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MODELING REPORT
CROSS CREEK AT ROSSVILLE, KANSAS

FLOODPLAIN MANAGEMENT SERVICES SPECIAL STUDY

FLOODING 2005, MAIN STREET ROSSVILLE, KS

Final – Sept. 16, 2014

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

SUMMARY OF RESULTS

Creation of an artificial diversion channel upstream of the flow split does show potential to significantly lower flood levels in Rossville. Although less expensive than the levee and channel system proposed under the 1990 Feasibility Study, development of a diversion channel will still require major investment in design, and construction, as well as a thorough analysis of potential induced damages caused by the diverted flow.

This study confirms the conclusions of previous studies that improving conveyance through the Highway 24 and railroad bridges is unlikely to reduce major flooding in Rossville. In addition, removal of obstructions such as the abandoned county bridges downstream of Highway 24 is also ineffective in reducing flood levels. The natural characteristics of the Cross Creek channel in addition to the tendency of Ensign Creek overflows to flood Rossville from the north make incremental measures such as removal of flow obstructions and improvement of bridges generally ineffective.

The convergence of the 1/50, 1/100, and 1/500 annual chance exceedance (ACE) water surface elevations upstream of Highway 24, predicted by the 2011 Flood Insurance Study is confirmed in general. However, the magnitude of flow remaining in Cross Creek below the diversion to Ensign Creek is not strictly limited to the 13,000 cubic feet per second (cfs) assumed in the FIS report. A split flow analysis conducted under this study suggests that flows used in previous models upstream of the Cross Creek-Ensign Creek split are too low, although flows evaluated in Cross Creek below the flow split are reasonable.

It is probable that runoff from the Cross Creek watershed is not regulated to the extent assumed by previous planning studies (see table 1). The split flow analysis modeled under this study gives a more complete picture of the relationships between total output from the Cross Creek Basin, magnitudes of flow split between Cross Creek and Ensign Creek and gage heights at the Rossville Gage. Unfortunately, recurrence intervals to those flows cannot be assigned due to lack of gage data above the flow split. The relative magnitude of the flow split between Cross and Ensign Creeks presented in this report are useful for evaluating diversion alternatives but cannot assign a precise level of protection associated with those alternatives.

Modeling conducted for this study and the associated Silver Jackets mapping project, and in partnership with the National Weather Service, has made possible the development of flood forecast inundation maps now available for viewing on the National Weather Service's Advanced Hydrologic Prediction Service (AHPS) web page. These maps serve as a valuable tool for communicating flood risk for planning purposes as well as communication of the probable extent of flooding on a real-time basis, based on National Weather Service forecasts at the Rossville Gage.

1.0 <u>Previous Studies</u>

Several previous hydrologic and or hydraulic studies have been undertaken within the community as summarized in this section.

1.1 1983 Reconnaissance Study

Following the severe flood event of June 10, 1982, the City of Rossville requested that the Corps of Engineers conduct a study of potential measures for reducing flood damages. A 1983 reconnaissance study, conducted under the continuing authority of Section 205 of the Flood Control Act of 1948, as amended, indicated that a feasible project to reduce flood damages could be developed on Cross Creek at Rossville, Kansas.

1.2 1990 Section 205 Feasibility Study

The U.S. Army Corps of Engineers (USACE) Kansas City District completed a Section 205 feasibility study of Cross Creek in Rossville in 1990. Plans considered included construction of a flood control dam upstream, channel relocation, ring levees with some sections of floodwall, various combinations of levees with channel relocation, and nonstructural measures. The recommended plan included a 3,800-foot relocated channel about a quarter of a mile west of Rossville plus a 9,500 foot trail levee parallel with the new channel and tied to high ground north of town and trailing off at a location adjacent to the existing channel south of town. The recommended plan would provide the City of Rossville with 0.2% ACE protection from Cross Creek flooding at a cost of $7.4 million at 1989 prices.

A protracted review period followed, centered on doubts concerning economic justification as well as local concerns about induced impacts of the project in nearby areas. The project ultimately was approved, but a bonds issue proposed by the city of Rossville to meet its required share of project funding was defeated by the community in a close 1994 contest decided by a few votes. The project subsequently was terminated in 1995. The flood event of October 2005 revived community interest in a project addressing flood risk, resulting in a request by the city for a new study.

1.3 2010 Section 205 Assessment

A second section 205 Study (Initial Assessment) was completed in January, 2010. The purpose of this assessment was to use available data from previous studies to identify at least one plan that promised to be feasible and effective at that point in time 20 years after the previous Feasibility Study and Definite Project Report. The initial assessment analyzed the existing and future without-project conditions. Hydraulic modeling confirmed that the recommended alternative from the 1990 study would remove the community of Rossville from the 1/10, 1/100, 1/500 ACE (10, 100 and 500 year) flood plains. Costs for this alternative were escalated to May 2009 levels yielding an updated cost of $13,417,000.

The 2010 study also conducted hydraulic modeling to evaluate the impact of improving conveyance through the Highway 24 and the railroad bridges in an effort to increase conveyance through town. The models were run with complete bridge removal as a first test of feasibility of the alternative. Model results showed that removal of the bridges would have only a minor effect on upstream flood profiles. Figures 1 and 2 show flood extents based on the 2010 study model results for the 1/10 ACE flood (10 year) flood for existing conditions and with the Highway 24 and railroad bridges removed. Table 1 shows flow data developed for the section 205 study. The 2010 Section 205 study relied on hydrology developed in the 1990 study. The regulated flow analysis was based on the assumption that 15 of the NRCS watershed dams had been constructed.

TABLE 1: FLOW DATA FROM "CROSS CREEK SECTION 205 STUDY" DATED JAN 2010, PREPARED FOR USACE NWK BY CDM.

Event	Flow from USGS Regression Equations, cfs	Unregulated Flow from Section 205 Report, cfs	Percent Difference	Regulated Flow from Section 205 Report, cfs
2-yr	5,540	7,384	-33.3%	5,083
5-yr	11,305	11,522	-1.9%	7,200
10-yr	16,405	16,510	-0.6%	8,645
25-yr	24,028	21,015	12.5%	11,791
50-yr	30,897	25,915	16.1%	13,913
100-yr	39,099	40,182	-2.8%	16,170

