEL STUDY OF THE PIMA COUNTY WATER RECLAMATION CAMPUS DIVERSION STRUCTURE

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CFD HYDRAULIC MODEL STUDY OF THE PIMA COUNTY WATER RECLAMATION CAMPUS DIVERSION STRUCTURE

1.0 INTRODUCTION

Pima county, Arizona is considering the construction of a new waste water diversion structure. The proposed diversion structure will be located in the City of Tucson, AZ, and is part of the ROMP Plant interconnect project. The facility is designed to divert an initial (Phase 1) Average Daily Flow (ADF) and Peak Wet Weather Flow (PWF) of 32 MGD and up to 64 MGD, respectively. Under Phase 2, the design flows are an ADF of 48 MGD and a PWF of up to 96 MGD. Flows exceeding the WRC pumping rate will be allowed to continue through the plant interconnect to the Ina Road Treatment Facility. The proposed facility has one proposed junction boxes with interconnecting pipes as shown in Figure 1.

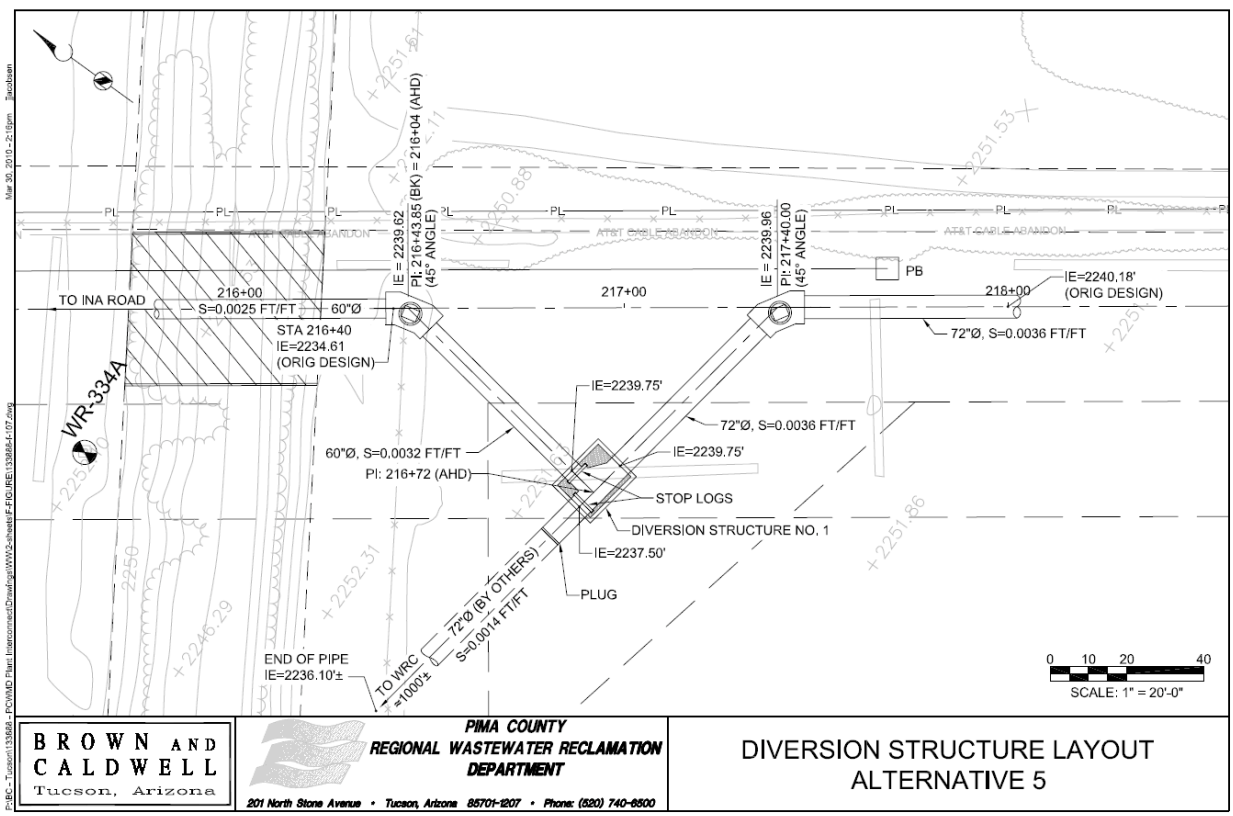

Figure 1. Pima county proposed diversion facility.

2.0 OBJECTIVES

The objective of the numeric modeling is to determine the flow characteristics and head loss associated with the proposed diversion structure at Pima County Regional Wastewater Reclamation facility.

3.0 APPROACH

A three-dimensional Computational Fluid Dynamics (CFD) program was used to model the diversion structure and predict the following for various flow conditions:

- Total head in both of the outlet pipes downstream of the diversion structures for each flow condition.
- Flow patterns in each of the three junction structures.

The flow split will be controlled by the pumping rate at the WRC influent pump station and was provided for each of the simulations.

The commercially available CFD software FLOW-3D was used for the simulations. The program solves the fully three dimensional Navier-Stokes equations in conjunction with an appropriate turbulence model for the creation, transport and dissipation of turbulent kinetic energy. FLOW-3D uses the Fractional Area/Volume Obstacle Representation (FAVOR) method (Hirt and Sicilian, 1985) for the modeling of solid obstacles, such as the pipes. The FAVOR method allows complex shapes to be simulated without resorting to 'stair stepping' the boundaries. It approaches the accuracy of more computationally intensive deformed boundary fitted grids.

The location of the free surface in FLOW-3D is computed using the Volume of Fluid (VOF) method (Hirt and Nichols, 1980). This formulation consists of three parts, a scheme to describe the shape and location of the free surface, a method to track the evolution of the shape and location of the free surface through time and space and a means for applying boundary conditions to the free surface. The simulation will not

include the movement of the air above the water; it is assumed that the air has no significant effect on the water movement.

There were three components in performing the CFD simulations: pre-processing, solving and post-processing. Pre-processing included building the model, creating and applying a suitable computational mesh, and entering necessary boundary conditions and fluid properties. The second stage was solving the governing equations and producing results. The final stage was post-processing the solution, interpreting the results of the computed flow data and flow visualization. Each component required making assumptions which can impact model results.

3.1 CFD Software

The following software was used in the modeling:

- FLOW-3D version 9.3 – program used for solving the governing equations of fluid flow with robust free surface model capability.
- AutoCAD 2008 – program used for creating model geometry.
- Gambit version 2.4.6 – FLUENT pre-processor program used for creating geometry and generating mesh.
- FiedView version 12.1 – program used for post-processing to produce images and animations.

3.2 Assumptions and Limitations

An unsteady simulation with the VOF method was used to predict the time evolution of the water free surface in the model. The water level at Ina, WRC, and Roger boundary was estimated by computing the normal depth.

3.3 Model Geometry and Computational Mesh

The model geometry was created using AutoCAD and Gambit. A three dimensional model for the Pima County diversion structure was created based on the construction drawings provided by Brown and Coldwell. The construction drawings are shown in Appendix A. The model domain for the Pima County diversion structure included a 72

inch pipe from “Roger” to “WRC”, the junction, the two bends, and a 60 inch diameter pipe from the Junction to "Ina". The model domain was about 300 feet (L) by 80 feet (W) by 10 ft (H). Figure 2 shows the CFD model geometry of the Pima County diversion structure.

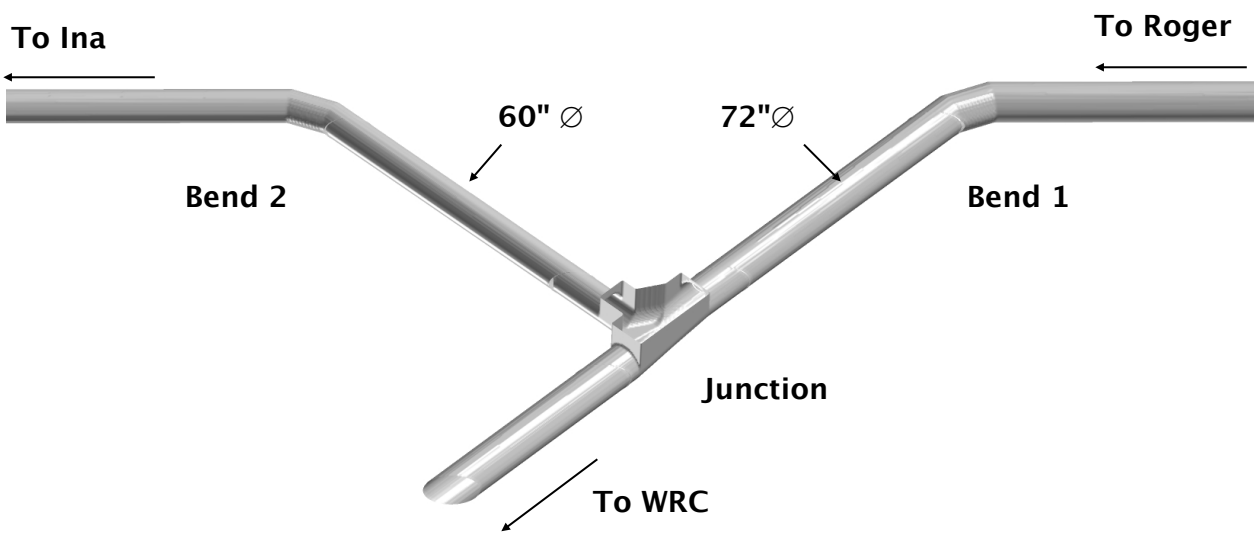

Figure 2. CFD model geometry of the Pima County diversion structure.

Creating an appropriate computational mesh is an important aspect of numeric modeling. The flow field is discretized into small finite volumes (cells) for solving. The governing equations of fluid flow are solved for each computational cell. In model regions with high gradients or flow separations, the cell size must be small enough to capture the flow features of interest. Typically, flow separations require at least 10 elements across the eddy to be resolved. Flow separations smaller than this will not be captured by the model.

FLOW-3D uses a structured hexagonal grid to discretize the flow field. Multiple mesh blocks are used to discretize complex structures where it is desirable to vary the grid resolution throughout the model. In this study, approximately 1 million cells were used in four mesh blocks. The horizontal grid resolutions was about x = 0.2 ft by y = 0.2 ft; while the vertical grid resolution vary from 0.01 ft to 0.04 ft and 0.08 ft to 0.2 ft depending on the flow scenario. Cases 1 and 4 used a smaller vertical cell size to better capture the shallow water in the low flow conditions. The computational mesh for the Pima County diversion structure model is shown in Figure 3.

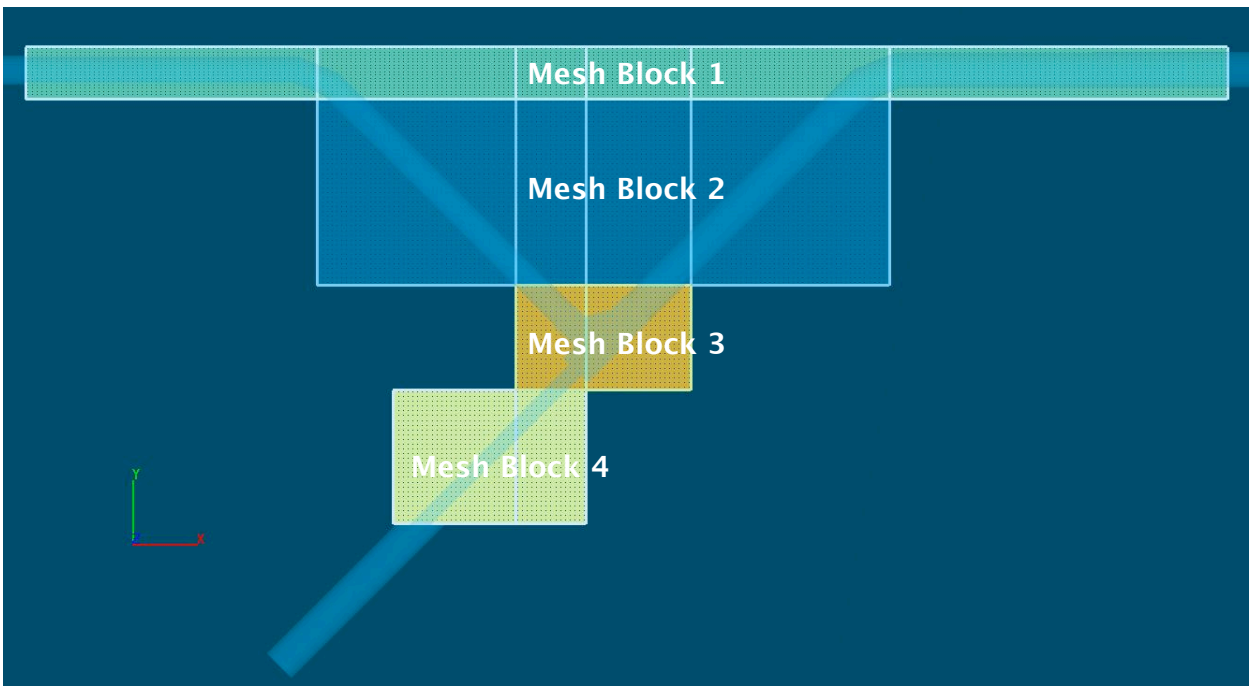

Figure 3. Computational mesh for the Pima County diversion structure model.

3.4 Boundary Conditions

Boundary conditions were specified at all model boundaries. Pipes, bends, and the junction structures were specified as no slip wall boundaries. At "Roger" an inflow boundary is specified with a volumetric flow rate. Similarly, at the "WRC" outflow

boundary an outflow velocity and water surface elevation were specified. At the "Ina" outflow boundary a water surface elevation was specified with a hydrostatic pressure distribution. The water surface elevation at the "WRC" and "Ina" outflow boundaries was computed using a normal depth calculation for the appropriate size pipe with the slope provided in the design documentation. The water surface was modeled as a free surface where the evolution, shape, and location of the free surface through time and space can be tracked.

3.5 Solver Settings

The Volume of Fluid (VOF) method in FLOW-3D was used to model free surface flow. In the FLOW-3D simulations, it was assumed that the air flow does not affect the water flow; therefore the air was not included in the simulations. Cells are filled or partially filled with water or they are void. For the steady state simulations performed in this study, the assumption is appropriate.

The Renormalized group (RNG) turbulence model was used to simulate the creation, transport and dissipation of turbulent kinetic energy. The turbulence model is consistent with the physics of turbulent flows and satisfies the mathematical constraints on the Reynolds stresses.

3.6 Post-Processing

The simulation results were post-processed and analyzed using the FieldView software. Post-processing involved both qualitative and quantitative analysis. Qualitative analysis includes the production of flow visualization showing the water surface colored by water surface elevation or velocity. Quantitative analysis includes calculation of the hydraulic and energy grade lines along the pipeline. Water level and cross sectional velocities were used at sections along the pipeline to compute the hydraulic and energy grade lines.

