



Protocol Implementation Plan for Monitoring Geomorphic Change along the Rio Grande in Big Bend National Park

Natural Resource Report NPS/CHDN/NRR—2019/1881



ON THE COVER

The Rio Grande. NPS Photo

Protocol Implementation Plan for Monitoring Geomorphic Change along the Rio Grande in Big Bend National Park

Natural Resource Report NPS/CHDN/NRR—2018/XXX

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Abstract

Big Bend National Park and the Chihuahuan Desert Inventory and Monitoring Network (CHDN) selected River Channel Characteristics (RCC) as a Vital Sign (CHDN 2010).

This Protocol Implementation Plan and the Standard Operating Procedures, provide the details of how CHDN will use the Big Rivers Geomorphology peer-reviewed and published protocol from the Northern Colorado Plateau Network (Perkins et al. 2017) to monitor changes in the geomorphology of the Rio Grande. In particular, significant historical demands in water use occurring on both sides of the US-Mexico border have altered the hydrology of the system, which in turn, affect the sediment delivery, floodplain dynamics, and riparian structure and function throughout the river. The previous work by NCPN in combination with USGS scientists have honed monitoring of big rivers (e.g., Colorado, Green, Gunnison, Yampa) across the Colorado Plateau and which are pertinent to monitoring similar changes occurring in the Rio Grande.

It should be noted that this Protocol Implementation Plan will undergo periodic scientific review and that modifications may occur if recommendations are made that significantly improve the monitoring and the generalization of using similar methodologies across more systems. However, any changes must be weighed against the value of long-term standardization and a strong argument must be made to deviate from the standardized approaches outlined herein. Likewise, the SOPS will also undergo similar scrutiny.

Version 1.00

Revision History Log

Previous version#	Revision date	Author	Changes made	Reason for change	New version #
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Introduction

Most rivers throughout the desert southwestern U.S. have undergone substantial geomorphic change over the past few centuries. These changes are primarily driven by dramatic reductions in both mean and peak stream flow with concomitant conditions of sediment and solute accumulation, floodplain accretion, and channel narrowing (Dean and Schmidt 2011). The Rio Grande in the Big Bend region of far west Texas and the Mexican States of Chihuahua and Coahuila is one of these rivers (Figure 1).

The Big Bend segment of the Rio Grande, or Río Bravo del Norte in Mexico, is the centerpiece of an international area of conservation interest in the northern Chihuahuan Desert and represents one of the most ecologically significant areas in North America. Two National Park Service (NPS) units are located along the Rio Grande/Río Bravo (RGRB) in far west Texas: Big Bend National Park (BIBE) and the Rio Grande Wild and Scenic River (RIGR) as well as two Texas Parks and Wildlife Department units: Big Bend Ranch State Park and Black Gap Wildlife Management Area. In addition, there are four units in Mexico under the management of the Comisión Nacional de Áreas Naturales Protegidas (CONANP) (National Commission of Natural Protected Areas): El Área de Protección de Flora y Fauna Cañón de Santa Elena, el Área de Protección de Flora y Fauna Maderas del Carmen, el Área de Protección de Flora y Fauna Ocampo, and el Monumento Natural Río Bravo del Norte. Together these eight units offer protection to 3.5 million acres of Chihuahuan Desert and 300 miles of the Chihuahuan Desert's largest river.

This RGRB segment undergoes repeated cycles of prolonged periods of channel narrowing interspersed with episodic channel widening events (Dean and Schmidt 2011). Historic accounts indicate that the RGRB was a wide meandering river with a thin and discontinuous riparian zone. However,

since the 1940s, channel narrowing has outpaced widening, and channel widths measured in 2008 were more than 50% narrower than in the 1940s (Dean and Schmidt 2011). Since the most recent channel widening flood in 2008, the Rio Grande has once again substantially narrowed. Narrowing is primarily a result of dramatic reductions in the number, magnitude and duration of flood flows that emanate primarily from the watershed of the upper parts of the mainstem basin, while flash floods from more local ephemeral tributaries continue to deliver large amounts of sediment to the river channel.

There is a feedback loop between sediment accumulation and colonization of the floodplain by vegetation (Dean and Schmidt 2011). During periods of low flow, vegetation (both native and non-native) establishes on low elevation surfaces, which stabilizes these deposits and reduces channel-margin flow velocities which thereby induces additional deposition. As channel narrowing progresses and fills backwaters and secondary channels with sediment, the diversity, abundance, distribution and quality of instream aquatic habitat is diminished. Vegetation encroachment occurs primarily through the expansion of giant cane, or carrizo (*Arundo donax*), an invasive non-native species, which has poor habitat value. Thus, the combined vegetative effects of channel narrowing in general, and the proliferation of non-native vegetation on channel deposits specifically, present a significant ecological concern. Within this physical and ecological context, BIBE and the Chihuahuan Desert Inventory and Monitoring (I&M) Network (CHDN) selected River Channel Characteristics (RCC) as a vital sign (NPS CHDN 2010).

BIBE management has responded to the threat of sediment accumulation in the river channel by cooperatively seeking

