HYDRAULIC MODEL STUDY OF THE PURGATOIRE RIVER AND TRINIDAD DAM

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Abstract

Reclamation's Sedimentation and River Hydraulics Group in collaboration with the Army Corps of Engineers, Albuquerque's District Office completed a hydraulic model of the Purgatoire River from Trinidad Dam to the end of the Purgatoire River Water Conservancy District boundary, a distance of approximately 42 miles. A range of flows from the low flow calibration flow of 250 cfs up to the 100-year flood of 21,000 cfs were modeled. The study focused on four key flows. The model utilized LiDAR data in the floodplain and survey data in the main channel. A total of 8 inline structures and 14 bridges were modeled. The HEC-GeoRAS utility in ArcGIS was used to prepare input data for the HEC-RAS model. The State of Colorado Division of Water Resources measured discharge at six locations during the low flow release of 250 cfs that was used for model calibration. Model results showed that the channel capacity has been reduced to 800 cfs. Future river restoration projects are being considered for the next set of studies of the river. It will be important to assess past, current, and future geomorphic, biological, and water resources conditions in an effort to understand the overall channel process prior to completion of river restoration projects.

INTRODUCTION

The Purgatoire River is 175 miles long and is formed by the confluence of the North Fork and Middle Fork of the Culebra Range of the Sangre de Cristo Mountains in southern Colorado. The river flows first east through Trinidad Lake then northeast past Comanche National Grassland to the Arkansas River just above John Martin Reservoir. The location map of the study reach is shown in Figure 1.

Trinidad Dam is part of the Trinidad Project, storing water from the Purgatoire River. The project was completed by the U. S. Army Corps of Engineers (COE) in the 1970's to provide flood control, irrigation, and recreation benefits. The U.S. Department of the Interior, Bureau of Reclamation (Reclamation) is responsible for oversight and repayment of the irrigation aspects of the project which are controlled by the Purgatoire River Water Conservancy District. This project is considered a post-compact project of the Arkansas River Compact and may not deplete useable Stateline flows beyond historical consumptive uses prior to 1949. Article III of the Operating Principles states that flood water should be passed "at the maximum non-damaging rate insofar as practicable." (Operating Principles for Trinidad Dam, USACE, 1994).

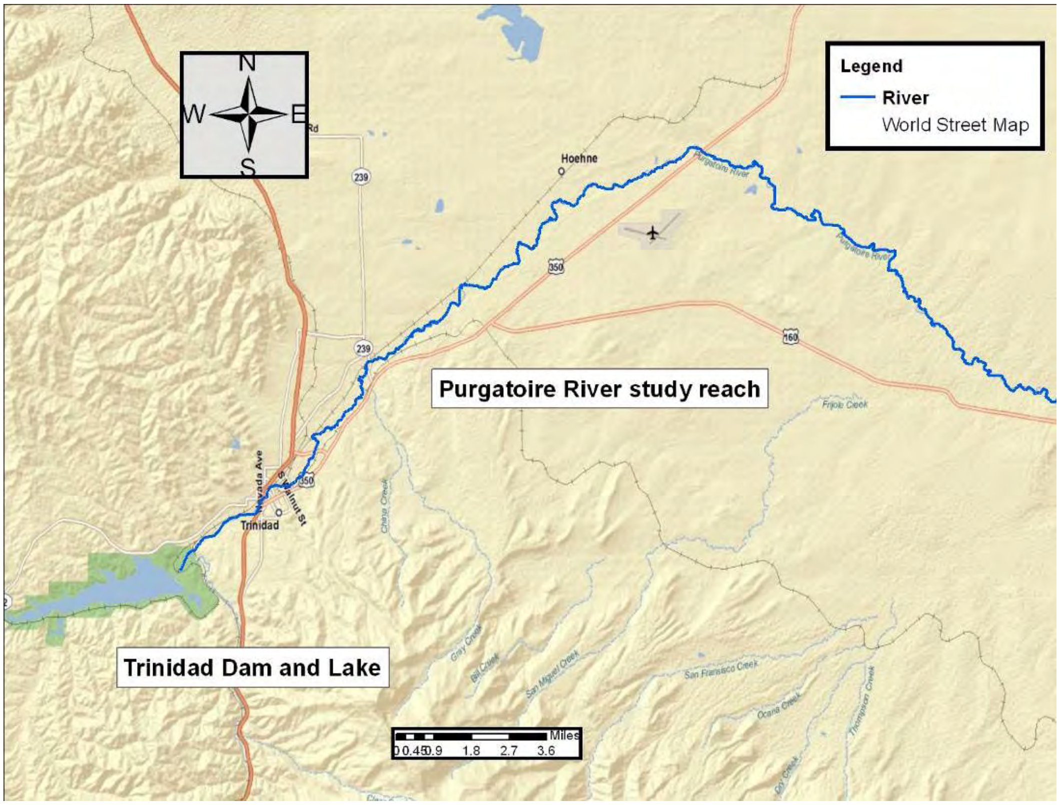

FIGURE 1-LOCATION MAP OF PURGATOIRE RIVER REACH.

