The Potential Importance of Conservation, Restoration and Altered Management Practices for Water Quality in the Wabash River Watershed

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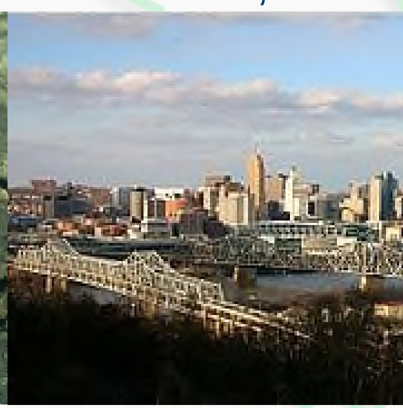

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Outline

- Objective
- Modeling – Optimization Framework
- CRAM Identification
- CRAM Placement Optimization
- Results
- Conclusions

Objective

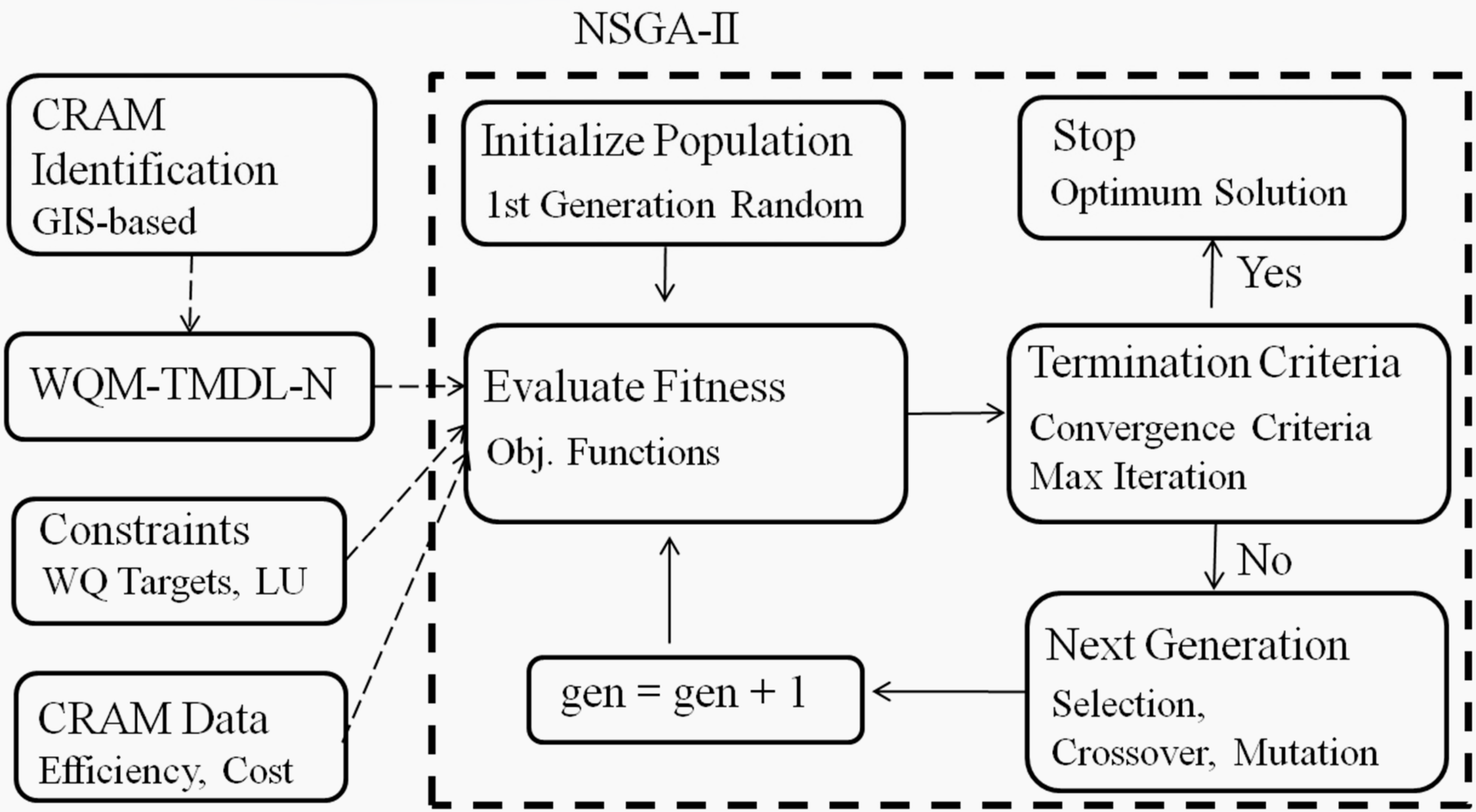
- To integrate critical methods/tools into a modeling-optimization framework, including a GIS-based CRAM siting method, a recently developed WQM-TMDL-N modeling approach to estimate nitrogen loading, and a multi-objective optimization tool to find cost-effective solutions of CRAM placement to reduce nutrient loads

* In support of TMDL development to meet water quality goals by providing trade-offs between different objectives, in this case, reducing N load and cost, for decision makers