4.0 FLOW CONDITIONS STUDIED

The phase 1 diversion structure is designed to divert an initial Average Daily Flow (ADF) of 32 MGD and PWF of up to 64 MGD. In a subsequent phase, the design capacity may be increased to divert an ADF of 48 MGD and PWF of up to 96 MGD. Flow in excess of the WRC pumping capacity continues through the plant interconnects to the Ina Road Treatment Facility.

A total of eight flow scenarios with various flow splits were considered in this study. The first three flow scenarios were designed for an initial (Phase 1) flow diversion. Scenario's 1, 2, and 3 correspond to the minimum, average, and maximum flow condition for Phase 1, respectively. Similarly, the next three flow scenarios were designed for future (Phase 2) flow diversion. Scenario's 4, 5, and 6 correspond to the minimum, average, and maximum flow condition for Phase 2, respectively. The remaining two flow scenarios simulated Peak Wet Weather flow conditions. Table 1 shows the flow conditions and associated flow splits.

Table 1: Flow conditions studied.

		Phase 1 - MGD		
Flow #		To Roger	To WRC	To Ina
1	Min	17	16	1
2	Ave	42	32	10
3	Max	60	46	14

		Phase 2 - MGD		
Flow #		To Roger	To WRC	To Ina
4	Min	26	24	2
5	Ave	63	48	15
6	Max	90	69	21

		Peak Wet Weather - MGD		
Flow #		To Roger	To WRC	To Ina
7	Peaks	145	96	49
8	Peaks	145	64	81

5.0 CFD SIMULATION RESULTS

CFD simulations were performed to determine flow patterns and head loss in the proposed diversion structure at the Pima County Regional Wastewater Reclamation facility. The diversion structure layout is shown in Appendix A-1. A total of eight simulations were conducted to compute the head loss for various flow conditions. Flow characteristics were analyzed by rendering the water surface. Flow visualization showing the water surface is shown in Figures D-1 to D-8. Each figure also shows the specified flow split. The energy and hydraulic grade lines are computed at discrete locations along the length of the pipe. The locations are numbered 1 through 30 as shown in Figures E-1 to E-8.

5.1 Hydraulic Grade Line

The predicted hydraulic grade line for each scenario is shown in Appendix B. The head loss from "Roger" to "WRC" varied from about 0.8 ft to 0.9 ft for Phase 1 and Phase 2 flow scenarios, respectively. For the Peak Wet Weather flow scenario, the head loss was about 1.5 ft. Similarly, the head loss from "Roger" to "Ina" varied from about 1.5 ft to 2.3 ft for Phase 1 and about 1.5 ft to 2.4 ft for Phase 2 flow scenarios. For the Peak Wet Weather flow scenario, the head loss varied from 2.4 ft to 3.2 ft. Table 2 summarizes the computed change in water surface elevation from "Roger" to "WRC" and from "Roger" to "Ina". For low flow conditions (Scenario's 1 and 4) the head loss from "Roger" to "Ina" was relatively small compared to high flow conditions.

Table 2: Change in Water Surface Elevation (ft)

Location		Flow Scenarios							
		Phase 1			Phase 2			Peak Wet Weather	
From	To	1	2	3	4	5	6	7	8
Roger	WRC	0.8	0.7	0.8	0.6	0.9	0.9	1.5	1.5
Roger	Ina	1.5	1.9	2.3	1.5	2.4	2.8	3.2	2.4

5.2 Energy Grade Line

The computed energy grade line for each scenario is shown in Appendix C. The head loss from "Roger" to "WRC" varied from about 1.3 ft to 1.4 ft for Phase 1 and Phase 2 flow scenarios, respectively. For the Peak Wet Weather flow scenarios, the head loss varied from about 2.3 ft to 2.5 ft. The head loss from "Roger" to "Ina" varied from about 2.0 ft to 2.6 ft for Phase 1 and about 2.3 ft to 3.2 ft for Phase 2 flow scenarios. For the Peak Wet Weather flow scenario, the energy head loss varied from 2.4 ft to 3.6 ft. Table 3 summarizes the predicted head loss from "Roger" to "WRC" and from "Roger" to "Ina".

Table 3: Total Head Loss (Static plus Dynamic) in Feet

Location		Flow Scenarios							
		Phase 1			Phase 2			Peak Wet Weather	
From	**To**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Roger	**WRC**	1.4	1.3	1.3	1.4	1.4	1.5	2.3	2.5
Roger	**Ina**	2.0	2.1	2.6	2.3	2.6	3.2	3.6	2.4

6.0 CONCLUSIONS

A CFD model study of the proposed Pima County Regional Wastewater Reclamation diversion structure facility was performed to determine flow patterns and the head loss in the system. The key findings of the simulations are summarized as follows:

- The change in water surface elevation between "Roger" and "WRC" was about 0.8 ft for Phase 1 and about 0.9 ft for Phase 2 flow scenarios. For the Peak Wet Weather flow scenario, the head loss was about 1.5 ft.
- The total energy loss from "Roger" to "WRC" was about 1.3 ft for Phase 1 and about 1.4 ft for Phase 2 flow scenarios. For the Peak Wet Weather flow scenario, the head loss varied from about 2.3 ft to 2.5 ft.

- The change in water surface elevation between "Roger" and "Ina" varied from about 1.5 ft to 2.3 ft for Phase 1 and about 1.5 ft to 2.4 ft for Phase 2 flow scenarios. For the Peak Wet Weather flow scenario, the head loss varied from 2.4 ft to 3.2 ft.
- The total energy loss from "Roger" to "Ina" varied from about 2.0 ft to 2.6 ft for Phase 1 and about 2.3 ft to 3.2 ft for Phase 2 flow scenarios. For the Peak Wet Weather flow scenario, the energy loss varied from 2.4 ft to 3.6 ft.
- The CFD results provided detailed information about the flow patterns and water surface elevations in the diversion structure.
- A hydraulic jump is observed in the diversion junction. At this location, the Bernoulli equation for pipe flow is not applicable due to turbulence, strong vertical velocities, and large flow separations. The total energy as computed using the Bernoulli equation is not applicable in a flow separation.

APPENDIX A: CONSTRUCTION DRAWINGS

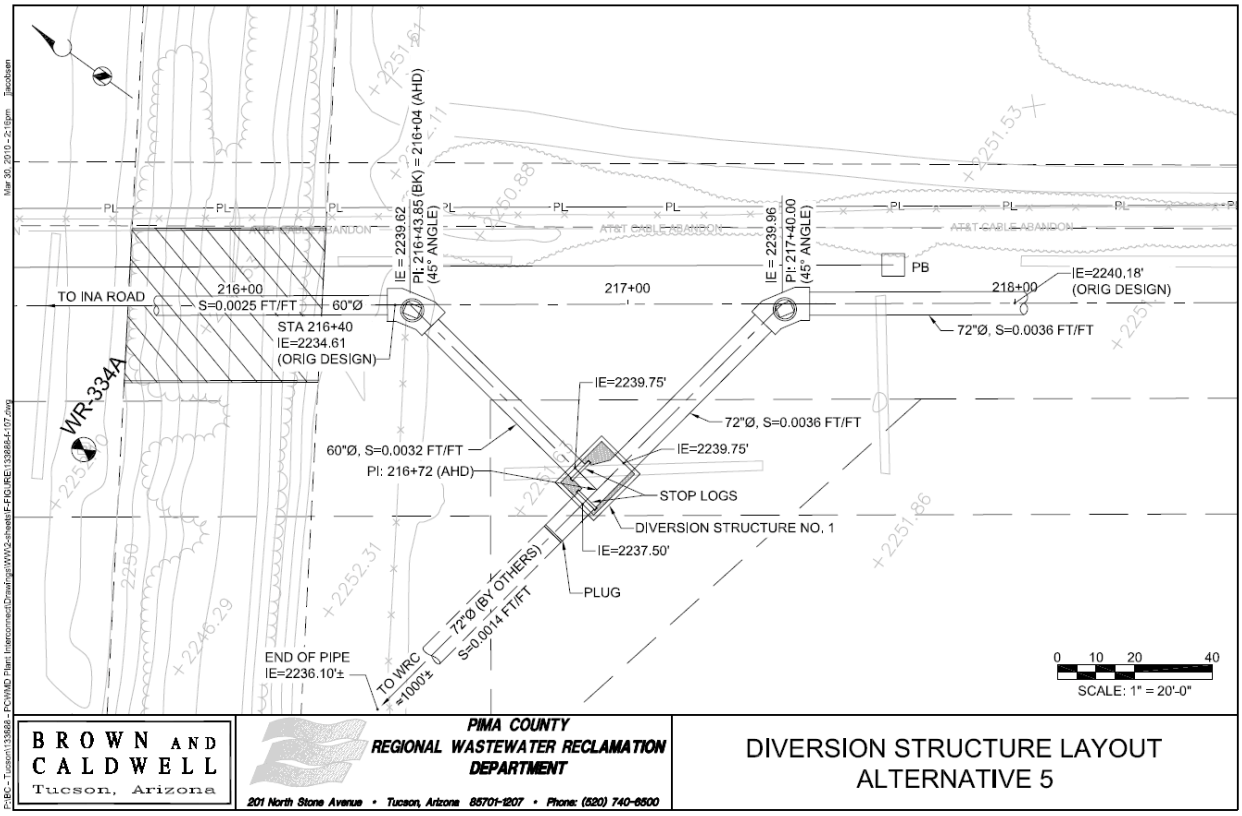

Figure A- 1. Pima county diversion structure layout.

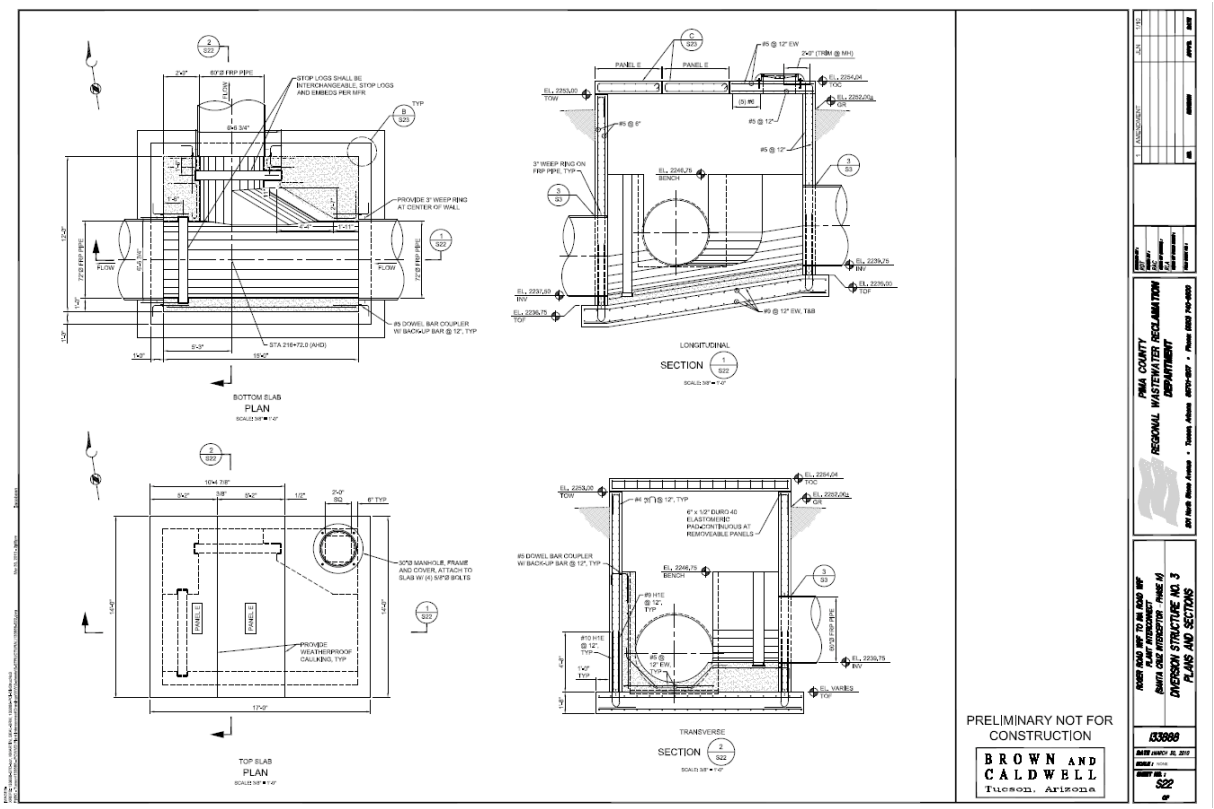

Figure A- 2. Diversion structure plans and sections.

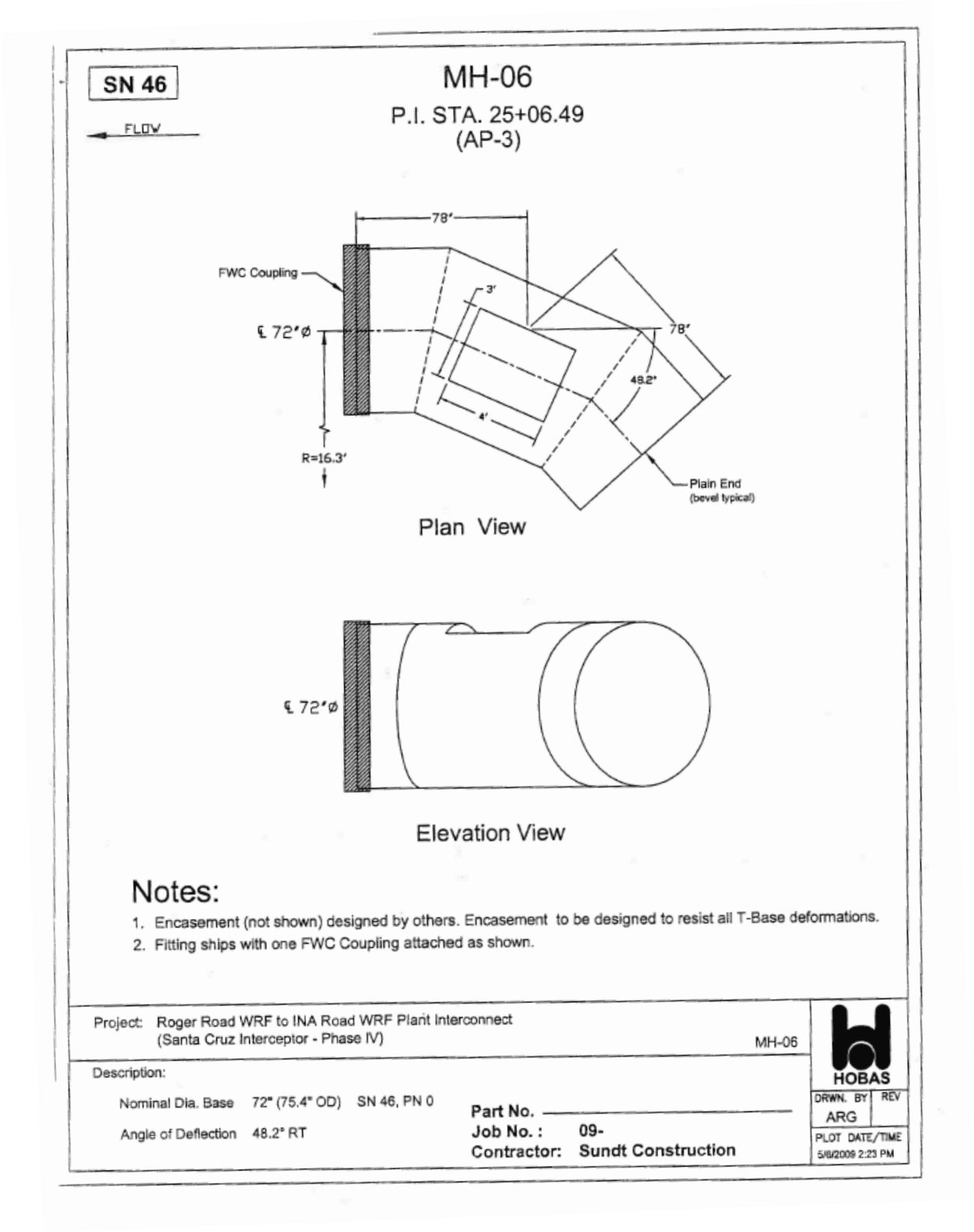

Figure A– 3. Pipe bend (MH–06).