The channel below the reservoir has deteriorated since closure of the Trinidad Dam due to vegetation growth, flow management, and land use changes, and there is uncertainty regarding what the “non-damaging” flow rate is below the dam. A flow of 5,000 cfs is listed as the estimated non-damaging flow in the COE’s Water Control Plan for Trinidad Dam. Based on recommendations from the COE, the State of Colorado has established modified release criteria where releases above 3,000 cfs will be made only in consultation with the COE. However, recent releases exceeding 1,000 cfs resulted in flood damage along the Purgatoire River. This decrease in channel capacity has become a point of concern with the signatories to the Project Operating Principles.

This project was broken up into two phases; this study comprises Phase I. The objective of Phase I was to determine the current minimum/maximum? channel capacity flow rate at which agricultural damages are incurred, determine the amount of inundation occurring at 3,000 and 5,000 cfs, and to formulate recommendations for future potential channel restoration efforts and studies to be conducted in Phase II. This was accomplished by constructing a one-dimensional hydraulic model, adjusted based on sensitivity analyses, to evaluate the present channel capacity for a range of flows up to 5,000 cfs. Phase II is to be conducted on an as-needed basis, and will include additional studies and recommendations for channel restoration including control of vegetation (Tamarisk and Russian Olives).

HYDRAULIC MODEL

The hydraulic model was constructed for 42 miles of the Purgatoire River from Trinidad Dam to near the canyon area Purgatoire River Water Conservancy District boundary (the river miles were number from upstream to downstream from Trinidad dam). The model utilized a three dimensional digital surface of the project area that was generated using both LiDAR and ground survey data. One of the biggest limitations of LiDAR data is its inability to penetrate below water. Therefore, survey data of the channel bottom and edge of water was collected to more accurately represent channel bathymetry. There are some geographic features such as bridges and diversions that are likely not adequately mapped with the LiDAR data and might not have available design data. Additional survey data was collected to define the geometry of structures not sufficiently covered by the aerial data as well as to validate LiDAR elevations.

LiDAR and ground survey data were processed in ArcGIS (ESRI, 2008). A digital three-dimensional topographic representation was generated using a Triangulated Irregular Network (TIN). The TIN represents the surface through a set of contiguous, non-overlapping triangles. The Army Corps of Engineers' HEC-GeoRAS (COE, 2008) interface with ArcGIS was utilized to obtain cross-section geometries for the HEC-RAS hydraulic model. HEC-RAS is a one-dimensional, backwater model capable of simulating both steady and unsteady flows; the steady flow algorithm was utilized for this study. Additional input for the model included hydraulic roughness, flow data, boundary conditions, structure data (bridges, weirs, and diversions), and additional hydraulic controls (levees, blocked obstructions, ineffective flow areas, etc.). All LiDAR and survey data was collected in the State Plane (Colorado South) NAD83/NAVD88 datums (National Geodetic Survey, NOAA, 2008).

The majority of the model topography was composed of LiDAR data and supplemented with survey data in the active channel area and around hydraulic structures such as bridges and inline structures. LiDAR data was omitted from the in-channel area. Five line themes, digitized from upstream to downstream, were created in ArcGIS and consisted of the following types: 1) top of left bank, 2) bottom of left bank, 3) channel thalweg, 4) bottom of right bank and 5) top of right bank.

Survey points were snapped to the five line themes. New points were created along each line theme at a 20 foot spacing. Elevations were estimated at each point through linear interpolation. The TIN was created from a combination of the line themes in the channel and contour data in the floodplain based on the LiDAR data. An example of the contour data in the floodplain and the points along the lines of the channel is shown in Figure 2. The combination of the survey data in the channel and the LiDAR data in the floodplain provided a good representation of the terrain for the hydraulic model.

