Frio River Biology and Fluvial Geomorphology Study to Determine Impacts of Sand and Gravel Activity

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APPENDICIES

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EXECUTIVE SUMMARY

An increasing volume of sand and gravel removal permit requests within the upper Frio River, coupled with a growing opposition to them by some downstream landowners, led the Texas Parks and Wildlife Department to suspend issuance of new permits in February 2017 until a biologic and geomorphic (river hydraulics and sediment transport) study could be completed. The goal of the study was to determine if sand and gravel dredging in the upper 26 miles of the Frio River was impacting the biological or geomorphological integrity of the river. Information from this study will be used by the Texas Parks and Wildlife Department to make better informed sand and gravel permitting decisions.

Prior to initiation of the study, the Texas Parks and Wildlife Department attended a Real County Commissioners Court meeting and conducted a landowner workshop and study scoping meeting to discuss sand and gravel permitting in the upper Frio River, the proposed study, and to receive landowner feedback. Landowners were updated on study progress and final results at subsequent meetings and were encouraged to provide feedback to the Texas Parks and Wildlife Department throughout the process.

The study area covered 26 miles of the upper Frio River from the joining of the East and West Frio rivers near Leakey, Texas to approximately one mile downstream of Concan, Texas. The Texas Parks and Wildlife Department partnered with the Texas A&M Forest Service to assess fish and aquatic benthic macroinvertebrate assemblages, riparian area composition and function, baldcypress age and overall health, water quality, and instream habitat during spring and summer 2018. This data was compared to permits issued from 2007 to 2016 throughout the study area to assess if there were any correlations between detected biological or water quality deficiencies and recent sand and gravel dredging.

An overall degradation of the fish and benthic macroinvertebrate community, as compared to standards established by the Texas Commission on Environmental Quality, were detected throughout much of the study area. The water quality predominately met established standards. No direct correlations between permitting levels and biological or water quality data were detected.

The riparian area ranged from healthy and functioning to non-functioning. Noted riparian deficiencies were due to an excess of gravel deposition downstream from sand and gravel dredging sites, channel down-cutting which has led to a disconnected floodplain in some locations, and a reduction in new plant regeneration and species richness due to landscaping practices and widespread trampling from unrestricted recreational access. The baldcypress population on the upper Frio River appeared healthy and no major concerns were noted except a lack of new tree regeneration in some areas.

The Texas Water Development Board collected topographic, bathymetric, and sediment data to develop a hydraulic and sediment transport model. Various permitting scenarios were modeled in three locations. Models demonstrated that dredge locations are prone to re-fill during large flood events and dredging activity changes sediment deposition and scour rates upstream and downstream of dig sites.

This study documented some fish and benthic macroinvertebrate assemblage deficiencies. While not directly correlated to recent sand and gravel activity, it is a likely one of several contributors. Modeling efforts support that sand and gravel activities destabilize the stream channel and alter the ability of the river to transport sediment effectively. Overall, based on study observations, it is probable that several factors including sand and gravel activity, recreational use impacts, degraded riparian areas, and dams and low water crossings are preventing the Frio River from fully functioning in balance.

INTRODUCTION

Study Need

In 2017, due to an increase in sand and gravel permit requests in the upper 16 km (10 mi) of the Frio River and a growing number of landowner complaints in opposition to those requests, the Texas Parks and Wildlife Department (TPWD) recognized the need to gather data to better inform future permitting decisions within the watershed. As such, TPWD suspended the issuance of all sand and gravel permits within the Frio River watershed, with the exception of those that pertained to public safety and infrastructure needs (i.e. road crossing maintenance), until a study could be completed to assess any potential impacts to the Frio River from the issuance of these permits. Upon completion of the study, TPWD would issue a letter of decision regarding changes, if any, to future sand and gravel permitting in the Frio River.

Sand and Gravel Permitting History

The state of Texas owns the sand and gravel in the stream bed of all navigable rivers, regardless of deeded property lines; therefore, any disturbance or take of this material requires a permit (TPWD 2019a). The authority to administer sand and gravel permits was granted to TWPD in 1975 under chapter 86, subtitle F, of the Texas Parks and Wildlife Code (TPWD 1975).

In accordance with Chapter 86, TPWD can only grant permits which have completed all application requirements and which TPWD finds will not do the following:

1. *damage or injuriously affect any island, reef, bar, channel, river, creek, or bayou used for navigation, or any oysters, oyster beds, fish, or wildlife in or near the water used in the operation;*
2. *change or injuriously affect any current that would affect navigation;*
3. *significantly and injuriously change the hydrology of the river;*
4. *significantly increase downstream nonpoint source pollution; or*
5. *significantly accelerate erosion upstream or downstream from the place where the taking occurs.*

Permit requests from the Frio River account for a disproportionate amount of all sand and gravel permit requests received. Between 2007 and 2016, a total of 25 permits were issued for the upper Frio River. This accounted for 11% of the permits issued in the state during that time period. For comparison, the upper Frio River accounts for only 0.013 % of the total stream mileage in the state.

Study Objectives

Study objectives were designed to directly assess conditions of sand and gravel permit legislation outlined above, specifically whether permitted activity was having a damaging effect of aquatic life and the riparian area, degrading water quality, altering river hydrology, or accelerating erosion up and downstream from locations of permitted activity. Specific study objects are listed below.

Study Objectives

1. Collect fish and benthic macroinvertebrate data throughout the study area to characterize overall community health and assess data for correlations with recent sand and gravel permitting activities;
2. Assess riparian corridor health throughout the study area;
3. Assess baldcypress health, age, and size distribution throughout the study area and compare growth rates between on-channel and off-channel trees;
4. Collect water quality and chemistry data throughout the study area to assess if it is meeting established water quality standards; and,
5. Develop a two-dimensional hydraulic and sediment transport model for priority reaches of the study area to assess various permitting scenarios and determine if they are likely to cause upstream and/or downstream sediment scour or deposition.

Stakeholder Meetings

Given that landowner comments regarding sand and gravel permits was one impetus for this study, and the clear understanding that there were public concerns for and against the issuance of these permits, TPWD initiated stakeholder meetings so landowners from the watershed could provide input. A series of well-attended public meetings were held prior to, during, and near completion of this study to update landowners and gather feedback (Table 1). Stakeholders were also encouraged to directly contact TPWD staff with any comments or questions. Stakeholder feedback obtained at and after the February 2019 meeting is included in Appendix A.

TABLE 1.—Date and purpose of all Frio River stakeholder meetings held as part of this process. TPWD attended the February 2017 meeting. All other meetings were organized by TPWD with assistance of study partners and Real County staff and held at the Real County Courthouse. All meetings were open to the public.

Date	**Meeting**	**Attendance**
February 2017	Real County commissioner’s court	20 stakeholders
March 2017	Riparian and stream function workshop	40 stakeholders
November 2017	Study design meeting	18 stakeholders
February 2019	Study results and feedback meeting	60 stakeholders

STUDY AREA

The Frio River is a tributary of the Nueces River in southwest Texas and is part of the Edwards Plateau ecoregion (Griffith et al. 2004). The river originates just north of Leakey, Texas in Real County, from the joining of the East and West Frio rivers. The river continues approximately 322 km (200 mi) until it joins the Nueces River just south of the city of Three Rivers, Texas; however, the river flows subsurface over some reaches, leaving long stretches of dry river bed under normal flow conditions.

Numerous springs originating from the Edwards and Glen Rose limestone formations feed the Frio River and its tributaries (Brune 1981). Spring flows are important for sustaining fish, wildlife, and plant species in this semi-arid region, and provide a substantial economic benefit to surrounding communities (Combs 2008). The Frio River has been listed as a Texas Natural Rivers System nominee by the National Park Service (NPS) based on its exceptional scenery, recreational value, wildlife value, and historical significance (NPS 2010). The upper Frio River has also been designated an ecologically significant stream segment for exceptional biological function, hydrologic function, water quality, and aesthetic value (TPWD 2019b).

The upstream boundary of this study occurred at the joining of the West Frio and East Frio rivers, approximately 1.6 km (1 mi) northeast of Leakey, Texas in Real County (Figure 1). The study area covered 42 km (26 mi) of river to the downstream boundary which is located approximately 2 km (1.25 mi) southeast of Concan, Texas in Uvalde County (Figure 1). To facilitate analysis and provide site replication, the river was divided into 21– 2 km (1.25 mi) reaches, numbered from upstream to downstream (Figure 1).

From 2007 through 2016, TPWD issued 25 permits for sand and gravel dredging within the study area (Figure 2). Eleven of the 21 study reaches had no permits issued during that time. Reaches one and two had the highest occurrence of permitting with five and seven permits issued respectively. It is important to note that this figure represents permits issued by TPWD for bed disturbances, but does not account for illegal, unpermitted activity which might also impact the system but cannot be quantified.

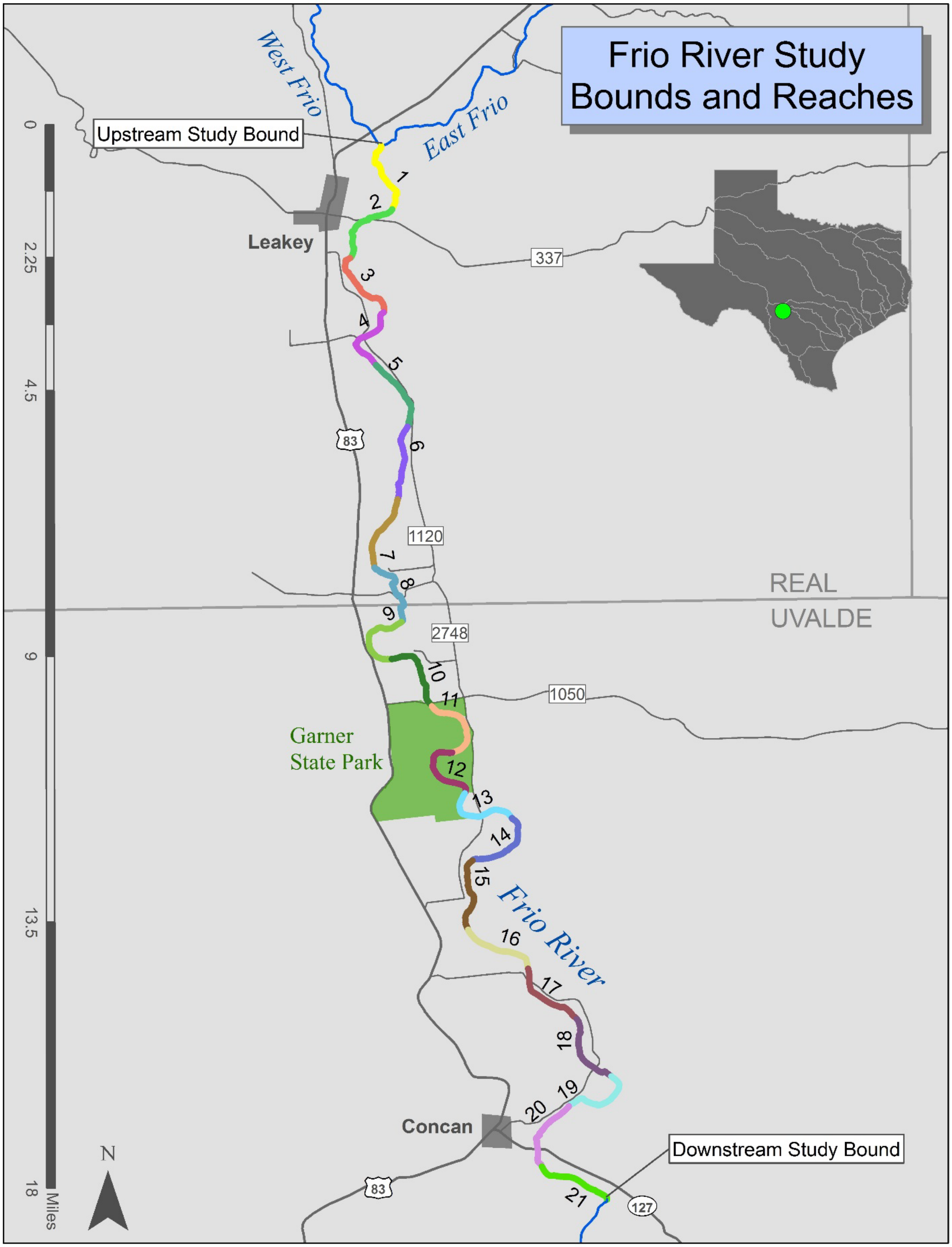


FIGURE 1.—Frio River study area and study reaches in Real and Uvalde counties, Texas. For this study the river was divided into 2 km study reaches, numbered one through 21.

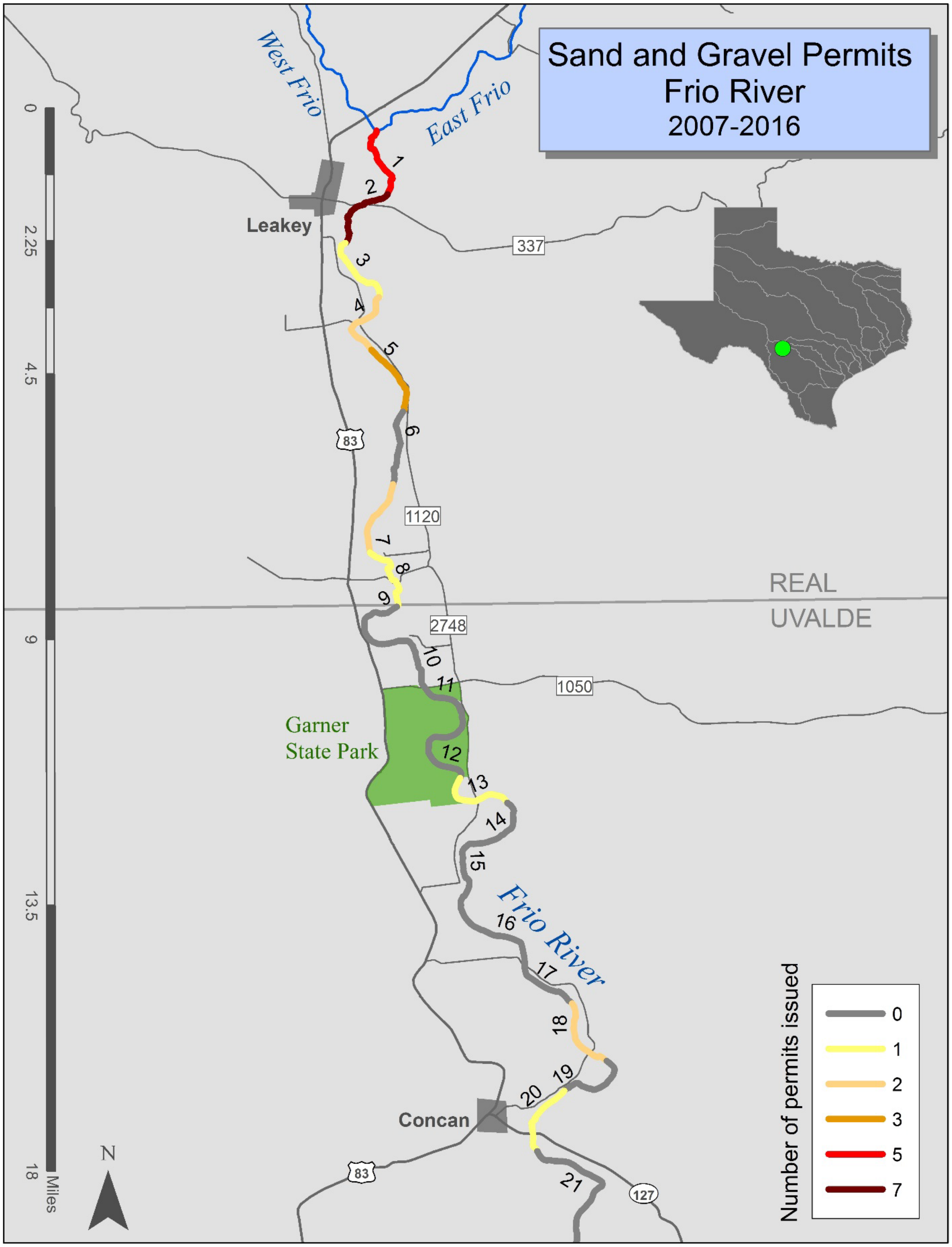


FIGURE 2.—Study reaches coded by number of sand and gravel permits issued by the Texas Parks and Wildlife Department from 2007 through 2016 for stream bed disturbance within the study area.

WATER QUANTITY

Instream biology and water quality data collection occurred March 7–May 3, 2018. During this period, Real and Uvalde counties were in varying degrees of drought condition. At the initiation of the study, the entire study area was classified in moderate drought by the National Drought Mitigation Center (Figure 3; NDMC et al. 2019). Despite rainfall totals of approximately 2 inches at the end of March, the April 17, 2018, the drought status map showed the entire study area classified in severe drought, with some areas of the region improving and some worsening to a state of extreme drought (Figure 3). Rainfall totals of approximately 0.5 inches at the end of April improved drought conditions in upper Real County slightly, but overall the regional drought condition continued worsen (Figure 3).

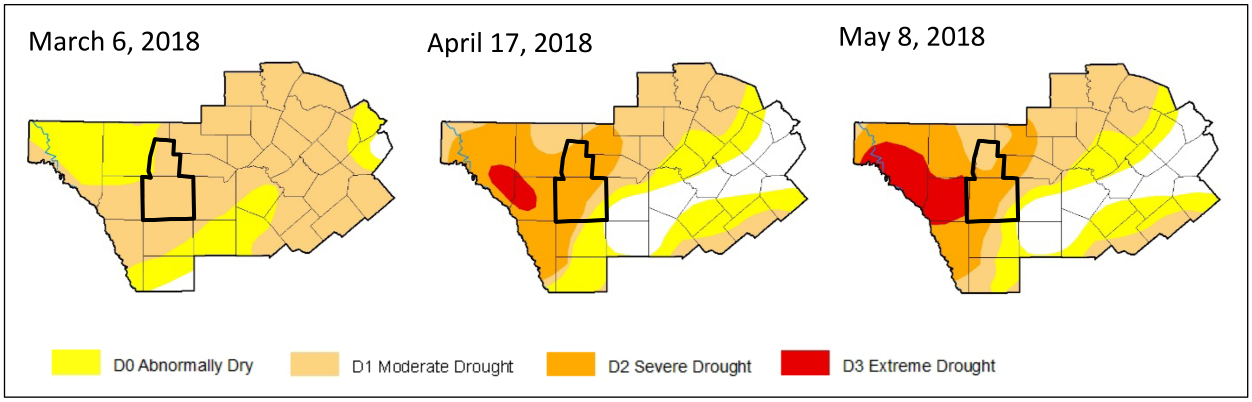


FIGURE 3.—Austin-San Antonio regional drought status maps provided by the National Drought Mitigation Center for March 6–May 8, 2018 (NDMC et al. 2019). Real and Uvalde counties are bolded in black.

The Frio River is located in the semi-arid region of Texas, with average annual rainfall in excess of 25 inches (HDR 2000). Flow in the basin is highly variable in magnitude and frequency as most significant rainfall originates from localized convective thunderstorms or from tropical storms and hurricanes covering wider areas. The sporadic nature of rainfall in the basin results in short periods of high flows, preceded and followed by long periods of low flows (HDR 2000).

Streamflow during the study period, as measured from the U.S. Geological Survey (USGS) gage on the Frio River near Concan, TX (gage number 08195000), ranged from a daily average of 28.5 cfs to 40 cfs (Figure 4; USGS 2019). As a result of drought, these flows were lower than the historical daily median flow which averaged 70 cfs during the same time period. While below normal, the river was still flowing, connected, and all mesohabitat types were present. Based on this information study partners determined data collected would still address study objectives. Data collected for the riparian corridor, baldcypress assessment, and development of the hydrologic model were not flow dependent, therefore not affected by the low flows.

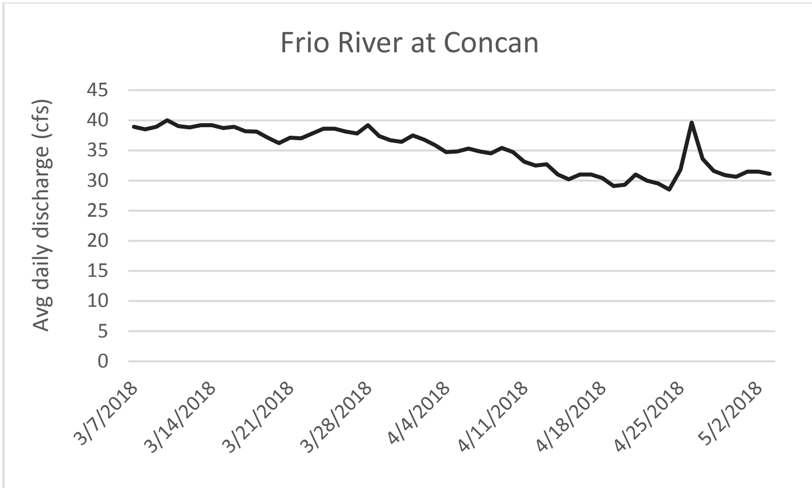


FIGURE 4.—Average daily stream discharge (cfs) from USGS gage no. 08195000, Frio River at Concan, Texas collected during the biology and water quality data collection period, March 7–May 3, 2018 (USGS 2019).

INSTREAM HABITAT

Methods: The study area was kayaked March 7–8 and 29–30, 2018 to collect instream habitat data. A Trimble GPS unit was used to delineate a center line down the river, which was coded by mesohabitat type. Mesohabitats were qualitatively classified as run (varying depths with moderate to fast current velocities and little to no water turbulence), riffle (shallow depths with fast current velocities and turbulent water), pool (varying depths with little to no current velocity), or backwater (edge or off-channel habitats with no current velocity or eddying flows). The GPS data was then post-processed and imported in to ESRI ArcGIS v10.5. The percentage of each mesohabitat type was calculated by reach.

Results and Discussion: Overall, the study area was dominated by pool and run habitats (46% and 34% respectively; Table 2). The river was made up of fairly consistent run, riffle, run, pool sequences with a few backwaters dispersed throughout (Figure 5).

TABLE 2.—Relative linear contribution, displayed as a percentage, of mesohabitat types by study reach in the Frio River in Real and Uvalde counties, Texas collected March 7–30, 2018.

Reach	Backwater	Pool	Riffle	Run
1	6	44	16	34
2	6	45	19	30
3	2	50	14	34
4	1	27	29	43
5	0	38	14	48
6	0	47	21	32
7	3	68	14	15
8	1	43	24	32
9	3	28	14	55
10	2	24	14	60
11	12	15	36	37

Reach	Backwater	Pool	Riffle	Run
12	5	51	16	28
13	0	66	14	20
14	0	45	23	32
15	0	53	23	24
16	1	79	13	7
17	1	57	19	23
18	0	28	25	47
19	1	43	15	41
20	1	41	18	40
21	2	58	7	33
Average	2	46	18	34

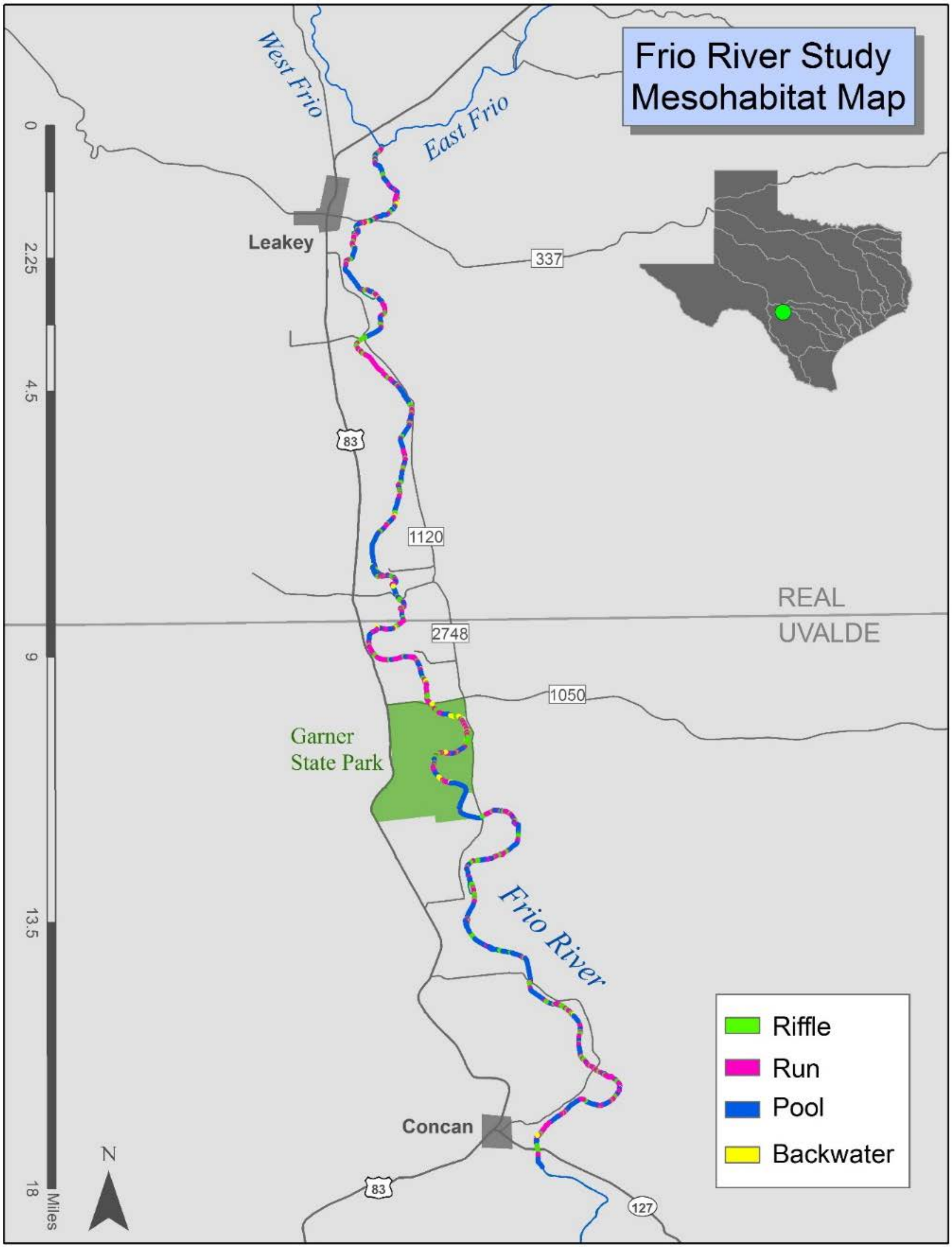


FIGURE 5.—Mesohabitat map of the entire study area on the Frio River as documented in March 2018.

BIOLOGICAL ASSESSMENT

Fish Assemblage

Methods: Fish were collected from each reach of the Frio River within the study area April 16–May 3, 2018 utilizing 15 ft. seines with 1/4" mesh. Sample points were randomly generated within each reach using the linear mesohabitat map (Figure 5). Points were stratified by mesohabitat type, with three riffle, three run, three pool, and one backwater sample location generated within each reach.

A Trimble GPS unit was used to navigate to each random sample location. Because all sample points were generated along the linear mesohabitat map, once at a location, biologists would assess the cross-section at a given point and use best professional judgement to select a seining location with the best available habitat for the expected mesohabitat type. For example, at a given cross-section on a riffle sample point, the river might be 70% riffle and 30% run. Biologists would choose a seining location along that cross-section in the riffle portion of the channel where depths and velocities were most effective for seining.

Gill nets were utilized in the upper study reaches; however, due to the necessary short set time and clear water, it was determined they were not effective enough to justify further use. Gill net data was omitted from analysis. Other gear types such as backpack electrofishers, mini-fyke nets, and hoop nets were not utilized due to the difficulty of transport downriver and in an effort to keep sampling standardized across reaches.

Given the short completion time for this study, sampling over the entire study reach was prioritized over intensive sampling with multiple gear types at a few sites. Due to the high variability in locality, scale, and timing of past permitted dredging projects, it was determined that there was not enough replication to evaluate site specific dredging impacts. Instead, a high-level, reach-scale approach was taken to assess overall impacts to the biological communities and water quality. Study reaches, classified as high, moderate, low, or no permitted activity, allow for replication in analyses and will serve as a baseline snapshot of the entire upper Frio River for future comparisons.

Large fish and most sport fish were identified to species, measured, photographed, and released. Smaller specimens were fixed in a 10% solution of formalin for identification and enumeration in the laboratory. All fish were examined for external deformities, disease, lesions, tumors, and skeletal abnormalities. Vouchered specimens will be permanently housed at the University of Texas' Biodiversity Collections in Austin, Texas after study completion. Data will be available online through the Fishes of Texas Project (Hendrickson and Cohen 2015).

Regionalized Index of Biotic Integrity (IBI) metrics developed for the Edwards Plateau ecoregion (Linam et al. 2002; TCEQ 2014a) were scored for each study reach. Metrics are calculated and then assigned a score of 1, 3, or 5. Scores are then summed by study reach to calculate an overall IBI score. Those scores are reported as an aquatic life use score and possible rankings include exceptional (greater than 51), high (42–51), intermediate (30–41), and limited (less than 30). The IBI provides a means of assessing fish assemblage health with regards to water quality impacts.

Fish Index of Biotic Integrity Scoring Metrics *(Linam et al. 2002)*

1. Total number of fish species
2. Number of native cyprinid (minnow) species
3. Number of benthic invertivore species
4. Number of sunfish species
5. Number of intolerant species
6. Percent of individuals as tolerant species
7. Percent of individuals as omnivores
8. Percent of individuals as invertivores
9. Percent of individuals as piscivores
10. Number of individuals in a sample
11. Percent of individuals as non-native species
12. Percent of individuals with a disease or other anomaly

Multidimensional scaling (MDS) was used to analyze similarities in fish assemblage data between reaches and determine if observed differences correlate to sand and gravel permitting history. Data were combined by study reach and then run through Primer-e v. 7, to normalize and perform MDS analysis. Analysis results were coded by factors representing the number of permits issued from 2007–2016. An additional analysis was run, combining data by individual seine haul and coding for mesohabitat type.

Results and Discussion: A total of 4,563 individuals consisting of 7 families and 18 species were collected across all reaches in the Frio River (Table 3; Figure 6). Reach 17 yielded the most fish species with 14 species and reach 10 the fewest, with only five total species. The most abundant species collected was Texas Shiner *Notropis amabilis*, followed by Blacktail Shiner *Cyprinella venusta* (Figure 6; Table 3).

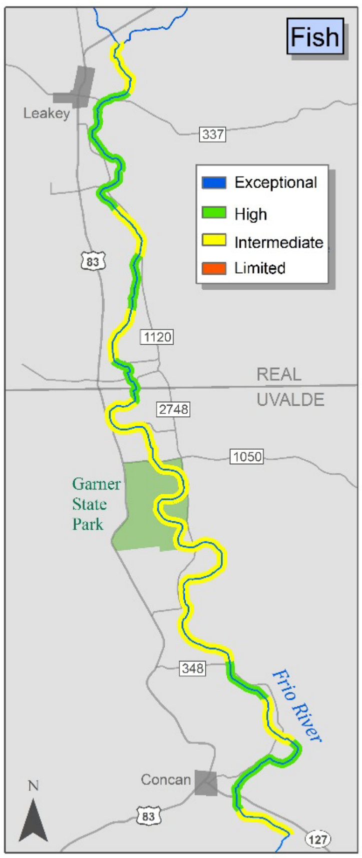
Six native cyprinid (minnow) species were collected across all study reaches (Table 3). One of those species, Nueces Roundnose Minnow *Dionda serena*, is classified as intolerant of poor water quality and habitat disturbances, meaning it is typically found at moderate to high quality sites (Linam and Kleinsasser 1998). This species was found across most reaches, but was more abundant in upper reaches (Table 3). One other species classified as intolerant was also collected, Greenthroat Darter *Etheostoma lepidum* (Linam and Kleinsasser 1998). Greenthroat Darters were found at eight of 21 sites in relatively low abundances (Table 3). Three species collected have been conversely classified as tolerant of habitat and water quality disturbances: Green Sunfish *Lepomis cyanellus*, Bluegill *Lepomis macrochirus*, and Rio Grande Cichlid *Herichthys cyanoguttatus* (Linam and Kleinsasser 1998).

Five sunfish and one black bass species (Largemouth Bass *Micropterus salmoides*) were collected (Table 3; Figure 6). Redbreast Sunfish *Lepomis auritus* and Longear Sunfish *L. megalotis* were the most abundant sunfish collected. Redbreast Sunfish was the only species to be collected across all 21 reaches (Table 3). Redbreast Sunfish are native to the eastern United States, but have been introduced in Texas and now occur throughout most the state.

FIGURE 6.—Fish species, from most abundant (upper left) to least (lower right), collected from all reaches of the Frio River in Real and Uvalde counties, Texas April 16–May 3, 2018. Species of greatest conservation need are noted by SGCN. From left to right and top to bottom: Texas Shiner, Blacktail Shiner, Nueces Roundnose Minnow, Western Mosquitofish, Largemouth Bass, Redbreast Sunfish, Longear Sunfish, Plateau Shiner, Sand Shiner, Central Stoneroller, Mexican Tetra, Rio Grande Cichlid, Greenthroat Darter, Headwater Catfish, Bluegill, Redear Sunfish, Yellow Bullhead, and Green Sunfish.

No state or federally listed species are known to occur in the Frio River; however, four species were collected that are classified as species of greatest conservation need (SGCN) in Texas: Plateau Shiner *Cyprinella lepida*, Nueces Roundnose Minnow, Texas Shiner, and Headwater Catfish *Ictalurus lupus*. Species are classified as SGCN by TPWD when there have been demonstrated declines in their populations or there is evidence that their habitat is being significantly threatened or is in decline. While SGCN status does not provide protection for these species, it allows TPWD to fund research to better understand their habitat needs, distribution, and life history. This information can support restoration efforts or, if necessary, state or federal listing.

Fish IBI scores for each reach ranged from 30–50, falling in either the intermediate or high aquatic life use classification (Figure 7). There was no apparent pattern to IBI scores when compared to permitting levels within study reaches, with high and intermediate classifications mixed throughout the study area (Figure 7).



Reach	Score	Aquatic Life Use Rating
1	36	Intermediate
2	42	High
3	46	High
4	42	High
5	38	Intermediate
6	42	High
7	40	Intermediate
8	44	High
9	40	Intermediate
10	30	Intermediate
11	40	Intermediate
12	36	Intermediate
13	38	Intermediate
14	40	Intermediate
15	38	Intermediate
16	38	Intermediate
17	50	High
18	36	Intermediate
19	44	High
20	42	High
21	34	Intermediate

FIGURE 7.—Regionalized indices of biotic integrity calculated based on fish assemblage data for each study reach using data collected from the Frio River in Real and Uvalde counties, Texas on April 16–May 3, 2018. Possible aquatic life use ratings are exceptional, high, intermediate, and limited.

Across all reaches, the IBI metrics (see methods for full list of metrics) that scored the highest were ‘percentage of individuals as tolerant’, which received the highest score of five for all reaches, and ‘percentage of individuals as omnivores’ and ‘percentage of individuals as invertivores’, which received fives for all reaches except for one each (Appendix B).

TABLE 3.—Fish species and abundances collected by study reach (1-21) in the Frio River in Real and Uvalde counties, Texas on April 16–May 3, 2018.

			Study Reach										
Family	**Scientific Name**	**Common Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Cyprinidae	*Campostoma anomalum*	Central Stoneroller	2	8	1		3	7	15	1	1		1
	Cyprinella lepida	Plateau Shiner		26	23	3	1	7	3		4		7
	Cyprinella venusta	Blacktail Shiner		6	17	77	10	45	11	13	37	4	50
	Dionda serena	Nueces Roundnose Minnow	42	151	151	12	70	20	29	52	3	1	
	Notropis amabilis	Texas Shiner		11	275	378	161	15	7	65	72		15
	Notropis stramineus	Sand Shiner				6							25
Characidae	*Astyanax mexicanus*	Mexican Tetra			5	1		4	7				
Ictaluridae	*Ameiurus natalis*	Yellow Bullhead	2										
	Ictalurus lupus	Headwater Catfish	2					2	2	1		2	1
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	1	10	1	1	2	65	17		1		88
Centrarchidae	*Lepomis auritus*	Redbreast Sunfish	3	7	1	9	22	7	14	2	3	3	2
	Lepomis cyanellus	Green Sunfish											
	Lepomis macrochirus	Bluegill											
	Lepomis megalotis	Longear Sunfish	17	4		4	11	2	5	9	4		7
	Lepomis microlophus	Redear Sunfish											
	Micropterus salmoides	Largemouth Bass	5	2	1	1		3	5	4		2	
Percidae	*Etheostoma lepidum*	Greenthroat Darter	3	6	1			3		2			
Cichlidae	*Herichythys cyanoguttatus*	Rio Grande Cichlid	3	3		6	1		1		14		
		Number of individuals	**80**	**234**	**476**	**498**	**281**	**180**	**116**	**149**	**139**	**12**	**196**
		Number of species	**10**	**11**	**10**	**11**	**9**	**12**	**12**	**9**	**9**	**5**	**9**

TABLE 3.—Continued.

			Study Reach										
Family	**Scientific Name**	**Common Name**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**Total**
Cyprinidae	*Campostoma anomalum*	Central Stoneroller	10	3	1	1		4		6	3	8	**75**
	Cyprinella lepida	Plateau Shiner	11	2		1	5	5	5	5	4	5	**117**
	Cyprinella venusta	Blacktail Shiner	93	64	31	45	172	195	229	84	74	57	**1,314**
	Dionda serena	Nueces Roundnose Minnow		2	4			3		1	12	7	**560**
	Notropis amabilis	Texas Shiner		13	10	10	148	78	86	11	1	138	**1,494**
	Notropis stramineus	Sand Shiner	3			3	6	14	17	4	1		**79**
Characidae	*Astyanax mexicanus*	Mexican Tetra		5		1		2			44	3	**72**
Ictaluridae	*Ameiurus natalis*	Yellow Bullhead											**2**
	Ictalurus lupus	Headwater Catfish		1				2					**13**
Poeciliidae	*Gambusia affinis*	Western Mosquitofish	7	5	2		1	13		15		25	**254**
Centrarchidae	*Lepomis auritus*	Redbreast Sunfish	27	5	11	6	3	2	7	2	5	8	**149**
	Lepomis cyanellus	Green Sunfish										1	**1**
	Lepomis macrochirus	Bluegill				4		4					**8**
	Lepomis megalotis	Longear Sunfish	5	8	2	7	2	2	1	21	4	3	**118**
	Lepomis microlophus	Redear Sunfish				6							**6**
	Micropterus salmoides	Largemouth Bass	2	2	2	2	1	169	1	14	1	8	**225**
Percidae	*Etheostoma lepidum*	Greenthroat Darter	1		5						1		**22**
Cichlidae	*Herichthys cyanoguttatus*	Rio Grande Cichlid	2	18				2		4			**54**
		Number of individuals	**161**	**128**	**68**	**86**	**338**	**495**	**346**	**167**	**150**	**263**	**4,563**
		Number of species	**10**	**12**	**9**	**11**	**8**	**14**	**7**	**11**	**11**	**11**	**18**

The metrics that consistently scored the lowest across reaches were ‘number of individuals per seine haul’ and ‘percentage of individuals as piscivores’ (Appendix B). A low seine catch rate on the Frio River is not surprising. The clear water makes seining less effective than in more turbid streams. We also noted a low prevalence of instream habitat such as aquatic vegetation, woody debris, and boulders which often serve as cover and nursery habitat for fish, especially picivourous species such as Largemouth Bass.

Fish assemblage data, combined by study reach, was assessed using an MDS analysis and coded with a factor for permitting level. Study reaches were placed into four categories based on the total number of sand and gravel permits issued from 2007–2016: high = 4–7 permits issued, medium = 2–3, low = 1, and none = 0 (Figure 2).

Permitting level did not show a significant correlation to fish assemblage structure (p=0.283; Figure 8). It is also important to note that fish assemblage data for this study was collected one year after permitted sand and gravel activity ceased. Due to the mobile nature of fish, it is likely that even if sand and gravel activity caused a temporary impact to the fish community, one year would be enough time for recovery. It is unknown if continual streambed disturbances, without recovery time, would ultimately lead to significant and permanent fish community shifts.

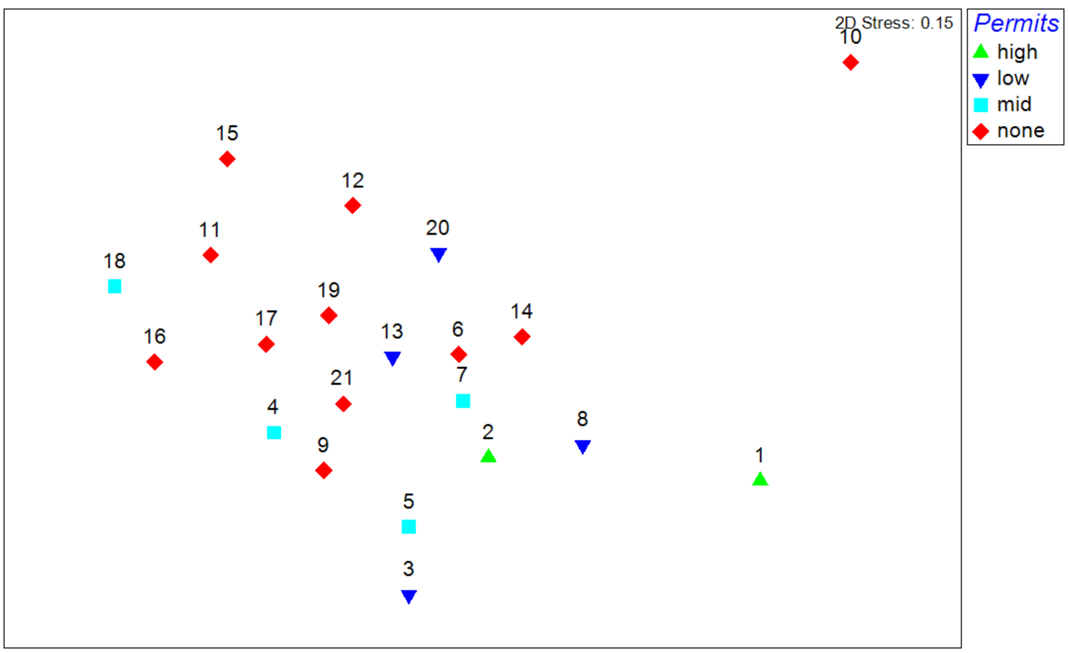


FIGURE 8.—Nonparametric multi-dimensional scaling analysis of fish assemblage data collected from the Frio River April 16–May 3, 2018, combined by study reach, and coded by 2007–2016 sand and gravel permitting levels. High represents 4–7 permits, mid represents 2–3 permits, low represents 1 permit, and none represents 0 permits. Fish assemblage data is not significantly correlated to permitting level (p=0.283).

Lastly, an MDS analysis was conducted on all individual sample points and coded by a factor of mesohabitat type (riffle, run, pool, or backwater). Fish collected at each sample point were significantly correlated to mesohabitat type (p=0.001; Figure 9). All mesohabitats had significantly different fish assemblages with the exception of pool and backwater habitats. This demonstrates the importance of maintaining all mesohabitat types to maintain the fish community.

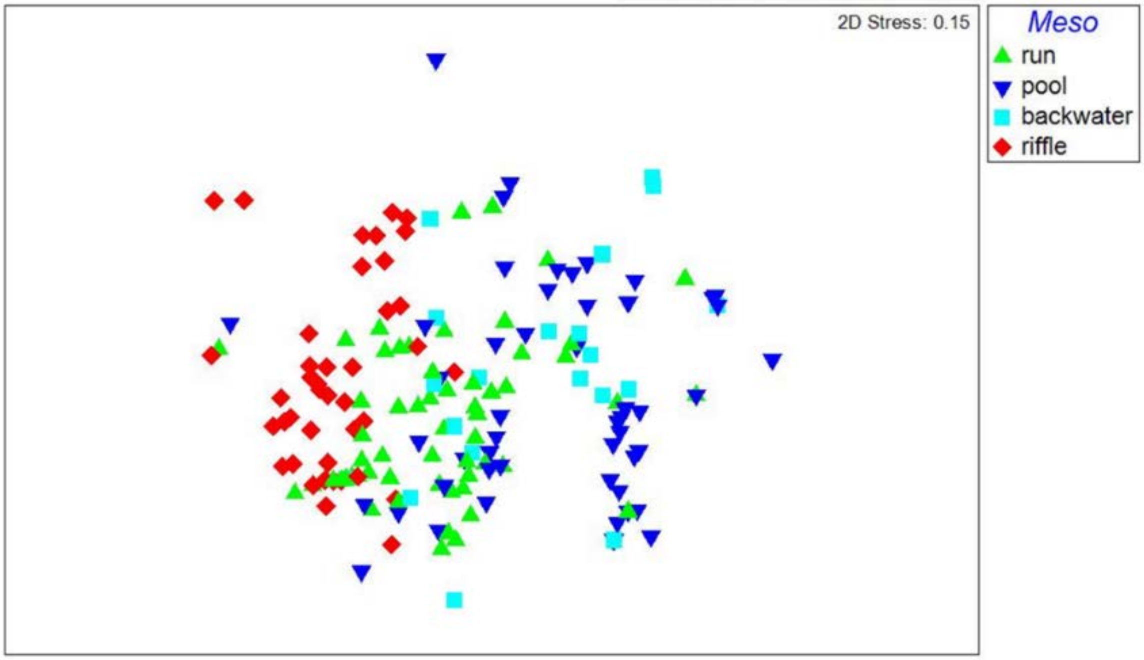


FIGURE 9.—Nonparametric multi-dimensional scaling analysis of individual fish assemblage sample points coded by mesohabitat type. Mesohabitat type is significantly correlated to fish assemblage data collected from the Frio River April 16–May 3, 2018 (p=0.001).

Overall, the fish assemblage in the upper Frio River appears to be in intermediate to high condition; however, the aquatic life use standard set by the Texas Commission on Environmental Quality (TCEQ) for the fish community in this segment of the Frio River is exceptional (TCEQ 2018). Data collected for all 21 study reaches failed to meet this standard. Findings from this study are similar to other recent fish data collected by TPWD and TCEQ which initially led the upper Frio River to be listed on the 303d list of impaired stream segments (TCEQ 2014b). This suggests an overall degradation to the system is impacting the fish community. Despite no direct correlation, continued bed and bank destabilization from sand and gravel activities could be contributing to this degradation. Other possible contributing factors could include impacts from heavy recreational use, lack of instream habitat, and low water crossings that serve as fish passage barriers. TCEQ (2014b) report a concern for impaired habitat.

Benthic Macroinvertebrate Assemblage

Methods: Benthic macroinvertebrates were collected from each reach of the Frio River within the study area on April 16–May 3, 2018 utilizing Hess and Surber samplers. Sample points were randomly generated utilizing the same methods used for fish (see fish assemblage methods); however, for benthic macroinvertebrates three points were generated for each study reach, all within riffle habitats.

A Trimble GPS unit was used to navigate to the random sampling points. Once at a point, the best habitat was selected at any location along the transect running through that point and perpendicular to flow. A Surber or Hess sampler was selected in an effort to most effectively sample based on site depth, velocity, and substrate. The area within the sampler was manually disturbed until all substrate and aquatic macrophytes were effectively sampled. Samples were individually bagged and stored in 100% ethanol for identification and enumeration in the laboratory.

Invertebrate data were combined by reach and a regionalized benthic index of biotic integrity (BIBI) developed for Surber samples collected in the central bioregion was calculated (TCEQ 2014a). Metrics listed below were calculated for each study reach and assigned a score of 1, 3, or 5.

Benthic Macroinvertebrate Index of Biotic Integrity Scoring Metrics *(TCEQ 2014a)*

1. Total invertebrate taxa
2. Number of Diptera (flies) taxa
3. Number of Ephemeroptera (mayflies) taxa
4. Number of intolerant taxa
5. Percent EPT (mayflies, stoneflies, and caddisflies) taxa
6. Percent of individuals as Chironomidae (midges)
7. Percent of tolerant taxa
8. Percent of individuals as grazers
9. Percent of individuals as gatherers
10. Percent of individuals as filterers
11. Percent dominance of top three taxa

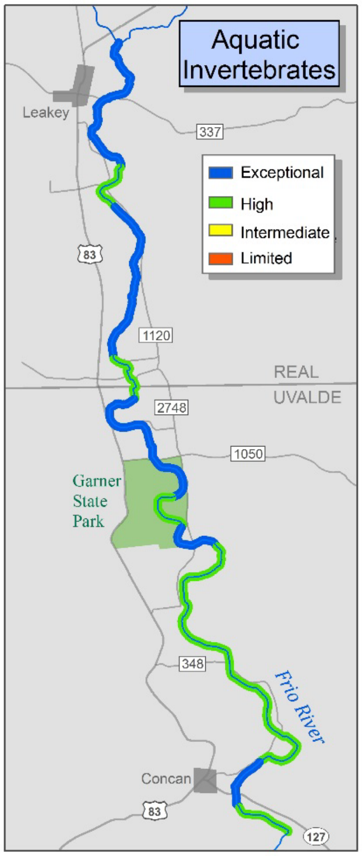
Metric scores were then summed by reach to obtain an overall BIBI score. Based on the BIBI score, each reach was classified as having an exceptional (greater than 40), high (31–40), intermediate (21–30), or limited (less than 21) aquatic life use (TCEQ 2014a).

Analogous to fish data analyses, MDS was used to analyze similarities in benthic invertebrate assemblage data between reaches and determine if observed differences correlate to sand and gravel permitting history. Data were combined by study reach and then run through Primer-e v. 7, to normalize and perform MDS analysis. Analysis results were coded by factors representing the number of permits issued from 2007–2016.

Results and Discussion: A total of 3,846 benthic macroinvertebrates were collected, representing 14 orders, 32 families, and 51 overall taxa (Table 4) from all study reaches on the Frio River. The dominant order was Coleoptera (aquatic beetles) with 33% of the overall catch. The most genus rich order was Ephemeroptera (mayflies) with 13 genera represented. Overall EPT taxa (members of the families Ephemeroptera, Plecoptera, and Trichoptera), which are typically indicators of good water quality, made up 46% of the total catch.

Aquatic life use categories from the regionalized BIBI scores for the study reaches were exceptional and high, with more exceptional scores occurring in the upper reaches and high scores occurring in the lower (Figure 10). There were no apparent patterns of BIBI scores and level of sand and gravel permits issued.

The metrics that scored highest across all study reaches were ‘number of intolerant taxa’, ‘percent individuals as grazers’, and ‘percent individuals a gatherers’ (Appendix C). The metric that received the lowest possible score across reaches was ‘percent individuals as tolerant taxa’. A high percentage of tolerant individuals is characteristic of a system degraded by frequent water quality or habitat disturbances.



Reach	Score	Aquatic Life Use Rating
1	41	Exceptional
2	41	Exceptional
3	41	Exceptional
4	37	High
5	41	Exceptional
6	41	Exceptional
7	41	Exceptional
8	37	High
9	43	Exceptional
10	41	Exceptional
11	41	Exceptional
12	37	High
13	41	Exceptional
14	39	High
15	39	High
16	37	High
17	39	High
18	39	High
19	39	High
20	41	Exceptional
21	37	High

FIGURE 10.—Regionalized benthic indices of biotic integrity designed for Surber samples and calculated based on aquatic macroinvertebrate assemblage data for each study reach using data collected from the Frio River in Real and Uvalde counties, Texas on April 16–May 3, 2018. Possible aquatic life use ratings are exceptional, high, intermediate, and limited.

Benthic macroinvertebrate assemblage data, combined by study reach, was assessed using an MDS analysis and coded with a factor for permitting level. Similar to fish analysis, study reaches were placed in to four categories based on the total number of sand and gravel permits issued from 2007–2016: high = 4–7 permits issued, medium = 2–3, low = 1, and none = 0 (Figure 2). Permitting level did not show a significant correlation to benthic macroinvertebrate assemblage structure (p=0.18; Figure 11).

Overall, the benthic macroinvertebrate community in the upper Frio River appears to be in high to exceptional condition; however, like the fish assemblage, the aquatic life use standard set by TCEQ for the benthic macroinvertebrate community in this segment of the Frio River is set at exceptional (TCEQ 2018). Data collected from 10 of the 21 study reaches in this study failed to meet this standard. Other recent collections yielded similar findings resulting in the upper Frio River being listed on the 303d list of impaired stream segments (TCEQ 2014b).

Any bed disturbances, including sand and gravel activity are likely to directly and immediately impact the benthic macroinvertebrate community since they live in and on the substrate and are not very mobile. However, it is likely that there was sufficient time for recovery since the last permits were issued one year prior to data collection.

TABLE 4.—Abundance of benthic macroinvertebrate taxa collected by study reach in the Frio River in Real and Uvalde counties, Texas, April 16–May 3, 2018.

			Study Reach																				
Order	**Family**	***Genus***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Amphipoda	Taltridae	*Hyalella*		1																			
Coleoptera	Elmidae	*Dubiraphia*							2														
		Hexacylloepus	12	5	1	7	3	13	30	48	3	5	4	16	43	8	13	1	9	5	6	1	3
		Macrelmis	7	21	25	21	56	42	37	40	14	13	2	23	4	2	15		2			11	3
		Microcylloepus	11	18	11	17	9	20	80	59	16	8	8	26	2	6	60	91	12	5	3	8	44
		Neoelmis									3												
	Lutrochidae	*Lutrochus*		3		5		13	5	5	2	4	12	6	1	9	13	63	1	1			8
	Psephenidae	*Psephenus*	10	11	2	3			1	1													
Diptera	Ceratopogonidae							1					1										
	Chironomidae		6	27	3	21	8	3	13	1	5	4	1	3	3	7	2	7	10	6	8	1	3
	Empididae		3		1		1		4	10	1	2											
	Simuliidae			4		1		9	16	2	3	4	1		2	2			1	1	1	8	2
	Stratiomyidae		16	16	17	22	19	15	5	3	3		2		2		1		1	2		4	2
Ephemeroptera	Baetidae	*Acentrella*				1		10				1	1										1
		Baetis		7		2		1															
		Baetodes										1	4		5		1		1	1	1	9	1
		Camelobaetidius	2	8	6	3	8	15	1	3			4	1	7	1	1	3	1	4	2	16	3
		Fallceon	13	39	13	9	8	24	7	8	16	1	2	10	2	6	5	11	10	3	3	2	5
		Procloeon				1																	
		Pseudocloeon					1									1							
	Heptageniidae	*Maccaffertium*	4	5	16	4	1	4			1				1								
	Leptohyphidae	*Vacupernius*	8	8	13	5	9	7	3	3	5	2			2	1	1	2	1	4	1	2	2
	Leptophlebiidae	*Neochoroterpes*	27	9		2			8												8		
		Thraulodes	3	4	7	9	11	12	16	3	1			2	13	1	8	2	56	11	6	71	2
	Oligoneuriidae	*Isonychia*		1	3	1	2	8				5	1		3		2		3	7	5	5	1
	Tricorythidae	*Tricorythodes*	38	10	5	37	4		1		1			2		2	3	3	1	14	4	1	1
Hemiptera	Gerridae	*Metrobates*			1	1			3					3					1		4	1	
	Naucoridae	*Ambrysus*	5	10	9	5	1	2	3	4		1				1	3		6			3	3

TABLE 4.—Continued.

Order	**Family**	***Genus***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Hempitera	Veliidae	*Rhagovelia*			5					3		2				1			1			4	
Hirudinea						1																	
Lepidoptera	Pyralidae	*Petrophila*				2	1		1														1
Megaloptera	Corydalidae	*Corydalus*	1	3	6	1	6	5	1	3	1		1	1	1	1	2		2			3	
Neuroptera	Sisyridae	*Climacia*																			1		
Odonata	Coenagrionidae	*Argia*	12	16	10	27	7	7	6	2	13	1		1	4		8		1	18	12	11	6
	Gomphidae	*Erpetogomphus*							2	1		2											
	Libellulidae	*Brechmorhoga*				1													1				
		Perithemis									1			1	1								
Oligochaeta	Oligochaeta	*Oligochaeta*	2					1	8	13	9	1	3	2		1	1		4		2		
Planariidae	Dugesiidae	*Dugesia*	5	5	4	4	7	1	3	5	4				1	2			35		1		1
Podocopa						1															8	4	1
Trichoptera	Hydropsychidae	*Cheumatopsyche*	44	42	25	4	38	67	8	10	30	27	9	14	3	9	44	40	15	1	4	7	3
		Hydropsyche														2		1			4		
		Potamyia		2	2																		
	Hydroptilidae	*Hyalella*	1																				
		Hydroptila				3			1			3				1	1				2	1	
		Neotrichia							1														
		Ochrotrichia								2			1	1				1	1				
		Oxyethira	2		1	1													1				
	Odontoceridae	*Marilia*	17	12	1	6					2				1	1		1	2				
	Philopotamidae	*Chimarra*	1	10	51		79	40	7	6	7	1	6		14	1		2	6	3	10	66	
	Polycentropodidae	*Polycentropus*	1	8	3	8	1	1		1	1	1					1						1

A recovery time of 30 days to seven months has been documented in other systems after bed disturbance (Matthaei et al. 1996; Mori et al. 2009). It is unclear if continued bed disturbance from sand and gravel activity would alter the characteristics of macroinvertebrate habitat, such as substrate embeddedness, which would ultimately lead to long-term shifts in the macroinvertebrate community.

