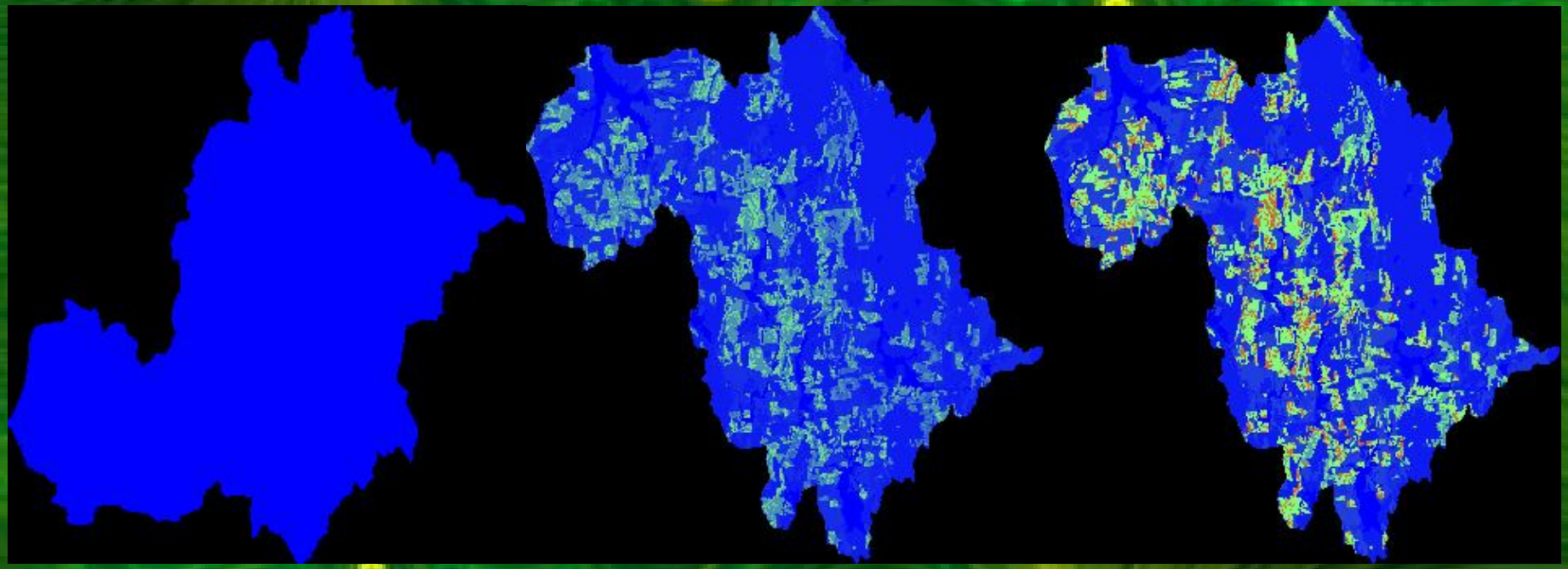
Tracking Watershed P-Loss Hotspots through Time and Space:

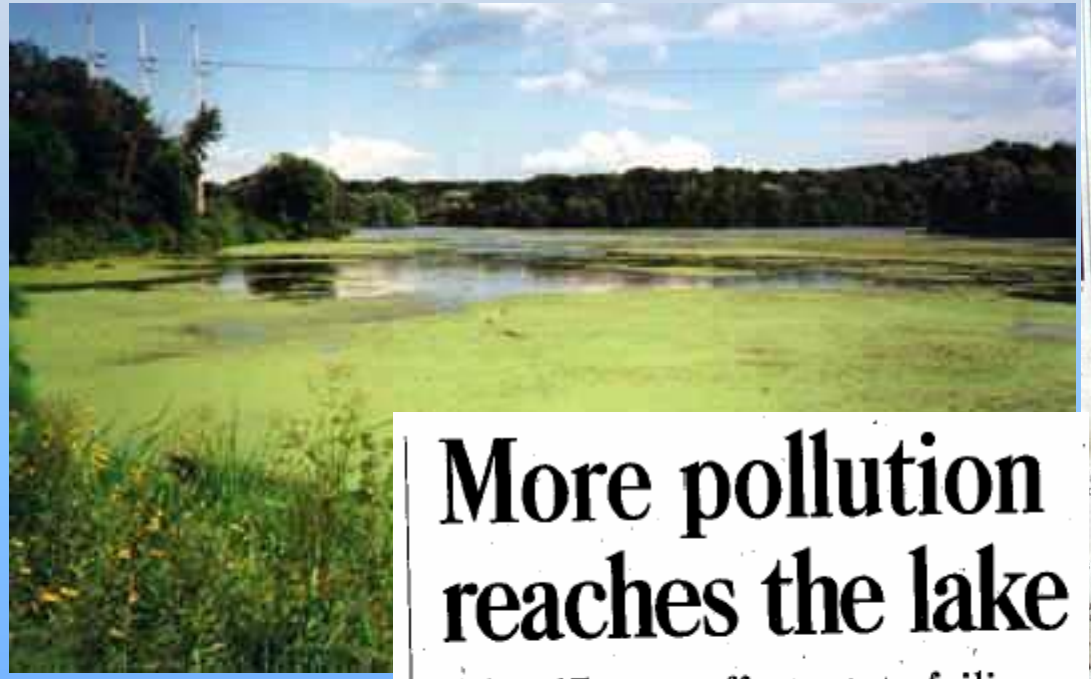
An Approach to Targeting Nonpoint Source Management Practices

D.W. Meals, D. Hughell, L. Wood

E.A. Cassell, W. E. Jokela, R. Parsons



Nation's lakes and reservoirs impaired by excessive P loads from nonpoint source pollution



More pollution reaches the lake

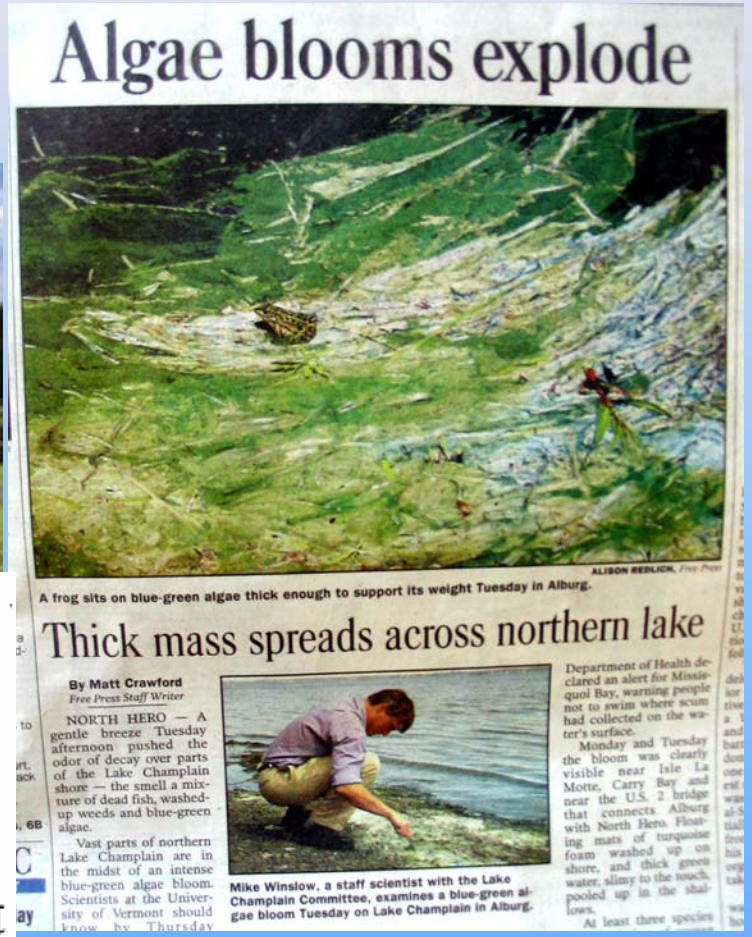
After 15-year effort, state failing to reach the phosphorus goal it set

By Candace Page
Free Press Staff Writer

Despite years of cleanup efforts, nearly 50 percent more phosphorus — Lake Champlain's primary pollutant — flowed into the lake in 2003-04 than in 1991,

Coming up

Starting Friday, The Burlington Free Press will examine the environmental threats to Lake Champlain in a six-part series, "Our Lake."



Algae blooms explode

ALISON REDLICK, Free Press

A frog sits on blue-green algae thick enough to support its weight Tuesday in Alburg.

Thick mass spreads across northern lake

By Matt Crawford
Free Press Staff Writer

NORTH HERO — A gentle breeze Tuesday afternoon pushed the odor of decay over parts of the Lake Champlain shore — the smell a mixture of dead fish, washed-up weeds and blue-green algae.

Vast parts of northern Lake Champlain are in the midst of an intense blue-green algae bloom. Scientists at the University of Vermont should know by Thursday

Mike Winslow, a staff scientist with the Lake Champlain Committee, examines a blue-green algae bloom Tuesday on Lake Champlain in Alburg.

Department of Health declared an alert for Missisquoi Bay, warning people not to swim where scum had collected on the water's surface.

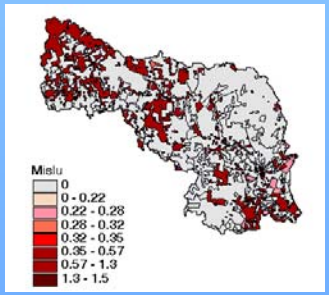
Monday and Tuesday the bloom was clearly visible near Isle La Motte, Carry Bay and near the U.S. 2 bridge that connects Alburg with North Hero. Floating mats of turquoise foam washed up on shore, and thick green water, slimy to the touch, pooled up in the shallows.

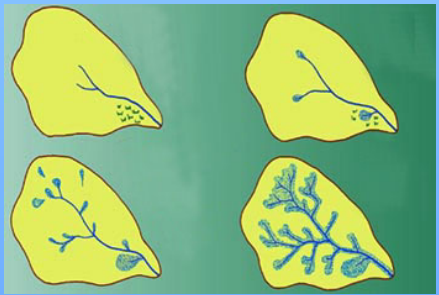
At least three species

MASS BALANCE

Long term imbalance between watershed P imports and exports leads to accumulation of P in watershed soils and strongly affects P available for loss

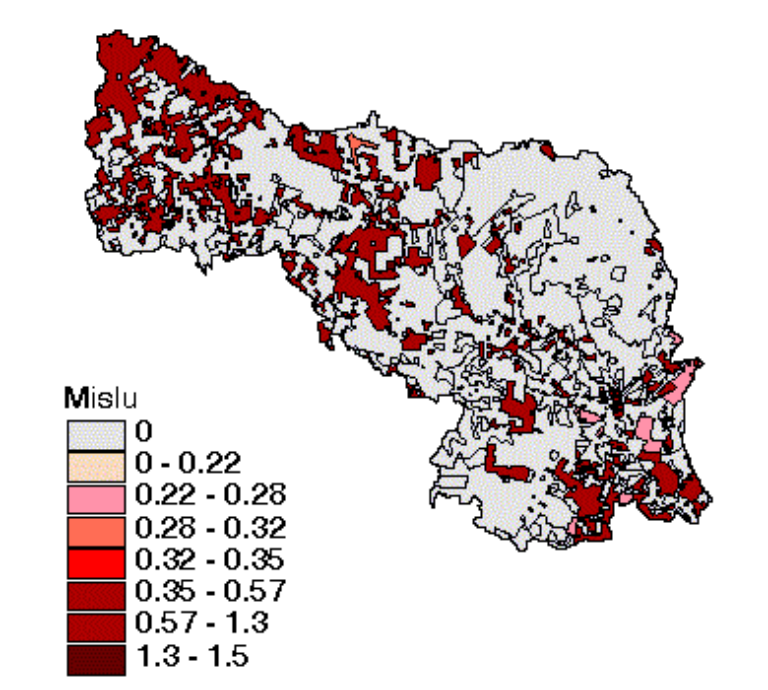
SPATIAL VARIATION





Variability in land characteristics and management causes areas of P accumulation to vary across a watershed;
Not all areas of a watershed contribute runoff all the time