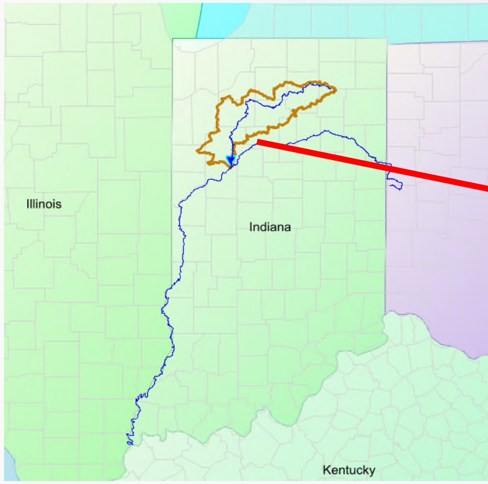
Why A Modeling – Optimization Approach

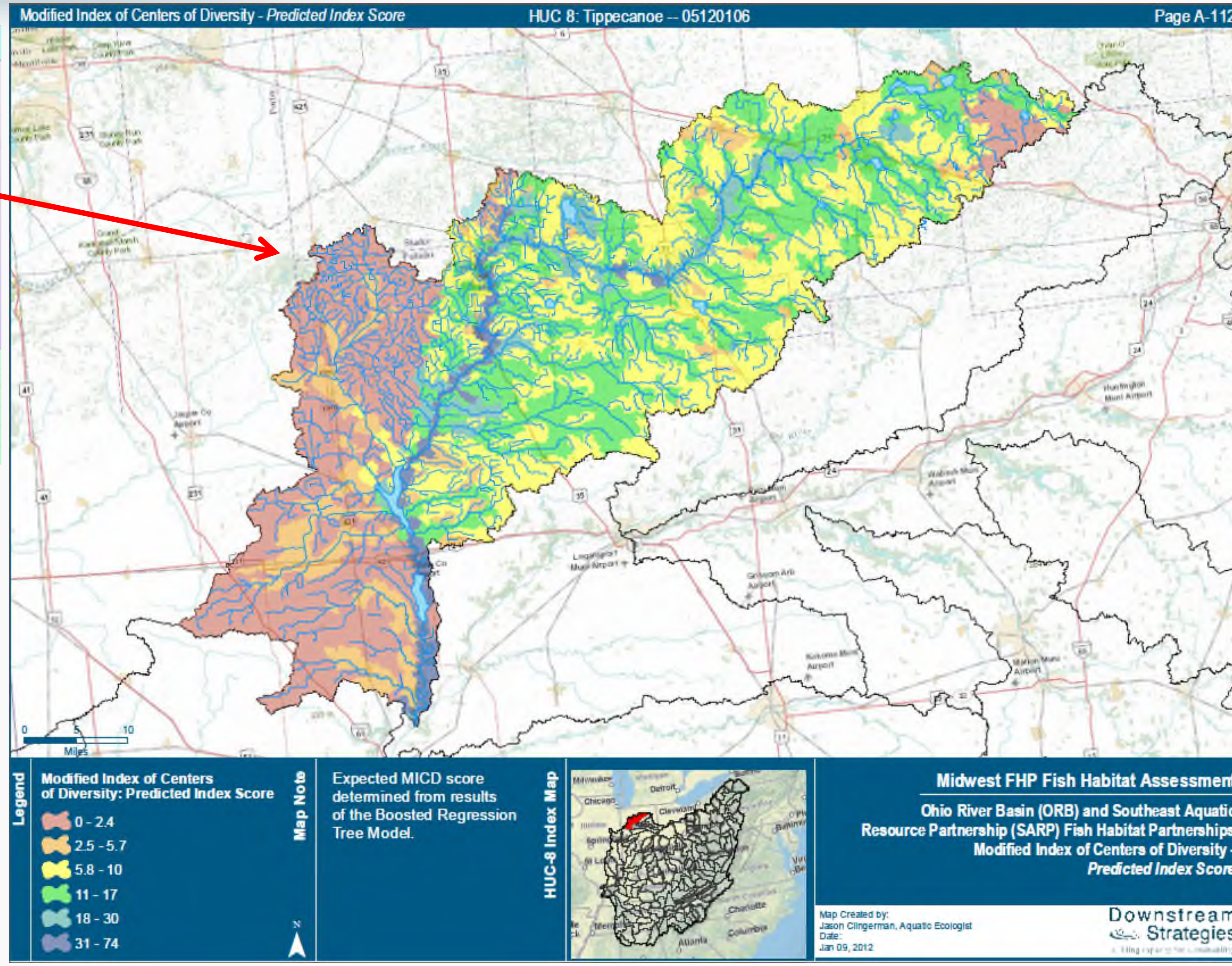
- Implementation of CRAM practices involves conflicting objectives, i.e., decreasing load while keeping cost low;
- Interactions between CRAMs may significantly affect their individual performance at a watershed scale by reducing the marginal benefit;
- Identification of CRAM sites through a traditional targeting method may become impractical in a large watershed, – the number of CRAM scenarios increases exponentially with watershed area;
- Load reduction by CRAMs at a local spatial scale could have a negligible impact on the entire watershed load.

