A Framework for Addressing Altered Hydrology
OUR DISCUSSION

- **Hydrologic Alteration** as an emerging issue
- **Context** relative to the Clean Water Act
- Need for a **science based** framework
- Illustration of a **science based framework**
- **Vision** for success
Final EPA-USGS Technical Report: Protecting Aquatic Life from Effects of Hydrologic Alteration

EPA Report 822-R-16–007
USGS Scientific Investigations Report 2016–5164
ALTERED HYDROLOGY – THE CONCERN

- No Numeric Standard
- Science based method
- Mitigation?

Habitat | Sediment & Nutrients | Geomorphology | Impaired Aquatic Life

Runoff

- Reduced time to peak
- Shorter recession
- Lower Baseflow
- Larger Baseflow
Figure 1. Flow duration curve for the Sand Hill River at Climax, Minnesota. The solid black line shows an increase in daily mean discharge for the 1980 – 2010 period, compared to the early 1945 – 1975 period.
How do you establish a load capacity for altered hydrology?

How do you develop a solution?

Some goal / target is needed.
NEED FOR SCIENCE BASED FRAMEWORK

- Impaired Aquatic Life
  - Science Based Framework
    - Definition
    - Assessment Method
    - Watershed Goal
    - Solutions
  - Watershed based goal
  - Voluntary
  - Regulatory
    - Suspended solids standard
    - Hydrologic standard?
    - Land use controls?
    - Ordinance?
A FRAMEWORK FOR PROGRESS

1. Define the Issue
   - Agreement on a common definition of “Altered Hydrology”

2. Establish Metrics
   - Based on ecosystem function and test to see if altered hydrology has occurred

3. Establish Benchmark
   - Desired time period or condition

4. Assess
   - Apply metrics to assess if changed hydrology has occurred

5. Set Goal
   - Set achievable goals to reach benchmark

6. Target Solutions
   - Target opportunities for solutions

7. Implement Change
   - Build projects and implement practices that improve hydrology

8. Monitor Results
   - Verify that you got it right
A FRAMEWORK FOR PROGRESS

Establish a common/agreed definition:

- Altered hydrology is defined as a discernable change in specific metrics derived from stream discharge, occurring through an entire annual hydrologic cycle compared to a benchmark condition, which exceed the measurement error.
A FRAMEWORK FOR PROGRESS

- Define the Issue
- Establish Metrics
- Establish Benchmark
- Assess
- Set Goal
- Target Solutions
- Implement Change
- Monitor Results

Habitat

Sediment & Nutrients

Geomorphology

Metrics

- Amount of Aquatic Habitat
- Aquatic Organism Life Cycle
- Geomorphic Stability and Ability to Transport Sediment
- Riparian Floodplain (Lateral Connectivity)

Define the Issue
Establish Metrics
Establish Benchmark
Assess
Set Goal
Target Solutions
Implement Change
Monitor Results
A FRAMEWORK FOR PROGRESS

- Define the Issue
- Establish Metrics
- Establish Benchmark
- Assess
- Set Goal
- Target Solutions
- Implement Change
- Monitor Results

Low flows/Baseflows
- 10-yr, 30-day low flow; 10-yr, 7-day low flow; median November flow

Shape and Timing
- Monthly flows; Julian day of maximum & minimum flows

Extreme flows and volumes
- Rate and Volume above 10-yr, 50-yr, 100-yr peak flow rates

Channel forming flows and volumes
- Rate, Volume above, Duration above 1.5-yr, 2-yr peak flow rates
- Changes in flow duration curve
A FRAMEWORK FOR PROGRESS

- **Benchmark** = desired hydrologic condition
- **Method** – establish periods that represent “benchmark” and “altered” conditions

![Graph showing cumulative runoff over years from 1940 to 2020, with two lines representing “Benchmark” and “Altered” conditions.](image-url)
GEOMORPHIC STABILITY ASSESSMENT