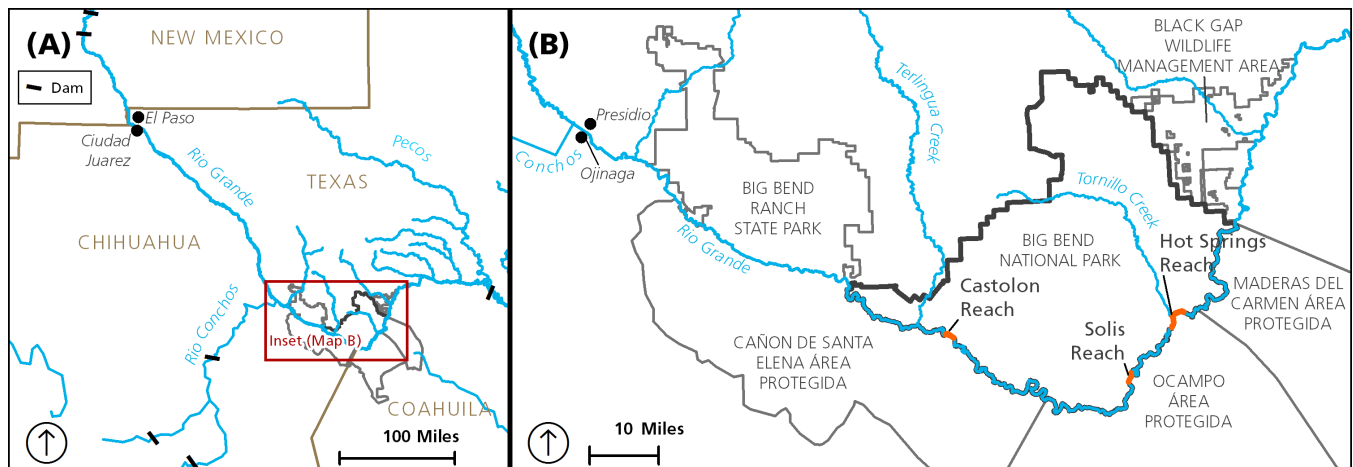


Figure 1. Regional map of the Big Bend region (a) with study reaches identified (b).

conversations with both the US and Mexican sections of the International Boundary and Water Commission concerning the implementation of a managed flow program to increase sediment transport, protect and maintain aquatic habitat, and decrease exotic riparian vegetation. In addition, the NPS in cooperation with the US Geological Survey has identified three geomorphology study and monitoring reaches: Castolon Reach, Solis Reach, and Hot Springs Reach (Figure 1, see Study Design below for more detail). Finally, in cooperation with public and private partners, BIBE has embarked on a vegetation management program along 40 miles of river to test the hypothesis that sediment transport can be increased by removing the exotic vegetation.

This Protocol Implementation Plan outlines the means by which channel cross section monitoring data will be collected, managed, and reported for the River Channel Characteristics Vital Sign as described in the CHDN monitoring plan (NPS CHDN 2010). The CHDN is implementing the Northern Colorado Plateau I&M Network's (NCPN) approved protocol for Big River Monitoring Protocol for the Park Units in the Northern Colorado Plateau Network (Perkins et al. 2018) as it relates to channel characteristics. The CHDN will not be implementing the vegetation component. For channel geomorphology, we used modifications to the base SOPs derived from the NCPN

peer-reviewed protocol for four of the standard operating procedures (SOPs) using standardized US Geological Survey (USGS) Grand Canyon Monitoring and Research Center (GCMRC) methodologies established in BIBE for selecting measurable attributes of cross sections (Dean et al. 2016). In particular, instead of width and depth, we are using cross-section area for inter-site and intra-site comparisons. These methodologies are based heavily on the work done by David Dean, USGS Researcher, who established the cross sections at locations selected by Dean and BIBE resource staff in 2010 (Figure 1) and has worked extensively with NCPN.

Both NCPN and CHDN use standardized cross sections to ascertain changes in channel geomorphology. The largest differences between the NCPN implementation and the CHDN implementation is that CHDN monitoring is set up so that cross-sections are spaced to facilitate the construction of 1-dimensional hydraulic models (and thus reach-specific precision is higher although the methodology is similar). In essence, it's a value-added component having a slightly more detailed design layout, but similar in concept to what NCPN does with their cross-sectional data. Thus, implementation of the NCPN protocol in BIBE will occur with modifications as outlined in the attached SOPs from the USGS Grand Canyon Monitoring and Research Center (GCMRC) (Schmidt et al. 2003; Dean and Schmidt 2011).

Study Design

Conceptual Framework for Monitoring

Understanding the effects of multiple concurrent stressors affecting the Rio Grande and mitigating the impacts of those stressors is an ongoing challenge for BIBE and RIGR unit managers (Table 1). Factors affecting aquatic and riparian habitat condition and availability, and water quality is driven primarily by upstream control, timing, and diminishment of flows in the RGRB (Dean et al. 2011; Stevens et al. 2001). Furthermore, dissolved solids (sediment), solutes, and organic matter accumulation have increased (now described as impaired by the state of Texas). Of primary concern are sediment accretion areas which obliterate aquatic habitat, become vegetated with exotic vegetation (native vegetation also colonizes constricting flow), alter riparian function and potentially establish biogeochemical environments suitable for mercury transformations, and salinity sinks (Smith et. al 2010; Miyamoto et al. 1995)

The hydrologic and geomorphic history of the RGRB in BIBE and RIGR have been well documented and remain under study by the USGS Grand Canyon Monitoring and Research Center, and others (e.g., Schmidt et al. 2003; Dean and Schmidt 2011). Before the inception of basin-wide regulation, beginning with construction of La Boquilla (Chihuahua, Mexico) and Elephant Butte (New Mexico, United States)

dams in 1911 and 1916 respectively, the RGRB was a highly variable system. The natural flow regime was comprised of both a spring snowmelt flood from its headwaters in the San Juan Mountains of Colorado and summer rains from the North American monsoon in the Sierra Madre Occidental of Northwest Mexico (e.g., Schmidt et al. 2003; Dean and Schmidt 2011). However, dam construction and stream-flow withdrawals significantly changed annual runoff patterns and the channel morphology of the entire RGRB. The decreased ability of the river to adequately transport the supplied sediment from tributaries caused the channel to narrow and aggrade throughout much of the RGRB below El Paso (Everitt 1998). In addition, increased suspended sediment and solutes and associated increased turbidity likely alters seasonal patterns of primary and secondary production. For example, the endangered Rio Grande Silvery minnow (*Hybognathus amarus*) is an episammic (sand) feeder specializing on a specific diatom community, and the contemporary environment may no longer be suited for production of that food source.