- Watershed P export largely controlled by coincidence of high-P source areas and RCAs



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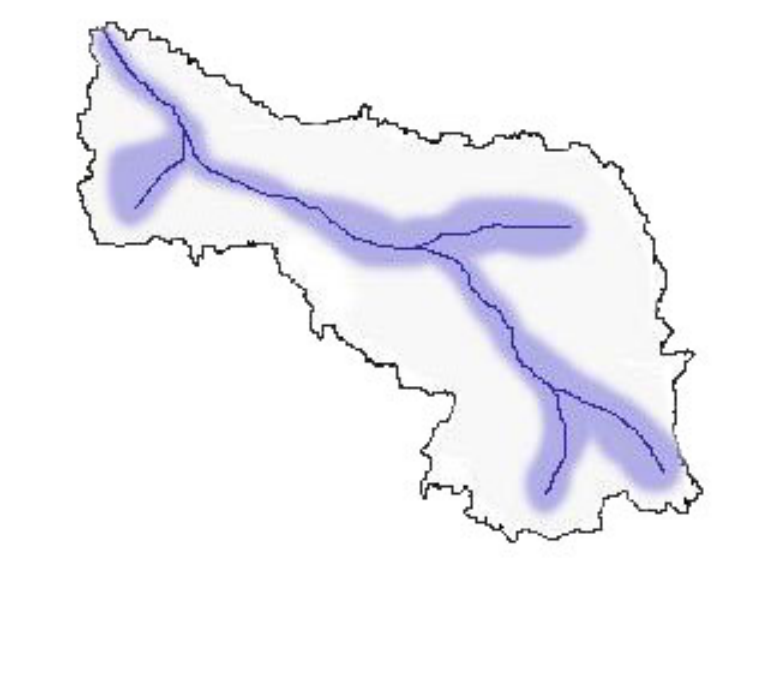
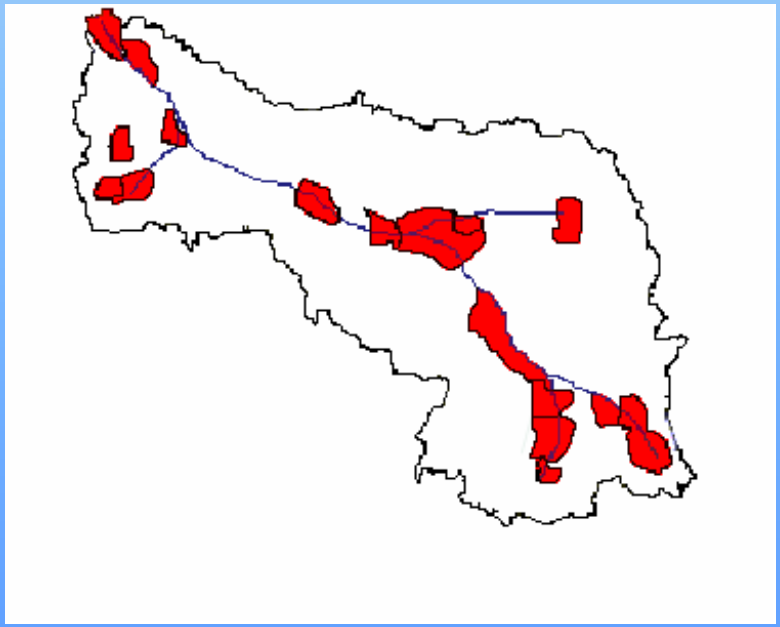
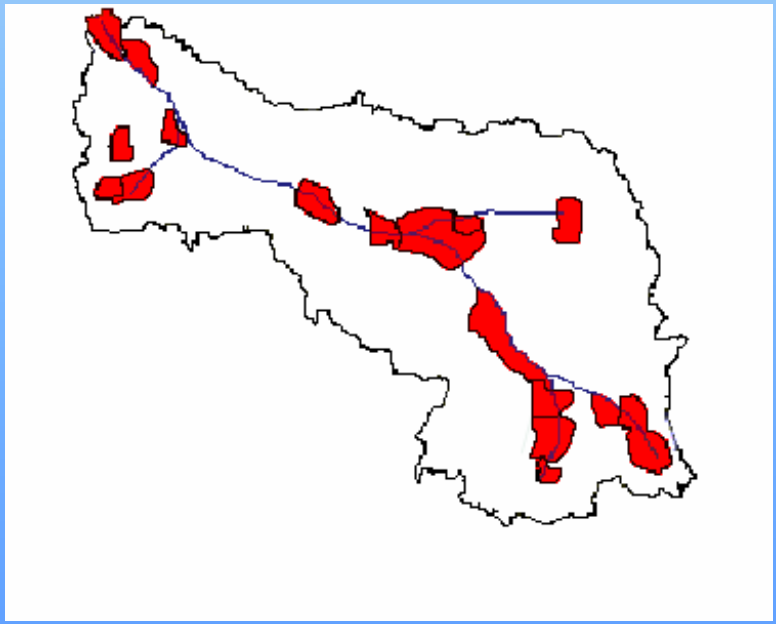


- Because of spatial and temporal variation in land characteristics, RCAs, and management - areas of concern for watershed P export vary in space and time



We lack tools that can effectively deal with both spatial and temporal aspects of this issue



Hypothesis:

Watershed management to reduce P export more cost-effective if:

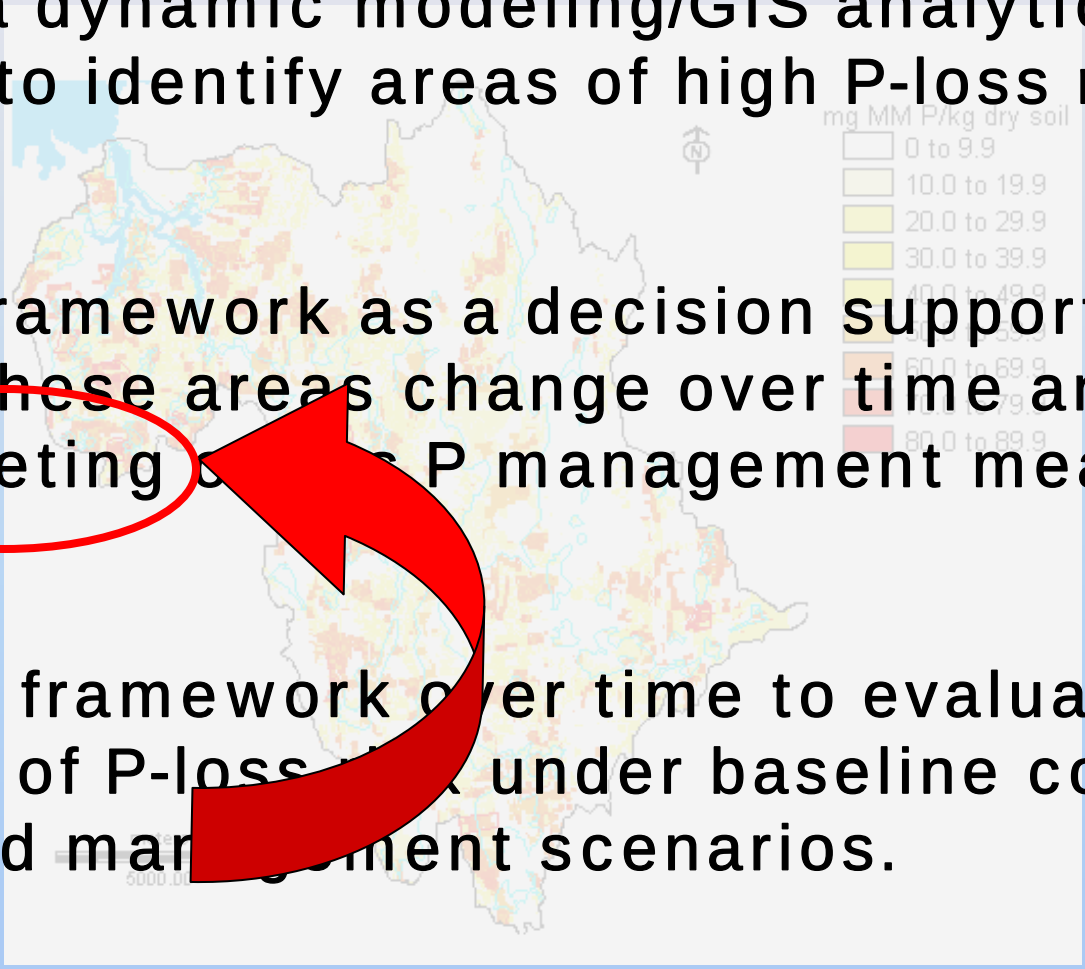
- Critical areas of high P loss risk (a.k.a. “hot-spots ”) could be identified in space and time;
- Treatments could be better targeted to highest risk P source areas; and
- Managers could better understand and visualize how these hot-spots can change over time.

Objectives:

- Develop a dynamic modeling/GIS analytical framework to identify areas of high P-loss risk in a watershed;

- Use the framework as a decision support tool to track how these areas change over time and to enable targeting of P management measures; and

- Apply the framework over time to evaluate the distribution of P-loss risk under baseline conditions and targeted management scenarios.



