Toward a Great Lakes Watershed Ecological Sustainability Strategy (GLWESS): Modeling Workshop

Lansing, MI

May 3, 2012

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Presentation Outline

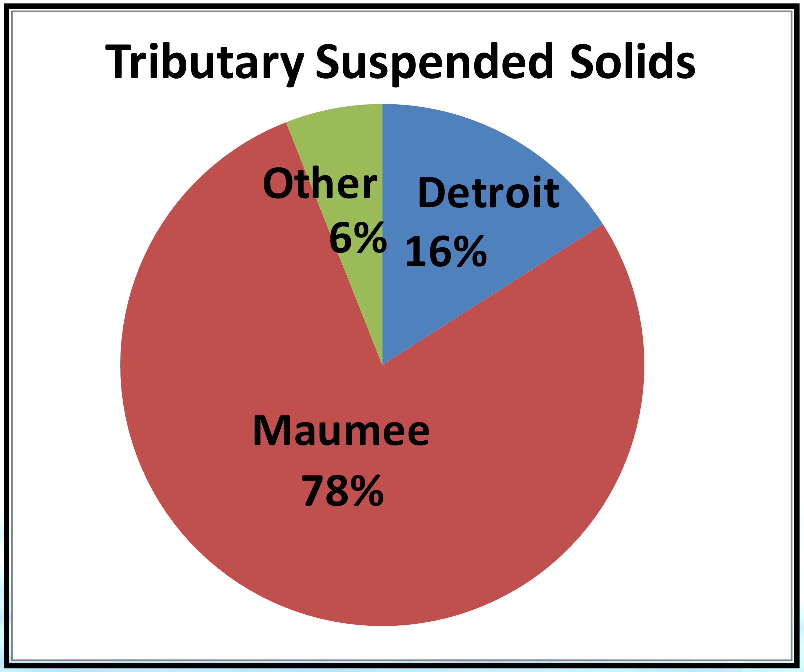
- Overview of ecological concerns
- General modeling overview
- How models can support transactions
- Specific modeling tools
  - SWAT watershed models
  - Western Lake Erie Ecosystem Model (WLEEM)
- Model uncertainties/limitations
- Interaction with related modeling efforts
- Summary

Overview of Ecological Concerns

- Impact of degraded stream habitat and water quality on fish and macroinvertebrate indicators
- Watershed export of sediment and nutrients:
  - Phosphorus (P), especially **soluble reactive P**
  - Nitrogen (N)
  - Suspended solids
- Eutrophication & sedimentation impacts in Western Lake Erie Basin (WLEB):
  - Harmful algal blooms (HABs)
  - Nuisance benthic algae in WLEB
  - High sedimentation rates in Federal navigation channel

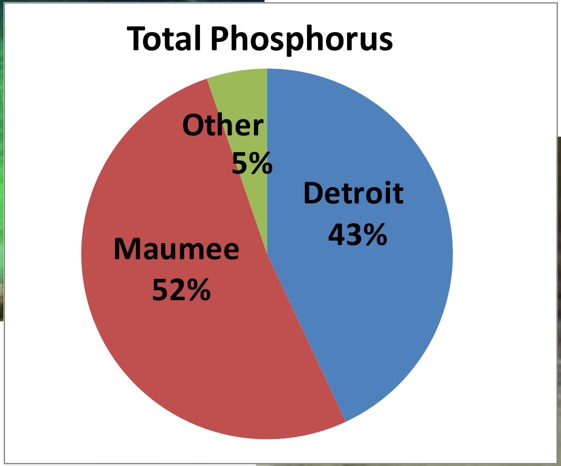
Toledo Harbor Sedimentation

- USACE has mandate to maintain Toledo Harbor Federal navigation channel
  - Annual dredging volume: ~640,000 yd^3 (70% to open lake)
  - Annual cost of dredging & disposal: $5 million



Harmful Algal Blooms & Nuisance Benthic Algae in WLEB

October 2011 *Microcystis* bloom in Maumee River plume in western/central Lake Erie



Lyngbya wollei blooms wash up on western basin shoreline

General Modeling Overview

(Modeling 101)

