Relationship Between Stream Discharge and Habitat Availability for the Devils River Minnow (*Dionda diaboli*) and Other Native Fishes in Portions of the Devils River and Dolan Creek, Val Verde County, Texas

Additional material not present in
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Abstract

Karst springs are the primary contributor to base flow for the Devils River in Val Verde County, Texas. Decreased spring flows as a result of increased groundwater withdrawal could have a negative impact on the quantity of habitat available to native fish species in this system. The relationship between physical habitat and stream discharge for the endangered Devils River Minnow (*Dionda diaboli*) and nine other native fishes within portions of the Devils River and Dolan Creek was examined using the Multi-Dimensional Surface Water Modeling System over a narrow range of discharges (15-75 cfs). Extreme drought, resulting in relatively stable discharges during the study period, and flat instream bathymetry limited the ability to draw inferences regarding changes in available habitat. Moderate declines in habitat for Devils River Minnow as discharges increased were predicted by the model at one of the two Devils River study sites; however, changes in depth or velocity predicted by the model were narrow under the observed discharges and results at this site may not be indicative of actual changes. Habitat changes at the other Devils River site were inconsequential and habitat at the Dolan Creek site could not be modeled as there was no variability in flow observed during the study period. Additional physical habitat data, collected under a wider range of discharges, are needed for the model to be more predictive of changes in instream habitat.

Introduction

Threats to native fish within the Devils River and Dolan Creek in Val Verde County, Texas associated with groundwater withdrawals are a concern to aquatic resource managers. Karst springs are the primary contributor to base flows for both these systems and decreases in spring flows could have detrimental effects on native fish assemblages as habitat is dewatered. The objective of this study was to examine the relationship between physical habitat and stream discharge for the endangered Devils River Minnow (*Dionda diaboli*) and nine other native fishes within portions of the Devils River and Dolan Creek.

Methods

Study sites

A 2.6 km reach of the Devils River upstream of Dolan Falls to just upstream of Finnegan Springs was selected as a study site (Figure 1). This portion of the river is bordered by the Devils River State Natural Area and Texas Nature Conservancy lands and was identified as an area historically having a high relative abundance of Devils River Minnows (Robertson and Winemiller 2003, Kollaus 2009, Kollaus and Bonner 2012, Myers et. al. 2012). In addition, the first 1.6 km of Dolan Creek (upstream from its confluence with the Devils River) was selected as a second study reach. This perennial stretch of Dolan Creek constitutes additional habitat for the Devils River minnow (Ryan Smith, The Nature Conservancy, personal communication).

Two-Dimensional Hydraulic Modeling

Three dimensional channel topographies and associated hydraulic calibration data, and mesohabitat data (type - riffle, run pool), substrate, aquatic vegetation, and point current velocities (ft/s) were provided by the Texas Parks and Wildlife Department River Studies Program. These data were used to calibrate two-dimensional hydrodynamic models at the study sites, and in conjunction with developed habitat suitability criteria for target fish species (Upper Rio Grande Basin and Bay Expert Science Team, 2012), including the Devils River Minnow (*Dionda diaboli*), used to simulate the relationship between discharge and physical habitat.

Hydraulic modeling was accomplished using the Multi-Dimensional Surface Water Modeling System (MD_SWMS) developed by the United States Geological Survey (McDonald et al., 2005). The system utilizes the FaSTMECH (Flow and Sediment Transport Morphological Evolution of Channels) model which is a steady-state, two-dimensional (depth-integrated) hydrostatic flow model based on the solution of the full vertically integrated equations for conservation of mass and momentum cast in a curvilinear coordinate system (Nelson et al., 2003). It relies on 3-dimensional riverbed topography, flow rate, and stage (i.e., water surface elevations) at the downstream mesh boundary as the boundary conditions for the model to calculate flow, velocities, and water surface elevations throughout the model domain. This model, along with its quasi-three-dimensional extension (Nelson and Smith (1989a) and Nelson and Smith (1989b), was written explicitly as a component of a morphologic evolution model for channel beds. It is also capable of accommodating spatially variable channel roughness. The technical description of this model and underlying equations can be found in the citations noted above.

Development of Computational Meshes

The curvilinear orthogonal mesh was generated for each of the three study sites using a smooth (gradually varying radius) stream centerline (Figures 2 through 4). Cell size of the mesh was chosen as small as possible given model and computational limitations.

Model Calibration

Three sets of measured water surface profiles and calibration discharges were used in the calibration of the hydrodynamic model for Devils River Upper and Lower sites. Streamflows at Dolan Creek were very stable during the study period and only a very low flow water surface-discharge pair could be obtained, thus making calibration of the model and subsequent habitat modeling runs impossible (Table 1). In Table 1, “low”, “medium” and “high” refer to the range of flows observed during the study. All of these flows are very low, and are in the range of subsistence flows.

The two-dimensional hydraulic model for Devils River Upper and Lower sites as well as Dolan Creek at low flow was calibrated to each measured water surface profile by adjusting roughness, viscosity and other parameters over the entire computational mesh. Delineated substrate and aquatic vegetation polygons (Figures 5 through 7), provided by TPWD, were used to assign spatially explicit roughness heights to each computational node within the mesh. The hydraulic roughness (Z_0) was calculated from the roughness height in combination with the roughness coefficient:

$$Z_0 = D(grainsize) * C$$

where *D(grainsize)* is the roughness height and *C* is the roughness coefficient.

When the roughness coefficient, lateral eddy viscosity value, and other parameter adjustments that generated accurate water surface elevation (WSE) predictions at all calibration flows were obtained throughout the study site, the hydraulic model was assumed to be calibrated. Flow versus stage relationships for Devils River Upper and Lower sites are shown in Appendix A (Figures A1 and A2).

All subsequent hydraulic simulations for various flows used in the habitat modeling were modeled with the same roughness heights, roughness coefficients, viscosity and other parameters.

Water surface modeling results were generally within (plus or minus) 0.4 inches (of elevation) over the entire spatial domain of the Devils River Upper site at each of the three calibration flows. They were within 0.1 inches at Devils River Lower site. Because measured water surface elevations at medium flow for this site were higher than water surface elevations measured at high flow, a decision was made to adjust WSEs at medium flow to fit between WSEs at high and low flows.

Calibrated WSEs at Dolan Creek were within 2.6 inches from the measured WSE values. Because only one discharge was collected at Dolan Creek, it was not possible to develop a stage discharge relationship or calibrate the model to additional calibration flows necessary for simulation of a range of discharges.

Appendix A (Figures A3-A9) shows the difference between measured and modeled water surface elevations at all calibration flows at the three study sites.

Ranges of Simulated Flows

The choice of simulated flows for the model is usually based on the quality of the simulations and the range of target flows desired for the assessments. Generally, the results of hydraulic modeling are considered to be reliable within the ranges of calibration flows (i.e. between the low and high calibration flows) and over some range of extrapolated flows. Additional model runs were made for a number of flows outside the calibration range (Table 2). Modeling of the low flows was limited by the sparse topography data: it caused convergence problems at flows lower than 20 cfs (convergence is defined as the percent deviation from the normalized discharge at each cross section in the numerical calculation. In other words, it is calculated as the predicted discharge at a cross-section divided by the specified discharge multiplied by 100).

Habitat Modeling

Physical habitat modeling was undertaken for a suite of target fish species representing a variety of mesohabitat use within the river (Table 3). Habitat suitability curves for these species were adopted from previous work by the Upper Rio Grande Bay and Basin Expert Science Team (2012) (Appendix B). The depth curves were examined to ensure that no suitability was associated with zero depths and that the first suitable depth was at least 1.5 estimated adult body depth. The velocity curves were examined to ensure that no suitability was associated with velocities greater than estimated burst speed, assumed to be 8 body lengths/second for adults of each species. Only adult life stages for each species were analyzed. Physical habitat was computed as the geometric mean of the component suitability of depth and velocity:

$$\text{Combined}_{\text{suitability}} = (\text{Depth}_{\text{suitability}} * \text{Velocity}_{\text{suitability}})^{0.5}$$

The amount of physical habitat was computed for each computational cell as Weighted Useable Area and then summed over all cells at a specific discharge:

$$\sum \text{WUA}_{\text{cell}} = \text{Combined Cell}_{\text{suitability}} * \text{Cell Area}$$

Results and Discussion

Predicted habitat as a function of discharge at the two Devils River study sites for all species are provided in in Figures 8 and 9 and the numerical results for the Devils River and Dolan Creek are provided in Table 4. Model simulations showed relatively constant habitat availability over the narrow range of simulated discharges for all species at the Upper Devils River site while the Lower study site showed slight to moderate declines as discharges increased.

This lack of apparent sensitivity to changing flow between 30 to 75 cfs for all species modeled is driven by the relationship between the flow dependent hydraulic simulations and habitat suitability curves. This is illustrated for the Devils River Upper site in Figures 10 and 11 which compares the depth and velocity between 35 and 75 cfs and the corresponding combined suitability for Devils River Minnow, which is indicative of all species modeled (because of the limited range in modeled discharge). Figures 12 and 13 provide this same information at the Devils River Lower site.

First, the relationship between stage (i.e., water surface elevation) and discharge only changes by less than a foot over the range (45 cfs) of simulated discharges (Appendix A). As would be expected the resulting changes in the magnitude of the velocities are also relatively small as indicted in Figures 10 and 12. Given the narrow change in either depth or velocity, there is little associated change in the combined suitability for the target species based on depth and velocities as shown in Figures 11 and 13. As indicated in both Figure 11 and 13, simulated habitat is primarily found along the stream margins and deeper sections of the river and the primary limiting factor are velocities (compare velocity suitability curves in Appendix B for velocities against the range of values in Figures 10 and 12).

Given the lack of sensitivity of the habitat versus discharge relationships for this range of flows modeled, no habitat time series were run since the resulting habitat duration curves would remain flat over the simulated ranges of discharge. However, what is apparent from the simulations is that as discharges are reduced below the lower simulation flows, the areas of habitat availability at the stream margins would be further reduced and the amount of habitat loss to incremental flow reductions would accelerate.

Habitat versus discharge results from this study are roughly comparable to the results of a simpler one-dimensional modeling effort completed as part of the Senate Bill 3 Bay and Basin Expert Science Team (BBEST) process. The study site for the BBEST's "Devils River at Juno" flow recommendations overlapped with the lower site from this study. Across the range of flows modeled in this study (30-75 cfs), the flow-weighted usable area curves for this site show similar flat curves for many of the same species (Figure 14). In addition, the BBEST modeling extended to a wider range of flows, including lower flows and down to zero flow and show the strong decline discussed above that would be expected as flows drop below the range of flows modeled in this study. It was impossible to make any inferences relative to flow dependent habitat changes at Dolan Creek given the single observed flow rate.

Acknowledgments

The author acknowledges: Texas Parks and Wildlife Department (TPWD) staff Karim Aziz, Sarah Robertson, Steve Magnelia, Ken Saunders, John Botros and Kevin Kolodziejcyk for their work gathering physical habitat data; Karim Aziz for producing study site and site habitat maps for the final report; Kevin Mayes and Steve Magnelia for providing reviews of the manuscript. Ryan Smith (Texas Nature Conservancy (TNC)) for assistance in physical habitat collections and review of the manuscript. Kristi Kollaus (Meadows Center for Water and the Environment), Dr. Timothy Bonner (Texas State University), Sarah Robertson (TPWD), Kevin Mayes (TPWD), Ryan Smith (TNC) for review of the HSI models. Partial funding for this study was provided by the United States Fish and Wildlife Service through Section 6 of the Endangered Species Act.

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Robertson, M.S. and K.O. Winemiller. 2003. Habitat associations of fishes in the Devils River, Texas. Journal of Freshwater Ecology 18:1 115-127.

