Targeting and Managing Conservation Practices to Critical Areas

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Images from Lake Champlain Basin Program

Background: Study Area

Study Area:

- Missisquoi Bay Basin (MBB)
- Along international boarder of US (Vermont) and Canada (Quebec).
- 2,539 km^2
- 67% forest
- 17% agriculture
- 12% undeveloped
- 4% developed

Critical Source Area (CSA) Identification Area:

- All areas in VT that contribute to the Missisquoi Bay Basin (US focused)
- Greater resources focused on input data development and model output resolution and analysis

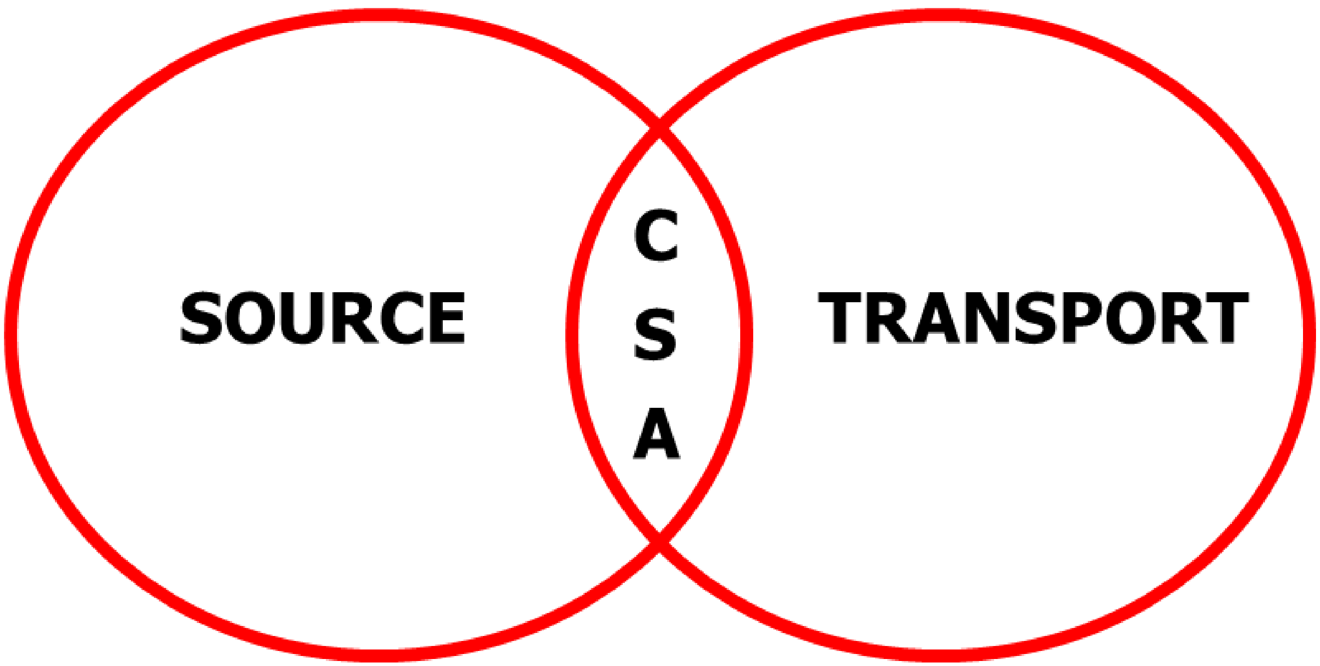
Background: Critical Source Areas

Critical Source Area (CSA) = Phosphorus (P) source + transport

P source = P stocks (e.g., soils) + current management

Transport = runoff, erosion, proximity to water

In the Northeast United States, runoff response is dominated by saturation excess from variable source areas. (Dunne and Black, 1970).



Background: Variable Source Areas, Compound Topographic Index

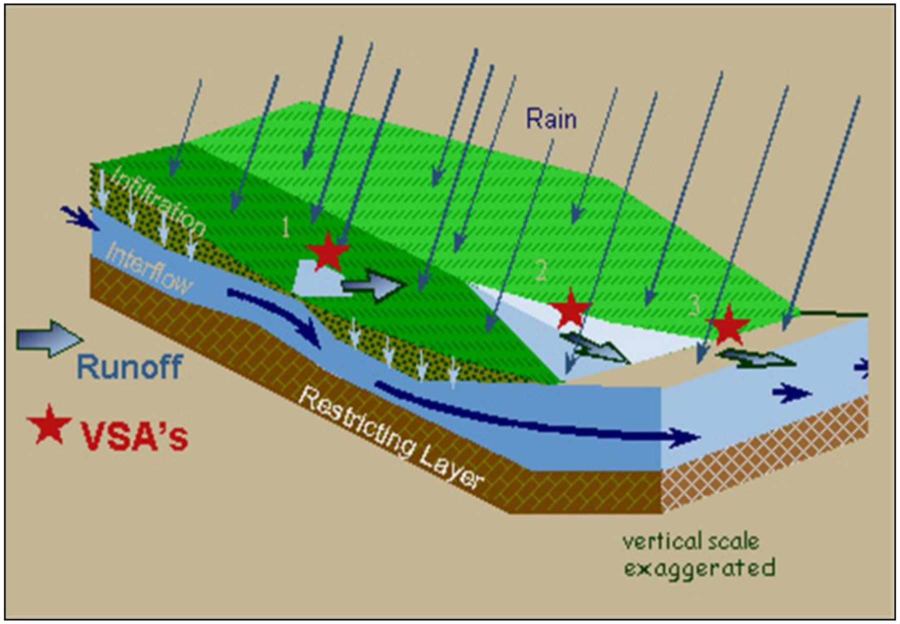
The compound topographic index has long been used to model variable source area hydrology. (Beven and Kirkby, 1979)

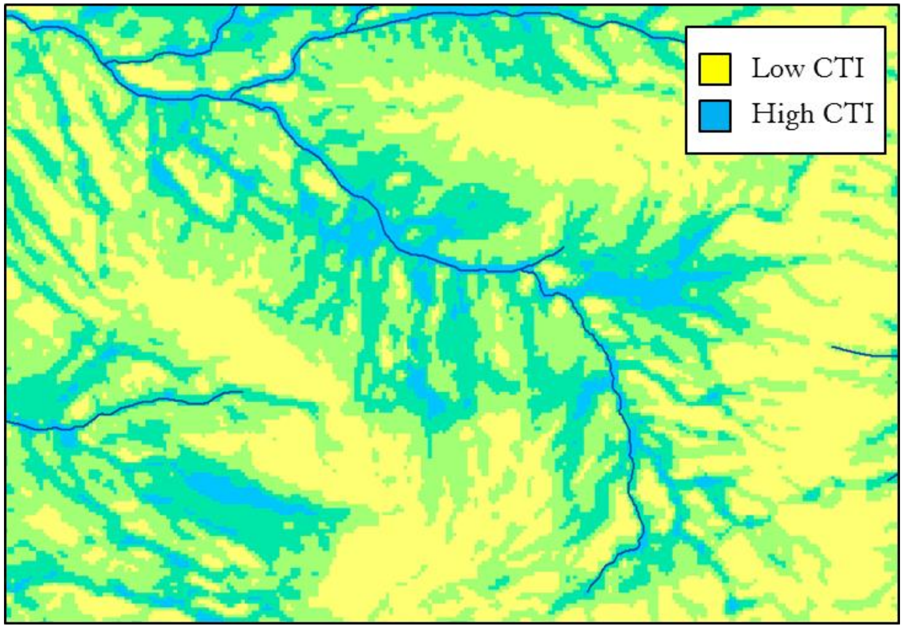
CTI = ln(a/ tan(b))

- a = upslope contributing area
- tan(b) = slope

High CTI indicates high potential for saturation excess runoff.

Low slope, high upslope area = high saturation potential.

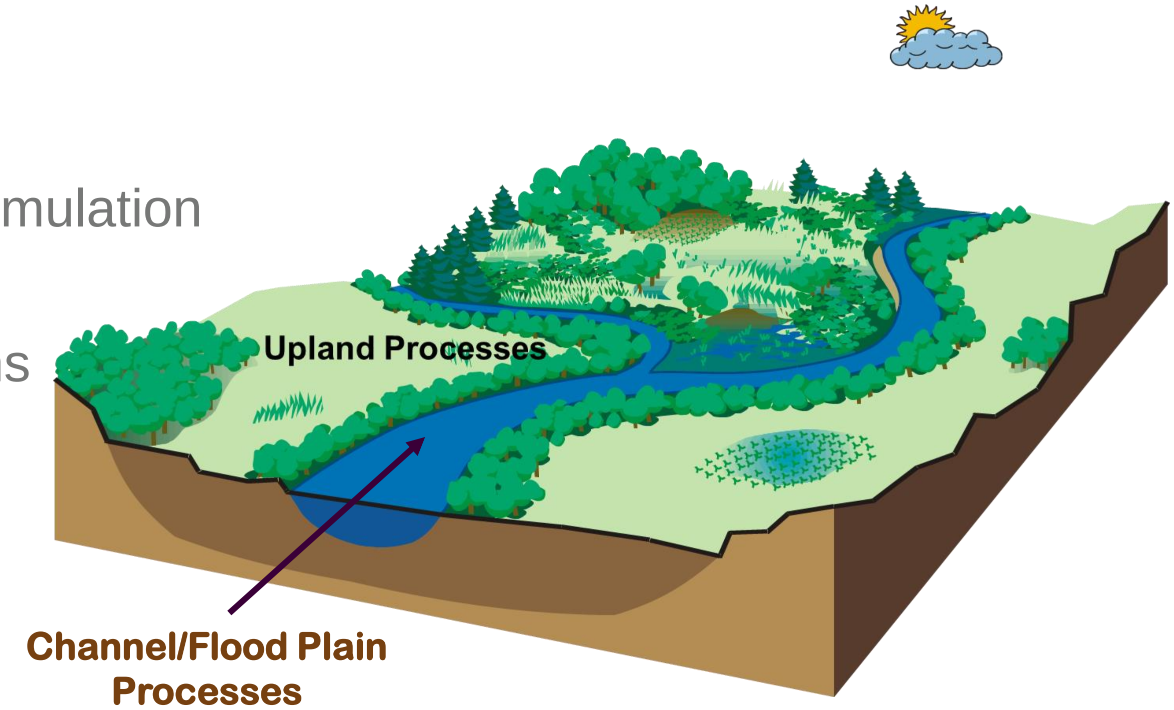




Background: Soil and Water Assessment Tool (SWAT)

SWAT Model Basics:

- Watershed scale
- Daily time-step, continuous simulation
- Physically based
- Simulates process interactions and agronomic management practices
- Models land surface and in-stream processes



