California Department of Fish and Wildlife
Stream Evaluation Report 2021-02

INSTREAM FLOW EVALUATION: SOUTHERN CALIFORNIA STEELHEAD ADULT SPAWNING AND JUVENILE REARING IN SAN ANTONIO CREEK, VENTURA COUNTY

APPENDICES

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ABBREVIATIONS AND ACRONYMS

1D	one-dimensional (hydraulic model)
AWS	area weighted suitability
cfs	cubic foot (feet) per second
Department	California Department of Fish and Wildlife
ft/s	foot (feet) per second
ft	foot (feet)
HSC	habitat suitability criteria
IFG4	Instream Flow Group model #4 hydraulic rating utility in SEFA
MANSQ	Manning's stage-discharge hydraulic rating utility in SEFA
PHABSIM	Physical Habitat Simulation system
Q	flow (discharge)
Q_{SF}	survey flow
Q_{SV}	flow calculated by SEFA from the Q_{SF} velocity profile
SEFA	System for Environmental Flow Analysis (computer software)
SZF	stage of zero flow
VAF	velocity adjustment factor
VDF	velocity distribution factor
USGS	United States Geological Survey
WSEL	water surface elevation
WSP	water surface profile hydraulic rating utility in SEFA

APPENDIX A. ONE-DIMENSIONAL MODEL DEVELOPMENT AND CALIBRATION

This appendix describes the one-dimensional (1D) hydraulic model development and calibration methods used to develop flow-habitat relationships in San Antonio Creek. The completed hydraulic models were later combined with habitat suitability criteria (HSC) for coastal rainbow trout/steelhead (*Oncorhynchus mykiss*) to estimate area-weighted suitability (AWS) by life stage over a range of flows.

A.1 Methods

The methods below fall into two categories: hydraulic model data collection and modeling using the program System for Environmental Flow Analysis (SEFA). Selection of sites and transects is covered in the main report. This section provides details on data collection once transects had been established, and then model development using those collected field data.

A.1.1 Hydraulic Model Data Collection

The data required for 1D modeling were collected at three distinct flows referred to here as the Low, Mid, and High flows. Sample flows were targeted using the 80%, 50%, and 20% exceedance flows for San Antonio Creek. The San Antonio Creek stream gage record was used to calculate these exceedance flows at <1, 1, and 7 cubic feet per second (cfs), respectively. Data collection was scheduled to coincide as near as possible to these predetermined target flows intended to capture the range of flows frequently experienced within the San Antonio Creek watershed. Hydraulic data were originally collected on the descending limb of the hydrograph from March through May of 2017. Staff returned in February and March of 2018 to resurvey hydraulic data due to calibration errors discovered in the 2017 data as a result of algae overgrowth. Only the 2018 data were used for model calibration (see Table A-4 and Table A-5).

Staff recorded water surface elevations (WSELs) and discharge at each survey event. The streambed profile for each transect cross section was surveyed during the first data collection event, typically the High flow survey. The velocity profile was generally recorded during the Mid flow survey, but seasonal fluctuations in flow led to the occasional velocity profile collection at the High flow survey. Stage of zero flow (SZF) measurements and substrate and cover coding were collected at Low flow (Table A-1).

Table A-1. Data collected at target flow regimes used in 1D modeling.

Flow Regime	Streambed Profile, Substrate, & Cover	WSEL/ Discharge	Velocity Profile	Stage of Zero Flow
High	-	Collected	Collected	-
Mid	-	Collected	Collected	-
Low	Collected	Collected	-	Collected

Streambed Profile Surveys, WSEL, and Vertical Controls

To provide a complete elevational bed profile, steel rebar were set at the ends of each transect, establishing a head pin and tail pin. An upstream-facing convention was used to establish the position of the head pin on the left bank and the tail pin on the right bank. Fiberglass measuring tapes were hooked to the head pins and wrapped around the tail pins during each survey to demarcate transect stations for velocity profiles and elevation surveys (Bovee 1997). Surveys were performed using standard differential survey methods consistent with the California Department of Fish & Wildlife's (the Department's) *Standard Operating Procedure for Streambed and Water Surface Elevation Data Collection in California* (CDFW 2013b). Streambed elevation measurements were collected at one-foot intervals along the transect using a stadia rod and an auto level fixed to a tripod. Vertical control was maintained at each mesohabitat unit by a vertical benchmark, consisting of lag bolts typically installed into mature tree roots or trunks (Figure A-1). All streambed elevations and WSELs were measured using a Nikon AE-7 automatic level and stadia rod (Figure A-2). All WSELs were measured at a minimum of three distinct stream discharges to the nearest 0.01 foot (ft). Staff gages were installed at each unit to monitor change in stage during data collection. Staff gages were graduated and read to the nearest 0.01 ft.

Figure A-1. Vertical benchmark driven into tree root near transect tail pin. The vertical benchmark and tail pin are marked with flagging tape.

Figure A-2. Department staff measuring WSEL and velocity along a transect in San Antonio Creek.

The 1D model assumes that the WSEL at each transect is of constant elevation. One representative WSEL must be chosen from the measurements recorded during each WSEL transect survey. The user's manual for 1D modeling (USGS 2001) provides the following guidance to select a representative WSEL based on levels of variance in the measurements:

> *The difference between the measured right and left bank water surface elevations can vary considerably with differences of 0.1 to 0.5 ft occurring in highly turbulent conditions. The analyst should select the average of the left bank and the right bank, only left or only right bank, or other water surface elevation at each cross section in the regression equations based on the conditions reported in the field notes.*

A minimum of three WSELs were recorded along each transect. One measurement was taken near each bank and another near the middle of the channel. Typically, the water surface was flat and WSELs did not vary by more than 0.05 ft. The mean was calculated for WSELs within this range generating a single representative WSEL. In some instances the water surface was varied, and more measurements were recorded to accurately depict the water surface height. Where WSELs differed by 0.05 and 0.1 ft, each transect was evaluated to determine if any of the WSEL measurements recorded were not representative of the water surface surveyed because of turbulent surface conditions or physical obstructions. Where the variation in WSEL exceeded 0.1 ft, transects were evaluated in detail by reviewing field notes, schematic diagrams, and photographs to understand potential causes of variance. Specific WSEL measurements that appeared to be impacted by the conditions described above were excluded from computation of the mean WSEL.

In mesohabitat units with a downstream control point, typically pool units, the elevation of the downstream control point represents the SZF (Figure A-3). At the SZF, all surface flow will be blocked by the control point. The SZF is most easily located at the lowest flow surveyed (USGS 2001). As a result, the SZF for each pool unit was surveyed during the Low flow event. The recorded SZF was later entered into SEFA for WSEL and discharge calibration.

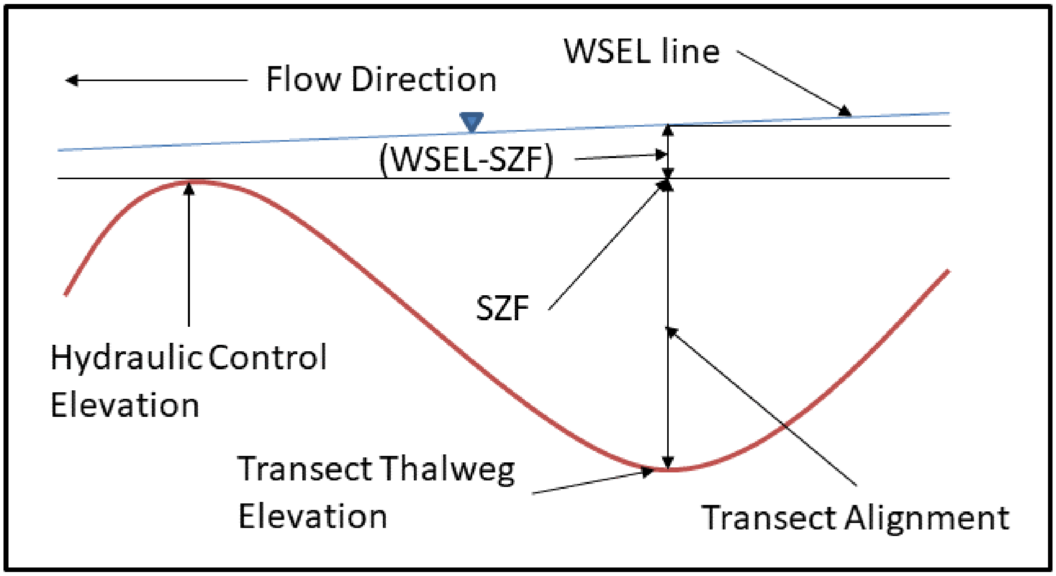

Figure A-3. Stage of zero flow (SZF) diagram.

Discharge

Discharge measurements were collected for each WSEL survey event at each distinct flow (either Low, Mid, or High) near the corresponding transect being surveyed. Discharge surveys were consistent with the Department's *Standard Operating Procedure for Discharge Measurements in Wadeable Streams in California* (Discharge SOP), released in 2013 and then updated to clarify details of the method in 2020 (CDFW 2020). The 2020 version most accurately describes methods followed in the Ventura and will be referenced throughout this section. A single discharge measurement could be used to represent the flow for multiple transects when transects were near one another and where there were no flow inputs or diversions between transects. If necessary, multiple discharge measurements were taken within a given reach to account for additional flow inputs or diversions and fluctuation in flow throughout a survey day.

Discharge sites were selected where the best hydraulic characteristics could be found in the stream reach near the transect(s). Ideal discharge cross-sections are relatively wide, uniform, and shallow (Figure A-4; Bovee 1997; CDFW 2013a). In all transects surveyed, discharge was measured in a minimum of 20 cells across the length of the transect. In areas of greater depth or velocity, cell width was reduced such that no one cell represented more than 5% of the total volume of flow. A temporary staff gage was installed during each discharge measurement (CDFW 2020). The depth of the staff gage was read before and after each discharge to ensure the stream stage remained constant during the measurement.

Figure A-4. Discharge measurement in San Antonio Creek Reach 2, flow pictured at approximately 0.4 cfs.

Water Velocity

Velocity measurements were collected along each transect at one-foot increments at both the High and Mid flow event. Velocities were measured using either a Marsh-McBirney Flowmate Model 2000 or Hach FH950 velocity meter. Velocity meters were calibrated and used in accordance with the Discharge SOP (CDFW 2020). The meters measured velocity in the water column to the nearest 0.01 feet per second (ft/s). For depths less than 2.5 ft, one velocity measurement was made at 0.6 of the total depth as measured down from the water's surface. Where the water depth was equal to or exceeded 2.5 ft, two velocity measures were collected and the mean of the two velocities was calculated; one at 0.2 and another at 0.8 of the total depth measured down from the water surface.

Substrate Classifications

Substrate size was also used to estimate AWS for spawning adults. Substrate size data were collected at the points selected for bed elevation measurements. All substrate assessments were based on visual estimation, and one substrate code was assigned to each point. The codes used to classify substrate are provided in Table A-2.

Table A-2. Substrate codes, descriptors, and particle sizes (USFWS 2011).

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1–1
1.2	Medium Gravel	1–2
1.3	Medium/Large Gravel	1–3
2.3	Large Gravel	2–3
2.4	Gravel/Cobble	2–4
3.4	Small Cobble	3–4
3.5	Small Cobble	3–5
4.6	Medium Cobble	4–6
6.8	Large Cobble	6–8
8	Large Cobble	8–10
9	Boulder/Bedrock	>12
10	Large Cobble	10–12

Field Data Quality Control

To ensure accuracy during data collection, equipment was calibrated according to the manufacturer's instructions. Details about field equipment calibration can be found in the Discharge SOP (CDFW 2020).

Data including but not limited to flow velocity, water depth, substrate, cover, WSEL, and bed elevation were documented in the field on data sheets. Field data were checked for accuracy and completeness by the field crew leader at the end of each field day. Any incomplete data were corrected in the field on the data sheets. Photographs of each transect were taken during each survey to document site conditions. Schematic drawings were prepared of each transect on the WSEL data sheet, indicating where obstacles such as downed trees, cobble bars, and boulders were located that may have affected WSELs and/or flow velocities.

Department scientific staff transcribed numerical data into Excel workbooks upon return to the office. If any errors in the physical data sheets were identified during the transcription process, the error on the physical data sheet was marked by strikeout, correction added, and each correction was initialed and dated by staff. After the data were entered electronically, a different Department scientific staff member reviewed the electronic data against the paper field data sheets to confirm the accuracy of the transcription. Any errors found by this second reviewer were corrected using the original data sheets. Staff logged the data entry date, quality control check completion date, and any data omissions or corrections in a spreadsheet to ensure that all field data forms were electronically entered and checked. Once the electronic data were verified and paper field forms were filed, the electronic forms were used in future analysis. All data generated by this project will be maintained in scanned field logbooks and/or data sheets, and electronic spreadsheet format. The Department will store all electronic data (including photographs, scanned data sheets, Excel workbooks, study plans, and report documents) on Department-maintained servers that are regularly backed up.

Some data were discarded after returning to the office due to data quality issues, such as discharge measurements that did not comply with standards outlined in the Discharge SOP (CDFW 2020), WSEL measurements that exceeded the margin of error, and changes in the bed profile due to substrate movement. These issues were noted in a data collection data quality log and the data were excluded from future analysis. When necessary, staff returned to the field site to re-take the field measurements.

During data analysis, data copied from one spreadsheet to another or from a spreadsheet to the report were quality checked by Department scientific staff using the same method described above. When data were imported into SEFA, HydroCalc, and Excel for analysis, the staff member verified that correct and complete data had been used and that the proper output data were incorporated in the reports.

Model Limitations

The hydraulic utilities in PHABSIM assume the water surface is level across each cross section (USGS 2001); therefore, randomly selected cross sections located where the WSEL varies by more than 0.1 ft are assumed to not be acceptable for hydraulic modeling in PHABSIM (see Section 1.1). The WSEL-discharge rating relationship of cross sections located where the WSEL varies beyond 0.1 ft are more likely to fail to meet standards for mean error, measured versus predicted WSEL, and/or VAF. Randomly selected cross sections where the WSEL varied beyond 0.1 ft were then resampled. Simulation flow range is described in detail in Section 1.2.

A.1.2 SEFA

The 1D method simulates the relationship between streamflow and physical habitat for fish by combining the results of hydraulic models with HSC to estimate AWS. The SEFA software program (Jowett et al. 2014) contains a suite of computer models for performing this analysis developed by the United States Geological Survey (USGS;

Milhous et al. 1989). The SEFA program was used to perform the 1D method computations for both study reaches in San Antonio Creek. Hydraulic model preparation, calibration, and simulation in SEFA followed the standard procedures and guidance given in the PHABSIM user's manual (USGS 2001).

Hydraulic modeling in the 1D method generally consists of the following procedures:

- rating curve development and calibration using stage-discharge pairs measured in the field;
- predictive hydraulic model utility selection;
- WSEL simulation;
- velocity simulation; and
- results validation using standard guidance criteria.

Hydraulic Data Preparation and SEFA Input

The electronic data were organized by reach and imported into SEFA directly from Excel. Before transect data were entered into SEFA, senior engineering staff reviewed the input files prepared by scientific staff. The data entered into SEFA for each transect included the streambed profile, paired WSEL and discharge data, SZF (if applicable), the velocity profile, and substrate codes. The mesohabitat type was entered manually into SEFA for each transect and reach.

Calculation Preferences

The calculation options in SEFA are set in one main menu, Hydraulic Habitat Options. The traditional default 1D options were used unless the SEFA support information indicated user inputs should be processed using another available option. The only non-default option selected was to use Instream Flow Group Model #4 (IFG4) emulation for the rating curve development and velocity prediction. The use of IFG4 emulation is recommended when the bed profile elevations are derived from differential level measurements as opposed to water depth measurements (Jowett et al. 2014). The options selected in the Hydraulic Habitat Options menu are summarized in Table A-3.

Table A-3. Summary of SEFA user settings selected.

Menu Item	Menu Sub-Item	Selected Setting
Cross section extrapolation	Vertical bank created if slope at section start or end is less than	0.05
Velocity distribution calculation method	N/A	Conveyance (traditional method)
Conveyance for WSP	N/A	Harmonic and/or arithmetic mean
Hydraulic rating roughness	N/A	Flow
Rating curve method	N/A	IFG4 emulation
Velocity prediction method	N/A	IFG4 emulation
Habitat calculations	Method of calculating combined suitability index	Multiplication of individual suitabilities

WSEL and Discharge Calibration

The program SEFA was used to develop rating curves from the paired WSEL and discharge measurements. Stage-discharge relationships were derived from rating curves developed for each transect. SEFA contains three utilities for developing stage-discharge relationships: IFG4, referred to herein as log-log regression; Manning's stage-discharge using Manning's n (MANSQ); and water surface profile model via step-back computation (WSP; Jowett et al. 2014).

Log-log regression uses three or more measured stage and discharge pairs, along with the SZF elevation, to develop a relationship between stage and discharge based on the following equation:

$$Q = A \times (WSEL - SZF)^{exp}$$

Where:

Q = flow (cfs)
A = regression coefficient
WSEL = water surface elevation (ft)
SZF = stage of zero flow (ft)
exp = exponential regression coefficient

The above equation is converted to log-log format and a log-log linear relationship is fit to the data. In a habitat unit where the slope of the longitudinal water surface is controlled by a downstream hydraulic control point, the elevation of that downstream control point is the SZF. SEFA includes a SZF optimization utility called *Best SZF* that solves for the best fit to the log-log linear relationship by varying the SZF. The Best SZF rating is automatically provided in the displayed ratings field (see Figure A-5) with MANSQ and log-log regression ratings. The Best SZF rating indicates how well the field-measured SZF may be performing when considering log-log regression.

In Figure A-5, the red line is the SZF rating or log-log regression rating, the green dashed line is the Best SZF rating or log-log regression with a synthetic SZF that optimizes the log-log regression rating, the black dotted line is the hydraulic rating (MANSQ), the blue dashed and dotted line is the critical flow rating, the black square is the survey stage used for velocity calibration, and the blue chevrons are the other stage-discharge pairs used to develop the ratings.

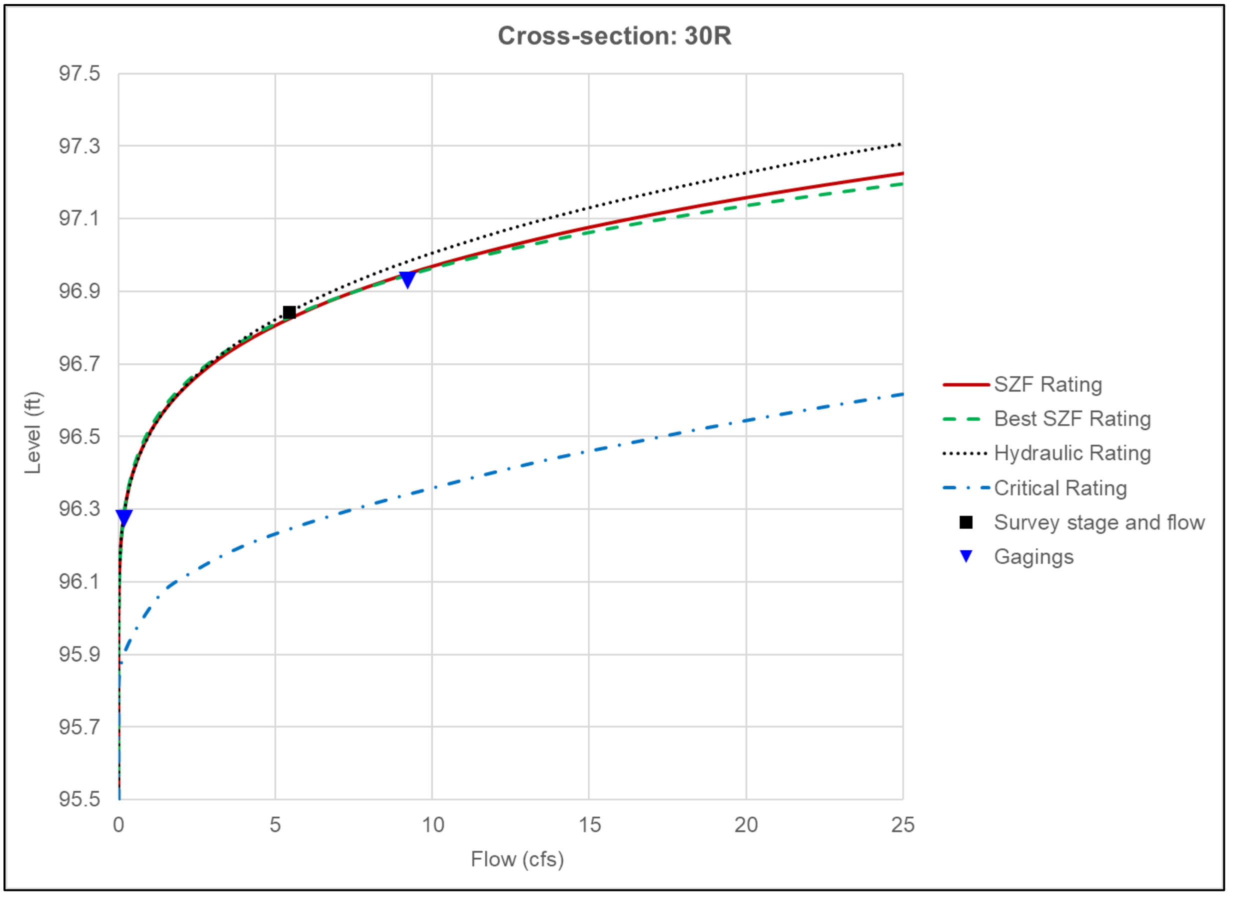

Figure A-5. Example SEFA rating curve output. Rating curves for additional transects are in Appendix B.

The critical flow rating refers to the rating curve derived so that the flow in the cross-section is critical. SEFA uses Manning's equation to solve for open channel flow, where the depth is assumed to be above the critical depth (Gupta 1995). The hydraulic utility MANSQ uses transect survey data and three or more measured stage and discharge pairs to develop a relationship between stage and discharge based on Manning's equation as follows:

$$Q = 1/N \times Area \times (R - R_{SZF})^{2/3} \times S^{1/2}$$

Where:

Q = flow (cfs)
$N = A \times Q^{beta}$
A = regression coefficient
beta = MANSQ exponential regression coefficient
Area = cross-sectional area of the transect (ft)
R = hydraulic radius (ft)
R_{SZF} = hydraulic radius at the SZF (ft)
S = slope of the water surface (ft/ft)

The water surface profile model, WSP, calculates the energy loss between transects to determine WSELs. The use of WSP requires data from the transect of interest and one downstream transect, at least three stages at both transects, and the three corresponding flows to perform a step backwater calculation (similar to HEC-RAS) to develop the stage discharge relationship. The data collection required to perform WSP was beyond the scope of this study and the method was not used.

The default hydraulic utility MANSQ was selected to predict stage-discharge at each transect because MANSQ uses the Manning's equation to solve for WSEL as opposed to log-log, which is an empirical relationship only. Log-log regression was used as the default modeling method for pool transects and for transects where the MANSQ mean error was 10% or greater. The optimized Best SZF rating was used when field-based estimates of SZF were obscured from measurement by large boulders or wood substrates.

Multiple references related to the use of the 1D method were consulted when developing a rationale for evaluating the calibration results of the two stage-discharge rating utilities. These references included: *User's Guide to the Physical Habitat Simulation System (PHABSIM)* (Milhous et al. 1981); *Using the Computer Based Physical Habitat Simulation System* (USFWS 1994); *PHABSIM for Windows, User's Manual and Exercises* (USGS 2001); and *User's Manual RHABSIM 3.0 Riverine Habitat Simulation Software for DOS and Windows* (Thomas R. Payne and Associates 1998).

The guidelines presented below were used when selecting the stage/discharge method for each transect.

- The mean error of predicted versus measured discharge does not exceed 10%;
- The maximum variance of any one predicted discharge compared to a measured discharge does not exceed 25%; and

- The difference between measured and predicted WSELs does not exceed 0.1 ft at a given calibration flow.

In addition, for MANSQ models, transects with beta values outside the range of 0 to 0.4 were evaluated further. For log-log regression models, the beta value must be within the range of 2.0 to 4.5. Preferred ranges of MANSQ beta vary amongst practitioners of instream flow studies. For example, the RHABSIM user's manual suggests 0 to 0.4 (Thomas R. Payne and Associates 1998) while the PHABSIM manual recommends 0 to 0.6 (USGS 2001).

Where MANSQ beta values exceeded 0.4, the senior engineering staff reviewed unit data to confirm stage/discharge results were not affected by errors in data collection or method application. Where predicted results for all the methods did not accurately predict measured values, staff reviewed field notes and digital images to understand potential causes for variance in predictive values versus field measurements.

Velocity Adjustment Factor Discharge Calibration

The survey flow (Q_{SF}) is the field discharge measurement associated with the selected velocity profile used to simulate velocities in SEFA. The VAF is the ratio between the survey flow and the discharge calculated in SEFA using the surveyed velocity profile.

$$VAF = Q_{SF}/Q_{SV}$$

For each transect, each velocity from the selected velocity profile is multiplied by the VAF such that $Q_{SV} = Q_{SF}$. A VAF can be used as one indicator of how well the transect velocity profile relates to the survey flow. The Department considers a VAF range of 0.75 to 1.25 to be acceptable (Milhous et al. 1989). Transects with VAFs outside of the recommended range are omitted from further analysis.

Discharge Simulation Range

Extrapolation beyond the highest measured flow is often necessary to evaluate the possible range of flows needed by a species for activities such as spawning or upstream passage. The range of discharge that can be simulated in 1D for a site while maintaining meaningful results is dependent on the characteristics of the transect including substrate size, hydraulic radius, bank geometry, and the presence of floodplains. Generally, to ensure extrapolated flows maintain their integrity, PHABSIM manuals have reported that 0.4 to 2.5 is an acceptable simulation range (USGS 2001), but more accurately, simulation range is limited by channel configuration, model performance, and data availability (USGS 2001).

Water Velocity Prediction

Velocities are simulated by multiplying the velocity profile collected during the survey flow by a range of VAF values. For velocity simulation, the recommended VAF range is 0.1 to 5.0. SEFA computes velocity distribution factors (VDFs) from the velocity profile measured in the field at each transect (Jowett et al. 2014). A VDF is the ratio of the field measured velocities to the velocities calculated by SEFA using the transect VAF described above in the *Velocity Adjustment Factor Discharge Calibration* section. A VDF is used to modify the magnitude of individual transect cell velocities to improve the shape of the velocity profile simulation. The VDFs are automatically modulated by the SEFA program to improve the VAF. Note that SEFA refers to VDFs as Manning N values interchangeably.

