Climate Change and Nonpoint Source Pollution in the Great Lakes Basin: Opportunities and Challenges

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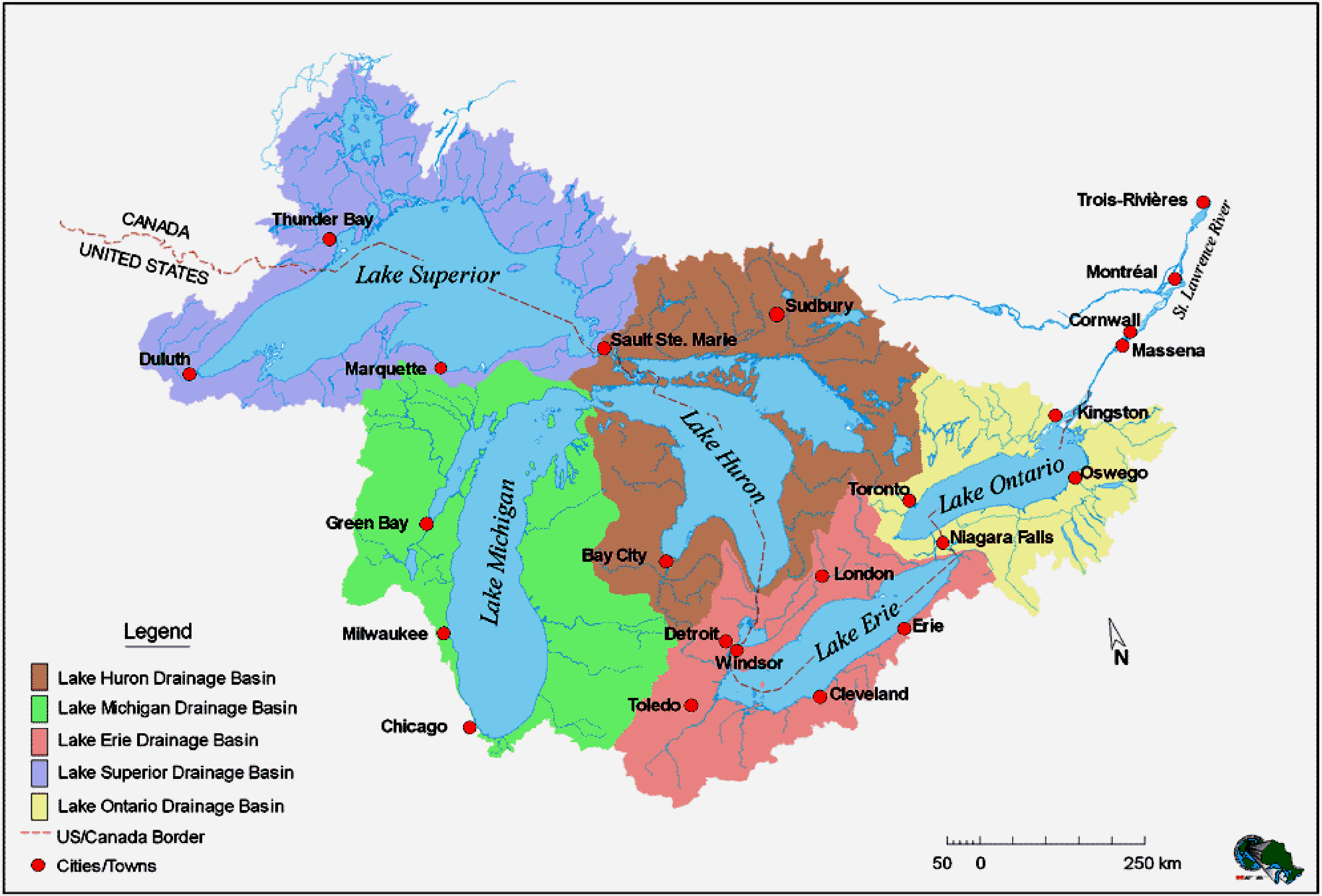
Outline

- NPS Pollution – A Critical Issue in the Great Lakes Basin
- Current Approaches to NPS Pollution
- Challenges in Estimating NPS Pollution
- Research Opportunities in NPS

Great Lakes Drainage Basin - St. Lawrence River



NPS Pollution – A Critical Issue in the Great Lakes Basin

- The U.S. Environmental Protection Agency (EPA) has identified contaminated sediments, urban runoff and storm sewers, and agriculture as the primary sources of pollutants that cause the impairment of Great Lakes shoreline waters (U.S. EPA 2002).
- The Great Lakes Regional Collaboration (GLRC) has also identified nonpoint source pollution (NPS) (particularly: nutrients, contaminants, pathogens, sedimentation, and altered flow regimes) as one of the 8 critical issues in the Great Lakes Basin (2005).
- NPS "threatens human health, reduces recreational opportunities, and increases the cost of treating drinking water and redging our harbors and marinas." (GLRC 2005)

- “Strategies to date have failed to deliver widespread widespread streams and lake restoration necessary for the protection and maintenance of the Great Lakes” (GLRC 2005).
- The GLRC recommends investing about $768 million to address NPS problems in the Great Lakes Basin over 5 years (by 2010).
- Some of the critical watersheds to focus on: western and central Lake Erie, Maumee River watershed, Green Bay, Saginaw Bay, Lake St. Clair, nearshore waters of Lake Michigan, and AOCs (GLRC 2005).

Current Approaches to NPS Pollution

- Soil Erosion and Sedimentation

  The Universal Soil Loss Equation and its variations.

- Nutrients, contaminants and pathogens

  Dissolved and sediment attached

- Altered Flow Regimes

  Peak runoff and channelization

The Universal Soil Loss Equation

A = R* K*LS*C*P

- A= the computed average soil loss per unit area, expressed in the units selected for K and for the period selected for R (usually tons/acre/year)
- R=the rainfall and runoff factor and is the number of rainfall erosion index (EI) plus a factor for runoff from snowmelt or applied water.
- K=the soil inherent erodibility of a particular soil. For a given soil, it equals the average soil loss per unit of factor R from a 72.6-foot length of 9% slope in clean-tilled continuous fallow.
- L=the slope-length factor and is the ratio of soil loss from the field slope length to that from a 72.6 -foot length under identical conditions.
- S=the slope-steepness factor and is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions.
- C=the cover and management factor and is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.
- P=the support practice factor and is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope.
- Wischmeier, W.H., and D.D. Smith, 1978

Models based on the USLE:

- ANSWERS (Areal Nonpoint Source Watershed Environment Simulation) (Beasley et al. 1980);
- CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) (Knisel 1980);
- GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Leonard et al. 1987);
- AGNPS (Agricultural Nonpoint Source Pollution Model) (Young et al. 1989);
- EPIC (Erosion Productivity Impact Calculator) (Sharpley and Williams 1990);
- WEPP (Water Erosion Prediction Project) (Laflen et al. 1991).
- SWAT (Soil and Water Assessment Tool) (Arnold et al. 1998) to name a few.
- HSPF (Hydrologic Simulation Program in FORTRAN) (Bicknell et al. 1996)
- EPA's BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)
- RUSLE2 (Revised Universal Soil Loss Equation Version 2) (Foster 2004).