Upper Rio Grande Basin and Bay Expert Science Team. 2012. Environmental Flows Recommendations Report. Final Submission to the Environmental Flows Advisory Group, Rio Grande Basin and Bay Area Stakeholders Committee and Texas Commission on Environmental Quality.

Table 1. Dates and magnitudes of measured flows for the three study sites. "Low", "medium" and "high" refer to the range of flows observed during the study. All of these flows are very low for this location, and are in the range of subsistence flows.

River / Site	Low Flow		Medium Flow		High Flow	
	Date	Q, cfs	Date	Q, cfs	Date	Q, cfs
Devils River Upper	9/9/2013	18.96	4/17/2013	25.31	2/21/2013	33.33
Devils River Lower	9/9/2013	40.14	4/17/2013	48.34	2/20/2013	57.47
Dolan Creek	9/10/2013	11.8				

Table 2. Modeled flows at the three study sites. Flows in bold are calibration flows.

Devils River Upper	Devils River Lower	Dolan Creek
cfs	cfs	cfs
75	75	**11.8**
70	70	
65	65	
60	60	
55	**57.5**	
50	55	
45	50	
40	**48.3**	
35	45	
33.3	**40.1**	
30	35	
25.3	30	
20		
19.0		
15		

Table 3. Fish species analyzed for physical habitat modeling.

Common Name	**habitat and other comments**
Rio Grande Darter	riffle, shallow run, vegetated outside of riffles (mainly riffles in Indy Creek)
Proserpine Shiner	riffle, shallow run
Manantial Roundnose Minnow	spring habitats, run-shallow
Devils River Minnow	deep run associated with aquatic vegetation
Texas Shiner	deep run
Mexican Tetra	shallow and deep run
Sand Shiner	shallow pool
Longear Sunfish	shallow pool
Largemouth Bass	deep pool
Rio Grande Cichlid	deep pool

Table 4. Available habitat (ft^2) as a function of discharge (cfs) at study sites.

Discharge (cfs)	D. diaboli	E. grahami	C. proserpina	D. argentosa	N. amabilis	A. mexicanus	N. stramineus	L. megalotis	M. salmoides	C. cyanoguttatum
15.0	51175	41959	32920	39938	48901	25254	28757	41442	49558	39156
19.0	50953	41850	32756	39606	48675	24930	28863	41167	49572	39045
25.3	50977	42021	33133	39667	48740	24923	29083	41168	49935	39182
30.0	50643	41712	32854	39214	48353	24408	29128	40782	49887	38983
33.3	50291	41334	32523	38733	47983	23912	28876	40331	49706	38680
35.0	50159	41285	32468	38646	47870	23884	28829	40223	49671	38639
40.0	49821	41020	32400	38451	47562	23668	28830	40024	49554	38542
45.0	49411	40532	31995	38022	47024	23042	28466	39633	49148	38155
50.0	48940	39970	31470	37484	46471	22243	28065	39194	48696	37727
55.0	48448	39318	30776	36868	45890	21270	27449	38678	48090	37164
60.0	48098	39082	30595	36651	45516	20991	27029	38433	47653	36827
65.0	47953	38807	30158	36228	45284	20195	26532	38132	47375	36506
70.0	47675	38513	29833	35885	44870	19701	25913	37806	46864	36081
75.0	47398	38040	29350	35343	44483	18956	25248	37335	46362	35598
Lower Devils River	Habitat Area (square feet)									
Discharge (cfs)	D. diaboli	E. grahami	C. proserpina	D. argentosa	N. amabilis	A. mexicanus	N. stramineus	L. megalotis	M. salmoides	C. cyanoguttatum
30.0	8832	7487	6548	7707	8836	5272	5721	7786	8790	7332
35.0	8796	7394	6436	7587	8761	5130	5639	7694	8708	7240
40.1	8830	7436	6468	7626	8799	5161	5670	7734	8752	7280
45.0	8859	7454	6470	7635	8819	5153	5685	7753	8777	7299
48.3	8897	7490	6498	7667	8853	5176	5716	7789	8811	7333
50.0	8899	7488	6489	7659	8851	5163	5710	7785	8809	7329
55.0	8930	7480	6458	7629	8850	5103	5694	7776	8805	7317
57.5	8943	7508	6496	7667	8873	5149	5717	7803	8824	7342
60.0	8986	7528	6500	7674	8896	5135	5729	7824	8843	7357
65.0	9011	7535	6498	7674	8902	5121	5725	7829	8842	7358
70.0	9019	7519	6465	7643	8878	5071	5701	7811	8815	7334
75.0	9060	7549	6492	7671	8900	5094	5715	7842	8827	7353
Dolan Creek	Habitat Area (square fee)									
Discharge (cfs)	D. diaboli	E. grahami	C. proserpina	D. argentosa	N. amabilis	A. mexicanus	N. stramineus	L. megalotis	M. salmoides	C. cyanoguttatum
11.8	15647	15479	15813	14073	14447	15099	13647	14408	13680	13378

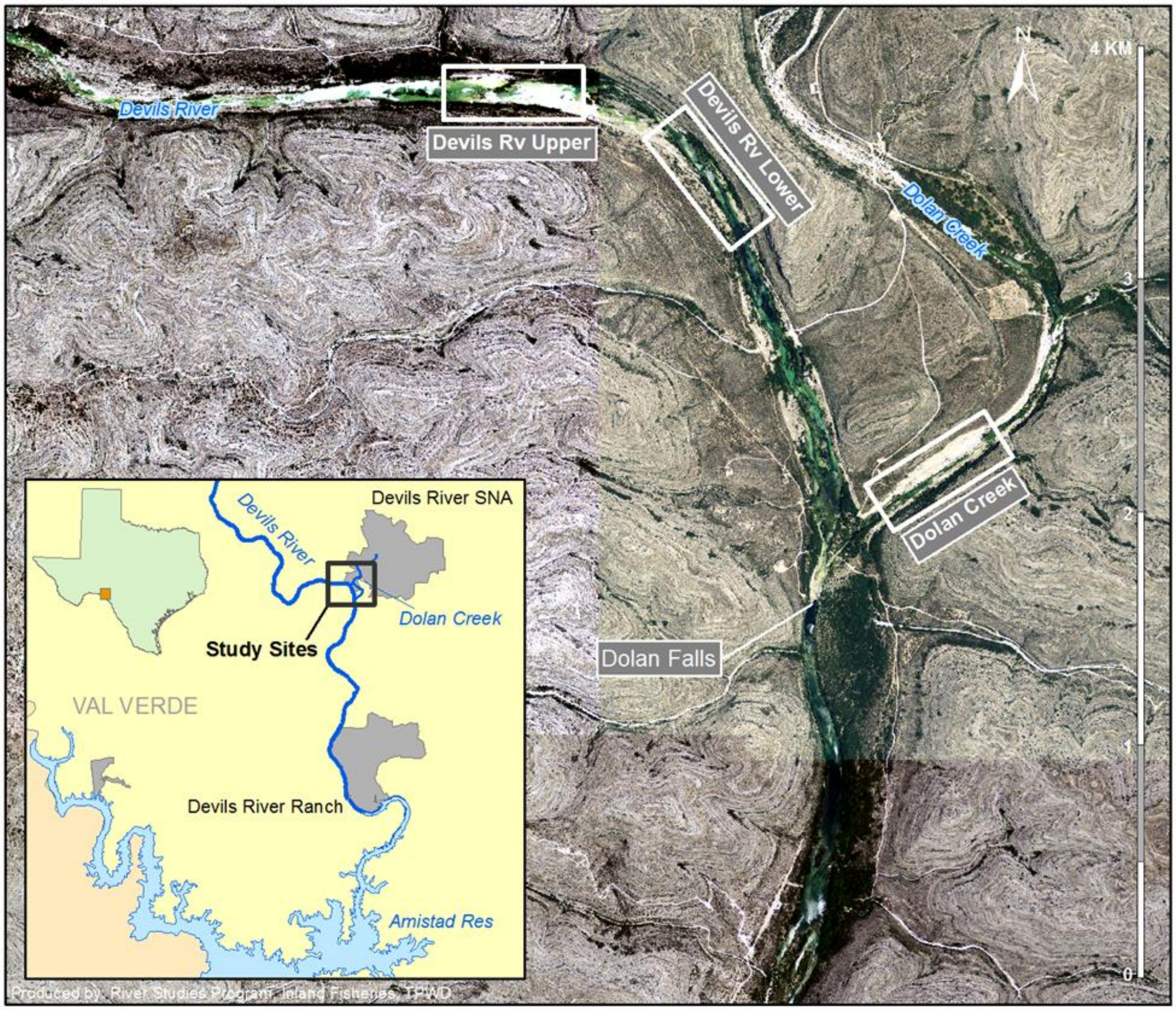

Figure 1. Study site locations for determining habitat availability for the Devils River Minnow (*Dionda diaboli*) and other native fish species under different river discharges.

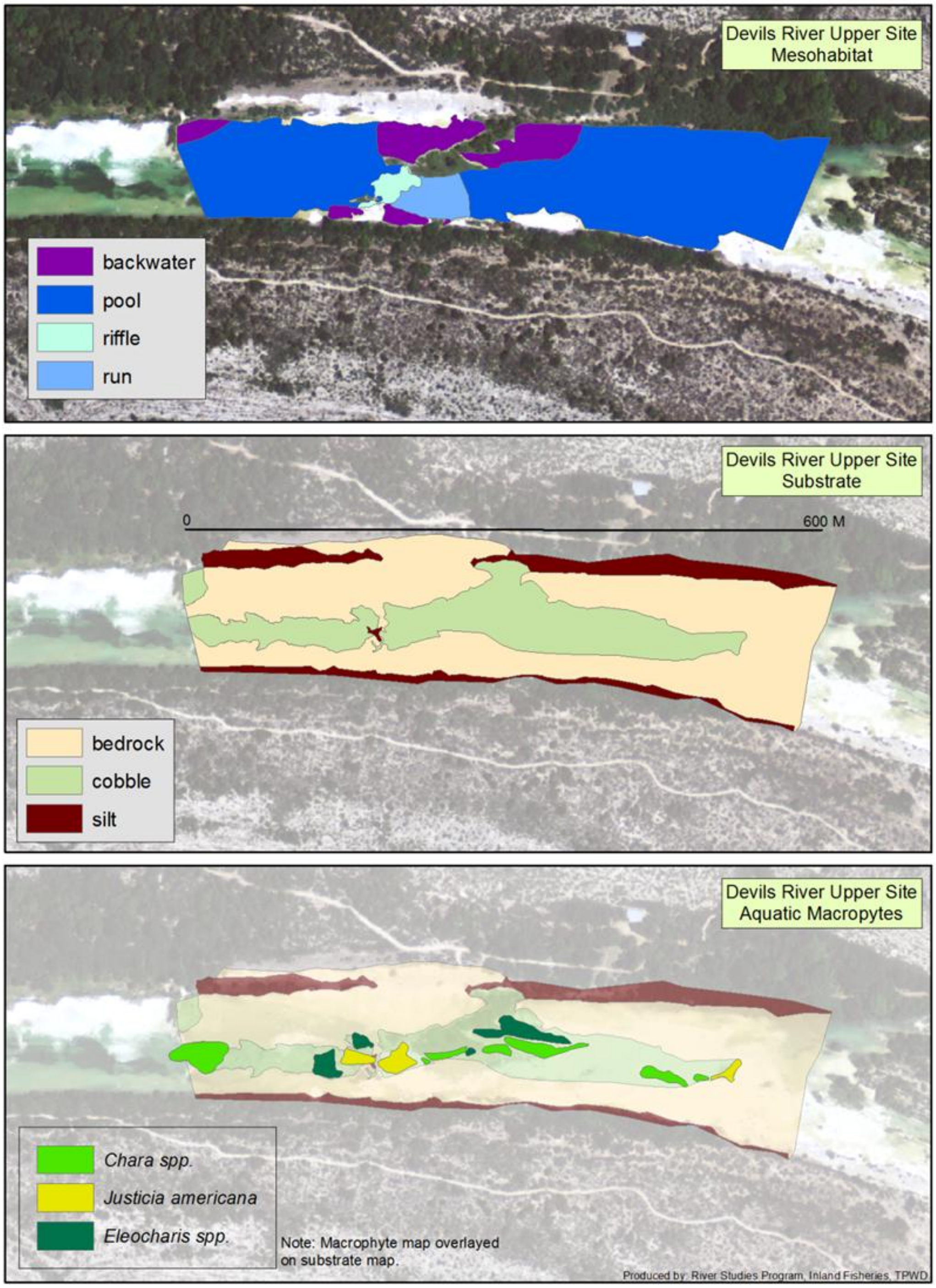

Figure 2. Mesohabitat and substrate distribution at the Devils River Upper site.