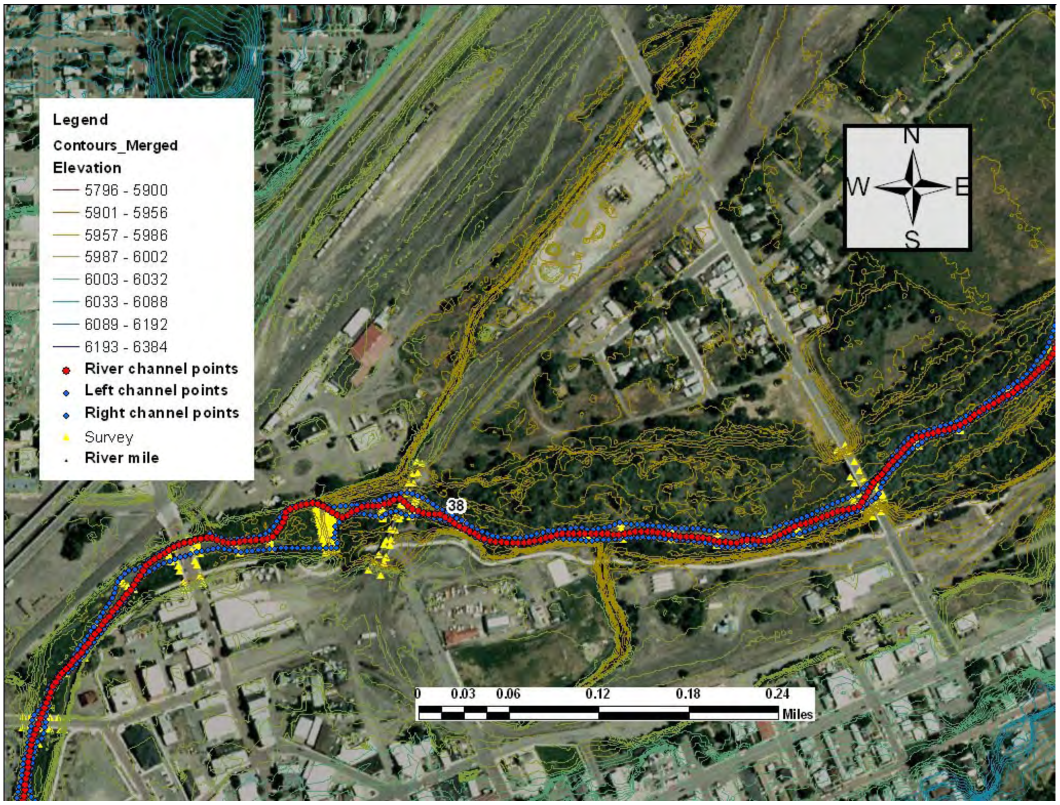

FIGURE 2 - EXAMPLE OF RIVER CHANNEL AND BANK POINTS AND CONTOUR DATA IN THE FLOODPLAIN USED TO GENERATE TIN.

The HEC-RAS model was created from a HEC-GeoRAS import file, which contained information on cross sections, bridges, and hydraulic structures. The details of the structures were input directly into HEC-RAS. Survey data on hydraulic structures and bridges was used to input elevation and structural data. A total of 744 cross sections were utilized in the model, and an additional 1,093 interpolated sections were included for added refinement. The cross section data was extrapolated from the TIN. A total of 8 inline structures and 14 bridges were modeled within the Purgatoire River Reach. These structures are identified in Table 1.

The structures were input into the HEC-RAS model using survey data and location information from ArcGIS. The gas pipeline bridge (see Table 1) was not identified during the site visits, but was identified on the maps. Naming conventions were clarified by a personal communication from Jeff Montoya (State of Colorado Water Commissioner on the Purgatoire River). The details of the structures were input directly into HEC-RAS. Survey data on hydraulic structures and bridges was used to input elevation and structural data.

Table 1. Locations of Inline Structures and Bridges

Inline Structure	Approximate Location (RM)	Bridge	Approximate Location (RM)
Lopez Ditch Diversion	41	1st Railroad Bridge	40.7
Picketwire Diversion	38	I-25 S Bridge	38.4
Couger Canyon Diversion	35	I-25 N Bridge	38.4
Southside Diversion	34.5	State Highway 12 and Nevada Bridge	38.3
Model Diversion	33	Animas Bridge	38.1
Hoehne Diversion	27	Cedar Bridge	37.8
Burns, Duncan 10, Lewelling, and McCormick Diversions	14	Linden Avenue Bridge	37.5
Salas Ditch Diversion	7.7	Kit Carson Bypass (Hwy 160) Bridge	36.4
		Gas Pipline Bridge	35.5
		El Moro (CR 85.1) Bridge	32.8
		CR 36 Bridge near Hoehne Diversion	27.3
		Hoehne (CR 85) Bridge	23.5
		Hwy 350 Bridge	19.3
		Small bridge on River Canyon Ranch	12

HYDROLOGY

Flood frequencies for a range of floods from the 10-year up to the 100-year recurrence interval were ran in the hydraulic model. Two additional key flows modeled for this study were 3,000 and 5,000 cfs based on flood releases authorized by the COE for Trinidad Dam. Low flows were also modeled to determine existing channel capacity. McLaughlin Engineers (2000) completed a flood study for the City of Trinidad that included data on the flood frequency of flows on the Purgatoire River. The flows listed in the McLaughlin study are shown in Table 2. The flood frequency analysis used in the determination of these flood values was based on the City of Trinidad Gage (located near RM 38.5). Additional flows used in the current HEC-RAS modeled were also added.