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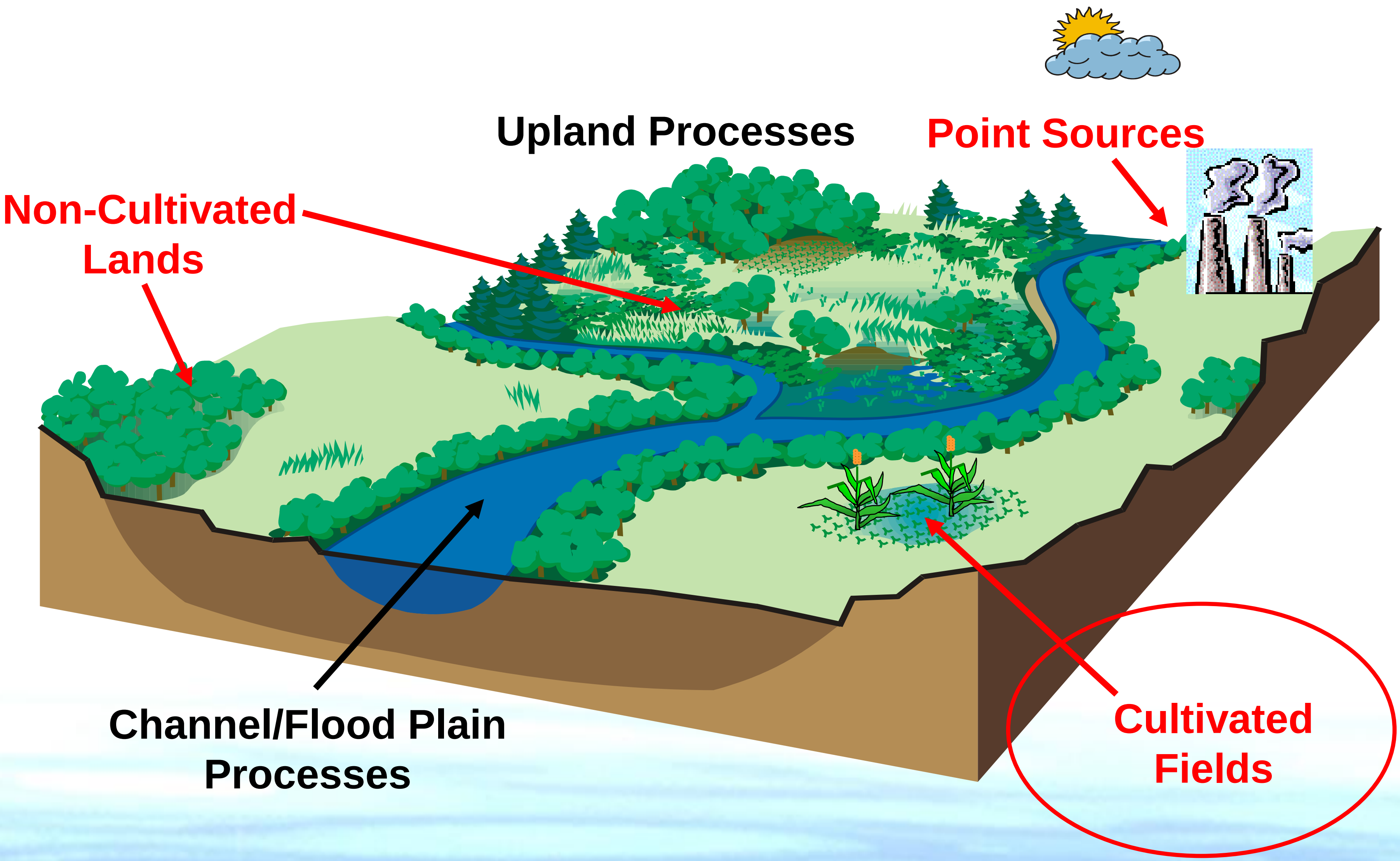
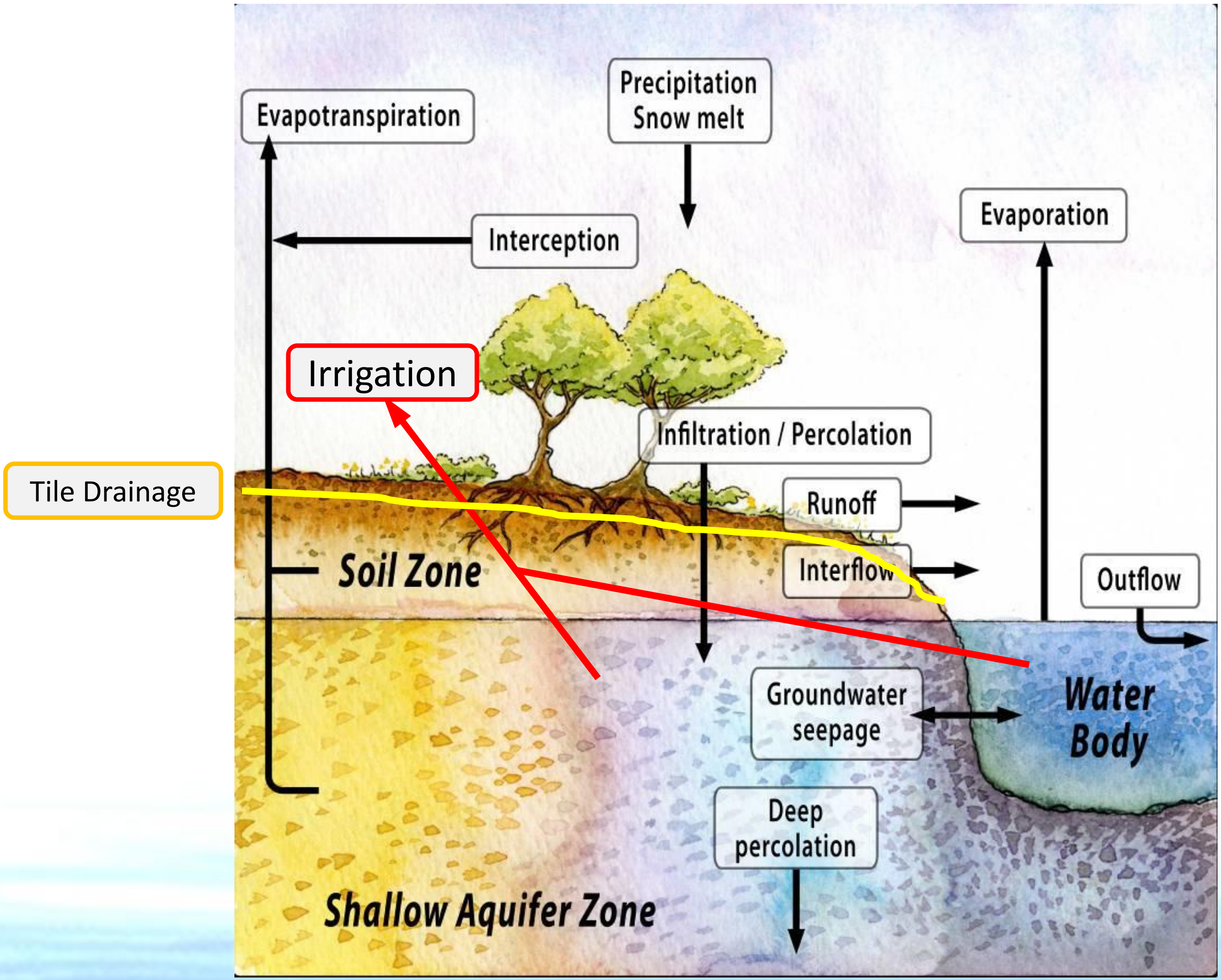
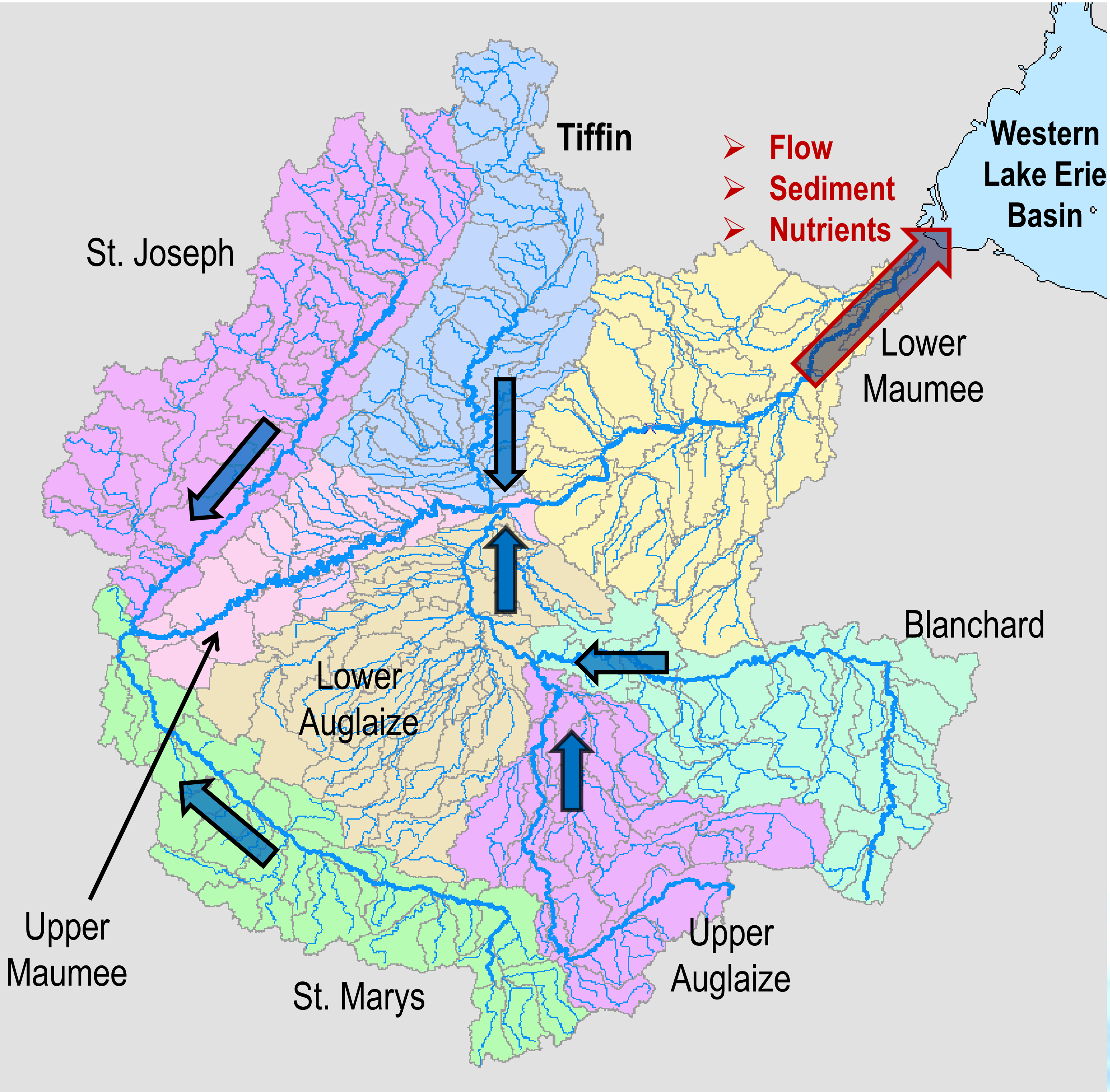
General Watershed Schematic



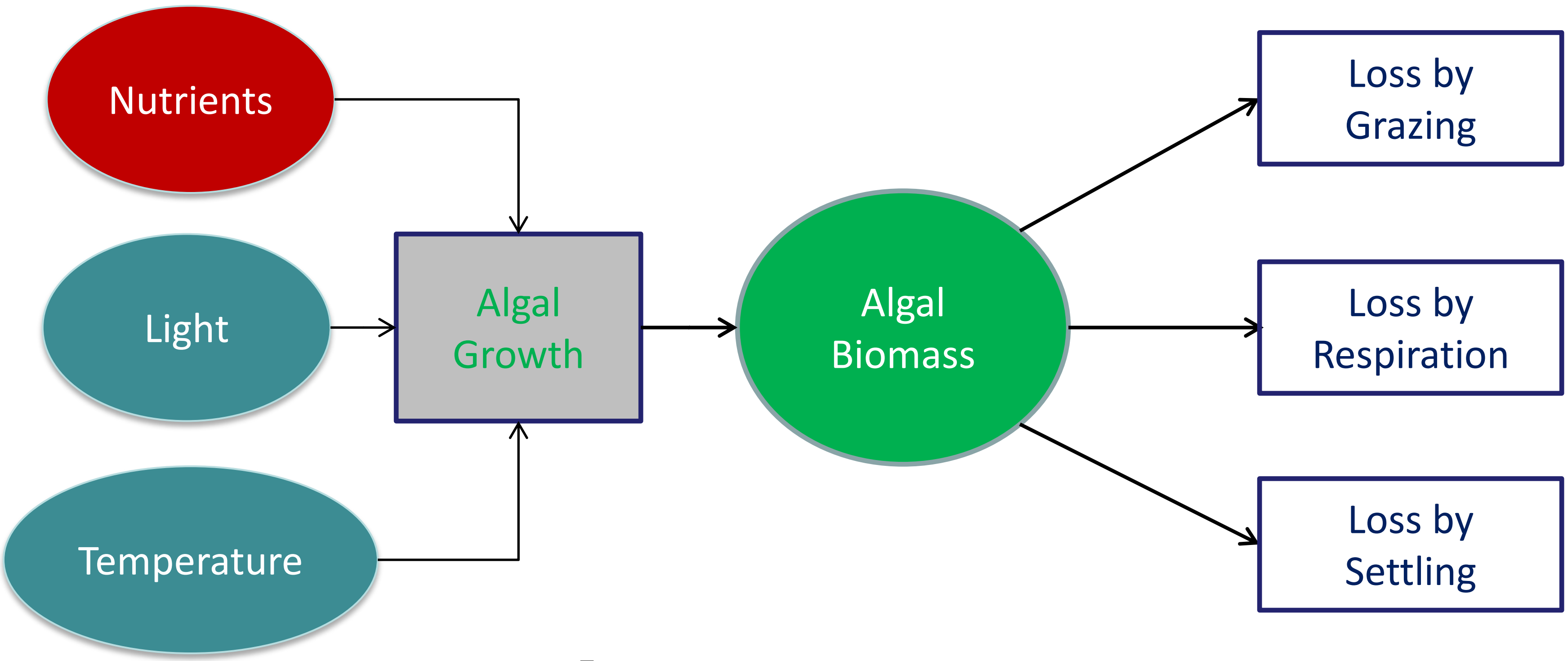
General Watershed Model



Maumee River Watershed (major basins, flow routing)