Modeling – Optimization Framework



Case study: Tippecanoe R. Watershed, IN

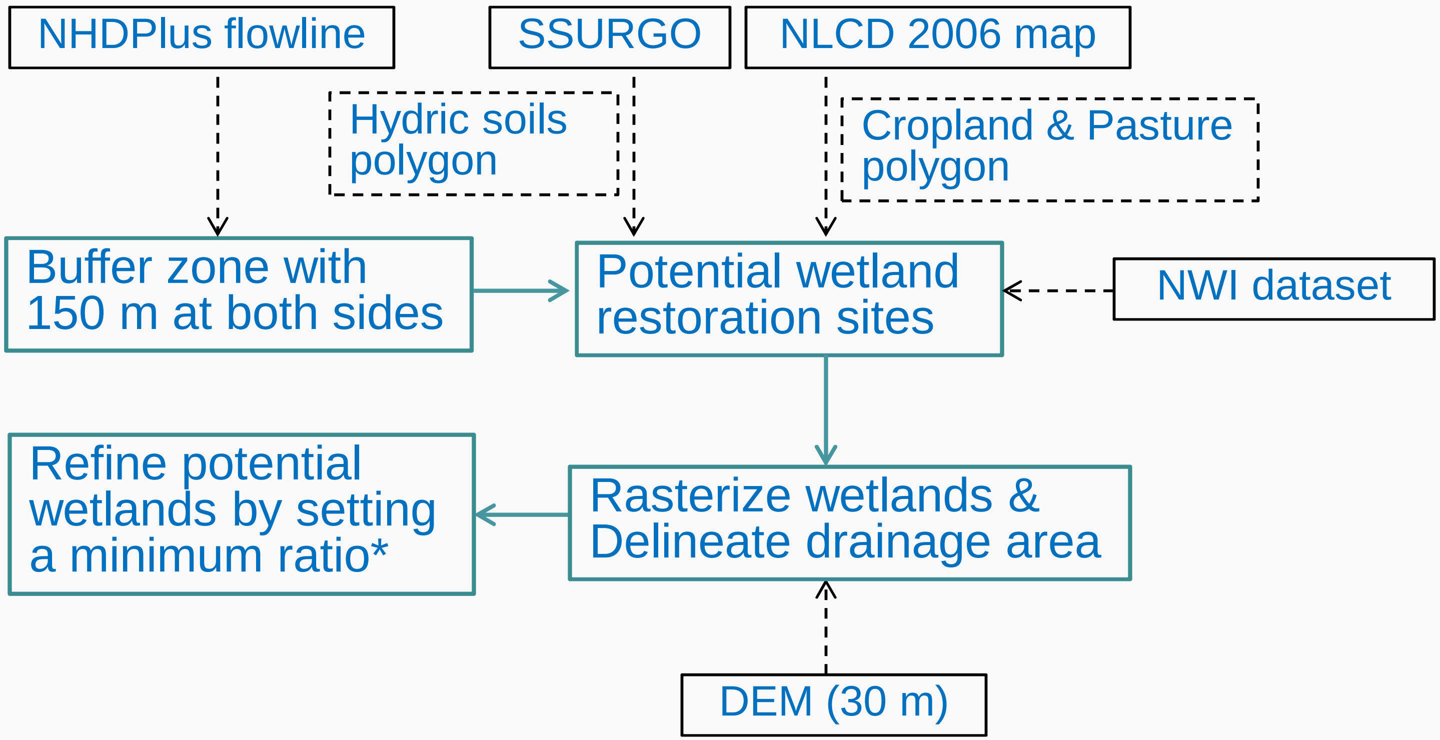




- ➢High biodiversity (fish)
- ➢BMP implementation
- ➢Effects on TN load?