Table 2. Flows and flood frequency flows used in the model.

Flow (cfs)	Description
200	Low flow
300	Low
500	Low
800	Minor flood
1,000	Minor flood
2,500	Moderate flood
3,000	Release based on Corps Standard Operating Procedures (SOP
5,000	Release based on Corps SOP
6,600	10-year flood
15,000	50-year flood
21,000	100-year flood

HYDRAULIC MODEL RESULTS

The HEC-RAS model was used to determine the hydraulics of the main channel.

Model Calibration

The Colorado Division of Water Resources measured stream flows during a controlled release from Trinidad Dam. The purpose of these measurements was to help Reclamation calibrate the hydraulic model for the channel capacity study. Reclamation requested that a series of measurements be made along the Purgatoire River throughout the reach of interest. A controlled release was made to facilitate measuring along the length of the project reach at a fairly consistent flow. Approximately 243 cfs was released for 24 hours beginning on April 3, 2008, at 3:00 p.m. The release was for satisfying delayed return flows (State of Colorado, Division of Water Resources, 2008). The channel discharge increased at the downstream end of the reach to 261 cfs at the Highway 350 Bridge near RM 19. Measurements could not be made at Patterson Crossing (near RM 7) because the bridge was submerged and velocities and depths were too great to allow for making measurements while wading. The flow point locations are shown in Figure 3.

Reclamation completed the survey of the channel and obtained water surface elevation measurements at the flow points and other locations. The measured water surface elevations were compared to the modeled water surface elevations for a flow of 250 cfs for calibration purposes.

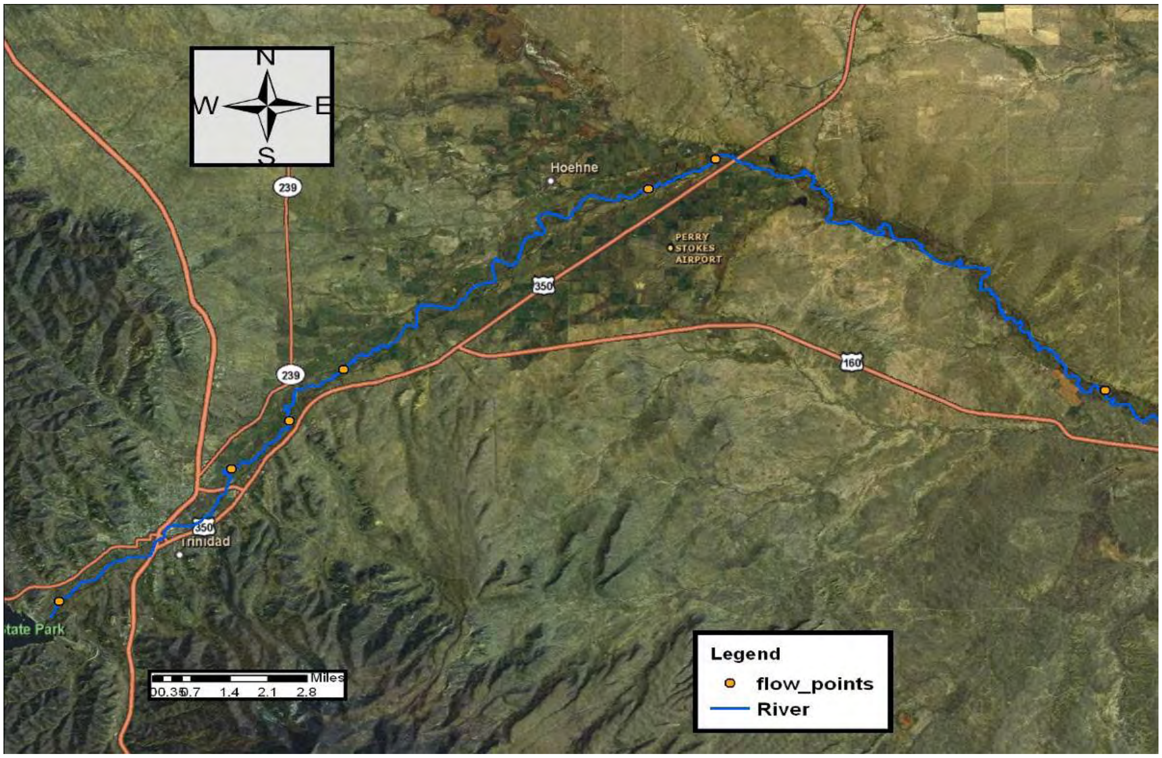

Figure 3 - Locations where flow measurements were completed by the State of Colorado during the April 2008 release.

