Forecasting Future Phosphorus Loading in the Great Lakes Region from Changing Land-Derived Nutrient Inputs

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IAGLR Session 22

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Presentation Outline

- Motivation
- Watershed and Model Characteristics
- Methodology: Modeling Inputs and Conceptual Relationship Diagram
- Future Phosphorus Loading Results
- Conclusion
- Future Work

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Impacts of Phosphorus in the Great Lakes

1. Harmful Algal Blooms:
    - Microcystis blooms (skin irritation and nausea)
    - Increase water treatment costs (City of Toledo)
2. Nuisance Algal Blooms: Cladophora (whole lakes)
    - Effect on recreational fishing and boating
    - Fouling of beaches
3. Lake Erie Dead Zone

http://www.utoledo.edu/as/lec/research/wq/index.html

"Lake Erie is the place fish go to die"

~Johnny Carson 1976

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http://detnews.com/article/20091010/METRO/910100364/Massive-algae-blooms-threaten-Lake-Erie
http://blog.cleveland.com/metro/2010/08/scientists_say_the_toxic_blue-.html
http://www.wleb.org/publicoutreach/conference/3-2%20-%20Tom%20Bridgeman%20-%20Maumee%20Bay%20Lake%20Erie%20Algal%20Blooms.pdf

Phosphorus in the Great Lakes

Sources of Total P to the Great Lakes:

- Point sources (Wastewater, Septic Systems, Industrial Operations)
- Agriculture (Fertilizer, Manure)
- Urban/residential (Lawn fertilizers, storm water, detergent)
- Atmospheric Deposition
- Other: Upper lake loads, in lake recycling, stream bank erosion

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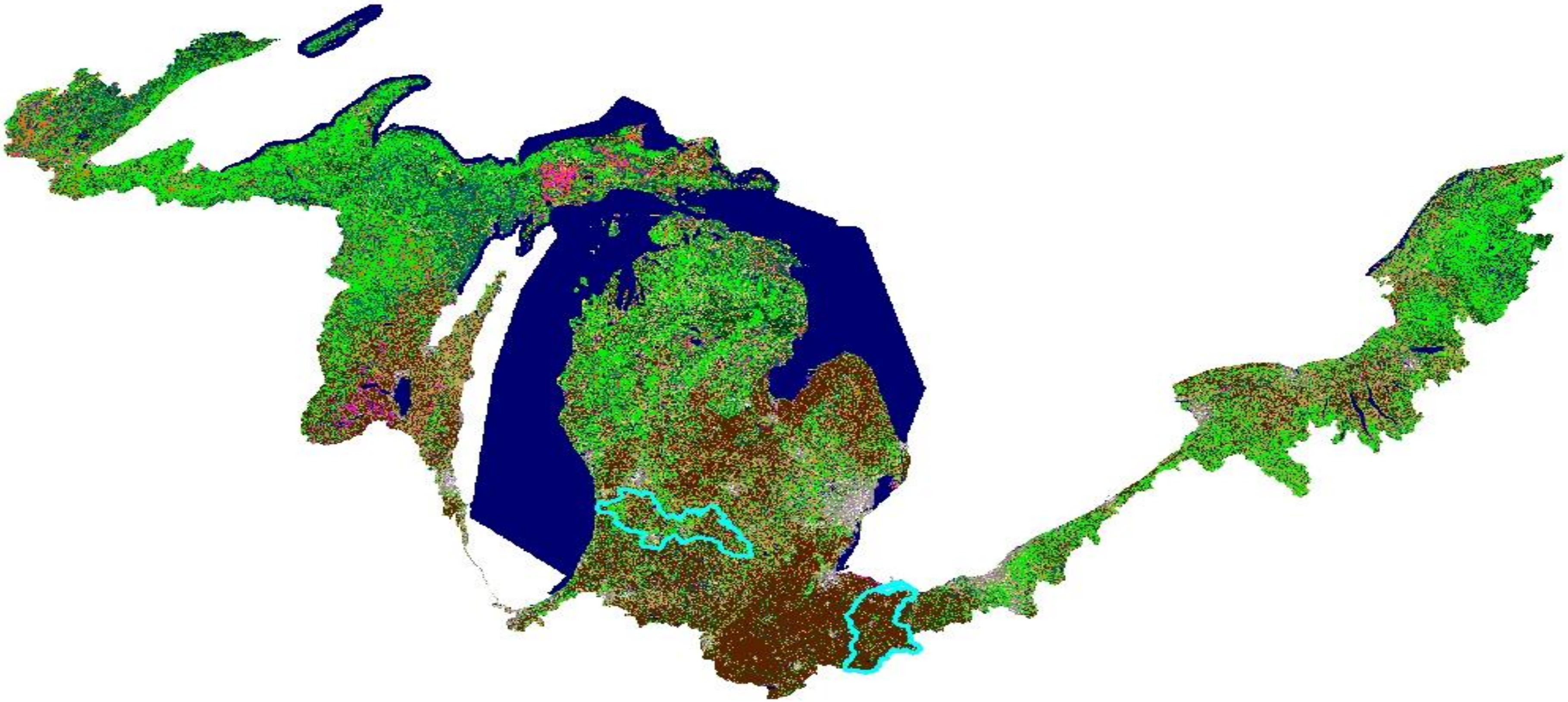
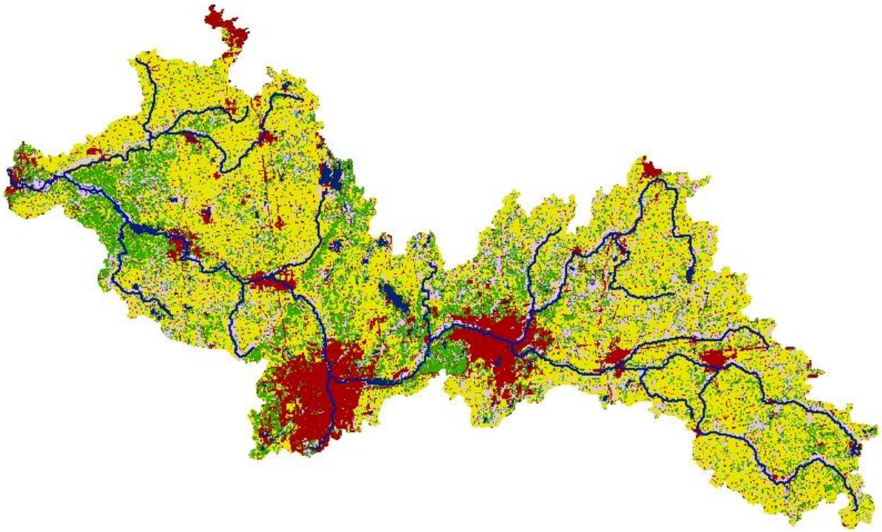
* Allan, J.D. and M.M Castillo, 2007

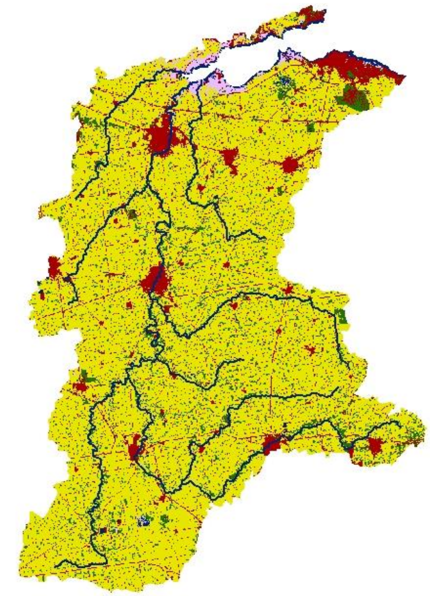


Watershed Characteristics

Kalamazoo Watershed: 04050003



Sandusky Watershed: 04100011



	Kalamazoo	Sandusky
Total Area (mi^2)	2030	1850
Urban Area	**14 %**	**10 %**
Undeveloped Area	**34 %**	**10 %**
Agriculture Area	**50 %**	**79 %**

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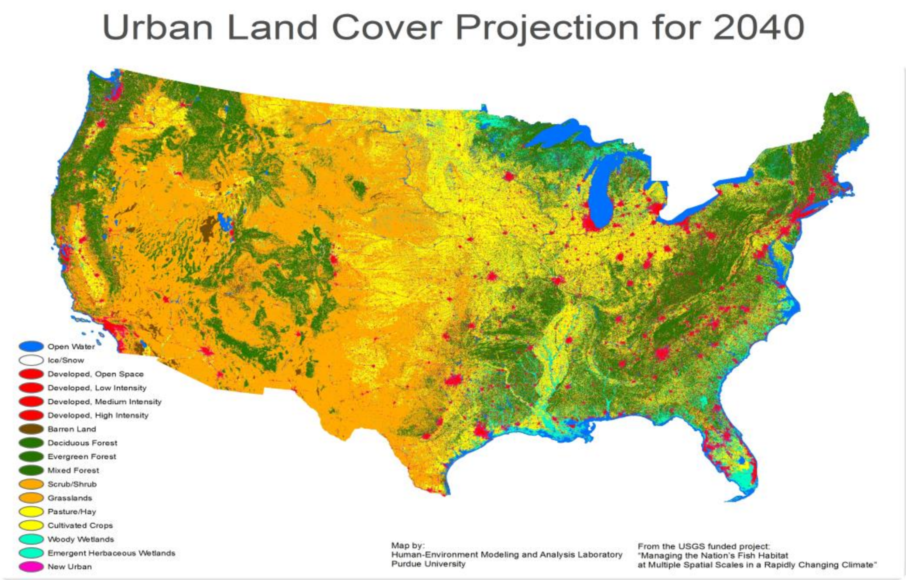
Phosphorus Predictor Models: LTM