CRAM Identification – GIS

GIS steps for potential wetland identification

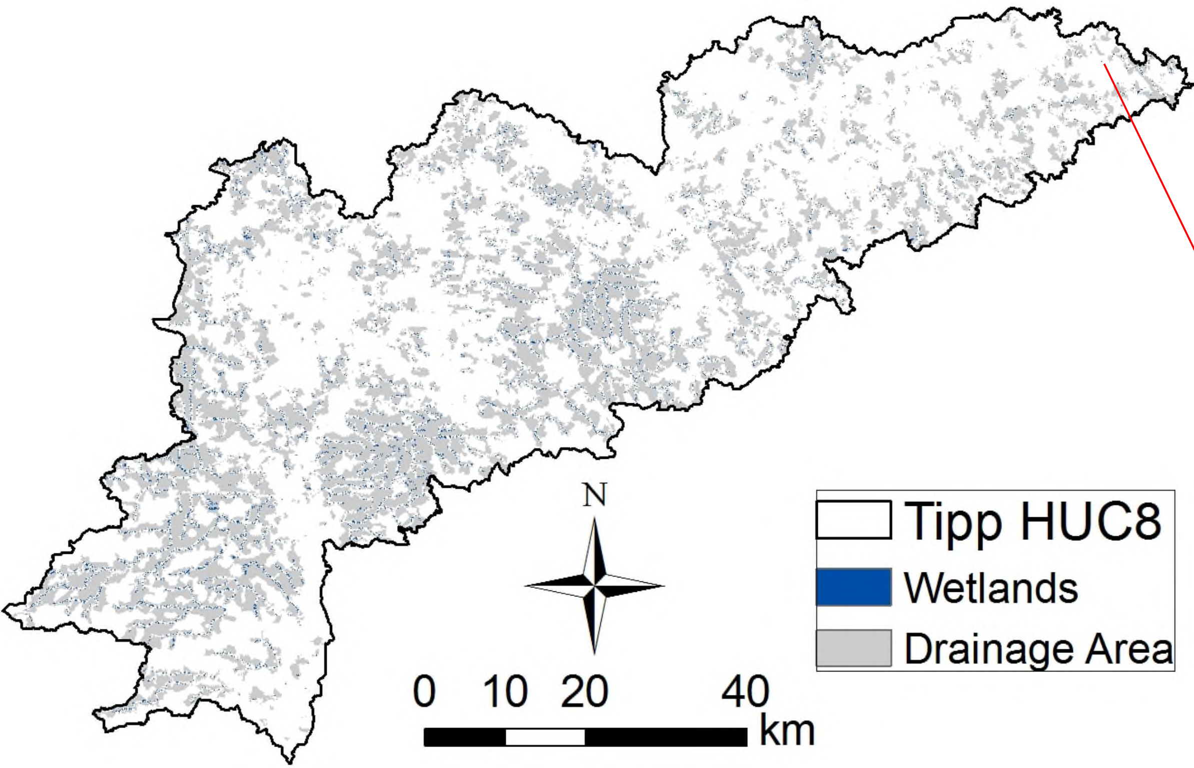


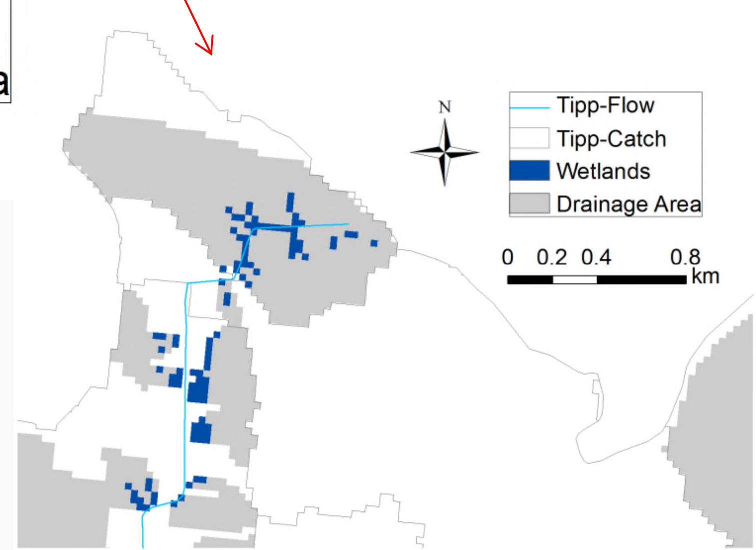
* Refine potential wetlands by setting the ratio of drainage area: wetland area > 5 : 1 (area > 0.5 ha), to maximize the potential performance of wetlands in nutrient removal.

NWI: National Wetlands Inventory

CRAM Identification – GIS

Potential wetland sites and their drainage areas





TN removal efficiency (Jordan et al., 2011):

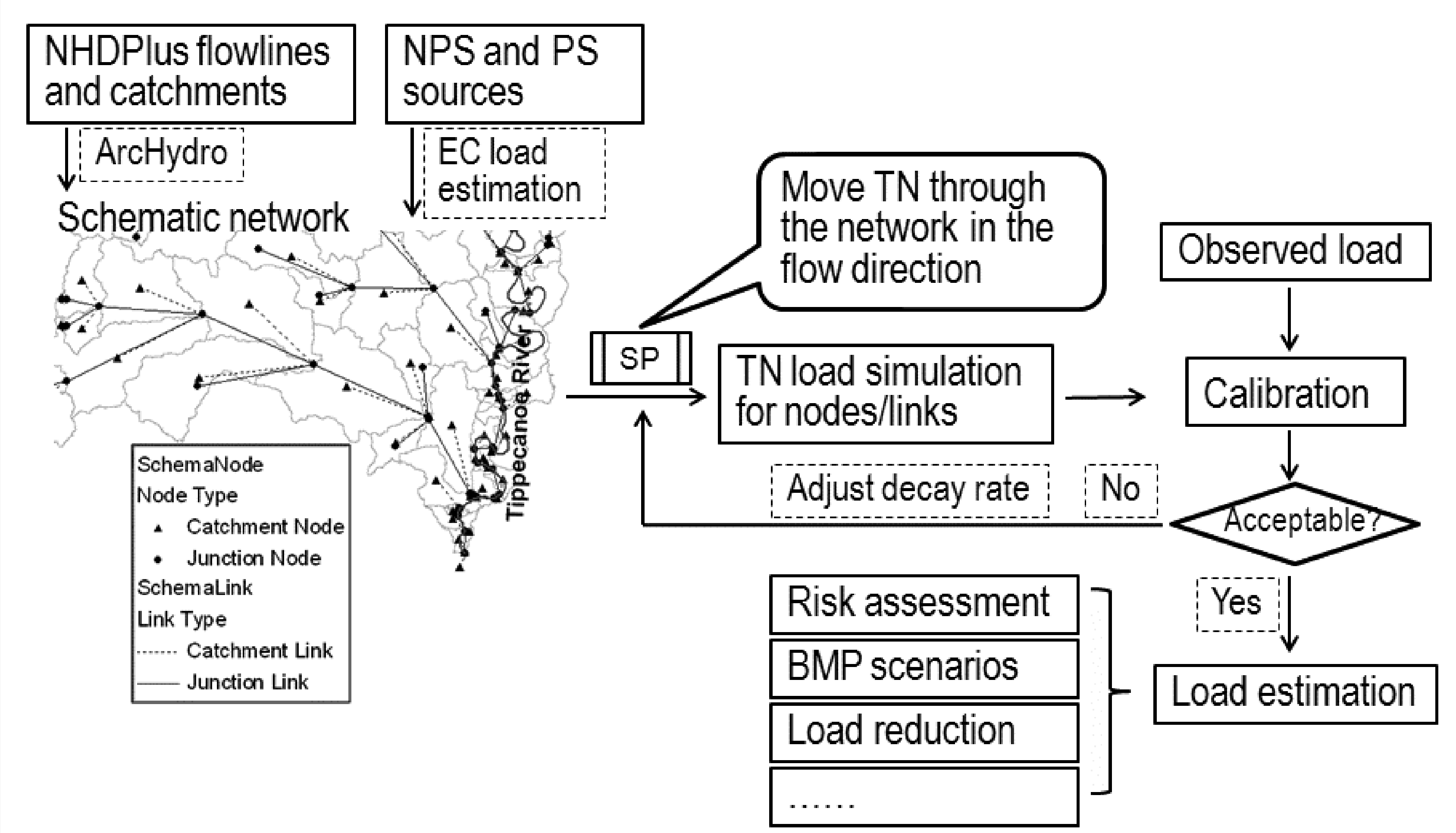
$\log_{10}(y) = 0.99 * \log_{10}(x) – 0.46$, $r^2 = 0.82$