Measurable Objectives

The primary goal of the CHDN Rio Grande cross section monitoring is to detect trends in cross sectional area within three index segments in BIBE and RIGR. To assess changes

Table 1. Factors affecting the Big Bend segment of the RGRB within the Chihuahuan Desert I&M Network and potential measures for vital signs monitoring.

Category	Management Issues informed by monitoring	Potential Measures
Sediment accumulation and habitat loss (aquatic) and gain (riparian)	Reintroduction of the Rio Grande Silvery Minnow (<i>Hybognathus amarus</i>), vegetation management, listing of T&E species: Texas Hornshell (<i>Popenaias popeii</i>), Rio Grande Cooter (<i>Pseudemys gorzugi</i>)	Streamflow ¹ , channel cross sections ² , aquatic habitat displacement and mapping, riparian habitat and habitat use monitoring, sediment supply and transport ¹ , vegetation monitoring
Sediment accumulation and channel narrowing	Increased flooding, threats to historic structures, threats to developed areas.	Streamflow ¹ , channel cross sections ² , flood frequency monitoring, historic structure monitoring, sediment supply and transport ¹
Sediment evacuation of tributaries and delivery of sediment to main Rio Grande	Restoration, reintroduction of the Rio Grande Silvery Minnow (<i>Hybognathus amarus</i>), listing of T&E species: Yellow-billed Cuckoo (<i>Coccyzus americanus</i>)	Streamflow ¹ , channel cross sections ² , develop watershed protection and rehabilitation program, sediment supply and transport ¹ , tributary restoration ¹
Increasing nutrients	Low dissolved oxygen and fish kills, reintroduction of the Rio Grande Silvery Minnow (<i>Hybognathus amarus</i>)	Streamflow ¹ , water quality monitoring ¹
Increasing salinity	Golden algae (<i>Prymnesium parvum</i>), human health,	Streamflow ¹ , water quality monitoring ¹
Increasing methylmercury concentrations	Human health	Streamflow ¹ , water quality monitoring ¹
Maintenance of baseflows (groundwater inputs)	Human health, aquatic ecosystems, reintroduction of the Rio Grande Silvery Minnow (<i>Hybognathus amarus</i>), vegetation management, potential listing of T&E species: Texas Hornshell (<i>Popenaias popeii</i>), Rio Grande Cooter (<i>Pseudemys gorzugi</i>)	Streamflow ¹ , water quality monitoring ¹ , seepage runs ¹ , participation in regional groundwater planning ¹

1 Measures in bold and italic are addressed through other monitoring initiatives by NPS or partners.

2 Measures in bold have been selected for inclusion in CHDN monitoring effort

in river channel characteristics in the Big Bend segment, two objectives are established (Table 2): 1) Determine transect cross-sections and ascertain inter-annual changes in cross-sectional area, width and channel-bed elevation, and 2) relate these changes to the concomitant flow and sediment regime in the three study reaches.

The CHDN River Channel Characteristics geomorphology objectives (above) are comparable to the objectives in the Big River Monitoring Protocol for the Park Units in the Northern Colorado Plateau Network for Curecanti National Recreation Area (Perkins et al. 2018) but are more focused. To accomplish these objectives, we plan to construct 1-dimensional hydraulic models using HECRAS (Hydrologic Engineering Center-River Analysis System) <http://www.hec.usace.army.mil/software/hecras/> and run model simulations to investigate bar/ floodplain inundation dynamics.

Methods

The CHDN will be monitoring channel characteristics using similar methods (Table 3) as developed and approved for implementation in the Northern Colorado Plateau Network (Perkins et al. 2018) using Real Time Kinematic surveying techniques and equipment to map each transect, with data analyzing methods developed by Dean and the USGS GCMRC.

1. Field data collection includes a Real Time Kinematic survey of individual cross sections during late winter or early spring. This timing is during lowest annual flows and just before spring thunderstorms.
2. Data collection is performed on foot and has a +0.05 m accuracy.
3. Survey data is post-processed unless initial set up is over a permanent benchmark.
4. Data are analyzed using geomorphic change detection techniques developed by Dean while at Utah State University (USU) and now at USGS GCMRC.

5. Each segment is equipped with a pressure transducers for the purpose of developing a segment-specific stage discharge relationship. In the Hot Springs Reach, there are two pressure transducers, in the Castolon reach, there is one pressure transducer, and in the Solis Reach, there are two pressure transducers.

Additional Operational Implementation Notes

The GCMRC has implemented a comprehensive sediment transport study for the Big Bend reach of the Rio Grande in addition to this proposed work that adds great value to the RCC monitoring.

- The GCMRC has installed two continuous suspended sediment monitors, one within the Castolon segment and one in the Hot Springs segment.
- Two event sampling have been established on tributaries to the Rio Grande: Terlingua and Tornillo Creeks.
- Cross section survey data is currently analyzed within the context of GCMRC sediment transport monitoring program.

Control Network

Permanent elevation control points have been established for each of the three study reaches with each reach having multiple control points (Appendix 1). Where possible, control points were established on USGS brass caps. The control monuments are stable survey marks permanently placed on rocks, bedrock ledges, or concrete structures by a cross-cut X or other symbol or a P-K hardened nail, or 3/8 inch rebar. We refer to a control point over which an Real Time Kinematic base station is placed as a benchmark.

Each control point is referenced to positions published within the National Spatial Reference System. Relating all control points together provides access to a common datum for all sites (Hazel et al. 2008).

Table 2. Monitoring objectives, sampling frame, and scale of analyses at BIBE as a part of the protocol for monitoring river channel characteristics.

Objective	Area sampled	Spatial design	Temporal Design	Scale of Analysis
Cross sectional area	Entire cross section from monument to monument or from endpoints that are "staked out" in GPS software.	Cross sectional widths are such that longitudinal changes in water surface slope could be bracketed to aid in the development of 1d hydraulic models	Winter/spring months or during annual low flows	Park, management unit, area of interest, transect.
Accretion/erosion rates	As above with special attention to fresh surfaces	Full cross section	Winter/Spring or during annual low flows	Park, management unit, area of interest, transect.

