Flood Mitigation Study
Zumbro River Watershed, Minnesota
Final Report

Stephen J. Druschel, Ph.D., P.E.
Minnesota State University, Mankato
Water Resources Center

With

Sarah L. Green, E.I.T.

And The Students of CIVE 402 Spring 2012
Michael Reimers, Project Manager
Nicholas Engel
Mitch Hatcher
Jacob Hovick
Jacob Michalowski
Cecilio Santana
Anthony Sellner
Shelby Sovell
Joshua Stier
Daniel Swanson
Anup Thapa

December 31, 2013

Table of Contents

Executive Summary

Flood mitigation of the Zumbro River was studied by students and faculty of Minnesota State University, Mankato, in response to effects of the September 2010 flood event. A topographic surface model of the watershed was built using State of Minnesota remote sensing data obtained for four counties for approximately 150 river miles. A hydraulic corridor was defined for the river by cutting river cross sections at 2765 locations. Bridges and other river crossings were field measured and river geometry verified. Rainfall events and storm water runoff were incorporated into the hydraulic model as inflow, developed from a review of Doppler radar observations, probabilistic characterization of precipitation, and a probabilistic river flow database.

Anecdotal measurements of flood levels and timings were recorded via public outreach and commentary as well as public records. A river flow model was created using the widely-accepted US Army Corps of Engineers software HEC-RAS, which allows prediction of flood levels depending upon rainfall and runoff conditions. However, calibration of the model was not accomplished at this time due to limitations of time and budget after receiving the public input.

Six public meetings were used to explore flood mitigation strategies and specific measures of: (1) infiltration and impoundments; (2) walls and levee structures; (3) do nothing and accept the risk; and (4) relocation and repurposing land.

The river flow model is made freely available to both government agencies and non-governmental organizations as well as the Zumbro watershed citizenry to help the people of the Zumbro watershed consider responses to past flood events and build protection from future flood events

1.0 Introduction

During the 2010-2011 academic year, Dr. Steve Druschel and his students in the Civil Engineering program at Minnesota State University, Mankato (Minnesota State), completed a capstone project that evaluated a portion of the Zumbro River Watershed devastated by a massive fall flood in 2010. Dr. Druschel's group worked closely with local partners, and given the quality of work provided, those partners (now known as Zumbro and Friends) contacted Dr. Shannon Fisher in December 2011 to discuss a collaboration of efforts.

As a result of ongoing discussions, the Zumbro and Friends coalition hosted a public informational session on March 18, 2012 to discuss Zumbro River flood mitigation and revitalization. The meeting was well attended and included several area legislators, local elected officials, civic leaders, flood-impacted property owners, clergy, and other concerned citizens. The session generated a terrific discussion about the need to model flood behaviors in the Zumbro Watershed - with the intended outcome to provide a deliverable that will help assess the strategies to ameliorate flood damages. As a result of this meeting, an LCCMR grant proposal was submitted by the local collaborators. The proposal requested significant funding and was ultimately rejected. During the following months a team of local leaders and university staff maintained communication with legislators. As a result, the funding for this grant agreement ($50,000) was provided through Minnesota Session Laws, 2012, Regular Session, chapter 292, article 4, section 15, to prepare a report identifying potential flood mitigation measures and projects within the Zumbro watershed.

A grant agreement was executed on September 24, 2012, between the State of Minnesota and the Minnesota State University, Mankato (Water Resources Center). Subcontractors on the grant include the Department of Mechanical and Civil Engineering, Zumbro and Friends, and the Zumbro Watershed Partnership. This report is the final deliverable to fulfill the grant agreement.

Table 1 presents a list of the Minnesota State Civil Engineering students that have contributed to the analyses presented in this report.

Table 1. Minnesota State Civil Engineering student contributors.

Student (Year of Graduation)	Senior Capstone 2011-12	Topographic Base Development	Bridge and Constriction Measurement	Rainfall History	Hydraulic Modeling	Public Meeting Involvement and Support
Sarah Green (2013)		X	X	X	X	X
Steven Muir (2013)			X			
Brandon Newberger (2013)			X			
Ryan Johnson (2013)			X			
Meghann Chiodo						X
Anthony Adderley			X			X
Frances Adimoraegbu				X		X
Becca Welch			X	X		X
Holly Mauch			X	X		X
Isabelle Race						X
Shauna McIntyre			X			X
Alex Fiebiger			X			X
Eric Hanninen (2010)					X	
Michael Reimers (2012)	X					
Nicholas Engel (2012)	X					
Mitch Hatcher (2012)	X					
Jacob Hovick (2012)	X					
Jacob Michalowski (2012)	X					
Cecilio Santana (2012)	X					
Anthony Sellner (2012)	X					
Shelby Sovell (2012)	X					
Joshua Stier (2012)	X				X	
Daniel Swanson (2012)	X					
Anup Thapa (2012)	X					

Notes: Team leaders included: Michael Reimers, Sarah Green and Joshua Stier. Senior capstone 2011-12 work was done for academic credit; other involvement was paid research assistance while matriculating at Minnesota State. Sarah Green was funded as a project subcontractor during the summer of 2013. Eric Hanninen, Sarah Green and Joshua Stier also volunteered their time as alumni.

2.0 Background

2.1 The Zumbro River Watershed

Quoting the Zumbro Watershed Partnership (http://www.zumbrowatershed.org/ourwatershed):

> *"The Zumbro Watershed encompasses more than 900,000 acres (or ~1,422 square miles) of agricultural and urban lands that drain into the three forks of the Zumbro River before joining the Mississippi River at Kellogg, MN. The watershed contains more than 288 miles of rivers and streams, including 57 miles of high-quality trout streams, a smallmouth bass fishery, and a designated canoe trail. The watershed covers parts of six counties - Dodge, Goodhue, Rice, Olmsted, Steele, and Wabasha - and 22 municipalities, including the growing City of Rochester.*
>
> *"The Zumbro Watershed is home to bald eagles, great blue herons, beavers, river otters, coyotes, smallmouth bass, brook trout and more than 150,000 people who live, work, and play within its boundary. The Zumbro Watershed is known for its diversity of landscape, ranging from deep fertile glacial-tills, to steep sandy soils of the bluffs. Portions of the Zumbro Watershed are included in what is called the "driftless area," the area was by-passed by the last continental glacier that has differential weathering and erosion that results in a steep, rugged landscape referred to as karst topography."*

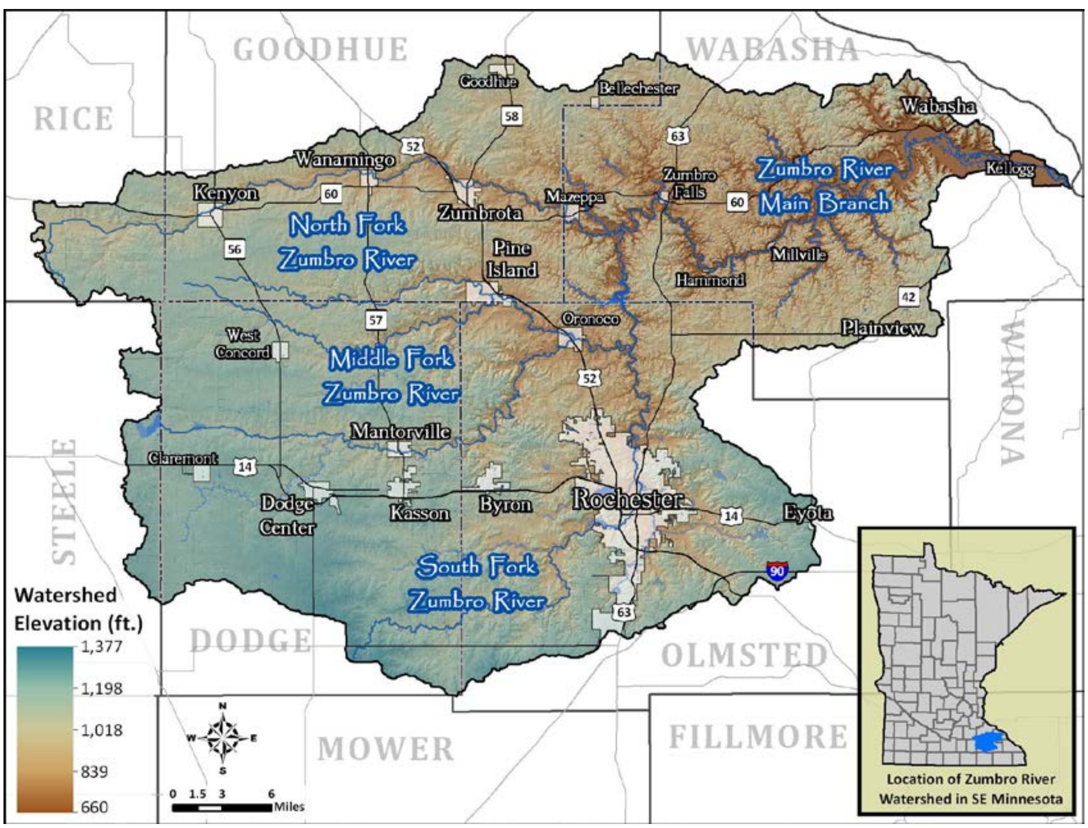

Figure 1. The Zumbro Watershed. Map courtesy of the Zumbro Watershed Partnership.

2.2 Conditions Leading to the 2010 Floods

Quoting U.S Geological Survey Scientific Investigations Report 2011-5045, Floods of September 2010 in Southern Minnesota (references omitted) (Ellison, et al, 2011):

> *"The September 2010 flooding in southern Minnesota was caused by heavy rainfall on areas that had already received above-normal precipitation. An exceptionally wet summer preceded the September flooding. Large seasonal rainfall totals were primarily the result of a wet June and heavy downpours in August. Summer rainfall totals as high as 20 in. were reported in southern Minnesota, exceeding the historical average by more than 4 in. Preliminary analysis of rainfall totals indicated that September was the wettest September in Minnesota's modern climate record that extends back to 1891.*
>
> *"The largest contribution to the new state-wide record came from southern Minnesota where monthly totals as high as 10 in. were common. During September 22-24, heavy rain developed over southern Minnesota, helped in part by deep tropical-origin moisture from former tropical cyclones. Moisture from the remnants of tropical storm Georgette in the eastern Pacific Ocean and Hurricane Karl in the Gulf of Mexico moved northward into the region and enhanced rainfall rates over southern Minnesota.*
>
> *"This moisture, along with instability, was brought northward by low pressure in the central Plains. The first low pressure on September 22 developed in Kansas and moved into northwest Iowa, uplifting the first surge of moist and unstable air across the area. Widespread heavy-rain producing storms developed and moved steadily from west to east over southern Minnesota, in an axis north of the surface warm front. A second low pressure system lifted northward into Minnesota on September 23, providing an even larger tropical moisture surge, which resulted in sustained heavy rainfall in southern Minnesota. The City of Amboy in Blue Earth County received 10.68 in. of rain between September 22 and 24, and Zumbro Falls in Wabasha County received 8.50 in. of rain in the same period.*
>
> *"The 100-year (annual exceedance probability of 0.01, or 1 percent) 72-hour rainfall for southern Minnesota is about 7 in."*

2.3 Impacts of the 2010 Floods

Impacts varied by location within the watershed. Upland areas reported deep mud and agricultural equipment stuck, but river valleys took the worst of the damage. Quoting from selected articles of the Rochester Post Bulletin (selected punctuation added for clarification within report format):

> ***Cities grapple with flooding.*** *Jeff Hansel and Christina Killion Valdez | Posted: Thursday, September 23, 2010 7:58 pm*
>
> *"Heavy rain Wednesday and Thursday flooded communities throughout southeastern Minnesota, although it appears that Dodge and Goodhue counties were hit the hardest. [In] Goodhue County, Zumbro Falls has lost phone service, and all 180 residents were evacuated, according to a dispatcher with the Wabasha County Sheriff's Office. The*

telephone office is on Main Street, and the phone company is trying to get a boat in to make repairs. City officials could not be reached. Pine Island had extensive flooding in low-lying areas, Mayor Paul Perry this morning. 'We had them just pull the power and lock the doors and leave,' Perry said. His own house was among those affected. About 25 to 30 people are at an emergency shelter. Firefighters and sheriff's deputies are making the rounds."