y: TN mass removed per area per time,

x: TN load, estimated from WQM-TMDL-N

WQM-TMDL-N Framework

Screening-level modeling framework – flow chart



NPS: non-point sources; PS: point sources;
EC: export coefficient; SP: schematic processor; TN: total nitrogen.

(Yang et al., 2014)

Genetic Algorithm

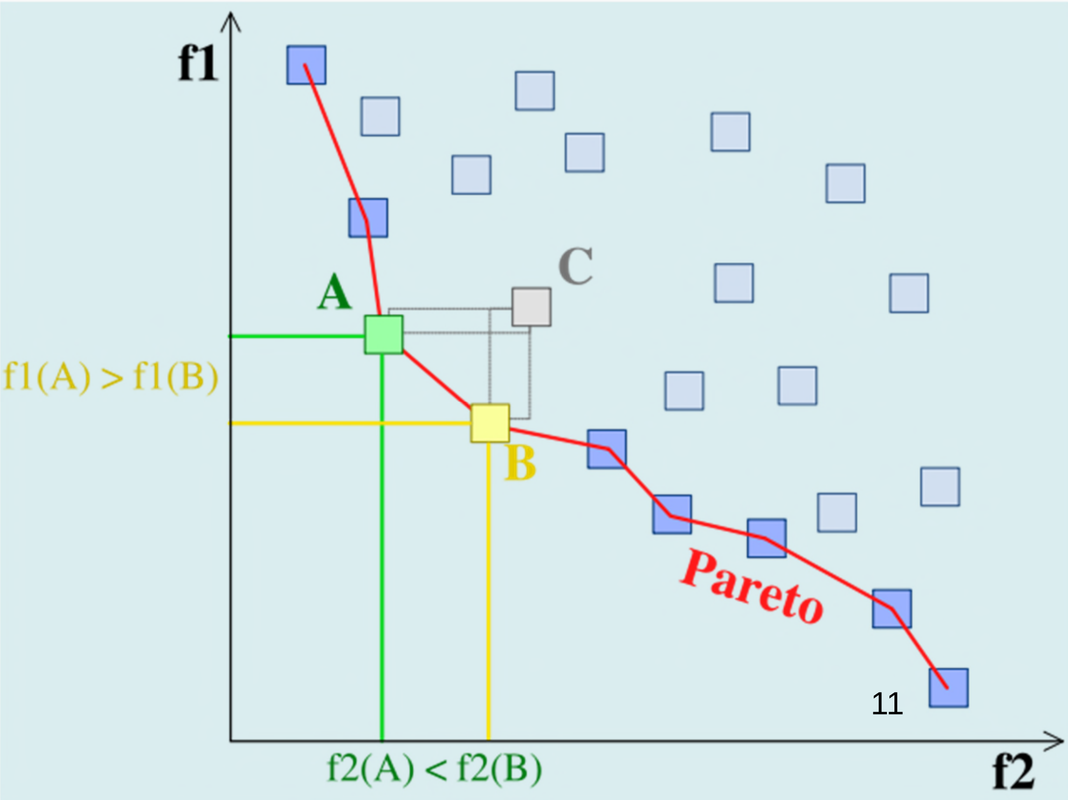
- A search technique to solve multi-objective optimization problems, derived from evolutionary concepts, e.g., selection, crossover and mutation.

A simple GA example

```
{
    initialize population;
    evaluate population;
    while TerminationCriteriaNotSatisfied
    {
        select parents for reproduction;
        perform crossover and mutation;
        evaluate population;
    }
}
```

Nondominated Sorting Genetic Algorithm II (NSGA-II)

- NSGA II is one of the most efficient multi-objective optimization GA algorithms, widely applied in multiple watershed management and planning studies;
- Nondominated solution: if none of the objective functions can be improved in value without degrading some of the other objective values;
- Without additional subjective preference information, all Pareto optimal solutions are considered equally good;
- The goal is finding a solution that satisfies the subjective preferences of a human decision maker – providing trade-offs between different objectives.



GA Optimization – Objective Functions

Two objective functions

1st: Maximize the TN load reduction, i.e., minimize the exported load at the watershed outlet,