Model Development and Usage:

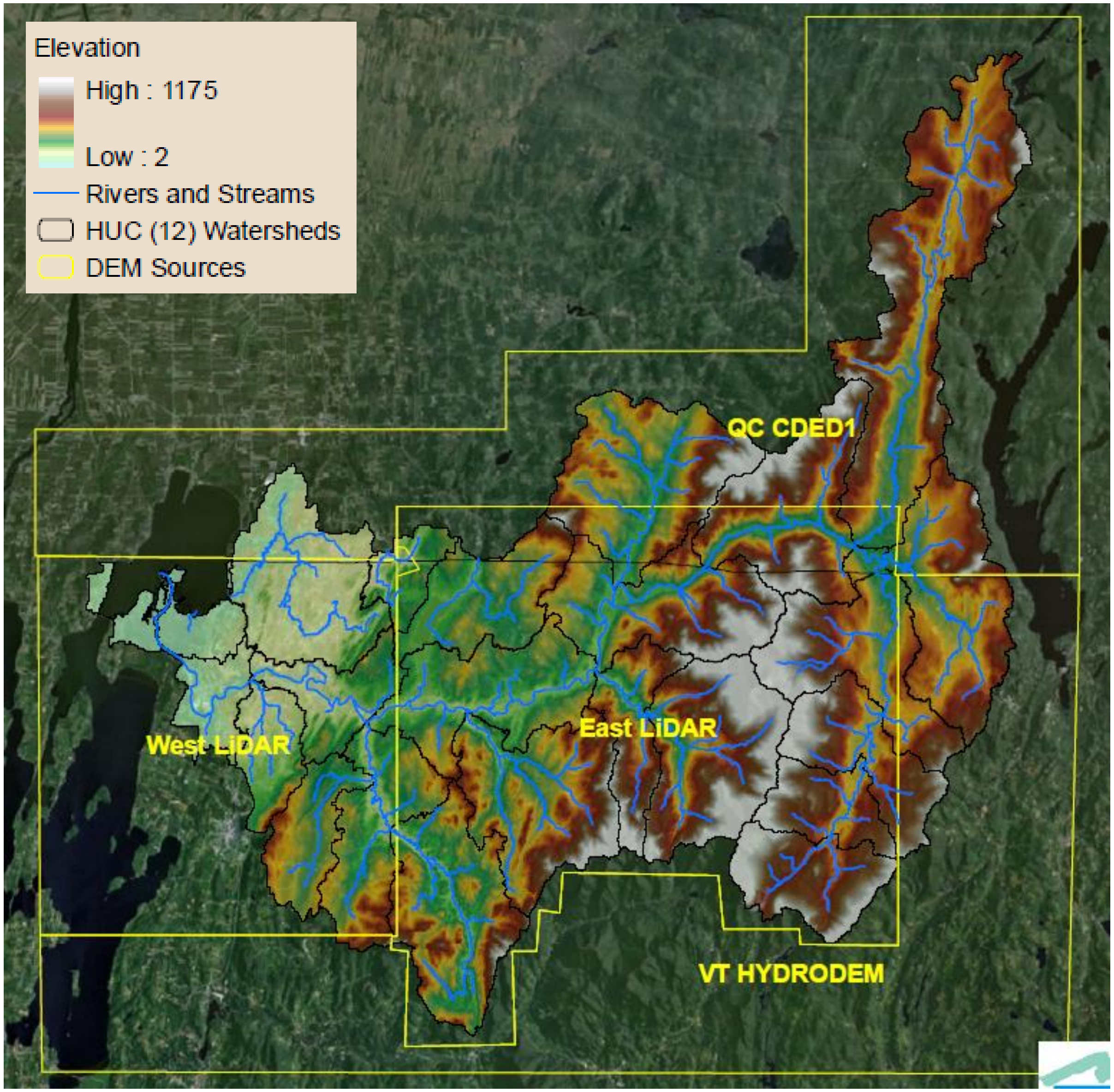
- Developed by USDA, Agricultural Research Service and Blackland Research and Extension Center in Temple Texas.
- Used internationally (annual conferences in Europe, Asia, North America).
- As of 2016, more than 2,828 peer reviewed publications on SWAT applications.

Model Development: Topographic Data

High-resolution (1.6 m) LiDAR data was available for much of the study area.

Other topographic data sources with lower resolution (10 m to 20 m) were available for remainder of the study area.

All sources were merged to create a 10-m Digital Elevation Model (DEM) covering the study area.



Model Development: CTI Distribution

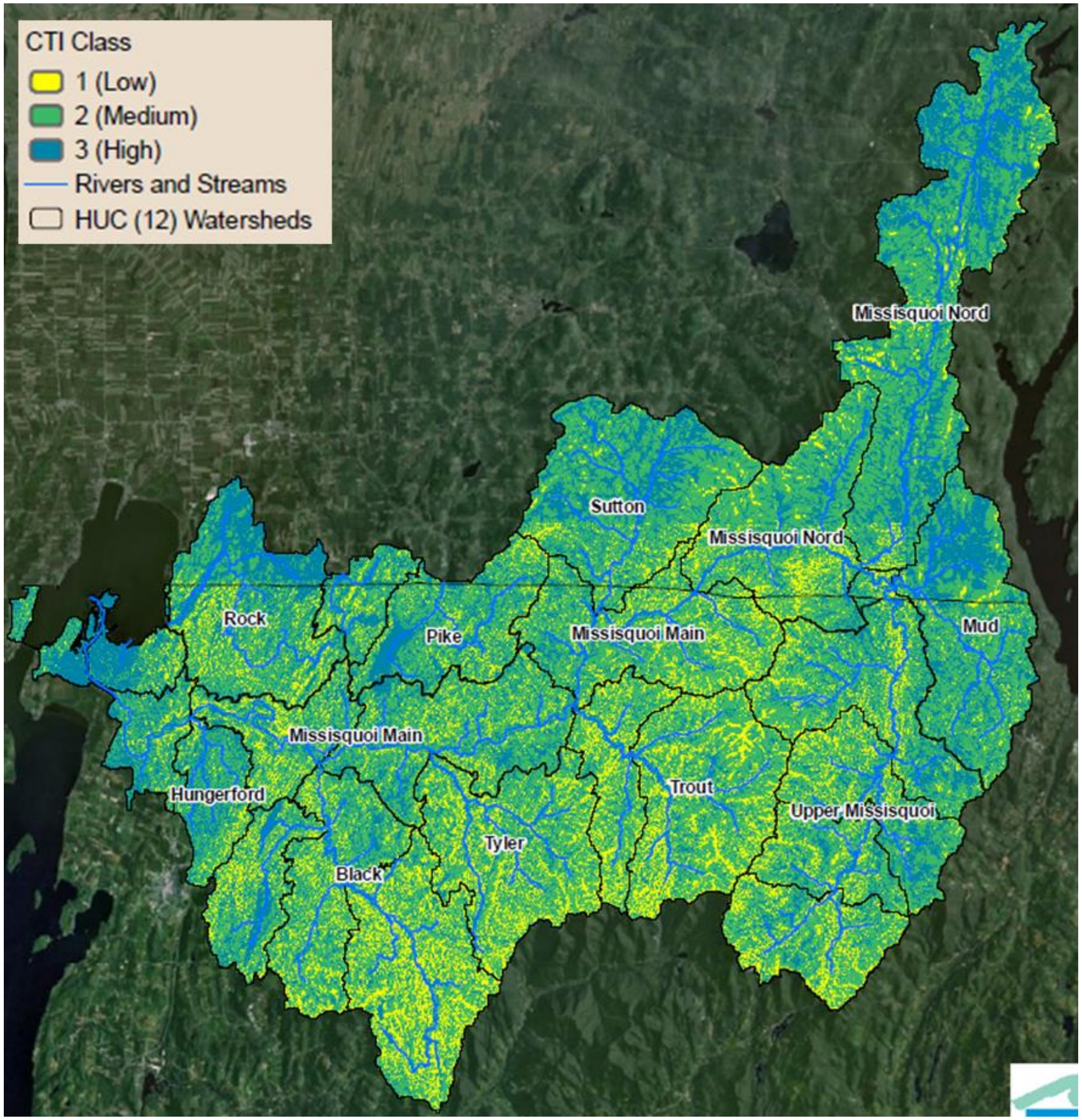
A Compound Topographic Index dataset (CTI) was developed for the study area.

CTI divided into 3 classes

- Class 1 (Lower 20%): lower runoff potential
- Class 2 (Middle 60%): moderate runoff potential
- Class 3 (Top 20%): higher runoff potential