Some wonder if they should just walk away. *Jeffrey Pieters | Posted: Sunday, September 26, 2010 10:34 pm*

"Substantial flood damage could cost small towns Zumbro Falls and Hammond many of their residents. Both cities lost an estimated two-thirds of their housing stock in the flood. It remains to be seen how many will rebuild and how many will move away. 'I hope we survive,' said Zumbro Falls Mayor Al VanDeWalker.

"While some Hammond residents said they will move away, Mayor Judy Radke said most 'have been here all their lives, and they're going to stay here.' Speaking for herself, it's 'going to be a decision whether we stay or leave.' Radke's home was among the most severely flooded. Jason Radke, her husband and head of the city's water system, said the manufactured home was installed five years ago and set on blocks 8 1/2 feet high to comply with flood regulations. On Friday, the water was 4 feet deep in their first floor. 'By the time we quit (sandbagging), I went in and grabbed an overnight bag,' Jason Radke said. 'I was up to my chest in water.'

"The average floodwater level in affected homes was 5 feet at the ground floor, according to Doug Neville, spokesman for the state's emergency operations center.

"In Zumbro Falls, Roger Luhmann, a 52-year-old, lifelong resident, lost his manufactured home, which was carried off its foundation and cracked against a tree. He saved some power tools, tractors and antique Model-T cars, but the rest of his possessions are lost. 'I was trying to move stuff, but I just never got it all out,' Luhmann said. By the time he gave up the fight, 'I was waist-deep in it, and it (the current) was strong.' 'I've seen floods,' Luhmann said, 'but nothing like this.' Sixty of the 90 houses in Zumbro Falls were flooded at an average level of 6 feet.

"Dallas and Vicki Williams of Hammond lost a home and a piece of history — an 1881 structure originally built as the Stagecoach Hotel. 'It's got quite a history,' Vicki Williams said, 'and we were hoping it might make it.' When the water started rising through their backyard on Thursday night, they were not alarmed, she said. But by 2 a.m., the water shot over the riverbanks, and 'I've never seen that before,' she said. Members of the Elgin Fire Department helped sandbag their yard, but it was futile. The house wound up taking water up to nearly the bottom of the second floor.

"Hammond has no flood-protection system, but Zumbro Falls added a 2-mile-long, 28-foot-tall levy to protect it in the aftermath of a 1965 flood that reached 28 feet, VanDeWalker said. On Friday, volunteers piled sandbags two layers high on top of the levy. 'All of a sudden, it just went,' the mayor said. Residents and business owners put

> *valued items on top of tables, desks and chairs. The water swept over all of those and even washed some toxic chemicals into the streets."*

The City of Rochester, while not receiving the largest rainfall amounts, also remained safe due to a flood protection system.

> ***Rochester reservoirs had room to spare.*** *Jeffrey Pieters | Posted: Tuesday, September 28, 2010 5:44 pm*
>
> *"Water elevations in at least five of Rochester's seven flood-control reservoirs spiked dramatically last week, but the reservoirs still had plenty of room to spare. Data from the city's Public Works Department tells the story: Peak elevations 5 to 10 feet higher than normal at the reservoirs at Chester Woods Park, on Willow Creek, near the Maine Street commercial development, on Silver Creek and east of the Kalmar Landfill. Metering equipment at another reservoir, south of the landfill, was out of service last week. A normally dry reservoir, near the Hathaway brush dump, registered no water.*
>
> *The reservoirs measured still had 4 to 10 feet of elevation remaining before water would have been gradually released through an emergency spillway. There has never been a flood event high enough to do that. The reservoirs are designed to protect Rochester against flooding from storms with a statistical probability of happening only once every 500 years. They can hold back 24 inches of rain over a 24-hour period without over-topping."*

People want protection, but also want the Zumbro to remain a viable and healthy ecosystem as it is a main reason the towns exist in the first place. Figures 2 through 6 provide views of the flood conditions and aftermath.

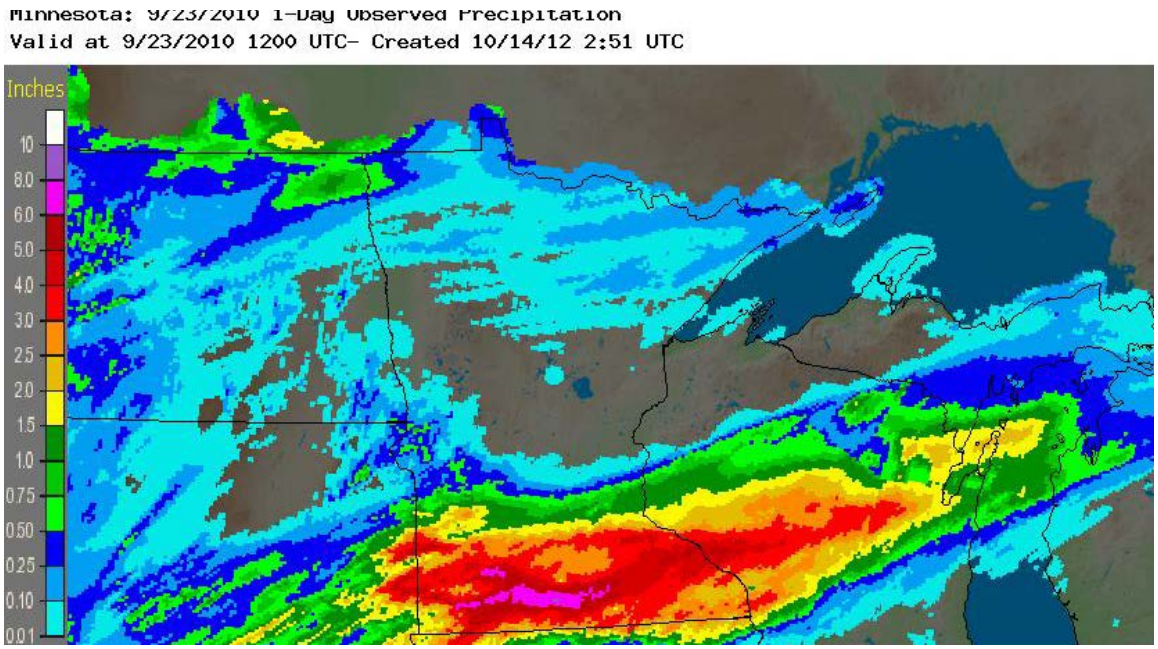

Figure 2. NOAA Doppler radar rainfall record.

Figure 3. Flooding in the downtown area of Pine Island, Minnesota. Photo courtesy of Abraham Algedi.

Figure 4. Flooding in the downtown area of Zumbro Falls, Minnesota. Photo courtesy of Chad Hofschulte.

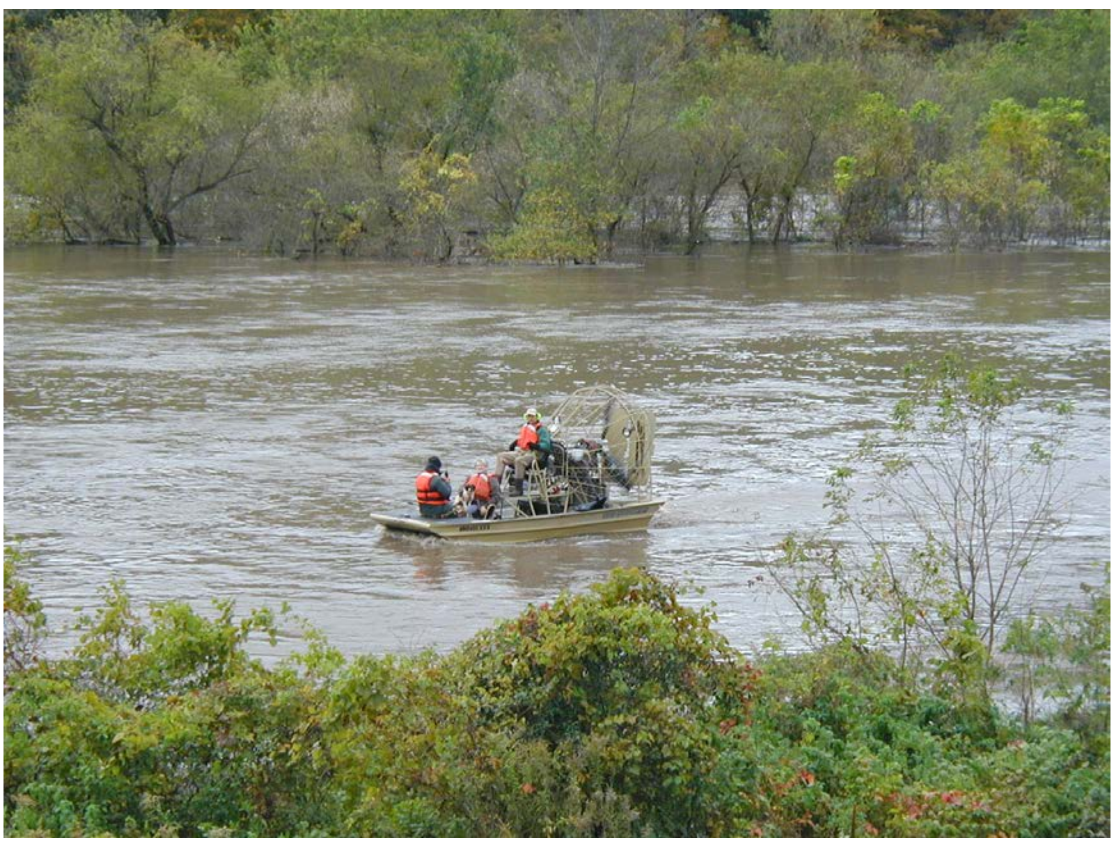

Figure 5. Evacuation by airboat, Hammond, Minnesota. Photo courtesy of Janice Domke & Chad Hofschulte.