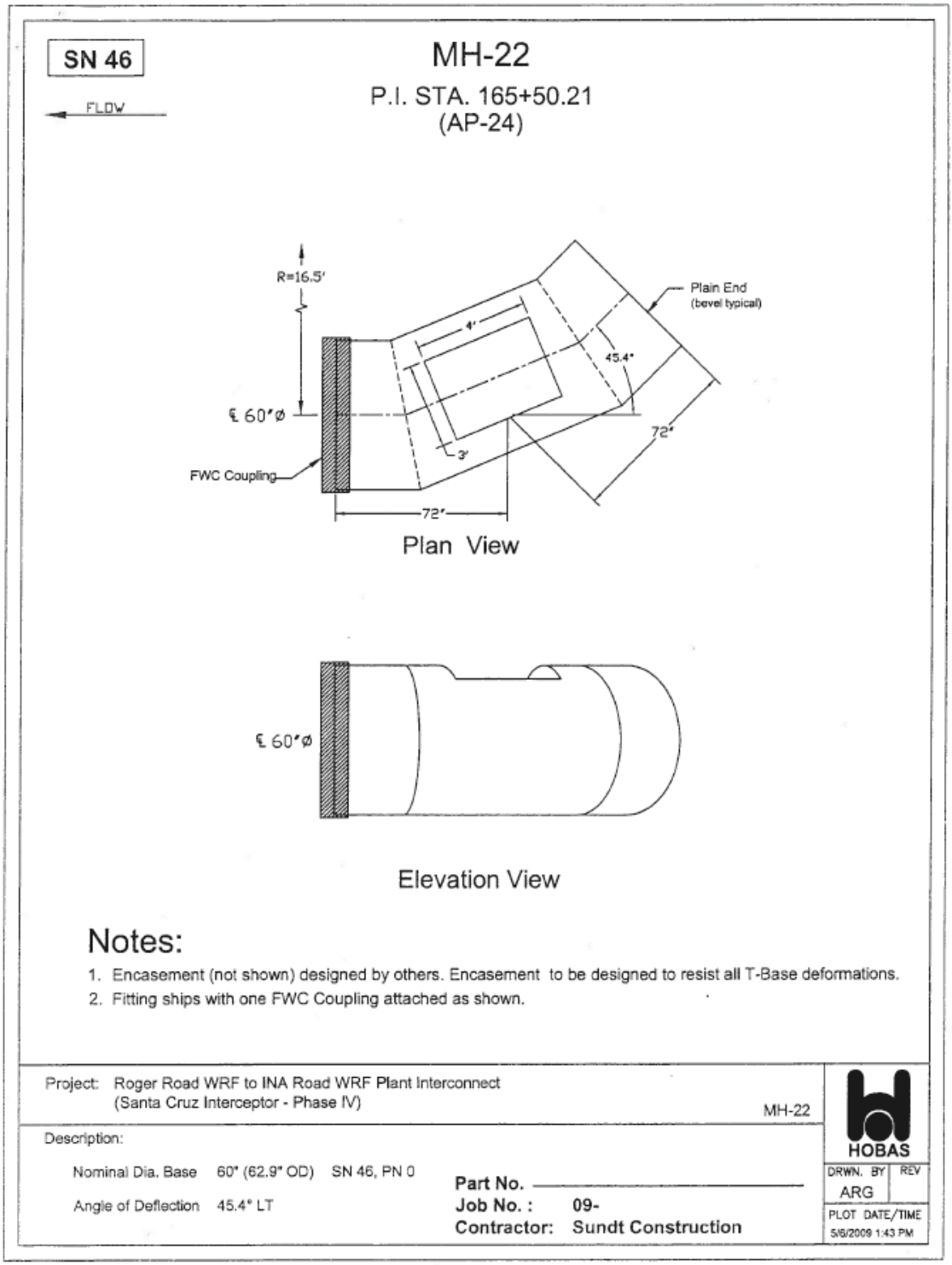

Figure A– 4. Pipe bend (MH–22).

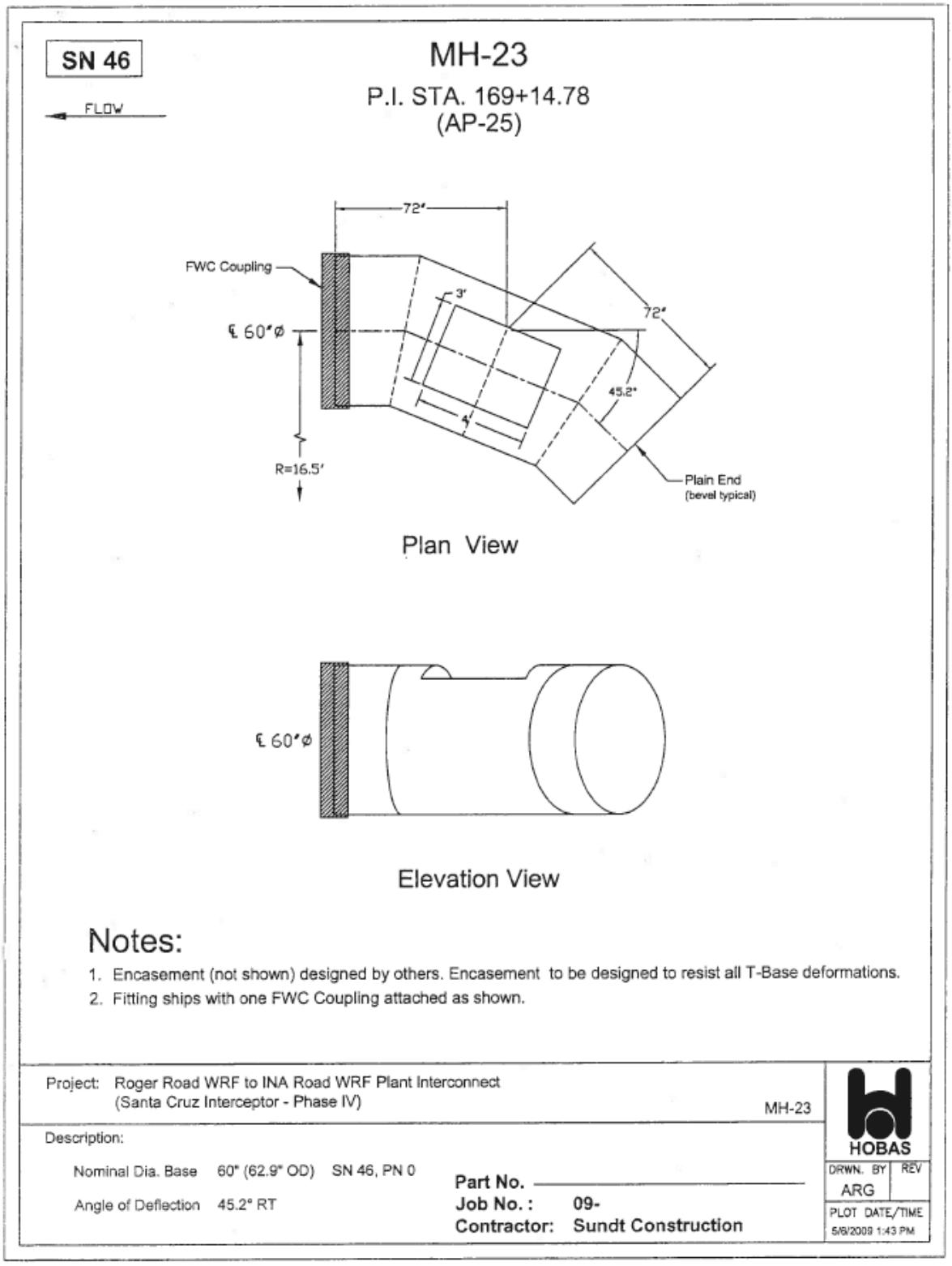

Figure A- 5. Pipe bend (MH-23).

APPENDIX B: HYDRAULIC GRADELINE

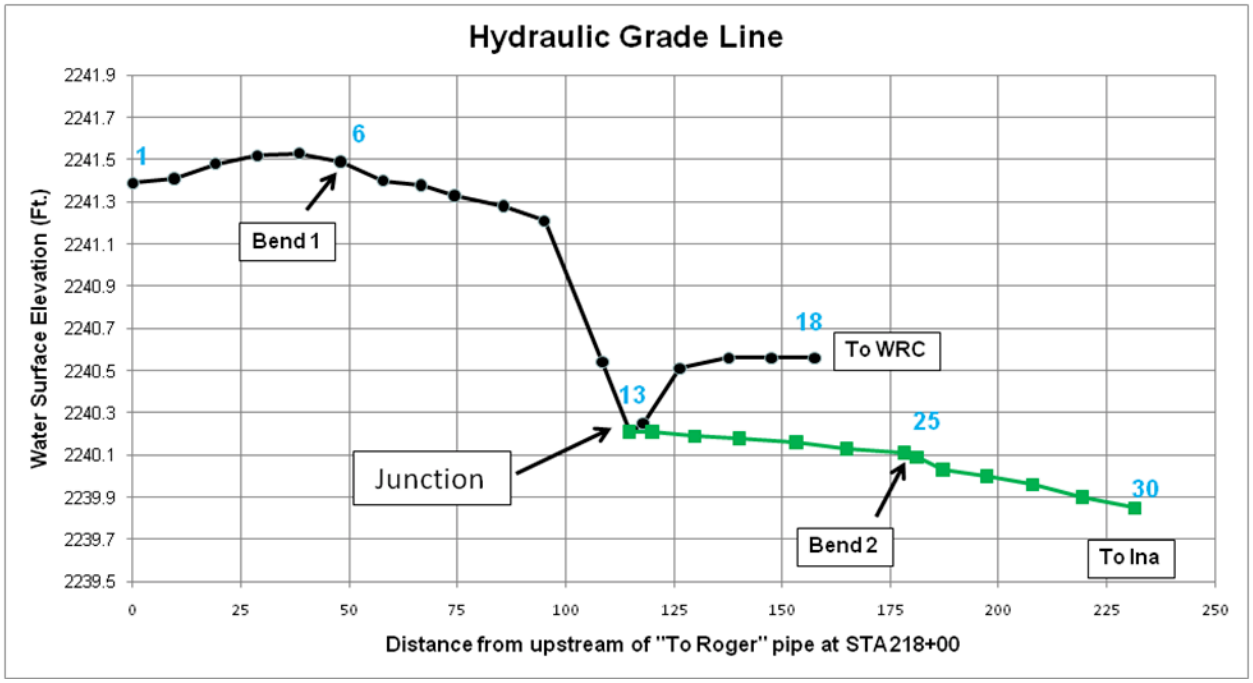

Figure B- 1. Hydraulic grade line for Scenario 1.

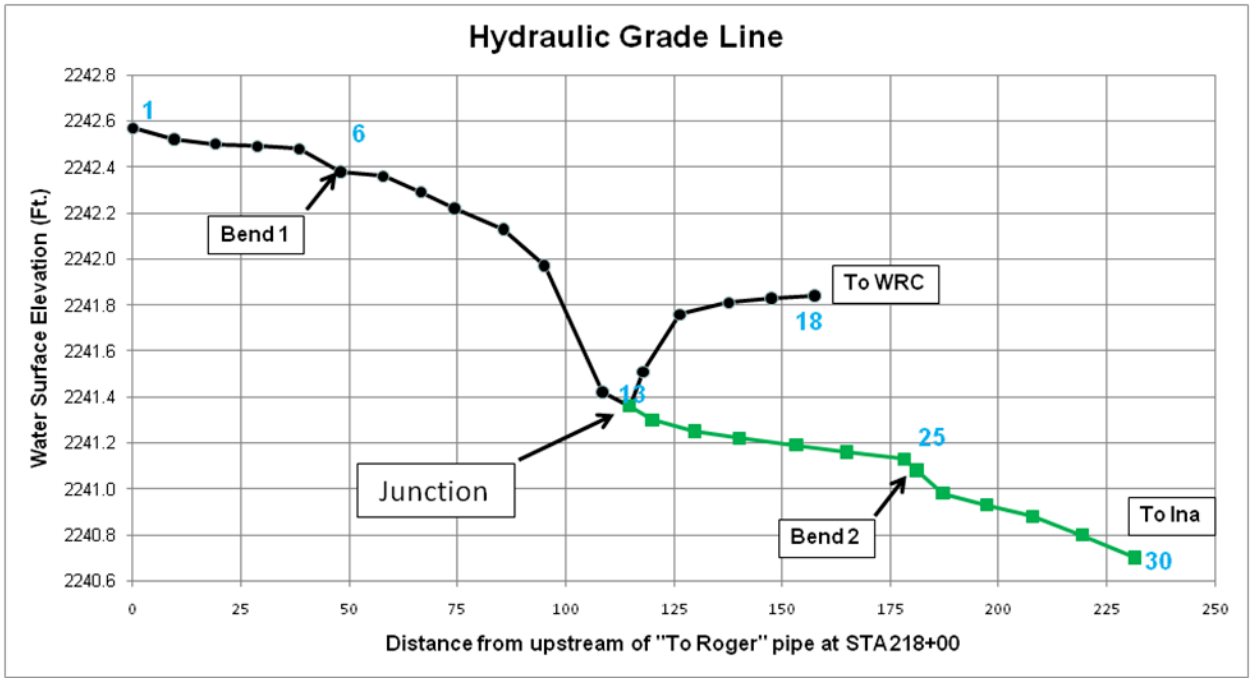

Figure B- 2. Hydraulic grade line for Scenario 2.