$$f(X) = \sum_{x \in X} L(x) * (1 - R(x))$$

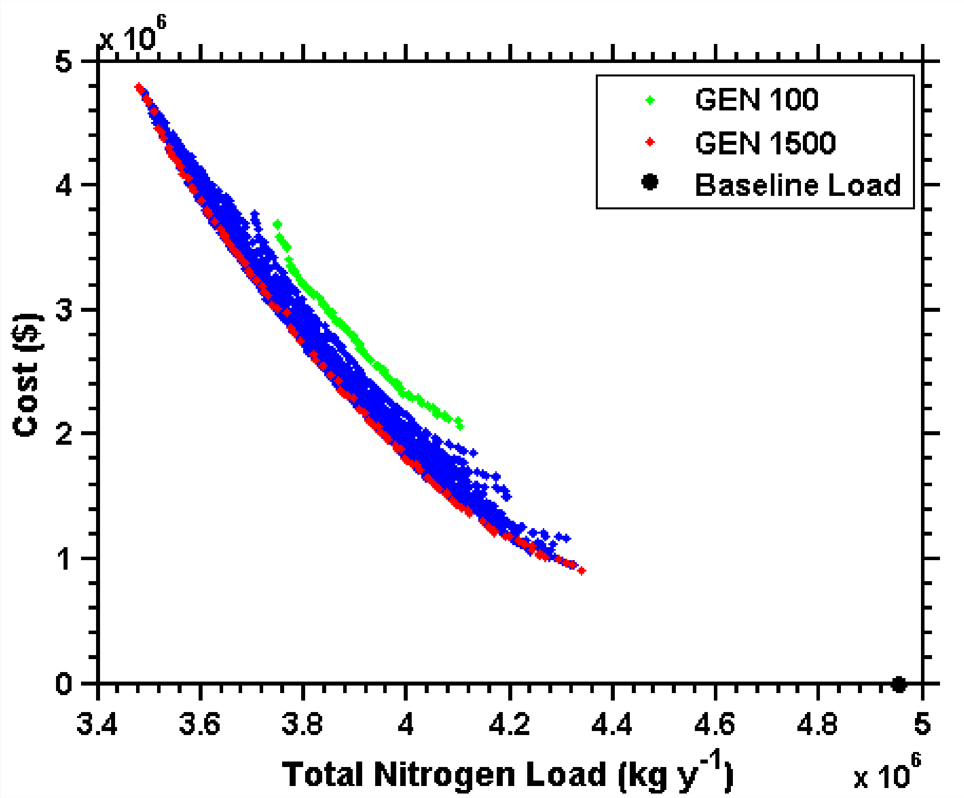
2nd: Minimize the cost of CRAM implementation,

$$g(X) = \sum_{x \in X} C(x)A(x)$$

where X represents the catchments in the watershed, L is catchment nutrient load, R is CRAM-nutrient removal efficiency, A is implementation area in a catchment, and C is CRAM-unit cost.

Optimization Results – 1

Wetland placement optimization



TN baseline load = TN load of the entire wetland drainage area of the watershed. This portion of the load is subject to potential removal by the wetland.

Unit cost: 0.074 \$ m^{-2} y^{-1}
(mean value; USEPA, 2011)

Pareto-optimal front progressing during optimization

GA generation #: 1500

Optimization Results – 2

Three wetland scenarios/solutions from final optimal front

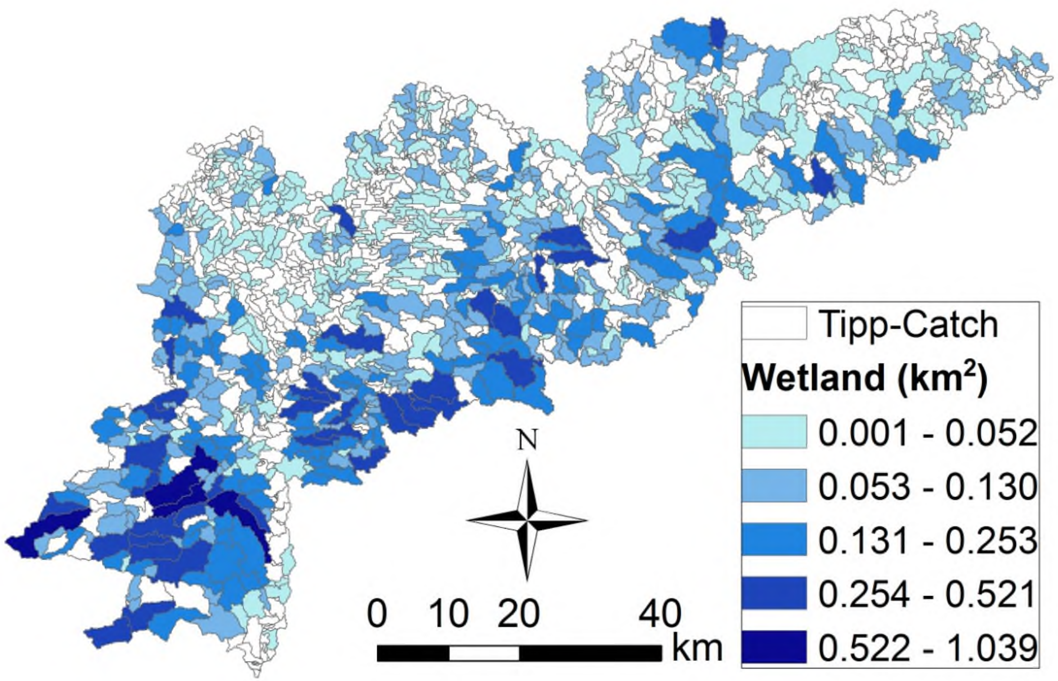
- Maximum TN load reduction, i.e., minimum exported load, with highest cost
- Median of the range of TN load reduction and cost
- Minimum TN load reduction with least cost

Scenarios	Load reduction (M kg y^{-1})	Load reduction (%)	Cost ($ M y^{-1})	# catchments with wetland	Wetland area (km^2)	Wetland area (% of total area)
Maximum	1.47	9.41	4.79	848	64.72	1.28
Median	1.07	7.06	2.33	601	31.47	0.62
Minimum	0.62	4.25	0.91	405	12.24	0.24

