Watertown: Building Connectivity Between People and Their River with Minimal Impacts Upstream

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Prepared on Behalf of

Carver County and the City of Watertown

Fall 2015

CARVER COUNTY

Resilient Communities Project

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This project was supported by the Resilient Communities Project (RCP), a program at the University of Minnesota that convenes the wide-ranging expertise of U of M faculty and students to address strategic local projects that advance community resilience and sustainability. RCP is a program of the Center for Urban and Regional Affairs (CURA) and the Institute on the Environment.

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1 Introduction

A stream restoration project has been proposed in Watertown, Minnesota on the South Fork of the Crow River. There is desire from the County to restore biological connectivity in the Crow River. Most importantly, the restoration project is aimed to restore fish passage beyond the small dam on the river in Watertown. This dam is the last remaining barrier in the South Fork of the Crow River. A large City Park surrounds the dam where some water recreation (canoeing, fishing, etc.) exists.

The current desire is to keep the dam in place and construct step-pool sequences to bring the water surface elevation downstream to the top of the dam to promote fish passage. The City of Watertown is also interested in pursuing a whitewater park as part of the restoration project to enhance revenue and recreation opportunities in the City.

2 Historical Data

2.1 Datum

NAVD 88 Datum is 0.27 feet higher than NGVD 29 Datum

2.2 Original Dam

The origins of the dam are not well documented. The original intent of the dam was to provide more lentic habitat for fish and access for fishing. Any benefit from the dam for flood mitigation would be limited. The original construction consisted mostly of placed rock to create a pool upstream and turbulent flow through the structure. A picture of the dam prior to the reconstruction project can be seen in Figure 1.

Figure 1. Existing Watertown Dam, prior to the 1988 reconstruction.

2.3 Dam Reconstruction (1988)

In order to create a lower maintenance structure that retains the upstream pool, a concrete weir was constructed in 1988. This structure included a low flow notch to pass lower flows through the center of the channel. A picture of the dam reconstruction can be seen in Figure 2.

Figure 2. Watertown Dam after reconstruction in 1988.

The dam was constructed with a crest elevation of 921.0 feet NGVD 29 which is approximately 921.3 feet NAVD 88. The low flow notch was constructed 0.5 feet lower with a 6 feet width. Riprap was placed along the right descending downstream bank of the river. A construction drawing is shown in Figure 3.

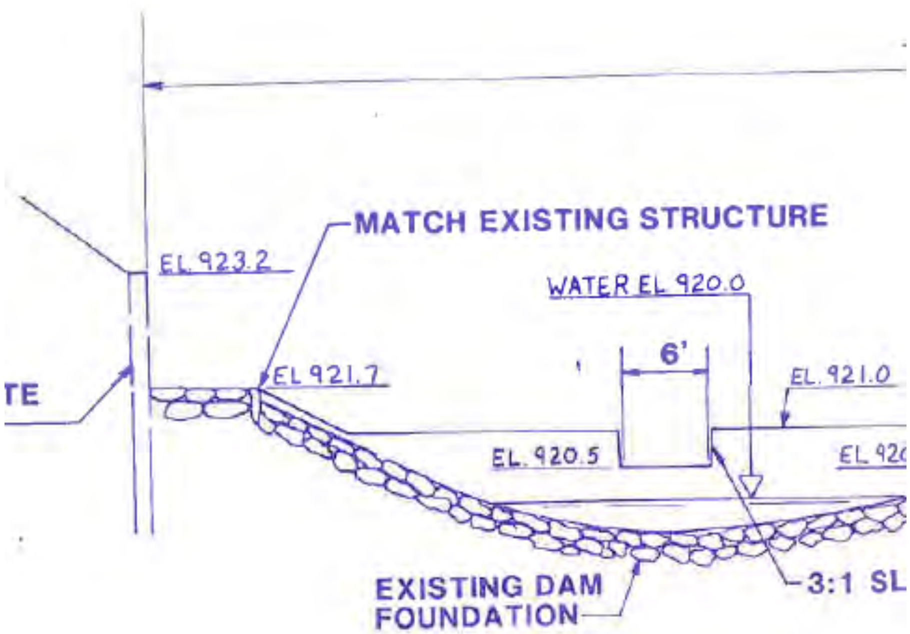

Figure 3. Construction drawing of Watertown Dam in 1988.

There is some discrepancy of the actual crest of the dam. The Flood Insurance Study (FIS) from 2007 assumes the crest is at elevation 921.5 feet NAVD 88. A survey of the dam found the crest to be at elevation 921.02 feet NGVD 29 (Figure 4), which equates to 921.29 feet NAVD 88.

As per your request, our survey crew did check the elevation of the newly constructed dam across the Crow River.

We found that the top of the dam was from elevation 921.01 to elevation 921.02 feet. I enclose a copy of our field notes for your reference.

Figure 4. Survey notes from the Watertown Dam As-Built survey.

For modeling purposes, the dam is modeled consistent with the FIS study which is reasonably close for hydraulic modeling.

2.4 Current Condition of the Dam

The current condition of the dam still functions similarly to the original intent. Some scour has occurred downstream of the dam but does not appear to reduce function of the dam. The dam is still popular as a fishing and recreation spot, however, fish passage from downstream to upstream is limited in duration annually due to the significant drop across the structure. Additionally, canoe and kayak passage is limited in a similar way. A picture of the current condition of the dam in 2015 is shown in Figure 5.

Figure 5. Current condition of the Watertown Dam in 2015.

2.5 Channel Migration Assessment

In order to assess the impact of the dam to the natural river channel processes of the South Fork Crow River, an analysis of historic aerial imagery was performed at Watertown. By analyzing various pre- and post-dam aerial images over the 20th century, the impact of the dam to natural channel migration can be qualitatively assessed. Images have been taken throughout Carver County and the Watertown area from 1937 through the present date. In the past few decades, the frequency of available aerial imagery has increased. While the changes from year to year are not very apparent, some major processes can be identified by comparing images over longer time spans. For comparison purposes, the approximate location of the channel banks for each time period were digitized. The 1937 imagery and approximate banks (in red) are shown in Figure 6.

Figure 6. Aerial image from 1937 of Watertown, MN and the South Fork Crow River with approximate channel banks (red)

In comparing the channel banks from 1937 to more recent years, some channel migration is evident. The most prominent channel movement near Watertown is the meander cutoff that occurred upstream of Watertown after 1937. This migration is evident in Figure 7 where the approximate 2013 banks (in black) are compared with the 1937 banks (in red).

Figure 7. Comparison of the channel migration of the South Fork Crow River banks from 1937 (red) to 2013(black)

The other major change in Watertown over the past 80 years is the widening of the banks through town. Both upstream and downstream of the dam, the banks appear wider in the recent aerial imagery than in 1937. The upstream bank widening is most likely capturing the wider inundation from the dam pool. The downstream widening, though, is most likely from increased velocities downstream of the dam leading to bank erosion.

Since channel migration appears to be a natural occurrence along the South Fork Crow River, it is important to determine whether the dam is hindering the natural processes of the river and if dam removal would encourage the river to return to a natural state. The topography of the area was accessed to analyze these questions. In looking at the digital elevation model (DEM) from LiDAR data, historic channel migrations can be seen upstream and downstream of Watertown (Figure 8).

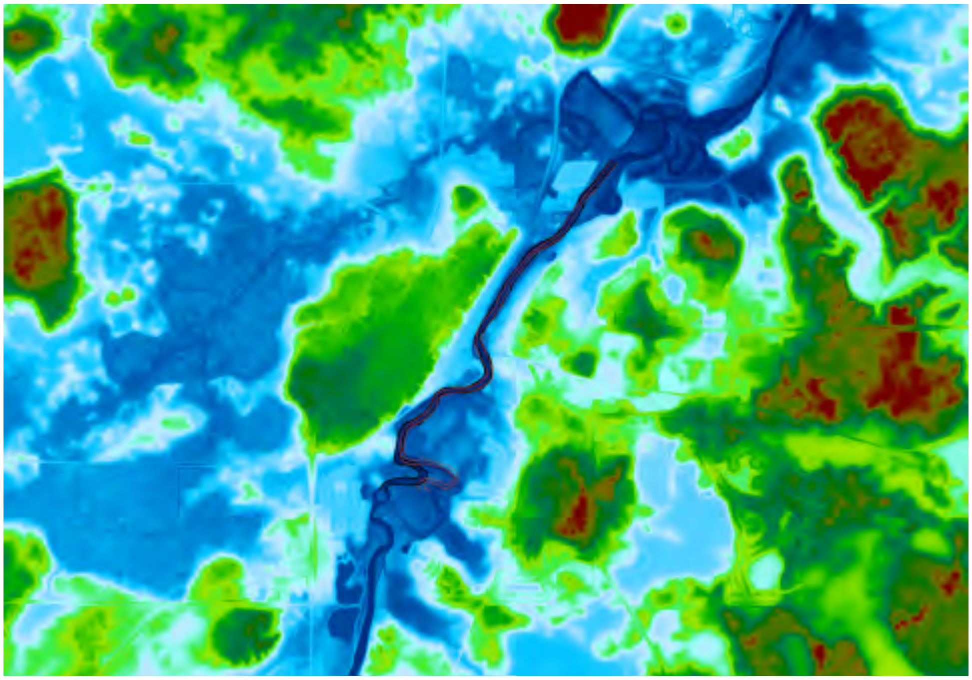

Figure 8. Digital Elevation Model (DEM) of Watertown area with lower elevations in blue and higher elevations in green/red

However, through town the channel appears to be fairly confined by the natural topography. It is unlikely that the channel would meander and migrate through this area with or without the dam in place. Additionally, since the town has developed around this area with bridges and properties in place, it is unlikely that meandering would be desired in Watertown and any migration that occurred would be quickly addressed.

3 Watershed Assessment

3.1 Background

The goal of the assessment of the South Fork Crow River watershed is to protect water quality from non-point sources nutrients, mainly nitrogen in the entire watershed rather that onsite of the project. According to MPCA, eighty-three percent of the South Fork Crow River's watershed land use is agricultural with row crops and pasture grass lands. Several lakes and parts of the South Fork Crow River do not meet water quality standards for beneficial uses as aquatic recreation, drinking, and swimming.

MPCA states that elevated nitrate levels impacts aquatic life that harm fish and have impacts on recreational opportunities, safe drinking water supplies and agriculture. The media is also becoming more involved in this issue. Shannon Prather from the Star Tribune reported that half the lakes and rivers in southern Minnesota are too polluted much of the time for safe swimming and fishing.

Figure 9 shows more than 12 pounds per acre per year in southern Minnesota of nitrate getting into surface waters and nitrogen loadings to surface water by source, and by large, croplands have the most Nitrogen loadings into the watersheds. By incorporating several Agricultural Best Management Practices throughout the South Fork Crow River watershed will help to manage reduce the N loadings into surface water and protect the aquatic environment t that will guarantee the 15 types of fish in this river will thrive.

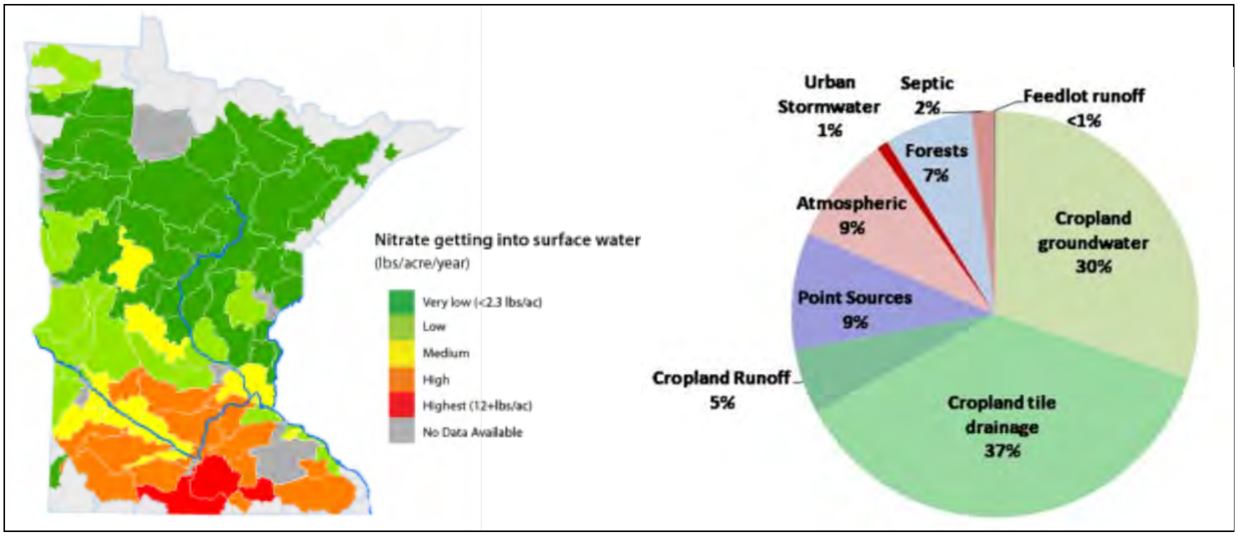

Figure 9. Statewide Nitrogen Loading to Surface water by source (Reference MPCA)

Also, a Watershed Nitrogen Reduction Planning Tool spreadsheet was developed by University of Minnesota to assist the Nitrogen issue statewide. The spreadsheet is used by planners and the goal of this tool is to improve water quality from Nitrogen impacts getting into waterbodies. A caveat is who will decide to implement the practices listed is the crop producers, since resource planners do not have direct control of adapting the agriculture BMP's.

Also, according to the author of the spreadsheet "one use of this model can be assisting to decide the levels of subsidize rather than Incentives: to offer to the producers farming in the watershed who will make such as implementation decisions".

The analysis is a three step process:

1. Select the watershed, then specify percentages of adoption rates of the BMP's that are reasonable to implement in the watershed.
2. Compare the combinations of the BMP's percentages that will attain any given reduction on N loading at minimum cost.
3. Adjust the models/scenarios.

The spreadsheet looks into several pathways of nitrate from cropland getting into waterbodies in the watershed and the loadings depends on the type of crops, tile drainage practices, cropland management, soils, climate, geology and other factors. By far, tile drainage is the highest estimated cropland source pathway (Lazarus et al., 2014).

Table 1 shows the agriculture BMPs practices and combinations from NBMP spreadsheet.

1. Reducing the fertilizer N rate on corn grain and silage acres to a target N rate
2. Including a nitrification inhibitor with fall N applications
3. Switching fall N applications to spring pre-plant
4. Switching fall N applications to a split spring replant and dressing application
5. Restoring wetlands

6. Installing tile line bioreactors
7. Installing controlled drainage,
8. Installing saturated buffers
9. Adding riparian buffers
10. Planting a rye cover crop on corn grain, soybeans, small grains, peas, sweet corn, sugar beets,
11. Planting a perennial crop on corn and soybean acres

Table 1: Agricultural BMPs from NBMP spreadsheet (Reference)
Source: Watershed Nitrogen Reduction Planning Tool (William F. Lazarus and others 2014)

3.2 Land Use

Land use in the Crow River watershed is shown in Figure 11 shows primarily agricultural with little urban development. It confirms a predominantly row crops of 72.3 percent, for 10.6 percent grass, pasture and hay, 4.2 percent forest, 5.8 percent development use. The watershed receives an average of 29 inches of precipitation per year with about 25 inches as rainfall. Average temperatures are 69°F in the summer and 13°F in the winter months (Baker and others, 1985).

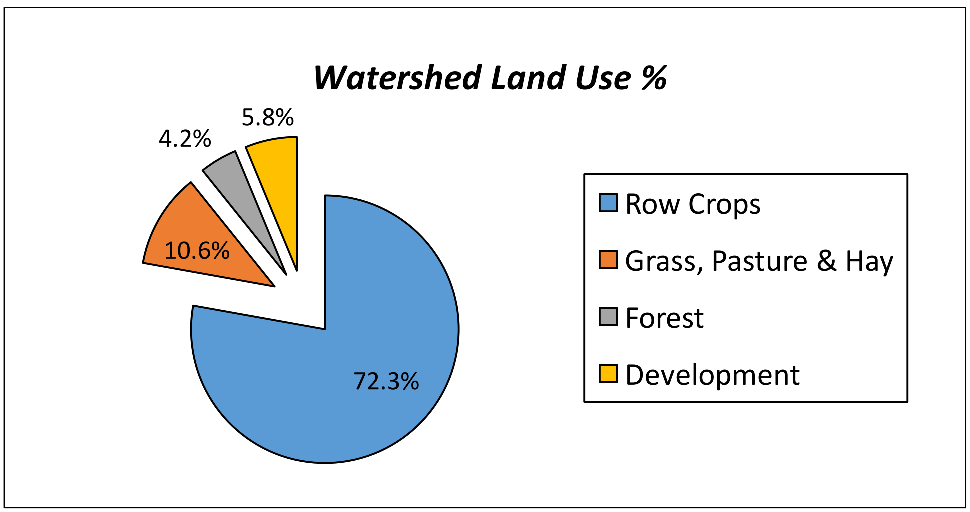

Figure 10. Percentage of land use in the Crow River Watershed

3.3 Water Quality Impairments

The Clean Water Act Section 303(d) TMDL List is required by EPA. It is a list of impaired waters for which TMDL reports are required. The MPCA has the authority to enforce in the state and it follows its own Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List.

The South Fork Crow watershed as of today is impaired for turbidity with no TMDL yet being modeled. There is an ongoing project addressing the exceedance of Minnesota's water quality standard for nutrients (phosphorus) for the lakes Eagle Lake, Oak Lake and Swede Lake in Carver County. Carver County Land and Water Services is developing the TMDL and coordinating implementation activities to restore these water bodies.

Table 2 represents totals of waterbodies: streams, lakes and wetlands with impairments. The South Fork Crow River lakes are located in Carver County, west of the Twin Cities metro area. The lakes are in the South Fork Crow River watershed in the Upper Mississippi River basin, in areas that are primarily rural.

2014 TMDL List Summary	
Pollutant or Stressor	**#**
Nutrient/Eutrophication Biological Indicators	450
Escherichia coli/ Fecal coliform	385
Mercury in fish tissue	353
Turbidity	300
Aquatic Macroinvertebrate Bio assessments	291
Fishes Bio assessments	266
PCB in fish tissue	144
Oxygen, Dissolved	107

Table 2: List of 2014 TMDL impairments in MN (Credit MPCA)

According to MPCA, there are 450 waters impaired for nutrients in the state of Minnesota as of 2014 and all waterbodies are lakes. Table 3 shows Nitrogen measurements on Oct 2015 at the project site. Eutrophication standards for streams are being developed it is expected to go public in 2016.

Location	*Avg. Site Nitrate (ppm)*	*Avg. TDN (mg/L)*
USDAMA	0.2685	0.9640
DSDAMB	0.2772	0.9900

Table 3 shows results of Nitrogen measurements in the project site (Credit: Abigail Tomasek)

3.4 What Drives Percentages Adoption Rates for input numbers in the spreadsheet?

Agricultural business is dynamic and complex and as table 1 shows there are 11 Ag BMPS' that can have an impact on the final recommendations and implementations of the BMP. Also, more knowledge is required to enter in the % adoption rates and is beyond the experience of the group. However, some numbers were ballpark numbers from the U of MN BBE Dept. professor for the wetland and tile drainage numbers.

On November 22, 2015, the Star Tribune published an article on *"Cover crops provide benefits but are a tricky proposition for Minnesota farmers."* Minnesota farmers are experimenting with cover crops, to reduce erosion during fall harvest and spring planting. But, it comes with a caveat: How important is soil conservation rather than cash? And weigh the benefits of decreasing erosion (saving the topsoil) as one of the main benefits of cover crops.