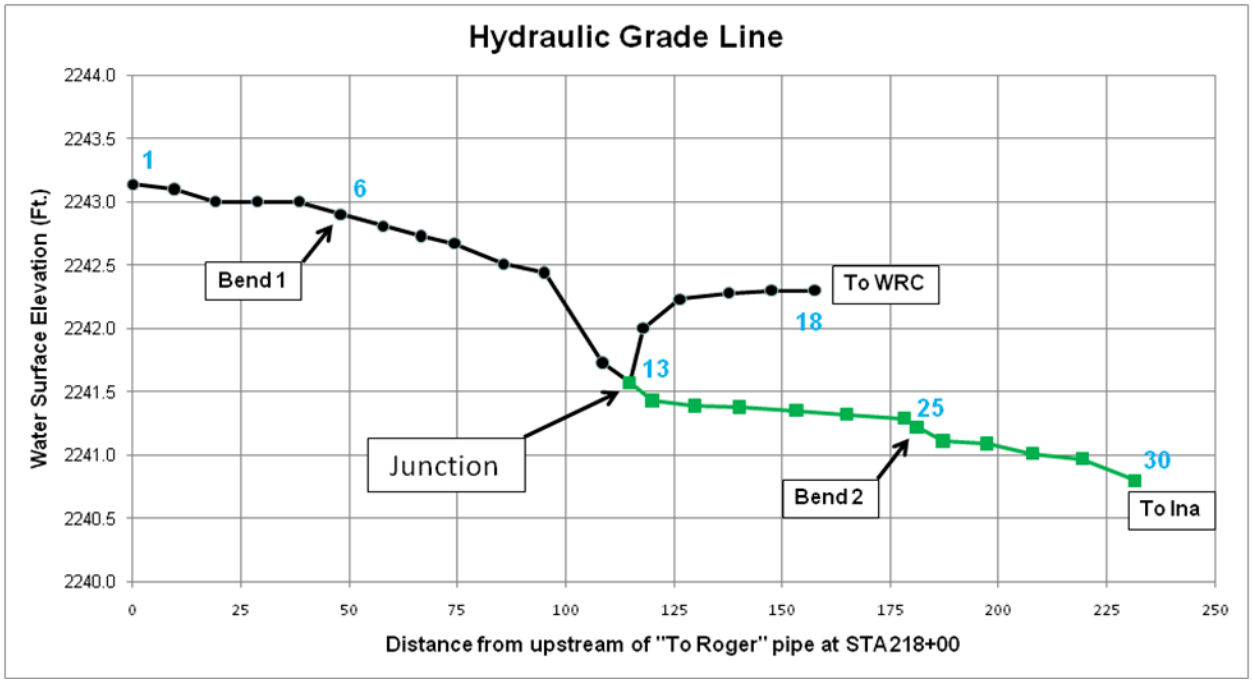

Figure B- 3. Hydraulic grade line for Scenario 3.

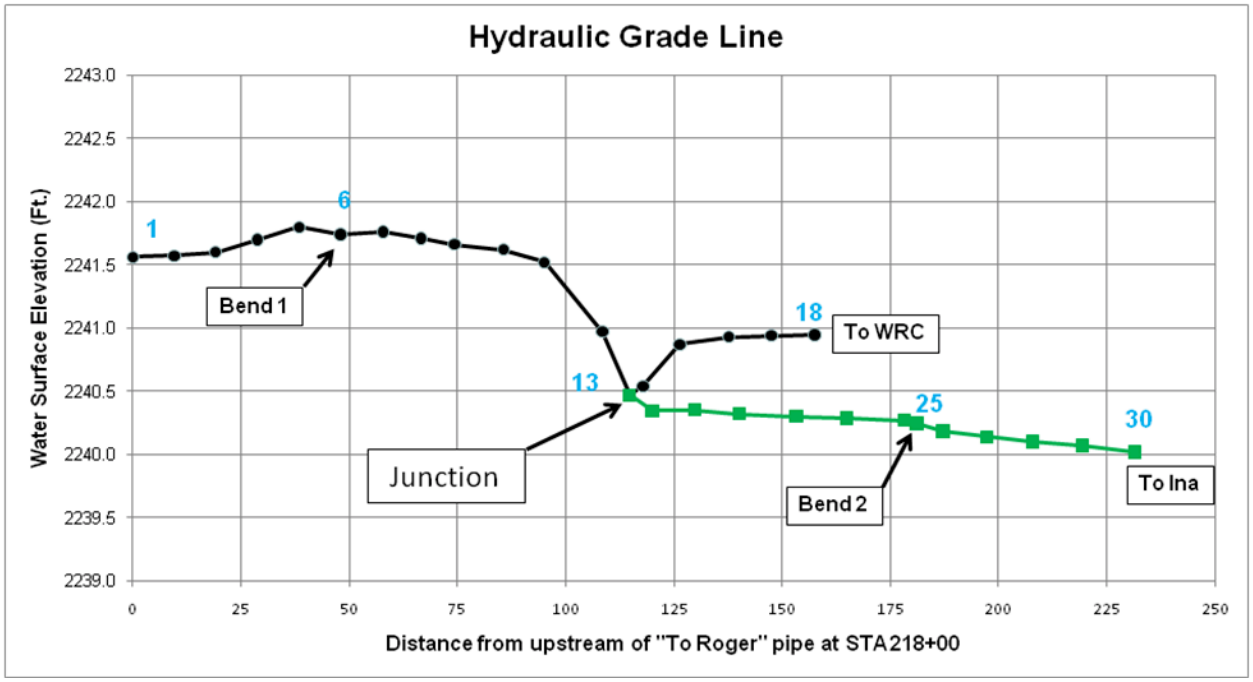

Figure B- 4. Hydraulic grade line for Scenario 4.

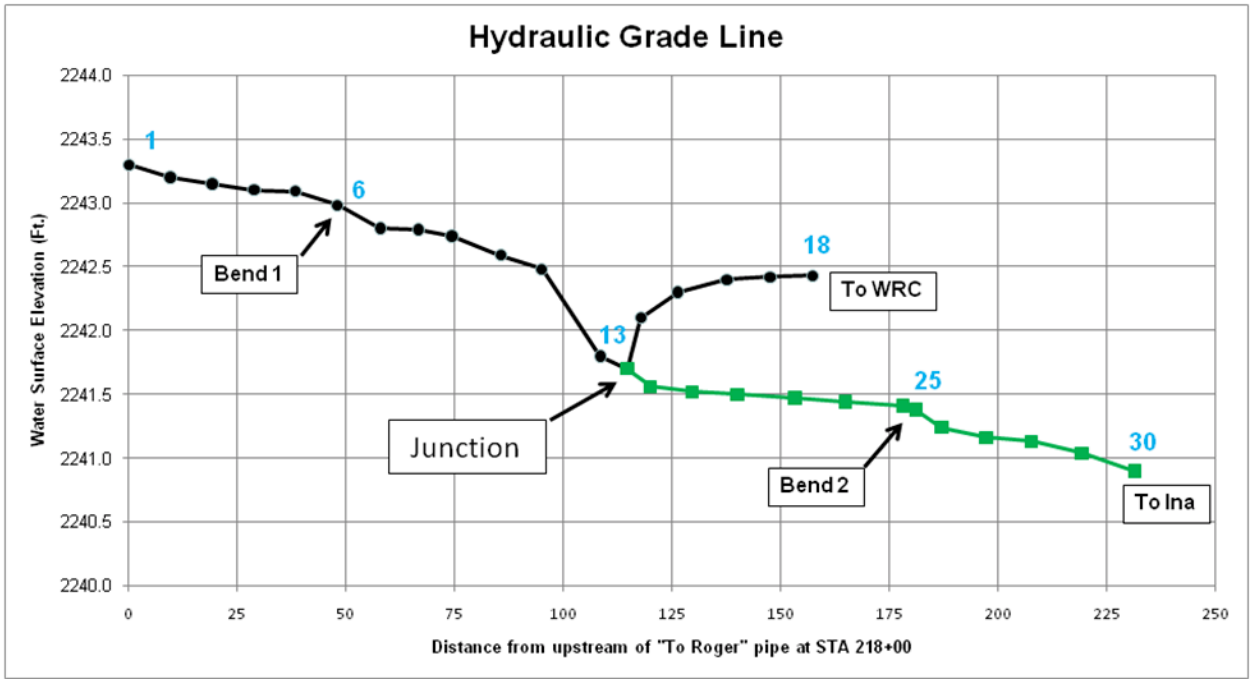

Figure B- 5. Hydraulic grade line for Scenario 5.

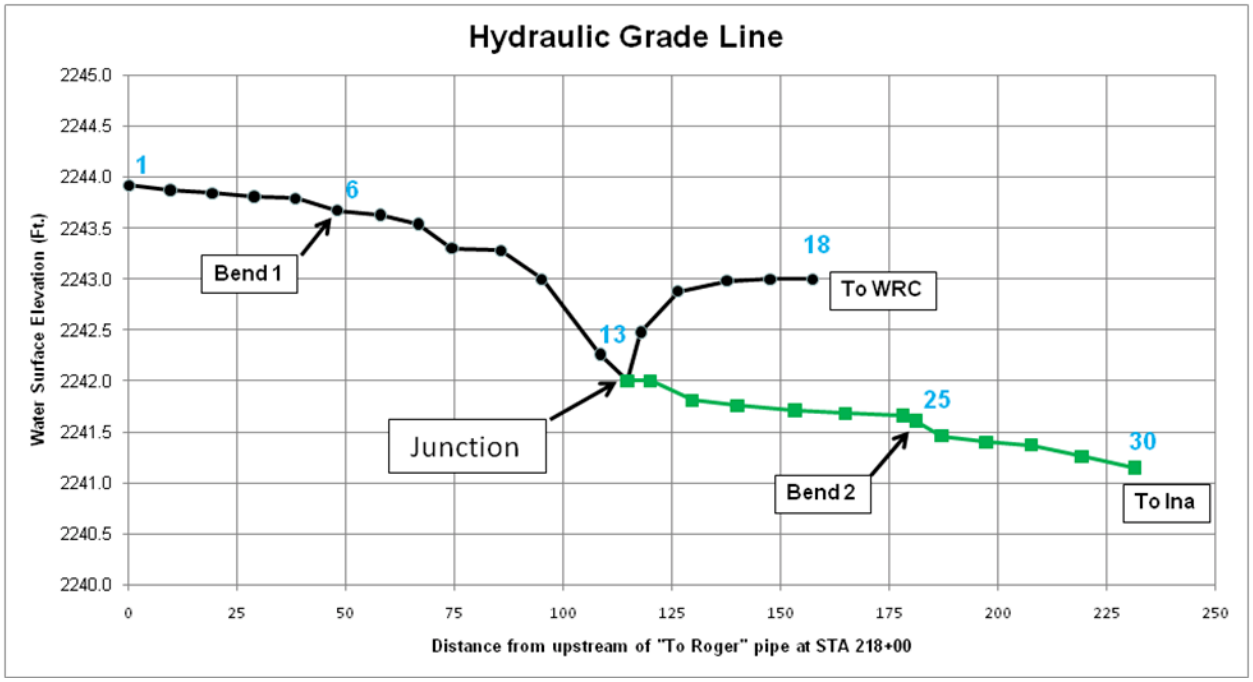

Figure B- 6. Hydraulic grade line for Scenario 6.

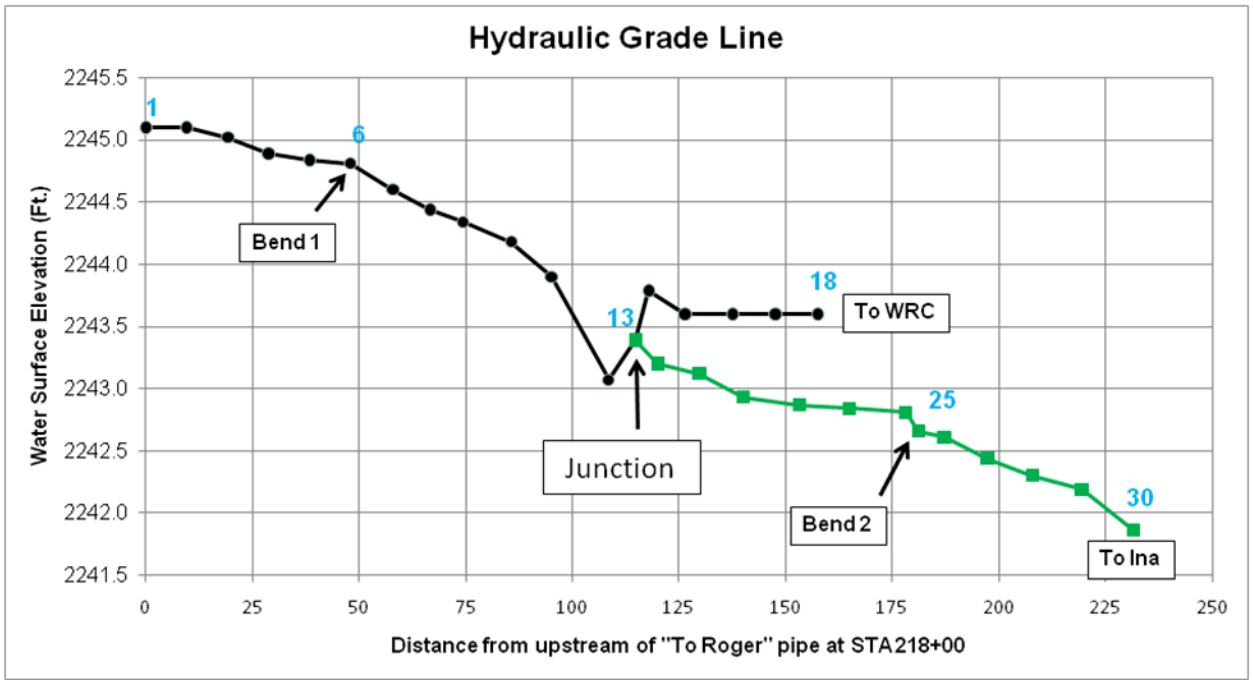

Figure B- 7. Hydraulic grade line for Scenario 7.