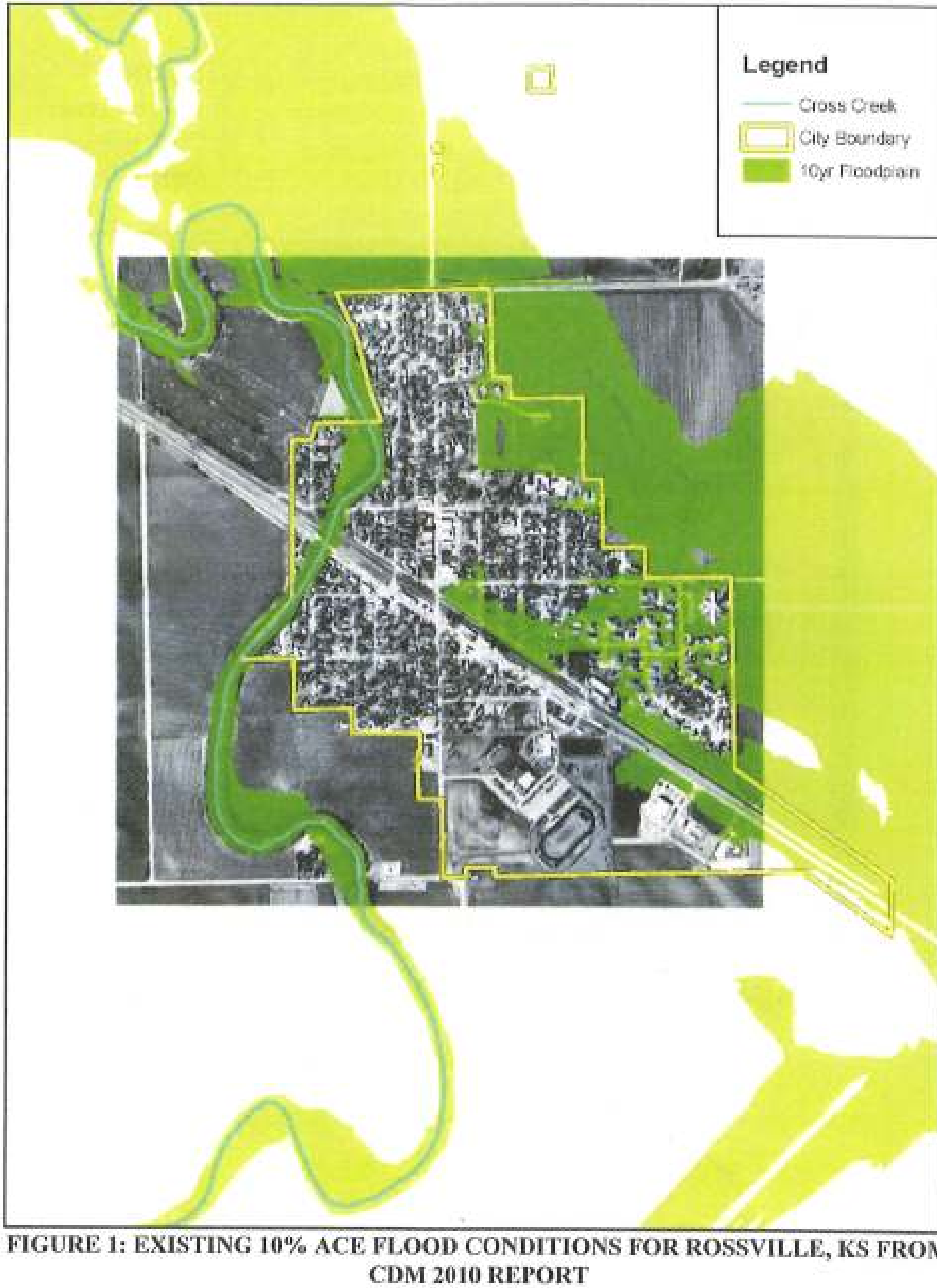

FIGURE 1: EXISTING 10% ACE FLOOD CONDITIONS FOR ROSSVILLE, KS FROM CDM 2010 REPORT

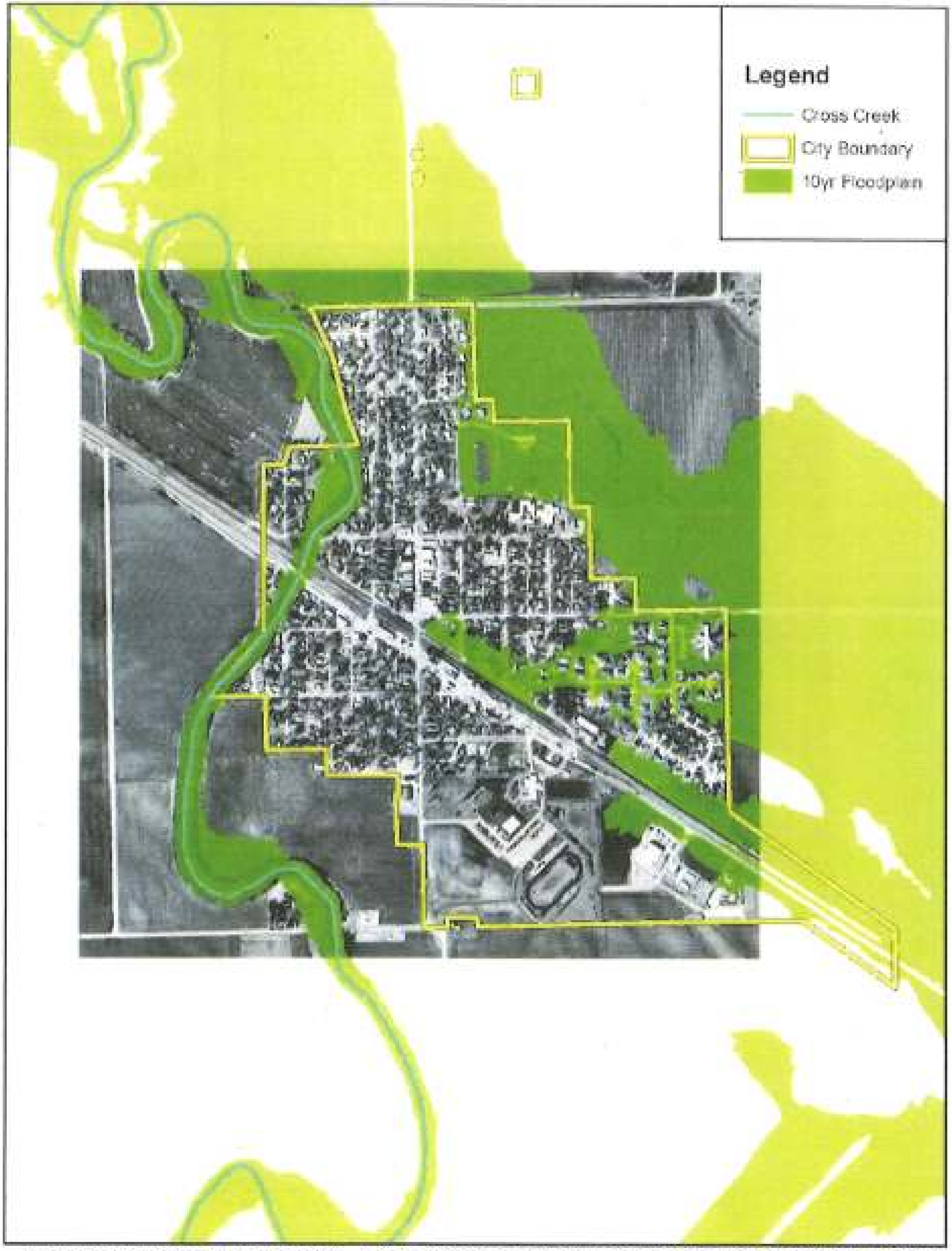

FIGURE 2: EXTENT OF 10% ACE FLOODING WITHOUT BRIDGES FROM CDM 2010 REPORT

1.4 2011 FEMA Flood Insurance Study Update

An updated FEMA Flood Insurance Study (FIS) and updated Digital Flood Insurance Rate Maps were published in 2011. The 2011 FIS report indicates that flooding from the Kansas River will be a fairly rare event, with the 1/500 ACE flood (500 year) elevation for the Kansas River backwater at the mouth of Cross Creek at approximately 924 feet. Land Surface elevations in Rossville are generally above 925 but not likely to range much higher than 930 feet. By Contrast, the study projects the 1/50, 1/100 and 1/500 ACE events for Cross Creek converging at the same elevation and ranging in elevation from 928 to 932 feet from downstream to upstream in the community. The 1/10 ACE event for Cross Creek is only slightly lower, ranging from 927 to 931 feet in Rossville.

The reason that the 1/50 through 1/500 ACE events converge at nearly the same elevation appears to be the diversion of significant portions of Cross Creek Flow at these discharge levels from Cross Creek into the Ensign Creek drainage.

The 2011 Flood Insurance Study (FIS) describes hydrologic analysis for Cross Creek as follows:

"A new detailed hydraulic study was completed for Cross Creek as part of this project. However, updated detailed hydrology for Cross Creek was deemed unnecessary by FEMA Region VII. Approximately 50 to 55 percent of the Cross Creek drainage area is controlled by flood water retarding dams or detention dams constructed by the Cross Creek WJD No. 42 and many of these dams provide retention for the 1-percent-annual-chance storm event. The flows in the previous FIS completed in June 1979 account for 8 of the approximately 30 dams constructed by the district. In addition to the watershed being controlled, another unique feature of Cross Creek is that a portion of the flows in excess of the 10-percent-annual-chance storm event are diverted out of Cross Creek into a drainage channel which connects to Ensign Creek. Regression analysis and also calibration of flows computed by regression to a near- by gaged watershed were options considered to obtain updated flows. Due to the complexity of the overflow channel and the fact that over 50% of the basin is controlled by dams, it was determined that using the flows computed for the 1979 FIS was the best option at this time. The Cross Creek drainage basin hasn't undergone significant changes over the last 25 years, and is primarily agricultural just as it was in 1979."

Table 2 is the table from the 2011 FIS showing the 1/10, 1/50, 1/100 and 1/500 ACE (10, 50, 100 and 500 year) flows for Cross Creel at Rossville.

TABLE 2 LISTS CROSS CREEK FLOWS FROM THE 2011 FIS REPORT

FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	10-Percent Annual-Chance	2-Percent Annual-Chance	1-Percent Annual-Chance	0.2-Percent Annual-Chance
BUTCHER CREEK					
Downstream of confluence with West Fork Butcher Creek	3.67	3340	4740	5340	6730
Upstream of confluence with Shunganunga Creek	5.58	5300	7420	8330	10430
COLLY CREEK					
Upstream of Confluence with South Branch Shunganunga Creek	4.5	3120	4580	5210	6700
CROSS CREEK **					
At north end of Rossville Main Channel	***173	11,500	13,000	13,000	13,000
Overflow Channel (Ensign Creek)		0	8,000	12,900	27,200

2.0 Overview of Current FPMS and Silver Jackets Studies

The high costs of the comprehensive solutions evaluated in the 1990 and 2010 Section 205 Studies have prevented the community from implementing these projects. The objective of this current Floodplain Management (FPMS) Special Study is to evaluate key hydraulic control points in the Cross Creek and Ensign Creek watersheds and evaluate incremental, cost effective improvements that have potential to lower the frequency and extent of flooding in the community. During the development of hydraulic modeling for this study funding became available through the Corps' Silver Jackets Program for development of the Flood Forecast Inundation Maps for Rossville. The modeling efforts for the two studies were combined to make the most effective use of available funds. At the time of this writing the maps are displayed on the Weather Services Advanced Hydrologic Prediction System (AHPS) web site .The maps can be viewed at the following link; http://water.weather.gov/ahps2/inundation/inundation_google.php?gage=rssk1

2.1 Objective of the FPMS Study

The 2010 Section 205 study evaluated the impact of removing the Highway 24 and the railroad bridges on flooding levels at the Cross Creek Gage. The removal of the bridges had a relatively minor effect on flood profiles in Rossville. Flood profiles in the flood insurance studies suggested that constrictions downstream of the two active bridges might be causing a backwater effect below the Highway 24 bridges resulting in the lack of response to the modeled bridge removal. The previous Section 205 Studies did not evaluate potential constrictions downstream of Highway 24.