- Uses long-term continuous daily flows.
- Minimum 20 years of data in each period; 30+ years in preferred.
- USGS# 05280000-Crow River at Rockford, MN
- Benchmark Period: 1940 – 1975
Define the Issue > Establish Metrics > Assess Benchmark > Set Goal > Target Solutions > Implement Change > Monitor Results

Table 10. Geomorphic stability and capacity to transport sediment metrics for the Crow River at Rockford, MN

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-Year Peak Discharge, Q(1.5) [cfs]</td>
<td>2,937</td>
<td>4,425</td>
<td>51.0%</td>
<td>+</td>
</tr>
<tr>
<td>Number of years with Discharge (Q) &gt; Qₘ₅₅ (1.5)</td>
<td>24</td>
<td>29</td>
<td>20.8%</td>
<td>+</td>
</tr>
<tr>
<td>Average number of days per year Q &gt; Qₘ₅₅ (1.5)</td>
<td>26</td>
<td>54</td>
<td>108.0%</td>
<td>+</td>
</tr>
<tr>
<td>Average annual cumulative volume &gt; Qₘ₅₅ (1.5) [ac-ft]</td>
<td>102,304</td>
<td>205,439</td>
<td>100.8%</td>
<td>+</td>
</tr>
<tr>
<td>2-Year Peak Discharge, Q(2) [cfs]</td>
<td>4,109</td>
<td>5,042</td>
<td>44.6%</td>
<td>+</td>
</tr>
<tr>
<td>Number of years with Discharge (Q) &gt; Qₘ₅₅ (2)</td>
<td>14</td>
<td>27</td>
<td>92.3%</td>
<td>+</td>
</tr>
<tr>
<td>Average number of days per year Q &gt; Qₘ₅₅ (2)</td>
<td>14</td>
<td>31</td>
<td>125.2%</td>
<td>+</td>
</tr>
<tr>
<td>Average annual cumulative volume &gt; Qₘ₅₅ (2) [ac-ft]</td>
<td>73,250</td>
<td>121,132</td>
<td>65.4%</td>
<td>+</td>
</tr>
</tbody>
</table>

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period
- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

Table 9. Select summary of the flow duration curves for the Crow River at Rockford, MN

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1%</td>
<td>13,785</td>
<td>11,700</td>
<td>-15.1%</td>
<td>-</td>
</tr>
<tr>
<td>1.0%</td>
<td>5,500</td>
<td>7,580</td>
<td>37.8%</td>
<td>+</td>
</tr>
<tr>
<td>10.0%</td>
<td>1,920</td>
<td>3,260</td>
<td>69.8%</td>
<td>+</td>
</tr>
<tr>
<td>25.0%</td>
<td>793</td>
<td>1,670</td>
<td>110.6%</td>
<td>+</td>
</tr>
<tr>
<td>50.0%</td>
<td>207</td>
<td>509</td>
<td>174.9%</td>
<td>+</td>
</tr>
<tr>
<td>75.0%</td>
<td>87</td>
<td>253</td>
<td>190.8%</td>
<td>+</td>
</tr>
<tr>
<td>90.0%</td>
<td>41</td>
<td>97</td>
<td>136.6%</td>
<td>+</td>
</tr>
<tr>
<td>99.0%</td>
<td>18</td>
<td>35</td>
<td>94.4%</td>
<td>+</td>
</tr>
<tr>
<td>99.9%</td>
<td>12</td>
<td>20</td>
<td>66.7%</td>
<td>+</td>
</tr>
</tbody>
</table>

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period
- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period