Figure 6. Houses condemned due to flood damage and being removed, Zumbro Falls, Minnesota. Photo courtesy of Janice Domke.

3.0 Analyses

The normal and flood levels of the Zumbro River were analyzed using a computer model created using the US Army Corp of Engineers Hydraulic Engineering Center – River Analysis System (HEC-RAS) software.

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and channels. The software was developed by the United States Army Corps of Engineers to manage rivers, harbors, and other public works. The program is one-dimensional, which means that there is no modeling of the hydraulic effect of bends or other two or three-dimensional aspects of flow. The computation procedures for steady flow are based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction/expansion. It is possible to use the software to model subcritical, supercritical, and mixed flow regime flow along with the effects of bridges, culverts, weirs, and ineffective flow areas.

3.1 Topographic Base Construction

The topographic base model of the river corridor was created using Graphic Information System (GIS) using the Arc-GIS extension HEC-GeoRAS. ArcGIS (Esri, Redlands, CA) is a proprietary geographic information system for working with maps and geographic information. The software is used for creating and using maps, compiling geographic data, analyzing mapped information, and managing geographic information in a database. HEC-GeoRAS is a GIS extension developed by the US Army Corp of Engineers Hydraulic Engineering Center that provides a set of procedures, tools, and utilities for both the preparation of GIS data for import into HEC-RAS and generation of GIS data from HEC-RAS output.

The topographic data sets loaded into the GIS programs were LiDAR ("Light Detection and Ranging"), an active remote sensing technology that uses laser light to detect and measure surface features on the earth. LiDAR is high resolution digital elevation data that provides a 1 meter grid of vertical elevation points with an accuracy of 10 centimeters. The GIS and LiDAR data used for the project were obtained from the Minnesota Geospatial Information Office website. LiDAR data used for the project consisted of datasets for each individual county (Dodge, Olmsted, Wabasha and Goodhue) within the watershed, which were then matched together.

HydroCAD is a computer aided design tool used by civil engineers for modeling storm water runoff. HydroCAD provides a wide range of commonly used drainage calculations including SCS and NRCS runoff hydrographs, rational method with IDF curves, hydrograph routing through ponds and reaches, and hydraulics and culvert calculation.

3.2 Hydraulic Corridor Definition

The topographic base geometry was imported into the HEC-RAS software as a series of cross sections. Creating an adequate number of cross- sections to produce a good representation of the channel bed and floodplain is critical; 2765 cross sections were made for the Zumbro River model. Aerial photographs and contour information were used to lay out the cross section cut lines. Guidelines that were followed when creating the cross sections include:

1. Cross-sections are one of the key inputs to HEC-RAS.

    - Cut lines should be perpendicular to the direction of flow;
    - Cross-sections should span over the entire flood plain to be modeled;
    - Cross-sections should be placed at points that represent average geometry of the stream reach and at changes in geometry, slope, channel, overbank roughness, and discharge;
    - Cross-sections should be spaced evenly where possible;
    - Cross-sections should be spaced approximately 500-1000 ft. apart in areas of less concern; and,
    - Cross-sections should be spaced approximately 50-300 ft. apart in areas of interest, the vicinity of structures and any abrupt changes in channel geometry.

2. HEC-RAS requires four cross sections to be entered to define each hydraulic structure. The four cross sections include:

    - A downstream cross section where flow is fully expanded;
    - A cross section at the downstream face of the structure;
    - A cross section at the upstream face of the structure; and,
    - A upstream cross section before flow contraction.

Once cross sections were imported into HEC-RAS, they were checked and any necessary adjustments made to the thalweg, river edge, and flood plain of the model to give an accurate representation of the Middle Fork Zumbro River.

Approximately 150 river miles were placed into the hydraulic model, organized into 22 river sections and 28 river reaches (HEC-RAS denotations) (Figure 7).

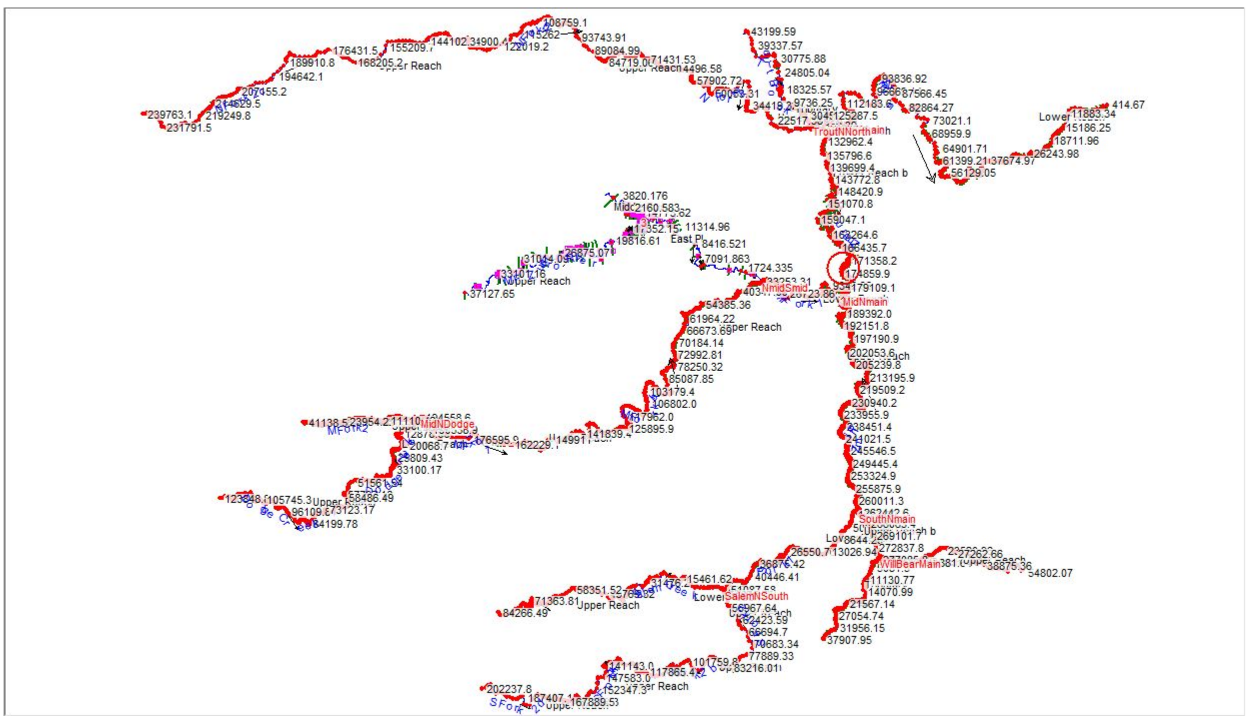

Figure 7. HEC-RAS model of the Zumbro River with selected cross section notation.

3.3 Constriction and Ineffective Flow Area Characterization

River flow can be impeded by constrictions such as caused by permanent features including bridges or culverts or by transitory features such as sand bars or tree snags. These constrictions can cause "ineffective flow areas", i.e., zones that appear on a HEC-RAS cross section as providing flow but which are actually unable to flow due to the constriction or impediment. These are important features to identify and incorporate into a HEC-RAS to obtain an accurate hydraulic model.

To evaluate ineffective flow areas and characterize river constrictions, the Minnesota State team went into the watershed on March 2, 2013. Bridges previously uncharacterized were physically measured:

- North Fork: 12 bridges;
- South Branch of the Middle Fork: 15 bridges; and,
- South Fork and Main Branch: 45 bridges.

The field notes and photographs of these bridges are included as Appendix A. These results also provided an opportunity for verification of the thalweg, river edge and flood plain characteristics in the areas up and downstream of the measured bridges.

3.4 Rainfall Event and Storm Water Runoff Evaluation

Rainfall events and storm water runoff are incorporated into the hydraulic model as inflow. Three methods were used to characterize potential inflow amounts.

First, a review of Doppler radar observed precipitation for the years 2005 to 2012 was obtained through the National Oceanic and Atmospheric Administration (NOAA) at their website: http://www.crh.noaa.gov/ncrfc/content/weather/precipitation/observed_precip.php. This approach uses the National Multisensor Precipitation Analysis creating precipitation records from an integration of multiple radar sensor signals. Maps representing monthly calculated precipitation records for 2005 to 2012 are included as Appendix B. These maps provide a graphical representation of significant precipitation events by which to evaluate public comments and expressions of past high water events to help understand inflow amounts, in particular those inflows related to the September 2010 flood event.

Second, probabilistic characterization of precipitation events by frequency of occurrence was obtained from the NOAA Atlas 14. This information was obtained for the watershed using the online mapper function at: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=mn . Results are included as Appendix C. Precipitation frequency data aid the discussion by providing a probability of occurrence for given levels of rainfall or other precipitation, and can be keyed to actual rainfall events experienced.

Third, modeled flow levels for streams and river reaches, a function of both precipitation received and runoff proportion (rather than infiltration or evaporation) were obtained for

Minnesota from the USGS website http://water.usgs.gov/osw/streamstats/minnesota.html . As stated on the website:

> *"Minnesota StreamStats incorporates regression equations for estimating instantaneous peak flows with annual exceedance probabilities of 66.7, 50, 20, 10, 4, 2, 1, and 0.002 percent. These peak flows have recurrence intervals of 1.5, 2, 5, 10, 25, 50, 100, and 500 years, respectively. The report below documents the regression equations available in StreamStats for Minnesota, the methods used to develop the equations and to measure the basin characteristics used in the equations, and the errors associated with the estimates obtained from the equations. This report describes the development of a region-of-influence method for estimating peak flows as well as the development of regression equations. StreamStats has not implemented the region-of-influence method. Users should familiarize themselves with the report before using StreamStats to obtain estimates of peak flows for ungaged sites."*

The Minnesota StreamStats data were the flows used in the hydraulic model of this effort, imported into HEC-RAS. A summary of the StreamStats flows are included as Appendix D.

3.5 River Hydraulic Model Calibration

To calibrate a river hydraulic model is to adjust the river frictional characteristics and the land runoff parameters such that the input from an actual storm event produces a model results that matches the actual behavior of the river. A calibrated model can be read by elevation, not just height. The general procedure to be used to calibrate and tune the model is outlined below.

- The river flow profile should be exported into HEC-RAS software;
- Calibrations should be made from known water surface elevations and flow rates by adjusting Manning's n value;
- Proposed mitigations and reduced flow profiles should be identified and drawn;
- Analysis should be run of proposed mitigations, if any;
- HEC-RAS results should be exported into ArcGIS; and,
- RAS Mapper should be used to show flood inundation for required flow events.