Potential constrictions to higher flows downstream of Highway 24 include two abandoned county bridges and a possible channel constriction approximately 10,000 feet downstream of the Highway 24, in the vicinity of the wastewater lagoons. The constriction may be related to an old river terrace that is higher than the surrounding flood plain, the placement of the waste water lagoon dikes, or a combination of both. This study extended hydraulic modeling downstream in order to evaluate whether increased conveyance downstream of town can significantly lower flood profiles at the highway and railroad bridges, and consequently make improvements to these structures more effective. If so, increasing conveyance through the bridges would need to be re-evaluated. If improved conveyance downstream of the Highway 24 Bridge was not effective in lowering flood levels, other alternatives would be explored.

2.2 FPMS Extension and Improvement of Existing HEC-RAS Models

Under the current study, funds were provided to the Corps of Engineers' Mobile District to extend the HEC-RAS hydraulic models developed for the 2010 study by CDM and evaluate the effectiveness of a number of incremental improvements to conveyance in Cross Creek downstream of Highway 24. Due to a high level of uncertainty in the magnitude of flow diverted to Ensign Creek at various discharge levels several modeling approaches were developed. Mobile District then extended the RAS model developed from the Section 205 Study downstream to below the Sewage lagoons and developed a diversion channel model west of Rossville. These models were provided to the Kansas City District and they were further developed in conjunction with development of the AHPS models. Results of Modeling of removal of downstream obstructions and development of stream diversion model are discussed later in this report.

2.3 FPMS 2D Model

A 2-dimensional (2-D) RMA2 model was developed by Mobile District to evaluate flow directions and velocities using the same boundary conditions as the Section 205 HEC-RAS model. A LIDAR data set was used to develop a finite element model mesh, and some existing and additional alternative idea simulations were completed. The 2-D model was useful in evaluating the flow split and confirming the impact of the Railroad and Highway 24 bridges on flooding in Rossville. Figure 3 shows the original LIDAR survey data imported and developed into 2D model bathymetry, and Figure 4 shows an existing condition simulation (flow velocity contours) of a simulated flood event using the assumed 1% ACE (100 year)flood flow from the previous studies.

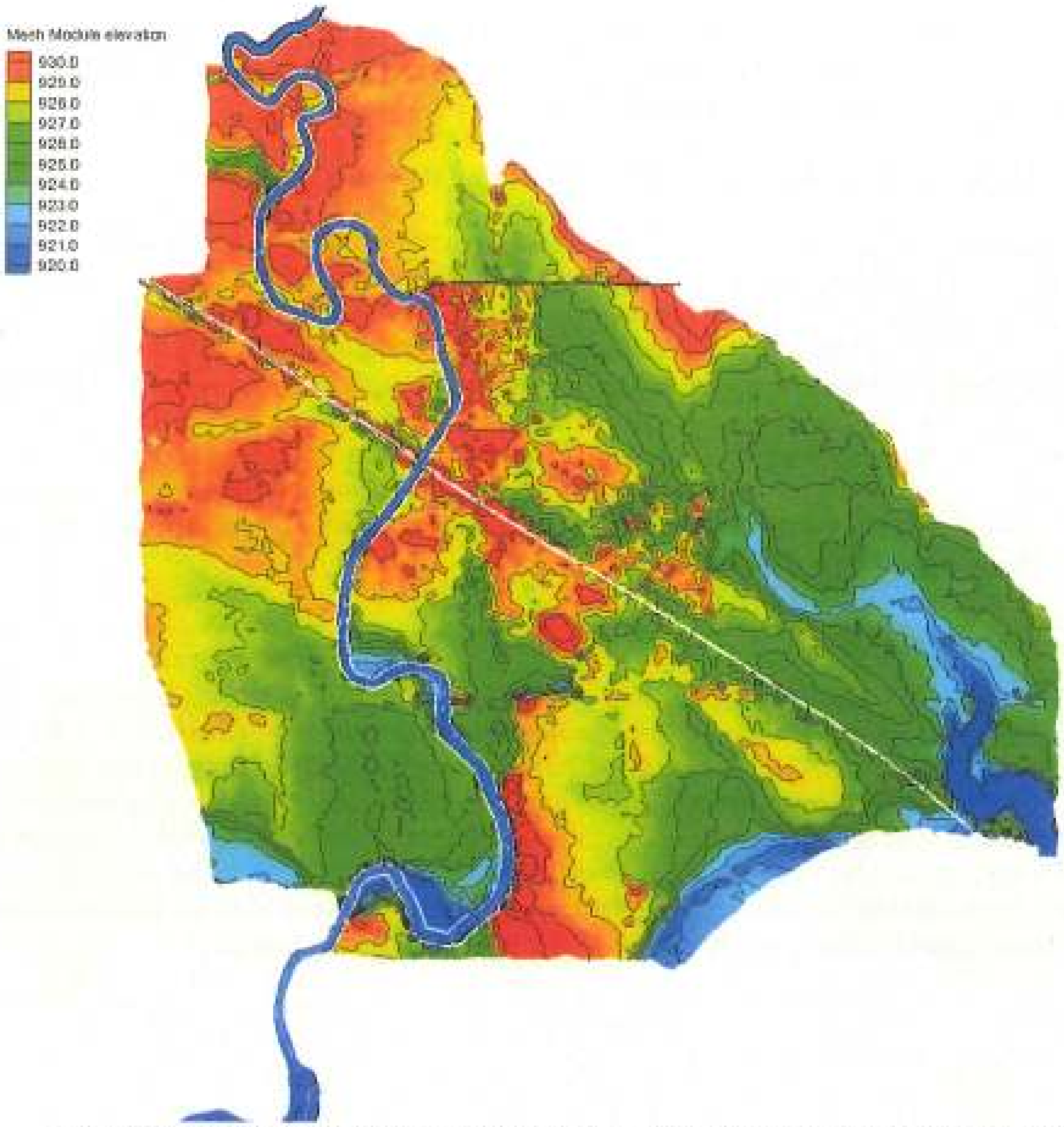

FIGURE 3: LIDAR SURVEY DEVELOPED INTO 2D MODEL BATHYMETRY

FIGURE 4: EXISTING CONDITION SIMULATION – 1% ACE FLOW VELOCITY CONTOURS

2.4 Silver Jackets AHPS HEC-RAS Model

In addition to structural measures (channel conveyance improvements and diversion channels) the development of the AHPS Flood Forecast Inundation Maps will allow the community to better manage residual flood risk. While the diversion models were being developed, funding became available to develop gage-based inundation maps tied to the National Weather Service forecast point at the Rossville Gage and to be displayed on the AHPS web site. Flooded area maps and depth grids have been prepared at one-foot increments on the Rossville Gage between stage 20 and 36 feet. As of this writing these maps are available on the AHPS web site for access by the public. This mapping will serve as an important tool in flood risk communication, planning and response.

A single 1-D HEC-RAS split-flow, steady-state model for Cross and Ensign Creeks was created for the AHPS mapping and is used for the final analysis under this study. Several variations of the model were developed and calibrated to recent flood events in an attempt to better define split flow and elevations across the community. These included separate models for Cross Creek and Ensign Creek with weirs developed to estimate discharge from Cross Creek to Ensign Creek. The single 1-D split flow model was ultimately found to calibrate with good accuracy and offered the simplest solution to evaluating various flow conditions; for these reasons this the 1-D model was chosen for inundation map development.

To develop the AHPS mapping, the previous versions of the HEC-RAS models were modified to provide a more accurate simulation of water surface elevation throughout the community. The models were calibrated to the 2005 flood event by comparing photographs and eye-witness accounts of maximum flood elevation to preliminary depth grids generated from the model. Calibration required refinement of the discharges on either side of the flow split. Several model geometry configurations were tested in order to get the best representation of flood flows through Rossville. Table 3 shows split flows developed for a range of one foot gage intervals on the AHPS mapping. These flows were chosen to best match one-foot intervals on the Rossville gage. They do not represent a flood frequency analysis, so return periods cannot be assigned to any particular discharge in the model without additional supporting analysis. Figure 5 shows the HEC-RAS Geometry for the split flow model.

TABLE 3 - STREAM FLOW IN CFS FOR GAGE ELEVATIONS AT CROSS CREEK

Gage Height	27 ft.	28 ft.	29 ft.	30 ft.	31 ft.	32 ft.	33 ft.	34 ft.	35 ft.
Cross Cr. Above Split	10,000	12,000	14,000	18,000	20,000	27,000	31,000	35,000	42,000
Cross Cr. Below Split	9,610	10,960	11,450	12,725	13,310	15,470	16,680	17,780	19,210
Ensign Cr.	390	1,040	2,550	5,275	6,690	11,530	14,320	17,220	22,790

Detailed documentation of development and calibration of the AHPS models and maps is presented in Appendix B. Figure 5 is an example of depth grids developed for the AHPS web site.