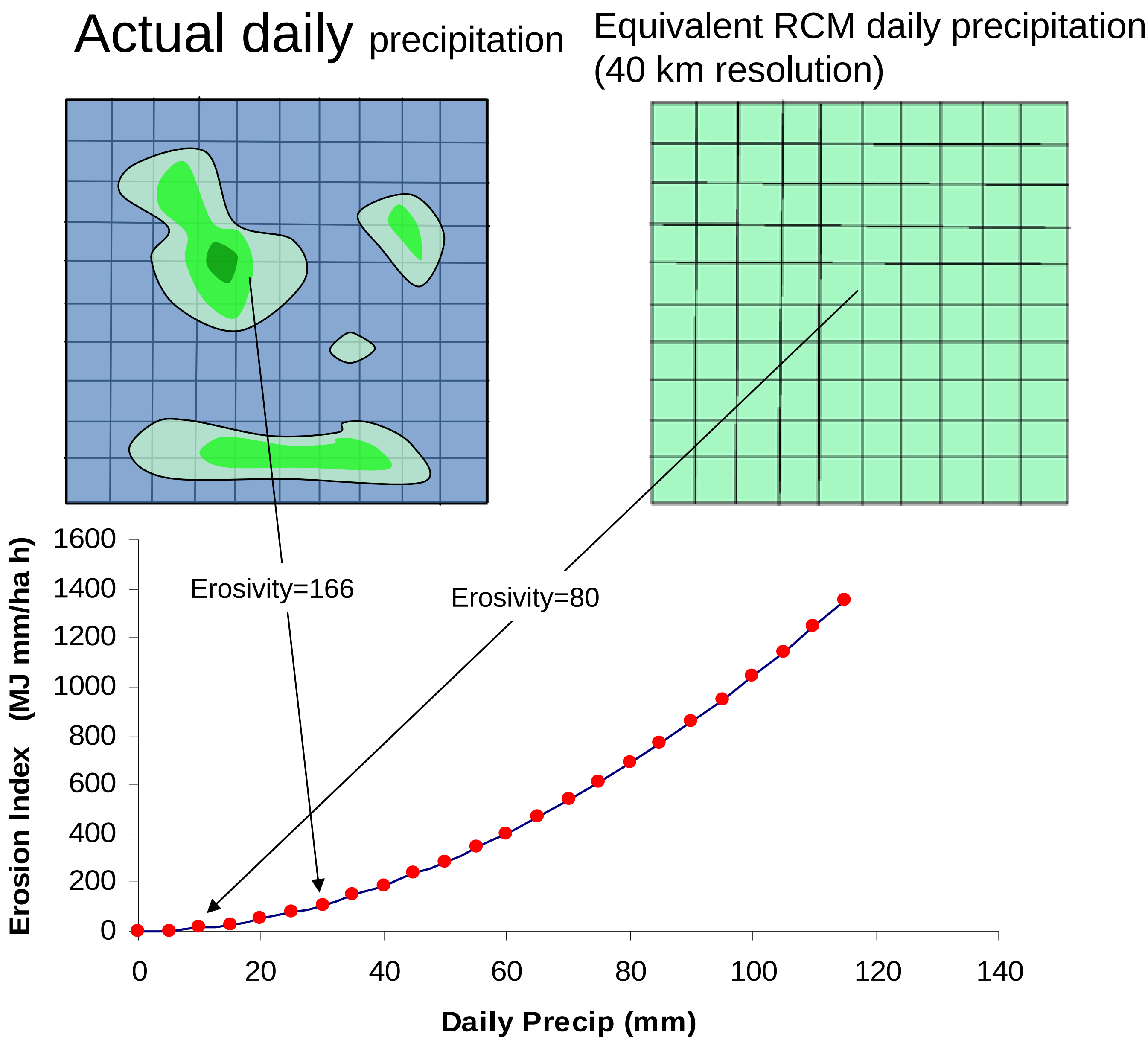
Digital Databases to support USLE

USLE Variables	Databases	Problems
R –Rainfall erosivity	NOAA GLERL meteorology and climate databases And NEXTRAD (1948-)	Daily Weather Station data and 4 by 4 km RADAR data
K-Soil erodibility	USDA STATSGO SSURGO	Static (1990s)
LS – Slope and slope length	USGS seamless DEM	Accuracy of DEMs
C – Cover and management	USGS NLCD 1992 and 2001	Static (need bi - weekly data)
P-Support practice	Inferred from land use and ag stats	Static (need bi-weekly data)

Challenge No.1

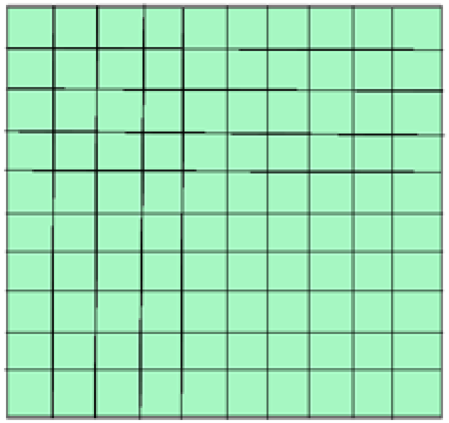
- How to best downscale GCM or RCM output to approximate individual storm erosivity at the watershed scale?

Effect of Scale in Assessing Climate Change Impact on Erosion

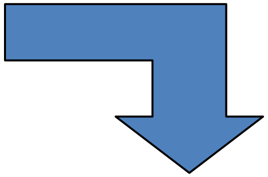


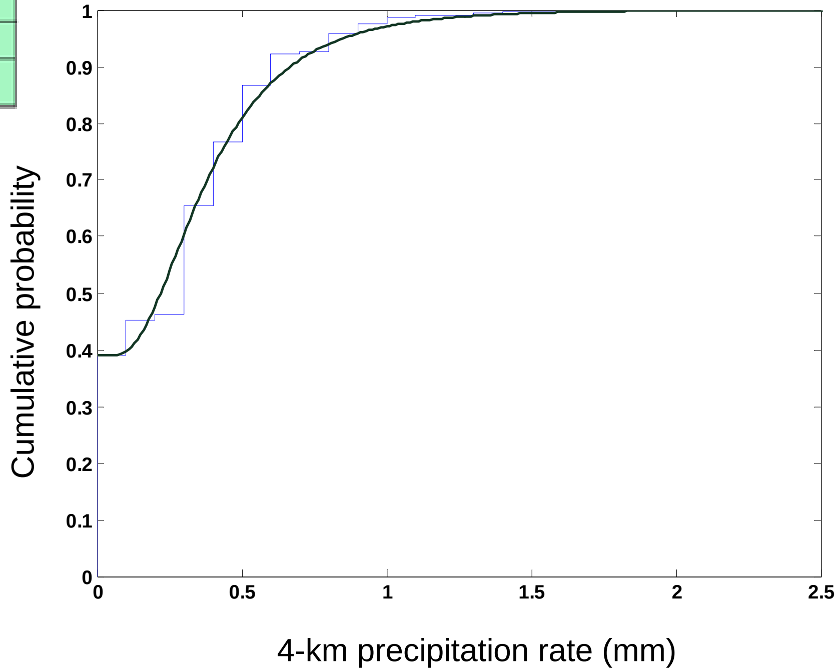
Compensating for the Scale Effects

RCM daily precipitation
(40 km resolution)