The most critical parameters to be evaluated include rainfall intensity and duration, soil moisture, infiltration rate, surface cover, sub-watershed hydrograph, watershed hydrograph, water depth, water velocity and water flow. In the end, water level is the summative parameter that is the result of interest to the watershed municipal officials. Assuming the data are sufficient, the model can assess water levels determined and calibrated to the 0.1 foot level. However, rainfall-flooding impact correlations are rarely straight forwards, as there will always be areas within the watershed missed by rain, even during a flood-causing event. Therefore, the model should be rerun at the time of a severe rain event with existing rainfall to determine actual flood level predictions, not just generic levels.

Calibration of the Zumbro River hydraulic model was not done on this project, due to limitations of schedule and budget. If the model is to be used for decision-making purposes, more than just informational, calibration must be done.

To aid in calibration when the time and effort are available, Minnesota State participated in a public meeting hosted by Zumbro & Friends in Pine Island on October 25, 2012. Selected people impacted by the September, 2010 flood were interviewed in open session, then attendees were encouraged to make notes about their experiences and concerns with Zumbro River flooding. Post cards were distributed to be filled out by people not at the public meeting. Emphasis was placed on high water experiences and timings, to provide anecdotal information of flood peaks throughout the watershed. A record of the comments and observations made by the attendees is included as Appendix E.

4.0 Evaluation

Hydraulic model results, uncalibrated as to actual elevation but still useful to see the relative amount of change in response to different flow recurrence intervals. Selected results of the hydraulic model are shown graphically by river reach as cross sections here; the full model is available by request (email to Stephen.Druschel@mnsu.edu). Note: scales vary between figures.

4.1 South Fork

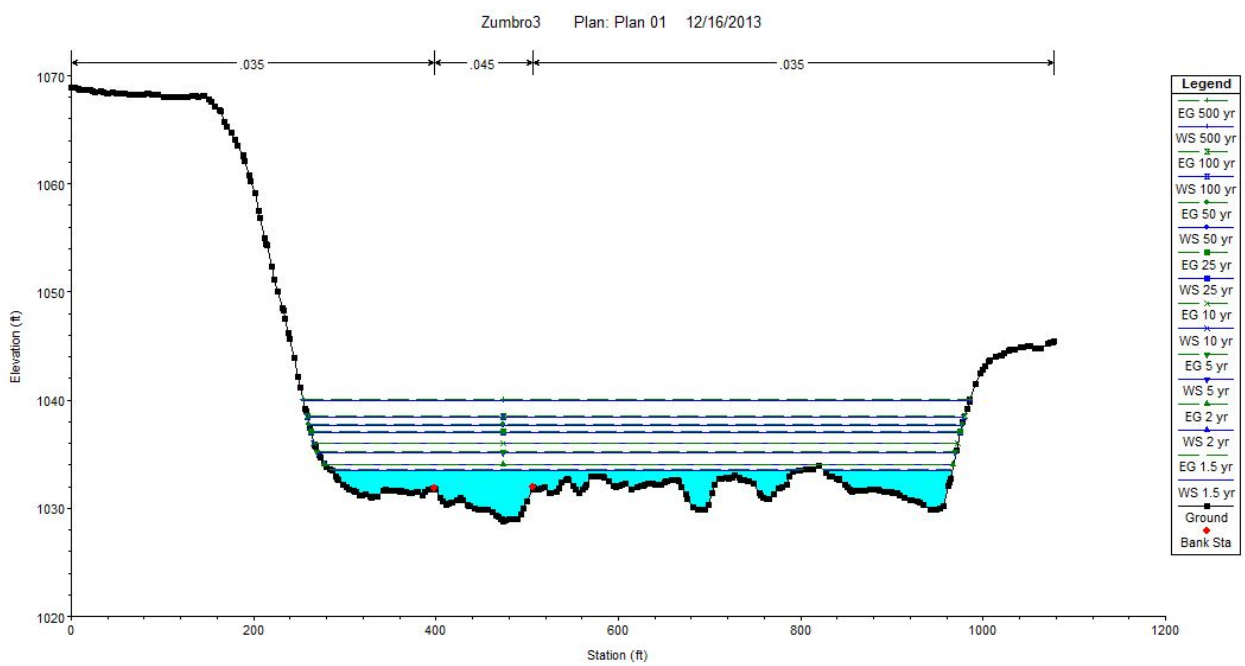

Figure 8. Zumbro River HEC-RAS cross section downstream of Salem Creek.

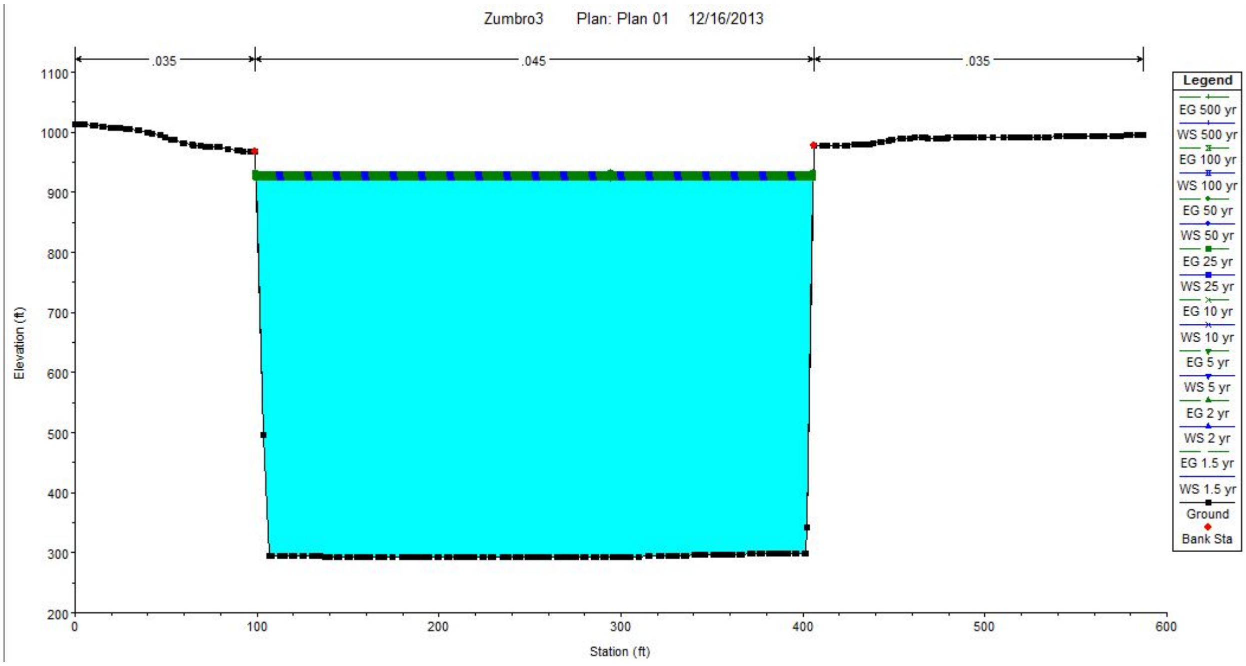

Figure 9. Zumbro River HEC-RAS cross section north of Rochester.

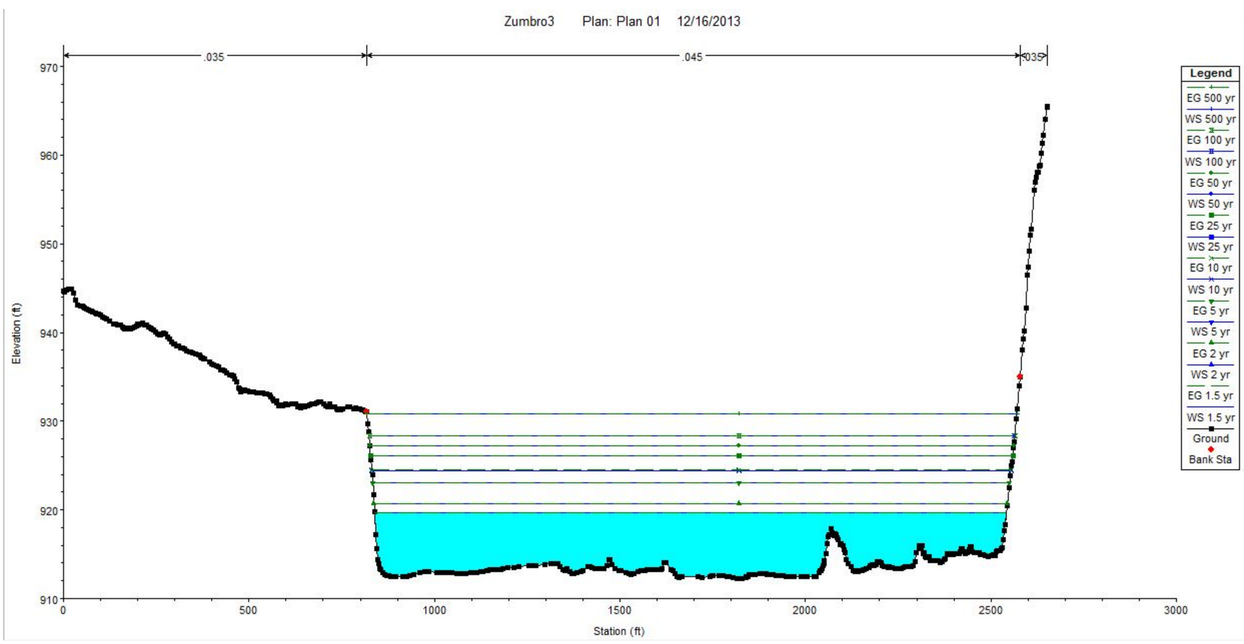

Figure 10. Zumbro River HEC-RAS cross section at Zumbro Lake.