GEOMORPHIC STABILITY ASSESSMENT
# A Framework for Progress

<table>
<thead>
<tr>
<th>Group</th>
<th>Metric</th>
<th>% Difference</th>
<th>Altered Hydrology Metric</th>
<th>Evidence of Altered Hydrology for Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic Habitat</td>
<td>10-year, Annual Minimum 30-day Mean Daily Discharge</td>
<td>118.40%</td>
<td>+</td>
<td>Yes - increase</td>
</tr>
<tr>
<td></td>
<td>10-year, Annual Minimum 7-day Mean Daily Discharge</td>
<td>121.60%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median November (Winter Base) Flow</td>
<td>329.80%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Aquatic Organism Life Cycle</td>
<td>Magnitude of Monthly Runoff Volumes</td>
<td>77.2% - 207.8%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distribution of Monthly Runoff Volumes</td>
<td>-30.7% - 71.5%</td>
<td>O</td>
<td>Maybe - increase</td>
</tr>
<tr>
<td></td>
<td>Timing of Annual Peak Discharge</td>
<td>10.70%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timing of Annual Minimum Discharge</td>
<td>4.30%</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Riparian Habitat (Lateral) Connectivity</td>
<td>10-year Peak Discharge Rate</td>
<td>7.70%</td>
<td>O</td>
<td>Yes - decrease</td>
</tr>
<tr>
<td></td>
<td>50-year Peak Discharge Rate</td>
<td>-18.4%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100-year Peak Discharge Rate</td>
<td>-27.1%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average Cumulative Volume above the Historic 10-year Peak Discharge</td>
<td>-52.3%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average Cumulative Volume above the Historic 50-year Peak Discharge</td>
<td>-100%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average Cumulative Volume above the Historic 100-year Peak Discharge</td>
<td>-100%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Geomorphic Stability and Capacity to Transport Sediment</td>
<td>1.5-year Peak Discharge Rate</td>
<td>51.0%</td>
<td>+</td>
<td>Yes - increase</td>
</tr>
<tr>
<td></td>
<td>2-year Peak Discharge Rate</td>
<td>44.6%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average Cumulative Volume above the Historic 1.5-year Peak Discharge</td>
<td>100.8%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average Cumulative Volume above the Historic 2-year Peak Discharge</td>
<td>65.4%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Duration above the Historic 1.5-year Peak Discharge</td>
<td>108.0%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Duration above the Historic 2-year Peak Discharge</td>
<td>125.2%</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flow Duration Curve</td>
<td>-15.1% - 190.8%</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

+ symbol indicates metric exhibits altered hydrology and an increase for the modern period compared to the historic period.
- symbol indicates metric exhibits altered hydrology and a decrease for the modern period compared to the historic period.
O symbol indicates fails to exhibit altered hydrology for the modern period compared to the historic period.
## A FRAMEWORK FOR PROGRESS

- Define the Issue
- Establish Metrics
- Establish Benchmark
- Assess
  - Set Goal
- Target Solutions
- Implement Change
- Monitor Results

### Table 14. Estimated storage goal for the Crow watershed upstream of Rockford, MN using method 3.

<table>
<thead>
<tr>
<th>Return Period (Years)</th>
<th>Change in flow ((Q_m-Q_h)) (cfs)</th>
<th>Probability of Occurrence</th>
<th>Change in flow* Probability (cfs)</th>
<th>Probability weighted flow (AF/Day)</th>
<th>Change in the number of days above flow (days)</th>
<th>Storage Volume (AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1,498</td>
<td>0.67</td>
<td>1,004</td>
<td>1,991</td>
<td>28</td>
<td>55,757</td>
</tr>
<tr>
<td>2</td>
<td>1,834</td>
<td>0.5</td>
<td>917</td>
<td>1,819</td>
<td>17</td>
<td>30,928</td>
</tr>
<tr>
<td>5</td>
<td>1,722</td>
<td>0.2</td>
<td>344</td>
<td>683</td>
<td>0.2</td>
<td>137</td>
</tr>
<tr>
<td>10</td>
<td>819</td>
<td>0.1</td>
<td>82</td>
<td>162</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total Volume Goal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>96,469 AF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.69 inches</td>
</tr>
</tbody>
</table>
Water Retention for Water Quality Benefits: Targeting Practices that Improve Environmental Flows

Jun Yang, Drew Kessler, Mark Deutschman, and Tim Erickson, Houston Engineering, Inc.