Lower CTI values occur in steeper, upslope areas

Higher CTI values occur in flatter, downslope areas



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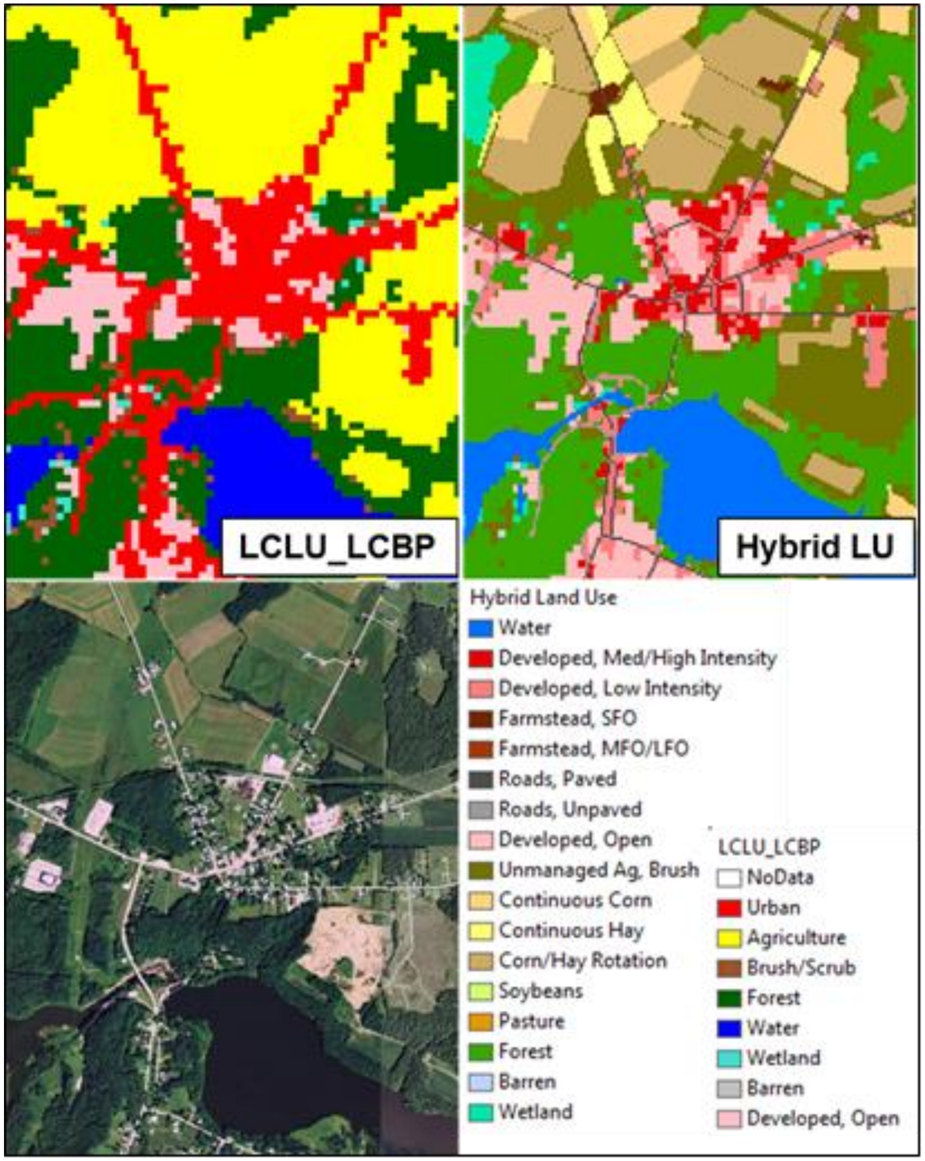
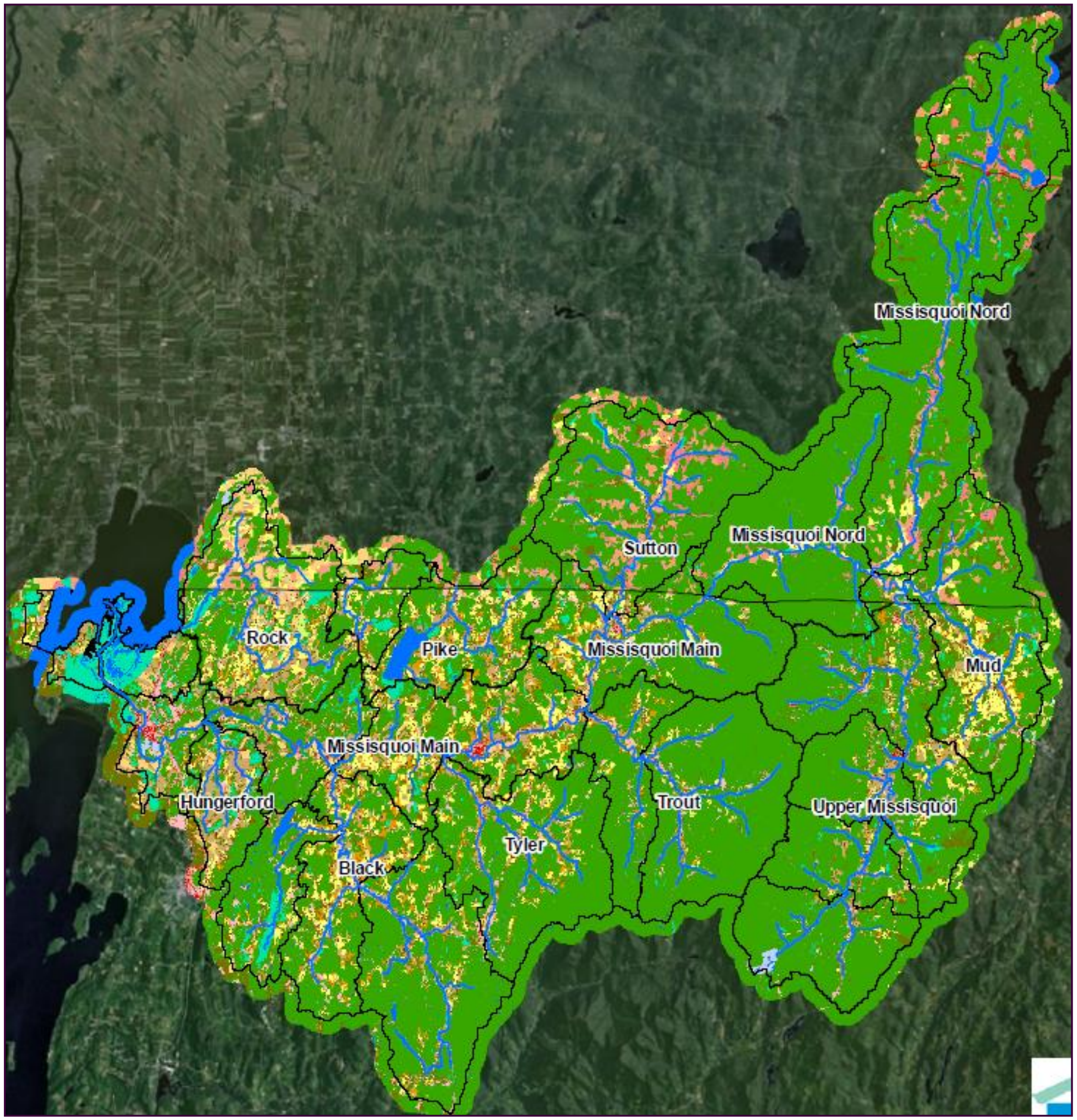
Model Development: Land Use

A 10-m resolution land use raster was created from multiple sources, including field level crop data and barnyards.





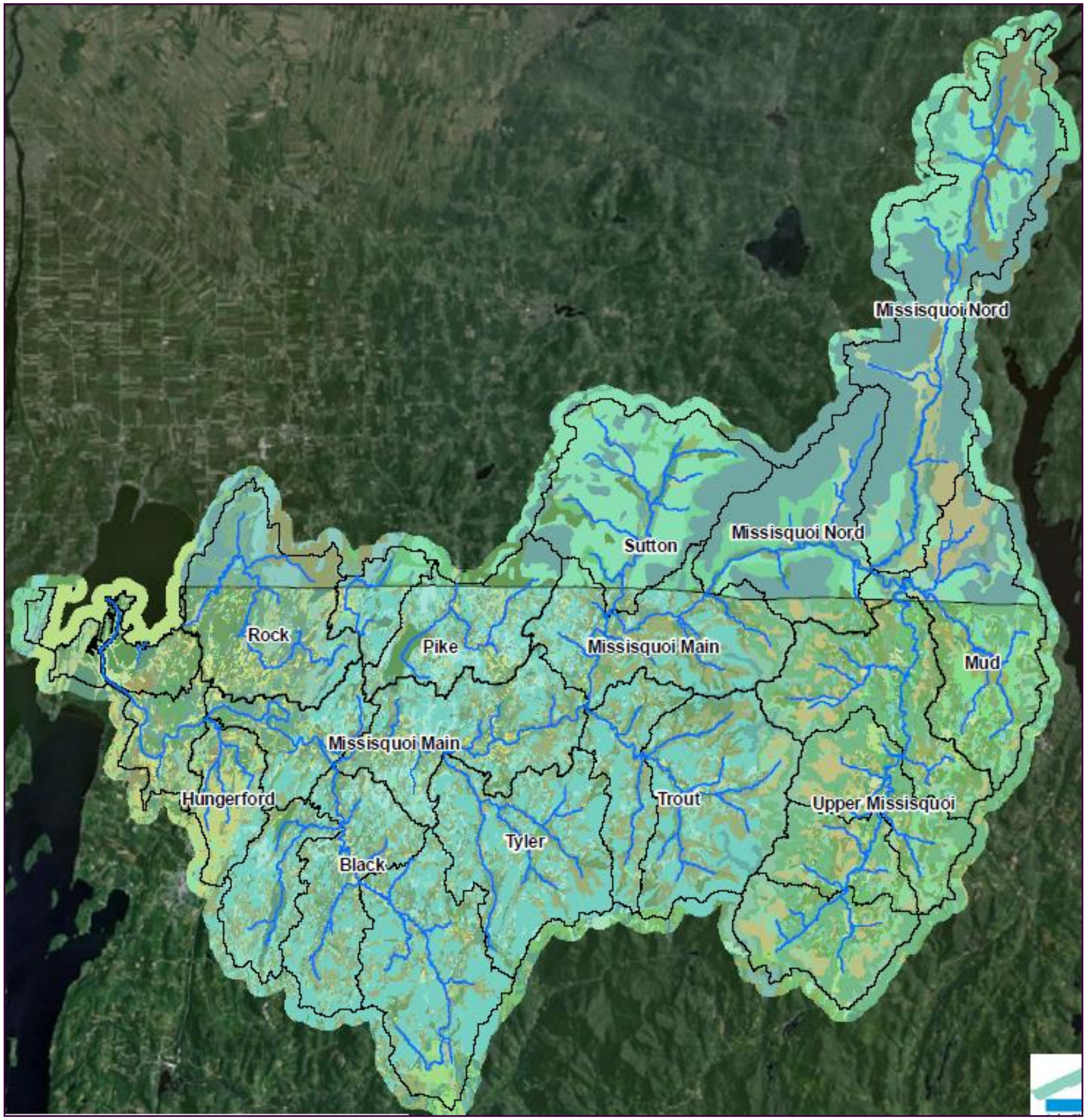
Model Development: Soil Data

VT Side:

- NRCS SSURGO dataset (1:24,000 scale)
- 303 soil map units aggregated to 112 unique soils

Quebec Side:

- Based on 1:63,000 scale dataset
- 26 unique soils



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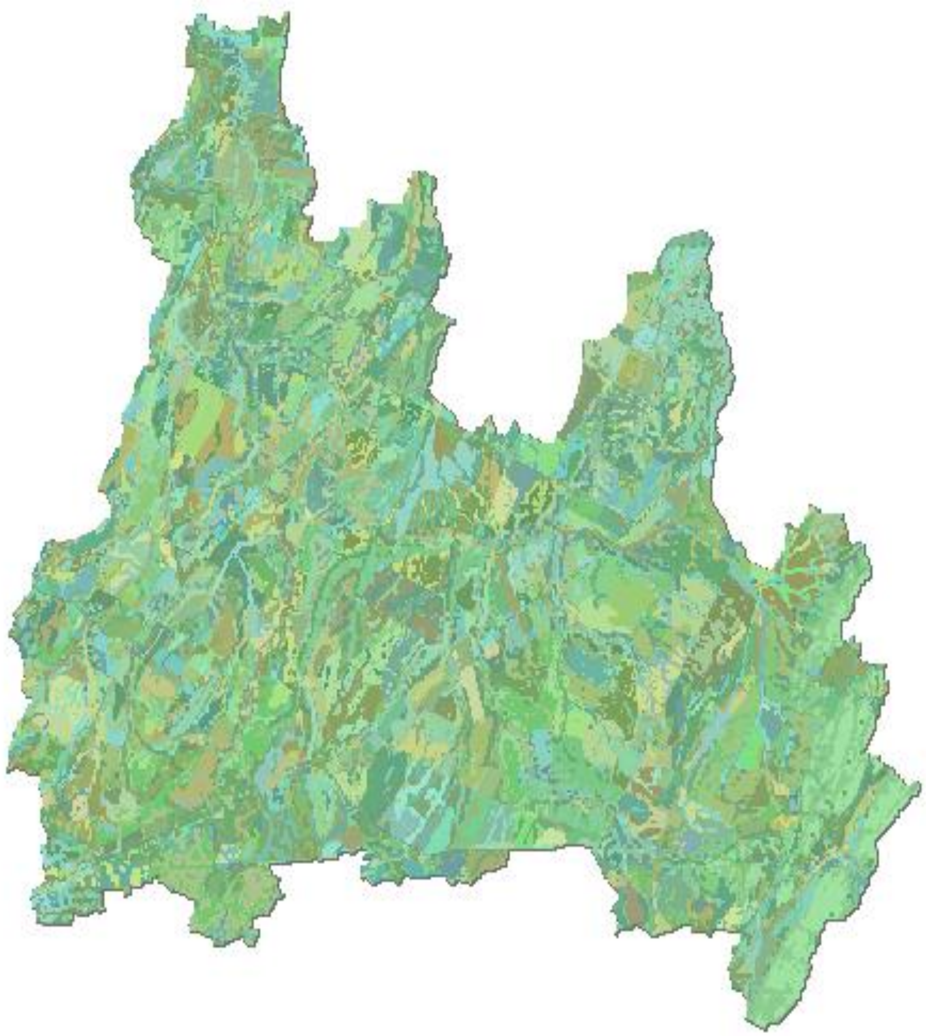
Model Development: Hydrologic Response Unit (HRU) Delineation

HRUs are the smallest landscape units in a SWAT model.

HRUs were delineated based on the following characteristics:

- Subbasins (223)
- Land use class
- Soils class
- CTI class
- Field boundary ID (CLU)

In total, the model consisted of 109,811 HRUs.



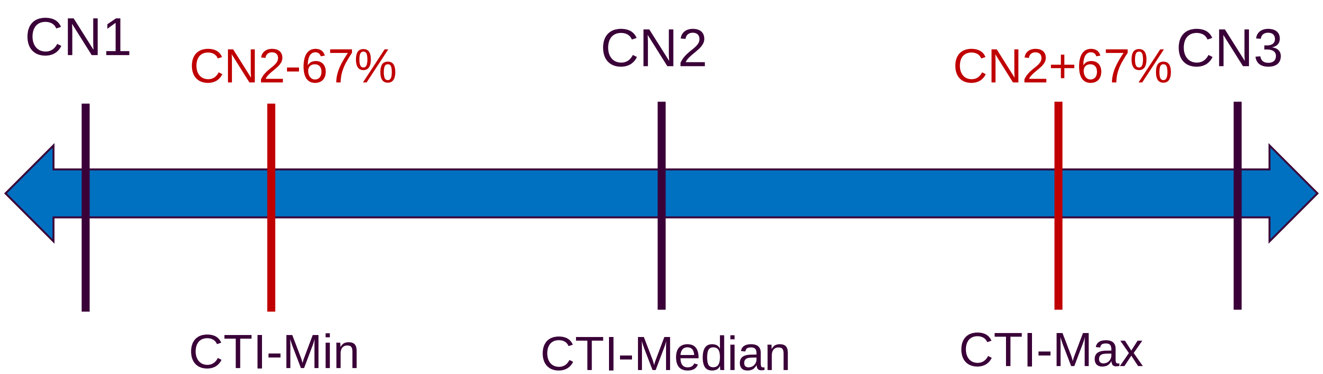
Model Development:
CTI Use in Identifying Runoff Potential

SWAT uses SCS runoff curve numbers in surface runoff calculations.

The SCS curve number is traditionally a function of land cover, and soil hydrologic group.

Areas with higher CTI values are prone to greater saturation excess runoff.

For each land use and hydrologic group, the standard CN2 values were adjusted to reflect the saturation excess runoff potential based on the cumulative distribution percentile of the HRUs local CTI.

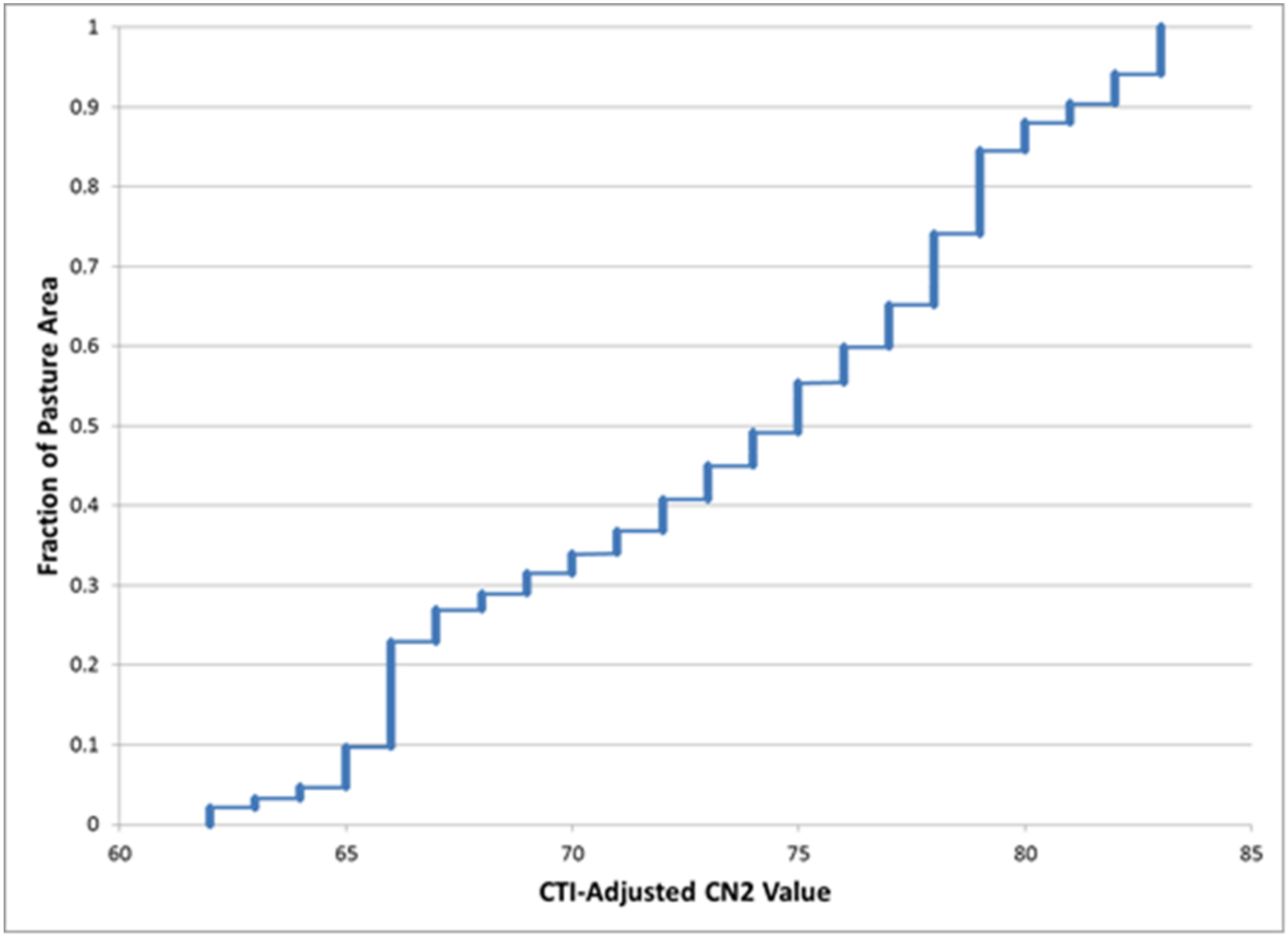


Model Development: CTI-Based Curve Number Definition

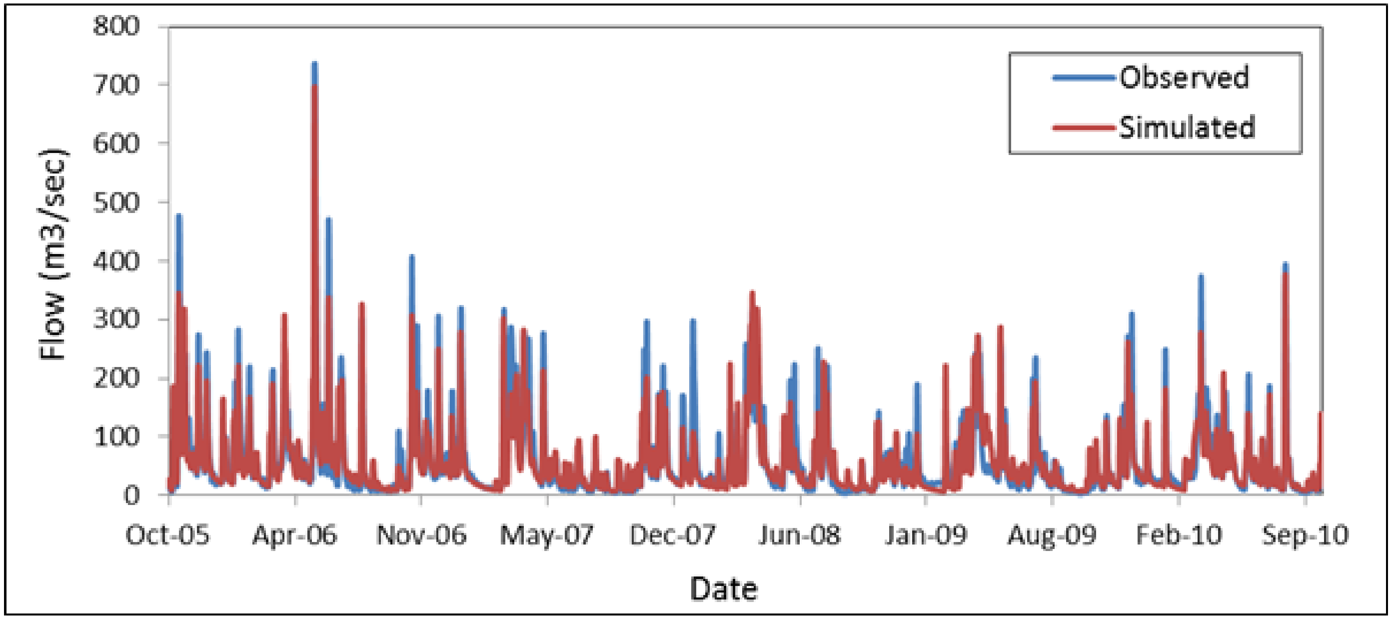
The CTI percentile for an HRU was based on all land uses and soils in the watershed.