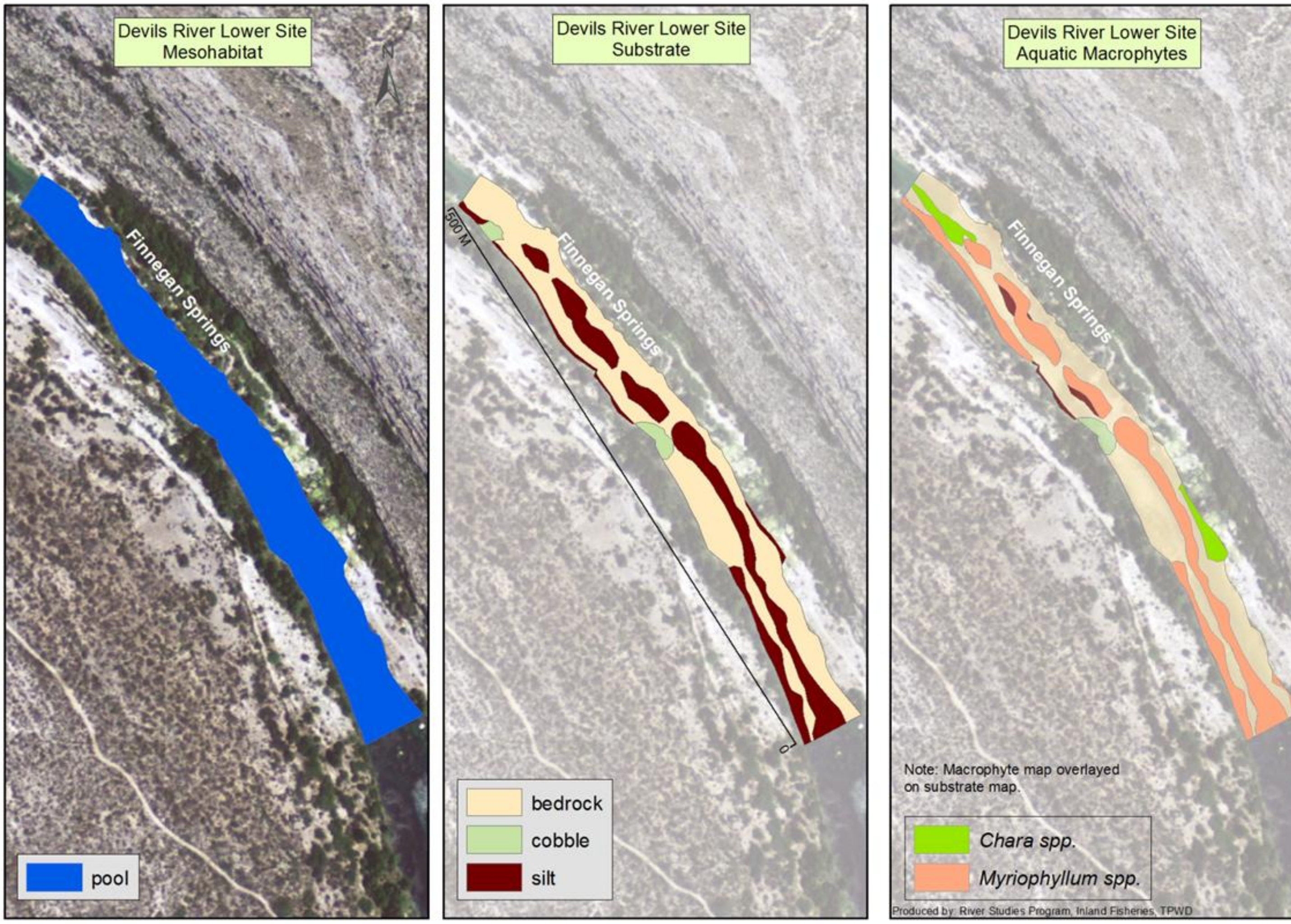

Figure 3. Mesohabitat and substrate distribution at the Devils River Lower site.

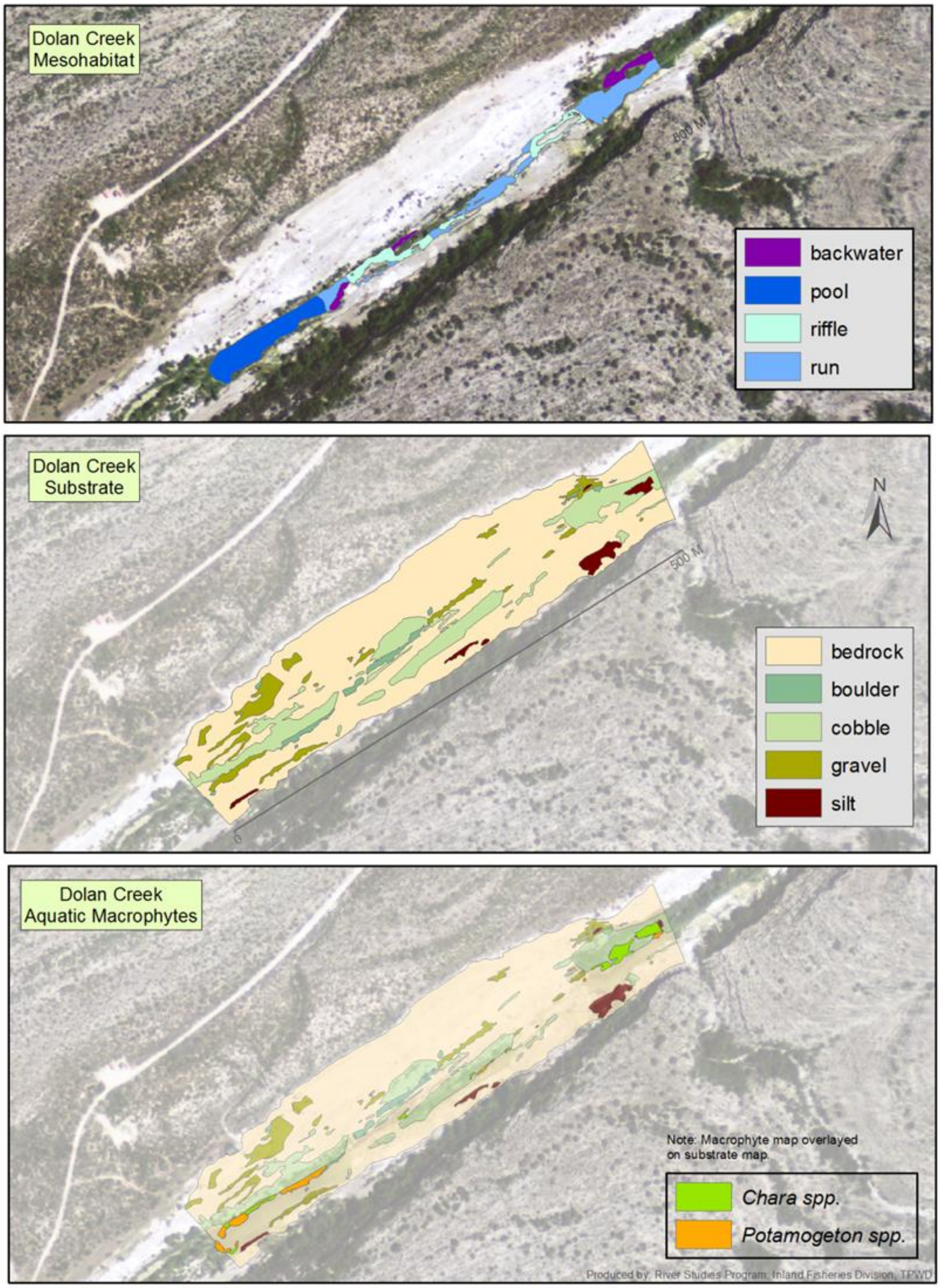

Figure 4. Mesohabitat and substrate distribution at the Dolan Creek site.

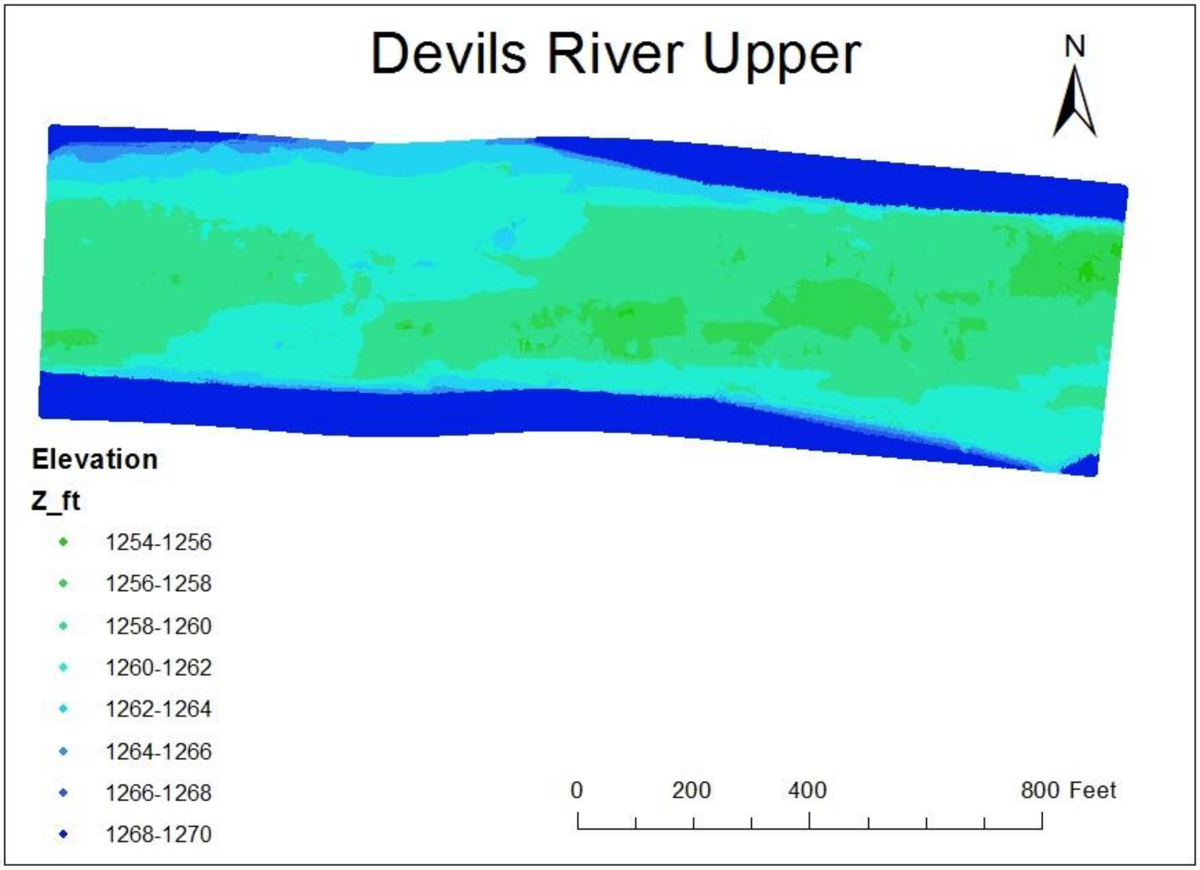

Figure 5. Computational mesh used in hydraulic and subsequent habitat modeling for Devils River Upper site. The mesh is 1830.8 ft long and 492.1 ft wide with a 2 x 2 ft cell size. The upstream boundary of the site is to the left. Elevation (Z) is feet above mean sea level.