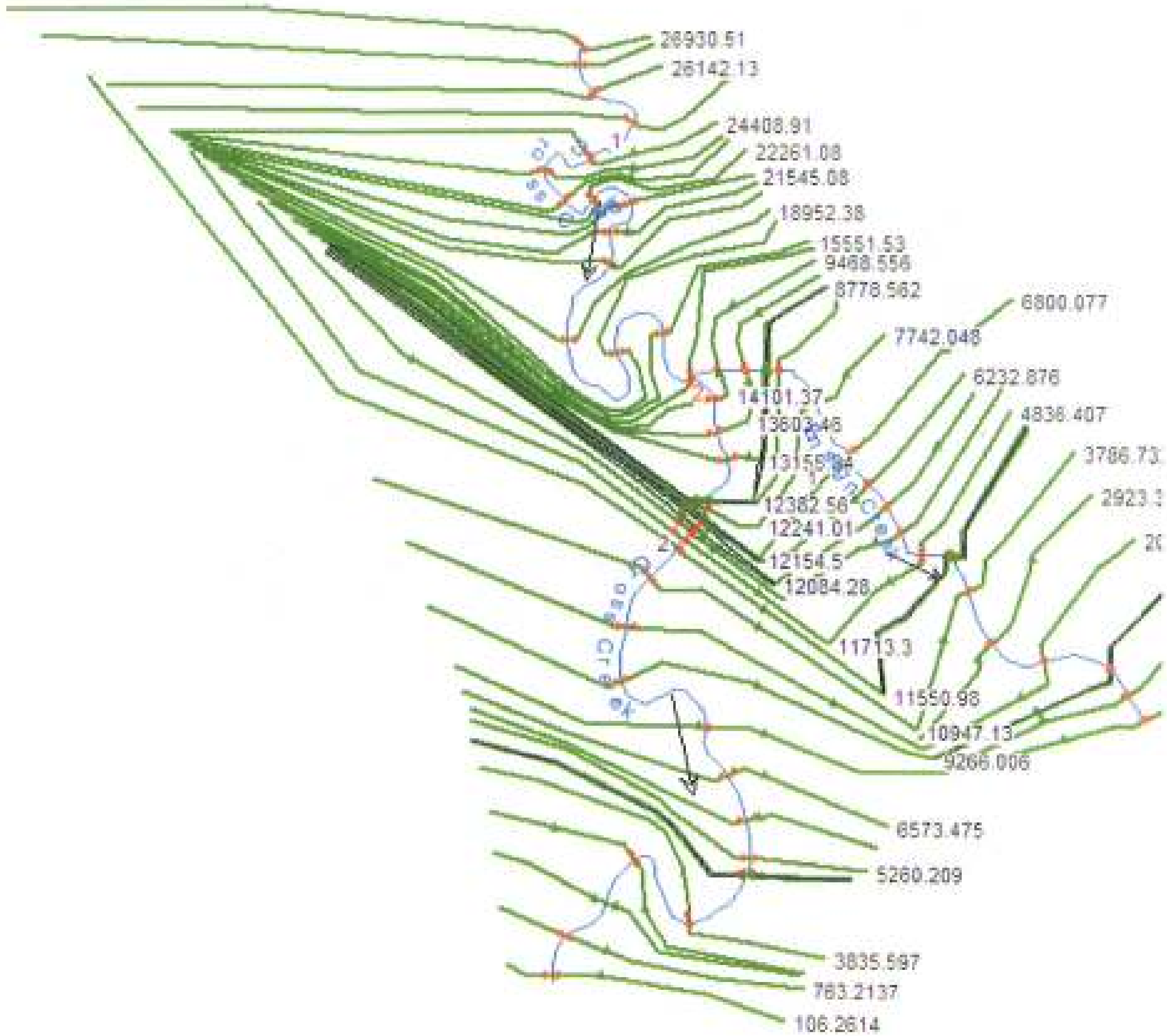

FIGURE 5: CROSS CREEK – ENSIGN CREEK SPLIT FLOW HEC-RAS MODEL GEOMETRY

FIGURE 6: AHPS INUNDATION MAP FOR GAGE HEIGHT OF 31 FT

The overall magnitude of the flow split between Cross Creek and Ensign Creek developed in the calibrated AHPS 1-D HEC-RAS model is generally consistent with the flow split in the 2011 FIS study at higher flows. Comparing flows from the various studies suggest that the 1/ 100 ACE (100 year) discharge used for the upstream boundary in the Section 205 study models was too low. See Tables 1, 3 and 4.

3.0 Bridge and Channel Modification Flood Risk Reduction Measures Considered

A number of active and abandoned bridges span Cross Creek in and immediately downstream of Rossville. The 2-D and HEC-RAS models were used to evaluate whether increasing conveyance at these bridges would be effective at lowering flood profiles in Rossville.

3.1 Union Pacific Railroad Bridge Span Evaluation

Results from the 2-D model indicate that the constriction at the Union Pacific Railroad Bridge is not the significant cause of Rossville flooding. More complete results from the Mobile District model analysis are included in Appendix A. As stated in Appendix A, "The flows under the Railroad Bridge do not change much with increased Cross Creek discharges. The simulated wider channel under the RR bridge, where the channel top width and bottom width were increased from 125 ft and 35 ft to 200 ft and 80 ft, respectively, does not increase conveyance under the RR bridge very much, either." The modeler concluded that flooding appears more of a function of limited channel capacity downstream and the flattening terrain and flatter channel slope encountered around and immediately upstream from Rossville. The 2-D model results support the conclusion reached in the 2010 Section 205 study that simply increasing conveyance through the Highway 24 and railroad bridges will not significantly lower flood levels in Rossville. Table 4 shows flow results for the 2-D model for removal of the railroad bridge.

TABLE 4: UNION PACIFIC RAILROAD BRIDGE SPAN EVALUATIONS FROM 2-D MODEL ANALYSIS

Annual Chance Exceedance[1]	Flow Under RR Bridge	Model Geometry Condition
1/100 - 16,170 cfs	10,300 cfs	Existing Conditions
1/50 - 13,913 cfs	9.700 cfs	Existing Conditions
1/25 - 11,791 cfs	9,030 cfs	Existing Conditions
1/100 - 16,170 cfs	10,750 cfs	Widen Channel at RR

[1]Note: The flow simulations in the 2-D model used the same 1/100 ACE discharge as an upstream boundary (upstream of the flow splits to Ensign Creek) that was used in the Section 205 study. The 2011 FIS and subsequent model runs discussed in the AHPS section of this report indicate that flows used in previous models above Ensign Creek at the upstream boundaries of the models are too low to represent the 1% ACE event and that the amount of the watershed regulation afforded by the NRCS dams is probably significantly less than previously estimated. Development of a more representative flow split is discussed in the AHPS portion of this report.

3.2 Improved Conveyance Downstream of Highway 24 Bridge

The revised split flow data developed during the AHPS modeling was combined with the extended model developed for Cross Creek to evaluate improved conveyance downstream of the Highway 24 Bridge. The only obvious obstructions noted in the extended model were two abandoned county road bridges (Figure 7). The most upstream of these bridges, at 46th Street, illustrated in Figure 8, is a steel structure with no remaining road deck and, in fact, no longer poses significant obstruction to flow based on visual inspection. The second bridge downstream on 42nd Terrace, illustrated in figure 9, has the deck remaining and likely creates a constriction to flow at higher discharges.

Modeling efforts failed to show that removing constrictions downstream of the Highway and Railroad bridges would significantly reduce flooding at Rossville. Figures 10 and 11 are flood profiles from the model run with and without the downstream county bridges. No significant reduction in flood profiles at the downstream edge of the railroad bridge is indicated. Table 5 contains water surface elevation changes for a location 150 feet downstream of Highway 24, predicted by the modeling from removal of the abandoned 42nd Terrace Bridge.

TABLE 5 – WATER SURFACE ELEVATIONS APPROXIMATELY 150 FT DOWNSTREAM OF HIGHWAY 24 BRIDGE WITH AND WITHOUT 42ND TERRACE BRIDGE REMOVAL

Plan Description	Water Surface Elevations for various stream gage heights (feet)						
	27	28	29	30	31	32	33
Existing Condition	925.24	925.80	926.24	926.92	927.18	928.01	928.23
With County Bridge Removal	925.23	925.79	926.22	926.82	927.06	927.97	928.31

A combination of the low gradient of Cross Creek downstream from Rossville and the capacity of the Ensign Creek drainage to divert flood flow upstream of town, appear to be the controlling factors for flood stages at Rossville. This, in turn, limits our ability to lower flood levels in Rossville by incremental improving the efficiency of the channel downstream of the flow split. Unfortunately, the diversion of flow to Ensign Creek that ultimately limits flood heights at Rossville is reached after significant flooding is already occurring, and the water diverted to the Ensign Creek drainage causes additional flooding to Rossville from the North and East.