Timing is another constrain: "Planting too early can also be a problem, experts say, because if cover crops start growing before corn and soybeans mature, they may compete enough to reduce yields, and some crop insurance policies will be invalidated" "it's just hard to figure out that best end-of-season time to plant," The University of Minnesota Sackett Eberhart is optimistic "What we're seeing around the Midwest is that farmers and researchers are thinking outside the box," she said. "It's that ingenuity that has renewed the interest in cover crops."

Figure 11. Cover crops, rye grass and radish. (Credit Liz Stahl - University of Minnesota Extension)

This is a hard implementation to make since there is not savings as the spreadsheet shows moving from the 20 to 40 percent adoption rates. Figure 13 shows a negative savings, a loss, even though there is a great reduction of nitrogen, of 35 percent but is not feasible because of the loss.

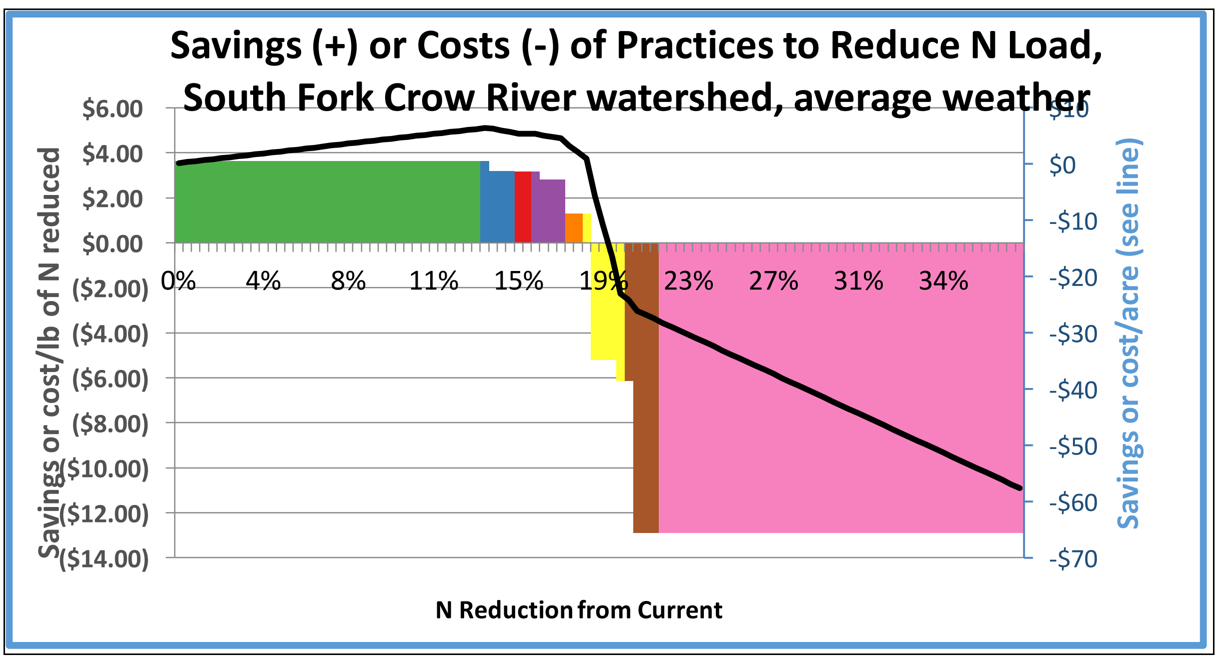

Figure 12. Future change of cover crops from 20 to 40% adoption rates.

3.5 Results

Appendix A shows three scenarios. For scenario 1 and scenario 2, the savings and cost of practices to reduce the Nitrogen loads uses the average weather input while scenario 3 includes wet weather patterns.

Scenario 1: Percentage Adoption Rates are input for controlled drainage five percent and restored wetlands of 10% or an area of 0.577 million acres in watershed. It incorporates an average weather that cannot be realistic.

Scenario 2: The percentage Adoption Rates are changed for controlled drainage ten percent and restored wetlands of twenty percent for an area of 0.577 million acres in watershed.

Scenario 3: A more realistic percentage Adoption Rates scenario that includes future weather patterns are input for controlled drainage five percent and restored wetlands of ten percent for an area of 0.577 million acres in watershed.

While analyzing the results, there are not big differences in savings and cost of practices for Scenario 1 and Scenario 2. To get an 18 % reduction, the farmer will save $1.5 per acre (green bar) while the combination of reducing nitrogen rate 40percent, nitrogen inhibitor 8.5 percent, spring pre-plant 8.5percent, sidedress nitrogen 8.5 percent, restore wetlands 1.3percent, controlled drainage 0.6 percent, saturated buffers 0.6 percent, riparian buffer 0.7 percent, corn and soybean cover crops 18 percent, perennial crops 3.9 percent (pink bar) shows a great reduction of nitrogen, but if the farmer wants to reduce the nitrogen greater than 18 percent to 36 percent he will lose almost $60 per acre.

Scenario 3 shows better results, since there are more savings, but as the reductions increase, the savings decrease. To get a 28 percent reduction, the farmer will save $1.5 per acre (yellow bar) while the combination of reducing nitrogen rate 36 percent, reduce nitrogen rate 40 percent ,nitrogen inhibitor 8.5 percent, spring pre-plant nitrogen 8.5 percent, sidedress nitrogen 8.5 percent, restore wetlands 2.7 percent, controlled drainage 1.1 percent, saturated buffers 0.6 percent, riparian buffer 0.7 percent, corn and soybean cover crops 18 percent (pink bar) shows a great reduction of nitrogen, but if the farmer wants to reduce the N from less than 29 percent to 36 percent, he will lose almost $22 per acre**.**

3.6 Recommendations

This tool can have go many ways to be interpreted, since agriculture is being driven by many factors. Realistic scenarios are difficult to narrow down. For instance, weather scenarios adds complexity and can be expensive to implement BMP's as shows in scenario 3 and this can be considered a realistic scenario.

But, there is not yet at a state level an adaptation to climate change from the MPCA to support the farmers. So the models show an average weather scenario and the adopted BMP's cannot be seems a bad combination, because it shows the more money the farmers loose in the first two scenarios, even though it use a n average climate which is not realistic. Nevertheless, *wet year scenario* cannot be discarded.

Also, this tool can be used to help decide levels of Subsidies rather than Incentives. For instance; there are two types of subsidies:

1) Increase production given to crop insurers. The caveat is targeted to corn and soy bean production , so if farms fails for many reasons (bad weather,) then farmers are able to get the 75% of their investment; and
2) Subsidies from the environment thru the NRSC and this provide payments to protect the water quality for Conservation Practices. Here comes an opportunity of implementation of the BMP's and the importance of outreach and understand the dynamics of what drives BMP's.

Ag as any other industries needs to produce and yields results to supply the demands and making changes to adopt BMP's will take a true understanding of not only today's economy, but projecting the results to a long term. Is this sustainable? How water quality will be in the next 5, 10, 20 years?

Some adoption rates will be expensive to adopt. For instance according to Mr. Bruening, a manager of the Pesticide and Fertilizer of the MDA, restored wetlands will be the more expensive to implement. Farmers will lose money. Today's price are $ 8000/acre based on crop yield in South Crow river watershed and the price get more expensive as it goes south. It will cost $12000/acre. This Ag lands yield 200 bush/acre corn. Ag Land will be less expensive further North. It produces 120 bush – acre corn. Next less expensive will be tile line bioreactors. Down the line, will be saturated buffers. They can be installed at the edge of the field. Farmers need to make a decision if they want to implement this BMP. It costs $ 8000 an acre of land and if these structures will use 3 acres, then the total price that a farmer lost is $ 24000 plus the construction cost of building the infrastructure and the less expensive will be controlled drainage.

Also, marginal lands are considered poor Ag land and there is more at the Northern part of MN. So a more realistic scenario will be to use and All Corn Soy, equal % because most of the nitrogen impairments are in the southern part of the state.

The Adoption Rates percentage of BMPs can rely on information from a social science research on the Red River Basin of Minnesota. This research aims to understand what drives agricultural conservation practices and three main points were important gathered in this assessment: 1) Identify factors of conservation practice adoption among agricultural producers. 2) The understanding that conservation practices of BMP's adoptions vary across the regions and 3) Suggest strategies that are sound research of ecologically, hydrologically, and socially relevant and responsive to changing conditions or policy-makers and stakeholders in the AG industry. (Source: Cannon River Watershed: Landowner Survey on Water Resources and Conservation Action)

How to put emphasis on Incentives? First, find out what BMP match s the specific farmer's situation. For instance, there are three players in the equation: a) look into ownership of land in the watershed, b) versus renting the land and lastly c) absentee landowners. Who of the three cares more on soils conservation or incentives? What are the Incentives to take care the land in the short term? Long term if I am thinking on profit. Recognizing that there are differences between these three players to manage the land it is important and it will make more sense to implement some of the Ag BMP's accordingly to who owns vs. who rents the land. What can change the perception of the results is stakeholders and farmers come to an agreement for a long term vision. The model spreadsheet show the savings and losses are for 1 year and if laws of implementation become more stringent from regulatory agencies and they wants to enforce, then $ 60 / acre per year might not be a bad option after all, since it will achieve a greater reduction rate and this is what maybe drives the implementation to get water quality in compliance and healthy watersheds and to guarantee a healthy fish population as well.

4 Data Collection

To support the hydrologic and hydraulic modeling and the project design, a data collection effort was established. At the onset of the project, a list of data needs was compiled and divided into data most likely already collected and data that would require collection at the site.

The list of data thought to already exist was presented to Tim Sundby, a Water Resources technician with Carver County. Tim provided the team with an array of existing information including; as-built plans for the dam, property mapping of Watertown, and aerial photography dating back to 1937. Past fish surveys conducted by the Minnesota Department of Natural Resources, spatial data from the Minnesota Pollution Control Agency, and LiDAR for the site form the Minnesota Department of Natural Resources was compiled as well.

Field data was collected on two separate occasions, October 10, 2015 and October 23, 2015. During the first visit, the bulk to necessary field data was gathered including channel cross sections, a water surface profile, Wolman pebble counts, and measurements of flow velocity at various channel cross sections. The channel cross sections were taken starting 25 feet downstream of the dam and continuing every 25 feet up to 250 feet downstream of the dam as well as one cross section taken 950 feet downstream of the dam. The cross sections were taken from the top of the riprap on the left bank to an acceptable height on the right slope given the topography and private right-of-way boundary. A water surface profile was also surveyed along the left bank from 300 feet upstream of the dam to 950 feet downstream of the dam. Flow velocity was recorded for two channel cross sections at 100 feet and 225 feet downstream of the dam. Wolman pebble counts were also completed at these cross sections.

Figure 13. Field Personnel Collecting Cross Section Data

The second field visit was conducted with representatives from Carver County to collect a channel cross section and flow velocity record upstream of the dam. The channel cross section and flow velocity measurements were taken at the same section 50 feet upstream of the dam. Finally, dissolved oxygen (DO) and temperature measurements upstream and downstream of the dam were taken.

4.1 Discharge Calculations

The measurements of flow velocity, channel cross sections, and water surface profile were used to estimate the discharge during the field visits. Table 4 presents the discharge estimated from the data of the gages in Delano and Mayer, with a travel time between them of 25 hours. approximately, and the discharge estimated from the field measurements. The calculated discharges closely match the estimated discharges from the gages data.

	Date	Discharge (gages)	Discharge (field)
Upstream (-50 ft.)	10/10/15	20.5 cfs	20 cfs
Downstream (100 ft.)	10/23/15	28 cfs	31 cfs

Table 4 Discharge estimated from the field measurements and discharge calculated from the gages in Mayer and Delano during the field visits in October 2015.

4.2 Water Quality Data

The dissolved oxygen levels are important for survival of aquatic life. If DO is too low, fish and other aquatic organisms may die or move to other areas. Figure 15 shows examples of oxygen requirements for different aquatic organisms.

Figure 14. Oxygen requirements for different aquatic organisms http://www.fondriest.com retrieved 12/9/15

The following Figure (Figure 16) displays the measured values of DO in the field and historic DO data at Watertown.

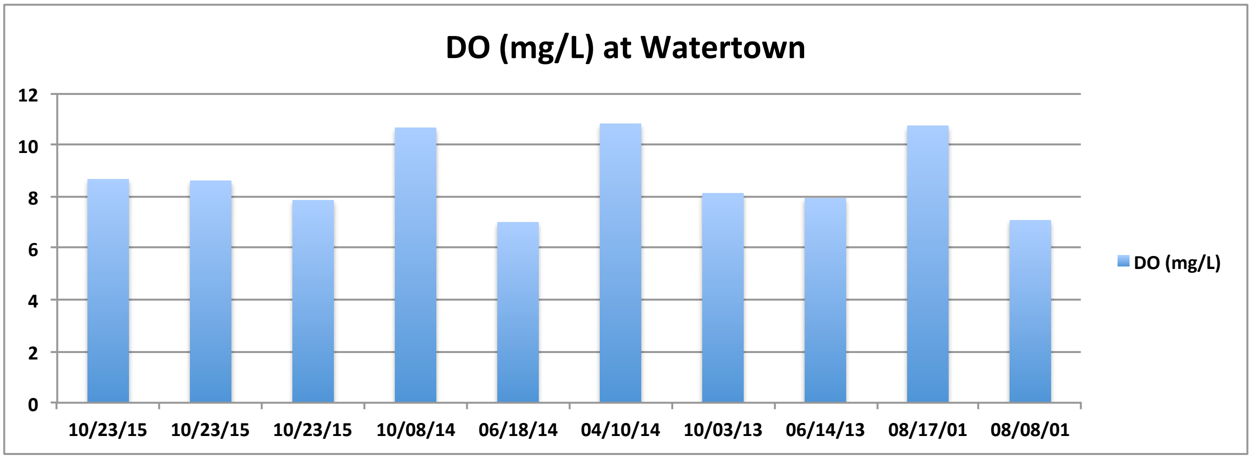

Figure 10. Dissolved Oxygen levels at Watertown

During October 23rd 2015 at 2pm, three DO measurements were taken. The first two data points represent the downstream of the dam conditions and the third data point the upstream conditions during that day. As it was expected, the DO upstream is lower than downstream. The average DO over time was 8.75 mg/L, which is a proper level for fish.

5 Hydrologic and Hydraulic Modeling

5.1 Hydrologic Modeling

A hydrologic analysis was conducted to determine design criteria for the restoration project. The hydrologic analysis includes developing a representative historic daily streamflow record for the Watertown site, developing a flow duration curve for the Watertown site, and determining design criteria/metrics for the stream restoration project. The design criteria include the 100-year streamflow event, the bankfull flow (assumed to be the 2-year recurrence event), and a low-flow flow to assure fish passage.

Long-term streamflow records were downloaded from the MNDNR/MPCA Cooperative Stream Gaging Network (http://www.dnr.state.mn.us/waters/csg/index.html). There were no long-term streamflow records where available at the Watertown dam site so the closest upstream and downstream gages were used to develop a representative flow record. The upstream gage is the South Fork Crow near Mayer at MN7 (MNDNR #19082001/USGS #05279000) and the downstream gage is the South Fork Crow at Delano (MNDNR #19001001). The available historic streamflow data is shown in Figure 17 for both the Mayer and Delano sites. As seen in Figure 17, the Mayer site (05079000) has a much longer historic record, with continuous data starting in 1934, running through 1979 with a break in data from 1979 to 1998, and data from 1998 to the present. The Delano site (19001001) has intermittent, continuous data from 1998 to the present.

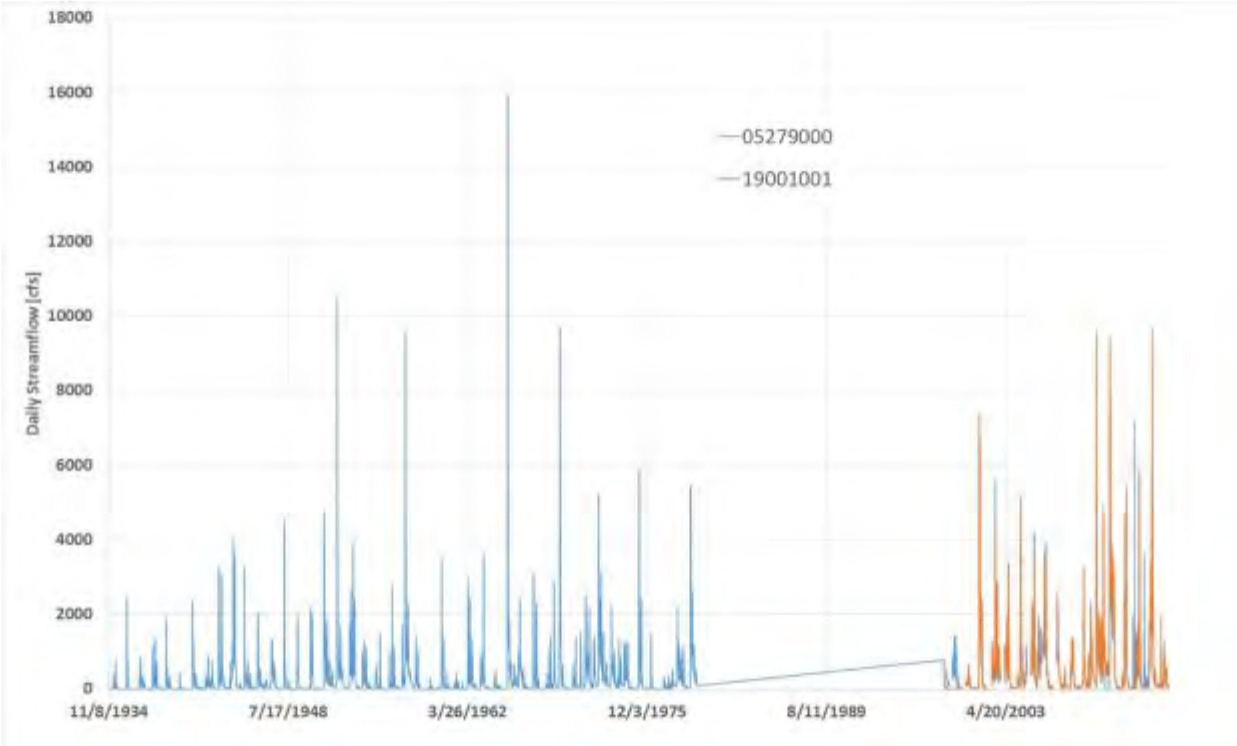

Figure 16. Historic daily streamflow records for the upstream and downstream sites near Watertown, MN.

The drainage are of the Watertown Dam is approximately 1,175 square miles, the drainage for the Mayer site is approximately 1,150 square miles and Delano is 1,269 square miles. The Mayer site is 26 square miles smaller than the Watertown drainage (or 2.2% smaller) and the Delano site is 92.5 square miles larger than the Watertown drainage (or 7.9% larger). There is no know major tributary between the Mayer and Delano sites, which could impact the use of either site as a surrogate for the Watertown site. The flow distributions for both sites were compared to see if there is significant difference between the flow distributions (Figure 18). The comparisons were made for days where both sites had recorded flows. As seen in Figure 18, there is little difference in the flow distributions, with the exception of were low flows. This difference in low flows is most likely due to the impact of the dam in Watertown, were during low flows the dam holds water and slowly releases water and creates a baseflow (as seen in the Delano record).