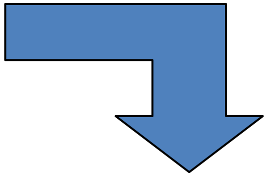


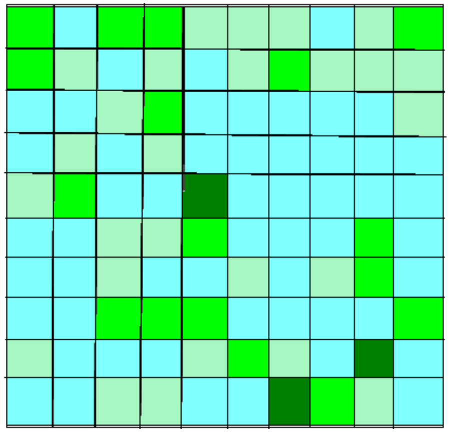
NOAA NCEP MPE data





Generation of an ensemble of
equiprobable conditional
precipitation realization





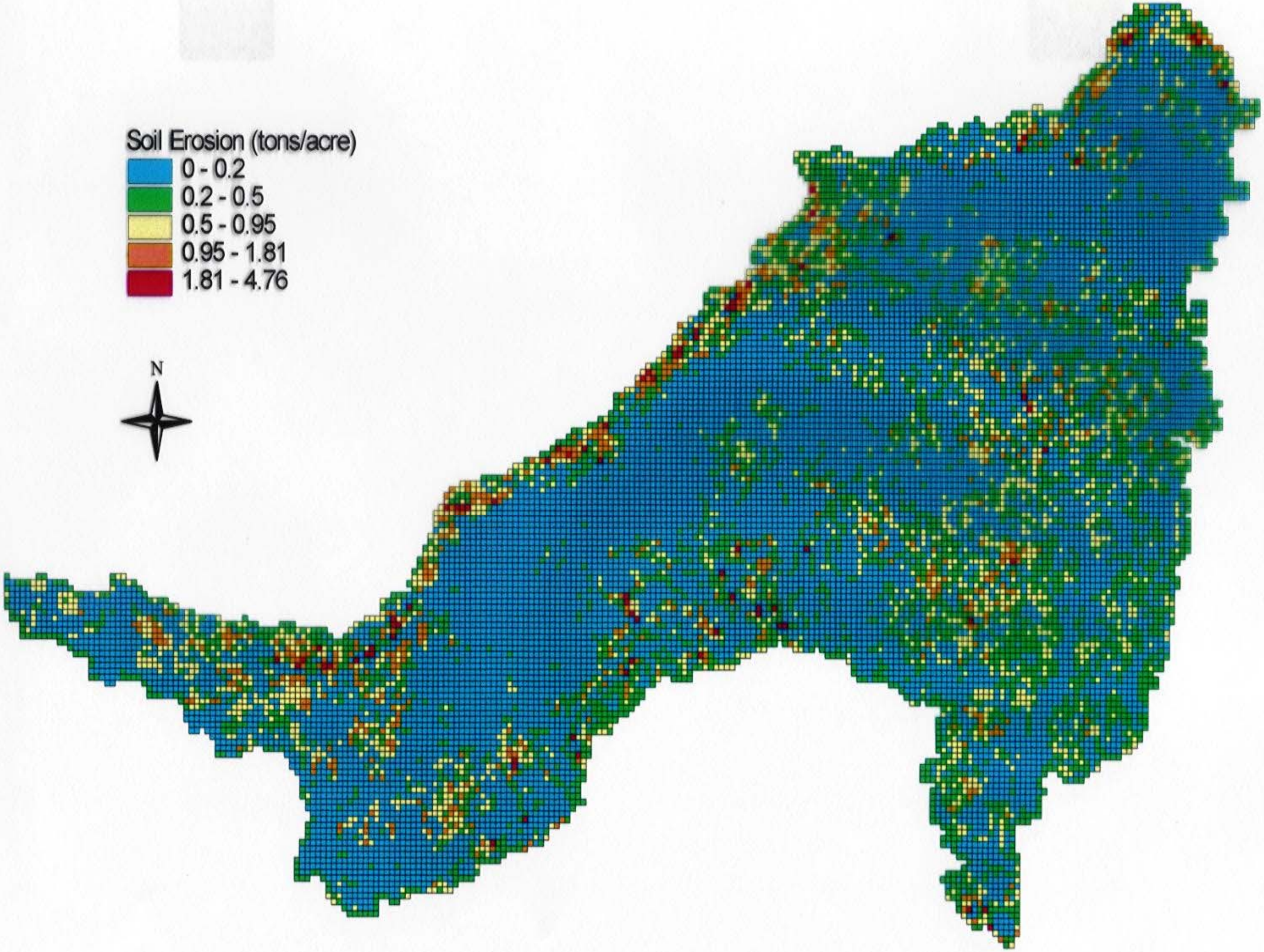


Figure 3. Soil Erosion in tons/acre in the Cass River Watershed (1984)