Table 3. Monitoring objectives, sampling methods, and variables measured at BIBE as a part of the protocol for monitoring changes in Rio Grande channel characteristics.

Objective	Sampling Method	Data Collected	Analysis tool	Derived Data
Changes in channel cross sectional Area	Real Time Kinematic (RTK) surveying techniques along fixed and monumented transects	X,Y, AND Z locational coordinates and photographs	GIS, geomorphic change detection (Dave Dean)	Geospatial data
Construct 1-dimensional hydraulic models using HEC-RAS and run model simulations to investigate bar/floodplain inundation dynamics	Survey elevational data from cross sections	As above	HEC-RAS hydraulic model	Simulated floodplain inundation dynamics models

Data Collection

Field work at each site is conducted deploying a Real Time Kinematic surveying system using global navigation satellite systems (GNSS). Since the system relies on satellite technology, a relatively unobstructed view of the sky is necessary. After set-up verification (SOP #2), data acquisition involves collecting ground points along established cross sections using feature-based methodology. Points are collected along important changes in slope such as tops and bottoms of bars and banks. Additional ground points are collected between breaklines at a spacing of 2 to 3 meters, or smaller if necessary to adequately capture breaks in slope of the ground surface. The data point collection goal with every survey is to reach the highest elevation measured during the highest recorded flow surveyed the previous year. It is assumed that these areas are stable and that no changes have occurred at elevations above the previous annual high flow. Ground points are also collected within the channel and current stream flow. As such, surveys are timed for the lowest flows of the year. When water depth requires, point data is collected with an extendable rod held adjacent to a watercraft.

Sampling Design and Monitoring Schedule

In 2009, USU and the NPS began monitoring geomorphic condition using channel/floodplain cross section surveys in two study reaches where biocontrol methods for cane and tamarisk were being implemented in a vegetation management program (Castolon and Hot Springs Reaches). In 2010, an additional reach was established near Solis where vegetation was not managed (Figure 1). The tamarisk beetle (*Diorhabda* sp.) has since spread throughout the region and is currently located in all three survey segments: Castolon, Solis, and Hot Springs reaches. In 2015, giant cane was also burned and treated in the Solis Reach. The Castolon segment is located just below Santa Elena Canyon, is approximately 2.5 km long and includes 19 cross sections and the Castolon gage. The Solis segment is approximately 75 km downstream, is also 2.5 km long and includes 16 cross sections. The Hot Springs segment is approximately 90 km downstream of the Castolon segment, is 6 km long, and includes 33 cross sections and the Rio Grande at Boquillas stream gage. Cross sections span the entire channel and generally reach from xeric conditions on both sides. Calculated changes in cross sectional area are used to determine relative rates of erosion and deposition. These changes are also related to sediment mass balance information provided by the USGS GCMRC. Most cross-sections have permanently monumented endpoints, however, some cross sections are not monumented and the endpoints are instead located using

the “stakeout” feature within the Real Time Kinematic GPS system.

Monitoring and mapping of changes to cross sections will occur annually during February or March, the time of year when flows are lowest. This is also before the beginning of spring thunderstorms. Resurveys of channel cross sections in the Castolon, Solis, and Hot Springs segments can determine whether channel contraction or expansion has been the preceding dominant process. For instance, the first five annual surveys have demonstrated that channel contraction has dominated through bed aggradation and channel narrowing.

Data Management, Analysis, and Reporting

The types of data to be collected and requisite processing steps as part of the Protocol Implementation Plan for Monitoring Geomorphic Change along the Rio Grande in Big Bend National Park are listed in Table 4.

Additional QA/QC is performed comparing these data to previously collected data to catch mistakes in cross section layout, survey rod height error, or other survey errors. Once data quality issues are resolved, analyses can be conducted. Two general types of analyses are performed:

1. Annual reporting of the most recent monitoring observations (annual reports and briefs), and
2. Comprehensive assessments of the long term data set primarily changes in cross section shape, change in cross section area, and bed elevation.

The mean active channel area, and minimum channel bed elevations in meters, and the channel gradient in percent slope are calculated for each reach using data from the geomorphology survey transects. When calculating changes in cross-section area, all endpoints must be corrected such that the same endpoint coordinates are used for every year. This ensures that all calculated changes in channel area are because of geomorphic change, and not uncertainty/variability in the endpoint coordinates.

Budget

Utah State University set up the segments with BIBE, Water Resources Division (WRD), CHDN and USU funds. The sediment monitoring equipment came from a USGS GCMRC grant and BIBE/WRD paid for the calibration and analysis. The CHDN funds have paid for cross sections, transducers, analysis, and report writing (Table 5).

There are multiple safety risks to consider when working along rivers with widely varying hydrographs. Additional risks

Table 4. Data processing and certification matrix for the CHDN river channel characteristic monitoring protocol.

Data Quality Level	Data Processing Level 0 (Unprocessed)	Data Processing Level 1 (Entered/Validated)	Data Processing Level 2 (Analysis)
Raw	RTK point collected in the field in digital form: controller/datalogger. Field quality assurance includes previous field notes and comparison against previous year's data (manually for paper forms or automated for field database).	Data transferred from controller to computer and immediately backed up to archive file. Corrected or processed RTK data (spreadsheets, shapefiles) Entered and transcribed field form data	NA
Provisional	–	Data originating from a field database are imported to the office database and reviewed for import problems. Corrected RTK data with errors and outliers trimmed. Entered and transcribed field form data with QA/QC applied. Distance coordinates are calculated as "distance from left end point" and is overlain on previous surveys for quality control check. Associated field notes are reviewed for completeness.	Preliminary analysis data are sometimes calculated from provisional data to be used to a limited amount for internal discussions.
Certified / Approved	Paper field forms are archived, scanned, and uploaded to DataStore. Digital field database is versioned and uploaded to DataStore.	Data in office database are reviewed for problems using data plots and calculations. Problem data are flagged if they should not be used and annotated with documentation to support the decision to exclude them from analyses. After the review for problems, the data are flagged as certified in the database. The certified database is made available on DataStore and managed as a data set.	Certified measurement data are feed into calculations to create transect and reach level summary attributes. These calculations are done within the database and are managed along with the lower processing level data.

are present when working in desert conditions. Safe working conditions can only be realized if risks are considered at the programmatic, personnel and site level. Programmatic-level safety information is presented here and procedures to mitigate risks associated with specific activities related to protocol implementation are addressed in standard operating procedures below.