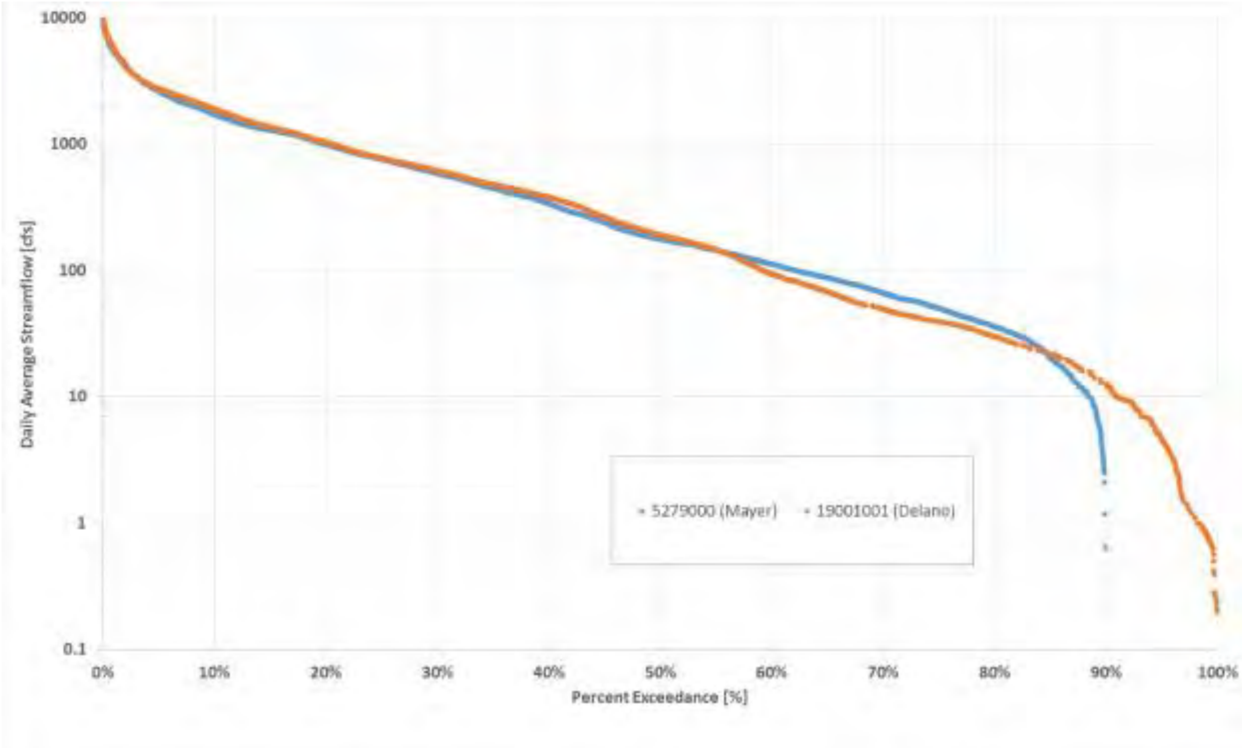

Figure17. Comparisons of flow distributions between Mayer, MN and Delano, MN gaging sites on the South Fork Crow River.

Since there is no significant difference in flow distributions between flow gaging stations (Figure 18), the small differences in drainage area, and the Mayer site has a much longer histioric record (Figure 17), it was dteremine the Mayer site is sufficant to represent flows at the Watertown dam.

The first few design metrics needed is the 100-year event and the channel forming flow, known as the bankfull flow. It was assumed the channel forming flow would be taken as the 2-year flood flow or a flow with a 2-year return period or 50% exceedence of annual maximum flows. To determine the 100-year event and the 2-year event, a flow duration curve of the annual maximum flows was generated (Figure 19). Figure 19 shows that, according to the Mayer streamflow record, the channel forming flow (i.e. bankfull flow) is approximately 2,560 cfs and the 100-year event is 15,900 cfs.

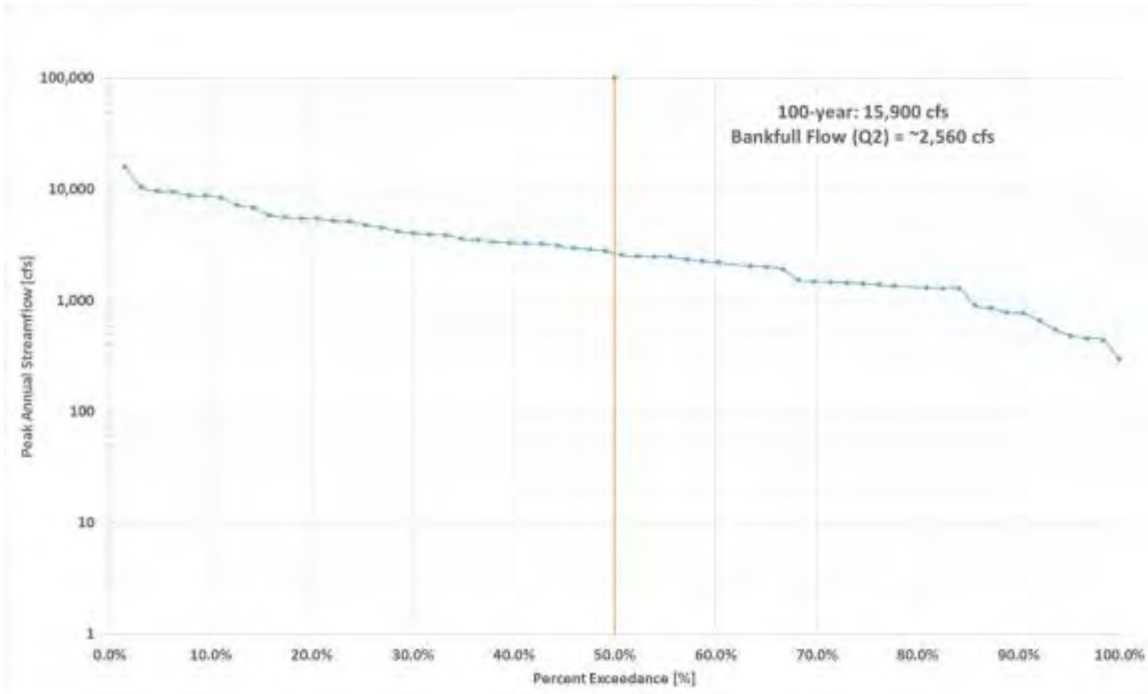

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Figure 18. Flow duration curve of maximum annual flows at Mayer, MN in the South Fork Crow River.

The 100-year event is also the maximum flow during the histroic record, so additional analysis was conduct to see if this is the hundred year event. The additional analysis was comparing the flows to the 100-year event used in the HEC-RAS model developed for the Federal Insurance Study (FIS) in the Crow River. The 100-year event from Figure 19 is a little higher than the 100-year event used in the FIS HEC-RAS model (e.g. 14,723 cfs). Since the FIS model determines the 100-year flood plain, the HEC-RAS model (used to aid the stream restoration design) is calibrated for a 100-year event of 14,723 cfs, and the uncertainity if the 100-year event in the streamflwo record is a true 100-year event, the FIS study 100-year event was determined to be more representative of the actual 100-yer event. Since the histroic record is much greater than 2 years, the 2-year bankfull flow was determined to be actual.

A goal of this restoration project was to allow greater fish passage by re-connecting the upstream and downstream potions of the dam. Through the hydrologic analysis , a realistic minimum design flow was determined to ensure greater fish passage. Fish passage throughout the year is not feasible, since the streamflow is zero during portions of the year and without completely removing the dam, some disconnect may occur. In addition, modeling the lowest flows may create uncertainity in the model and design that maybe greater than desired and not be cost effective. Because of the added uncertainity, it was determined the goal of providing additional fish would be to increase the portion of the year where fish passage is possible and ensure fish passage during spanning months (i.e. April and June). To determine the design low flow, a few metrics were investigated, including monthly flow distribution, 7-day low flows, and the liomits of the HEC-RAS model. To start the low flow analysis, a daily flow duration curve for the whole streamflow record at the Mayer site was created (Figure 20) for comparison purposes.

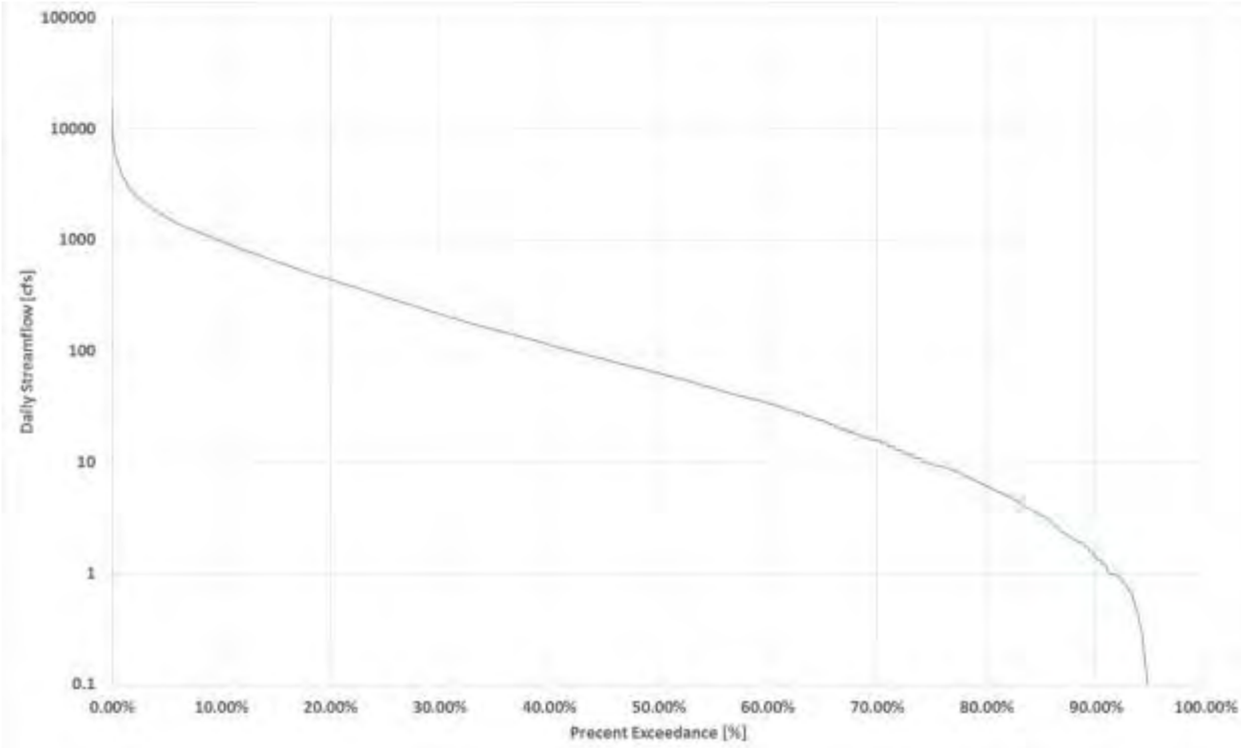


Figure19. Flow duration curve for daily streamflows at Mayer, MN is the South Fork Crow River.

The first metric investigated is the 7-day low flow which a typical water qality parameter. The 7-day low flow is the lowest 7-day average flow in a year. The flow duration curve for the miminum 7-day average flows is provided in Figure 21. The 2-year return period 7-day low flow is 7.3 cfs. This flow is the miinum flow which occurs at least 50% of the time.

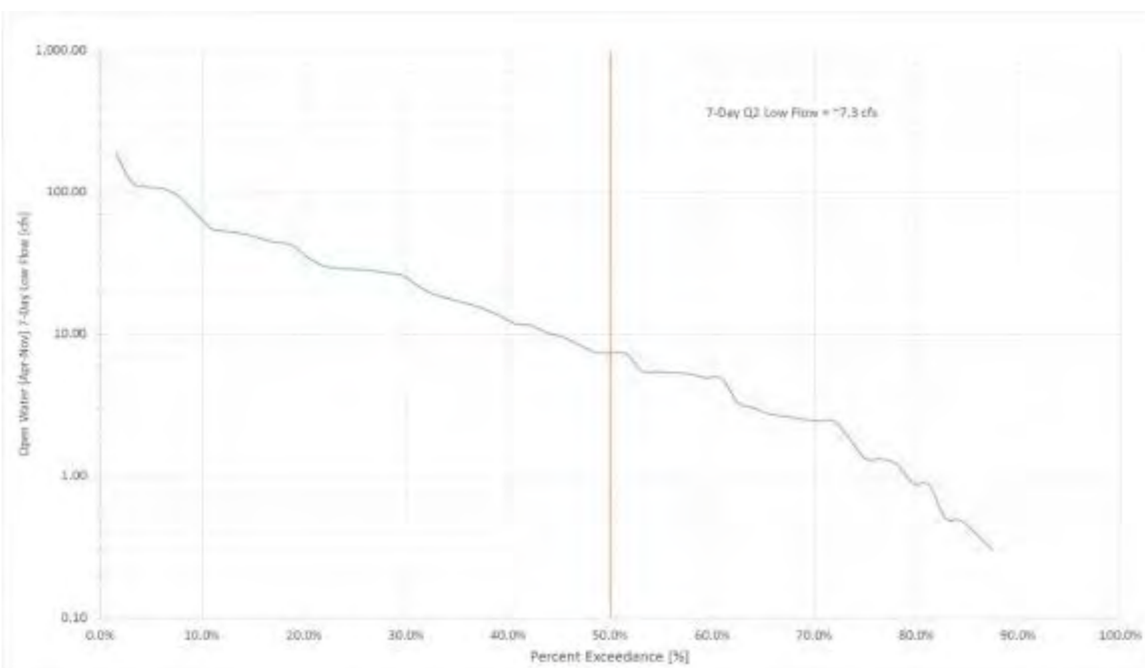


Figure20. Flow duration curve for annual minimum 7-Day low flow at Mayer, MN in the South Fork Crow River.

Next, the monthly flow distributions during the open water season (April-November) were plotted to see what flows occurred during important months (Figure 22). Figure 22 shows the lowest flows by month decrease throughout the open water season, with the highest low flows occurring during April and decreasing throughout the year, with the lowest low flows during the open water season occurring in November.

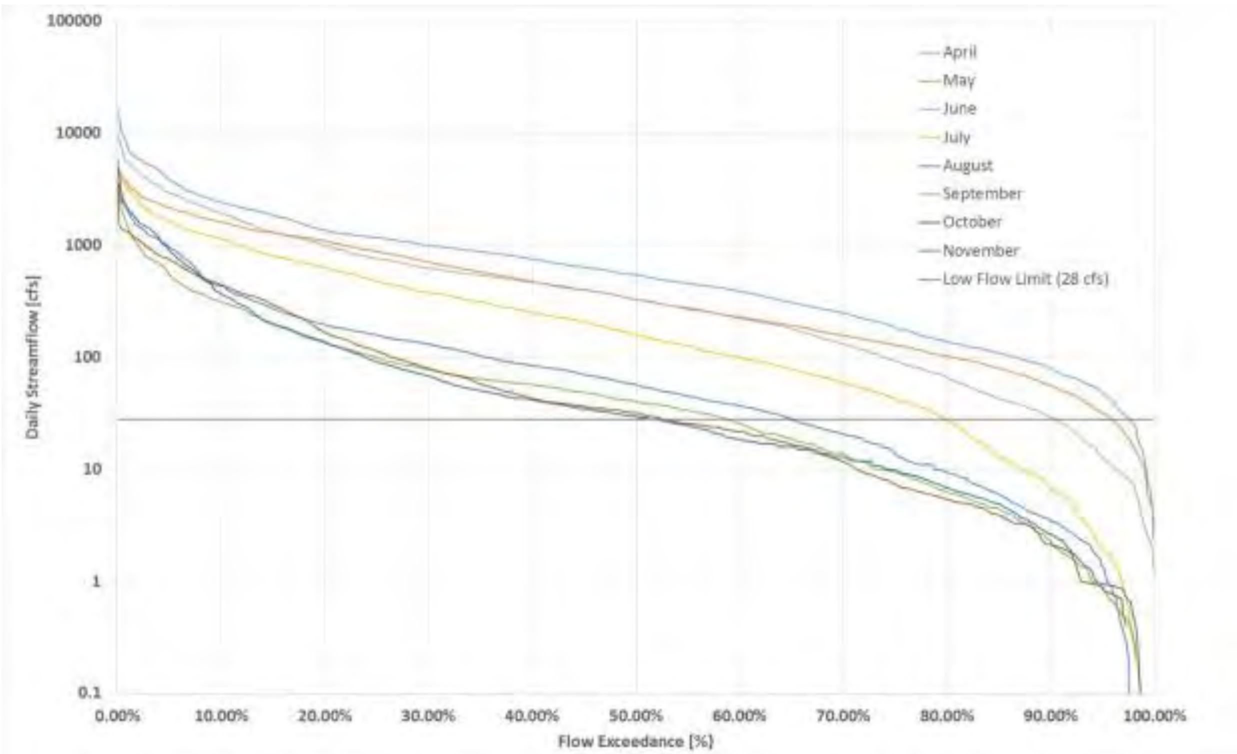


Figure21. Flow duration curves by month for daily streamflows at Mayer, MN in the South Fork Crow River.

During study of the Watertown Dam project, two field surveys were conducted. During those field studies, water surface elevation and flows were measured. The flow during one of those field visits was 28 cfs. The field observations were then use to calibrate the HEC-RAS model. It was determined that since observed data was available for the 28 cfs flow regime, it would be best to use that as the low flow condition to ensure canoe and fish passage. This design low flow will occur at least 62.5% of the time throughout the year (Figure 20) and will occur at least 90% of the time during important spawning months (April-June) and will provide connectivity during important months without add addition costs to design for lower flows.

5.3 Hydraulic Modeling

Hydraulic modeling was performed to both assess the current condition of the dam and to compare the with-project conditions to quantify the performance for fish passage, recreational passage, upstream pool conditions, and flood conditions. Both a one-dimensional HEC-RAS hydraulic model and a two-dimensional Adaptive Hydraulics (AdH) model were used in assessment of the hydraulic conditions. Four flow conditions were selected to analyze in each hydraulic model. A description of these flow conditions is found in Table 5.

Flow (cfs)	**Description**
28 cfs	*Low-flow conditions, present during surveying*
575 cfs	*Moderate flow, tailwater conditions match dam crest elevation*
2,560 cfs	*Bankfull conditions, occur approximately every two years*
14,723 cfs	*1% Annual Chance Exceedance Event*

Table 5: Flow conditions selected for hydraulic modeling purposes.

Modeling of flow conditions through this range should allow for a thorough assessment of fish and boat passage for a full range of flows and help in the design of the selected layout and rock sizing. The first step in the modeling process is to calibrate the model to existing conditions. Surveyed cross-sections collected in October 2015 were merged into the geometry and the model was calibrated to a low-flow and high-flow condition. The low-flow condition was the flow measured on the date the survey data was collected. The flow, estimated at 28 cfs, is a reasonable lower limit to pass fish for a dam modification at this site. A detailed water surface profile of the 28 cfs profile was collected along with the surveyed cross-sections. This data allows for detailed calibration for this event. The high-flow calibration involved calibrating the updated geometry to the previous Flood Insurance Study (FIS) for the 1% annual chance exceedance event (1/100-year event). The 28 cfs calibration for both the 1D and 2D model compared to surveyed data is shown in Figure 17. The FIS flow calibration for the updated 1D model is shown in Figure 17.