A. Land Transformation Model V 1.1 (Dr. Bryan Pijanowski and the Human-Environment Modeling and Analysis lab at Purdue University)



1. Land Use Forecasting Model that examines the spatial and temporal aspects of the driving forces for land use change, through neural network technology
2. Land use predictions for 2010, 2020, 2030, and 2040
3. Two modeled scenarios urban expansion and corn-based ethanol expansion

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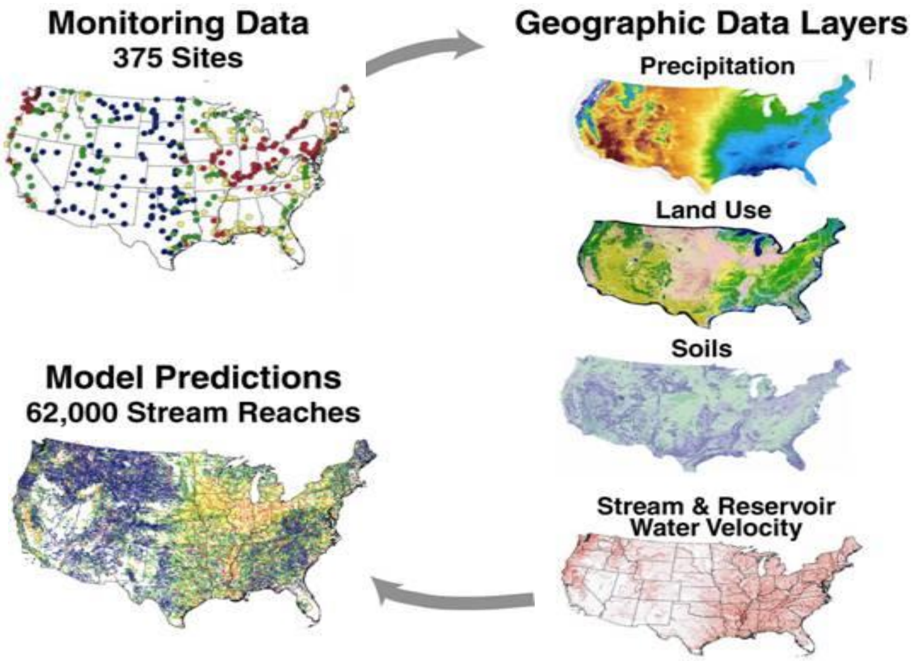
Phosphorus Predictor Model: USGS SPARROW

B. SPARROW (SPAtially Referenced Regressions On Watershed attributes)

- Hybrid statistical and mechanistic process structure; mass-balance constraints; data-driven, nonlinear estimation of parameters
- Separates land and in-stream processes
- Predictions of mean-annual flux reflect long-term, net effects of nutrient supply and loss processes in watersheds



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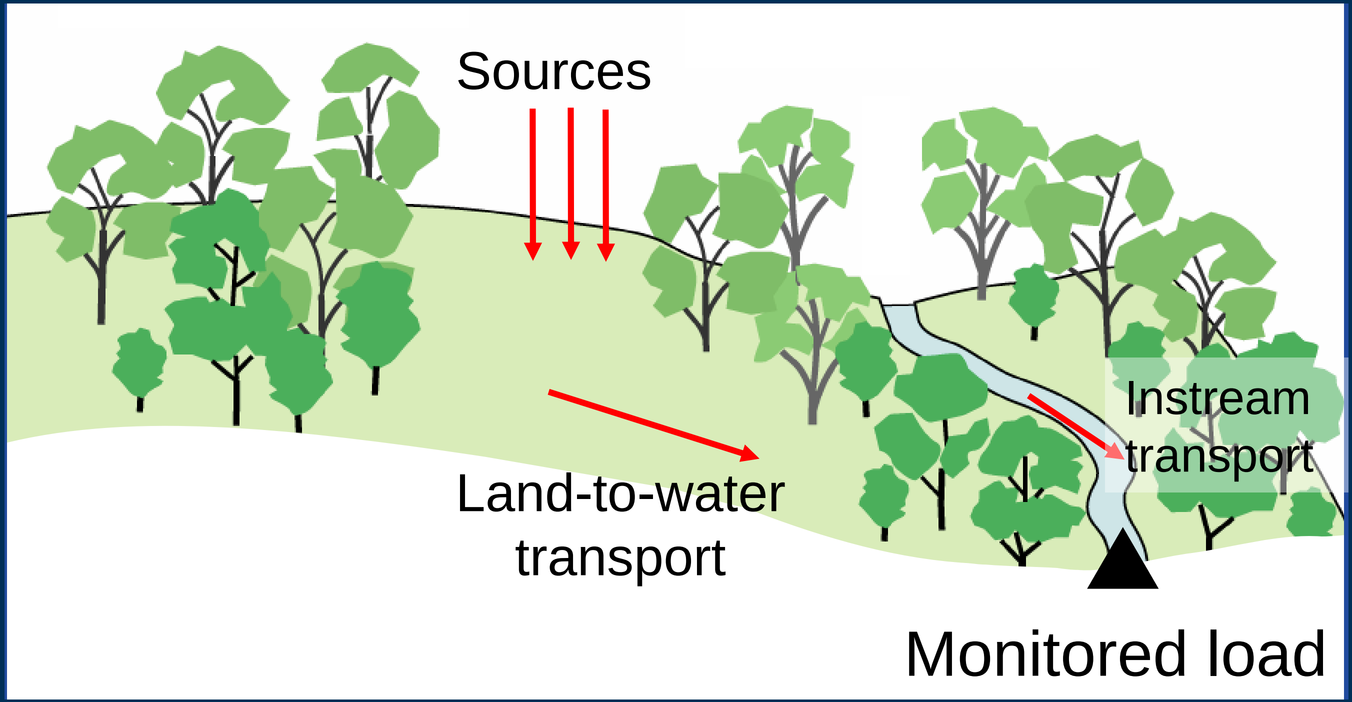
* Robertson, Dale. 2008. Presentation at Midwest Partnership Meeting

SPARROW modeling approach:

- Regress water-quality conditions (monitored load) on upstream sources and factors controlling transport
- Incorporates in-stream decay of nutrients



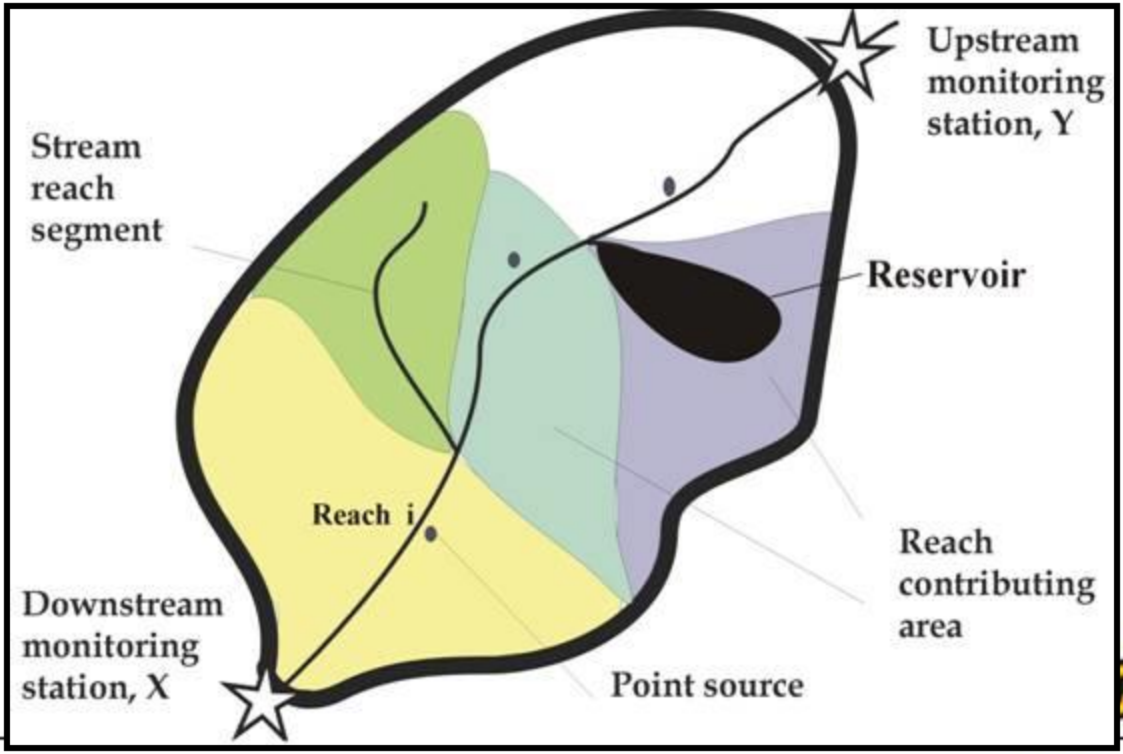
USGS

* Robertson, Dale. 2008. Presentation at Midwest Partnership Meeting

SPARROW's Reach-Scale Mass Balance

Reach network relates watershed data to monitored loads

Load leaving a reach	=	**Load generated within upstream reaches** and transported to the reach via the stream network	+	**Load originating within the reach's incremental watershed** and delivered to the reach segment	-	**In-stream Losses**



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* Robertson, Dale. 2008. Presentation at Midwest Partnership Meeting

SPARROW Inputs

Total Phosphorus SPARROW Model Sources:
Quantification of all major sources of TP