Safety

Job Hazard Analyses (JHAs) have been completed for all personnel who implement portions of the protocol or other resources related activities. JHAs identify risks and risk abatement strategies including training needs.

Specific safety concerns include:

- Slip and fall hazards due to work on uneven terrain sometimes with dense vegetation.
- Slip and fall hazards near or in water.
- Crew member will regularly work in remote areas with difficult or troublesome communications.

- Crew members will be working on an international border.

Based on the Job Hazards Analysis (JHAs) and associated risk abatement measures it was determined that this protocol can be safely implemented provided that the CHDN and partner staff implement it in accordance with the referenced SOPs and recommended risk abatement strategies. Personnel must review the relevant documents, SOPs, and JHAs (Table 6). They must also sign the JHA associated with this protocol (see below). All partner staff and CHDN personnel will follow the Safe Practices Manual and Emergency Operations Plan from BIBE.

Standard Operating Procedures

To ensure consistent implementation of the NCPN protocol in BIBE, the following Standard Operating Procedures (SOPs) have been identified or developed (Table 7). SOPs are adopted from procedures approved and implemented at NCPN for their Big Rivers protocol unless otherwise noted.

Table 5. Placeholder budget

Category	Expense	Unit	Cost
Personnel	GCMRC Geomorphologist (PI)	2 pay periods (\$3625/period)	\$7,250
	GCMRC contractor Big Bend Field Scientist	28\$/hr – 40 hours/week, 6 weeks + benefits	\$5,700
Travel	Per diem	(2 people at 20 days @\$46/day)	\$1,840
	Park housing	(2 people at 15 days/yr – 10\$/night	\$300
	PI flight	1 flight	\$500
	PI Rental car	1 time	\$500
	Field Scientist mileage	20 trips of 200 miles at 0.52/mile	\$2000
Equipment	–	Maintenance of replacement	\$2000
Total	n/a	n/a	\$20,090

Table 6. Safety documents and file locations

Relevant Document, SOP, or JHA	Location of electronic version on BIBE ScRM server
SOP#1 Prior to the field season	ScRM_Shared\WNPBIBEEMS31330\VM: \Programs\Physical_Sciences\Projects\CHDN Protocol
SOP#2 Trimble RTK Basic Operation Instructions	ScRM_Shared\WNPBIBEEMS31330\VM: \Programs\Physical_Sciences\Projects\CHDN Protocol
SOP#3 After the field season	ScRM_Shared\WNPBIBEEMS31330\VM: \Programs\Physical_Sciences\Projects\CHDN Protocol
SOP#4 Data analysis and reporting	ScRM_Shared\WNPBIBEEMS31330\VM: \Programs\Physical_Sciences\Projects\CHDN Protocol
Topographic surveying on the river, JHA	ScRM_Shared\WNPBIBEEMS31330\VM: \SAFETY
Float Plan – safety sign out sheet	ScRM_Shared\WNPBIBEEMS31330\VM: \SAFETY
Small boat operations JHA	ScRM_Shared\WNPBIBEEMS31330\VM: \SAFETY
Back Country Travel Plan	ScRM_Shared\WNPBIBEEMS31330\VM: \SAFETY

Table 7. Sources of the original Standard Operating Procedures required to implement the CHDN River Channel Characteristics Protocol. SOPs are listed by category. Current modified SOPs are included.

Topic	Source SOP/ Protocol	SOP #	Original SOP Citation Source	Notes	Link to published document/IRMA record
Monitoring	Pre-season	1	Modified from NCPN Big River Monitoring Protocol – SOP#1 – Version 1.00 December 2011	TBD	https://irma.nps.gov/DataStore/Reference/profile/2258536
Monitoring	Transect surveys using RTK	2	Modified from NCPN Big River Monitoring Protocol – SOP #11 – Version 1.00 January 2017	TBD	https://irma.nps.gov/DataStore/Reference/profile/2258536
Monitoring	After the field season	3	Modified from NCPN Big River Monitoring Protocol – SOP 3	TBD	https://irma.nps.gov/DataStore/Reference/profile/2258536
Data Management	Data analysis and reporting	4	Modified from NCPN Big River Monitoring Protocol – SOP#12- December 2011	TBD	https://irma.nps.gov/DataStore/Reference/profile/2258536
Monitoring	After the field visit	10	NCPN Big River Monitoring Protocol – SOP#10 – Version 1.0 December 2011 (used as is)	TBD	https://irma.nps.gov/DataStore/Reference/Profile/2254835
Safety	Big Bend Science and Resource Management JHAs	–	BIBE JHAs	TBD	n/a