FIGURE 7: LOCATION OF ABANDONED COUNTY BRIDGES

FIGURE 8: ABANDONED 46TH STREET BRIDGE

FIGURE 9: ABANDONED 42ND TERRACE BRIDGE

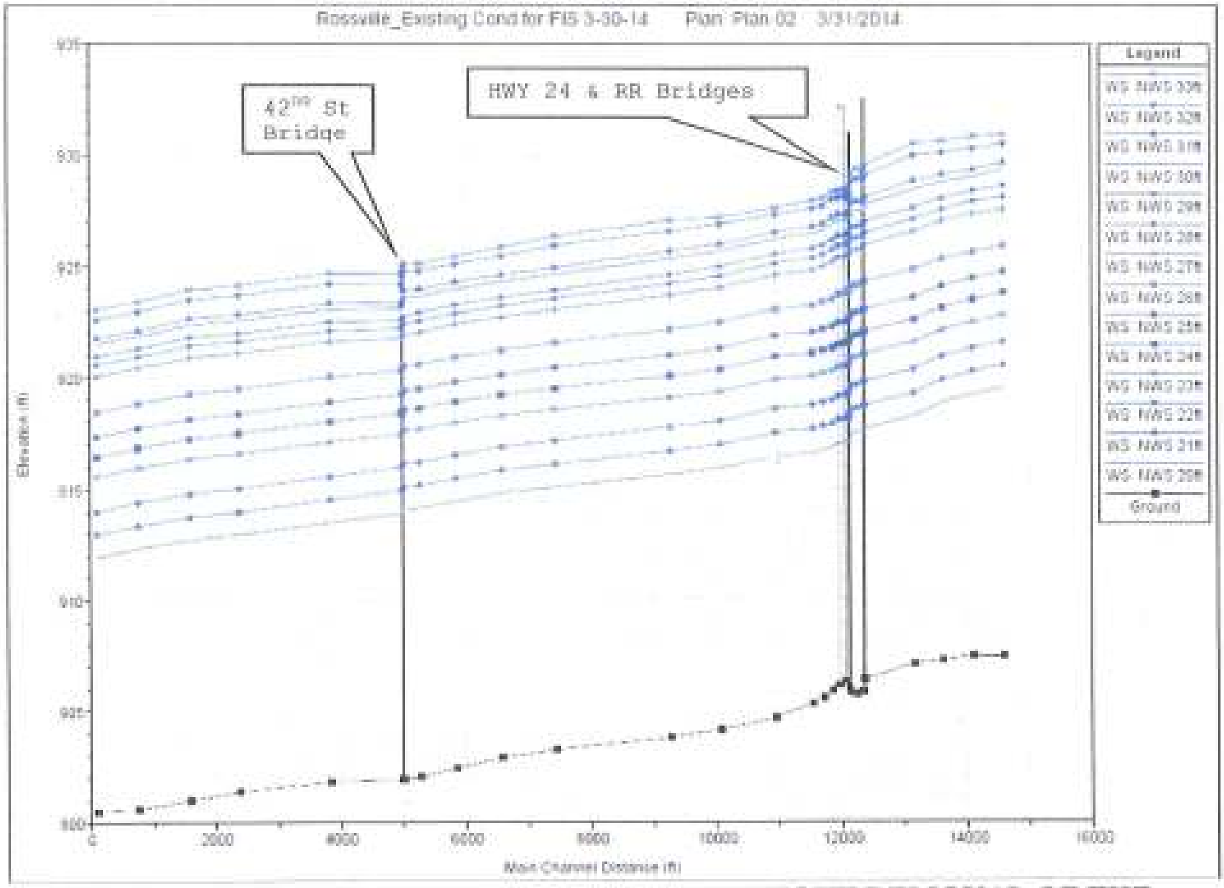

FIGURE 10: WATER SURFACE PROFILES WITHOUT REMOVAL OF THE ABANDONED 42ND TERRACE BRIDGE

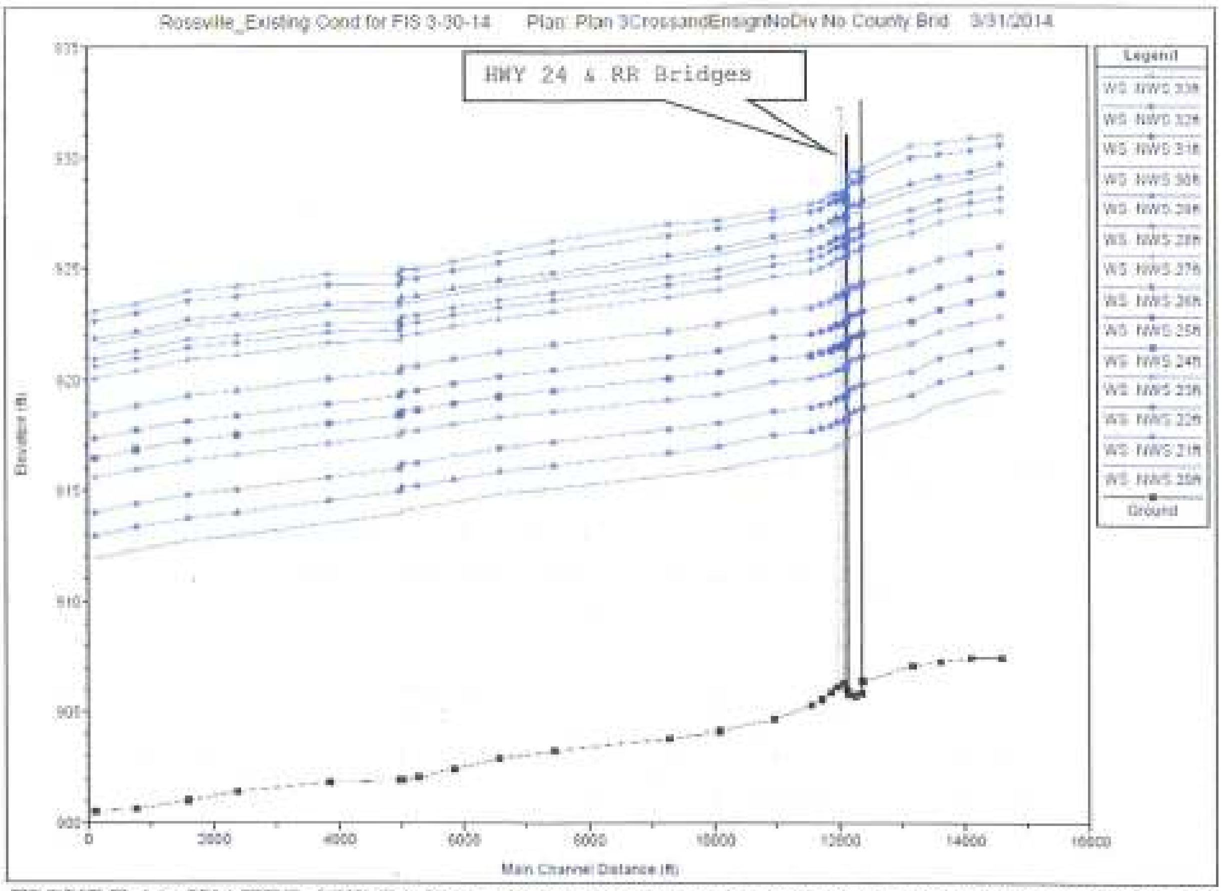

FIGURE 11: WATER SURFACE PROFILES WITH REMOVAL IF THE ABANDONED 42ND TERRACE BRIDGE

4.0 Analyses of Man-made Diversions

Based on the lack of effective options for increasing conveyance downstream of highway 24, the focus of modeling was shifted to evaluate the effectiveness of high flow diversion channels upstream of the Cross Creek-Ensign Creek low split. Due to the limited remaining funding available for this analysis, a limited number of diversion scenarios were evaluated. More detailed analysis of channel designs, invert elevations, as well as potential induced agricultural and other damage for each diversion scenario will need to be evaluated if diversion options show promise.

The diversion models were developed based on the AHPS steady-flow HEC-RAS model. Additional refinements were made to this model to allow for more consistent comparisons of the various diversion geometries. Once each diversion channel was coded into the model, flow splits were re-optimized to balance flow between Cross Creek, Ensign Creek and the specific channel being modeled. To accomplish this, the optimization tool was run in HEC-RAS, the resulting flows were copied from the data output tables and pasted into an excel spread sheet where they were compared to flows from the previous optimization run. If differences from the previous iteration were significant the new values were entered into the flow table of the model and the diversion simulation was re-run. When differences from the previous iteration had reduced to less than one cubic foot per second (cfs) optimization was stopped.

4.1 Cross Creek and Ensign Creek Diversions

A diversion to the west of Rossville, under Highway 24 and the railroad was the initial choice for evaluation because it impacts primarily agricultural land and enters the Kansas River very near the mouth of Cross Creek. The hydraulic model was modified to include galleries of 17 culverts ranging from 4-ft to-8 ft diameter, under the railroad and highway, along with a 200-ft wide 4,400-ft long channel leading to low ground draining to the Kansas River near the mouth of Cross Creek. The 17 culvert barrels were originally proposed in modeling done by Mobile District. This was the number required in the original screening modeling to get desired conveyance with pipes size limited by the height of the road and railroad embankments. This original model was modified over a range of pipe sizes in this investigation to better evaluate pipe sizing versus the impact of the diversion on water surface profiles in Rossville.

The modeling revealed that a diversion has the potential to lower water surface elevations at the Rossville gage for more common flood events (where gage heights without the diversion would be in the range of 26 to 29 feet) by up to 2 feet using 4-foot diameter culverts and up to 5 feet using 8-foot diameter culverts. The models indicate that the benefits drop off rapidly at flows that would be over 30 feet at the gage without the diversion. Similar decreases in water surface elevations are seen on the Ensign Creek drainage on the north and east sides of town. Tables 6, 7, 8 and 9 illustrate the change in water surface elevation and flow discharge at specific cross sections along Cross and Ensign Creek for the various culvert and inlet elevations simulated for a Cross Creek Diversion. Figure 12 shows possible diversion locations. Figures 13, 14, 15 and 16 illustrate changes in water surface elevations for various diversion options.