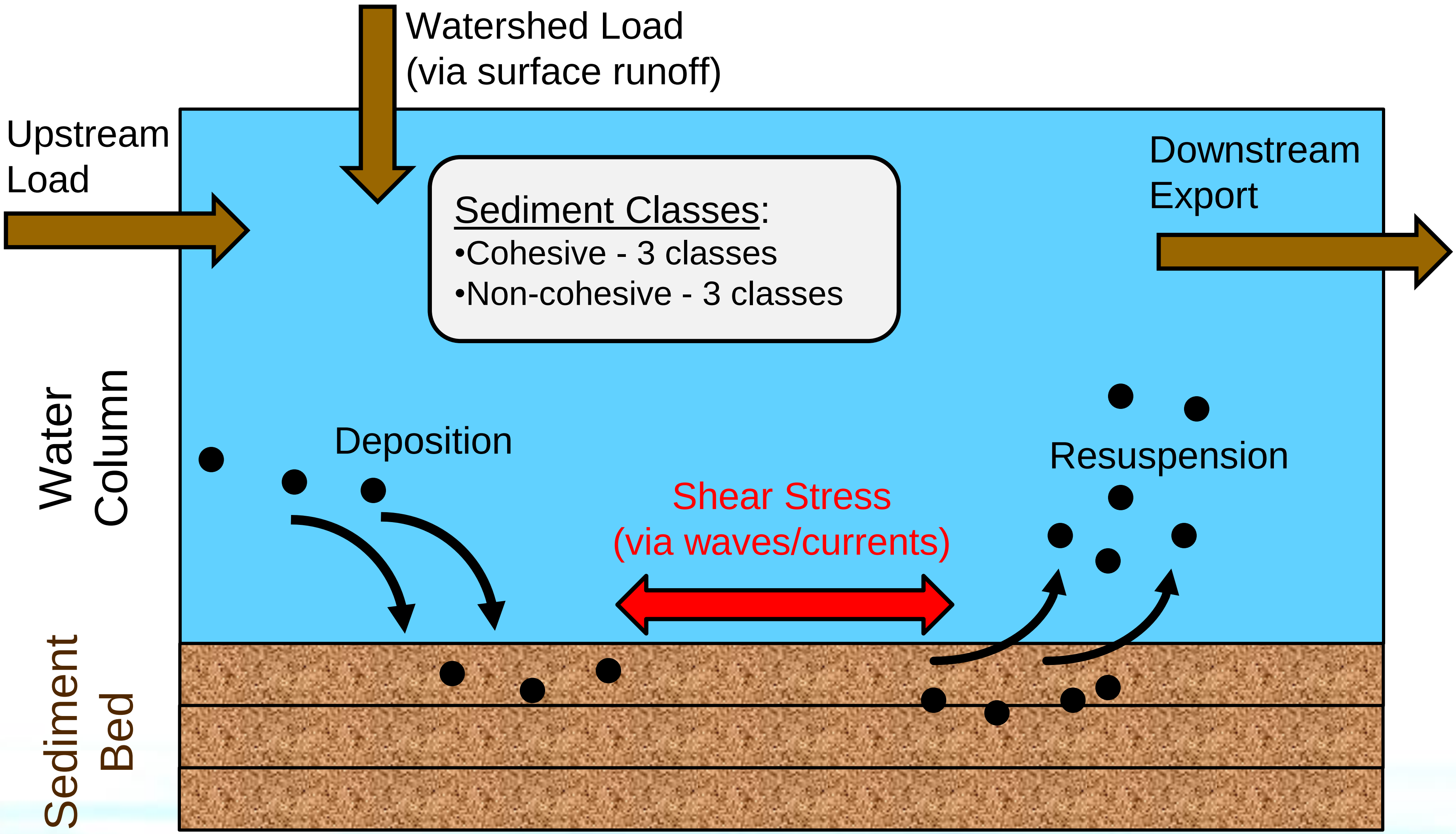


Modeling Algal Biomass



$$V\frac{dA}{dt} = R_{growth} - R_{loss}$$

Sediment Transport Modeling



Scientific Basis for Modeling

- Watershed Model:
  - Decades of research & field studies of surface runoff, erosion, evapotranspiration, groundwater flow, etc.
  - Development of empirical relationships to describe surface runoff and erosion behavior as a function of 1) land use/cover, 2) soil drainage, and 3) land slope
  - Studies of sediment/nutrient transport in stream networks
- Aquatic Ecosystem Model:
  - Decades of research on nutrients, algal dynamics, sediment movement, etc. in river and lake environments
  - Well-established relationships between nutrient (N/P) availability, water clarity, and algal growth
  - Adequate data required to constrain model processes

How Models Can Support Transactions

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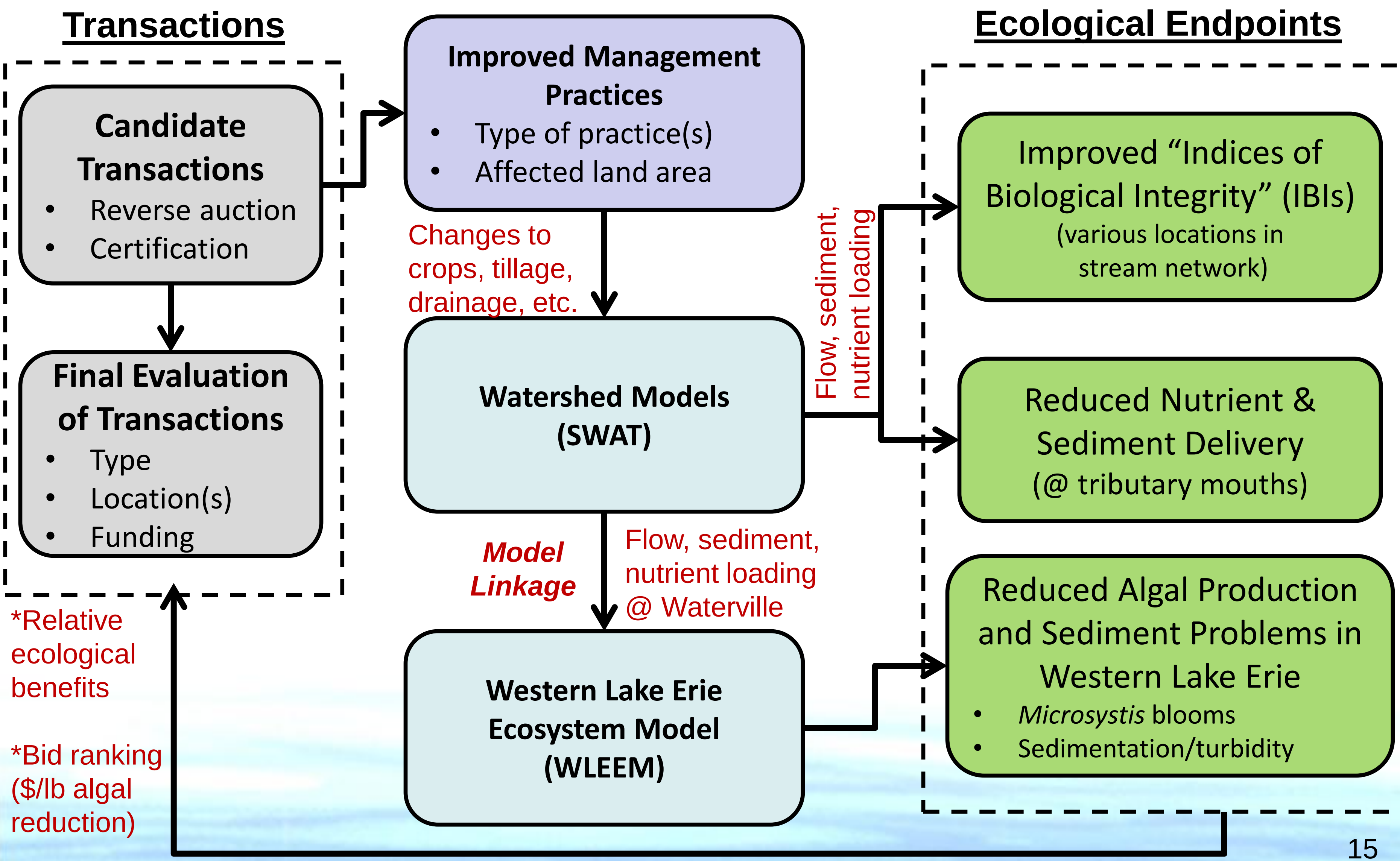
Linked Models to Support Transactions

- Linked watershed-lake model provides physically-based tool for estimating ecological benefits resulting from candidate agricultural management actions
- Watershed model:
  - Quantify current delivery of sediment/nutrients to Lake Erie
  - Attribute sediment/nutrient loads to specific land areas
  - Predict sediment/nutrient loading reductions in response to management actions
- Aquatic ecosystem model:
  - Quantify relationship between algal production and nutrient loadings (+ water clarity)
  - Quantify reductions in algal production in response to reduced nutrient loading (via watershed management actions)
  - Quantify sediment-related ecological endpoints: sedimentation in Maumee Bay/navigation channel, turbidity at water intakes