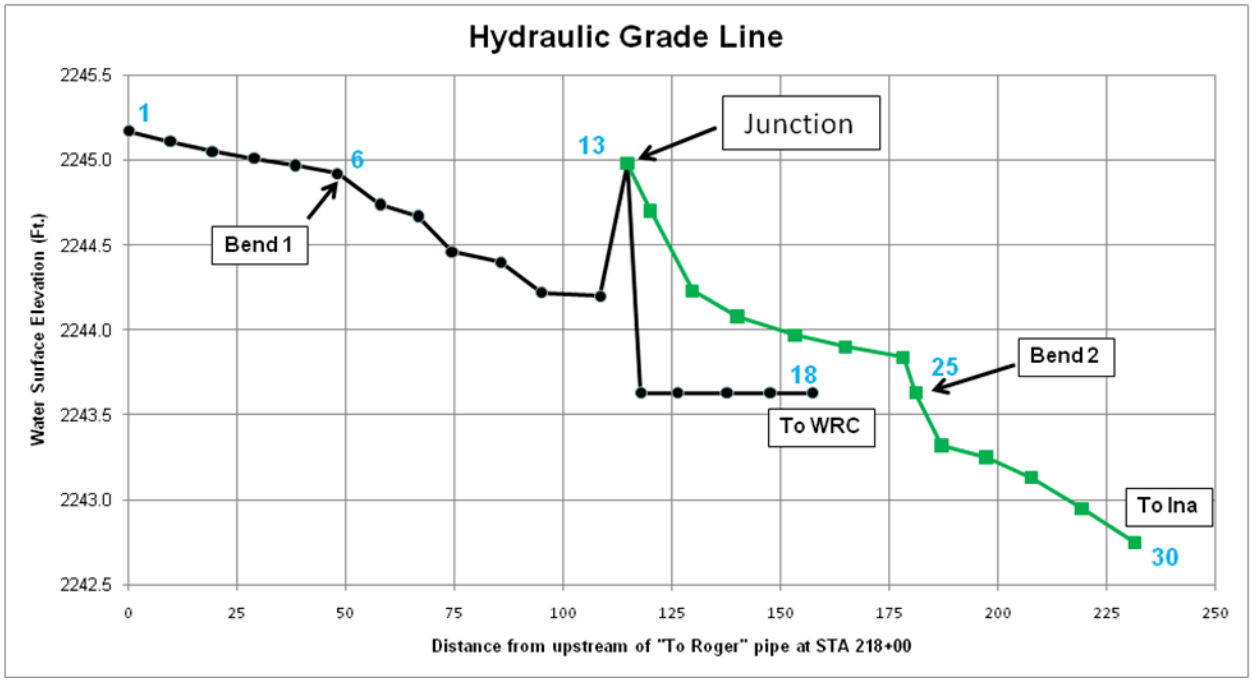

Figure B- 8. Hydraulic grade line for Scenario 8.

APPENDIX C: ENERGY GRADELINE

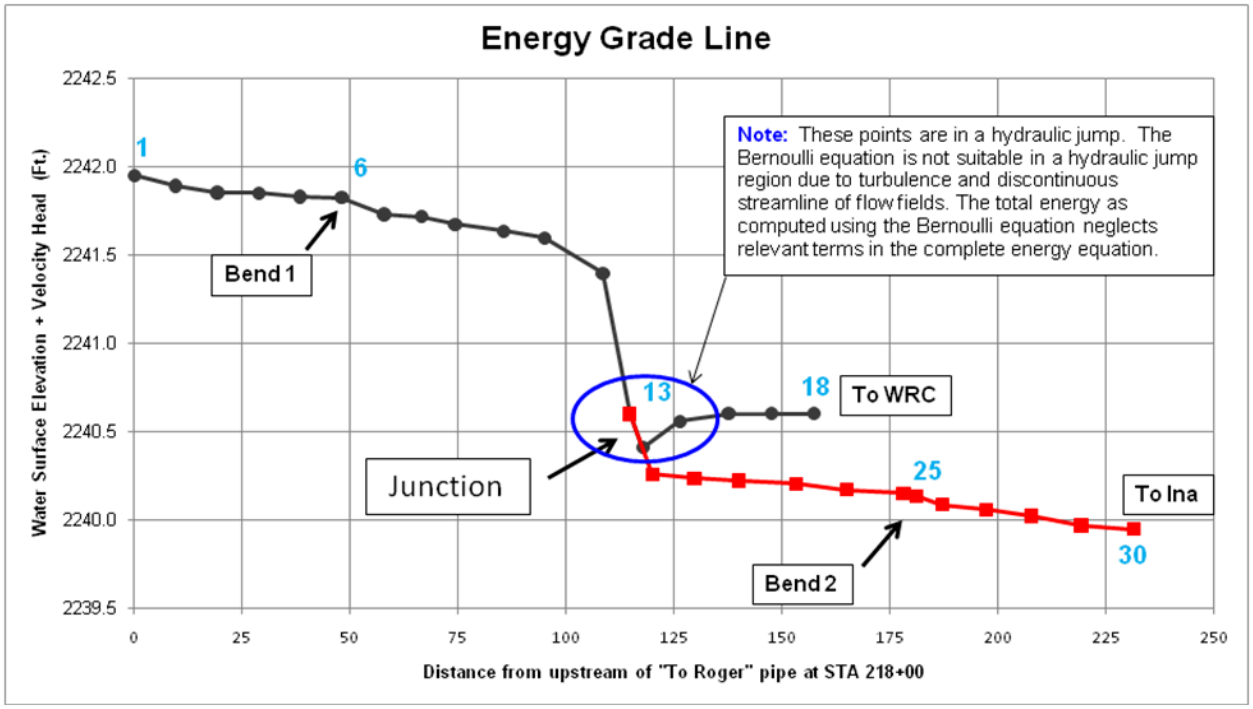

Figure C- 1. Energy grade line for Scenario 1.

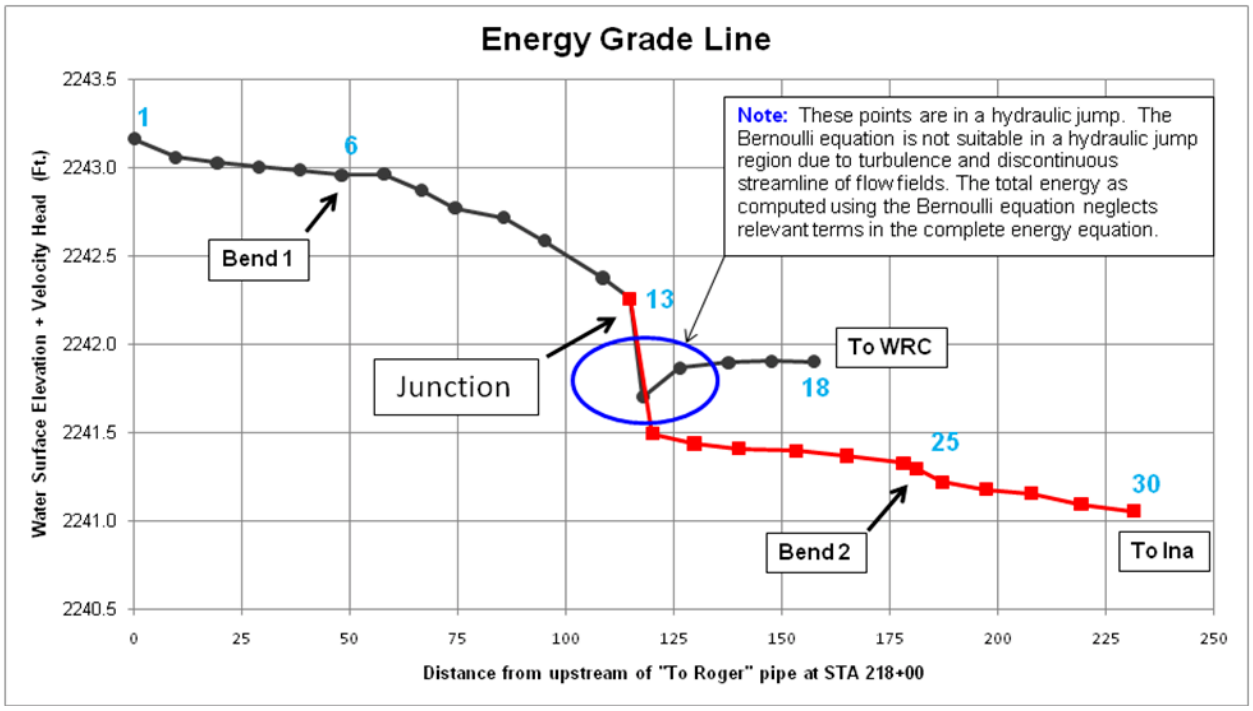

Figure C- 2. Energy grade line for Scenario 2.

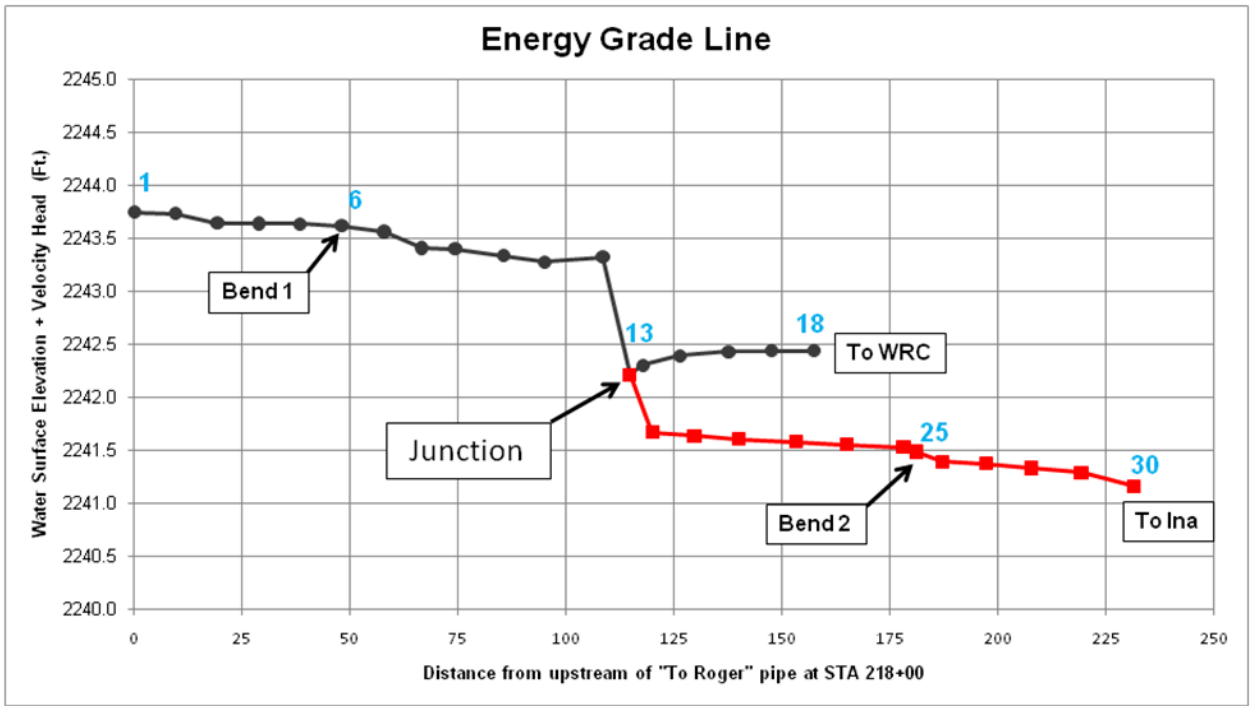

Figure C- 3. Energy grade line for Scenario 3.

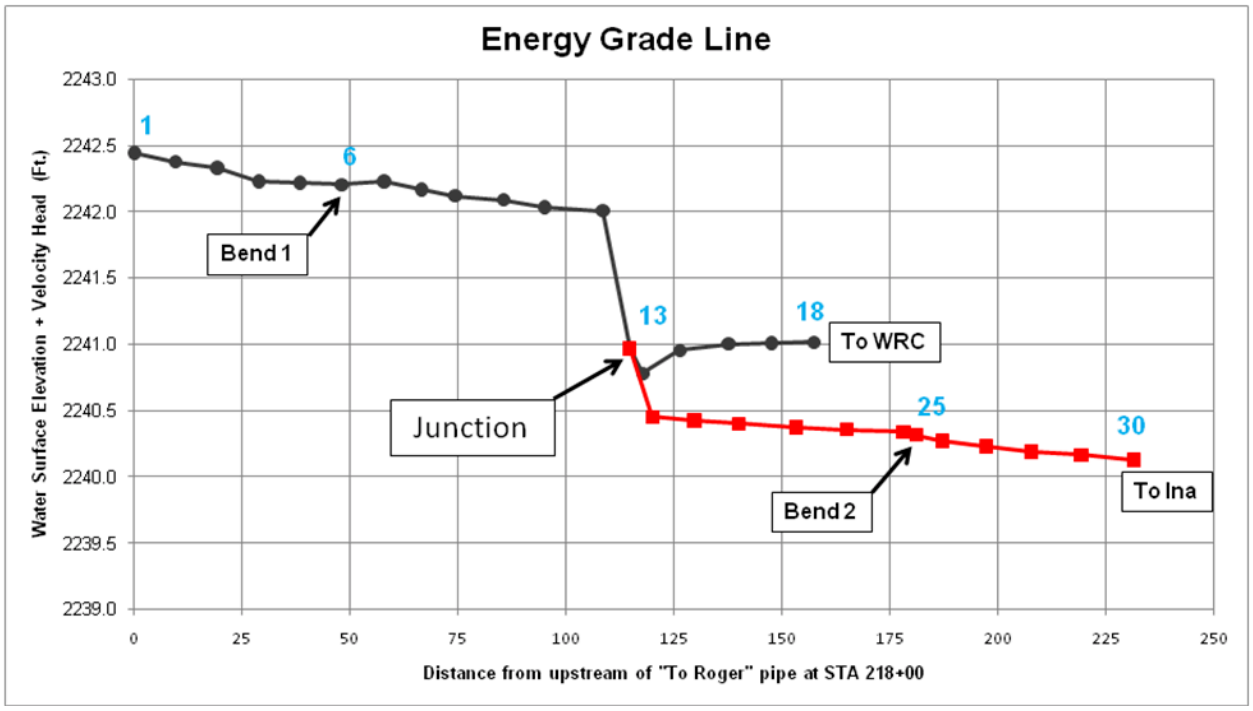

Figure C- 4. Energy grade line for Scenario 4.