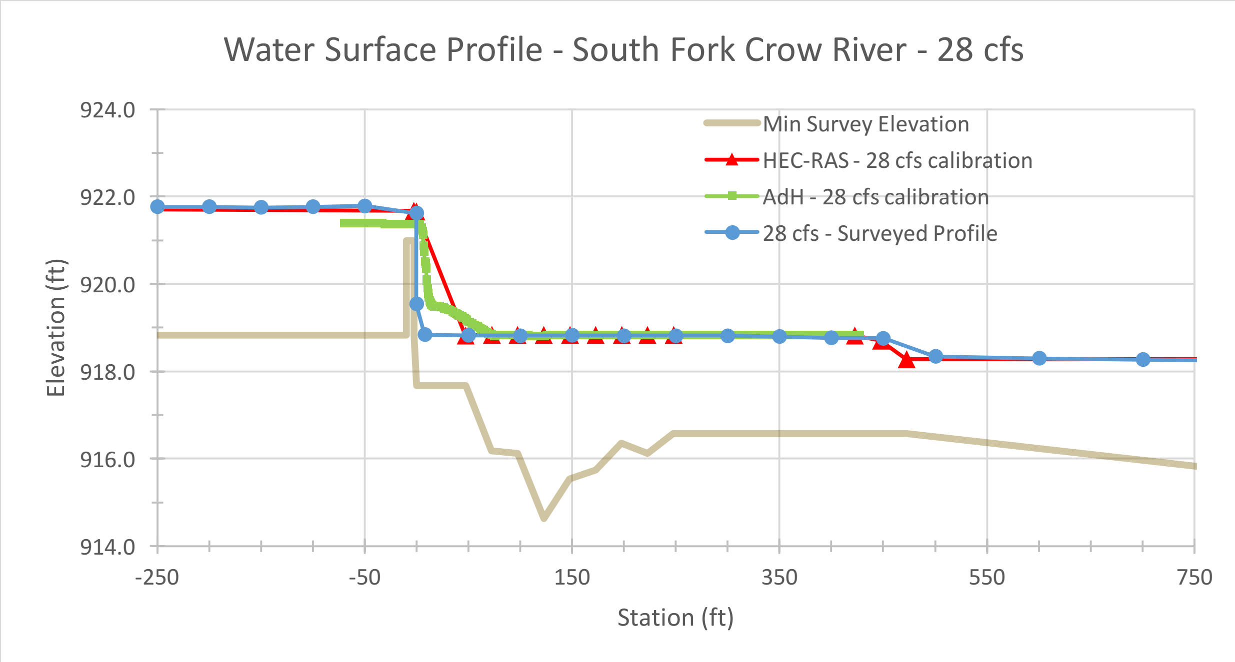


Figure 22. Hydraulic Modeling Calibration to Existing Conditions for 28 cfs profile

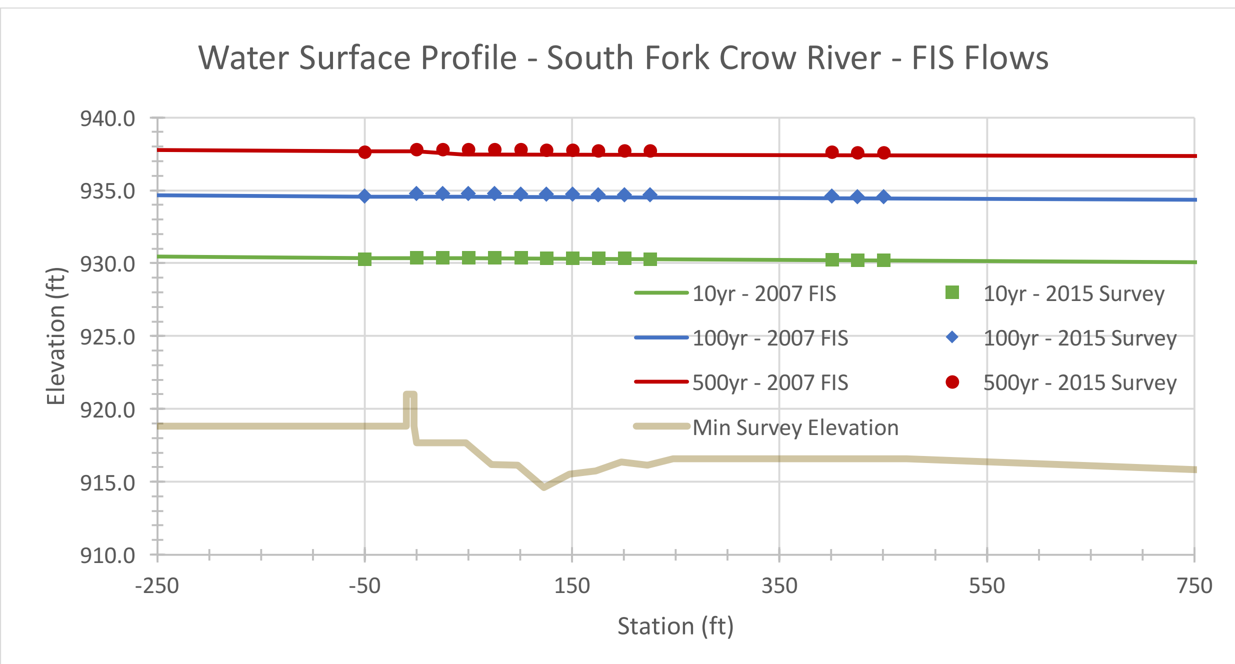


Figure23. 1D Calibration to FIS Flood Profiles

A three-dimensional surface that represents the conditions in both the 1D and 2D models is shown in Figure 25.

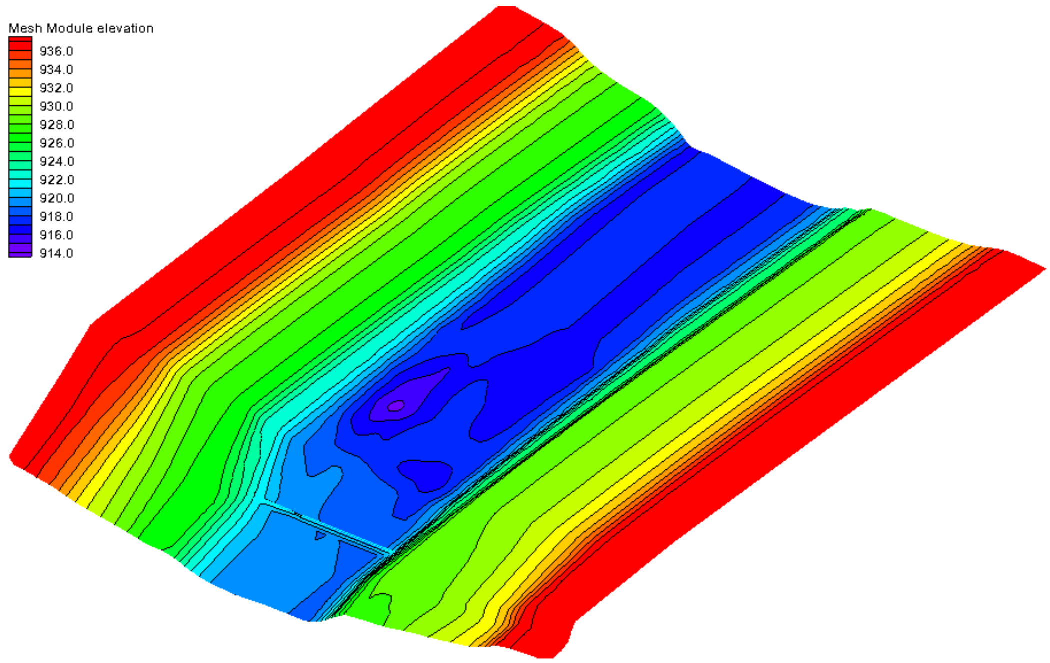


Figure24. Three-dimensional surface of the existing conditions used in both the 1D and 2D models.

The proposed design for the modification to the Watertown Dam involves both modification of the dam itself and the addition of rock structures downstream of the dam. The main concept behind this design is to include downstream rock structures to create headloss and raise the tailwater below the dam so that low to moderate flows pass over the dam as subcritical flow rather than plunging over the dam in supercritical flow. The selected way to achieve this headloss is to install a series of rock "deflectors" downstream of the dam. Deflectors direct flow toward the center of the channel rather than the banks. By designing these rows of deflectors as "double deflectors", or complimentary deflectors that meet near the middle of the channel, low flows are concentrated through a narrow opening. This design creates a series of pools between each double deflector row. For fish trying to migrate upstream, they can travel through short bursts between the deflectors and rest in the intermediate pools. Canoes and kayaks traveling downstream can drop gradually in elevation across a series of drops rather than one large, fairly impassable drop. With the downstream deflectors in place, the notch in the dam can be enlarged without losing the upstream pool. This larger notch with give a better passage for both fish and boats across the dam. A planview and profile sketch of a typical deflector is shown in Figure 26. A sketch of the modification of the dam notch is shown in Figure 27.

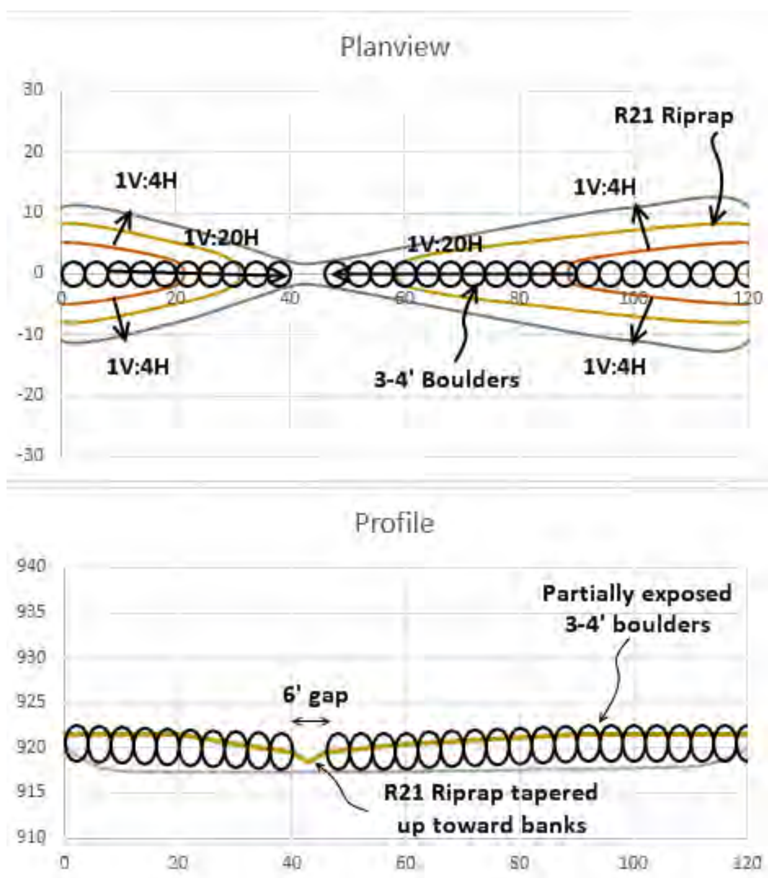


*Figure25. **Planview and Profile View of a Typical Deflector***

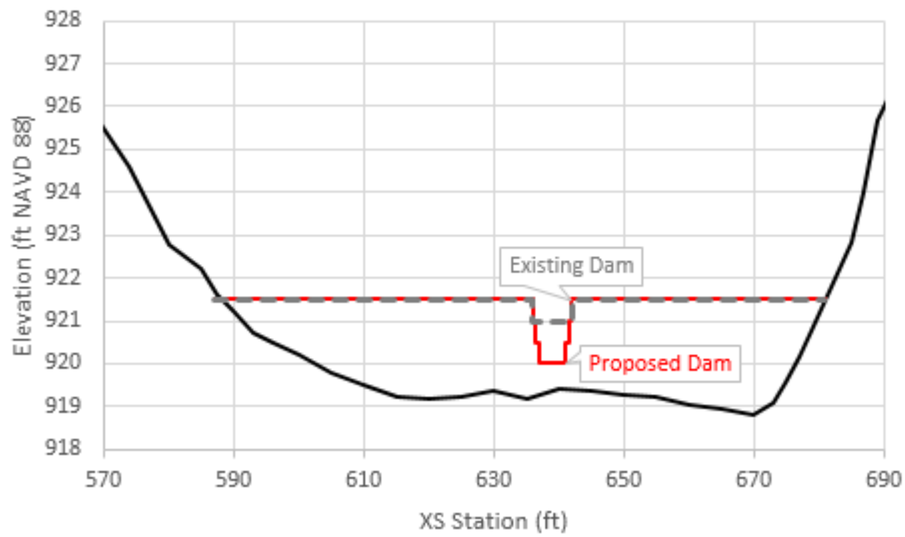


*Figure 26. **Comparison of Existing Dam Crest with Proposed Notch Modification***

The proposed design includes 5 rows of double deflectors downstream of the dam. A configuration of 5 double deflectors allows fish passage for flows as low as the calibrated 28 cfs profile. Alternate configurations with more deflectors could allow fish passage for even lower flows. Conversely, an alternate configuration with less deflectors could be more cost effective, but may not pass fish for as wide of range of flows. The 3D surface of the design geometry for the 1D and 2D model is shown in Figure 28.

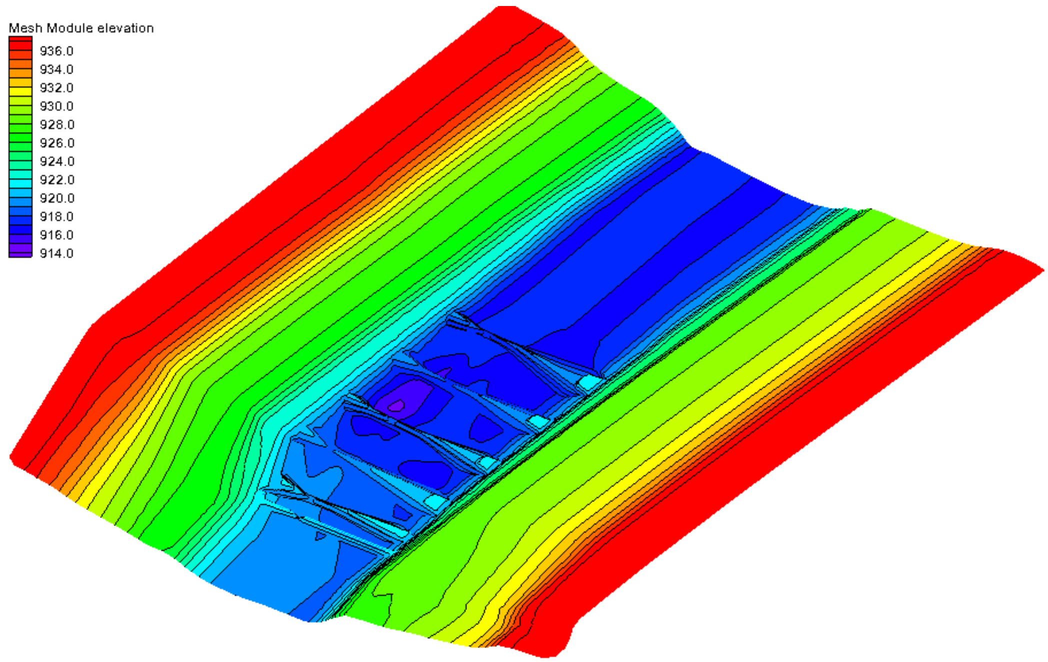


Figure27. Three-dimensional surface of the proposed design used in both the 1D and 2D models.

The first goal is to adjust the design to ensure the upstream pool elevation is not reduced during low flows and not increased during flood flows. After adjustments were made to the downstream deflectors and dam notch, the proposed design achieved the upstream pool goals. The modeling results for these two goals are shown in Figure 29 and Figure 30.

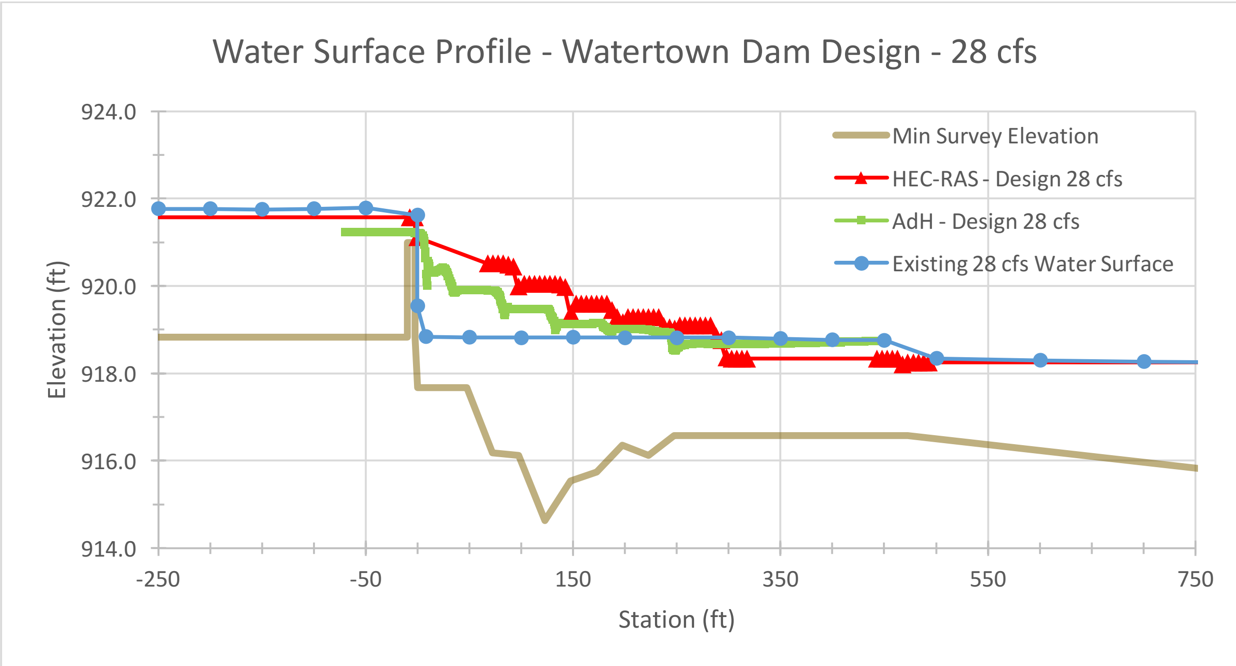


*Figure28. **Proposed Design Conditions compared to Existing Surveyed Conditions.***

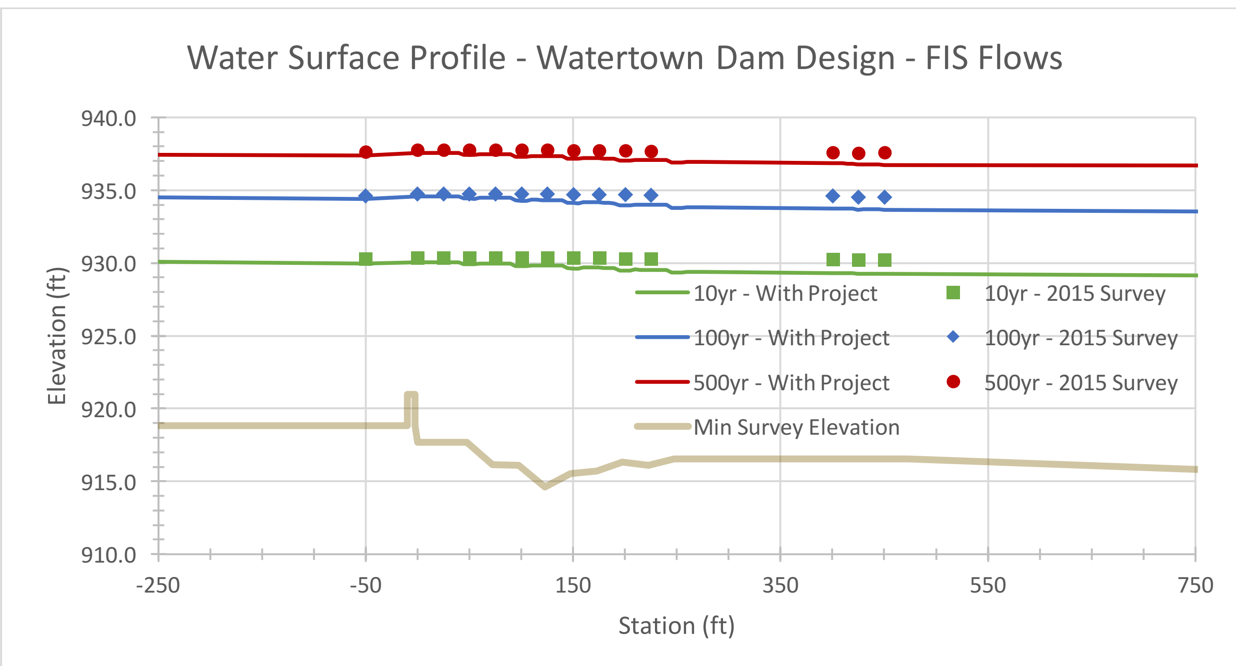


*Figure29. **Proposed Design Conditions compared to FIS Flood Flow Conditions showing no upstream impacts.***

The following series of plots (Figure 31 through Figure 34) show the 2D model results for existing and with project conditions for comparison.