Transactions ↔Ecological Endpoints



Modeling Tools:
SWAT Watershed Model

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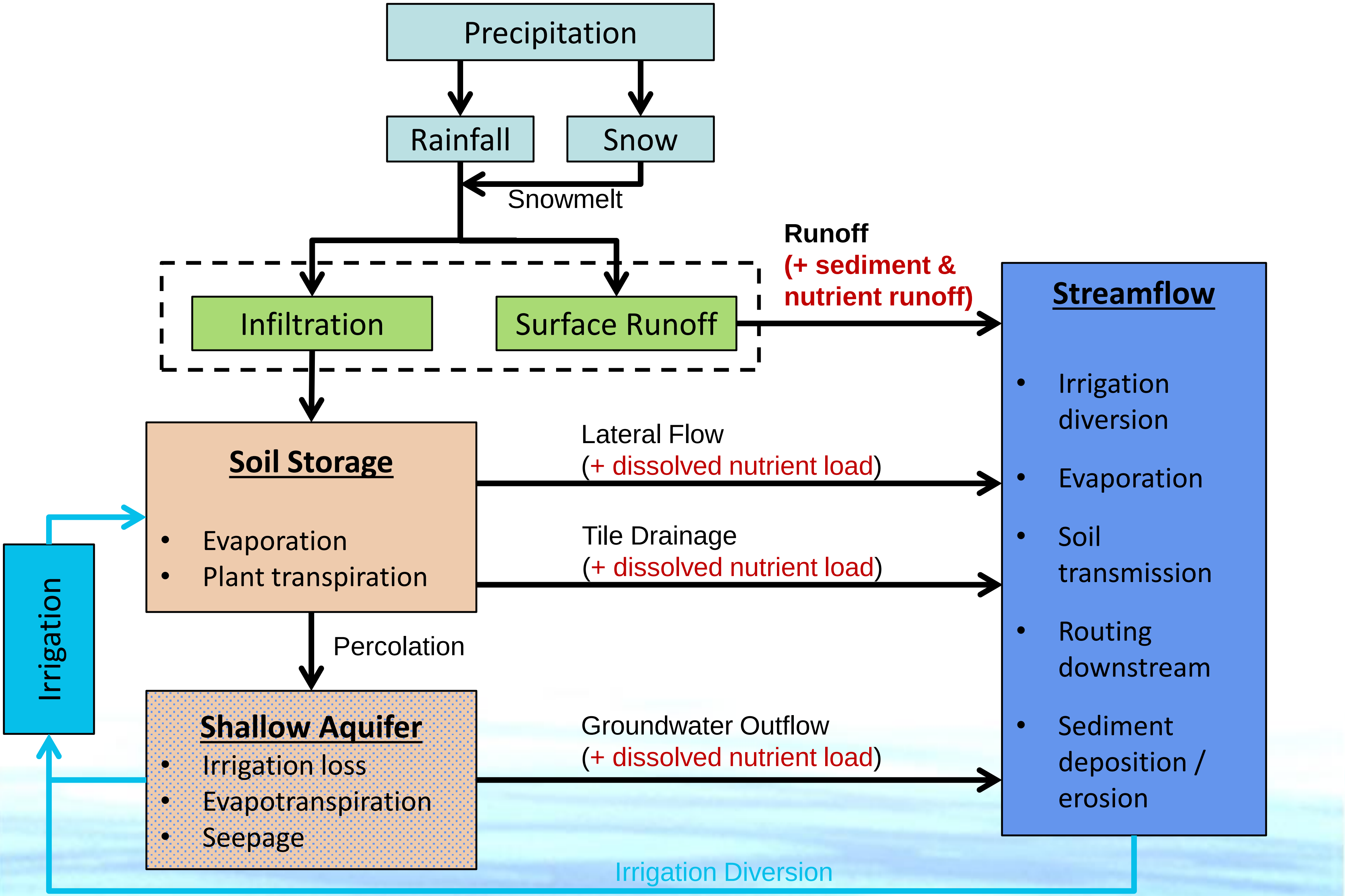
Soil & Water Assessment Tool (SWAT)

- Developed in the late 1980s by NRCS-ARS
- Designed to simulate hydrology in large agricultural watersheds
- Simulates on a daily timescale:
  - Hydrology (runoff, baseflow, channel routing)
  - Sediment erosion & delivery to/from streams
  - Nutrient delivery to/from streams
  - Pesticide delivery
- Accounts for varying land use/cover, soils, management practices (e.g., tillage operations)

SWAT Conceptual Diagram



Soil & Water Assessment Tool (SWAT)

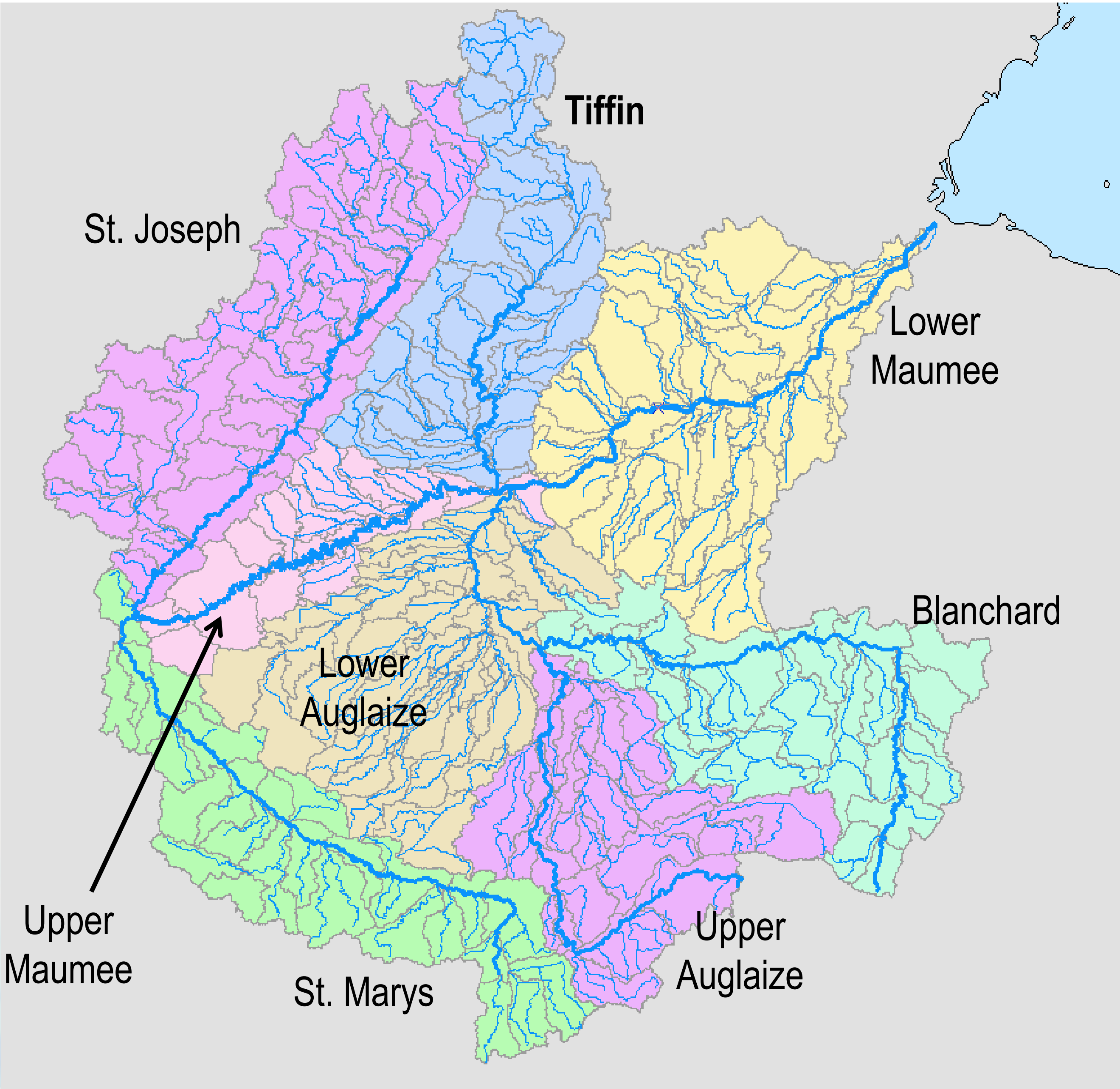
- SWAT can represent:
  - Water movement through all major pathways
  - Sediment and nutrient yield (primarily via runoff)
  - Relative improvements in hydrology & pollutant loading reductions resulting from watershed management actions
- SWAT can’t represent:
  - Every individual parcel / farm in the Maumee basin (due to data limitations, runtime constraints)
  - Regional groundwater flow or deep groundwater storage

Soil & Water Assessment Tool (SWAT)

- Key Model Inputs:
  - **Climate** (rainfall, air temperature, etc.)
  - **Physical** (land use/cover, soil type, land slope)
  - Fertilizer/pesticide application rates (& timing)
  - Land management practices (e.g., tillage, tile drainage)
  - Point source loads (location, magnitude)
- Key Model Outputs (available for any reach):
  - Daily flow rate (m^3/s)
  - Total sediment loading (kg/day)
  - Nitrogen & phosphorus loading (kg/day)
  - Pesticide loading (kg/day)