Wednesday, October 18th
3:00 Session-Track A
WHAT SOLUTIONS LOOK LIKE?

Management Practices

Best Practices

Structural Practices

Soil Health & Productivity

Standards Operating Procedures / Processes

Monitor
A FRAMEWORK FOR PROGRESS

- Define the Issue
- Establish Metrics
- Establish Benchmark
- Assess
- Set Goal
- Target Solutions
- Implement Change
- Monitor Results

**Most important steps!!!!**
NEXT STEPS

- Using framework to establish storage goal in 1w1p’s-in North Fork Crow 1w1p
- Using terrain analysis products to identify storage opportunities
- Evaluating methods to downscale approach to 12-digit HUC
- Developing approaches for assessing multiple benefits related to the metrics
- Need continued refinement of framework
Critical to have a science based framework or we all lack credibility
Framework should be applicable statewide
Focus on solutions rather than cause
Need means to set goal
Realize success won’t come from structural practices alone
Be adaptable
THANK YOU!

Questions?

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Mark Deutschman  Email: mdeutschman@houstoneng.com
Drew Kessler      Email: dkessler@houstoneng.com
No Assumption of Causality

Although it is important to water resource management to understand the mechanics behind the changes in hydrology, the focus of this methodology is developing a definition for altered hydrology, a method for assessing whether it has occurred within a watersheds, and establishing goals for addressing altered hydrology.
Minnesota Public Drainage Manual (MPDM)

Updated 2016
Published in Wiki
Funded by a FY 2014 CWF Appropriation ($235,000)
Original MPDM Objectives:

- Promote uniformity in the interpretation of Minnesota drainage law, without speculating as to what drainage law ought to say;
- Suggest procedures for consistent implementation state drainage law;
- Provide standardized forms for use in drainage proceedings.
- Inform about the interaction between drainage law and other state and federal laws;
Additional MPDM Update Objectives:

- Reflect changes in drainage law and pertinent case law since 1991
- Create a web-based, user-friendly and easily updatable version of the manual;
- Provide enhanced guidance related to multipurpose water management considerations and authorities in drainage law;
- Provide guidance in a new chapter regarding implementation of BMPs for drainage projects and systems. (New Chapter 5);
MPDM Chapters

- CHAPTER 1: Introduction and Definitions
- CHAPTER 2: Administration and Legal Issues
- CHAPTER 3: Engineering and Environmental Review
- CHAPTER 4: Viewing/Appraising
- CHAPTER 5: Drainage System Best Management Practices
- CHAPTER 6: Supporting Information/ Appendices
The Minnesota Public Drainage Manual

- Published in a wiki format - still accessible by chapter.
- New ways to navigate coming on line in October 2017.
- Print with your browser.

https://drainage.pca.state.mn.us/index.php?title=Main_Page
Questions

Tim Gillette – Conservation Drainage Engineer, Board of Water and Soil Resources

tim.gillette@state.mn.us  - 651-297-8287
Thank You!

Tim Gillette

tim.Gillette@state.mn.us

651-297-8287
Evolution of the Ag BMP Handbook

Water Resources Conference
October 18, 2017

Margaret Wagner
Clean Water Tech. Assistance Unit

Christian Lenhart
Brad Gordon
Bioproducts & Biosystems Engineering

Walter Eshenaur
Leah Gifford
Outline

• History of the Ag BMP Handbook
• How has it been used
• Key features and updates
• Where is it available
BMPS grouped by landscape position in Ag BMP Handbook

- Avoiding loss of pollutants
- Controlling or regulating rate of loss
- Trapping pollutants at end of pipe / edge of field

Avoid
Control
Trap
Timeline and Funding

- Original Ag BMP Handbook released in 2012
- Updated Handbook completed in November 2017
- Both supported through the Minnesota Department of Agriculture’s Clean Water Fund Research Program
For landowners, agency staff, consultants

Reading level - grade 12

Focus on Minnesota, applies to upper Midwest

- Some processes are similar across region
- Others are very different, i.e. cover crops and drainage water management
How is it used?