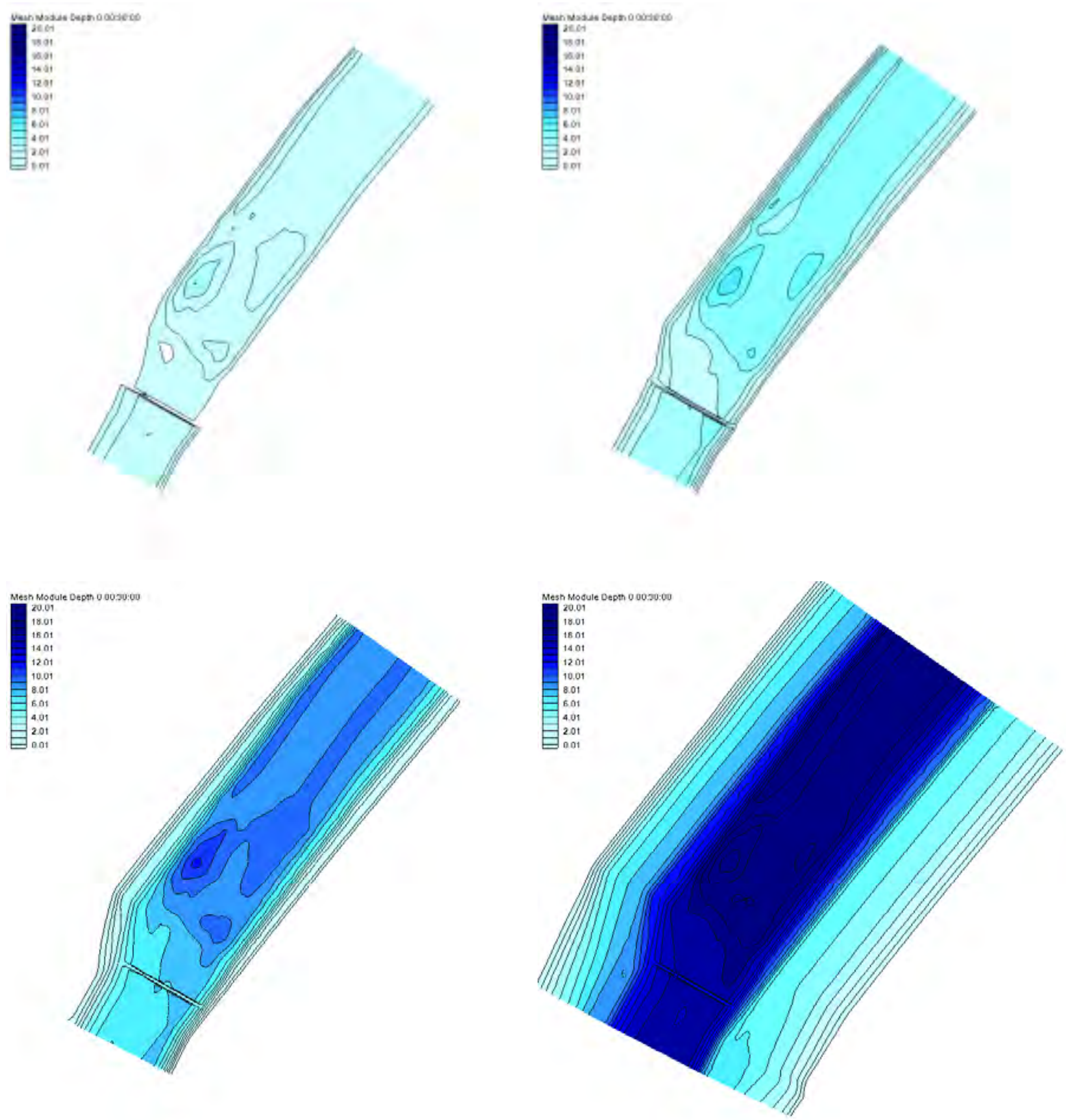


*Figure30. **Depth (ft.) plots of the existing condition model runs***

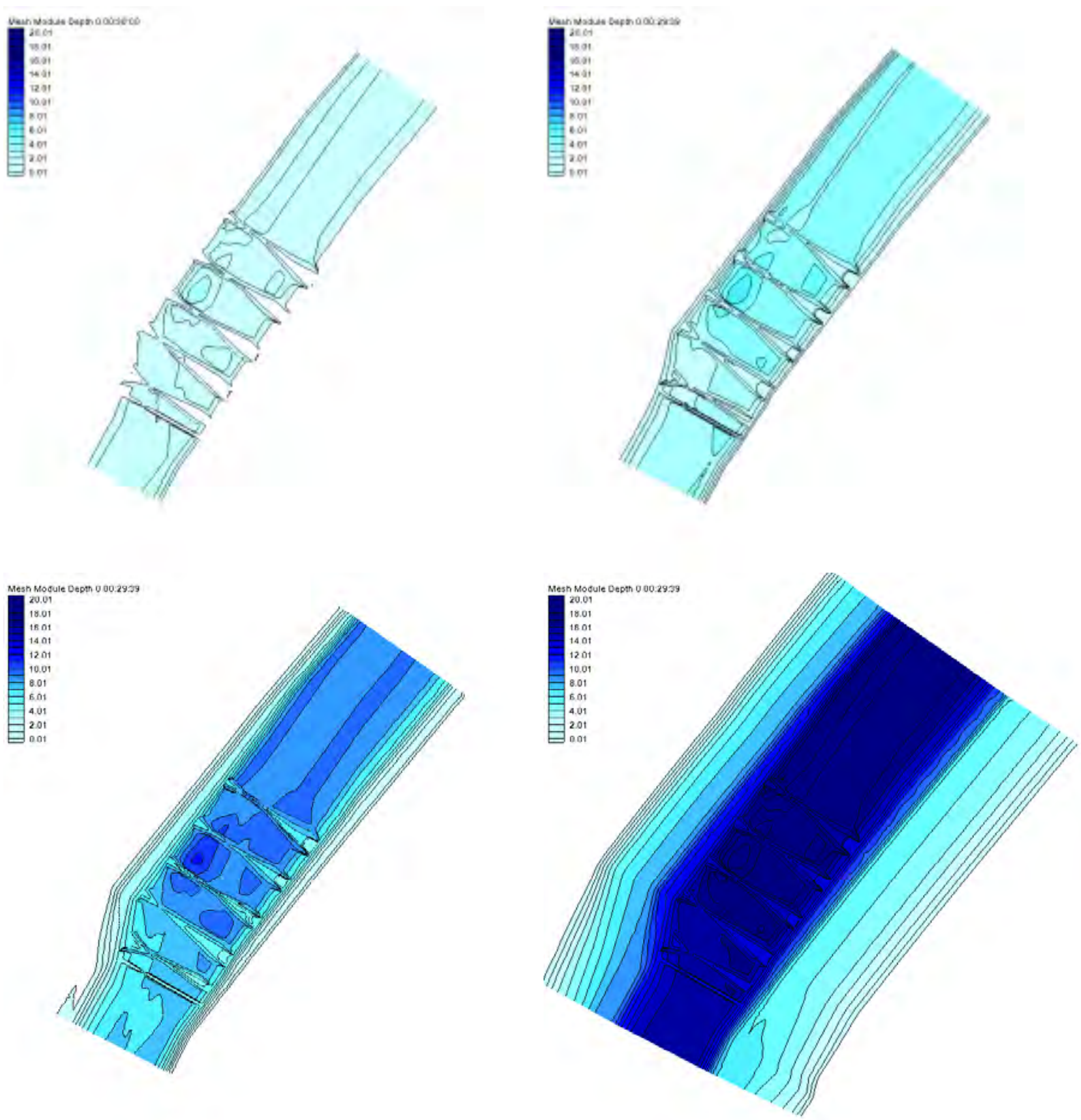


Figure 31. ***Depth (ft.) plots of the proposed design model runs***

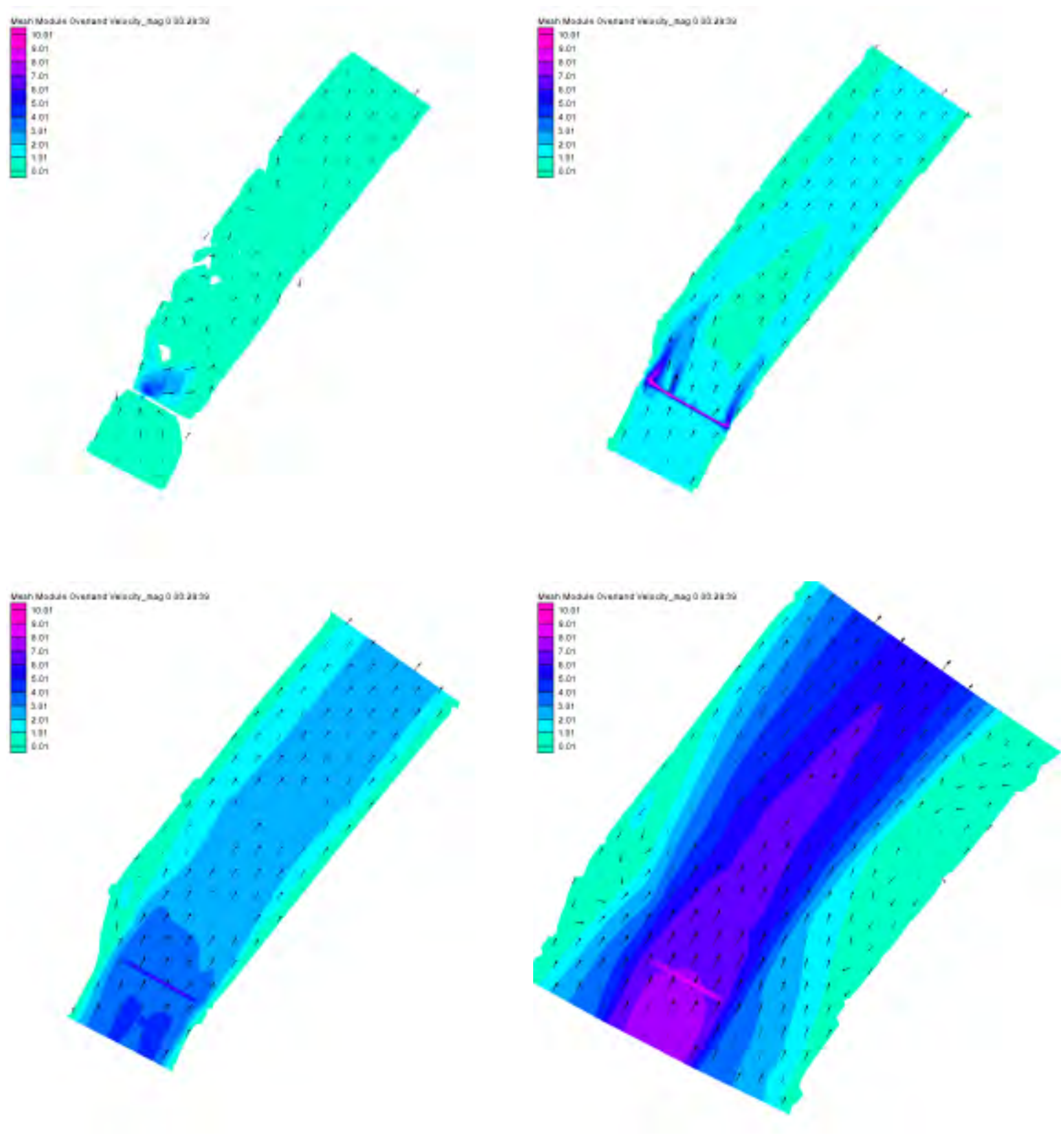


Figure 32. Velocity (ft./s) plots of the existing condition model runs

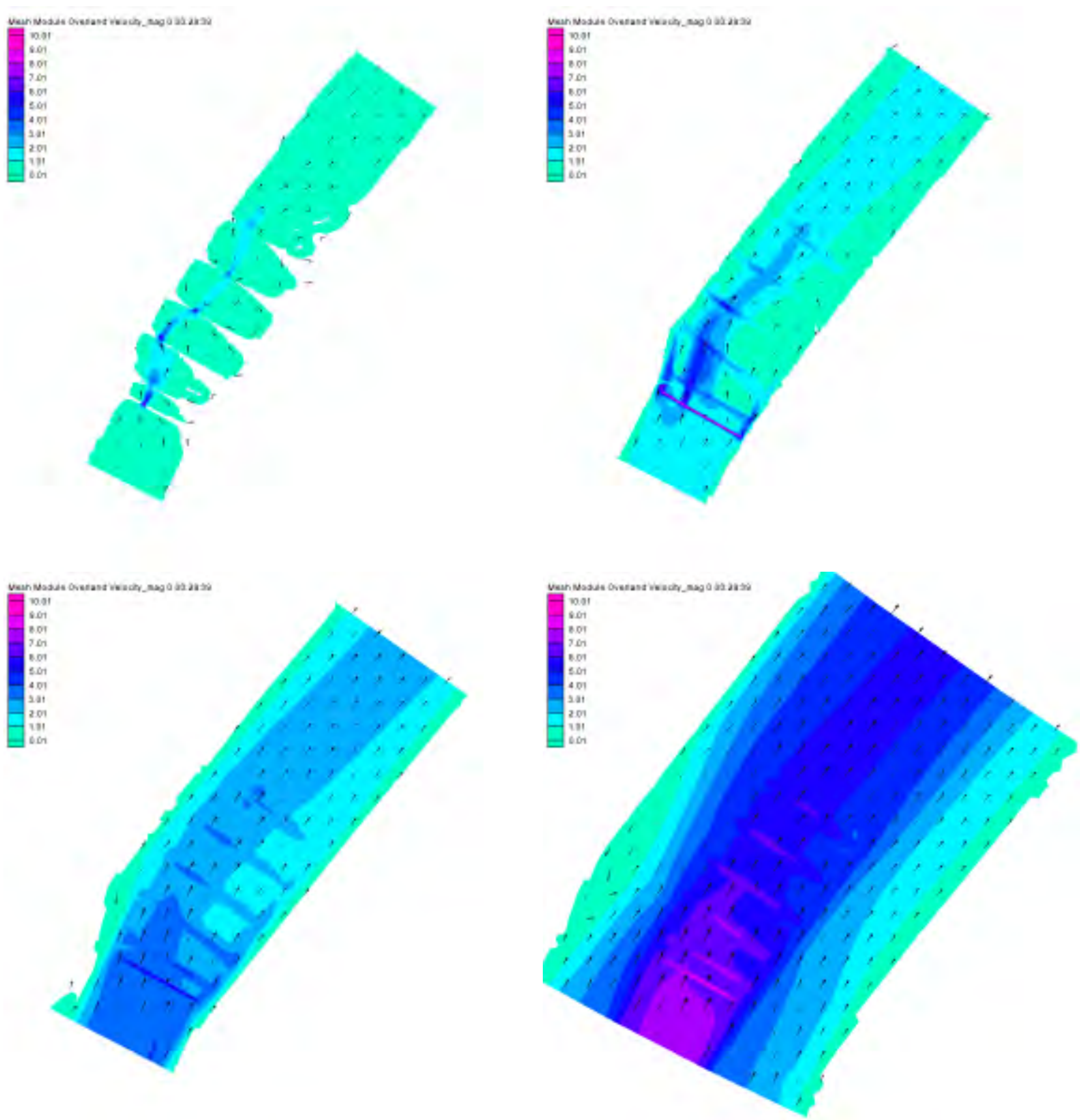


Figure 11. Velocity (ft./s) plots of the proposed design 28cfs, 575cfs, 2560cfs, and 14723cfs model runs

In general, the proposed design improves conditions for both fish passage upstream and boat passage downstream and meets the upstream pool constraints for low flows and high flows. Table 6 gives a summary of depths and velocities for the existing and with-project conditions shows passable areas for fish for the full range of flows.

Table 6. Summary of Depth and Velocity Conditions for with and without proposed project design

		Existing Dam Conditions			w/Project Dam Conditions			w/Project Deflector Conditions		
		Center*	Fringe**		Center	Fringe		Center	Fringe	
28 cfs	Velocity	?***	-	ft./s	8.0	4.0	ft./s	5.5	3.0	ft./s
575 cfs		12.5	11.5	ft./s	8.5	4.5	ft./s	4.0	2.5	ft./s
2560 cfs		5.0	3.5	ft./s	4.5	3.0	ft./s	3.5	2	ft./s
14723 cfs		8.0	6.0	ft./s	8.0	6.0	ft./s	6.5	5	ft./s
28 cfs	Depth	~0	0	ft.	1.0	0.5	ft.	1.2	0.9	ft.
575 cfs		0.6	0.1	ft.	1.5	0.8	ft.	3.5	1.5	ft.
2560 cfs		5.0	4.0	ft.	6.0	4.5	ft.	8	6	ft.
14723 cfs		14.5	14.0	ft.	14.3	13.8	ft.	16.5	14.5	ft.

*The "Center" values refer to peak velocities through the opening in the dam or between the deflectors and the associated depth

**The "Fringe" values refer to representative velocities away from the center (either around the dam or over the deflectors) where there is at least 0.5 ft. of depth

***For the existing conditions at the dam during the 28 cfs run, flow through the notch is three-dimensional and velocities and depths cannot be modeled in 2D. Conditions are impassable for fish.

6 Erosion and Sediment Transport

6.1 Sediment Transport

In order to estimate sediment transport, we have analyzed the 3 cross-sections surveyed in the field. One cross-section is 50ft upstream of the dam, and the other two cross-sections are 100 and 225ft downstream of the dam. The three cross-sections have different bed topographies and grain size distributions. The analysis of the downstream sections has been divided into different subdivisions, representing singular conditions. In the first downstream cross-section (100ft), there are deep pool and shallow pool subdivisions. In the second downstream cross-section (225ft), the subdivisions represent two different characteristic grain sizes (boulders + gravel and sand) in the center and side of the section.

Two flow conditions have been evaluated: low and high flows. The low flow is comparable to the conditions seen in the field during the October field visits ($Q_{low\ flow}$= 28cfs). High flow has been assumed to be the upstream bankfull discharge (Q2); the water depth and discharge have been estimated based on the cross-section topography and Manning's equation ($Q_{high\ flow}$= 2,560cfs).

Cross-sections maximum water depths studied:

	Upstream (-50 ft)	Downstream (100ft)		Downstream (225ft)
		Shallow pool	Deep pool	
Water Depth low flow [ft]	2.8	1.2	3.42	1.36
Water Depth high flow [ft]	7.6	8.2	10.4	8.4

The first parameter needed to estimate bed load is the dimensionless Shield's stress (τ*) (1936). Assuming a gravity driven, steady and uniform channel, the Shield's stress can be calculated as:

$$\tau_0 = \rho g R S$$

Where, ρ_f=998kg/m^3 ; g =9.81m/s^2 ; R (hydraulic radius) which is assumed to be the water depth when the channel width is much greater than the water depth; and the slope (S).