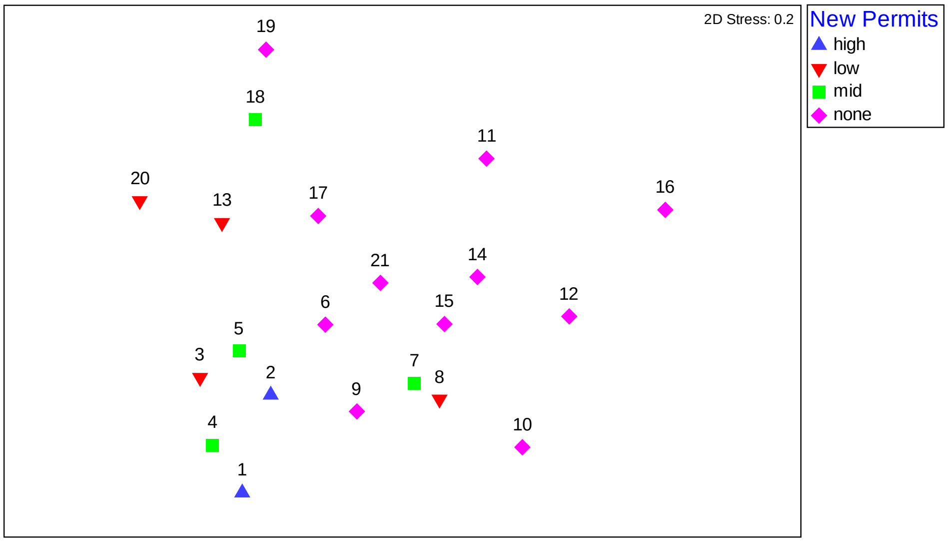


FIGURE 11.—Nonparametric multi-dimensional scaling analysis of benthic macroinvertebrate assemblage data collected from the Frio River April 16–May 3, 2018, combined by study reach, and coded by sand and gravel permitting level. High represents 4–7 permits, mid represents 2–3 permits, low represents 1 permit, and none represents 0 permits. Benthic macroinvertebrate data is not significantly correlated to permitting level (p=0.18).

Riparian Corridor

Methods: An assessment of riparian functional condition was conducted for the entire study area during multiple trips from March through June 2018, utilizing the Riparian Bull's-Eye Evaluation described in *Your Remarkable Riparian, Third Edition* (Nueces River Authority 2016). This evaluation tool utilizes ten metrics that serve as indicators to riparian functional condition.

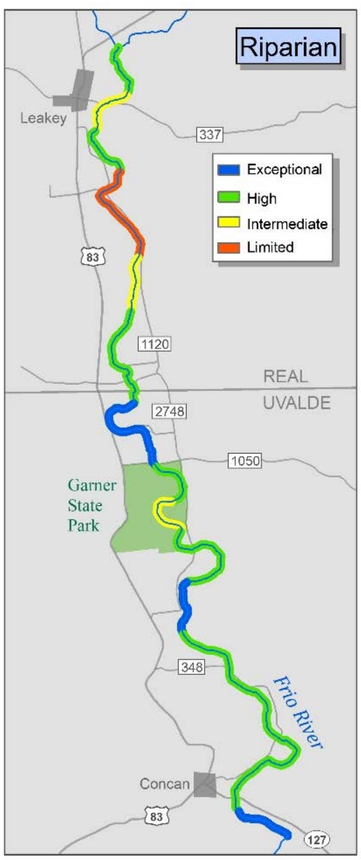
Riparian Bull's-Eye Evaluation Metrics (Nueces River Authority 2016)

1. Active Floodplain: Does floodwater have access to a floodplain?
2. Energy Dissipation: Is there enough "stuff" in channels, on banks, and in the floodplain to dissipate flood energy?
3. New Plant Colonization: Are new plants successfully colonizing on fresh sediment?
4. Stabilizing Vegetation: Are banks covered with strong stabilizing plants, those with a stability rating of 6 or better?
5. Age Diversity: Are young, middle-aged and mature riparian plants present?
6. Species Diversity: Are several key, native riparian plant species present?
7. Plant Vigor: Are riparian plants vigorous and healthy?
8. Water Storage: Are the banks and floodplains storing water?
9. Bank/Channel Erosion: Are bank and channel erosion balanced with deposition on point bars?
10. Sediment Deposition: Is sediment being deposited in a balanced way, on point bars downstream from eroded banks?

Each of the study reaches were evaluated by kayak and answers to the above indicators were placed in one of three Riparian Bull's-Eye Evaluation zones: outer zone (poor, dysfunctional condition); mid zone (at-risk condition); or bull's-eye (high functional condition). Within a given study reach, areas of the riparian area might range from dysfunctional to highly functional; however, scores were assigned based on the dominant condition present within that study reach. Given the subjective nature of scoring, two researchers would evaluate each study reach in tandem and discuss their observations before assigning scores.

Metrics were assigned scores ranging from 1 to 5. These scores were summed for all metrics and an overall study reach score was obtained. The Riparian Bull's-Eye Evaluation typically assigns an overall score falling in one of the three previously mentioned categories (outer zone, mid zone, or bull's-eye); however, in an effort to make scoring analogous to fish and benthic macroinvertebrate scoring, for the purposes of this study, scoring was divided into four groups. Those groups are exceptional (high functional condition; score greater than 40), high (at low to moderate risk; 30–40), intermediate (at high risk; 20–30), and limited (dysfunctional riparian condition; < 20).

Results and Discussion: Due to different land ownership along the river and consequently diverse land management strategies and objectives, the riparian scores for the study area were quite variable and had no consistent pattern (Figure 12).



Reach	Score		Bull's-eye designation
1	32		High
2	21.5		Intermediate
3	32.5		High
4	16		Limited
5	19		Limited
6	28		Intermediate
7	31		High
8	34		High
9	43.5		Exceptional
10	45.5		Exceptional
11	30.5		High
12	25.5		Intermediate
13	38.5		High
14	38		High
15	41.5		Exceptional
16	35		High
17	34.5		High
18	34		High
19	35		High
20	34.5		High
21	45		Exceptional

FIGURE 12.—Riparian Bull's-Eye Evaluation scores and classification by study reach on the Frio River in Real and Uvalde counties, Texas March–June 2018. Limited represents dysfunctional condition, intermdiate represents at high risk condition, high represents at moderate to low risk condition, and exceptional represents at functional condition.

The indicators that scored the highest across the study area were ‘species diversity’ and ‘connectivity to an active floodplain’, while indicators that scored the lowest were ‘sediment deposition’ and ‘bank or channel erosion’ (Appendix D). Approximately one third of the reaches scored as limited (dysfunctional condition) or intermediate (high risk of becoming dysfunctional). In general, reaches that scored as exceptional or high were comprised of a diversity of bank stabilizing grasses, shrubs, and trees of varying age classes (Figure 13). These areas were not heavily impacted by recreation or manicured lawns, had targeted recreational access sites (Figure 14), were not impacted by road crossings, and were not located adjacent to former gravel dredging sites. These reaches provide better habitat for wildlife and will be less impacted by flooding than areas with degraded riparian areas.

FIGURE 13.—Examples of functioning riparian areas on the Frio River from reaches 19 and 21 respectively. These areas are well vegetated with a diversity of grasses, shrubs, and trees of varying ages which provide shade to the river channel and stabilize banks.

FIGURE 14.—Examples of riparian-friendly access points on the Frio River that reduce impact to the riparian area but still allow for recreational access to the river.

In contrast, reaches that scored as limited or intermediate typically had large areas of riparian corridor with mostly unvegetated or highly manicured banks (Figure 15). These areas often showed signs of bank erosion, sometimes severe enough to cause loss of mature trees as a result of bank sloughing. These were often located in areas that were adjacent to road crossings that impeded sediment flow, were up- or down-stream from former sand and gravel operations, or had ongoing heavy recreational use impacts (i.e. heavily trampled or continuously manicured by mowing/weed eating; Figure 16). One of the primary concerns in degraded riparian areas, especially in the case of highly manicured areas, is the loss of tree regeneration. As the mature trees eventually die of old age, there are no new seedlings establishing to take their place.

FIGURE 15.—Examples of dysfunctional riparian areas on the Frio River. The left photos shows extreme erosion that has led to the loss of some trees and a floodplain that is disconnected from the river. The right photo is located downstream from an area of past sand and gravel dredging and shows high levels of deposition of gravel which has degraded the riparian area on the right bank. The left bank shows a highly manicured riparian area.

FIGURE 16.—Examples of recreational access with a high impact to the riparian area through trampling (left photo) or manicuring (right photo).

Functioning riparian areas are essential to the health of river ecosystems. They provide shade, which reduces water temperature and helps maintain dissolved oxygen levels for aquatic life use; armor banks and prevent erosion; slow floodwaters; and trap and hold new sediments, which store water in the banks and slowly release water back into the river during times of drought (Nelle 2014).

Baldcypress Health, Age, and Growth

<u>Methods</u>: In response to landowner concerns and as a complement to the riparian corridor assessment, the Texas A&M Forest Service (TFS) conducted a study to assess the age, growth, and overall health of baldcypress *Taxodium distichum* trees on the Frio River. Trees were visually inspected as a group for overall health throughout the study area via kayak on April 17–18, 2018. Health components examined included evidence of pests, diseases, damages and impacts from any cause, and overall vigor.

In addition, a sampling of baldcypress trees along the riverbank were also measured and cored to estimate age and growth rates and to investigate whether a relationship exists between size and age. Since there was concern by stakeholders that trees left "high and dry" by changes in the river course after flood events would die, a sampling of trees located more than 15 m away from the water's edge were also measured and cored for growth comparison. Two trips were made to gather tree measurement data. Eleven trees were cored and measured on July 19, 2018, and an additional 10 trees were cored and measured on January 15, 2019.

Measurements taken included: diameter at breast height (DBH; 4.5 ft above ground level and measured to the nearest tenth of an inch); tree height (measured to the nearest ft); average crown width (measured to the nearest ft); and distance to water (measured to the nearest ft). Tree cores (5.15 mm diameter) were extracted from bark to pith of each tree. Tree locations were documented with GPS coordinates and referenced to nearby landmarks or other prominent trees. All study trees were photographed (Appendix E).

A 75-foot Spencer Logger's tape was used for diameter, crown width, and distance to water and reference monument measurements. A Haglof VL5 laser rangefinder and Suunto clinometer were used to measure tree heights. A Haglof 32 in, 5.15 mm core, 3 thread increment borer was used for tree core extraction.

In the field, extracted tree cores were immediately placed into 6 mm diameter plastic straws for protection. Straws were then labeled with a tree identification number and placed into a sturdy plastic drafting tube for safety in transporting from the field to the lab.

In the lab, cores were removed from straws and set aside to dry for 48 hr. After drying, cores were mounted with wood glue onto 36 in basswood slats with a ¼ in diameter routed semicircular groove along its length. Cores were kept in the same orientation (transverse) as they were when removed from the tree. Zip ties were used to secure cores in place while the glue dried. After 24 hr, zip ties were removed and cores were sanded with 220, 400, 800, and 1500 grit sandpaper. Proper and sufficient sanding is necessary to microscopically differentiate between true annual rings and "false" intra-annual rings in baldcypress. Photos of tree cores are included in Appendix E.

Cores were then examined under a microscope to count annual rings from pith outward toward bark. One annual ring equals one year's growth. To determine periodic, 10-year, diameter growth rates the distance to the nearest tenth of an inch was measured for each ten year grouping of growth rings and doubled. Diameter growth occurs from the radial growth on each side of the pith of the tree. Then an average periodic diameter growth rate was determined for all trees combined for each 10 yr period in question.

Results and Discussion: The visual assessment of health indicated localized areas of excessively exposed tree roots and areas of excessive gravel and rocks piled around the bases of other trees. Gravel deposits appeared to be caused by natural flood events and were perhaps exacerbated by improper gravel removal operations where loosened gravel was left adjacent to the river instead of removed from floodplain. Blunt force damage was also witnessed at the base and upward along the bole of a scattering of trees, likely from large debris propelled by floods. Trees appeared to be recovering from these wounds as evidenced by new woody growth beginning to surround the wound areas. Despite these flood impacts, overall tree health and vigor appeared excellent. No evidence of widespread pests or disease was observed.

Baldcypress regeneration was excellent in many undisturbed natural areas along the river, especially in open areas with ample sunlight exposure. It should be noted, however, that extensive areas of erosion and soil compaction was evidenced, especially along areas of the river with high recreational use. These areas showed very little to no tree regeneration. This is concerning for the resiliency and longevity of the baldcypress forest ecosystem in these areas as there is nothing to replace the larger trees as they naturally senesce and die over time.

For the individual tree assessment, a total of 21 trees were measured and cored within the study area. The original plan to core a larger number of trees was hampered due to the high percentage of private property along the banks of the Frio River and the inherent logistics involved in securing access permission and scheduling field work. This study does serve, however, as a good start and can be expanded and refined to include additional trees in the years to come.

Even with the small number of participating landowners, data collection was distributed representatively along the study area (Figure 17), while also focusing efforts on upper reaches where sand and gravel permits were concentrated. Three trees were measured and cored at the confluence of the East and West Frio rivers and three trees were measured and cored within a nearby abandoned channel downstream. Data was also collected from five trees in two areas south of Leakey, Texas, just downstream of the heaviest concentrations of sand and gravel removals. Another five trees were measured and cored along the middle sections of the study area from near the lower FM 1120 crossing to just downstream of Garner State Park. Finally, five trees were cored and measured just downstream of Concan, Texas.

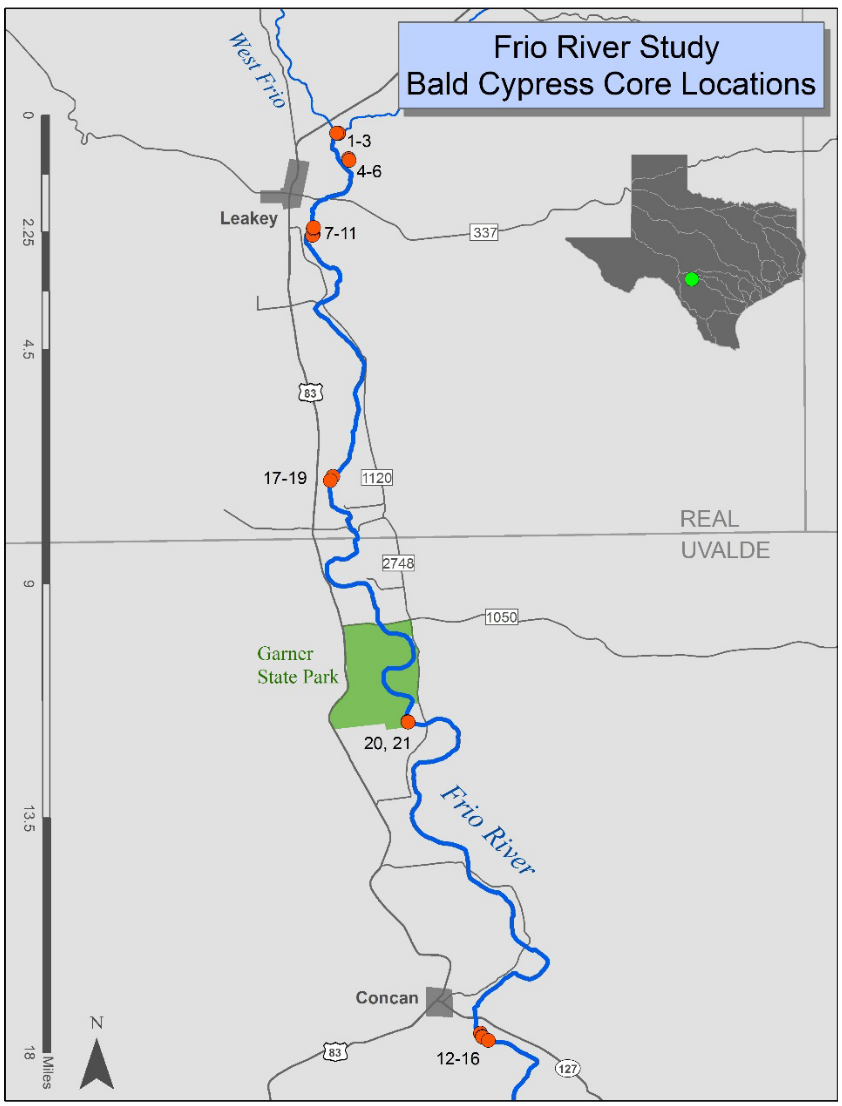


FIGURE 17.—Locations of baldcypress trees that were measured and cored for this study on the Frio River in Real and Uvalde counties, Texas in July 2018 and January 2019.

Tree measurement data are shown in Table 5. Total tree height averaged 22 m (72.3 ft) with a range of 13.7–33.5 m (45–110 ft.). Crown width averaged 16 m (52.5 ft) with a range of 6–27 m (20–90 ft). Diameter at breast height averaged 0.96 m (37.6 in) with a range of 0.4–1.5 m (16.9–60.8 in). Tree locations ranged in distance from water's edge to over 240 m from the main Frio River channel.

The results of the tree core analysis are shown in Table 6. The average estimated age of the trees was 153 years with a range of 64–352 years. Age was estimated by counting true annual rings under a microscope and making adjustments for age at core collection height and for missing wood at tree center due to heart rot. Evidence of heart rot, a natural occurrence in older trees, was found in three of the core samples beginning at the 150–180 year mark, leading to the last several inches of the soft core to become twisted and segmented. Length in the table refers to the radial length in inches from the pith of the tree at the various ages. Doubling this figure would give an estimate of tree diameter. For example, Tree #3 would be expected to be 24 inches DBH at age 60. Examining the data in the table, it is readily apparent that growth rates are highly variable. In the "Length at 90 years" column, Tree #12 and #13 are only 8.4 inches and 10.4 inches DBH respectively, while Tree #1 and #6 are 38.2 inches and 40.6 inches DBH respectively. This represents a large difference in size, but all trees are the same age.

Average cumulative annual DBH growth of the 21 trees measured was 5–7.6 mm (0.2–0.3 in) per year in early years, topping out around age 80, followed by steep declines to below 3.8 mm (0.15 in) per year after age 150 (Figure 18). The cumulative annual DBH growth ranged from 1.3 mm (0.05 in) per year to a maximum of 14 mm (0.55 in) per year. Growth of off-channel trees (50 ft or more from river channel) was equal to or slightly greater than trees directly on the edge of river channel (Figure 18). Based on these data trees left "high and dry" by changes in the river course due to recent floods have roots that are still reaching water, are continuing to grow, and are not predicted to be at an increased level of threat for an early demise.

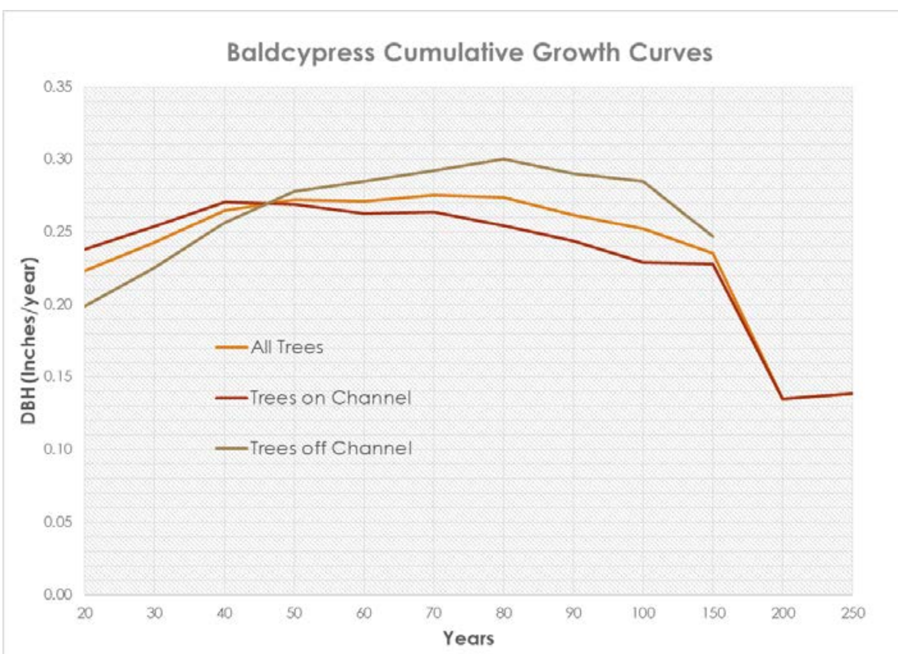


FIGURE 18.—Cumulative annual growth of all baldcypress (orange line), on channel trees (red line), and off channel trees (brown line) cored for this study on the Frio River in Real and Uvalde counties, Texas on July 19, 2018 (trees 1–11) and January 15, 2019 (trees 12–21).

When looking at 10 yr periodic annual growth, individual trees range anywhere from 1–19 mm (0.04–0.74 in) per year. Growth of any individual tree is site specific, so age of a tree cannot be easily determined by looking at the size (DBH or height). In fact only 43% of the variability in age of the baldcypress analyzed in this study can be explained by DBH alone (Figure 19). Other factors such as sunlight exposure, competition from other trees and plants, and soil depth and fertility create such variability in growth along the Frio River that an 180 yr old tree can be anywhere from 0.5–1.5 m (20–60 in) DBH and a 0.5 m (20 in) DBH tree can be anywhere from 60 to 180 years old.

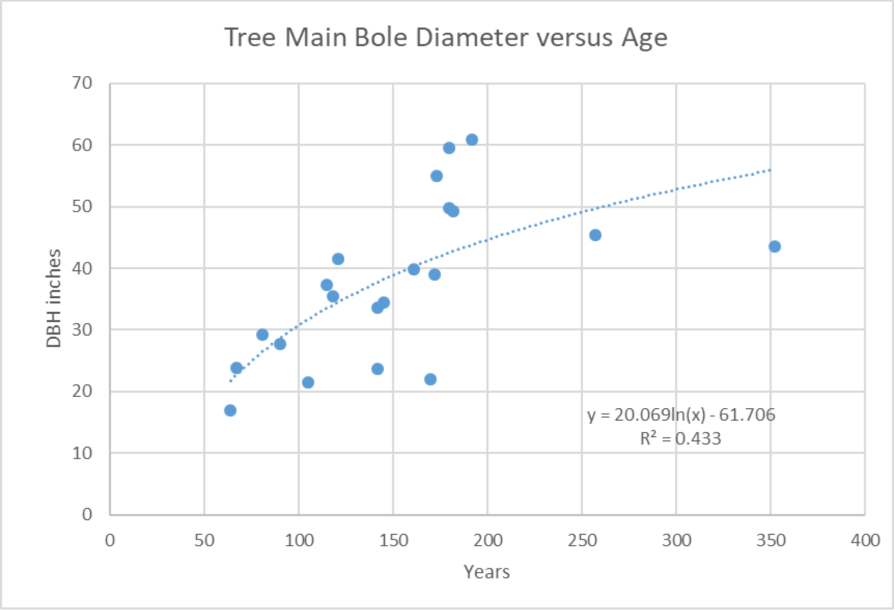


FIGURE 19.—Relationship between diameter at breast height (DBH) and age of baldcypress trees measured and cored as part of this study on the Frio River in Real and Uvalde counties, Texas on July 19, 2018 (trees 1–11) and January 15, 2019 (trees 12–21).

Overall, the baldcypress population along the study area of the Frio River is healthy and vigorous. The low levels of damage (exposed roots, blunt force bole damage) witnessed is not unusual for a river system prone to periodic flash floods. Baldcypress trees have adapted to this system over many millennia and exposed roots are common for this species. Piling loose gravel around trees with exposed roots may serve an aesthetic purpose but does not provide additional structural support for the trees and may even serve to add extra force to damage trees in high flood events. The loosened gravel will also likely wash away from the trees in the next flood event and become deposited downstream. The disruption and compaction of the stream bed and banks by heavy equipment used to move gravel will likely do more harm to the baldcypress trees and the river system as a whole in the long-run. As the river recovers naturally in between floods it is likely that sediment will naturally fill in the areas around the exposed tree roots. Uprooted and fallen trees are a natural part of any healthy functioning river system and serve to provide needed in-stream habitat for greater biodiversity, as well as, needed structure for bank stabilization.

High density water-related recreational areas on the Frio River are a threat to the long-term health and resiliency of the baldcypress ecosystem, as these areas typically lack regeneration and establishment of new trees due to trampling and vegetation manicuring. Recommendations would be to limit river access to small defined areas (Figure 14) and to supplement tree regeneration by planting baldcypress and other native tree seedlings or saplings between these access points.

TABLE 5.—Baldcypress measurements taken from 21 trees within the study reach on the Frio River in Real and Uvalde counties, Texas on July 19, 2018 (trees 1–11) and January 15, 2019 (trees 12–21).

Tree ID	*Lat*	*Long*	*Study Reach*	*Channel Proximity*	*Dia. (in)*	*Dist to H20 (ft)*	*Tree Height (ft)*	*Crown width (ft)*	*Crown 90° wd (ft)*	*Notes: (Damage, Disease, Insects, Soil Compaction, Exposed Roots, Leaning, etc.)*
1	29°44'28"	99°44'58.7"	1	On-channel	60.8	25	85	65	60	340°; 11.1 ft to center of tree from SW cnr of concrete slab at the Confluence of West and East Branch
2	29°44'28.2"	99°44'59"	1	On-channel	45.3	4	78	38	34	152°; 8.5 ft to center of tree from SW cnr of concrete slab at the Confluence of West and East Branch
3	29°44'28.2"	99°45'0.6"	1	On-channel	35.5	29	70	55	40	This is the western most Cypress at the Conlfuence. It was across the river channel from the park in 7/2018
4	29°44'01.4"	99°44'48.4"	1	Abandonded dry channel	41.5	820	110	70	50	256°; 66 feet to large Live Oak
5	29°44'02.8"	99°44'48.7"	1	Abandonded dry channel	49.7	820	89	90	70	211°; 92 feet to large Live Oak
6	29°44'1"	99°44'48.2"	1	Abandonded dry channel	55.0	820	96	50	50	316°; 170 ft to large Live Oak
7	29°42'47"	99°45'24.2"	3	Off-channel	22.0	300	65	47	40	61°; 42 ft to 76" DBH Cypress; Deeply buried
8	29°42'46.3"	99°45'24.6"	3	Off-channel	37.3	300	79	58	50	28°; 109 ft to 76" DBH Cypress, some evidence of borer activity
9	29°42'45.9"	99°44'24.9"	3	Off-channel	33.6	300	62	65	51	~20°; 159 ft to 76" DBH Cypress, this tree had more limbs at a lower height
10	29°42'52.7"	99°45'24"	2	On-channel	59.5	4	65	80	64	22°; 67 ft to S/W Cnr of concrete slab of picnic table
11	29°42'53.8"	99°45'23.7"	2	On-channel	21.5	4	69	65	60	174°; 67 ft to S/W Cnr of concrete slab of picnic table
12	29°29'27.2"	99°42'36.7"	21	On-channel	39.0	9	67	69	47	old limb scar on left about 10' up when looking at tree from bank
13	29°29'27.6"	99°42'36.9"	21	On-channel	23.6	4	59	46	28	downed tree on back edge of tree
14	29° 29' 24.5"	99° 42' 35.3"	21	Off-channel	34.4	28	60	63	43	near photo point - knee to left of tree as facing river
15	29° 29' 23.8"	99° 42' 34.8"	21	Off-channel	49.3	58	50	72	61	chained to picnic table - small hole at base of tree (evidence of rot) - core was soft and twisted
16	29° 29' 20.3"	99° 42' 28.9"	21	Off-channel	29.2	93	76	46	20	woody flood debris on uphill side of tree
17	29° 38' 44.7"	99° 45' 04.4"	7	On-channel	23.8	4	46	43	23	at waters edge - leaning over water
18	29° 38' 40.6"	99° 45' 06.9"	7	On-channel	16.9	1	45	28	24	near flat backwater area behind house
19	29° 38' 44.6"	99° 45' 05.0"	7	On-channel	39.9	6	53	64	55	near mouth of small tributary feeding into Frio
20	29° 34' 39.3"	99° 43' 49.7"	13	On-channel	27.7	2	105	28	28	Garner SP below dam below rock slide area
21	29° 34' 38.8"	99° 43' 49.2"	13	On-channel	43.6	4	89	84	80	Garner SP below dam below rock slide area - core was soft and twisted - evidenece of rot
				Average:	**37.6**		**72.3**	**58.4**	**46.6**	
				Max:	**60.8**	**820**	**110**	**90**	**80**	
				Min:	**16.9**	**1**	**45**	**28**	**20**	

TABLE 6.—Baldcypress tree ring measurements (inches) and age estimates taken from 21 trees within the study reach on the Firo River in Real and Uvalde counties, Texas on July 19, 2018 (trees 1–11) and January 15, 2019 (trees 12–21).

Tree ID	*True Rings*	*Length 20 yrs*	*Length 30 yrs*	*Length 40 yrs*	*Length 50 yrs*	*Length 60 yrs*	*Length 70 yrs*	*Length 80 yrs*	*Length 90 yrs*	*Length 100 yrs*	*Length 150 yrs*	*Length 200 yrs*	*Length 250 yrs*	*Age Estimate*
1	146	4.2	7.5	11.1	12.9	14.8	16.5	18.6	19.1	19.8	21.2			192
2	242	2.3	4.3	5.5	8.6	9.4	10.1	10.6	11.2	11.5	14.2	17.2	21.2	257
3	103	4.8	7.5	9.1	10.9	12.0	13.4	14.1	14.7	15.0				118
4	106	4.9	7.2	9.6	12.7	13.8	15.2	16.3	17.1	17.6				121
5	170	0.6	0.8	1.6	3.1	5.4	7.1	9.0	11.4	12.3	19.0			180
6	163	2.2	4.5	6.4	8.8	11.4	14.8	18.5	20.3	22.1	26.1			173
7	160	1.0	2.0	3.5	4.4	4.9	5.7	6.7	7.3	8.1	10.8			170
8	105	2.8	4.1	6.3	8.6	10.8	12.6	13.9	15.3	16.3				115
9	120	1.7	3.2	5.4	6.6	8.1	9.1	10.6	11.3	12.2				142
10	100	2.2	3.8	6.4	8.0	9.6	11.2	12.8	14.3	16.6	26.1			180
11	95	4.2	5.0	6.8	8.2	9.3	9.9	10.6	10.9	11.2				105
12	162	1.2	1.7	2.3	2.6	2.9	3.2	3.5	4.2	5.2	12.1			172
13	132	0.9	1.7	2.2	2.7	3.2	3.8	4.4	5.2	6.0				142
14	135	2.7	3.9	5.5	6.6	7.1	7.8	8.5	9.6	10.3				145
15	172	0.6	1.1	1.7	2.3	3.5	5.0	6.5	8.7	11.2	18.1			182
16	71	2.1	4.1	6.5	9.1	10.5	12.3	14.6						81
17	57	1.7	3.1	4.5	5.5	6.3								67
18	54	1.7	2.5	3.4	4.9	6.1								64
19	151	2.4	4.0	5.2	6.8	9.2	11.2	12.2	13.3	13.8	21.3			161
20	80	1.5	3.1	5.8	6.9	9.4	10.6	12.1	13.5					90
21	342	1.1	1.4	2.5	2.8	3.1	3.8	4.5	4.7	5.0	7.7	9.8	13.5	352
*Length is in inches														
Average Radial Length		2.23	3.64	5.30	6.81	8.13	9.65	10.95	11.78	12.60	17.66	13.50	17.35	153

Landowner's should not be overly concerned for the health of the baldcypress trees that are no longer along the water's edge, as the river naturally changes its course after floods. Once baldcypress trees are established, their roots dig down and outward, deep into the water table and are able to access water even though it appears no water is present on site. Baldcypress is a rather drought hardy species once established. This study showed that established baldcypress trees located away from the water were growing at rates equivalent or slightly better than those directly along the water's edge. Also, it is just as likely that the river may change its course during the next flood and those same trees will be back along the water once again.

This study also showed that care must be exercised in estimating age of baldcypress based on DBH. Although age range extremes may be estimated based on the DBH and average growth rates presented, honing in on a reliable age for an individual tree based solely upon size is an exercise in futility. There is too much variability in growth rates from site to site along the river. Coring is the only effective way to estimate live tree age with any level of confidence.

WATER QUALITY

Methods: Instantaneous water quality stations were placed at the center of each of the 21 study reaches (Figure 20). Physicochemical data collected at each station included water temperature, pH, specific conductance, and dissolved oxygen and were taken using a YSI EXO1 multi-parameter sonde. Additionally, a Secchi depth was taken with each sonde reading.

Continuous physicochemical measurements were made at three stations (Figure 20). Locations were selected in an effort to document diel water quality patterns at representative reaches with varying levels of sand and gravel dredging activity. The three reaches selected represent a high level of recent permitting (reach 2), an area downstream of a moderate level of recent permitting (reach 7), and an area with no recent permitting (reach 21). YSI multi-parameter sondes were deployed for a period of approximately one month and were programmed to collect a measurement of temperature, pH, dissolved oxygen, specific conductance, and turbidity once every half hour.

Water chemistry and periphyton samples were collected at stations within even numbered reaches, n=10 (Figure 20). Water chemistry samples were collected at a depth of 0.3 m and preserved on ice for delivery to the Lower Colorado River Authority – Environmental Services Lab (LCRA-ELS) for analysis. Parameters that were analyzed include: total dissolved solids (TDS), total suspended solids (TSS), volatile suspended solids (VSS), total phosphorus (TP), fluoride, bromide, chloride, and sulfate.

Periphyton was collected by sampling five submerged rocks at each sampled station. Rocks were selected which were covered in periphyton and had a flat surface where a "square" could be measured to calculate total area sampled. Periphyton was gently brushed off with a soft-bristled tooth brush while being flushed with de-ionized (DI) water. The area scrubbed was calculated and recorded for each rock. The rinsate for each rock was collected in a pan and the composite of all 5 rocks was transferred to a 250 ml plastic container which was placed in an amber bag and preserved on ice until the samples could be further processed at the end of the day. Post processing of the periphyton samples consisted of diluting each sample to the nearest 100 mL with DI water. The sample was shaken to ensure homogenization and 5–8 mL of each sample was transferred via pipette to a vacuum filter.

Two filters were processed for each sample, one for ash-free dry mass (AFDM) and one for chlorophyll-a/pheophytin-a analysis. The filters were folded in quarters, placed in a tin foil wrapper, preserved on dry ice, and delivered to the LCRA-ELS.

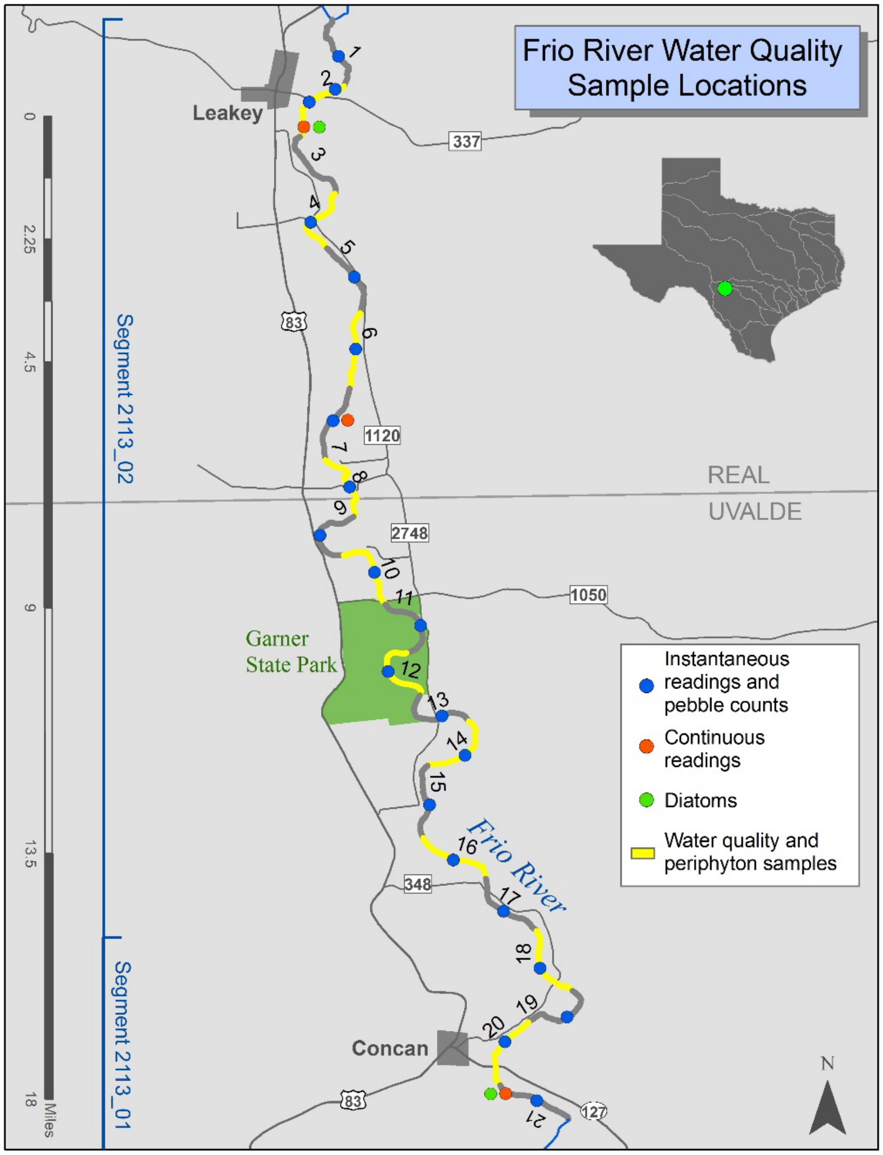


FIGURE 20.—Water quality stations and the type of data collected at each station on the Frio River in Real and Uvalde counties, Texas over the spring and summer of 2018.

In addition to AFDM and chlorophyll-a/pheophytin-a analysis, diatom communities were evaluated at two sites (Figure 20). One site was within reach 2 and selected to represent an area of high intensity, recent dredging and the other was in reach 21 and selected to represent an area with no recent dredging. For these two sites, the diatom community was identified and enumerated from the homogenized periphyton sample after removing the aliquots to be filtered for ash-free dry mass and chlorophyll-a/pheophytin-a. Approximately 60 mL of the remaining sample was transferred to a glass jar and preserved with 2 mL of glutaraldehyde. A duplicate 60 mL sample was also preserved for quality assurance purposes.

For purposes of analysis and discussion, results from the duplicate samples were combined. Both samples were sent to an algal taxonomist for diatom community analysis. Samples were cleaned by boiling in acid and slides were fixed for diatom identification and enumeration. Five hundred cells were counted from each sample, representing a qualitative tabulation of the first 500 diatoms encountered in sequential random fields on a slide. Permanent voucher slides of each taxon were retained. Barbara Winsborough of Winsborough Consulting conducted the identification and enumeration of the diatom communities.

Methods for calibration, post-calibration, sample collection, diel measurements, and field parameter measurements are outlined in the Surface Water Quality Monitoring (SWQM) Procedures Manual Volume I (TCEQ 2012).

Wolman's Pebble Count was used to quantify the surface sediment bed material size at each wadeable transect (Wolman 1954). The pebble count measures approximately 100 randomly chosen stones along transects across the wetted width of the stream and categorized them based on the Wentworth Scale of grain sizes (Wentworth 1922). The percent frequencies of each particle size class were calculated, based on the Wentworth Scale, then the cumulative percent frequencies were calculated. The cumulative percent frequencies, representing the particle size distribution for a given transect, were then graphed and the median (D50) was calculated using a spreadsheet from Jeff Clark, Professor of Geology at Lawrence University in Appleton, Wisconsin. Particle size distribution curves and percent in range of each grain size class histograms were created for each transect with this spreadsheet.

Results and Discussion: Based on data collected during this study, the overall water quality for the study area is good. All field parameters measured fell within the exceptional aquatic life use limits outlined in the Texas Surface Water Quality Standards for the upper Frio River segment 2113 which are established by the TCEQ (Table 7; TCEQ 2018).

Chloride and sulfates increased longitudinally downstream, with a pronounced increase in sulfates across reaches 16 through 20 (Table 8; Figure 21). Overall sulfates increased from 8.4 mg/L in reach 2 to 33.1 mg/L in reach 20. This could be attributed to increasing longitudinal spring flow contributions to the river which may be adding chloride and sulfates from groundwater or from non-point sources such as agriculture.

Fluoride also increased longitudinally, but was not significant. Bromide had two peaks, one at reach 10 and one at reach 18. Total dissolved solids samples collected at even numbered study reaches were all below the Texas Surface Water Quality Standard of 400 mg/L with the exception of the sample collected in study reach 20 which was 2,850 mg/L. Total phosphorus data was mostly below detection limits or within expected ranges with the exception of reach 8 that had a value of 34.9 mg/L, which occurred at the confluence of the Frio River and the Little Dry Frio. The community of Rio Frio is just upstream on the Little Dry Frio, so the elevated TP could be from septic fields.

TABLE 7.—Instantaneous physiochemical measurements recorded at water quality stations on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

Reach	Temperature (°C)	pH	Specific Conductance (µmhos/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (%)	Secchi Depth (m)	Total Depth (m)
1	18.5	7.8	440	9.0	96.7	> 1.2	0.47
2a*	20.5	8.0	438	9.8	109.3	> 1.2	0.80
2b*	21.0	7.8	432	9.9	112.5	> 1.2	0.67
4	20.4	7.8	443	7.4	82.6	> 1.2	0.26
5	20.6	8.0	447	8.3	92.7	> 1.2	0.30
6	21.2	8.0	440	9.9	111.5	> 1.2	0.83
7	22.9	8.1	433	10.1	117.9	> 1.2	0.17
8	22.2	7.8	426	8.6	99.4	> 2.4	2.40
9	18.5	7.8	439	7.7	82.9	> 2.3	2.30
10	18.6	8.1	438	9.6	102.3	-	0.83
11	24.8	8.2	434	10.1	121.8	> 1.2	0.49
12	24.5	8.3	425	9.8	117.2	> 1.2	0.69
13	19.6	8.1	411	9.8	106.7	-	0.46
14	18.8	8.0	418	7.8	83.5	> 1.6	1.60
15	19.2	8.0	417	8.3	90.7	-	0.05
16	19.4	8.1	409	9.4	101.9	> 1.2	0.32
17	22.4	8.1	415	8.1	93.0	> 1.2	0.08
18	21.6	8.0	425	8.5	86.3	> 1.2	0.32
19	19.5	8.1	461	8.1	88.3	> 1.2	0.40
20	21.4	8.0	453	9.3	105.4	-	0.35
21	23.1	8.0	447	9.6	112.5	> 2	2.00
TCEQ Standard	≤ 32.2	6.5-9.0	N/A	6.0	N/A	N/A	N/A

*Two samples were collected within reach 2 and none in reach 3 (Figure 3).

Table 8.—Results from water chemistry samples collected at the mid-point of the even numbered study reaches on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

Reach	Bromide (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Total Phosphorus (mg/L)	Sulfate (mg/L)	Total Dissolved Solids (mg/L)	Total Suspended Solids (mg/L)	Volatile Suspended Solids (mg/L)
2	0.0377	9.57	0.105	<0.0200	8.4	245	<1.00	<1.00
4	0.0353	9.99	0.108	0.0347	9.16	253	<1.00	<1.00
6	0.0373	10.3	0.1	0.0205	9.68	240	<1.00	<1.00
8	0.0377	10.3	0.117	34.9	9.92	219	<1.00	<1.00
10	0.0541	10.4	0.11	<0.0200	10.1	238	<1.00	<1.00
12	0.0397	10.9	0.109	<0.0200	13.7	242	<1.00	<1.00
14	0.0297	10.4	0.136	<0.0200	13.9	238	<1.00	<1.00
16	0.0289	10.6	0.12	<0.0200	15.7	226	<1.00	<1.00
18	0.0557	11.1	0.13	<0.0200	19.2	253	<1.00	<1.00
20	0.04	11.8	0.121	<0.0200	33.1	2850	<1.00	<1.00
TCEQ Standard	N/A	≤ 50	N/A	N/A	≤ 50	≤ 400	N/A	N/A

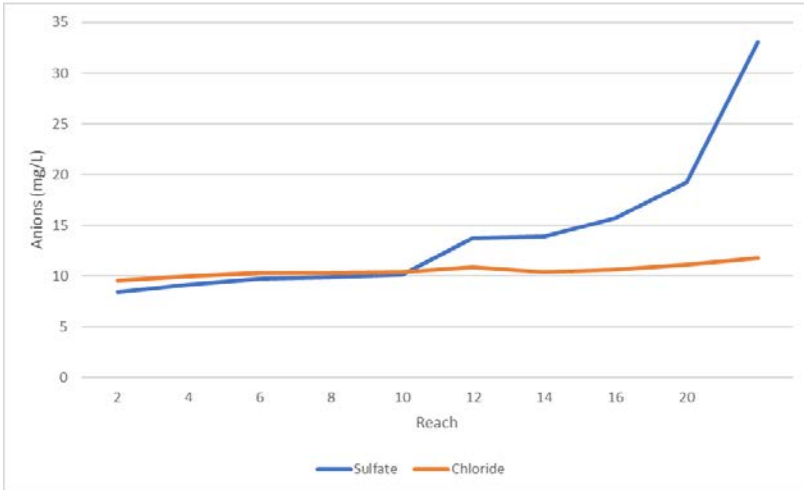


FIGURE 21.—Sulfate and chloride concentrations from water quality samples taken on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

Continuous dissolved oxygen measurements varied widely in reach 2 and the dissolved oxygen diurnal curve resembles that of a curve from potentially eutrophic waters (Table 9; Figure 22). Approximately 50% of the dissolved oxygen measurements were below the 6.0 mg/L standard designated for exceptional aquatic life use. The diurnal dissolved oxygen curves measured in reaches 7 and 21 followed a sinusoidal pattern and minimums were above the designated 6.0 mg/L in the Texas Surface Water Quality Standards.

TABLE 9.—Continuous diel physiochemical data collected from three reaches on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

		Temperature (C)			pH			DO (mg/L)			Specific Conductance (µmhos/cm)		
Reach	Deployment Period	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
2	4/16/18-5/30/18	18.3	22.4	19.9	7.3	8.0	7.6	0.4	12.2	5.9	461	576	518
7	4/16/18-5/30-18	18.2	23.3	20.5	7.8	8.1	7.9	6	10.3	8.5	420	450	440
21	4/17/18-5/30/18	18.6	24.6	21.4	8.0	8.3	8.1	7.6	10.5	8.9	426	452	443

In addition to the water quality sondes, two instruments that measured turbidity were deployed alongside the sondes in reaches 2 and 21. The turbidity sonde at reach 21 failed to collect data, so only the data from reach 2 is presented in this report. During deployment the average, minimum, and maximum turbidity measured was 5.0, 2.9, and 18.5 NTU (Nephelometric Turbidity Units) respectively. The turbidity sonde deployed in reach 2 captured several spikes in turbidity (Figure 23). Of note were the three highest peaks, occurring on April 25, 2018, May 4, 2018, and May 10, 2019. The peaks on April 25, 2018 and May 4, 2018 can be attributed to rainfall events. The peaks recorded on May 10, 2018 are not associated with any rainfall event and the cause is undetermined.

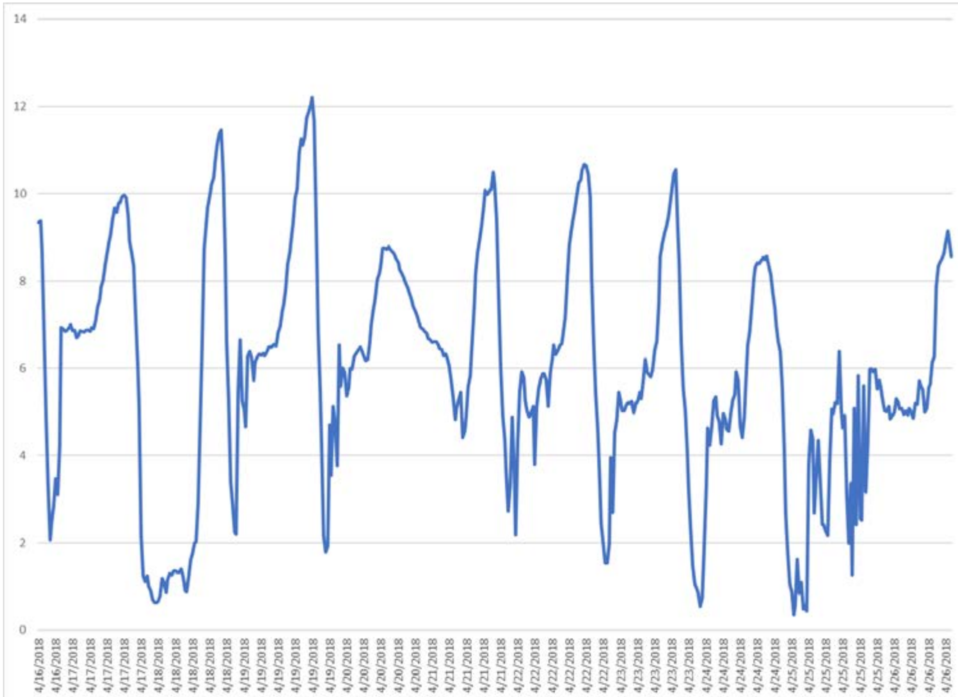


FIGURE 22.—Diurnal dissolved oxygen measurements (mg/L) from study reach 2. Only the first 10 days of measurements (April 16, 2018 through April 26, 2018) are shown.

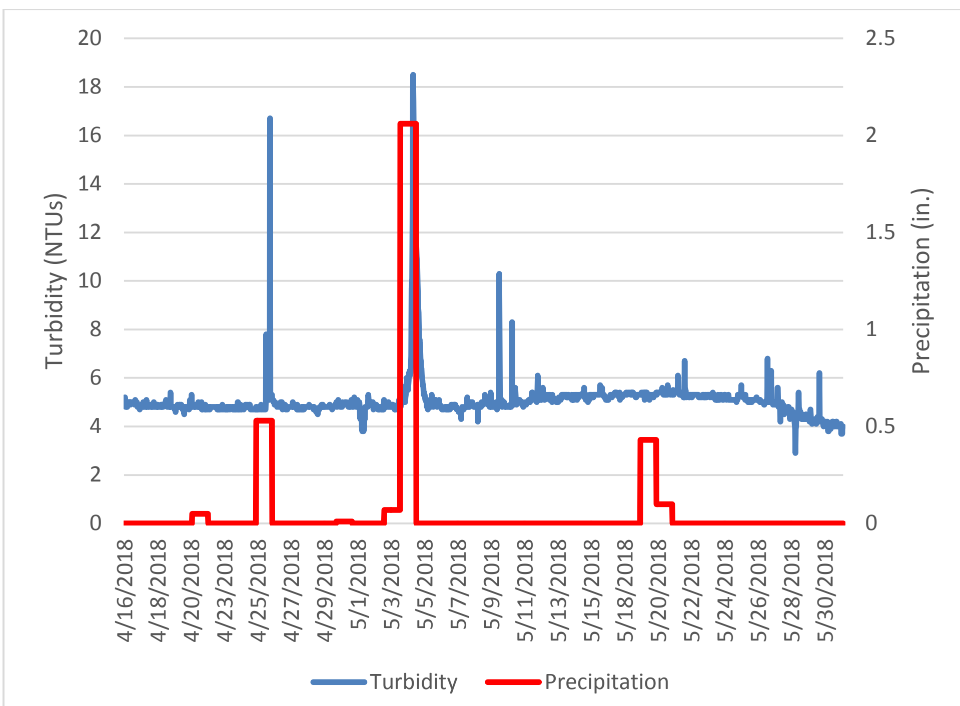


FIGURE 23.—Continuous turbidity data collected every 30 minutes within reach 2 on the Frio River from April 16–May30, 2018 in Real County, Texas. Precipitation data was downloaded from Weather Underground.

Of the 18 pebble count transects conducted, five consisted of over 50% bedrock (reaches 4, 5, 15, 16, and 19). The highest percent frequency grain size for all pebble counts combined was very coarse gravel (33–64 mm) at 28% followed by bedrock (27%), and coarse gravel (17–32 mm) at 16% (Figure 24).

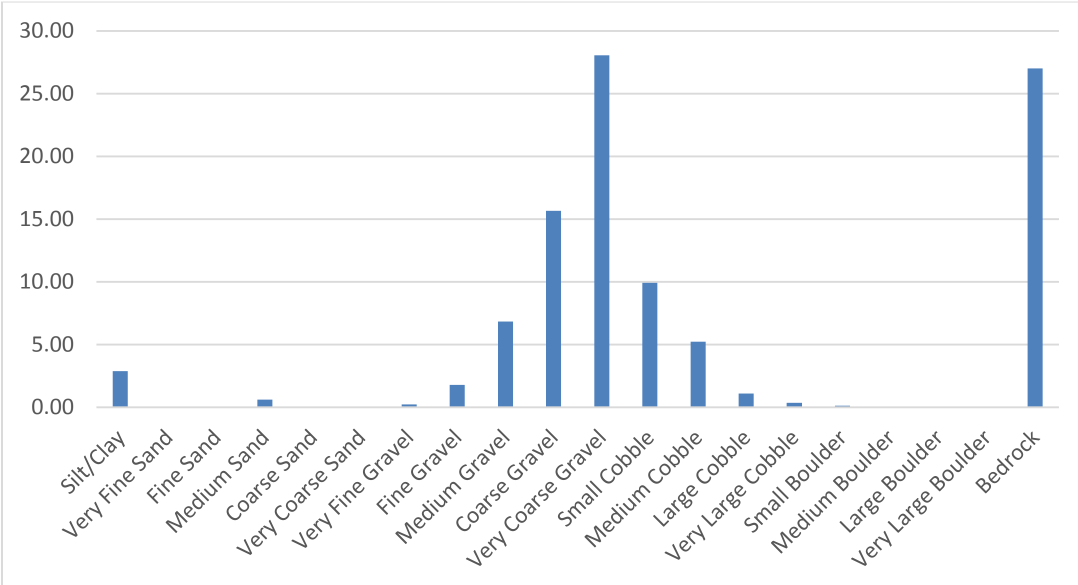


FIGURE 24.—Combined pebble count data for 21 transects within the study area on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

The pebble counts were also categorized by habitat type (riffle, glide, run, pool). Pools and riffles had the lowest amount of bedrock present (an average of 0% and 0.5%, respectively), while glides contained 25% bedrock and runs contained 37% bedrock. It is likely that pools were under-represented in the sampling due to the difficulty of obtaining samples in deeper water. Pools and glides each had 6% silt/sand while runs had 1% and riffles had 2% sand/silt.

Analysis from periphyton samples showed AFDM mass ranged from 0.017 to 0.503 mg/cm^2, and chlorophyll ranged from 5.58 to 116.6 mg/m^2 (Figure 25). In general, these two estimates are closely correlated, as seen with the peaks at stations in reaches 4 and 20, and nadirs at stations in reaches 2 and 8. Periphyton biomass can have extreme seasonal variability, as high as three orders of magnitude (Biggs 1996). Environmental factors leading to higher biomass include sunlight (i.e. amount of canopy cover) and adequate nutrients in the water (i.e. nitrogen and phosphorus). Disturbance, both natural (i.e. flooding/scouring) and manmade (i.e. mining, sedimentation), can lead to reductions in biomass. A study of New Zealand streams found that 5 mg/cm^2 was a good rule-of-thumb for determining whether periphyton biomass had increased to nuisance levels (Biggs and Price 1987). Values from this study were all about an order of magnitude below that threshold. For temperate streams in North America, thresholds were specified to aid in evaluating benthic algal chlorophyll levels in terms of the overall trophic state of the stream (USEPA 2001). In general, a mean value of 20 mg/m^2 is the boundary between oligotrophic and mesotrophic streams, and a mean of 70 mg/m^2 the boundary between mesotrophic and eutrophic. Comparing the single values collected in this study to these thresholds, six of the values fall in the oligotrophic category (i.e. low nutrients and productivity), four in mesotrophic (i.e. moderate productivity), and two in the eutrophic category (i.e. high nutrient load and high productivity).