FIGURE 12: POSSIBLE CROSS CR. AND ENSIGN CREEK DIVERSIONS

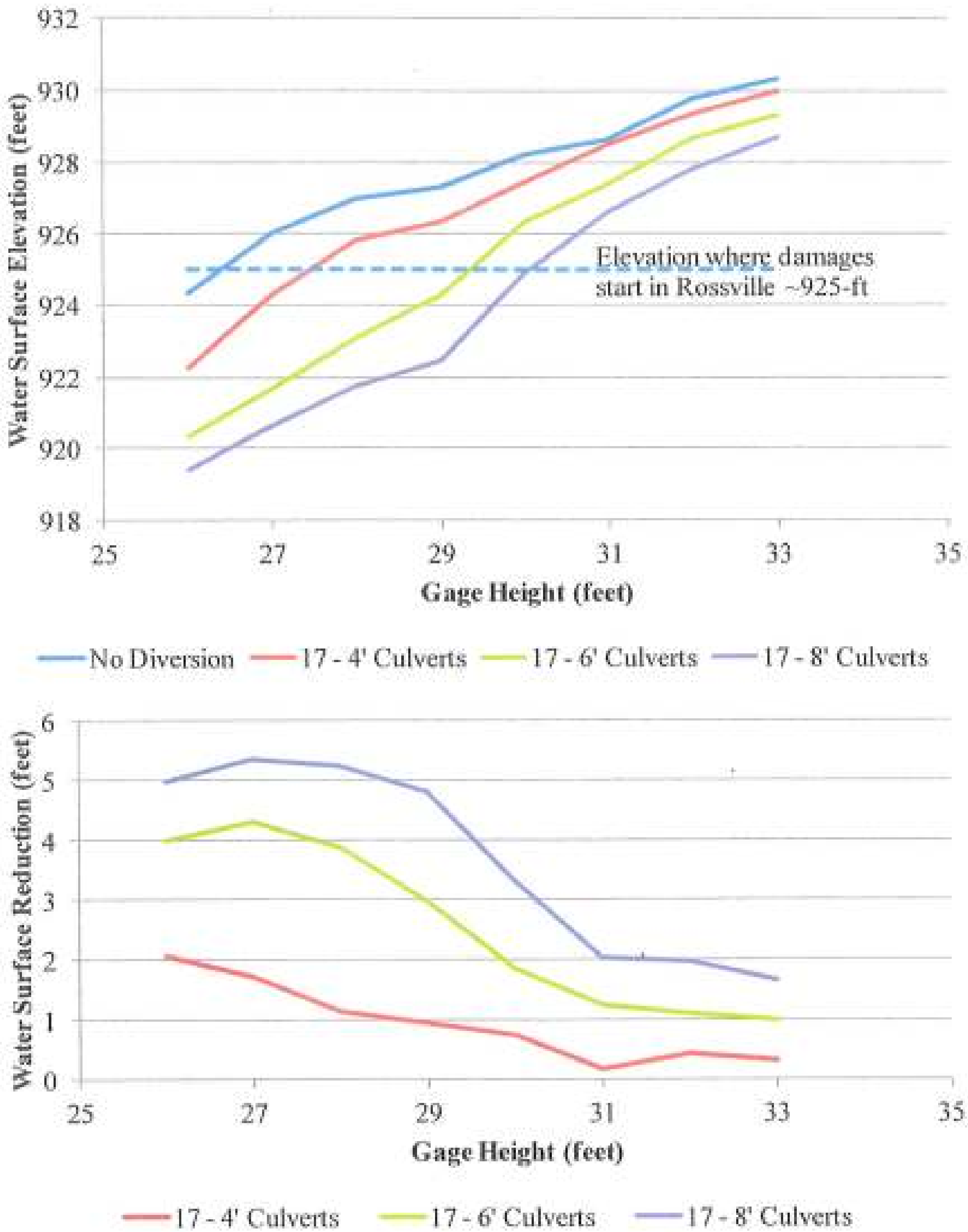

FIGURE 13: DIVERSION ANALYSIS WATER SURFACE ELEVATION COMPARISON ON CROSS CREEK AT RIVER STATION 12383

TABLE 6: RESULTS FROM CROSS CREEK DIVERSION ANALYSIS AT RIVER STATION 12383

Plan Description	Gage Height (ft)	Flow at the Gage (cfs)	W.S. Elev (ft)	Decrease in Stage (ft)
No Diversion	26	8000	924.36	
17 - 4' Culverts	26	6330	922.29	2.07
17 - 6' Culverts	26	5060	920.35	4.01
17 - 8' Culverts	26	4520	919.38	4.98
No Diversion	27	9760	926.00	
17 - 4' Culverts	27	7960	924.28	1.72
17 - 6' Culverts	27	5950	921.69	4.31
17 - 8' Culverts	27	5230	920.64	5.36
No Diversion	28	11440	926.96	
17 - 4' Culverts	28	9650	925.82	1.14
17 - 6' Culverts	28	7020	923.07	3.89
17 - 8' Culverts	28	5980	921.73	5.23
No Diversion	29	10970	927.29	
17 - 4' Culverts	29	10520	926.35	0.94
17 - 6' Culverts	29	8060	924.31	2.98
17 - 8' Culverts	29	6550	922.48	4.81
No Diversion	30	11790	928.21	
17 - 4' Culverts	30	11700	927.46	0.75
17 - 6' Culverts	30	10320	926.36	1.85
17 - 8' Culverts	30	8630	924.89	3.32
No Diversion	31	12160	928.67	
17 - 4' Culverts	31	13040	928.49	0.18
17 - 6' Culverts	31	11490	927.42	1.25
17 - 8' Culverts	31	10640	926.65	2.02
No Diversion	32	13830	929.83	
17 - 4' Culverts	32	14680	929.39	0.44
17 - 6' Culverts	32	13170	928.72	1.11
17 - 8' Culverts	32	11960	927.86	1.97
No Diversion	33	14770	930.34	
17 - 4' Culverts	33	15620	930.02	0.32
17 - 6' Culverts	33	14480	929.33	1.01
17 - 8' Culverts	33	13130	928.69	1.65