Modifications to VDFs can be useful when small negative velocities caused by eddies occur along the transect near the stream margin. Eddies are typically caused by vegetation or large obstacles upstream of a transect (Figure A-6). In SEFA, simulation velocity profiles are generated by multiplying the survey flow velocities by the VAF. A byproduct of this method is that the magnitude of small negative velocities become increasingly negative with higher simulated flows (Figure A-7).

Figure A-6. Example of vegetation and boulders near the stream margins causing velocity eddies. San Antonio Creek transect, looking downstream.

As the mid-column cell depth rises with increased flow volume, the effect of bank vegetation and obstacles may naturally dissipate or remain the same, depending upon the density of the vegetation and size of the upstream obstacle. In Figure A-7, the small left side margin velocity increases in negative magnitude to over -2 ft/s at the high simulation flow. Adjustments were made to VDFs if the negative magnitude of a simulated cell velocity exceeded -1 ft/s or where the shape of the simulated velocity profile was not consistent with the surveyed velocity profile.

Modifications to VDFs are also useful when the shape of the simulated velocity profile contradicts the shape of the velocity profile measured in the field. For example, in Figure A-8 the shape of the field velocity profile near stations 9 and 10 is inconsistent with the shape of the simulated velocity profile. The SEFA Software Manual (Jowett et al. 2014) recommends reviewing the field notes and reducing VDFs accordingly to improve the shape of the velocity profile.

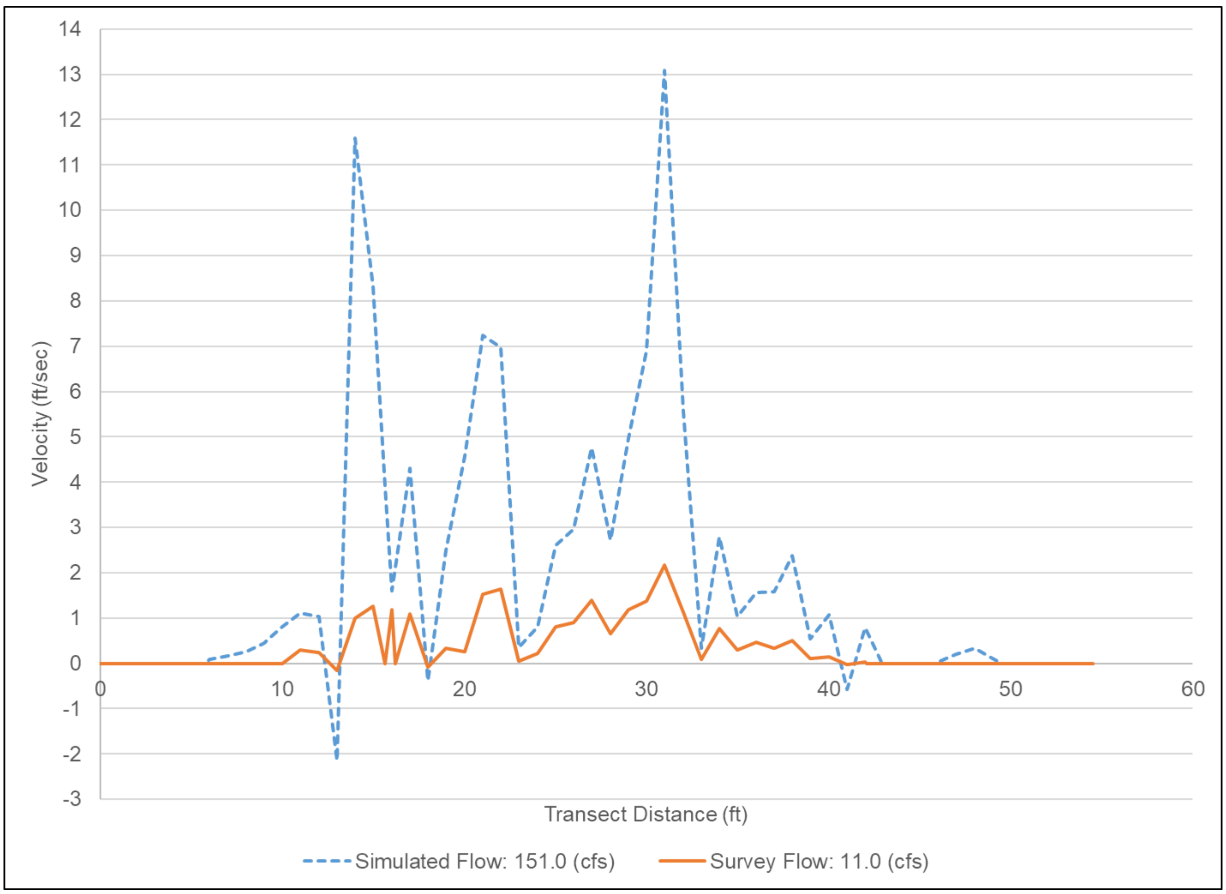

Figure A-7. Example simulation of small negative velocities in SEFA. Velocities increase in negative magnitude at higher simulated flow levels.

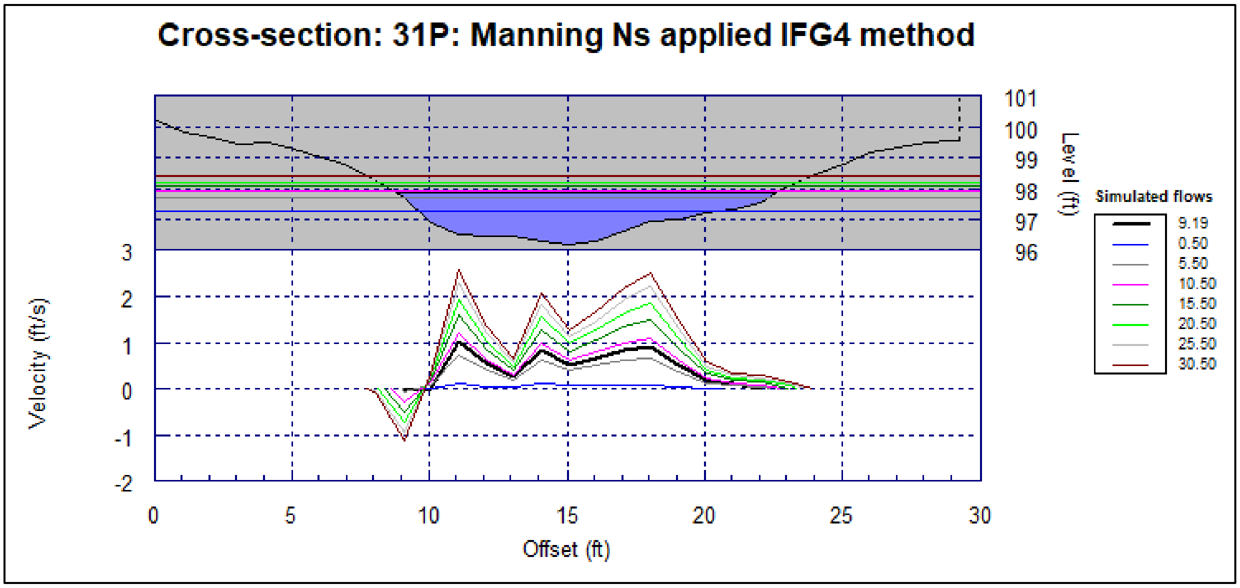

Figure A-8. Example transect showing the pattern of the simulated velocities. On this transect, the simulated velocities do not follow the trend of the field-measured velocity profile, bold black line, at offset 9 and 10.

A.2 Results

The model calibration results for the two reaches in San Antonio Creek are described in the following sections. The specific outputs related to model performance are provided in Section A.2.3 and Appendix B through Appendix E.

A.2.1 Calibration Discharge

The discharge measurements used to develop the stage-discharge rating for each transect in SEFA are provided in Table A-4 and Table A-5. Discharge measurements were taken at locations near the transect to minimize the impact of stream gains and losses between the position of the transect and the discharge measurement. Typically, the discharge measurements were taken at the closest glide unit to the transect unit being surveyed.

Table A-4. Transect discharges by date for Reach 1. Flow events that were not modeled are entered as -.

Transect	Date	Flow (cfs)	Flow Event	Modeled Flow Event
22R	3/15/2018	9.2	High	Yes
22R	3/14/2018	5.4	Mid	-
22R	2/13/2018	0.2	Low	-
23L	3/15/2018	9.2	High	Yes
23L	3/14/2018	5.4	Mid	-
23L	2/13/2018	0.2	Low	-
26P	3/15/2018	9.2	High	-
26P	3/14/2018	5.4	Mid	Yes
26P	2/13/2018	0.2	Low	-
29L	3/15/2018	9.2	High	Yes
29L	3/14/2018	5.4	Mid	-
29L	3/13/2018	0.7	Low	-
30R	3/15/2018	9.2	High	-
30R	3/14/2018	5.4	Mid	Yes
30R	2/13/2018	0.2	Low	-
31P	3/15/2018	9.2	High	Yes
31P	3/14/2018	5.4	Mid	-
31P	2/08/2018	0.2	Low	-
32L	3/15/2018	9.2	High	Yes
32L	3/14/2018	5.4	Mid	-
32L	2/08/2018	0.2	Low	-
52R	3/15/2018	9.2	High	-
52R	3/14/2018	5.4	Mid	Yes
52R	2/08/2018	0.3	Low	-
55P	3/15/2018	9.2	High	Yes
55P	3/14/2018	5.4	Mid	-
55P	3/13/2018	0.7	Low	-

Table A-5. Transect discharges by date for Reach 2. Flow events that were not modeled are entered as -.

Transect	Date	Flow (cfs)	Flow Event	Modeled Flow Event
88R	3/26/2018	10.4	High	Yes
88R	3/14/2018	6.3	Mid	-
88R	3/13/2018	1.3	Low	-
88R	2/27/2018	0.2	Low	-
90P	3/26/2018	10.4	High	Yes
90P	3/14/2018	6.3	Mid	-
90P	3/13/2018	1.3	Low	-
90P	2/27/2018	0.2	Low	-
95L	3/26/2018	9	High	Yes
95L	3/14/2018	6.3	Mid	-
95L	3/13/2018	1.3	Low	-
95L	2/27/2018	0.2	Low	-
105R	3/26/2018	9	High	Yes
105R	3/14/2018	6.3	Mid	-
105R	2/28/2018	0.1	Low	-
117P	3/14/2018	8.5	High	-
117P	3/13/2018	4.4	Mid	-
117P	3/15/2018	4.2	Mid	Yes
117P	3/13/2018	0.4	Low	-
127L	3/14/2018	8.5	High	Yes
127L	3/13/2018	4.4	Mid	-
127L	3/15/2018	4.2	Mid	-
127L	2/08/2018	0.3	Low	-

A.2.2 Stage-Discharge Rating Curve Utility Selection and Calibration

The stage-discharge rating relationship was computed for each transect using two utilities available in SEFA: log-log regression and MANSQ. The rating curves generated for each transect and utility are provided in Appendix B. The hydraulic model utility calibration results are given in Appendix C. These results include the reach calibration results for mean error of predicted versus measured discharge, beta value for either method, and VAF for the selected rating utility. In Appendix C, the mean error of the rating utility selected is indicated in bold. The minimum, maximum, and mean of calibration mean error by reach are summarized in Table A-6.

Three transects in Reach 2 were omitted. Transects 81R and 132L were omitted because they failed to meet the hydraulic utility mean error standard of <10%. Transect 83L was omitted because the rating curve fell below the Critical Rating at approximately 17 cfs. Refer to Table C-2 in Appendix C.

Table A-6. Summary of calibration mean error, WSEL error, calibration flow VAF, and simulation velocity VAF results for Reach 1 and Reach 2 of San Antonio Creek.

Reach	Parameter	Guidance Range	Min.	Max.	Mean
1	Calibration Mean Error	≤10%	1.91%	9.11%	6.58%
1	WSEL (Error; ft)	≤0.1	0.00	0.05	0.01
1	Calibration Flow VAF	0.75–1.25	0.89	1.25	1.09
1	Simulation Velocity VAFs	0.1–5.0	0.08	5.38	1.62
2	Calibration Mean Error	≤10%	1.46%	9.28%	6.58%
2	WSEL (Error; ft)	≤0.1	0.00	0.05	0.02
2	Calibration Flow VAF	0.75–1.25	0.75	1.17	0.97
2	Simulation Velocity VAFs	0.1–5.0	0.19	6.07	1.33

A.2.3 WSEL Simulation

The stage-discharge utility selected in SEFA (above) was used to predict WSELs. The field-measured WSELs and the matching WSELs predicted by SEFA are reported in Table A-7 and Table A-8 for each transect and survey discharge. All predicted WSELs were within the threshold in the USFWS guidelines for PHABSIM, which recommended a difference of 0.1 ft or less (USFWS 1994) between surveyed and modeled WSEL. The minimum, maximum, and mean difference between measured and predicted WSEL by reach are summarized in Table A-6.

Table A-7. Calibration flows and WSELs in Reach 1 transects.

Transect	Flow (cfs)	SEFA WSEL (ft)	Field WSEL (ft)	(+/-)
22R	9.2	96.12	96.12	0.00
22R	5.4	96.07	96.08	0.01
22R	0.2	95.81	95.80	0.01
23L	9.2	96.78	96.78	0.00
23L	5.4	96.70	96.70	0.00
23L	0.2	96.29	96.28	0.01
26P	9.2	97.12	97.11	0.01
26P	5.4	97.02	97.03	0.01
26P	0.2	96.62	96.61	0.01
29L	9.2	99.28	99.28	0.00
29L	5.4	99.18	99.21	0.03
29L	0.7	98.89	98.89	0.00
30R	9.2	96.98	96.93	0.05
30R	5.4	96.84	96.84	0.00
30R	0.2	96.29	96.27	0.02
31P	9.2	97.89	97.85	0.04
31P	5.4	97.72	97.76	0.04
31P	0.2	97.17	97.17	0.00
32L	9.2	98.08	98.08	0.00
32L	5.4	98.01	98.03	0.02
32L	0.2	97.67	97.67	0.00
52R	9.2	97.66	97.68	0.02
52R	5.4	97.63	97.63	0.00
52R	0.3	97.25	97.24	0.01
55P	9.2	95.97	95.96	0.01
55P	5.4	95.91	95.93	0.02
55P	0.7	95.72	95.72	0.00

Table A-8. Calibration flows and WSELs in Reach 2 transects.

Transect	Flow (cfs)	SEFA WSEL (ft)	Field WSEL (ft)	(+/-)
88R	10.4	96.02	96.02	0.00
88R	6.3	95.88	95.87	0.01
88R	1.3	95.57	95.58	0.01
88R	0.2	95.37	95.36	0.01
90P	10.4	95.82	95.86	0.04
90P	6.3	95.68	95.64	0.04
90P	1.3	95.37	95.36	0.01
90P	0.2	95.13	95.13	0.00
95L	9.0	97.17	97.17	0.00
95L	6.3	97.07	97.03	0.04
95L	1.3	96.77	96.74	0.03
95L	0.2	96.57	96.58	0.01
105R	9.0	97.84	97.84	0.00
105R	6.3	97.76	97.71	0.05
105R	0.2	97.28	97.24	0.04
117P	8.5	97.45	97.45	0.00
117P	4.4	97.36	97.36	0.00
117P	4.2	97.35	97.35	0.00
117P	0.4	97.08	97.07	0.01
127L	8.5	96.97	96.97	0.00
127L	4.4	96.81	96.78	0.03
127L	4.2	96.80	96.75	0.05
127L	0.3	96.39	96.37	0.02

A.2.4 Simulated Flow Range and Velocity Calibration by VAF

The transect velocity profiles collected during the survey flow were imported into SEFA and used to predict velocity over the range of simulated flows. The simulated velocity profiles are presented in Appendix D for each transect. Velocities for each reach were initially simulated using the recommended range of 0.4 times the lowest measured flow to 2.5 times the highest measured flow (USGS 2001). The simulation range was extended to 30.5 cfs, 3.3 times the highest measured flow, for all transects based on the results of the hydraulic simulations, which showed that the slope of the banks remained consistent up to 30.5 cfs for each transect. The simulation range was expanded to provide better resolution of the AWS curves in Figure 17 and Figure 18 of the main report.

The VAFs for all the simulated flows were plotted with discharge on the x-axis and VAF on the y-axis. Summary discharge/VAF plots for the two reaches are provided in Figure A-9 and Figure A-10. The minimum, maximum, and average VAFs for the velocities simulated by reach are summarized in Table A-6. As a result of expanding the simulation range the maximum simulated velocity VAF value for both reaches exceeded 5.0. The analysis is not impacted because the range of simulated velocities above VAF 5.0 are not being used to evaluate fish habitat. The lowest simulated velocity VAF in Reach 1 was 0.08 for transect 55P at 0.5 cfs. The VAF is slightly below the recommended threshold of 0.1. The impact of this deviation will be weighed as flows in the range of 0.5 cfs are considered for fish habitat.

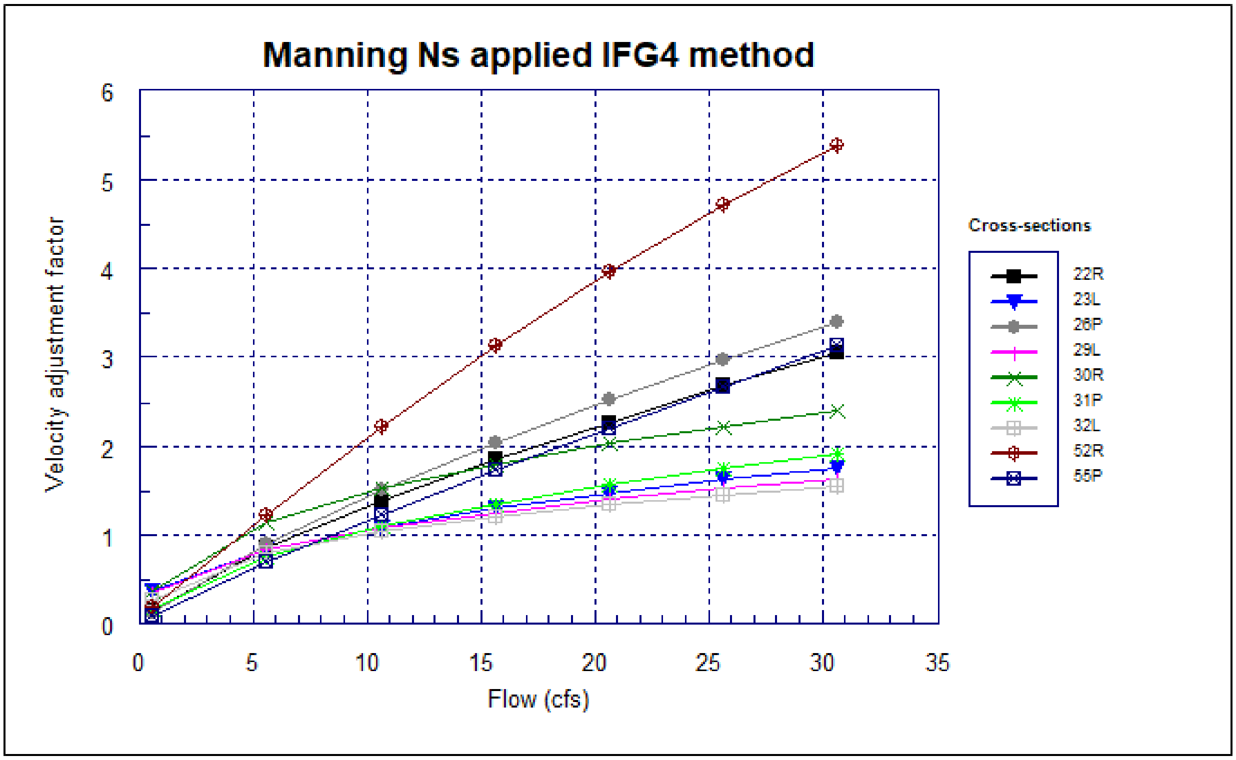

Figure A-9. Velocity simulation VAFs by discharge in Reach 1.

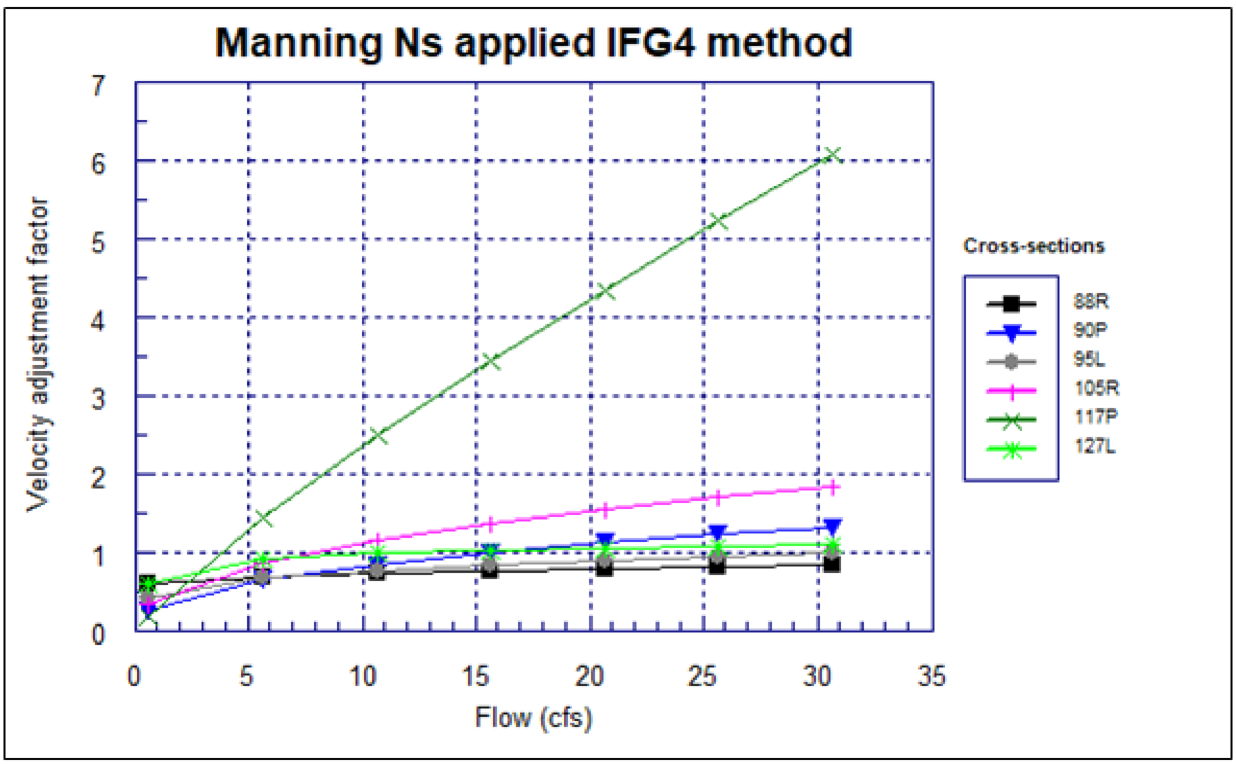

Figure A-10. Velocity simulation VAFs by discharge in Reach 2.

A.2.5 Velocity Distribution Factors

The simulated velocity profiles for each transect were reviewed to determine whether the simulated velocity patterns were consistent with the pattern of the velocity profile measured in the field. Attention was also placed on transects containing negative velocities. As discussed in Section 1.2, small negative velocities were present in some of the transects near the stream margins. Modifications were made to VDFs in six total transects between Reaches 1 and 2 (Table A-9). The VDFs in transects 31P, 55P, 117P were modified to make the simulated velocity pattern consistent with the pattern of the velocity profile measured in the field. The VDFs in transects 88R, 90P, and 127L were modified to minimize the magnitude of negative velocities to >(-1) ft/s. The velocity patterns for each transect, before and after the VDFs were modified, are provided in Appendix D. The graphic display of VDFs before and after modification are provided in Appendix E.

Table A-9. Adjusted VDFs.

Reach	Transect	Offset Distance (ft)	Default VDF	Initial Maximum Simulated Velocity (ft/s)	Revised VDF	Final Maximum Simulated Velocity (ft/s)
1	31P	9	-0.168	-1.100	-0.901	-0.194
1	31P	10	0.918	0.335	0.291	1.001
1	55P	6	-0.054	-0.898	-0.122	-0.335
1	55P	7	-0.032	-3.567	-0.108	-0.899
1	55P	8	-0.061	-2.422	-0.180	-0.698
1	55P	14	-0.129	-1.218	-0.247	-0.537
1	55P	15	-0.072	-2.205	-0.146	-0.913
2	88R	6	0.057	0.636	0.149	0.205
2	88R	7	0.057	1.606	0.200	0.388
2	88R	8	0.057	1.909	0.147	0.626
2	90P	1	0.075	2.251	0.296	0.651
2	90P	2	0.075	2.421	0.300	0.692
2	117P	6	-0.013	-4.122	-0.086	-0.602
2	127L	6	0.031	1.583	0.198	0.264
2	127L	7	0.031	2.209	0.120	0.610
2	127L	8	0.031	2.959	0.097	1.008

Appendix A References

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APPENDIX B: SEFA RATING CURVES

The rating curve outputs for each transect are provided in this appendix. The plots compare predictions for each of the three flow/water level predictive relationship utilities included in this report: SZF Rating (log-log regression), Best SZF Rating (log-log regression where SZF is optimized), and hydraulic rating (MANSQ).

In the figures, the red line is the SZF Rating or log-log regression rating, the green dashed line is the Best SZF rating or log-log regression with a synthetic SZF that optimizes the log-log regression rating, the black dotted line is the hydraulic rating (MANSQ), the blue dashed and dotted line is the critical flow rating, the black square is the survey stage used for velocity calibration, and the blue chevrons are the other stage-discharge pairs used to develop the ratings. More details are available in A.1.2 *WSEL and Discharge Calibration*.