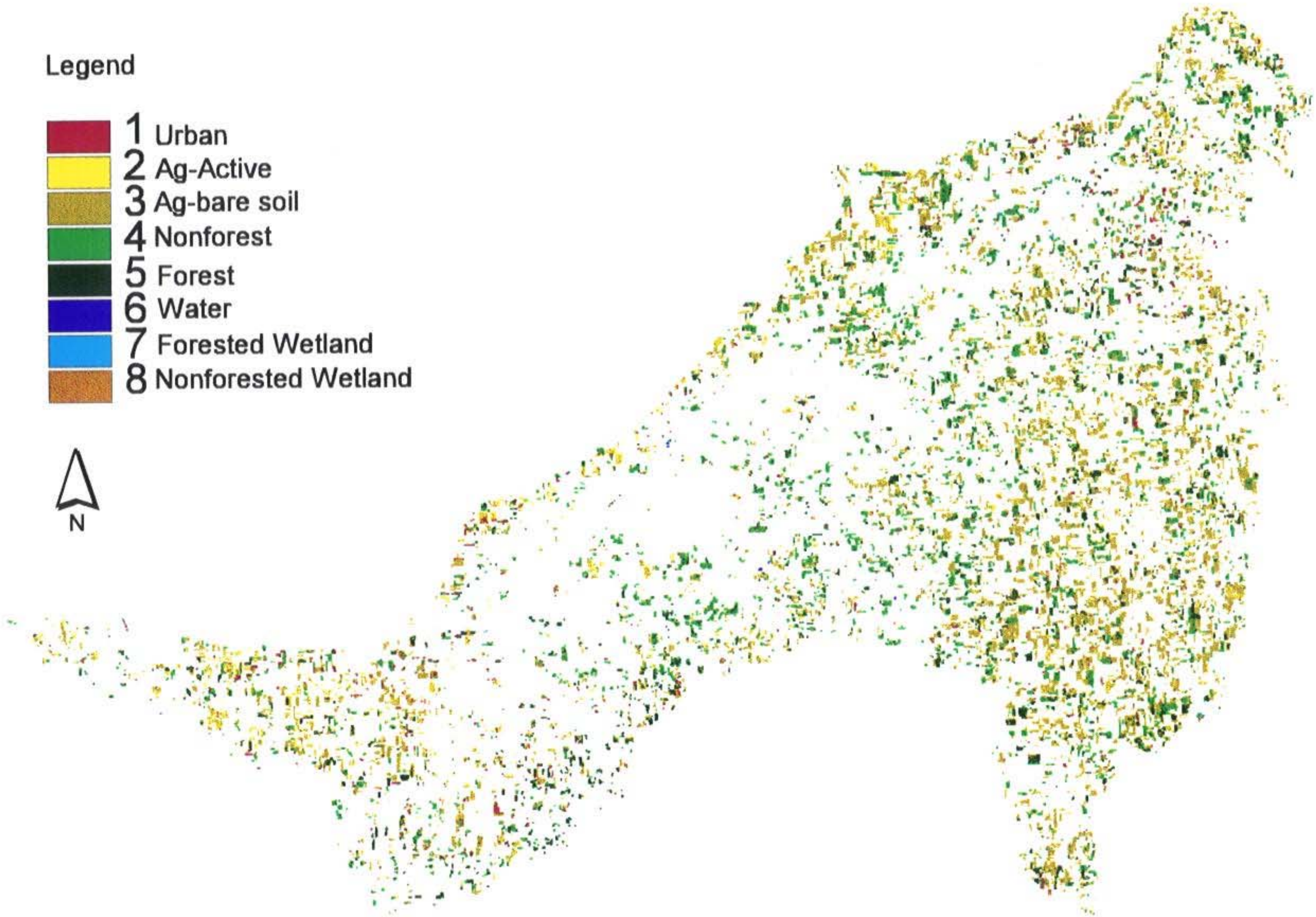
Challenge No.2

- How to determine the dynamic coefficient values of C and P in response to crop growth stages for better estimating soil erosion rates at the watershed scale?
- How does climate change affect crop growth?

Monthly C and P Values

JAN_C	JAN_P	FEB_C	FEB_P	MAR_C	MAR_P	APR_C	APR_P	MAY_C	MAY_P	JUN_C
0.0040	0.30	0.0040	0.30	0.0040	0.30	0.0030	0.30	0.0030	0.30	0.0020
0.0040	0.30	0.0040	0.30	0.0040	0.30	0.0030	0.30	0.0030	0.30	0.0020
0.0040	0.30	0.0040	0.30	0.0040	0.30	0.0030	0.30	0.0030	0.30	0.0020
0.0040	0.30	0.0040	0.30	0.0040	0.30	0.0030	0.30	0.0030	0.30	0.0020
0.0040	0.30	0.0040	0.30	0.0040	0.30	0.0030	0.30	0.0030	0.30	0.0020
0.5200	1.00	0.5200	1.00	0.5200	1.00	0.5200	1.00	0.5200	1.00	0.5200
0.5200	1.00	0.5200	1.00	0.5200	1.00	0.5200	1.00	0.5200	1.00	0.5200



Detected land cover change in 1992 compared to land cover in 1984 in the Cass River Watershed.

Challenge No.3

Altered Flow Regimes

Peak runoff and channelization

- How to best incorporate dynamic responses of the Curve Number /Manning's coefficient to land use/cover, slope, and soil to estimate the peak flow rates of individual storms and the related soil erosion rates at the watershed scale?

SCS Method for Estimating Runoff

$$Pe = \frac{(P-0.2S)^2}{P+0.8\,S}$$

$$S = \frac{1000}{CN} - 10$$

- The runoff curve number CN is related to potential abstraction S
- Pe=runoff (inches)
- S=potential maximum retention (storage held for a long period of time and depleted by evaporation) (inches).
- CN=SCS curve number representing relationships between cumulative rainfall and cumulative runoff.

Description of Land Use	Hydrologic Soil Group			
	A	B	C	D
Paved parking lots, roofs, driveways	98	98	98	98
Streets and Roads:				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Cultivated (Agricultural Crop) Land*:				
Without conservation treatment (no terraces)	72	81	88	91
With conservation treatment (terraces, contours)	62	71	78	81
Pasture or Range Land:				
Poor (<50% ground cover or heavily grazed)	68	79	86	89
Good (50-75% ground cover; not heavily grazed)	39	61	74	80
Meadow (grass, no grazing, mowed for hay)	30	58	71	78
Brush (good, >75% ground cover)	30	48	65	73

SCS Curve Number Method

Advantages:

- Easy and practical;
- Fewer parameters (rainfall, curve number based on soil and land use);
- Widely used worldwide.

Limitations of the Curve Number method

- 1) Lack of consideration of the time distribution of precipitation (Kawkins 1978; Smith 1978; Beven 2000).
- 2) No explicit account of the effect of the antecedent moisture conditions in runoff computation;
- 3) Difficulties in separating storm runoff from the total discharge hydrograph;
- 4) Runoff processes are not considered with empirical formulae (Beven 2000).
- Curve Number is insensitive to changes in land use/cover and management practices

Use of the SCS Curve Number method may also result in incorrect estimates of nonpoint source pollution rates.

Estimating Discharge in Ungauged Rivers

- The Manning Equation

V=the average velocity in the stream cross section (ft/sec)

R_h = hydaulic radius (ft)=area (A)/wetted perimeter (P)

s=energy slope as approximated by the water surface slope (ft/ft)

n=Manning's roughness coefficient

$$V = \frac{1.49}{n} R_h^{\,2/3} s^{1/2}$$

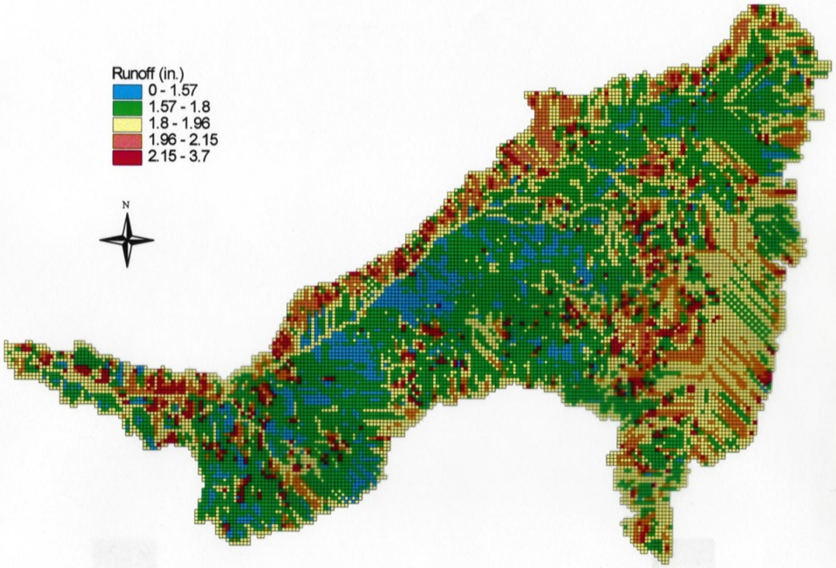


Figure 1. Accumulated Runoff (downstream) in inches in the Cass River Watershed (1984)