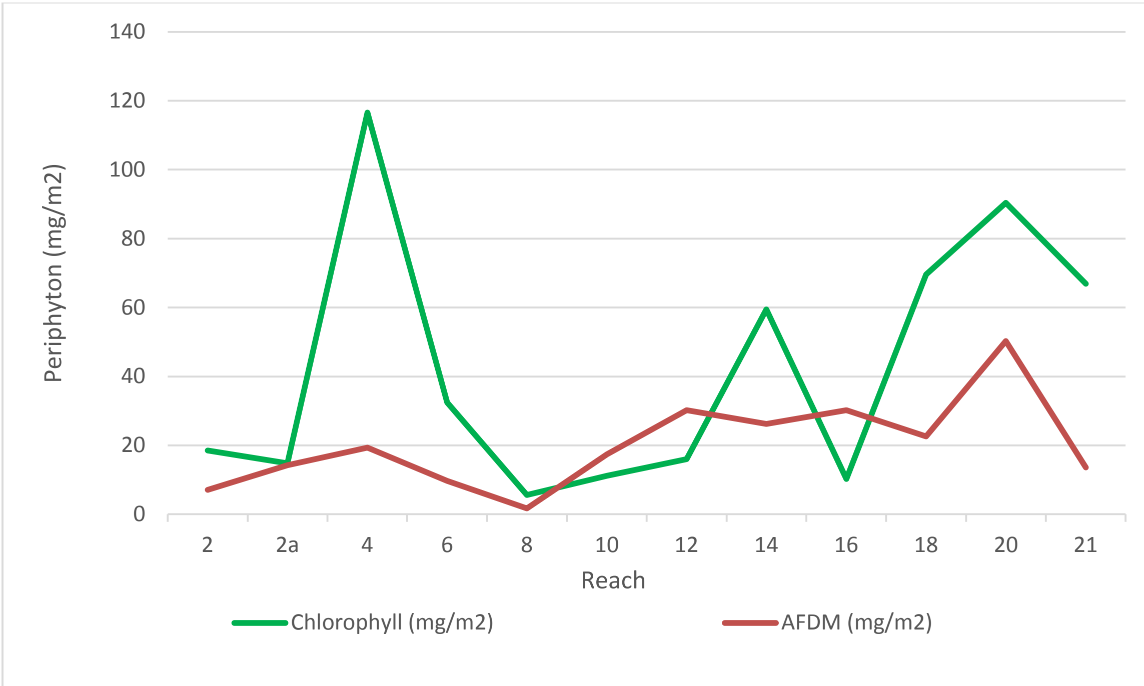


FIGURE 25.—Chlorophyll-a/pheophytin-a concentrations and ash-free dry mass for periphyton samples collected from rocks within each study reach on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

Periphyton samples from reaches 2 and 21 were analyzed for diatom communities and overall, 47 species of diatoms were identified, 38 species in reach 2 and 43 species in reach 21 (Table 10). Species that are more dominant in reach 21, the area with no recent dredging, included *Achnanthidium caledonicum, Mastogloia smithii,* and *Nitzschia serpentiraphe*. Species that were more dominant in reach 2, the area with high levels of recent dredging, included *Encyonema evergladianum, Adlafia bryophila, Achnanthidium gracillimum,* and *Navicula eidrigiana.* No previous diatom studies for the Frio River exist for comparison. Geographical differences in species preferences and tolerances to water quality and other environmental characteristics make comparison of these results to other rivers unreliable.

One method to evaluate stream disturbance or function using diatoms is to look at the siltation index, which is the percentage of motile diatoms in a population or those that can move on their own. Presumably increased siltation and/or increased streambed instability favors the survival of motile species in a population. Some of the diatom genera and species known to be motile were found in the Frio River samples, namely *Navicula, Nitzschia, Adlafia, Sellaphora, Pinnularia,* and *Amphora copulata.* Based on the data collected for this study, the siltation index was higher in the reach with higher dredging activity, with 15% of motile taxa present in reach 2 versus 13% in reach 21. This could be indicative of increased siltation and reduced bed disturbance in reach 2.

TABLE 10.—Number of cells by species of diatom analyzed from periphyton samples collected from rocks within reaches 2 and 21 on the Frio River in Real and Uvalde counties, Texas on April 16–28, 2018.

Species	Reach 2	Reach 21
Achnanthidium caledonicum	19	135
Achnanthidium gracillimum	61	6
Achnanthidium minutissimum	15	18
Adlafia bryophila	93	1
Amphora copulata		1
Brachyseira vitrea	22	2
Caloneis silicula		2
Caloneis tenuis		1
Cymbella cymbiformis var. nonpunctata	1	20
Cymbella neocistula	6	
Cymbella vulgata	2	4
Delicata delicatula	91	75
Delicata verena var. sandrae	42	8
Denticula elegans	6	18
Denticula kuetzingii	32	65
Diatoma moniliformis	1	1
Encyonema (Encyonopsis) evergladianum	339	223
Encyonema jemtlandicum	25	1
Encyonema silesiacum	1	
Encyonopsis microcephala	57	44
Eucocconeis (Achnanthes) flexella	8	6
Eunotia arcus	3	14
Fallacia tenera	5	32
Fragilaria famelica	3	2

Species	Reach 2	Reach 21
Fragilaria sepes	1	8
Gomphonema acuminatum		4
Gomphonema intricatum var vibrio		6
Gomphonema lateripunctatum	11	9
Gomphonema mclaughlinii		2
Gomphonema vibrioides	8	14
Mastogloia lacustris	14	36
Mastogloia smithii	17	91
Melosira varians	4	
Navicula cryptocephala		8
Navicula cryptotenella	12	4
Navicula eidrigiana	37	
Navicula oblonga	3	1
Navicula radiosa	7	16
Nitzschia semirobusta	18	20
Nitzschia serpentiraphe	8	58
Pinnularia divergens	2	1
Pinnularia viridis		1
Rhopalodia gibba	2	11
Sellaphora laevissima		2
Sellaphora pupula	1	3
Sellaphora stroemii	14	10
Ulnaria ulna	9	16

All water quality field parameter measurements taken for this study were well within the established Texas Surface Water Quality Standards (TCEQ 2018) except for one TDS sample from Site 20. Water quality, particularly dissolved oxygen, was lower in the area with more sand and gravel dredging while the water quality at the sites with fewer sand and gravel removal operations were all above expected dissolved oxygen levels. The water quality sonde measuring turbidity that was deployed in the study reach that has had more sediment disturbance recorded a spike in turbidity that could be attributed to an unauthorized sand and gravel removal event.

Monitoring of periphyton chlorophyll and AFDM both upstream and downstream of any future dredging operations is recommended. Deployment of turbidity sondes may be a good way to detect spikes in turbidity which may arise from substrate disturbance. As water quality indicators showed in this study, samples are representative of a unique point in time and are often back to normal background levels shortly after a disturbance in the channel.

FLUVIAL GEOMORPHOLOGY

At the request of the Texas Parks and Wildlife Department, the Texas Water Development Board (TWDB) agreed to complete a study to evaluate the physical impacts of in-channel sediment removal from the Frio River utilizing hydraulic and sediment hydrodynamic computer models. The development of the models required the collection of high-quality surface topography, both in the floodplain and within the channel. These models were utilized to assess the impact of three different volumes of material removed at three locations along the river. Methods and results are summarized below. Appendix F includes the full TWDB report and additional details of the work performed to meet these study goals.

Methods: With funding from the TWDB, the University of Texas at Austin-Bureau of Economic Geology collected airborne LiDAR (light detection and ranging) data throughout the study area. Topographical and bathymetric LiDAR data, in addition to elevation data collected on the ground, were combined to develop a high resolution topographic digital elevation model (DEM; Figure 26).

A two-dimensional (2D) hydraulic model, Adaptive Hydraulics (AdH) Modeling (US-ERDC 2017), was developed for a section of the upper Frio River (Figure 27) using the DEM, water surface elevations, substrate characterization, instream cover, and stream discharge.

The entire 42 km study area was not modeled due to study time constraints and the high resolution of the DEM, which makes developing and running models time consuming. Since most of the permitted sand and gravel dredging sites since 2007 are located in the upper portion of the Frio River, this area was chosen as the priority for modeling efforts (Figure 27). Model runs were based on parameters of actual past sand and gravel dredging permits. Figure 27 shows the boundary of the modeled area which stretches from the confluence of the east and west forks of the Frio River to approximately one mile downstream of the upper Ranch Road 1120 crossing.

The hydraulic and sediment models used in this study were run using a 24-hour flow hydrograph based on a flow event that was recorded at the Concan USGS gage on September 8, 2018 (Figure 28). The flow hydrograph used in the model was translated from the Frio River at Concan gage to the upstream boundary of the study reach and then routed through the entire length of the hydraulic model. The intent of this study was to quantify the potential effects of material removal from the channel, therefore actual flows and water surface elevation data were not collected within the study area. That being said, the models and subsequent output are an estimate of the inundation that would occur if similar flows occurred in the study area.

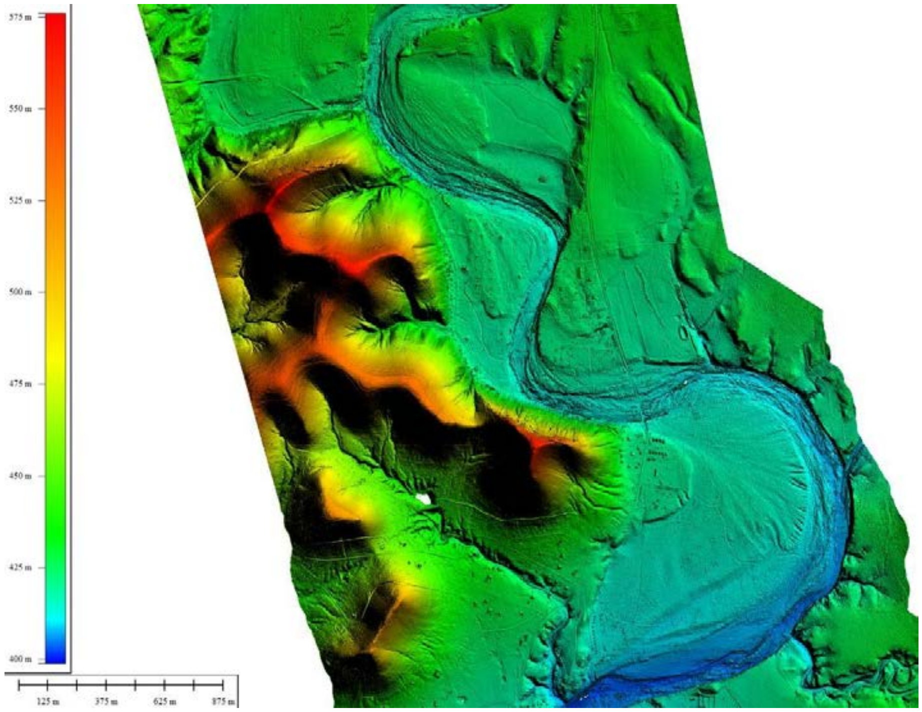


FIGURE 26.—Portion of the bare earth digital elevation model of the Frio River near Garner State Park.

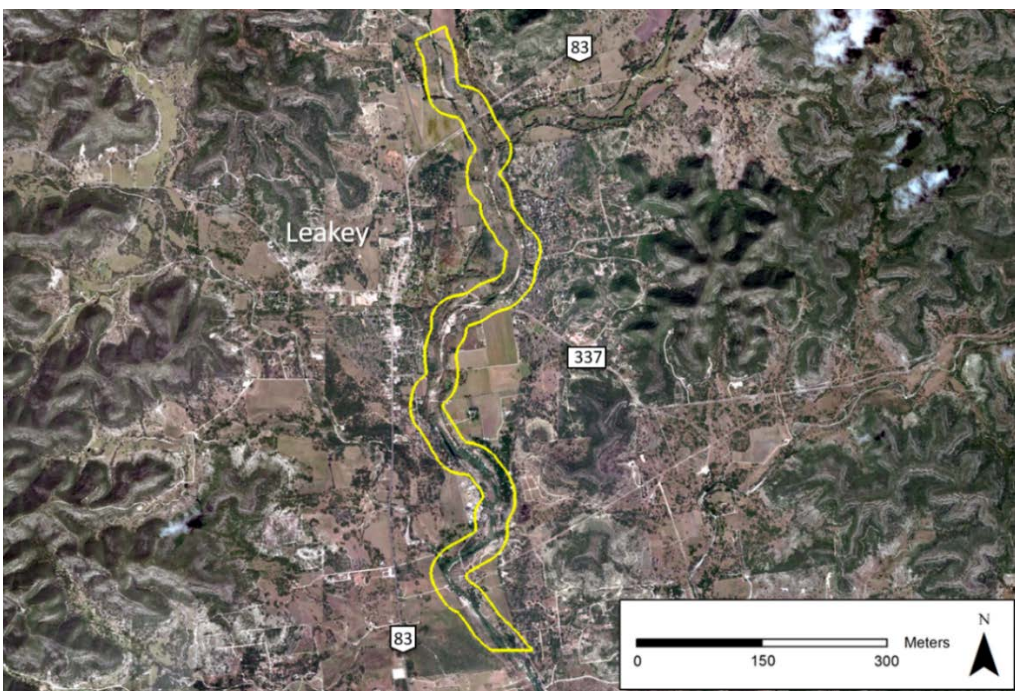


FIGURE 27.—Boundary of the two-dimensional model of the Frio River in Real County, Texas, from the confluence of the East and West Frio rivers to one mile downstream of the upper Ranch Road 1120 crossing.

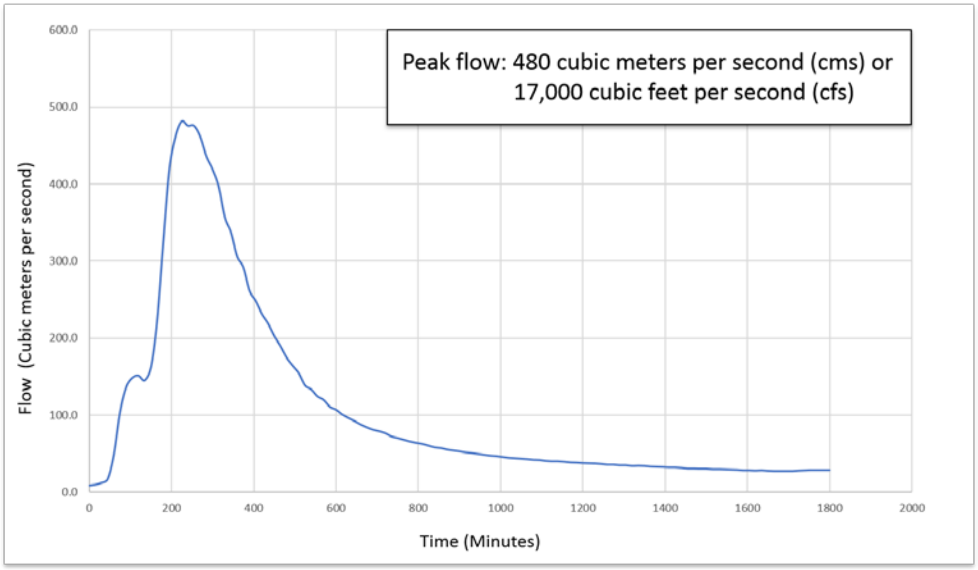


FIGURE 28.—Flow hydrograph for USGS gage number 08195000, Frio River at Concan, Texas, September 8, 2018.

The sediment analysis for this study was preformed using the AdH model in conjunction with a sediment transport library (SEDLIB). This method allows for assessment of capacity and transportation of silt, clay, sand, and gravel sediments through the system. It also assesses erosion and deposition within the system under different scenarios.

Three locations were selected for modeling of sediment removal (Figure 29). Three sediment removal amounts were modeled at each location: 76 m^3 (100 yd^3), 229 m^3 (300 yd^3), or 765 m^3 (1,000 yd^3). The first two scenarios are consistent with typical permitted sand and gravel dredging operations on the upper Frio River. The last scenario is representative of the maximum removal amount for a general use sand and gravel permit.

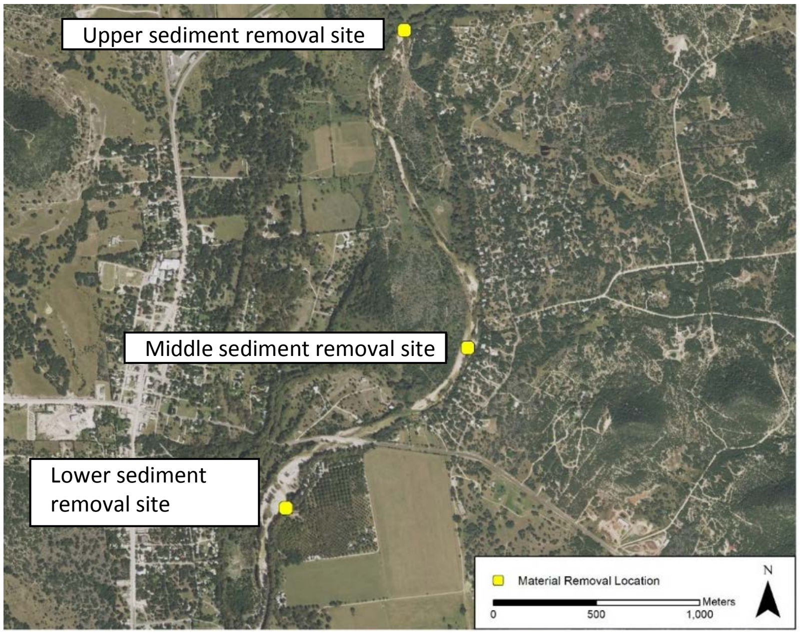


FIGURE 29.—Locations where sediment removal was modeled on the Frio River in Real County, Texas.

Results and Discussion: Bed gradations in the Frio River varied considerably both vertically and longitudinally along the river. Such high variability of bed material gradations is often found in gravel streams and also frequently in sand bed rivers. The bed material make up of the channel collected during this study and used in modeling is shown in Figure 30.

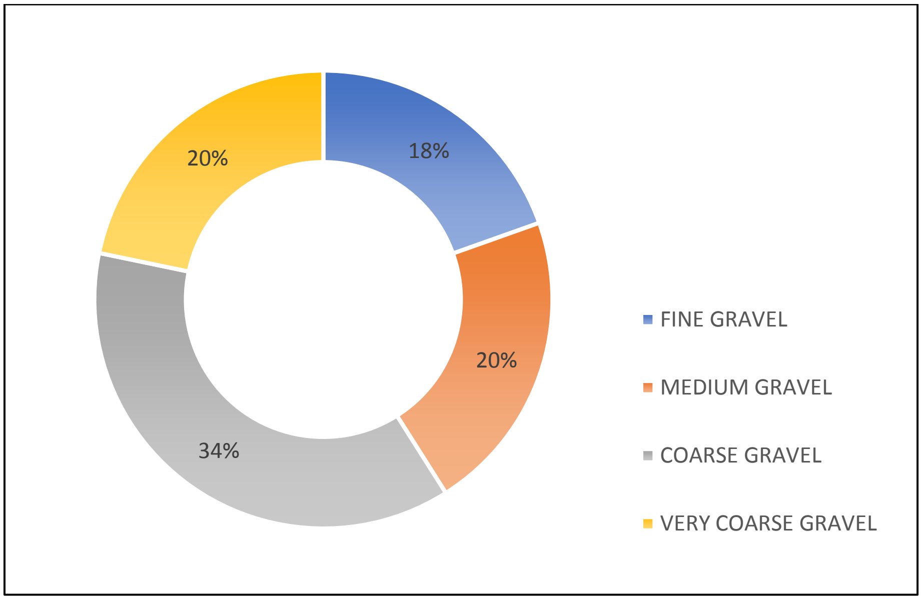


FIGURE 30.—Bed material types and proportions used in the model runs of the Frio River in Real County, Texas.

The model computed movement of very coarse gravel at the highest flows and only calculated significant bed material movement at flows over 350 cms (12,360 cfs). Computations show the river is moving more medium gravel than fine gravel (Figure 31). This indicates that the Frio River's capacity to carry fine gravel is limited by the amount of fine gravel in the river bed. Part of the difference between the fine gravel and medium gravel transport can also be attributed to the hiding of smaller gravel under and within the larger sized gravel.

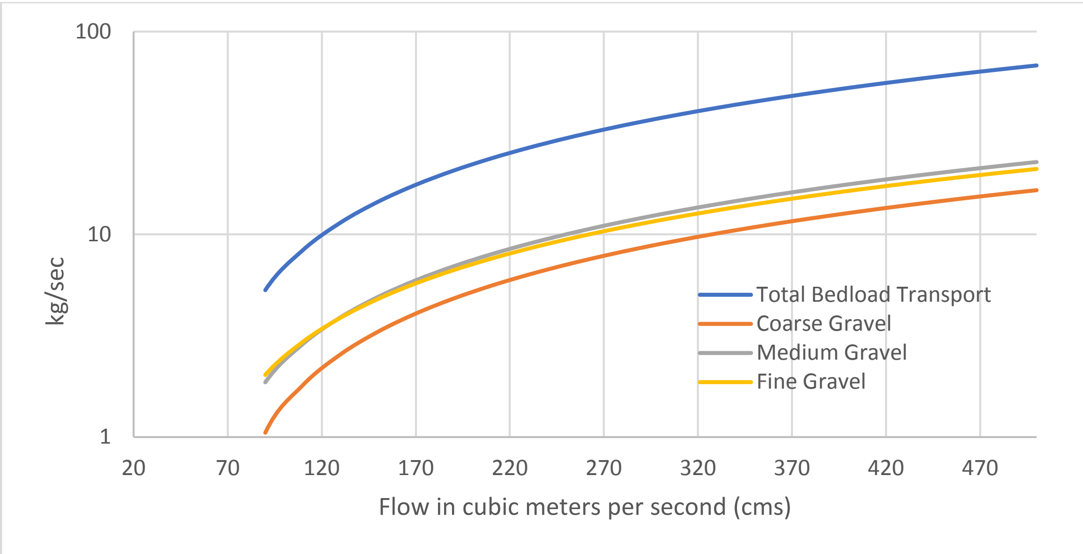


FIGURE 31.—Sediment rating curve for the Frio River at cross-section 12.

The model showed sediment deposition at each of the three material removal sites. Figures 32–34 show the base sediment model at three locations followed by the change in deposition and erosion patterns near those sites under three different removal scenarios (100 yd^3, 300 yd^3, and 1,000 yd^3). The base sediment runs show normal expected channel change related to the flood event (24-hour flow hydrograph) used in this study only. Therefore, the proposed material removal scenarios of 100, 300, and 1,000 cubic yards, at the three modeled locations fill (*i.e.*, induce sediment deposition) in the material removal sites and change deposition and scour patterns in areas adjacent to and for some distance downstream of the sites.

Table 12 shows the change in depositional quantities at each of the three material removal sites and for each removal quantity of 100, 300, and 1,000 cubic yards. The change in deposition quantities are for the center node of the removal area and most likely would not represent the largest nor average deposition in each of the material removal sites.

In reviewing Table 12, it can be seen that in the base sediment model run (no sediment removal) in the upper and middle sites show a tendency for a slight amount of erosion, while all three sediment removal scenarios (*i.e.* 100, 300, and 1,000 cubic yards) show a depositional pattern. The lower site tends to be slightly depositional in the base condition run and significantly more depositional in the sediment removal runs. The quantities may appear to be small but this deposition is taking place in a few hours during a single 24-hour storm. A similar storm to the one used in this study would be expected to occur, on average, at least once in any two year period (and may occur more often).

TABLE 12.—Deposition (in meters) at the center node of each material removal site.

	Upper Site	Middle Site	Lower Site
Base Sediment Run	-0.02	-0.06	0.08
Material Removal 100 yd^3	0.13	0.24	0.29
Material Removal 300 yd^3	0.13	0.22	0.30
Material Removal 1,000 yd^3	0.14	0.20	0.18

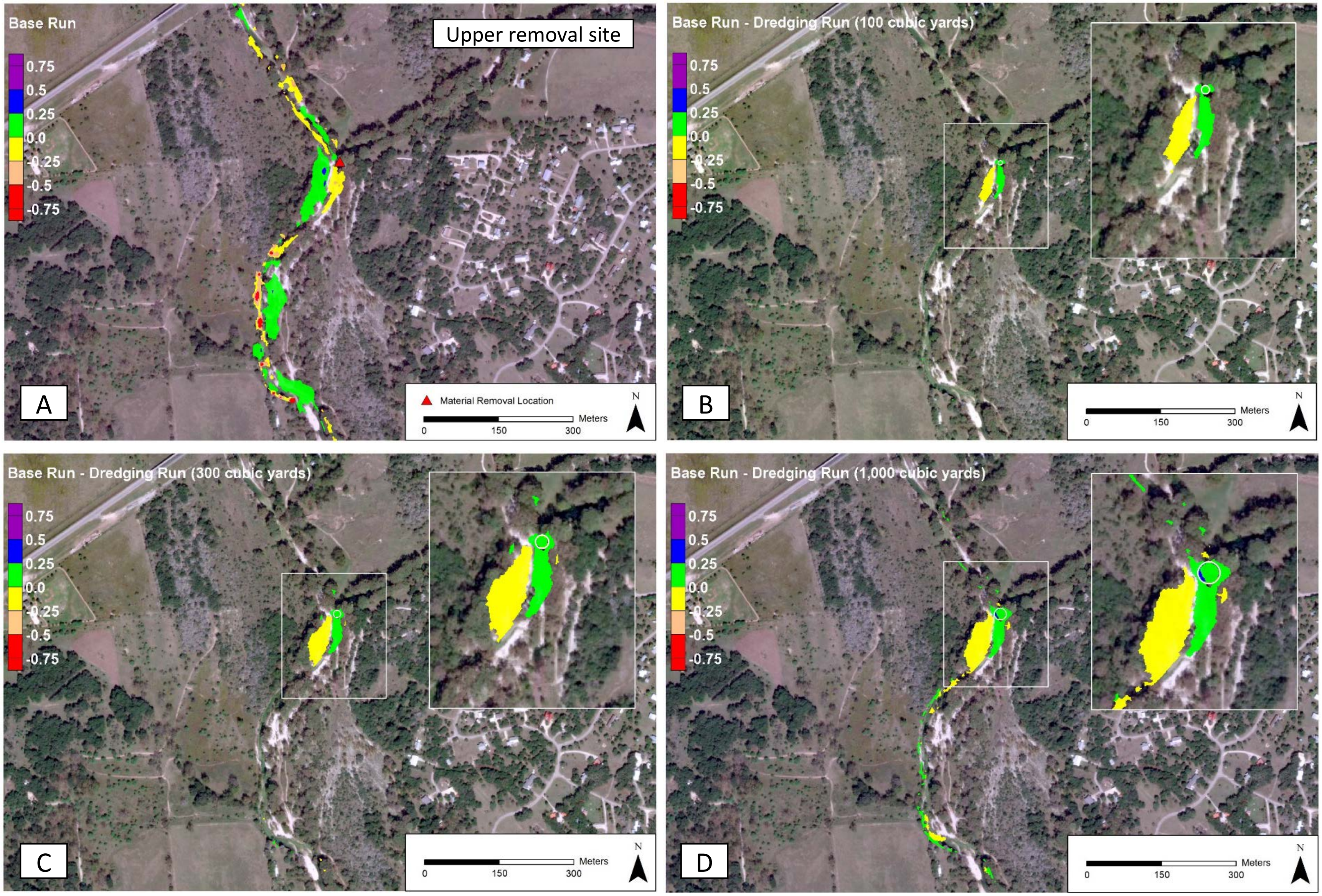


FIGURE 32.—Image (a) shows sediment transport model results for the upper sediment removal site (Figure 29) prior to sediment removal. This run serves as a control for sediment removal runs and displays sediment deposition (green to purple) and scour (yellow to red) in meters in response to a 480 cms (17,000 cfs) flood pulse. Modeled scenarios (b)–(d) show the change in deposition between the control and various levels of sediment removal. Those levels are as follows: (b) 100 cubic yards of material; (c) 300 cubic yards of material; and (d) 1,000 cubic yards of material. The white circle in images b–d denotes the location where material was removed.

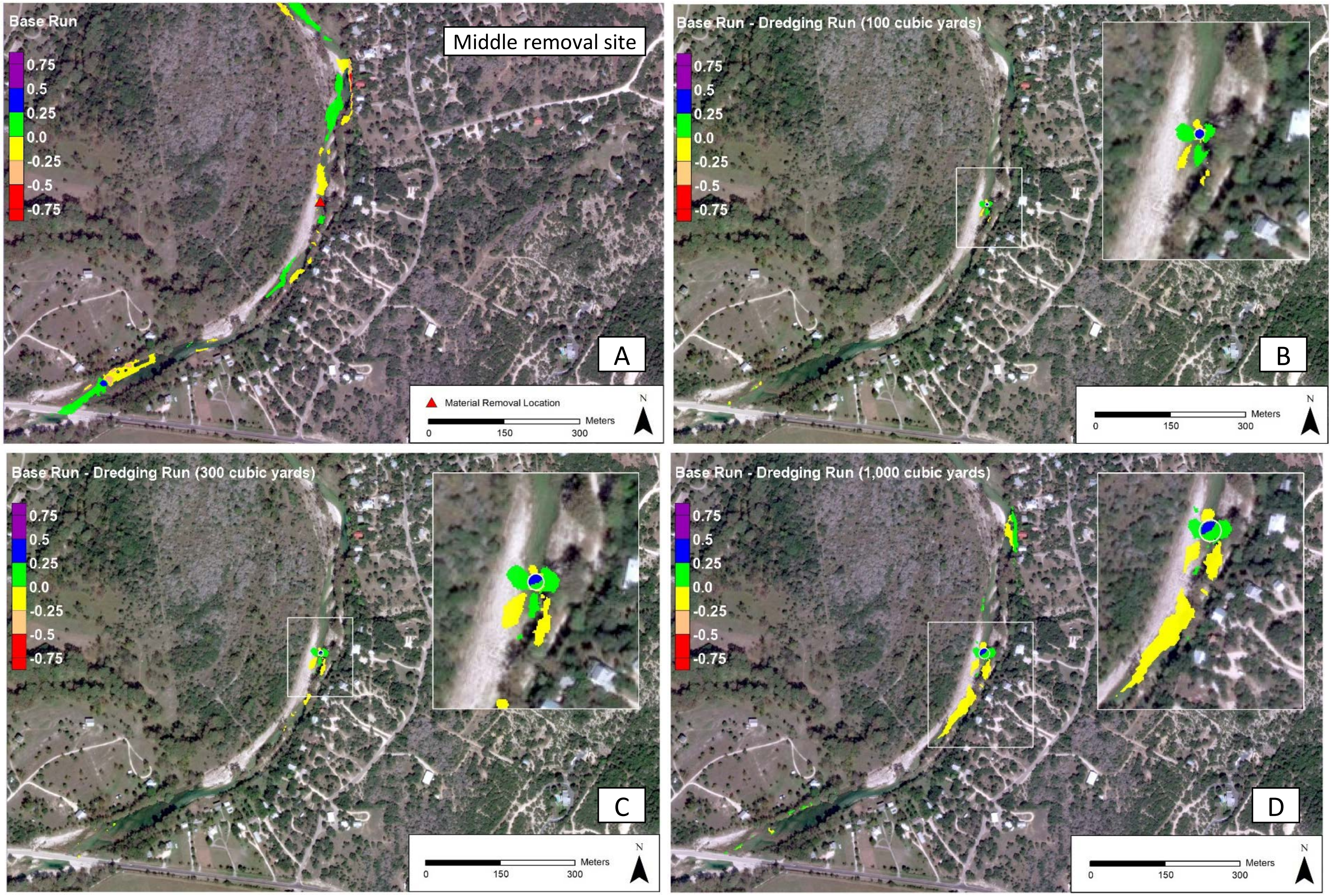


FIGURE 33.—Image (a) shows sediment transport model results for the middle sediment removal site (Figure 29) prior to sediment removal. This run serves as a control for sediment removal runs and displays sediment deposition (green to purple) and scour (yellow to red) in meters in response to a 480 cms (17,000 cfs) flood pulse. Modeled scenarios (b)–(d) show the change in deposition between the control and various levels of sediment removal. Those levels are as follows: (b) 100 cubic yards of material; (c) 300 cubic yards of material; and (d) 1,000 cubic yards of material. The white circle in images b–d denotes the location where material was removed.

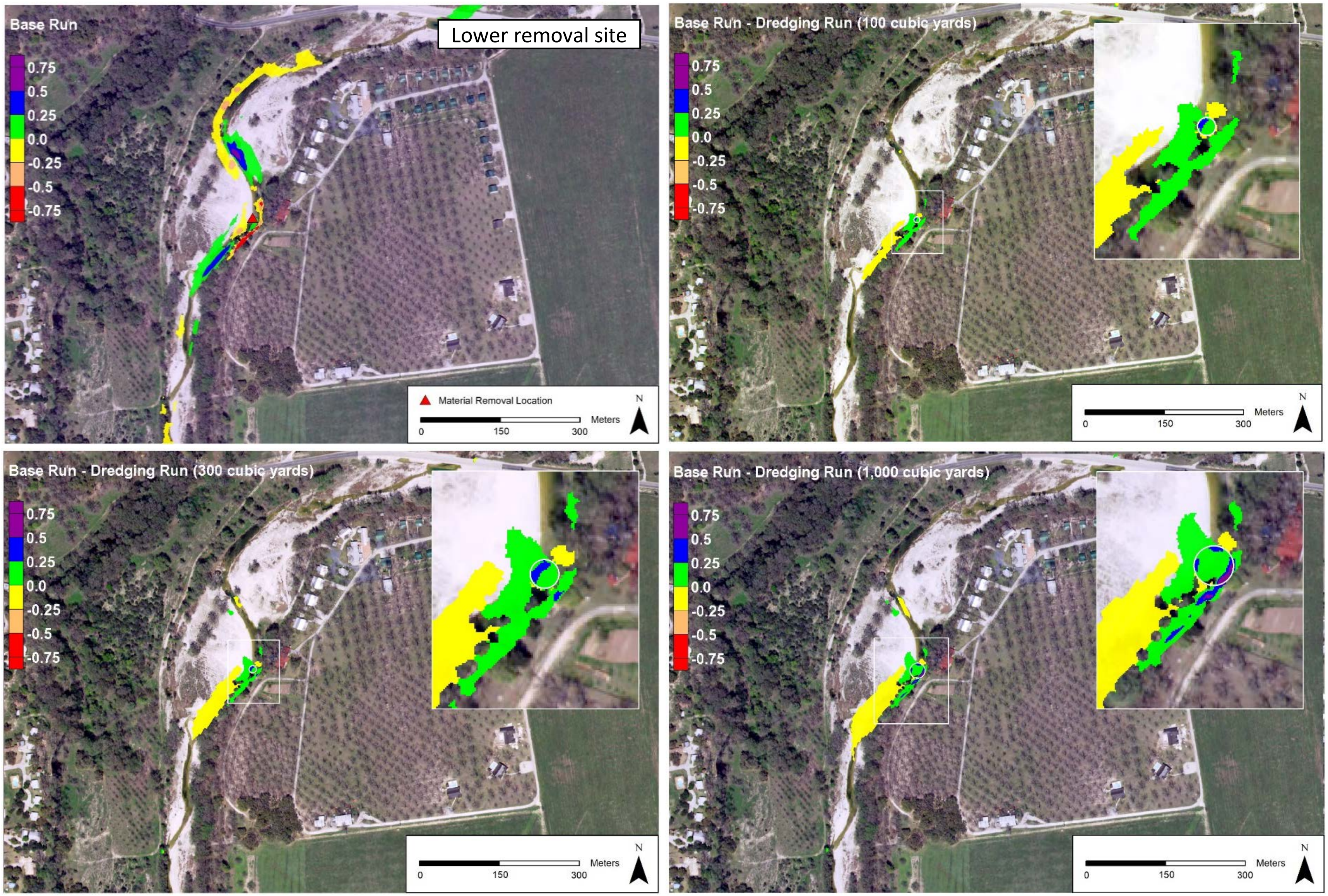


FIGURE 34.—Image (a) shows sediment transport model results for the lower sediment removal site (Figure 29) prior to sediment removal. This run serves as a control for sediment removal runs and displays sediment deposition (green to purple) and scour (yellow to red) in meters in response to a 480 cms (17,000 cfs) flood pulse. Modeled scenarios (b)–(d) show the change in deposition between the control and various levels of sediment removal. Those levels are as follows: (b) 100 cubic yards of material; (c) 300 cubic yards of material; and (d) 1,000 cubic yards of material. The white circle in images b–d denotes the location where material was removed.

When the sediment deposition pattern changes, the bedload movement in the channel must also change. Figures 35 and 36 focus on the upper removal site for the base sediment model run and the 1,000 cubic yard material removal scenario. The results for hour 2 of the model run are shown in Figure 35. For the base sediment model run at hour 2 (Figure 35–left), the sediment transport shows normal sediment bedload movement with the expected spacial variability that river flow patterns predict. In the 1,000 cubic yard material removal scenario (Figure 35–right), no sediment movement is seen in the area where the material was removed. The flow at hour 2 is about 150 cms (5,300 cfs) and with the additional depth of water where the material has been removed, the flow dynamics do not cause bed load movement.

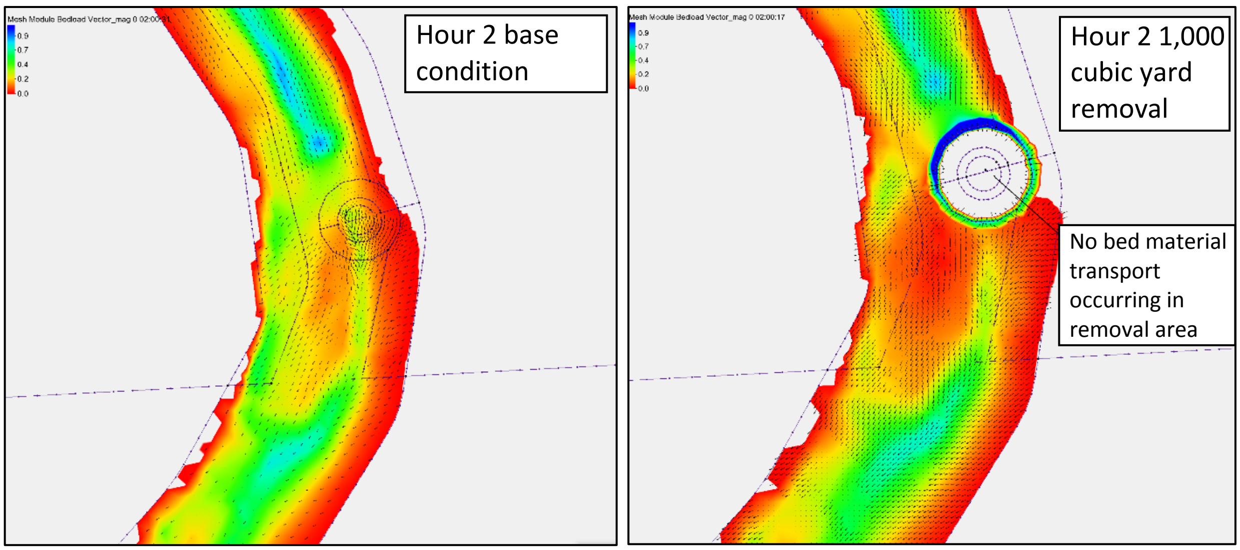


FIGURE 35.—Bedload transport magnitude in kilograms per second (Kg/sec; color scale) and direction (arrows) at hour 2 of the base sediment model run (left) and model scenario with 1,000 cubic yards of material removed (right) for the upper modeled sediment removal site.

The results of the base sediment and 1,000 cubic yard removal scenarios for hour 4 of the model run are shown in Figure 36.

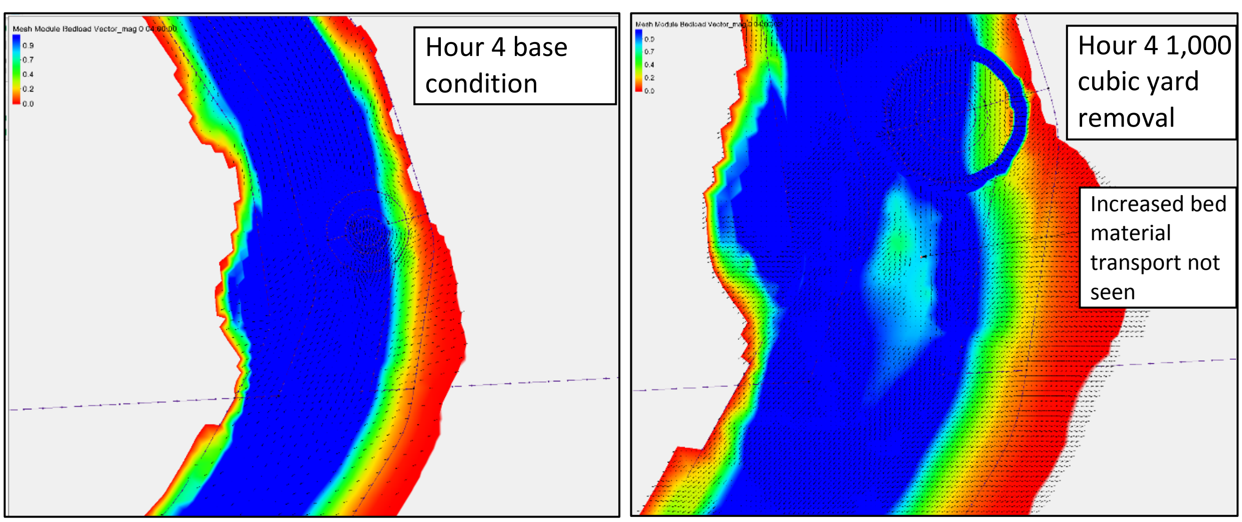


FIGURE 36.—Bedload transport magnitude in kilograms per second (Kg/sec; color scale) and direction (arrows) at hour 4 of the base sediment model run (left) and model scenario with 1,000 cubic yards of material removed (right) for the upper modeled sediment removal site.

At hour 4, the flow in the Frio River is about 470 cms (16,600 cfs). Figure 36 shows some disruptions to bedload movement around the area of the material removal site, but more importantly, it shows a region downstream of the material removal site that is experiencing lower bedload movement rates. This change in bedload is most likely resulting from a change in flow patterns and from the loss of bed material load due to sediment deposition replacing material removed for this scenario. The figure shows that if larger quantities of material are removed from the upper site, there is a corresponding larger amount of sediment being trapped at the site, and less bed material load will be transported downstream.

The model runs of the 100, 300, and 1000 cubic yard dredging scenarios at the three modeled locations show a tendency for the dredge sites to re-fill (*i.e.,* induce sediment deposition) over time under high flow conditions, as well as, to change deposition and scour patterns in areas upstream and downstream of the sites. These results are consistent with the principles of fluvial geomorphology, which indicate that in-channel material removal typically causes incision (down-cutting or degradation) both upstream and downstream of an excavation pit (Figure 37).

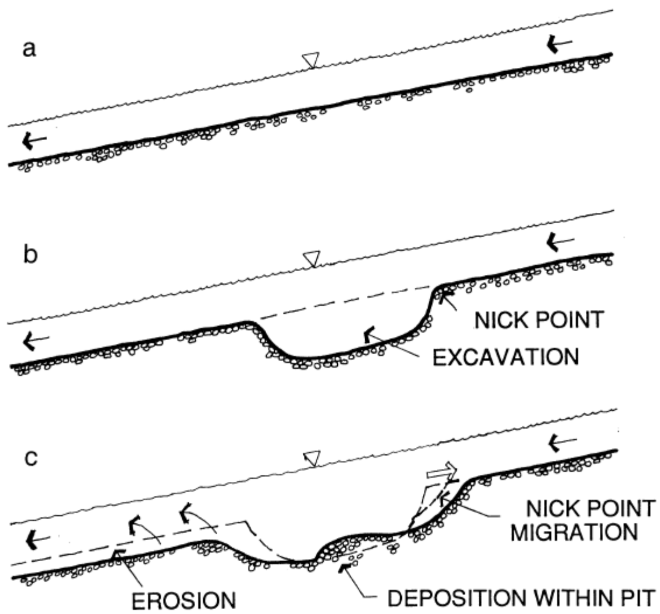


FIGURE 37.—Impact of an in-channel pit on channel stability. A stable channel (a) is lowered in a localized area by excavation of material (b). Over time (c), the channel is lowered by means of a nick point migration (upstream) and erosion (downstream; Kondolf 1997).

Part (a) of Figure 37 shows the profile of a stable river channel prior to material removal. The flow and sediment load moved by the flow are the same along the length of the stream segment. Dredging of sediment from the streambed, shown in part (b), lowers the channel elevation in a portion of the channel. Flow in the entire stream segment remains the same as during the pre-excavation condition. At the top of the stream segment (right side of the figure), the sediment moved by the flow also remains at pre-disturbance levels; however, in the area of the pit, flow depth increases dramatically, reducing the velocity and capacity of the flow to transport sediment. A portion of the sediment carried by the water drops out and begins to build up the bottom of the pit. Downstream of the pit (left side of the figure), a much shallower flow depth is reestablished, increasing the velocity and capacity of the flow to move sediment.

This so-called “hungry water”, which lost some of its sediment load in the excavation pit, now mobilizes sediment from the bed of the channel downstream of the pit until the sediment load reaches pre-disturbance levels.   This process down cuts the bed of the channel downstream of the pit (termed degradation or incision). At the same time, the steep head wall upstream of the pit is susceptible to collapse, further building up the material in the bottom of the pit. Head wall collapse sends a nick point moving upstream, much like a head cut in a gully, lowering the bed elevation of the channel upstream of the pit as well.

The channel shape (geometry or bathymetry) of an alluvial river adjusts in response to the range of flows that mobilize the boundary sediments. A stable channel shape is important because it maintains habitat conditions that support biological resources both within the channel and in near-channel riparian areas. Material removal is damaging if it negatively impacts the long-term creation and maintenance of desired aquatic and riparian habitats. Beyond material removal, changes in the flow regime of a stable channel can also cause unstable conditions due to changes in the rate of erosion, sediment transport, and/or sediment deposition.

Because sediments are constantly moving within a river system, in an unimpacted river channel shape is also always adjusting from these movement to create a stable channel, or what river engineers call “dynamic equilibrium.” This means that while these changes and adjustments are occurring naturally, in stable channels they are happening in balance with one another such that the stream neither aggrades (fills in with excess sediment), nor degrades (excessively erodes). Once dynamic equilibrium is disrupted, the channel will be unstable while these processes work to reestablish equilibrium. The channel does this by changing the channel geometry (width, depth), width-depth ratio, sinuosity, and slope (Schumm, 1969). Such changes in channel geometry have the potential to alter the amount and nature of aquatic and riparian habitats and therefore biological communities.

Once a stream has been subjected to activities that cause a disruption in stream processes (i.e. gravel mining, road crossings that inhibit sediment transport, or land management practices that allow for excessive erosion and sedimentation into the stream), over time the changes within the channel geometry will eventually stabilize as the stream reaches a new dynamic equilibrium. While it seems intuitive to remove excess sediment from the streambed, by doing so, this itself causes a disruption and further delays the ability of stream processes to re-establish a dynamic equilibrium. Excessive erosion and deposition will continue until the stream has time to reestablish a new geometry to accommodate the movement of sediment and hydrology.

SUMMARY AND RECOMMENDATIONS

Fish and benthic macroinvertebrate data collected in the upper Frio River in 2018 as a part of this study did not fully meet surface water quality standards (TCEQ 2018). This suggests an overall degradation of the biotic integrity of the system. The benthic macroinvertebrate assemblage appears to be faring better than the fish; however, it also showed signs of degradation in some reaches. Water quality met standards throughout the study area, with the exception of one TDS measurement from reach 20. While no direct correlations between sand and gravel activity levels and biological or water quality data were detected in the upper Frio River, it is important to note that permitted sand and gravel dredging activities had been halted for a year prior to collection these data. This was likely sufficient time for natural recovery in impacted reaches. Observed biologic degradation is likely the result of continued bed disturbance from several factors including sand and gravel dredging, high levels of recreational use, degraded riparian corridors, and dams and low water crossings which impede sediment transport.

The riparian corridor ranged from exceptional to dysfunctional. Noted riparian deficiencies were due to an excess of gravel deposition downstream of sand and gravel dredging or road crossings that impede sediment movement, channel down-cutting leading to a loss of connectivity of the stream to its floodplain, and a reduction in new plant regeneration, diversity, and vigor due to landscaping practices and widespread trampling from recreational access.

The baldcypress population of the upper Frio River appeared healthy and no major concerns were noted, except for the lack of recruitment of young trees in some reaches with degraded riparian corridors. Riverside trees and those located off water had similar growth rates, indicating no impact to trees located on abandoned river channels. Cored trees were estimated at ages ranging from 64 to 352 years old.

The sediment transport models demonstrated that when gravel is removed from the streambed, the holes created from the excavation of the sediment are re-filled during large flood events and the areas upstream and downstream of gravel removal sites are impacted by changes in scour and deposition patterns.

Implementation of the following recommendations can prevent further degradation of the biological assemblages and riparian habitats of the Frio River:

- *Redesign or alter road crossings*: While not directly studied in this project, field observations noted that some road crossings on the Frio River act as sediment transport and fish passage impediments; therefore, as road crossings are repaired or rebuilt, they should consider the accommodation of the bank full channel to allow for sediment transport. This will prevent the backing up of water and sediment behind the crossings, which in turn is causing head cuts up stream, further compounding sediment issues many streamside landowners are now experiencing.
- *Maintain or restore riparian areas*: Riverside landowners can allow for a more diverse array of vegetation by reducing mowing, weed eating, and trampling of banks through recreational access by the creation of targeted access sites. By concentrating access in a smaller area, the landowner will then allow for healthier riparian habitats, which in turn will help to anchor the soil, prevent erosion, trap and filter sediment, and provide shading to the stream.

- *Protect baldcypress*: Riverside landowners with baldcypress trees can help stabilize the sediment around roots by planting native riparian grasses and sedges (i.e. sawgrass, switchgrass, emory sedge, etc.) within and around exposed roots. Landowners can contact TPWD for assistance in selecting appropriate plants and to explore cost-sharing options. It is also important to avoid compaction of sediment around roots by eliminating use of heavy machinery and reducing foot traffic in areas directly surrounding baldcypress trees.
- *Reduce instream disturbances*: Instream disturbances, such as dredging, reduce channel stability and alter sediment transport dynamics of a stream system. Dredging, regardless of the scale of the project, has some impact on erosion and deposition rates upstream and downstream of the dredged site. Continued disturbances from these activities impact the streams ability to reestablish a dynamic equilibrium. Any instream dredging should be limited to essential needs and have in place methods to mitigate up and downstream impacts.

Stable streams are ones in which a dynamic equilibrium in sediment transport exists. This means that there are always changes occurring within the stream, but those changes are happening in balance with one another such that the stream neither aggrades (fills in with sediment) nor degrades (excessive erosion) over time. When sand and gravel dredging, improperly designed road crossings, degraded riparian habitats, and other in-stream structures (i.e. dams) are present, these changes disrupt natural stream function. When these activities lead to changes in the sediment regime, the system stays out of balance and scour and deposition rates are drastically altered and can lead to accelerated channel aggradation and/or degradation. Evidence from this study suggests that the upper Frio River is not functioning in a state of dynamic equilibrium or meeting the exceptional aquatic life use standards set by the TCEQ.

Frio River at Garner State Park *Photo by Clint Robertson*

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APPENDIX A

Stakeholder Comments

Dear Ms. Parker,

My family has owned a house and property along the Frio River for over 50 years. We were downstream from a site where swimming holes were dug out and gravel dams constructed numerous times for over 25 years. We were unaware of the permitting process until more recent years.

The river changed quite bit throughout that time of construction in the river. More subtle changes at first, then increasing impact became obvious to most anyone, then up to the point where family members wouldn't even want to visit the Frio due to such poor river conditions. On our stretch of the river, massive amounts of silt appeared, more and more over time. The silt hadn't been there before and still doesn't exist upstream of the gravel construction site. We witnessed a reduction in the number of bass, sunfish, crawfish and fish nests, while all appear to have continued to be to be present upstream, above the site. There had been a significant change in the type of aquatic vegetation on our stretch of the river, while there was no noticeable difference in the vegetation upstream of the site. The composition of fish types throughout the years changed as well. The river became increasingly murky in the deeper pools where it had been clear prior to the years of gravel construction. We never found any such murkiness in the river upstream of the site. Everyone along the river has been complaining about ever-increasing gravel build-up coming in after flood events. I'd suspect it's quite a bit worse on our stretch of the river due to all the construction.

I'm not sure what the Texas Parks & Wildlife study will show regarding the impact of permits, however, any family member and most of our guests have clearly witnessed that our stretch of the river was severely impacted by gravel construction upstream throughout the past 25 years.

If more of this type of gravel construction is allowed into the future by Texas Parks & Wildlife, I'd recommend a much more thorough process to insure that the entire upper Frio isn't impacted like ours had been.

Thank you for all your efforts to study the impact of granting such permits.

A Concerned Riverside Landowner

Dear River Study Team:

Thank you all for your participation in the Frio River study. I believe that the study is invaluable to the future preservation of the pristine Frio River.

As a Texan who has enjoyed yearly family vacations on the Frio for over 20 years, I am delighted to learn that the study showed the Frio River to currently be healthy; and, because
I want to continue to enjoy that beautiful part of Texas, I want to do what I can to make sure that this river (and others) stays healthy.

My position is:

1. The **moratorium on all Sand and Gravel Permits along the Frio River should continue** until such time there is a process in place to inspect and certify compliance with the terms of a permit.

2. An application for a permit should include an environmental impact statement and remediation for any negative impacts.

3. Any permit should be subject to oversight AND inspection to certify that the work was done in compliance with the terms of the permit. If permits are granted, there must be some way to make sure
that the work was completed as specified in the permit guidelines.

4. Property owners who will be affected by a Sand and Gravel Permit should be notified when a permit is filed in order to provide for review of the environmental impact statement and comment before
the permit is approved. Comments should be taken into consideration in the terms of the approved permit.

5. Each permit should have its impact modeled and those impacts found acceptable to downstream landowners -- at a minimum.

In 2017 while floating on the Frio, I remember seeing large, large piles of gravel laying just off to the side of the river in the area of Criders Resort. At the time I did not understand why it was there. I now
believe the piles of gravel resulted from **non compliance to** terms contained in a Sand and Gravel
permit. Specifically -- failing to relocate the dredged gravel to a location outside of the hundred-year flood plain. Issuance of a permit having no oversight, no inspection, and no certification of compliance, along with the flooding in the fall of 2018, caused damage downstream to a beautiful, natural, deep swimming hole which
we have enjoyed for many years. IT IS NOW FILLED WITH GRAVEL. Because of the lack of PERMIT MANAGEMENT we have also observed a significant acceleration of erosion downstream from the disturbing and taking of the gravel.

During the many years that we have visited and floated the Frio we have always enjoyed the beauty of the river; and therefore, we have always taken care not to leave our mark on the river when we left. I know that not all visitors
feel the same or care what they leave behind; but I hope that that feeling does not extend to officials who can do something about keeping the river clean and healthy. Please give serious consideration to the concerns I expressed
above.

Also, please forward this information to any agency, commission, or person who is involved in the extension of the moratorium.
DON'T MESS WITH TEXAS' RIVERS!

Respectfully,
Marilyn Wright

Dear Ms Robertson,

My family has owned property along the Frio River for south of Rio Frio, Tx for 50 years. Over the years, the river has changed due to the natural evolution of riverways. We have to understand and deal with nature and any unwanted consequences. However, recent changes to the Frio River are due to individual and institutional negligence. Excavation of sand and gravel without regard to the impact on other property owners along the river should not be tolerated.

The **moratorium on all Sand and Gravel Permits along the Frio River should continue** until such time there is a process in place to inspect and certify compliance with the terms of the permit. An application for a permit should include an environmental impact statement and remediation for any negative impacts. Any permit should be subject to oversight and inspection to certify that the work was done in compliance with the terms of the permit.

Property owners who will be affected by a Sand and Gravel Permit should be notified when a permit is filed in order to provide for review of the environmental impact statement and public comment before the permit is approved.

Signed,
Janet Eakes

Dear Mr. Heger,

My family has owned property and a home along the Frio River south of Rio Frio, Tx for 50 years. Over the years, the river has changed due to the natural evolution of riverways. We have to understand and deal with nature and any unwanted consequences. However, recent changes to the Frio River are due to individual and institutional negligence. Excavation of sand and gravel without regard to the impact on other property owners along the river should not be acceptable.

The **moratorium on all Sand and Gravel Permits along the Frio River should continue** until such time there is a process in place to inspect and certify compliance with the terms of a permit. An application for a permit should include an environmental impact statement and remediation for any negative impacts. Any permit should be subject to oversight and inspection to certify that the work was done in compliance with the terms of the permit.

Property owners who will be affected by a Sand and Gravel Permit should be notified when a permit is filed in order to provide for review of the environmental impact statement and comment before the permit is approved. Comments should be taken into consideration in the terms of the approved permit.

Signed,

Linda K Cherrington

Linda K. Cherrington

Good morning, Melissa,

I am a land owner on the Frio River. I am writing to express my deep concern for, and opposition to, allowing property owners to dredge/dig on the Frio. We are grateful to have such a healthy river and work hard to maintain its natural, healthy environment. Not only will digging disturb all of the natural balances in the river, but it will also endanger many river species. Our land is in a trust and tiered for three generations. It is located next to a conservation and a quiet neighborhood. All of our community works to keep our river clean and natural.

I am aware that many camps and land owners would like to change their river frontage by digging deeper swimming holes to have a more desirable swimming area. The river is forever changing with each rise. Having purchased our land in 1974, we have witnesses many changes in depth of areas, as well as, rerouting of the flow due to nature. A deep area can become a shallow area after a rise. We cannot just dig and dredge. Number one, this disrupts wildlife and fish. Number two, it is not a fix! The Frio is a natural river. Let it run as it always had. Number three, digging a nice swimming hole upriver, has an impact on all of us down river. Where do you think the rocks go? It causes everything down river to turn completely muddy and shallowness for everyone downstream. Build a swimming pool if maintaining a "deep swimming hole" is of such importance. This is a river. It will never remain constant. The only solution to this, is to build a permanent swimming pool. Digging would be required all the time in order to maintain a desired, deeper, "swimming hole" resulting in constant interruption of the Frio and destroying the natural balance.

Please protect our Frio, the wildlife that inhabits it, and the natural balance that allows the Frio to be one of the few, clean, balanced rivers that Texas has left.

Thank you for your time and consideration. This is of extreme importance. Save our rivers.

Regi J. Bright

Ms. Parker,

I appreciate the work and studies that TPWD have done and continue to do to monitor the quality of the Frio River. I also realize that your agency is under pressure from some Real County resort and property owners to allow permits for dredging the Frio in certain locations for what those owners consider improvement of their "swimming holes." However, as a property owner in the southern part of the Frio River area, I have observed the changes in the water quality in our area after some of that dredging was done in the past. The water in our area south of Hwy. 1120 had a muddy appearance and a different smell for several days after those dredging events occurred up river.