4.2 Middle Fork South Branch

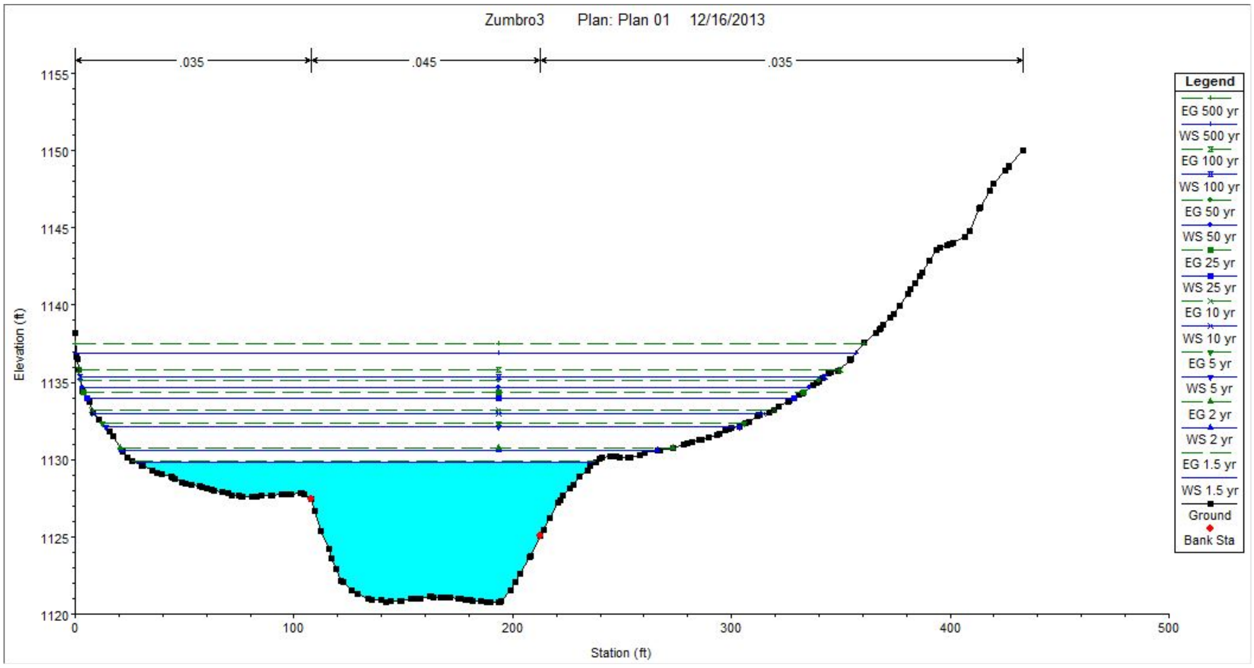

Figure 11. Zumbro River HEC-RAS cross section at Mantorville.

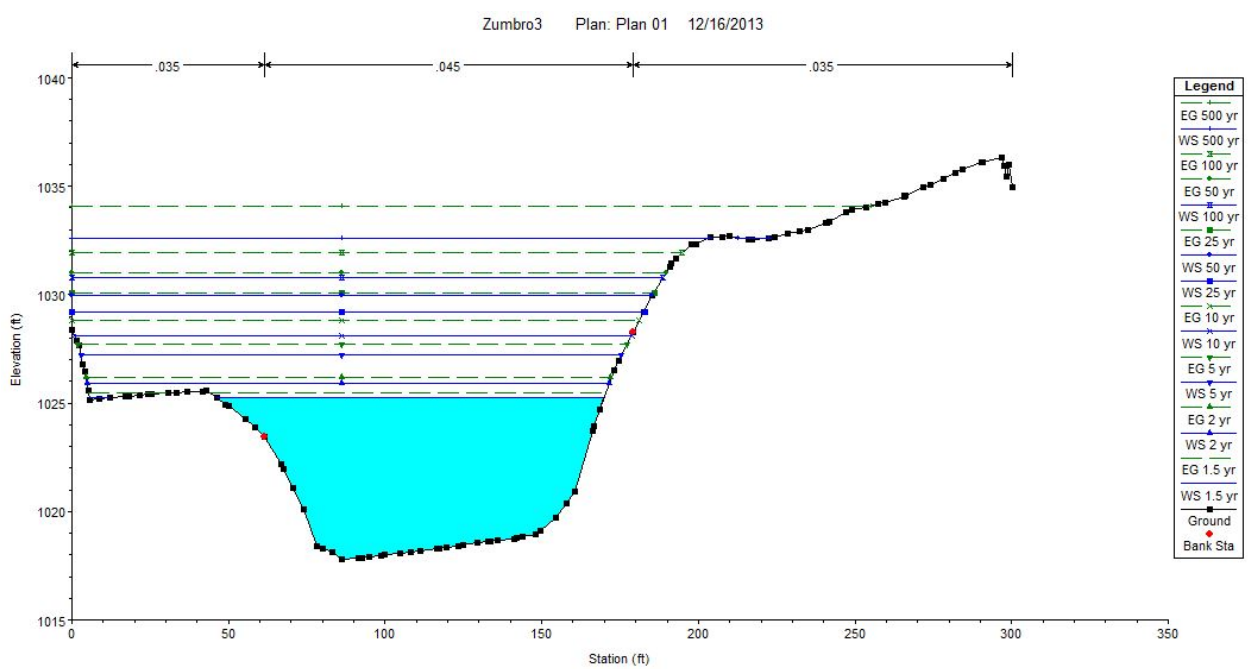

Figure 12. Zumbro River HEC-RAS cross section at Oxbow Park near Byron.

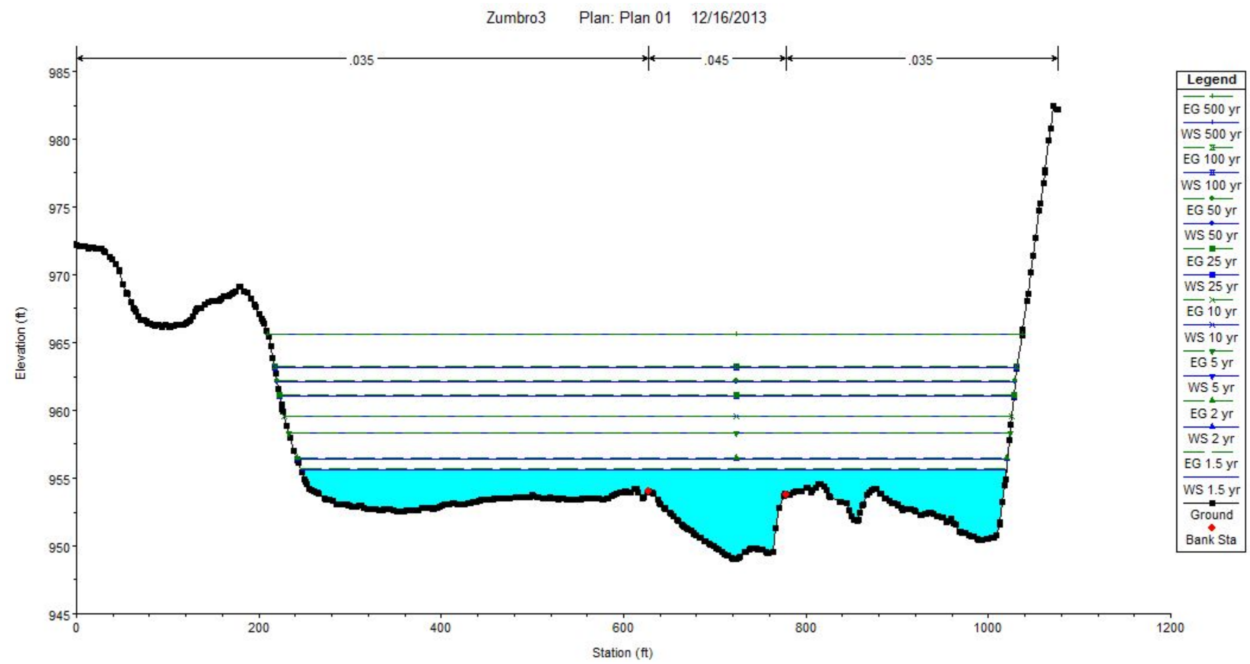

Figure 13. Zumbro River HEC-RAS cross section upstream (southwest) of Oronoco.

4.3 Middle Fork Middle Branch

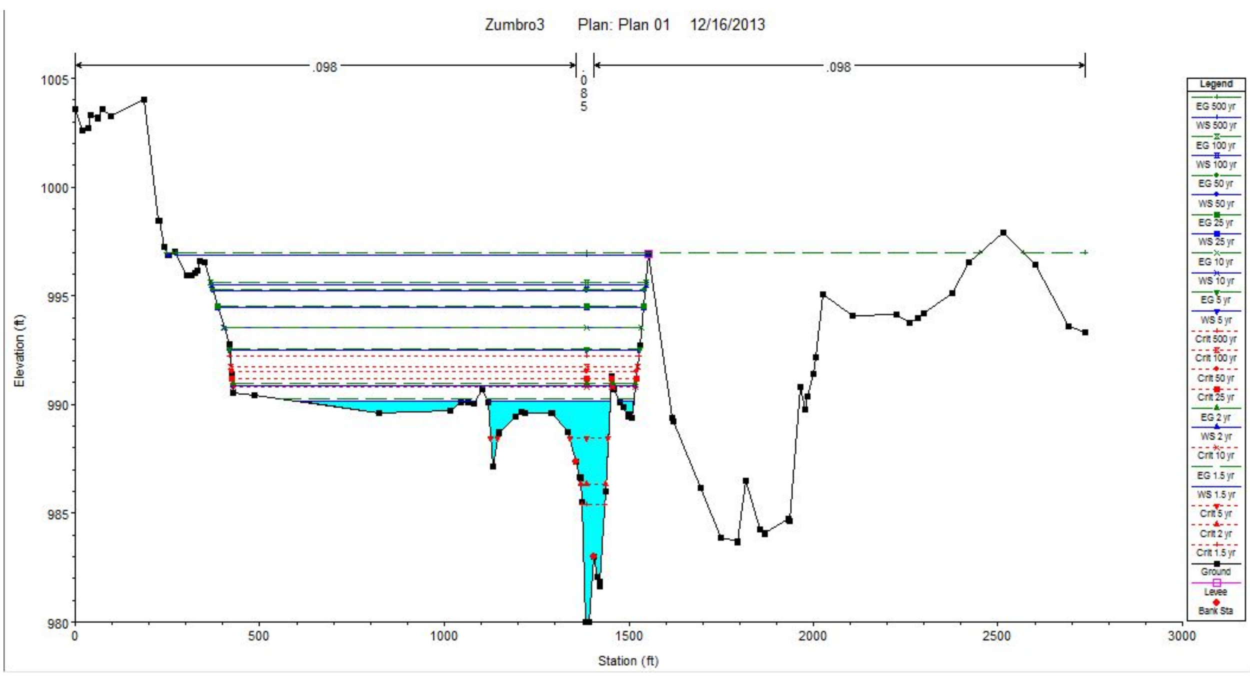

Figure 14. Zumbro River HEC-RAS cross section just upstream (southwest) of Pine Island.