Approach

- Apply dynamic mass-balance model of P flux in mixed land use watershed

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- Use P Index and other criteria to identify evolution of critical areas

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- Make process spatially-explicit using GIS and other programming tools

Approach

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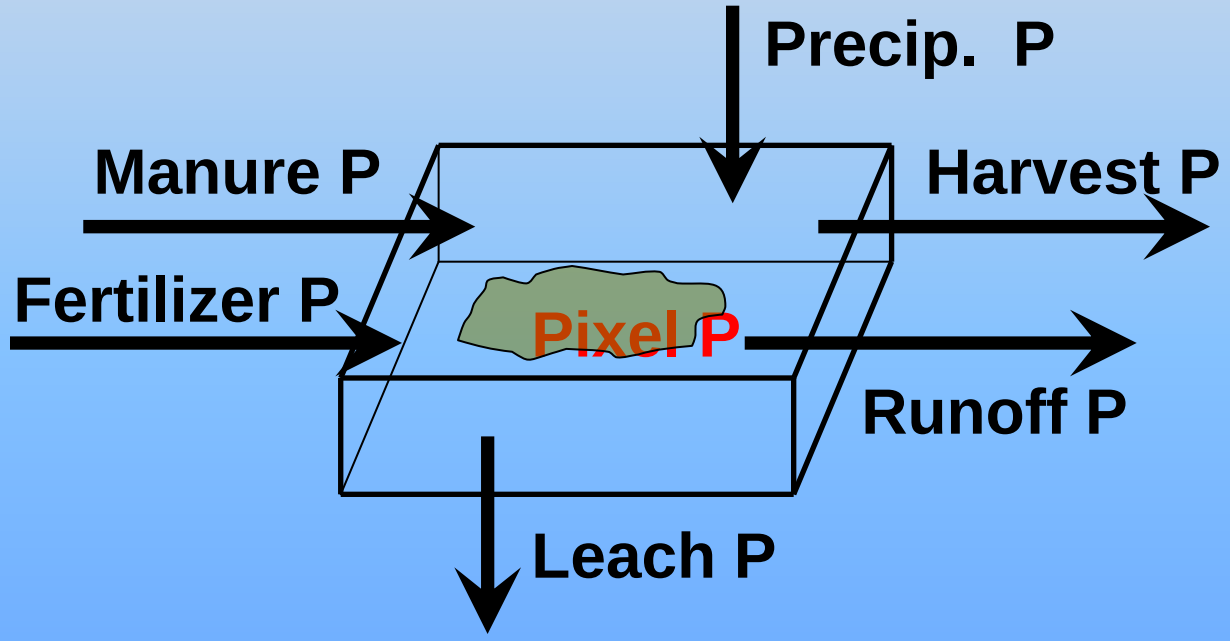
- Use P Index and other criteria to identify evolution of critical areas
- Identify runoff contributing areas
- Determine hot-spots of high P-loss risk →high P accumulation/loss + high runoff probability
- Make process spatially-explicit using GIS and other programming tools
- Simulate baseline conditions and management measures applied to hot-spots over long time horizon

- Dynamic simulation modeling of P flux in mixed land use watershed

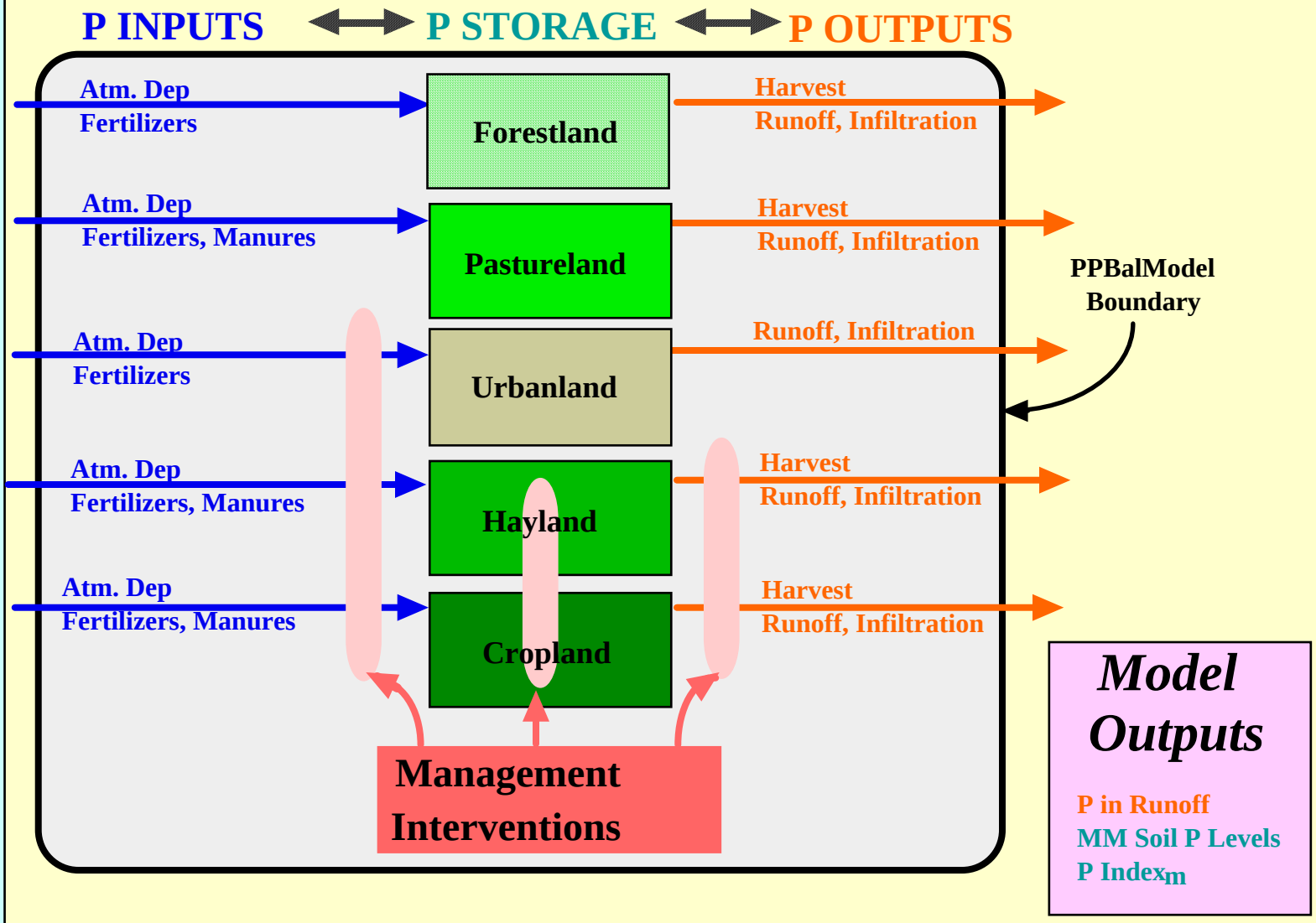
Pixel-scale P mass-balance model

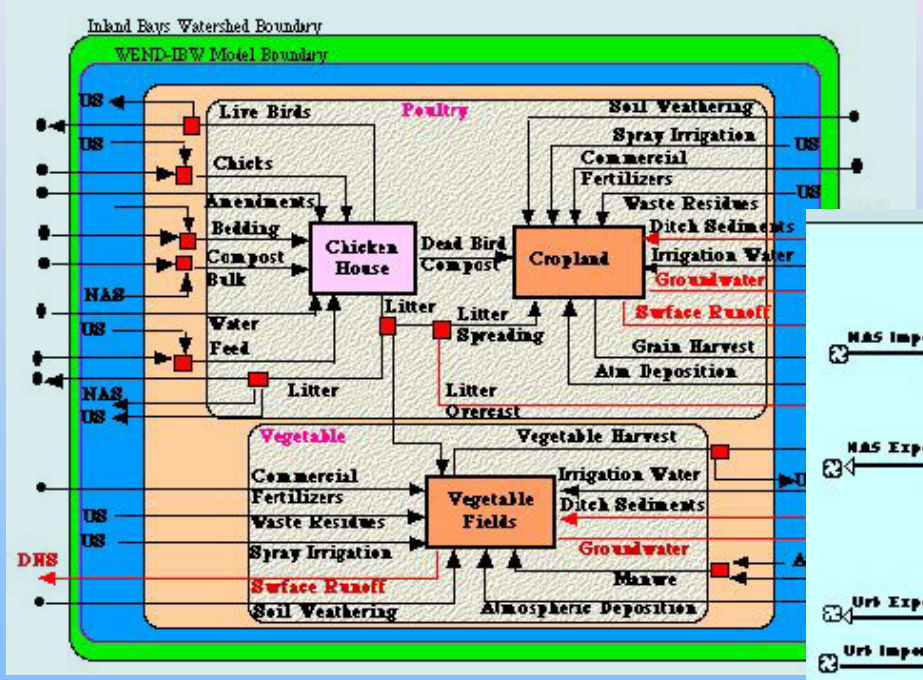


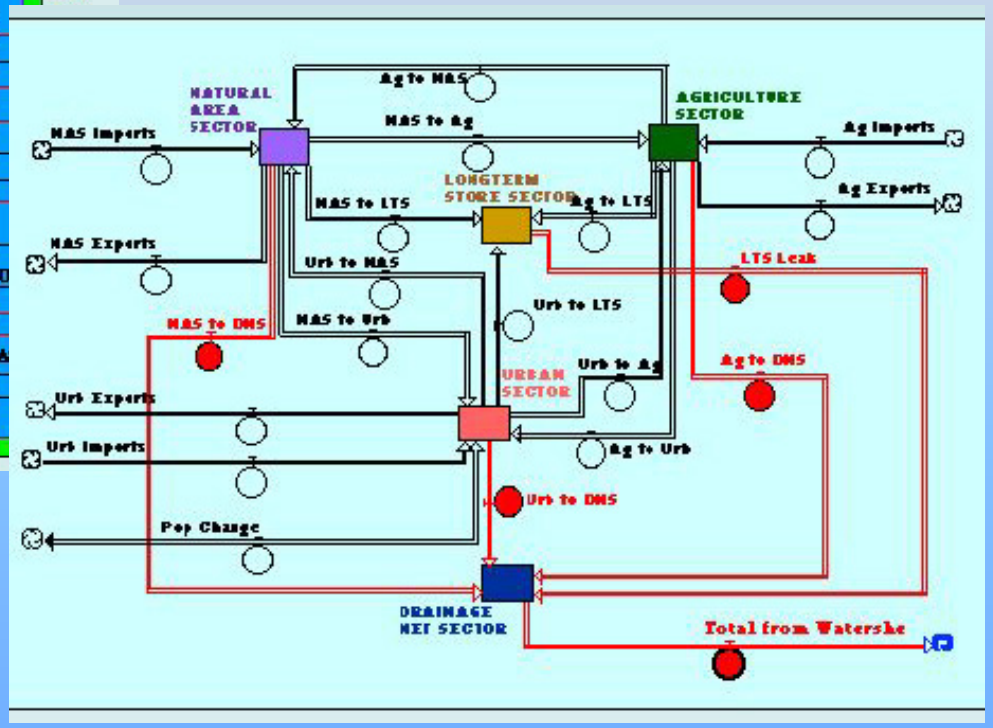
Pixel P = the amount of P stored in pixel at any given time

Pixel Phosphorus Balance Model

- Management Interventions and Outputs




Inland Bays Watershed Boundary
WEND-IBW Model Boundary
Poultry
Live Birds
Chicks
Amendments
Bedding
Compost
Bulk
Water
Feed
Chicken House
Dead Bird Compost
Litter
Litter Spreading
Cropland
Soil Weathering
Spray Irrigation
Commercial Fertilizers
Waste Residues
Ditch Sediments
Irrigation Water
Groundwater
Surface Runoff
Grain Harvest
Atm Deposition
Overcast
Vegetable
Vegetable Harvest
Commercial Fertilizers
Waste Residues
Spray Irrigation
Vegetable Fields
Irrigation Water
Ditch Sediments
Groundwater
Manure
Atmospheric Deposition
Soil Weathering
US
NAS
DNS