That type of disruption of the river's water as well as the grounds below and beside the river are not the kind of result that we can ignore and expect the Frio to continue to be the special waterway it is in the state of Texas. The short term "improvements" of dredging are not worth the long term negative effects that can occur. Therefore, I hope TPWD will continue to avoid granting any dredging permits for the Frio River except for emergency needs.

Sincerely,

Betsy Polgue

PROTECT THE FRIO RIVER

Melissa Parker,

It is my understanding , that past permits have been issued without OVER SITE DURING THE EXECUTION OF THE PERMIT, AND NO INSPECTION to certify that the work was done in compliance with the terms of the permit. Specifically the permit term to "relocate the dredged gravel to a location outside of the hundred year flood plain."

The moratorium on all Sand and Gravel Permits must continue until such time there is a process in place to inspect and certify completion of the permit as to the terms stated in the permit.

Additionally, using property tax records, institute a notification by mail,to all of the property owners, both upstream and down stream within a mile of the permit location, at the time the permit application is filed.

Each permit should have its impacts modeled and those impacts found acceptable to downstream landowners, at a minimum.
DON'T MESS WITH TEXAS' RIVERS!

Please forward this information to any agency, commission or person who is involved in the extension of the moratorium.

Sincerely,
Paul Hardwick

It is my understanding, that past permits have been issued without OVER SITE DURING THE EXECUTION OF THE PERMIT, AND NO INSPECTION to certify that the work was done in compliance with the terms of the permit. Specifically the permit term to " relocate the dredged gravel to a location outside of the hundred year flood plain."

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DON'T MESS WITH TEXAS' RIVERS!

Please forward this information to any agency, commission or person who is involved in the extension of the moratorium.

Sincerely,

Susan Burch

Dear River Study Team,

Thank you all for your participation in the Frio River study. The Study is invaluable to the future preservation of the Pristine Frio River.

It was great to see that the study showed that River is currently healthy.

You all made a great team.

My position is:
The **moratorium on all Sand and Gravel Permits must continue** until such time there is a process in place to inspect and certify completion of the permit as to the terms stated in the permit.
Additionally, using property tax records, institute a notification by mail,to all of the property owners, both upstream and down stream within a mile of the permit location, at the time the permit application is filed.
Each permit should have its impacts modeled and those impacts found acceptable to downstream landowners, at a minimum.

It is my understanding, that past permits have been issued without OVER SITE DURING THE EXECUTION OF THE PERMIT, AND NO INSPECTION to certify that the work was done in compliance with the terms of the permit.

In 2017 and 2018 , while floating, I remember seeing large, large piles of gravel laying just off to the side of the river in the area of Criders Resort.

At the time I did not understand why it was there. I now believe the piles of gravel resulted from **non compliance** to the terms contained in a Sand and Gravel permit. Specifically, failing to relocate the dredged gravel to a location outside of the hundred year flood plain.

Issuance of a permit having no over site, no inspection and no certification of compliance , and the flooding in the fall of 2018, caused damage downstream to our beautiful, natural, deep swimming hole which we have shared, protected and enjoyed for 48 years. IT IS NOW FILLED WITH GRAVEL.   Because of the lack of PERMIT management we have experienced a significant acceleration of erosion downstream from the disturbing and taking of the gravel.

We have owned our river property a since 1972. It is located about two tenths of a mile down stream of Criders Frio River Resort .
Our property is located in The Chisum Subdivision, which includes land on both sides of the river.
We have always practiced good riparian ownership.
We have made the "float" on the Frio from 1120 crossing down to our property thousands of times.

DON'T MESS WITH TEXAS' RIVERS!

Save our rivers,
Caitlin Wylie

Dear TP&W Frio River Study Personnel,

Thank you for your diligent efforts in evaluating how best to do the work of TP&W in protecting the Frio River. In the event the moratorium on Sand and Gravel Permits is lifted, I sincerely believe the permitting process needs to be overhauled. Below are some suggestions to add to the permitting process.

<u>If Sand and Gravel Permits are resumed:</u>

(1) The number of permits should be limited to only what is deemed can be handled by the river, (i.e., flooding events that cleanse the river will allow more permits that year, etc.). Perhaps a waiting list could be established.

(2) A permit should only be for a one-time disturbance event, not over a period of time.

(3) Both the Landowner and Contractor should be the Applicant and sign the permit application.

(4) The "terms and conditions" of the permit should be specifically initialed or acknowledged in some manner to better insure Permittee's understanding of TP&W's expectations.

(5) TP&W personnel should personally discuss with Applicant their explanation of how they intend on complying with the terms and conditions. Applicant's explanation should be made clear and specific before the granting of a permit.

(6) Permittee should be required to give TP&W prior notice of the specific date the river work/disturbance will occur. Failure to do so, should result in revocation of the permit.

(7) The Applicant (Landowner and Contractor) should acknowledge in the permit application whether either has engaged in unauthorized work in river (a disturbance) within the 6 months prior to the application and pledge not to do so in the future.

(8) TP&W should visit the disturbance site either during or soon after to make a timely notation on whether the work appears to be generally in compliance with the Permit.

(9) A violation should have consequences (i.e., lose the right to be granted future permits and/or a monetary penalty; and an escalated penalty for a 2nd violation or unauthorized work).

(10) Should consider whether permit applications should be divided into classes based upon the size and scale of the particular disturbance being applied for. Such that, if the surface area of the bottom to be disturbed is less than 5,000 sq. ft, it would be deemed a "Residential" Permit. Anything larger deemed a "Commercial" Permit. More Residential Permits would be granted by TP&W and perhaps involve a less scrutiny than a Commercial Permit.

(Optional for Consideration) - An Applicant (or certainly a violator) should be required to attend a TP&W approved workshop.

Anonymous, from a long time riverfront landowner

Dear River Study Team,

Thank you all for your participation in the Frio River study. The Study is invaluable to the future preservation of the Pristine Frio River.

I attended all the meetings that we're held in Leakey concerning the Frio River study.

I was great to see that the study showed that River is currently healthy.

You all made a great team.

My position is:

The **moratorium on all Sand and Gravel Permits must continue** until such time there is a process in place to inspect and certify completion of the permit as to the terms stated in the permit.

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Please forward this information to any agency, commission or person who is involved in the extension of the moratorium.

Respectfully,

Gary & Janet Eakes

Good morning,

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We have always practiced good riparian ownership.

We have made the "float" on the Frio from 1120 crossing down to our property thousands of times.

I have included a photo dated September 2017 of our beautiful solid rock natural swimming hole, full of fish. Literally thousands of floaters would stop each year to enjoy this spot in the river.

DON'T MESS WITH TEXAS' RIVERS!

Please forward this information to any agency, commission or person who is involved in the extension of the moratorium.

Respectfully,
Francie Wylie

Good morning my name is Jimmy Boyd and I'm a property owner on the Frio River below Rio Frio. I'm concerned about land owners wanting permits to dredge in the Frio River for their own benefit. The Frio is a very fragile river system that over the years has been abused by land owners and the public. I understand that people want their own little swimming holes. Most people don't understand that when you dredge the river and break through the bedrock that this will allow for the water to go back underground. The Frio River goes underground several places down stream of Concan before reaching Choke Canyon. I knew when I purchased my property that at times the river might not provide the ideal swimming conditions but that was alright because I knew how the river system works. This river is feed by underground springs only so when the spring levels drop due to lack of rain things slow down. Again I feel that these land owners that are wanting the permits is for their benefit only and not in the interest of others or the river. I would hope that TPWD would not grant any permits for any type of dredging on the Frio River. Thank you for your time. Fill free to call me with any questions about this anytime.

Jimmy Boyd

Good morning, Melissa,

I am a land owner on the Frio River. I am writing to express my deep concern for, and opposition to, allowing property owners to dredge/dig on the Frio. We are grateful to have such a healthy river and work hard to maintain its natural, healthy environment. Not only will digging disturb all of the natural balances in the river, but it will also endanger many river species. Our land is in a trust and tiered for three generations. It is located next to a conservation and a quiet neighborhood. All of our community works to keep our river clean and natural.

I am aware that many camps and land owners would like to change their river frontage by digging deeper swimming holes to have a more desirable swimming area. The river is forever changing with each rise. Having purchased our land in 1974, we have witnesses many changes in depth of areas, as well as, rerouting of the flow due to nature. A deep area can become a shallow area after a rise. We cannot just dig and dredge. Number one, this disrupts wildlife and fish. Number two, it is not a fix! The Frio is a natural river. Let it run as it always had. Number three, digging a nice swimming hole upriver, has an impact on all of us down river. Where do you think the rocks go? It causes everything down river to turn completely muddy and shallowness for everyone down stream. Build a swimming pool if maintaining a "deep swimming hole" is of such importance. This is a river. It will never remain constant. The only solution to this, is to build a permanent swimming pool. Digging would be required all the time in order to maintain a desired, deeper, "swimming hole" resulting in constant interruption of the Frio and destroying the natural balance.

Please protect our Frio, the wildlife that inhabits it, and the natural balance that allows the Frio to be one of the few, clean, balanced rivers that Texas has left.

Thank you for your time and consideration. This is of extreme importance. Save our rivers.

Thank you,
Ian and Sara Groff

Good morning, Melissa,

I am a land owner on the Frio River. I am writing to express my deep concern for, and opposition to, allowing property owners to dredge/dig on the Frio. We are grateful to have such a healthy river and work hard to maintain its natural, healthy environment. Not only will digging disturb all of the natural balances in the river, but it will also endanger many river species. Our land is in a trust and tiered for three generations. It is located next to a conservation and a quiet neighborhood. All of our community works to keep our river clean and natural.

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Thank you for your time and consideration. This is of extreme importance. Save our rivers.

Page H. Hall
Executive Director
CASA of the Coastal Bend

Good morning. We want to thank you for the workshop, in which the preliminary results of the Frio River Study were shared. We would to share a few of our comments indicating what additional information need to be included in the Study.

It is no secret that Tex DOT and the Real & Uvalde Counties have several road crossings that do not enhance to efficiency and effectiveness of the river. The stake holders along the Frio River can try and improve the river's effectiveness, but poor river crossings will undo what ever we do. As part of the river study, we would like to have your team assess each of the river crossings. We would like to see two lists, one for state owned crossings and one for county crossings, be develop listing the crossings in highest priority to lowest priority as to what needs to be done to correct the inefficient crossings. We realize this will take time but we would like the highest priority crossing to submitted to the State and Counties respectfully in order to be considered for funding. In addition, we would like your Team to also develop a "stop gap" measures for each of the crossings, that will be cheaper but possibly be completed in the near future to alleviate some of the issues at these crossings. We believe that small steps are better than no steps. Your Team and the Property owners made many inroads working in small steps. Just addressing the Arundo plant is one of the success stories we have.

Concerning the Cypress Tree Study presentation by Jeff McFall, we were disappointed in his presentation. All the other speakers stayed within their field of expertise except for Mr McFall. He made several negative comments about removing gravel from the river. I do not believe he is an expert in this area and he should not have made the comments. He also stated there were no leaning Bald cypress trees, yet we have at least 3 obvious ones that are leaning on our stretch of the river. He also stated that all Bald Cypress trees have roots that will go down into the gravel 80 ft. Portions of the Frio River have a solid bed rock many feet thick and encompasses the whole river bottom. I don't believe the Bald Cypress tree has the kind of root system that can bore through the finest cracks on the bed rock and bore down into the ground beneath the bedroom. I believe the trees are considered "water seekers", e.g. they spread out. Over the 30 years I have floated the river, I have seen huge cypress trees become uprooted with huge root system that was definitely not directed downward into the ground. We believe additional study needs to be completed to address this issue. Just like huge the huge pin oak trees on land that have a root system that branches out; real wet weather and high winds and a huge canopy, these trees can easily be uprooted. I believe additional expertise is needed to address the Bald Cypress trees that are growing where there is a bedrock. One only has to look upstream and downstream from the high bridge near Garner to see what the bedrock looks like. There are also examples down river from Seven Bluffs. Placing additional gravel on top of the root structure and planting grasses, trees, etc may help to establish a more robust root system.

Finally, we believe the TPWD Gravel Division needs to revisit their strict stance on gravel relocation versus removal. We have all learned so much concerning the Riparian area (flood plan) and its importance to the effectiveness and efficiency of a river. If we are going to move forward and replant the flood planes etc, we need to establish an effective flood plane. From my earlier experience with Mr Mayben's review of the Riparian areas and the determination of what is an efficient river (I have already shared his report with TPWD), there may be areas that need strengthening of the flood plane and creating a more defined, effective river channel. In my opinion, I believe we all learned so much more about our river and realize that with the proper planning, planting of vegetation, less manicuring of the river banks, stopping the erosion of the river banks which causes the river to be too wide and ineffective, etc (the list goes on) we can start salvaging our river. Mother nature may still send huge floods down the river, but a properly maintained flood plane can withstand. (That is what Mr Mayben and I saw after the huge flood that started this river study. Many flood planes withstood the flood.)
Please feel free to include this email to the study. Please leave my name on the email. I am willing to meet with anyone who wants to discuss anything I have stated. As I have stated numerous times, I am willing to come to Austin to discuss in person. A lot of time and money has been spent on this River Study and I believe this is just the beginning. More funding is needed to continue. We need to get our State crossings submitted to the State to seek funding. We need to work with Real and Uvalde Counties. We need to work with TPWD to get seeds distributed to property owners for seeding the flood planes and funding for planting bald cypress trees. As you know, I am one of those persons that believe we can make a difference. It may be small steps and take a long time, but at least we be improving the River.
-David Alimena, in coordination with 10 additional landowners

Dear River Study Team,

Thank you all for your participation in the Frio River study. The Study is invaluable to the future preservation of the Pristine Frio River.

I attended all the meetings that we're held in Leakey concerning the Frio River study.
I was great to see that the study showed that River is currently healthy.
You all made a great team.

My position is:
The **moratorium on all Sand and Gravel Permits must continue** until such time there is a process in place to inspect and certify completion of the permit as to the terms stated in the permit.
Additionally, using property tax records, institute a notification by mail, to all of the property owners, both upstream and downstream within a mile of the permit location, at the time the permit application is filed.

It is my understanding, that past permits have been issued without OVER SITE DURING THE EXECUTION OF THE PERMIT, AND NO INSPECTION to certify that the work was done in compliance with the terms of the permit.

In 2017 and 2018 , while floating, I remember seeing large, large piles of gravel laying just off to the side of the river in the area of Criders Resort.
At the time I did not understand why it was there. I now believe the piles of gravel resulted from **non compliance** to the terms contained in a Sand and Gravel permit. Specifically, failing to relocate the dredged gravel to a location outside of the hundred year flood plain.
Issuance of a permit having no over site, no inspection and no certification of compliance , and the flooding in the fall of 2018, caused damage downstream to our beautiful, natural, deep swimming hole which we have shared, protected and enjoyed for 48 years. IT IS NOW FILLED WITH GRAVEL. Because of the lack of PERMIT management we have experienced a significant acceleration of erosion downstream from the disturbing and taking of the gravel.

We have owned our river property a since 1972. It is located about two tenths of a mile downstream of Criders Frio River Resort .
Our property is located in The Chisum Subdivision, which includes land on both sides of the river.
We have always practiced good riparian ownership.
We have made the "float" on the Frio from 1120 crossing down to our property thousands of times.

DON'T MESS WITH TEXAS' RIVERS!

Please forward this information to any agency, commission or person who is involved in the extension of the moratorium.
Sincerely,

Steve Hardwick
Land owner

Melissa,

Due to worsening conditions in our swimming hole from upstream dam construction, we hired an out of state River Engineer in 2011. The engineer's report concluded the gravel dams constructed at this site had "destabilized the banks and disturbed the sediment transport in the channel". He reported "fine sediment had been released and deposited downstream and the water was turbid due to suspension of fine particles". He found significant differences upstream of the dam vs downstream. He concluded that if the TP&W or Core of Engineers were aware of this situation, they would mandate for removal of the dams and reclamation of the area.

Regards,

A Frio River Landowner

Dear River Study Team,

Thank you for your contribution to the Frio River report! My family currently has 5 separate properties on the Frio River. We have been enjoying the Frio River for over 66 years.

I believe that it is important that the moratorium on all sand and gravel permits remain intact until there is an effective and accurate method to inspect and certify that any project has been completed to the exact terms of the permit.

Are we certain that there has been effective oversight of any and all permits?
There are reports that Texas Parks and Wildlife does not have adequate personnel to maintain a vigil to insure that all permits are following the terms. I am a researcher in several areas, including Wildlife Management, Aquatic Biology, and Environmental Impact studies. I would be glad to take pictures of any permitted sites that are nearby and send them to your office. I am comfortable running turbidity tests or other commonly used sampling equipment.

Please forward this information to any agency, commission or person who is involved in the extension of the moratorium.

Yours for effective management of Texas' Natural Resources
John Hardwick, Jr., BS in Ed.(Biology), MS in Wildlife Mgmt./Aquatic Biology, & Ed. D.

March 15, 2019

Melissa Parker
Texas Parks and Wildlife
Austin, Texas

RE: FRIO RIVER STUDY

Dear Ms. Parker,

I enjoyed the presentation you all did in Leakey on your findings from your studies. You worked hard on the reports and we appreciate all your efforts. I personally did not hear or see anything that would keep some of us from moving a few rocks around in the river to enhance our ability to enjoy the scenery we live with and see every day and use in warm times. There are areas of the river that seem to have more trouble with rocks than others. We have moved rocks at River Haven Cabins for 40 years to protect the trees and to help our guests enjoy a safe area to swim.

We have the property just past the Pecan Farm with land on both sides. Our rock problem began when the bridge on 337 was worked on and then had to be raised again because it was not high enough (that is what we were told). There are big pieces of cement that can be found in the rock behind our house. Our property on the east side of the river goes to the Flatrock bridge and on the other side is between Pecan Farm and Doyle Brooks. This stretch has an inordinate amount of rocks.

With this last flood there are tons of rock that came in and blocked the river and now it is flowing behind where the natural flow has been for the last 25-30 years that we know of and with trees not even in the river bed. We are unsure what needs to be done here. We are also concerned with the "navigable river" designation. This river may be 30' in a few places but getting to those places is not easy! We have a lot of tourists that stop even though we are not on a major thoroughfare and the floating is not great behind our house and some are not nice at all. Why do property owners not have rights when we have bought and paid for the property and pay taxes? We should not have to let people stop and spend the afternoon drinking beer and listening to loud music in our back yard. I tell the people from the Pecan Farm who wander down here to play that they are on private property here and they have paid to play there, not here. People rent places here in the canyon so they will have a place to enjoy the river without trespassing on private property.

In the past we have received a permit to move rocks that have been moved downstream by the river rising due to excess rainfall upstream. This year there was excessive rainfall from labor day up through mid-October. These rises in the river have washed in excessive rocks and gravel and changed the course of the river moving rocks and soil away from the base of the Bald Cypress trees placing them in jeopardy of falling over in future floods. With a permit we should be able to move the dislocated rock and soil over the roots to preserve and protect these valuable trees that are over 100 years old. I respect the fact that your study was done to protect fish and other aquatics but the fact is the fish and other aquatics are probably far downstream from the several floods that occurred in September/October 2018. The cypress trees cannot be replaced. Nature has a way of negating much of this study. We feel very strongly that there should be permission given to save these trees and also to permit the owners of the camps along the river to preserve the river as it was before the excessive intrusion of soil and rocks from upstream. The character of the river is deteriorating due to the rocks.

These are our feelings and the facts as we know them. Please consider our concerns. Thank you.

Sincerely

Fred & Barbara Huff
[redacted]

Nueces River Authority

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Tel: (830) 278-6810 • Fax: (830) 278-2025

COASTAL BEND DIVISION
602 N. Staples Street, Suite 280
Corpus Christi, Texas 78401
Tel: (361) 653-2110 • Fax: (361) 653-2115

March 25, 2019

Mr. Tom Heger
Texas Parks and Wildlife Department
4200 Smith School Road
Austin, TX 78744

Re: Permitting of gravel manipulations on the Frio River and other streams in the upper Nueces Basin

Dear Mr. Heger:

We, greatly, appreciate the studies you have had conducted on impacts of gravel manipulations on the ecology of the upper Frio River.

Please know that we would be in support of Texas Parks and Wildlife Department requesting modeling of site specific and wider downstream impacts of gravel manipulations on stream morphology and floodplain inundation for each future permit application and issuance of permits only when the modeled up and downstream impacts are acceptable to TPWD and effected landowners.

Sincerely,

Con Mims
Executive Director

APPENDIX B

Regionalized Fish Indices of Biotic Integrity by Study Reach

TABLE B1.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 1 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 1, Real Co.					
Collector: Curtis, Aziz, Heger, Bendik			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	10	Number of Fish Species	10	3
	Number of Native Cyprinid Species	2	Number of Native Cyprinid Species	2	1
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	2	% of Individuals as Tolerant Species[a]	2.5	5
Trophic Composition	Number of Individuals as Omnivores	4	% of Individuals as Omnivores	5.0	5
	Number of Individuals as Invertivores	69	% of Individuals as Invertivores	86.3	5
	Number of Individuals as Piscivores	5	% of Individuals as Piscivores	6.3	3
Fish Abundance and Condition	Number of Individuals (Seine)	80	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	8.0	1
	Number of Individuals in Sample	80	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	3	% of Individuals as Non-native Species	3.8	1
	# of Individuals With Disease/Anomaly	3	% of Individuals With Disease/Anomaly	3.8	1
			Index of Biotic Integrity Numeric Score:		**36**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B2.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 2 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 2, Real Co.					
Collector: Aziz, Heger, Bendik, Curtis			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	11	Number of Fish Species	11	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	26	% of Individuals as Tolerant Species[a]	11.1	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	224	% of Individuals as Invertivores	95.7	5
	Number of Individuals as Piscivores	2	% of Individuals as Piscivores	0.9	1
Fish Abundance and Condition	Number of Individuals (Seine)	234	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	23.4	1
	Number of Individuals in Sample	234	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	7	% of Individuals as Non-native Species	3.0	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**42**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B3.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 3 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 3, Real Co.					
Collector: Aziz, Heger, Bendik, Curtis			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	10	Number of Fish Species	10	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	1	Number of Sunfish Species	1	1
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	23	% of Individuals as Tolerant Species[a]	4.8	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	474	% of Individuals as Invertivores	99.6	5
	Number of Individuals as Piscivores	1	% of Individuals as Piscivores	0.2	1
Fish Abundance and Condition	Number of Individuals (Seine)	476	Number of Individuals in Sample		3
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	47.6	3
	Number of Individuals in Sample	476	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	1	% of Individuals as Non-native Species	0.2	5
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**46**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B4.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 4 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 4, Real Co.					
Collector: Curtis, Aziz, Heger, Bendik			April-18	Ecoregion 30	
Metric Category	Intermediate Totals for Metrics		Metric Name	Raw Value	IBI Score
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	11	Number of Fish Species	11	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	3	% of Individuals as Tolerant Species[a]	0.6	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	497	% of Individuals as Invertivores	99.8	5
	Number of Individuals as Piscivores	1	% of Individuals as Piscivores	0.2	1
Fish Abundance and Condition	Number of Individuals (Seine)	498	Number of Individuals in Sample		5
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	49.8	5
	Number of Individuals in Sample	498	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	9	% of Individuals as Non-native Species	1.8	3
	# of Individuals With Disease/Anomaly	3	% of Individuals With Disease/Anomaly	0.6	3
			Index of Biotic Integrity Numeric Score:		**42**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B5.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 5 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 5, Real Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			April-18	Ecoregion 30	
Metric Category	Intermediate Totals for Metrics		Metric Name	Raw Value	IBI Score
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	9	Number of Fish Species	9	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	1	% of Individuals as Tolerant Species[a]	0.4	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	278	% of Individuals as Invertivores	98.9	5
	Number of Individuals as Piscivores	0	% of Individuals as Piscivores	0.0	1
Fish Abundance and Condition	Number of Individuals (Seine)	281	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	28.1	1
	Number of Individuals in Sample	281	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	22	% of Individuals as Non-native Species	7.8	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**38**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B6.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 6 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 6, Real Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			April-18	Ecoregion 30	
Metric Category	Intermediate Totals for Metrics		Metric Name	Raw Value	IBI Score
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	12	Number of Fish Species	12	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	7	% of Individuals as Tolerant Species[a]	3.9	5
Trophic Composition	Number of Individuals as Omnivores	2	% of Individuals as Omnivores	1.1	5
	Number of Individuals as Invertivores	168	% of Individuals as Invertivores	93.3	5
	Number of Individuals as Piscivores	3	% of Individuals as Piscivores	1.7	1
Fish Abundance and Condition	Number of Individuals (Seine)	180	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	18.0	1
	Number of Individuals in Sample	180	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	7	% of Individuals as Non-native Species	3.9	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**42**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B7.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 7 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 7, Real Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			April-18	Ecoregion 30	
Metric Category	Intermediate Totals for Metrics		Metric Name	Raw Value	IBI Score
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	12	Number of Fish Species	12	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	3	% of Individuals as Tolerant Species[a]	2.6	5
Trophic Composition	Number of Individuals as Omnivores	2	% of Individuals as Omnivores	1.7	5
	Number of Individuals as Invertivores	94	% of Individuals as Invertivores	81.0	5
	Number of Individuals as Piscivores	5	% of Individuals as Piscivores	4.3	3
Fish Abundance and Condition	Number of Individuals (Seine)	116	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	11.6	1
	Number of Individuals in Sample	116	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	14	% of Individuals as Non-native Species	12.1	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**40**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B8.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 8 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 8, Real Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			April-18	Ecoregion 30	
Metric Category	Intermediate Totals for Metrics		Metric Name	Raw Value	IBI Score
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	9	Number of Fish Species	9	3
	Number of Native Cyprinid Species	4	Number of Native Cyprinid Species	4	3
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	0	% of Individuals as Tolerant Species[a]	0.0	5
Trophic Composition	Number of Individuals as Omnivores	1	% of Individuals as Omnivores	0.7	5
	Number of Individuals as Invertivores	143	% of Individuals as Invertivores	96.0	5
	Number of Individuals as Piscivores	4	% of Individuals as Piscivores	2.7	1
Fish Abundance and Condition	Number of Individuals (Seine)	149	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	14.9	1
	Number of Individuals in Sample	149	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	2	% of Individuals as Non-native Species	1.3	5
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**44**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B9.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 9 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 9, Uvalde Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			April-18	Ecoregion 30	
Metric Category	Intermediate Totals for Metrics		Metric Name	Raw Value	IBI Score
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	9	Number of Fish Species	9	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	4	% of Individuals as Tolerant Species[a]	2.9	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	138	% of Individuals as Invertivores	99.3	5
	Number of Individuals as Piscivores	0	% of Individuals as Piscivores	0.0	1
Fish Abundance and Condition	Number of Individuals (Seine)	139	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	13.9	1
	Number of Individuals in Sample	139	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	3	% of Individuals as Non-native Species	2.2	3
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**40**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B10.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 10 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 10, Real Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	606			
Species Richness and Composition	Number of Fish Species	5	Number of Fish Species	5	1
	Number of Native Cyprinid Species	2	Number of Native Cyprinid Species	2	1
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	1	Number of Sunfish Species	1	1
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	0	% of Individuals as Tolerant Species[a]	0.0	5
Trophic Composition	Number of Individuals as Omnivores	2	% of Individuals as Omnivores	16.7	1
	Number of Individuals as Invertivores	8	% of Individuals as Invertivores	66.7	5
	Number of Individuals as Piscivores	2	% of Individuals as Piscivores	16.7	5
Fish Abundance and Condition	Number of Individuals (Seine)	12	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	1.2	1
	Number of Individuals in Sample	12	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	3	% of Individuals as Non-native Species	25.0	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**30**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B11.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 11 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 11, Uvalde Co.					
Collector: Aziz, Parker, Best, Heger, Curtis			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	9	Number of Fish Species	9	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	0	Number of Intolerant Species	0	1
	Number of Individuals as Tolerants[a]	7	% of Individuals as Tolerant Species[a]	3.6	5
Trophic Composition	Number of Individuals as Omnivores	1	% of Individuals as Omnivores	0.5	5
	Number of Individuals as Invertivores	194	% of Individuals as Invertivores	99.0	5
	Number of Individuals as Piscivores	0	% of Individuals as Piscivores	0.0	1
Fish Abundance and Condition	Number of Individuals (Seine)	196	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	19.6	1
	Number of Individuals in Sample	196	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	2	% of Individuals as Non-native Species	1.0	5
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**40**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B12.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 12 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 12, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	10	Number of Fish Species	10	3
	Number of Native Cyprinid Species	4	Number of Native Cyprinid Species	4	3
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	11	% of Individuals as Tolerant Species[a]	6.8	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	149	% of Individuals as Invertivores	92.5	5
	Number of Individuals as Piscivores	2	% of Individuals as Piscivores	1.2	1
Fish Abundance and Condition	Number of Individuals (Seine)	161	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	16.1	1
	Number of Individuals in Sample	161	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	27	% of Individuals as Non-native Species	16.8	1
	# of Individuals With Disease/Anomaly	1	% of Individuals With Disease/Anomaly	0.6	3
			Index of Biotic Integrity Numeric Score:		**36**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B13.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 13 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 13, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	12	Number of Fish Species	12	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	2	% of Individuals as Tolerant Species[a]	1.6	5
Trophic Composition	Number of Individuals as Omnivores	1	% of Individuals as Omnivores	0.8	5
	Number of Individuals as Invertivores	122	% of Individuals as Invertivores	95.3	5
	Number of Individuals as Piscivores	2	% of Individuals as Piscivores	1.6	1
Fish Abundance and Condition	Number of Individuals (Seine)	128	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	12.8	1
	Number of Individuals in Sample	128	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	5	% of Individuals as Non-native Species	3.9	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**38**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B14.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 14 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 14, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	9	Number of Fish Species	9	3
	Number of Native Cyprinid Species	4	Number of Native Cyprinid Species	4	3
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	0	% of Individuals as Tolerant Species[a]	0.0	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	65	% of Individuals as Invertivores	95.6	5
	Number of Individuals as Piscivores	2	% of Individuals as Piscivores	2.9	1
Fish Abundance and Condition	Number of Individuals (Seine)	68	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	6.8	1
	Number of Individuals in Sample	68	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	11	% of Individuals as Non-native Species	16.2	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**40**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B15.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 15 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 15, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	11	Number of Fish Species	11	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	4	Number of Sunfish Species	4	5
	Number of Intolerant Species	0	Number of Intolerant Species	0	1
	Number of Individuals as Tolerants[a]	5	% of Individuals as Tolerant Species[a]	5.8	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	83	% of Individuals as Invertivores	96.5	5
	Number of Individuals as Piscivores	2	% of Individuals as Piscivores	2.3	1
Fish Abundance and Condition	Number of Individuals (Seine)	86	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	8.6	1
	Number of Individuals in Sample	86	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	6	% of Individuals as Non-native Species	7.0	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**38**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B16.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 16 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 16, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	8	Number of Fish Species	8	3
	Number of Native Cyprinid Species	4	Number of Native Cyprinid Species	4	3
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	0	Number of Intolerant Species	0	1
	Number of Individuals as Tolerants[a]	5	% of Individuals as Tolerant Species[a]	1.5	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	337	% of Individuals as Invertivores	99.7	5
	Number of Individuals as Piscivores	1	% of Individuals as Piscivores	0.3	1
Fish Abundance and Condition	Number of Individuals (Seine)	338	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	33.8	1
	Number of Individuals in Sample	338	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	3	% of Individuals as Non-native Species	0.9	5
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**38**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B17.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 17 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 17, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	14	Number of Fish Species	14	5
	Number of Native Cyprinid Species	6	Number of Native Cyprinid Species	6	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	3	Number of Sunfish Species	3	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	9	% of Individuals as Tolerant Species[a]	1.8	5
Trophic Composition	Number of Individuals as Omnivores	2	% of Individuals as Omnivores	0.4	5
	Number of Individuals as Invertivores	320	% of Individuals as Invertivores	64.6	3
	Number of Individuals as Piscivores	169	% of Individuals as Piscivores	34.1	5
Fish Abundance and Condition	Number of Individuals (Seine)	495	Number of Individuals in Sample		5
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	49.5	5
	Number of Individuals in Sample	495	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	2	% of Individuals as Non-native Species	0.4	5
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**50**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B18.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 18 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 18, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			**April-18**	**Ecoregion 30**	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	7	Number of Fish Species	7	3
	Number of Native Cyprinid Species	4	Number of Native Cyprinid Species	4	3
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	0	Number of Intolerant Species	0	1
	Number of Individuals as Tolerants[a]	5	% of Individuals as Tolerant Species[a]	1.4	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	345	% of Individuals as Invertivores	99.7	5
	Number of Individuals as Piscivores	1	% of Individuals as Piscivores	0.3	1
Fish Abundance and Condition	Number of Individuals (Seine)	346	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	34.6	1
	Number of Individuals in Sample	346	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	7	% of Individuals as Non-native Species	2.0	3
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**36**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B19.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 19 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 19, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			April-18	Ecoregion 30	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	11	Number of Fish Species	11	3
	Number of Native Cyprinid Species	6	Number of Native Cyprinid Species	6	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	5	% of Individuals as Tolerant Species[a]	3.0	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	147	% of Individuals as Invertivores	88.0	5
	Number of Individuals as Piscivores	14	% of Individuals as Piscivores	8.4	3
Fish Abundance and Condition	Number of Individuals (Seine)	167	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	16.7	1
	Number of Individuals in Sample	167	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	2	% of Individuals as Non-native Species	1.2	5
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**44**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B20.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 20 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 20, Uvalde Co.					
Collector: S.Robertson, Linam, Grubh, P.Bean			April-18	Ecoregion 30	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	11	Number of Fish Species	11	3
	Number of Native Cyprinid Species	6	Number of Native Cyprinid Species	6	5
	Number of Benthic Invertivore Species	1	Number of Benthic Invertivore Species	1	3
	Number of Sunfish Species	2	Number of Sunfish Species	2	3
	Number of Intolerant Species	2	Number of Intolerant Species	2	5
	Number of Individuals as Tolerants[a]	4	% of Individuals as Tolerant Species[a]	2.7	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	146	% of Individuals as Invertivores	97.3	5
	Number of Individuals as Piscivores	1	% of Individuals as Piscivores	0.7	1
Fish Abundance and Condition	Number of Individuals (Seine)	150	Number of Individuals in Sample		1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	15.0	1
	Number of Individuals in Sample	150	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	5	% of Individuals as Non-native Species	3.3	1
	# of Individuals With Disease/Anomaly	0	% of Individuals With Disease/Anomaly	0.0	5
			Index of Biotic Integrity Numeric Score:		**42**
			Aquatic Life Use:		**High**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

TABLE B21.—Regionalized index of biotic integrity assessing fish assemblage data collected in study reach 21 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 21, Uvalde Co.					
Collector: S. Robertson, Curtis, Stevens			April-18	Ecoregion 30	
Metric Category	**Intermediate Totals for Metrics**		**Metric Name**	**Raw Value**	**IBI Score**
	Drainage Basin Size (km^2)	1007			
Species Richness and Composition	Number of Fish Species	11	Number of Fish Species	11	3
	Number of Native Cyprinid Species	5	Number of Native Cyprinid Species	5	5
	Number of Benthic Invertivore Species	0	Number of Benthic Invertivore Species	0	1
	Number of Sunfish Species	3	Number of Sunfish Species	3	3
	Number of Intolerant Species	1	Number of Intolerant Species	1	3
	Number of Individuals as Tolerants[a]	6	% of Individuals as Tolerant Species[a]	2.3	5
Trophic Composition	Number of Individuals as Omnivores	0	% of Individuals as Omnivores	0.0	5
	Number of Individuals as Invertivores	246	% of Individuals as Invertivores	93.5	5
	Number of Individuals as Piscivores	9	% of Individuals as Piscivores	3.4	1
Fish Abundance and Condition	Number of Individuals (Seine)	263	Number of Individuals in Sample	263	1
	Number of Individuals (Shock)	0	Number of Individuals/seine haul	26.3	1
	Number of Individuals in Sample	263	Number of Individuals/min electrofishing		
	# of Individuals as Non-native species	8	% of Individuals as Non-native Species	3.0	1
	# of Individuals With Disease/Anomaly	3	% of Individuals With Disease/Anomaly	1.1	1
			Index of Biotic Integrity Numeric Score:		**34**
			Aquatic Life Use:		**Intermediate**
This data should be incorporated with water quality, habitat, and other available biological data to assign an overall stream score.					
[a] Excluding Western Mosquitofish					

APPENDIX C

Benthic Macroinvertebrate Indices of Biotic Integrity by Study Reach

TABLE C1.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 1 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 01, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	21	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	19	5
	% EPT Taxa	64.14	5
	% Chironomidae	2.39	3
	% Tolerant Taxa	27.89	1
Trophic Composition	% Grazers	20.77	5
	% Gatherrs	42.94	5
	% Filterrs	19.15	3
Taxa Abundance Condition	% Dominance (3 taxa)	80.08	1
		Total Score	37
		Aquatic Life Use	High

TABLE C2.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 2 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 02, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	22	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	9	5
Indicator Taxa Composition	Intolerant Taxa	21	5
	% EPT Taxa	54.25	5
	% Chironomidae	8.82	3
	% Tolerant Taxa	30.72	1
Trophic Composition	% Grazers	22.77	5
	% Gatherrs	33.50	5
	% Filterrs	24.09	3
Taxa Abundance Condition	% Dominance (3 taxa	73.20	1
		Total Score	37
		Aquatic Life Use	High

TABLE C3.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 3 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 03, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	23	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	18	5
	% EPT Taxa	60.58	5
	% Chironomidae	1.24	3
	% Tolerant Taxa	21.99	1
Trophic Composition	% Grazers	17.50	5
	% Gatherrs	31.67	5
	% Filterrs	34.79	3
Taxa Abundance Condition	% Dominance (3 taxa)	76.76	1
		Total Score	37
		Aquatic Life Use	High

TABLE C4.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 4 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 04, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	26	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	11	5
Indicator Taxa Composition	Intolerant Taxa	24	5
	% EPT Taxa	40.85	5
	% Chironomidae	8.94	3
	% Tolerant Taxa	25.11	1
Trophic Composition	% Grazers	20.04	5
	% Gatherrs	47.71	5
	% Filterrs	7.41	1
Taxa Abundance Condition	% Dominance (3 taxa)	62.98	3
		Total Score	37
		Aquatic Life Use	High

TABLE C5.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 5 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 05, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	19	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	8	5
Indicator Taxa Composition	Intolerant Taxa	17	5
	% EPT Taxa	57.86	5
	% Chironomidae	2.86	3
	% Tolerant Taxa	23.57	1
Trophic Composition	% Grazers	17.74	5
	% Gatherrs	29.81	5
	% Filterrs	43.79	3
Taxa Abundance Condition	% Dominance (3 taxa)	82.14	1
		Total Score	37
		Aquatic Life Use	High

TABLE C6.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 6 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 06, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	20	3
	Diptera Taxa	4	3
	Ephemeroptera Taxa	8	5
Indicator Taxa Composition	Intolerant Taxa	18	5
	% EPT Taxa	59.43	5
	% Chironomidae	0.94	3
	% Tolerant Taxa	26.42	1
Trophic Composition	% Grazers	22.62	5
	% Gatherrs	30.66	5
	% Filterrs	41.15	3
Taxa Abundance Condition	% Dominance (3 taxa)	61.01	3
		Total Score	41
		Aquatic Life Use	Exceptional

TABLE C7.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 7 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 07, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	23	3
	Diptera Taxa	4	3
	Ephemeroptera Taxa	6	5
Indicator Taxa Composition	Intolerant Taxa	19	5
	% EPT Taxa	19.41	3
	% Chironomidae	4.76	3
	% Tolerant Taxa	14.29	1
Trophic Composition	% Grazers	35.66	5
	% Gatherrs	42.20	5
	% Filterrs	13.33	3
Taxa Abundance Condition	% Dominance (3 taxa)	83.88	1
		Total Score	37
		Aquatic Life Use	High

TABLE C8.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 8 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 08, Real Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	22	3
	Diptera Taxa	4	3
	Ephemeroptera Taxa	4	3
Indicator Taxa Composition	Intolerant Taxa	16	5
	% EPT Taxa	15.45	1
	% Chironomidae	0.43	3
	% Tolerant Taxa	15.88	1
Trophic Composition	% Grazers	36.70	5
	% Gatherrs	46.02	5
	% Filterrs	8.64	1
Taxa Abundance Condition	% Dominance (3 taxa)	79.83	1
		Total Score	31
		Aquatic Life Use	High

TABLE C9.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 9 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 09, Uvalde Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	21	3
	Diptera Taxa	4	3
	Ephemeroptera Taxa	5	5
Indicator Taxa Composition	Intolerant Taxa	17	5
	% EPT Taxa	45.07	5
	% Chironomidae	3.52	3
	% Tolerant Taxa	43.66	1
Trophic Composition	% Grazers	19.42	5
	% Gatherrs	33.57	5
	% Filterrs	30.34	3
Taxa Abundance Condition	% Dominance (3 taxa)	71.83	1
		Total Score	39
		Aquatic Life Use	High

TABLE C10.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 10 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 10, Uvalde Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	18	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	5	5
Indicator Taxa Composition	Intolerant Taxa	16	5
	% EPT Taxa	47.19	5
	% Chironomidae	4.49	3
	% Tolerant Taxa	39.33	1
Trophic Composition	% Grazers	21.69	5
	% Gatherrs	22.09	5
	% Filterrs	46.79	3
Taxa Abundance Condition	% Dominance (3 taxa)	80.90	1
		Total Score	37
		Aquatic Life Use	High

TABLE C11.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 11 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 11, Uvalde Co., Ecoregion 30			
Collector: Kolodziejcyk; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	14	1
	Diptera Taxa	4	3
	Ephemeroptera Taxa	5	5
Indicator Taxa Composition	Intolerant Taxa	14	5
	% EPT Taxa	44.44	5
	% Chironomidae	1.59	3
	% Tolerant Taxa	22.22	1
Trophic Composition	% Grazers	28.43	5
	% Gatherrs	33.99	5
	% Filterrs	33.99	3
Taxa Abundance Condition	% Dominance (3 taxa)	68.25	1
		Total Score	37
		Aquatic Life Use	High

TABLE C12.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 12 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 12, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	14	1
	Diptera Taxa	1	1
	Ephemeroptera Taxa	4	3
Indicator Taxa Composition	Intolerant Taxa	11	5
	% EPT Taxa	26.79	3
	% Chironomidae	2.68	3
	% Tolerant Taxa	18.75	1
Trophic Composition	% Grazers	36.79	5
	% Gatherrs	42.45	5
	% Filterrs	14.15	3
Taxa Abundance Condition	% Dominance (3 taxa)	90.18	1
		Total Score	31
		Aquatic Life Use	High

TABLE C13.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 13 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 13, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	18	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	16	5
	% EPT Taxa	44.35	5
	% Chironomidae	2.61	3
	% Tolerant Taxa	10.43	1
Trophic Composition	% Grazers	35.96	5
	% Gatherrs	35.96	5
	% Filterrs	20.18	3
Taxa Abundance Condition	% Dominance (3 taxa)	87.83	1
		Total Score	37
		Aquatic Life Use	High

TABLE C14.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 14 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 14, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	17	1
	Diptera Taxa	2	1
	Ephemeroptera Taxa	6	5
Indicator Taxa Composition	Intolerant Taxa	16	5
	% EPT Taxa	38.46	5
	% Chironomidae	10.77	3
	% Tolerant Taxa	32.31	1
Trophic Composition	% Grazers	24.11	5
	% Gatherrs	33.63	5
	% Filterrs	27.38	3
Taxa Abundance Condition	% Dominance (3 taxa)	76.92	1
		Total Score	35
		Aquatic Life Use	High

TABLE C15.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 15 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 15, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	17	1
	Diptera Taxa	2	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	15	5
	% EPT Taxa	36.22	5
	% Chironomidae	1.08	3
	% Tolerant Taxa	30.81	1
Trophic Composition	% Grazers	30.81	5
	% Gatherrs	33.53	5
	% Filterrs	27.42	3
Taxa Abundance Condition	% Dominance (3 taxa)	90.81	1
		Total Score	35
		Aquatic Life Use	High

TABLE C16.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 16 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 16, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	12	1
	Diptera Taxa	1	1
	Ephemeroptera Taxa	5	5
Indicator Taxa Composition	Intolerant Taxa	12	5
	% EPT Taxa	28.95	3
	% Chironomidae	3.07	3
	% Tolerant Taxa	20.61	1
Trophic Composition	% Grazers	32.73	5
	% Gatherrs	37.78	5
	% Filterrs	27.47	3
Taxa Abundance Condition	% Dominance (3 taxa)	96.93	1
		Total Score	33
		Aquatic Life Use	High

TABLE C17.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 17 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 17, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	23	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	16	5
	% EPT Taxa	51.58	5
	% Chironomidae	5.26	3
	% Tolerant Taxa	38.95	1
Trophic Composition	% Grazers	24.60	5
	% Gatherrs	30.07	5
	% Filterrs	14.99	3
Taxa Abundance Condition	% Dominance (3 taxa)	64.21	3
		Total Score	39
		Aquatic Life Use	High

TABLE C18.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 18 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 18, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	14	1
	Diptera Taxa	3	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	13	5
	% EPT Taxa	55.81	5
	% Chironomidae	6.98	3
	% Tolerant Taxa	29.07	1
Trophic Composition	% Grazers	17.65	5
	% Gatherrs	42.35	5
	% Filterrs	16.47	3
Taxa Abundance Condition	% Dominance (3 taxa)	74.42	1
		Total Score	35
		Aquatic Life Use	High

TABLE C19.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 19 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 19, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	18	3
	Diptera Taxa	2	1
	Ephemeroptera Taxa	8	5
Indicator Taxa Composition	Intolerant Taxa	15	5
	% EPT Taxa	52.08	5
	% Chironomidae	8.33	3
	% Tolerant Taxa	28.13	1
Trophic Composition	% Grazers	18.48	5
	% Gatherrs	30.07	5
	% Filterrs	28.99	3
Taxa Abundance Condition	% Dominance (3 taxa)	61.46	3
		Total Score	39
		Aquatic Life Use	High

TABLE C20.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 20 on the Frio River in Uvalde County, Texas in April 2018.

Frio River @ Reach 20, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	19	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	7	5
Indicator Taxa Composition	Intolerant Taxa	15	5
	% EPT Taxa	75.31	5
	% Chironomidae	0.42	3
	% Tolerant Taxa	10.88	1
Trophic Composition	% Grazers	27.22	5
	% Gatherrs	26.93	5
	% Filterrs	36.43	3
Taxa Abundance Condition	% Dominance (3 taxa)	83.68	1
		Total Score	37
		Aquatic Life Use	High

TABLE C21.—Benthic index of biotic integrity for Surber samples assessing benthic macroinvertebrate data collected in study reach 21 on the Frio River in Real County, Texas in April 2018.

Frio River @ Reach 21, Uvalde Co., Ecoregion 30			
Collector: Grubh; April 2018			
	Metric Category	**Value**	**Score**
Taxa Richness and Composition	Total Taxa	18	3
	Diptera Taxa	3	1
	Ephemeroptera Taxa	8	5
Indicator Taxa Composition	Intolerant Taxa	16	5
	% EPT Taxa	20.62	3
	% Chironomidae	3.09	3
	% Tolerant Taxa	13.40	1
Trophic Composition	% Grazers	36.72	5
	% Gatherrs	41.81	5
	% Filterrs	8.47	1
Taxa Abundance Condition	% Dominance (3 taxa)	83.51	1
		Total Score	33
		Aquatic Life Use	High

APPENDIX D

Riparian Bulls-Eye Evaluations by Study Reach

TABLE D1.—Riparian indicator metrics and scores for the Bulls-Eye Evaluation by study reach on the Frio River, Real and Uvalde counties, Texas as evaluated March–May 2018.

	Study Reach																				
Metrics	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Active Floodplain	3	1.5	4.5	3	3	3	3	4.5	4.5	5	5	5	5	5	5	5	5	5	5	5	5
Energy Dissipation	4	3	4.5	1	3	3	3.5	4.5	4.5	4.5	3	3	4	3	4.5	3	3	3	3	3	5
New Plant Colonization	4	2	3	1	2.5	3	3.5	3.5	5	5	2.5	2.5	4	4	4	3	3	3	3.5	3.5	4.5
Stabilizing Vegetation	3	3	3	1	1	3	3	3	3	4	3	3	4	3	4	3	3	3	3	3	5
Age Diversity	4	1.5	3	3	1	3	3	3.5	4.5	5	3.5	3	3.5	5	4	3.5	3	3	3	3	4.5
Species Diversity	4	3	3	1	1	1.5	3	3	5	5	3.5	3	4	5	5	5	5	5	5	5	5
Plant Vigor	3	2.5	2.5	1	1	3	3	3	3	5	3	1	3.5	4	4	3.5	3.5	3	3	3	5
Water Storage	3	3	3	3	3	3	3	3	4.5	3.5	3	3	4	3	3	3	3	3	3	3	3
Bank/Channel Erosion	2	1	3	1	2.5	2.5	3	3	4.5	3.5	1	1	4	3	5	3	3	3	3.5	3	3
Sediment Deposition	2	1	3	1	1	3	3	3	5	5	3	1	2.5	3	3	3	3	3	3	3	5
Total Score	**32**	**21.5**	**32.5**	**16**	**19**	**28**	**31**	**34**	**43.5**	**45.5**	**30.5**	**25.5**	**38.5**	**38**	**41.5**	**35**	**34.5**	**34**	**35**	**34.5**	**45**

APPENDIX E

Baldcypress Health, Age, and Growth Study Photos

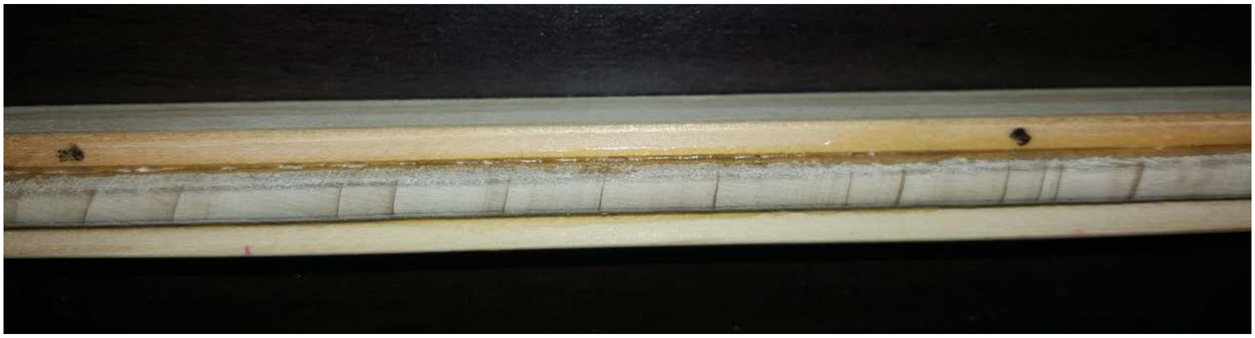


FIGURE E1.—Ten-year section of a mounted baldcypress tree core.

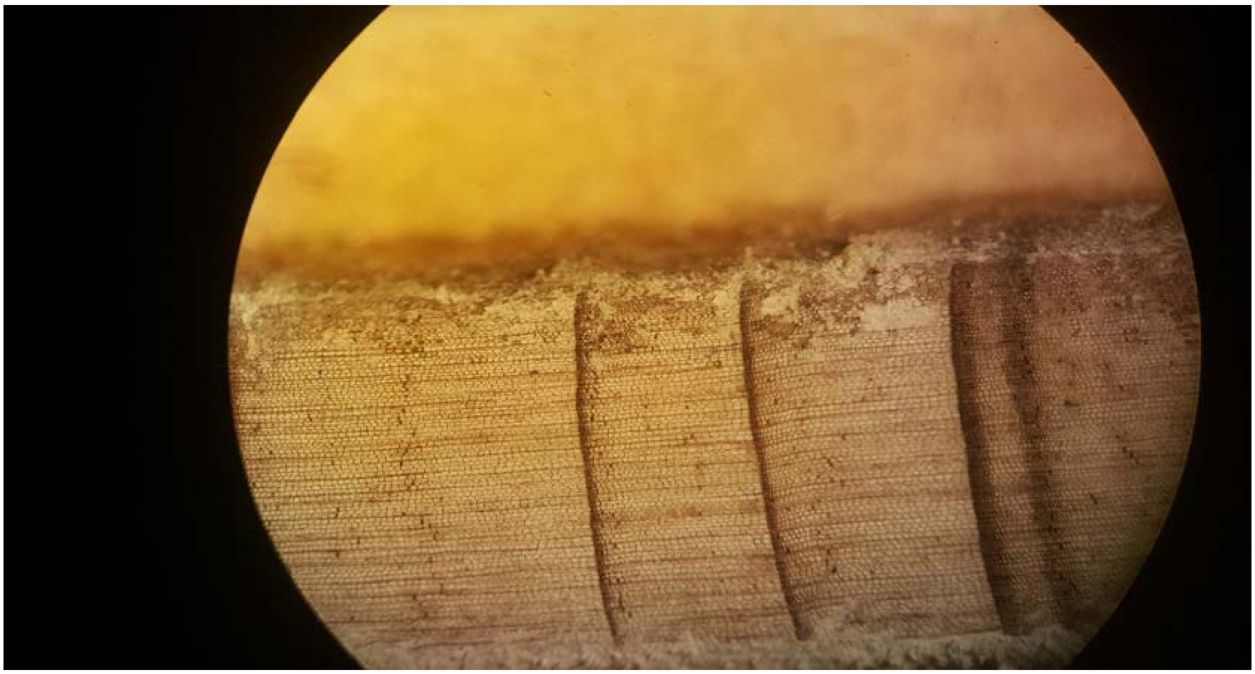


FIGURE E2.—Four-year segment of a baldcypress core viewed under a microscope. Notice the false ring on the far right which has less-defined edges than the true ring just to the left of it.

FIGURE E3.—Baldcypress tree cores collected during this study and mounted on wood for aging.

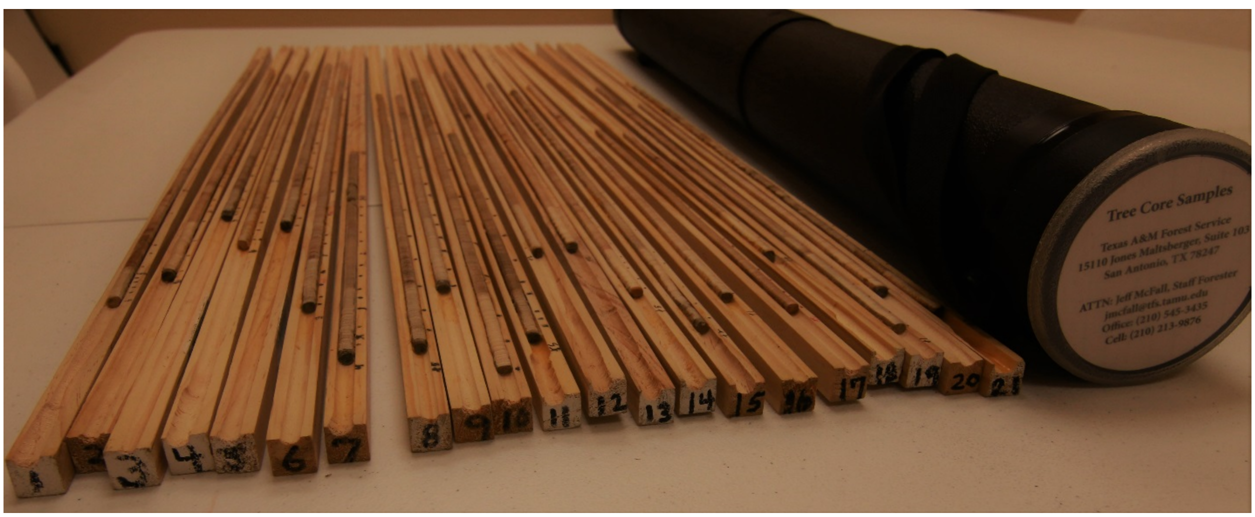


FIGURE E4.—Baldcypress tree cores collected during this study and mounted on wood for aging.

FIGURE E5.—Tree no. 1: DBH= 60.8 inches; Height= 85 feet; Age estimate= 192 years


FIGURE E6.—Tree no. 2: DBH= 45.3 inches; Height= 78 feet; Age estimate= 257 years

FIGURE E7.—Tree no. 3: DBH= 35.5 inches; Height= 70 feet; Age estimate= 118 years

FIGURE E8.—Tree no. 4: DBH= 41.5 inches; Height= 110 feet; Age estimate= 121 years

FIGURE E9.—Tree no. 5: DBH= 49.7 inches; Height= 89 feet; Age estimate= 180 years

FIGURE E10.—Tree no. 6: DBH= 55 inches; Height= 96 feet; Age estimate= 173 years

FIGURE E11.—Tree no. 7: DBH= 22 inches; Height= 65 feet; Age estimate= 170 years

FIGURE E12.—Tree no. 8: DBH= 37.3 inches; Height= 79 feet; Age estimate= 115 years

FIGURE E13.—Tree no. 9: DBH= 33.6 inches; Height= 62 feet; Age estimate= 142 years

FIGURE E14.—Tree no. 10: DBH= 59.5 inches; Height= 65 feet; Age estimate= 180 years

FIGURE E15.—Tree no. 11: DBH= 21.5 inches; Height= 69 feet; Age estimate= 105 years

FIGURE E16.—Tree no. 12: DBH= 39.0 inches; Height= 67 feet; Age estimate= 172 years

FIGURE E17.—Tree no. 13: DBH= 23.6 inches; Height= 59 feet; Age estimate= 142 years

FIGURE E18.—Tree no. 14: DBH= 34.4 inches; Height= 60 feet; Age estimate= 145 years

FIGURE E19.—Tree no. 15: DBH= 49.3 inches; Height= 50 feet; Age estimate= 182 years


FIGURE E20.—Tree no. 16: DBH= 29.2 inches; Height= 76 feet; Age estimate= 81 years


FIGURE E21.—Tree no. 17: DBH= 23.8 inches; Height= 46 feet; Age estimate= 67 years

FIGURE E22.—Tree no. 19: DBH= 39.9 inches; Height= 53 feet; Age estimate= 161 years

FIGURE E23.—Tree no. 20: DBH= 27.7 inches; Height= 105 feet; Age estimate= 90 years

FIGURE E24.—Tree no. 21: DBH= 43.6 inches; Height= 89 feet; Age estimate= 352 years

APPENDIX F

Full Report on Hydraulic and Sediment Transport Modeling

FLUVIAL GEOMORPHOLOGY

Introduction

At the request of the Texas Parks and Wildlife Department, the Texas Water Development Board (TWDB) agreed to complete a study evaluating the physical impacts of in-channel material removal from the Frio River. This required the collection of high-quality surface topography both adjacent to and under the water surface, the development of hydraulic and sediment hydrodynamic computer models, and assessment of the impact of three different volumes of material removed at three locations. The following sections detail the work performed to meet these study goals.