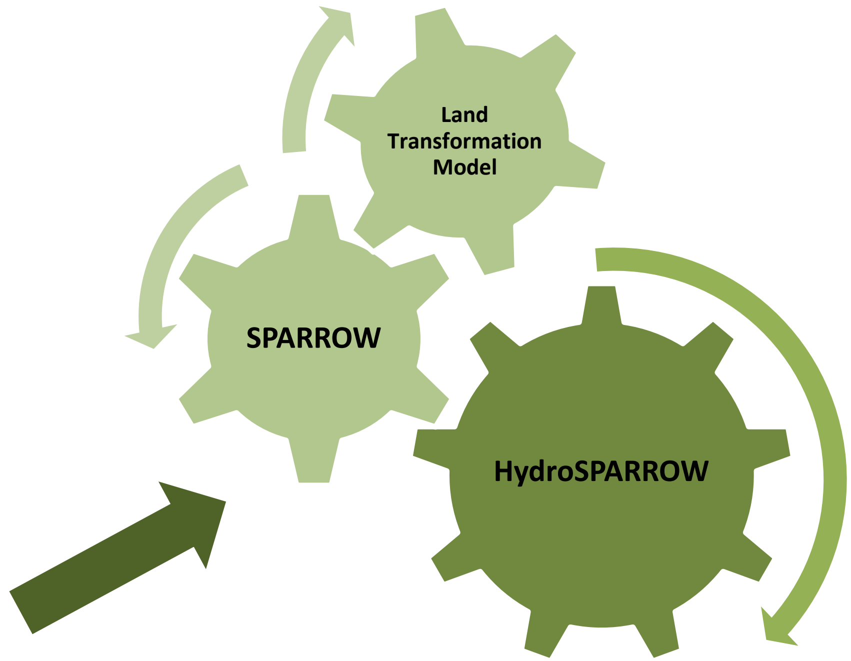
1. Point Sources (kg/yr)
2. Urban Land (acreage)
3. Undeveloped Land (acreage)
4. Farm Fertilizers (kg/yr)
5. Manure Confined (kg/yr)
6. Manure Unconfined (kg/yr)

Future Source Amounts are inputs into SPARROW to produce hydroSPARROW: the predictive water quality model

Linkage of Phosphorus Predictor Models

INPUTS directly into SPARROW DSS V1.0* from LTM and Data Models:

- Predicted undeveloped, urban land and agriculture acreage
- Area-weighted predictions models for future amounts of farm fertilizer and manure
- Area-weighted rates for point sources in catchments with existing point sources



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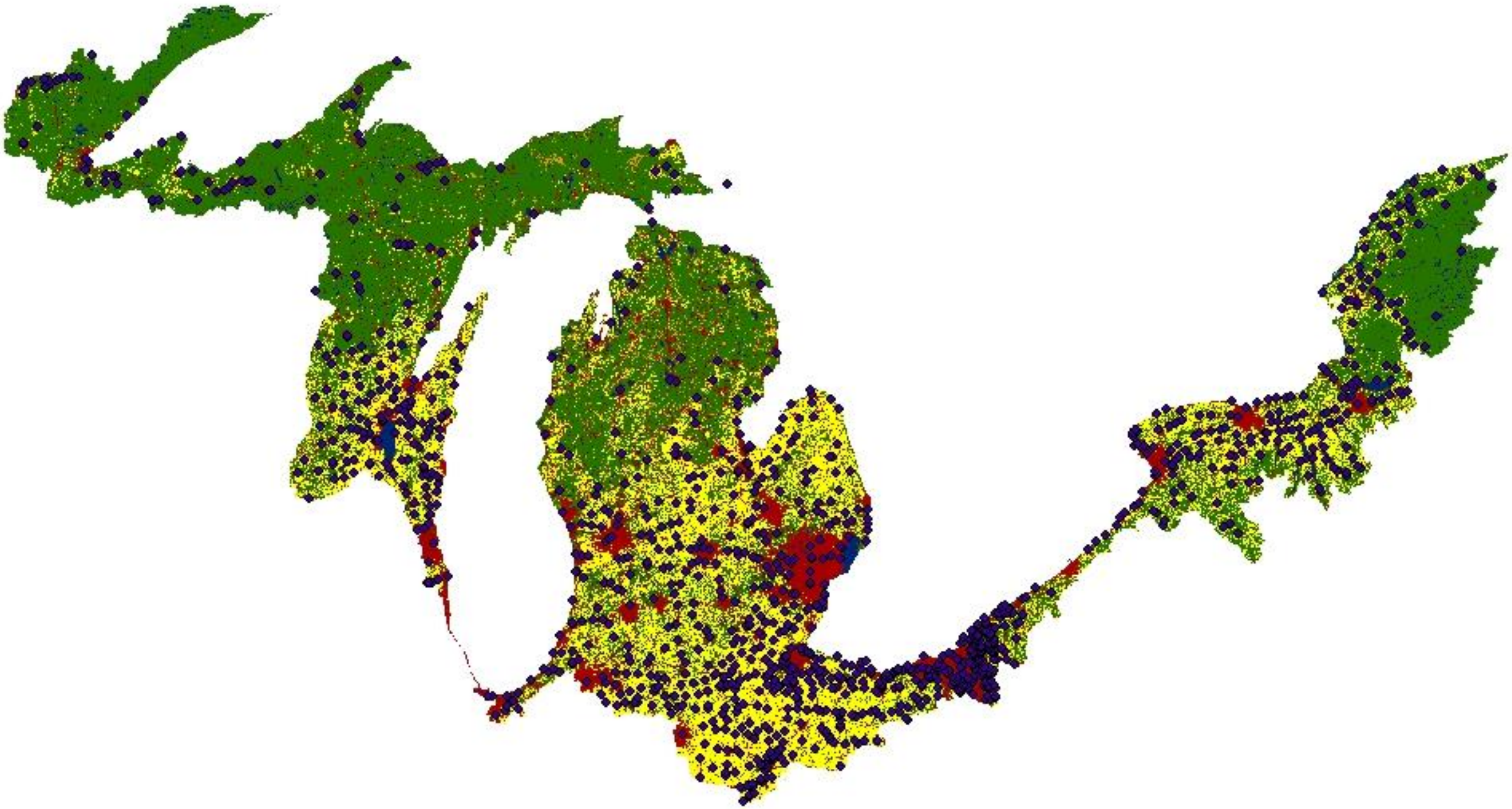
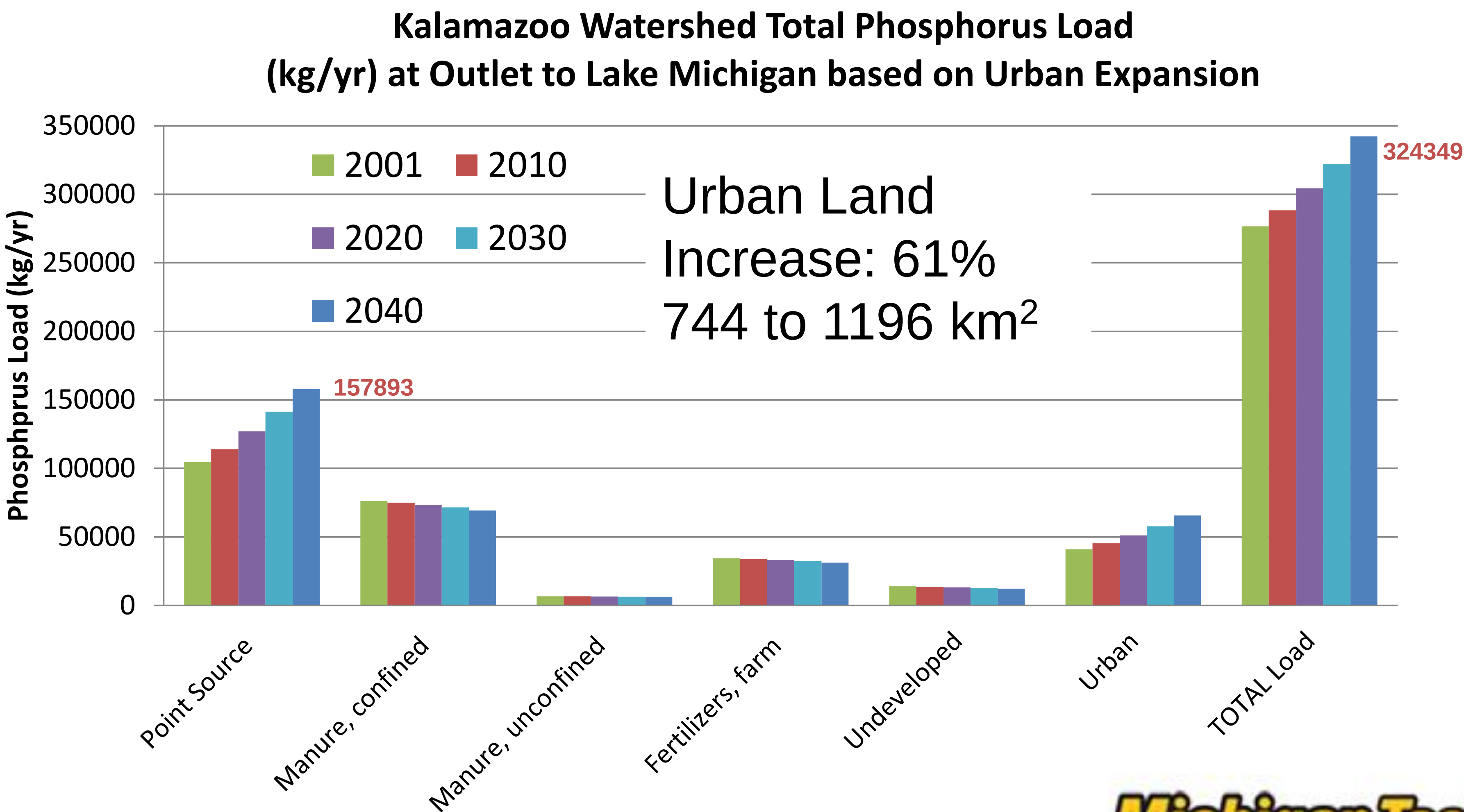
* USGS CIDA