B.1 San Antonio Creek Reach 1

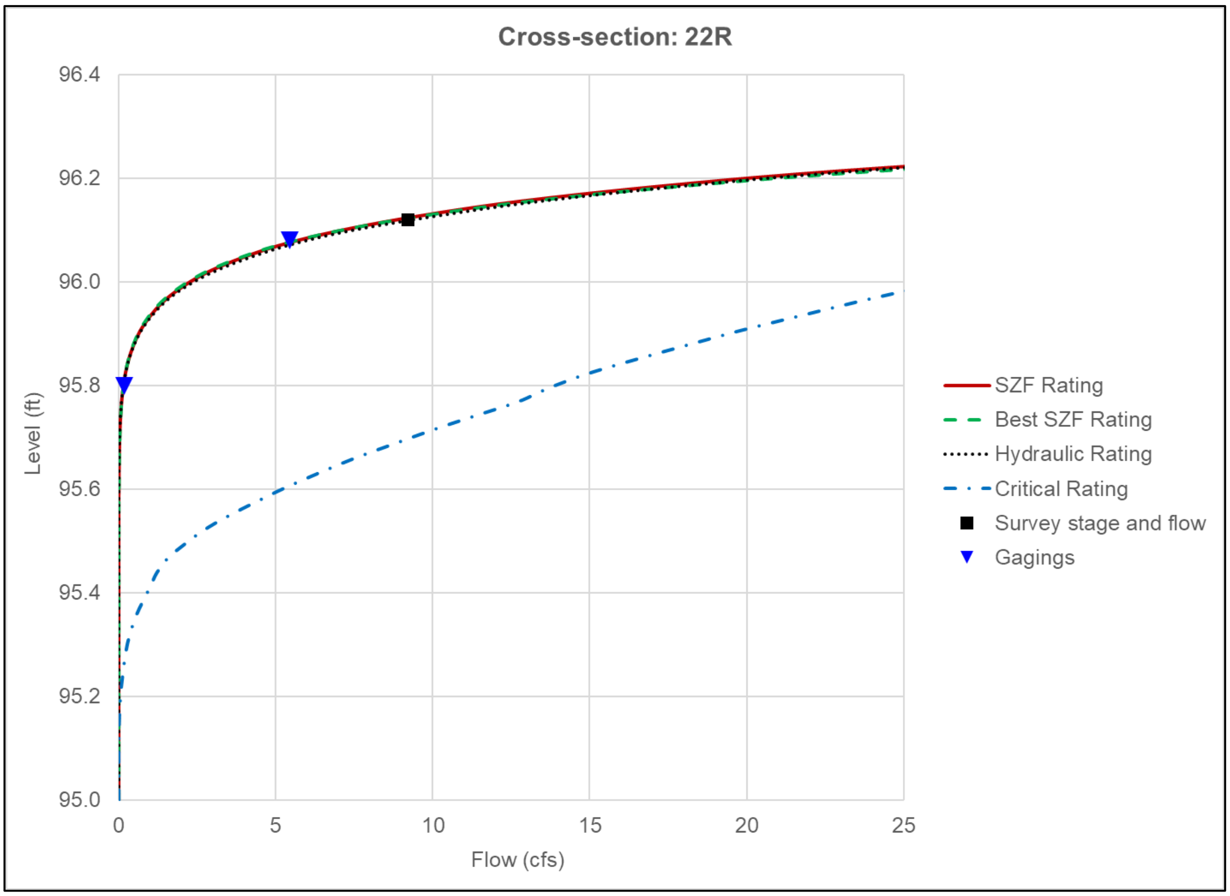

Figure B-1. Rating curve outputs for Reach 1, cross section 22R.

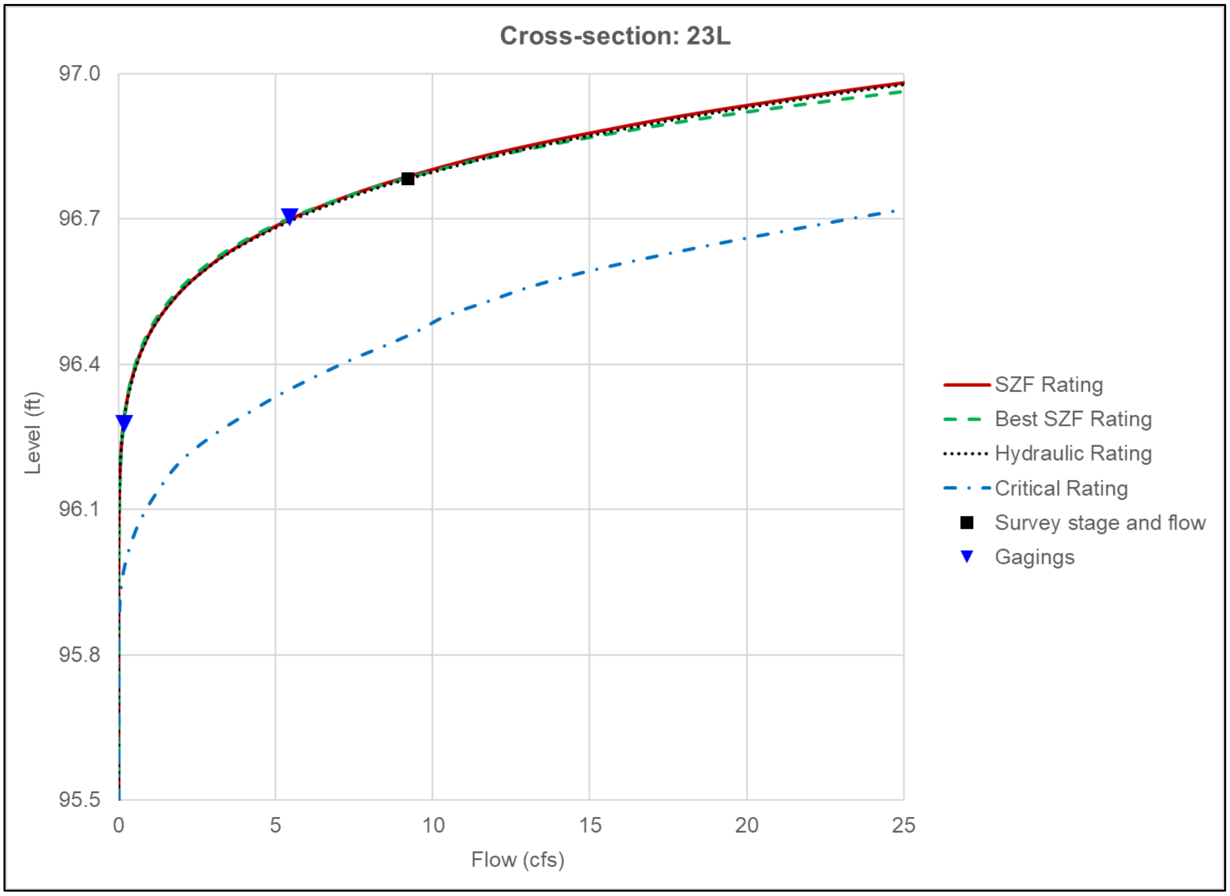

Figure B-2. Rating curve outputs for Reach 1, cross section 23L.

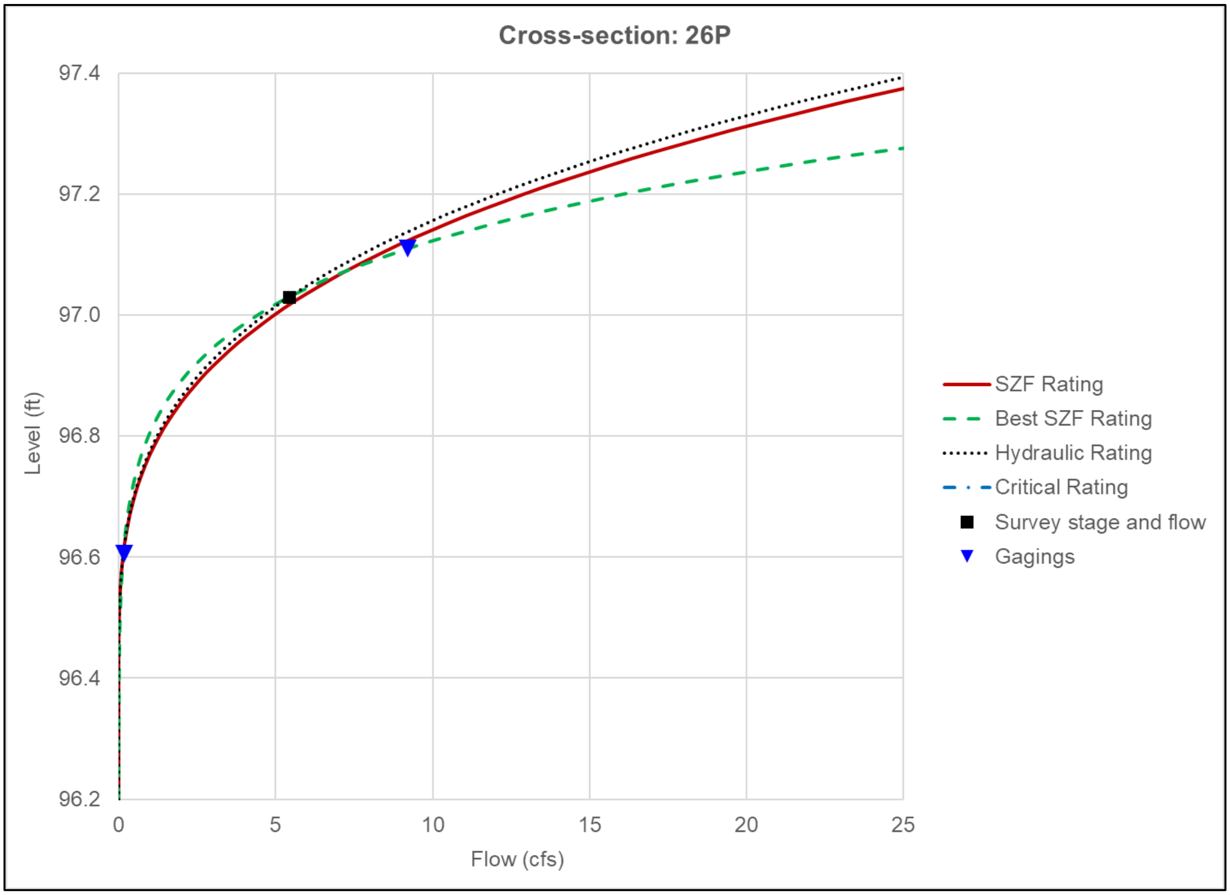

Figure B-3. Rating curve outputs for Reach 1, cross section 26P. This rating curve also appears as an example in Appendix A.

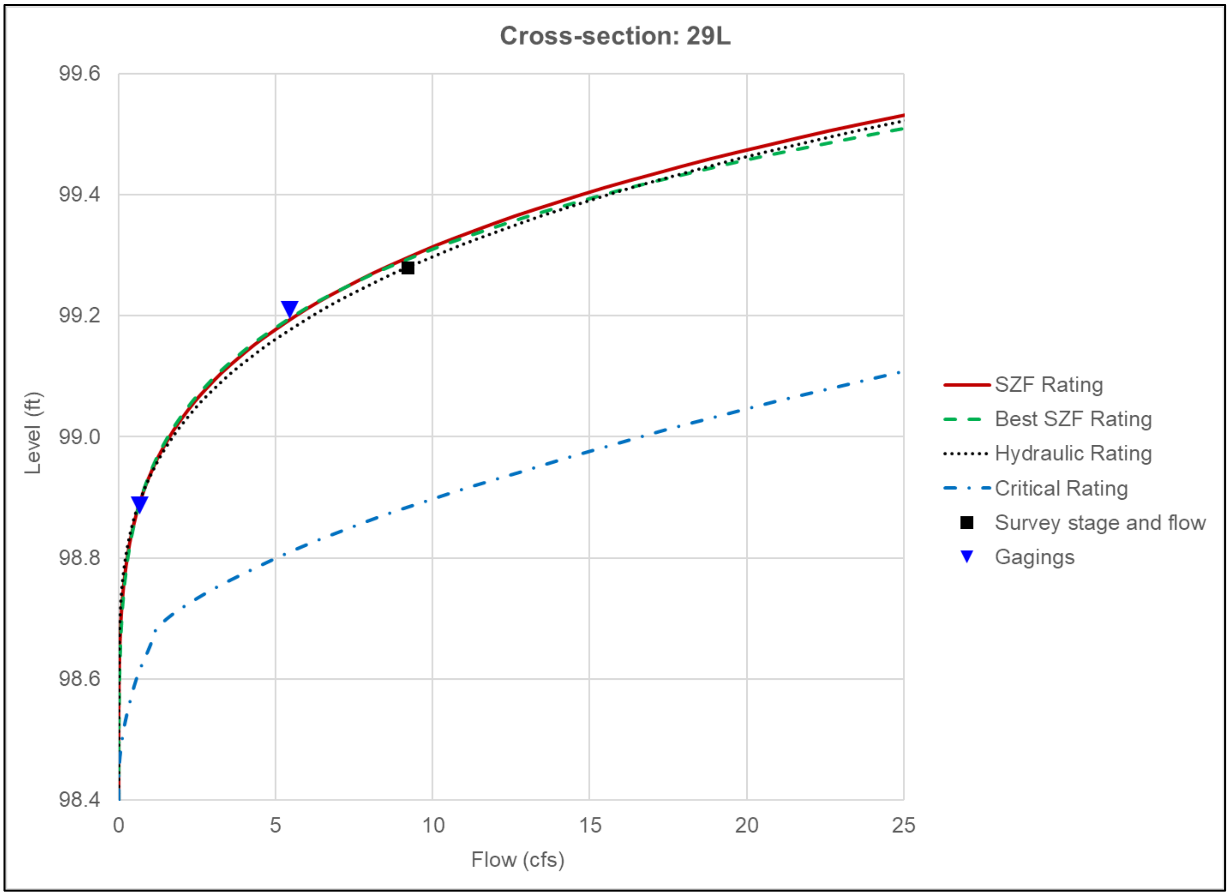

Figure B-4. Rating curve outputs for Reach 1, cross section 29L.

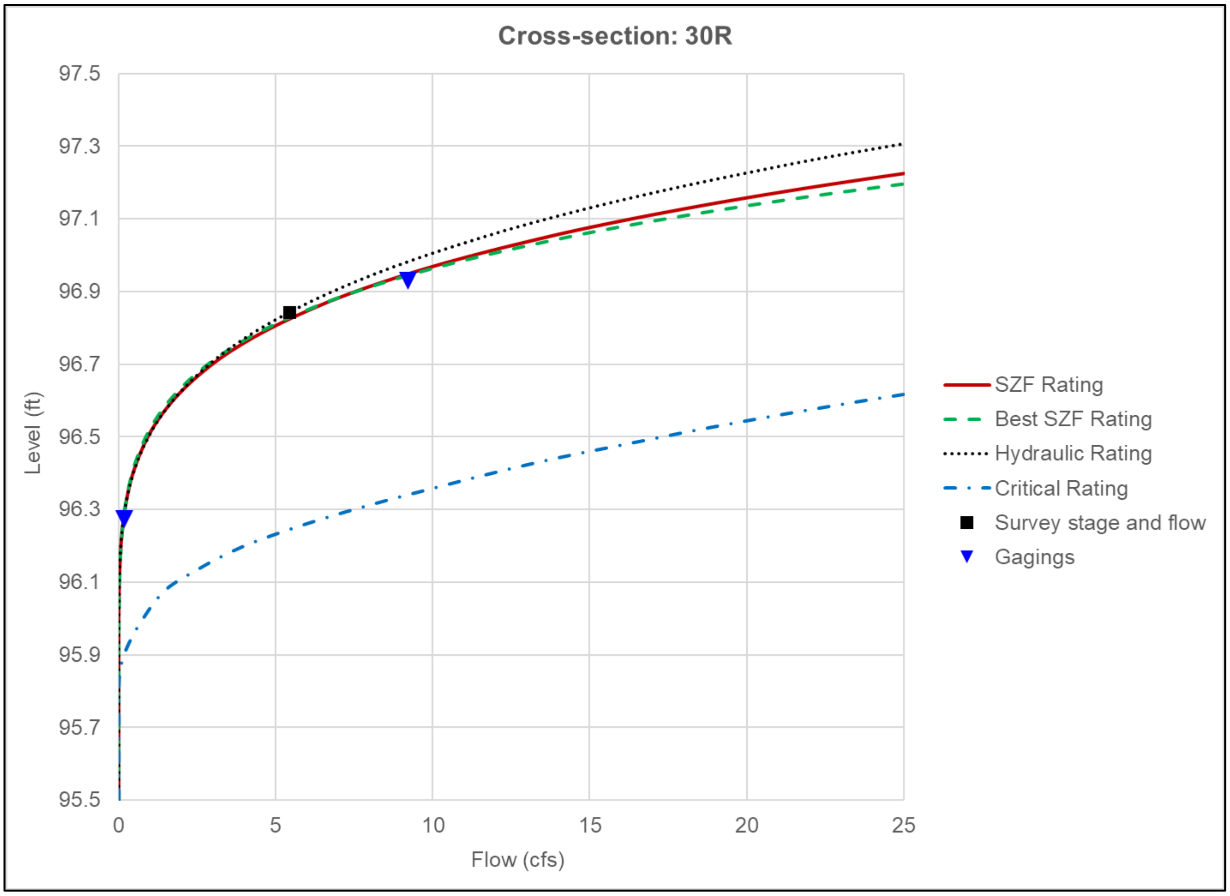

Figure B-5. Rating curve outputs for Reach 1, cross section 30R.

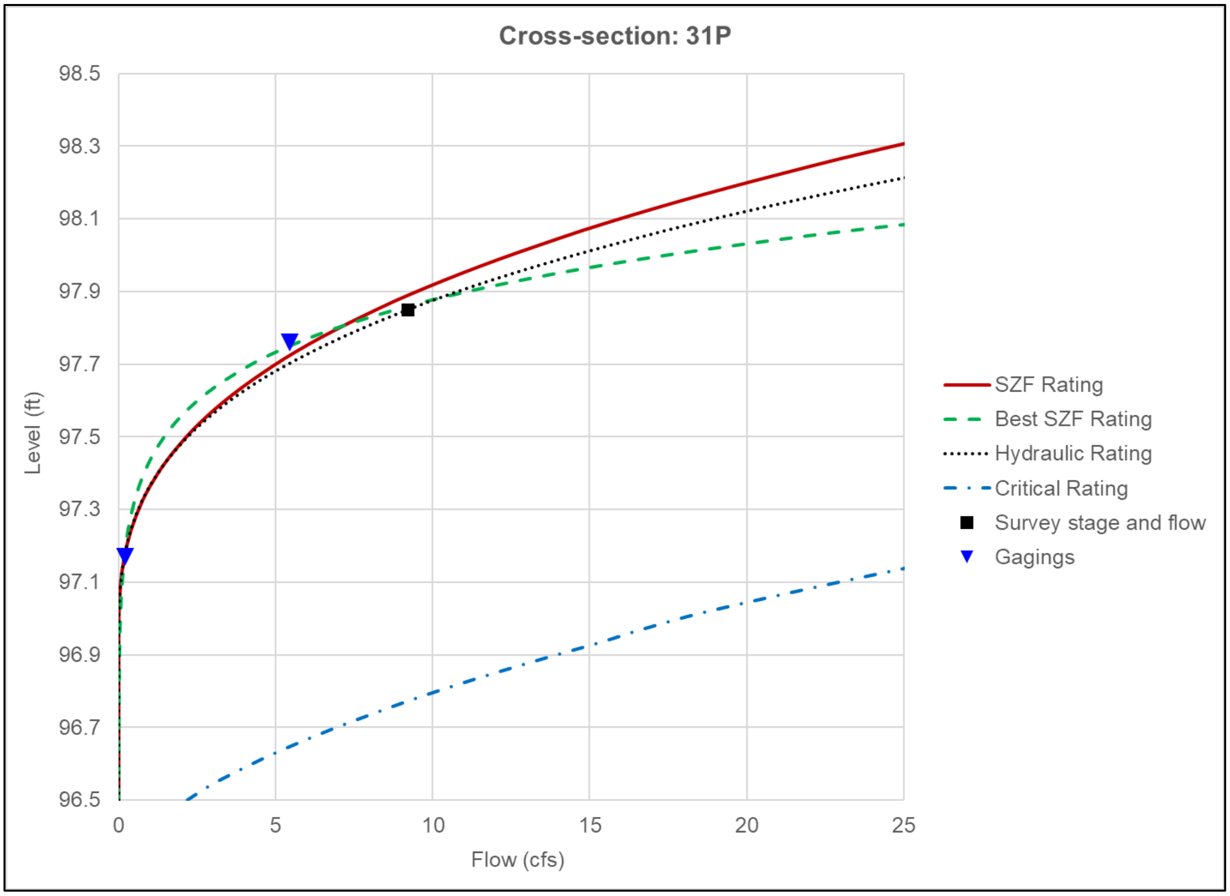

Figure B-6. Rating curve outputs for Reach 1, cross section 31P.

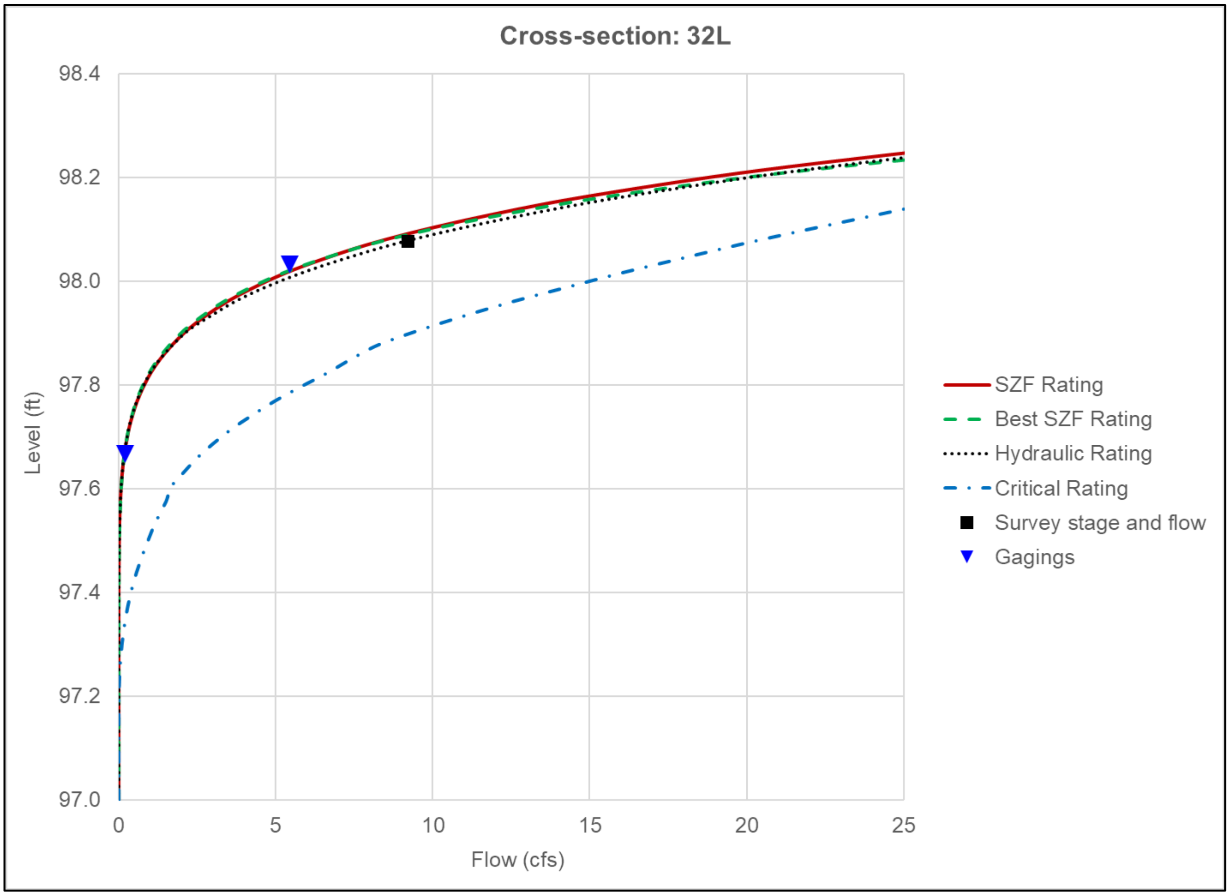

Figure B-7. Rating curve outputs for Reach 1, cross section 32L.

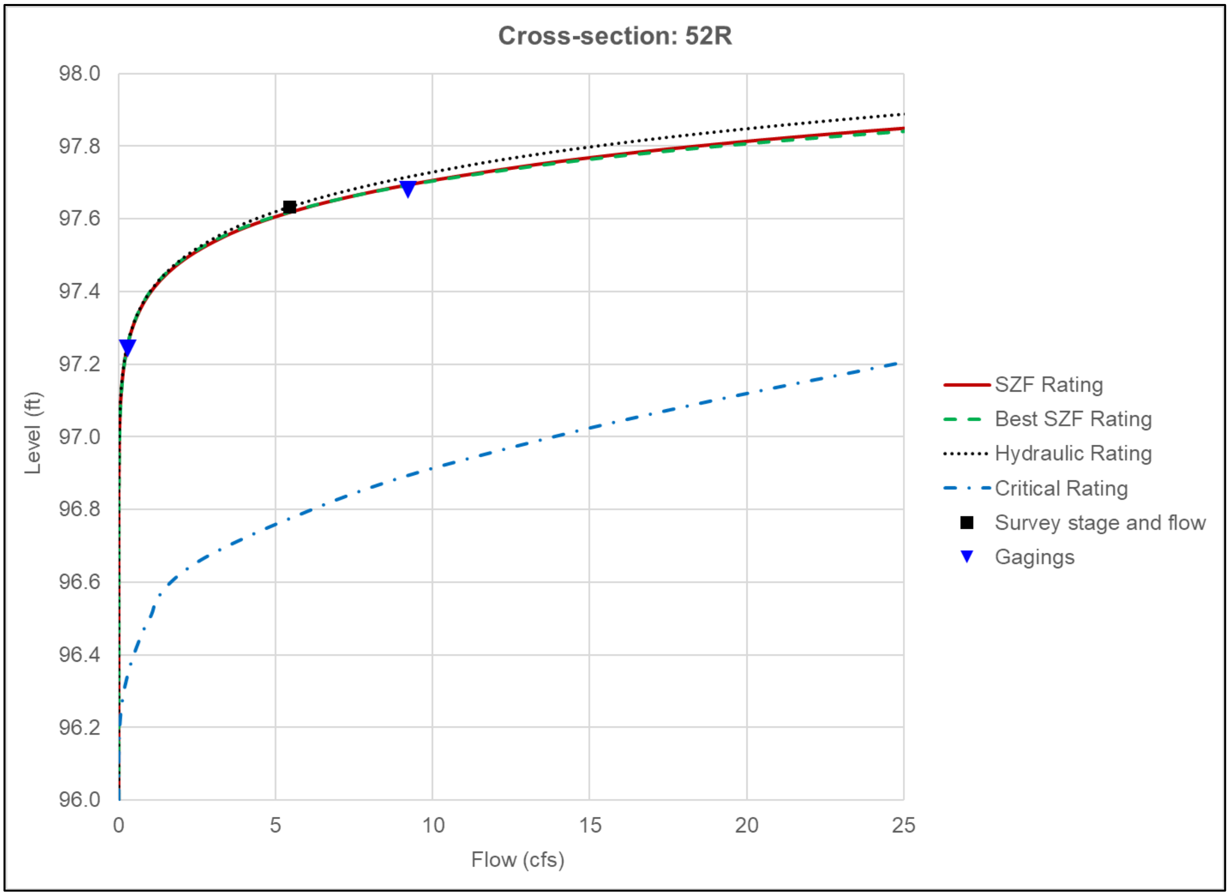

Figure B-8. Rating curve outputs for Reach 1, cross section 52R.