This resulting distribution of CN2 values for a given land use / soil hydrologic group combination varied between:

CN2 – (0.67 * (CN2-CN1))
CN2 + (0.67 * (CN3-CN2))

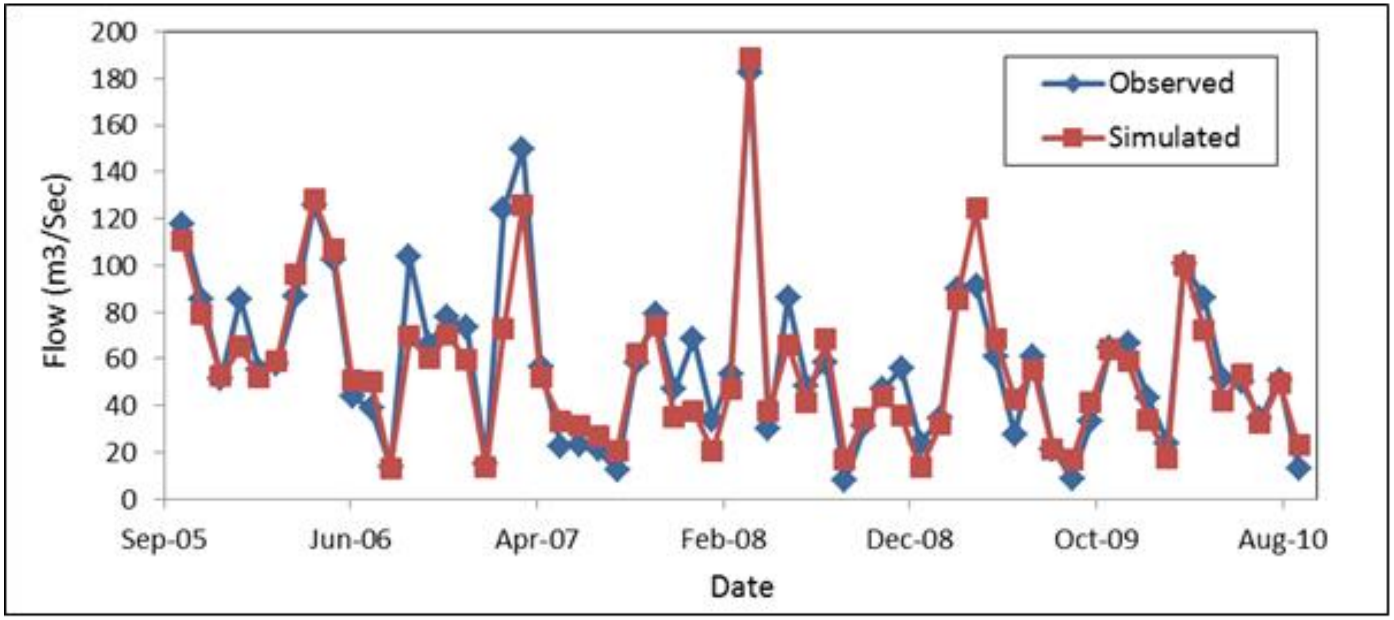


Model Calibration: Hydrology Calibration Results



Missisquoi at Swanton Daily, Calibration

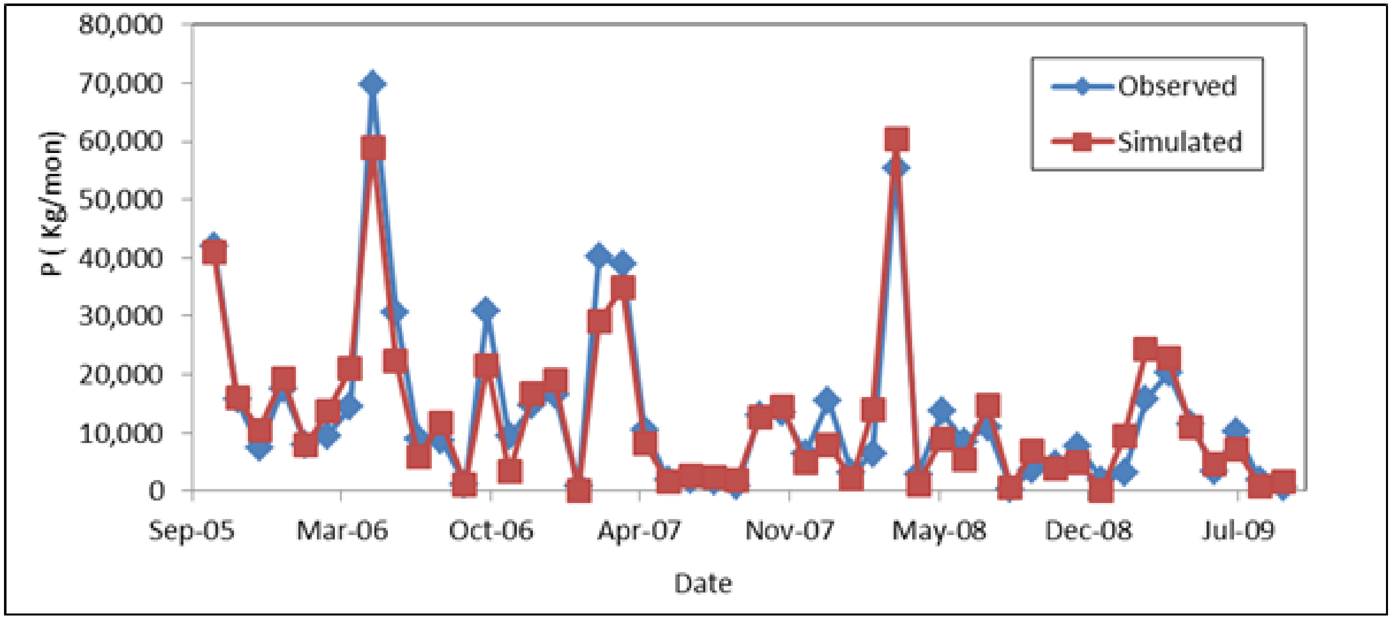
NSE = 0.77
PBIAS = 5.1%



Missisquoi at Swanton Monthly, Calibration

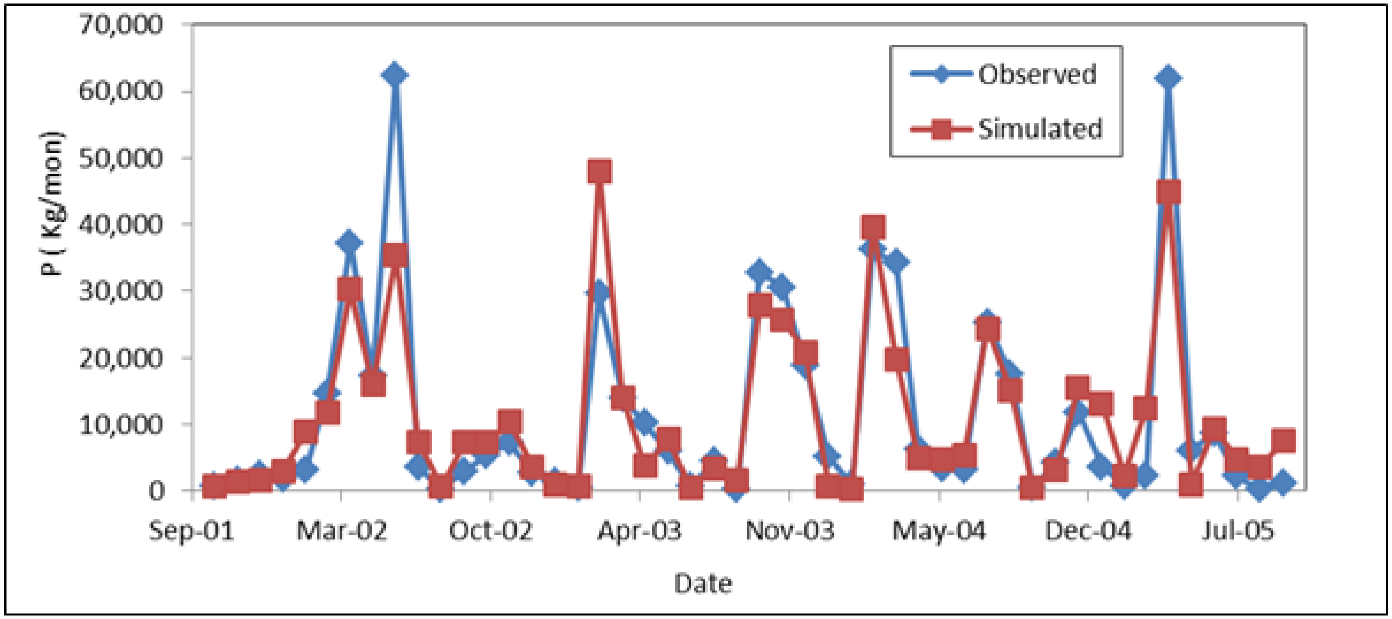
NSE = 0.86

Model Calibration: Phosphorus Calibration Results



Missisquoi at Swanton Monthly, Calibration

NSE = 0.91
PBIAS = 3.2%



Rock River at St. Armand Monthly, Calibration

