Nature-Based Solutions: How Much Do You Need to Meet Flood Mitigation Targets?

Case Study Area: Madison, WI

Caroline Burger, PE

TFMA 37th ANNUAL MEETING / MARCH 27TH, 2025

carollo

Photo credit: Phil Goebler, City of Madison, WI

Questions to ask yourself

- Has your agency/organization conducted a nature-based solutions analysis?
- What tools/models did you use and/or would you use?
- Did you find out what you wanted to know and/or what would you want to know?

Agenda

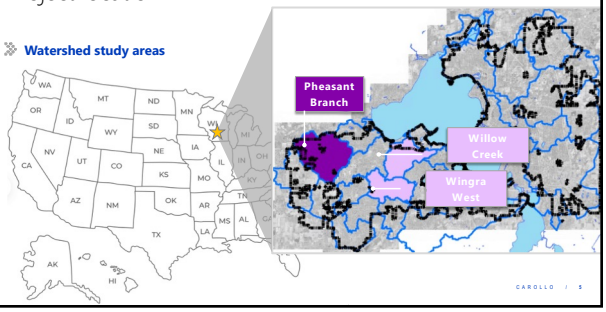
1. Project Location
2. Purpose of Analysis
3. Approach of Analysis
4. Watershed Study Model Overview
5. Phase I
6. Phase II
7. Conclusions
8. City's Approach Going Forward

01

Project Location

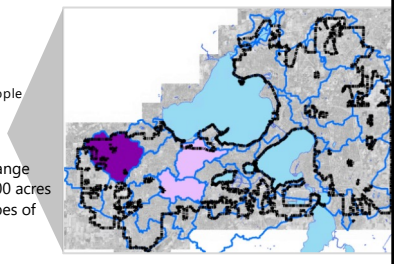
Project location

Watershed study areas



Project location

- ★City of Madison, WI
  - » ~77 square miles
  - » Population ~270,000 people
  - » Capital of Wisconsin
  - » Major University
  - » Larger tech companies
- Watershed study areas range from ~500 acres to 15,000 acres
- Lakes create different types of outfall conditions



02 Purpose of Analysis

Purpose of analysis

To understand if traditionally sized nature-based solutions can be used to meet flood control targets.

- Targets include:
  - 10% Annual Exceedance Probability (AEP) (10-yr) event
    - 4.09 inches over 24 hours
    - No surcharging onto the street
  - 4% AEP (25-yr) event
    - 5.02 inches over 24 hours
    - Maximum of 0.5' on the centerline of the road
  - 1% AEP (100-yr) event
    - 6.66 inches over 24 hours
    - No structure flooding
- Targets focused on peak water surface elevations (feet)

Purpose of analysis

- Understand what works/doesn't work for the City of Madison
  - Pheasant Branch is one of the City's 22 watersheds
- Watershed study/flood mitigation purpose only
  - No in-depth look at other water components:
    - MS4 permit compliance
    - Lake levels
    - Drinking water quality
    - Etc.
  - The City of Madison does not have combined sewer, thus no consent decree

03 Approach to Analysis

Grey versus nature-based solutions (NBS)

GREY
- Temporarily stores or conveys stormwater
  - » Detention ponds
  - » Underground storage
  - » Storm pipes

NATURE-BASED
- Infiltrates stormwater
  - » Biofilters
  - » Rain gardens
  - » Pervious pavements
  - » Infiltration trenches
- Referred to as "Volume Control Infrastructure" in the watershed studies

How/when are nature-based solutions typically used?

- Meet EPA consent decrees
  - » Municipalities with CSOs (Combined Sewer Overflows)
  - » Volume reduction (million gallons, cubic feet)
- Meet development/redevelopment stormwater management requirements
  - » Total suspended solids reduction
  - » Volume reduction (cubic feet)
- Typically sized for:
  - » 100% AEP (1-yr) storm event (2.49 inches over 24 hours), or,
  - » Average annual rainfall
- City of Madison's analysis is atypical

Approach to City's analysis

- High-level/planning-level analysis
- Evaluate NBS effectiveness watershed-wide
- Include opportunities analysis
  - Intensive GIS desktop analysis
  - Understand where NBS could be placed
- No field investigations conducted

Photo credit: Phil Goebler, City of Madison, WI

How are the NBS sized?