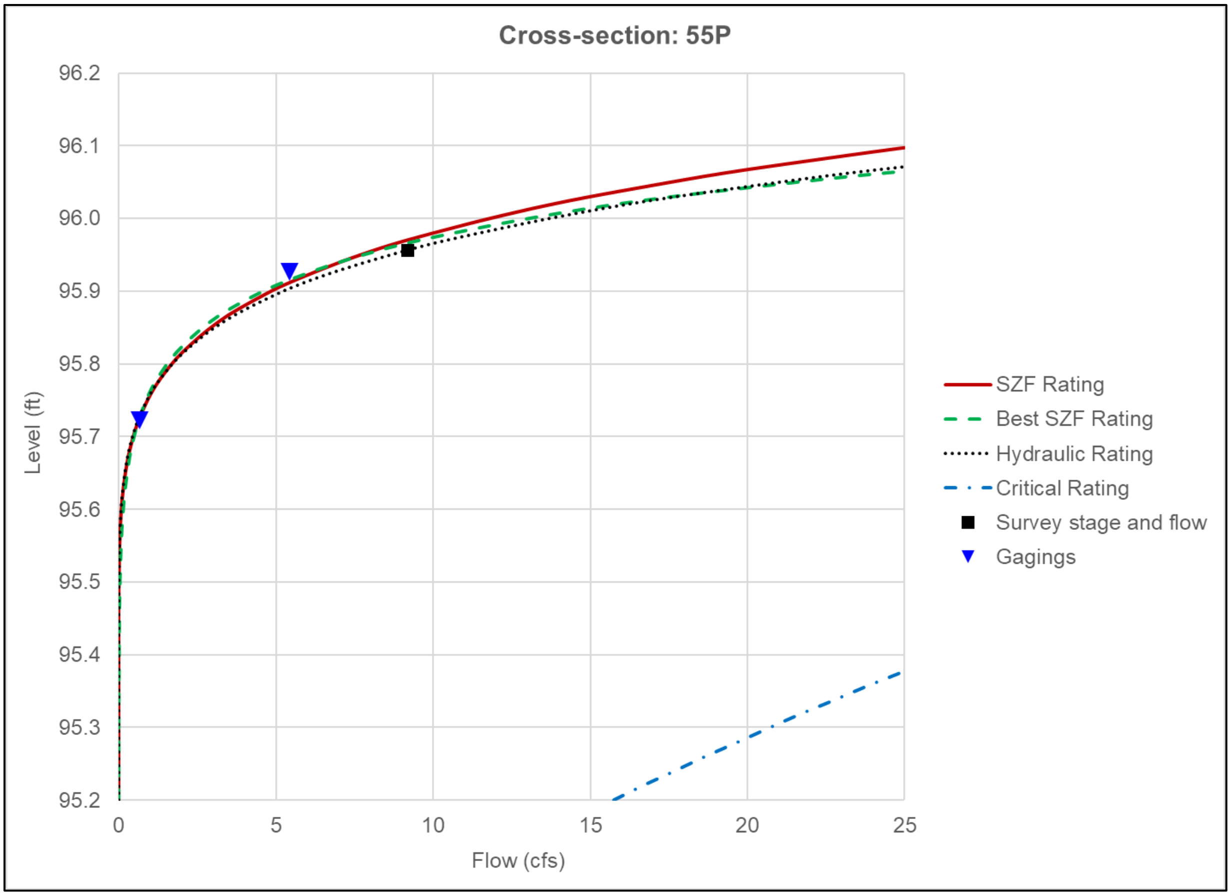

Figure B-9. Rating curve outputs for Reach 1, cross section 55P.

B.2 San Antonio Creek Reach 2

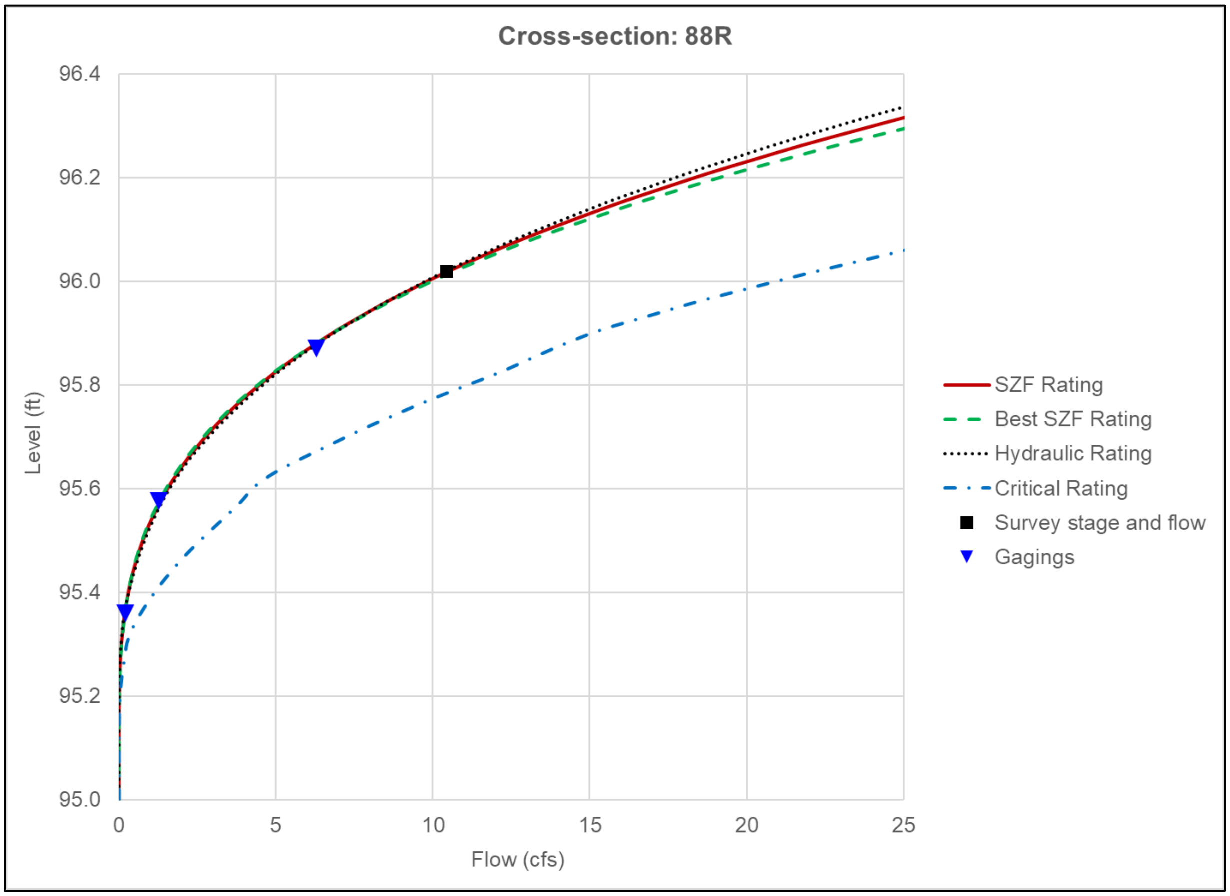

Figure B-10. Rating curve outputs for Reach 2, cross section 88R.

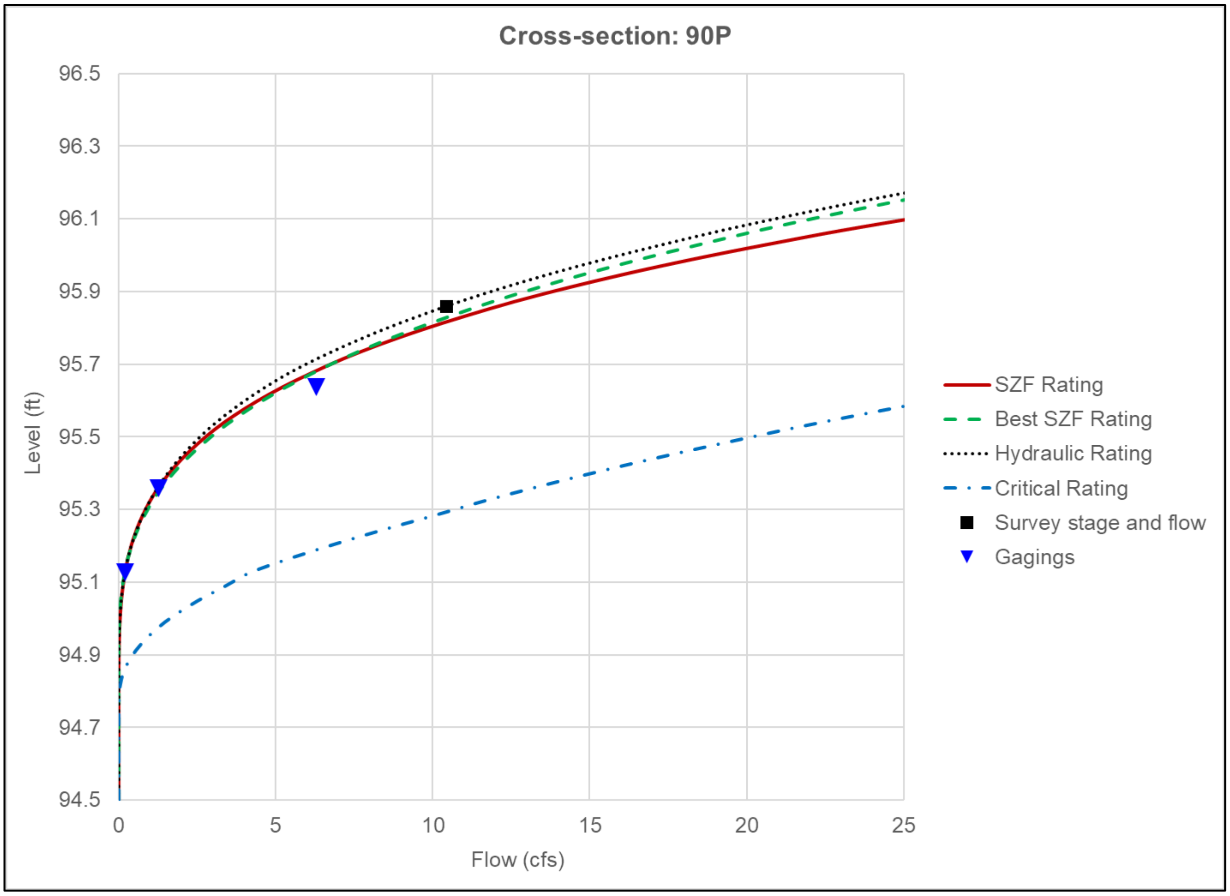

Figure B-11. Rating curve outputs for Reach 2, cross section 90P.

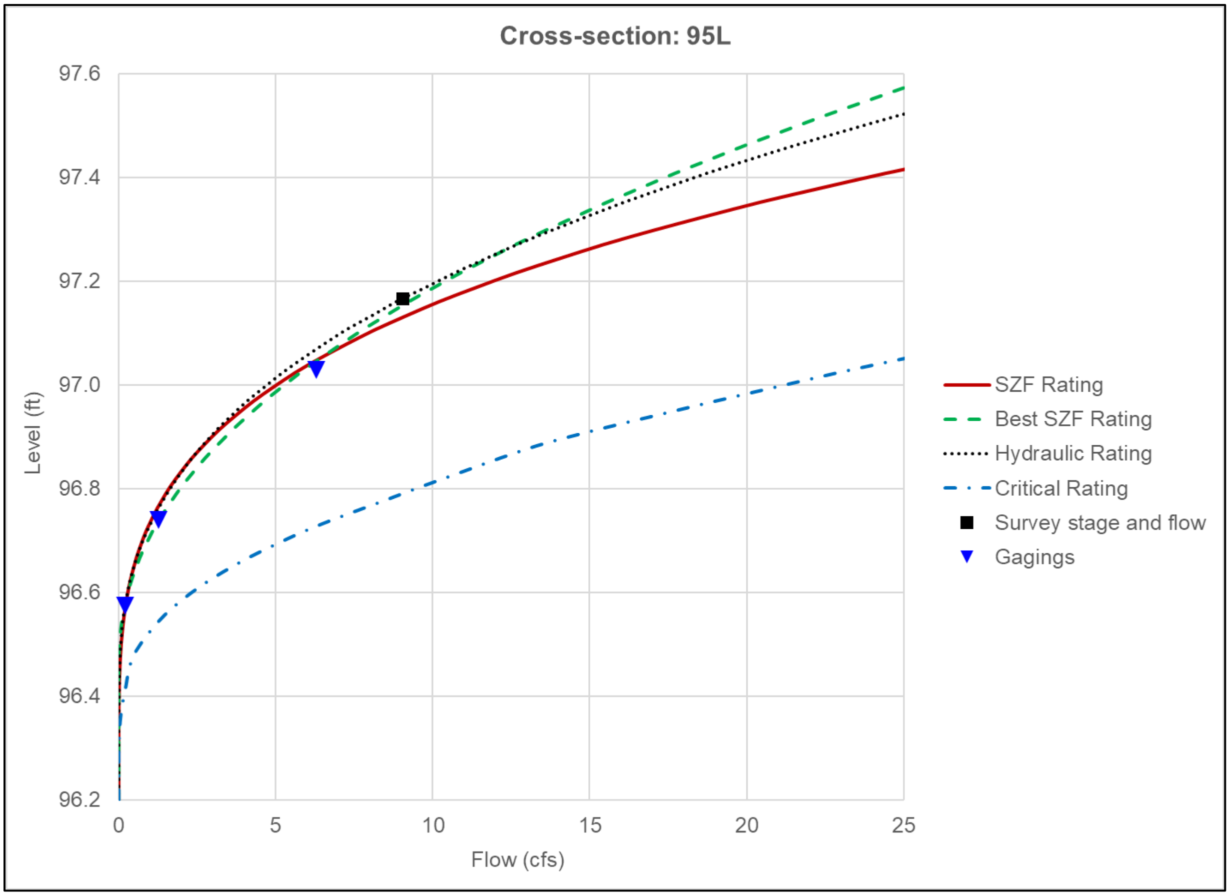

Figure B-12. Rating curve outputs for Reach 2, cross section 95L.

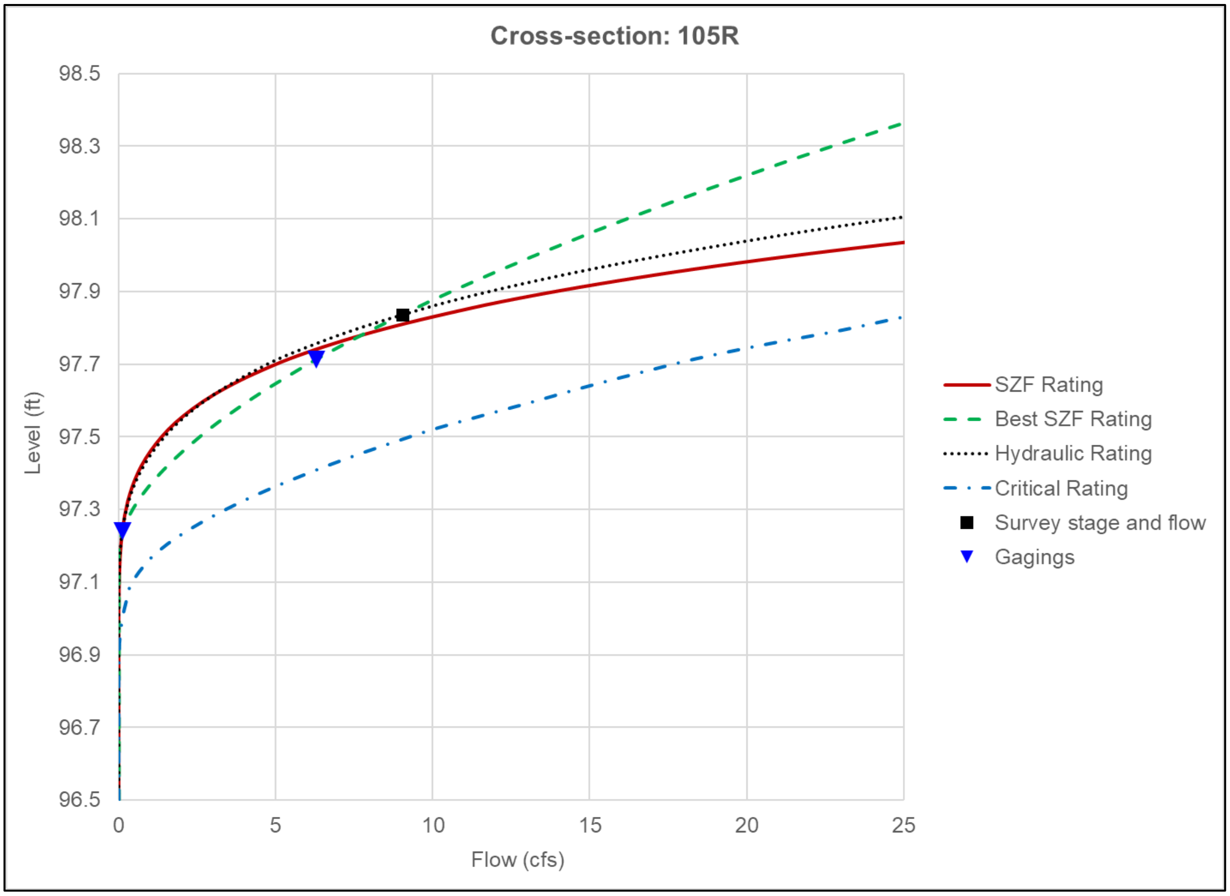

Figure B-13. Rating curve outputs for Reach 2, cross section 105R.

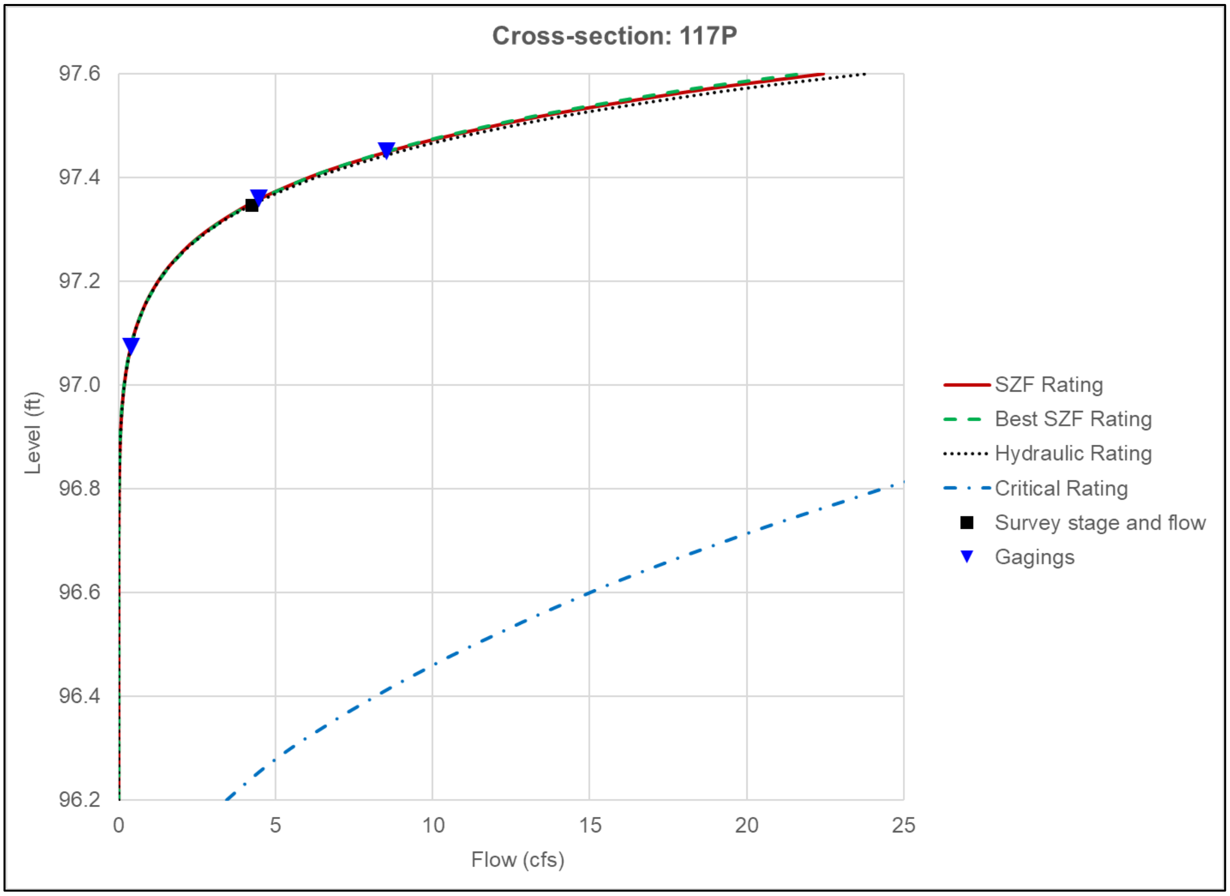

Figure B-14. Rating curve outputs for Reach 2, cross section 117P.

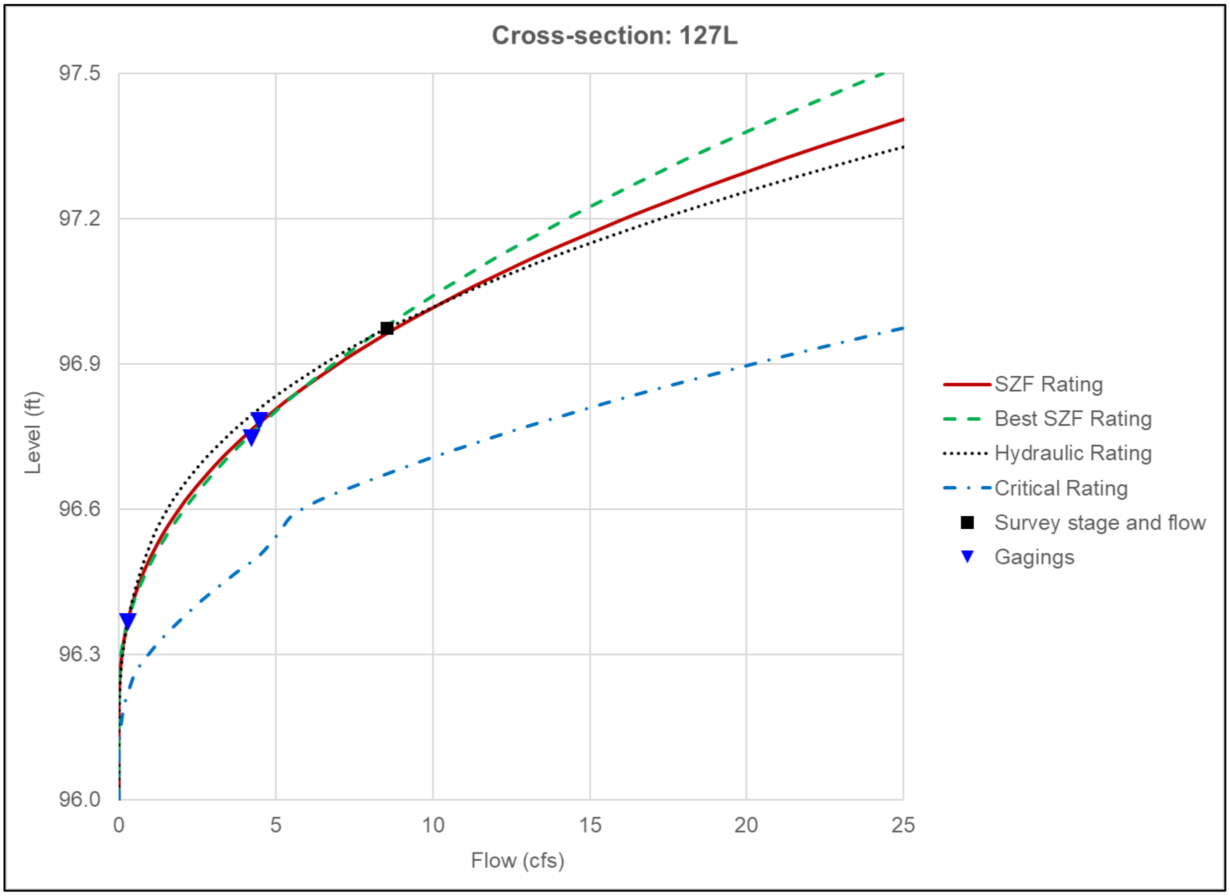

Figure B-15. Rating curve outputs for Reach 2, cross section 127L.

APPENDIX C: SEFA HYDRAULIC MODEL UTILITY CALIBRATION RESULTS

The following notes and definitions explain the equations and quantities used to quantify the hydraulic model utility calibration results for each reach of the San Antonio Creek 1D analyses using the program SEFA. The hydraulic model utility selected for simulation of depth and velocity is indicated by the **bolded mean error** and a dagger (†) in the following tables.