Literature Cited

- Dean, D. J., D. J. Topping, J. C. Schmidt, R. E. Griffiths, and T. A. Sabol. 2016. Sediment supply versus local hydraulic controls on sediment transport and storage in a river with large sediment loads. *Journal of Geophysical Research: Earth Surface* 121. doi:10.1002/2015JF003436.
- Dean, D. J., and J. C. Schmidt. 2011. The role of feedback mechanisms in historical changes of the lower Rio Grande in the Big Bend region. *Geomorphology* 126: 333–349. doi:10.1016/j.geomorph.2010.03.009.
- Everitt, B. L. 1998. Chronology of the spread of tamarisk in the central Rio Grande, *Wetlands* (1998) 18: 658. doi:10.1007/BF03161680.
- Hazel J. E., Jr., M. Kaplinski, R. Parnell, K. Kohl, and J. C. Schmidt. J.C. 2008. Monitoring fine-grained sediment in the Colorado River Ecosystem, Arizona—control network and conventional survey techniques: US Geological Survey Open-File Report 2008-1276, 15 p.
- Miyamoto S., L. B. Fenn, and D. Swietlik. 1995. Flow, salts, and trace elements in the Rio Grande. Texas Water Resources Institute Report MP 1764/TR-169.
- National Park Service, Chihuahuan Desert Inventory and Monitoring Network. 2010. Chihuahuan Desert Network vital signs monitoring plan. Natural Resource Report NPS/CHDN/NRR—2010/188. National Park Service, Fort Collins, Colorado.
- Perkins D. W., M. Scott, G. Auble, M. Wondzell, C. Holmquist-Johnson, E. Wahli, H. Thomas, and A. Wight. 2018. Big rivers monitoring protocol for park units in the Northern Colorado Plateau Network: Version 1.01. Natural Resource Report. NPS/NCPN/NRR—2018/1707. National Park Service. Fort Collins, Colorado.
- Schmidt, J. C., B. L. Everitt, and G. A. Richard. 2003. Hydrology and geomorphology of the Rio Grande and implications for river rehabilitation. In *Aquatic Fauna of the northern Chihuahuan Desert*, Special Publication of Texas Tech University. Number 46.
- Smith, A., A. A. Abuzeineh, M. M. Chumcal, T. H. Bonner, and W. H. Nowlin. 2010. Mercury contamination of the fish community of a semi-arid and arid river system: spatial variation and the influence of environmental gradients. *Environmental Toxicology and Chemistry* 8: 1762-72. doi: 10.1002/etc.224.
- Stevens, L. E. , T. J. Ayers, J. B. Bennett, K. Christensen, M. J. C. Kearsley, V. J. Meretsky, A. M. Phillips III, R. A. Parnell, J. Spence, M. K. Sogge, A. E. Springs, and D. L. Wegner. 2001. Planned flooding and Colorado River riparian trade-offs downstream from Glen Canyon Dam, Arizona, *Ecological Applications* 11(3): 701-710.

Appendix

Study reaches and respective cross-sections and control point coordinates for the “Protocol Implementation Plan for Monitoring Geomorphic Change along the Rio Grande in Big Bend National Park” (Tables A1-A3; Figures A1-A3).

Table A1. Solis Reach Control Points and Endpoints.

PT	N	E	EI	Code
BM1	3214136.688	684311.754	566.5115	Solis_BRASS
BM2	3214374.973	684277.028	580.237	SOLIS_BS
E1	3213736.738	684343.154	561.162	MXS1_LEP_TP
E2	3213728.616	684399.424	560.267	MXS1_REP_TP
E3	3214001.017	684340.525	562.978	MXS2_LEP_TP
E4	3213978.226	684431.687	561.904	MXS2_REP_TP
E5	3214116.774	684374.201	562.224	MXS3_LEP_TP
E6	3214097.55	684452.452	562.185	MXS3_REP_TP
E7	3214245.727	684419.724	558.247	XS4_LEP
E8	3214224.551	684471.044	559.362	XS4_REP
E9	3214326.256	684420.621	559.585	MXS5_LEP_TP
E10	3214292.423	684506.733	562.675	MXS5_REP_TP
E11	3214432.743	684492.452	557.612	XS6_LEP
E12	3214408.079	684547.63	560.744	XS6_REP
E13	3214634.433	684584.754	561.661	XS7_LEP
E14	3214603.299	684636.736	558.077	XS7_REP
E15	3214741.378	684656.018	560.746	MXS8_LEP_TP
E16	3214706.93	684702.489	560.779	MXS8_REP_TP
E17	3214920.686	684829	559.882	XS9_LEP
E18	3214879.345	684871.387	559.188	XS9_REP
E19	3214995.329	684865.368	560.756	MXS10_LEP_TP
E20	3214981.141	684931.271	559.828	MXS10_REP_BR
E21	3215131.126	684882.484	560.894	MXS11_LEP_TP
E22	3215124.4	684986.545	562.474	MXS11_REP_TP
E23	3215304.55	684924.782	558.813	XS12_LEP
E24	3215303.083	684991.979	561.828	XS12_REP
E25	3215526.046	684899.62	560.587	MXS13_LEP_TP
E26	3215530.802	685003.683	563.496	MXS13_REP_TP
E27	3215622.608	684860.271	560.093	MXS14_LEP_TP
E28	3215653.836	684994.897	559.049	MXS14_REP_TP
E29	3215777.587	684800.257	560.781	MXS15_LEP_TP
E30	3215808.129	684968.124	556.862	MXS15_REP_BR
E31	3215976.374	684808.038	558.656	MXS16_LEP_TP
E32	3215957.58	684945.782	560.057	MXS16_REP_BR

Cross sections: Solis

Big Bend National Park



Figure A1 .Big Bend National Park Rio Grande Geomorphology Monitoring Location - Solis Reach