Mechanisms of Transformation

Area of Influence for Each Sewerage Point Source to Urban Area



Kalamazoo: Total Phosphorus Predictions



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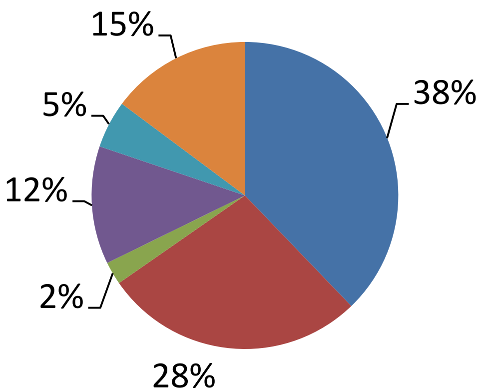
KALAMAZOO WATERSHED

Urban Growth Scenario



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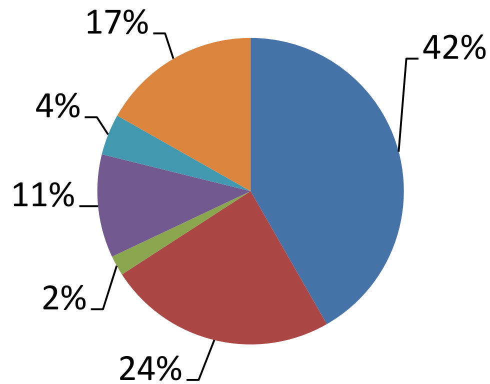

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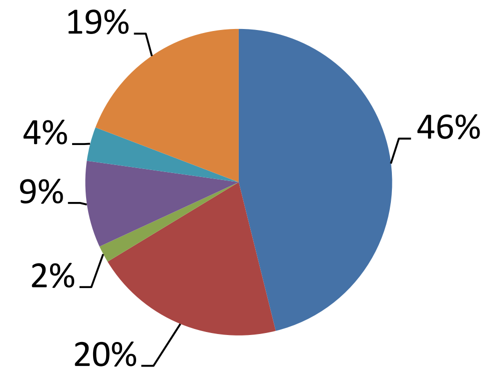

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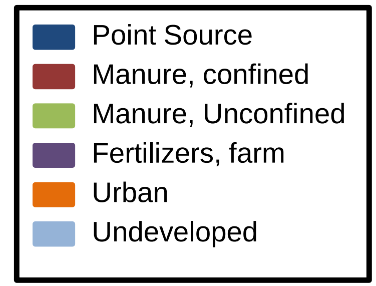
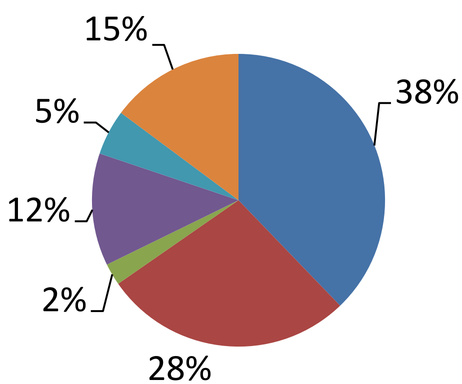


Agriculture Expansion: Ethanol Production Scenario



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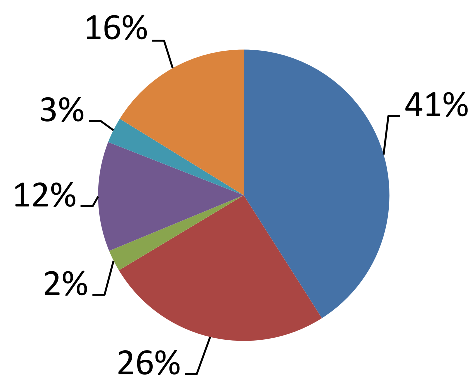

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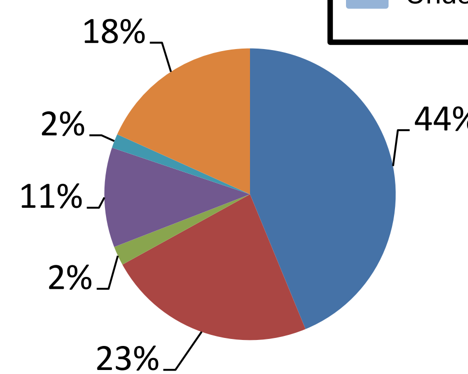

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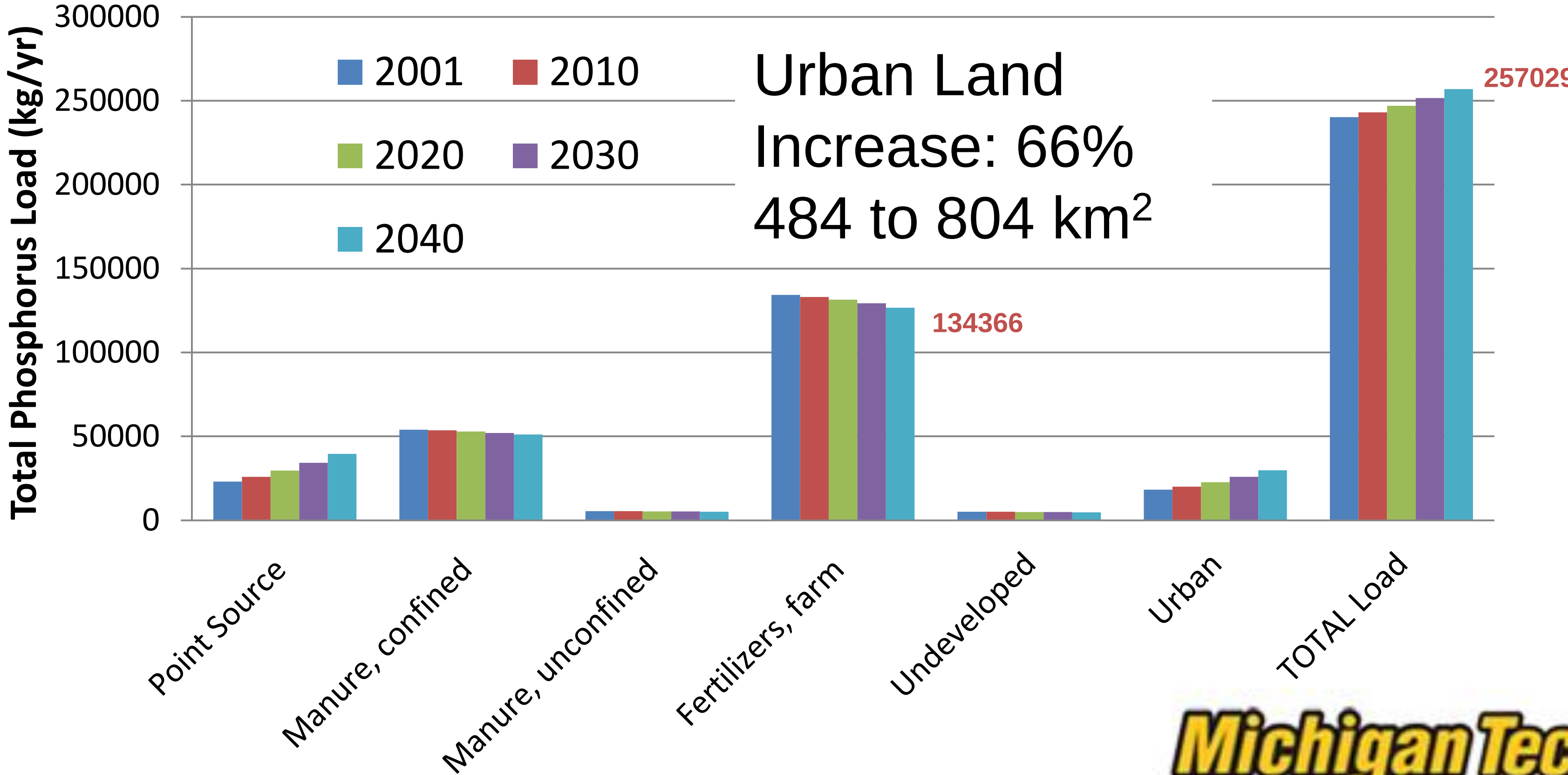
Sandusky: Total Phosphorus Predictions

Total Phosphorus Load (kg/yr) at the mouth of the Sandusky Watershed based on Urban Expansion



Watershed TP Comparisons

		Total Unit Area Load (kg/yr/km^2)					
	Land Use Scenarios	2001	2010	2020	2030	2040	Total Change
Kalamazoo	Urban	53	55	58	61	65	24%
	Ethanol	53	55	59	63	69	30%
Sandusky	Urban	50	51	52	52	54	7%
	Ethanol	50	52	54	56	57	14%