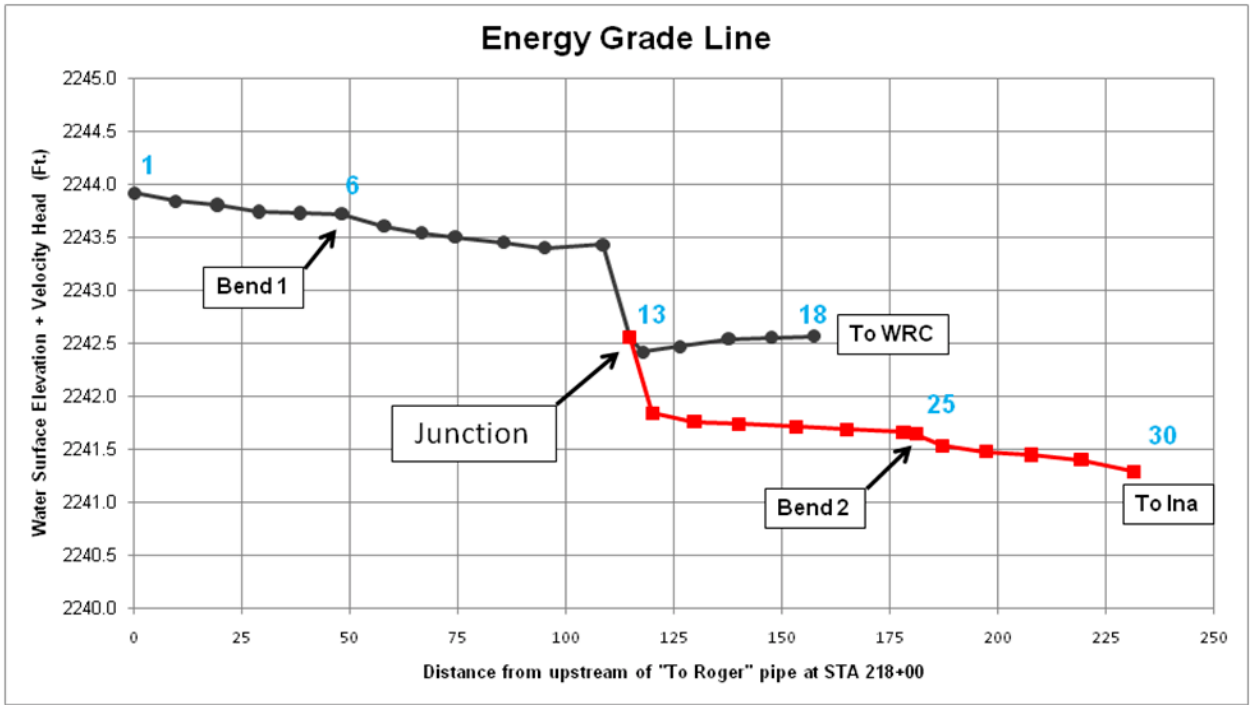

Figure C- 5. Energy grade line for Scenario 5.

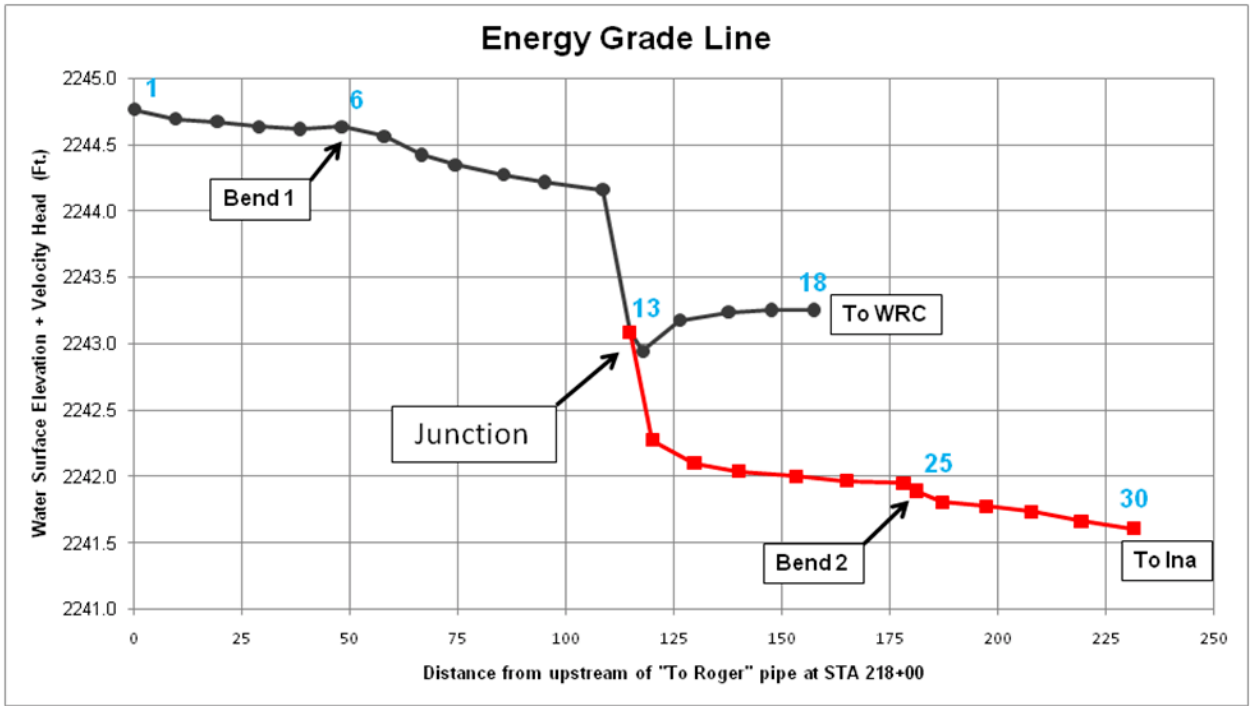

Figure C- 6. Energy grade line for Scenario 6.

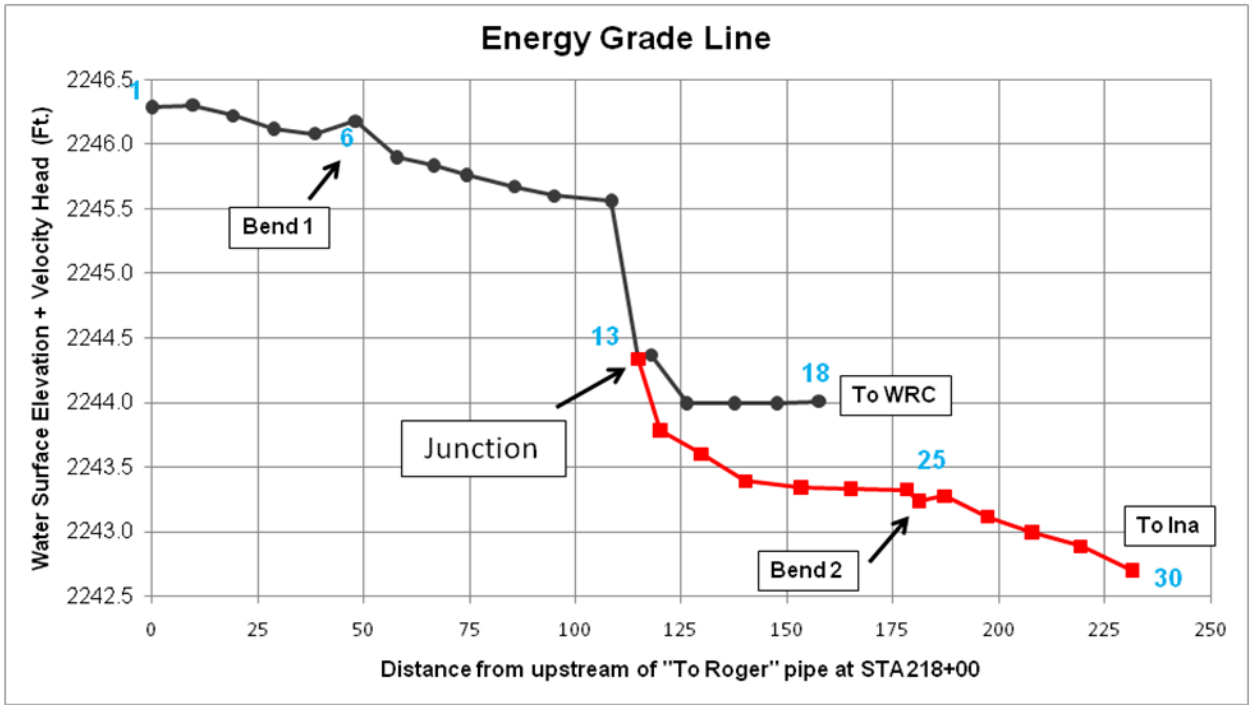

Figure C- 7. Energy grade line for Scenario 7.

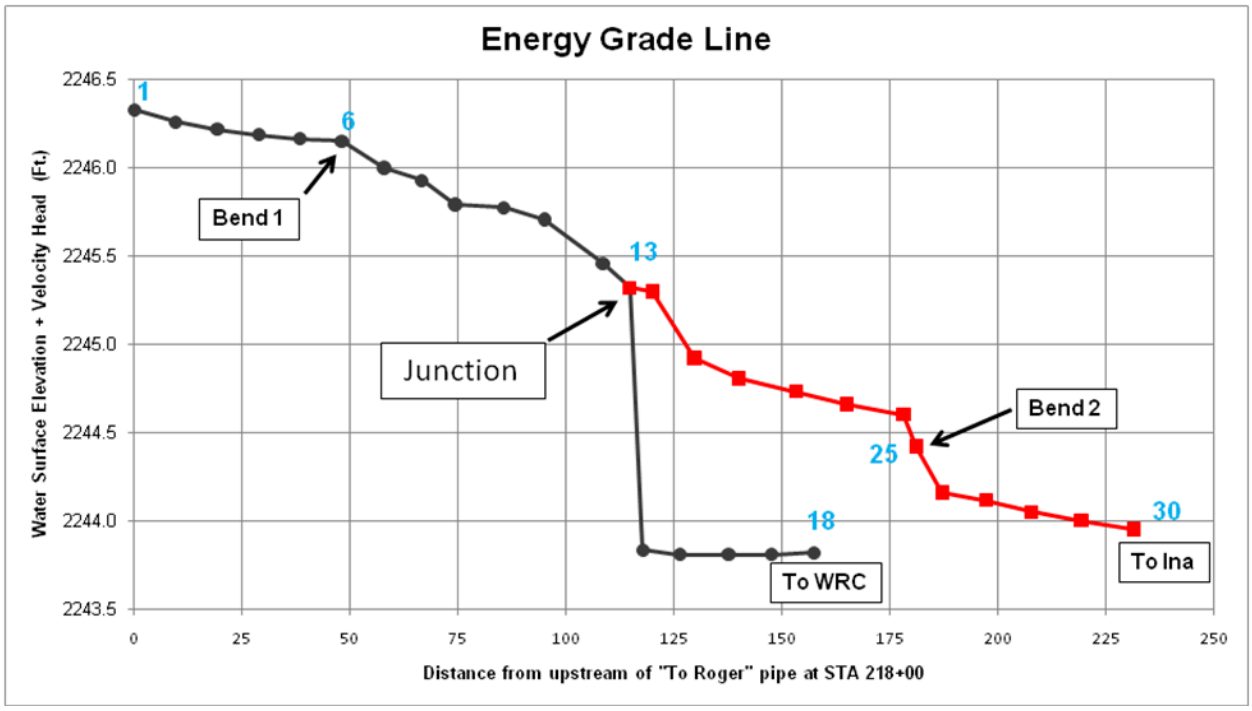

Figure C- 8. Energy grade line for Scenario 8.

APPENDIX D: WATER SURFACE PLOTS

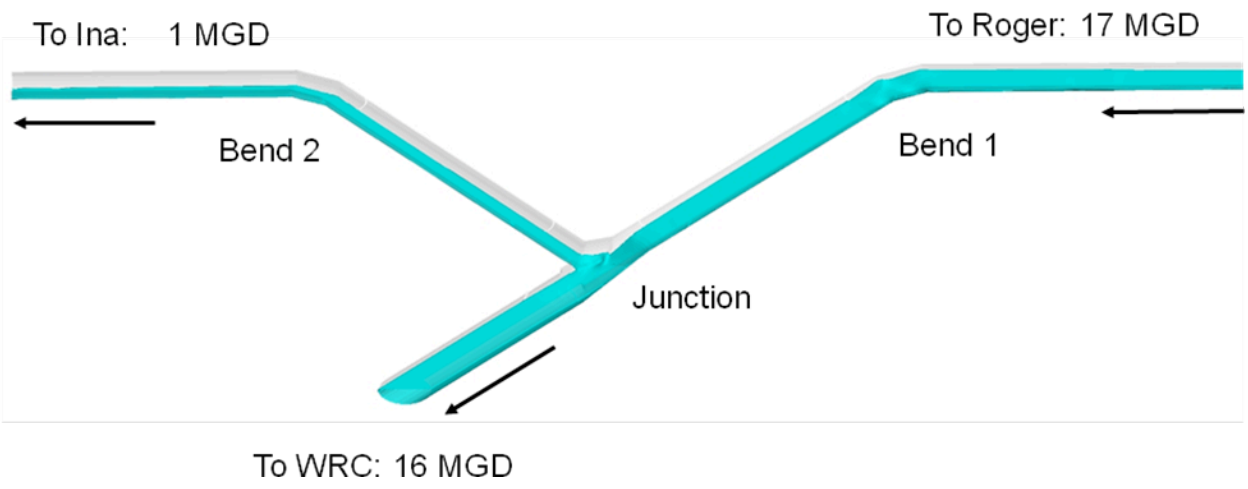

Figure D- 1. Water surface plot for Scenario 1.

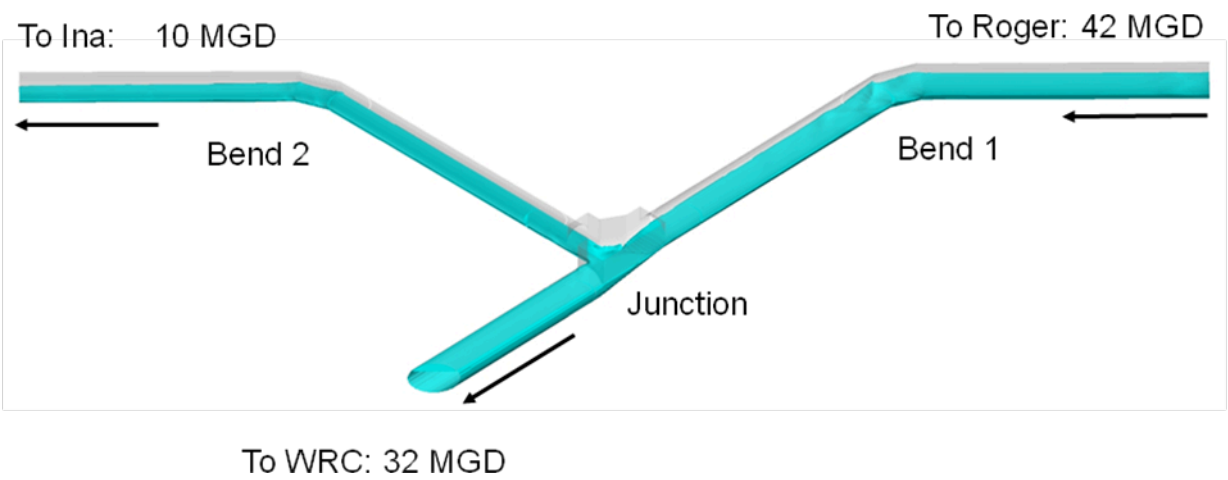

Figure D- 2. Water surface plot for Scenario 2.