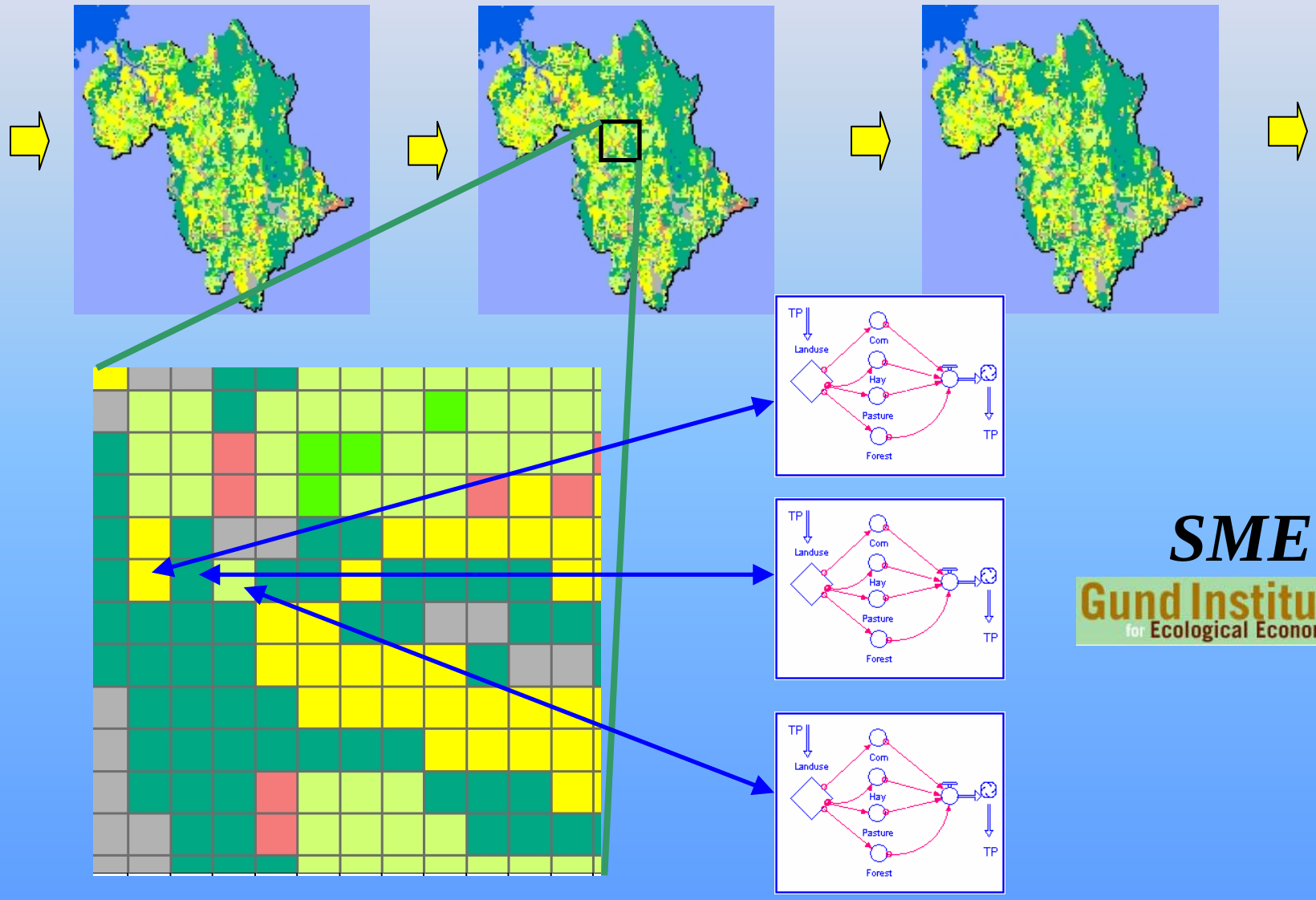

NATURAL AREA SECTOR
AGRICULTURE SECTOR
LONGTERM STORE SECTOR
URBAN SECTOR
DRAINAGE NET SECTOR
NAS Imports
NAS Exports
Ag Imports
Ag Exports
Urb Imports
Urb Exports
Pop Change
Ag to NAS
NAS to Ag
NAS to LTS
Ag to LTS
Urb to NAS
NAS to Urb
Urb to LTS
Urb to Ag
Ag to Urb
NAS to DNS
Urb to DNS
Ag to DNS
LTS Leak
Total from Watershe

STELLA

PixelPBal Model Application

Simulation year:

. . . 10 years **11 years** **12 years . . .**



SME

Gund Institute for Ecological Economics

Major data inputs

Watershed scale

- Land use – corn, hay, pasture, urban, forest
- Pixel area
- Total annual precipitation
- Total annual PET
- P input from atmospheric deposition

Pixel scale

- Runoff contributing area (RCA) probability

For each land use

- Curve number
- RUSLE factors (K, LS, C, P)
- Initial soil test P
- Thickness of surficial soil layer

Specific to pixel land use and management

- P input from manure
- P input from fertilizers
- P output in harvest

Relationships

- CN – annual runoff
- Soil test P vs. soil TP
- Soil test P vs. surface runoff P conc.
- Soil test P vs. pore water P conc.

Model watershed

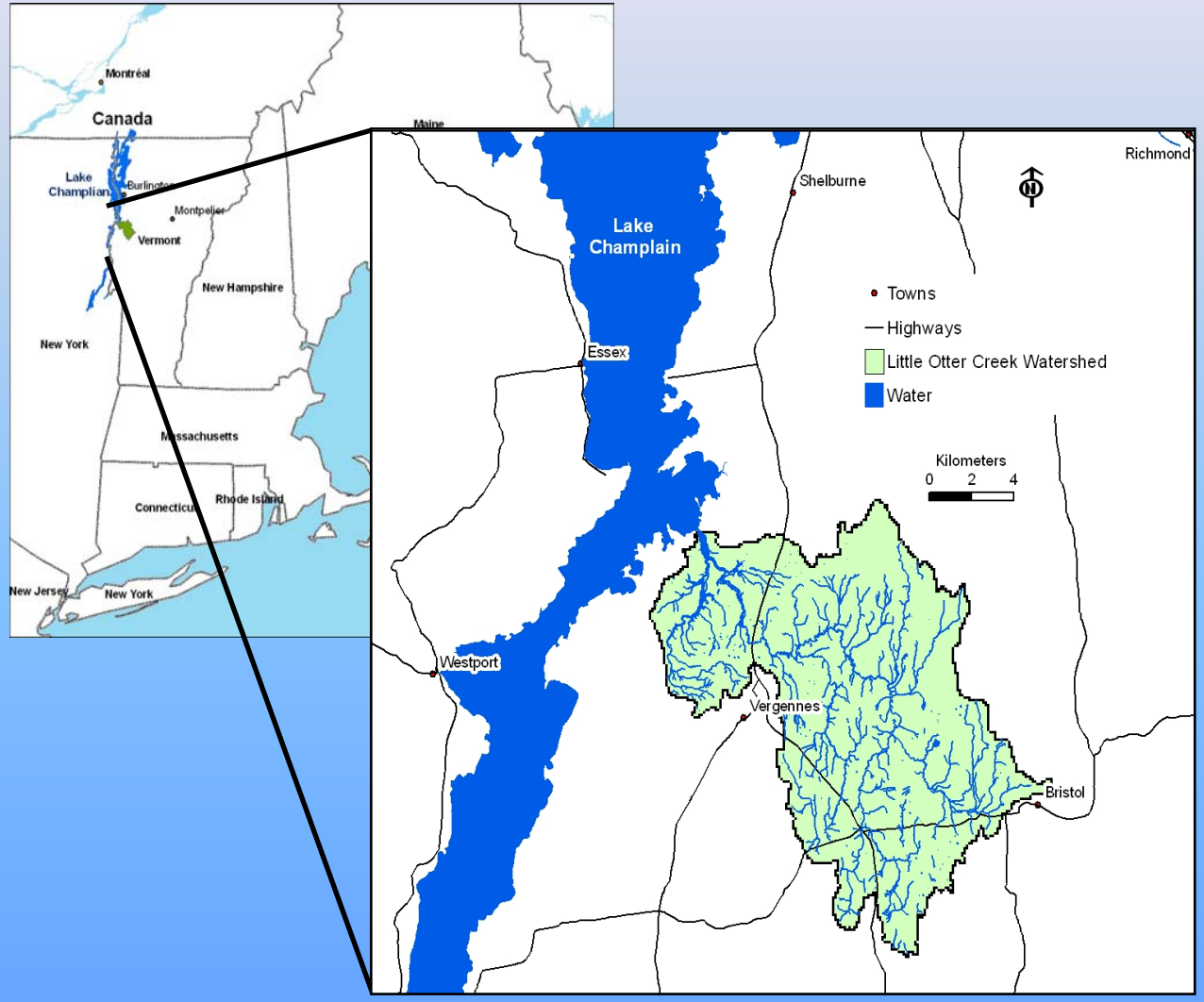


Figure 4.1. Location map of the Little Otter Creek watershed.