Topographic and bathymetric data collection

Developing accurate hydraulic and sediment transport computer models requires detailed land surface data. Airborne Lidar was determined to be the most cost-effective means of collecting the needed topographic (land surface) and bathymetric (land surface beneath the water) data. The TWDB funded the Lidar collection efforts, the Texas Department of Transportation (TxDOT) carried out the airborne flight services, and researchers at the Bureau of Economic Geology (BEG) at the University of Texas at Austin (UT Austin) acquired, processed, and analyzed the data.

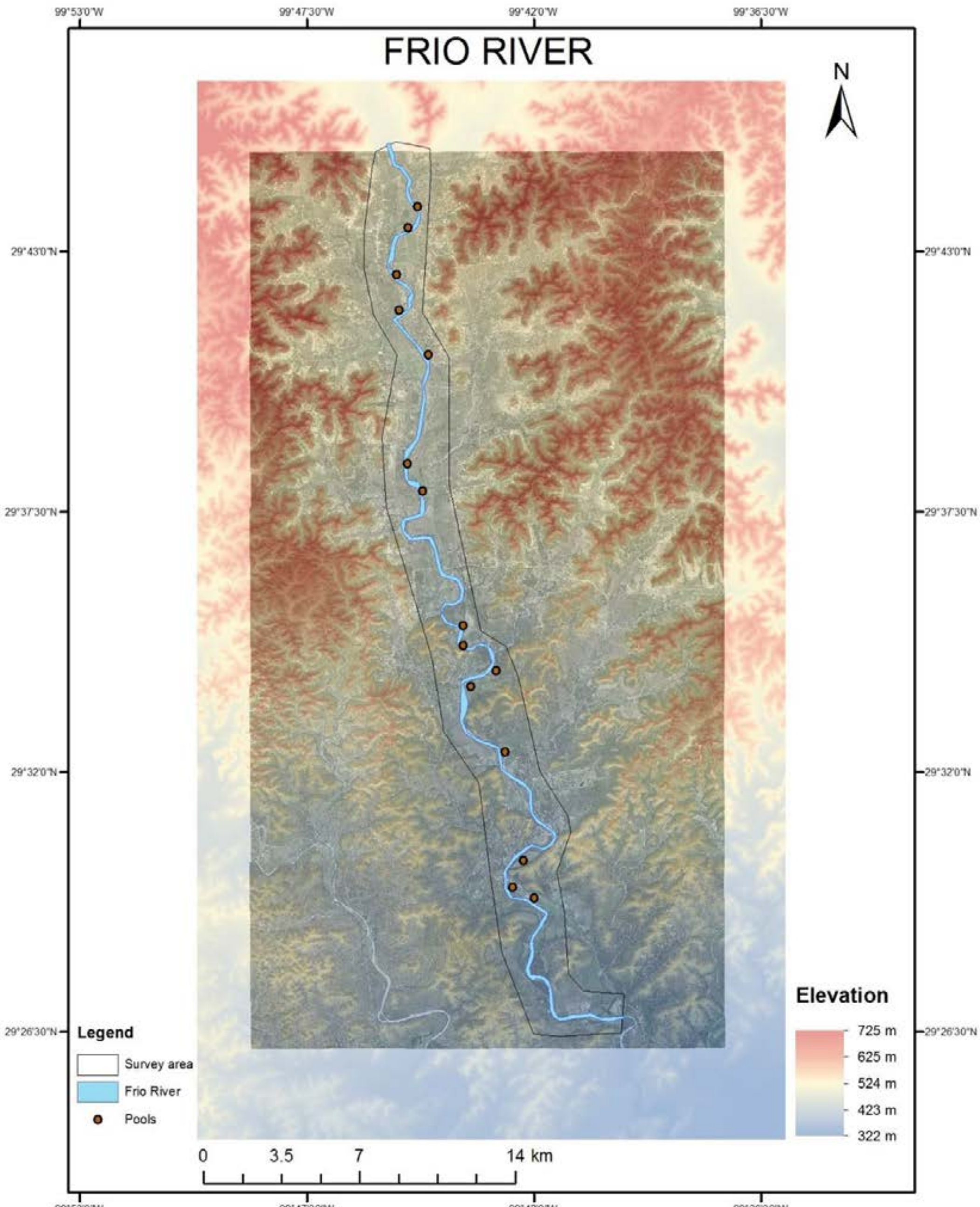
Airborne Lidar Bathymetry (ALB) is a scientific technology for characterizing the depth of the water column in relatively shallow, clear waters from an airborne platform using a scanning and pulsed light beam. The BEG owns and operates an ALB system, Leica AHAB "Chiroptera" (Figure F1) and have access to survey aircraft with varying mission capabilities (Figure F2).

FIGURE F1.—Leica AHAB Chiroptera.

FIGURE F2.—Cessna 176, TxDOT aircraft with the tail number N147TX.

The system uses a near-infrared (NIR) wavelength (1 nm) for topographic and a green wavelength (0.5 nm) for bathymetric data collection. The effective range is 400 to 500 m for the bathymetric scanner, which acquires data with a continuous waveform signal. The topographic scanner enables surveys at 1,500 m above ground level and can record pulses up to 400 kHz at lower altitudes. Both scanners direct the light beam with a fixed incident angle of 14° at fore and aft, and 20° to each side, creating an elliptical pattern on the surface. These scanners have advantages with a capability to map sloped surfaces and underneath tree canopies at certain scan angles. Additionally, ALB systems integrate cameras on board with either natural or spectral imaging capabilities for acquiring high resolution imagery simultaneously with Lidar data acquisition. The project area mapped by BEG is the polygon shown in Figure 3.

FIGURE F3.—Frio River study area.



For shallow water surveys, ALB has proved to be a versatile, cost-effective, and detailed method compared to other remote sensing technologies such as sonar and satellite imaging (Ebrite *et al.*, 2001; Guenther *et al.*, 2002). A number of river surveys have been conducted using ALB in recent years

(Hilldale and Raff, 2008; Kinzel *et al.*, 2013; Legleiter, 2012; Mandlburger *et al.*, 2013; Pan *et al.*, 2015; Saylam, 2016) and results prove the technology a viable and accurate method for geologic mapping and habitat monitoring. However, river projects can be complicated as there are various limiting aspects, especially with surveying the water near riparian areas (Mandlburger *et al.*, 2013; McKean *et al.*, 2014). In general, overhanging vegetation limit Lidar beams and create a shadow effect underneath in the point cloud data. An example of a point cloud in cross-section is shown in Figure 4.

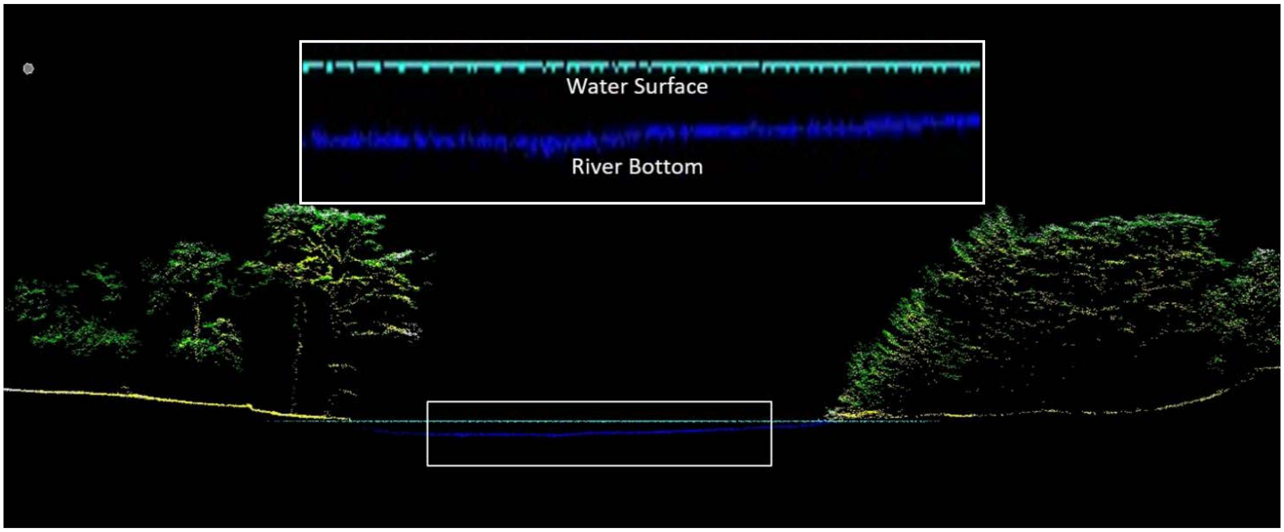


FIGURE F4.—Point cloud representation of the Frio River near Garner State Park.

The scanning pattern of the Chiroptera is advantageous for river surveys with overhanging riparian vegetation since it is possible to scan underneath the canopies at certain angles. The BEG approached pool locations from different angles, to minimize shadow effects, and conducted dual-beam echo sounder (sonar) surveys in conjunction with airborne data acquisition. The BEG has been involved in airborne Lidar surveys (ALS) since 2000 (Paine *et al.*, 2005, 2004) and has completed hundreds of ALS and ALB survey hours at diverse locations and conditions, applying specific know-how and quality management methods (Saylam *et al.*, 2018). The BEG combined the topographical and bathymetric Lidar data, revealing the water depth and floodplain geomorphology. Furthermore, the BEG correlated ALB results with other supplemental surveys (*e.g.* sonar, water transparency, GPS) for accuracy.

The end products developed by the BEG were topographic digital elevation models (DEMs) and aerial digital orthophotos. Figure 5 contains an example of the product produced by the BEG.

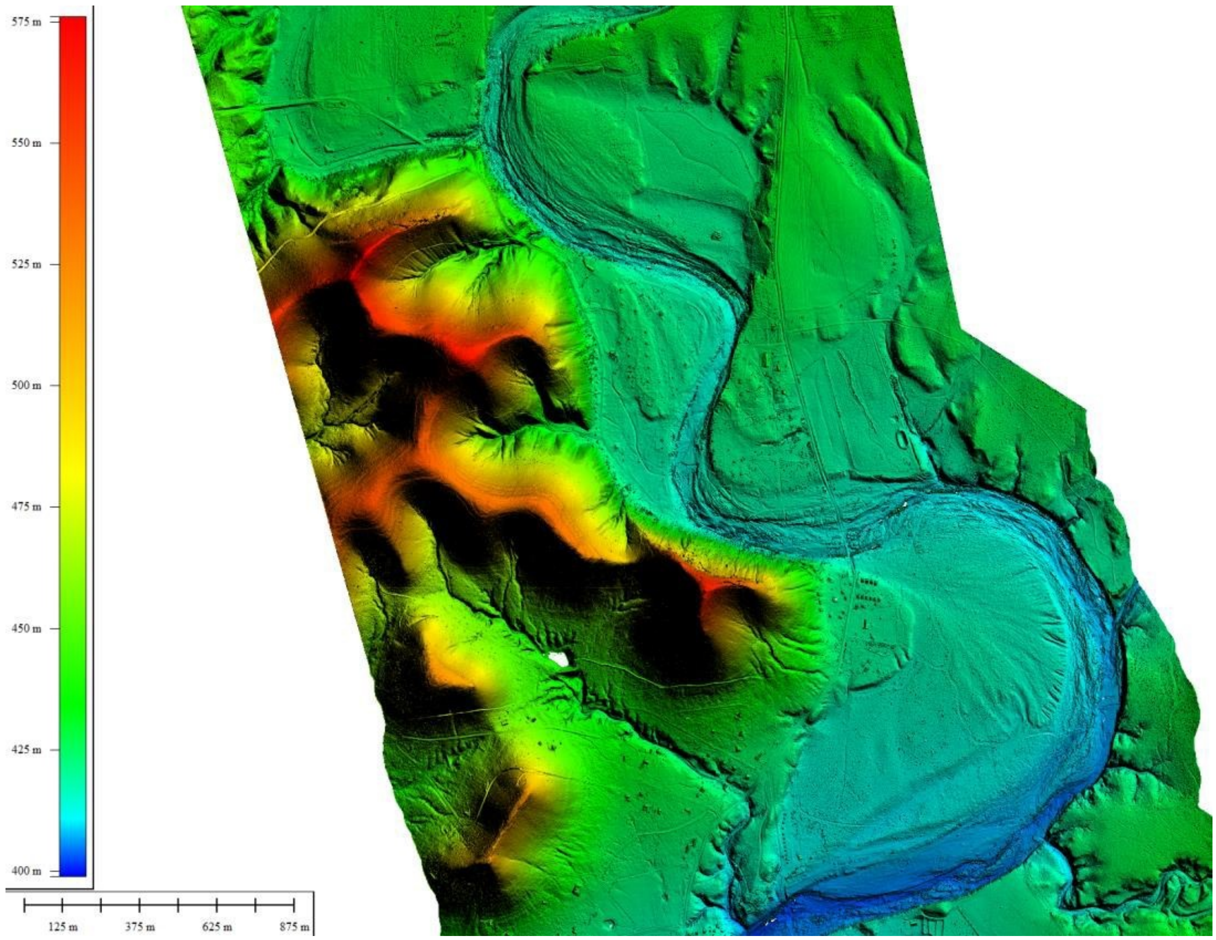


FIGURE F5.—Bare earth digital elevation model (DEM) of the Frio River near Garner State Park.

Adaptive hydraulics modeling (AdH)

The two-dimensional (2D) hydraulic computer model used for this study was the Adaptive Hydraulics (AdH) Modeling system developed by the Coastal and Hydraulics Laboratory at Vicksburg, Mississippi. AdH is an unstructured finite element computer software package capable of modeling 2D and three-dimensional (3D) shallow water equations, 3D Navier-Stokes equations, groundwater equations and groundwater-surface water interactions. Figure 6 shows the modules available in the AdH model. AdH solves the hydraulic and sediment transport equations while dynamically adapting the mesh so that a coarse mesh can give results as accurate as a mesh with finer resolution (see Figure 7).

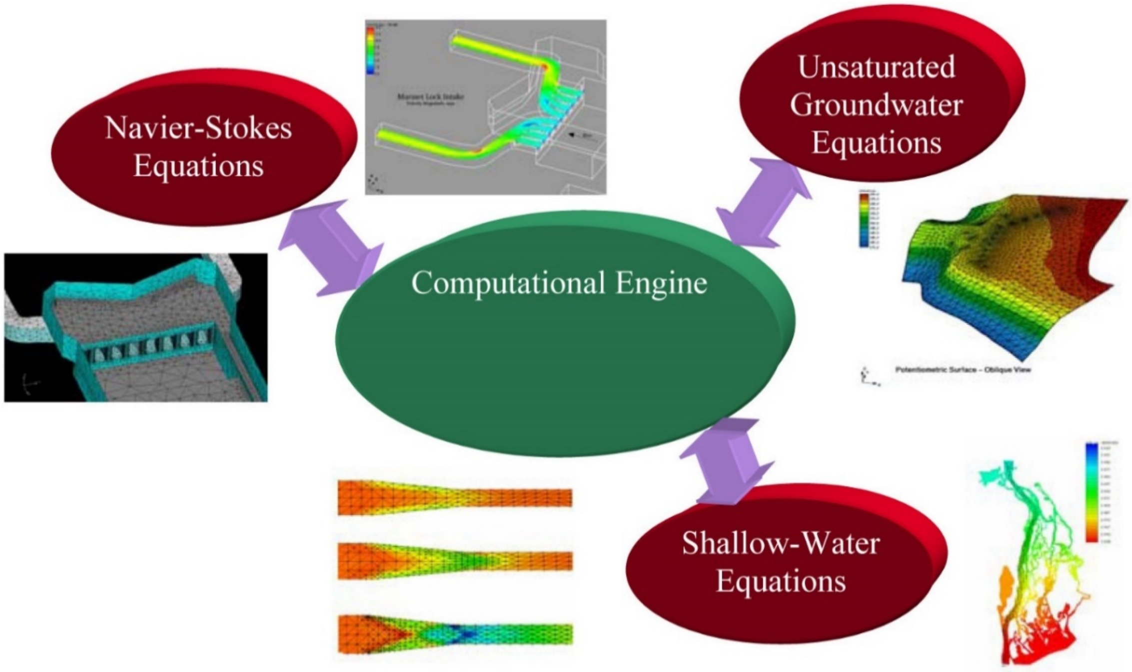


FIGURE F6.—Diagram of modules available in the Adaptive Hydraulic (AdH) model.

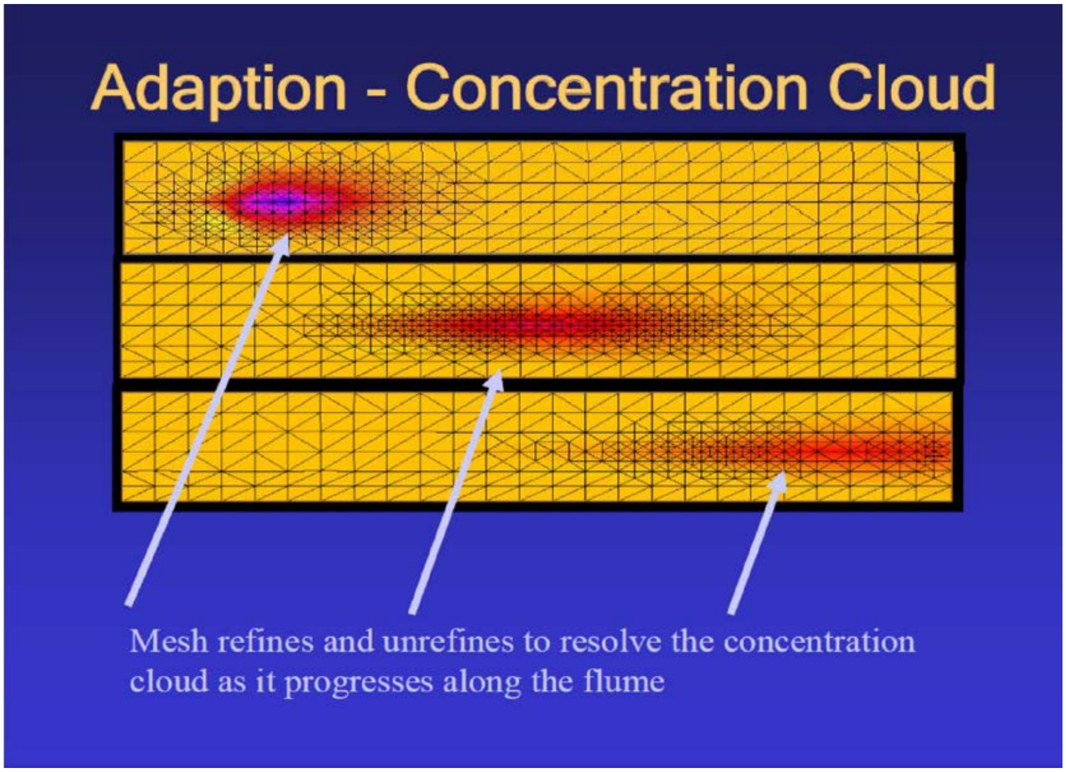


FIGURE F7.—Example of the dynamically adaptive mesh of AdH showing how the mesh characteristics change over time (top, middle, bottom panels) to model a sediment plume moving downstream (left to right) (Berger *et al.*, 2011).

AdH contains other useful features such as wetting and drying and completely coupled cohesive and non-cohesive sediment transport. The user's manual for AdH (US-ERDC, 2017) provides additional information on the hydrodynamic modeling capabilities.

Field data necessary to construct an AdH model include the following:

- Topography/bathymetry
- Water surface elevations
- Discharge
- Substrate
- Instream cover

In-channel material removal causes incision (or degradation) both upstream and downstream of an excavation pit (Figure 8). Part (a) of Figure 8 shows the profile of a stable river channel prior to material removal. The flow and sediment load moved by the flow are the same along the length of the stream segment. Excavation of a pit, shown in part (b), lowers the channel elevation in a portion of the channel. Flow in the entire stream segment remains the same as during the pre-excavation condition. At the top of the stream segment (right side of the figure), the sediment moved by the flow also remains at pre-disturbance levels. However, in the area of the pit, flow depth increases dramatically, reducing the capacity of the flow to transport sediment. A portion of the sediment carried by the water drops out and begins to build up the bottom of the pit. Below the pit (left side of the figure), a much shallower flow depth is reestablished, increasing the capacity of the flow to move sediment. The "hungry water" that has lost some of its sediment in the excavation pit now mobilizes sediment from the bed of the channel downstream of the pit until the sediment load reaches pre-disturbance levels. This process lowers the bed of the channel downstream of the pit (termed degradation or incision). At the same time, the steep head wall of the pit is susceptible to collapse, further building up the material in the bottom of the pit. Head wall collapse sends a nick point moving upstream, much like a head cut in a gully, lowering the bed elevation of the channel upstream of the pit as well.

The channel shape (geometry or bathymetry) of an alluvial river adjusts in response to the range of flows that mobilize the boundary sediments. A stable channel shape is important because it maintains habitat conditions that support biological resources both within the channel and in near-channel riparian areas. Material removal is damaging if it negatively impacts the long-term creation and maintenance of desired aquatic and riparian habitats. Changes in the flow regime of a stable channel can also cause unstable conditions due to changes in the rate of erosion, sediment transport, and/or sediment deposition.

While sediments are moving in any river and channel shape is always adjusting, a stable channel exhibits what river engineers call "dynamic equilibrium." Once dynamic equilibrium is disrupted, the channel will be unstable while these processes work to reestablish equilibrium by changing the channel geometry (width, depth), width-depth ratio, sinuosity, and slope (Schumm, 1969). Such changes in channel geometry have the potential to alter the amount and nature of aquatic and riparian habitats and therefore biological communities.

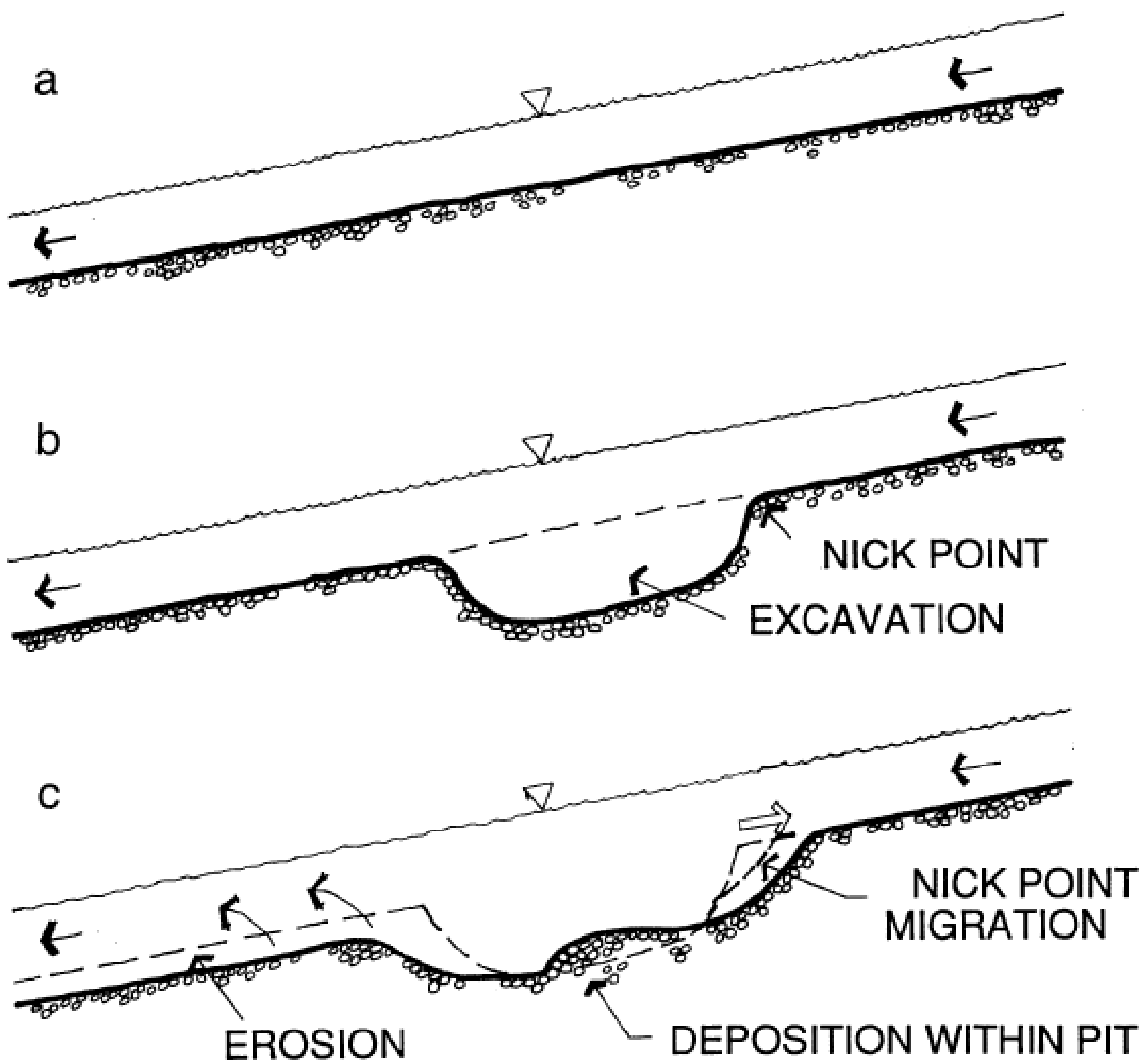


FIGURE F8.—Impact of an in-channel pit on channel stability. A stable channel (a) is lowered in a localized area by excavation of material (b). Over time, (c) the channel is lowered by means of nick point migration (upstream) and erosion (downstream) (Kondolf, 1997).

Only a portion of the Frio River was chosen for a more in-depth modeling effort due to the following reasons:

- A massive amount of bare earth topographic points were generated from the Lidar study
- The computing power required to solve the 2-D finite element sediment models
- The limited time for completing the modeling efforts

Since most of the permitted material removal sites issued since 2007 were located in the upper portion of the Frio River, this area was chosen as the priority for this study. Figure 9 shows the boundary of the modeled area which stretches from the confluence of the east and west forks of the Frio River to approximately one mile downstream of the upper Ranch Road 1120 crossing.

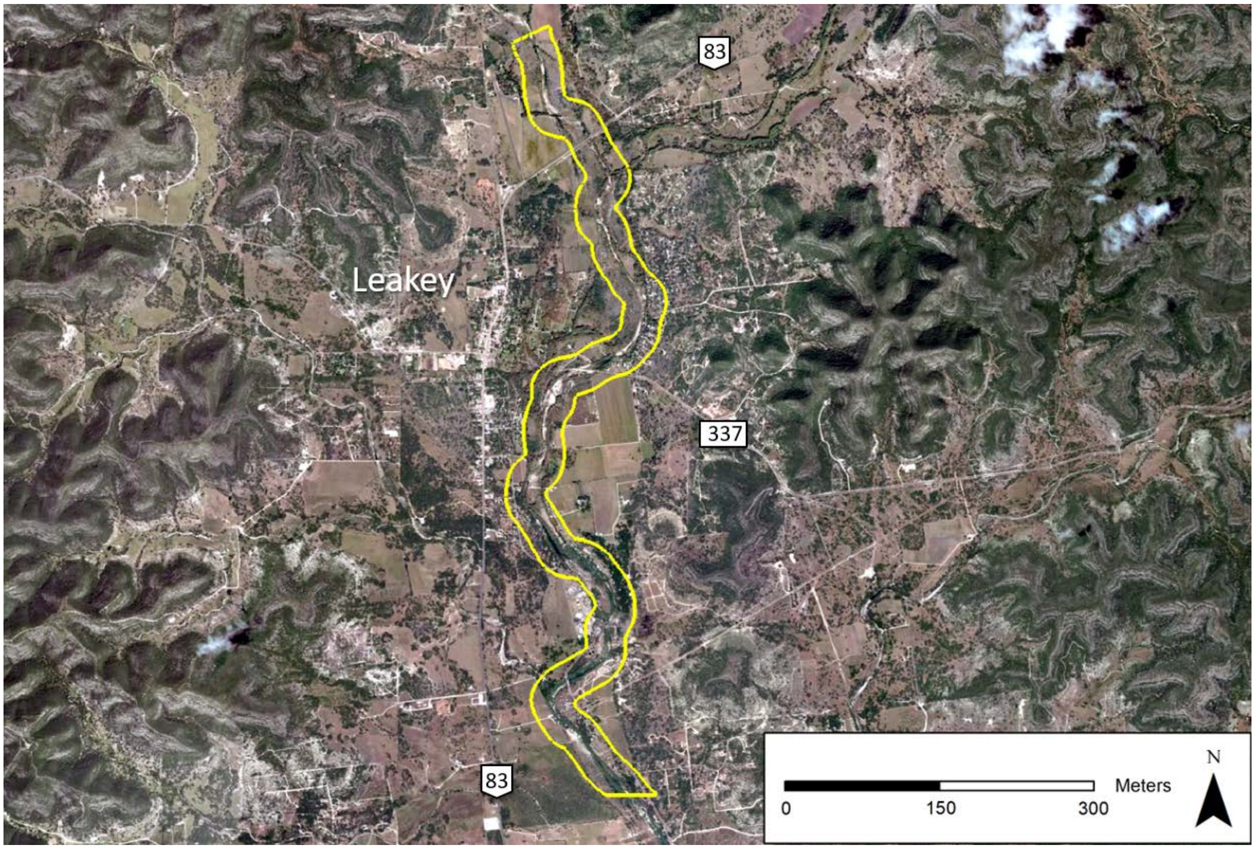


FIGURE F9.—Two-dimensional model boundary.

A finite element mesh was interpolated from the digital elevation models derived from the Lidar effort. The mesh elements were placed about 2 m apart near the center of the river with progressively larger spacing away from the river centerline. This allowed for fewer elements overall while maintaining the highest modeling capabilities in areas near in-channel material removal operations. Figure 10 is an image of the mesh near the Ranch Road 337 East crossing. The inset shows the fine mesh detail in the channel.

Hydrology

The Frio River is located in the semi-arid region of Texas, with average annual rainfall in excess of 25 inches (HDR, 2000). Flow in the basin is highly variable in magnitude and frequency as most significant rainfall originates from localized convective thunderstorms or from tropical storms and hurricanes covering wider areas. The sporadic nature of rainfall in the basin results in short periods of high flows, preceded and followed by long periods of low flows (HDR, 2000). The Frio River at US Geological Survey (USGS) gage number 08195000 at Concan, TX has a drainage area of approximately of 389 square miles. Figure 11 is a flow duration curve developed from 15-minute flow data for January 1, 2000 to March 8, 2019 at the Concan gage. For further clarity, Figure 12 is the same data and timeframe as Figure 11 but with only up to the 5 percent exceedance shown. Table 1 contains the number of 15-minute periods that flows of various magnitudes occurred.

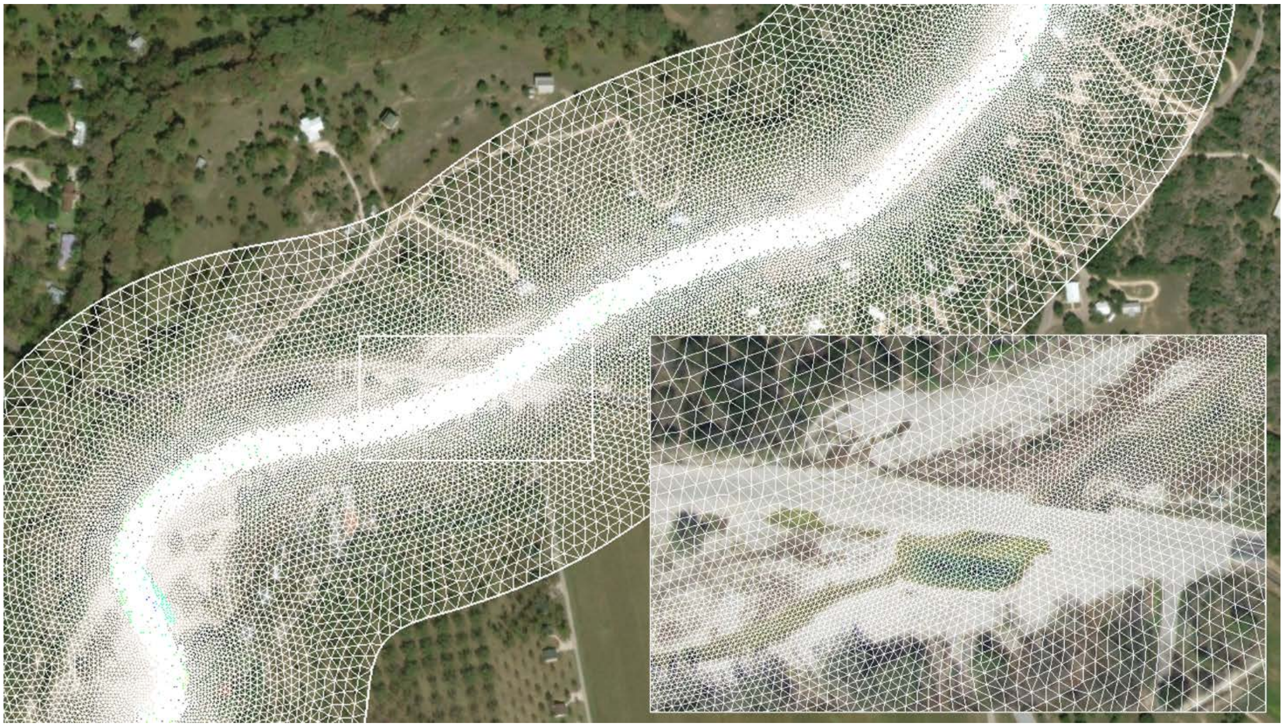


FIGURE F10.—AdH mesh on the Frio River near Leakey, Texas. Notice the greater number of computation nodes and elements closer to the center of the channel for higher resolution.

TABLE 1.—Frio River at Concan, number of 15-minute periods that flows of various magnitudes occurred from January 1, 2000 to March 8, 2019.

L ess 50 cfs	G reater 50 cfs	G reater 100 cfs	C reater 250 cfs	C reater 500 cfs	C reater 1000 cfs	C reater 1500 cfs	C reater 2000 cfs	C reater 2500 cfs	C reater 5000 cfs
3 25,508	3 33,818	1 78,810	4 6,305	1 6,332	5 ,769	2 ,488	1 , 641	1 ,214	5 85

The hydraulic models and sediment models that will be discussed later in this section were run using a 24-hour flow hydrograph based on a flow event that was recorded at the Concan gage. The flow hydrograph used in the model was translated from the Frio River at Concan gage to the upstream boundary of the study site and then routed through the entire length of the hydraulic model. Figure 13 is the flow hydrograph used in all modeling scenarios. The intent of this study was to quantify the effects of material removal from the channel, therefore actual flows and water surface elevation data were not collected within the study area. That being said, the models and subsequent output are only an estimate of the inundation that would occur if similar flows occurred in the study area.

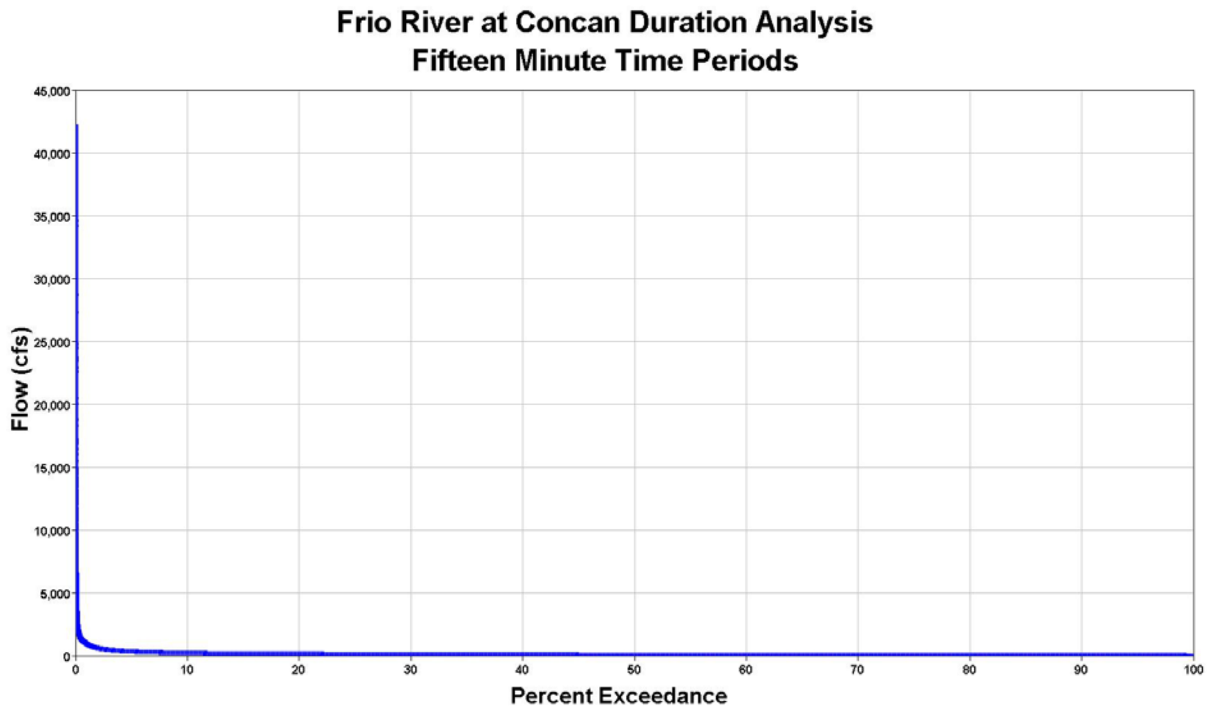


FIGURE F11.—Flow-duration curve for the period January 1, 2000 through March 8, 2019, Frio River at Concan.

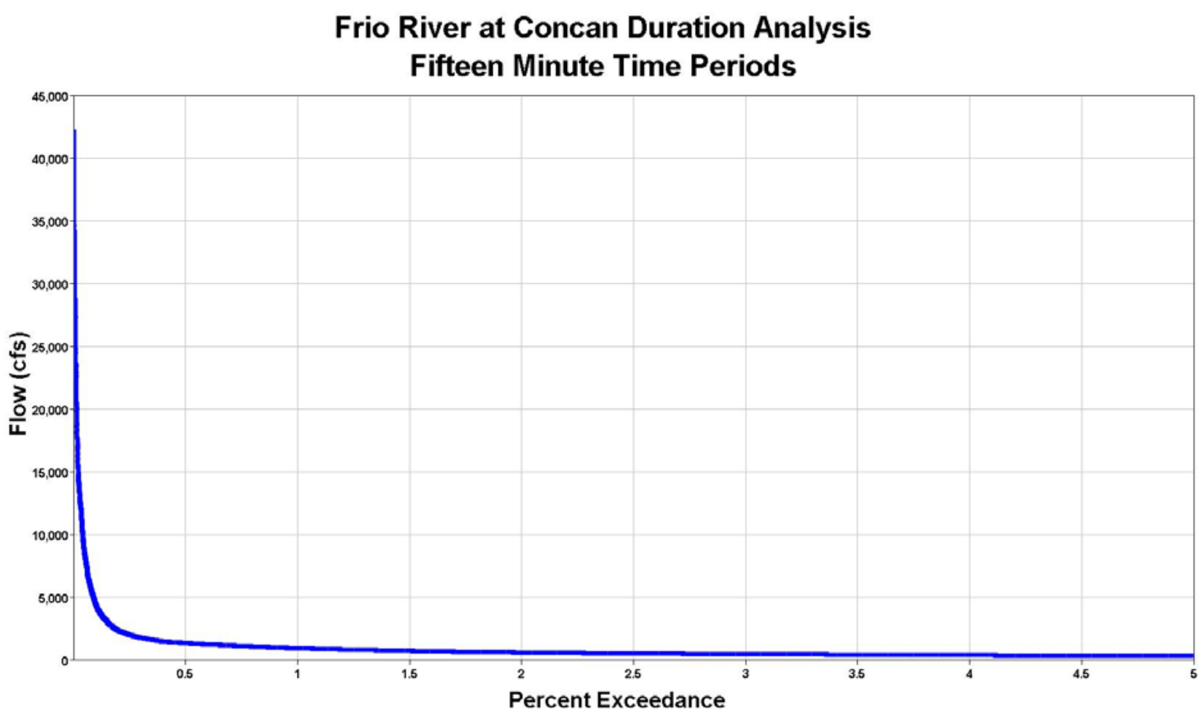


FIGURE F12.—Flow-duration curve for the period January 1, 2000 through March 8, 2019, for the 5 percent exceedance, Frio River at Concan.

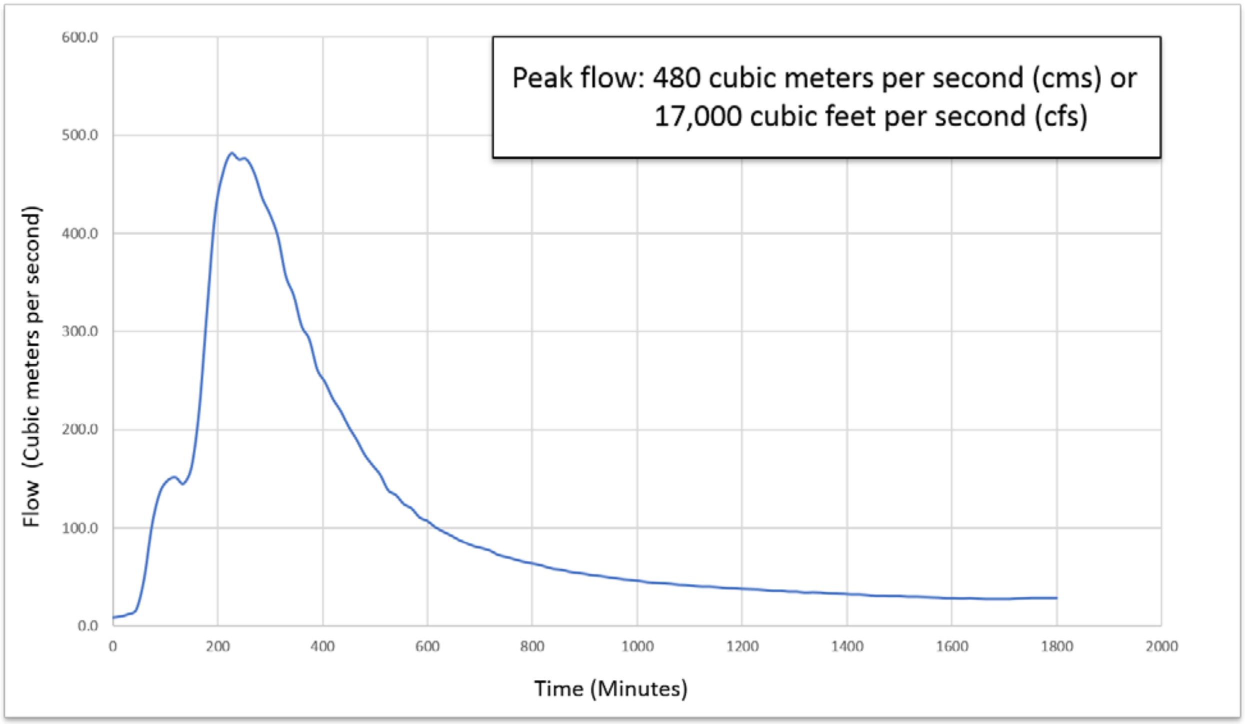


FIGURE F13.—Flow hydrograph for USGS gage number 08195000 Frio River at Concan, TX, September 8, 2018.

Sediment Analysis

The sediment analysis for the Frio River was performed with the previously described Adaptive Hydraulics (AdH) Modeling system Version 4.6 (US-ERDC, 2017). Sediment modeling using AdH consists of linking the AdH hydrodynamic code with the sediment transport library (SEDLIB). SEDLIB is a compressive set of computer modules that calculate sediment transport of cohesive, non-cohesive, and mixed suspended sediment loads and bed loads. Developing the sediment library independent from the AdH code allows users to select the hydrodynamic program that addresses the hydraulic complexities of a particular problem, and then couple to the sediment library for performing sediment transport analysis. The model calculates suspended load transport (for silt and clay classes), both bedload and suspended load transport (for sand classes), and bedload transport (for gravel classes) for each grain class.

As discussed by Leech *et. al.* (2018) the AdH/SEDLIB sediment model contributes several capabilities to flow/sediment modeling and analysis, including the following:

- The model possesses quasi-3D flow and transport formulations, which uses analytical and semi-empirical methods to approximate the 3D character of the flow and sediment transport. phenomena while solving the 2D depth-averaged shallow water equations (Brown, 2008, 2012b).
- The model computes the effects of helical flow through a river bendway on the suspended and bedload sediment transport by utilizing the bendway vorticity transport algorithm given by Bernard (1992).

- The SEDLIB module simulates multi-grain class suspended load and bedload sediment transport phenomena. Computes generalized multi-grain class bed processes, including armoring, sorting, erosion to a solid boundary, and the storage of discrete depositional strata.
- AdH uses an unstructured model mesh that permits very high resolution in areas of interest and high-fidelity resolution of shoreline geometry.

Using the AdH model to perform a detailed sediment analysis of a river or estuary requires the modeler to development a 2D mesh and boundary input file which consists of 10 to 12 input parameters. A detailed discussion of all input required is available in the users' manual (US-ERDC, 2017). This report presents the inputs that directly influence the results of the sediment analysis, specifically the development of the mesh, the hydrologic inputs needed to execute a model run, the bed material gradation, and the selection of a sediment function to compute the sediment transport and bed change associated with the chosen hydrologic data set. Discussion of the mesh developed for this study and the hydrologic input used to perform the sediment analysis are discussed in previous sections of this report.

Bed Material Gradation

As seen in Figure 14, the bed material consists of 96 to 98 percent gravel with 2 to 4 percent sands, which are considered wash load. Wash load is often considered the smallest 10% of the bed material and does not contribute to changes in channel shape or morphology.

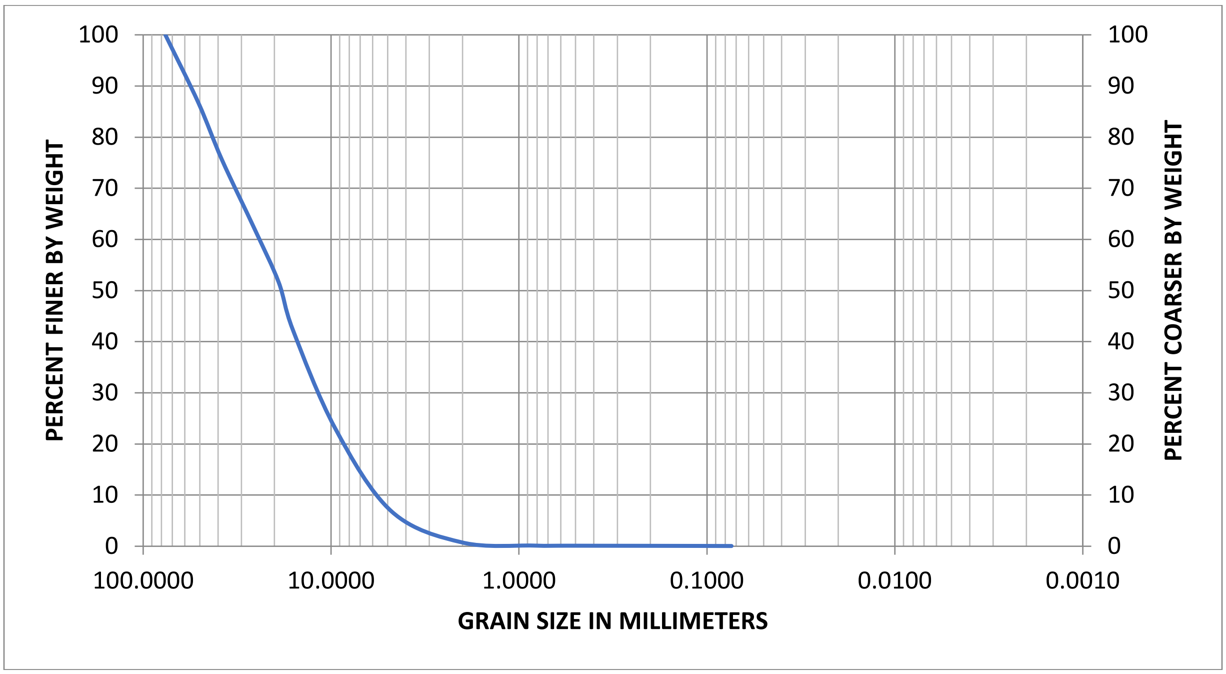


FIGURE F14.—Bed gradation, Frio River, Texas.

The bed material gradation curve in Figure 14 was used to develop the bed material gradations used in this modeling effort to compute bedload transport. Sediment class sizes used for numerical modeling were taken from the sediment groups identified and subdivided based on the American Geophysical Union Classification Scale. Four size classes of gravel were used in this study. Table 2 shows the sediment material, grain diameter, and geometric mean of the grain size classifications. The geometric mean of the grain size was used in the bedload transport equations for calculating bedload transport.

TABLE F2.—Sediment material, grain diameter, and geometric mean for each grain size classification.

Sediment Material	Grain Diameter (mm)	Geometric Mean (mm)
Fine Gravel (FG)	4-8	5.65
Medium Gravel (MG)	8-16	11.31
Coarse Gravel (CG)	16-32	22.62
Very Coarse Gravel (VCG)	32-64	45.25

Bed gradations in the Frio River vary considerably both vertically and longitudinally along the river. Such high variability of bed material gradations is often found in gravel streams and also frequently in sand bed rivers. In response, a comprehensive bed material data collection program may be developed and executed, or a limited number of samples that are representative of the majority of the bed material in the channel may be collected. Time and budget constraints did not allow for comprehensive bed material sampling; therefore, bed material samples were taken at locations that appeared consistent within a given reach of the river. A sensitivity analysis was performed by developing a model run with two sets of bed material inputs made up of coarse and very coarse gravel. Analysis of the model results indicated that a larger gradation had somewhat smaller bed material loads. However, locations of erosion and deposition remain at virtually the same place in the river as the model using four sediment gradations. The bed material make up of the channel used in this study is shown in Figure 15.

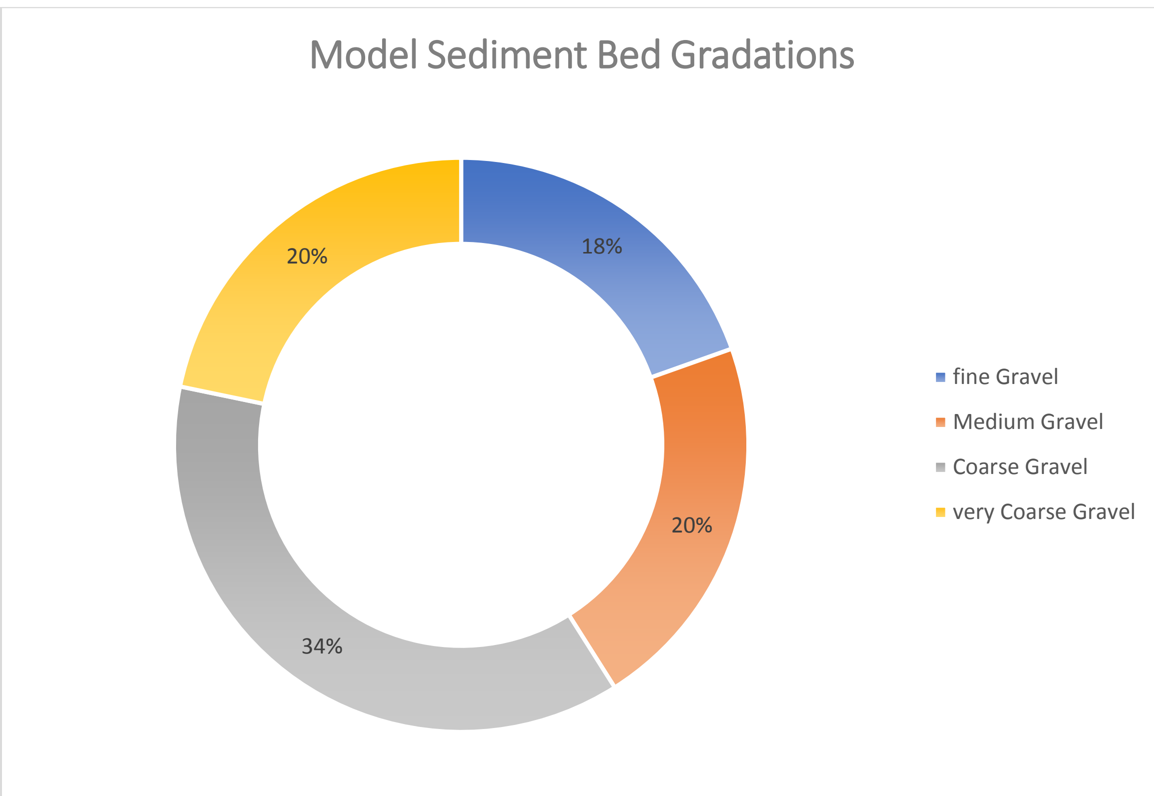


FIGURE F15.—Bed material types used in this study.

Sediment transport function

The Meyer-Peter and Müller with Wong Parker Correction bed-load entrainment function was used for this sediment transport analysis. Because the Frio River in the study reach is 96 to 98 percent gravel, no suspended load sediment function was chosen. Suspended load is usually computed when modeling sands, silts and/or clays.

Sediment model vs sediment analysis

There is a tendency to view all studies that use a computation tool such as AdH/SEDLIB as a numerical model study, when in fact, many of the studies like this one should be considered desktop sediment analysis. A complete numerical model study requires a rigorous model calibration exercise and then model verification by checking the model's ability to reproduce an event not used in the calibration process. The Frio River, in the study reach, does not have any gaging stations near the upstream and downstream boundaries and time and budget restraints did not allow for the purchase and installation of temporary gaging stations. Like most gravel-bed streams, no bedload measurements are available. The lack of observed bedload measurements can often be overcome by measuring a river cross-section at two different times. The Frio River did not have any cross-sectional data available before the Lidar data was collected. Because of the lack of calibration data, this work should be considered a desktop sediment analysis.

Modeled scenarios

Three locations were chosen for modeling material removal, as shown in Figure 16. Three scenarios were modeled at each location, specifically material removal of:

- 76 cubic meters (100 cubic yards)
- 229 cubic meters (300 cubic yards)
- 765 cubic meters (1,000 cubic yards)

Material removal was modeled by forming a "pool" in the computational mesh at the three locations shown in Figure 16. The depressions for each scenario were 4, 7 and 10 meters in radius with a depth of approximately 2 meters. The three "pool" sizes compared to the existing channel bottom at one of the material removal locations is shown in Figure 17.

Numerical model output

The AdH/SEDLIB model used an option to develop an equilibrium transport boundary condition near the upstream boundary of the model. The option works by using the bed material gradation and the chosen sediment transport equation to calculate the transport capacity at the given cross-section (upstream boundary). The difference between this computation and other computations at other nodes in the model is that the model does not compute bed change at the nodes specified as equilibrium transport.