Table A2. Hot Springs Reach Control Points and Endpoints

PT	N	E	EI	Code
BM1	3230255.587	697103.807	536.36	USGSBrassPlate
BM2	3230325.978	697072.386	571.567	DR_Base
BM3	3229548.313	694869.316	569.871	HS_Base
BM4	3229235.948	694695.129	557.5906667	TC_Base_OPUS_Corr
BM5	3227008.115	694588.574	552.317	GP_Base
E1	3226520.411	694338.637	543.232	MXS1_LEP_TP
E2	3226464.901	694450.663	548.337	MXS1_REP_TP
E3	3226901.565	694515.873	546.665	MXS7_LEP_TP
E4	3226860.978	694627.812	543.775	MXS7_REP_TP
E5	3227494.239	694769.003	545.137	MXS14_LEP_TP_M
E6	3226639.251	694434.849	542.858	mxs2_lep
E7	3226614.172	694510.849	544.246	mxs2_rep
E8	3226901.565	694515.873	546.665	MXS7_LEP_TP
E9	3226860.978	694627.812	543.775	MXS7_REP_TP
E10	3227103.295	694647.324	543.367	xs8_LEP
E11	3227059.879	694730.265	543.28	xs8_REP
E12	3227494.27	694769.018	545.122	MXS14_LEP_TP
E13	3227435.6	694924.837	542.925	MXS14_REP_TP
E14	3227733.93	694836.013	542.444	MXS18_LEP_TP
E15	3227739.992	694961.014	547.357	MXS18_REP_TP
E16	3228007.48	694822.754	542.674	MXS21_LEP_TP
E17	3228024.655	694929.906	546.161	MXS21_REP_bedrock
E18	3228210.87	694812.405	542.998	XS22_LEP
E19	3228226.583	694886.991	542.239	XS22_REP
E20	3228468.908	694740.068	541.815	XS23_LEP
E21	3228488.061	694838.564	541.324	XS23_REP
E22	3228698.394	694642.29	541.888	MXS27_LEP_TP
E23	3228731.232	694796.984	542.699	MXS27_REP_TP_M
E24	3228825.053	694658.965	540.955	XS28_LEP
E25	3228917.395	694773.511	542.942	XS28_REP
E26	3228885.024	694646.516	543.826	XS29_LEP
E27	3228953.889	694761.877	543.269	XS29_REP
E28	3229065.792	694670.852	543.431	MXS32_LEP_TP
E29	3229045.514	694767.33	542.689	MXS32_REP_TP
E30	3229262.313	694715.882	541.943	MXS34_LEP_TP
E31	3229242.704	694818.753	543.904	MXS34_REP_TP
E32	3229387.753	694753.408	543.416	MXS36_LEP_TP
E33	3229315.819	694851.675	543.062	MXS36_REP_TP
E34	3229428.37	694802.155	541.717	MXS37_LEP_TP
E35	3229358.963	694872.481	543.624	MXS37_REP_TP2
E36	3229481.96	694847.395	542.514	XS38_LEP_TP
E37	3229419.68	694910.849	542.674	XS38_REP_TP
E38	3229524.539	694874.391	547.919	MXS39_LEP_TP
E39	3229456.402	694941.626	542.294	MXS39_REP_TP_M
E40	3229663.955	695062.112	541.714	XS40_LEP

PT	N	E	EI	Code
E41	3229603.254	695113.766	540.107	XS40_REP
E42	3229708.695	695121.046	542.4482	XS41_LEP_BR
E43	3229619.324	695162.491	539.7602	XS41_REP
E44	3229759.484	695151.85	542.66	MXS44_LEP_TP
E45	3229612.164	695237.001	545.161	MXS44_REP_TP
E46	3229841.723	695188.706	543.127	XS45_LEP
E47	3229679.478	695274.658	543.891	XS45_REP
E48	3229827.711	695201.457	542.765	XS46_LEP
E49	3229753.734	695312.072	541.816	XS46_REP
E50	3229880.199	695255.782	542.626	MXS47_LEP_TP
E51	3229791.718	695339.375	541.269	MXS47_REP_TP
E52	3229932.33	695357.149	540.968	XS48LEP
E53	3229887.378	695436.812	541.234	XS48REP
E54	3229964.827	695392.922	541.613	MXS51LEP_TP
E55	3229905.999	695466.312	541.955	MXS51REP_TP
E56	3230008.868	695631.694	534.538	XS53LEPVERT
E57	3229938.74	695595.848	538.752	XS53REPVERT
E58	3230002.799	695699.416	535.525	XS54_LEP_OS
E59	3229936.924	695701.394	535.483	XS54_REP_Vert
E60	3230034.252	695828.743	539.372	MXS56_LEP_TP
E61	3229940.03	695858.951	537.859	MXS56_REP_TP
E62	3230162.061	696047.766	541.835	MXS59_LEP_BR
E63	3230080.4	696131.877	542.68	MXS59_REP_BR
E64	3230249.402	696224.911	536.752	XS60_LEP
E65	3230186.705	696270.871	540.019	XS60_REP
E66	3230366.953	696760.929	540.588	MXS66_LEP_TP
E67	3230244.829	696743.654	539.389	MXS66_REP_TP_A
E68	3230300.388	697067.644	547.708	MXS68_LEP_TP
E69	3230148.376	697014.439	538.738	MXS68_REP_TP_M
E70	3230194.209	697279.686	539.343	XS69_LEP_A
E71	3230030.133	697175.175	539.261	XS69_REP_M

Cross sections: Hot Springs Canyon

Big Bend National Park



Figure A2. Big Bend National Park Rio Grande Geomorphology Monitoring Location - Hot Springs Reach