NSE = 0.70
PBIAS = 1.4%

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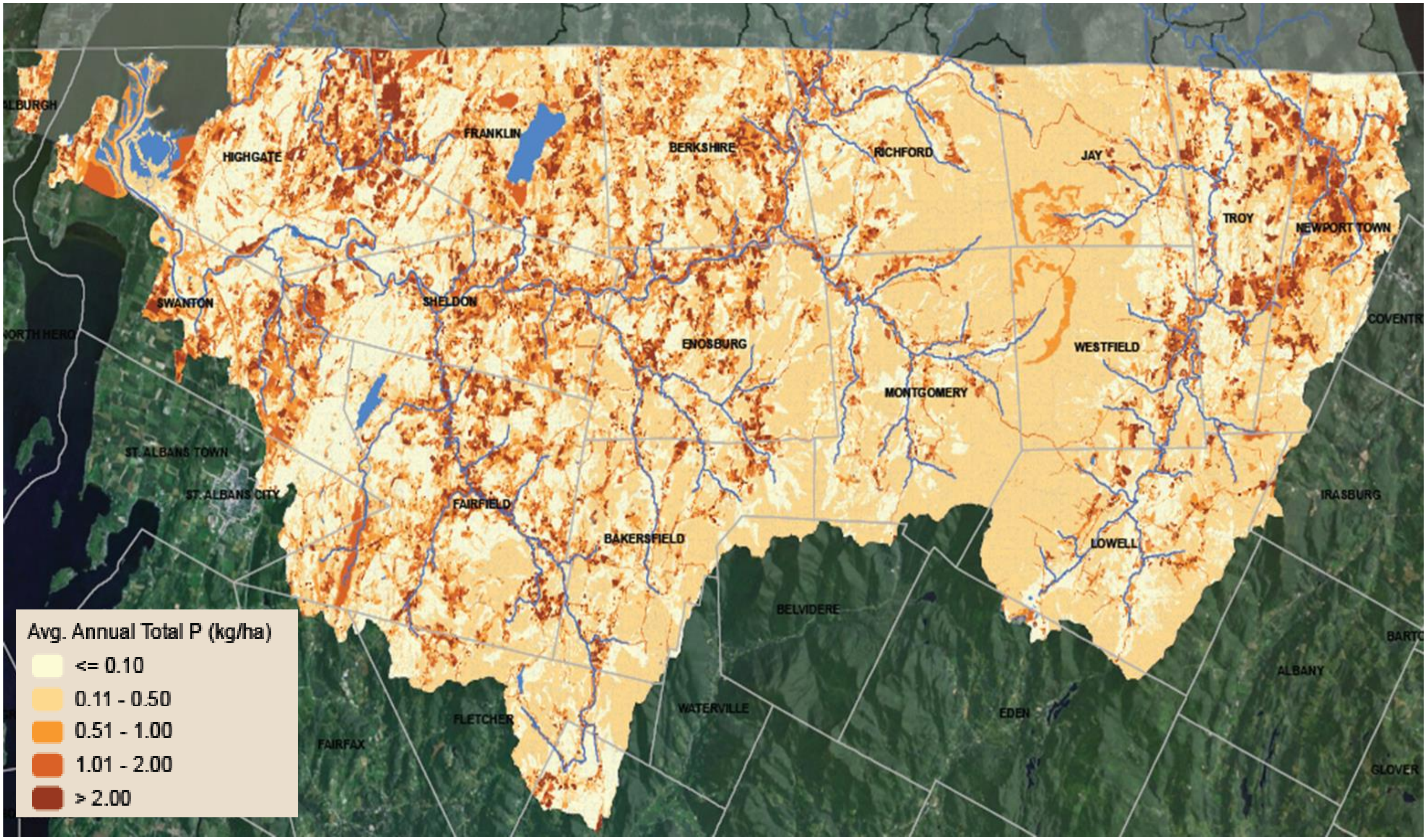
Model Application: HRU Level Results

Average annual P loading rates were calculated for the 103,666 Vermont sector HRUs.

Results reflect HRU physical and management characteristics.



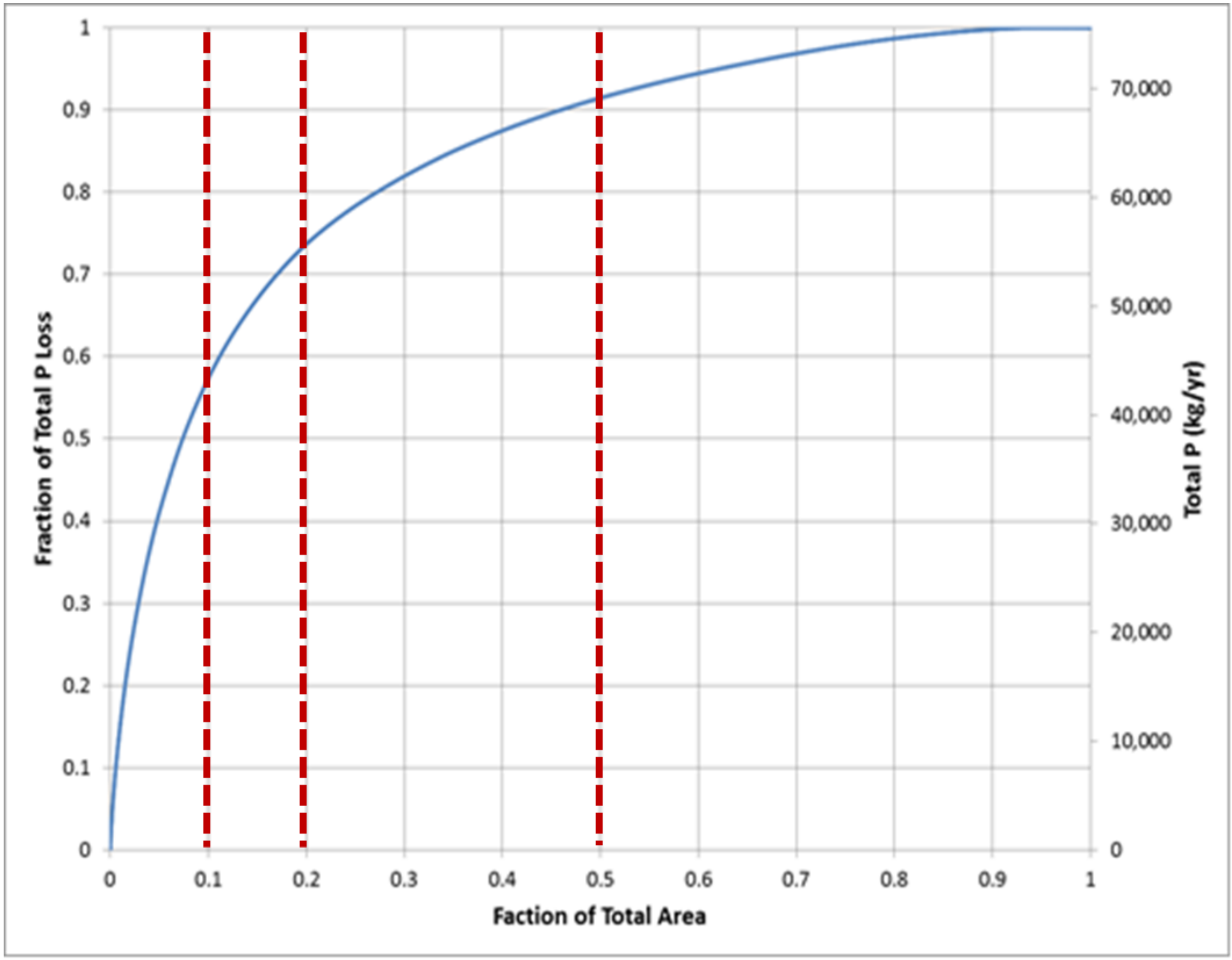
Model Application: Cumulative Area Distribution of Total Upland P Generated

SWAT was run for 30 years.

57% of the total upland P is generated from 10% of the area.

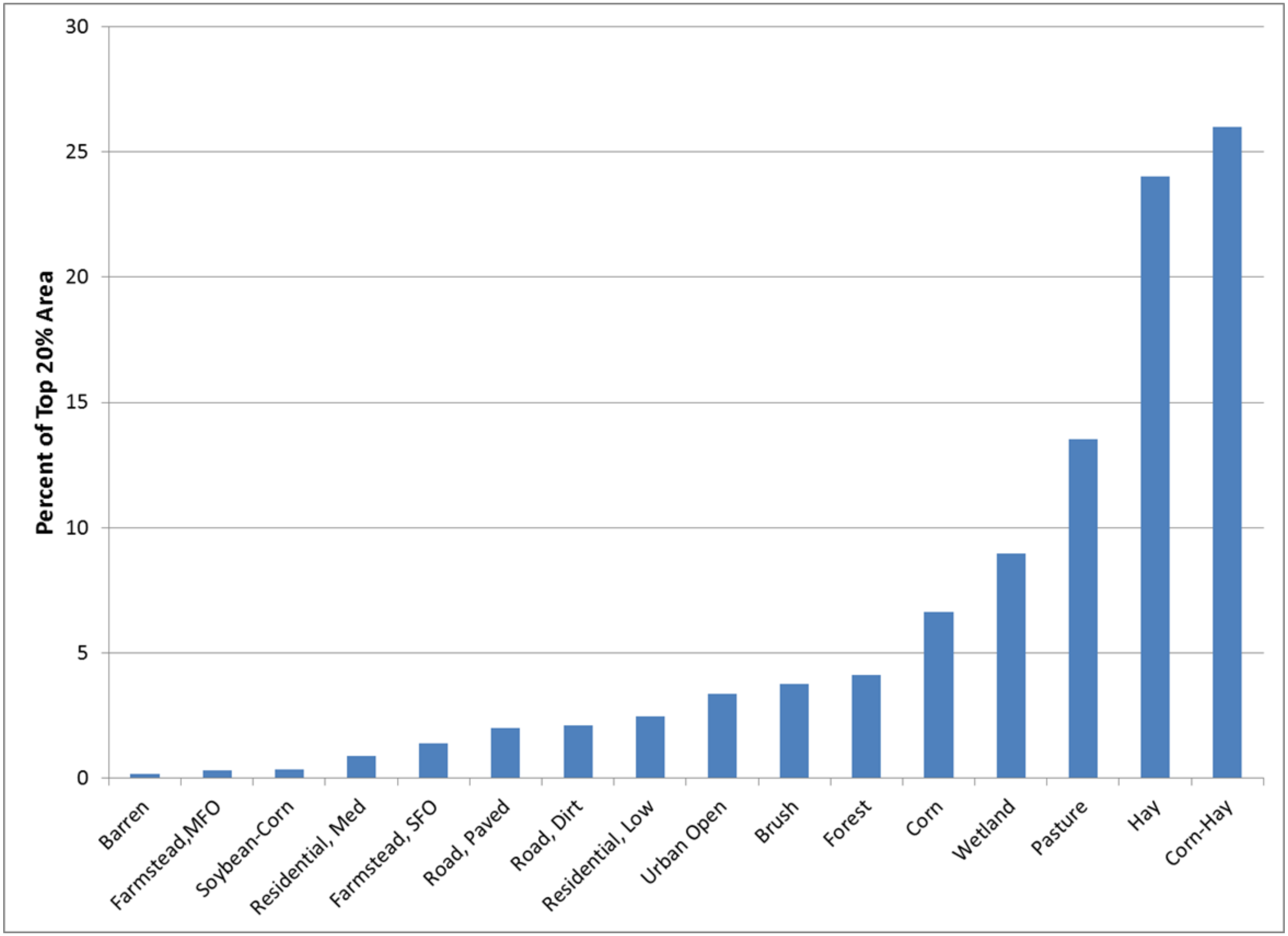
74% of the total upland P is generated from 20% of the total area.