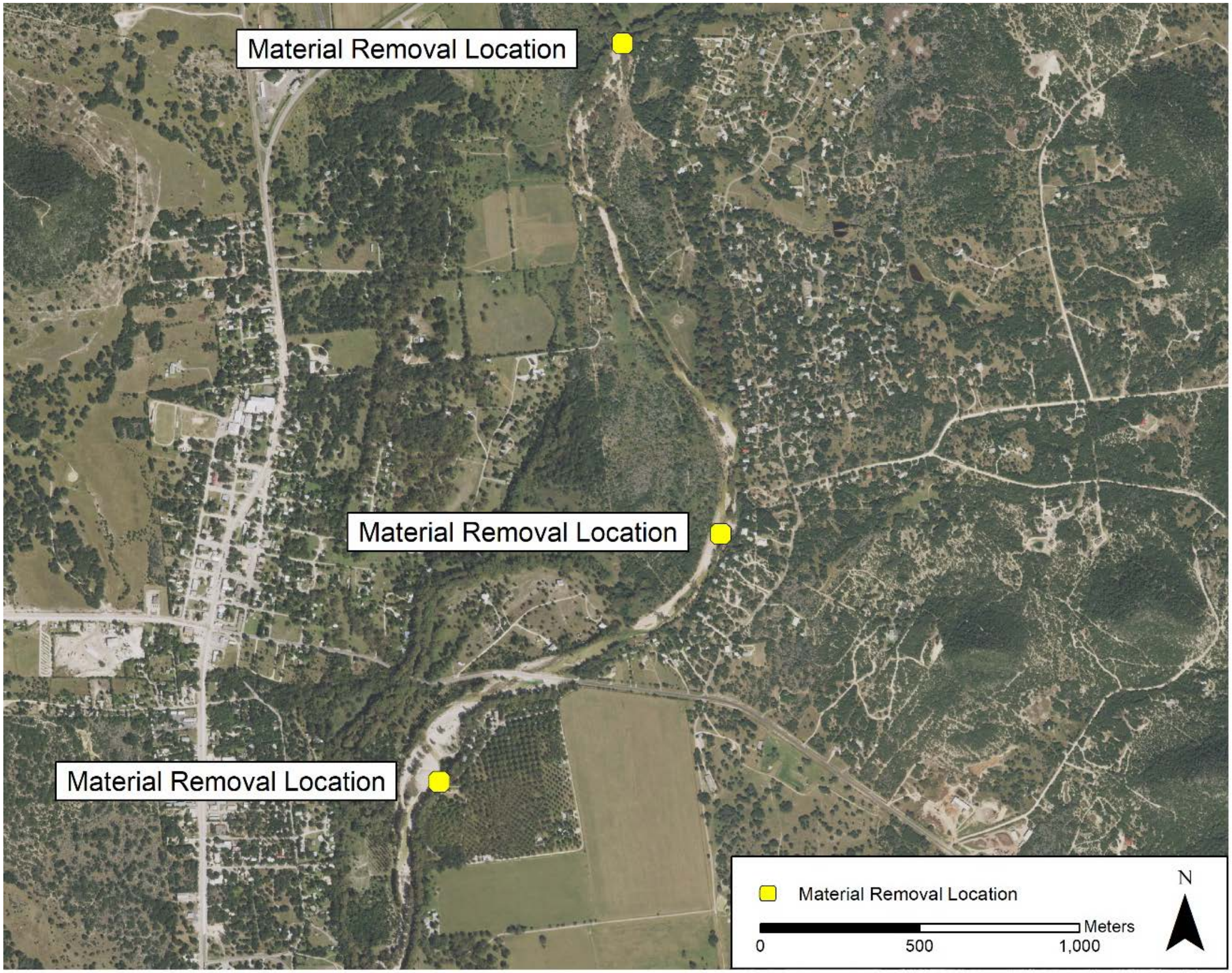


FIGURE F16.—Locations where material removal was modeled.

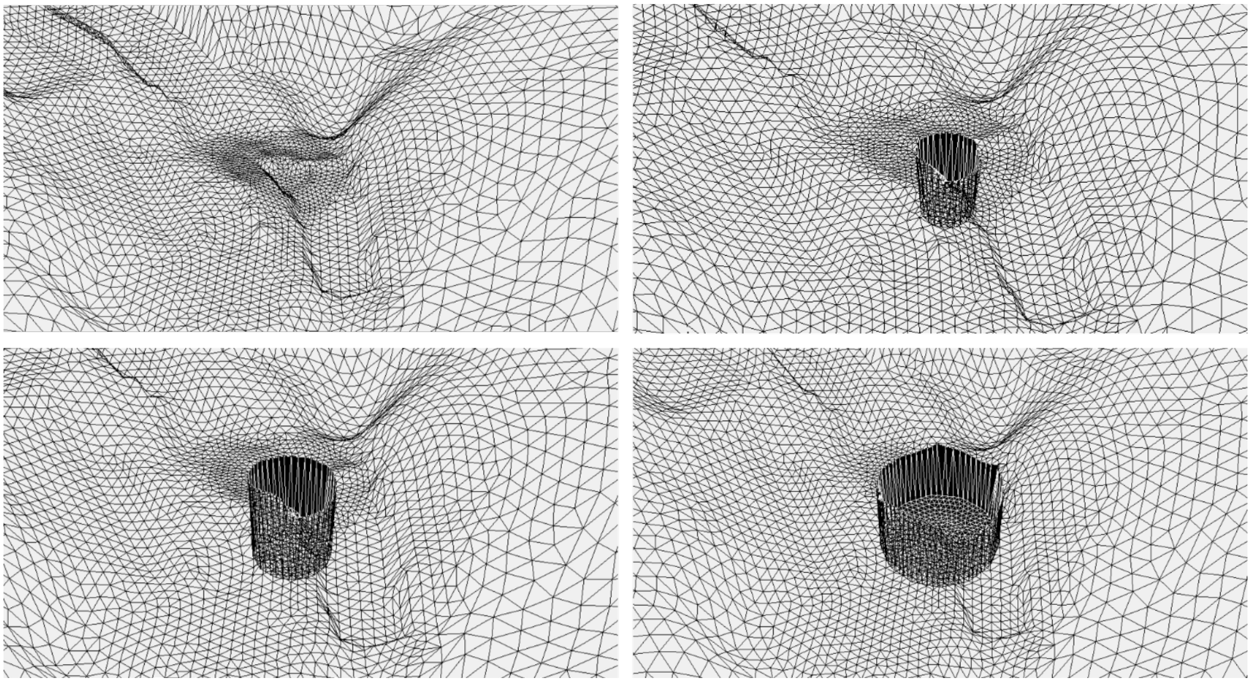


FIGURE F17.—Top left – Frio River mesh with no material removal; Top right – Frio River mesh with 100 cubic yards of material removed; Bottom left – Frio River mesh with 300 cubic yards of material removed; Bottom right – Frio River mesh with 1,000 cubic yards of material removed.

Figure 18 shows a sediment rating curve just upstream of the first material removal site. The data presented in Figure 18 is from the base sediment scenario. The rating curve is very similar for all three modeled scenarios because this cross-section is upstream of the disturbance made by proposed material removal activities. Figure 18 shows only three of the gravel sizes are transported at this cross-section, *i.e.* Fine Gravel, Medium Gravel, and Coarse Gravel. The model computed movement of Very Coase Gravel at the highest flows and only calculated significant bed material movement at flows over 350 cms (12,360 cfs). One additional thing to note in Figure 18, is that computations are showing the river is moving more Medium Gravel than Fine Gravel. This indicates that the Frio River's capacity to carry Fine Gravel is limited by the amount of Fine Gravel in the river bed. Part of the difference between the Fine Gravel and Medium Gravel can also be attributed to the hiding of smaller gravel with the larger sized gravel. The location of the cross-section that the sediment rating curve was developed is shown in Figure 19 and labeled as Cross-Section 12. The rating curve shows that almost all of the bedload transport occurs in the Frio River when flow is above 70 cms, or about 2,500 cfs. This flow condition occurred in 1,200 15-minute time periods between Jan 1, 2000 and March 8, 2019, which represents a total of 12.5 days.

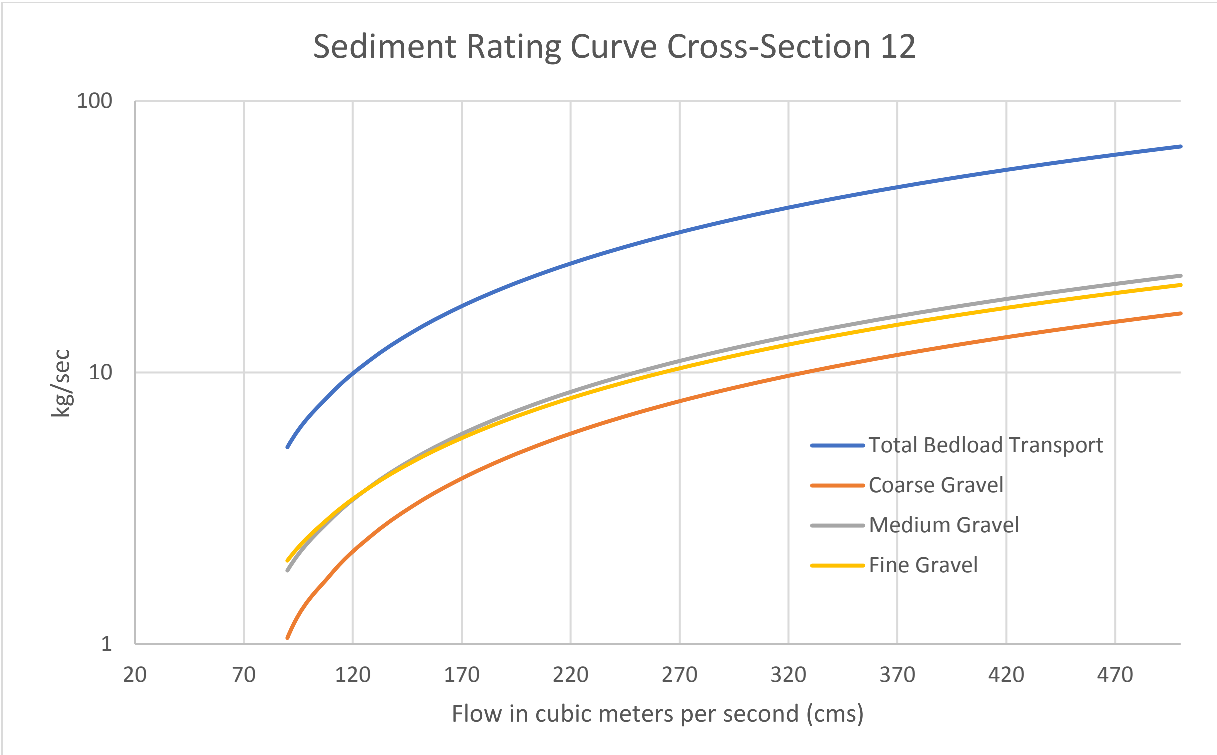


FIGURE F18.—Sediment rating curve at Cross-Section 12.

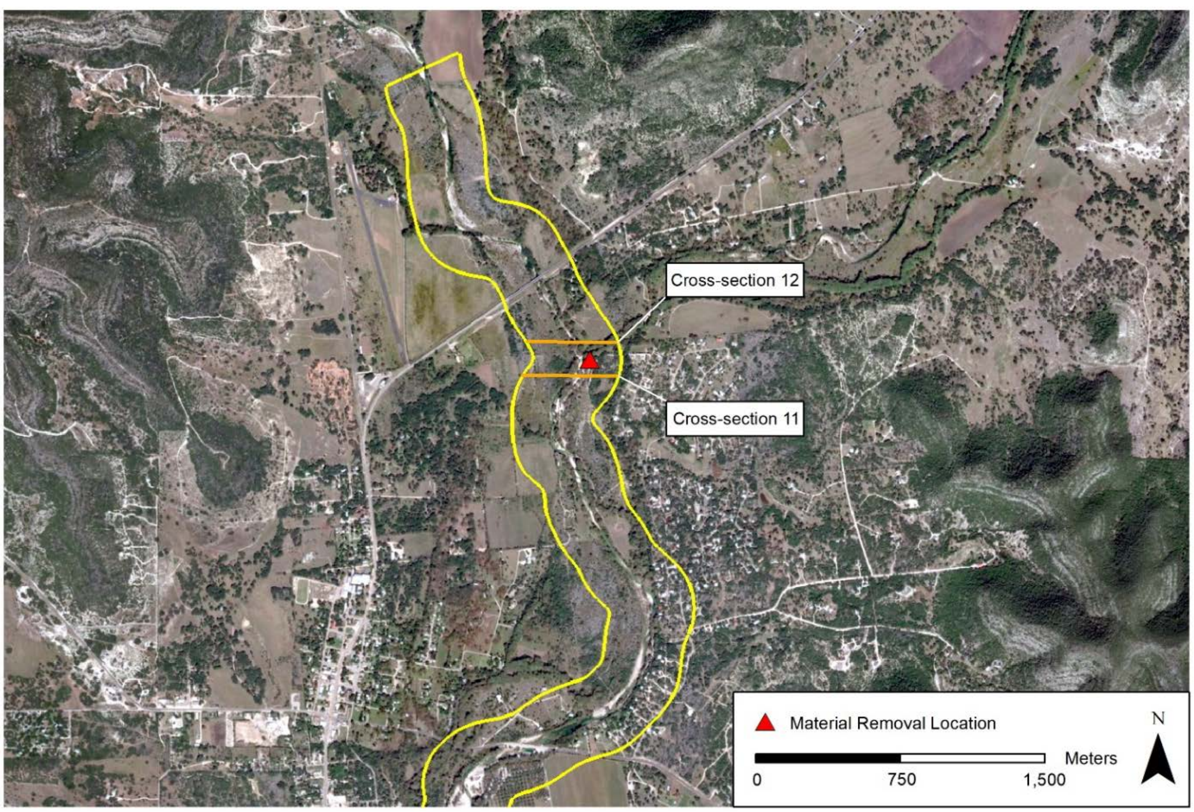


FIGURE F19.—Location of sediment Cross-Sections 11 and 12.

Sediment Model Results

The model showed sediment deposition at each of the three material removal sites. Figures 19-30 show a plan view of the change in deposition and erosion patterns near the three material removal sites. Note that Figures 19, 23, and 27 are for the base sediment model run without material removed. These three figures show channel change related to the 24-hour flow hydrograph used in this study only. Therefore, the proposed material removal scenarios of 100, 300, and 1,000 cubic yards, at the three modeled locations, fill (*i.e.*, induce sediment deposition) in the material removal sites and change deposition and scour patterns in areas adjacent to and for some distance downstream of the sites.

Table 3 shows the change in depositional quantities at each of the three material removal sites and for each removal quantity of 100, 300, and 1,000 cubic yards. The change in deposition quantities are for the center node of the removal area and most likely would not represent the largest nor average deposition in each of the material removal sites.

TABLE F3.—Deposition (in meters) at the center node of each material removal site.

	Upper Site	Middle Site	Lower Site
Base Sediment Run	-0.02	-0.06	0.08
Material Removal 100 yd^3	0.13	0.24	0.29
Material Removal 300 yd^3	0.13	0.22	0.30
Material Removal 1,000 yd^3	0.14	0.20	0.18

In reviewing Table 3, it can be seen that in the base sediment model run (no material removal) the upper and middle sites show a tendency for a slight amount of erosion, while all three sediment removal scenarios (*i.e.* 100, 300 and 1,000 cubic yards) show a depositional pattern. The lower site tends to be slightly depositional in the base condition run and significantly more depositional in the material removal runs. The quantities may appear to be small but this deposition is taking place in a few hours during a single 24-hour storm. A similar storm to the one used in this study would be expected to occur, on average, at least once in any two year period (and may occur more often).

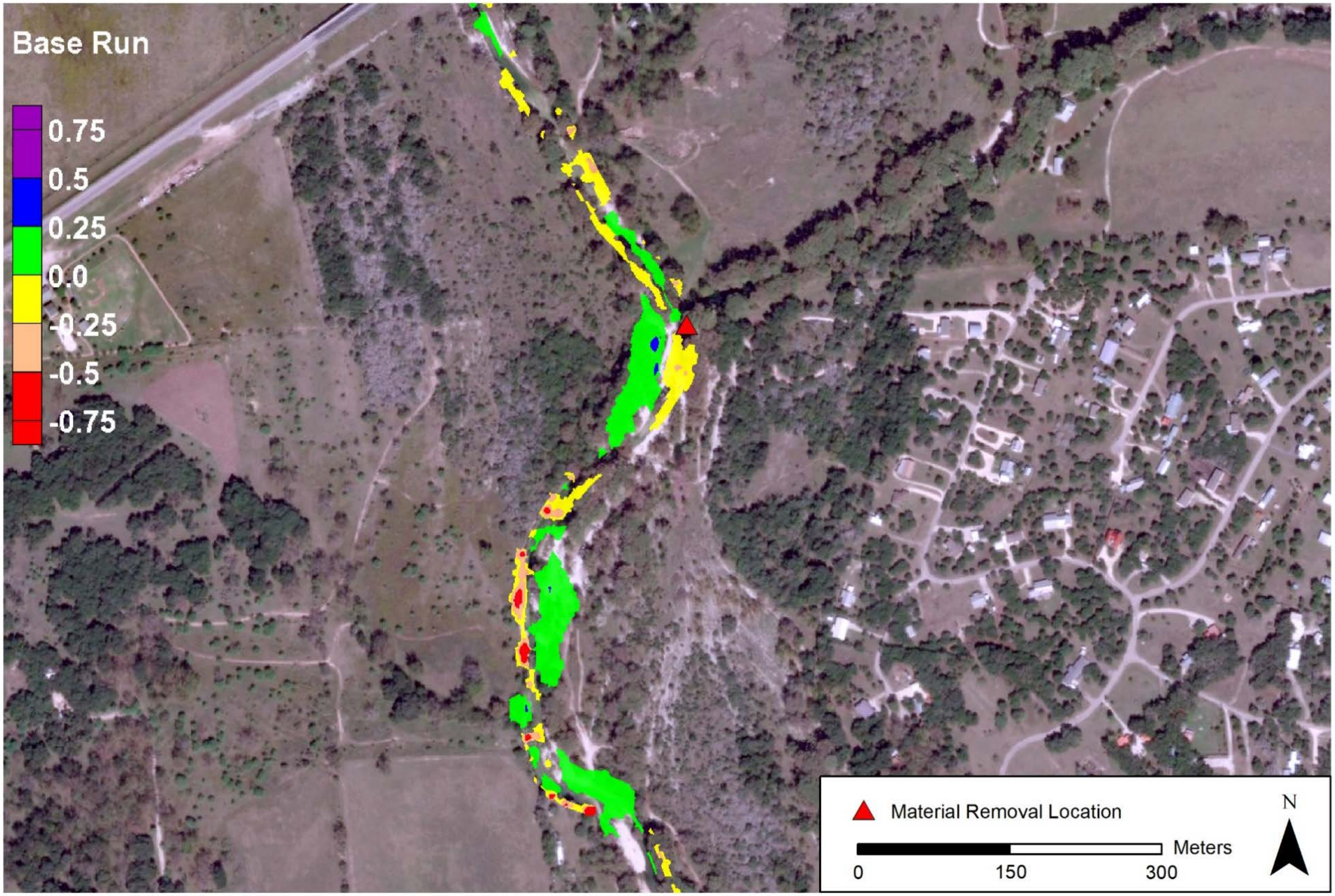


FIGURE F19.—Sediment deposition for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs.

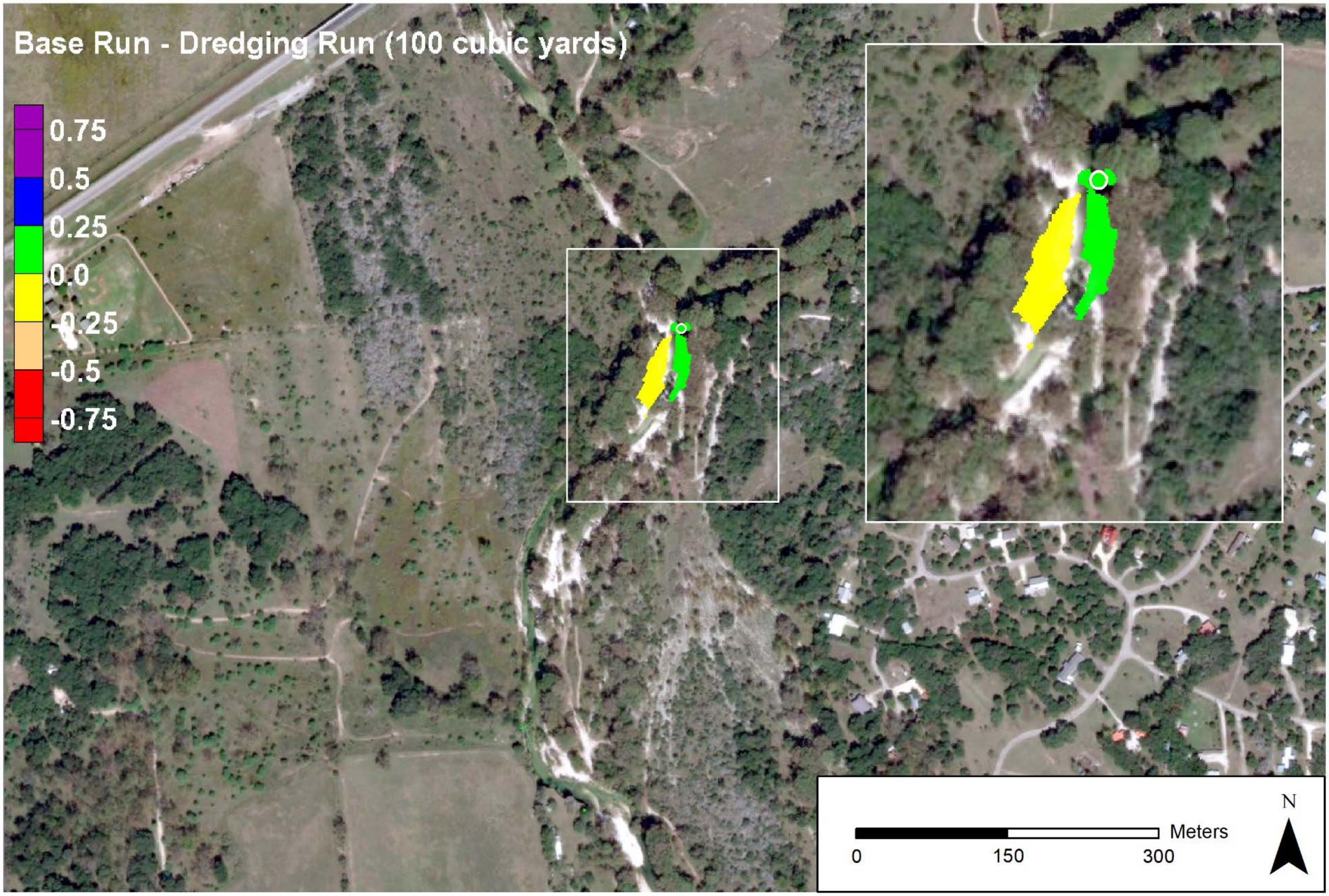


FIGURE F20.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 100 cubic yards of material. Note the material removal site by the white circle.

FIGURE F21.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 300 cubic yards of material. Note the material removal site by the white circle.

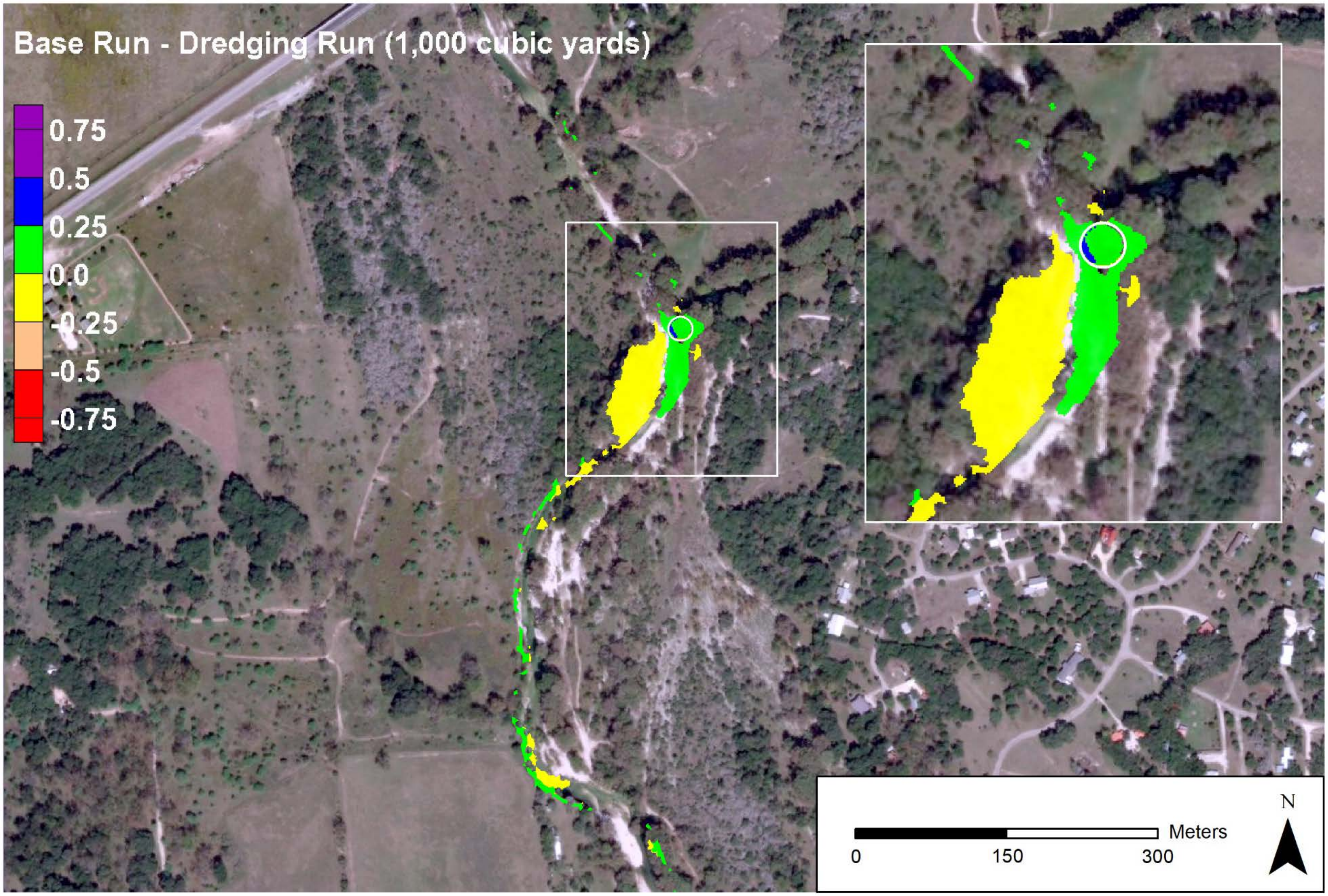


FIGURE F22.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 1,000 cubic yards of material. Note the material removal site by the white circle.

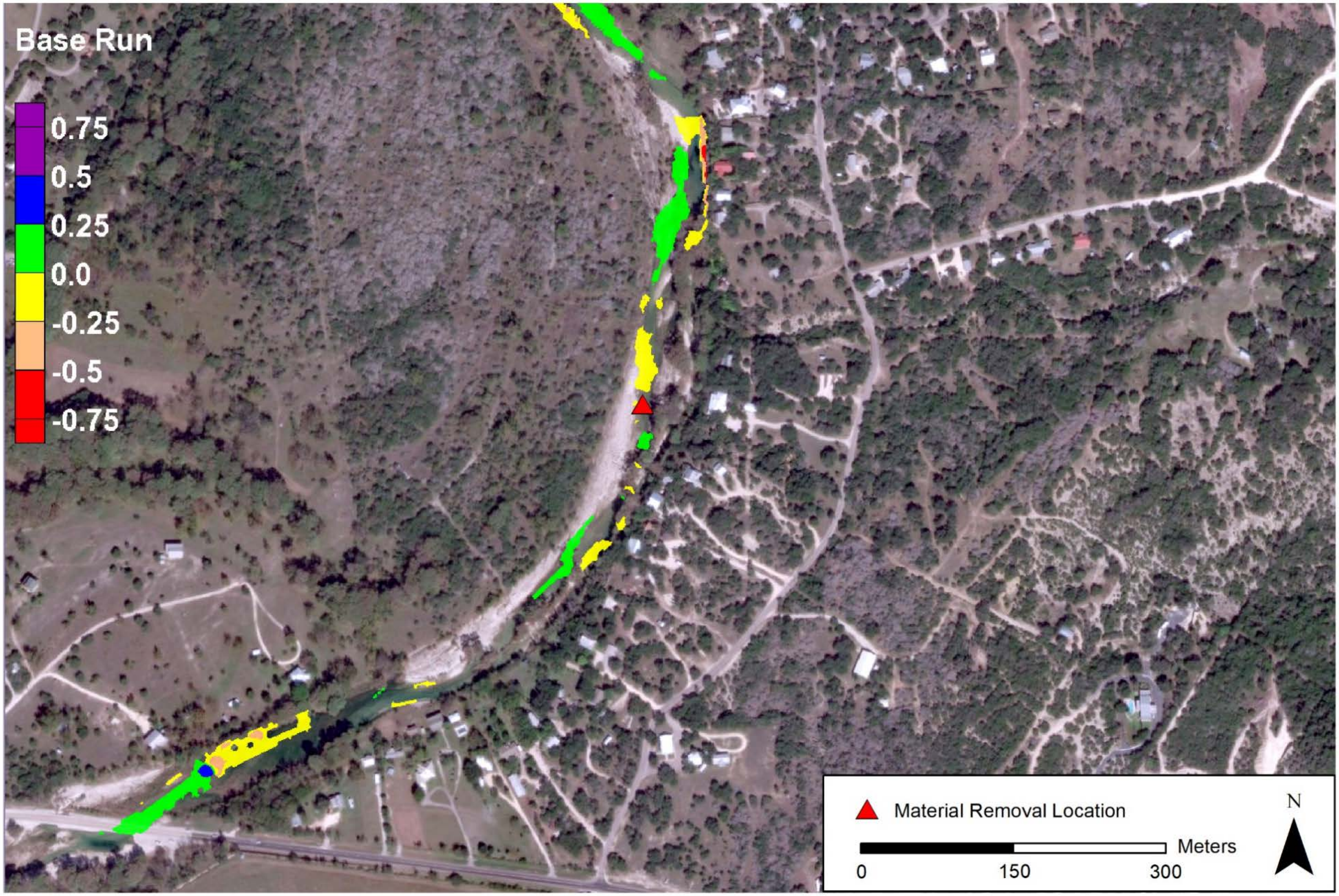


FIGURE F23.—Sediment deposition or scour (in meters) for the base sediment model run with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs.

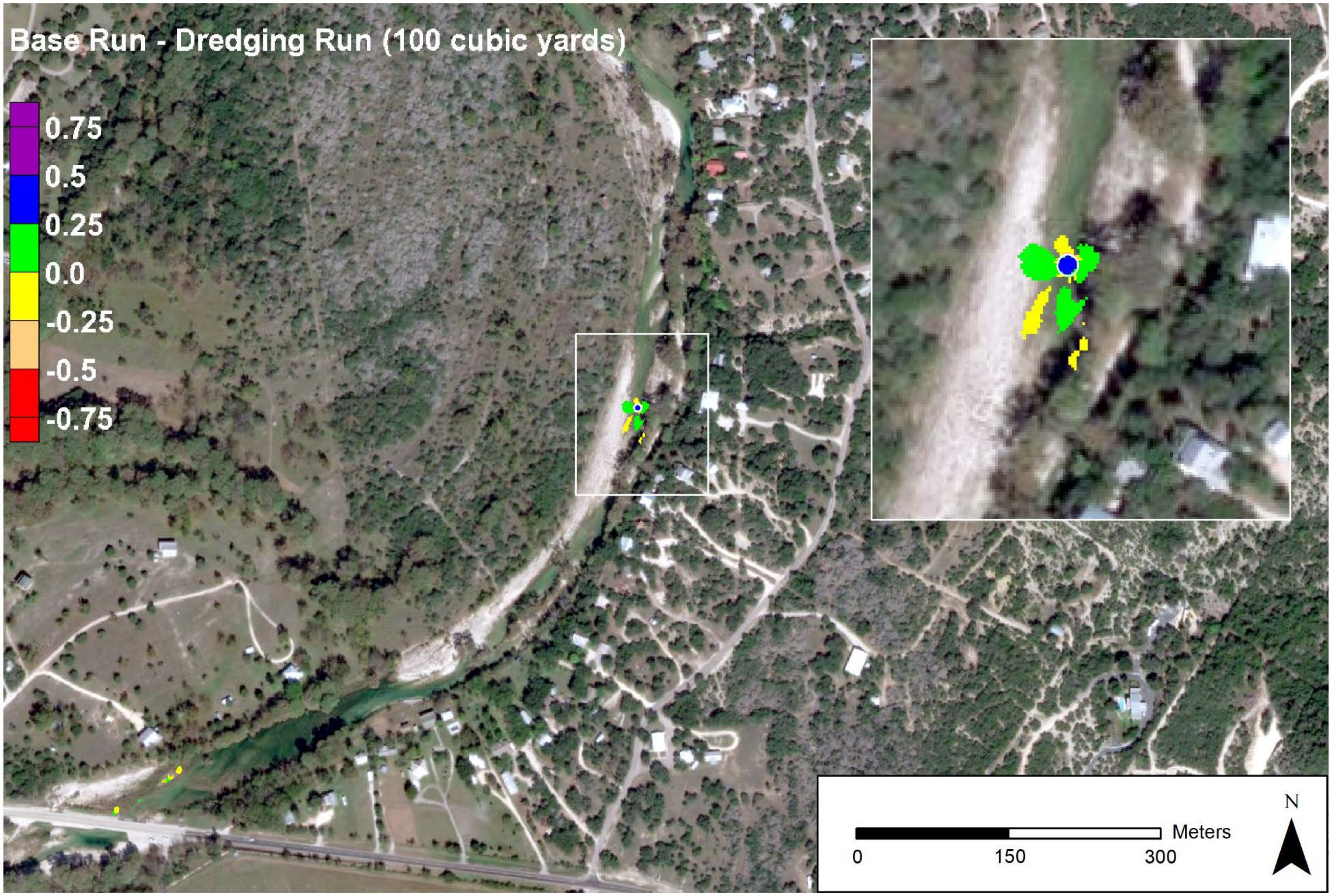


FIGURE F24.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 100 cubic yards of material. Note the material removal site by the white circle.

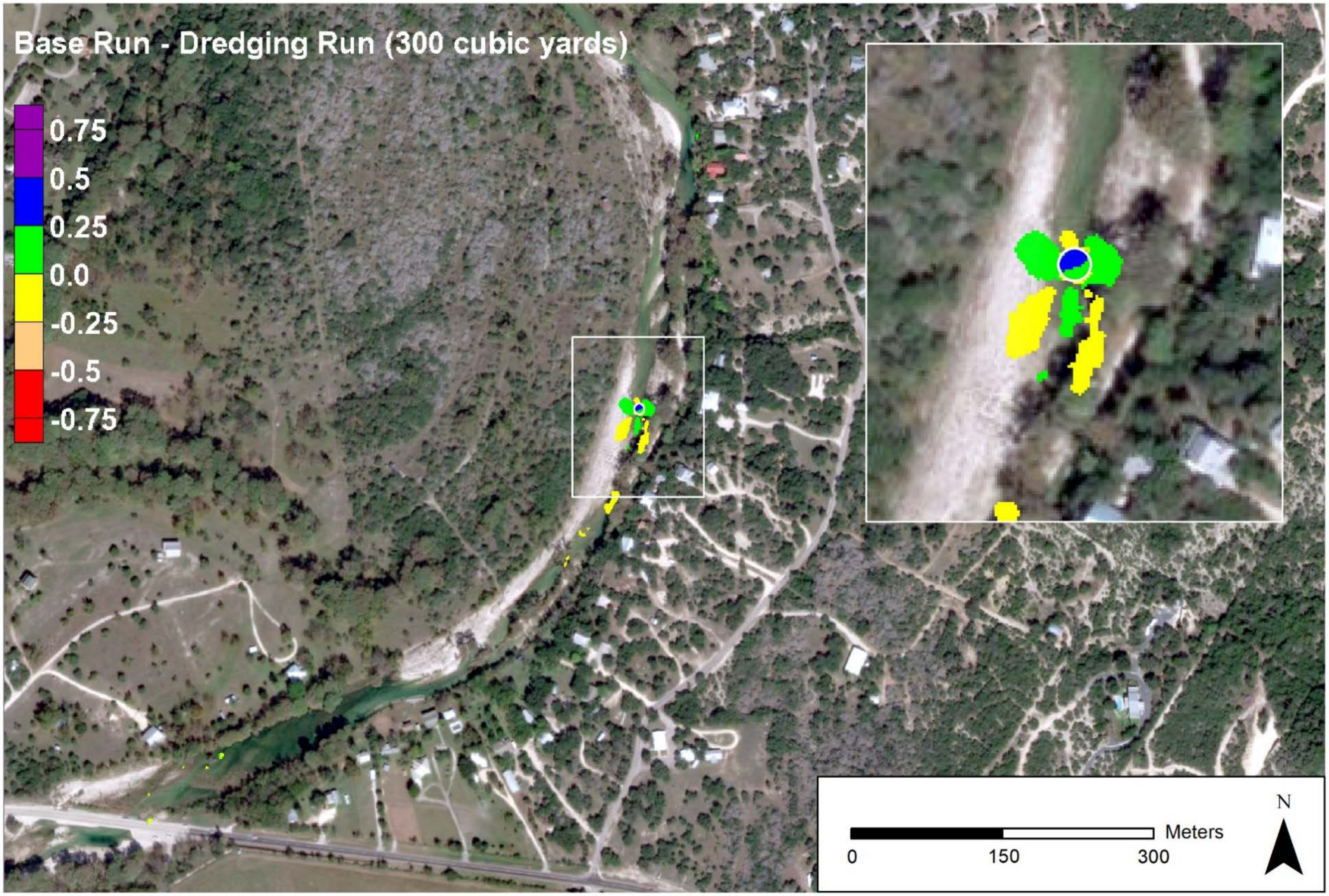


FIGURE F25.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 300 cubic yards of material. Note the material removal site by the white circle.

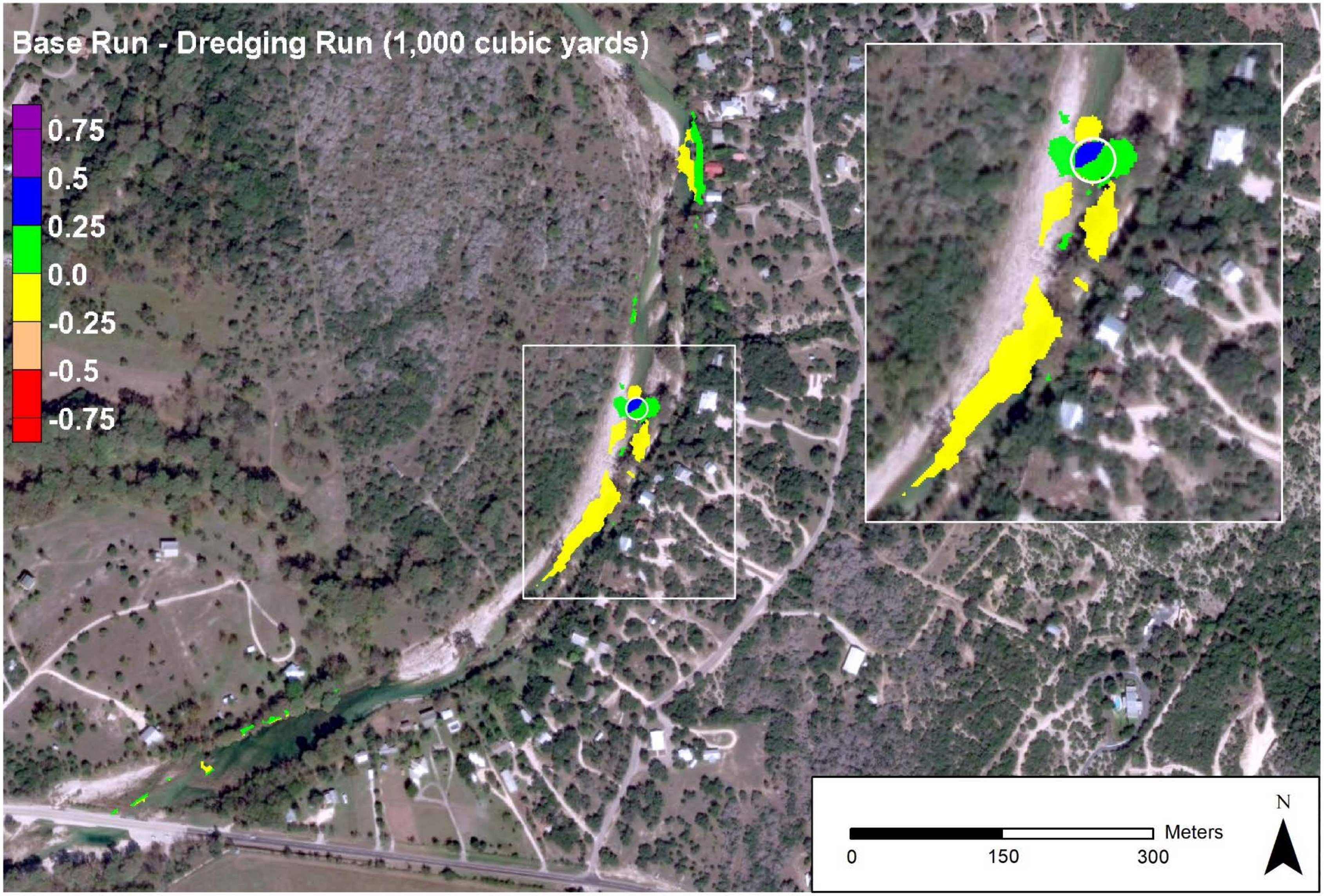


FIGURE F26.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 1,000 cubic yards of material. Note the material removal site by the white circle.

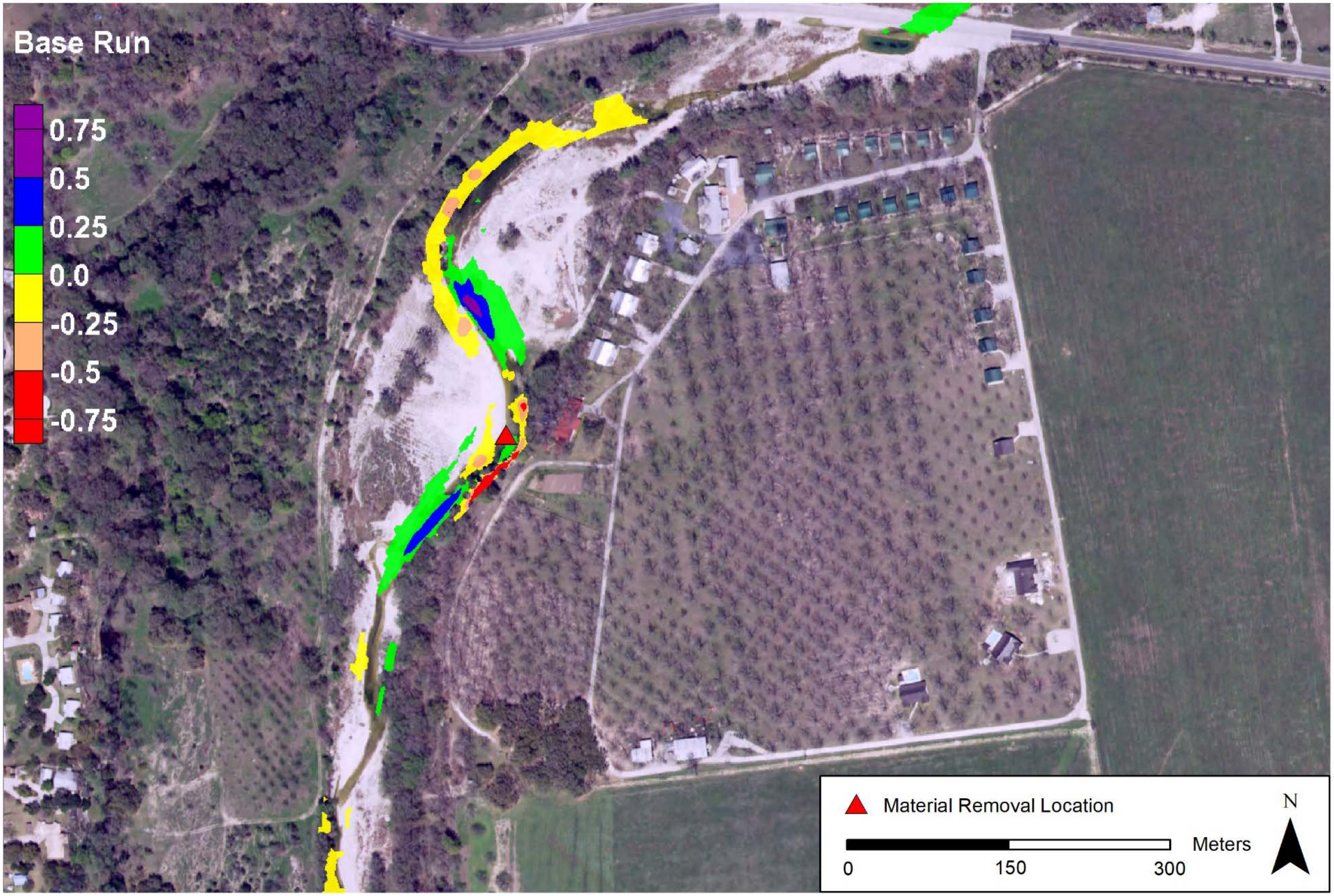


FIGURE F27.—Sediment deposition for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs.

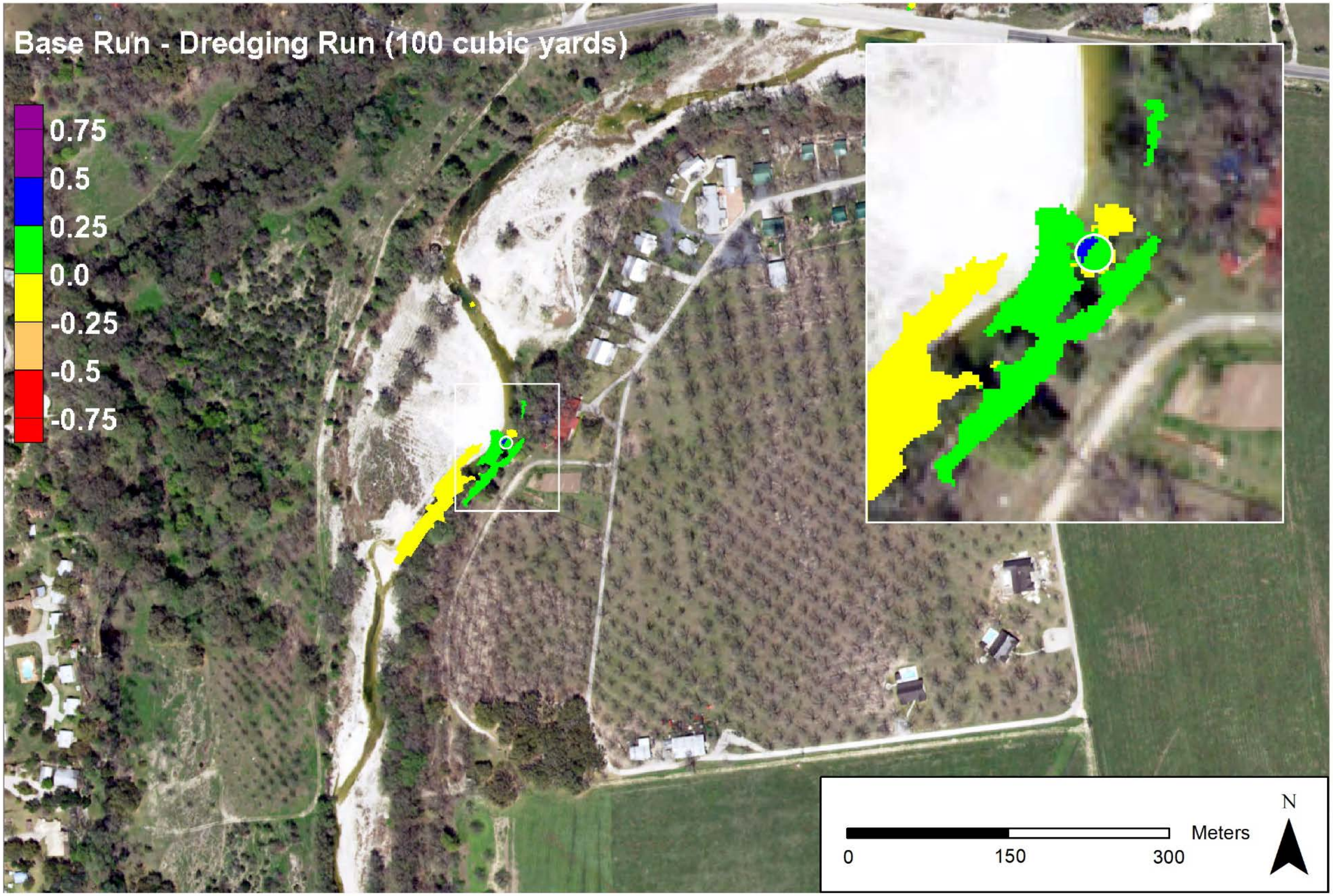


FIGURE F28.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 100 cubic yards of material. Note the material removal site by the white circle.

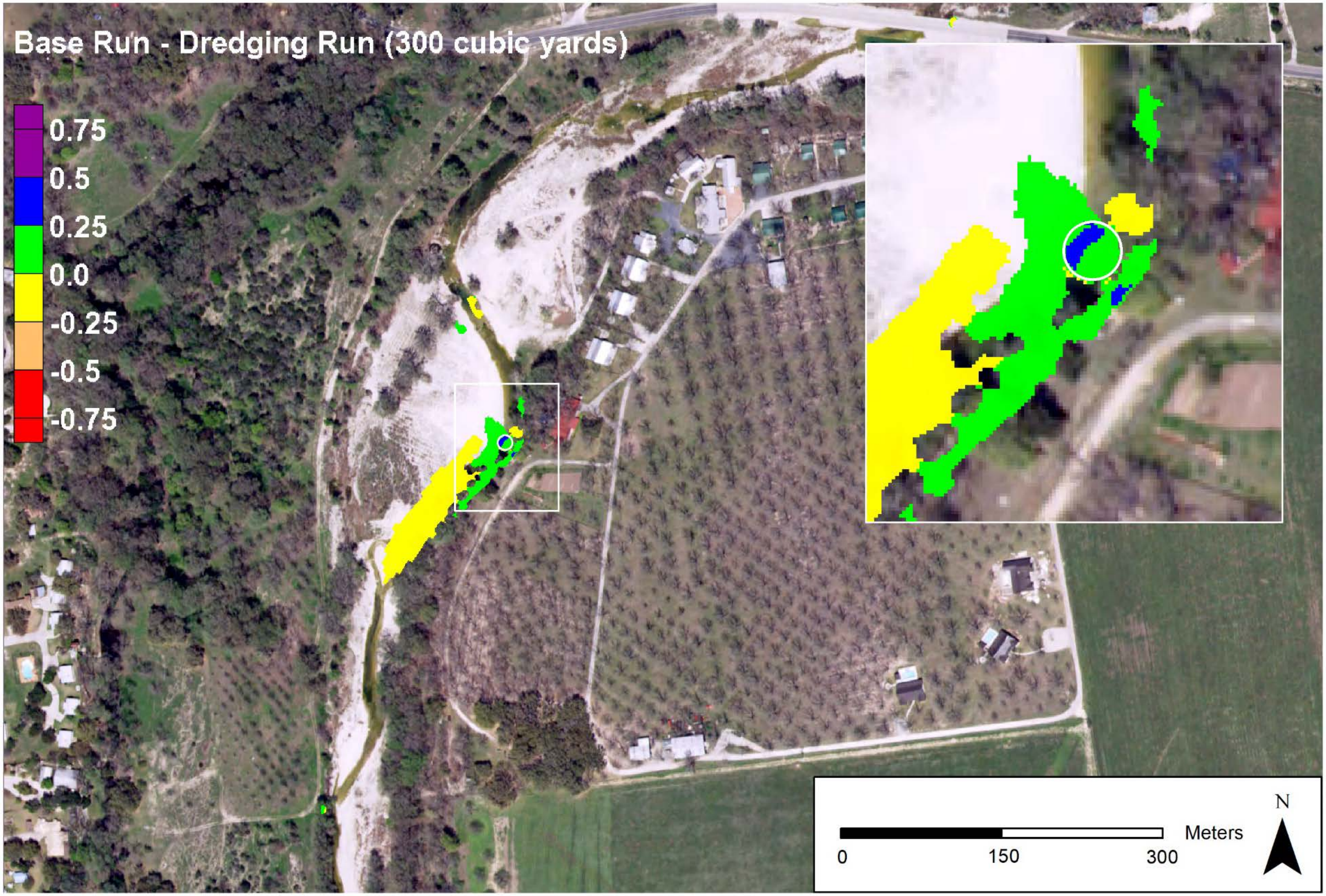


FIGURE F29.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 300 cubic yards being removed. Note the material removal site by the white circle.

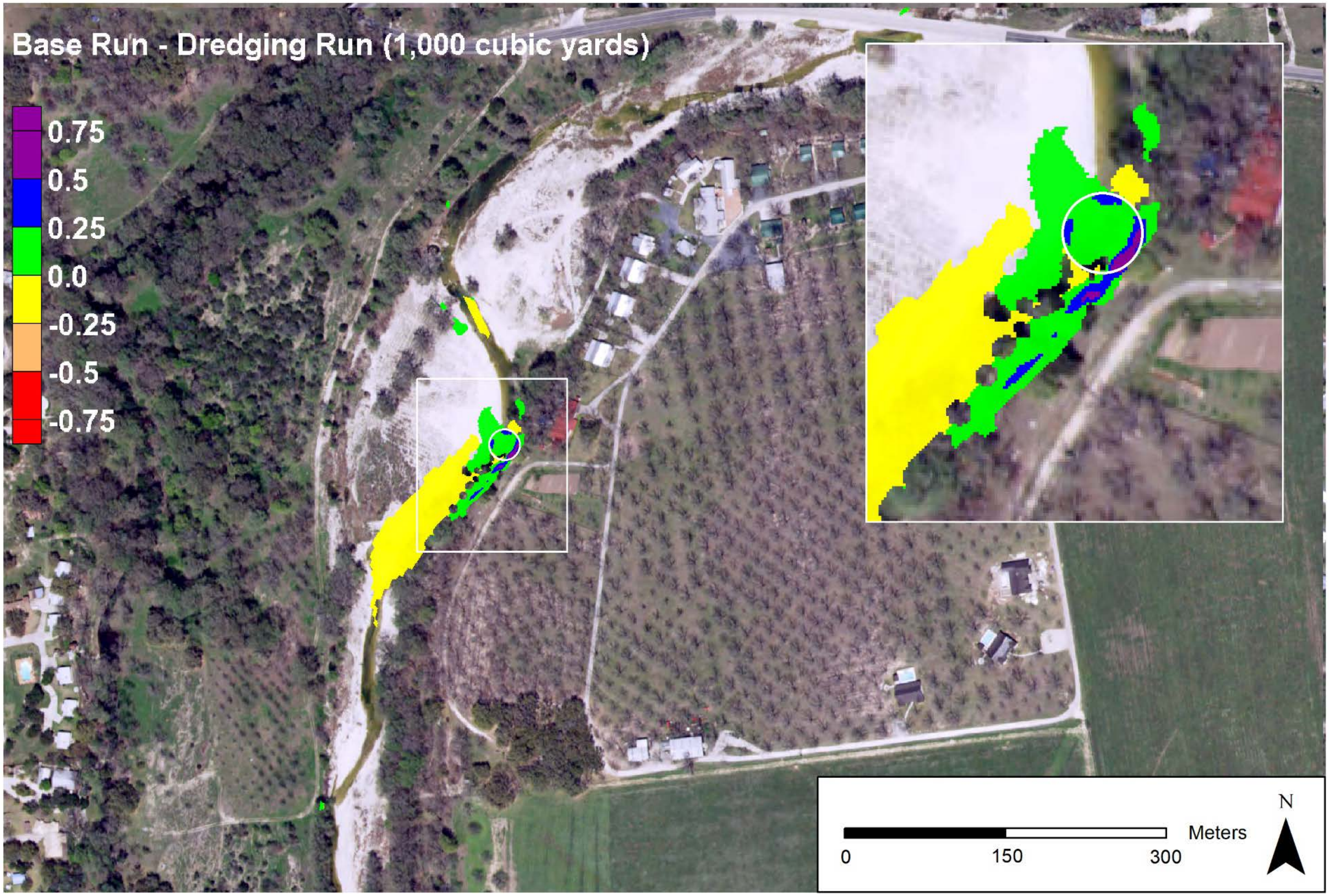


FIGURE F30.—This map shows the amount of change in deposition (relative to the base sediment model run, in meters) following removal of 1,000 cubic yards of material. Note the material removal site by the white circle.

Changes in bedload movement

When the sediment deposition pattern changes, the bedload movement in the channel must also change. Figures 31-35 focus on the upper removal site for the base sediment model run and the 1,000 cubic yard material removal scenario. This site is located between Cross-Sections labeled 11 and 12 in Figure 19. The results for hour 2 of the model run are shown in Figures 31 and 32. For the base sediment model run at hour 2 (Figure 31), the sediment transport shows normal sediment bedload movement with the expected spacial variably that river flow patterns predict. In Figure 32, which is the 1,000 cubic yard material removal scenario, no sediment movement is seen in the area where the material was removed. The flow at hour 2 is about 150 cms (5,300 cfs) and with the additional depth of water where the material has been removed, the flow dynamics do not cause bed load movement.