SZF rating (log-log regression): Fitted as best fit to survey stage and flow, rating calibration stages and flows, and stage for zero flow: $Q = A \times (WSEL - SZF)^{exp}$

Where:

Q = flow (cfs)
A = regression coefficient
WSEL = water surface elevation (ft)
SZF = stage of zero flow (ft)
exp = exponential regression coefficient

Best SZF rating (log-log regression using the Best SZF utility): Fitted as best fit to survey stage and flow, rating calibration stages and flows, with best fit stage for zero flow: $Q = A \times (WSEL - const)^{exp}$

Where:

Q = flow (cfs)
A = regression coefficient
WSEL = water surface elevation (ft)
exp = exponential regression coefficient
const = constant

Hydraulic formula (MANSQ): $Q = 1/N \times Area \times (R - R_{SZF})^{2/3} \times S^{1/2}$

Where:

Q = flow (cfs)
$N = A \times Q^{beta}$
A = regression coefficient
beta = MANSQ exponential regression coefficient
Area = cross-sectional area of the transect (ft^2)
R = hydraulic radius (ft)
R_{SZF} = hydraulic radius at the SZF (ft)
S = slope of the water surface (ft/ft)

- The mean error (%) and coefficient of determination (R^2) show the goodness of fit of the rating to the gagings.
- The mean error is the average percentage error in predicted and rating calibration discharges as a percent of the rating calibration discharges.
- The coefficient of determination is derived by comparing measured and predicted stages.
- R^2 = 1 - Residual sum of squares / Total sum of squares
- Residual sum of squares = Sum ((Measured stage - Predicted stage)^2)
- Total sum of squares = Sum (Measured stage^2) - (Sum (Measured stage))^2 / Number of points on rating
- Ratings are fitted by the least-squares geometric mean method to x and y deviations as described in the manual.

Table C-1. San Antonio Creek Reach 1 SEFA outputs comparing SZF rating (log-log regression) with hydraulic rating (MANSQ) by transect. A dagger (†) by the bolded mean error signifies which WSEL/flow rating utility was chosen, log-log regression or MANSQ.

Transect	SZF rating exp	SZF rating A	SZF rating SZF	SZF rating R	SZF rating mean error	Hydraulic rating A	Hydraulic rating beta	Hydraulic rating R	Hydraulic rating mean error	VAF of chosen utility
22R	10.958	6.364	95.09	0.999	3.253	0.076	-0.746	0.999	**3.963†**	1.25
23L	5.485	11.015	95.82	1.000	1.793	0.056	-0.436	1.000	**1.911†**	1.02
26P	3.382	26.27	96.39	0.998	**4.498†**	0.163	-0.480	0.998	4.760	0.89
29L	4.158	16.705	98.43	0.994	6.085	0.056	-0.398	0.992	**7.972†**	1.01
30R	4.586	5.072	95.81	0.997	5.501	0.044	-0.438	0.996	**6.934†**	1.13
31P	2.716	10.903	96.95	0.990	**8.365†**	0.094	-0.353	0.993	9.435	1.11
32L	6.474	14.554	97.16	0.996	6.902	0.056	-0.481	0.995	**8.282†**	0.97
52R	10.671	0.068	96.11	0.996	7.180	0.036	-0.736	0.995	**8.186†**	1.20
55P	5.68	96.854	95.31	0.988	**9.106†**	0.018	-0.704	0.990	10.157	1.19

Table C-2. San Antonio Creek Reach 2 SEFA outputs comparing SZF rating (log-log regression) with hydraulic rating (MANSQ) by transect. A dagger (†) by the bolded mean error signifies which WSEL/flow rating utility was chosen, log-log regression or MANSQ. Asterisks signify transects that were omitted because they did not meet calibration standards for mean error, variance in WSEL, or calibration VAF.

Transect	SZF rating exp	SZF rating A	SZF rating SZF	SZF rating R	SZF rating mean error	Hydraulic rating A	Hydraulic rating beta	Hydraulic rating R	Hydraulic rating mean error	VAF of chosen utility
81R*	17.833	0	95.55	0.980	14.918	0.099	-0.777	0.976	14.050	-
83L**	4.465	23.336	98.32	0.983	18.468	0.015	-0.351	0.997	8.691	1.16
88R	3.052	14.505	95.12	0.999	3.016	0.060	-0.078	0.999	**4.928†**	0.92
90P	3.684	8.804	94.77	0.987	**9.281†**	0.087	-0.365	0.988	7.566	0.94
95L	3.524	15.971	96.28	0.990	13.755	0.094	-0.174	0.995	**9.026†**	0.75
105R	4.784	11.510	96.86	0.993	10.027	0.021	-0.393	0.994	**6.804†**	1.08
117P	7.848	2.865	96.30	1.000	**1.458†**	0.019	-0.761	1.000	2.826	1.17
127L	2.400	15.350	96.18	0.998	3.567	0.058	-0.177	0.993	**7.965†**	0.99
132L*	4.923	122.699	91.67	0.966	18.485	0.048	-0.447	0.963	15.796	-

*81R and 132L: Omitted because the mean error for both MANSQ and log-log exceeded 10%.
**83L: Omitted because the hydraulic rating is the only utility with a mean error <10%, but the rating curve falls below the Critical Rating at approximately 17 cfs.

APPENDIX D: TRANSECT VELOCITY PROFILES

The following figures present the predicted discharge-WSEL pairs and velocity profiles for each transect. The predicted discharge-WSEL pairs and velocity profiles were plotted over a range of 0.5 to 30.5 cfs and a fixed interval of 5 cfs. Each of the figures contains a layered plot with the transect length coordinates (Offset (ft)) on the x-axis, water level (ft) on the upper y-axis, and velocity (ft/s) on the lower y-axis. The thicker black lines represent the survey flow (the reference discharge-WSEL pair) used to predict WSEL and velocity by SEFA. The upper half of each figure shows the transect profile with a horizontal line representing the water level of each simulated flow, including the survey flow. The filled-in blue area represents water below the survey flow. The lower half of each figure is the velocity profile for each flow simulated to compute AWS, including the survey flow (thicker black line). Please refer to Section A.1.2 *Discharge Simulation Range* and *Water Velocity Prediction* for further detail about discharge-WSEL and velocity prediction.

D.1 San Antonio Creek Reach 1

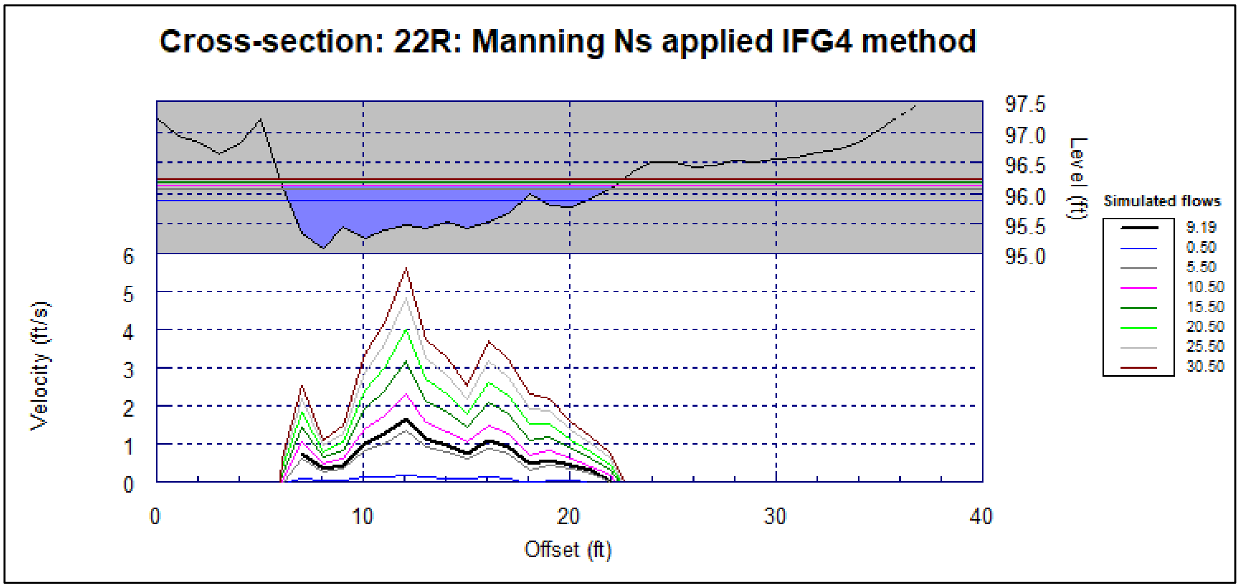

Figure D-1. Cross section 22R at simulated flows ranging from 0.5 cfs to 30.5 cfs.

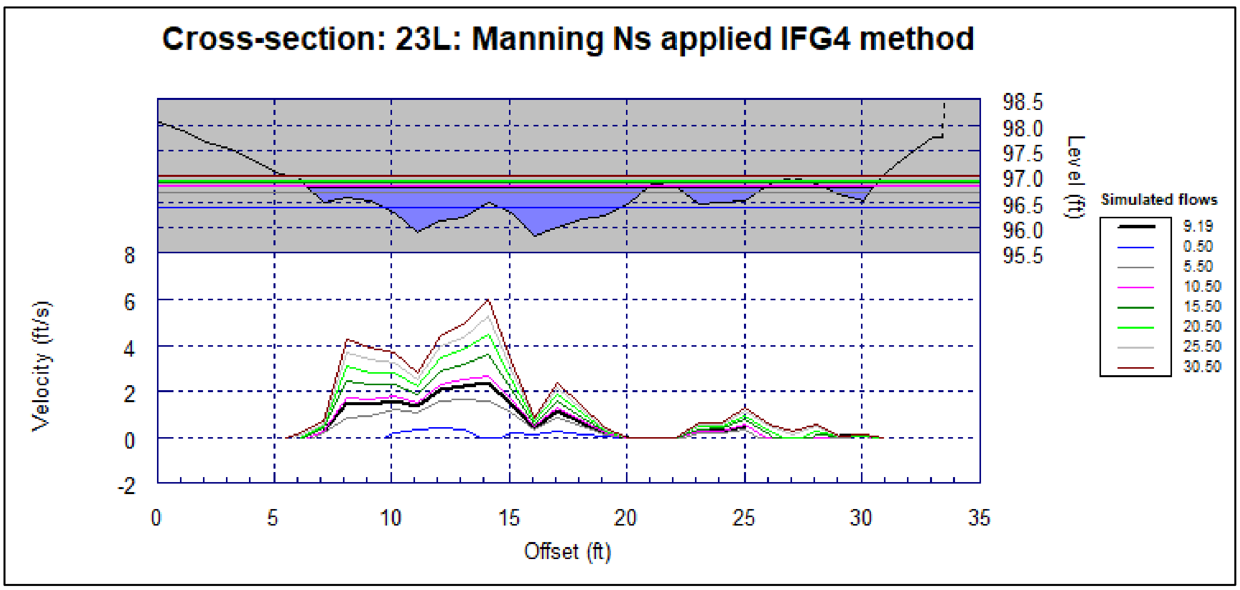

Figure D-2. Cross section 23L at simulated flows ranging from 0.5 cfs to 30.5 cfs.

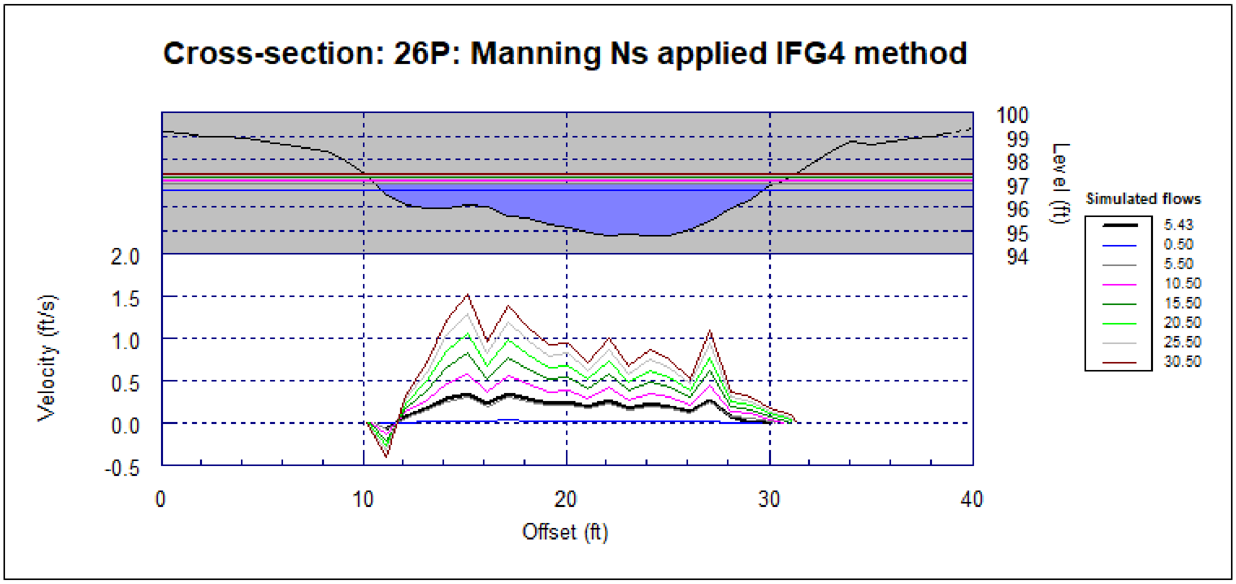

Figure D-3. Cross section 26P at simulated flows ranging from 0.5 cfs to 30.5 cfs.

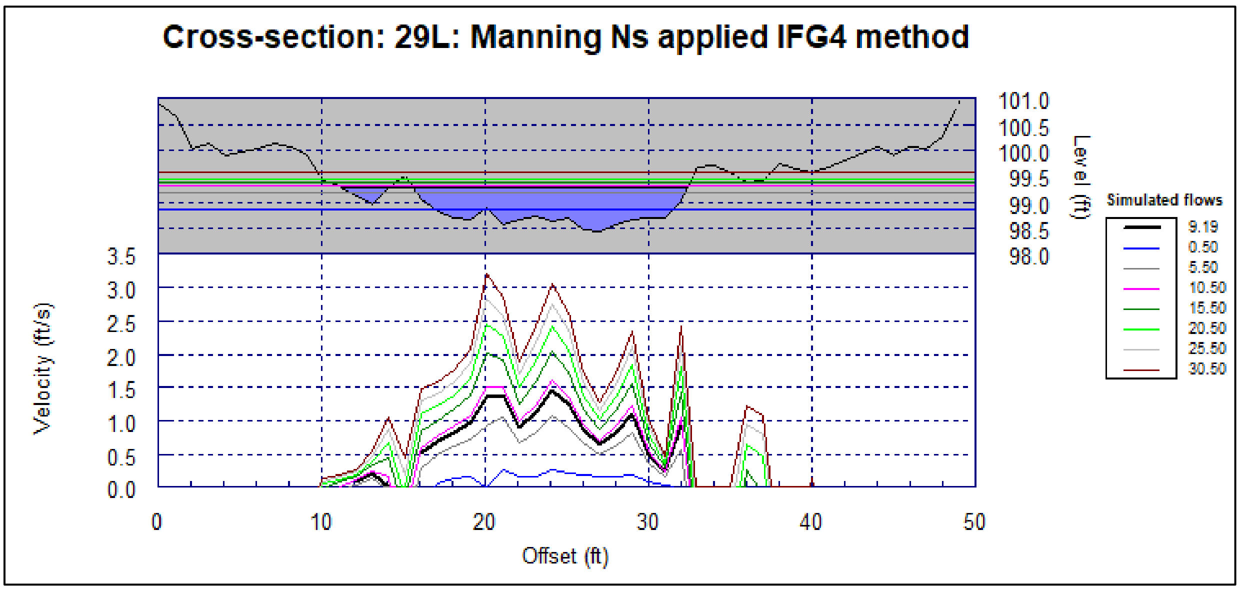

Figure D-4. Cross section 29L at simulated flows ranging from 0.5 cfs to 30.5 cfs.

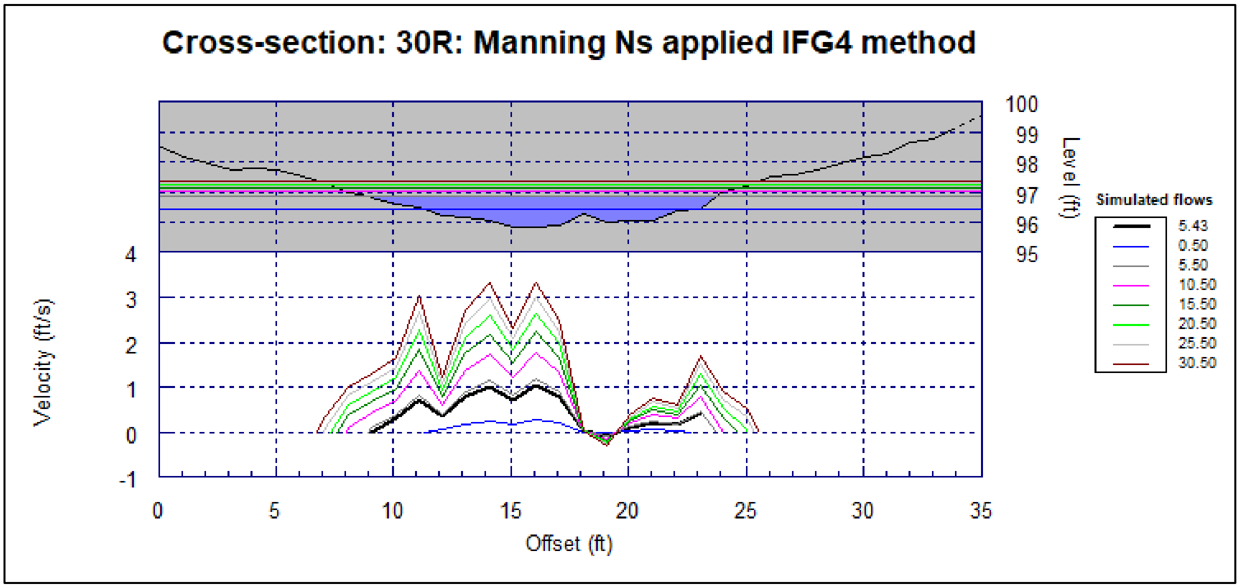

Figure D-5. Cross section 30R at simulated flows ranging from 0.5 cfs to 30.5 cfs.

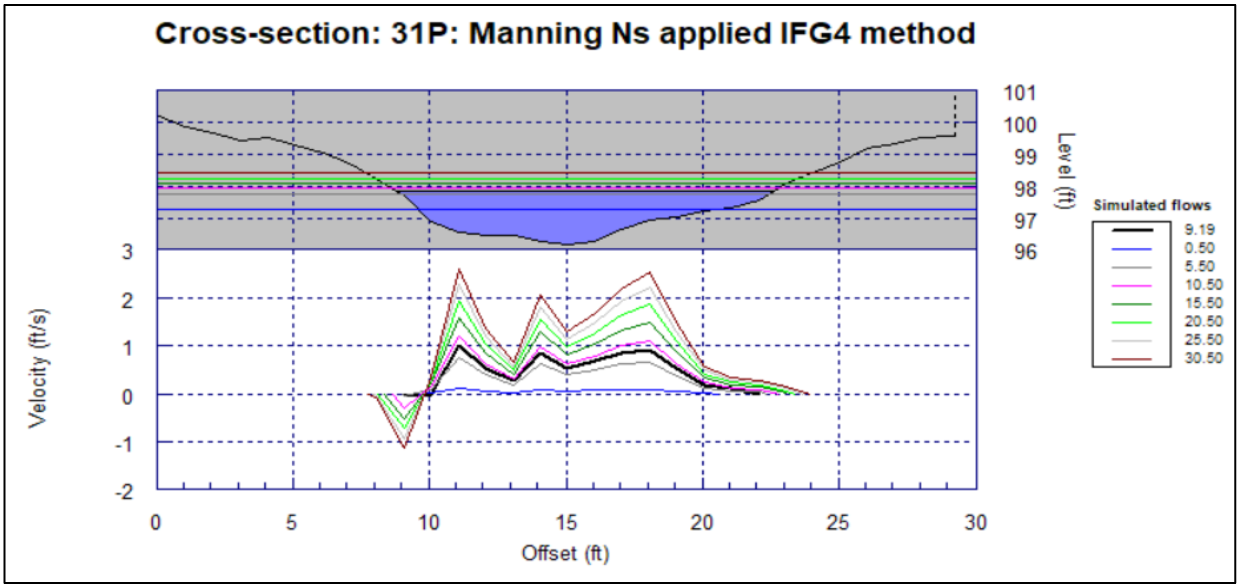

Figure D-6. Cross section 31P before VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

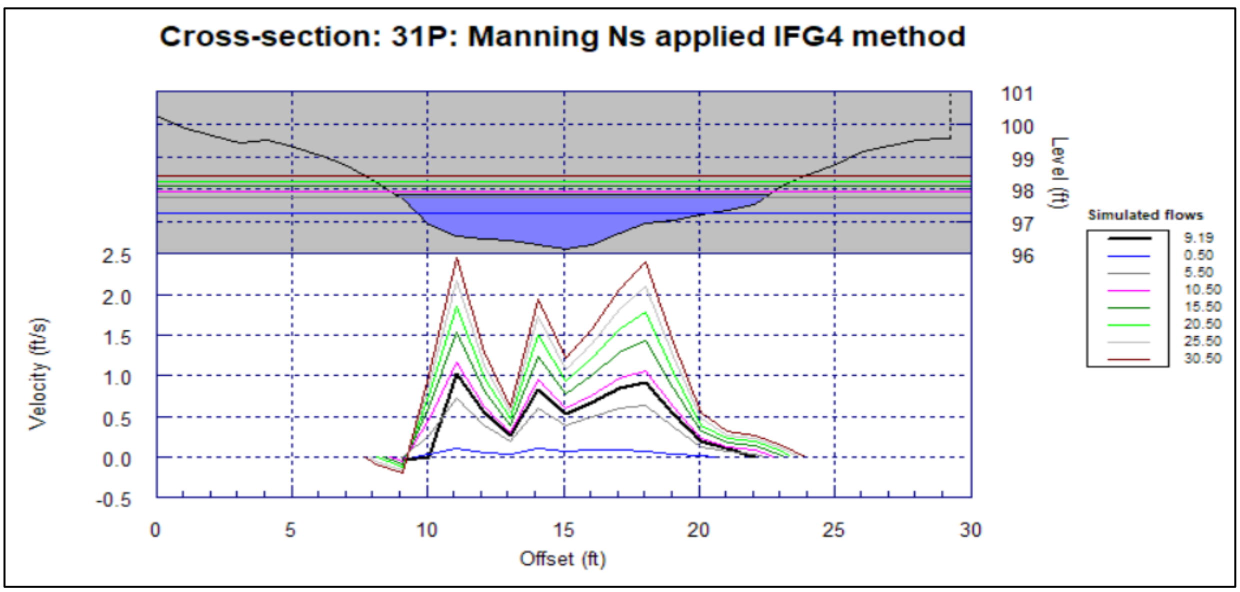

Figure D-7. Cross section 31P after VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

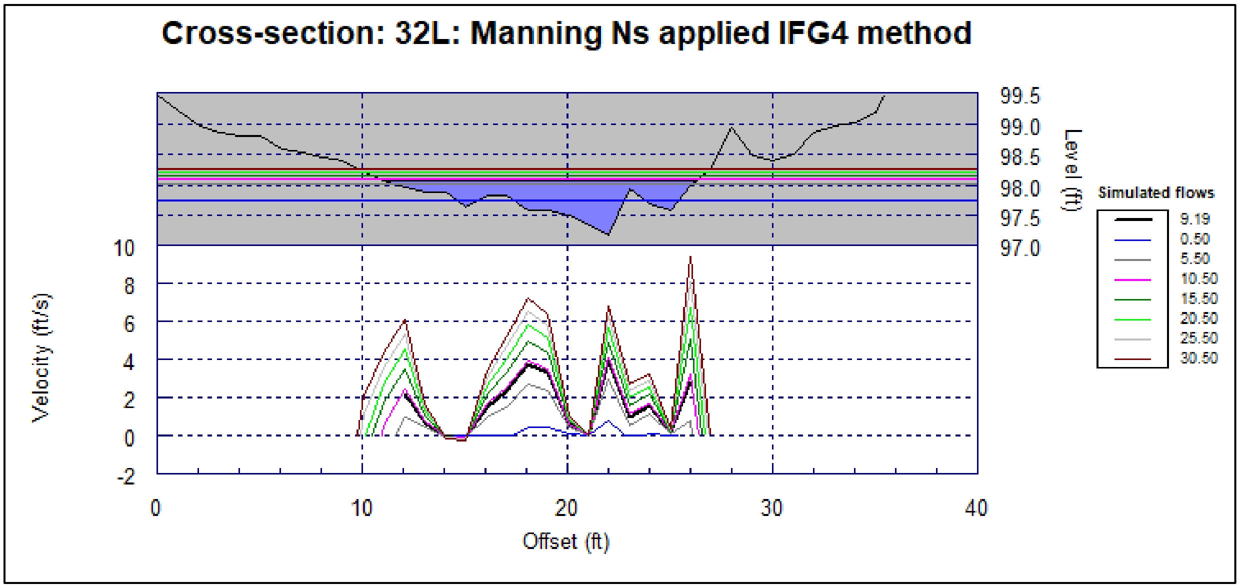

Figure D-8. Cross section 32L at simulated flows ranging from 0.5 cfs to 30.5 cfs.

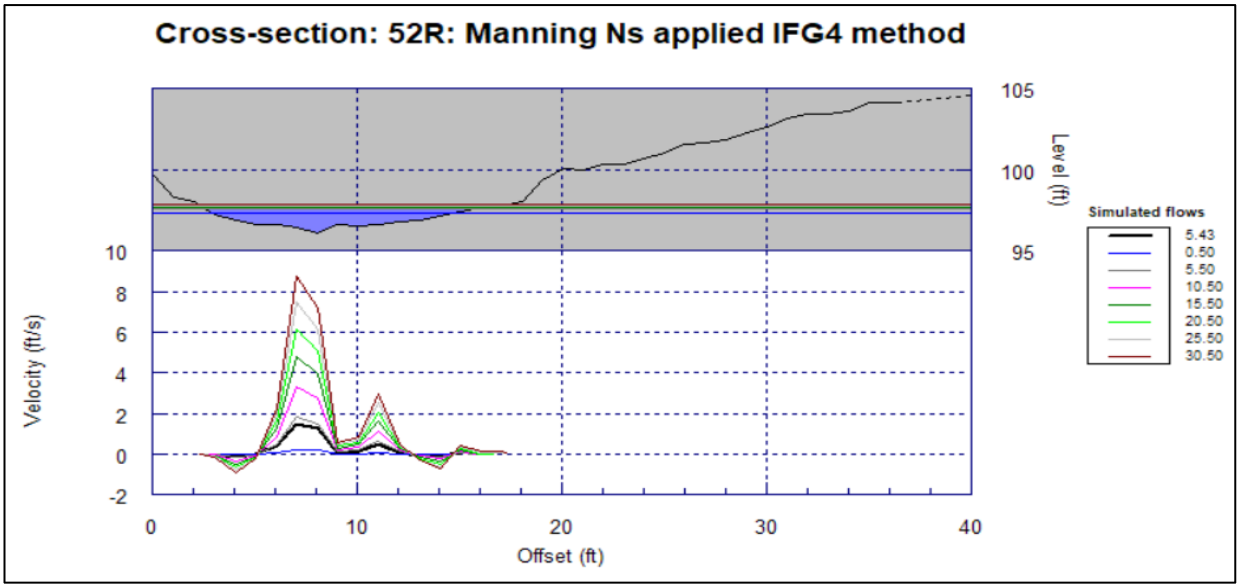

Figure D-9. Cross section 52R at simulated flows ranging from 0.5 cfs to 30.5 cfs.