Maumee SWAT Model - Subbasins

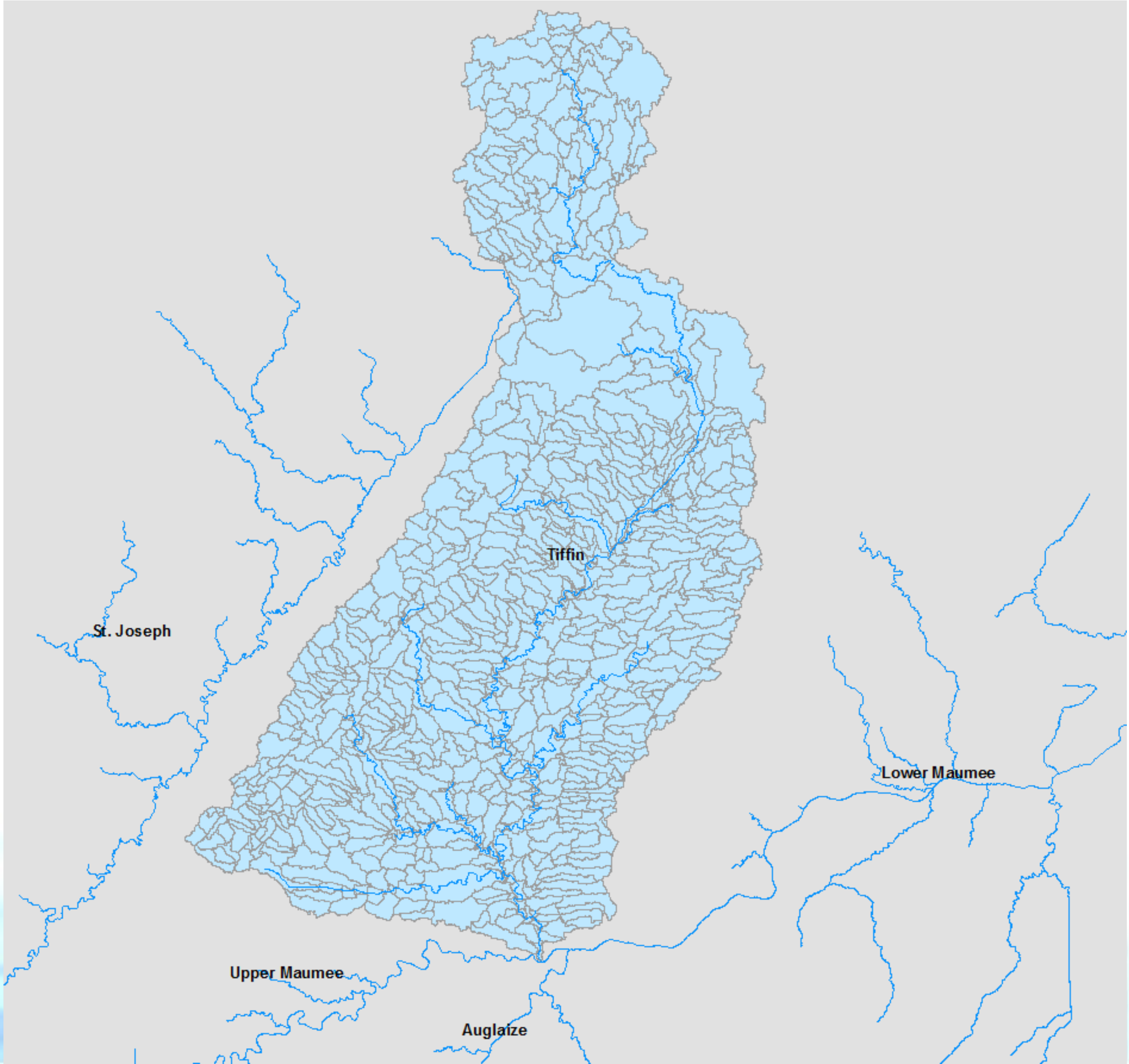
Subbasin Scale:
- Based on USGS "HUC-12"
- Average surface area: ~17,000 acres (70 km^2)



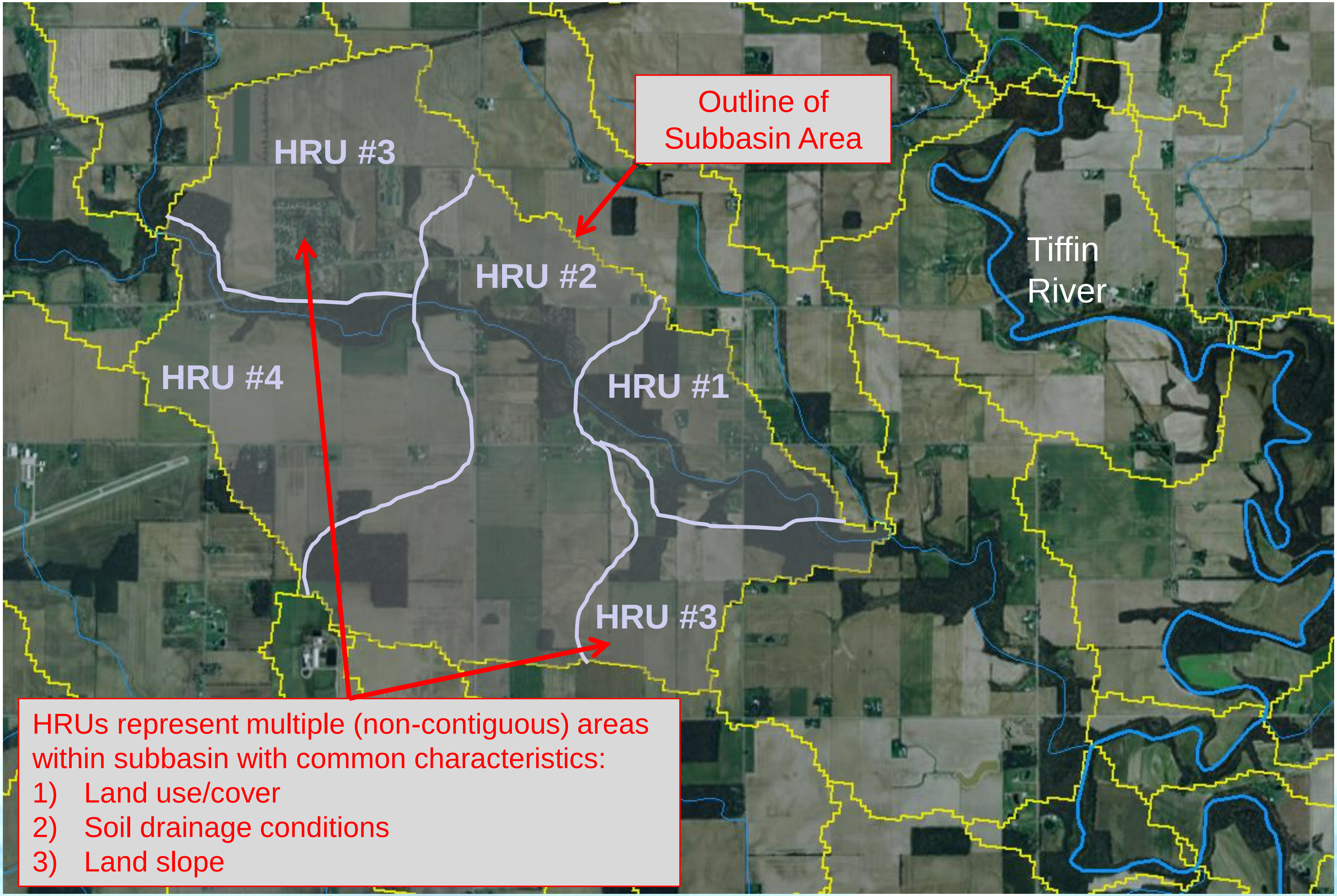
Tiffin River SWAT Model - Subbasins

<u>Subbasin Scale</u>:

- Based on “NHDPlus” (medium resolution)
- Average surface area: 600 acres (2.4 km^2)



SWAT "Hydrologic Response Units" (HRUs)



Modeling Tools: Western Lake Erie Ecosystem Model (WLEEM)

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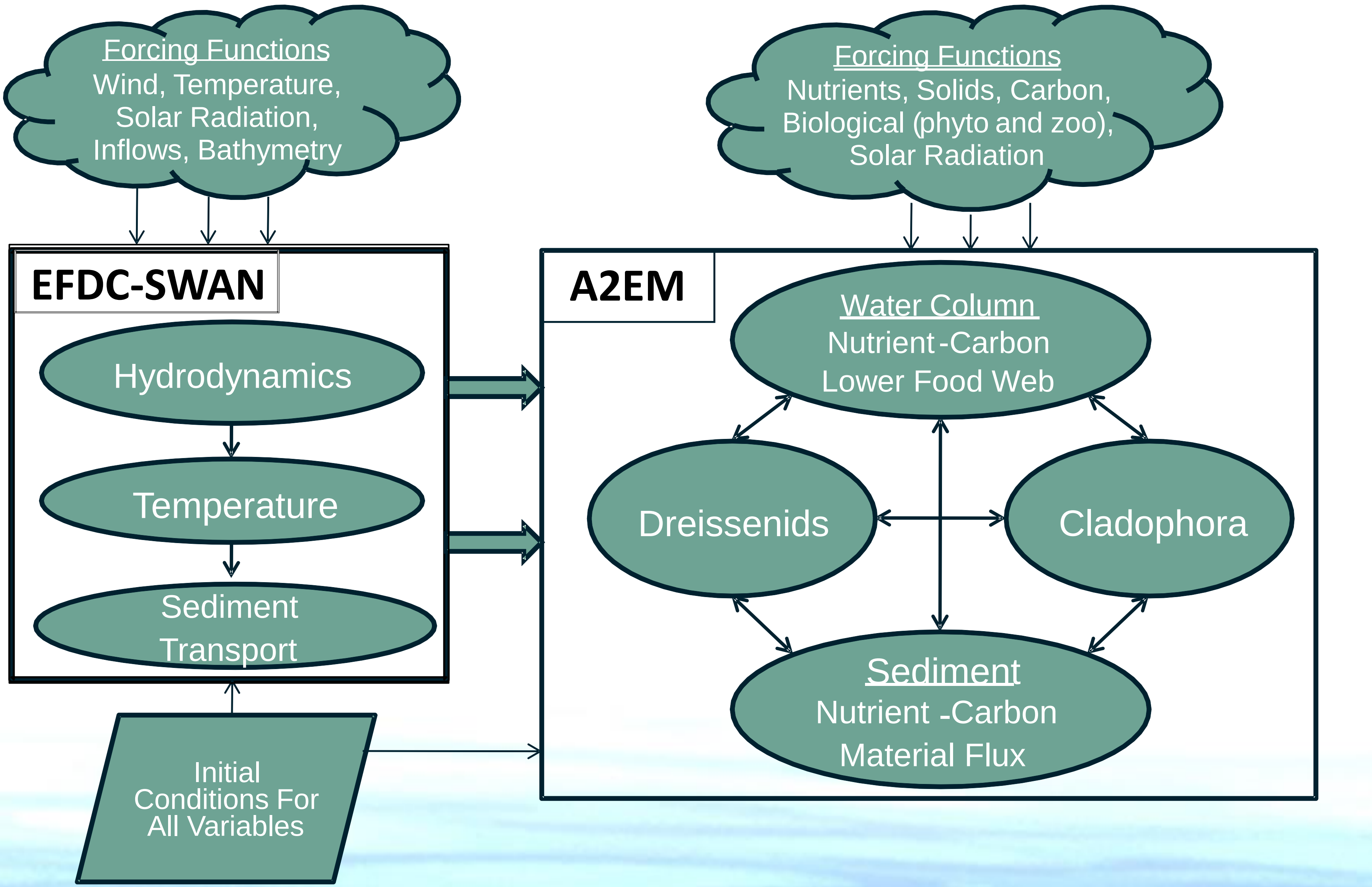
Western Lake Erie Ecosystem Model (WLEEM)