- For this analysis – "traditionally sized" means:
  - Sized for small storm events (100% AEP/1-yr Event)
  - Treats impervious areas
- For this analysis – NBS assumed to be:
  - 2 feet deep
  - 1 foot filled with engineered soil with porosity of 0.3
  - 3-foot buffer to grade into existing grades
  - No underdrain
  - Native soil seepage rate of 0.3 in/hr (Madison generally has silty soils)
  - Area adjusted based on needs for treatment

Photo credit: Phil Goebler, City of Madison, WI

04 Watershed Study Model Overview

Watershed Study Model overview

- 1D/2D Computer Modeling Software
  - » XP-SWMM™ or PC-SWMM™
  - » Pipes and some channels/ ponds modeled in 1D
  - » Surface overflow, channels/ ponds modeled in 2D
- Watersheds ranging from 500 acres to 15,000 acres
- SWMM hydrology

- Subcatchments separated into:
  - » Directly Connected Impervious Area (DCIA)
  - » Non-Directly Connected Impervious Area (NDCIA)
  - » Pervious Area
- Models constructed for purposes of flood analysis – aka – large storms
  - » Looking at Peak Flow (cfs – cubic feet per second and Peak Water Surface Elevations (feet)

Watershed Study Model overview

Subcatchments separated into:

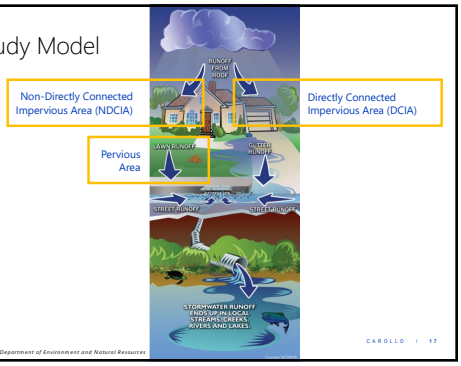


Image Credit: North Carolina Department of Environment and Natural Resources

Watershed Study Model overview

DCIA data is a combination of two sources:

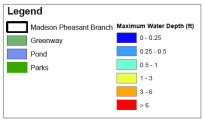
1. Surface cover data created for the City
2. Default percent connectedness from commonly used water quality program
   - » Program includes Standard Land Use data
   - » Provides typical percent connectedness of all source areas (roofs, sidewalks, driveways, etc.)

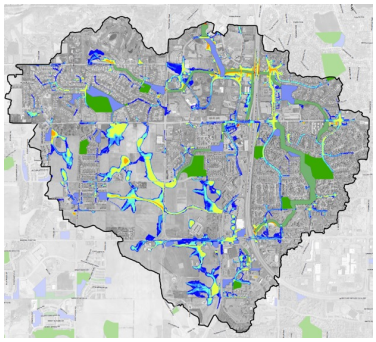
Watershed Study Model overview

Main Deliverable:

Inundation Mapping

1% AEP (100-yr) Inundation Mapping Existing Conditions

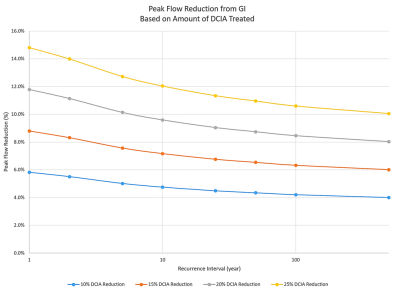




05 Phase I Analysis

Phase I Analysis

- Evaluated peak flow reduction from traditional amounts of NBS
  - Treating 10%, 15%, 20%, 25% DCIA
- As expected, peak flow reduction goes down as the storm event size increases
- 1% AEP (100-yr) peak flow reduction ranges from 4% to 10.5%