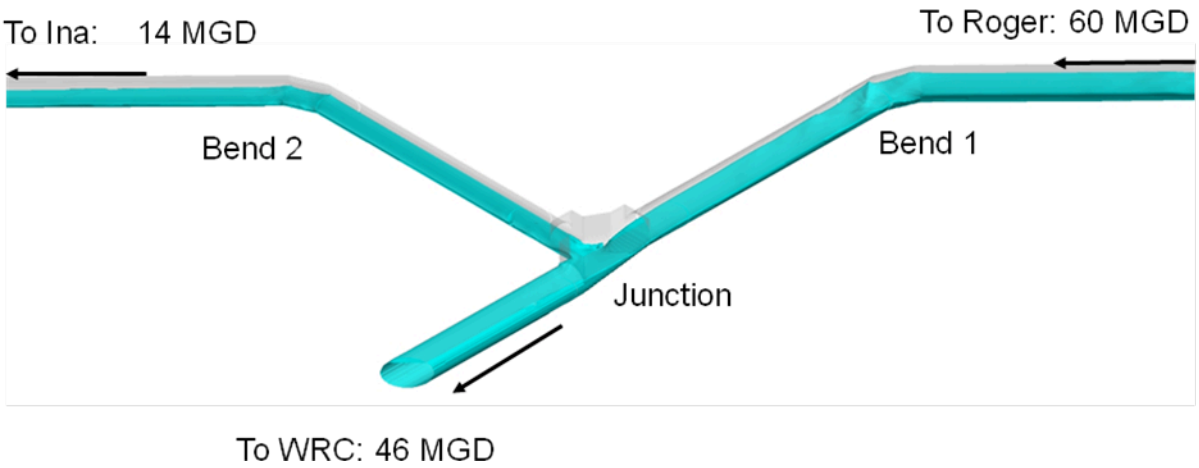

Figure D- 3. Water surface plot for Scenario 3.

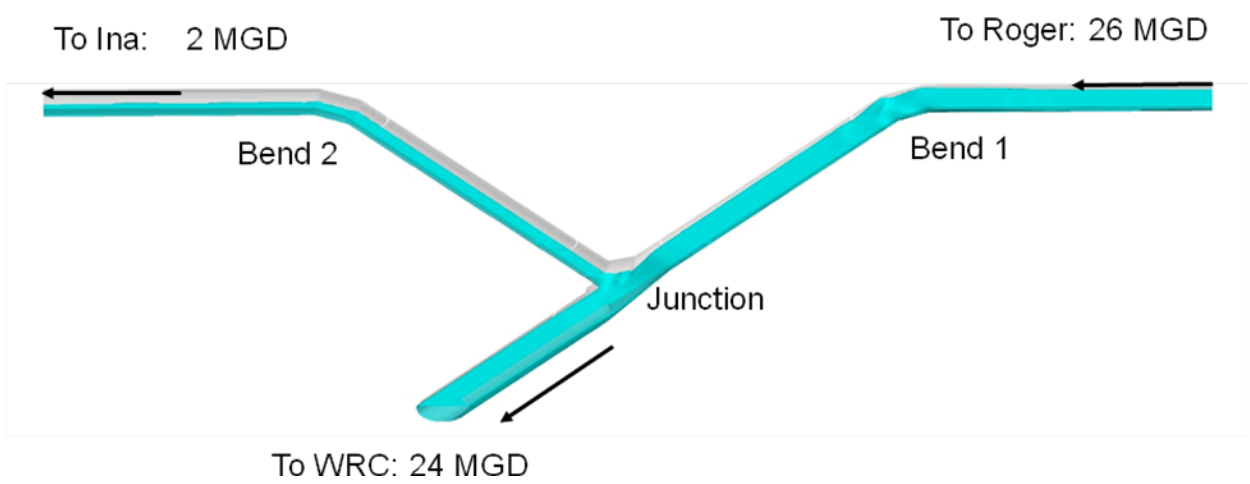

Figure D- 4. Water surface plot for Scenario 4.

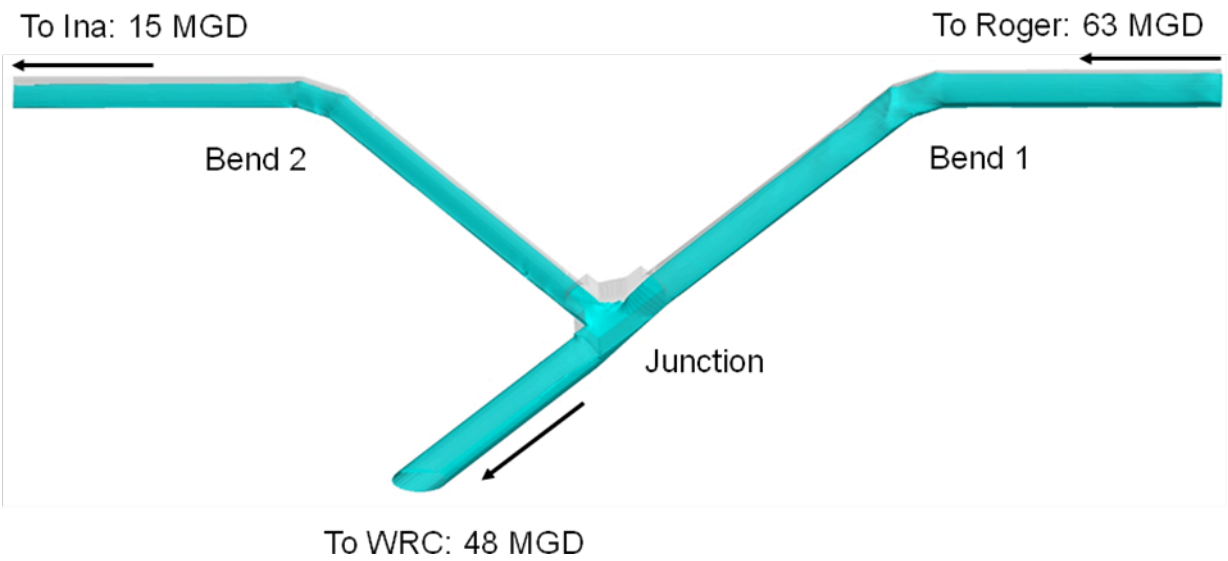

Figure D- 5. Water surface plot for Scenario 5.

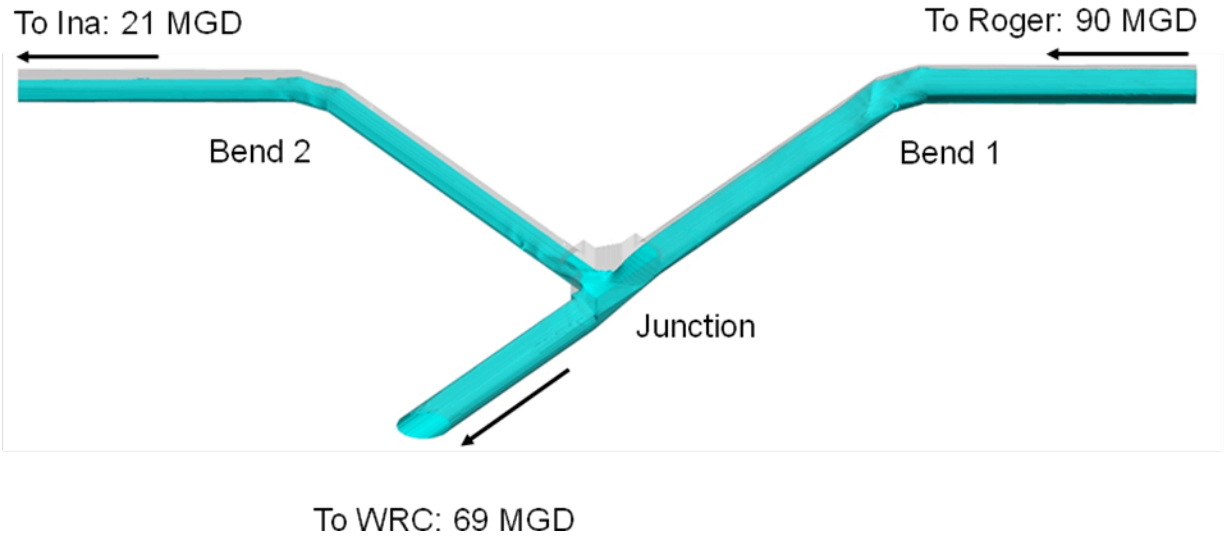

Figure D- 6. Water surface plot for Scenario 6.

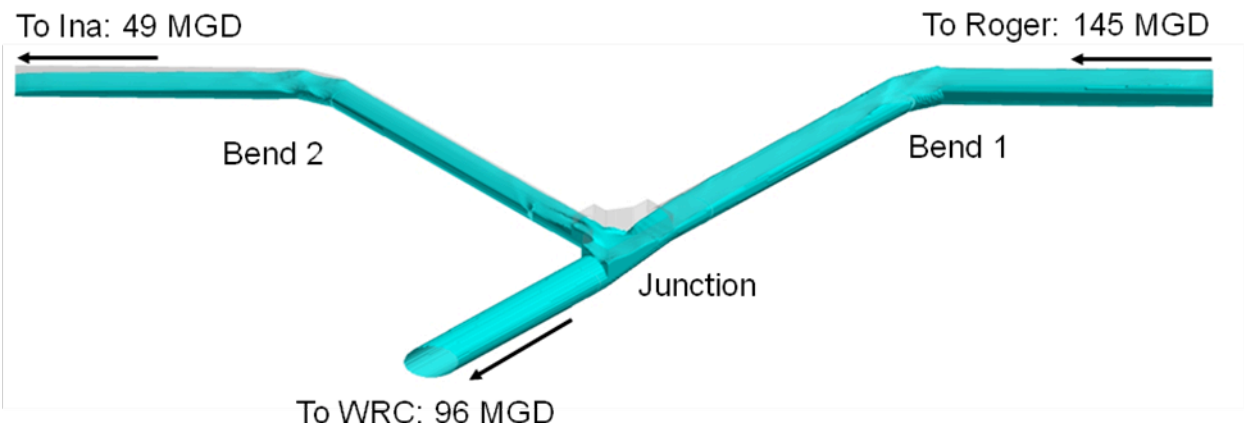

Figure D- 7. Water surface plot for Scenario 7.

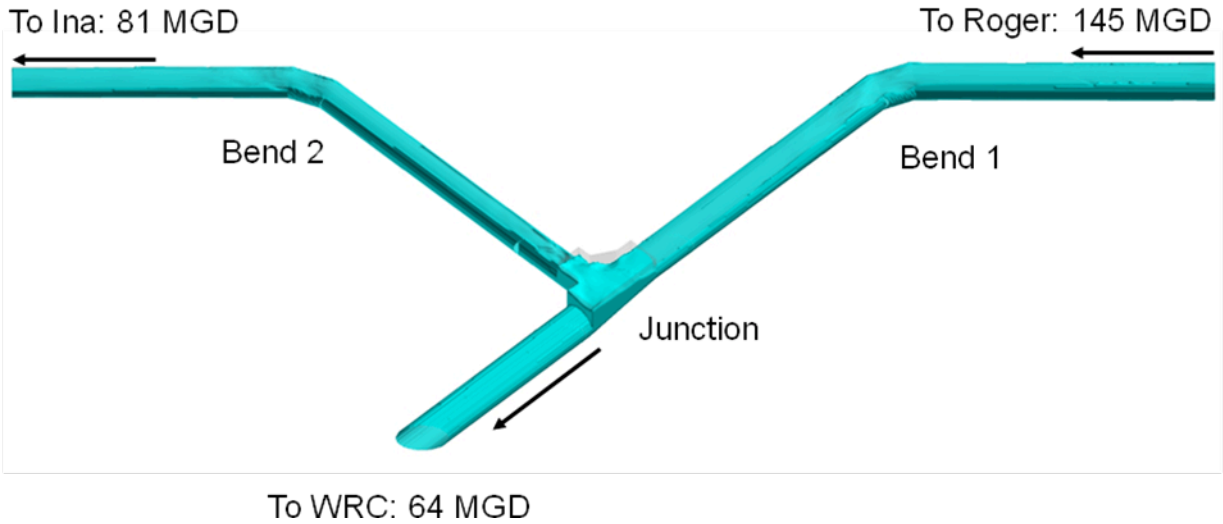

Figure D- 8. Water surface plot for Scenario 8.

APPENDIX E: WATER SURFACE ELEVATION

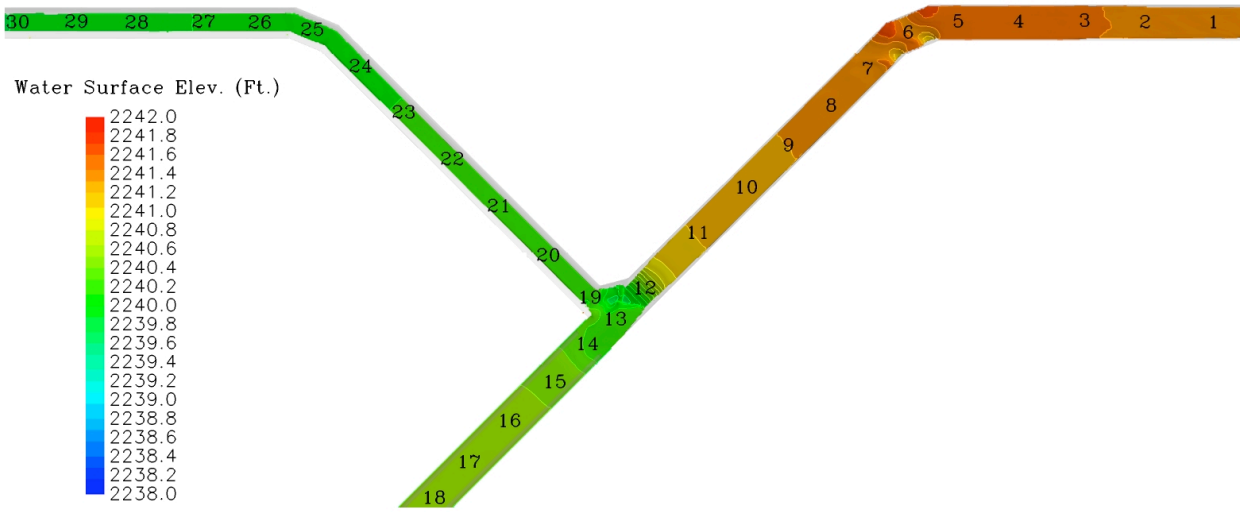

Figure E- 1. Iso-surface plot of water colored with water surface elevation for Scenario 1.