- Used to support watershed planning, largest users are SWCD staff
- Pollutant load estimates used for TMDLs, WRAPS & computer modeling
  - PTMapp and alternative buffer tools
- State nutrient reduction strategies for N & P by the MPCA
- *Agricultural Conservation Planning Framework* M. Tomer, Iowa State and other GIS tools
- Cited in peer reviewed research articles
Handbook as a Critical Resource

“A handy resource when talking BMPs with landowners”
- SWCD staff

“The most comprehensive Ag BMP reference handbook available”
- Ag Professional
Updated Handbook- NEW!

- Interactive PDF
- New project website
- Updated references
- Expanded to include additional conservation practices
- Better define the variability of BMP effectiveness by season, geologic setting, soil characteristic, and rainfall regime
- Includes management and maintenance requirements
- More detailed costs and economic considerations
New: Saturated buffers

Utt, Jaynes and Albertsen 2015. Demonstrate and Evaluate Saturated Buffers at Field Scale to Reduce Nitrates and Phosphorus from Subsurface Field Drainage Systems. Project report for USDA CIG
Bioreactors

- Numerous media assessed (biochar, woodchips, corncobs, other carbon sources)
- USDA-ARS (Feyereisen)
- UMN- Magner, Krider, Wilson et al.
- Primarily for nitrate-nitrogen removal

Installation in Martin County
Two-stage ditches

- Many built in Ohio and Indiana
- Effective at Nitrogen removal but at a low level, ~ 10% of load
- Notre Dame research
- Mower County – U of M researchers Wilson, Magner, Krider
- Constructed wetlands
- Primarily for nitrate-nitrogen removal
- New research: greater phosphorus removal via plant uptake

Problem: BMP variability effectiveness

- Need to recognize BMP effectiveness is highly variable
- Problems: failure to meet water quality goals
- Some BMPs are well-studied; others not so much
  - Historical context: efforts to control sediment from the SCS etc.; relative success of TSS and TP measures
  - Recent focus on nitrate for hypoxia in coastal areas
  - Dissolved phosphorus we have the least knowledge about – Ohio example
Variability sources

- **Design factors**
  - Reliability (guidelines, replicability)

- **Management and maintenance**
  - Lifespan, change in effectiveness over time?

- **Economic**
  - Implementation; management, easements or land purchase?

- **Social**
  - Adoption, fit with local systems, local landowner values

- **Climate & hydrology**
  - Inter-annual & seasonal
  - Tile drainage vs. Surface runoff

Annual streamflow in Minnesota
Most BMPs geared to sediment

Conservation Cover

Contour Strip-Cropping

Photo by David Hansen
Problems with dissolved pollutants

Gulf Hypoxia: a nitrate issue

Source: NOAA

Lake Erie re-eutrophication: Dissolved phosphorus issue

Source: Huffington Post
Meta-analysis of studies

- Values obtained from literature around the country (insufficient data from MN)
- Focus on field studies
- Group by flow path
- By landscape position
  Avoiding/controlling/trapping
- Pollutant type
Particulate

- Process of removal are well–understood
- Goal of the Soil Conservation Service and later NRCS programs since 1930s

Dissolved

- Dissolved P gets flushed (BMP may becomes a source, unlike sediment or nitrate)
Range of pollutant removal averages by type
Variability of pollutant removal rates by type

C.V – coefficient of variation

- dissolved P
- Nitrate
- NH$_4$
- total N
- total P
- particulate P
- total sediment

DISSOLVED SOLID TOTAL
Issues and research needs: dissolved P

- Legacy phosphorus
- Mobilization of phosphorus from topsoil; trapping BMPs
- Need for dissolved phosphorus retention and removal

Lake Erie

Ag BMP Handbook | WRC October 2017
Future research needs

- Combinations of BMPs or “treatment trains” lacking data
- Need for water storage and nutrient filtration
- Effectiveness of BMPs for less well understood pollutants
  - Pesticides
  - Emerging contaminants
Where you will find it?