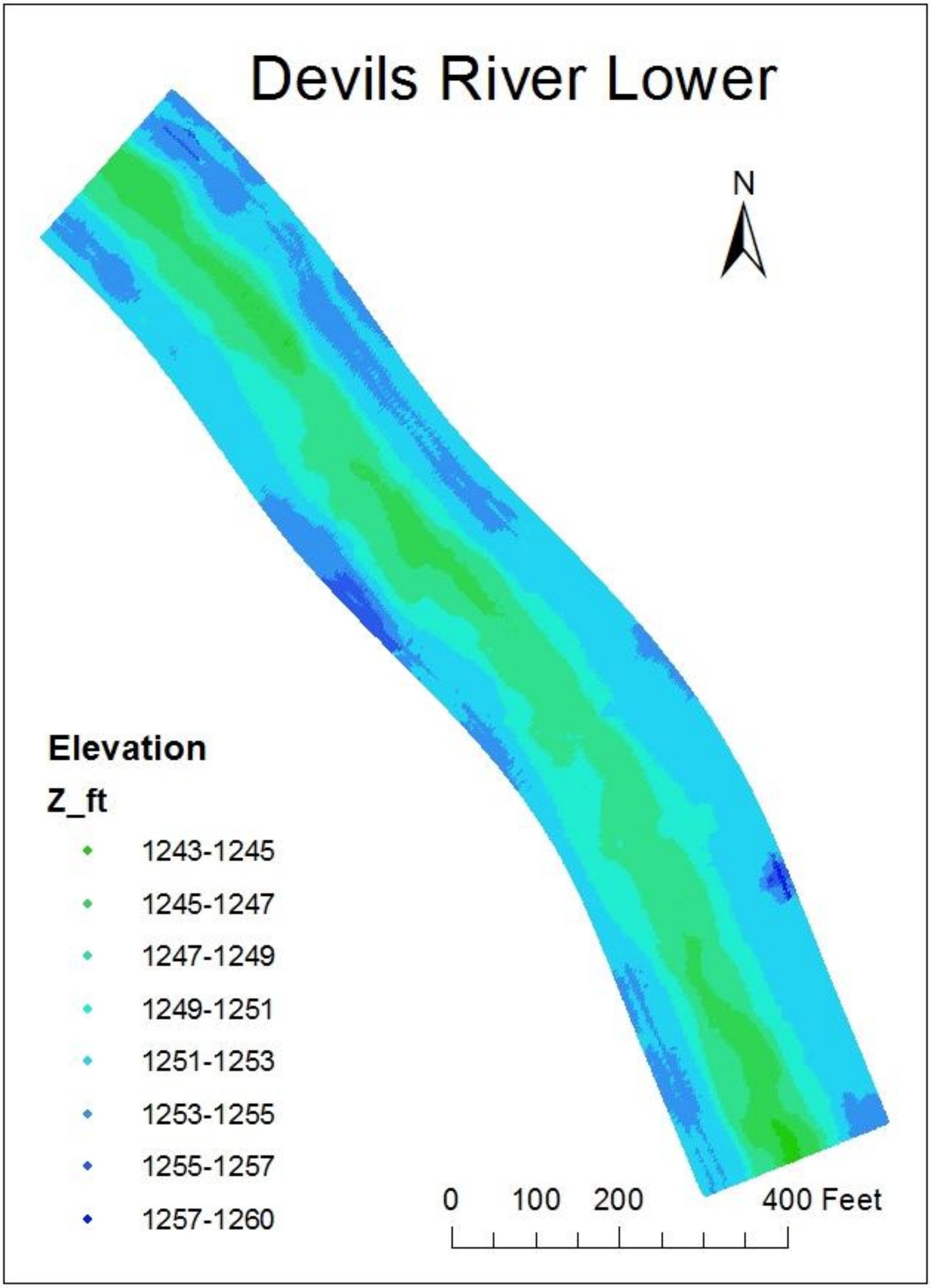

Figure 6. Computational mesh used in hydraulic and subsequent habitat modeling for Devils River Lower site. The mesh is 1454.3 ft long and 229.7 ft wide with a 1.6 x 1.6 ft cell size. The upstream boundary of the site is at the top of the figure. Elevation (Z) is feet above mean sea level.

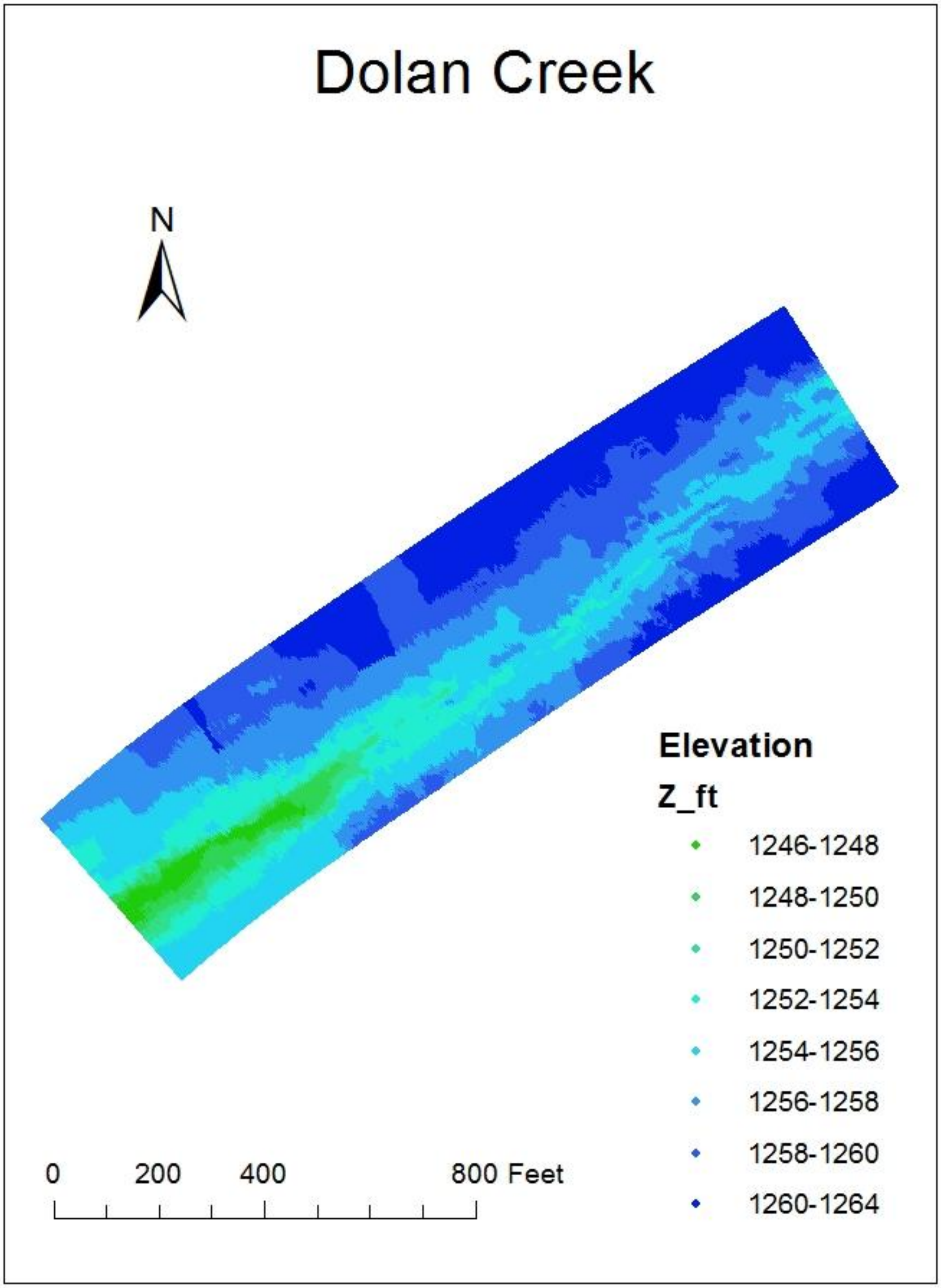

Figure 7. Computational mesh used in hydraulic modeling for Dolan Creek. It is 1668.8 ft long and 393.7 ft wide with a 1.5 x 1.5 ft cell size. The upstream boundary of the site is at the top of the figure. Elevation (Z) is feet above mean sea level.

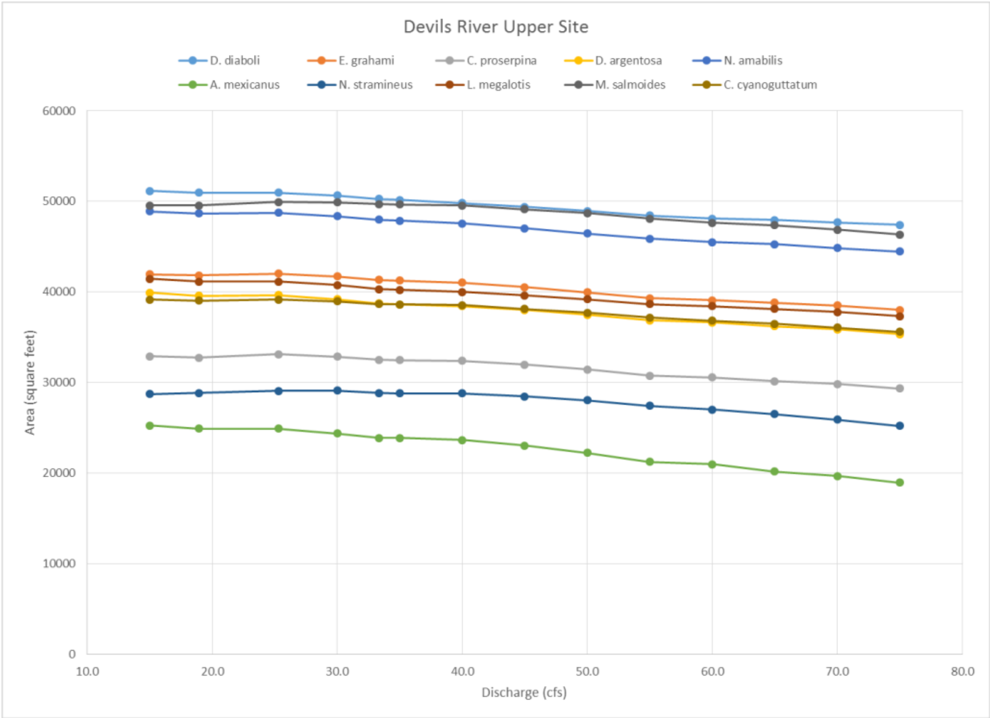

Figure 8. Available habitat versus discharge for modeled fish species in the Devils River Upper site.