92% of the total upland P is generated from 50% of the total area.



Model Application: Phosphorus CSAs by Land Use

Agricultural land uses comprise a significant portion of the top 20%.



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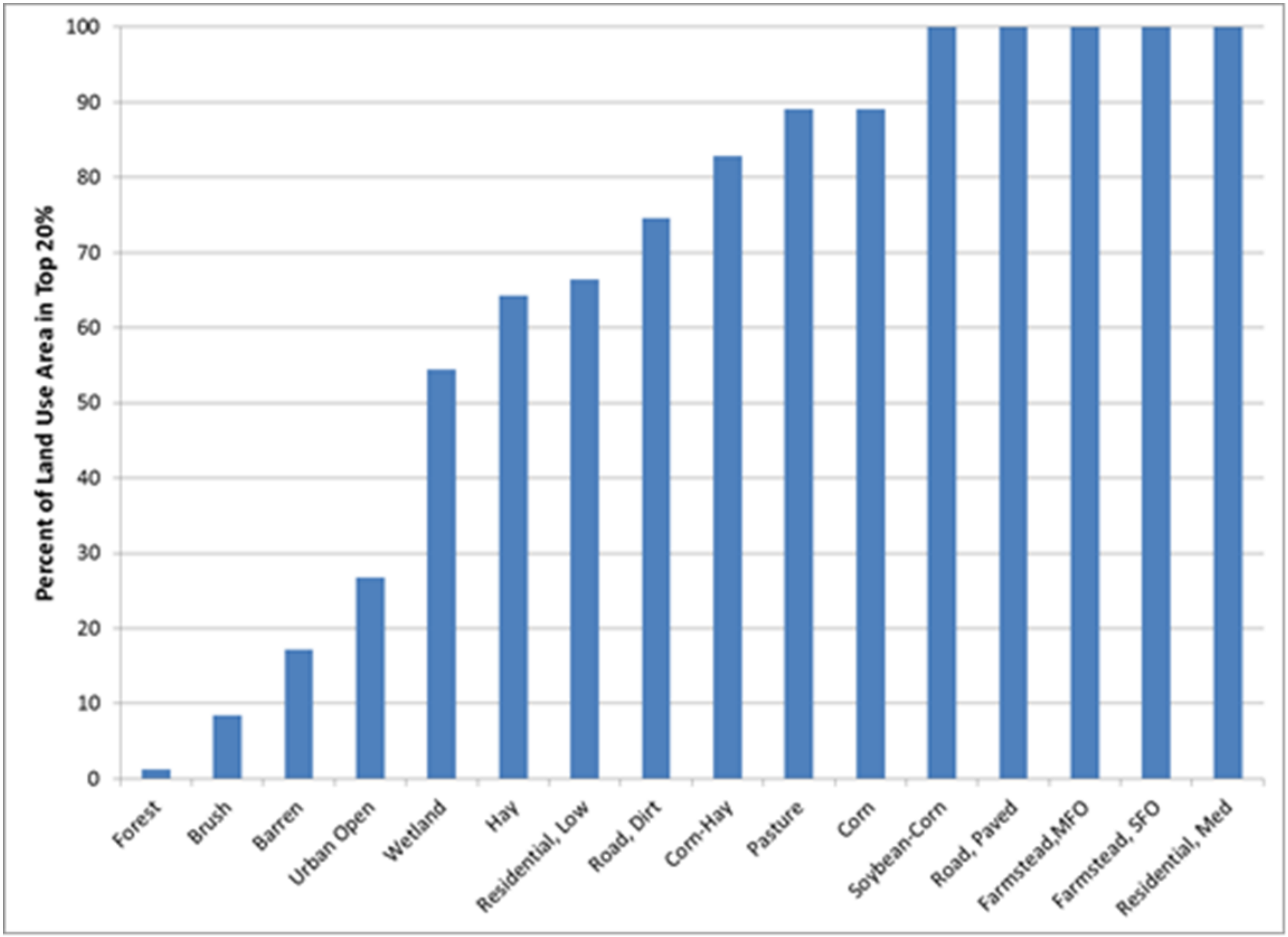
Model Application: Phosphorus CSAs by Land Use

Several land use classes fall 100% within the top 20% of CSAs.



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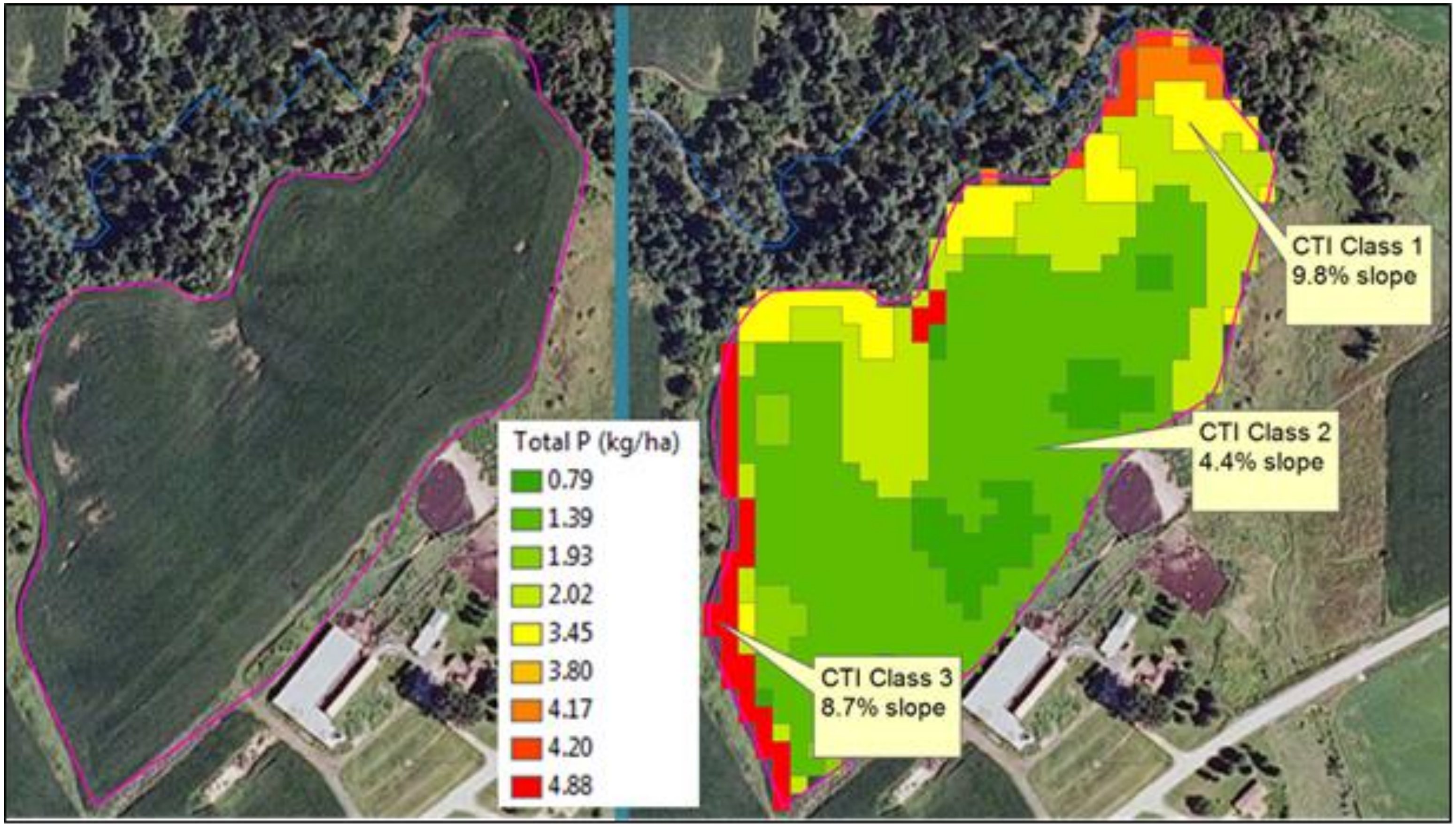
Model Application: CSA HRU Level Results, Sub-Field Level

Model results at the sub-field level may be used to identify critical sections of fields.

Can help to determine specific locations for BMP implementation.