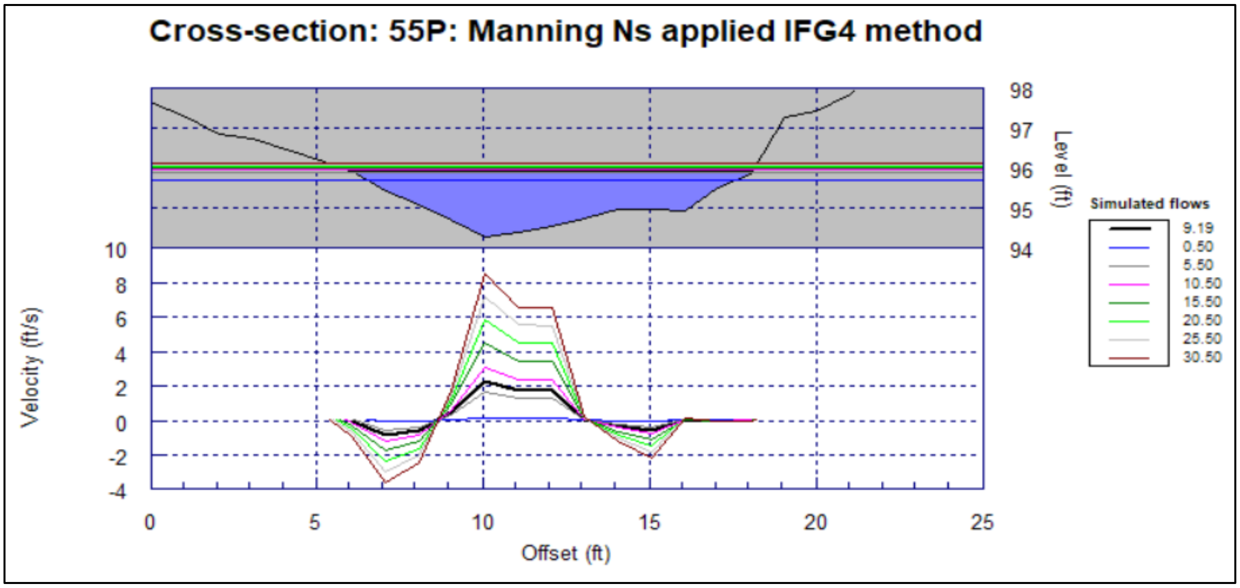

Figure D-10. Cross section 55P before VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

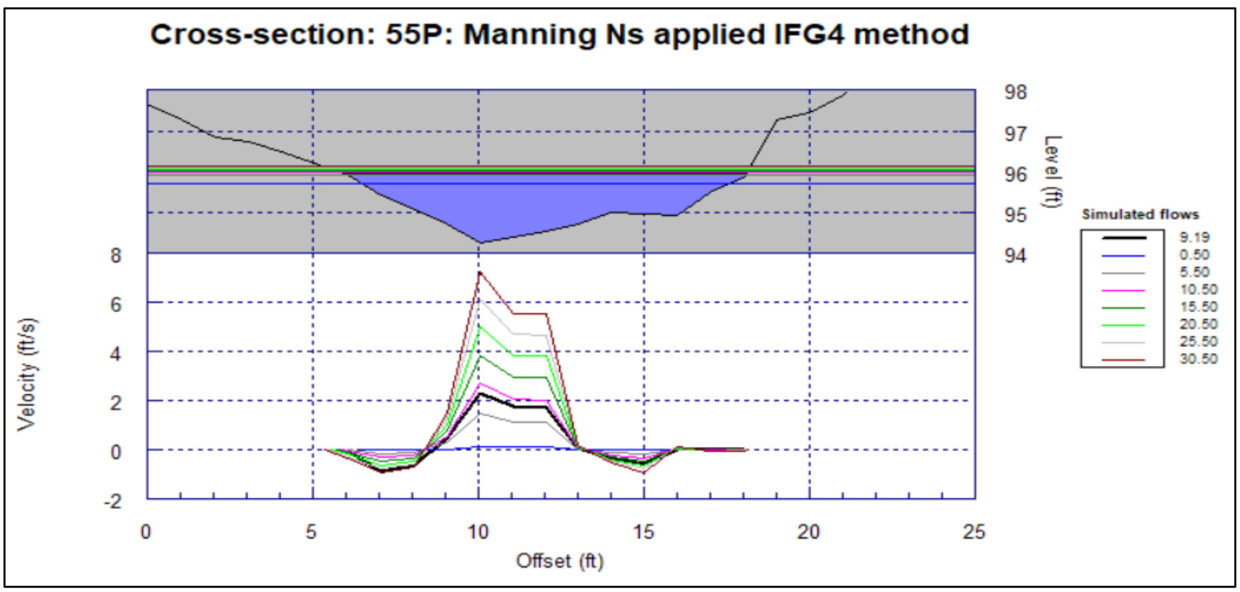

Figure D-11. Cross section 55P after VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

D.2 San Antonio Creek Reach 2

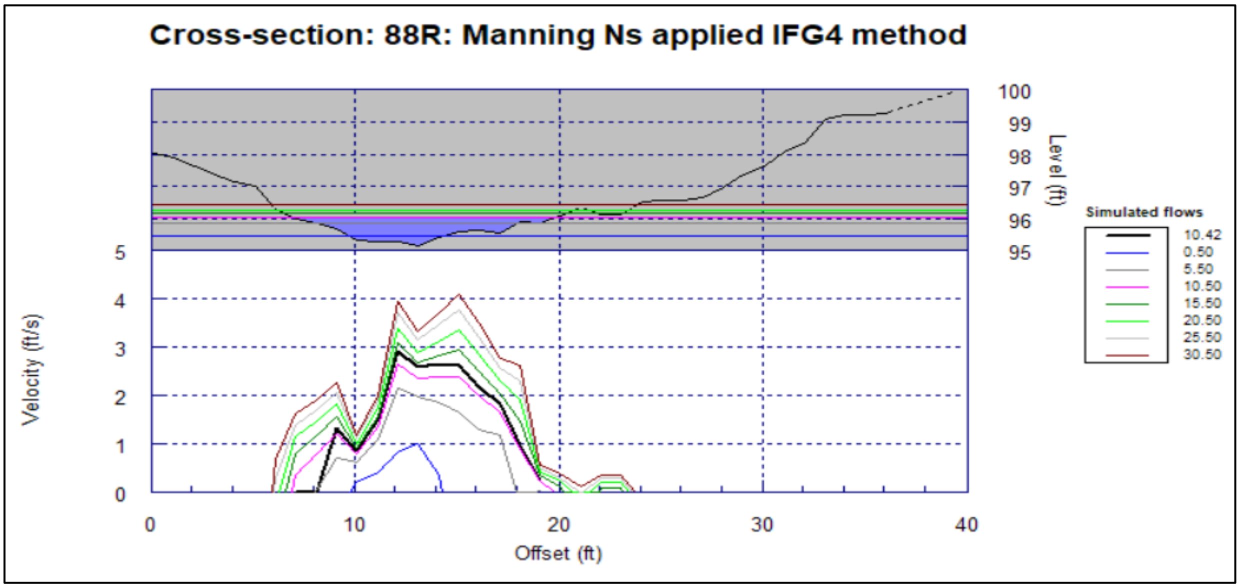

Figure D-12. Cross section 88R before VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

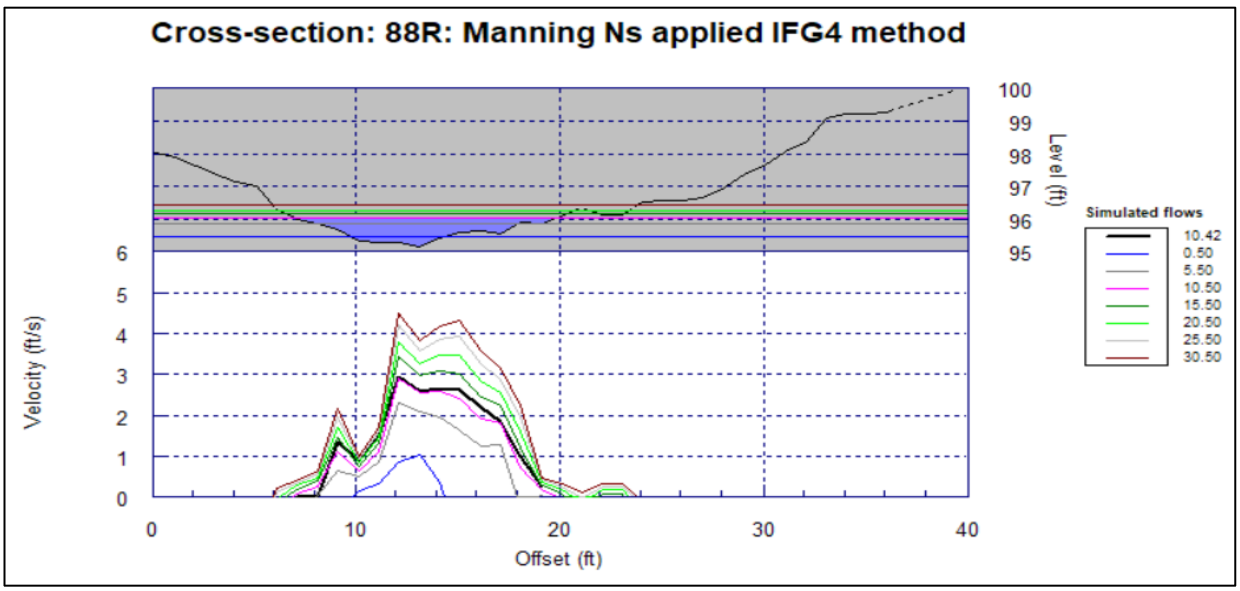

Figure D-13. Cross section 88R after VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

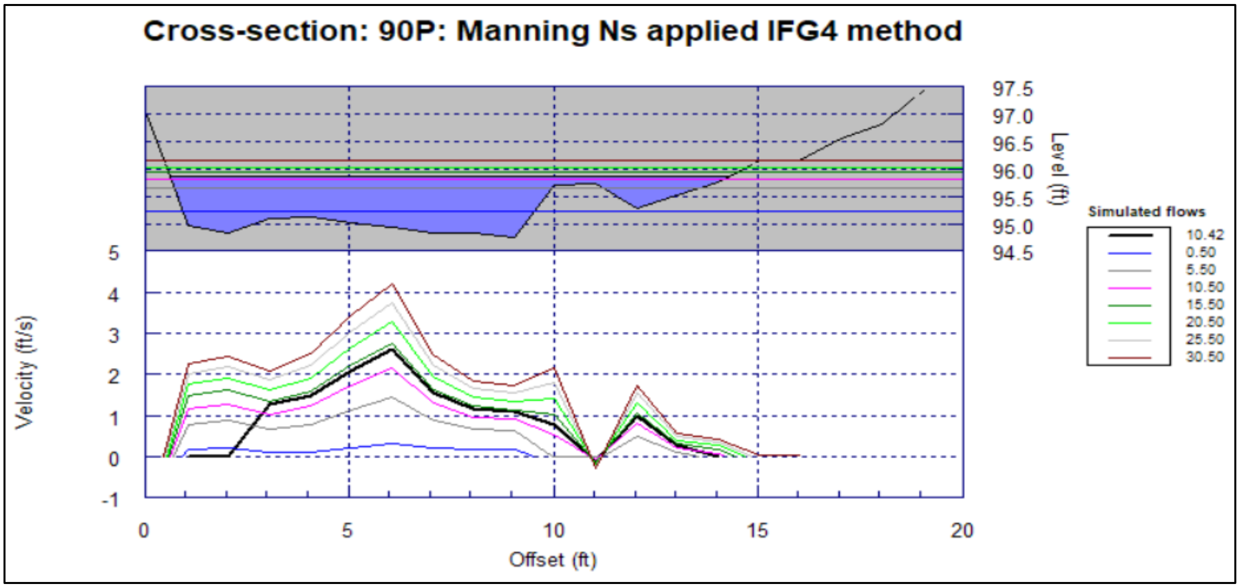

Figure D-14. Cross section 90P before VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

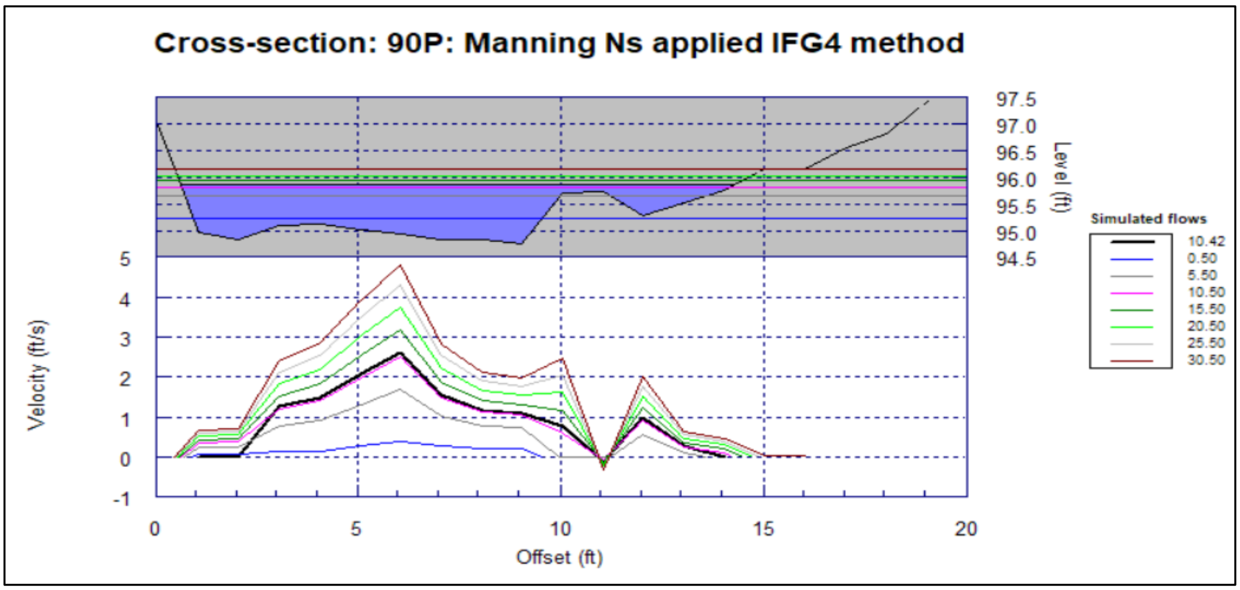

Figure D-15. Cross section 90P after VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

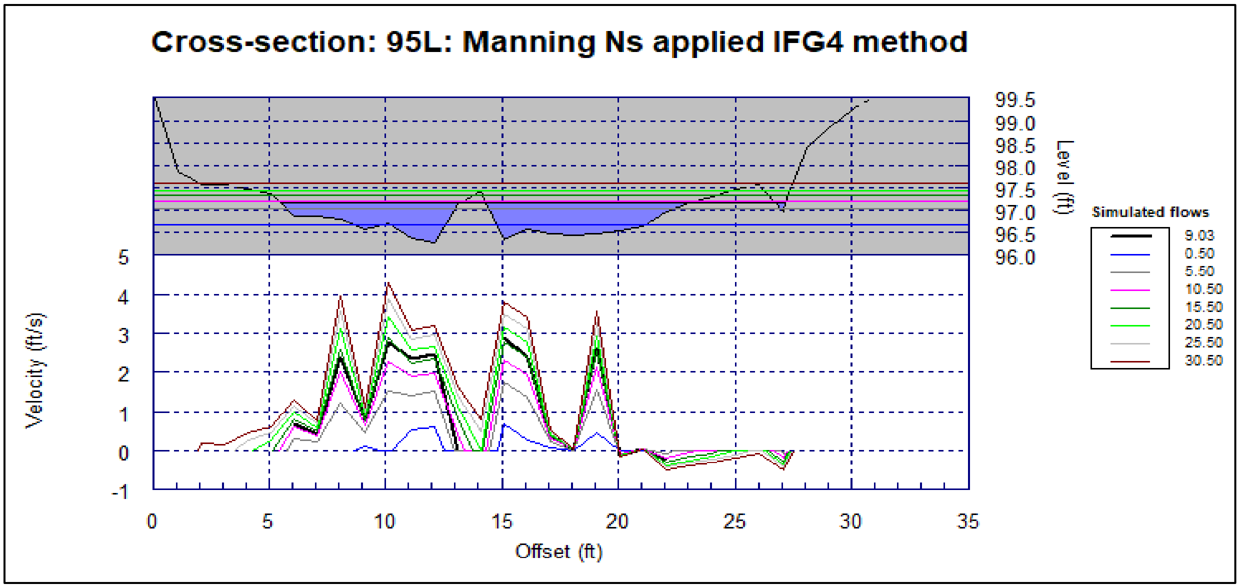

Figure D-16. Cross section 95L at simulated flows ranging from 0.5 cfs to 30.5 cfs.

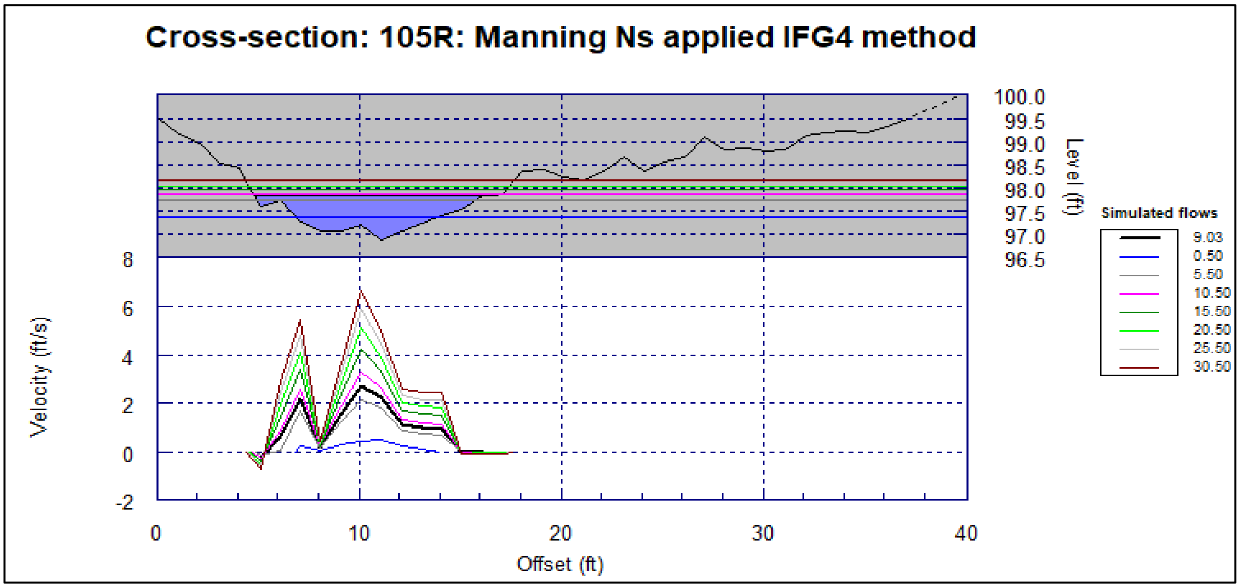

Figure D-17. Cross section 105R at simulated flows ranging from 0.5 cfs to 30.5 cfs.

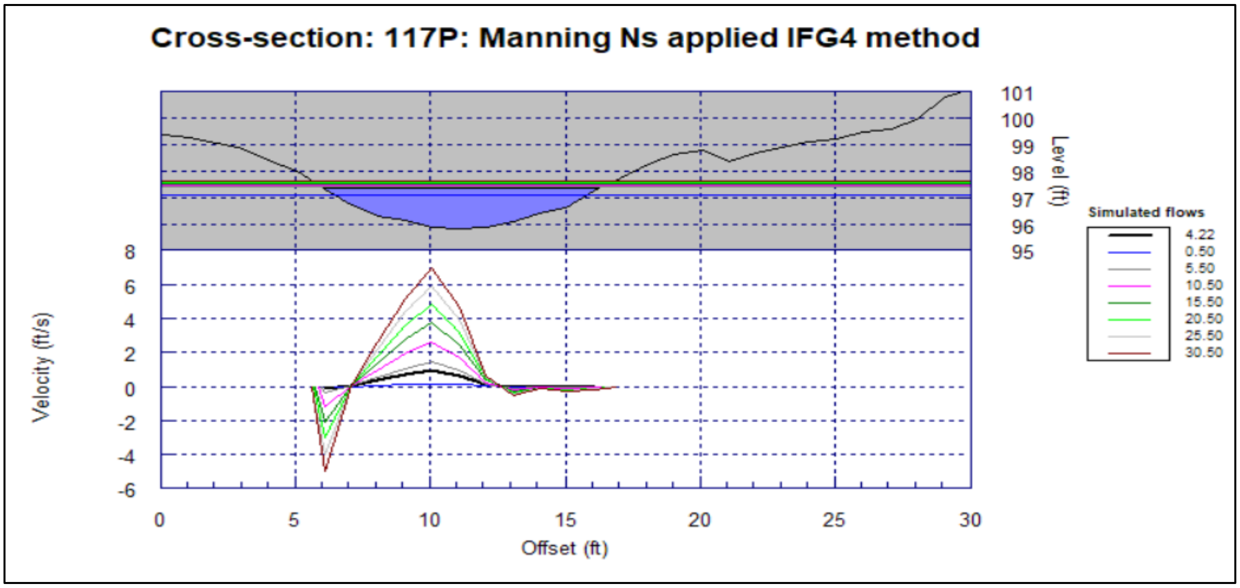

Figure D-18. Cross section 117P before VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

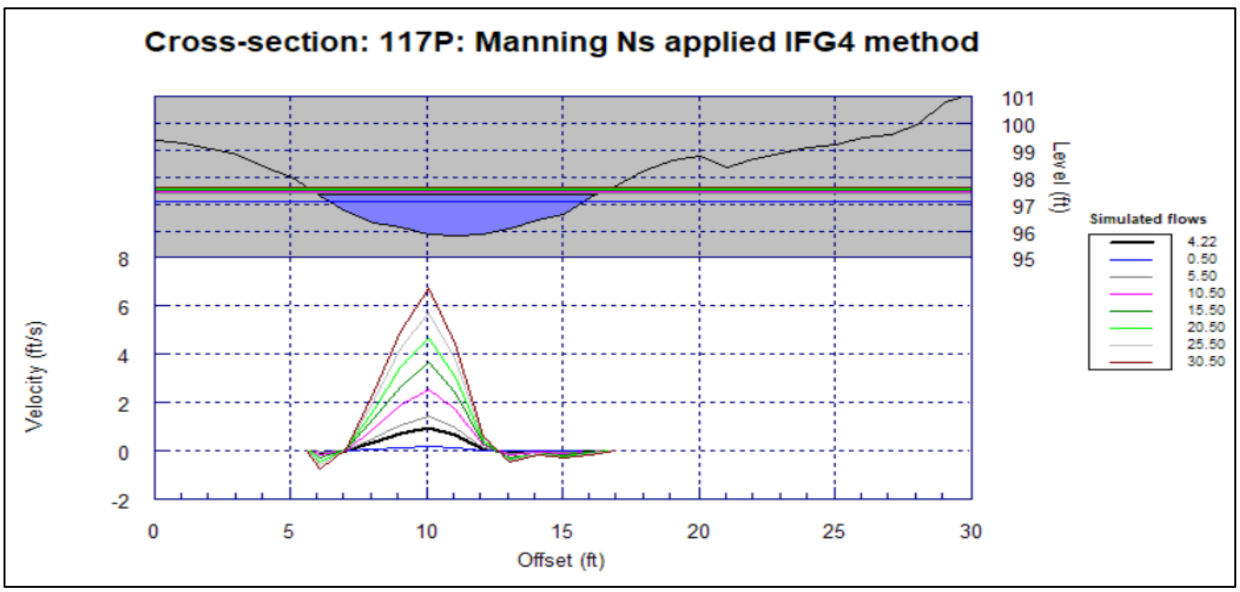

Figure D-19. Cross section 117P after VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

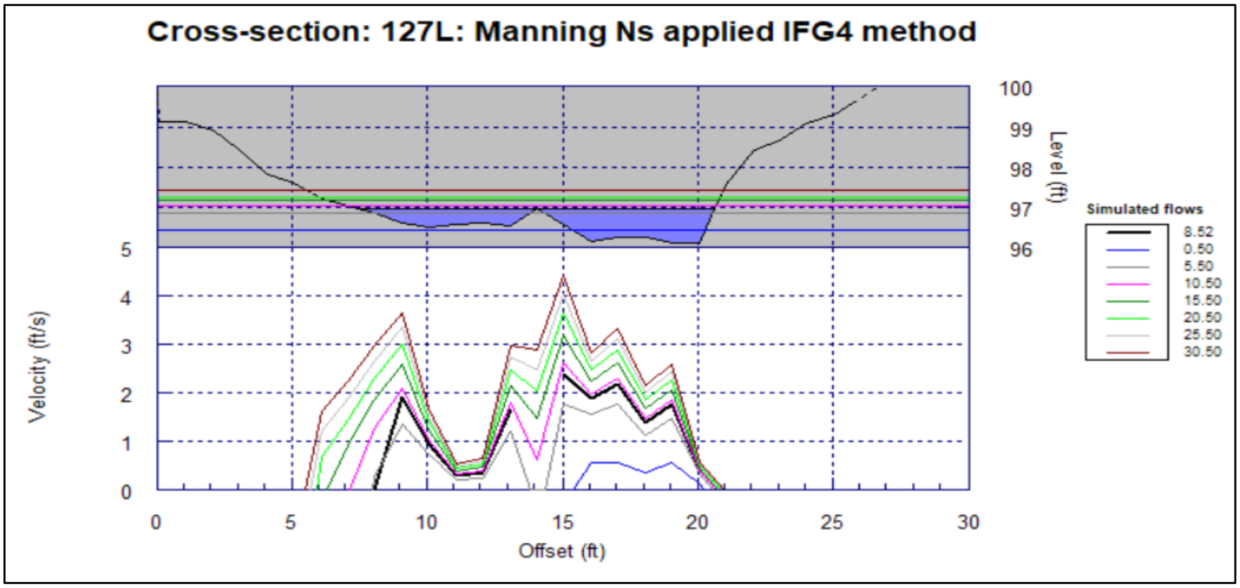

Figure D-20. Cross section 127L before VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

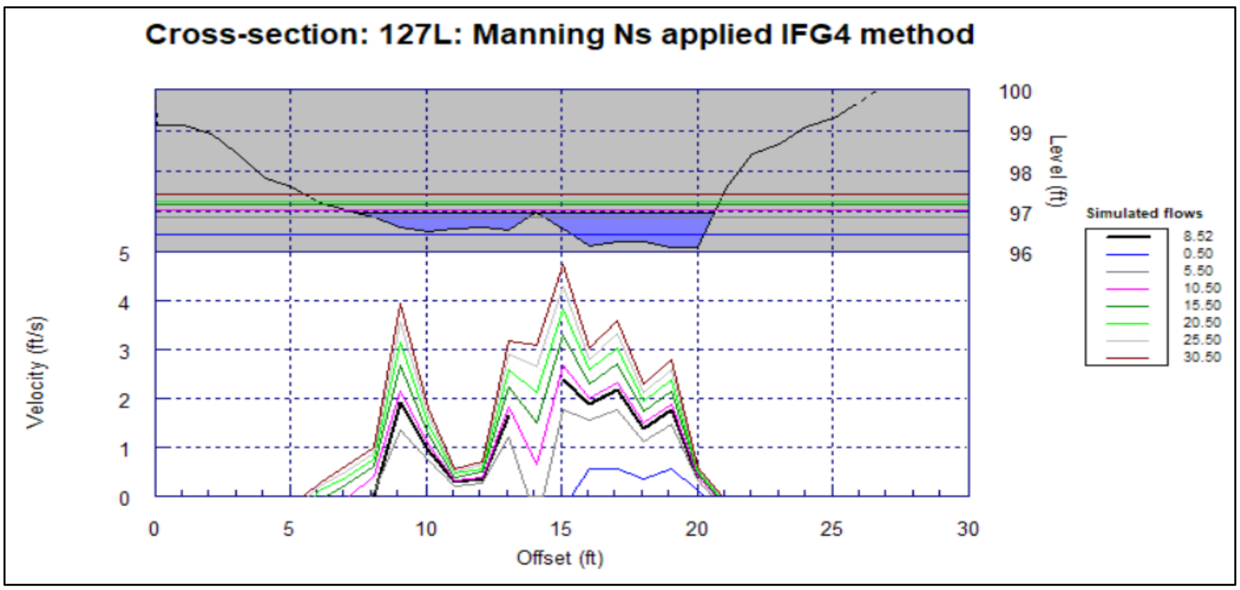

Figure D-21. Cross section 127L after VDF modification at simulated flows ranging from 0.5 cfs to 30.5 cfs.