Table A3. Castolon Control Points and Endpoints

PT	N	E	EI	Code
BM2	3225072.87	642071.267	641.218	NEW_CAST_Base2
BM3	3225120.952	642035.266	640.969	Leica Base
BM5	3224863.677	642244.1375	630.0675	1Mile US from Castolon
MXS1_LEP_TP	3224905.264	641440.238	628.771	Rebar
MXS1_REP_TP	3224782.035	641489.735	628.823	Rebar
MXS2_LEP_TP	3224919.041	641469.536	628.423	Rebar
MXS2_REP_TP	3224794.442	641540.119	628.808	Rebar
MXS4_LEP_TP	3224963.597	641590.417	628.61	Rebar
MXS4_REP_TP	3224816.825	641625.517	629.094	Rebar
XS5LEP	3225007.499	641680.348	628.606	Virtual End Point
XS5REP	3224940.485	641705.637	627.98	Virtual End Point
XS6LEP	3225066.349	641779.875	628.59	Virtual End Point
XS6REP	3225001.359	641805.962	626.971	Virtual End Point
XS7LEP	3225097.791	641906.169	628.675	Virtual End Point
XS7REP	3225013.994	641902.993	627.299	Virtual End Point
MXS11_LEP_TP	3225106.337	642016.677	630.153	Rebar
MXS11_REP_TP	3224920.228	642001.389	628.379	Rebar
XS12LEP	3225055.416	642073.481	629.299	Virtual End Point
XS12REP_TP	3224920.657	642025.222	628.42	Virtual End Point
XS13LEP	3224942.795	642151.281	627.319	Virtual End Point
XS13REP	3224904.26	642092.315	626.675	Virtual End Point
MXS15_LEP_TP	3224851.989	642259.397	628.742	Rebar
MXS15_REP_TP	3224747.082	642194.038	628.181	Rebar
XS16LEP	3224774.658	642367.817	627.484	Virtual End Point
XS16REP	3224660.944	642317.266	627.618	Virtual End Point
MXS19_LEP_TP	3224727.612	642616.729	627.826	Rebar
MXS19_REP_TP	3224598.168	642573.897	627.94	Rebar
MXS20_LEP_TP	3224711.084	642693.637	627.54	Rebar
MXS20_REP_TP	3224571.515	642646.563	627.537	Rebar
MXS21_LEP_TP	3224692.06	642778.568	627.447	Rebar
MXS21_REP_TP	3224528.832	642700.294	627.636	Rebar
XS22LEP	3224467.131	642935.206	627.258	Virtual End Point
XS22REP	3224405.39	642881.104	625.117	Virtual End Point
MXS25_LEP_TP	3224433.935	643054.677	627.53	Rebar
MXS25_REP_TP	3224308.872	642995.844	627.772	Rebar
XS26_LEP	3224331.843	643190.506	627.394	Virtual End Point
XS26_REP	3224273.961	643162.988	627.105	Virtual End Point
MSX31LEP_TOP	3224219.891	643334.762	626.412	Rebar
MSX31REP_TOP	3224134.627	643250.314	627.076	Rebar
MXS33_LEP_TP	3224143.367	643507.777	627.345	Rebar
MXS33_REP1_TP	3224057.212	643482.576	624.545	Rebar

Cross sections: Castolon

Big Bend National Park

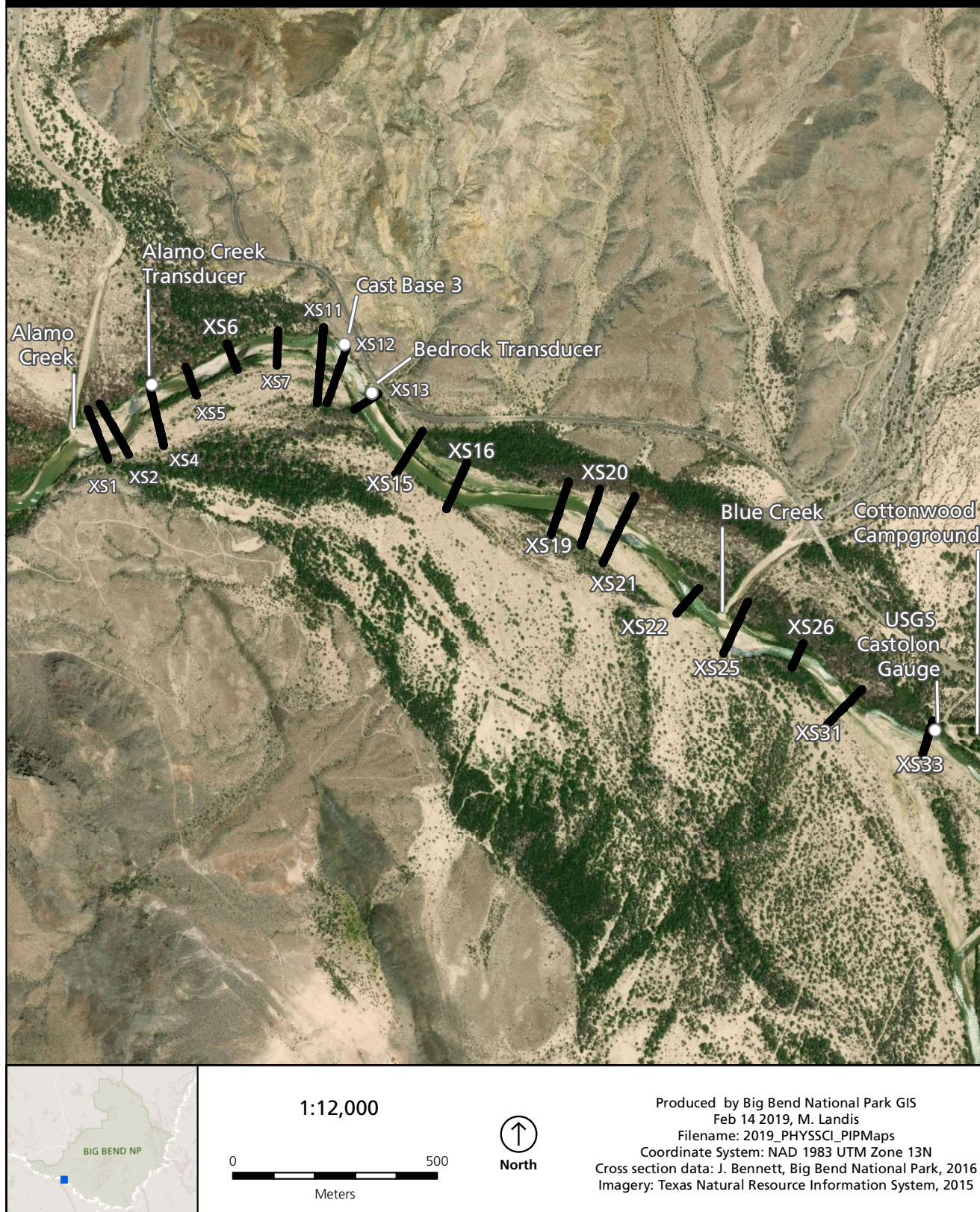


Figure A3. Big Bend National Park Rio Grande Geomorphology Monitoring Location - Castolon Reach

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