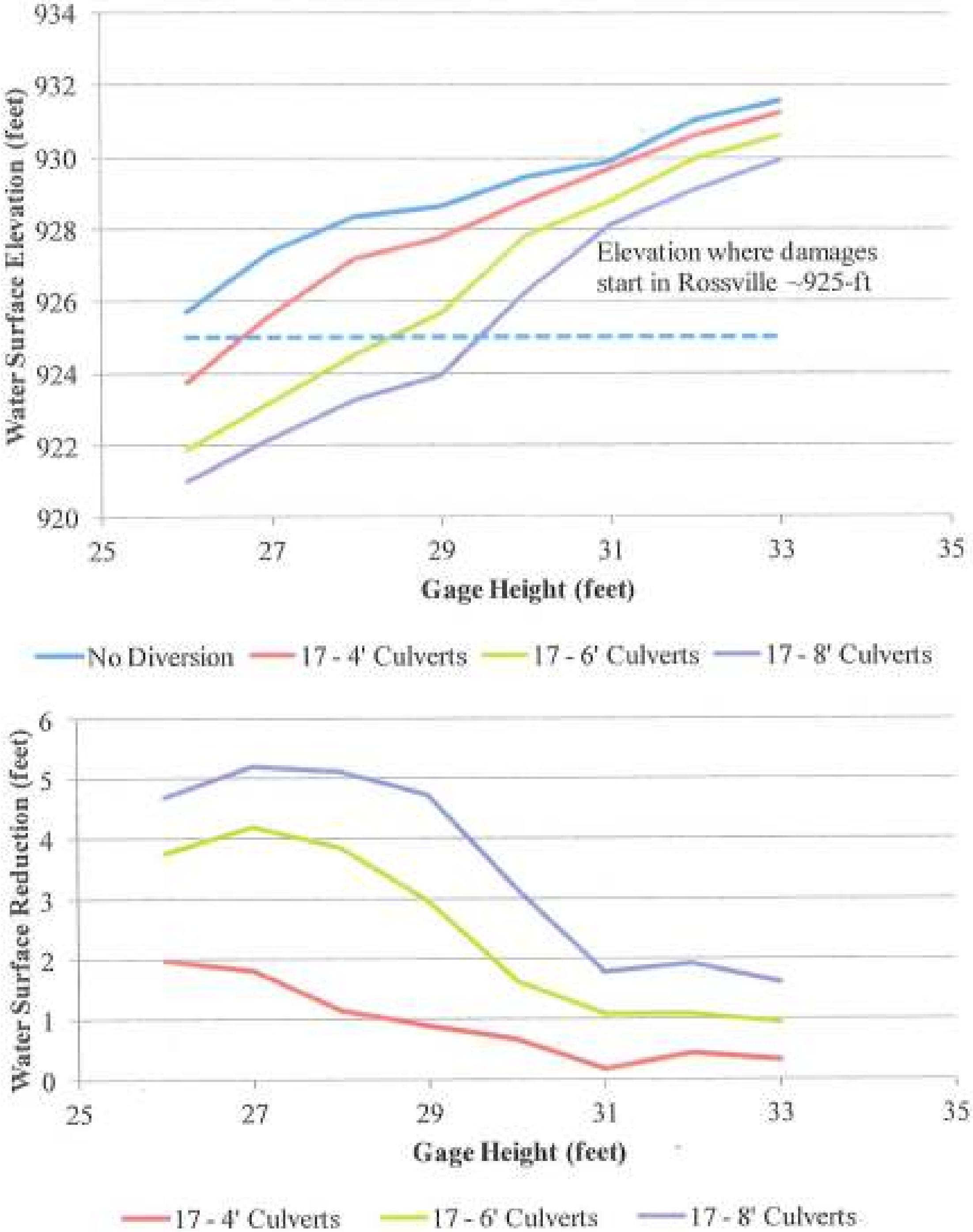

FIGURE 14: DIVERSION ANALYSIS WATER SURFACE ELEVATION COMPARISON ON CROSS CREEK AT RIVER STATION 14101

TABLE 7: RESULTS FROM CROSS CREEK DIVERSION ANALYSIS AT RIVER STATION 14101

Plan Description	Gage Height (ft)	Flow at the Gage (cfs)	W.S. Elev (ft)	Decrease in Stage (ft)
No Diversion	26	8000	925.69	
17 - 4' Culverts	26	6330	923.72	1.97
17 - 6' Culverts	26	5060	921.91	3.78
17 - 8' Culverts	26	4520	920.99	4.7
No Diversion	27	9760	927.40	
17 - 4' Culverts	27	7960	925.61	1.79
17 - 6' Culverts	27	5950	923.20	4.2
17 - 8' Culverts	27	5230	922.19	5.21
No Diversion	28	11440	928.36	
17 - 4' Culverts	28	9650	927.21	1.15
17 - 6' Culverts	28	7020	924.50	3.86
17 - 8' Culverts	28	5980	923.24	5.12
No Diversion	29	10970	928.65	
17 - 4' Culverts	29	10520	927.77	0.88
17 - 6' Culverts	29	8060	925.68	2.97
17 - 8' Culverts	29	6550	923.94	4.71
No Diversion	30	11790	929.45	
17 - 4' Culverts	30	11700	928.80	0.65
17 - 6' Culverts	30	10320	927.81	1.64
17 - 8' Culverts	30	8630	926.26	3.19
No Diversion	31	12160	929.88	
17 - 4' Culverts	31	13040	929.72	0.16
17 - 6' Culverts	31	11490	928.80	1.08
17 - 8' Culverts	31	10640	928.10	1.78
No Diversion	32	13830	931.05	
17 - 4' Culverts	32	14680	930.62	0.43
17 - 6' Culverts	32	13170	929.97	1.08
17 - 8' Culverts	32	11960	929.14	1.91
No Diversion	33	14770	931.55	
17 - 4' Culverts	33	15620	931.23	0.32
17 - 6' Culverts	33	14480	930.60	0.95
17 - 8' Culverts	33	13130	929.94	1.61

TABLE 8: RESULTS FROM DIVERSION ANALYSIS AT ENSIGN CREEK, RIVER STATION 8216

Plan Description	Gage Height (ft)	Ensign Flow (cfs)	W.S. Elev (ft)	Decrease in Stage (ft)
No Diversion	26	0	921.44	
17 - 4' Culverts	26	0	921.44	0
17 - 6' Culverts	26	0	921.44	0
17 - 8' Culverts	26	0	921.44	0
No Diversion	27	240	926.01	
17 - 4' Culverts	27	0	921.44	4.57
17 - 6' Culverts	27	0	921.44	4.57
17 - 8' Culverts	27	0	921.44	4.57
No Diversion	28	1560	927.33	
17 - 4' Culverts	28	30	925.25	2.08
17 - 6' Culverts	28	0	921.44	5.89
17 - 8' Culverts	28	0	921.44	5.89
No Diversion	29	3030	928.03	
17 - 4' Culverts	29	620	926.95	1.08
17 - 6' Culverts	29	0	921.44	6.59
17 - 8' Culverts	29	0	921.44	6.59
No Diversion	30	6210	929.01	
17 - 4' Culverts	30	3230	928.32	0.69
17 - 6' Culverts	30	900	926.90	2.11
17 - 8' Culverts	30	0	921.44	7.57
No Diversion	31	7840	929.37	
17 - 4' Culverts	31	5720	929.13	0.24
17 - 6' Culverts	31	3430	928.29	1.08
17 - 8' Culverts	31	1050	927.11	2.26
No Diversion	32	13170	930.31	
17 - 4' Culverts	32	9560	929.95	0.36
17 - 6' Culverts	32	6990	929.34	0.97
17 - 8' Culverts	32	4630	928.69	1.62
No Diversion	33	16230	930.76	
17 - 4' Culverts	33	12520	930.43	0.33
17 - 6' Culverts	33	9530	929.88	0.88
17 - 8' Culverts	33	7130	929.37	1.39

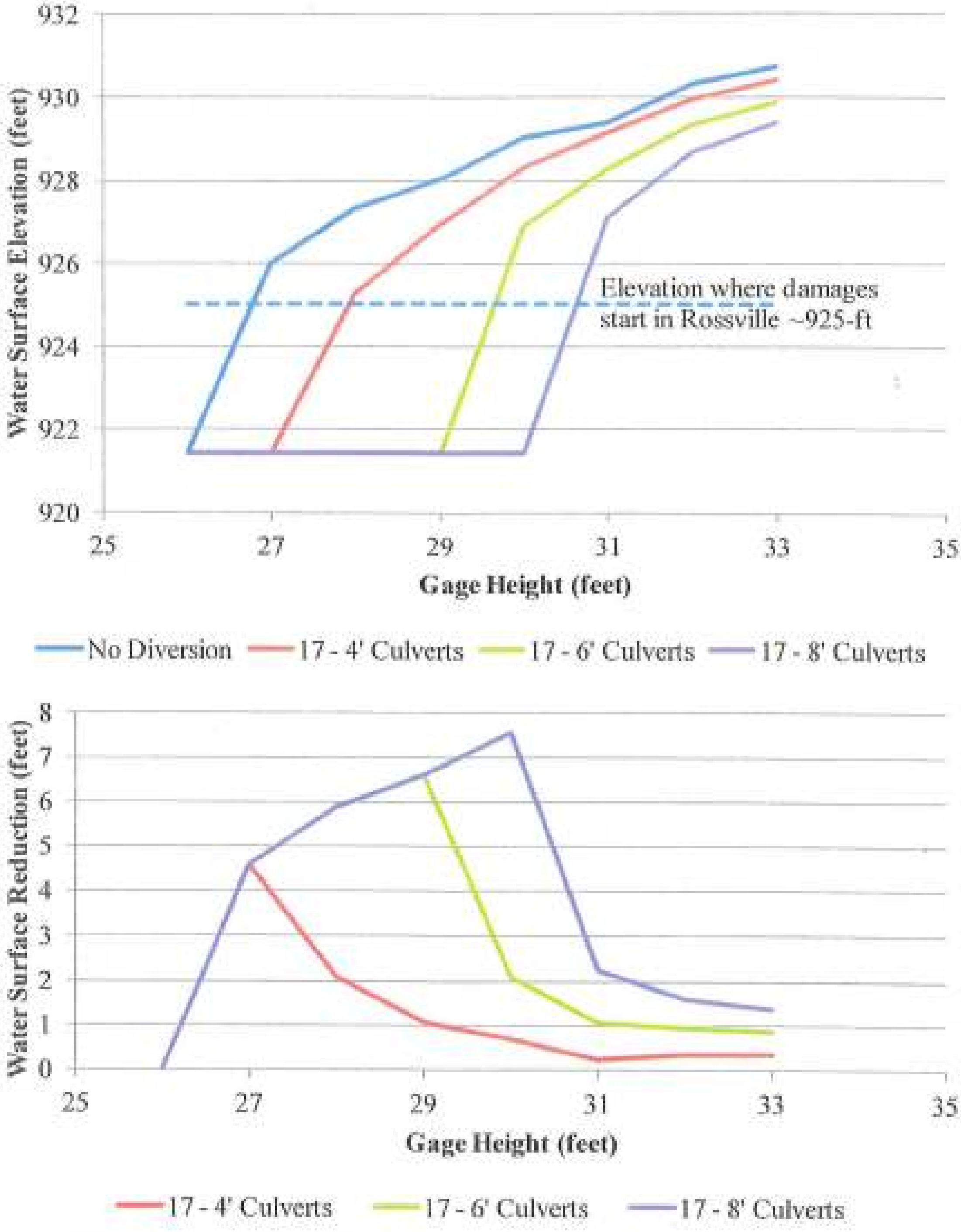

FIGURE 15: DIVERSION ANALYSIS WATER SURFACE ELEVATION COMPARISON ON ENSIGN CREEK AT RIVER STATION 8216

*Cross Section numbering for Cross Creek Diversion differs somewhat from other models. Closest correlated cross section was at river station 7742

4.2 Ensign Creek Diversion

A second diversion was evaluated through the Ensign Creek drainage, north and east of Rossville. This option eliminates the expense of the large gallery of culverts under Highway 24 and the railroad, but requires a channel on the order of 15,000 feet long on the northeast side of town to efficiently convey water past Rossville.

A single diversion configuration was modeled for Ensign Creek with an entrance invert set at 920 feet. The 200-foot wide channel modeled has the potential to lower water surface elevations at the Rossville gage on Cross Creek by approximately 2 to 3 feet for discharges where the existing condition stages are between 26 and 29 and by 1 to 2 feet between stages 30 and 33. Water surface elevations along the Ensign Creek side of town have the potential to be lowered by as much as 4 feet for some flows.