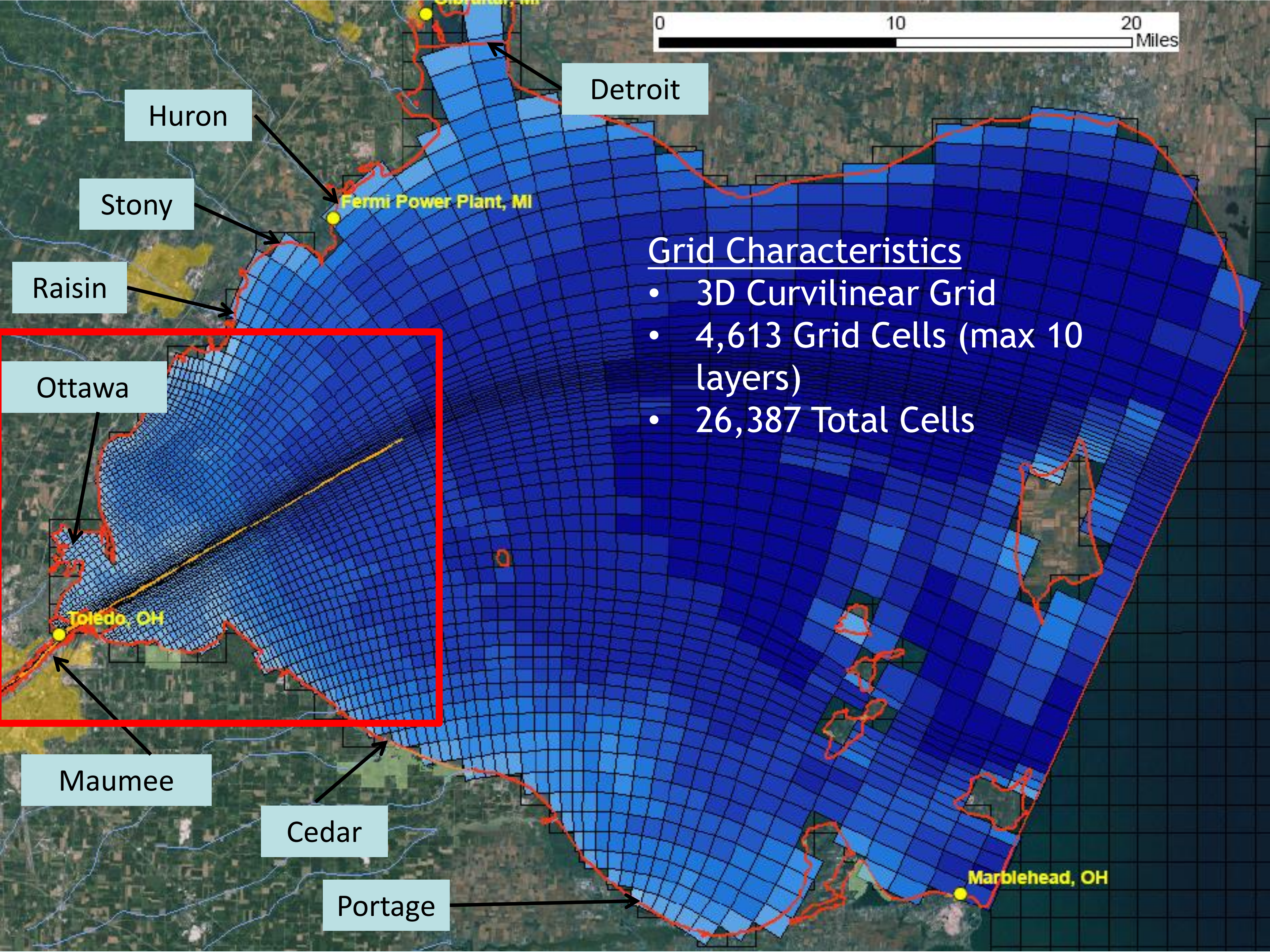
- Developed by LimnoTech based on public domain modeling tools:
  - **EFDC** (hydrodynamics, sediment transport water temperature)
  - **A2EM** (water quality, eutrophication processes)
- Original funding provided by USACE-Buffalo District
- Continuing development funded by NSF Water Sustainability and Climate Project

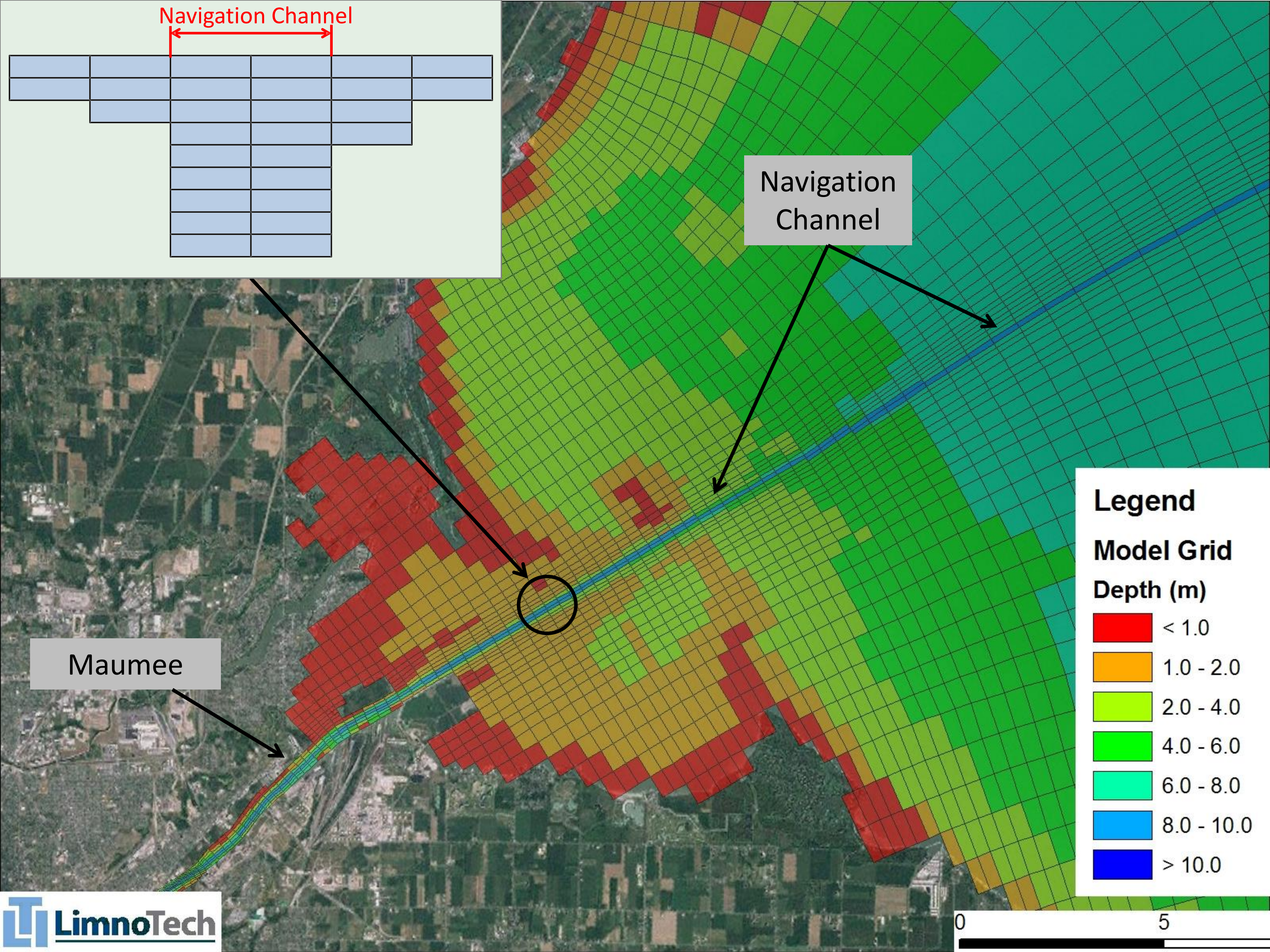
EFDC-A2EM Modeling Framework



Western Lake Erie Ecosystem Model (WLEEM)