Manning's roughness values were calibrated to 0.033 for the main channel and 0.075 for the overbanks. The main channel roughness was reduced to 0.03 at the Highway 350 Bridge near RM 19 because of a decrease in the bed material size to a gravelly sand. The overbank n was reduced near the lower end of the model at RM 4 due to a decrease in vegetation

A sensitivity analysis was conducted on the roughness by varying this parameter 20 percent. This resulted in roughness values for the main channel between 0.026 and 0.04 (original roughness value of 0.033). For the overbanks, roughness was varied between 0.06 and 0.09 (original roughness of 0.075), and 0.052 and 0.078 (original roughness of 0.065). The results for variation of the roughness values for a 3,000 cfs flow are shown in Figure 4. The figure provides a close up view of a small section of the reach to show how little difference changes in roughness values made to the water surface elevations. Average water surface elevation differences were also computed. Results showed that for a 20 percent decrease in roughness, the average water surface elevation decreased by 0.3 feet. For an increase in roughness of 20 percent, the average water surface elevation increased by 0.26 feet.

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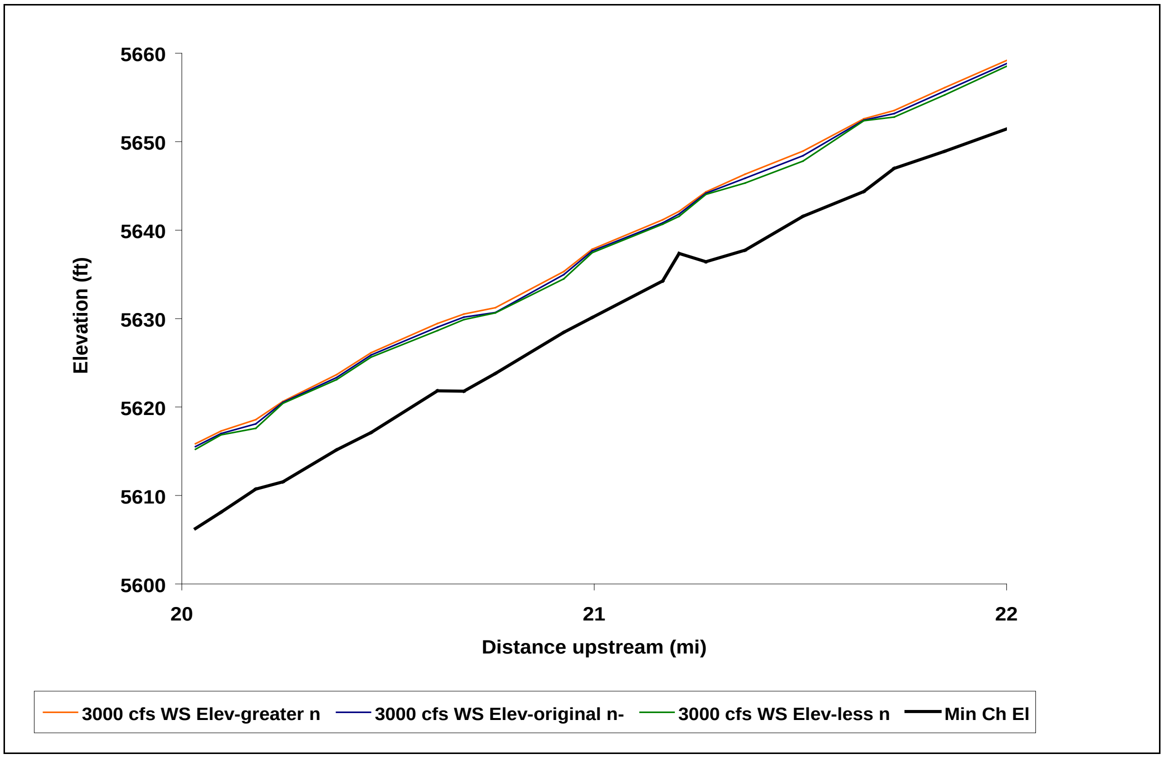

Figure 4 - Closeup view from the HEC-RAS model for 3,000 cfs showing changes in water surface elevations with variation of roughness values.

Model Results

Model results show that most of the flow remains in the channel at an 800 cfs discharge and flows exceeding this will inundate low lying agriculture lands. The water surface elevations for 3,000 and 5,000 cfs are relatively close with the average difference in water surface elevation of 1.75 feet. Model results show that the average energy grade slope for the entire reach is 0.0022 feet/feet and 0.0014 feet/feet for the lower 10 miles of the reach. Velocities for a 5,000 cfs flow average approximately 8 feet/sec. For the lower 10 miles of the reach, velocities average 7.7 feet/sec. The average top width for this flow is approximately 930 feet. The current channel capacity is approximately 800 cfs.