Application in “model” watershed

Basic data

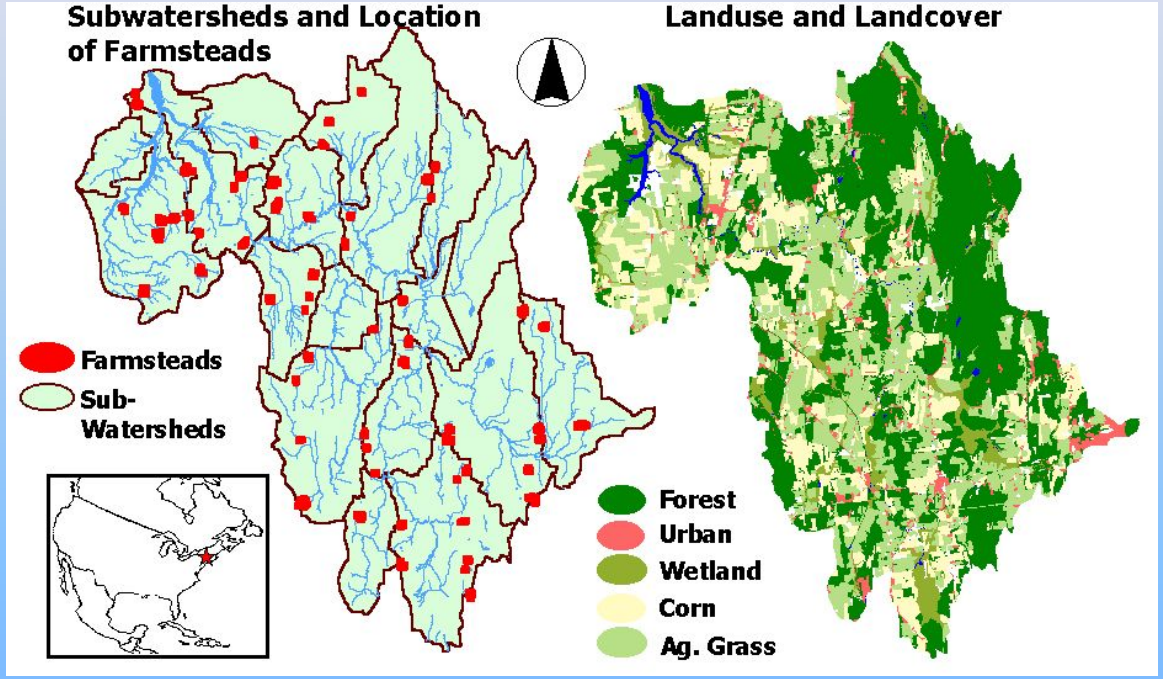
- Streams
- DEM
- Land use
- Soils

Derived data

- Soil hydrol. group
- CN
- Soil texture
- RUSLE factors
- RCA probability

Estimated data

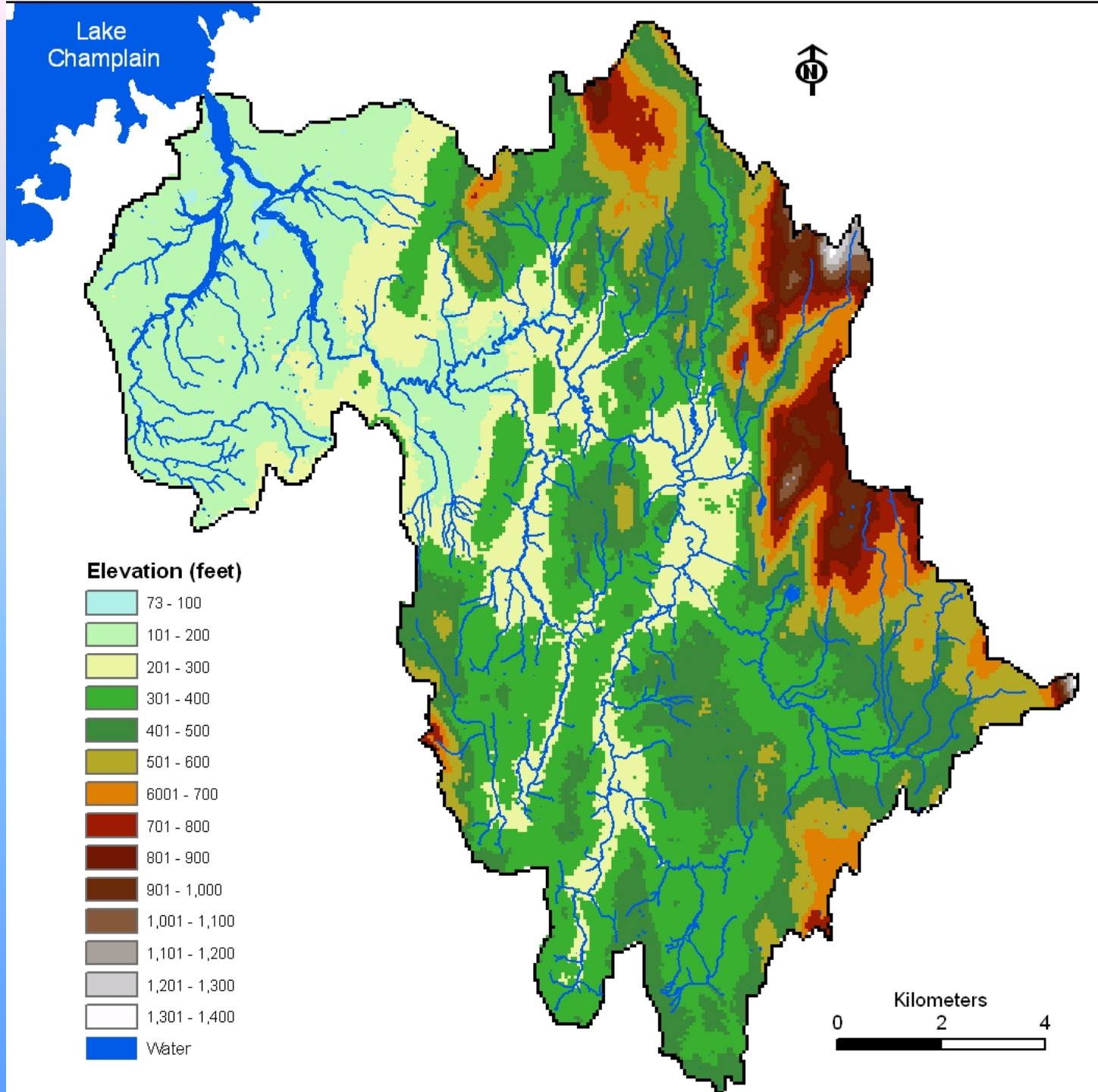
- Initial soil P
- Soil Aluminum
- Manure/fertilizer inputs



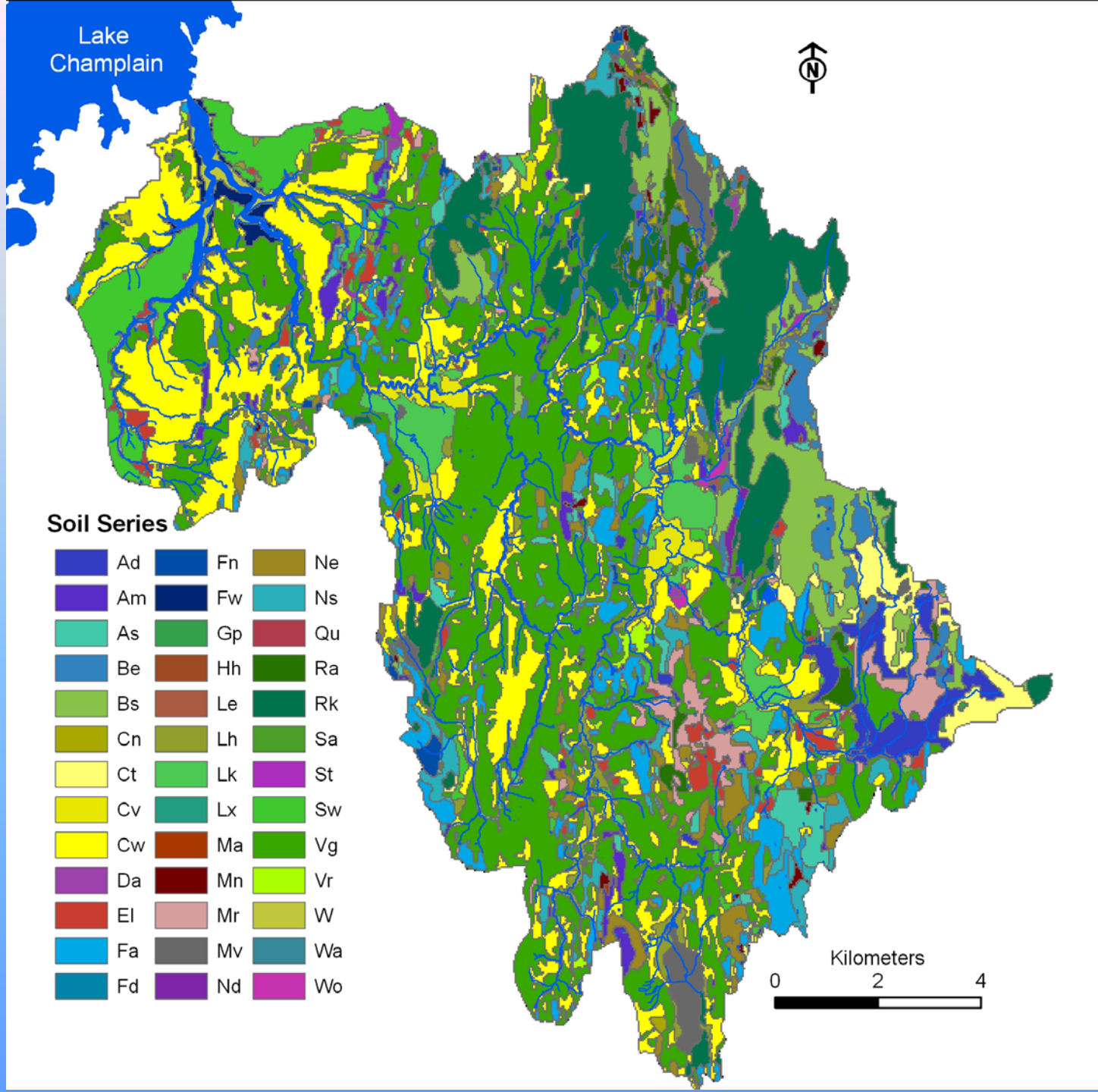
(47,155 60 x 60 m pixels)

P Index

DEM


Lake Champlain
N
Elevation (feet)
73 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
6001 - 700
701 - 800
801 - 900
901 - 1,000
1,001 - 1,100
1,101 - 1,200
1,201 - 1,300
1,301 - 1,400
Water
Kilometers
0
2
4

Soil Series


Lake Champlain
N
Soil Series
Ad
Am
As
Be
Bs
Cn
Ct
Cv
Cw
Da
El
Fa
Fd
Fn
Fw
Gp
Hh
Le
Lh
Lk
Lx
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Mn
Mr
Mv
Nd
Ne
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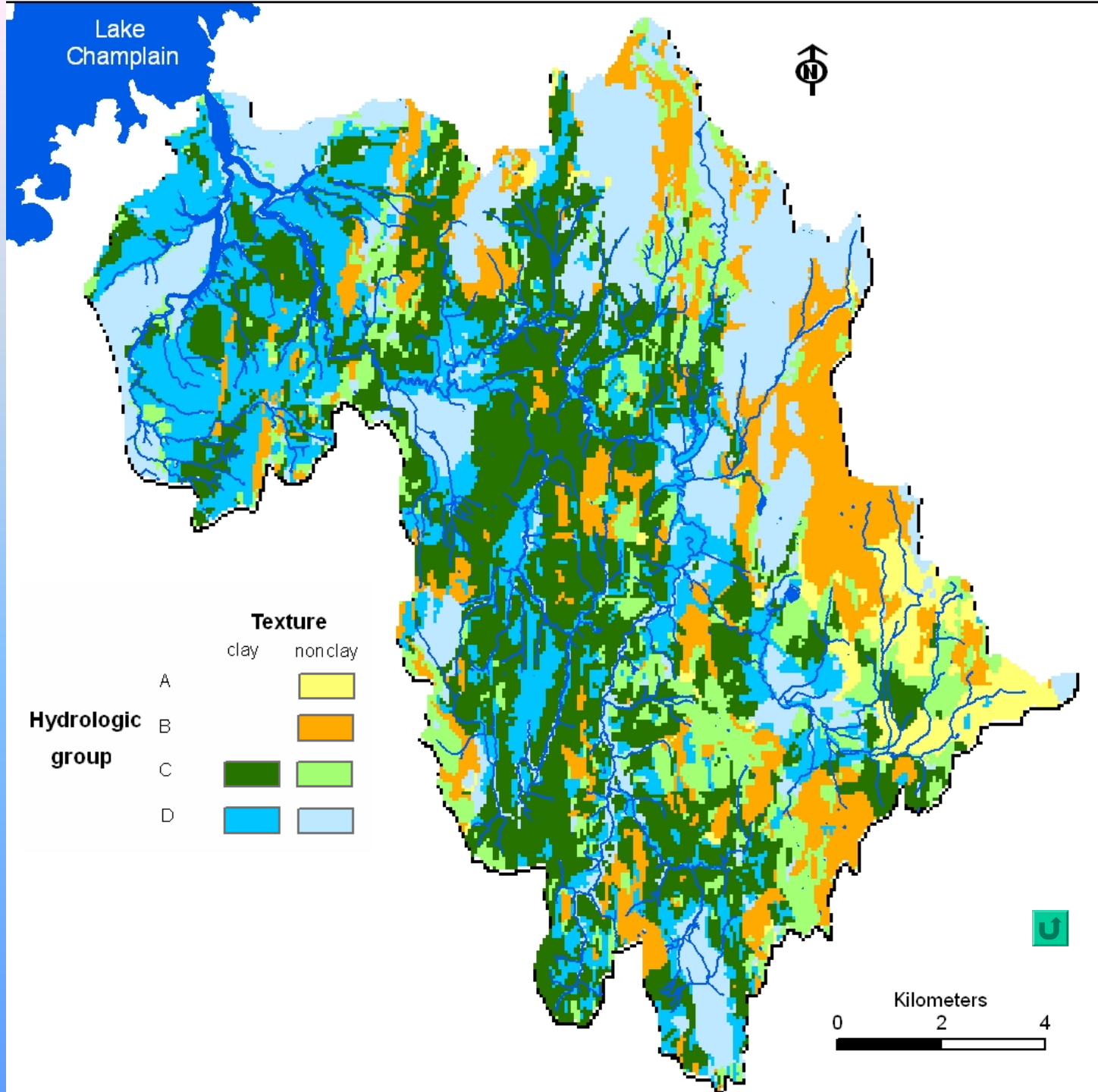
Soils