Phase I Analysis

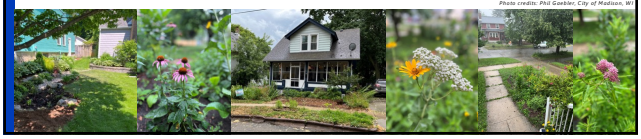
Peer Review

- Outside consultant reviewed Engineering's process, approach, and results
- Found analysis was reasonable and provided a few suggestions

Corroborating Analysis

- Similar analysis conducted in two watersheds by consultants
  - » Willow Creek
  - » Wingra West
- Analyses found similar levels of peak flow reductions

Photo credits: Phil Gaebler, City of Madison, WI



06 Phase II Analysis

Phase II Analysis

- Purpose: How much traditionally sized NBS does it take to achieve the flood control targets?
- Targets not met in Pheasant Branch Watersheds (as of December 2022)
  - » 10% AEP event
    - 9.9 out of 52.1 lane-miles of streets (19%)
  - » 4% AEP event
    - 13.1 out of 52.1 lane-miles of streets (25%)

Photo credits: Phil Gaebler, City of Madison, WI

  - » 1% AEP event
    - 118 out of 2,920 structures (4%)
    - 14 out of 14 greenway crossings (100%)
- Continue to add NBS until targets are met

Phase II Analysis

Results

	Street Segments (miles) 10-year Storm Event			Structures (#) 100-year Storm Event		
Total	52.1			2,920		
Scenario	**Flooded**	**Percent**	**Removed**	**Flooded**	**Percent**	**Removed**
Existing Conditions	9.9	19%	N/A	118	4%	N/A
Nature-Based Solutions						
25% DCIA	8.7	17%	1.1	109	4%	9
75% DCIA	5.8	11%	4.1	79	3%	39
100% DCIA	2.3	4%	7.5	51	2%	67

Phase II Analysis

Comparison to Grey Infrastructure

	Street Segments (miles) 10-year Storm Event			Structures (#) 100-year Storm Event		
Total	52.1			2,920		
Scenario	**Flooded**	**Percent**	**Removed**	**Flooded**	**Percent**	**Removed**
Existing Conditions	9.9	19%	N/A	118	4%	N/A
Nature-Based Solutions						
25% DCIA	8.7	17%	1.1	109	4%	9
75% DCIA	5.8	11%	4.1	79	3%	39
100% DCIA	2.3	4%	7.5	51	2%	67
Grey Infrastructure						
Proposed Conditions	1.0	2%	8.9	57	2%	61

Phase II Analysis

Impact on MS4 permit

» City's Total Phosphorus (TP) TMDL goal (via the MS4 permit):

Scenario	Estimated TP Reduction (lbs)	Estimated NBS Construction Cost ($)	Cost per lb TP Removed ($/lb)
25% DCIA Treated	381	$18-49 million	$48,000-128,000
75% DCIA Treated	1,140	$55-147 million	$48,000-128,000
100% DCIA Treated	1,527	$74-196 million	$48,000-128,000

» City just updated its agreement for adaptive management with Madison Metropolitan Sewerage District and is paying ~$100/lb for TP

07

Conclusions

Conclusions

- Nature-based solutions can be effective at reducing flooding; however, it requires a significant amount
- Can reduce the size of our grey infrastructure, OR, do full-size of both to add resilience to our stormwater management system

Photo credit: Phil Gaebler, City of Madison, WI

08

City's Approach Going Forward

City's approach going forward

- Current approach
  - » Current Stormwater Ordinance
    - – NBS required as part of new and redevelopment process
    - – NBS to treat at least first ½ inch of runoff from impervious areas
  - » NBS installed on street projects where appropriate
  - » NBS Pilot Study with USGS
- Watershed Studies
  - » Add NBS to watersheds where goals cannot be met with grey infrastructure

Photo credit: Phil Goebler, City of Madison, WI

09 Back to You

Questions you asked yourself

- Has your agency/organization conducted a nature-based solutions analysis?
- What tools/models did you use and/or would you use?
- Did you find out what you wanted to know and/or what would you want to know?


Thank you!
Questions?
Caroline Burger, PE, cburger@carollo.com
CAROLLO.COM
carollo