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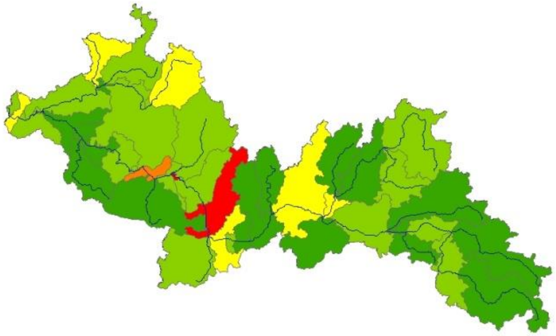
KALAMAZOO WATERSHED: Catchment Incremental Area Loads for Urban Expansion



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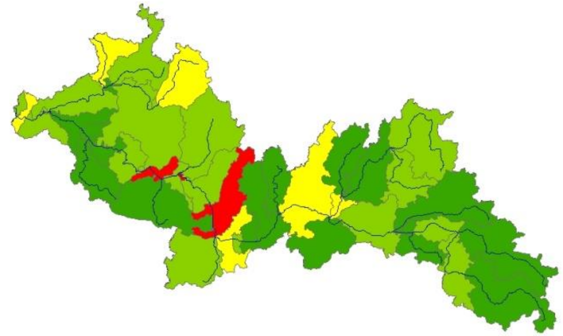

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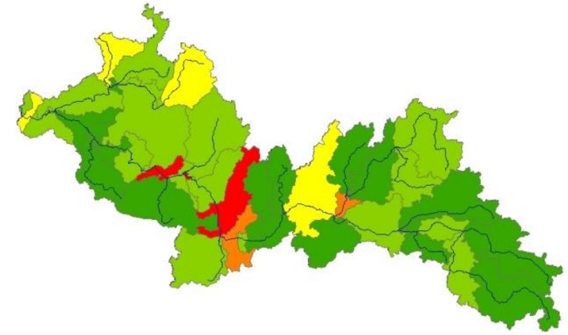

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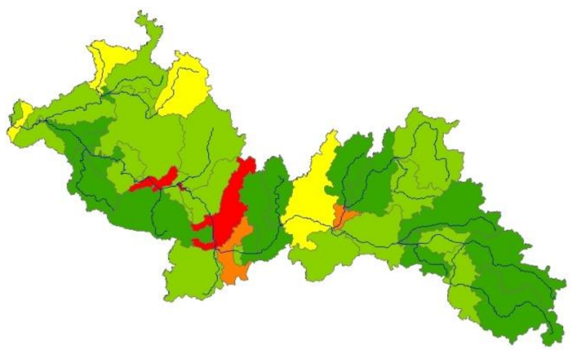

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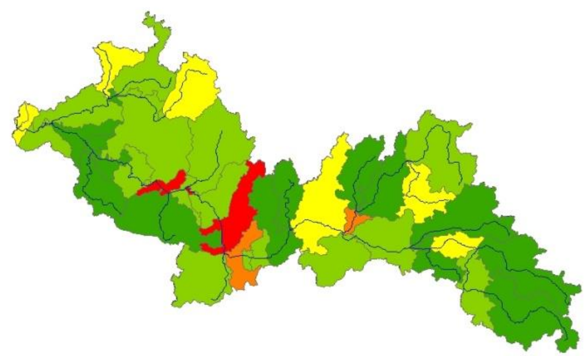


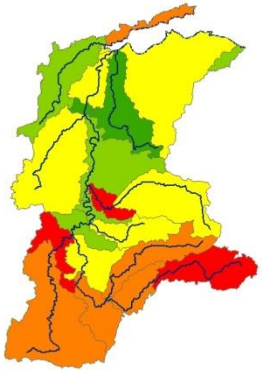
2040

Legend

Area Load (kg/yr/km^2)

- 8 - 34
- 35 - 69
- 70 - 138
- 139 - 276
- 277 - 555

SANDUSKY WATERSHED: Incremental Area Loads for Agriculture Expansion



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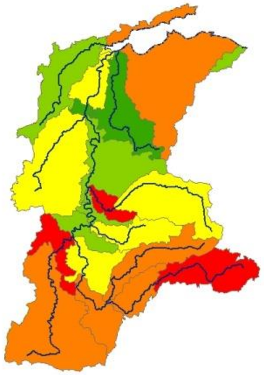

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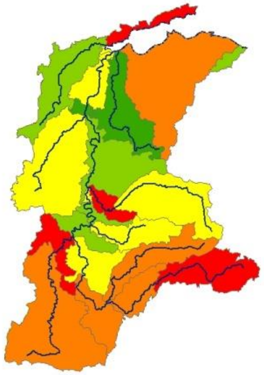

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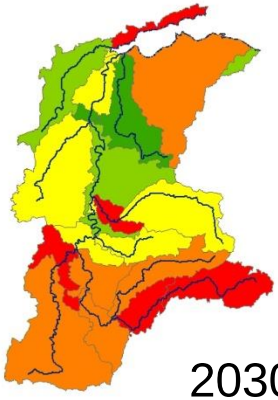

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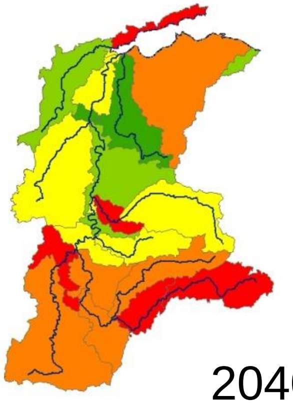

2040

Legend

Area Load (kg/yr/km²)

- 30 - 38
- 39- 50
- 51 - 75
- 75 - 100
- 101 - 155

Future Phosphorus Observations

- Increases in urban land and point sources: around cities
- Decreases in agriculture sources, some buffered by potential increases in ethanol production
- The Sandusky and Kalamazoo outlets are experiencing total load increases from 2001-2040 based on both future urban and agricultural expansion scenarios

Implications/Conclusions

1. Future P predictions illustrate an increase in Point Source and Urban P: with a greater loading in the Kalamazoo Watershed
2. Ethanol Expansion similarly increases watershed loading
3. “Over-riding evidence indicates point (effluent) rather than diffuse (agricultural) sources of phosphorus provide most significant risk for river eutrophication, even in rural areas with high agricultural phosphorus losses” (Jarvie et al, 2008)

Will this effect harmful and nuisance algal blooms in the Great Lakes for the future?

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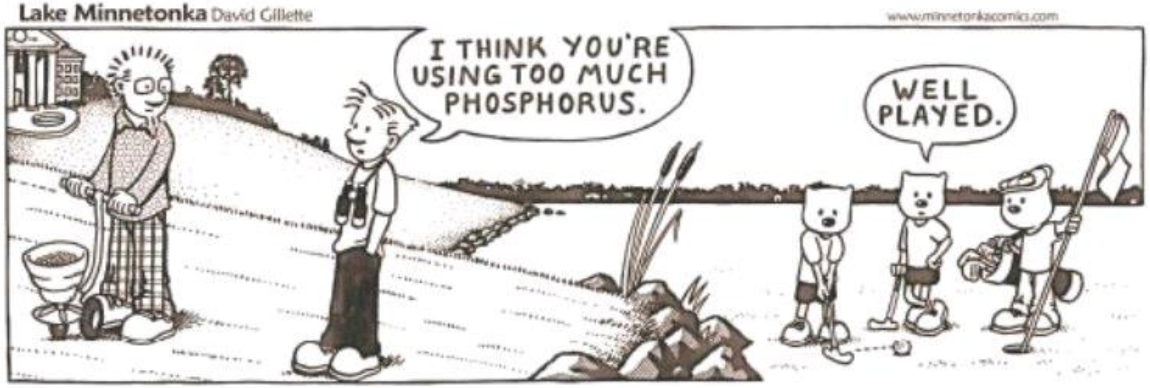
Future Work

1. Extension to the entire Great Lakes Basin
2. Develop greater spatial resolution model predictions of future point sources changes
3. Assess the differences in attenuation capacities of the watersheds: vulnerability index of diffuse vs. point sources



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- Human-Environment Modeling and Analysis Laboratory, Dr. Bryan Pijanowski: Purdue University
- Research Assistants: Cara Shonsey and Emily Van Dam

National Science Foundation
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Center for Water and Society
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QUESTIONS?

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3. http://detnews.com/article/20091010/METRO/910100364/Massive-algae-blooms-threaten-Lake-Erie, last accessed March 15, 2011
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Agriculture & Urban Phosphorus

	Agricultural (Diffuse)	Point
Phosphorus Phase Significant Input	Particulate P, (except manure and fertilizer P can also be transported dissolved form)[2]	Soluble Reactive P
Greatest Effects/Timing	High flow	Low-flow (summer)*
Output Mode	Highly Seasonal	Semi-continuous

"Over-riding evidence indicates point (effluent) rather than diffuse (agricultural) sources of phosphorus provide most significant risk for river eutrophication, even in rural areas with high agricultural phosphorus losses"[1]

Importance in Great Lakes?