- Key Model Inputs:
  - Bathymetry
  - Tributary inflows
  - Meteorological data (wind, air temperature)
  - Sediment & nutrient loadings via watershed model (or data-based estimates)
  - Parameters controlling key processes
    - e.g., rate of algal growth
- Key Model Outputs:
  - Nutrient concentrations (temporal and spatial profile)
  - Biomass of different algal groups (temporal and spatial profile)
    - Cyanobacteria (Blue-green algae) (*Microcystis*)
    - Other “good” phytoplankton (e.g., Diatoms)
    - Benthic algae (*Lyngbya*)
  - Sedimentation rates and suspended solids profiles


0
10
20
Miles
Detroit
Huron
Stony
Raisin
Ottawa
Maumee
Cedar
Portage
Fermi Power Plant, MI
Toledo, OH
Marblehead, OH
Grid Characteristics
• 3D Curvilinear Grid
• 4,613 Grid Cells (max 10 layers)
• 26,387 Total Cells



Navigation Channel
Navigation Channel
Maumee
Legend
Model Grid
Depth (m)
< 1.0
1.0 - 2.0
2.0 - 4.0
4.0 - 6.0
6.0 - 8.0
8.0 - 10.0
> 10.0
0
5
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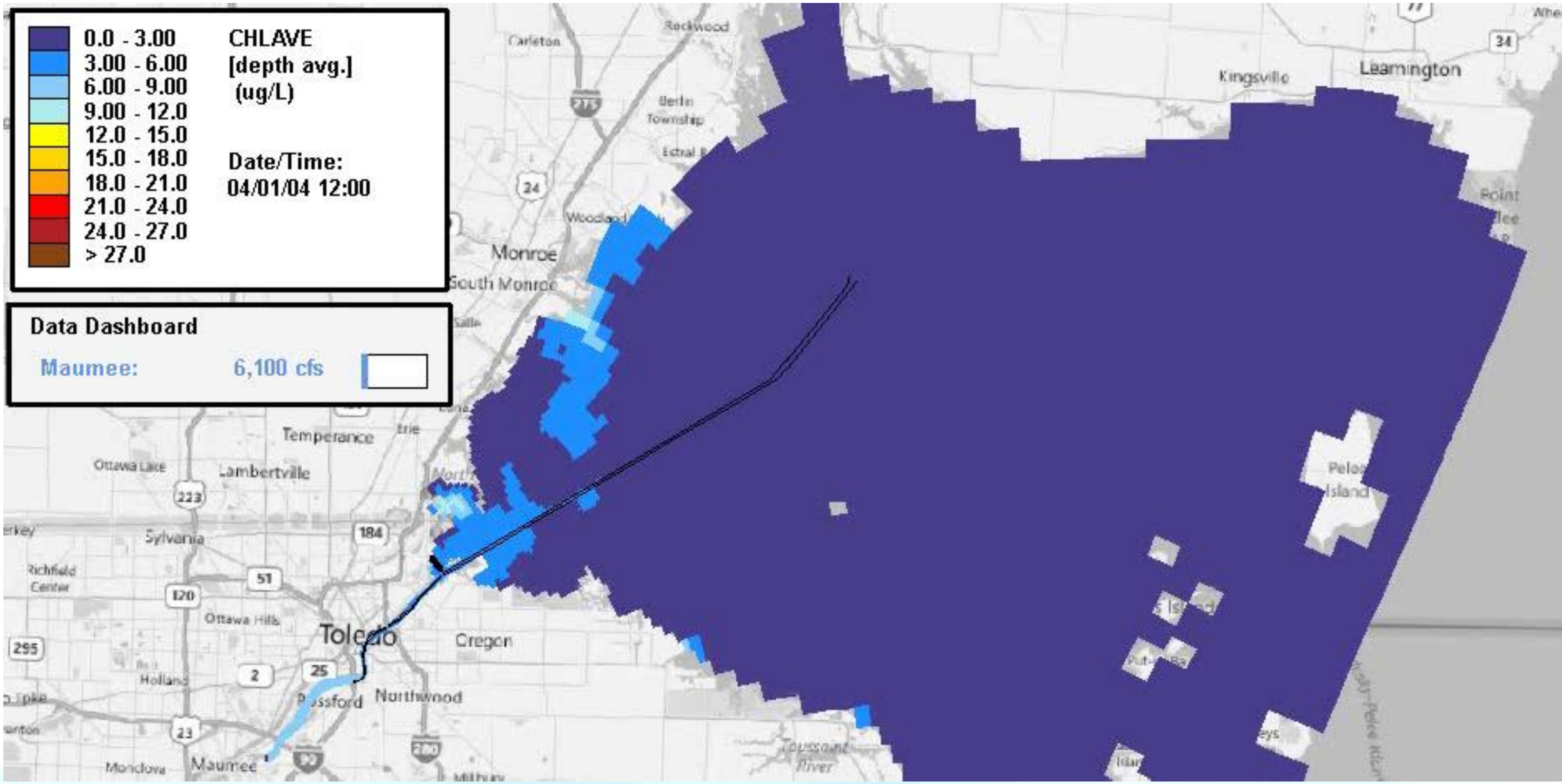
WLEEM Chlorophyll-a Animation



Key Model Limitations & Uncertainties

- General sufficiency of watershed and lake datasets to support robust calibration of models
- Yield of sediment/nutrients from land vs. instream sources (e.g., bank or bed erosion)
- Attribution of sediment or nutrient loadings to different watershed land areas:
  - Land use/cover conditions can change over time
  - Ag practices can change over time (implementation & effectiveness)
- Other environmental conditions that affect algal growth (e.g., light, temperature, Dreissenids)

Interaction with Other Watershed Modeling Efforts

1. Tiffin River watershed modeling
   - Funded via USACE's tributary modeling program - 516(e)
   - LimnoTech currently developing model, preliminary calibration to occur in fall
   - Will be used to inform reverse auction transactions in Tiffin watershed
2. WLEB Biological Endpoints Project (TNC/NRCS)
   - Funded by "Conservation Effects Assessment Project" (CEAP)
   - Involves development of a fine-scale SWAT model of entire Maumee basin ("NHDPlus" scale)
   - Expected to serve as the long-term model to inform GLWESS transactions across the full watershed

Summary – How Models Interact with the Transaction Process

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Using Model Results to Inform Transactions

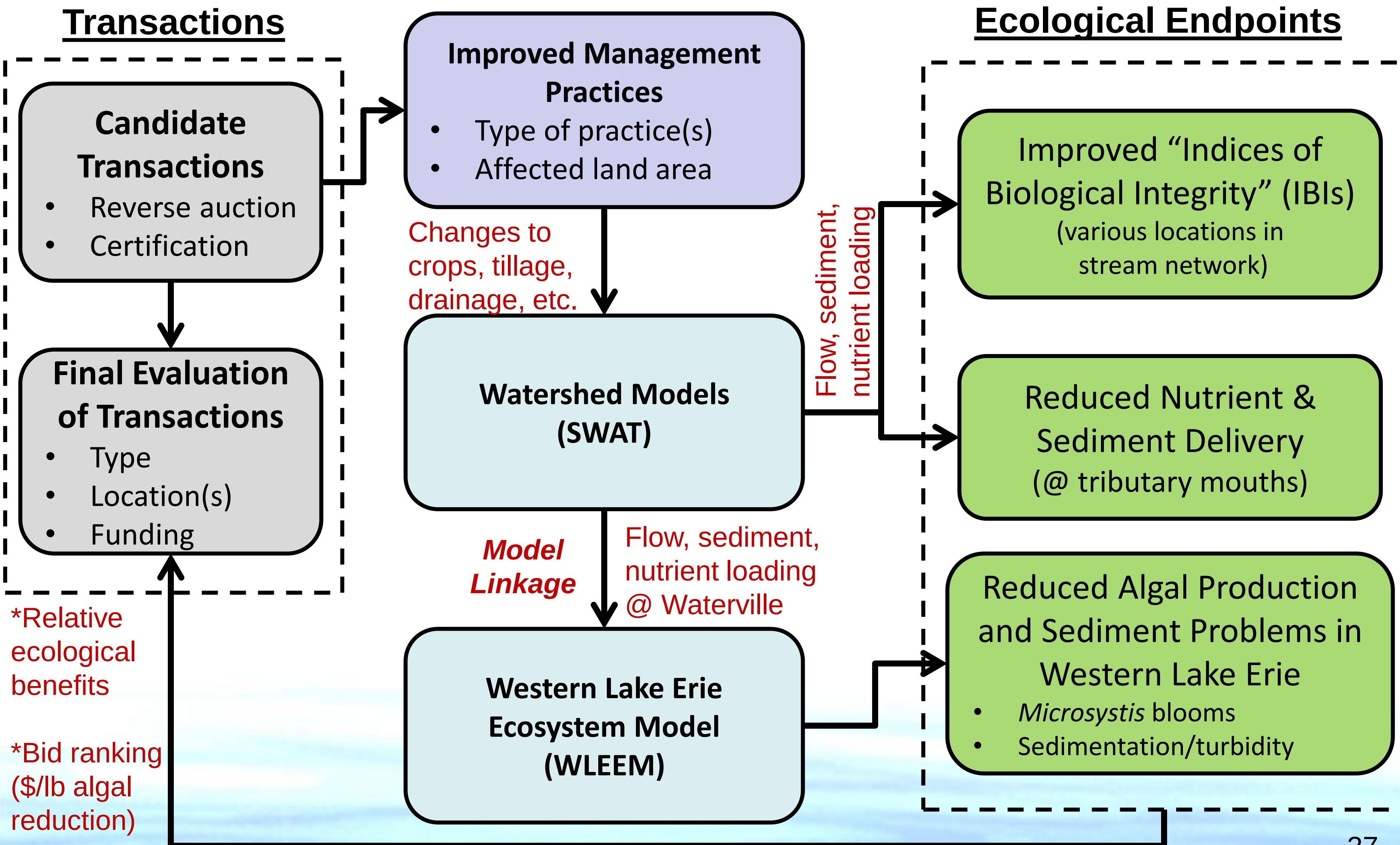
- Provide guidance on areas to target for transactions
  - Based on subbasin/HRU nutrient yields in "baseline" model
- Evaluate candidate transactions & associated management actions:
  1. Represent proposed changes to crop rotation, tillage practices, etc. as scenarios in SWAT model
  2. Link changes in flow, sediment, nutrient loading to WLEEM
  3. Calculate ecological benefit as predicted reduction in algal biomass production (i.e., lbs of algae biomass 'removed')
  4. Reverse auction bids (or other transactions) ranked based on cost-effectiveness with respect to algal biomass reduction