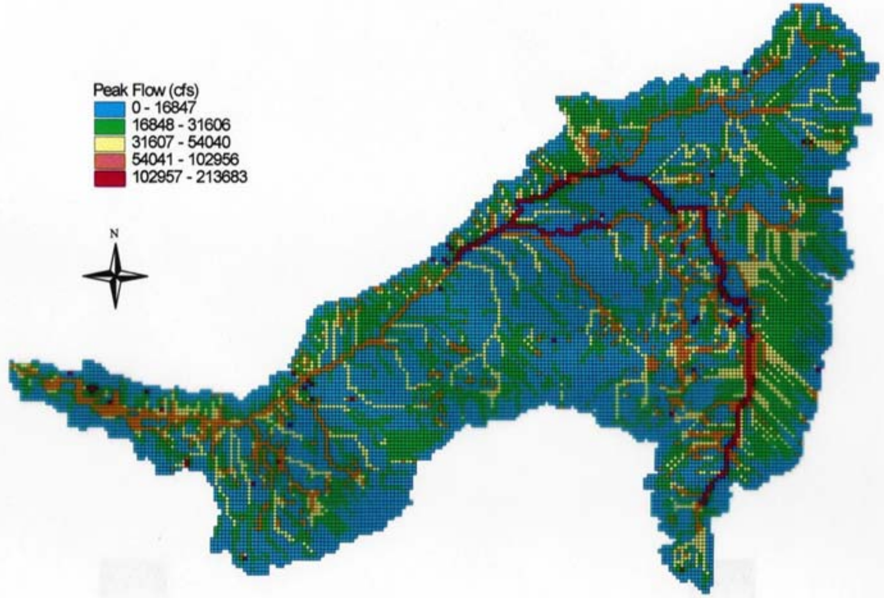


Figure 2. Peak flow (downstream) in cubic feet per second (cfs) in the Cass River Watershed (1984)

Challenge No.4

- How to best estimate the nutrient loading from the Great Lakes watersheds to rivers and lakes?

Nutrients Loading

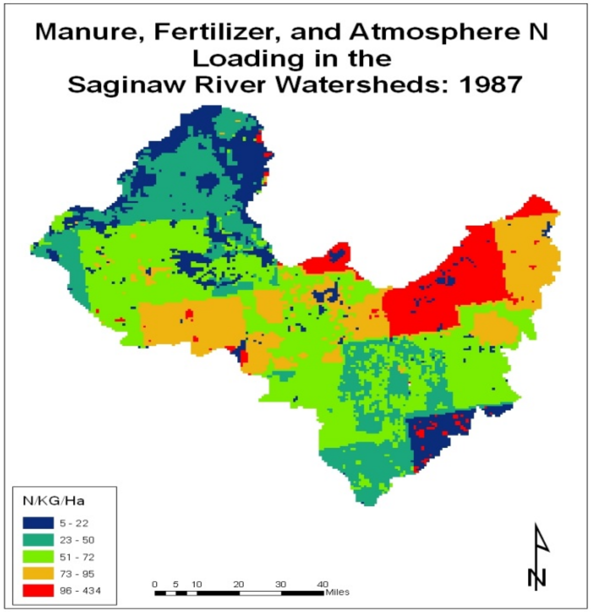
- Better accounting of farm level nutrient balance

  ΔN = Soil N + Manure and Fertilizer N - Plant uptake N - Volatilization N + atmospheric deposition N

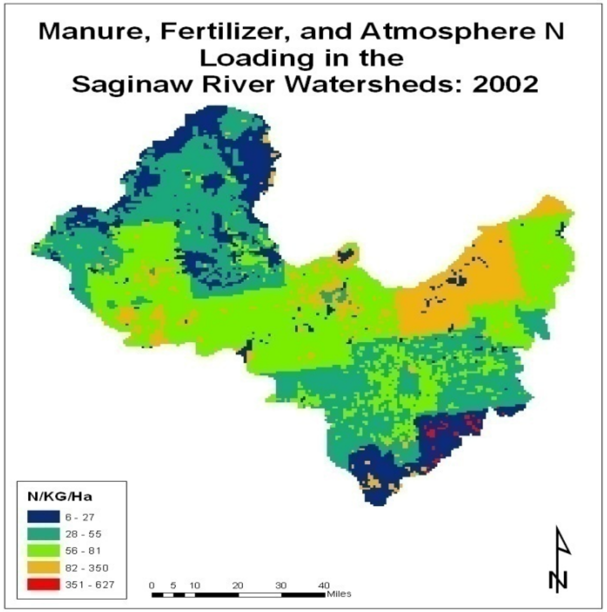
  ΔP = Soil P + Manure and Fertilizer P - Plant uptake P - Volatilization P

Poor understanding of nutrient balance at the watershed scale and regional Level

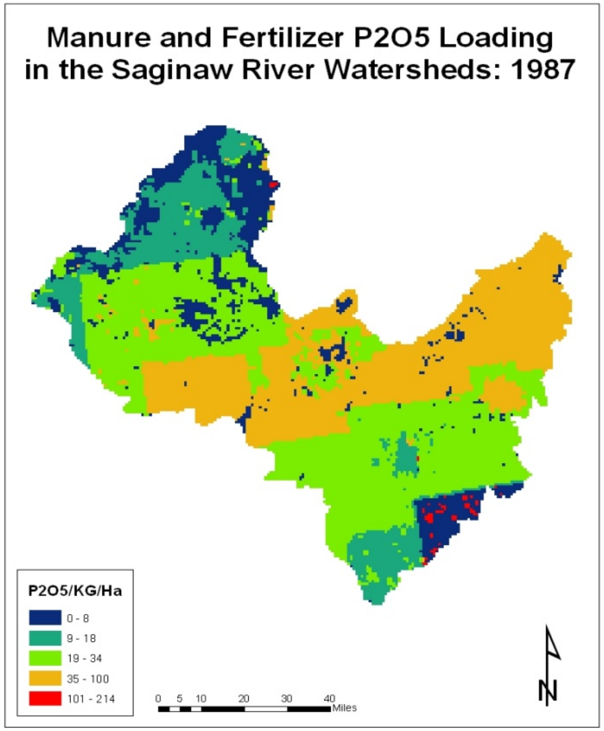
- County Level fertilizer data available for 1945-1985 and 1982-2001 (Ruddy et al. 2006). (Source: http://pubs.usgs.gov/sir/2006/5012/).
- Atmospheric deposit of N for 1985-2001
- Estimating N and P Load from Animal Manure at Zip Code Level (He and Croley 2006; He, DeMarchi and Croley 2008).
- Estimating Pesticide Applications at County Level - Restricted use pesticide (RUP) in Michigan (He, DeMarchi and Croley 2008).