Note: Optimized load reduction by scenarios is NOT proportional to wetland area

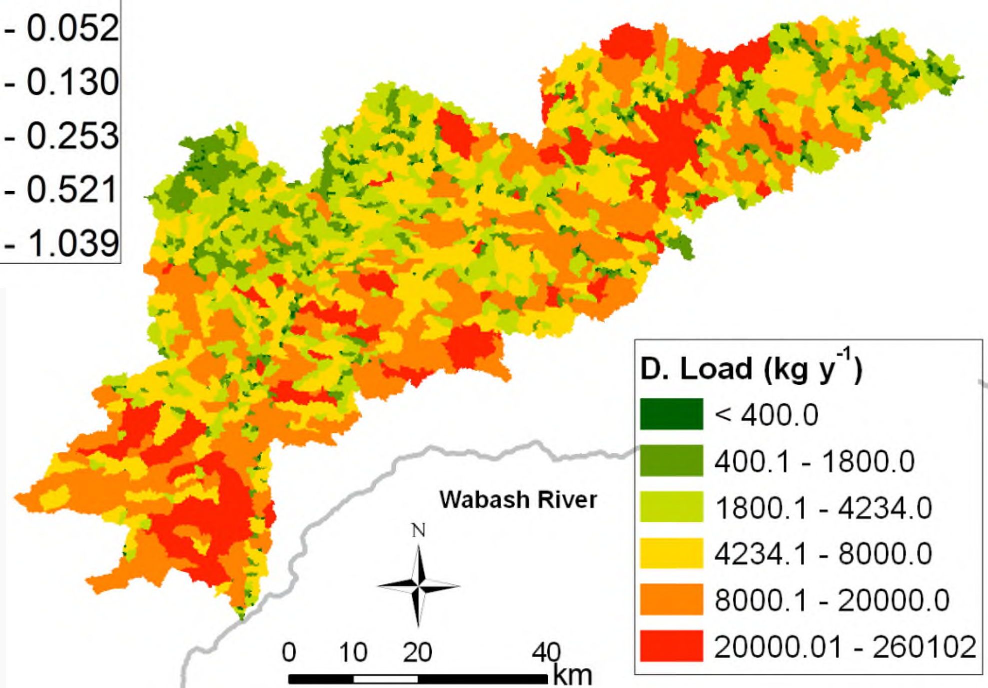
Optimization Results – Spatial Map 1

Maximum scenario in the final optimal front



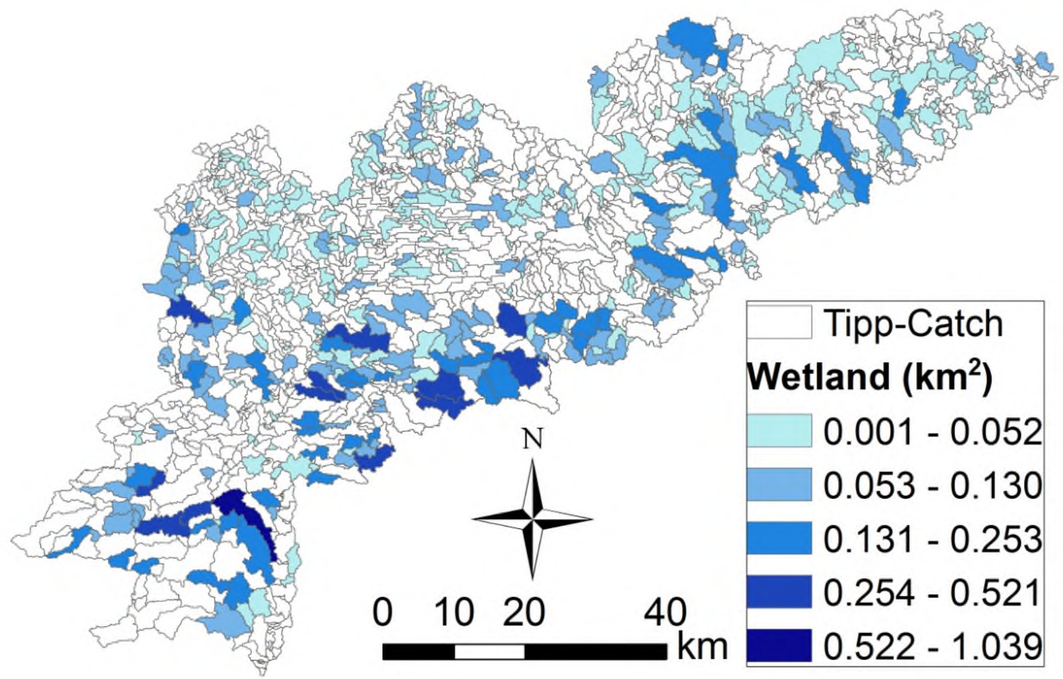
Potential wetland placement
Load reduction: 9.41%
Wetland area: 1.28 %

Delivered TN load to outlet (without CRAM)