APPENDIX E: SELECTED VELOCITY DISTRIBUTION FACTOR (VDF) PROFILES

Appendix E presents the graphical Velocity Distribution Factor (VDF) results for modifications made to six of the total 15 transects used to estimate flow-habitat relationships in San Antonio Creek. VDFs were only modified to improve velocity profile prediction or to minimize the exaggeration of negative velocities measured near stream margins.

Each of the figures contains a layered plot with the transect length coordinates (Offset (ft)) on the x-axis, water level (ft) and velocity on the upper y-axis, and the Manning N value or VDF for each transect velocity profile point on the lower y-axis. The upper plot shows the transect and velocity profiles. The survey flow water level is indicted by a solid blue fill. The lower plot is the profile of the unmodified Manning N value or VDF, for the transect being evaluated.

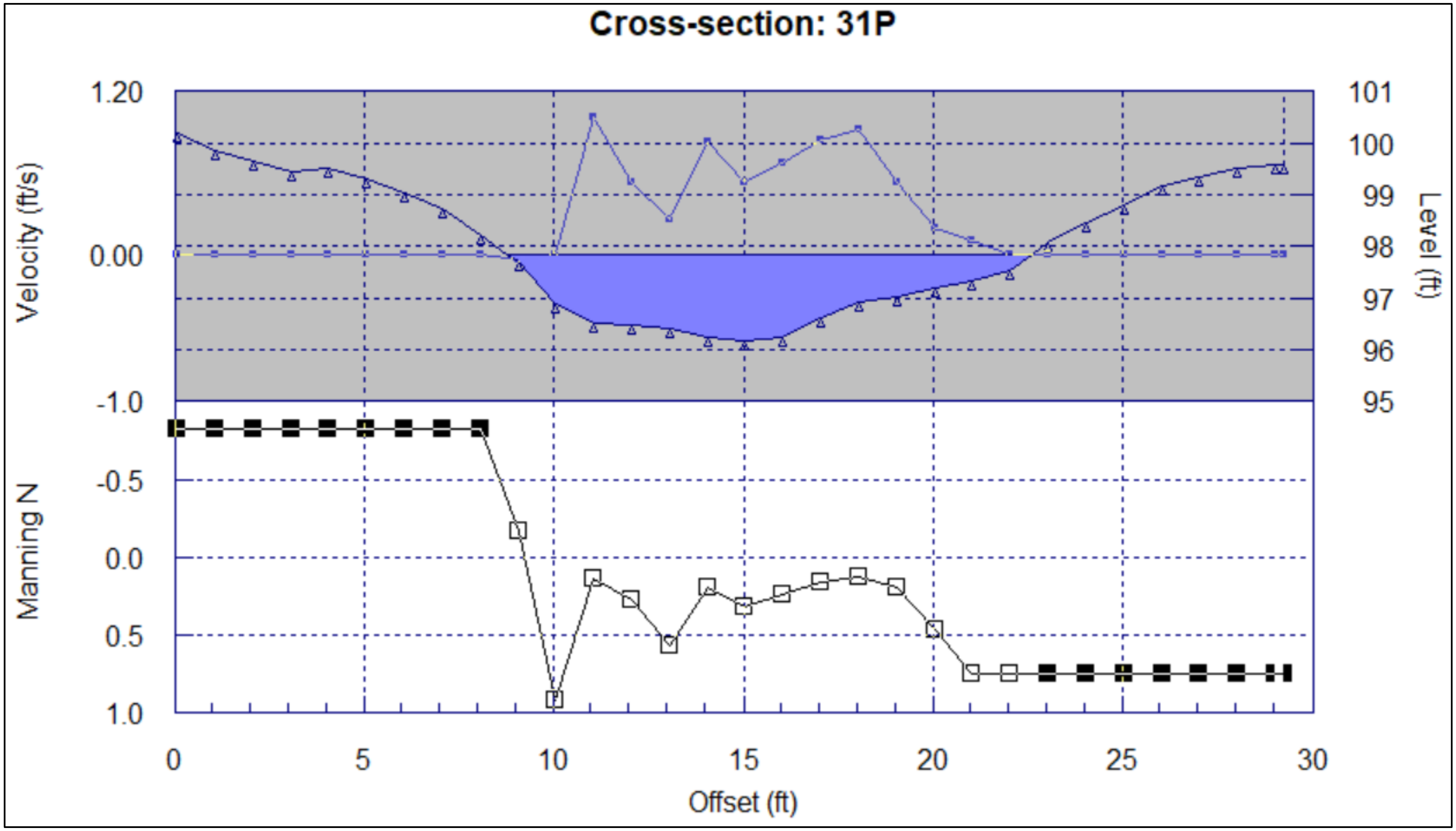

Figure E-1. Reach 1 transect 31P before VDF modification.

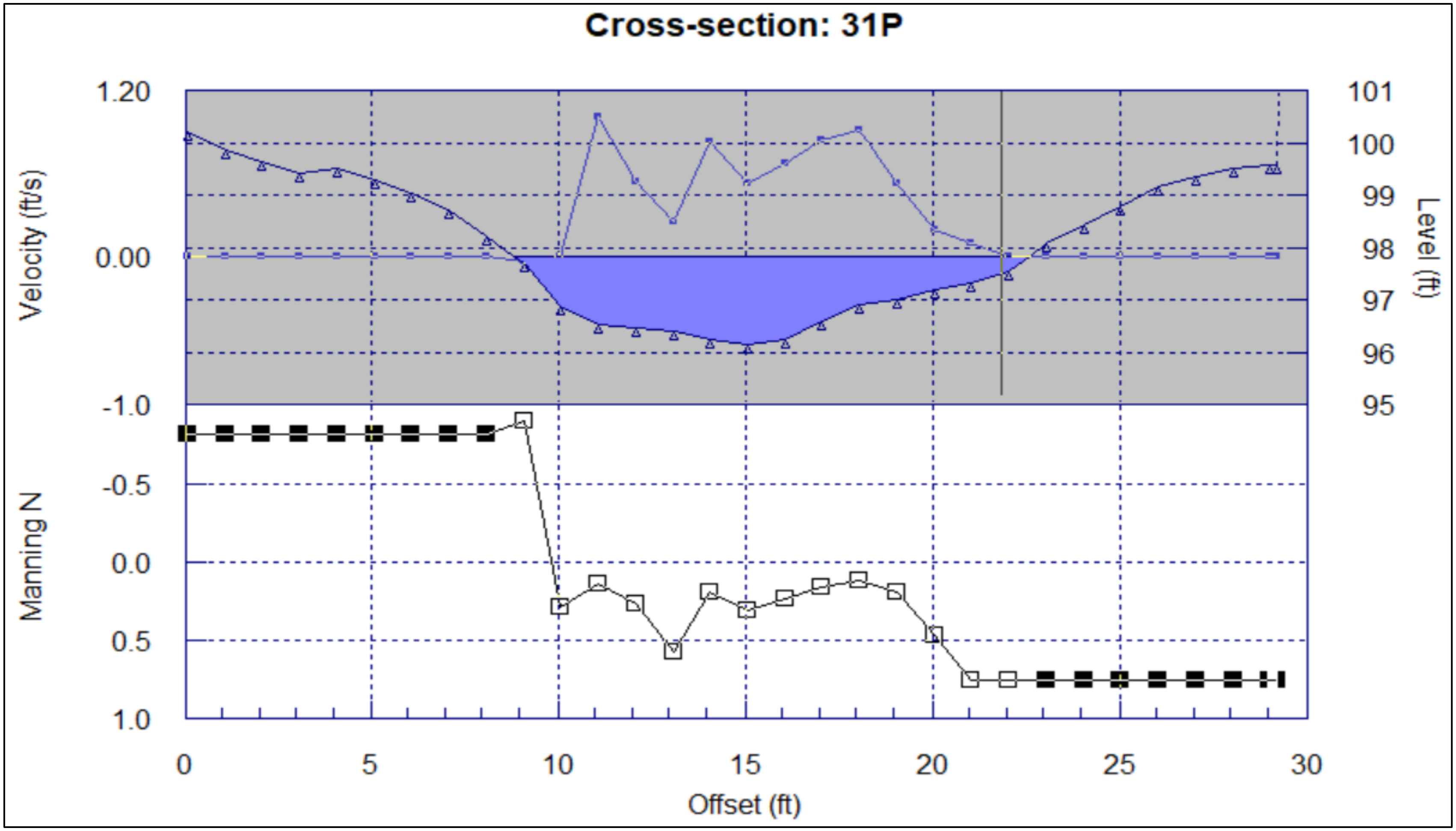

Figure E-2. Reach 1 transect 31P after VDF modification.

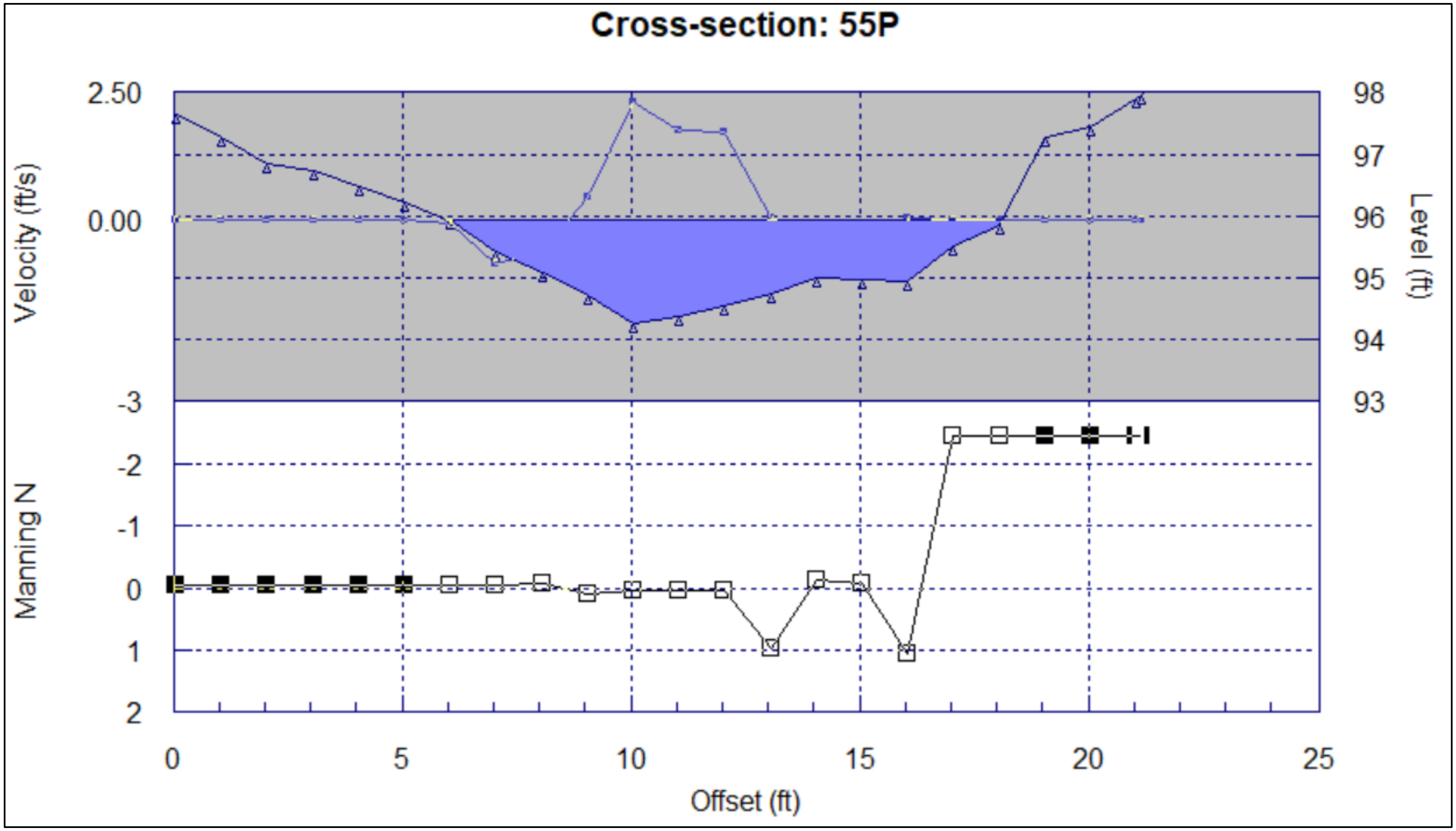

Figure E-3. Reach 1 transect 55P before VDF modification.

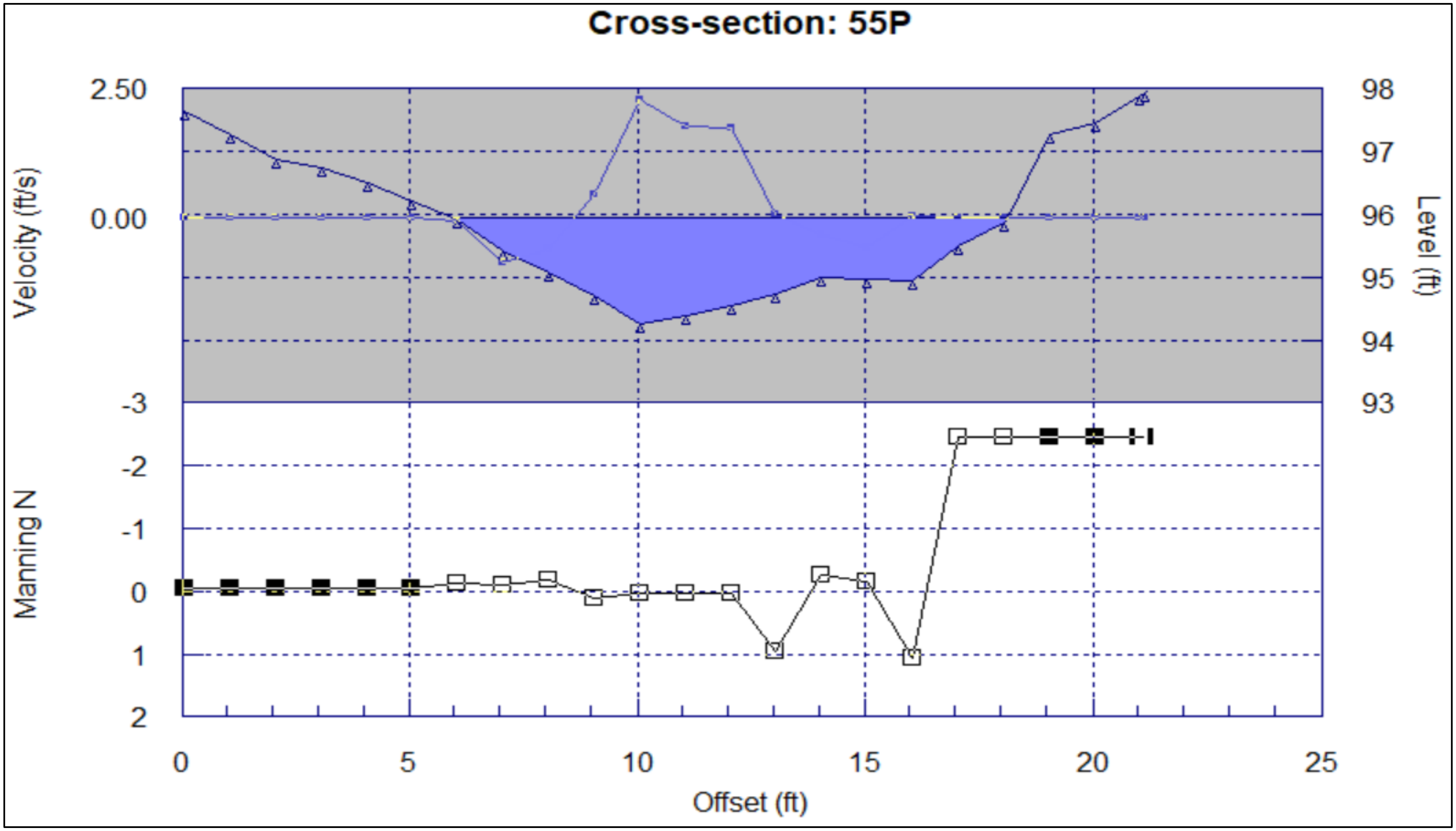

Figure E-4. Reach 1 transect 55P after VDF modification.

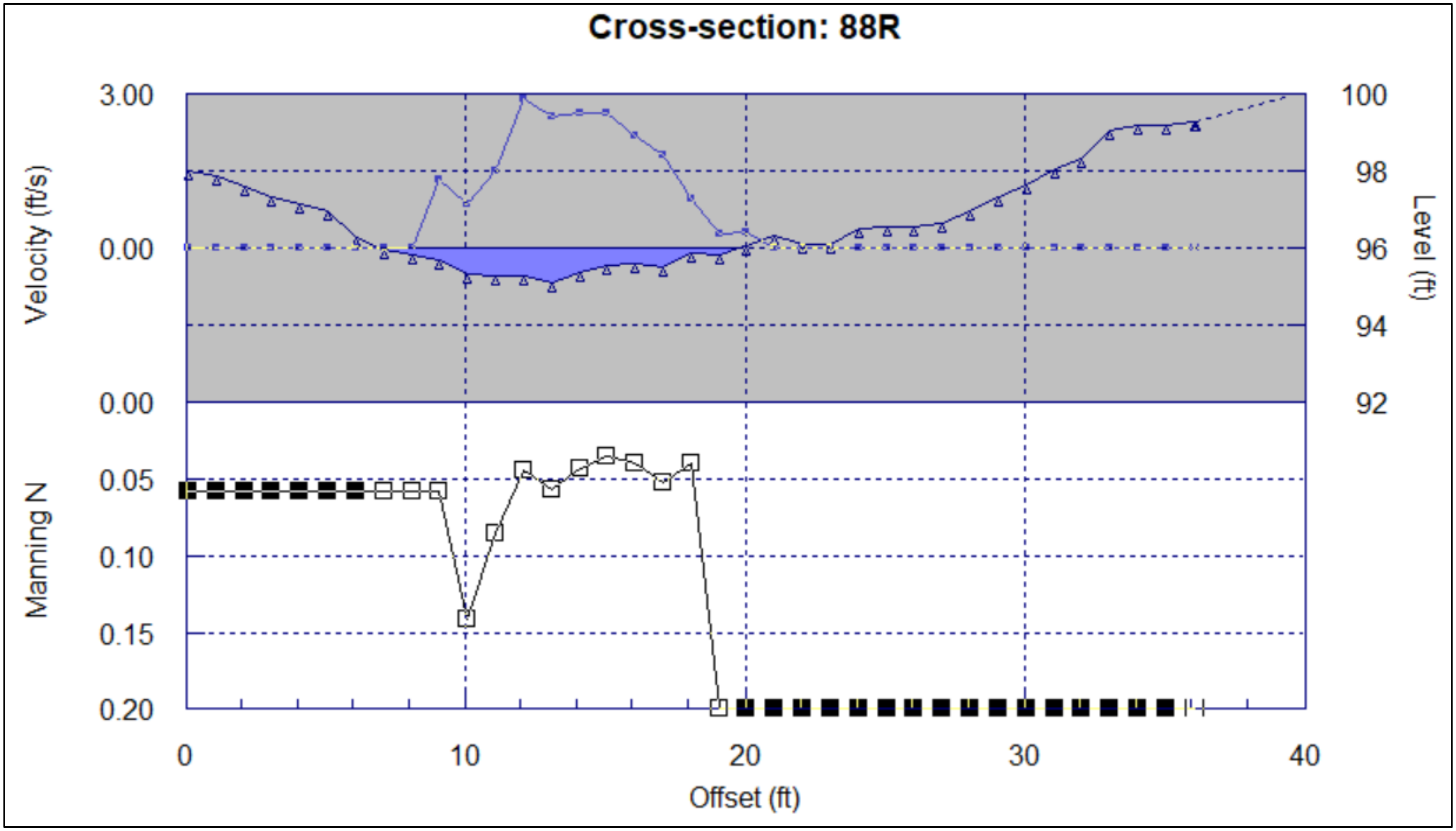

Figure E-5. Reach 2 transect 88R before VDF modification.

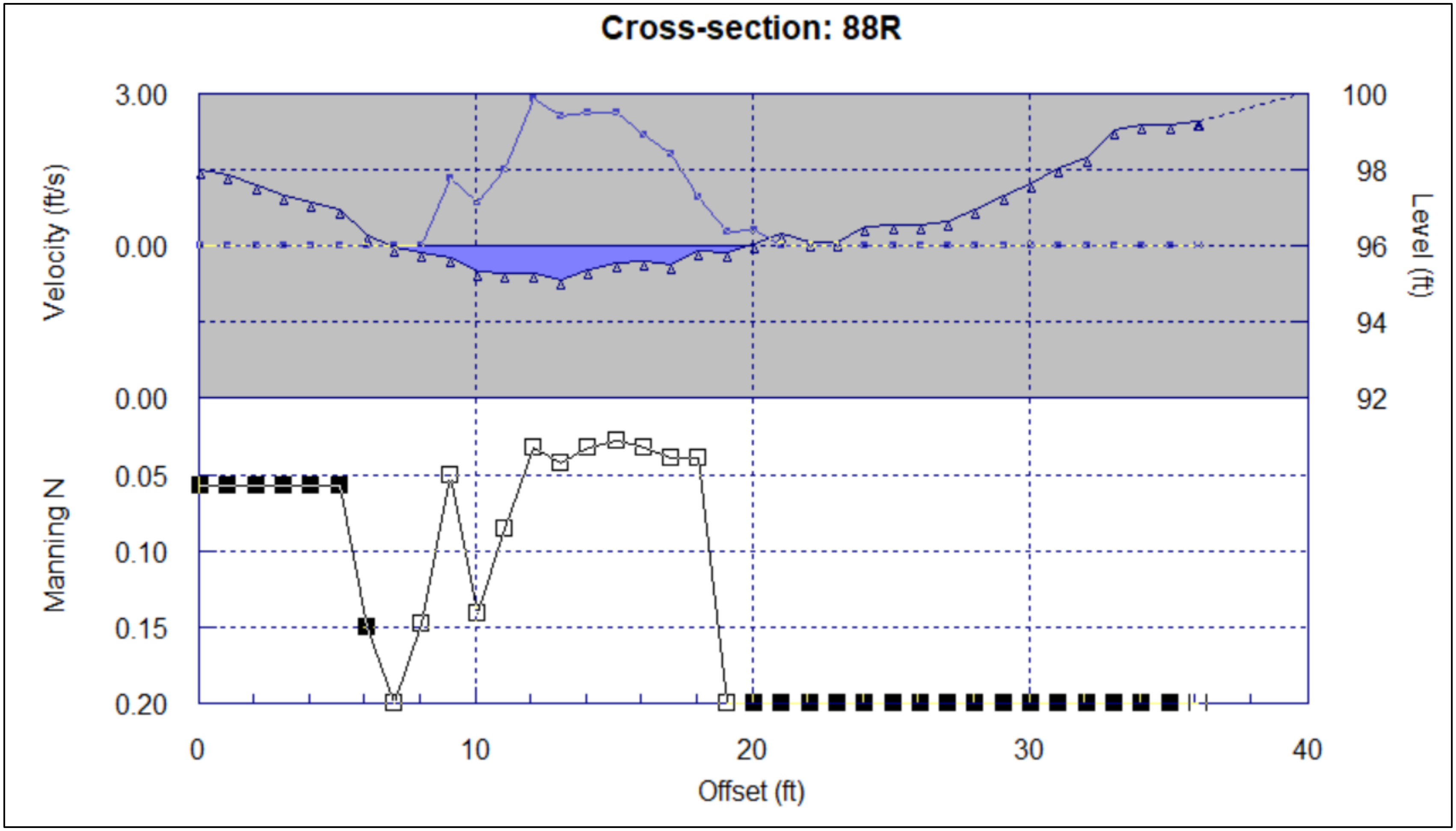

Figure E-6. Reach 2 transect 88R after VDF modification.