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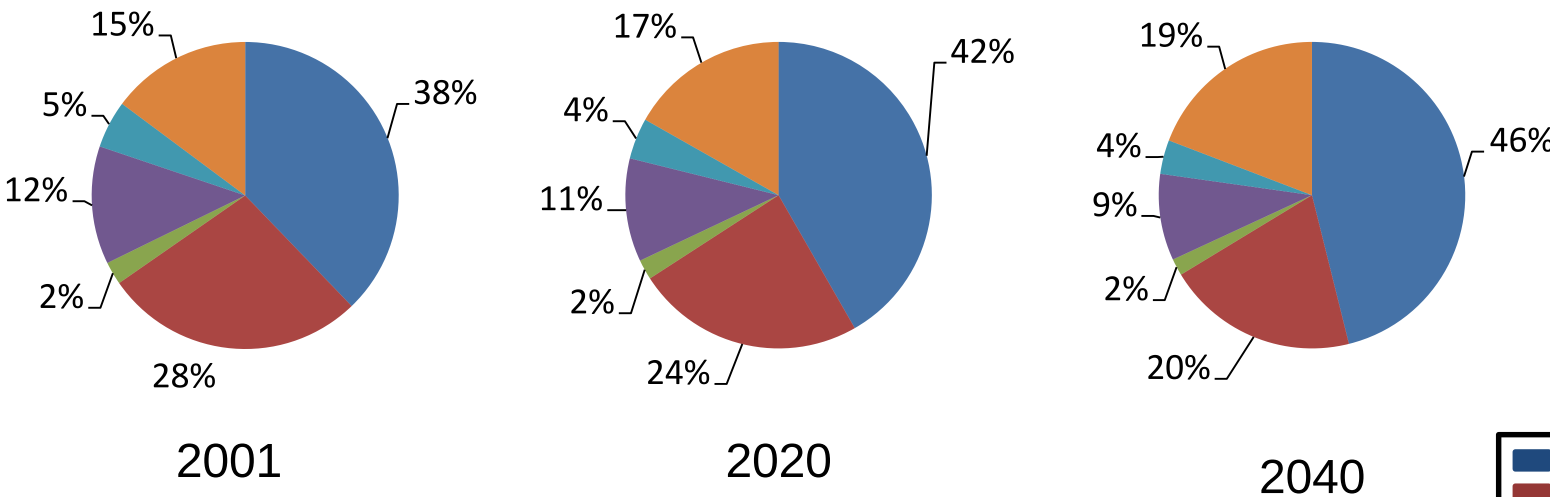
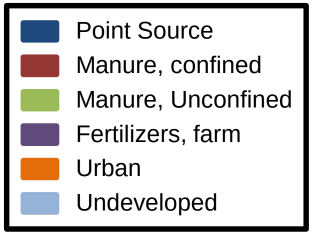
([1]Jarvie, H.P. C.Neal, and P.J.A. Withers, 2006.), ([2]Allan, J.D. and M.M. Castillo, 2007), (Mainstone and Parr, 2002.), (Bowes et al., 2008)

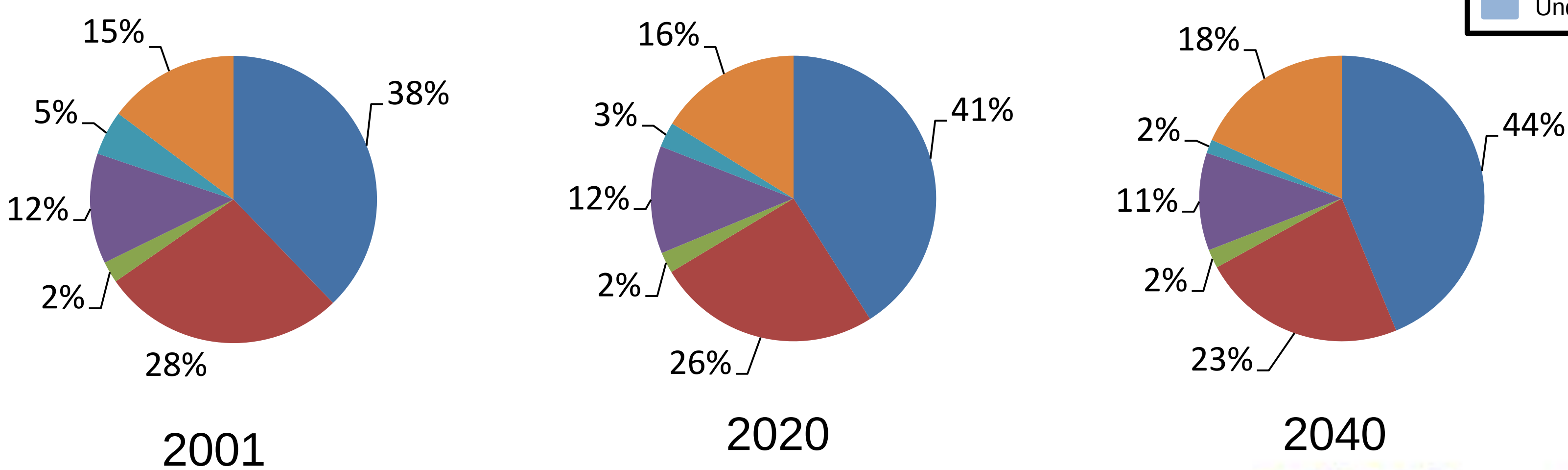
KALAMAZOO WATERSHED

Urban Growth Scenario





Agriculture Expansion: Ethanol Production Scenario



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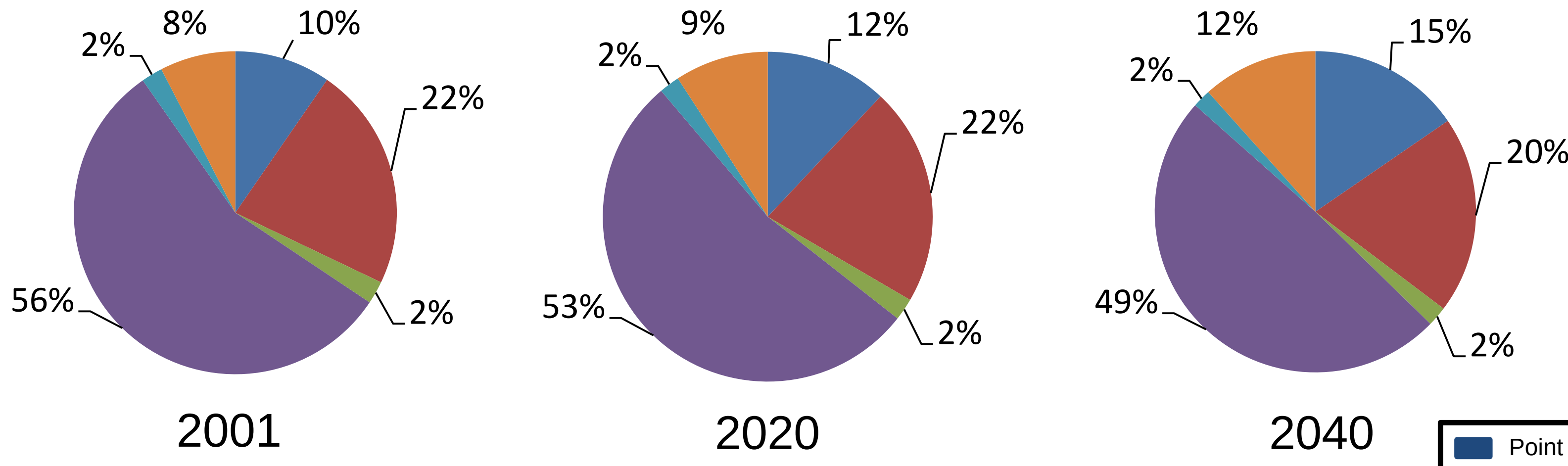
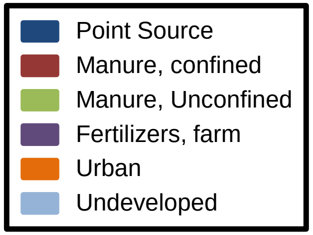
SANDUSKY WATERSHED

Urban Growth Scenario





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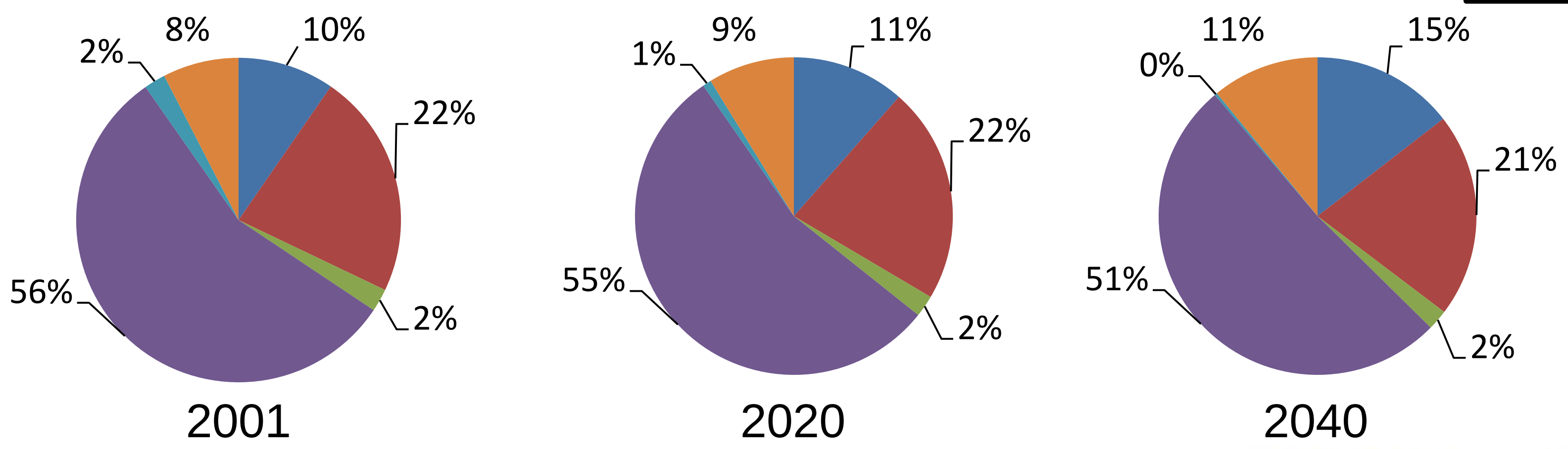