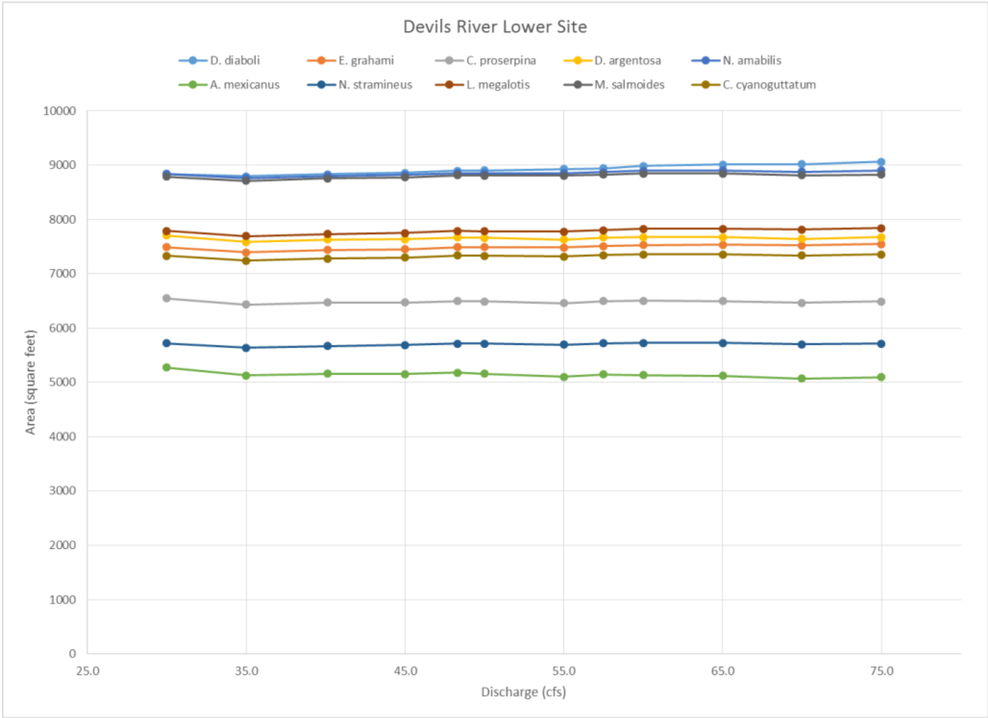

Figure 9. Available habitat versus discharge for modeled fish species in the Devils River Lower site.

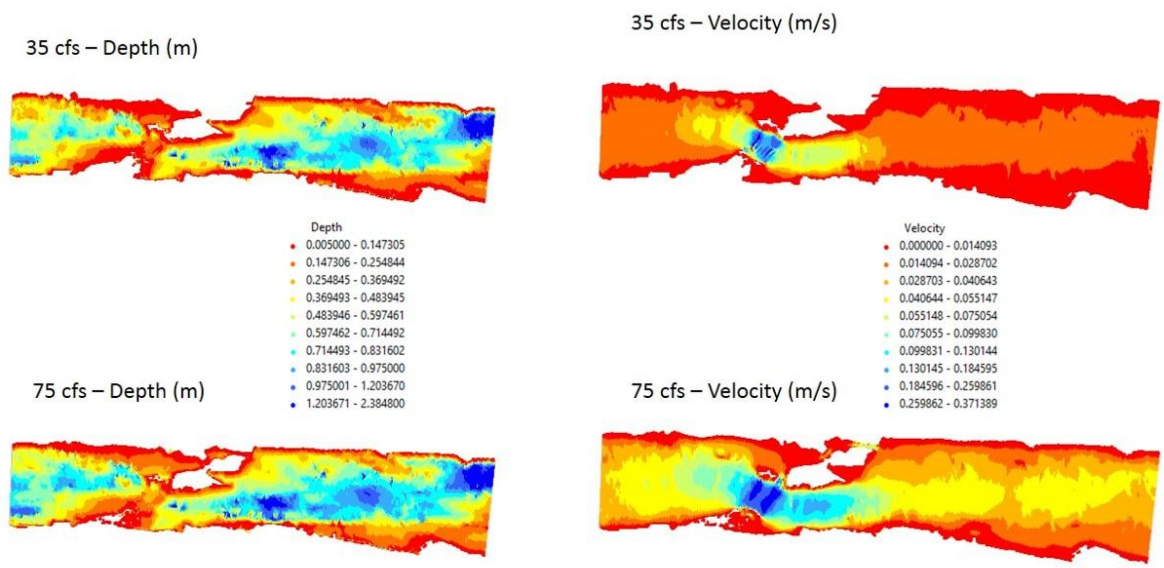

Figure 10. Depth and velocity contours at 35 and 75 cfs in the Devils River Upper site.

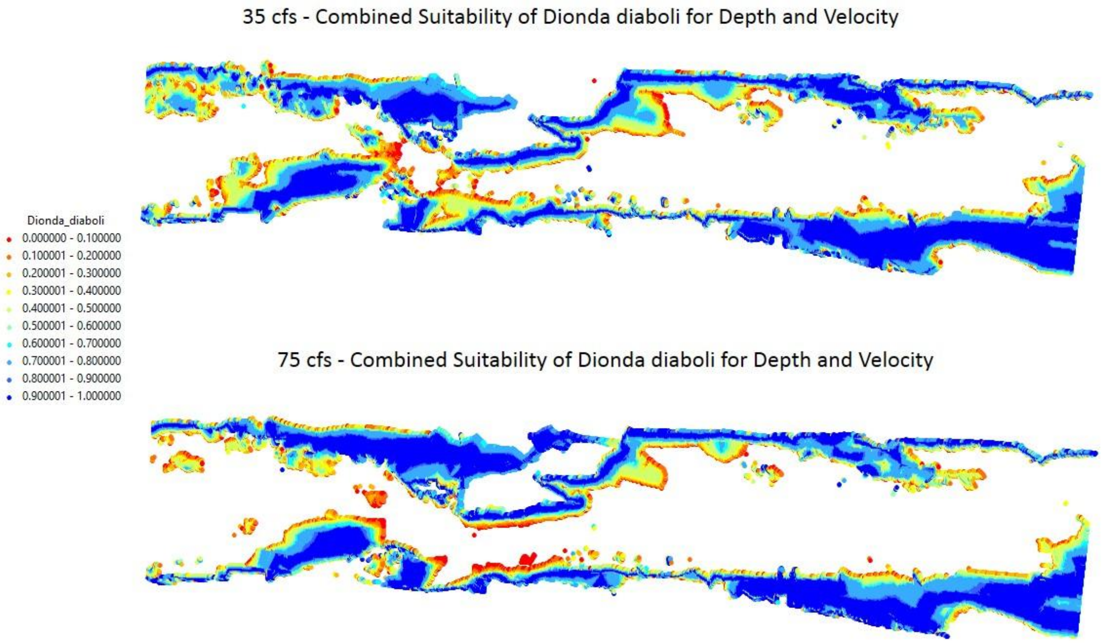

Figure 11. Comparison of combined depth and velocity suitability for Devils River Minnow within the Devils River Upper site at 35 and 75 cfs.

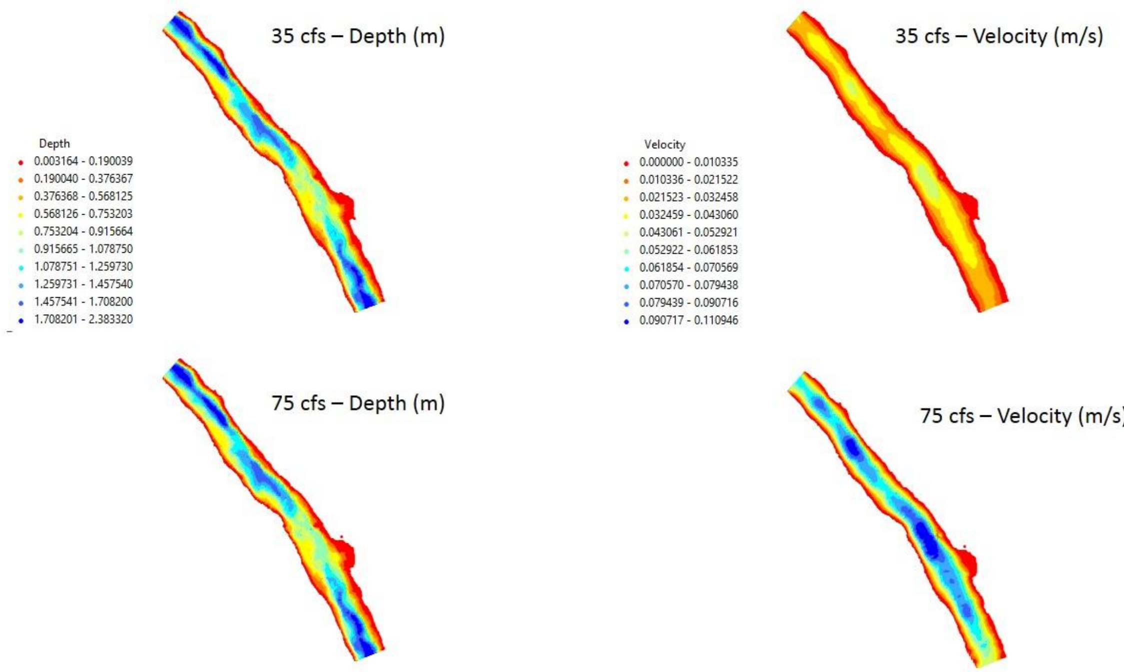

Figure 12. Depth and velocity contours at 35 and 75 cfs in the Devils River Lower site.

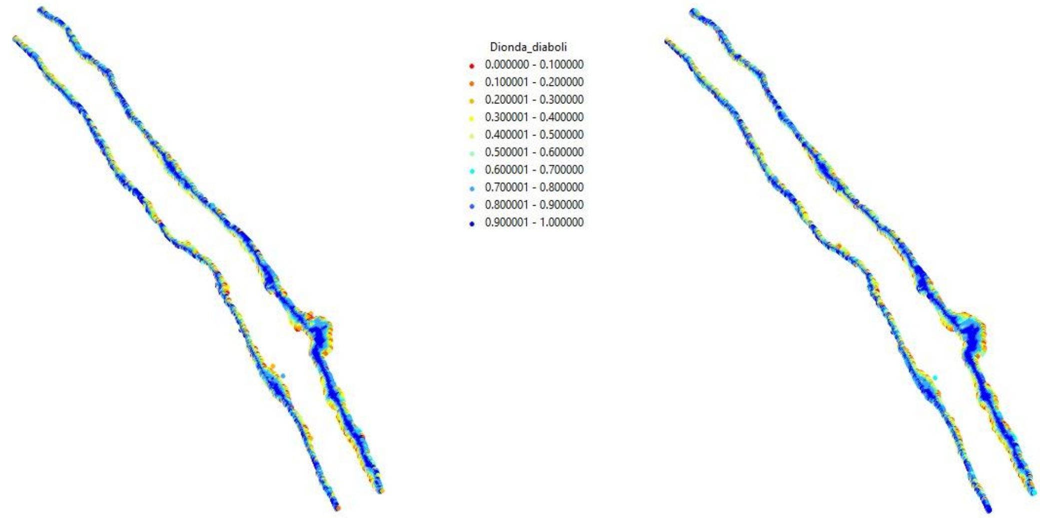

Figure 13. Comparison of combined depth and velocity suitability for Devils River Minnow within the Devils River Lower site at 35 and 75 cfs.