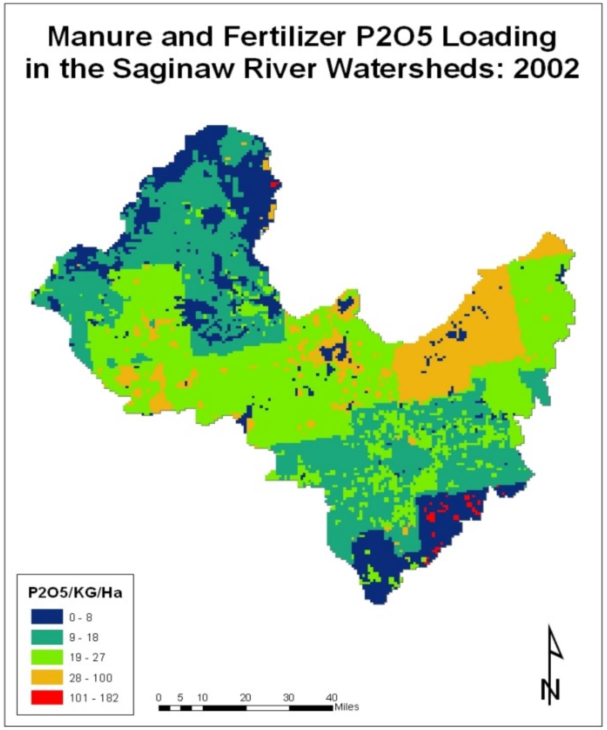
Manure, Fertilizer, and Atmosphere N Loading in the Saginaw River Watersheds: 1987
N/KG/Ha
5 - 22
23 - 50
51 - 72
73 - 95
96 - 434
0 5 10 20 30 40 Miles
N



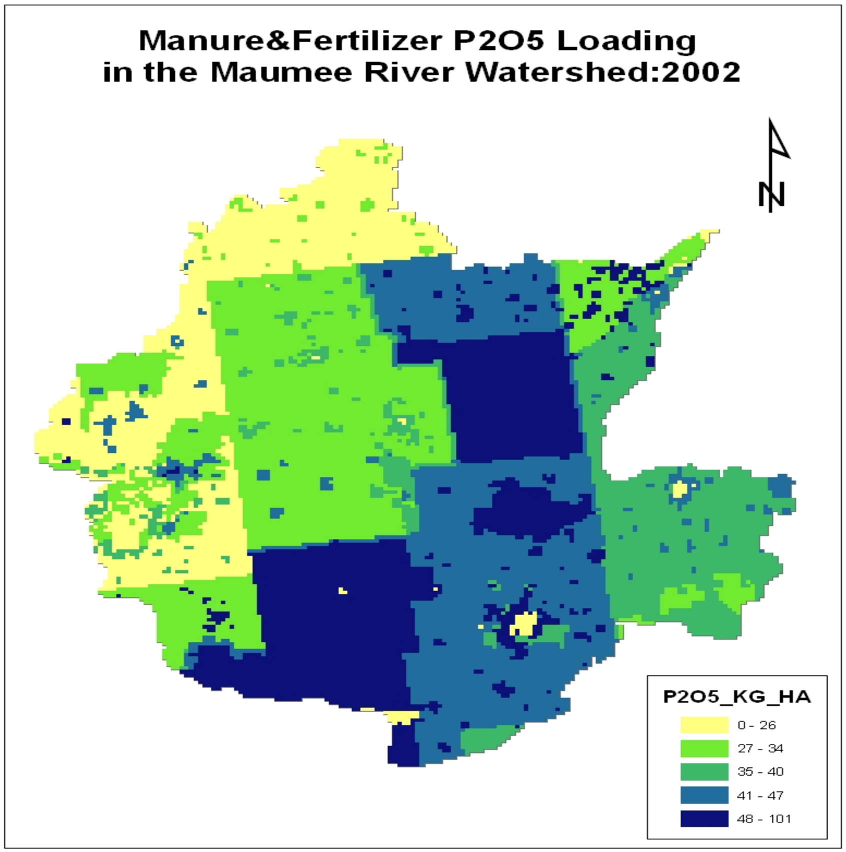
Manure, Fertilizer, and Atmosphere N Loading in the Saginaw River Watersheds: 2002
N/KG/Ha
6 - 27
28 - 55
56 - 81
82 - 350
351 - 627
0 5 10 20 30 40 Miles
N

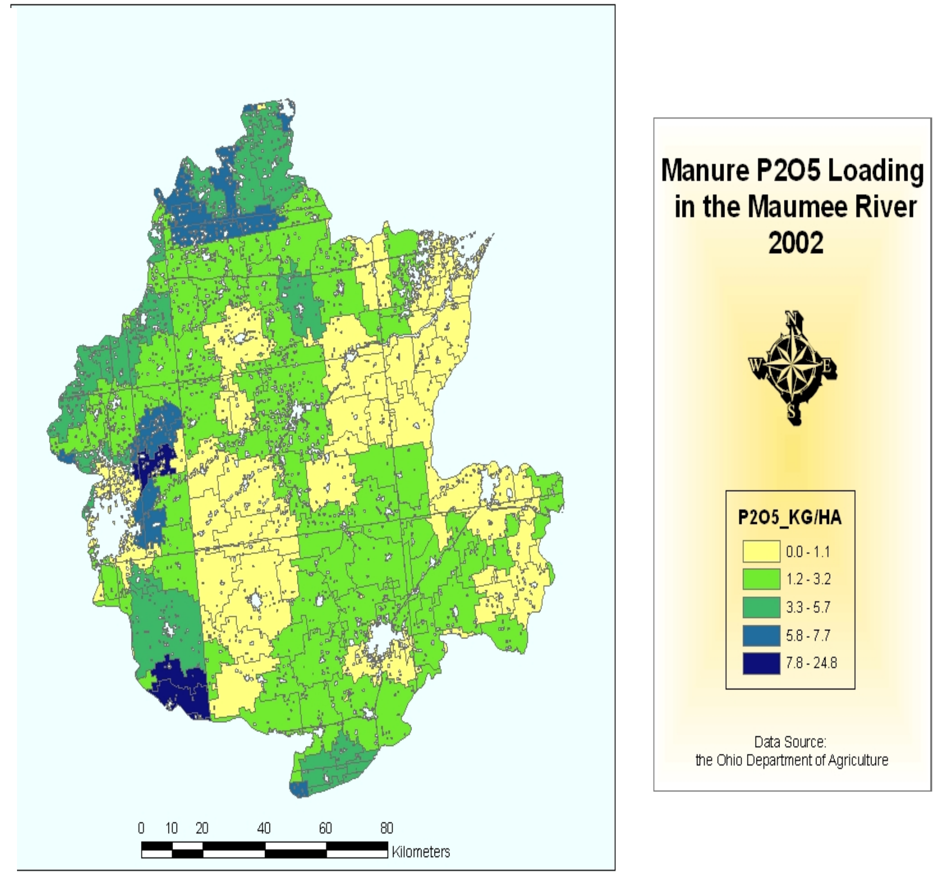


Manure and Fertilizer P2O5 Loading in the Saginaw River Watersheds: 1987
P2O5/KG/Ha
0 - 8
9 - 18
19 - 34
35 - 100
101 - 214
0 5 10 20 30 40 Miles
N



Manure and Fertilizer P2O5 Loading in the Saginaw River Watersheds: 2002
P2O5/KG/Ha
0 - 8
9 - 18
19 - 27
28 - 100
101 - 182
0 5 10 20 30 40 Miles
N


Manure&Fertilizer P2O5 Loading
in the Maumee River Watershed:2002
N
P2O5_KG_HA
0 - 26
27 - 34
35 - 40
41 - 47
48 - 101