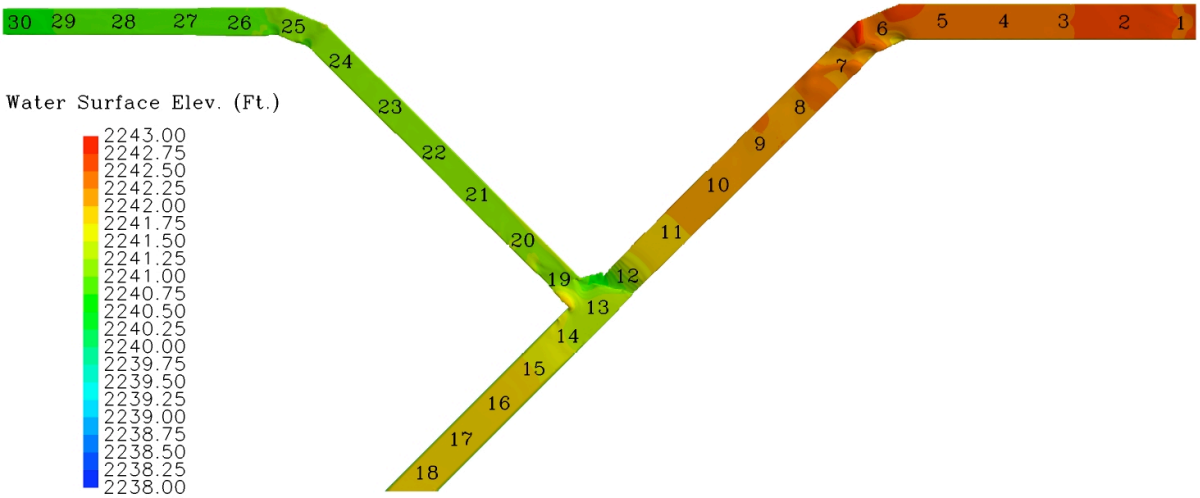

Figure E- 2. Iso-surface plot of water colored with water surface elevation for Scenario 2.

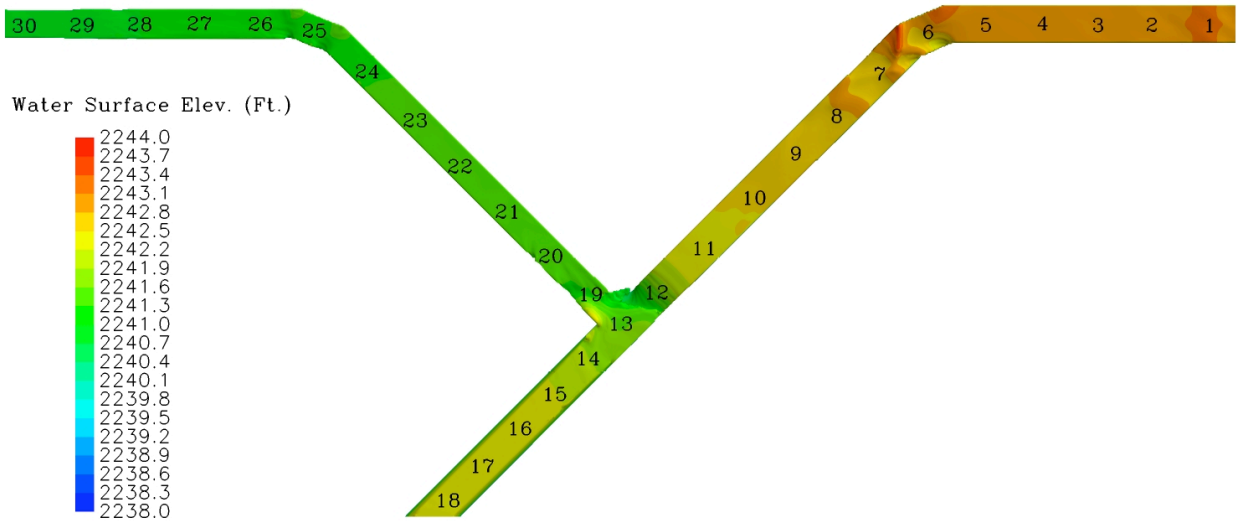

Figure E- 3. Iso-surface plot of water colored with water surface elevation for Scenario 3.

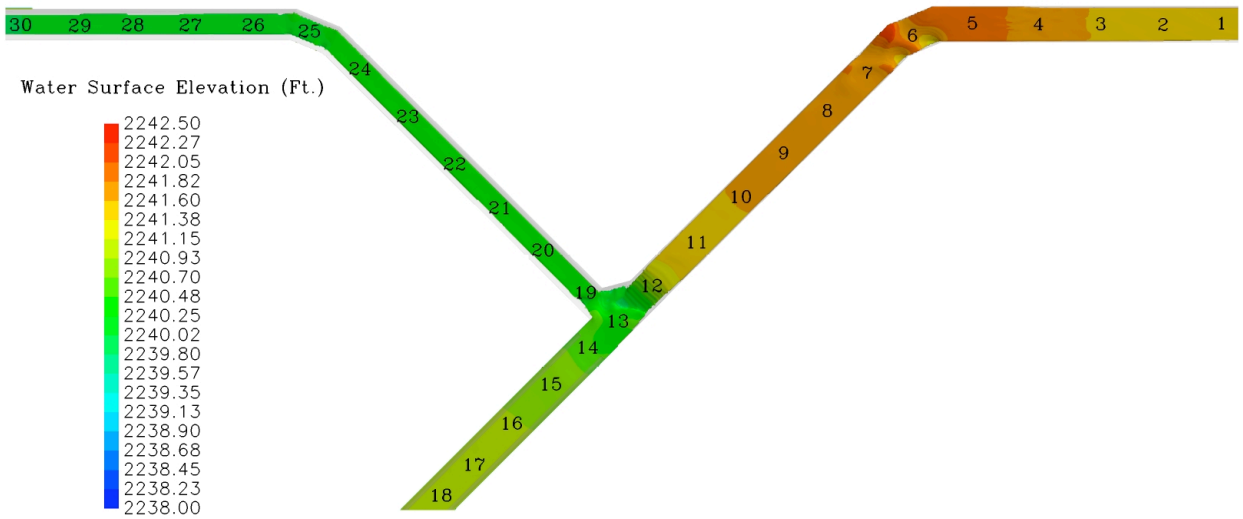

Figure E- 4. Iso-surface plot of water colored with water surface elevation for Scenario 4.

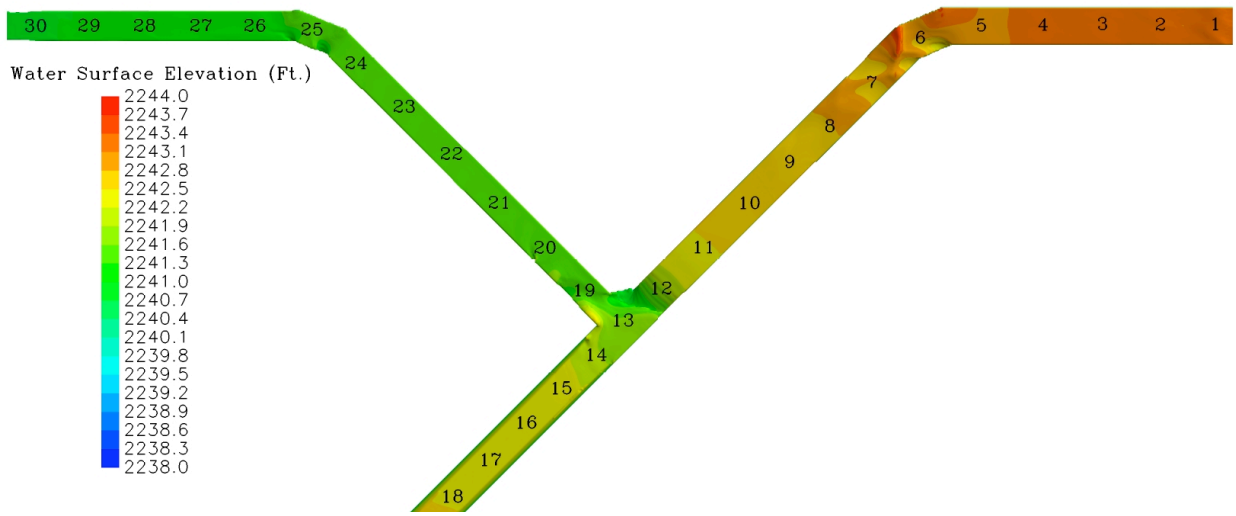

Figure E- 5. Iso-surface plot of water colored with water surface elevation for Scenario 5.

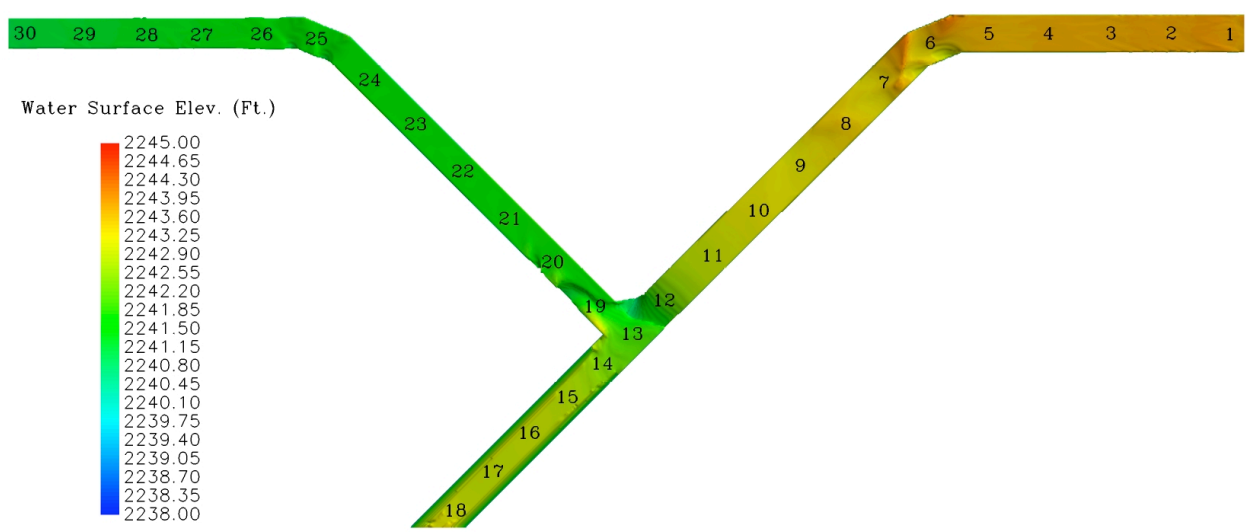

Figure E- 6. Iso-surface plot of water colored with water surface elevation for Scenario 6.

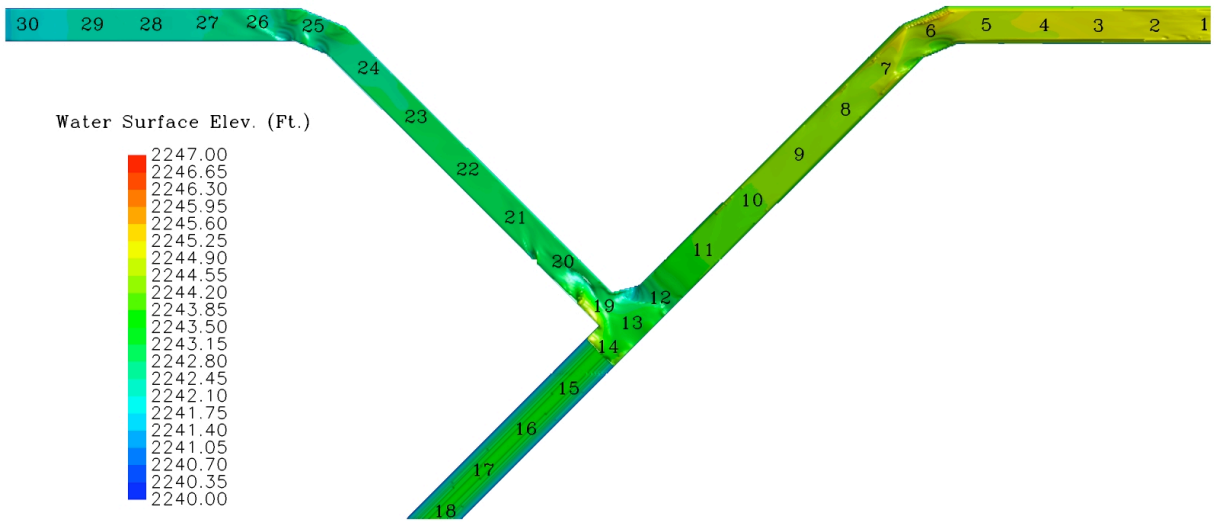

Figure E- 7. Iso-surface plot of water colored with water surface elevation for Scenario 7.

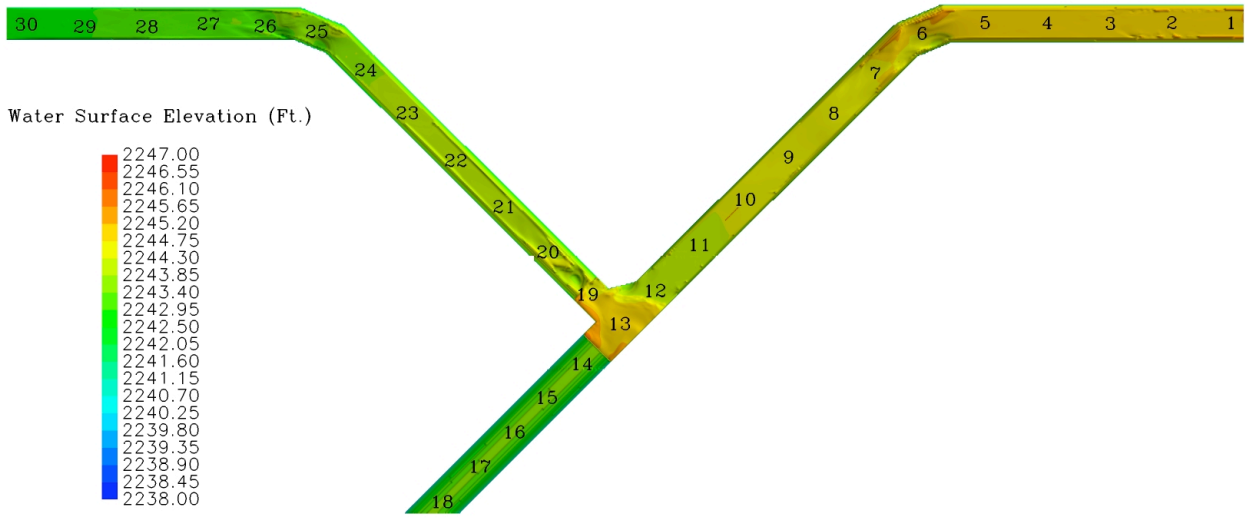

Figure E- 8. Iso-surface plot of water colored with water surface elevation for Scenario 8.