4.4 Middle Fork North Branch

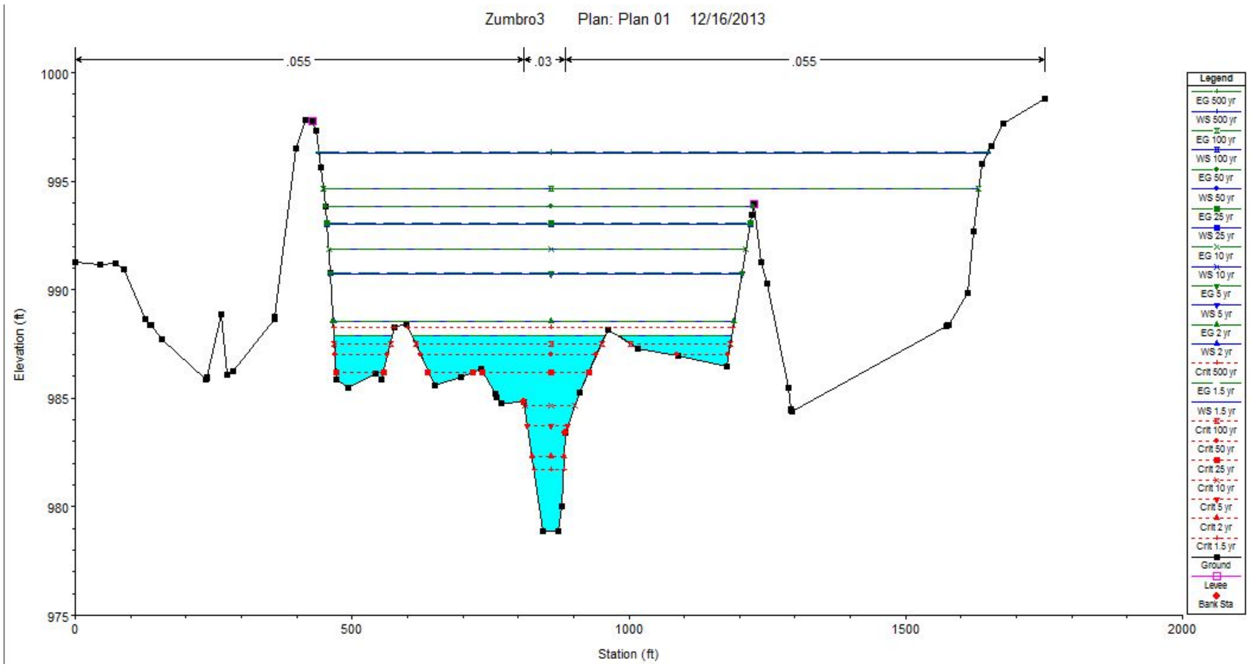

Figure 15. Zumbro River HEC-RAS cross section just upstream (northwest) of Pine Island.

4.5 Middle Fork

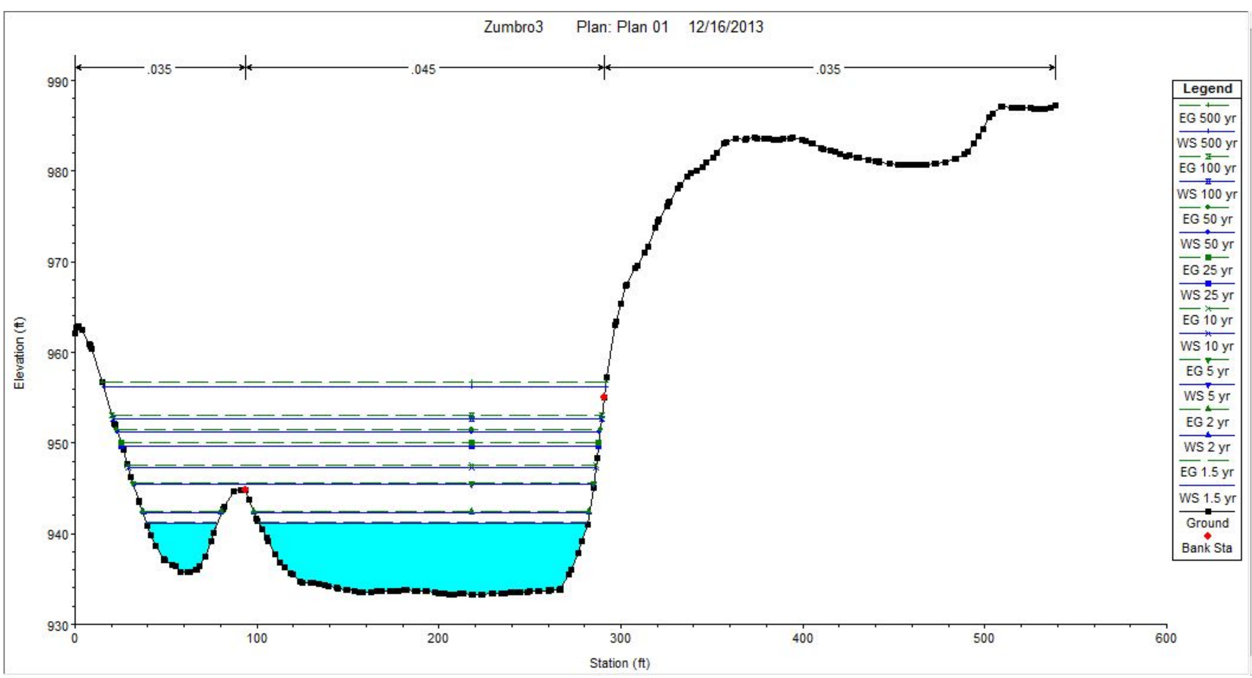

Figure 16. Zumbro River HEC-RAS cross section just below Oronoco.

4.6 North Fork

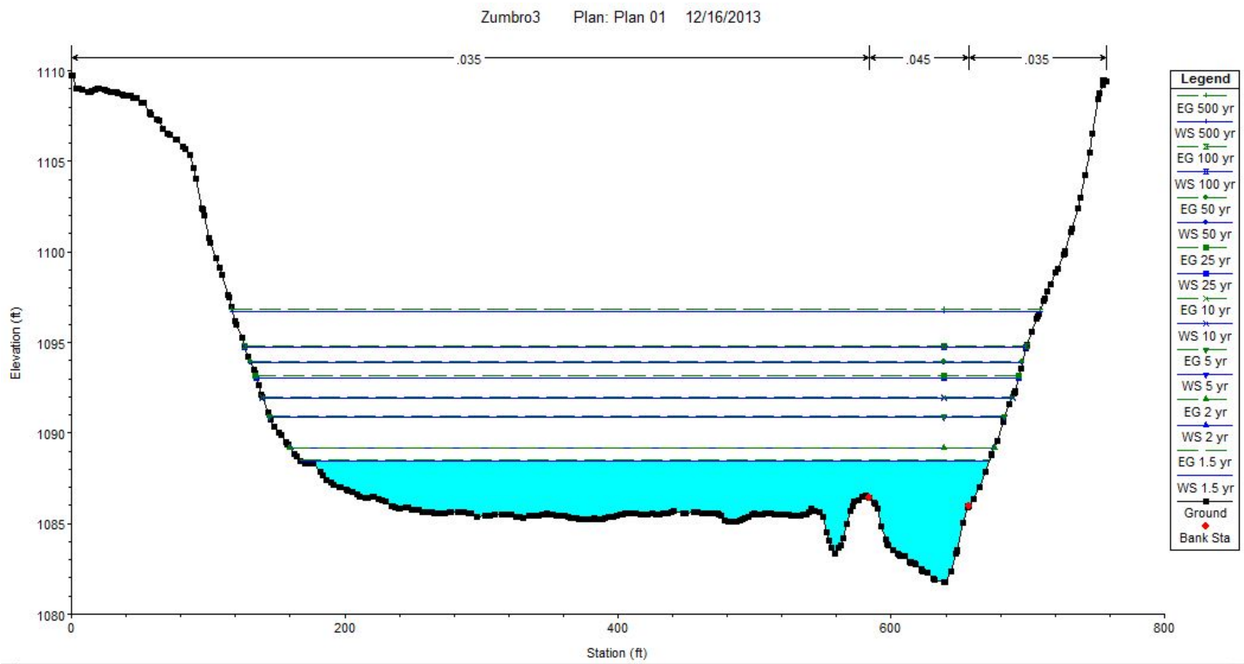

Figure 17. Zumbro River HEC-RAS cross section at Kenyon.

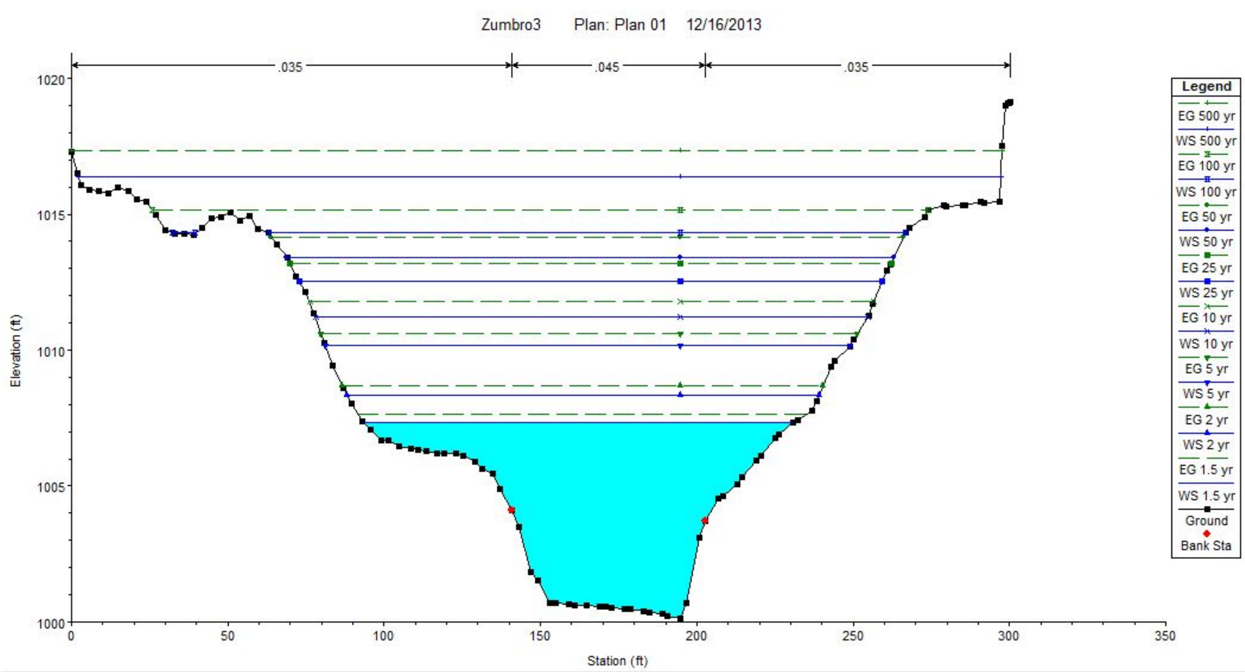

Figure 18. Zumbro River HEC-RAS cross section at Wanamingo.