0 10 20 40 60 80
Kilometers
Manure P2O5 Loading
in the Maumee River
2002
N
W
E
S
P2O5_KG/HA
0.0 - 1.1
1.2 - 3.2
3.3 - 5.7
5.8 - 7.7
7.8 - 24.8
Data Source:
the Ohio Department of Agriculture

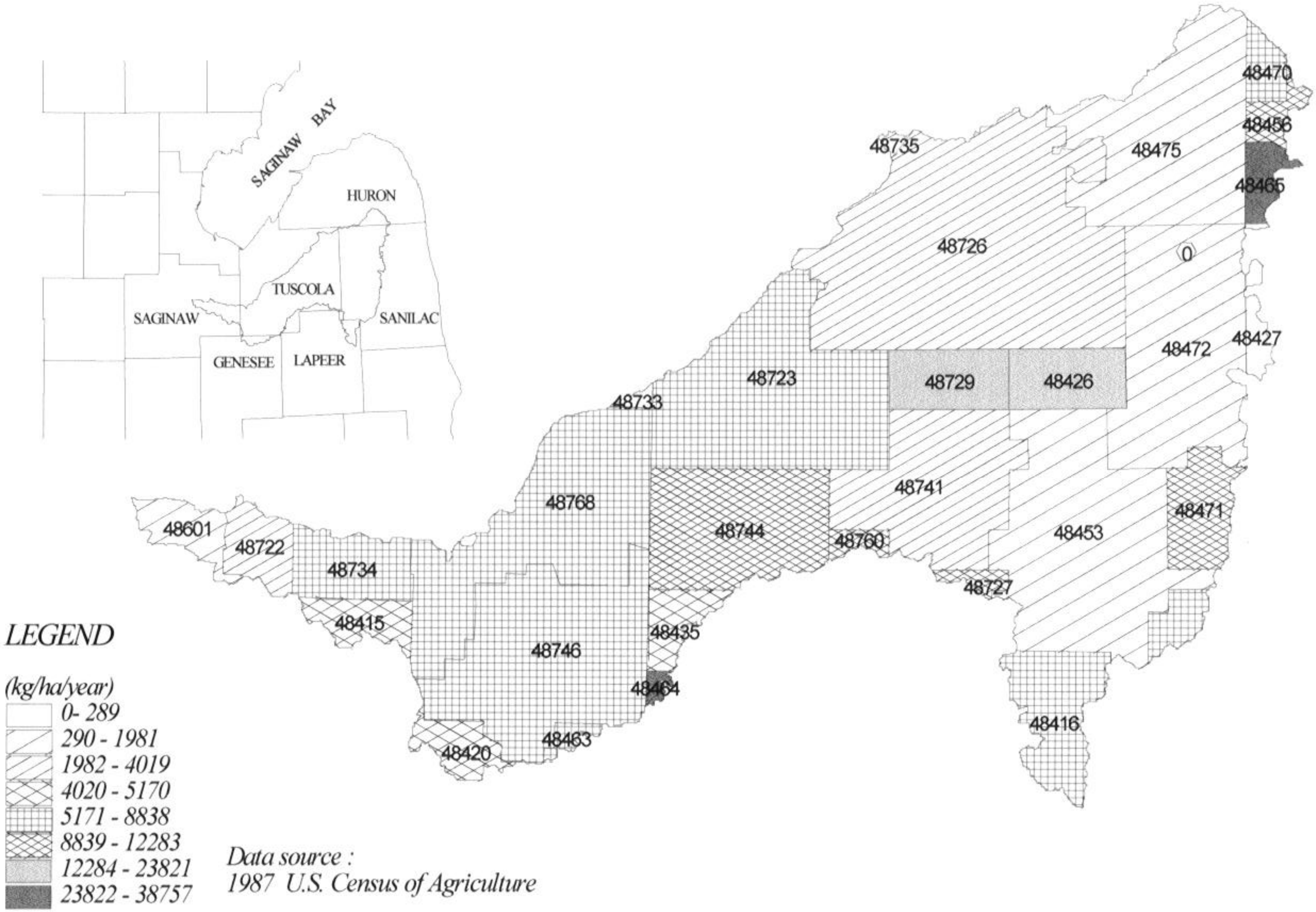


Figure 4. Animal manure application potential in kg/ha by zip code in the Cass River watershed

A spatially distributed, large basin runoff model (DLBRM) to evaluate loadings of sediment, nutrients, pesticides, bacteria and viruses from runoff, erosion, animal manure, chemical applications, and combined sewage overflows at the watershed level in the Great Lakes Basin (Croley and He 2002; 2005a,b; 2006; 2007; Croley et al. 2005; He and Croley 2002; 2004; 2005; 2006; 2007a,b,c.)

Hydrologic Resource Sheds to link the movement of pollutants from the watershed landscape to rivers and lakes.