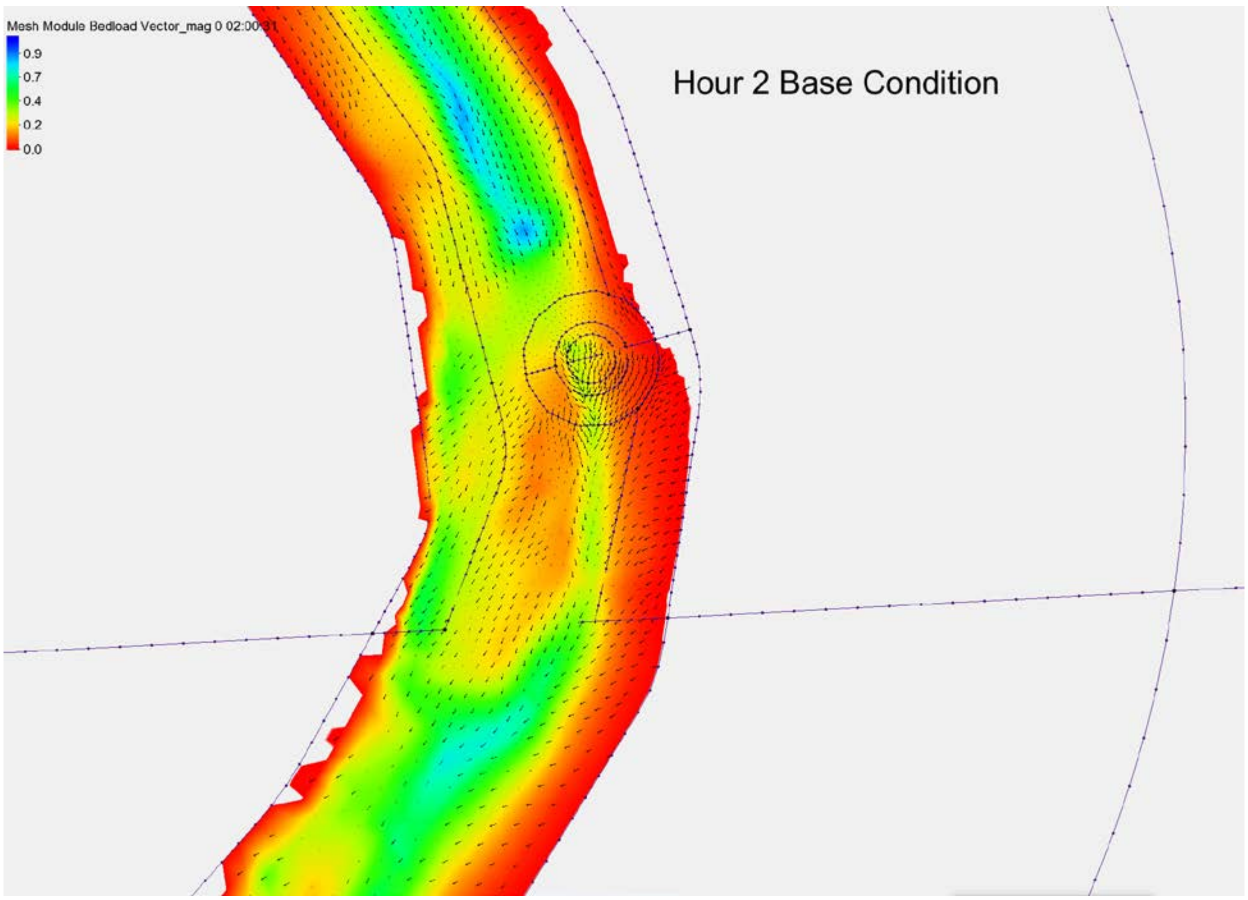


FIGURE F31.—Bedload magnitude in kilograms per second (Kg/sec) and bedload direction at hour 2 of the base sediment model run.

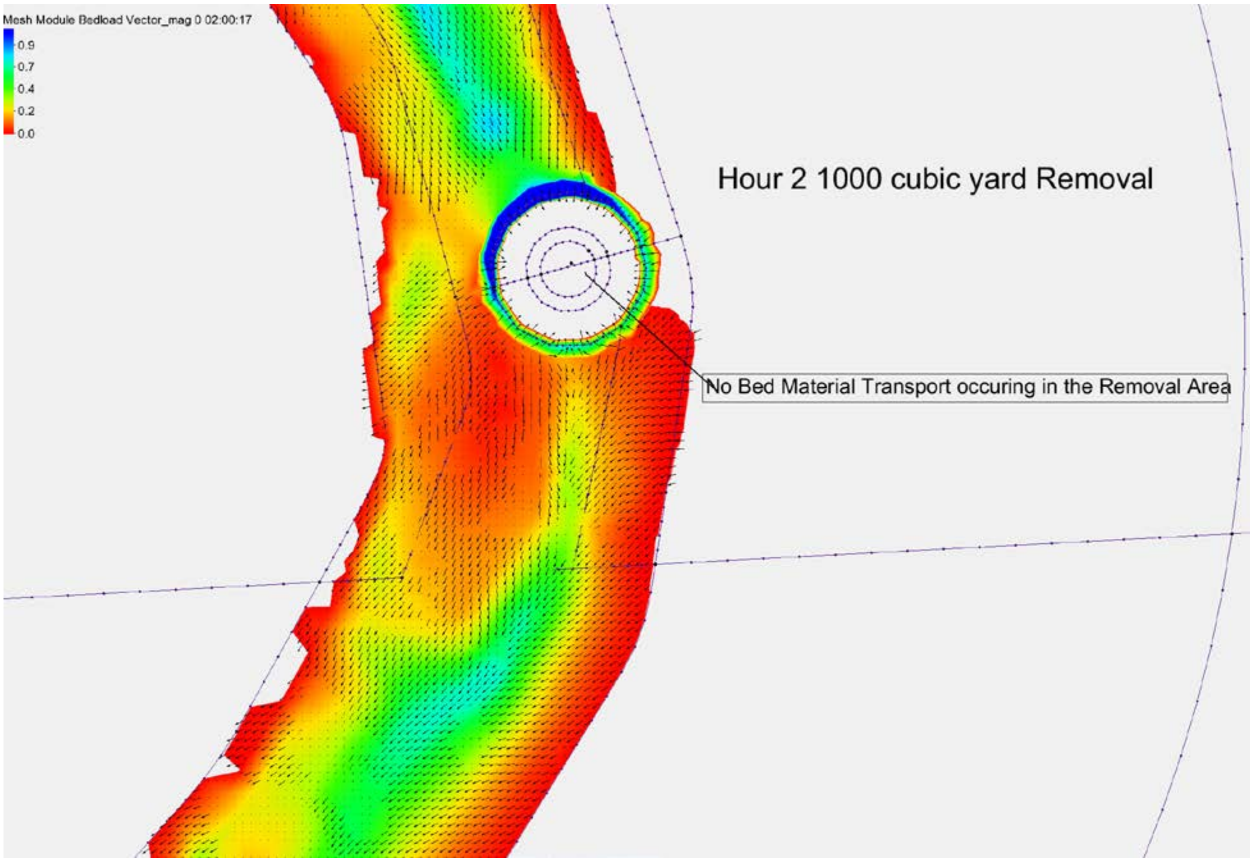


FIGURE F32.—Bedload magnitude in kilograms per second (Kg/sec) and bedload direction at hour 2 of the model scenario with 1,000 cubic yards of material removed.

The results of the base sediment and 1,000 cubic yard removal scenarios for hour 4 of the model run are shown in Figures 33 and 34. At hour 4, the flow in the Frio River is about 470 cms (16,600 cfs). Figure 34 shows some disruptions to bedload movement around the area of the material removal site, but more importantly, it shows a region downstream of the material removal site that is experiencing higher bedload movement rates. This change in bedload is most likely resulting from a change in flow patterns and from the loss of bed material load due to sediment deposition replacing material removed for this scenario. Figure 35 shows the bedload passing Cross-Section 11 in Figure 19. The cross-section is downstream of the upper material removal site and shows the amount of sediment being passed to the downstream reaches of the river. The figure shows that if larger quantities of material are removed from the upper site, there is a corresponding larger amount of sediment being trapped at the site, and less bed material load will be transported downstream.

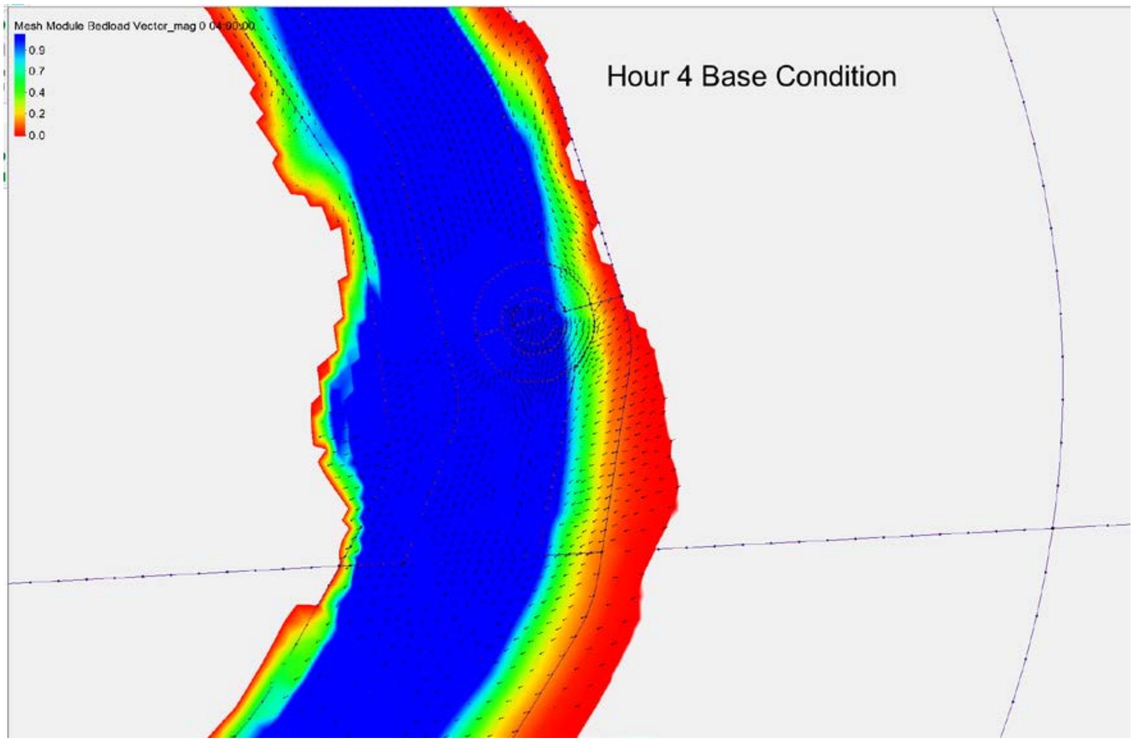


FIGURE F33.—Bedload magnitude in kilograms per second (Kg/sec) and bedload direction at hour 4 of the base sediment model run.

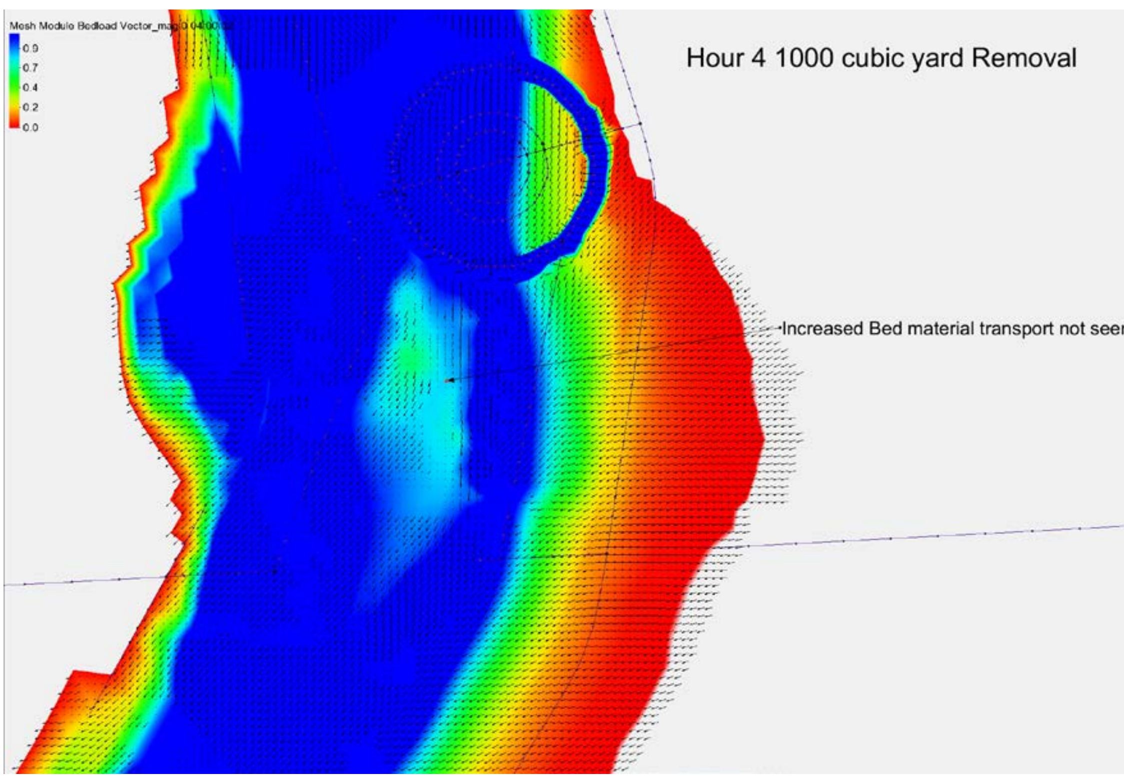


FIGURE F34.—Bedload magnitude in kilograms per second (Kg/sec) and bedload direction at hour 4 of the model scenario with 1,000 cubic yards of material removed.

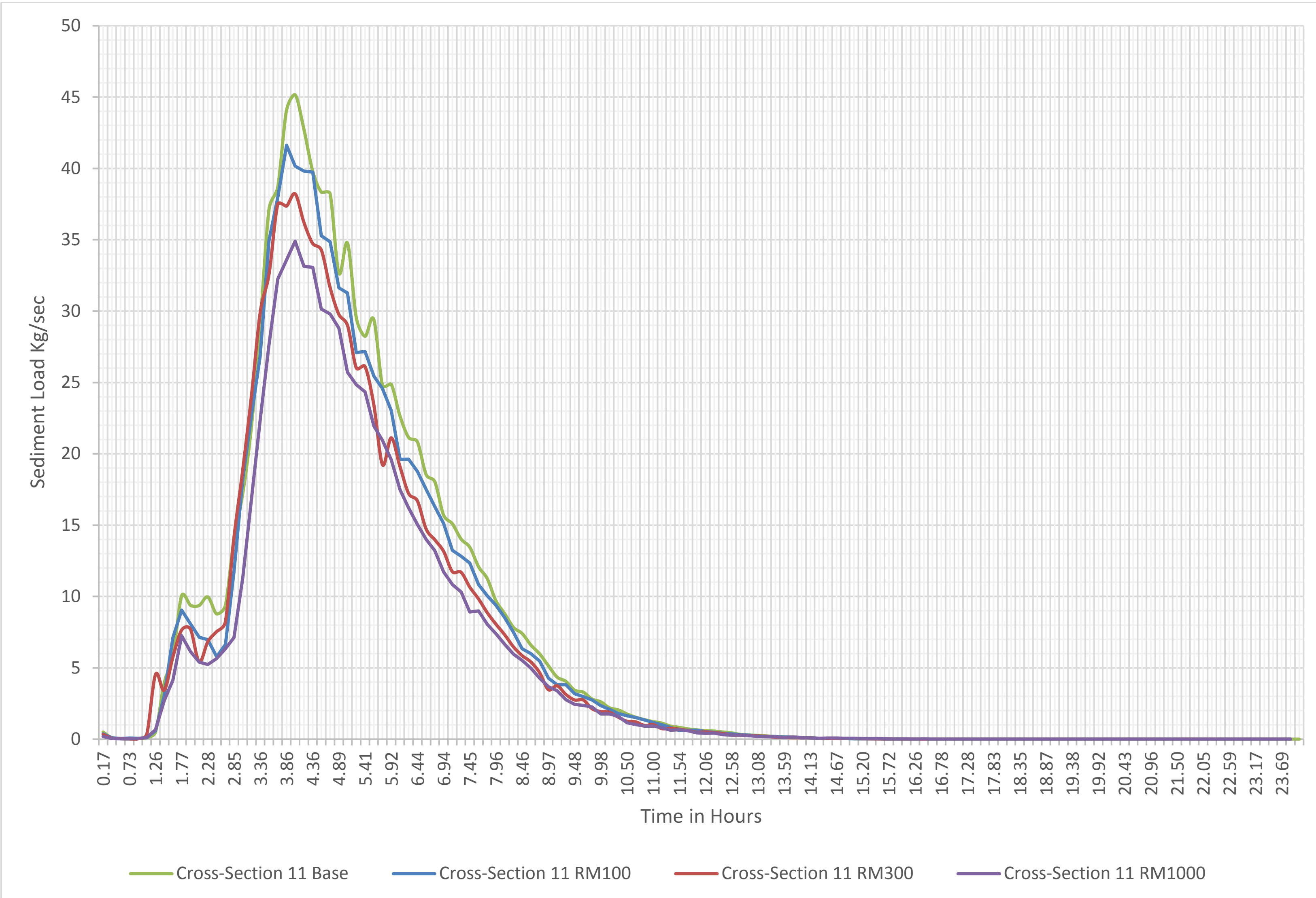


FIGURE F35.—Bed load passing Cross-Section 11 for all four model runs (base and removal of 100, 300, and 1,000 cubic yards).

Summary

The intent of this project was to evaluate the potential impacts of in-channel material removal from the Frio River. This required the collection of high-quality land surface topography and bathymetric data, development of hydraulic and sediment transport hydrodynamic computer models, and an assessment of the impacts of three different volumes of material removed from three separate permitted locations.

Since the intent of this study was to quantify the effects of material removal from the channel, actual flows and water surface elevation data within the study reach were not collected. Therefore, the computer models and subsequent output are only an estimate of flood flow inundation. Furthermore, the hydraulic models and sediment models that were run used a 24-hour flow hydrograph recorded at the USGS gage number 08195000 Frio River at Concan, Texas. This hydrograph was translated to the study site since no other gages were present either above or below the study site. Additionally, since the bedload portion of sediment transport was not sampled during this study and there was no calibration process for the computer models developed, this work is considered a desktop sediment analysis. Results of this study should not be used to estimate the extent of inundation associated with similar sized flows or the exact volume or depth of sediment deposition (or scour) expected. However, the models are appropriate to identify the general location and magnitude of differences in deposition (or scour) associated with in-channel material removal.

The results from the study indicate that the proposed material removal scenarios of 100, 300, and 1,000 cubic yards, at the three modeled locations, fill (*i.e.*, induce sediment deposition) in the material removal sites and change deposition and scour patterns in areas adjacent to and for some distance downstream of the sites.

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APPENDIX G

Additional Sediment Transport Modeling Results

The sediment transport modeling, as discussed in Appendix F of this report, focused on a 24-hour flow hydrograph that occurred on September 8, 2018 at the USGS gage number 08195000, Frio River at Concan, TX. Changes in scour and depositional patterns at three locations in the upper portion of the Frio River (see Figure 16) were modeled. These comparisons were for sediment model runs with no material removed compared to 76, 229, and 756 cubic meters (100, 300 and 1,000 cubic yards, respectively) of material removed from each of three locations in the modeled segment of the Frio River.

Additional sediment transport modeling was conducted by the TWDB to look at the scour and depositional patterns that occur with material removal from the same three locations after a longer time period, with the addition of multiple flow peaks that occurred in September and October of 2018 as shown in Figure F1. Note: the low flows between the peaks in the hydrograph were eliminated because it previous modeling demonstrated that there is almost no bedload transport at flows less than 70 cms (2,500 cfs).

A longer model duration with multiple flow peaks was the only change made for this modeling effort. The following assumptions and parameters stayed the same:

- The computational mesh developed for the study reach (Figure 9) was used for this analysis.
- The 2-D Adaptive Hydraulics (AdH) Modeling software was used for this analysis.
- Bed material gradation remained the same (see Figure 14, Table 2 and Figure 15 for the bed material gradation, grain diameter, and geometric mean for each grain size classification).
- The Meyer-Peter and Müller with Wong Parker Correction bed-load entrainment function was again used for this sediment transport analysis.

The following plots contain the model outputs for the base condition (no material removed) and each scenario (76, 229, and 756 cubic meters of material removed) at the three removal locations. Plots were generated for each of four time steps of the model. The model output was viewed at 4 hours, 21 hours, 60 hours and 100 hours. These times correspond to the three peaks in flow and the end of the simulation.

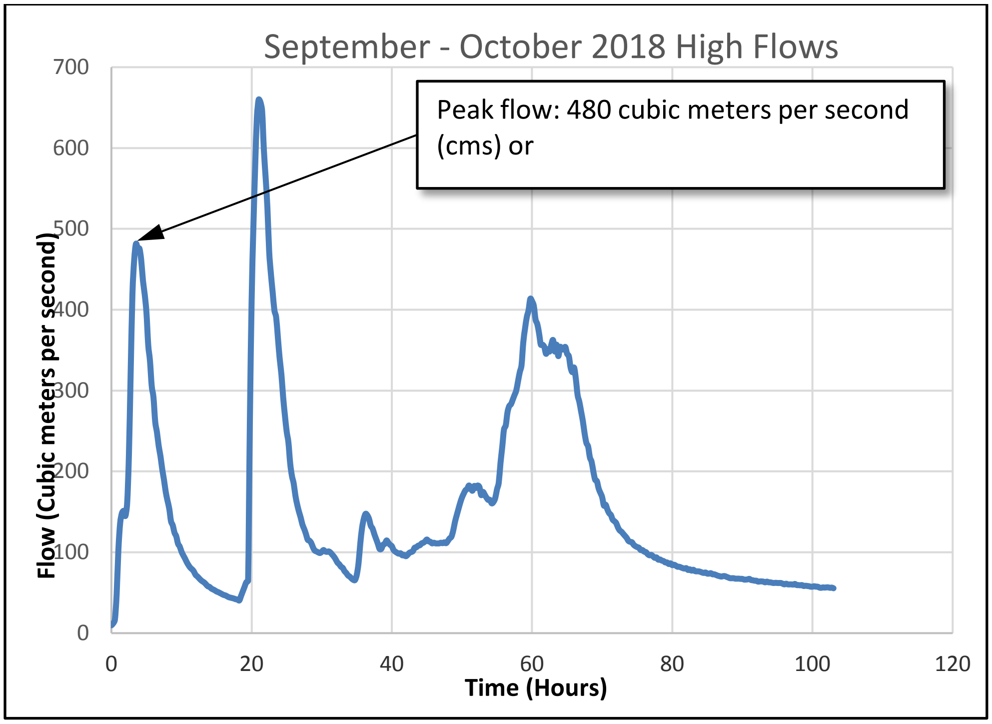

FIGURE G1.—Model flow hydrograph developed from USGS gage number 08195000 Frio River at Concan, TX, for September 8, October 8, and October 15-18, 2018 flows in sequence.

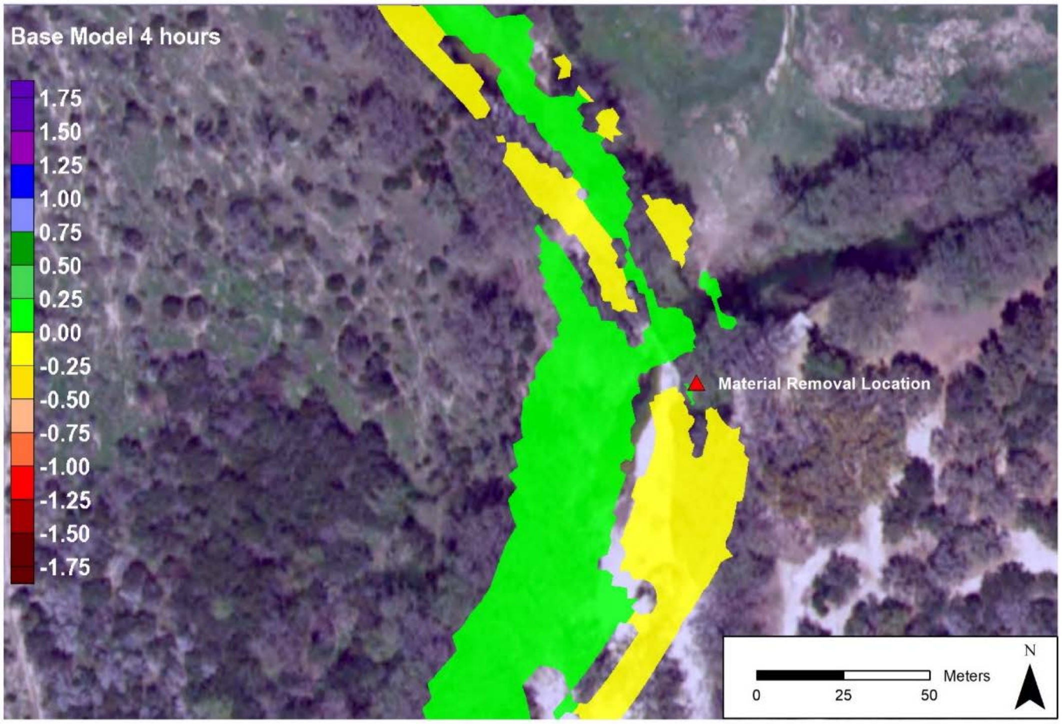

FIGURE G2.—Sediment deposition after 4 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (upper site).

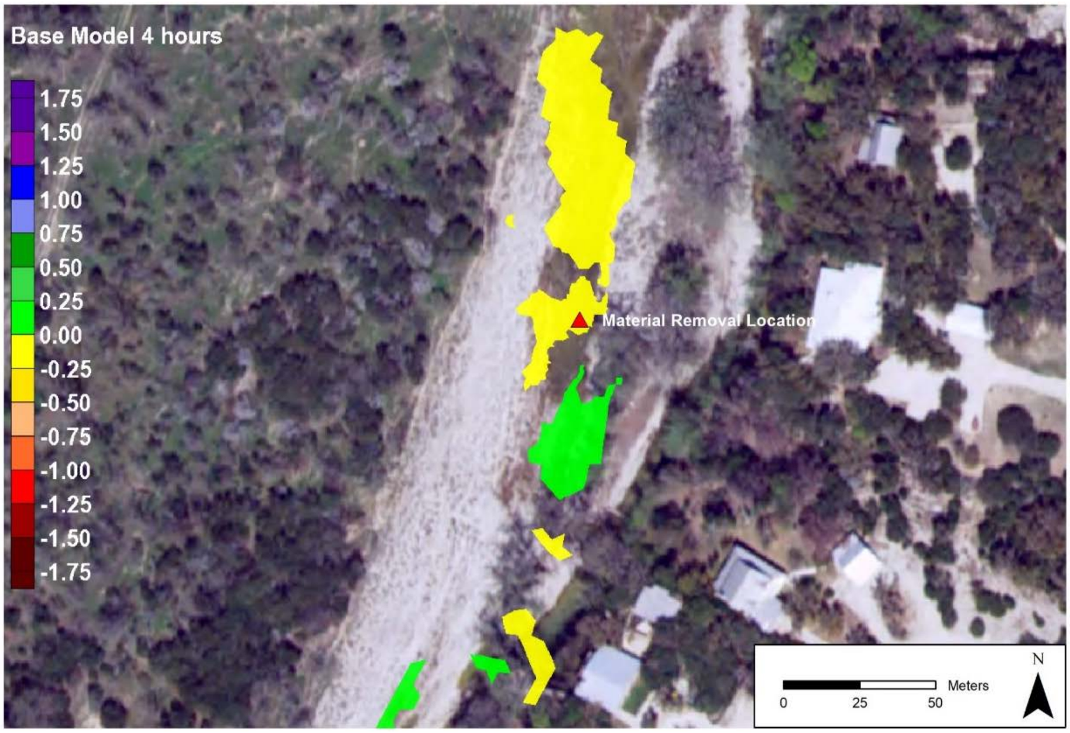

FIGURE G3.—Sediment deposition after 4 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (middle site).

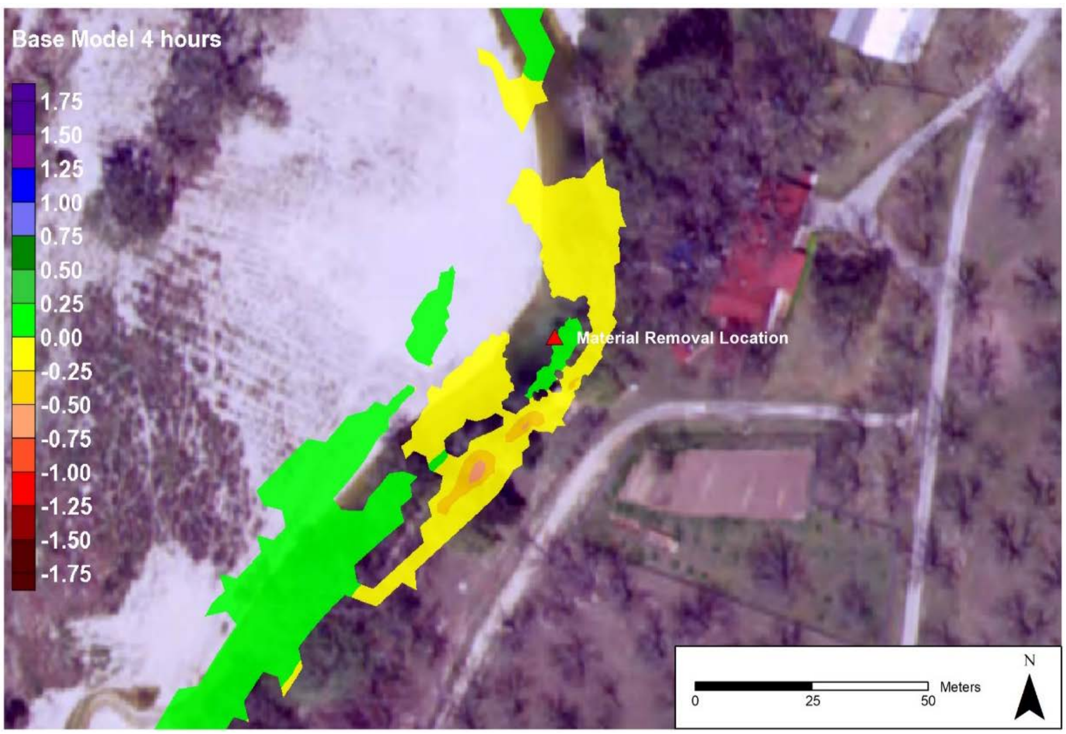

FIGURE G4.—Sediment deposition after 4 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (lower site).

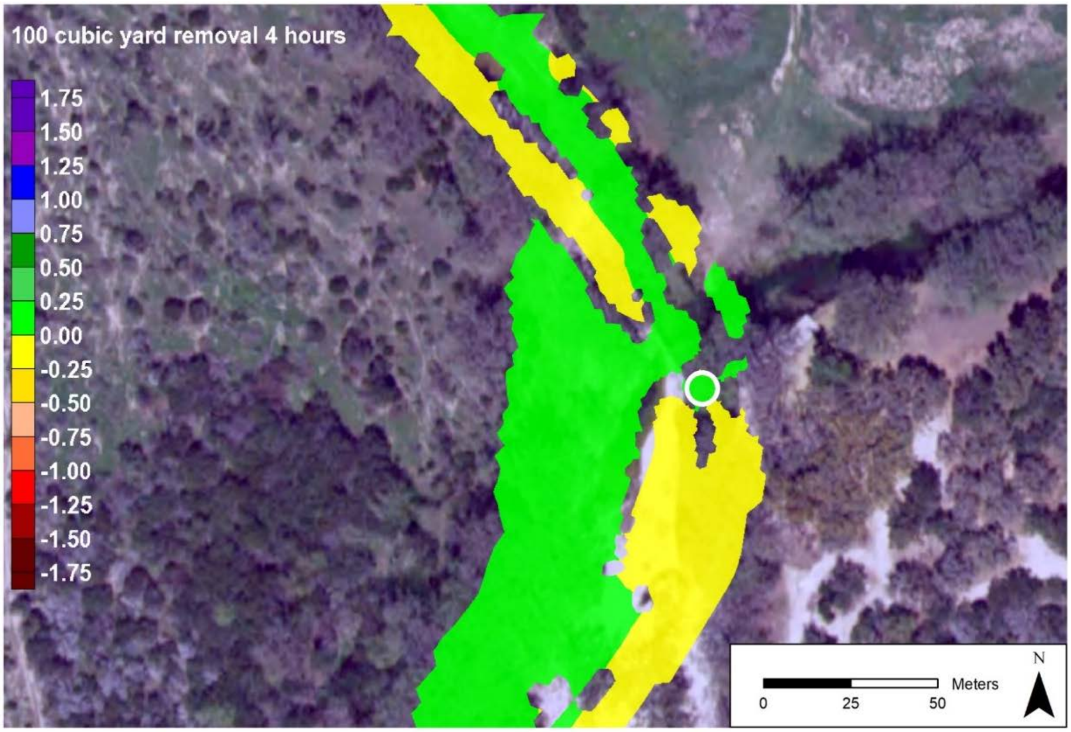

FIGURE G5.—Sediment deposition after 4 hours of simulation (in meters), 100 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G6.—Sediment deposition after 4 hours of simulation (in meters), 100 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

FIGURE G7.—Sediment deposition after 4 hours of simulation (in meters), 100 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

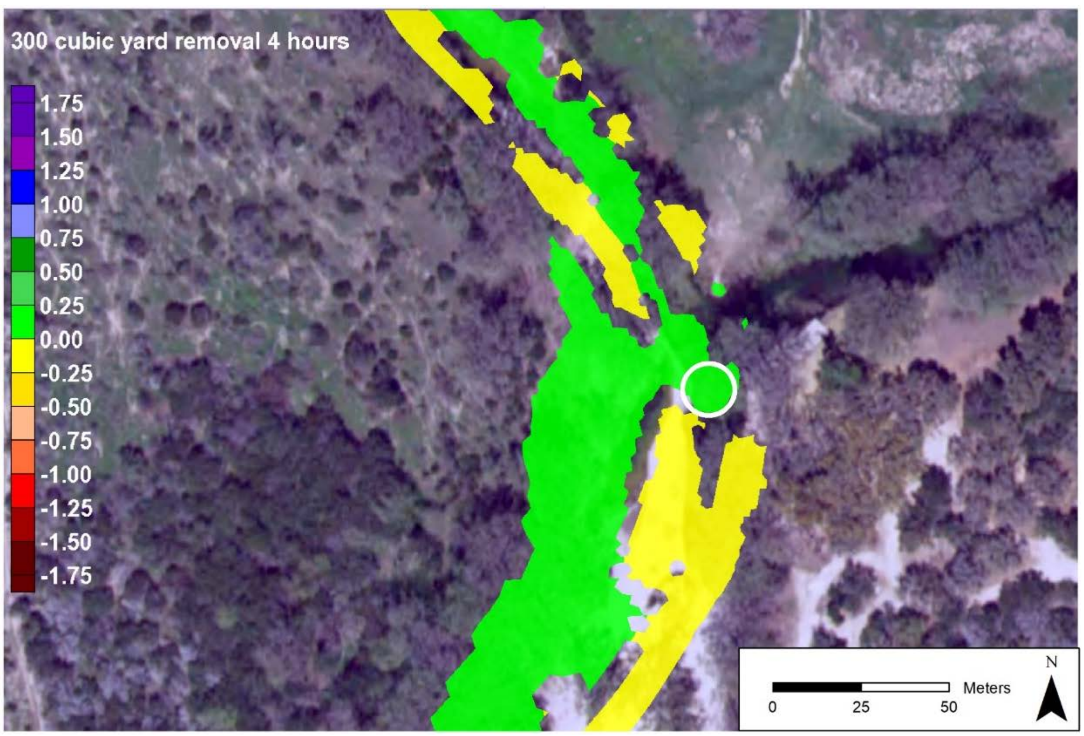

FIGURE G8.—Sediment deposition after 4 hours of simulation (in meters), 300 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G9.—Sediment deposition after 4 hours of simulation (in meters), 300 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

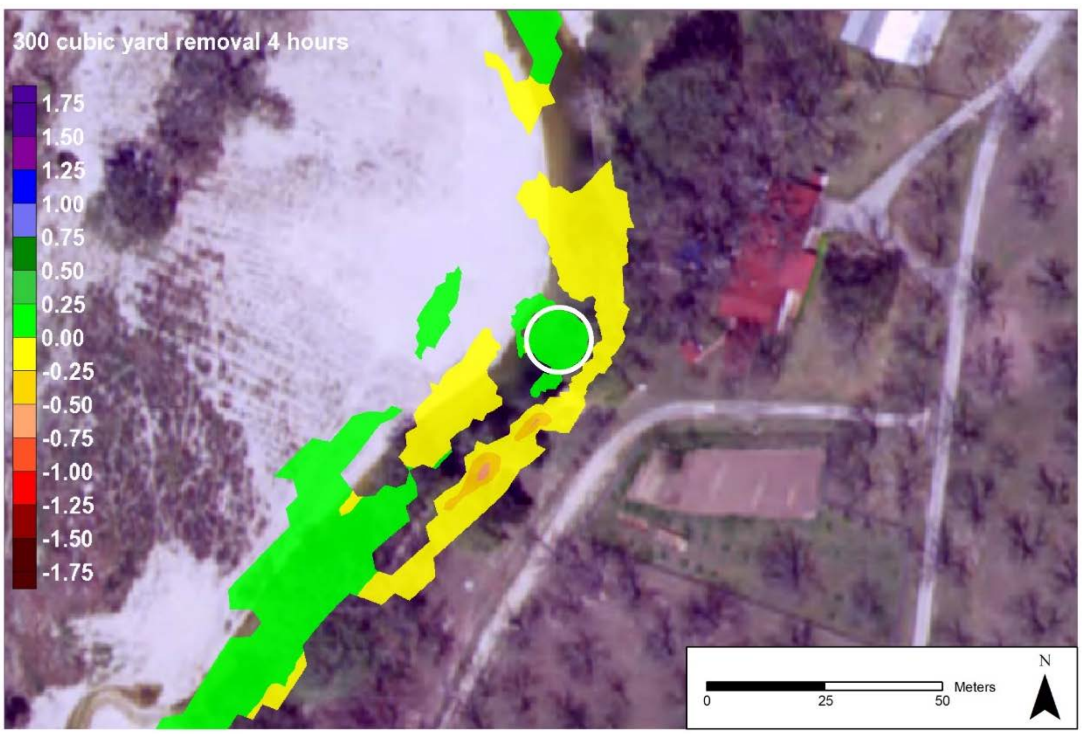

FIGURE G10.—Sediment deposition after 4 hours of simulation (in meters), 300 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

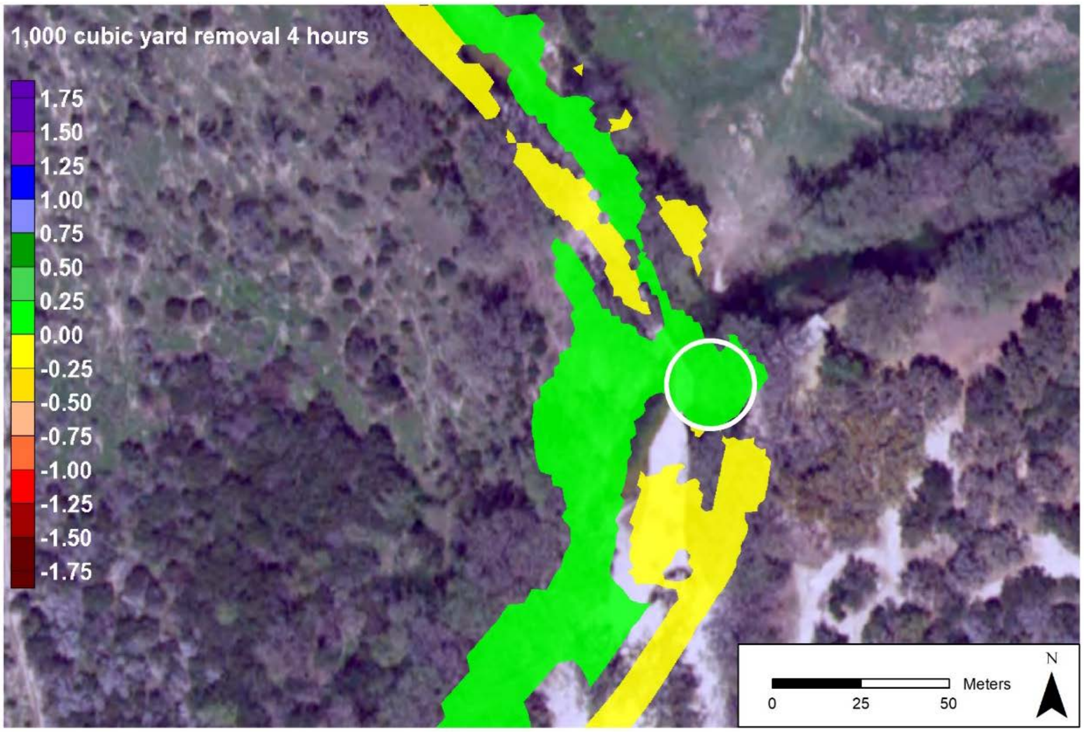

FIGURE G11.—Sediment deposition after 4 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G12.—Sediment deposition after 4 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

FIGURE G13.—Sediment deposition after 4 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

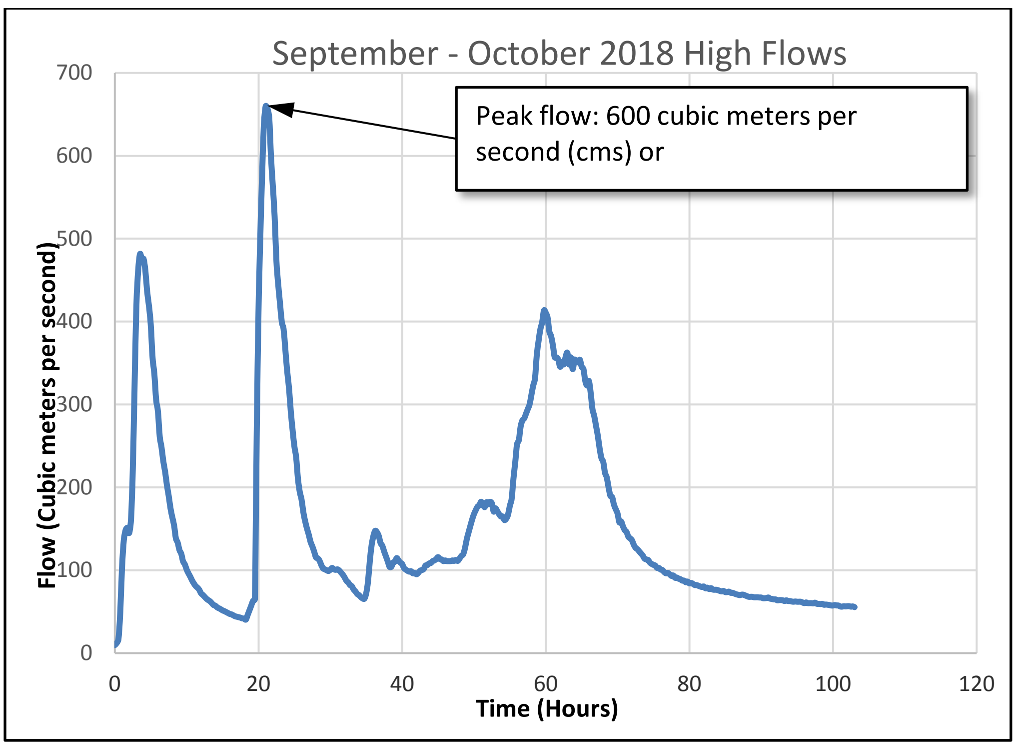

FIGURE G14.—Model flow hydrograph developed from USGS gage number 08195000 Frio River at Concan, TX, with September 8, October 8, and October 15-18, 2018 flows in sequence.

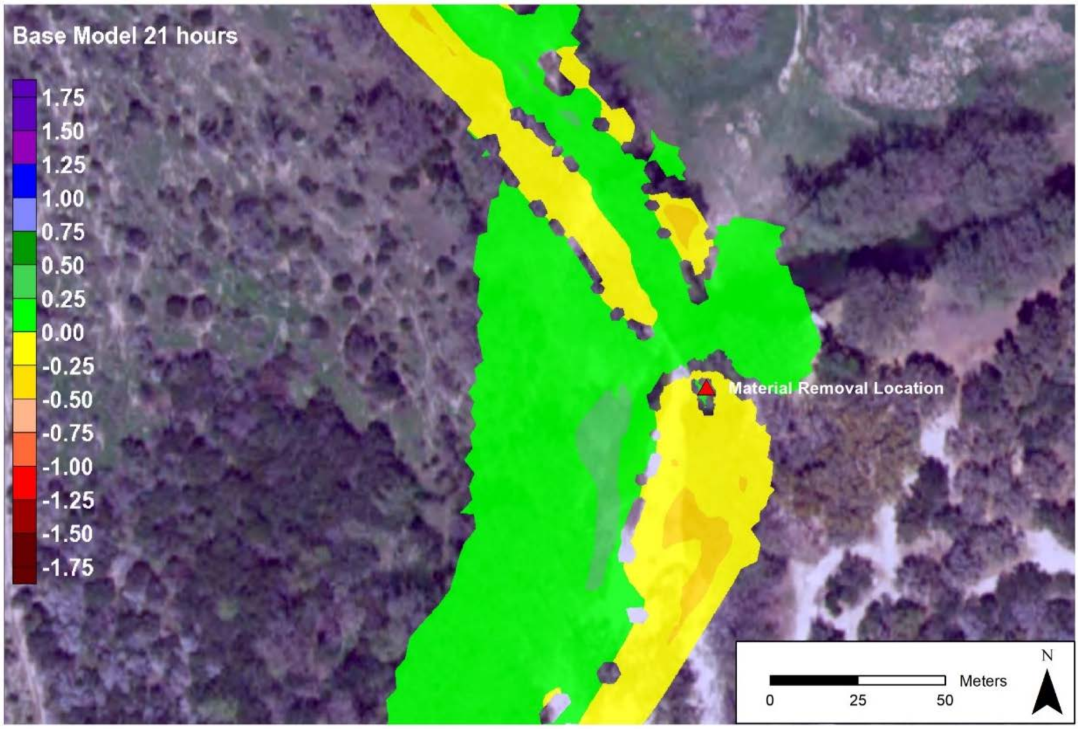

FIGURE G15.—Sediment deposition after 21 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (upper site).

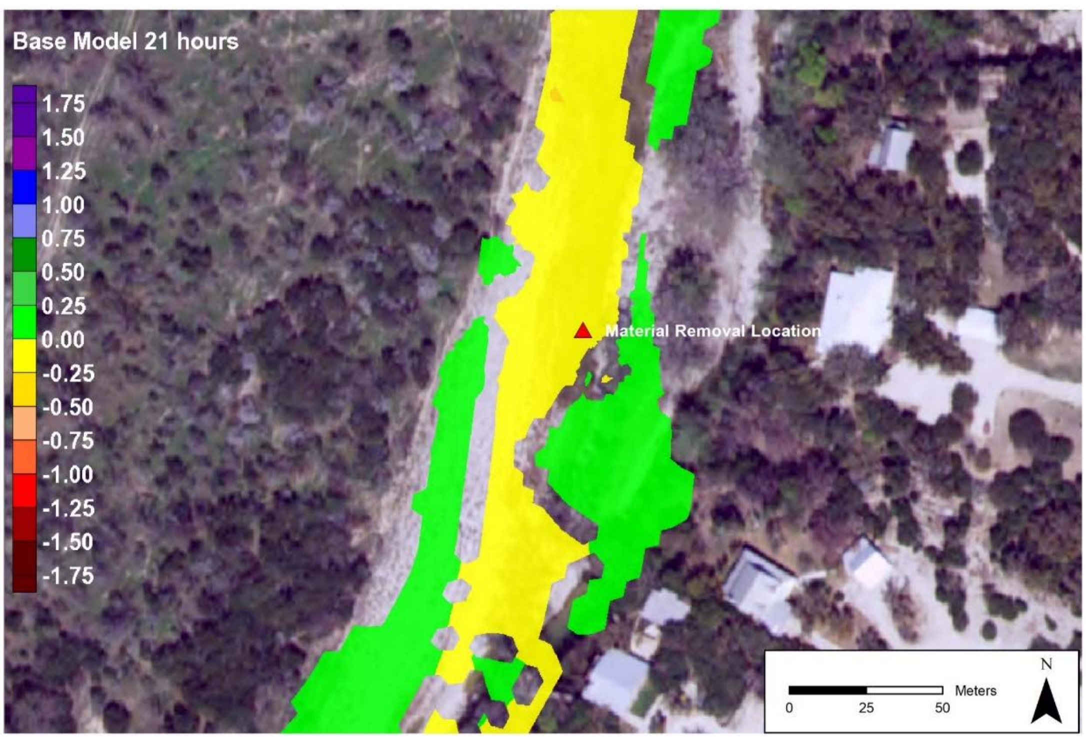

FIGURE G16.—Sediment deposition after 21 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (middle site).

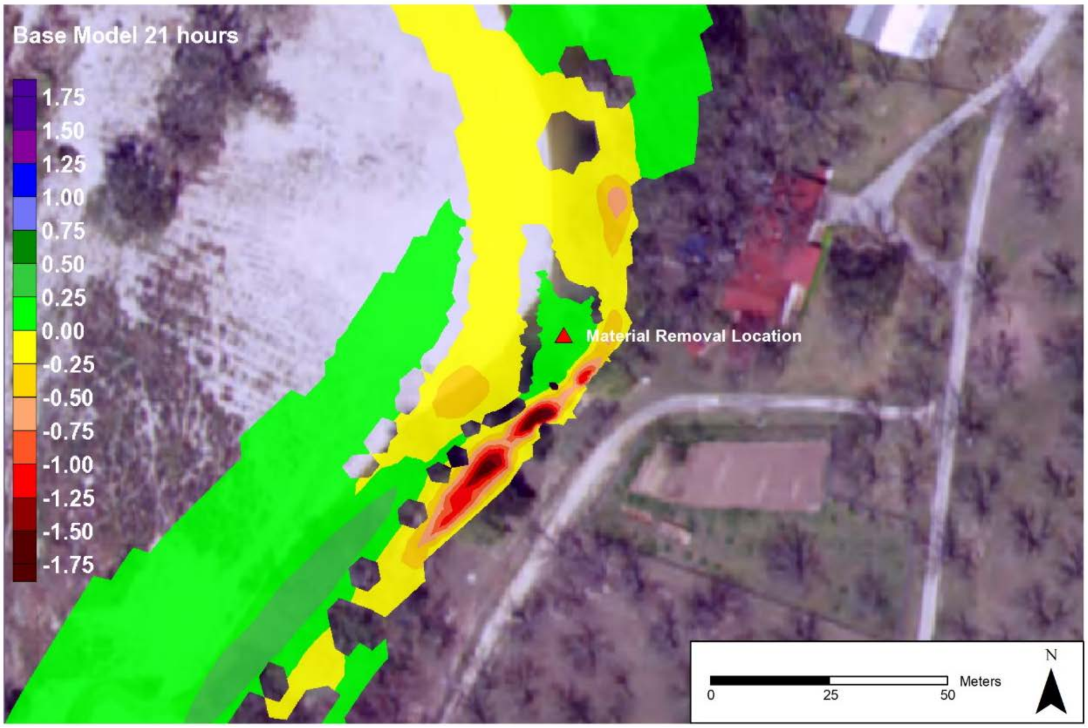

FIGURE G17.—Sediment deposition after 21 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (lower site).