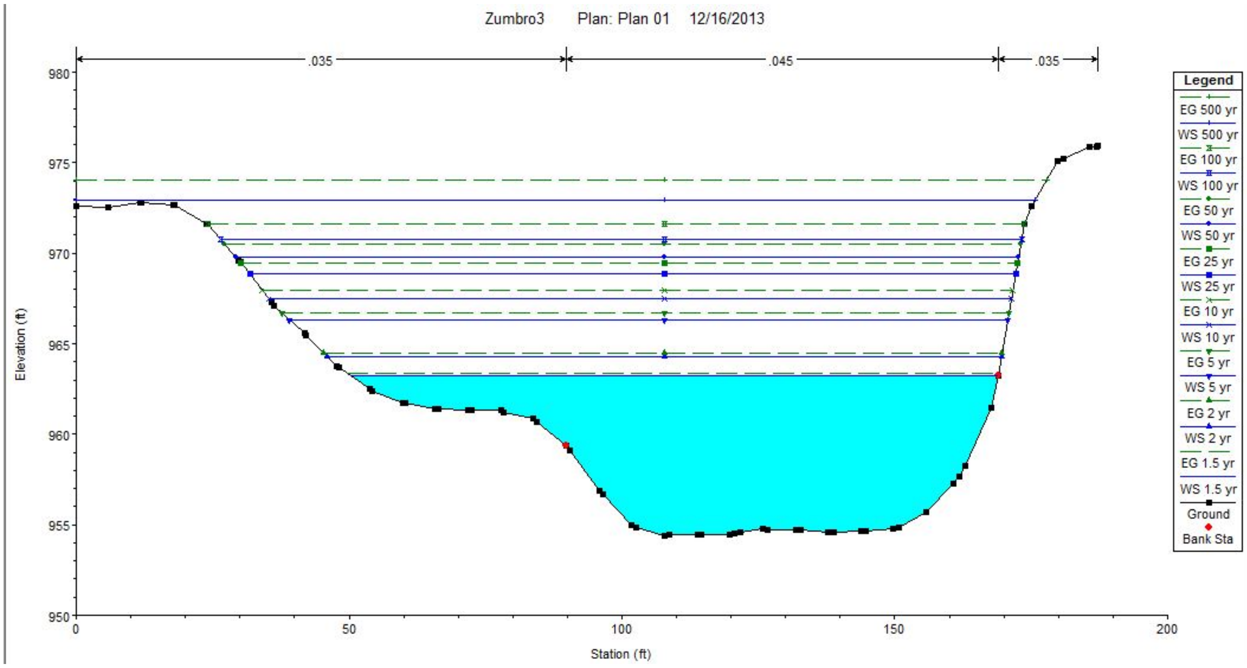

Figure 19. Zumbro River HEC-RAS cross section at Zumbrota.

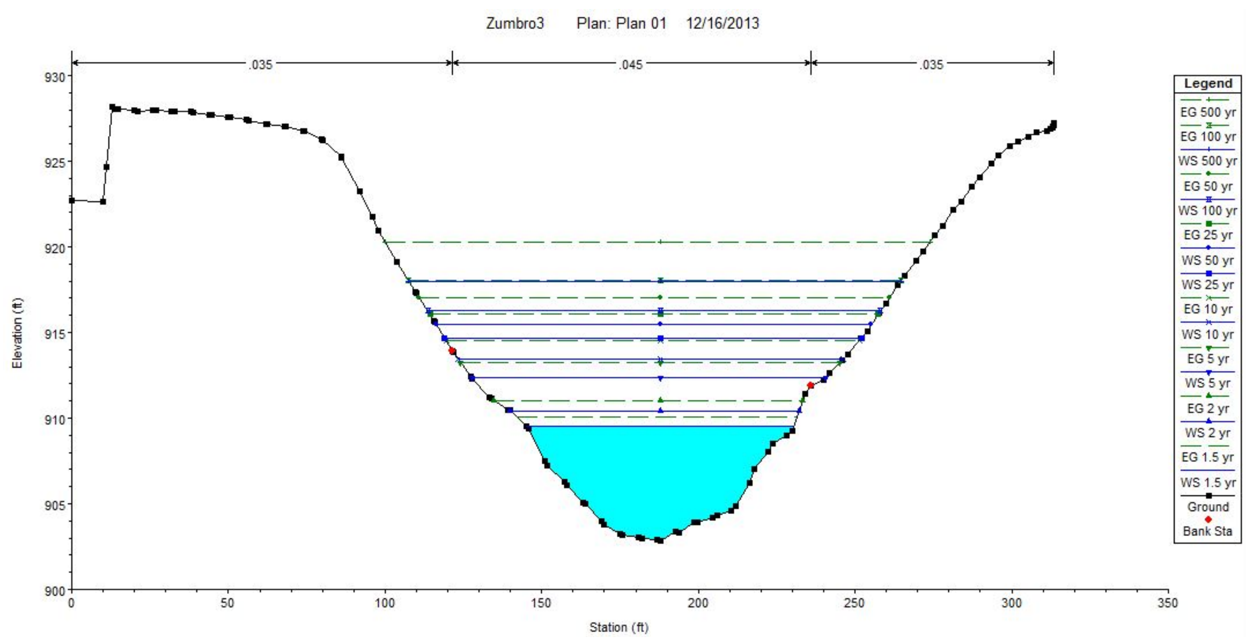

Figure 20. Zumbro River HEC-RAS cross section at Mazeppa.

Main Reach

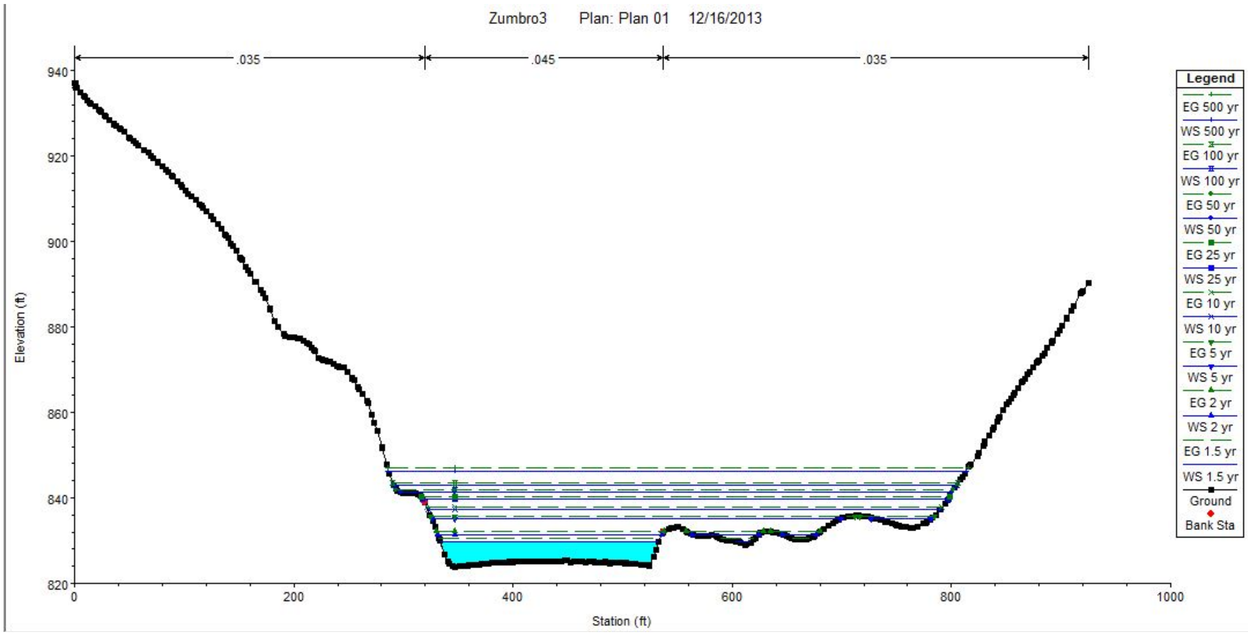

Figure 21. Zumbro River HEC-RAS cross section at Zumbro Falls.

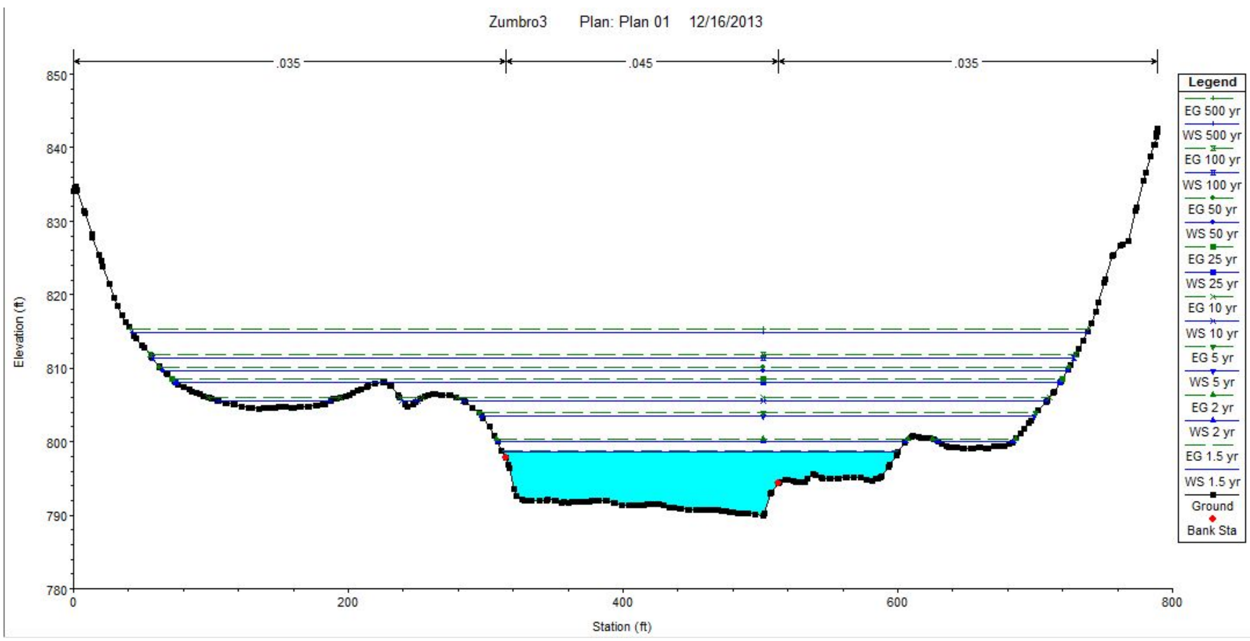

Figure 22. Zumbro River HEC-RAS cross section at Hammond.