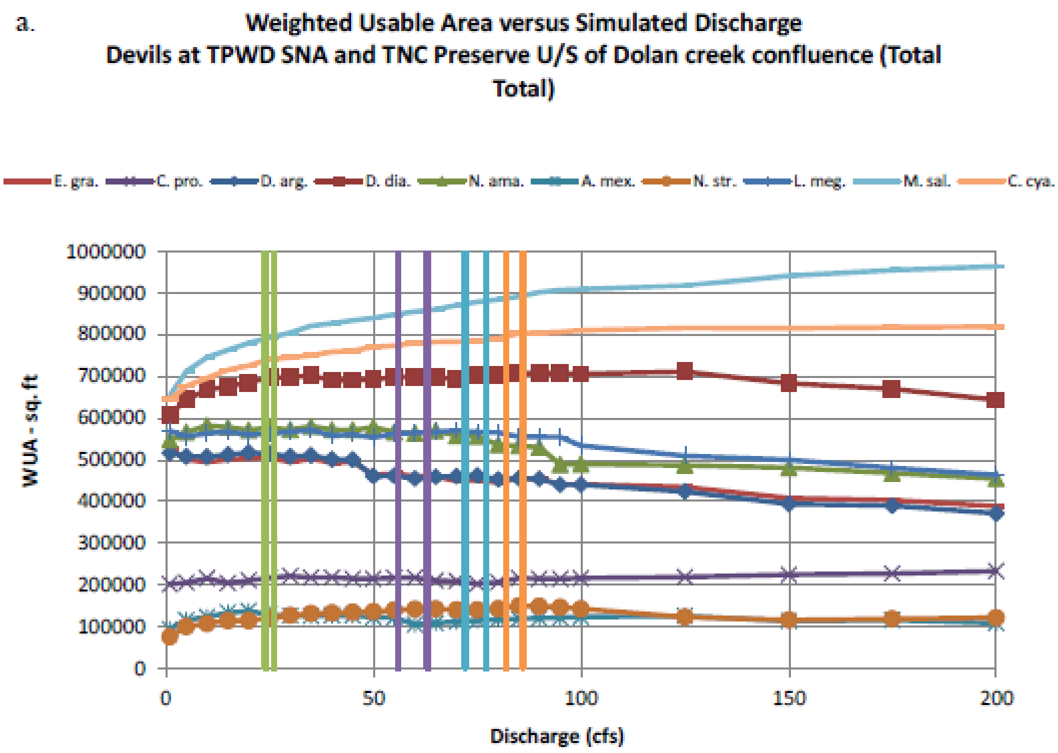

Figure 14. Weighted usable area versus discharge relationships for 10 species from the Senate Bill 3 BBEST report (extract from Figure 3.8-2 in Upper Rio Grande BBEST 2012). Species codes are: E. gra.=Rio Grande darter, C. Pro.=Proserpine shiner, D. arg.=manantial roundnose minnow, D. dia.=Devils River minnow, N. ama.=Texas shiner, N. str.=sand shiner, A. mex.=Mexican tetra, L. meg.=longear sunfish, M. sal.=largemouth bass and C. cya.=Rio Grande cichlid

Appendix A - Hydraulic Modeling Documentation

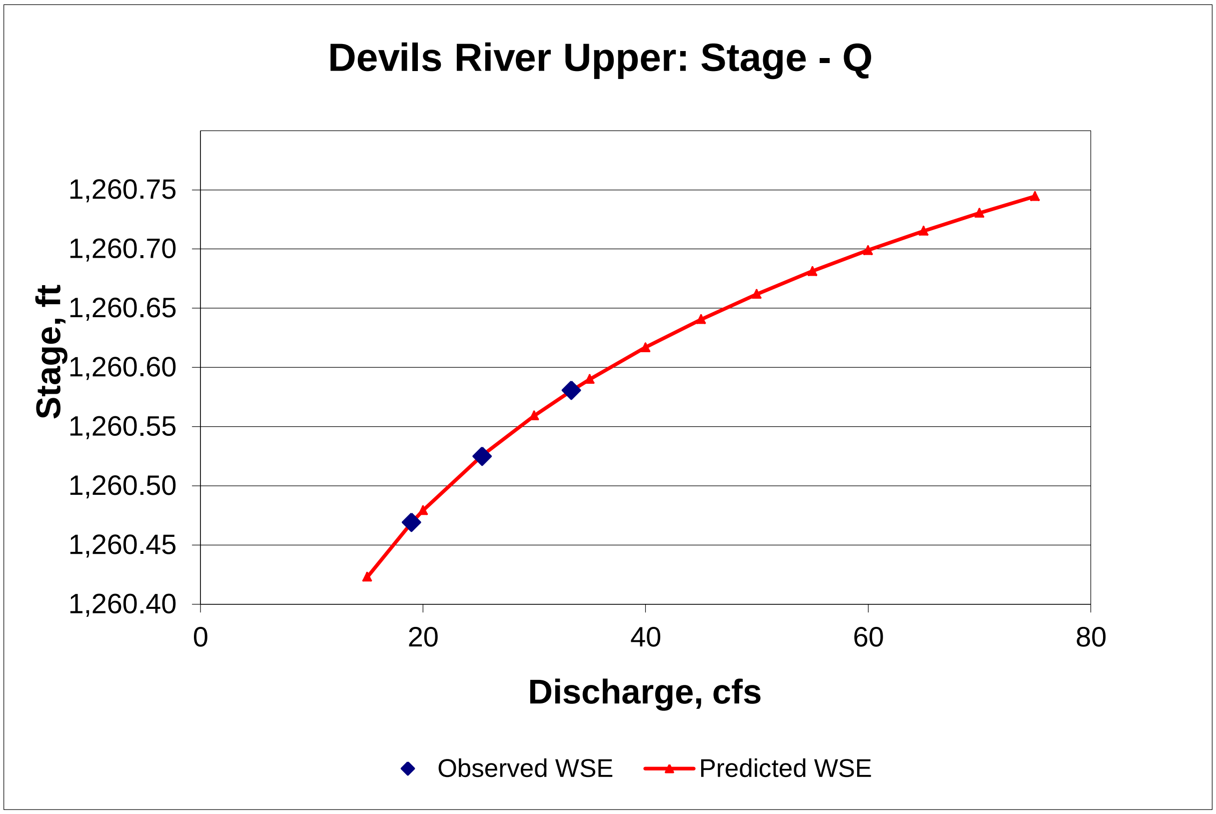

Figure A1. Stage (ft msl) versus discharge (cfs) relationship at the Devils River Upper site.

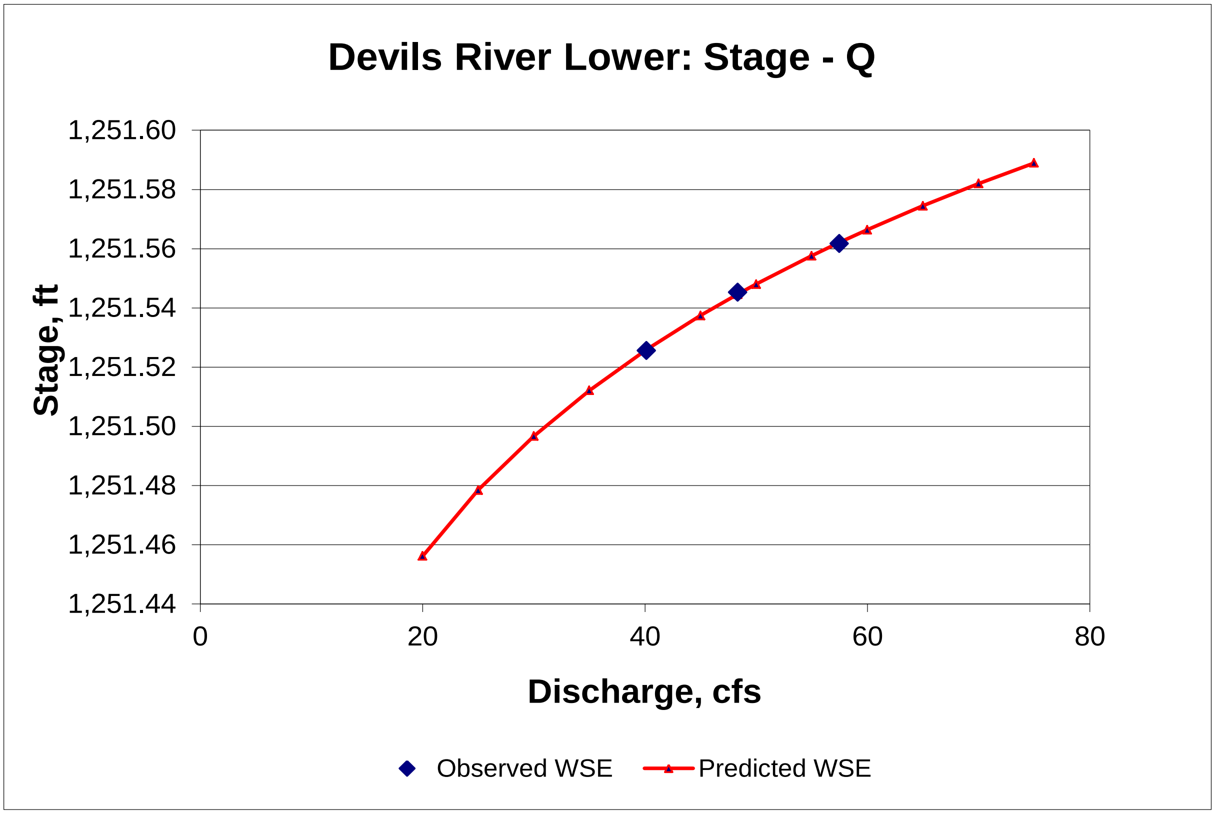

Figure A2. Stage (ft msl) versus discharge (cfs) relationship at the Devils River Lower site.

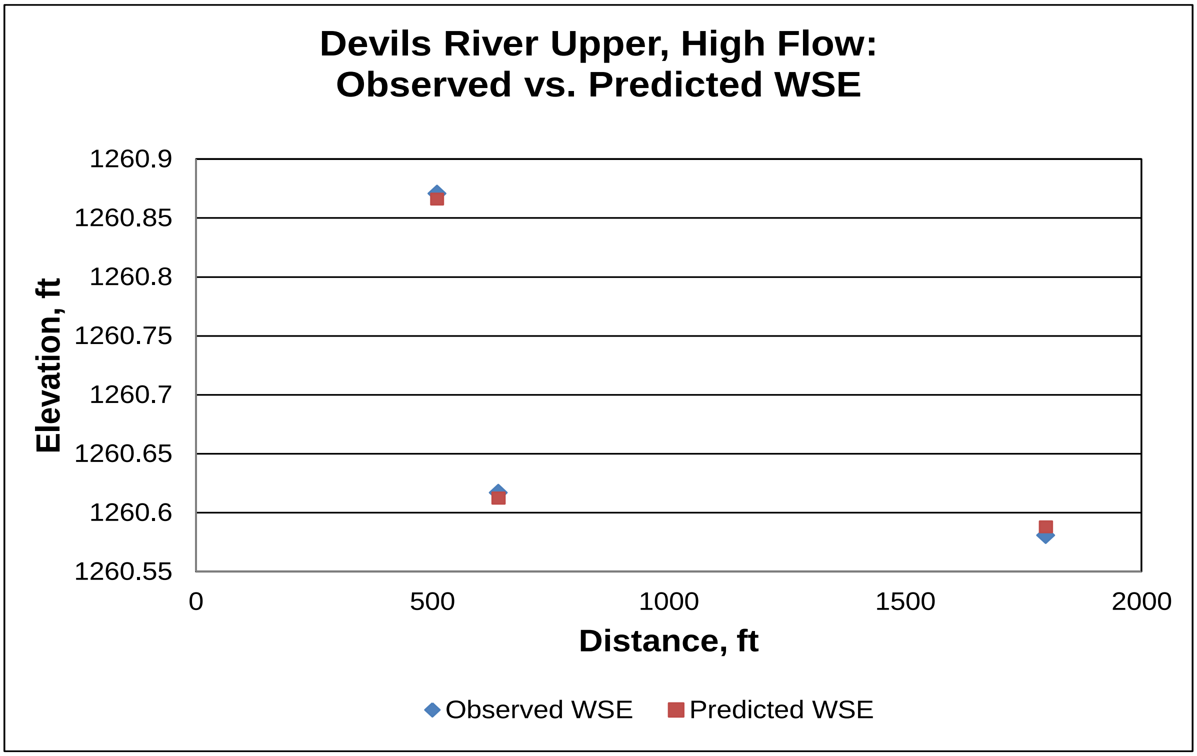

Figure A3. Comparison between observed and predicted water surface elevations (ft msl) at Devils River Upper site at high flow (February).