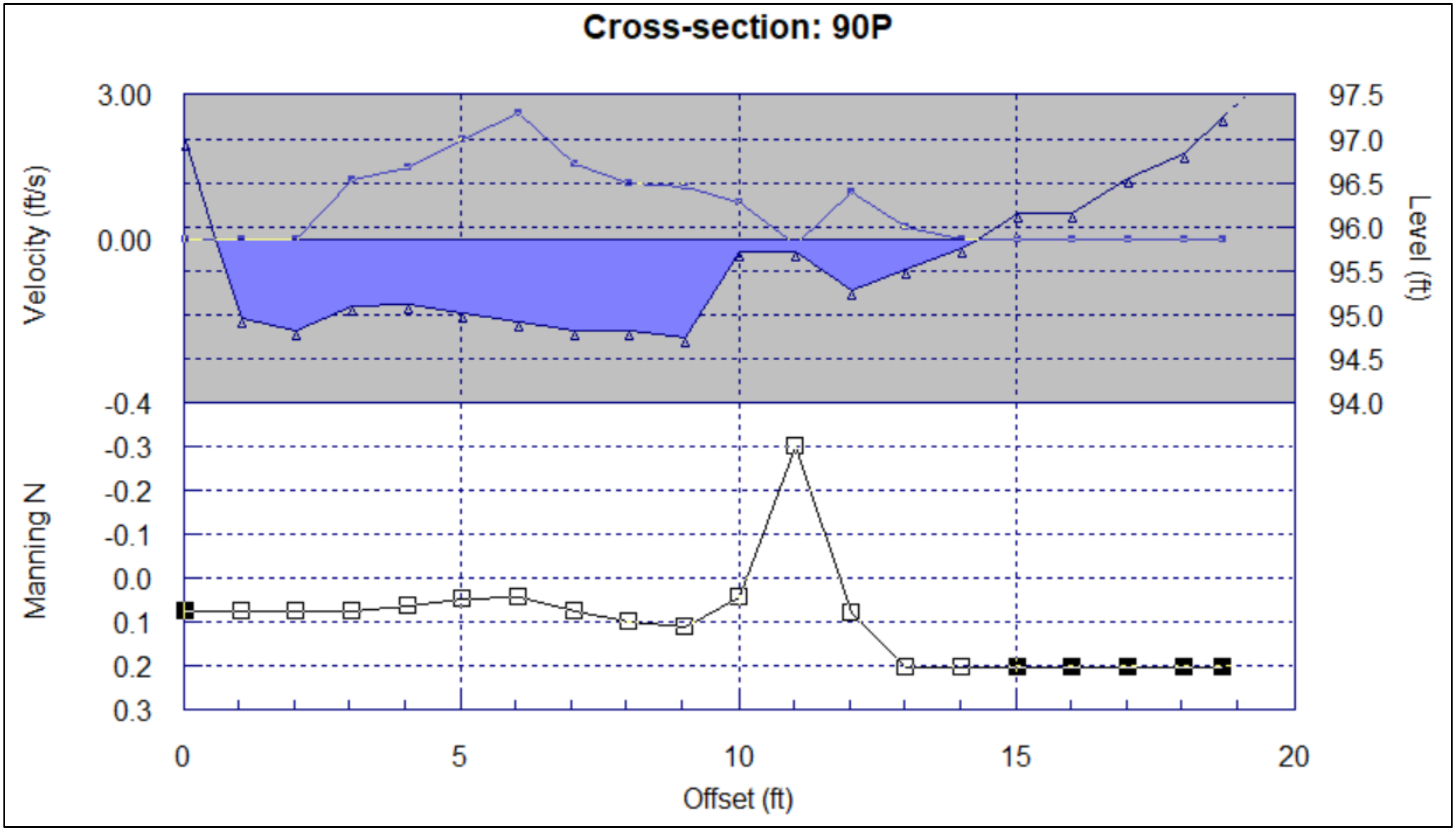

Figure E-7. Reach 2 transect 90 before VDF modification.

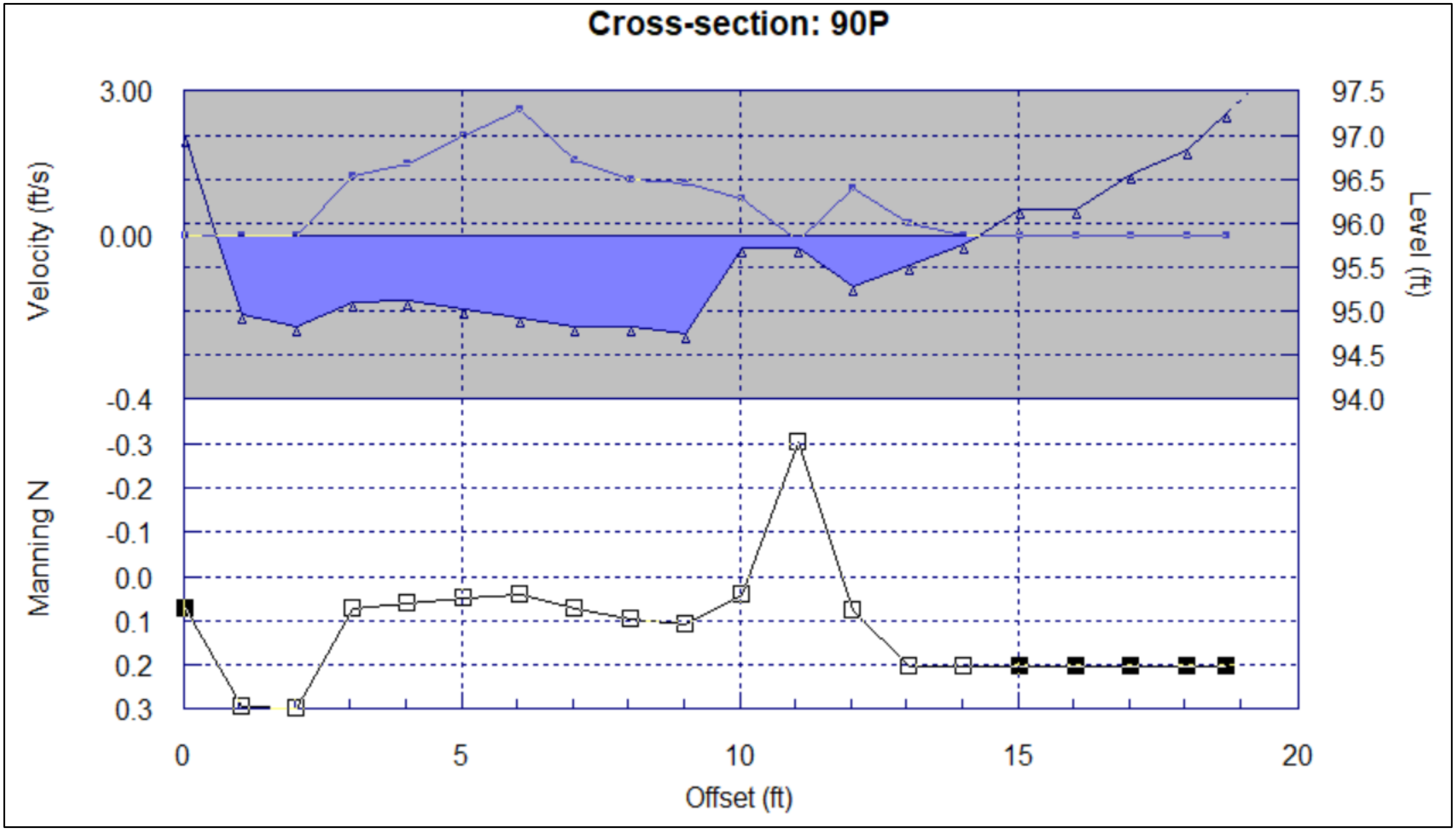

Figure E-8. Reach 2 transect 90P after VDF modification.

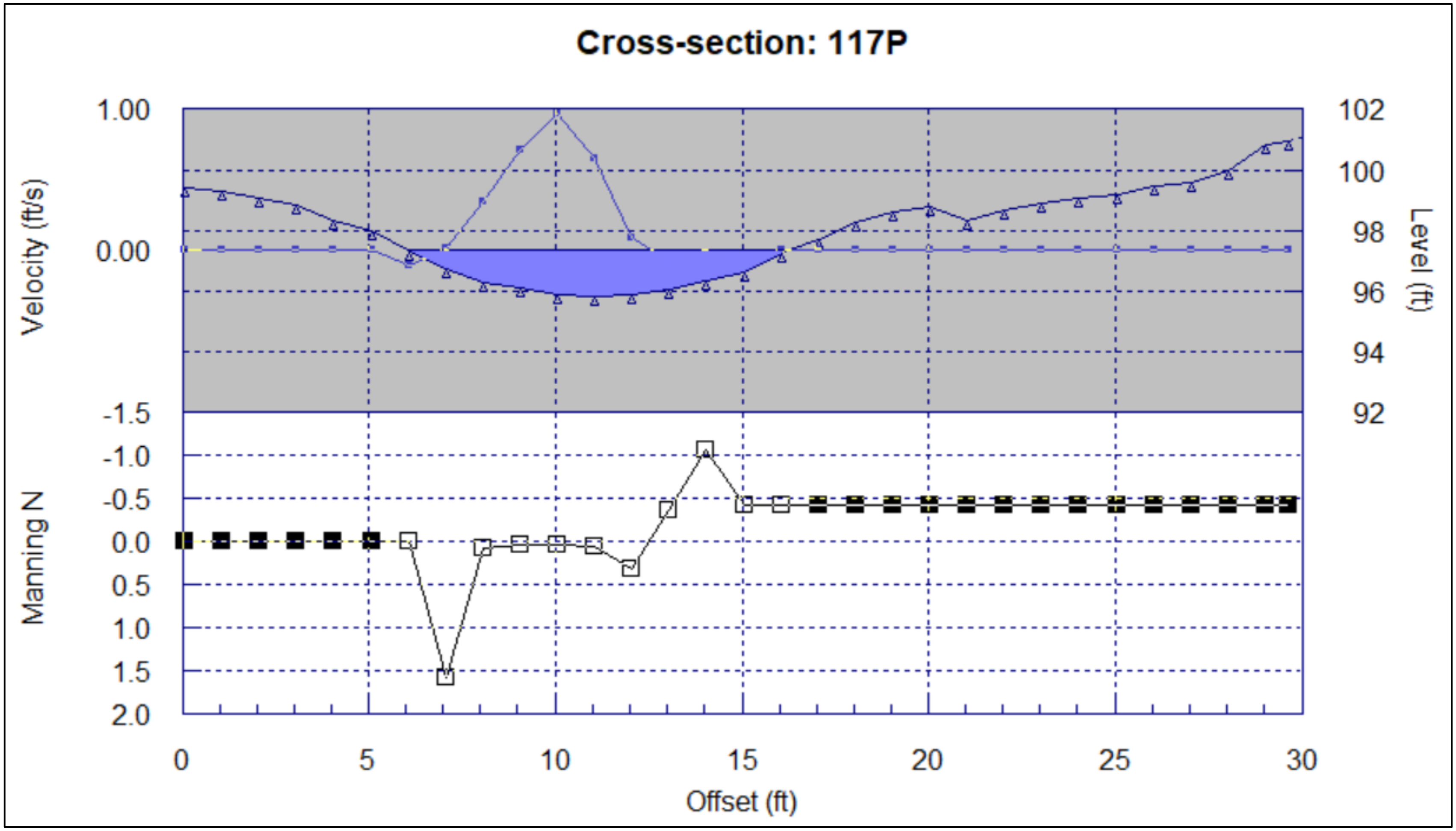

Figure E-9. Reach 2 transect 117P before VDF modification.

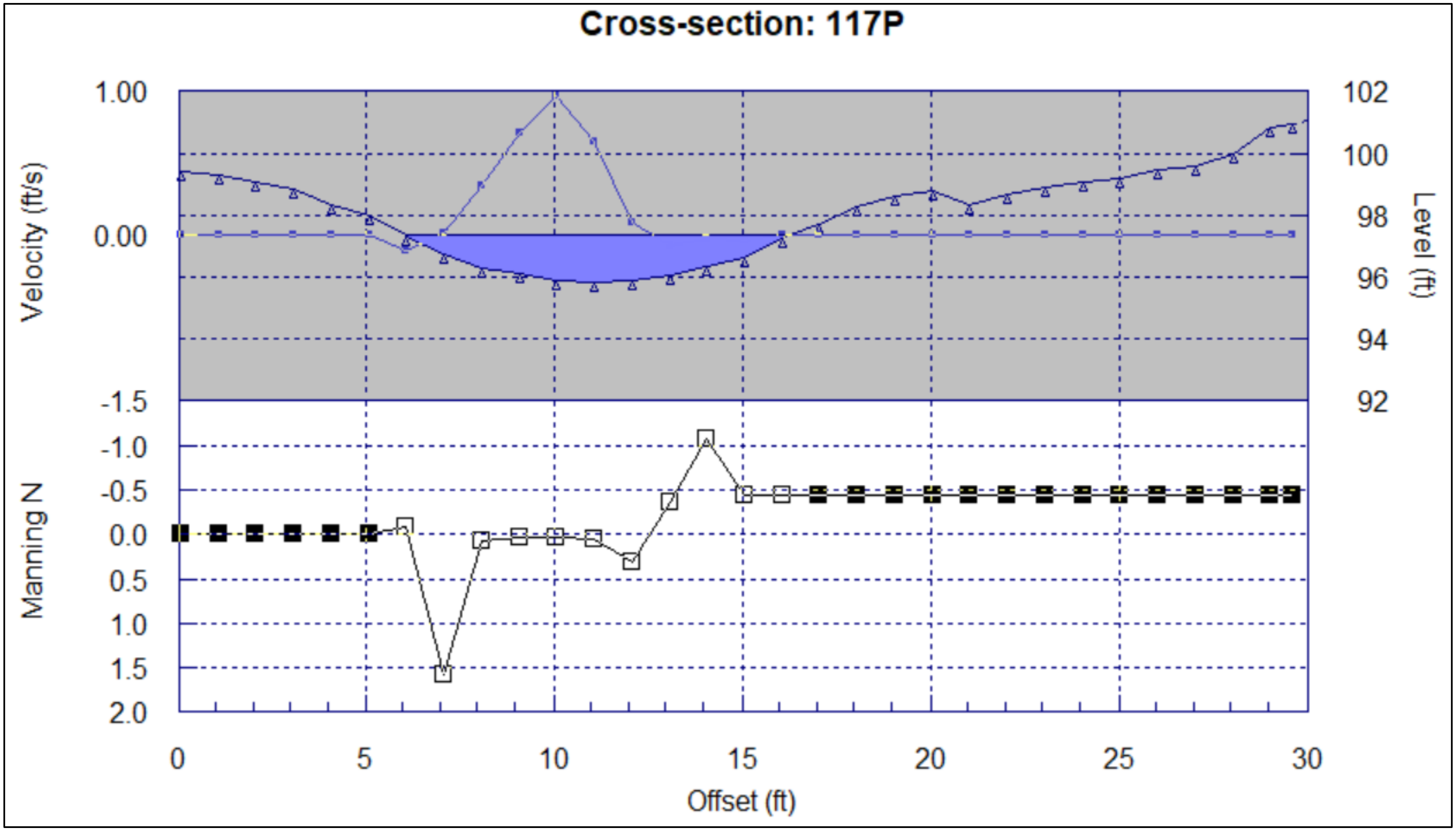

Figure E-10. Reach 2 transect 117P after VDF modification.

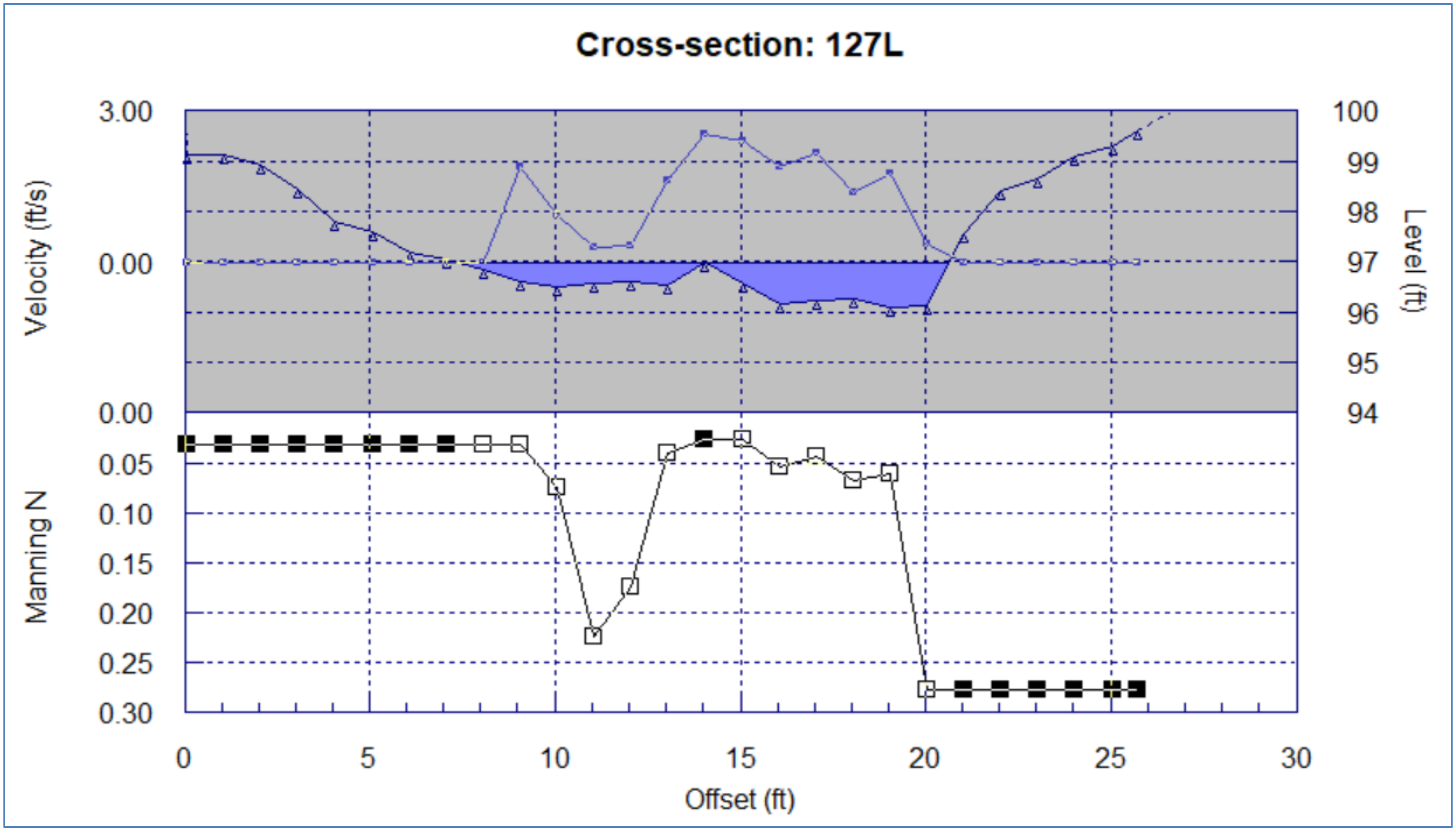

Figure E-11. Reach 2 transect 127L before VDF modification.

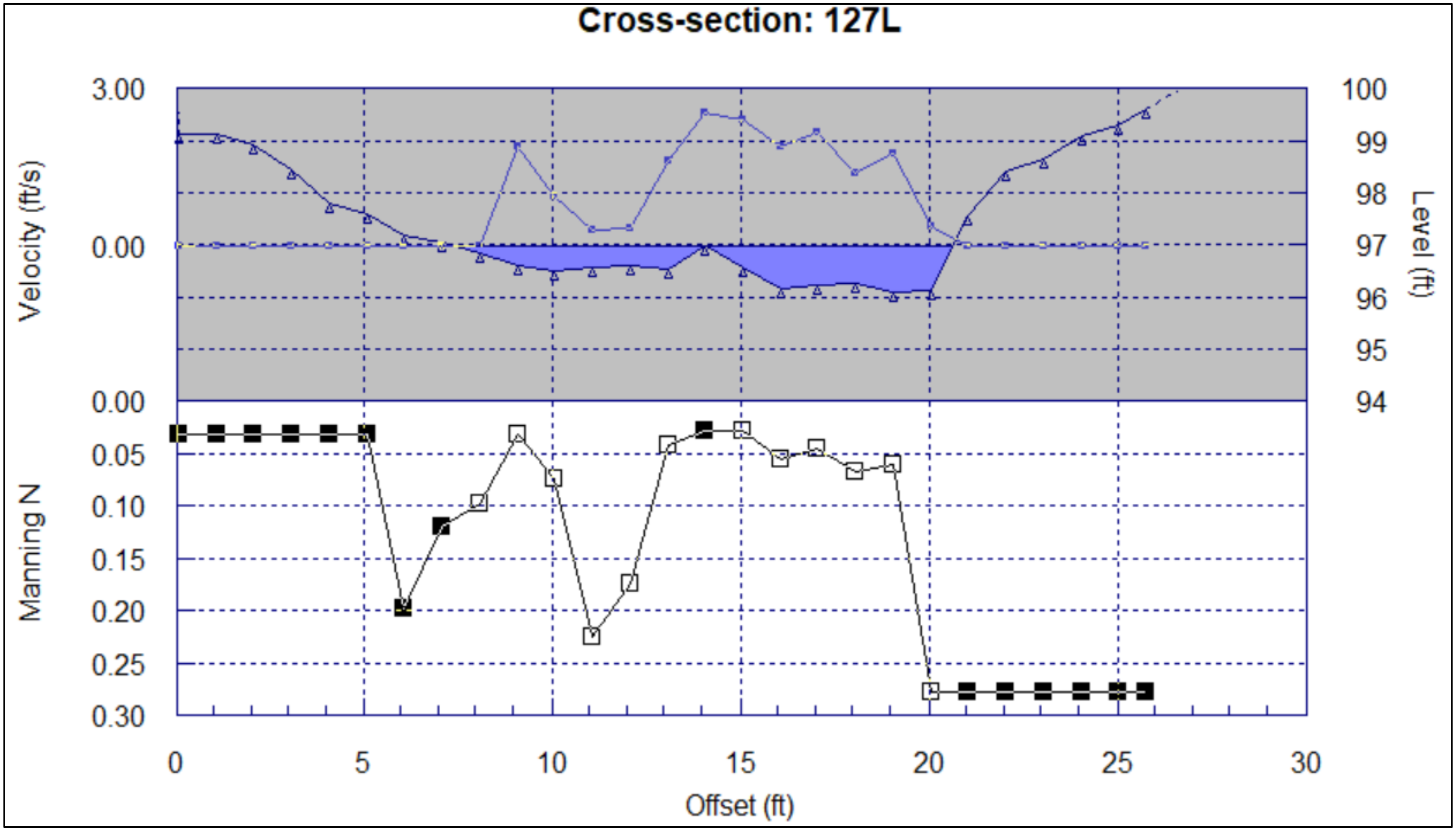

Figure E-12. Reach 2 transect 127L after VDF modification.

APPENDIX F: HABITAT AND STREAMFLOW RELATIONSHIP TABLES

Table F-1. San Antonio Creek Reach 1 streamflow/steelhead habitat relationship. The peak AWS value in each column is indicated with a dagger (†) within a grey box.

Discharge (cfs)	AWS for Juvenile Steelhead (6–9 cm)	AWS for Juvenile Steelhead (10–15 cm)	AWS for Adult Spawning Steelhead
0	1.266	0.834	0.000
1	3.864	2.461	0.010
2	5.016	3.239	0.047
3	5.800	3.935	0.218
4	6.412	4.495	0.497
5	6.899	4.938	0.801
6	7.292	5.304	1.112
7	7.596	5.641	1.422
8	7.836	5.963	1.709
9	8.033	6.223	1.964
10	8.185	6.401	2.182
11	8.298	6.524	2.365
12	8.382	6.623	2.539
13	8.450	6.708	2.699
14	8.504	6.785	2.841
15	8.546	6.852	2.966
16	8.558	6.898	3.067
17	**8.561†**	6.925	3.153
18	8.551	6.944	3.241
19	8.539	6.957	3.327
20	8.518	**6.963†**	3.398
21	8.491	6.963	3.457
22	8.459	6.959	3.503
23	8.421	6.951	3.536
24	8.377	6.937	3.557
25	8.322	6.911	**3.563†**
26	8.267	6.886	3.562
27	8.214	6.858	3.559
28	8.164	6.831	3.552
29	8.116	6.805	3.544
30	8.068	6.779	3.534

Table F-2. San Antonio Creek Reach 2 streamflow/steelhead habitat relationship. The peak AWS value in each column is indicated with a dagger (†) within a grey box.

Discharge (cfs)	AWS for Juvenile Steelhead (6–9 cm)	AWS for Juvenile Steelhead (10–15 cm)	AWS for Adult Spawning Steelhead
0	0.109	0.000	0.000
1	1.650	0.573	0.012
2	2.862	0.930	0.167
3	3.538	1.421	0.487
4	4.057	1.927	0.899
5	4.512	2.413	1.329
6	4.969	2.903	1.739
7	5.369	3.260	2.117
8	5.647	3.473	2.456
9	5.817	3.612	2.755
10	5.931	3.705	3.008
11	5.979	3.755	3.218
12	6.003	3.802	3.385
13	6.022	3.879	3.516
14	6.045	3.990	3.616
15	6.054	4.100	3.680
16	6.037	4.143	3.701
17	6.033	4.171	**3.706†**
18	6.040	4.191	3.705
19	6.042	4.214	3.704
20	6.055	4.252	3.698
21	**6.066†**	4.282	3.690
22	6.062	**4.300†**	3.676
23	6.039	4.296	3.649
24	6.001	4.277	3.603
25	5.965	4.260	3.552
26	5.939	4.247	3.502
27	5.923	4.238	3.458
28	5.912	4.237	3.416
29	5.912	4.242	3.370
30	5.922	4.258	3.327