Hydrologic Groups & Texture



Initial soil test P

Land Use	Soil test P (mg/kg)
Corn	9.0
Hay	6.0
Pasture	5.5
Forest	3.0
Urban	15.0

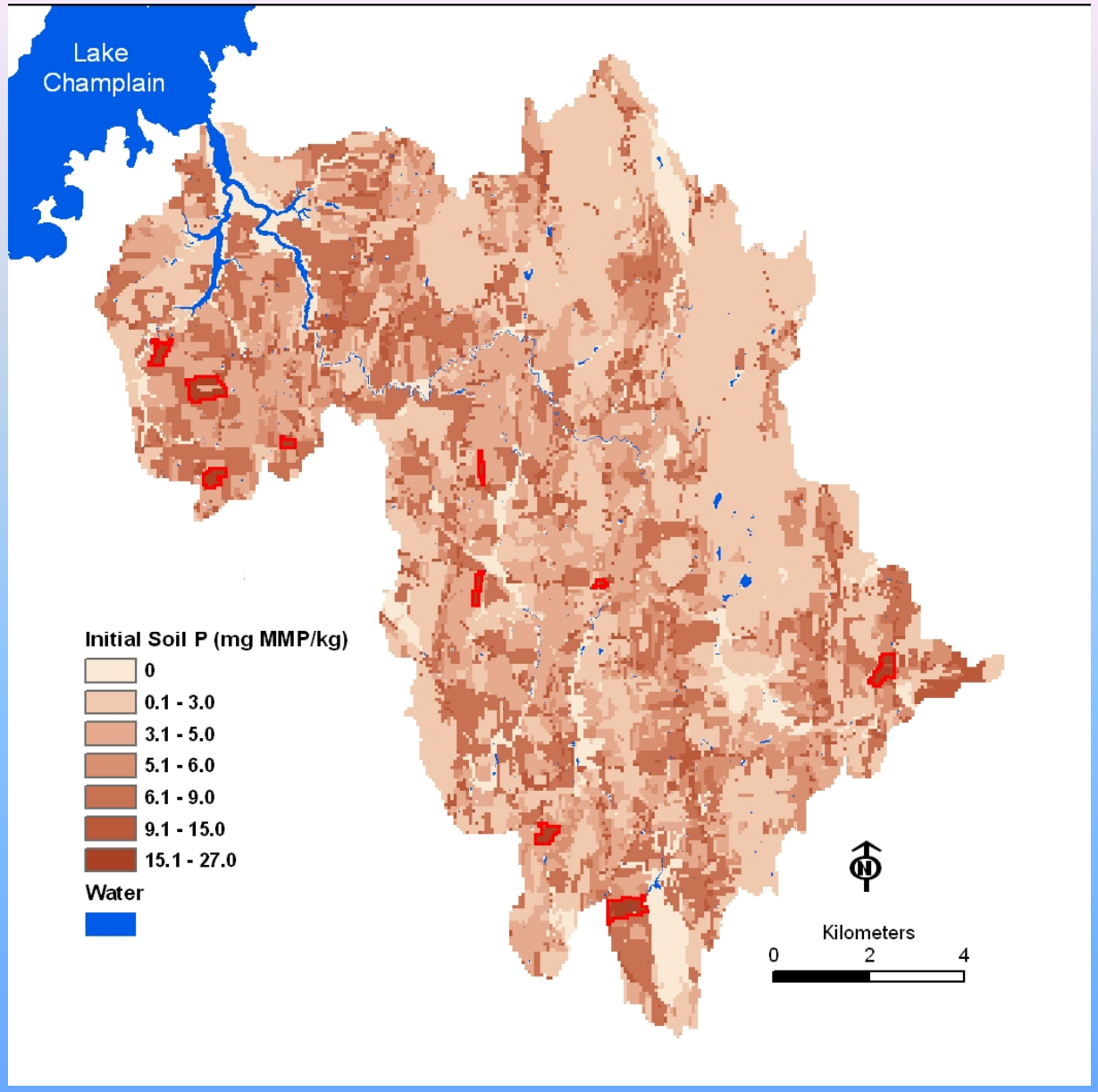


Figure 4.7. Map of initial soil test P data set for Little Otter Creek watershed.

- P Index to identify critical areas in watershed

Vermont P Index

- **soil test P**
- **reactive soil Al**
- **manure app. rate**
- **manure app. method**
- **fertilizer app. rate**
- **soil type**
- **crop type**
- **erosion controls**

Identify probable runoff contributing areas

- **Estimate storm runoff by distributed watershed CN**

- **Estimate % total watershed contributing area as:** $\frac{\text{Runoff depth}}{\text{Precip. depth}}$

(Gburek et al. 2002)

- **Use topographic "wetness index" to identify specific RCAs**

(D.G. Tarboton, Utah State) $\ln(\tan b/a)$

b = slope
a = catchment area

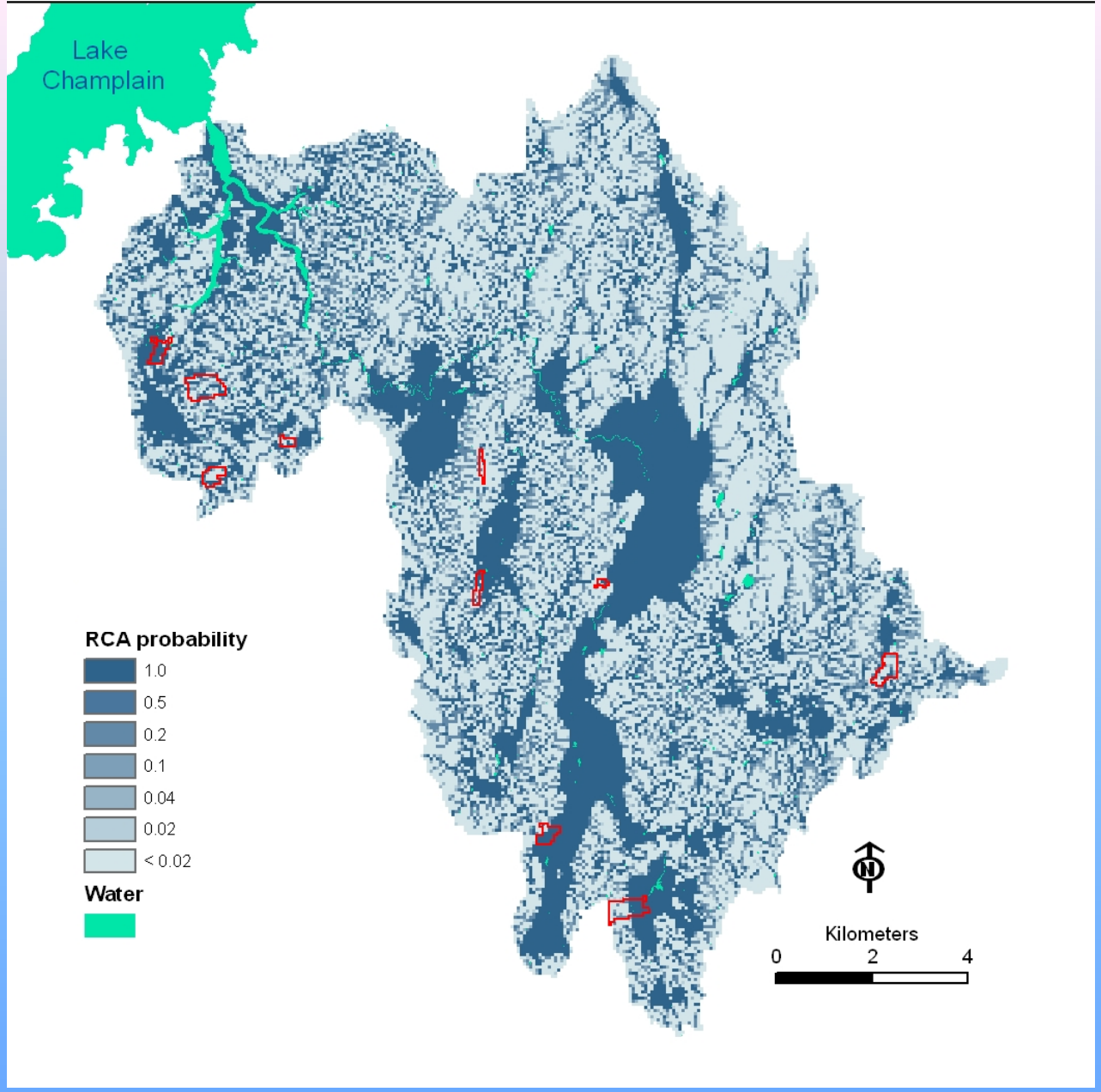


Figure 4.9. Map showing Runoff Contributing Area (RCA) probability for pixels in the LOC watershed. A pixel with $RCA_P = 1.0$ is expected to generate surface runoff in a 1-year storm, i.e., each year; a pixel with $RCA_P = 0.1$ is expected to generate runoff only from a 10-year or greater storm, i.e., one year in ten. Pixels assigned a RCA_P <0.02 are expected to generate runoff only from storms exceeding a 50-year return period.

The Model

Dynamic Interactive Simulation of P Loss Areas

DISPLA

Management Scenarios

Baseline – present day conditions of P inputs and management remain constant into future

P applied in excess of crop need/removal

Average conditions of erosion control

Management Scenarios

Nutrient Management

NM applied to corn and hay;
remedial P inputs allowed if soil test P < 3 mg/kg
Urban P fertilizer restricted

Two possible levels of agricultural NM triggered when pixel soil test P exceeds a threshold: >10 and >20 mg/kg

Urban NM invoked as uniform regulation

Management Scenarios

Erosion control

"Best practical" measures applied to corn land

fall chisel plow, spring disk;

5 years corn/5 years hay/legumes mix;

cross-slope row arrangement

strip cropping

Adjustments in RUSLE C and P factors

Applied to all RCA_p 1.0 corn pixels in Year 10;