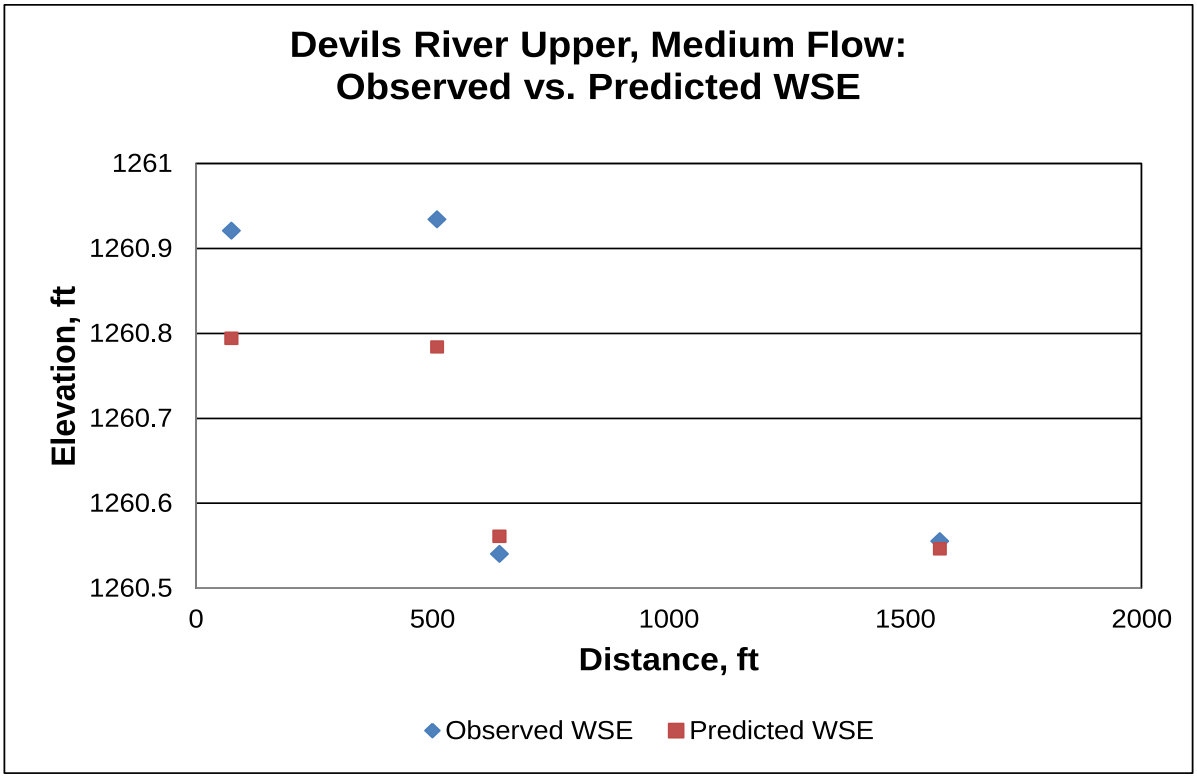

Figure A4. Comparison between observed and predicted water surface elevations (ft msl) at Devils River Upper site at medium flow (April).

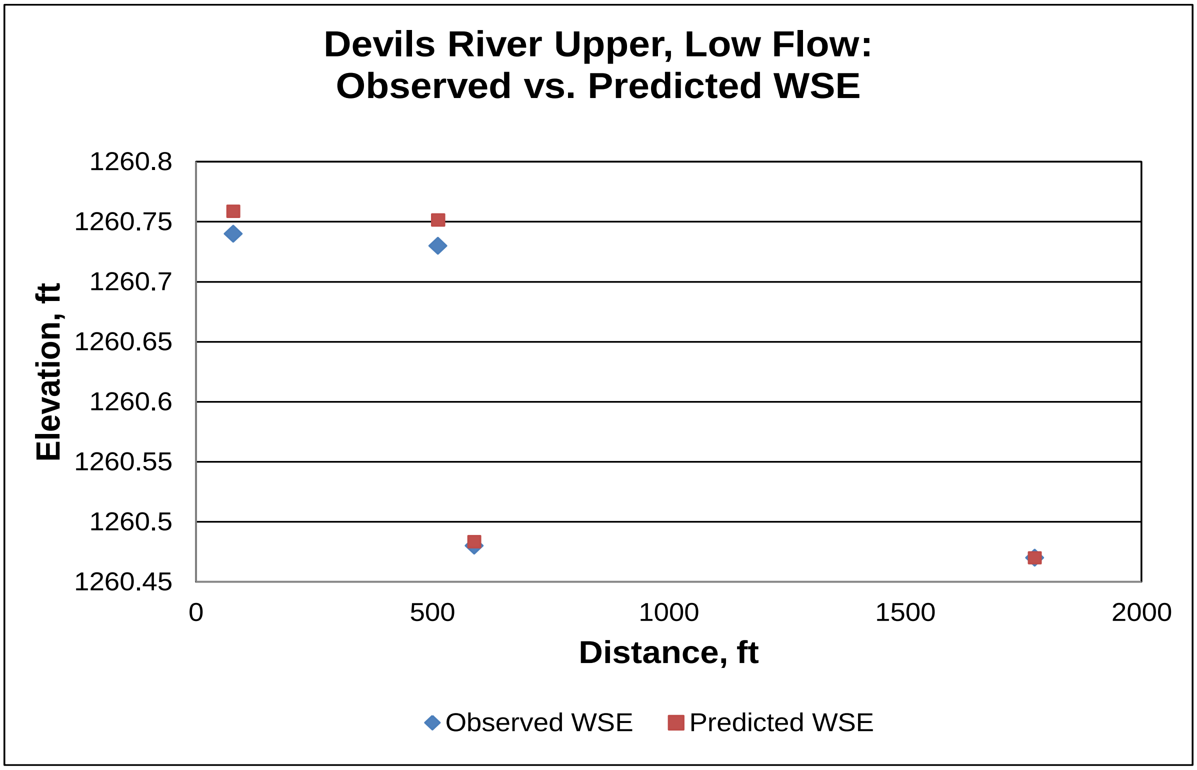

Figure A5. Comparison between observed and predicted water surface elevations (ft msl) at Devils River Upper site at low flow (September).

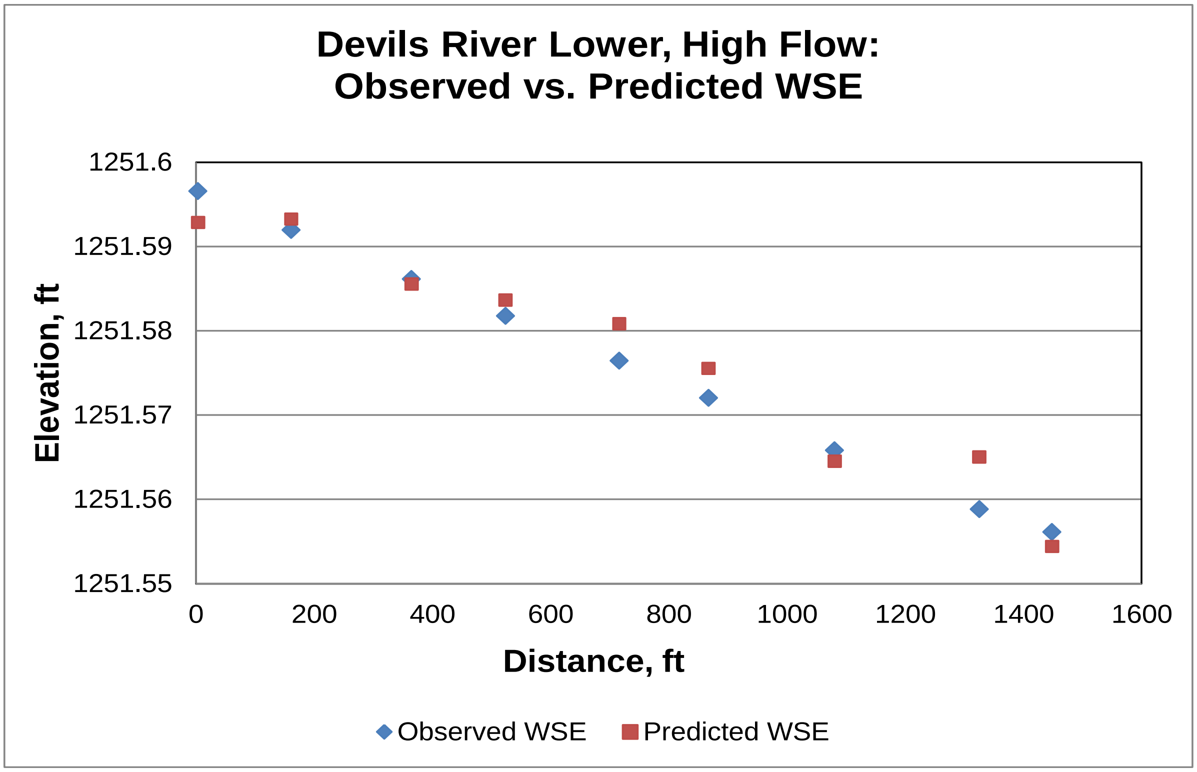

Figure A6. Comparison between observed and predicted water surface elevations (ft msl) at Devils River Lower site at high flow (February).

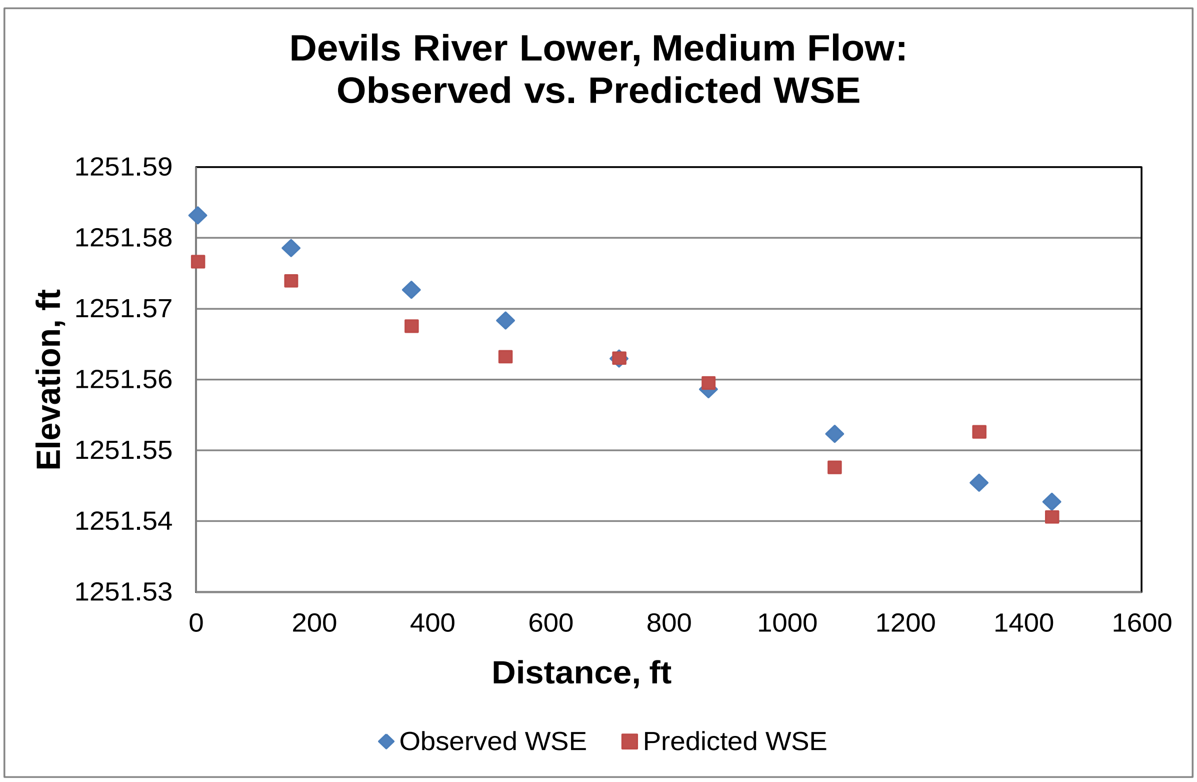

Figure A7. Comparison between observed and predicted water surface elevations (ft msl) at Devils River Lower site at medium flow (April).