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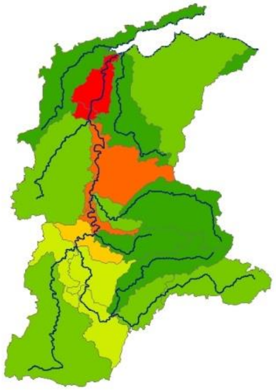
SANDUSKY WATERSHED: Total Loads for Agriculture Expansion



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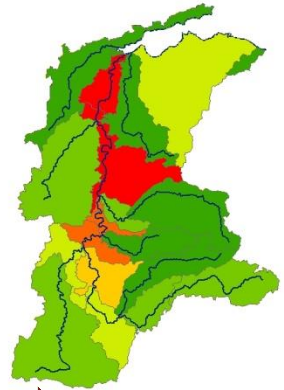

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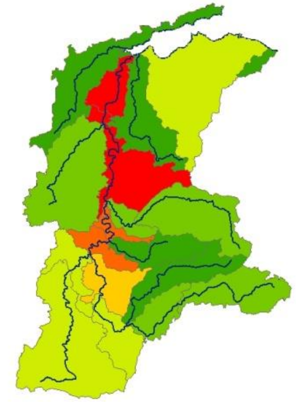

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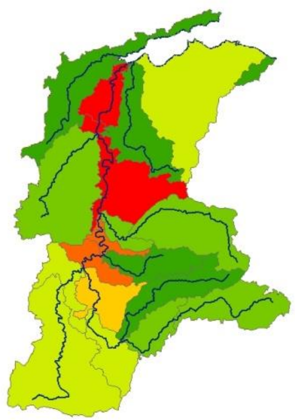

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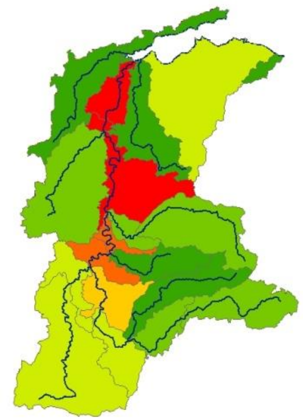

2040

Legend

total_tl

- 21.8 - 30424.4
- 30424.5 - 47887.4
- 47887. - 83972.2
- 83972.3- 160445.5
- 160445.6 - 206461.8
- 206461.9- 275725.4

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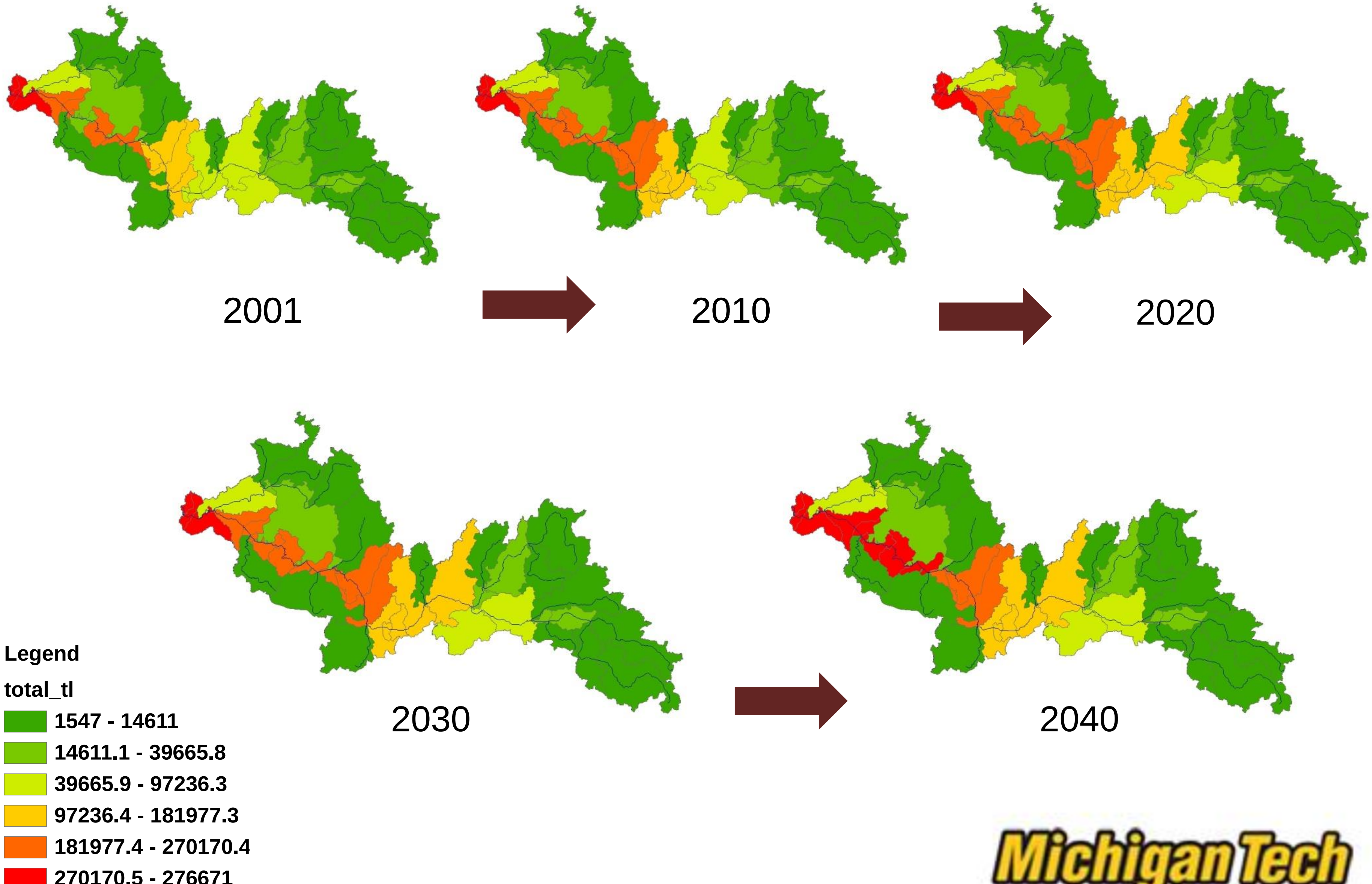
KALAMAZOO WATERSHED: Catchment Total Loads for Urban Expansion



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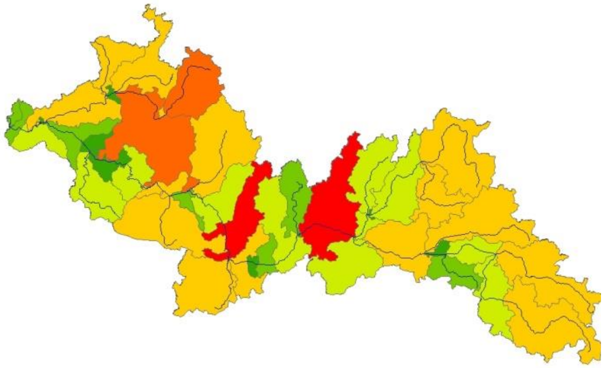
KALAMAZOO WATERSHED: Catchment Incremental Loads for Urban Expansion



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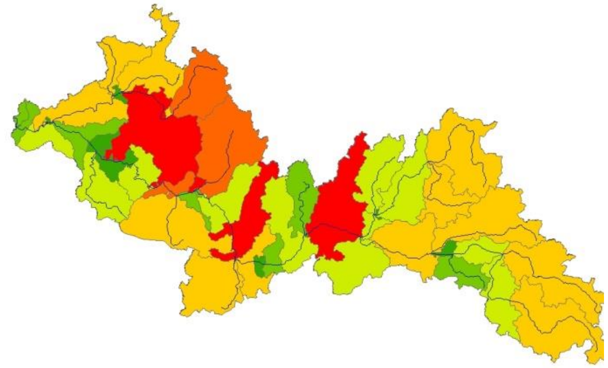

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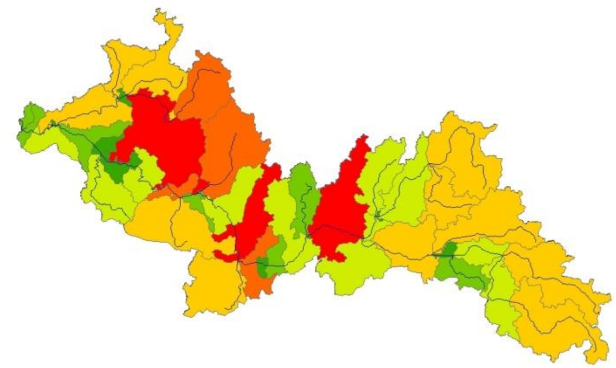
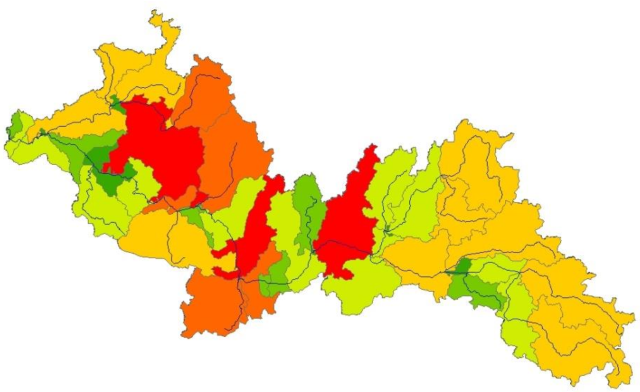
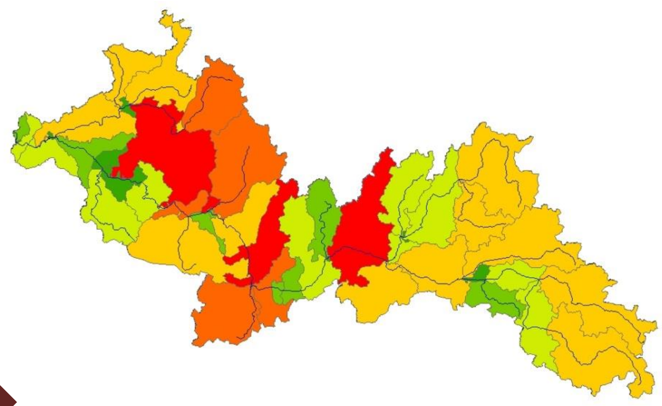