Floodplain maps of areas of inundation for a portion of the reach (River miles 42 to 33) are shown in Figures 5 through 8 for discharges of 800 cfs and 5000 cfs. The inundated area for selected discharges is shown in Table 3. The difference in inundated area between 3,000 and 5,000 cfs is about 20 percent. The 100 year flood of 21,000 cfs inundates an area roughly twice the size of the 5,000 cfs area

Table 3 Inundated flood area for select discharges.

Flow (cfs)	Area (sq mi)
800	1.1
3,000	4.0
5,000	5.1
21,000	10.3

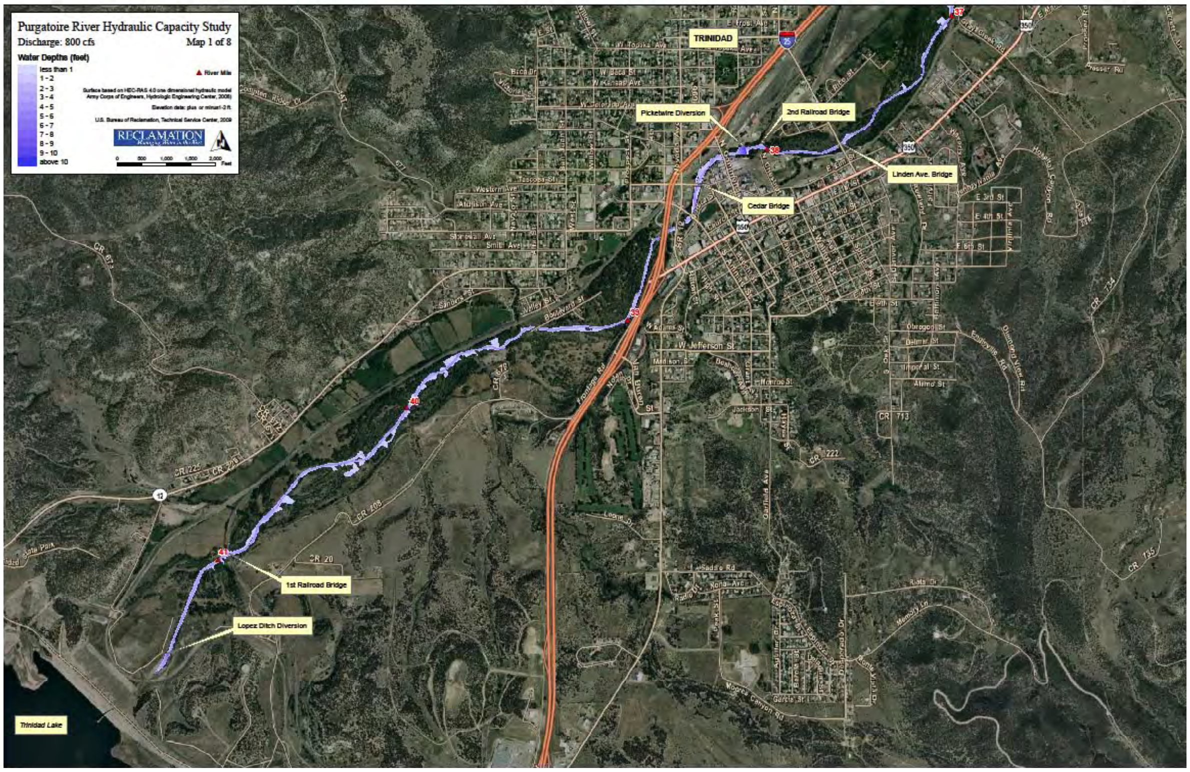

Figure 5 – Inundated flood area for a discharge of 800 cfs from River Mile (RM) 42 to RM 37.