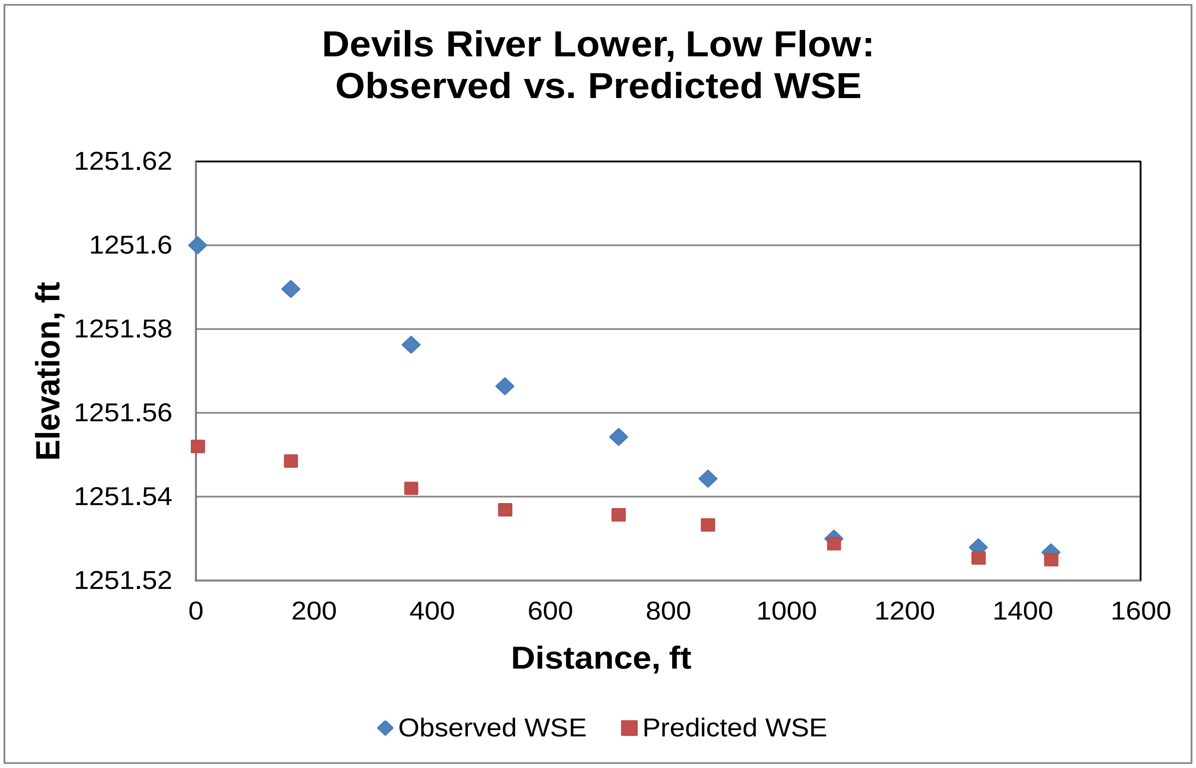

Figure A8. Comparison between observed and predicted water surface elevations (ft msl) at Devils River Lower site at low flow (September).

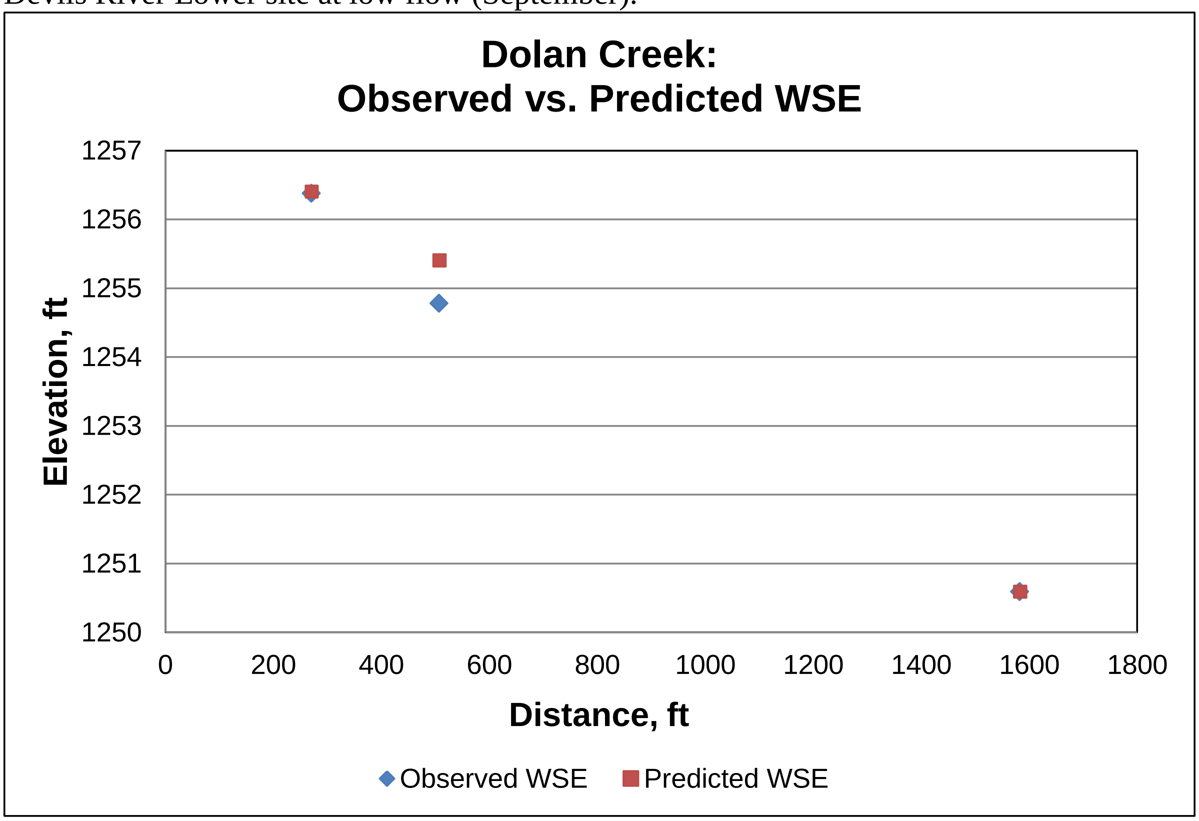

Figure A9. Comparison between observed and predicted water surface elevations at Dolan Creek at low flow (September).

Appendix B – Habitat Suitability Criteria

Dionda diaboli					*Etheostoma grahami*			
Velocity (ft/s)	Suitability	Depth (f)	Suitability		Velocity (ft/s)	Suitability	Depth (f)	Suitability
0.00	1.00	0.00	0.00		0.00	1.00	0.00	0.00
0.66	1.00	0.33	0.00		2.30	1.00	0.33	0.20
0.98	0.20	0.66	0.50		2.62	0.50	0.66	1.00
1.31	0.00	0.98	0.50		2.95	0.20	1.64	1.00
		1.31	1.00		3.28	0.10	1.97	0.50
		2.62	1.00		3.61	0.00	2.30	0.20
		2.95	0.50				2.62	0.20
		3.61	0.50				2.95	0.10
		3.94	0.20				3.28	0.10
		4.27	0.20				3.61	0.00
		4.59	0.00					

Cyprinella proserpina					*Dionda argentosa*			
Velocity (ft/s)	Suitability	Depth (f)	Suitability		Velocity (ft/s)	Suitability	Depth (f)	Suitability
0.00	1.00	0.00	0.00		0.00	1.00	0.00	0.00
1.97	1.00	0.33	0.20		0.98	1.00	0.33	0.50
2.30	0.50	0.66	1.00		1.31	0.50	0.66	1.00
2.62	0.50	1.64	1.00		1.64	0.50	1.31	1.00
2.95	0.20	1.97	0.50		1.97	0.20	1.64	0.50
3.28	0.20	2.95	0.50		2.30	0.20	1.97	0.50
3.61	0.10	3.28	0.20		2.62	0.10	2.30	0.20
3.94	0.00	3.61	0.20		2.95	0.10	2.62	0.20
		3.94	0.00		3.28	0.00	2.95	0.10
							3.28	0.00

Notropis amabilis					*Astyanax mexicanus*			
Velocity (ft/s)	Suitability	Depth (f)	Suitability		Velocity (ft/s)	Suitability	Depth (f)	Suitability
0.00	1.00	0.00	0.00		0.00	1.00	0.00	0.00
1.31	1.00	0.33	0.10		1.31	1.00	0.33	0.50
1.64	0.50	0.66	0.50		1.64	0.50	0.66	1.00
1.97	0.20	0.98	1.00		1.97	0.50	1.31	1.00
2.30	0.20	2.30	1.00		2.30	0.20	1.64	0.20
2.62	0.10	2.62	0.50		2.62	0.20	1.97	0.10
2.95	0.00	2.95	0.50		2.95	0.10	2.30	0.10
		3.28	0.10		4.59	0.10	2.62	0.00
		3.61	0.10		4.92	0.00		
		3.94	0.00					

Notropis stramineus					*Lepomis megalotis*			
Velocity (ft/s)	Suitability	Depth (f)	Suitability		Velocity (ft/s)	Suitability	Depth (f)	Suitability
0.00	1.00	0.00	0.00		0.00	1.00	0.00	0.00
0.33	1.00	0.33	0.20		0.66	1.00	0.33	0.10
0.66	0.50	0.66	0.50		0.98	0.50	0.66	0.20
0.98	0.50	0.98	1.00		1.31	0.20	0.98	1.00
1.31	0.00	1.97	1.00		1.64	0.20	1.97	1.00
		2.30	0.10		1.97	0.10	2.30	0.50
		2.62	0.00		2.30	0.00	2.62	0.20
							3.28	0.20
							3.61	0.00

Micropterus salmoides					*Cichlasoma cyanoguttatum*			
Velocity (ft/s)	Suitability	Depth (f)	Suitability		Velocity (ft/s)	Suitability	Depth (f)	Suitability
0.00	1.00	0.00	0.00		0.00	1.00	0.00	0.00
0.66	1.00	0.33	0.00		0.66	1.00	0.33	0.20
0.98	0.50	0.66	0.20		0.98	0.50	0.66	0.50
1.31	0.20	0.98	1.00		1.31	0.50	0.98	1.00
1.97	0.20	2.62	1.00		1.64	0.20	1.97	1.00
2.30	0.10	2.95	0.50		2.30	0.20	2.30	0.50
2.62	0.10				2.62	0.10	2.62	0.50
2.95	0.00				2.95	0.10	2.95	0.20
					3.28	0.00		