RCA_p 0.5 corn pixels in Year 20

Management Scenarios

Land Use Change

~conversion of critical row crop to permanent cover

land use changed from corn to hay

all inputs, erosion and runoff convert to values characteristic of new land use

soil test P inherited

Change triggered when P Index exceeds 75

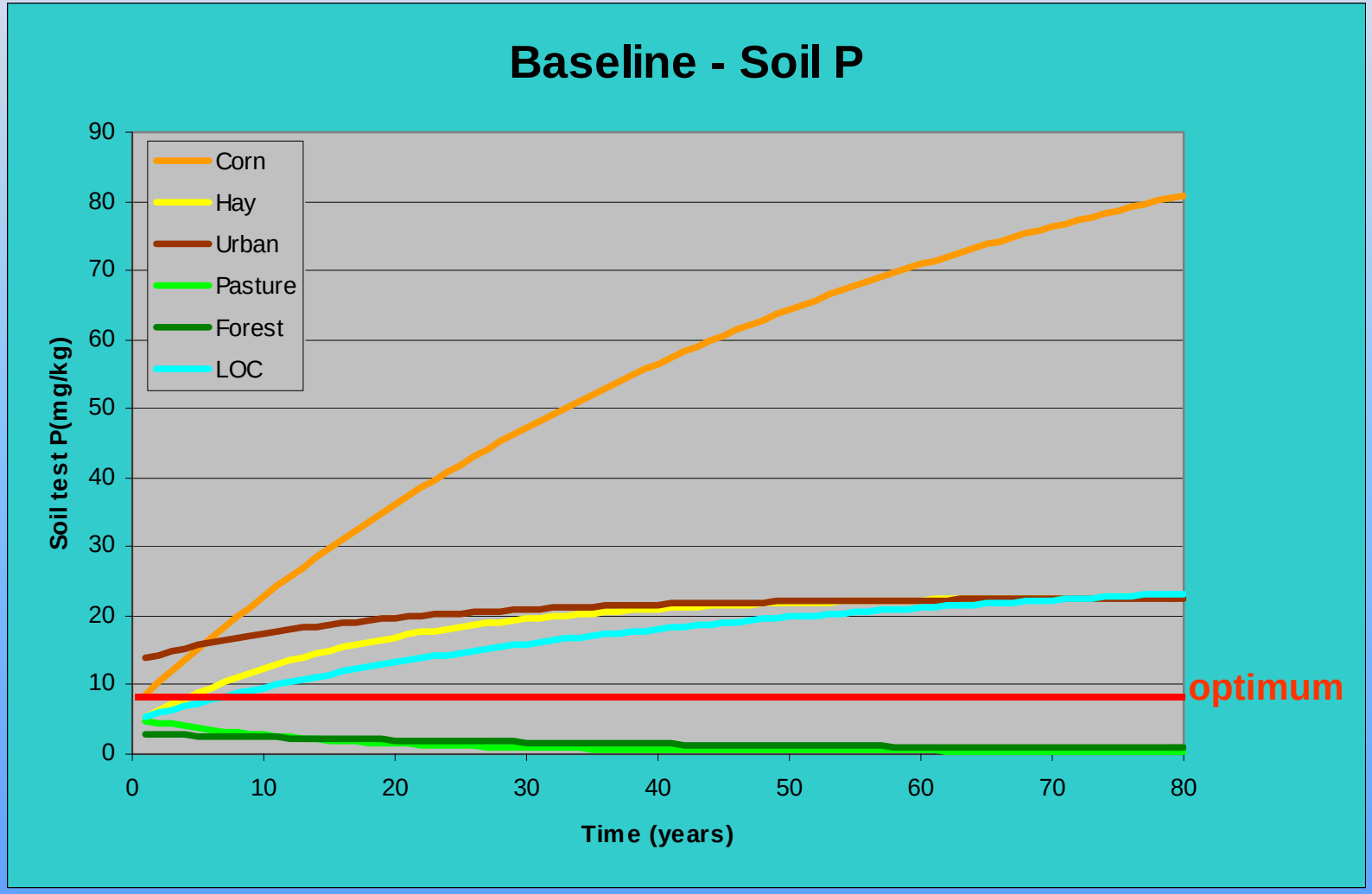
Management Scenarios

All Management

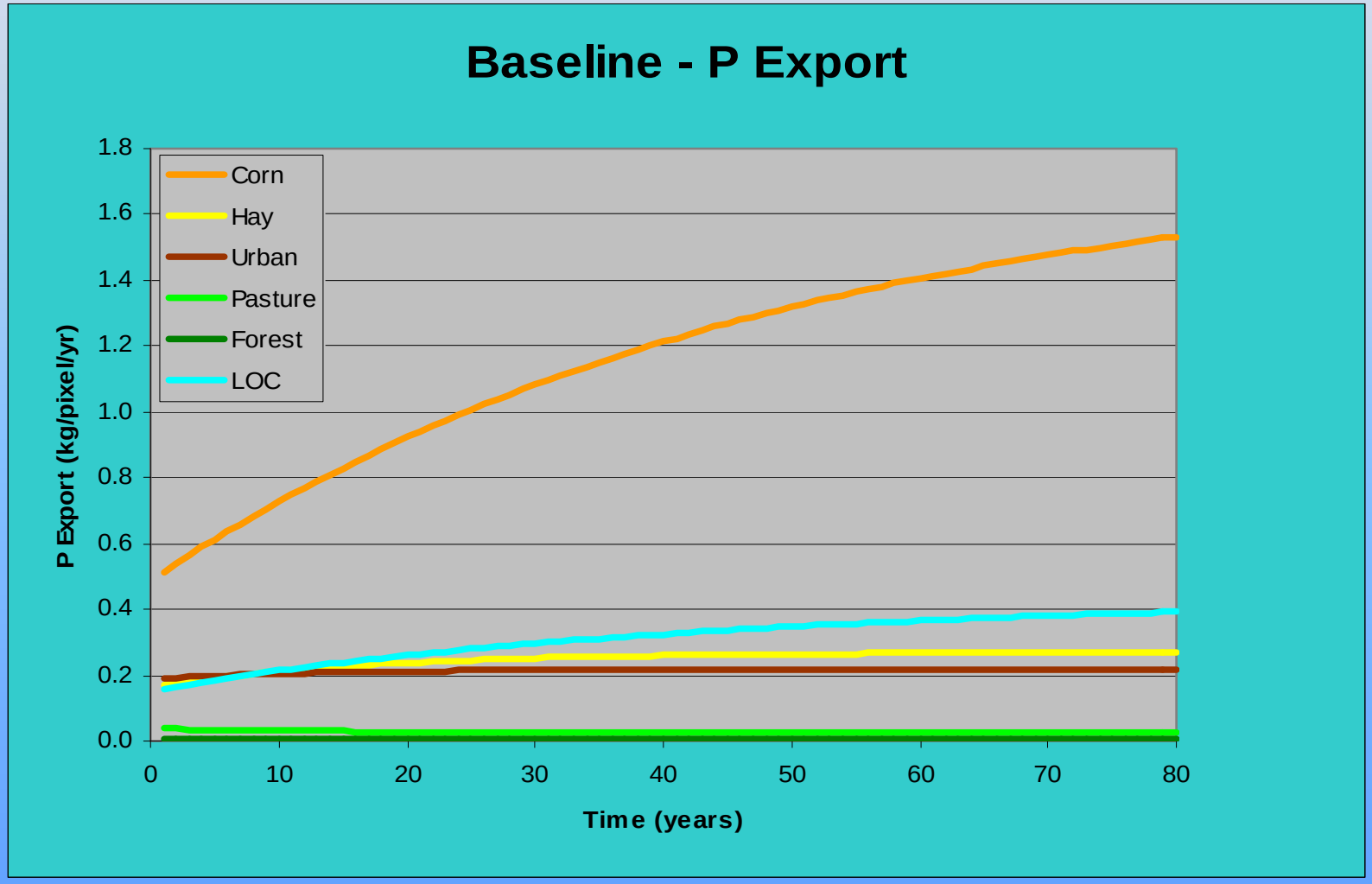
Nutrient management, erosion control, and land use change permitted by own triggers

Note:
For all scenarios, management measures become active at or after Year 10 of simulations