The longitudinal slopes observed are $S_{upstream}$= 2E-4ft/ft., $S_{downstream100}$= 4E-4ft/ft., and $S_{downstream225}$= 1E-6ft/ft.

The dimensionless form of the shear stress is:

$$\tau_* = \frac{u_*^2}{g(s-1)D} \qquad u_* = \sqrt{\frac{\tau_0}{\rho}}$$

Where, D is the characteristic particle size. The D_{50} has been used as a representative particle size. The different D_{50} used are:

1. Upstream D_{50}= 0.5mm (approximation from the sediment sample, but it has not been analyzed in the laboratory)
2. Downstream 100ft: D_{50}= 34.84mm
3. Downstream 225ft (2 subdivisions): D_{50}= 100mm (boulders+gravel) D_{50}= 1mm(sand)

The dimensionless Shield's stress is different for the 10 cases studied due to the different water depths and characteristic grain sizes:

	Upstream (-50 ft)	Downstream (100ft)		Downstream (225ft)	
		Shallow pool	Deep pool	D1 (gravel)	D2 (sand)
τ* low flow	0.21	0.001	0.004	2.50E-06	3.00E-04
τ* high flow	0.56	0.009	0.011	1.55E-05	0.002

The second parameter needed to know if there is sediment transport is the critical shear stress. We have used Brownlie's formula:

$$\tau_c^* = 0.22\,\mathbf{Re}_p^{-0.6} + 0.06 \cdot 10^{(-7.7\mathbf{Re}_p^{-0.6})} \qquad \mathbf{Re}_p = \frac{\sqrt{(s\text{-}1)gD}\,D}{\nu}$$

	Upstream (-50 ft)	Downstream (100ft)		Downstream (225ft)	
		Shallow pool	Deep pool	D1 (gravel)	D2 (sand)
τc*	0.03	0.06	0.06	0.03	0.06

When the dimensionless Shields' stress is greater than the critical shear stress, then sediment transport occurs. Looking at the Shield's and critical shear stresses from the previous tables, only in the upstream section this condition happens in both high and low flow.

Based on these two parameters we have calculated the bed load at the upstream section using three methods:

- Meyer-Peter & Müller (1948) formula:
  $q^*b=K^*(\tau^*-\tau^*c)^{3/2}$ (K=4, Parker's modification).

- Ashida-Michiue (1972) formula for bedload:
  $q^*b=17^*(\tau^*-\tau^*c)^*(\sqrt{\tau^*}-\sqrt{\tau^*c})$

- Parker (1979) fit to Einstein (1950):
  $q^*b=11.2^*(\tau^{*1.5})^*(1-(\tau^*c/-\tau^*))^{4.5}$

The results are dimensionless; in order to convert to a dimensional load, the D_{50}, g and R are needed.

Summary of bedload (m2/s)	Meyer-Peter & Müller formula	Ashida-Michiue	Parker (1979) fit to Einstein (1950)
Upstream Low flow	0.01	0.02	0.01
Upstream High flow	0.08	0.12	0.09

The greatest bedload occurs during high flows. During the field visits, the sediment accumulated behind the dam was measured. The small volume of sediment accumulated is a sign of the particles being flushed downstream during high flow events. In the design proposed the same flashing process will happen.

The Van Rijn (1984a,b) equations have been used to estimate the suspended load upstream of the dam. Based on the Van Rijn's equations, 1.79E-5 m^2/s of suspended load exists in the present conditions. For the designed solution with the modified dam, the estimated suspended load is 1.89E-5 m^2/s (percentage of increase in suspended load: 5.6%).

6.2 Scour Downstream of Deflectors

In our design we have incorporated stream deflectors, constructed one on each bank opposite to each other. These hydraulic structures limit the flow channel width and accelerate the flow through the constricted segment. The increased flow velocity at depth can generate an area of scouring, forming a pool downstream of the deflectors. Pagliara et al. (2015) investigated the scour phenomena downstream of log deflectors in straight horizontal channels and developed equations to predict the main scour parameters (maximum scour depth and length).

An estimation of the maximum scour depth has been done following Pagliara et al. (2014 and 2015) results. Pagliara et al. (2014) developed two non-dimensional parameters:

$Z^* = (z_m/h_{st})/(l_{st}/B)$ and $Z^{**} = Z^* /(h_{st}/h_{tw})$,

Where z_m is the maximum scour depth, h_{st} and l_{st} are the height and length of the structure, and h_{tw} is the tailwater depth.

Pagliara et al. (2015) developed the following equation for log deflectors:

$Z^{**} = 6.6\ \eta^{0.7}$

Where $\eta = F_d^2 \cdot \Delta y/h_{st}$ (Pagliara and Kurdistani, 2013); F_d is the densimetric Froud number; Δy is the difference between water surface upstream and downstream of the structure.

According to their flume experiments, the design suggested for this project is similar to their morphology Type C (Figure 35), which corresponds to an observed $\eta \leq 0.46$.

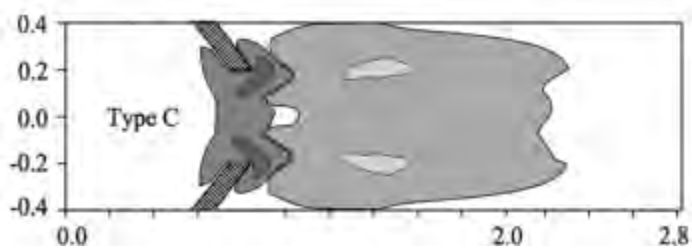


Figure34. Morphology Type C for double-wing log deflector. Pagliara et al. (2015)

Using the design parameters of height and length of the deflectors, in addition to the estimated tailwater depth for low flows where the deflectors are not submerged, the non-dimensional parameters are Z^{**}= 3.48 and Z^{*}= 3.97. The maximum scour depth has been estimated to be approximately 2.4m. In these calculations, the effect of having a consecutive set of deflectors is not taken into account, which would reduce the scour depth. Assuming that the effect of having a series of deflectors would decrease the scour depth and taking into account that the results represent maximum scour depth, we have added to the design a 1 m pool after the deflectors as an approximation of the scouring process. Finally, the last deflector will have the greatest scouring depth, and the sediment will be transported downstream. In order to minimize that scouring depth, this last deflector should have a shorter length, letting a wider opening between deflectors.

An additional model run was completed for the future conditions, assuming the maximum estimated scour occurred at the site. The maximum estimated scour for the intermediate pools is 1 meter (~3 ft.) and for the downstream end of the structure it is estimated at 2 meters (~6 ft.). The modeled water surface elevation and velocity show little difference than the proposed design conditions, although as expected, depths are greater between the deflectors. Plots of the depths and velocities for 28 cfs during future conditions are shown in Figure 36.

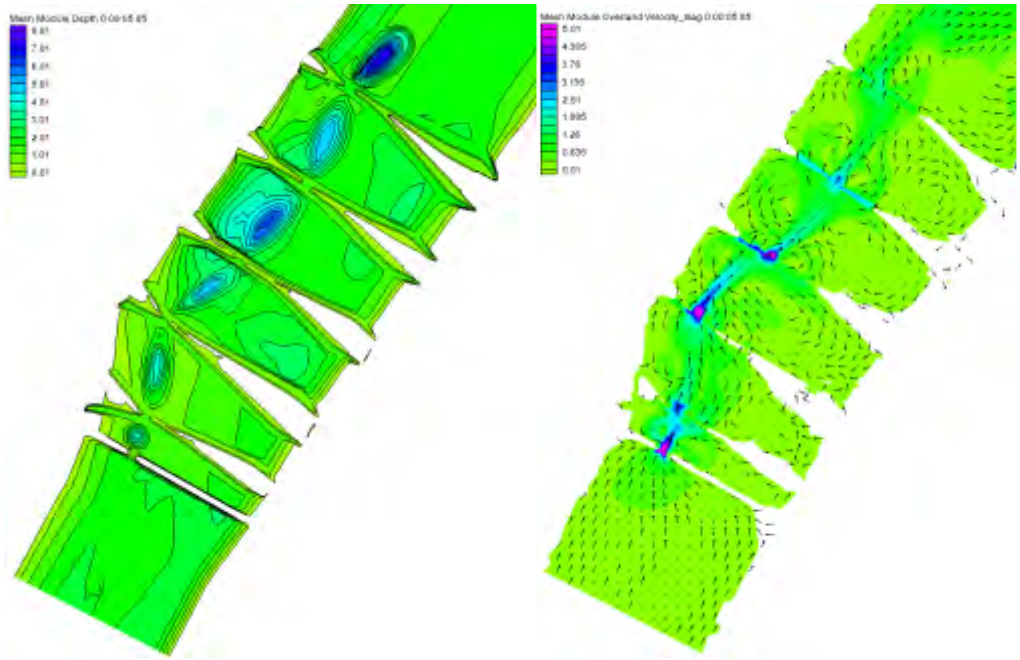


Figure35. ***Depth (left) and Velocity (right) plots of future conditions with estimated maximum scour depths***

6.3 Bank Erosion (Rosgen Analysis)

A Rosgen analysis was completed on the large, bare right bank directly downstream of the dam. It is evident that a significant amount of sediment enters the river from this bank during high flow events. The bank shows signs of sloughing and instability given the near vertical slope.

Figure36. Eroded Bank

The first step of the Rosgen analysis was to develop Bank Erosion Hazard Index, also known as a BEHI. The following table was used to determine the BEHI Rating.

Bank Erosion Hazard Index (BEHI): 100-ft Downstream of Dam						
Study Bank Height to Bankfull Height						
A		B		C		BEHI Score (fig. 3-7)
Study Bank Height (ft.)	11	Bankfull Height (ft.)	7.8	(A)/(B)	1.42	5 (Moderate)
Root Depth to Study Bank Height						
D		A		E		BEHI Score (fig. 3-7)
Root Depth (ft.)	8.2	Study Bank Height (ft.)	11	(D)/(A)	0.74	3 (Low)
Weighted Root Density						
		F		G		BEHI Score (fig. 3-7)
		Root Density as %	60	(F) X (E)	44%	4.5 (Moderate)
Bank Angle						
				H		BEHI Score (fig. 3-7)
				Bank Angle in Degrees	85	7 (High)
Surface Protection						
				I		BEHI Score (fig. 3-7)
				Surface Protection as a %	60	3.5 (Low)
Bank Material Adjustment						
Bedrock (Overall Very Low BEHI) Boulders (Overall Low BEHI) Cobble (Subtract 10 points) Gravel/Composite Matrix (Add 5-10 points depending on Sand Content) Sand (Add 10 Points) Silt/Clay (No adjustment, unless primarily clay- then subtract 20 points)					▶	0
Total Score:						**23 (Moderate)**

A total BEHI scores is an adjective rating of moderate. This rating will be used with the Near-Bank Stress rating to determine the annual erosion rate from the specified slope.

The Near-Bank Stress was determined by dividing the mean bankfull depth across the channel by the maximum near-bank depth at bankfull. The mean bankfull depth at the riffle cross section at the start of the study bank is 8.92 feet. The maximum near-bank depth at bankfull along the study bank is 10.41 feet. The ratio is 1.17 giving the Near-Bank Stress an adjective rating of low.

With the Near-Bank stress and the BEHI rating, the annual erosion volume in cubic feet as well as the unit volume in tons per linear foot were determined. The annual erosion volume expected from the specified slope is approximately 132 cubic feet per year. The annual unit erosion rate is 0.06 tons per year per linear foot.

Station	BEHI Rating	NBS Rating	Bank Erosion Rate (ft./yr.)	Length of Bank (ft.)	Study Bank Height (ft.)	Erosion Subtotal (ft.^{3}/yr.)	**Unit Erosion Rate (tons/ft./yr.)**
SF Crow Dam	Moderate	Low	0.12	100	11	132	**0.06**

Reductions to this rate of erosion would be expected with the proposed restoration work. The rock ramp design should concentrate the flows away from the banks thus lowering the Near-Bank Stress and the additional slope stability provided by riprap will help reduce the expected annual bank erosion.

7 Biological Condition (Fish Habitat)

A healthy fish population is not only important ecologically but financially as well, every year anglers spend $1.8 billion dollars in Minnesota (MN DNR 2015). By designing a system that will allow fish passage under most flow rates fish will now be able to hunt for food up and down the full 96 miles of the south fork of the Crow River. A way of testing if fish species will be able to swim upstream is by comparing the water velocity models with fish burst speeds (speed a fish can swim for 15 seconds). The following table shows 11 fish species found in the South Fork of the Crow River with their ability to pass through to the dam.

Fish	**Fish passage post mod 28cfs dam/ deflector**	Fish passage pre mod 575 cfs	**Fish passage post mod 575 cfs dam/ deflector**	Fish passage pre mod 2560 cfs	**Fish passage post mod 2560 cfs dam/ deflector**	Fish passage pre mod 14723 cfs	**Fish passage post mod 14723 cfs dam/ deflector**
Bluegill	**Yes/No**	No	**No/Yes**	Yes	**Yes/Yes**	No	**No/No**
Channel Catfish	**No/Yes**	No	**No/Yes**	Yes	**Yes/Yes**	No	**No/No**
Common Carp	**Yes/Yes**	No	**Yes/Yes**	Yes	**Yes/Yes**	No	**No/No**
Largemouth Bass	**No/Yes**	No	**No/Yes**	No	**Yes/Yes**	No	**No**
Northern Pike	**No/Yes**	No	**No/Yes**	No	**Yes/Yes**	No	**No/No**
Pumpkin Seed	**No/No**	No	**No/No**	No	**No/Yes**	No	**No/No**
Smallmouth Bass	**Yes/Yes**	No	**Yes/Yes**	Yes	**Yes/Yes**	Yes	**Yes/Yes**
Spotfin Shiner	**No/No**	No	**No/No**	No	**No/No**	No	**No/No**
Walleye	**Yes/Yes**	No	**Yes/Yes**	Yes	**Yes/Yes**	YEs	**Yes/Yes**
White Sucker	**Yes/Yes**	No	**Yes/Yes**	Yes	**Yes/Yes**	No	**No/Yes**
Yellow Perch	**Yes/Yes**	No	**Yes/Yes**	Yes	**Yes/Yes**	No	**No/Yes**

To determine if the fish can swim through the dam, burst speeds (HDR Engineering 2014) had to be greater than the water velocity as well as water depth had to greater than .5ft. Also, as shown on the chart some fish are able to swim in the area around the deflectors but are not able to make it through the notch in the dam. The area around the deflectors should add cover for fish habitat so there is some benefit in fish being able to swim in this area but not make it up the dam.

At 28 cfs no fish are able to pass through the dam in its existing condition but 5 of the 11 fish species are able to pass if modifications are made. At 575 cfs no fish are able to pass pre modifications and 5 of the 11 fish after modification. At 2560 cfs the bankfull flow, 7 fish will be able to pass pre modification and 9 fish after modification. Finally, at 14723 cfs the walleye and smallmouth bass are the only two fish able to swim upstream under extremely high flows in both the pre and post modification model. There are two considerations with this test, that burst speeds are not a very conservative estimate for fish travel and that the velocity are not precise enough to predict the very slowest regions of flow like along the bottom or sides of the channel.

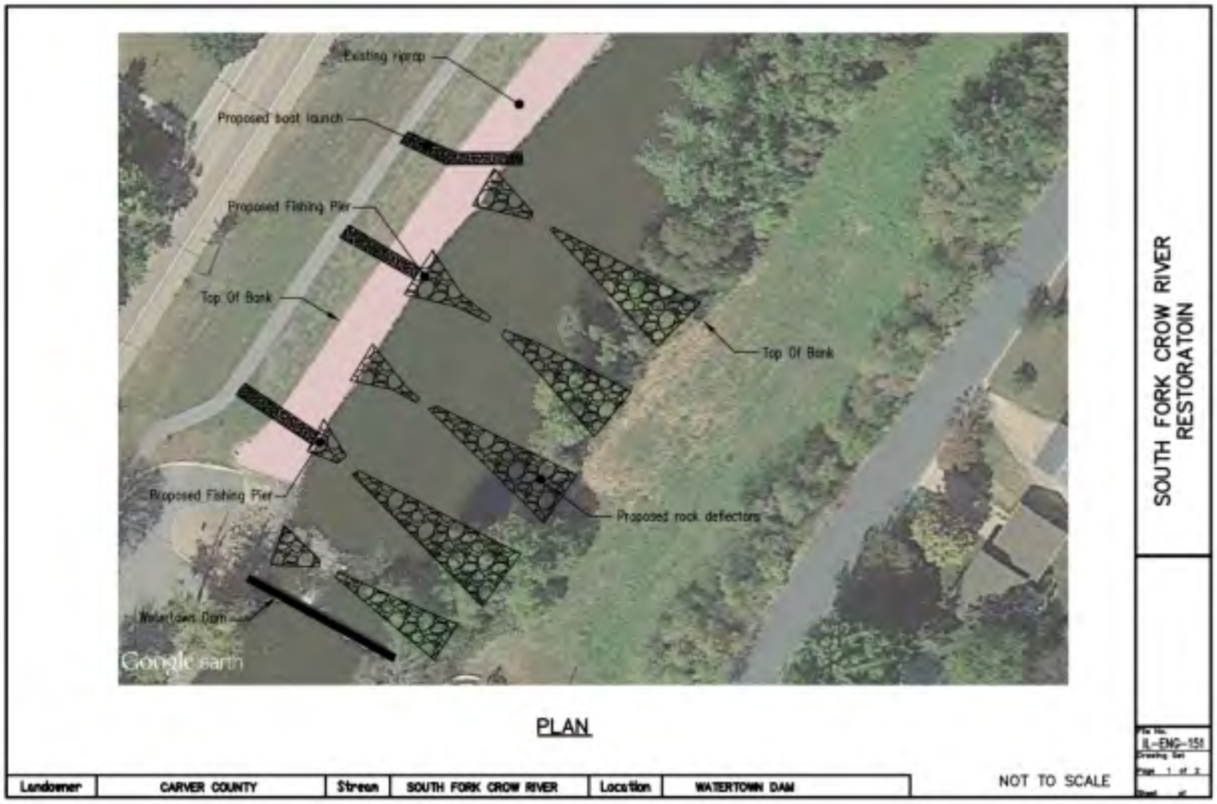
It's important to consider the entire ecology of the stream, large game fish prey on smaller fish and mussels depend on fish migration for dispersal, reproduction (Aadland 2010) and require certain fish species as hosts. Therefore, the ultimate goal should be that all fish species are able to swim upstream. In conclusion, by making modifications to the dam we improve fish migrations in 3 of the 4 modeled water velocities and allow 55 % of the fish to pass at 28 cfs and 575 cfs, flow rates that were impassable in the existing condition.