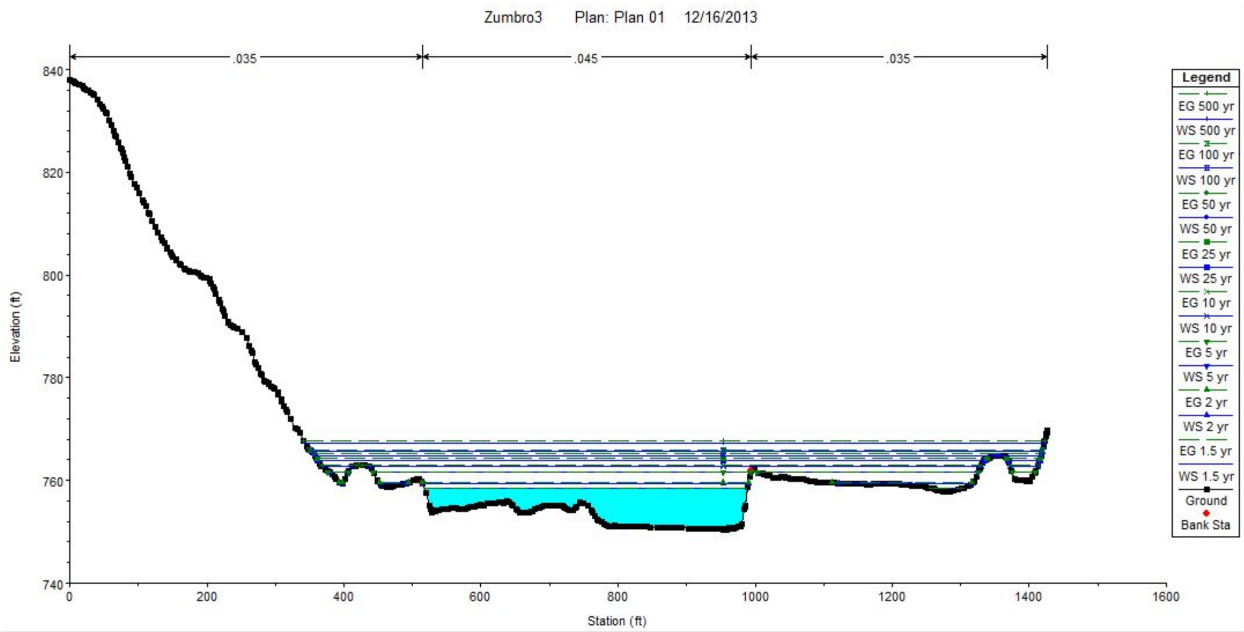

Figure 23. Zumbro River HEC-RAS cross section at Milleville.

5.0 Flood Mitigation Strategies

Flood mitigation involves comprehensive strategies balancing land use, water management and ecological services of the resources in the watershed. Many different avenues are possible, though funding, public acceptance and permitting will each place important requirements on the process.

Quoting from the report: Brief Analysis of Flooding in Minnesota – Recent Flood Events, Statewide Flood Risk Assessment, and Hazard Mitigation, prepared by Al Kean, Chief Engineer Minnesota Board of Water and Soil Resources (March, 2011):

> *"The Minnesota All-Hazard Mitigation Plan and local plans include a number of goals and strategies addressing flood mitigation. Following is a consolidated summary:*
>
> - *Promote and assist flood risk assessment and mitigation planning;*
> - *Promote and assist public awareness and support for flood hazard mitigation and flood insurance;*
> - *Identify repetitive loss structures and lands (urban and agricultural), prioritize, and target for buyout or floodproofing (which can involve floodplain easements);*
> - *Assist local communities to identify and prioritize mitigation projects and partnership strategies involving flood warning, peak flow reduction, and protection.*

"Flood warning is a strategy most applicable for landscapes that have substantial topographic relief and are conducive to flash flooding. Current technology has greatly advanced the potential to use telemetry and other electronic capabilities to provide rapid flood warning. Strategically located stream and river gages can also provide substantial assistance for optimizing operation of gated floodwater impoundments and for flood level modeling and prediction that assists flood preparations and flood fighting. Recent economic constraints at the federal, state and local levels have caused substantial challenges for maintenance of existing gages and installation of new gages at strategic locations.

"Acquisition (buyout and/or relocation) is a mitigation strategy directed primarily at high risk, repetitive loss structures, and/or structures substantially damaged by a flood. Since 1989, approximately 2,500 structures have been acquired by local communities in Minnesota with federal and state financial assistance. During that period, a number of additional flood prone structures were elevated above the 100-yr. flood level to reduce the risk of flood damage.

"Levees, floodwalls, diversions and runoff impoundments (temporary storage) are typical structural measures to prevent or reduce flooding. Because these types of measures are often quite expensive, design and implementation typically requires the involvement of one or more government units with applicable authority, expertise and funding capabilities. Watershed based hydrologic and hydraulic studies, and alternative analyses involving economic and environmental assessments, are typically required. Federal, state and local partnerships are often necessary for these types of projects.

"In some areas of Minnesota, runoff reduction through floodwater storage is a substantial component of an overall flood mitigation plan. In the Red River Basin (Minnesota, North Dakota, South Dakota and Manitoba), floodwater storage is a major component of a long-term flood solution being developed at this time. Associated hydrologic analyses indicate that approximately 1 million acre-ft. of additional temporary storage throughout the tributary watersheds would reduce the peak flow on the main stem of the Red River by 20% for a flood equivalent to the 1997 flood. (An acre-ft. of volume is equal to 1 ft. of water over an acre of area, or about 326,000 gallons.)

"Peak flow reduction through temporary storage can be accomplished at different scales: lot, neighborhood, field, drainage system, subwatershed, and watershed.

"A variety of practices can be used to implement temporary storage in urban and agricultural landscapes, including: raingardens, stormwater ponds, conservation tillage, terraces, water and sediment control basins, wetland restorations, side inlet controls to ditches and streams, culvert sizing at road crossings of ditches and streams, and larger impoundments involving dams. Some of these practices can also reduce flood volume via infiltration and long term storage.

"Because headwater ditches and streams greatly outnumber main stem rivers, the opportunities for peak flow reduction practices are correspondingly greater at the small watershed scale. The effects of many temporary storage practices at the small watershed

scale accumulate at the larger watershed scale, although typically in a less than linear relationship.

"The record 24-hr. rainfall in the state occurred in August 2007 (15.10 inches at an official rain gage) in southeast Minnesota. While many conservation practices on private lands such as grassed waterways, terraces and water and sediment control basins suffered some damage during that record event, overall these practices held up very well. This flood event prompted an inventory of the water and sediment control basins and ponds in Winona County, which was found to total approximately 1,600. These types of conservation practices have been constructed over many years, and have provided peak flow reduction and associated erosion reduction for countless runoff events throughout the headwaters of the streams and rivers in the areas where they have been implemented across Minnesota.

"Since 1986, conservation easements through the Reinvest in Minnesota (RIM) Reserve program, together with associated state-federal program partnerships, have helped prevent flood damage on thousands of acres of flood prone agricultural lands in floodplains and topographic depressions, in conjunction with restoring numerous wetlands, floodplain and prairie areas for erosion control, wildlife habitat, and runoff reduction. Use of marginal lands for natural resource enhancement and runoff reduction can also help protect higher quality agricultural lands.

"A comprehensive flood mitigation strategy involves a variety of prevention and protection practices. The wide range of temporary runoff storage practices can also have erosion reduction and water quality benefits by reducing peak flows in ditches, ravines, streams, and rivers. Reduced erosion potential and sediment transport capacity reduces bed load and suspended sediment, which are greatest at high flows. Managing peak flows helps manage the geomorphology of ravines, streams and rivers (i.e. channel stability), which is a major factor affecting erosion and sediment sources in the Minnesota River Basin, based on sediment source fingerprinting conducted by the St. Croix Research Station of the Science Museum of Minnesota and other research projects conducted by the University of Minnesota."

As referenced by Kean (2011), the Minnesota statewide flood risk assessment prepared by the Minnesota Department of Public Safety, Division of Homeland Security and Emergency Management (HSEM) produced the potential economic loss estimates for 100-year flood statewide flood risk assessment. When considering flood mitigation, it is highly instructive to consider these estimates for the four main counties of the Zumbro watershed (Table 2):

Table 2. Potential Economic Loss Estimates for 100-Year Flood.

County	Potential Economic Loss Estimates for 100-Year Flood
Goodhue	\$50 - \$100 million
Wabasha	\$100 - \$200 million
Dodge	Less than \$20 million

County	Potential Economic Loss Estimates for 100-Year Flood
Olmsted	$200 - $500 million

6.0 Public Outreach and Presentation of Preliminary Study Results

Zumbro and Friends conducted a series of public meetings during the late Summer of 2013 at which Minnesota State presented preliminary results of this study and requested comment. Public meetings were held at the following dates and places:

- August 22nd (morning) – Hammond;
- August 22nd (afternoon) – Rochester (discussion with Zumbro Watershed Partnership);
- September 17th – Mazeppa;
- September 19th – Mantorville;
- September 24th – Wanamingo; and,
- September 26th – Oronoco.

Students interviewed attendees and recorded answers to questions during meetings in Mazeppa, Wanamingo and Oronoco. These interview sheets are included as Appendix F. Comments received ranged from "we need more protection" to "we've already made our changes by accepting the FEMA buyouts and moving" to "you can't make changes to the river ecosystem" (comments paraphrased for emphasis). Clearly, there are many concerns of the public that must be incorporated into any future flood mitigation study and potential action.

7.0 Conclusions

In accordance with Minnesota Session Laws, 2012, Regular Session, chapter 292, article 4, section 15, Minnesota State has prepared this report regarding potential flood mitigation measures within the Zumbro watershed. A river flow model has been prepared, uncalibrated as to actual elevation but still useful to see the relative amount of change in response to different flow recurrence intervals. Selected results of the hydraulic model are shown within this report; the full model is available by request (email to Stephen.Druschel@mnsu.edu).

References

Ellison, C.A., Sanocki, C.A., Lorenz, D.L., Mitton, G.B., and Kruse, G.A., 2011, Floods of September 2010 in Southern Minnesota: U.S. Geological Survey Scientific Investigations Report 2011–5045, 37 p., 3 app.

Hansel, J. and Killion, Christina. **Cities grapple with flooding.** Rochester Post Bulletin. Posted: Thursday, September 23, 2010 7:58 pm. Downloaded December 12, 2013 from http://www.postbulletin.com

Kean, A., 2011. Brief Analysis of Flooding in Minnesota – Recent Flood Events, Statewide Flood Risk Assessment, and Hazard Mitigation. Minnesota Board of Water & Soil Resources, downloaded December 12, 2013 from http://www.bwsr.state.mn.us/publications/flooding_analysis-2011.pdf

Pieters, J. **Some wonder if they should just walk away.** Rochester Post Bulletin. Posted: Sunday, September 26, 2010 10:34 pm**.** Downloaded December 12, 2013 from http://www.postbulletin.com

Pieters, J. **Rochester reservoirs had room to spare.** Rochester Post Bulletin. Posted: Tuesday, September 28, 2010 5:44 pm. Downloaded December 12, 2013 from http://www.postbulletin.com

Zumbro Watershed Partnership (2013). The Zumbro River Watershed. http://www.zumbrowatershed.org/ourwatershed. Downloaded December 15, 2013.