Using Model Results to Inform Transactions

- Example of ranking for reverse auction bids:

Auction Bid	Total Cost	Estimated Algal Biomass Reduction (lbs)	Cost-Effectiveness ($/lb)	Final Bid Ranking
Bid #1	$20,000	1,000	$20	2
Bid #2	$30,000	2,000	$15	1
Bid #3	$25,000	1,000	$25	3

Transactions ↔Ecological Endpoints



Questions/Discussion

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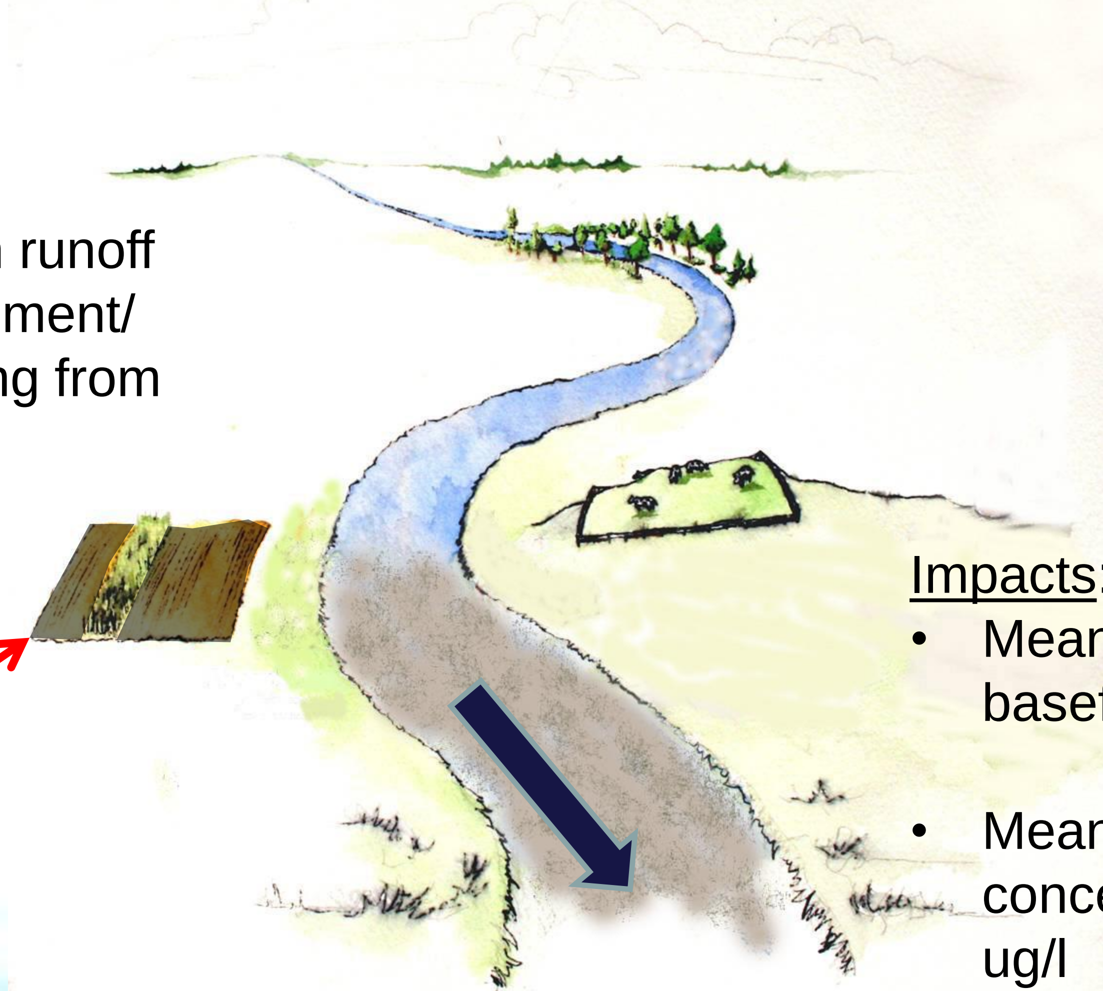
Illustrative Example: "Baseline" Condition

Problem: high runoff yield and sediment/ nutrient loading from cropland



Conventional Fall Tillage

Impacts:

- Mean summer baseflow: 100 cfs
- Mean phosphorus concentration: 300 ug/l

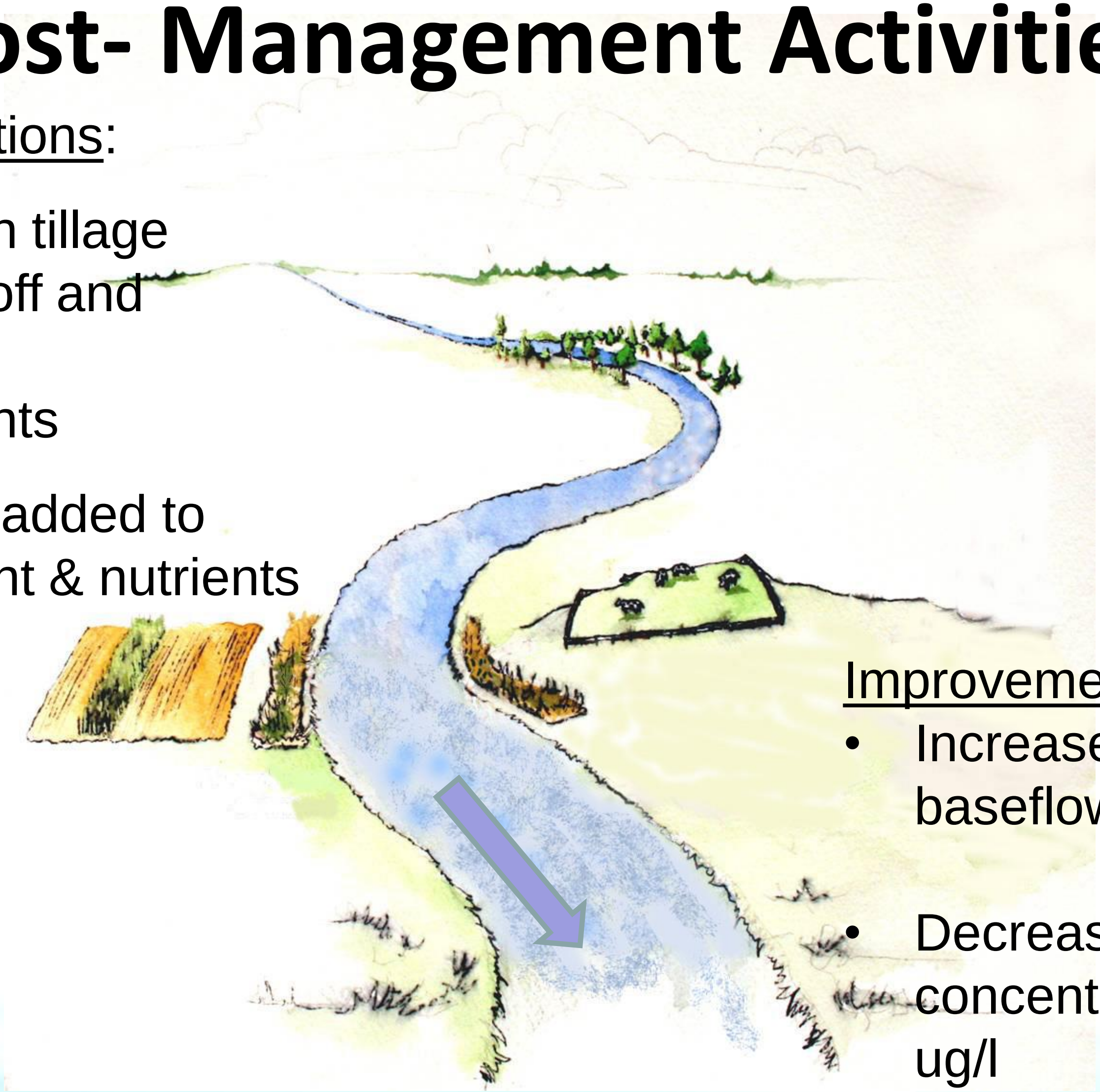
Numbers are illustrative

Illustrative Example:
Post- Management Activities

Management Actions:

1. Conservation tillage reduces runoff and delivery of solids/nutrients

2. Buffer strips added to filter sediment & nutrients



Improvements:

- Increased summer baseflow to 110 cfs

- Decreased phosphorus concentration to 100 ug/l

Numbers are illustrative