2020



2030



2040

Legend

total_ic

- 2.90 - 632.3
- 632.4 - 2333.2
- 2333.3 - 5921.7
- 5921.8 - 10920.6
- 10920.7 - 18699.1
- 18699.2 - 85577.2

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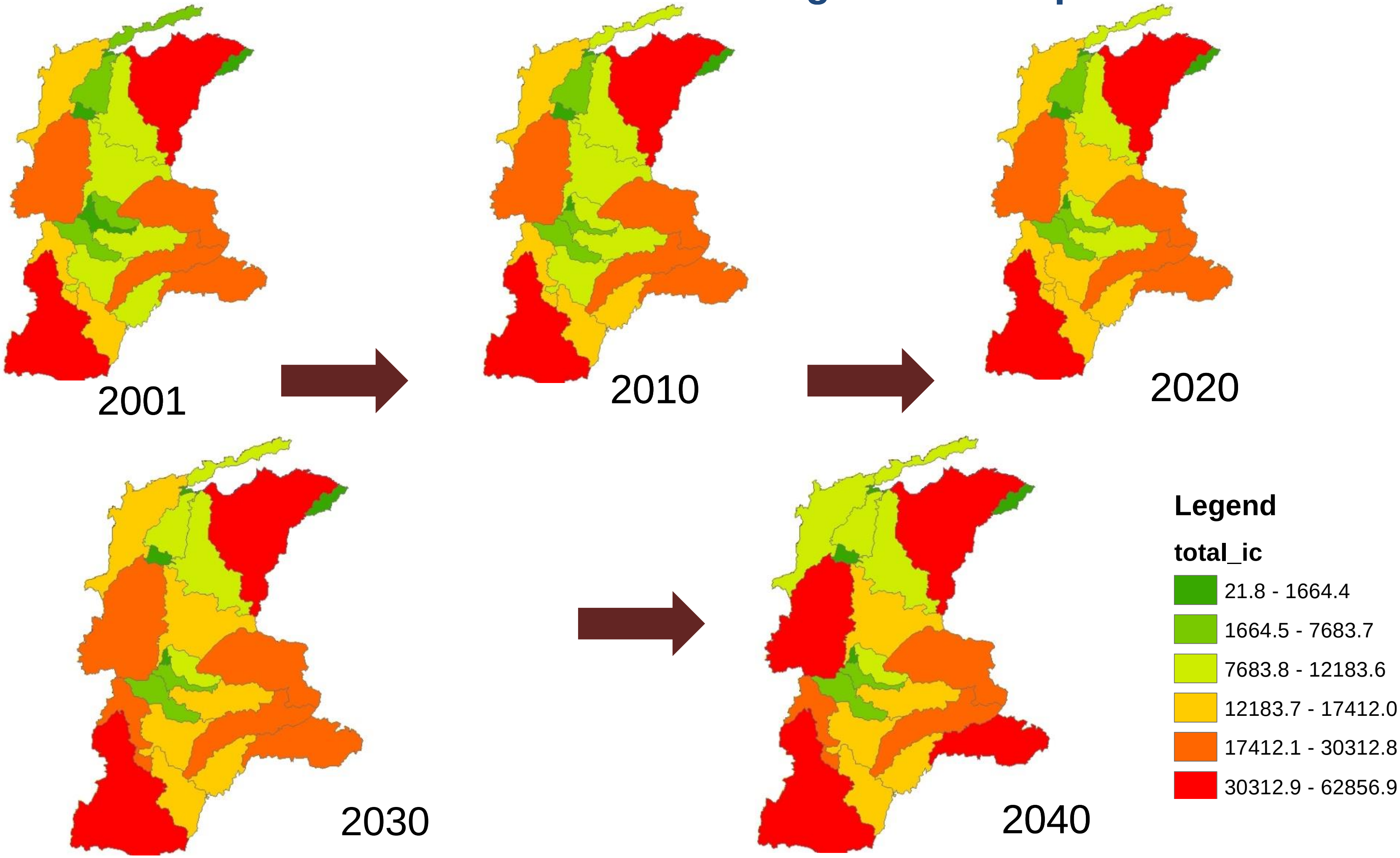
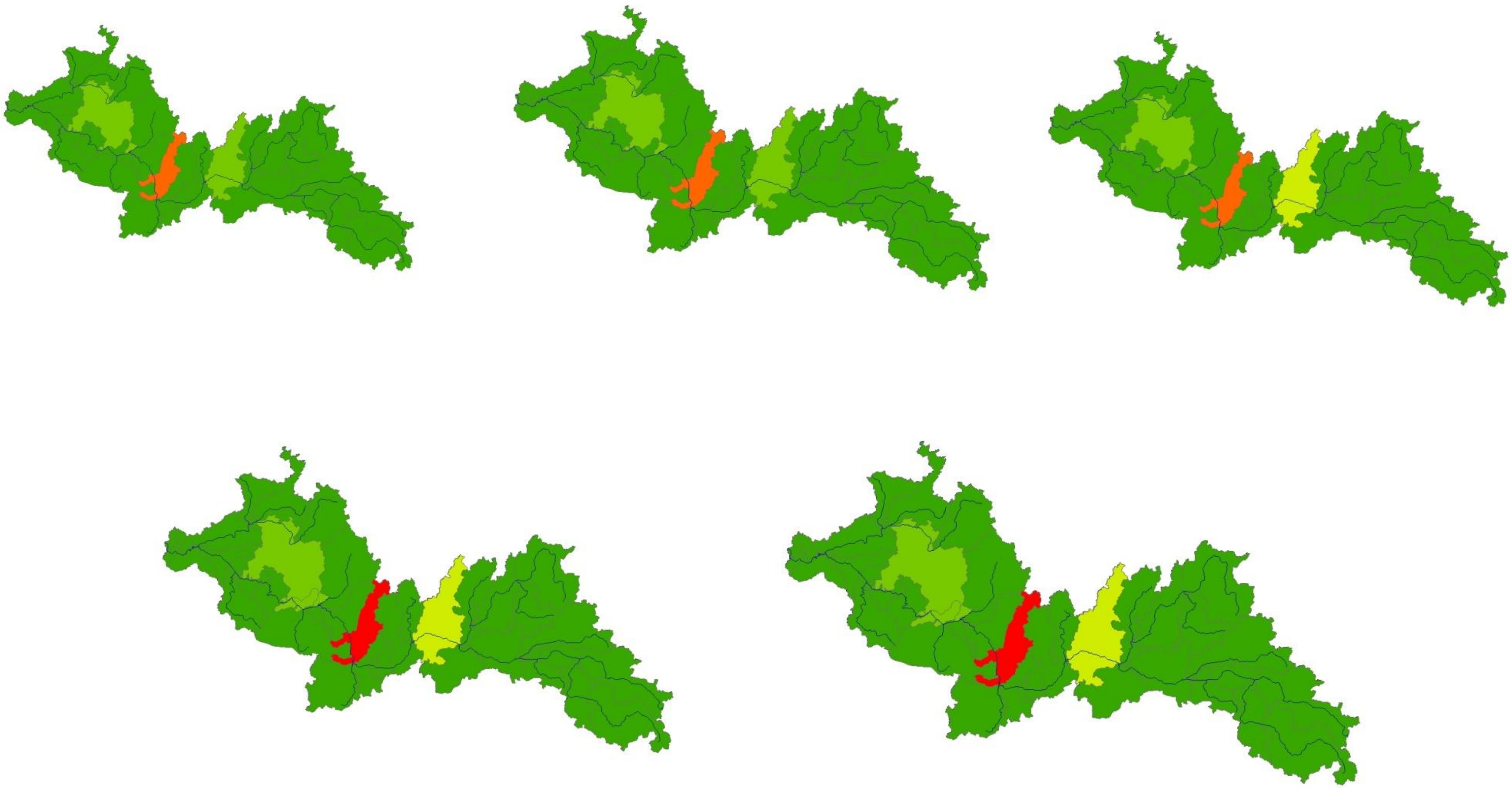
SANDUSKY WATERSHED: Incremental Loads for Agriculture Expansion





Legend

total_ic

(dark green)	2.900000 - 14165.000000
(green)	14165.000001 - 28332.000000
(yellow-green)	28332.000001 - 42499.000000
(yellow)	42499.000001 - 56666.000000
(orange)	56666.000001 - 70833.000000
(red)	70833.000001 - 85000.000000

Phosphorus in the Great Lakes

"Lake Erie is the place fish go to die"

~Johnny Carson 1976

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http://www.uswaternews.com/archives/arcquality/2divdis10.html