www.mda.state.mn.us/mnwrl

BBE website:  www.bbe.umn.edu

MDA website:  www.mda.state.mn.us/cleanwaterfund
Acknowledgements

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Heidi Peterson, Minnesota Department of Agriculture (MDA)

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Improving the effectiveness of conservation in the Le Sueur River basin

Amy Hansen, Ph.D.
St. Anthony Falls Lab, University of Minnesota

Minnesota Water Resources Conference
October 18, 2017
REACH Research Team:

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Sergey Rabotyagov         | U of Washington               
Le Sueur River Basin
Le Sueur annual contaminant yields - compared to rest of MN

TSS

Nitrate

TP

(MPCA 2017)
Le Sueur River water quality progress

(MPCA: Le Sueur River Watershed Clean Water Accountability Progress Report 2016)

The Le Sueur River Watershed Restoration and Protection Strategy calls for a minimum 60% reduction in TP, a 65% reduction in sediment, and a 45% reduction in nitrogen, in order to achieve water quality goals.
Improved edge of field water quality may not propagate towards improved water quality at the basin outlet.

Is the water quality problem intractable or could we do better if we shift from a field to a watershed perspective?

**Water quality improvement spending in the LeSueur River Watershed, 2008 – 2015**

<table>
<thead>
<tr>
<th>Source</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landowner</td>
<td>$320,633</td>
</tr>
<tr>
<td>Local</td>
<td>$111,721</td>
</tr>
<tr>
<td>State</td>
<td>$1,107,398</td>
</tr>
<tr>
<td>Federal</td>
<td>$5,240,672</td>
</tr>
</tbody>
</table>

*The figures in this report are based on data from several agencies. For details, see: [www.pca.state.mn.us/water/clean-water-fund](http://www.pca.state.mn.us/water/clean-water-fund).*
Hydrology, which is mediated by drainage systems and weather patterns, is the primary driver of pollutant export

(Foufoula-Georgiou et al. 2016, Kelly et al. 2017)

Near channel sediment sources (bluff and bank erosion) are significant and released during high streamflows

(Belmont et al. 2011, Cho et al. in prep)

Wetlands and lakes are significant locations of nitrate removal, and reduce peak flows

(Hansen et al. 2016, Hansen et al. accepted, Czuba et al. in review)
REACH modeling framework

- Daily time step
- Decadal run length

**Inputs**
- Precipitation
- Candidate landscapes, cost

**Models**
- SWAT – Hydrology, TP, terrestrial processes
- MOSM - Sediment
- NNM - Nitrate

**Outputs**
- TP
- TSS
- NO3

Evaluate objective function, define new candidates
SWAT watershed model

Land Cover and Management

Soils

Topography

http://swat.tamu.edu
Near channel sediment – MOSM model

(Cho et al. in prep)
Aquatic nitrate removal – NNM model

(Czuba et al. in review)
Can we meet water quality targets?

How much will it cost?

What management options will get us there?
Fraction of annual yield removed (compared to existing landscape)

- % NO3 reduction from baseline
- % TSS reduction from baseline
- % P reduction from baseline

Bar chart showing the reduction in different pollutants from baseline for various management practices.
Cost-benefit tradeoff frontier
Management options selected in more optimal solutions:

(Fertilizer management, tillage options were rarely selected. Low cost but not as effective.)

Optimal placement of management options TBD.)
Can we meet our water quality targets? What will that look like?

- 25% reduction in nitrate
  - Cover crops

- 25 x 25 (25% reduction NO3, TP, TSS)
  - Cover crops, some flow-through marshes, near channel sediment stabilization.

- Le Sueur River Watershed Restoration and Protection Strategy
  - Many more small flow-through marshes, cover crops, near-channel sediment stabilization

$ = $1 million/yr

Reported costs include recurring loss from taking land out of production
Questions?

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