Optimization Results – Spatial Map 2

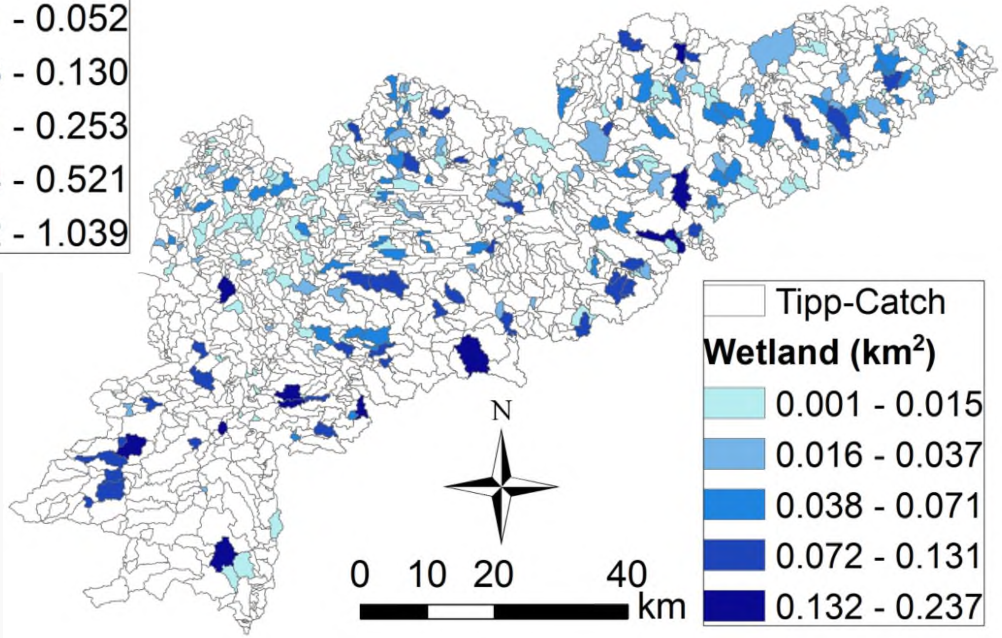
Median and minimum scenarios in the final optimal front



Potential wetland placement

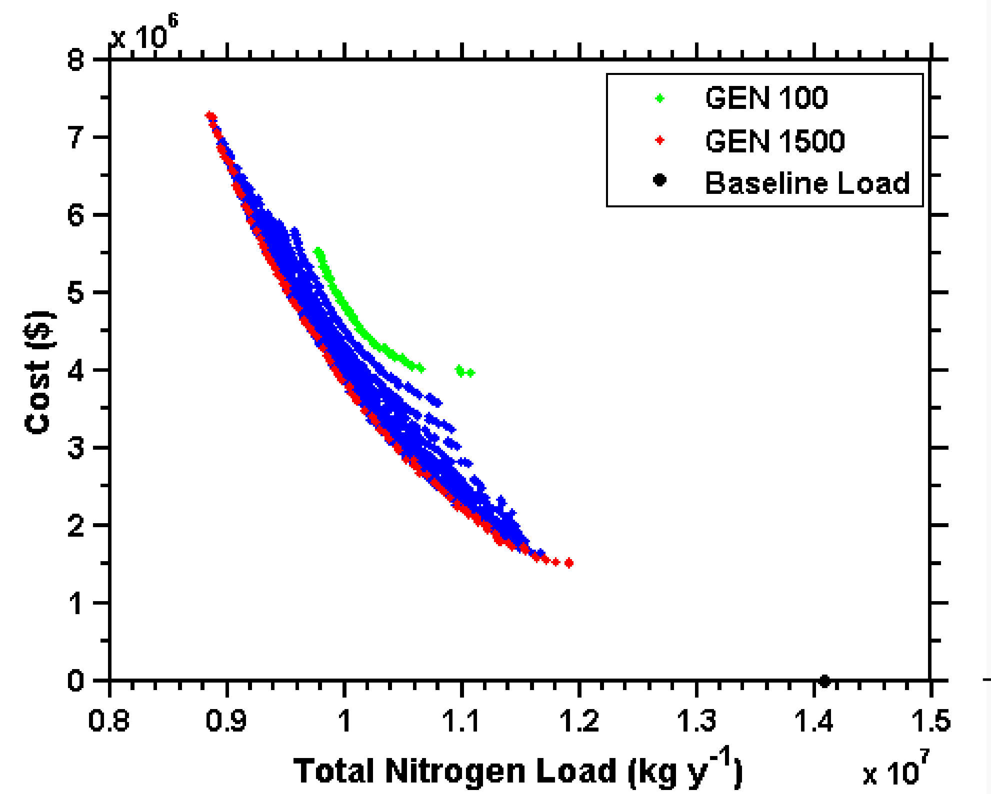
Load reduction: 7.06%
Wetland area: 31.47 km^2

Load reduction: 4.25%
Wetland area: 12.24 km^2



Optimization Results – 3

Buffer strip placement optimization



Pareto-optimal front progressing during optimization

GA generation #: 1500

TN baseline load = TN load of approx. all catchments in the watershed. This load is subject to potential removal by buffer strips.

Load reduction: 2.18 – 5.24 M kg/y (15.5% – 37.2%)

Cost: 1.51 – 7.28 M $

Buffer strips	TN removal (%)*	Cost $ ($ m^{-2} y^{-1})*
Grass buffer	30	0.040
Forest buffer	42	0.055

* Mean value in USEPA (2011)

Conclusions

- This modeling – optimization framework is a combination of modeling tools to assist decision makers in watershed management, e.g., by providing trade-off solutions between different objectives;
- A 20% load reduction goal (in Tippecanoe R.W.; or to a State-accepted TMDL standard) in a watershed could be reached by combining different CRAM activities;
- In this approach, TN removal by wetlands is more sophisticated than by buffer strips. For wetlands, wetland physiographic characteristics from Jordan et al. (2011), for buffer strips merely ‘buffer strip category’ (grass or forest), are included.

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Thank you!