An Ensign Creek diversion would also increase the frequency of flooding on a larger area of agricultural lands along Ensign Creek downstream of Rossville and would require evaluation of potential impacts on the town of silver lake several miles downstream.

Table 9 shows the change in water surface elevation and flow discharge at specific cross sections along Cross and Ensign Creek for the simulated Ensign Cr. diversion.

TABLE 9: RESULTS FROM ENSIGN CREEK DIVERSION ANALYSIS AT CROSS CREEK RIVER STATION 12383

Plan Description	Gage Height (ft)	Ensign Flow (cfs)	W.S. Elev (ft)	Decrease in Stage (ft)
No Diversion	26	8000	924.25	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	26	5790	921.47	2.78
No Diversion	27	9760	925.91	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	27	6580	922.53	3.38
No Diversion	28	10440	926.47	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	28	7400	923.56	2.91
No Diversion	29	10970	926.98	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	29	8190	924.45	2.53
No Diversion	30	11790	927.74	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	30	9720	925.87	1.87
No Diversion	31	12160	928.05	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	31	10450	926.46	1.59
No Diversion	32	13830	929.09	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	32	12260	928.10	0.99
No Diversion	33	14770	929.47	
Ensign_Div_Plan_2_Chnl_Dsgn_Opt_3	33	13070	928.66	0.81

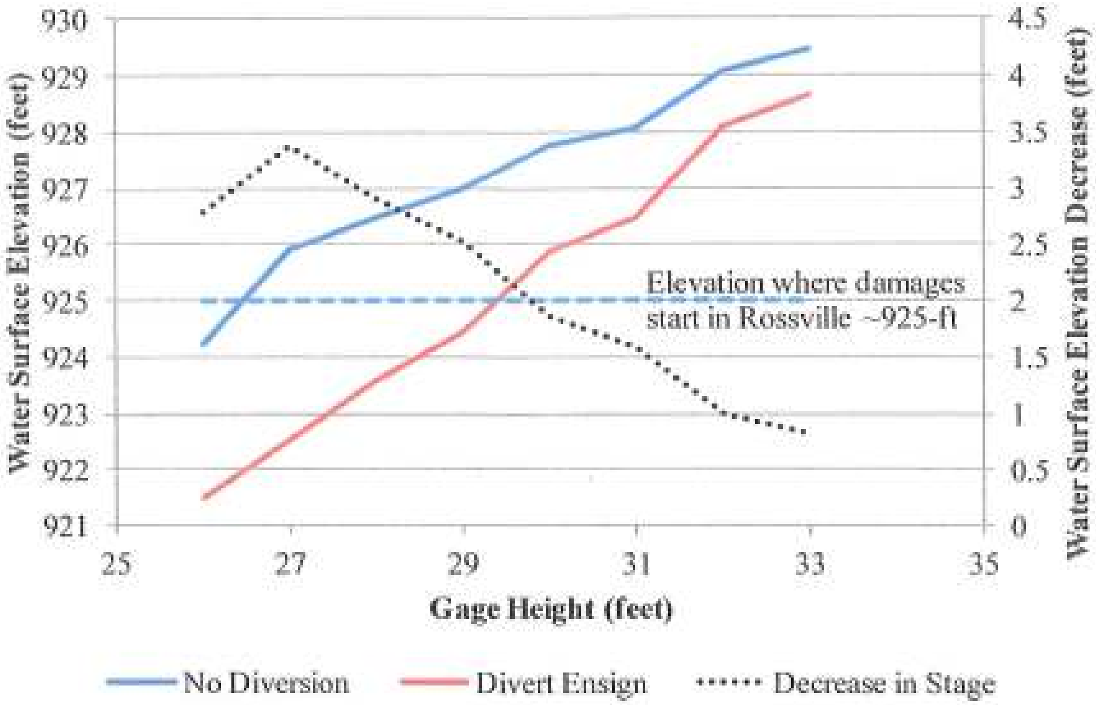

FIGURE 16: ENSIGN CREEK DIVERSION ANALYSIS AT CROSS CREEK RIVER STATION 12383

Note: The flood flows in Cross Creek downstream of the flow split that show greatest decrease in water surface are similar to those used in 2010 Section 205 study and in the 2011 Flood Insurance Study for flows in the 1/10 ACE (10 year) recurrence interval and more frequent. Due to the complex split flow relationship and the different methods used in previous studies it is not possible to make a direct correlation between the stage levels referenced in current model and specific recurrence intervals. A new hydrologic model is currently being developed to update the flow frequency discharges from Cross Creek and to better define the flow split between Cross and Ensign Creeks for various discharge floods.

5.0 Cost

Existing funding is not sufficient to perform detailed cost analysis on these channel options.

6.0 Conclusions

Creation of an artificial diversion channel upstream of the flow split does show potential to significantly lower flood levels in Rossville. Although less expensive than the levee and channel system proposed under the 1990 Feasibility Study, development of a diversion channel will still require major investment in design, and construction, as well as a thorough analysis of potential induced damages caused by the diverted flow.

This study confirms the conclusion of previous studies that improving conveyance through the

Highway 24 and railroad bridges is unlikely to reduce major flooding in Rossville. In addition, removal of obstructions such as the abandoned county bridges downstream of Highway 24 is also ineffective in reducing flood levels. The natural characteristics of the Cross Creek channel in addition to the tendency of Ensign Creek overflows to flood Rossville from the north make incremental measures such as removal of flow obstructions and improvement of bridges generally ineffective.

The flow split at cross creek is controlled by a combination of limited downstream conveyance and the elevation at which water can overflow into the Ensign Creek drainage. Once the water surface elevation reaches the overflow elevation the limited conveyance downstream on cross creek begins to limit increased flow in Cross Creek and pushes most of the additional discharge into the Ensign Creek drainage. The convergence of the 1/50, 1/100, and 1/500 annual chance exceedance (ACE) water surface elevations upstream of Highway 24, predicted by the 2011 Flood Insurance Study is confirmed in general. However, the magnitudes of flow remaining in Cross Creek below the diversion to Ensign Creek is not strictly limited to the 13,000 cubic feet per second (cfs) assumed in the FIS report.

A split flow analysis conducted under this study suggests that flows used in previous models upstream of the Cross Creek-Ensign Creek split are too low, although flows evaluated in Cross Creek below the flow split are reasonable. It is probable that runoff from the Cross Creek watershed is not regulated to the extent assumed by previous planning studies (see table 1). The split flow analysis modeled under this study gives a more complete picture of the relationships between total output from the Cross Creek Basin, magnitudes of flow split between Cross Creek and Ensign Creek and gage heights at the Rossville Gage. Unfortunately, recurrence intervals to those flows cannot be assigned due to lack of gage data above the flow split. Flow splits presented in this report are useful for evaluating diversion alternatives but cannot assign a precise level of protection associated with those alternatives.

Modeling conducted for this study and the associated Silver Jackets mapping project, and in partnership with the National Weather Service, has made possible the development of flood forecast inundation maps now available for viewing on the National Weather Service's Advanced Hydrologic Prediction Service (AHPS) web page. These maps serve as a valuable tool for communicating flood risk for planning purposes as well as communication of the probable extent of flooding on a real-time basis, based on National Weather Service forecasts at the Rossville Gage.

7.0 Recommendations

Three major floods between 1982 and 2005 call into question the conclusion of previous studies that the Soil Conversation Service Dams in the Cross Creek Watershed will prevent damages to buildings in Rossville from flood events in the range of 25- to 50-year frequency upstream (north) and 50-year frequency downstream (south) of the railroad bridge. Although it is possible for three 25-year or larger storms to occur in less than a 35 year period, results of the Split flow modeling conducted for this study also indicates that previous hydrologic studies have overestimated effectiveness of these dams in regulating the Cross Creek watershed and have underestimated the magnitude of flow diverted to Ensign Creek. The split flow analyses modeled for this study allow for better estimates of total inflow to Rossville and the proportions of flow split between Cross Creek and Ensign Creek with relation to stream stages at the Rossville gage, but they do not allow for analysis of the recurrence intervals of these flows. A hydrologic model needs to be developed for the Cross Creek basin to evaluate the existing level of regulation provided by the existing watershed dams and to quantify return period of various flood stages on Cross and Ensign Creeks. Cost estimates should be developed for the two diversion options in order to evaluate feasibility of a future project.

8.0 References

1. U.S. Army Corps of Engineers. (1990). *Section 205 Feasibility Study Rossville, Kansas; Cross Creek.* Kansas City, MO: U.S. Army Corps of Engineers Kansas City District.

2. U.S. Army Corps of Engineers, Kansas City District and CDM. (2010). *Cross Creek Section 205 Study Rossville, Kansas.* Kansas City, MO: U.S. Army Corps of Engineers Kansas City District.

3. Federal Emergency Management Agency (2011). *Flood Insurance Study – Shawnee County, Kansas.* Washington, D.C.: Federal Emergency Management Agency.

9.0 Appendices

Appendix 1 Hydraulic Modeling Report, Rossville, KS Flood Inundation Maps

Appendix 2 Rossville, KS, Flood Control Evaluations, 2 Dimensional Model Development and Preliminary Results, Sep 2012 – Feb 2013