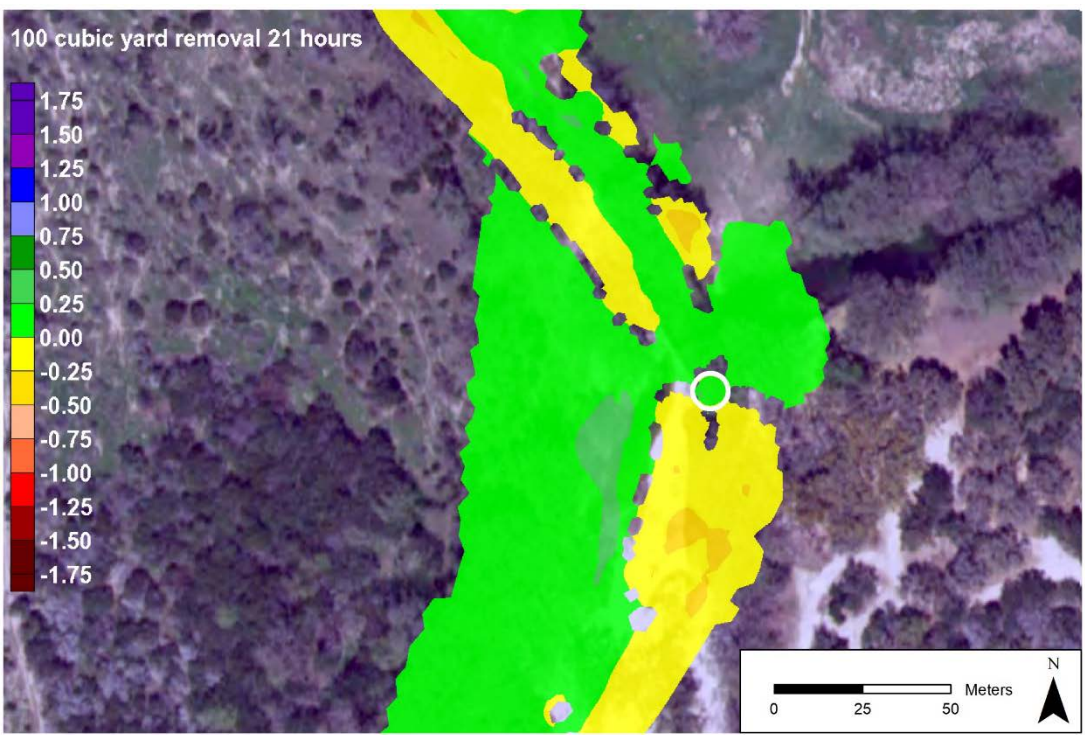

FIGURE G18.—Sediment deposition after 21 hours of simulation (in meters), 100 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

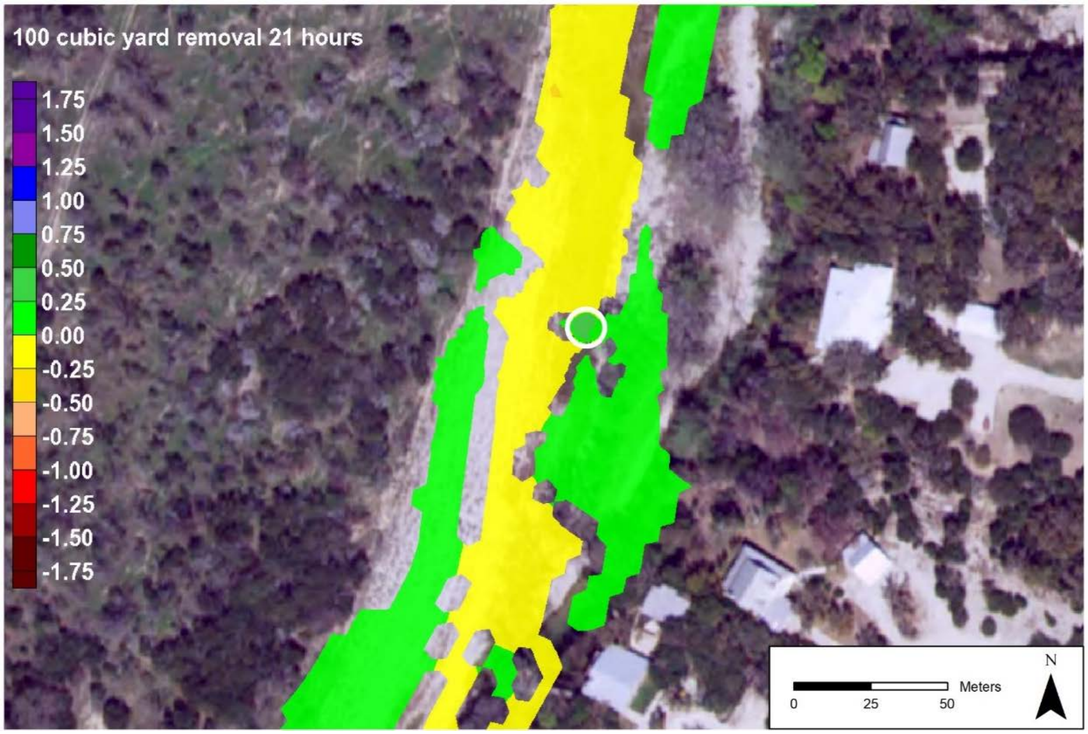

FIGURE G19.— Sediment deposition after 21 hours of simulation (in meters), 100 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

FIGURE G20.—Sediment deposition after 21 hours of simulation (in meters), 100 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

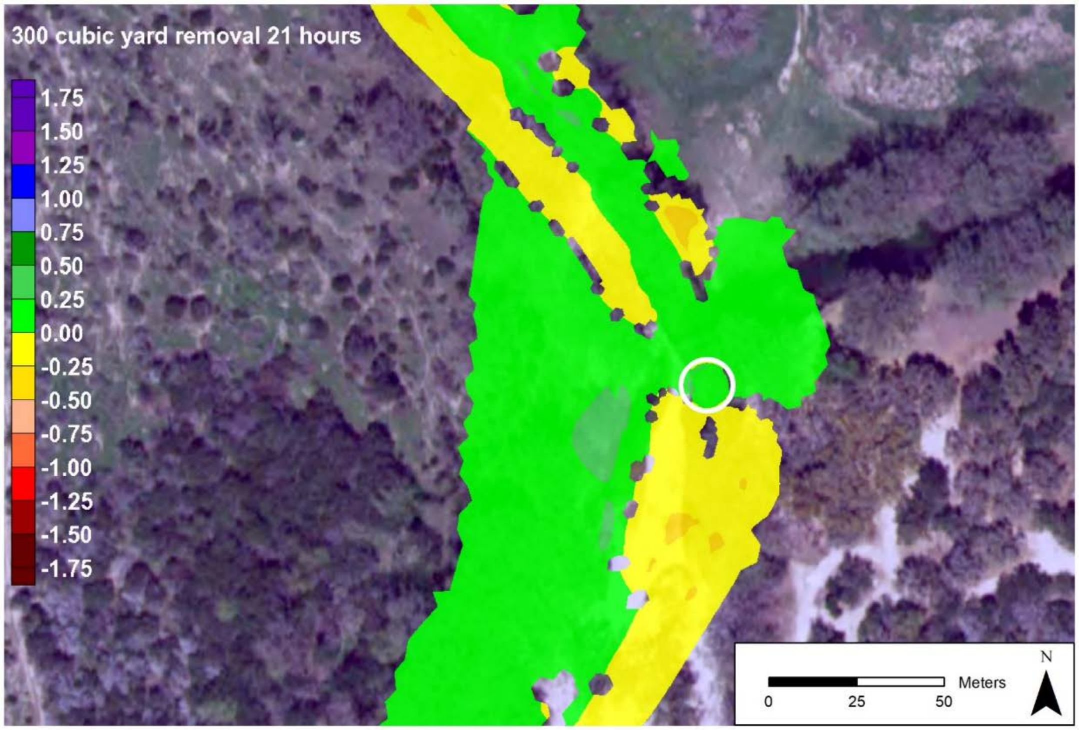

FIGURE G21.—Sediment deposition after 21 hours of simulation (in meters), 300 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

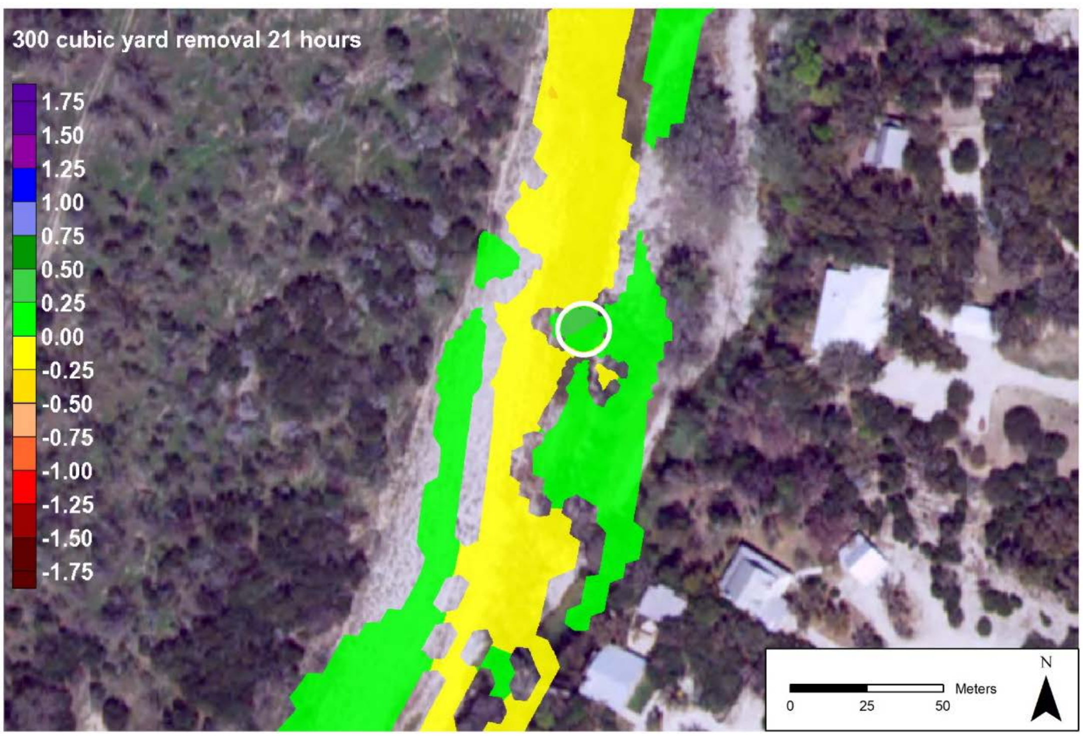

FIGURE G22.—Sediment deposition after 21 hours of simulation (in meters), 300 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

FIGURE G23.—Sediment deposition after 21 hours of simulation (in meters), 300 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

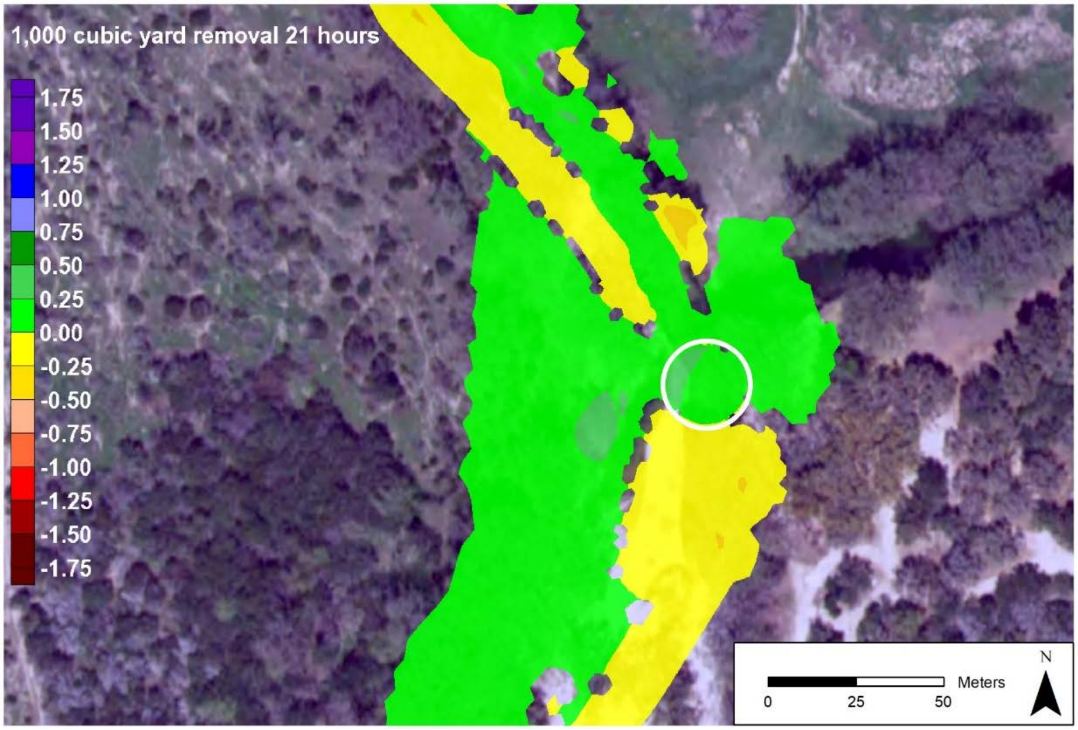

FIGURE G24.—Sediment deposition after 21 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G25.—Sediment deposition after 21 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

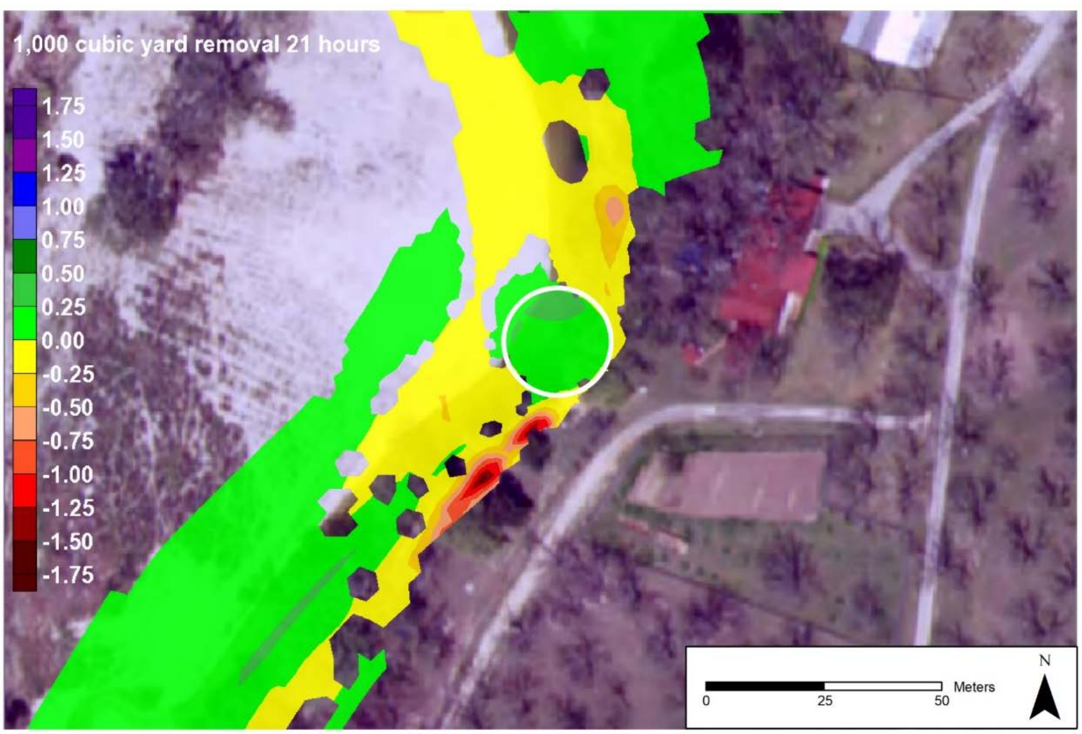

FIGURE G26.—Sediment deposition after 21 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

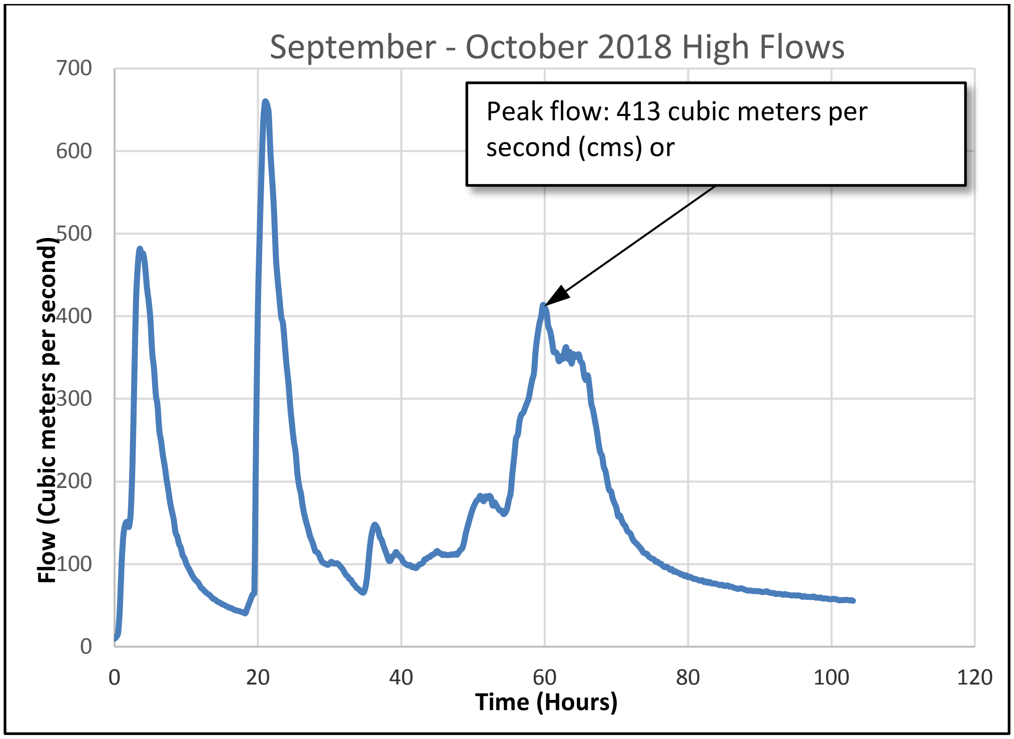

FIGURE G27.—Model flow hydrograph developed from USGS gage number 08195000 Frio River at Concan, TX, with September 8, October 8, and October 15-18, 2018 flows in sequence.

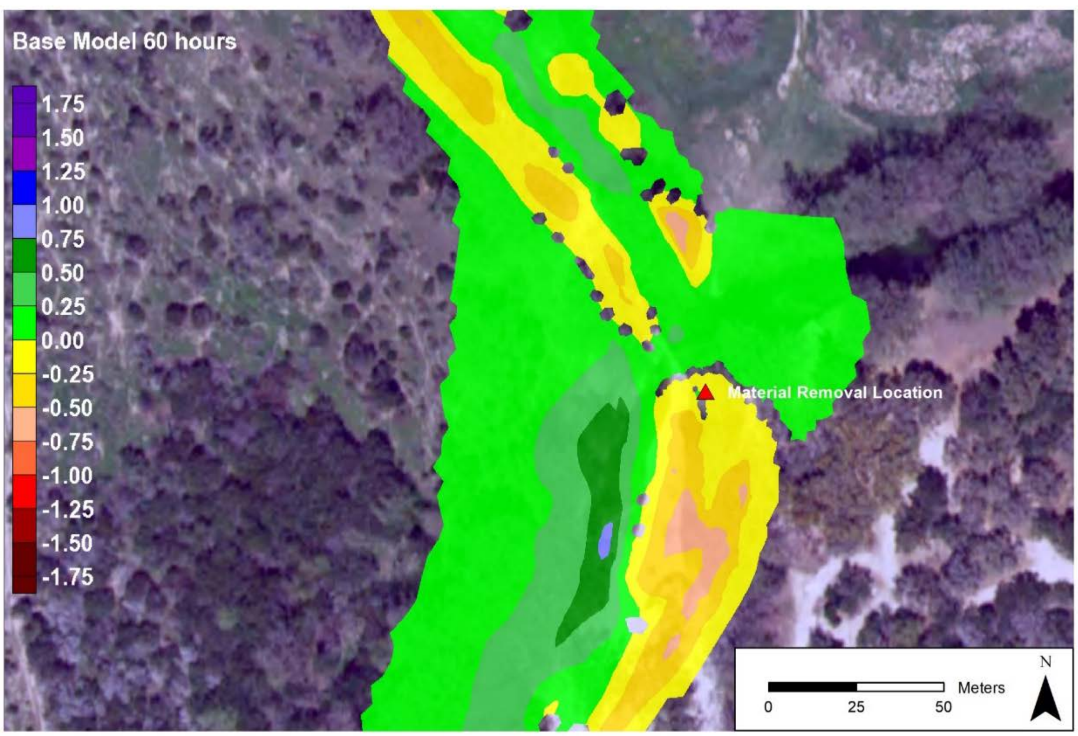

FIGURE G28.—Sediment deposition after 60 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (upper site).

FIGURE G29.—Sediment deposition after 60 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (middle site).

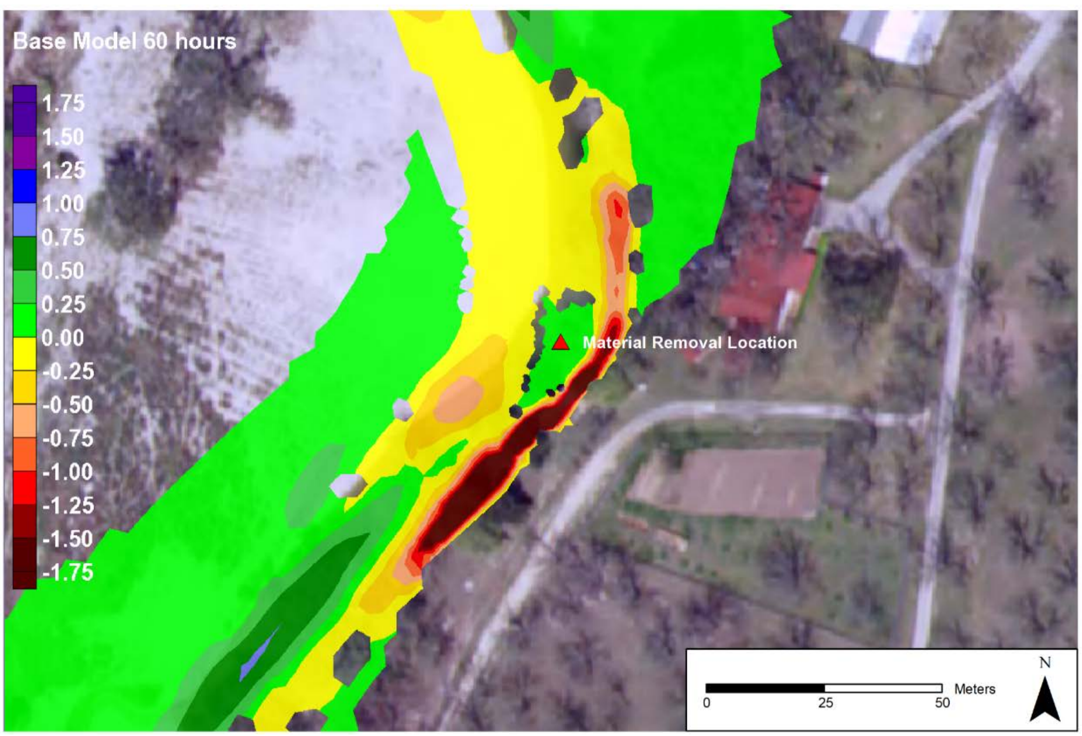

FIGURE G30.—Sediment deposition after 60 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (lower site).

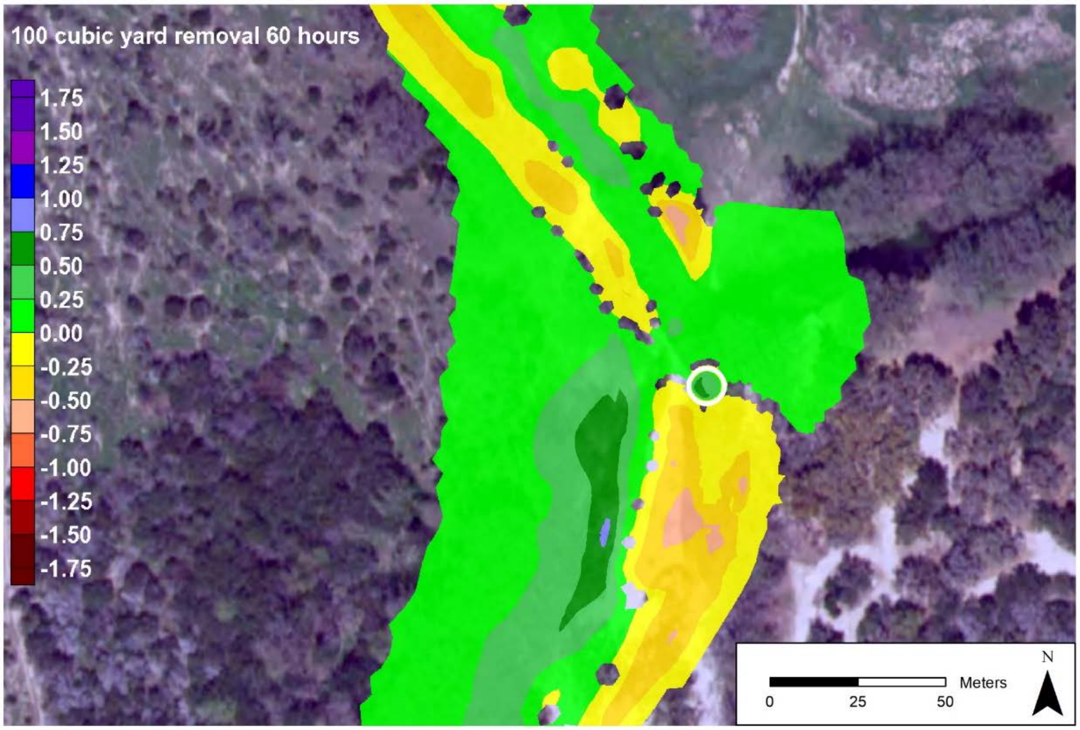

FIGURE G31.—Sediment deposition after 60 hours of simulation (in meters), 100 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G32.—Sediment deposition after 60 hours of simulation (in meters), 100 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

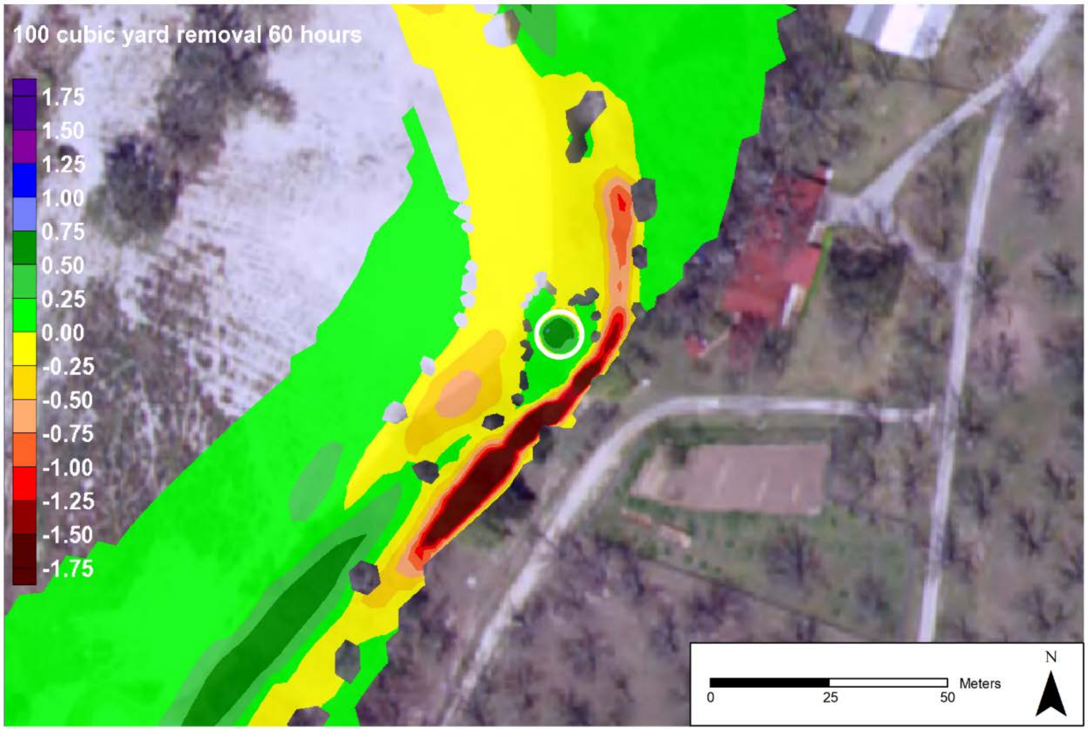

FIGURE G33.—Sediment deposition after 60 hours of simulation (in meters), 100 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

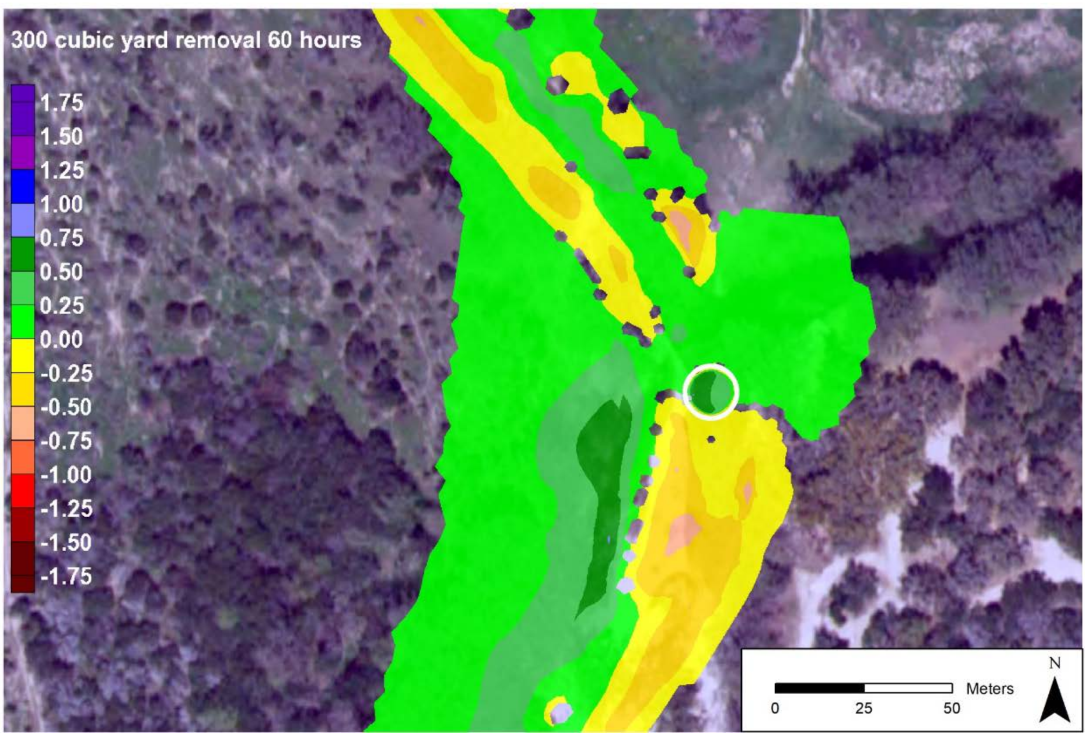

FIGURE G34.—Sediment deposition after 60 hours of simulation (in meters), 300 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G35.—Sediment deposition after 60 hours of simulation (in meters), 300 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

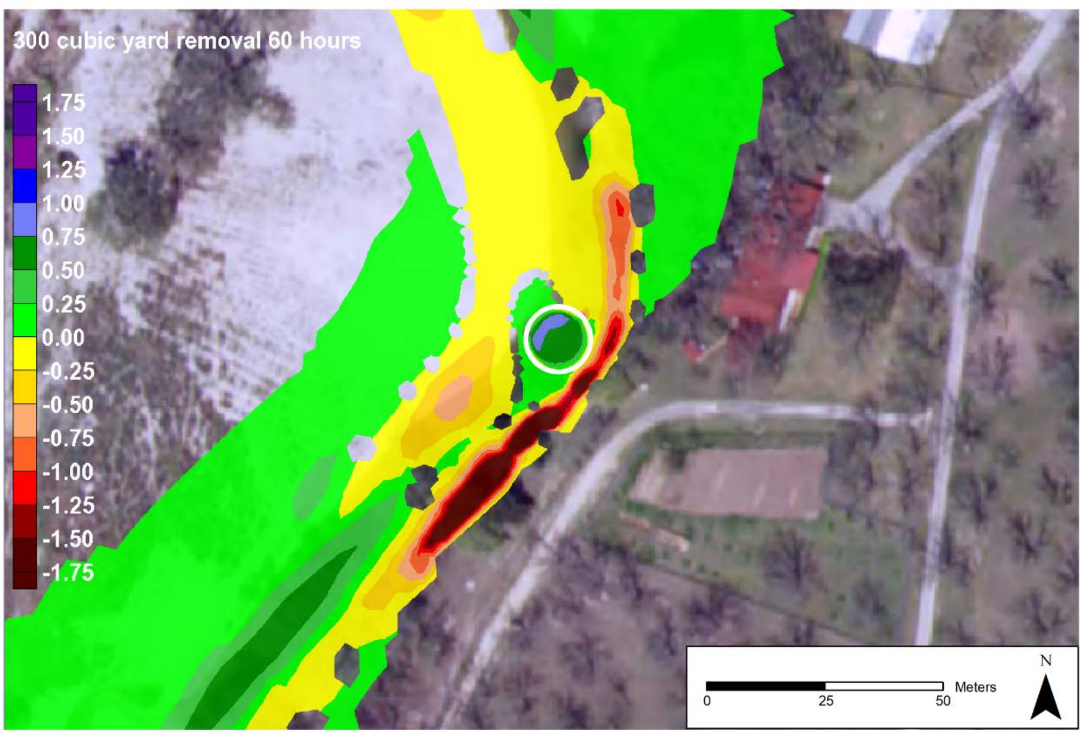

FIGURE G36.—Sediment deposition after 60 hours of simulation (in meters), 300 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

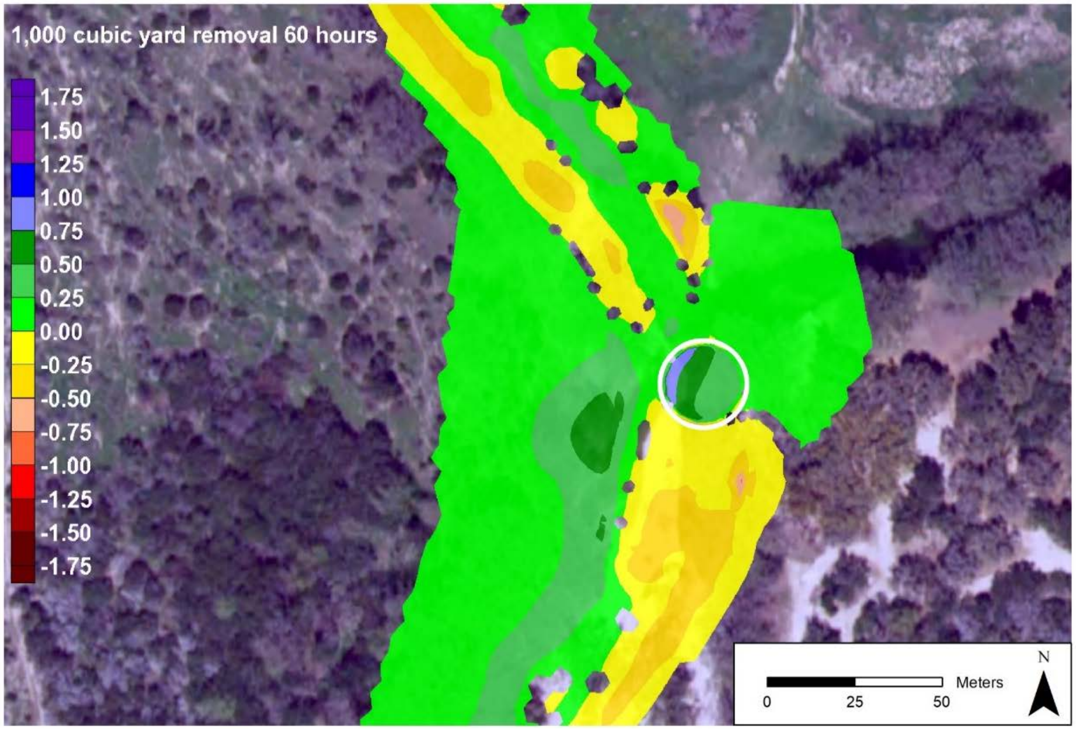

FIGURE G37.—Sediment deposition after 60 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G38.—Sediment deposition after 60 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

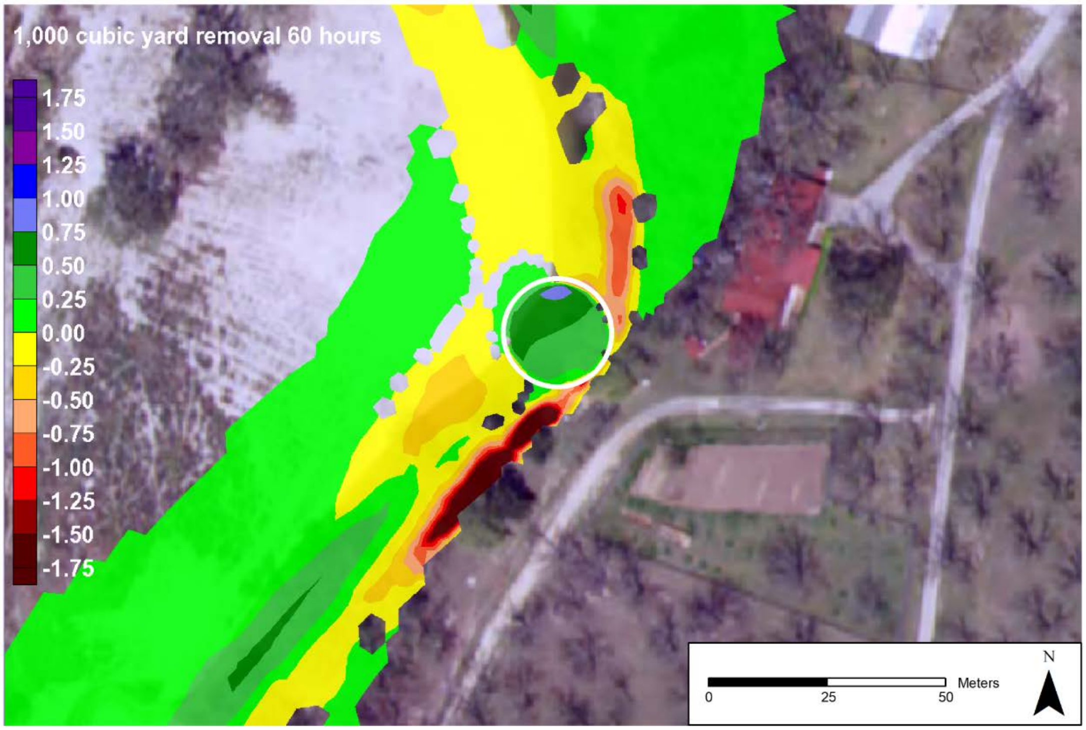

FIGURE G39.—Sediment deposition after 60 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

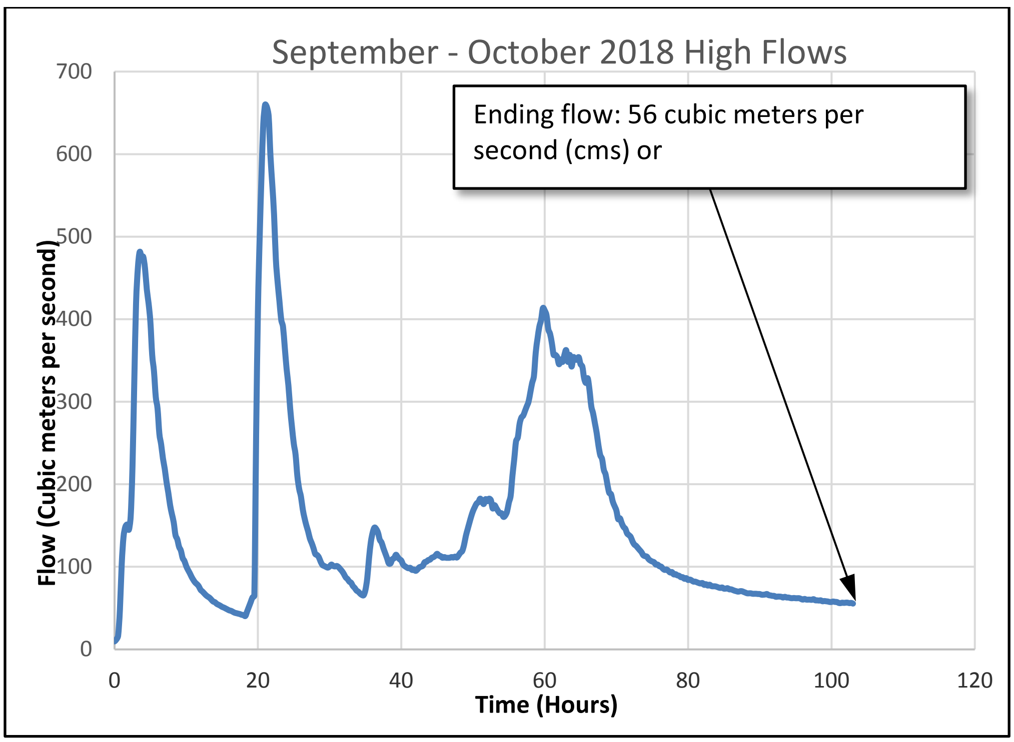

FIGURE G40.—Model flow hydrograph developed from USGS gage number 08195000 Frio River at Concan, TX, with September 8, October 8, and October 15-18, 2018 flows in sequence.

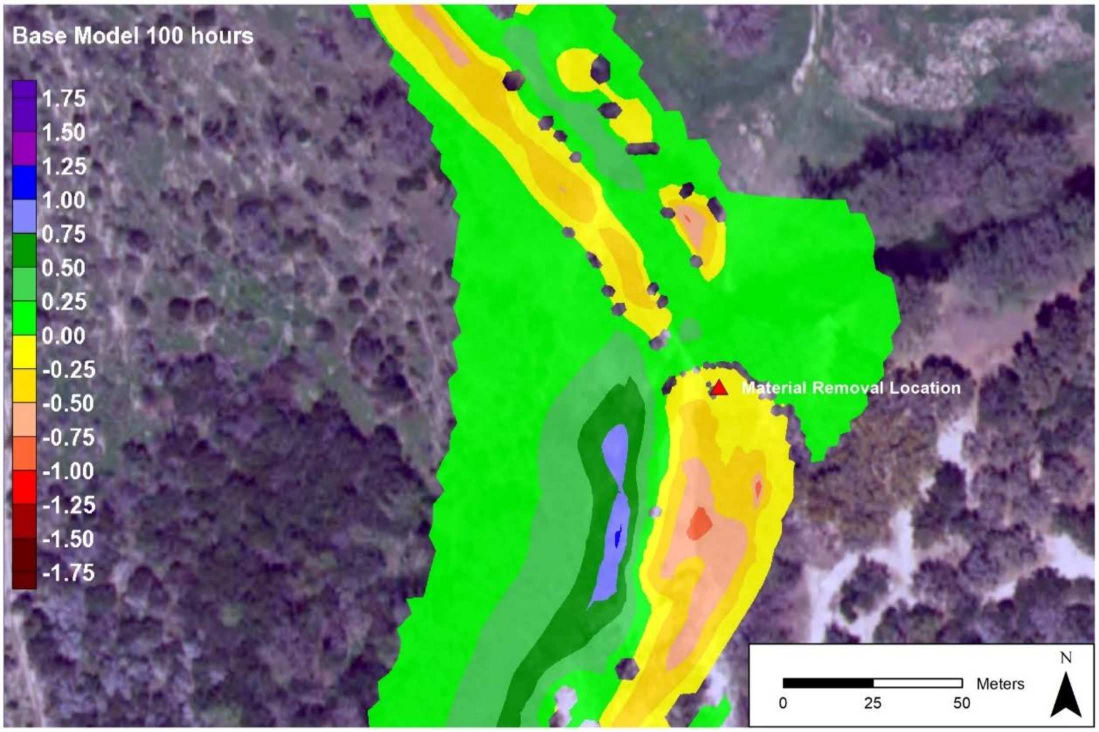

FIGURE G41.—Sediment deposition after 100 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (upper site).

FIGURE G42.—Sediment deposition after 100 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (middle site).

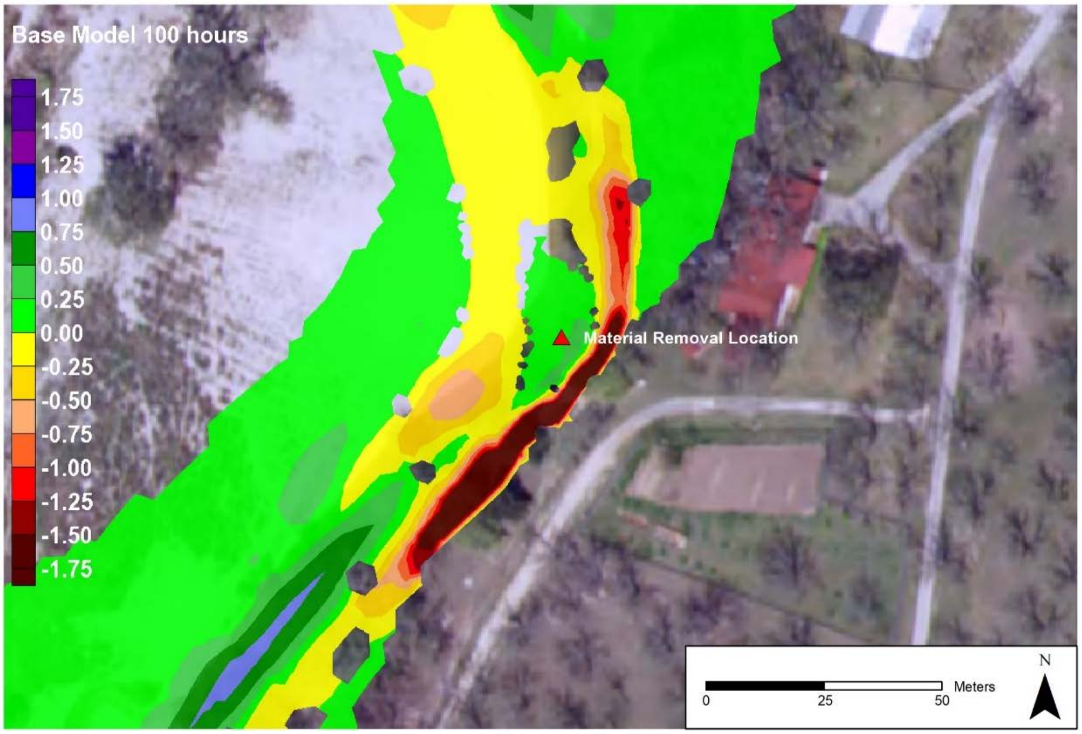

FIGURE G43.—Sediment deposition after 100 hours of simulation for the base sediment model run (in meters) with no material removed from the river. The red triangle denotes the location where material removal will occur in later model runs (lower site).

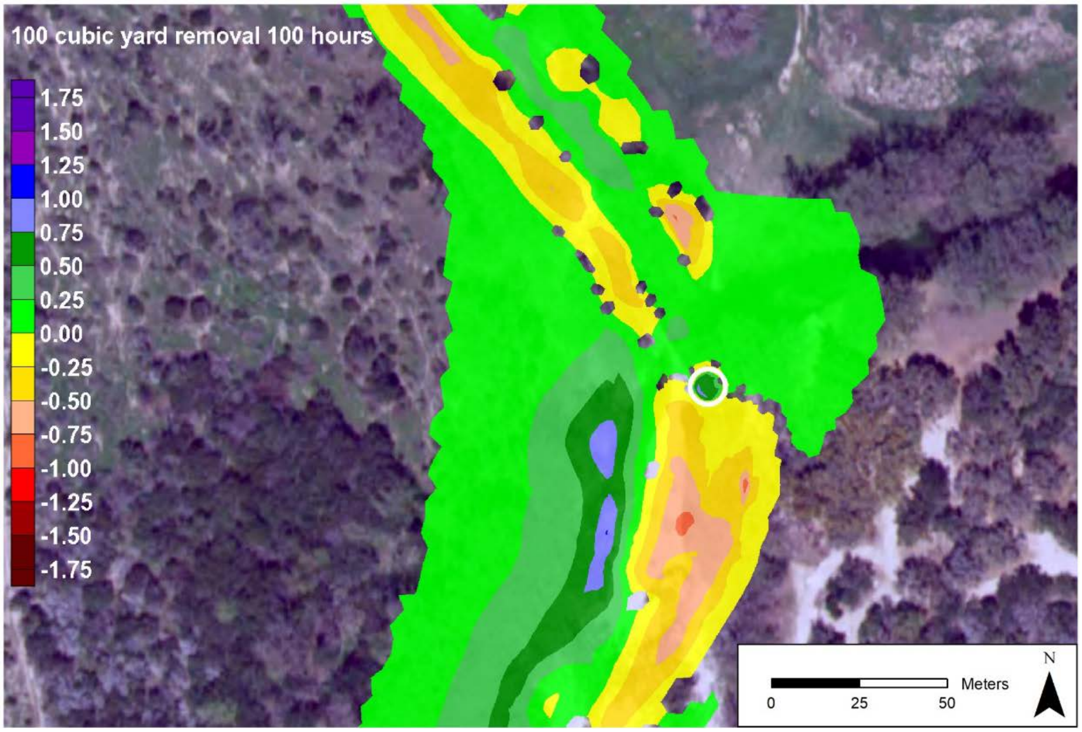

FIGURE G44.—Sediment deposition after 100 hours of simulation (in meters), 100 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G45.—Sediment deposition after 100 hours of simulation (in meters), 100 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

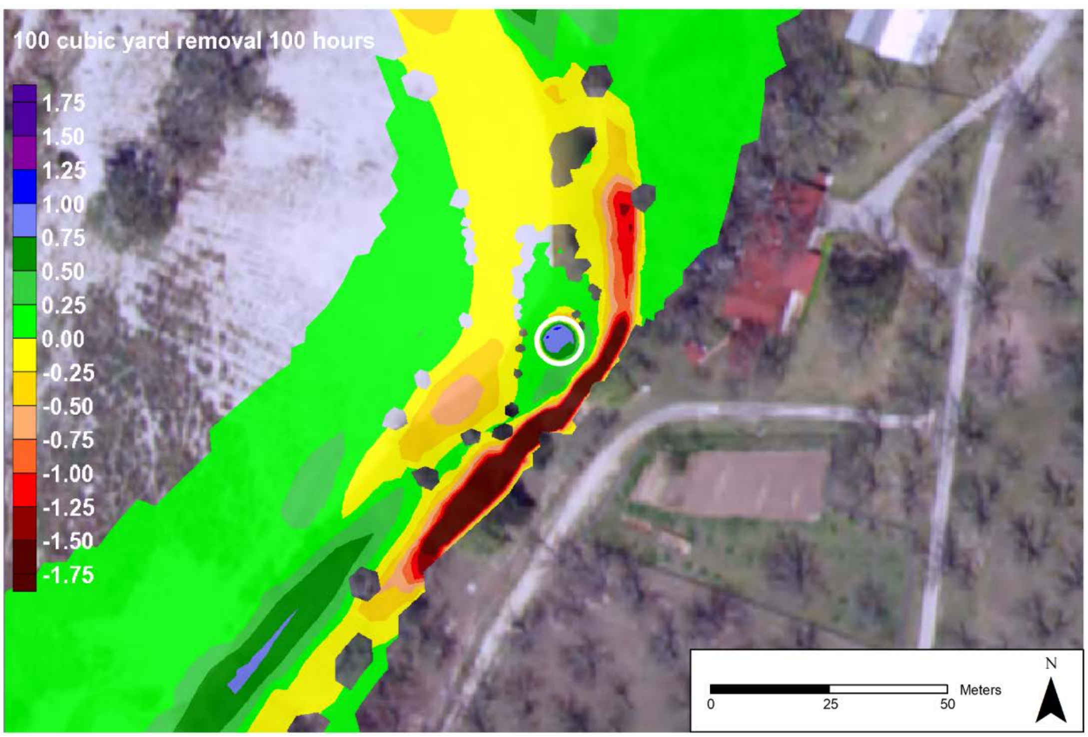

FIGURE G46.—Sediment deposition after 100 hours of simulation (in meters), 100 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

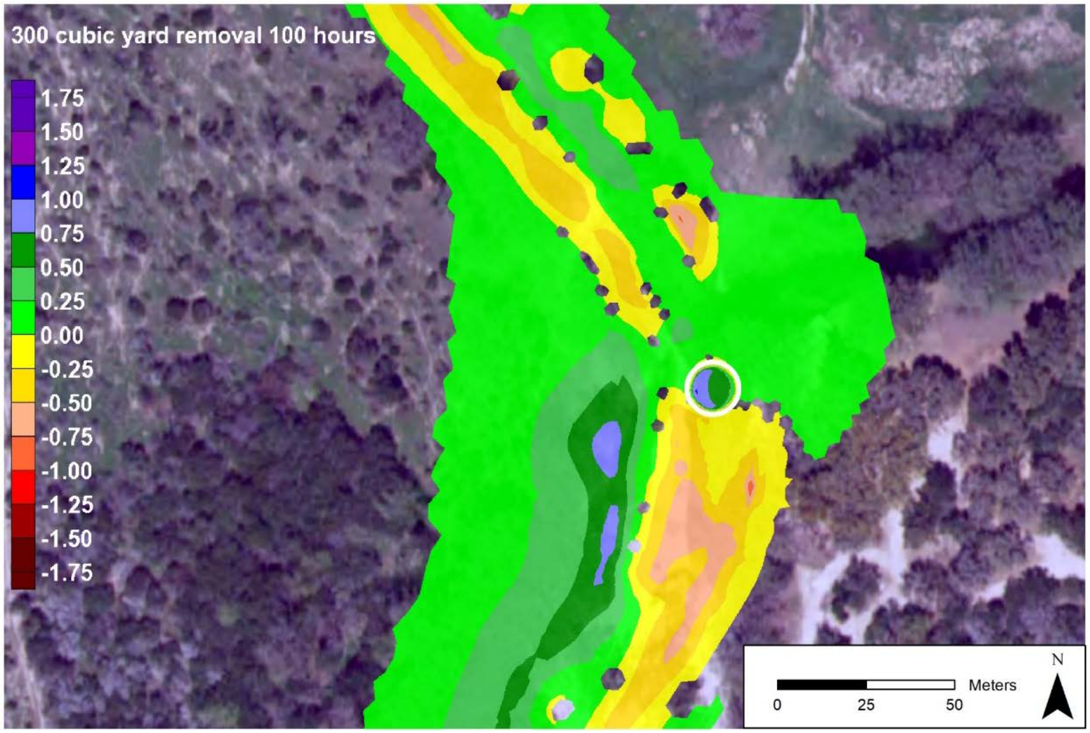

FIGURE G47.—Sediment deposition after 100 hours of simulation (in meters), 300 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G48.—Sediment deposition after 100 hours of simulation (in meters), 300 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

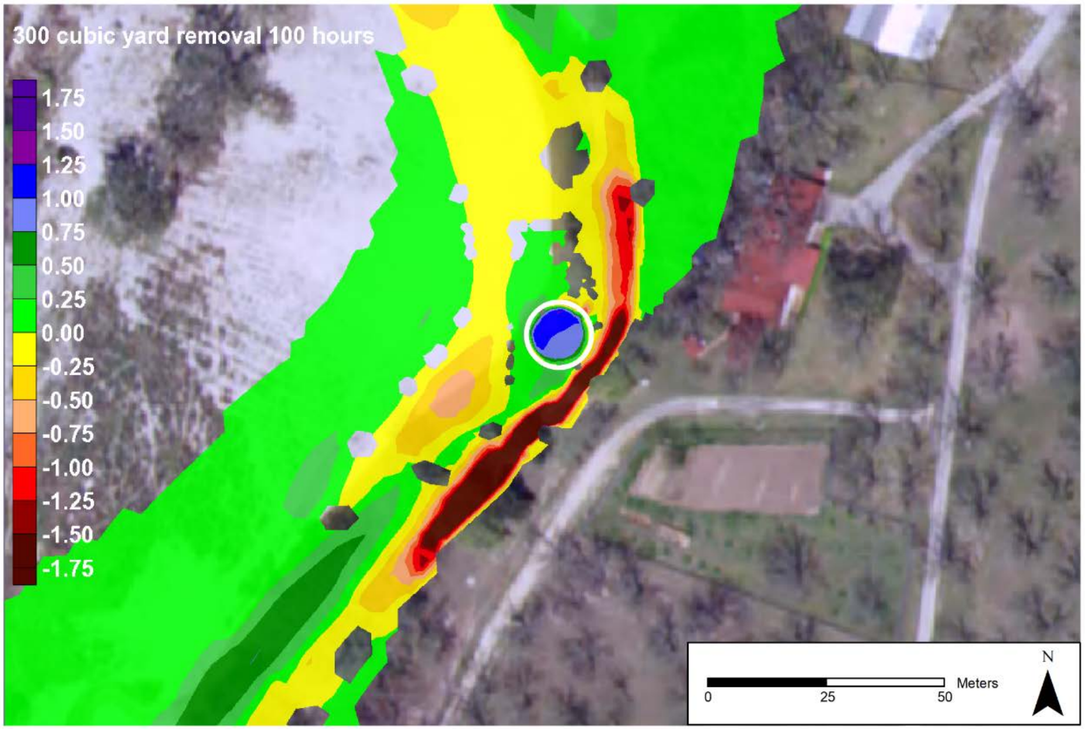

FIGURE G49.—Sediment deposition after 100 hours of simulation (in meters), 300 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

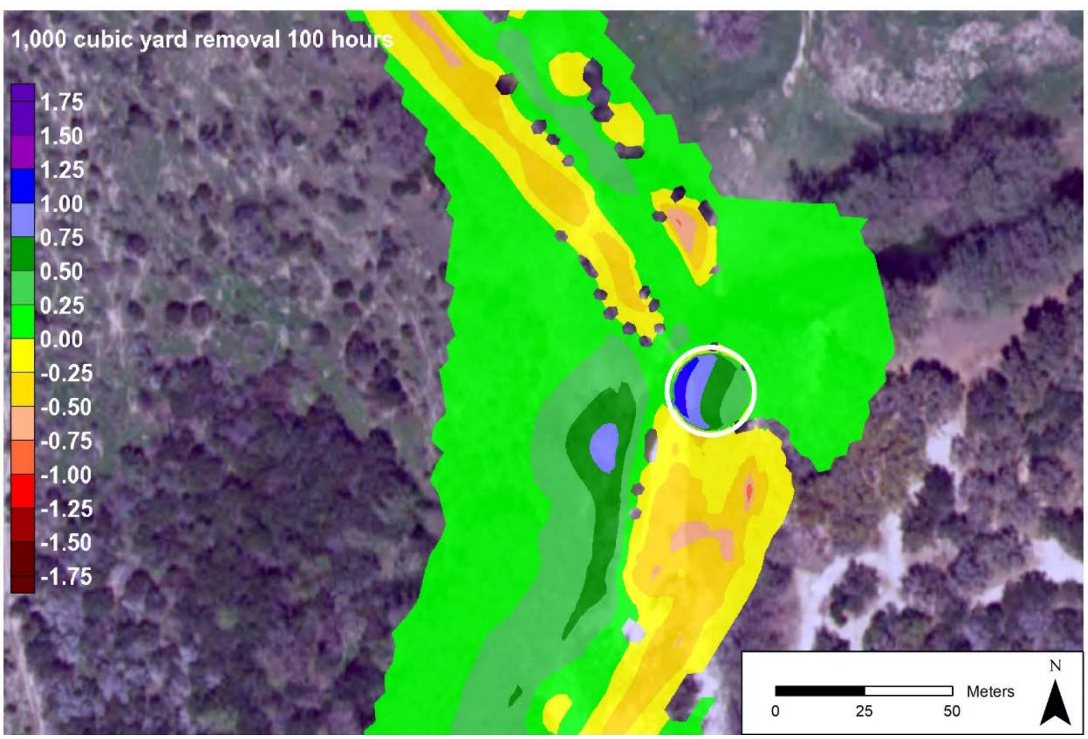

FIGURE G50.—Sediment deposition after 100 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the upper site. The white circle denotes the location where material was removed.

FIGURE G51.—Sediment deposition after 100 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the middle site. The white circle denotes the location where material was removed.

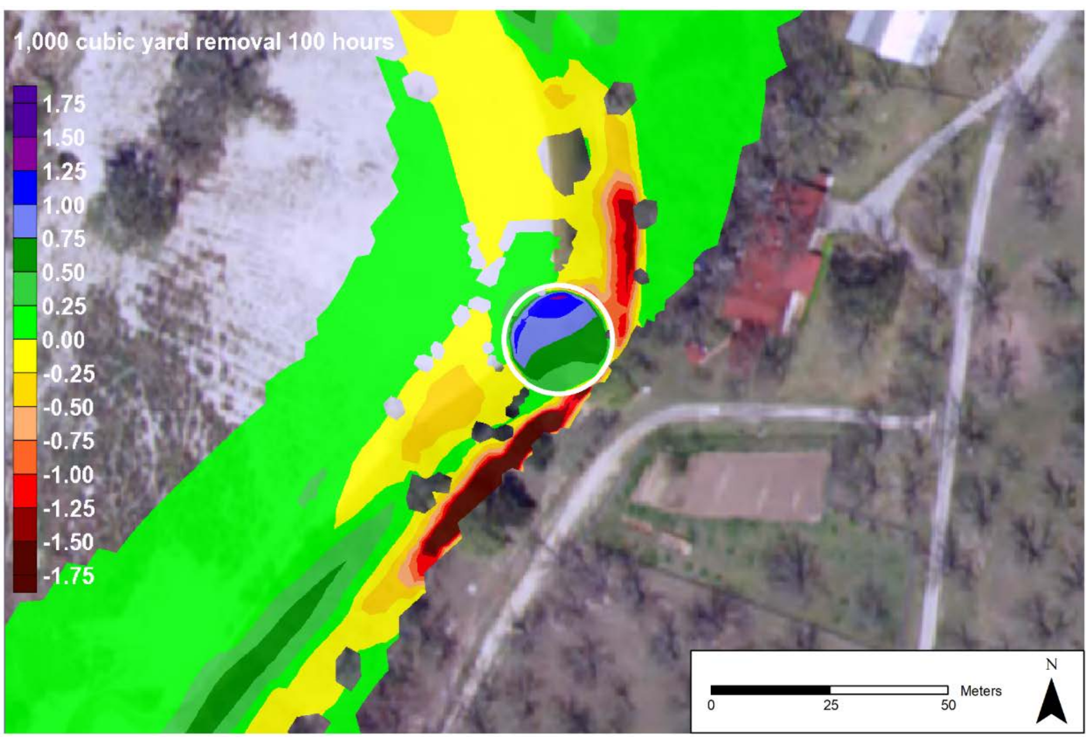

FIGURE G52.—Sediment deposition after 100 hours of simulation (in meters), 1000 cubic yards of material removed from the river at the lower site. The white circle denotes the location where material was removed.

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