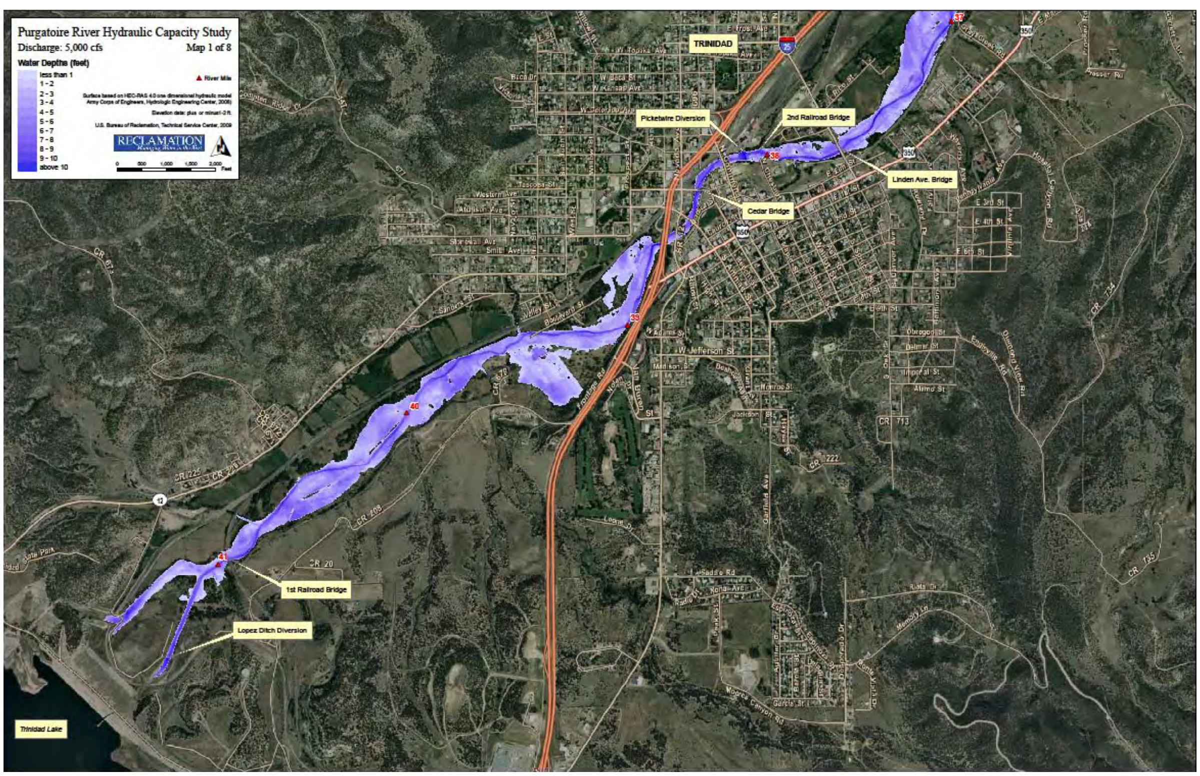

Figure 6 - Inundated flood area for a discharge of 5000 cfs from River Mile (RM) 42 to RM 37.

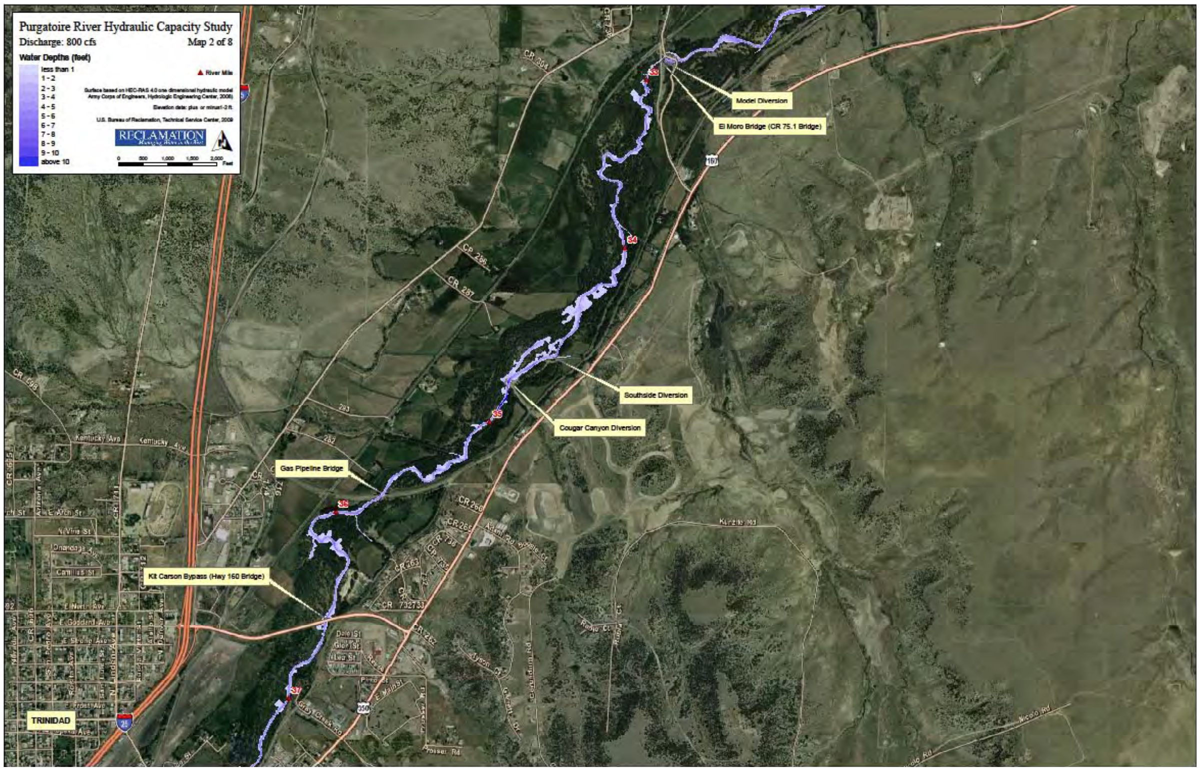

Figure 7 - Inundated flood area for a discharge of 800 cfs from River Mile (RM) 37 to RM 33.