8 Preliminary Design Recommendations

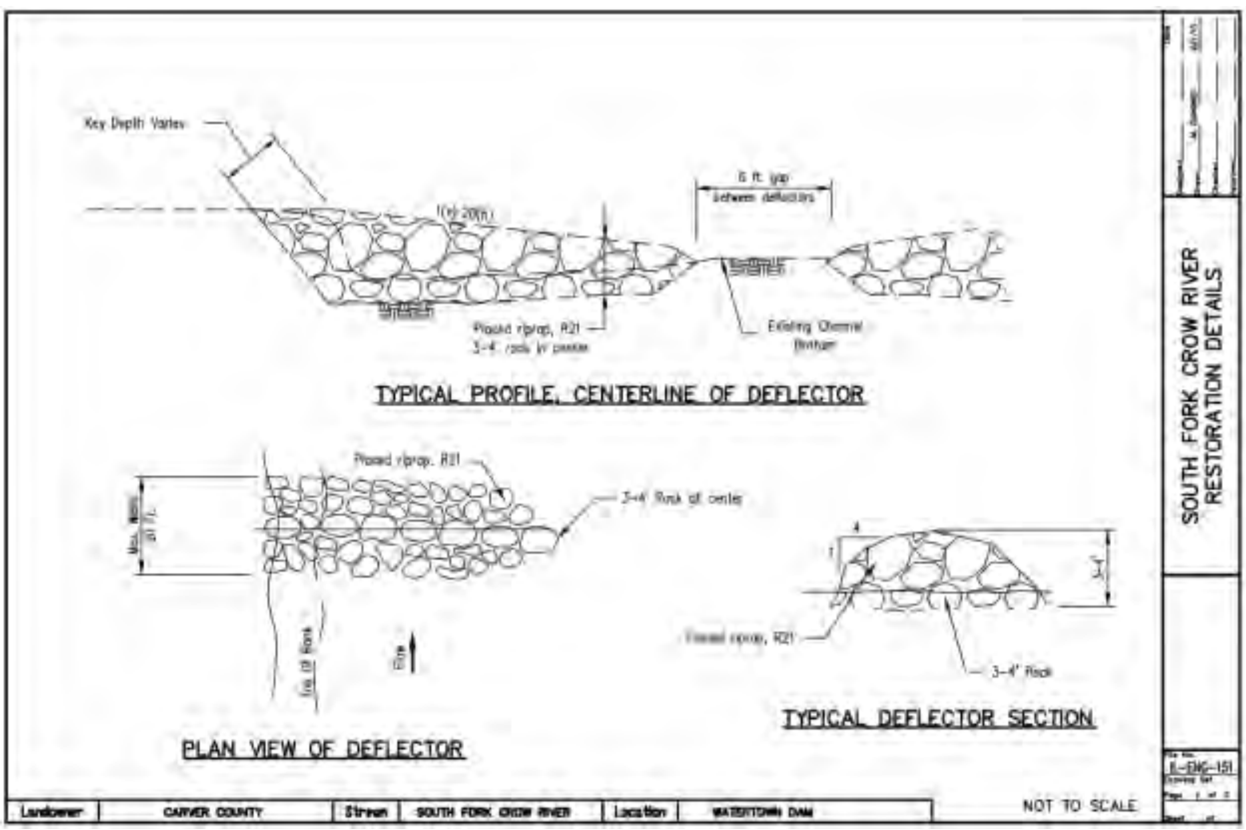
An emerging new sport especially in Colorado is river surfing. By constricting the flow of a river a standing wave can be created where surfers and whitewater kayakers play. A design like this was contemplated by our team but we quickly found that the topography was too flat and the flow wasn't enough. At the opposite end of the spectrum by slowing down the water at the dam and by leveling the water surface elevation before and after the dam, fish will now be able to migrate through. In our design a balance was achieved that will allow fish passage under most conditions as well as provide ample room between deflectors to provide an enjoyable family friendly canoe or kayak paddle.

8.1 Design Elements

The following figures depict the preliminary design recommendations for the restoration project.



Existing riprap
Proposed boat launch
Proposed Fishing Pier
Top Of Bank
Top Of Bank
Proposed rock deflectors
Proposed Fishing Pier
Watertown Dam
PLAN
SOUTH FORK CROW RIVER RESTORATOIN
IL-ENG-151
Landowner
CARVER COUNTY
Stream
SOUTH FORK CROW RIVER
Location
WATERTOWN DAM
NOT TO SCALE



Key Depth Varies
6 ft. gap between deflectors
Placed riprap, R21
Existing Channel Bottom
TYPICAL PROFILE, CENTERLINE OF DEFLECTOR
Placed riprap, R21
3-4' Rock at center
Flow
PLAN VIEW OF DEFLECTOR
Placed riprap, R21
3-4' Rock
TYPICAL DEFLECTOR SECTION
SOUTH FORK CROW RIVER RESTORATION DETAILS
IL-ENG-151
Landowner
CARVER COUNTY
Stream
SOUTH FORK CROW RIVER
Location
WATERTOWN DAM
NOT TO SCALE

8.2 Cost Estimate

The table below represents a cost estimate of the large work items associated with the project.

Item	Quantity	Unit	Unit Price	Total
Mobilization	1	Lump Sum	$22,000	$23,000
Survey/Staking	1	Lump Sum	$4,000	$4,000
Erosion Control/Turf Establishment	1	Lump Sum	$6,000	$6,000
Turf Establishment	1	Lump Sum	$3,000	$3,000
Riprap	2,000	Cubic Yard	$100	$200,000
Fishing Piers	2	Each	$6,000	$12,000
Asphalt Pathway	5	Ton	$80	$400
			Sub-Total	$248,400
			Contingency (10%)	$24,840
			Grand Total	$273,240

9 Community Involvement

9.1 Target Audience

The South Fork Crow River Communication Plan will target the residences and business owners in Watertown, Minnesota.

The target residences will be determined through a combination of proximity to the proposed project, use of the existing area, the ability to reach the audience with the communication plan, and the expected levels of participation. The goal will be to increase the awareness to the existing barriers to connectivity, identify the changes that could be expected with the proposed project, and layout the participation level expected from the community to ensure the project succeeds.

The target business owners will be determined through their reliance on the existing area from a business perspective and/or their expected economic benefit or failure if the proposed project is implemented. The goal will be to provide information on the expected use changes with the proposed project and what impact those changes could have on business owners. It will include the steps we would encourage business owners to take to help with the success of the project.

9.2 Channels for Communication

- News Release: The overall goal will be to provide basic project information along with information on the purpose and need of the project.
- Direct Mail: The overall goal will be to provide initial communication and to help define the proposed project. The direct mail will also include a survey to gage the public perspective of the existing river system in terms of fish passage.
- Point of Contact/Personal Communication: The goal will be to conduct the personal communications after the mailing has gone out so we can conduct educated discussions with our target audiences.

9.3 Implementation

The news release and direct mail will go out initially to both the residents and business owners. They will contain general information on the existing conditions of the area and the objectives and strategies for the proposed project. The direct mailer will provide the residents and business owners with some background before we conduct personal communication.

Once we get to the communication stage, we hope that at least some of the target audience has reviewed the information provided so an educated discussion on the project can be had with each audience.

9.4 Evaluation

Evaluation will occur through several methods as demonstrated below.

1. Tracking survey responses before and after the implementation of the communication plan to gage if the public perspective was changed by the communication plan.
2. Tracking hits on the project website as a gage for public interest in the project progression.
3. Follow-up communication initiated by the target audience as an indication again of the public interest in the project.

10 Post Construction Monitoring Plan

The proposed monitoring plan would last for a period of five years; the first two years having semi-annual assessments, and the following three years having annually inspections. In addition, it is recommended to have post 2-year storm events inspections. The construction contract should specify who is responsible for monitoring the stream restoration project.

The objectives, metrics, supporting data, and analysis should be specified for a monitoring plan to be successful (Zeff, 2009).

Objectives:

1. Enhance fish habitat.
2. Connectivity between upstream and downstream.
3. Keep upstream water elevation.
4. Maintain the structures (deflectors and dam) stable during storm events.
5. Prevent soil particles in bank from eroding into river.

Metrics, Supporting Data, and Analysis:

1. Increase fish habitat 5-10%
    a. Fish survey, underwater camera, and fishermen survey.
        i. Compare baseline habitat conditions with post-construction
    b. Flow velocity
        i. Compare velocities with the maximum recommended for fish passage.
    c. DO measurements
        i. Compare DO measurements with the minimum recommended for fish habitat.
2. Connection between upstream and downstream of the dam during spring, summer, and early fall.
    a. Recreation services survey
        i. Analyze users’ responses about connectivity and accessibility to the river.
3. Water elevation upstream – same as pre-construction.
    a. Measure water elevation upstream of the dam during the first 2 years

        i. Compare post-construction with existing water levels for different events.

4. Structures remain undamaged, with no substantial change (< 5% of the boulders out of place)
    a. Survey channel
    b. Take pictures of the structures
        i. Compare design with post-construction state of the structures.
    c. Evaluate dam stability with observations
        i. The dam should remain in the same location as in the current conditions.
5. Change in channel geometry (stable after 1 year) and reduced bank erosion (do not increase from current conditions).
    a. As-built and post-construction topographic surveys
        i. Compare design cross-sections with post-construction.
        ii. Compare maximum scour depth and compare with projected.
    b. Bank erosion measurements
        i. Compare current conditions with post-construction.

11 Conclusions

As demonstrated in this report, a viable restoration project exists that will accomplish the goal to restore biological connectivity in the South Fork Crow River with the benefit of an added water recreation in Watertown. The proposed configuration with 5 double deflectors allows fish passage for flows as low as the calibrated 28 cfs profile. Configurations with more deflectors could allow fish passage for even lower flows. In our design, a balanced project that allow fish passage under most conditions as well as an enjoyable family friendly canoe or kayak paddle.

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APPENDIX A

Scenario 1: % Adoption Rates are input for Controlled drainage 5% and Restored wetlands of 10% for an area of 0.577 million acres in watershed.

South Fork Crow River

58

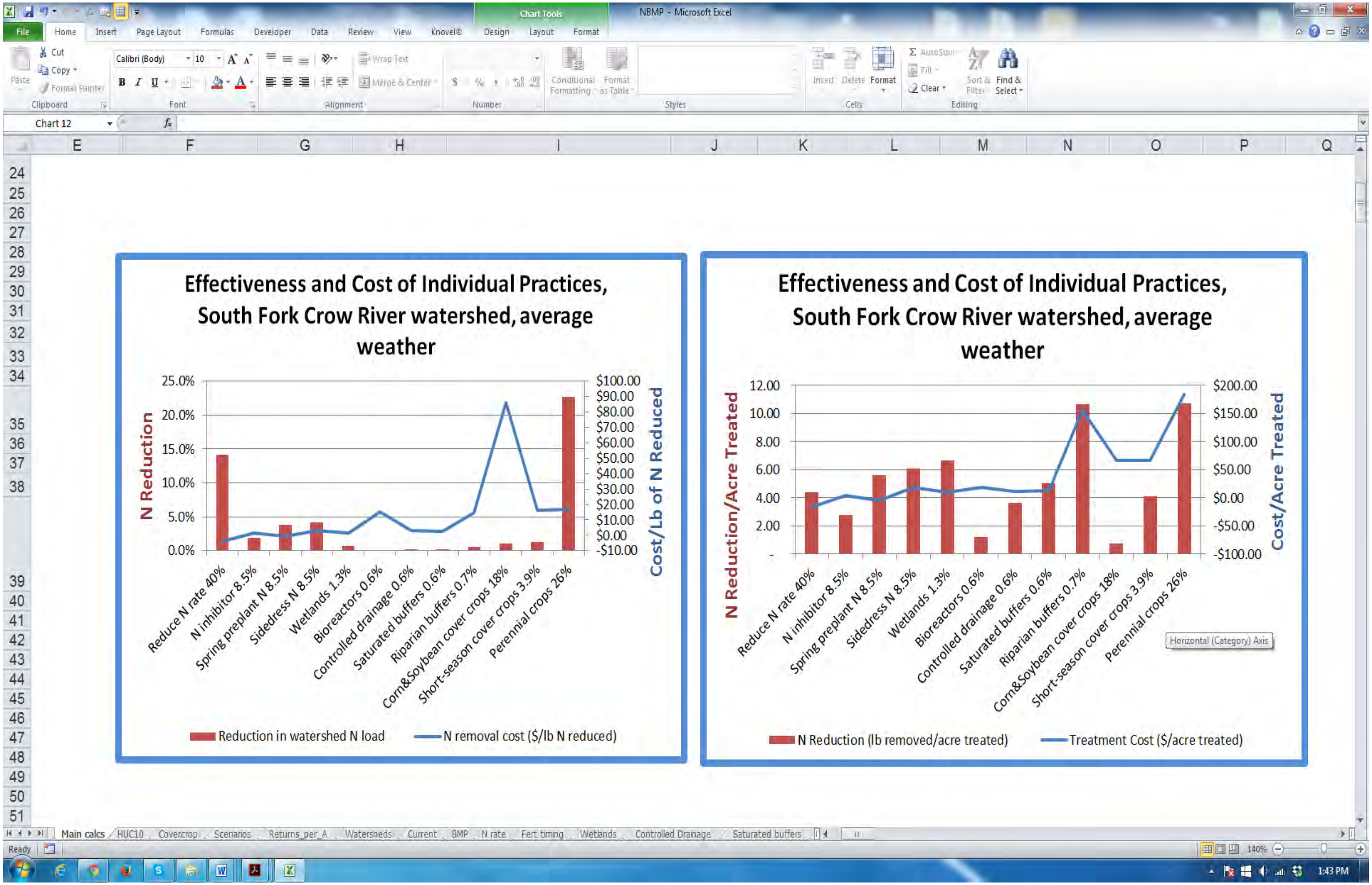
HUC10 Subwatershed	% suitable	% adoption	% treated	% treated, combined	combined
Corn acres receiving target N rate, no inhibitor or timing shift	50.37%	80%	40.30%	23.12%	133.40
Fall N target rate acres receiving N inhibitor	21.37%	40%	8.55%	5.91%	34.08
Fall N applications switched to spring, % of fall-app. acres	21.37%	40%	8.55%	3.54%	20.45
Fall N switch to split spring/sidedressing, % of fall acres	21.37%	40%	8.55%	3.54%	20.45
Restored wetlands	13.46%	10%	1.35%	1.35%	7.77
Tile line bioreactors	11.18%	5%	0.56%	0.56%	3.22
Controlled drainage	11.18%	5%	0.56%	0.56%	3.22
Saturated buffers	11.18%	5%	0.56%	0.56%	3.22
Riparian buffers 100 feet wide	2.80%	25%	0.70%	0.69%	4.00
Corn grain & soybean acres w/cereal rye cover crop	87.78%	20%	17.56%	12.13%	69.99
Short season crops planted to a rye cover crop	7.82%	50%	3.91%	3.85%	22.18
Perennial crop % of corn & soy area (all corn&soy, equal %)	88.20%	30%	26.46%	26.43%	152.49

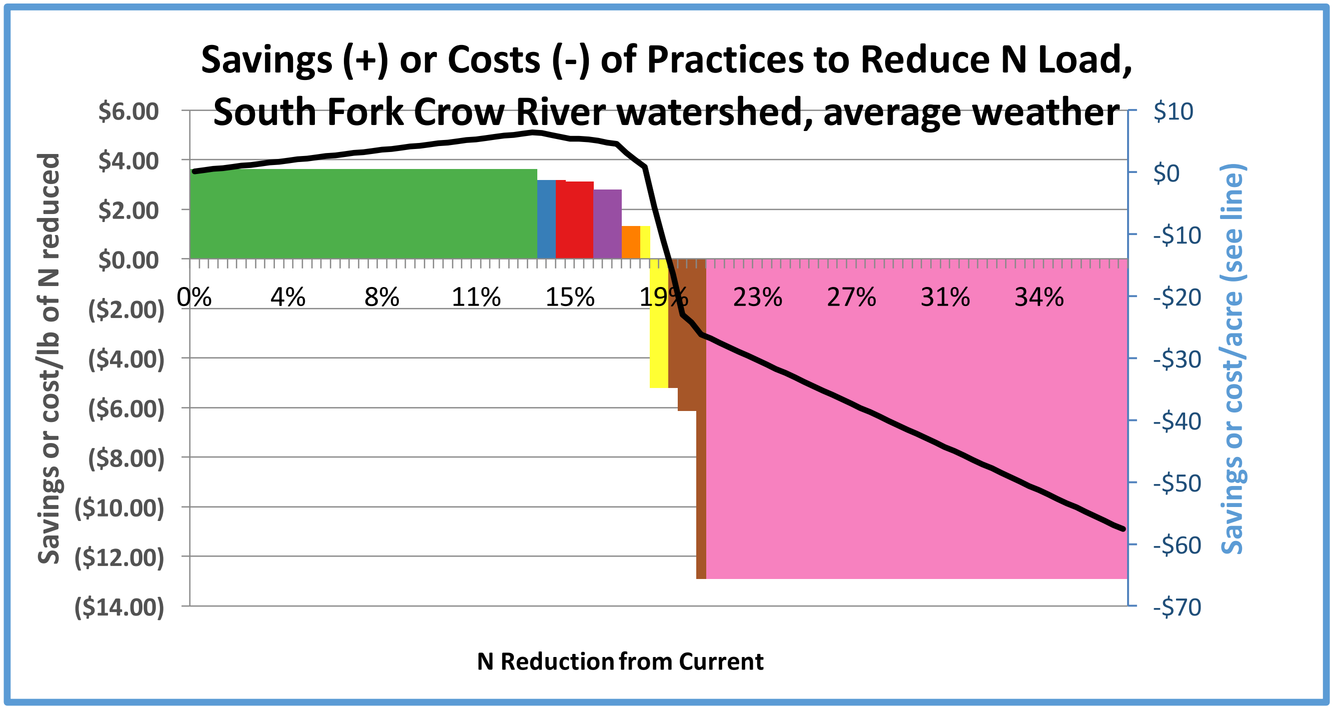
Average

Weather scenario: Average weather - all of preplant N is available

preplant N is available

1


NBMP - Microsoft Excel
Chart Tools
Chart 12
Effectiveness and Cost of Individual Practices, South Fork Crow River watershed, average weather
N Reduction
Cost/Lb of N Reduced
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
$100.00
$90.00
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$0.00
-$10.00
Reduce N rate 40%
N inhibitor 8.5%
Spring preplant N 8.5%
Sidedress N 8.5%
Wetlands 1.3%
Bioreactors 0.6%
Controlled drainage 0.6%
Saturated buffers 0.6%
Riparian buffers 0.7%
Corn&Soybean cover crops 18%
Short-season cover crops 3.9%
Perennial crops 26%
Reduction in watershed N load
N removal cost ($/lb N reduced)
Effectiveness and Cost of Individual Practices, South Fork Crow River watershed, average weather
N Reduction/Acre Treated
Cost/Acre Treated
12.00
10.00
8.00
6.00
4.00
2.00
-
$200.00
$150.00
$100.00
$50.00
$0.00
-$50.00
-$100.00
Reduce N rate 40%
N inhibitor 8.5%
Spring preplant N 8.5%
Sidedress N 8.5%
Wetlands 1.3%
Bioreactors 0.6%
Controlled drainage 0.6%
Saturated buffers 0.6%
Riparian buffers 0.7%
Corn&Soybean cover crops 18%
Short-season cover crops 3.9%
Perennial crops 26%
Horizontal (Category) Axis
N Reduction (lb removed/acre treated)
Treatment Cost ($/acre treated)
Main calcs
HUC10
Covercrop
Scenarios
Returns_per_A
Watersheds
Current
BMP
N rate
Fert timing
Wetlands
Controlled Drainage
Saturated buffers



Key to graph colors by BMP (left to right, the numbers are percent of the watershed, from above)

Green	Reduce N rate 40%
Blue	reduce N rate 40%,restore wetlands 1.3%,saturated buffers 0.6%
Red	reduce N rate 40%,spring preplant N 8.5%
Purple	reduce N rate 40%,spring preplant N 8.5%,restore wetlands 1.3%,saturated buffers 0.6%
Orange	reduce N rate 40%,sidedress N 8.5%,restore wetlands 1.3%,saturated buffers 0.6%,riparian buffer 0.7%
Yellow	reduce N rate 40%,spring preplant N 8.5%,restore wetlands 1.3%,saturated buffers 0.6%,corn&soybean cover crops 18%
Brown	reduce N rate 40%,N inhibitor 8.5%,spring preplant N 8.5%,sidedress N 8.5%,restore wetlands 1.3%,controlled drainage 0.6%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%
Pink	reduce N rate 40%,N inhibitor 8.5%,spring preplant N 8.5%,sidedress N 8.5%,restore wetlands 1.3%,controlled drainage 0.6%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%,perennial crops 3.9%

Scenario 2: The % Adoption Rates are changed for Controlled drainage 10% and Restored wetlands of 20% for an area of 0.577 million acres in watershed