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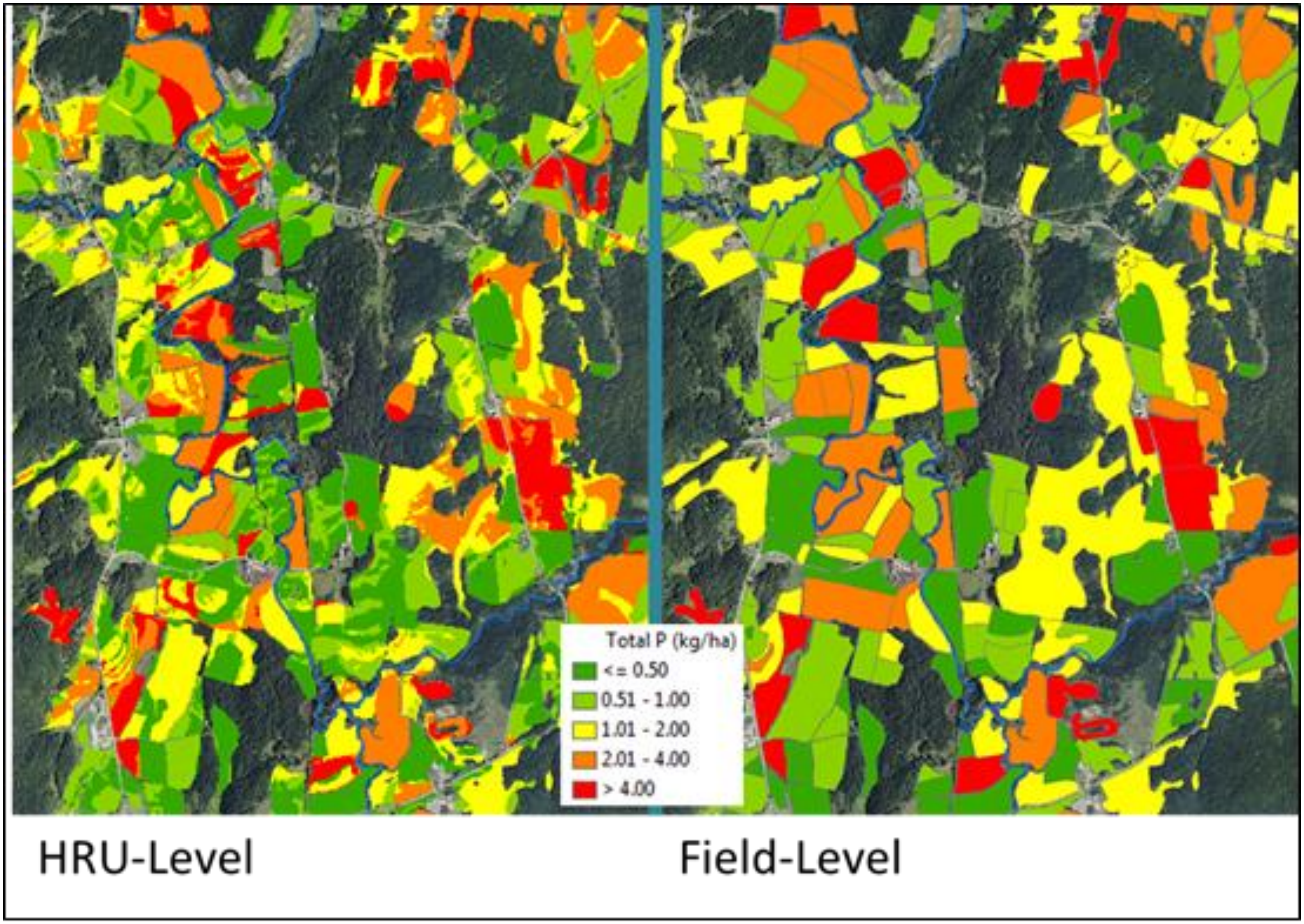
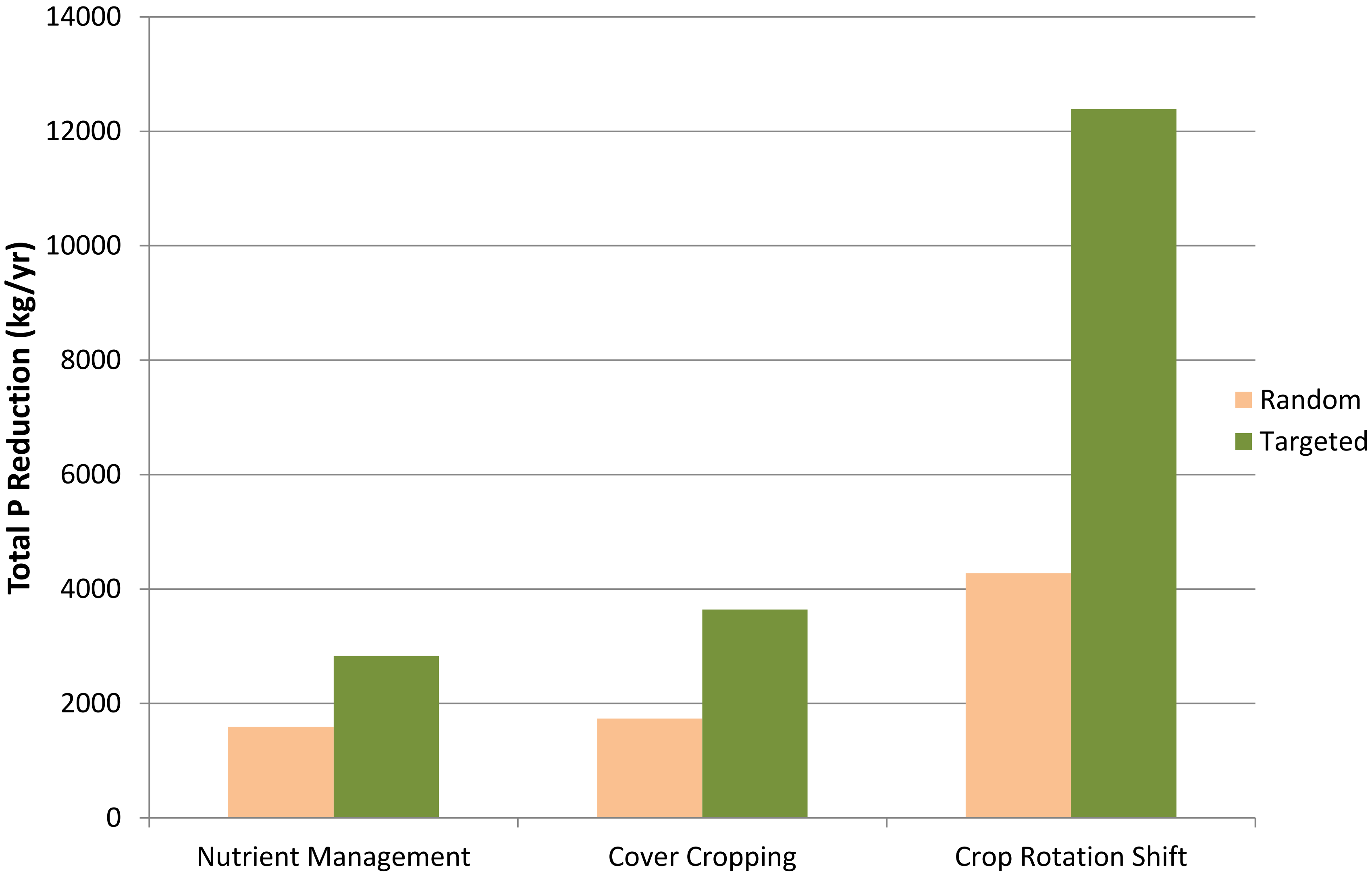
Model Application: CSA Aggregation to Field Level

HRU aggregation to the field level allows ranking and prioritization of BMPs for individual fields.



Model Application: Evaluation of Watershed-Scale BMPs

Targeted BMP implementation to 20% of the crop areas was 1.8 to 2.9 times more effective than random implementation.



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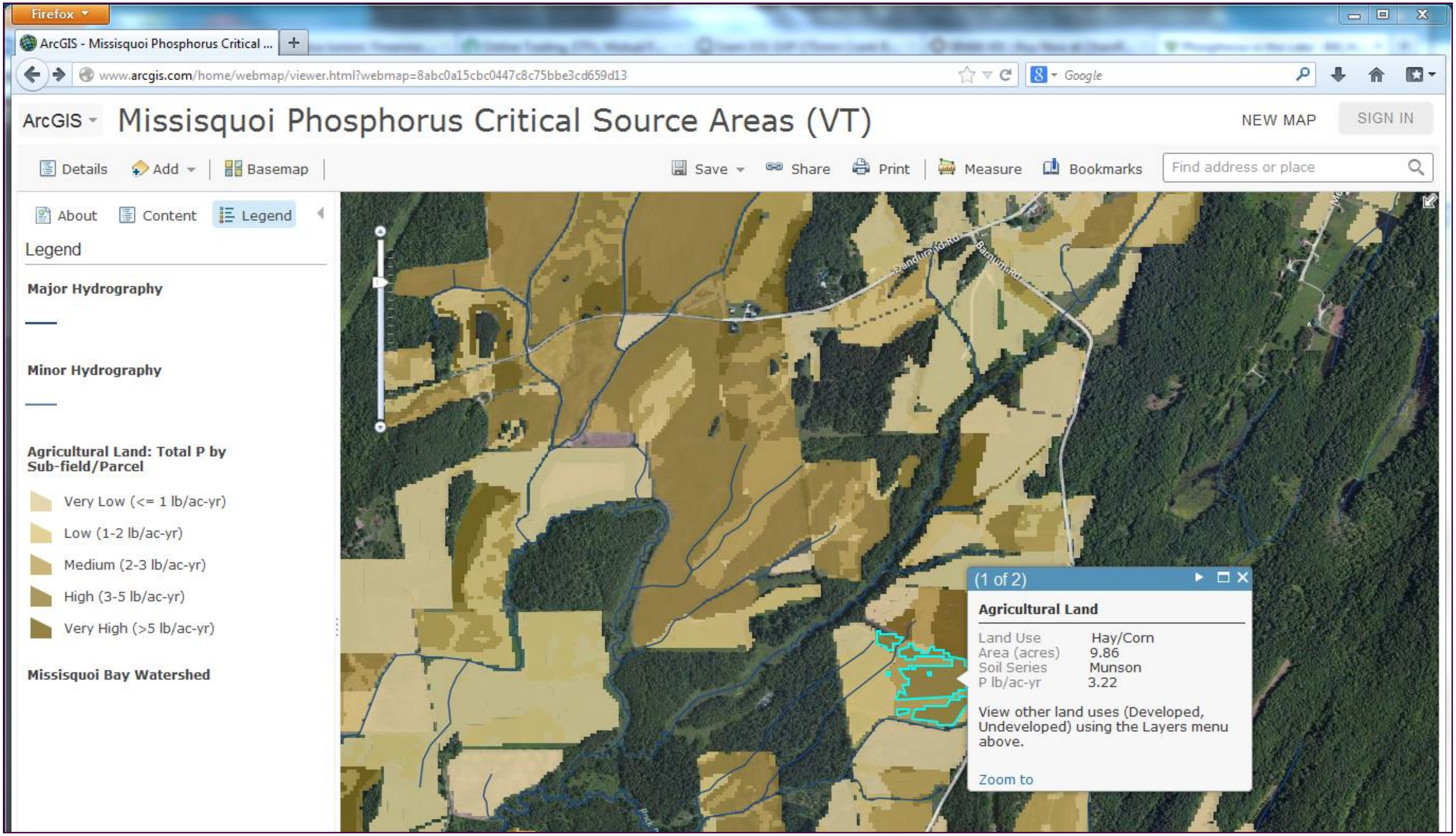
Model Application: Model Analysis via Online Mapping Tool

Model inputs and results publically available via an ArcGIS Online map.



Summary and Conclusions

An SWAT modeling approach considering land use, soils, CTI and field boundaries was applied to enable sub-field level identification of phosphorus critical source areas.

The incorporation of the CTI allowed landscape areas more prone to saturation excess runoff generation to be distinguished and independently parameterized.

A comparison of random versus targeted conservation practice implementation designed to reduce P loads demonstrated the advantages of the targeted approach.

The modeling approach has allowed conservation planners to allocate finite mitigation funds to fields which will have the greatest benefit on the water quality of Lake Champlain.

References

Beven, K.J. and Kirkby, M.J., 1976. Towards a simple physically-based variable contributing model of catchment hydrology. School Geogr., Univ. of Leeds, Leeds, Work. Pap. No. 154.

Dunne, T., and Black, R. D. 1970. "Partial area contributions to storm runoff in a small New England watershed." Water Resour. Res. 6:1296–1311.