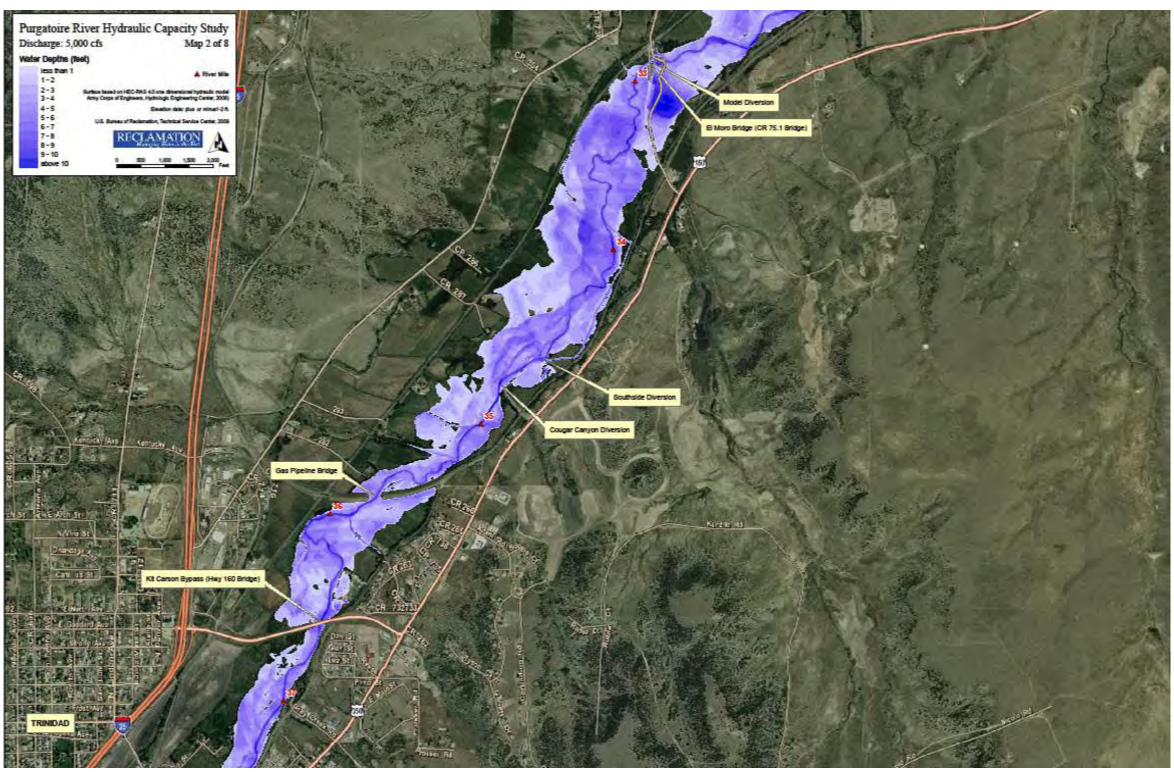

Figure 8 - Inundated flood area for a discharge of 5000 cfs from River Mile RM 37 to RM 33.

CONCLUSIONS

Reclamation's Sedimentation and River Hydraulics Group completed a one-dimensional hydraulic model of the Purgatoire River from Trinidad Dam to the end of the Purgatoire River Water Conservancy District boundary, a distance of approximately 42 miles. A range of flows from a low flow calibration flow of 250 cfs up to a 100-year flood of 21,000 cfs were modeled; the study focused on four key flows. The model utilized a digital terrain composed of LiDAR data in the floodplain and survey data in the main channel. A total of 8 inline structures and 14 bridges were modeled. The HEC-GeoRAS utility in ArcGIS was used to prepare input data for the HEC-RAS model. The State of Colorado Division of Water Resources measured discharge at six locations during a low flow release of 250 cfs for model calibration purposes.

RECOMMENDATIONS

Possible future studies are recommended for the reach as a Phase II. A brief geomorphic assessment of the reach should be completed. This study could be used to assess river changes since closure of Trinidad Dam. Old aerial photographs would be helpful for this study. Additional mapping of the geology, bedrock outcrops, and vegetation of the reach would also be useful. Vegetation mapping both before and after dam construction would be beneficial to understanding the current river conditions. A sediment transport model could also be useful to determine vertical and lateral channel stability and widening. Bed material data along the channel would be beneficial in completion of the sediment transport study. If river restoration projects are to be implemented, it would be important to assess past, current, and future geomorphic, biological, and water resources conditions in an effort to understand the overall channel process.

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