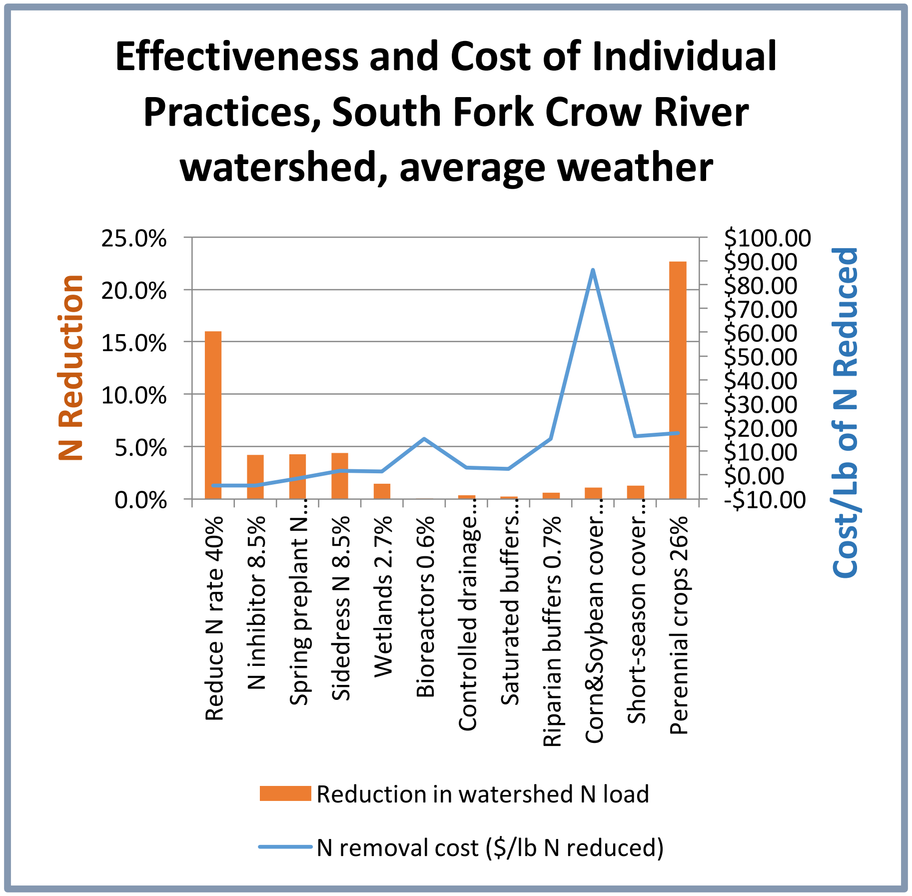
South Fork Crow River

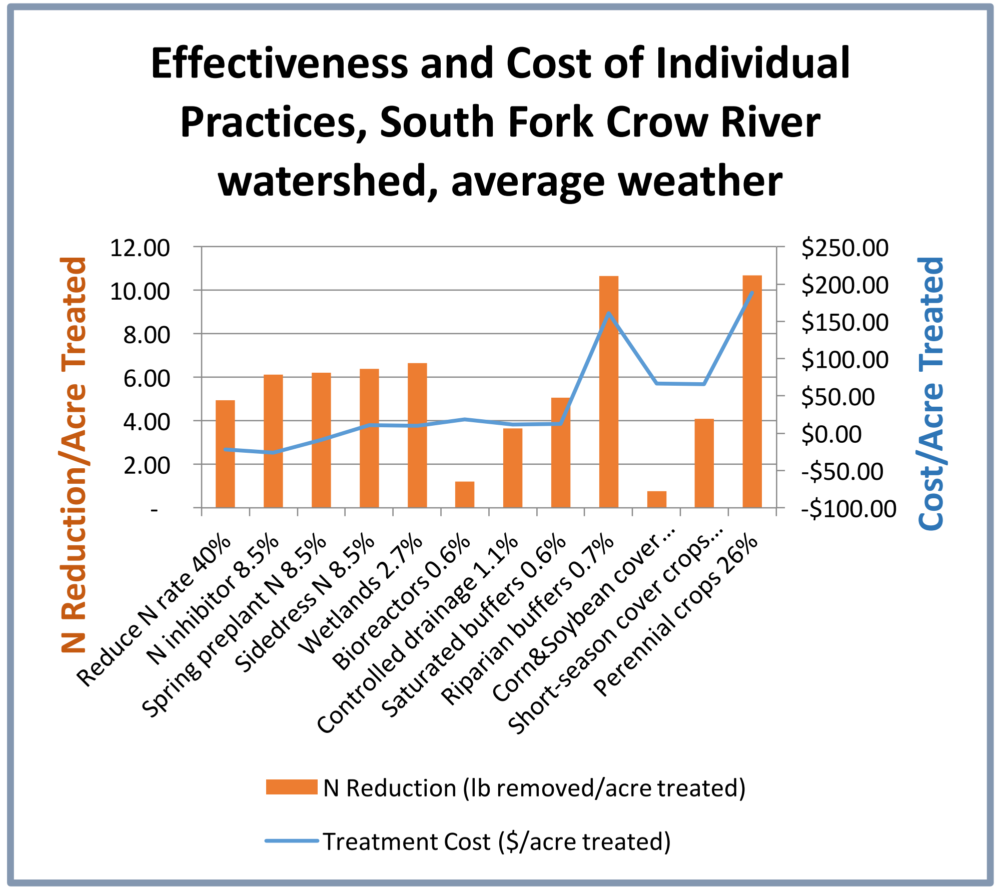
HUC10 Subwatershed	% suitable	% adoption	% treated	% treated, combined	combined
Corn acres receiving target N rate, no inhibitor or timing shift	50.37%	80%	40.30%	23.08%	133.16
Fall N target rate acres receiving N inhibitor	21.37%	40%	8.55%	5.90%	34.02
Fall N applications switched to spring, % of fall-app. acres	21.37%	40%	8.55%	3.54%	20.41
Fall N switch to split spring/sidedressing, % of fall acres	21.37%	40%	8.55%	3.54%	20.41
Restored wetlands	13.46%	20%	2.69%	2.69%	15.54
Tile line bioreactors	11.18%	5%	0.56%	0.56%	3.22
Controlled drainage	11.18%	10%	0.56%	1.12%	6.45
Saturated buffers	11.18%	5%	0.56%	0.56%	3.22
Riparian buffers 100 feet wide	2.80%	25%	0.70%	0.69%	4.00
Corn grain & soybean acres w/cereal rye cover crop	87.78%	20%	17.56%	12.11%	69.86
Short season crops planted to a rye cover crop	7.82%	50%	3.91%	3.85%	22.18
Perennial crop % of corn & soy area — all corn&soy, equal %	88.20%	30%	26.46%	26.41%	152.39

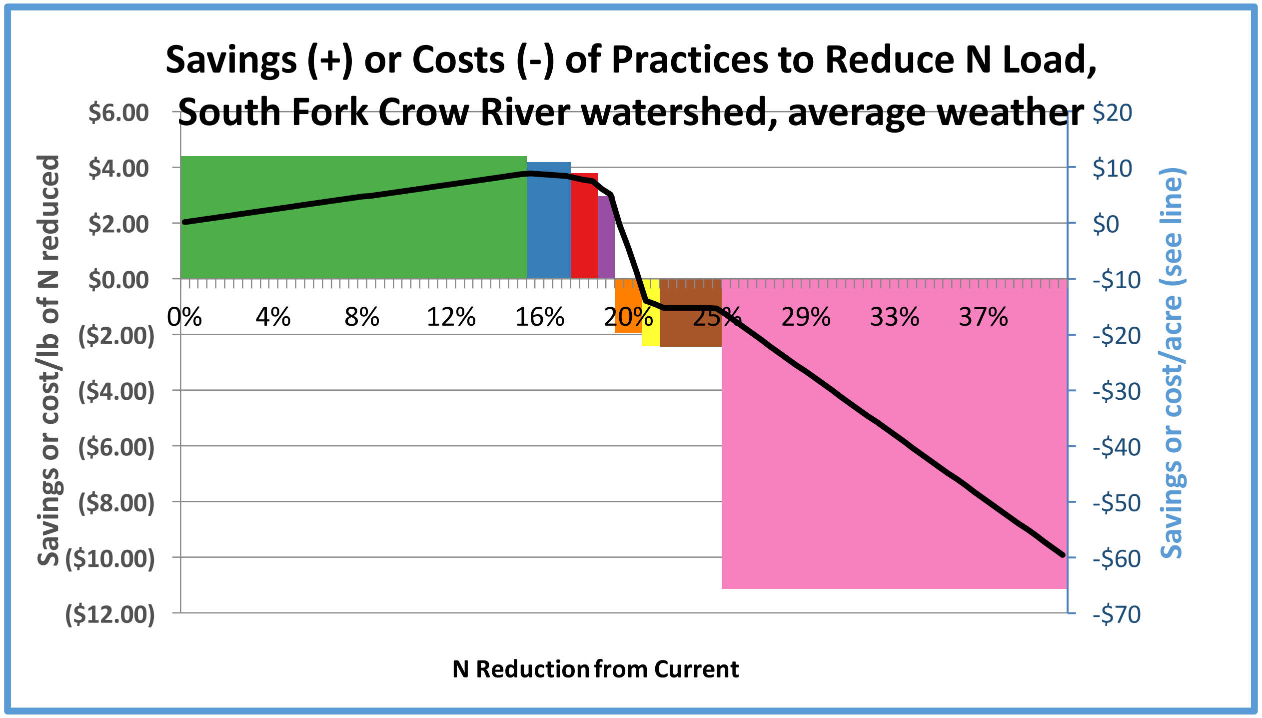
Average

Weather scenario: Average weather - all of preplant N is available

preplant N is available 1


Effectiveness and Cost of Individual Practices, South Fork Crow River watershed, average weather
N Reduction
Cost/Lb of N Reduced
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
$100.00
$90.00
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$0.00
-$10.00
Reduce N rate 40%
N inhibitor 8.5%
Spring preplant N...
Sidedress N 8.5%
Wetlands 2.7%
Bioreactors 0.6%
Controlled drainage...
Saturated buffers...
Riparian buffers 0.7%
Corn&Soybean cover...
Short-season cover...
Perennial crops 26%
Reduction in watershed N load
N removal cost ($/lb N reduced)

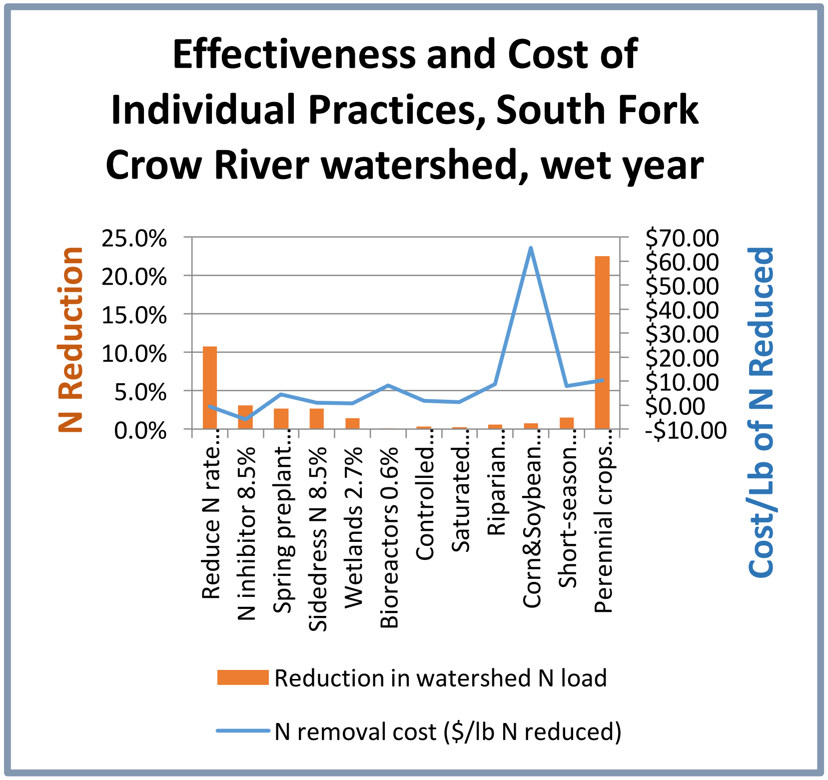

Effectiveness and Cost of Individual Practices, South Fork Crow River watershed, average weather
N Reduction/Acre Treated
Cost/Acre Treated
12.00
10.00
8.00
6.00
4.00
2.00
-
$250.00
$200.00
$150.00
$100.00
$50.00
$0.00
-$50.00
-$100.00
Reduce N rate 40%
N inhibitor 8.5%
Spring preplant N 8.5%
Sidedress N 8.5%
Wetlands 2.7%
Bioreactors 0.6%
Controlled drainage 1.1%
Saturated buffers 0.6%
Riparian buffers 0.7%
Corn&Soybean cover...
Short-season cover crops...
Perennial crops 26%
N Reduction (lb removed/acre treated)
Treatment Cost ($/acre treated)

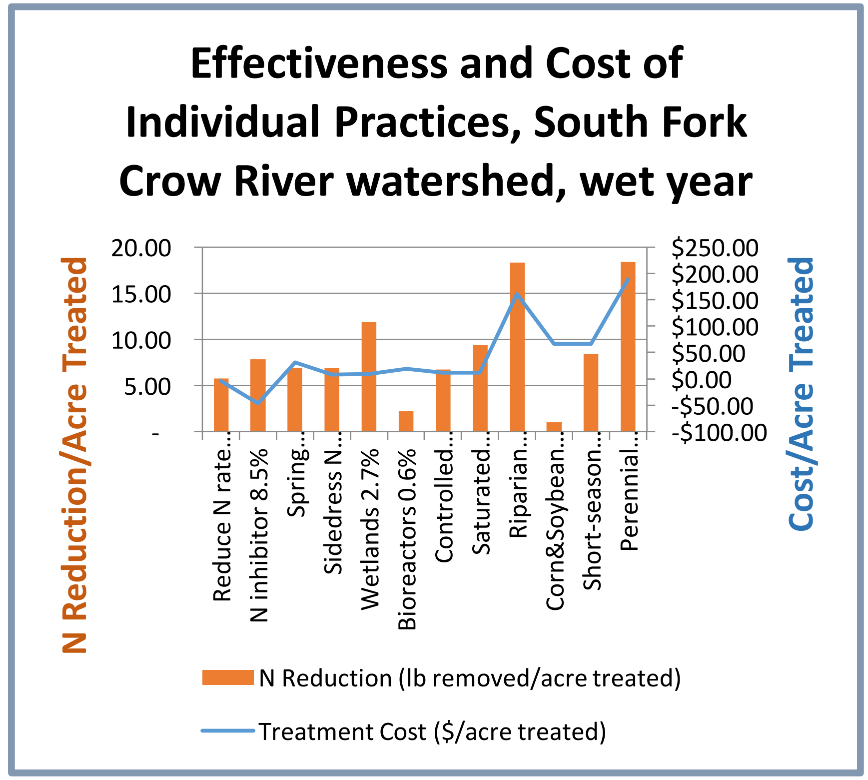


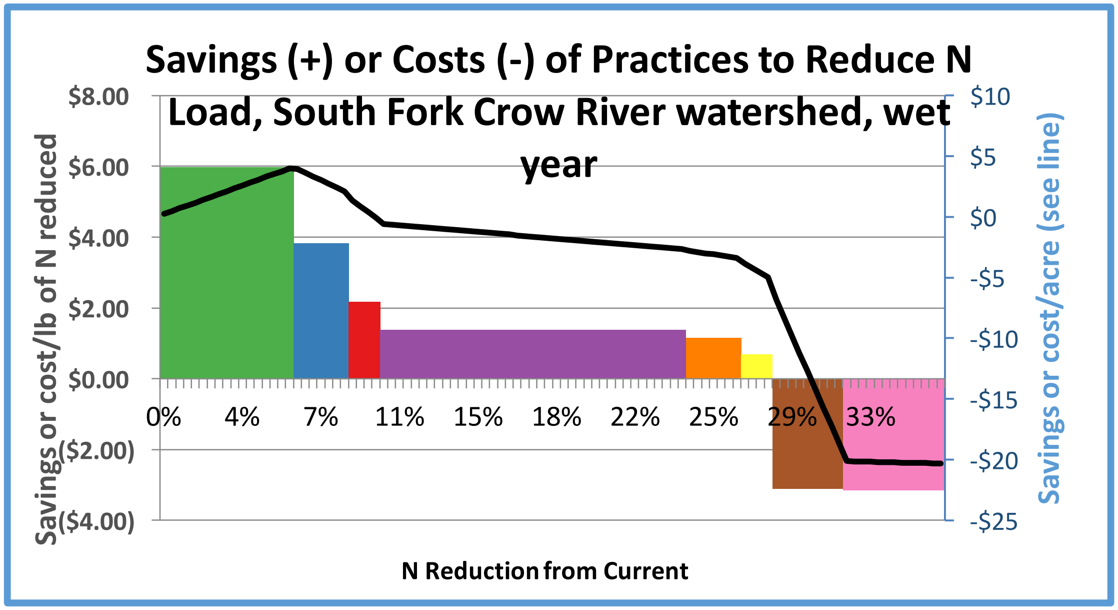
Key to graph colors by BMP (left to right, the numbers are percent of the watershed, from above)

(green)	Reduce N rate 40%
(blue)	reduce N rate 40%,N inhibitor 8.5%
(red)	reduce N rate 40%,N inhibitor 8.5%,restore wetlands 2.7%
(purple)	reduce N rate 40%,spring preplant N 8.5%,restore wetlands 2.7%,saturated buffers 0.6%,riparian buffer 0.7%
(orange)	reduce N rate 40%,N inhibitor 8.5%,restore wetlands 2.7%,corn&soybean cover crops 18%
(yellow)	reduce N rate 40%,spring preplant N 8.5%,restore wetlands 2.7%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%
(brown)	reduce N rate 40%,N inhibitor 8.5%,spring preplant N 8.5%,sidedress N 8.5%,restore wetlands 2.7%,controlled drainage 1.1%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%
(pink)	reduce N rate 40%,N inhibitor 8.5%,spring preplant N 8.5%,sidedress N 8.5%,restore wetlands 2.7%,controlled drainage 1.1%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%,perennial crops 3.9%

Scenario 3: A more realistic % Adoption Rates scenario that includes future weather patterns are input for Controlled drainage 5% and Restored wetlands of 10% for an area of 0.577 million acres in watershed.







Key to graph colors by BMP (left to right, the numbers are percent of the watershed, from above)

(green)	N inhibitor 8.5%
(blue)	N inhibitor 8.5%,restore wetlands 2.7%
(red)	N inhibitor 8.5%,restore wetlands 2.7%,saturated buffers 0.6%,riparian buffer 0.7%
(purple)	reduce N rate 40%,N inhibitor 8.5%
(orange)	reduce N rate 40%,N inhibitor 8.5%,restore wetlands 2.7%
(yellow)	reduce N rate 40%,N inhibitor 8.5%,restore wetlands 2.7%,controlled drainage 1.1%,riparian buffer 0.7%
(brown)	reduce N rate 40%,N inhibitor 8.5%,restore wetlands 2.7%,controlled drainage 1.1%,corn&soybean cover crops 18%
(pink)	reduce N rate 40%,N inhibitor 8.5%,spring preplant N 8.5%,sidedress N 8.5%,restore wetlands 2.7%,controlled drainage 1.1%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%
(grey)	reduce N rate 40%,N inhibitor 8.5%,spring preplant N 8.5%,sidedress N 8.5%,restore wetlands 2.7%,controlled drainage 1.1%,saturated buffers 0.6%,riparian buffer 0.7%,corn&soybean cover crops 18%,perennial crops 3.9%