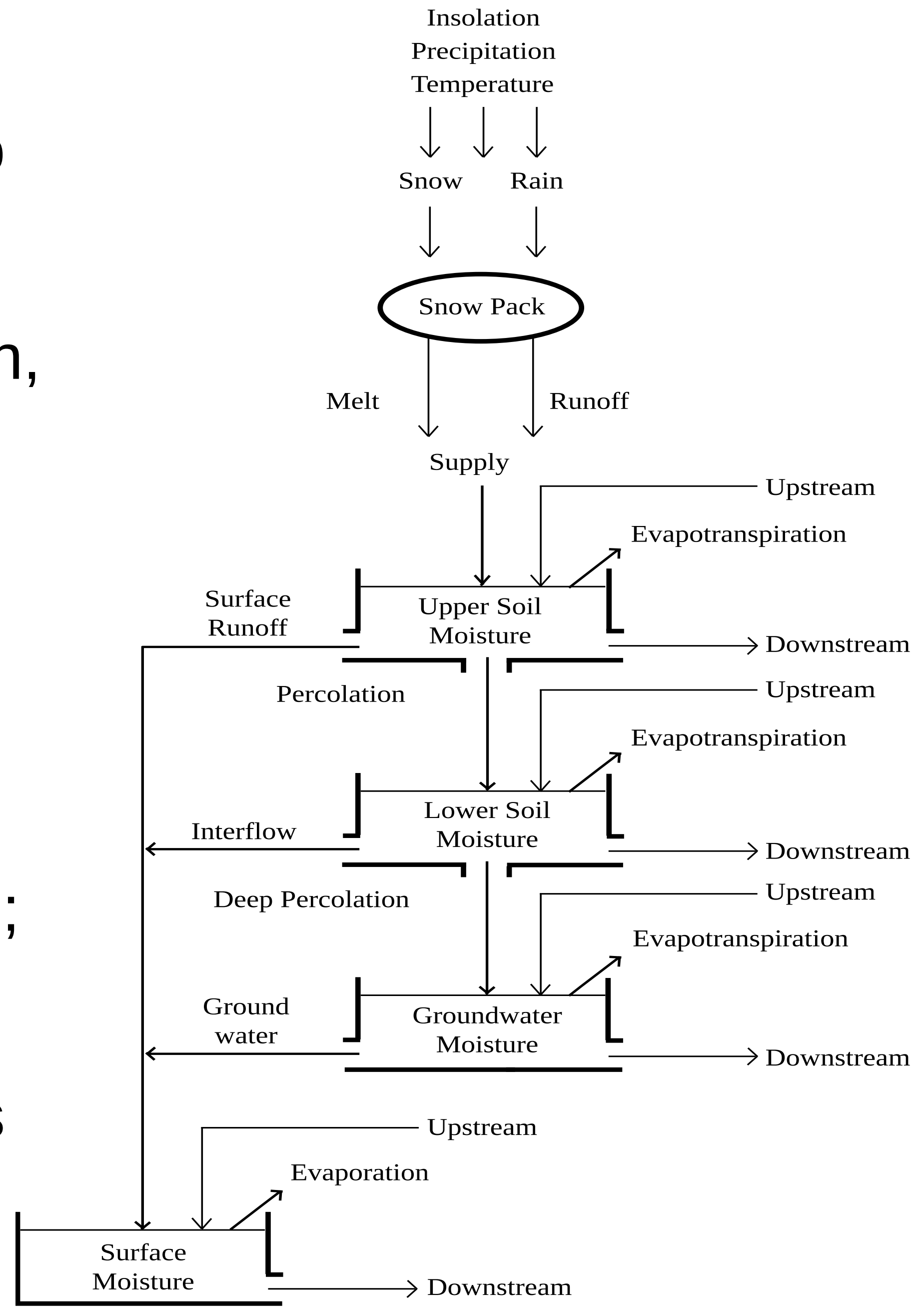
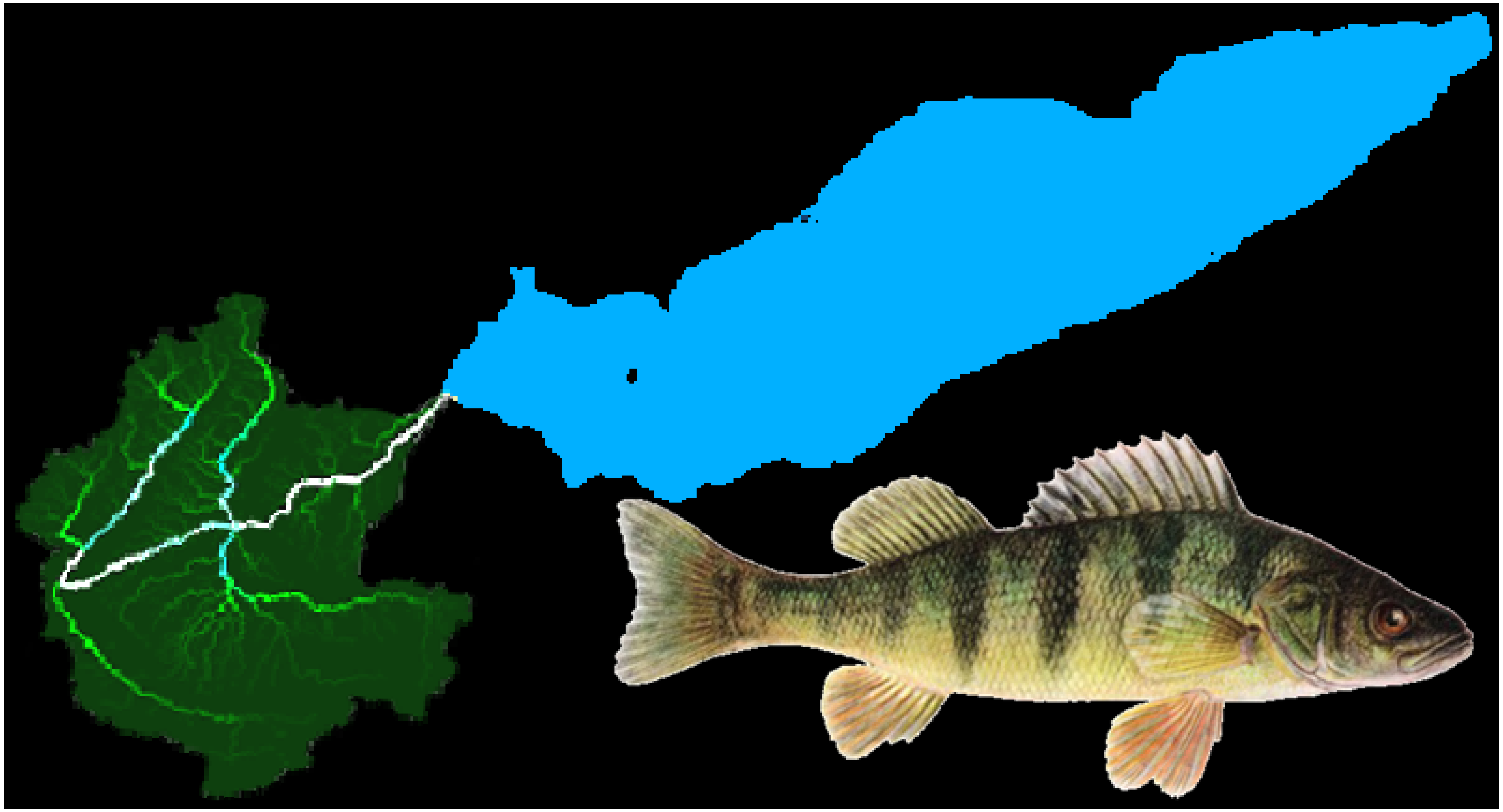


Figure 1. Tank cascade schematic of Distributed Large Basin Runoff Model.



Hydrologic Resource Sheds to link the movement of pollutants from the watershed landscape to rivers and lakes

Challenge No.5

- How to improve the sensitivity of DLBRM to climate and land use/cover changes?
- How to use the sporadic water quality databases to calibrate the DLBRM and apply it to a number of Great Lakes Watersheds?

Calibration of the DLBRM Water Quality Simulations

Available databases

- EPA STORET (www.epa.gov/STORET):
  The Legacy Data Center contains information prior to 1999 and
- The Modernized STORET contains information since 1999.
- Permit Compliance System (PCS)- EPA, CSO and SSO – Michigan
- EPA NPDES Management System (NMS)- Michigan Department of Environmental Quality
- USGS Water Quality Data (http://waterdata.usgs.gov/nwis)
- 2002 and 2003 monthly average P concentrations by tributary for lake Erie from David Dolan, University of Wisconsin - Green Bay and Pete Richards at Heidelberg College

Problems:

- Sporadic sampling,
- Poor temporal and spatial coverage,
- Uncertain data quality,
- Lack of water quality parameters
  (80321 Suspended sediment concentrations; 00310 BOD;
  50922 E-coli; l00625 Total Kjeldahl Nitrogen (TKN); 00665 Total P; 00670 Dissolved P; 39033 Atrazine)
- Uneasy to manipulate data (ASCII and HTML format)

SUMMARY

There are a number of challenges /opportunities to accurately assess the effects of climate change on NPS pollution in the Great Lakes Basin, including

- Downscale of the GCM or RCM output to watershed scale;
- Responses of crop growth to climate change;
- Sensitivity of curve numbers to land use/cover change and best management practices;
- Incorporation of infiltration schemes and soil erosion and water quality components to the DLBRM.

Successful completion of the development of the distributed large basin runoff model will help us meet those challenges and to address NOAA's goal to "protect, restore and manage use of coastal, ocean and Great Lakes resources.