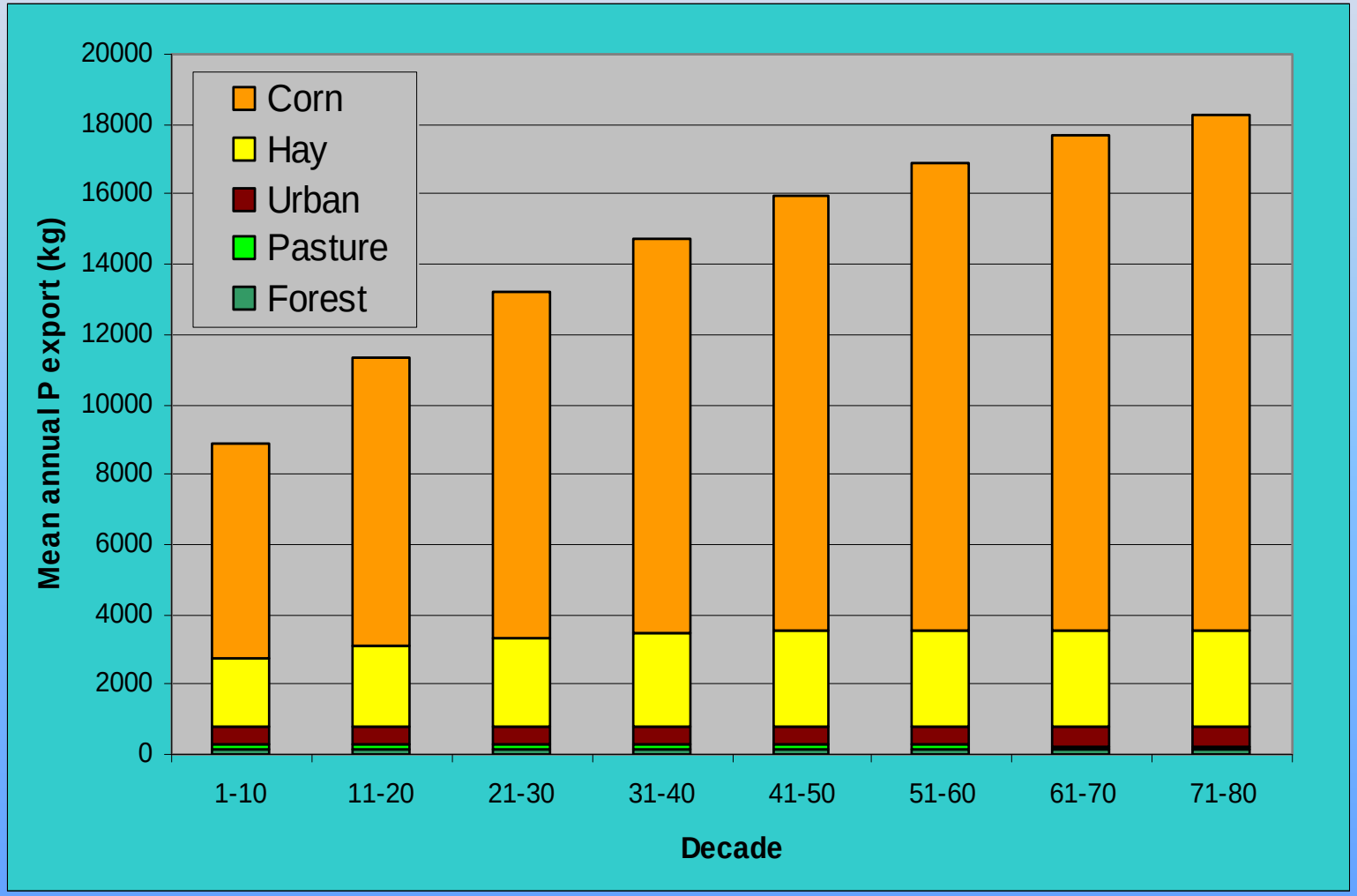
Model results
Baseline



Model results
Baseline



Model results
Baseline



Model results
Reality Check

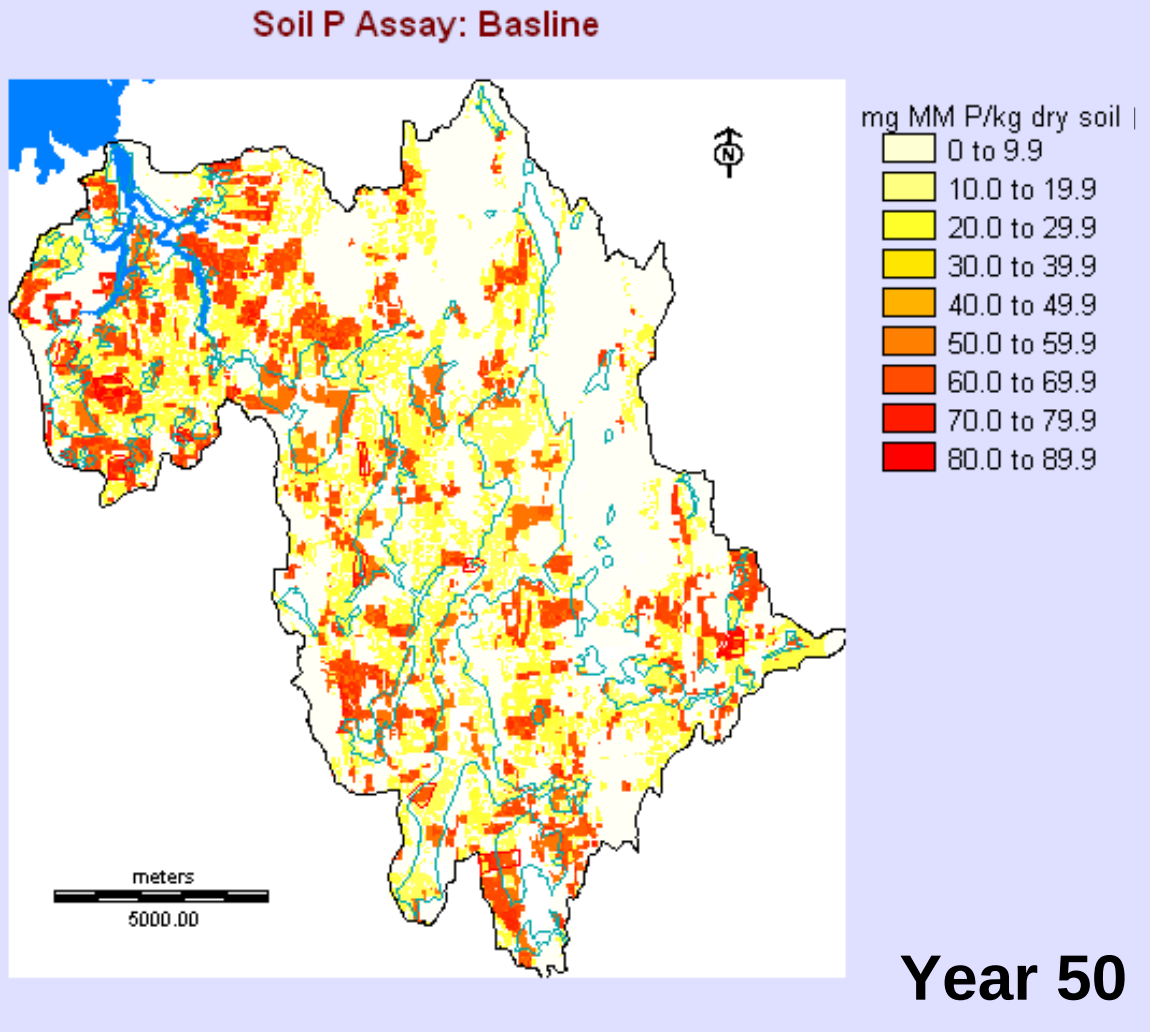
Mean pixel P export (kg/ha/yr)

	Simulation Year 1	Literature
Corn	1.4	0.8 – 2.4
Hay	0.5	0.4 – 1.3

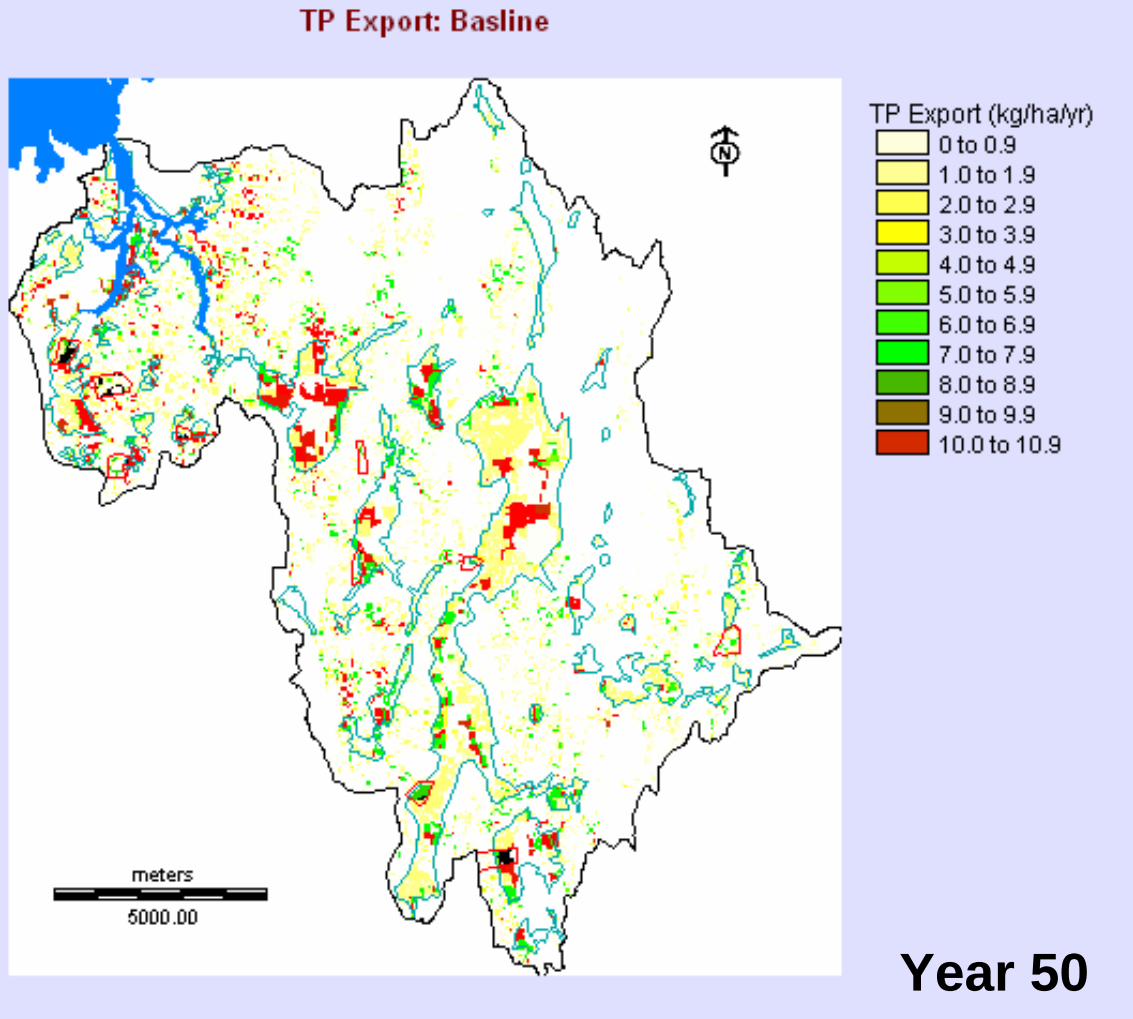
Aggregate P export (t/yr)

Simulation Year 1	LOC 1995 - 2000
8.8	5 - 15

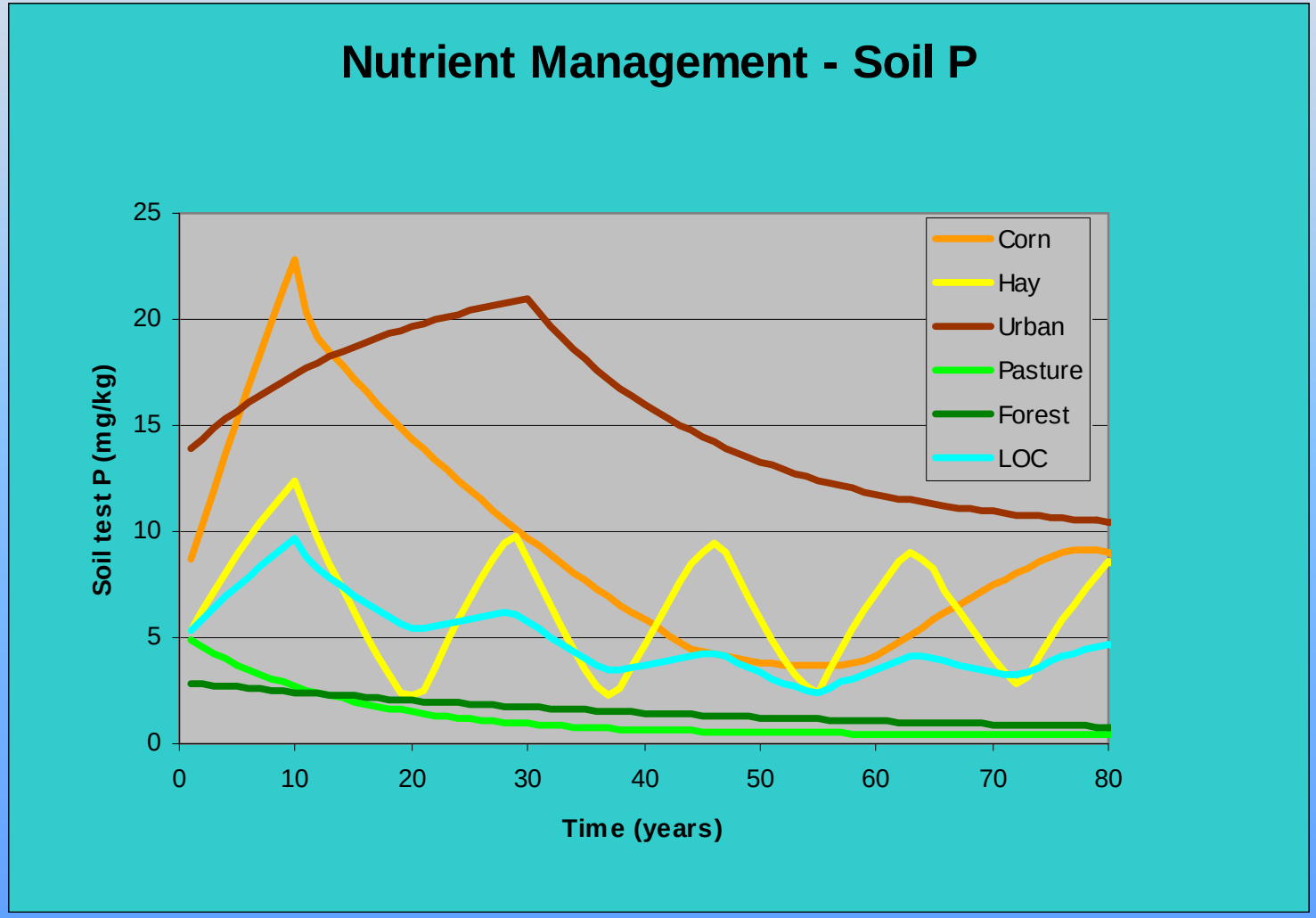
Model results
Baseline – soil test P



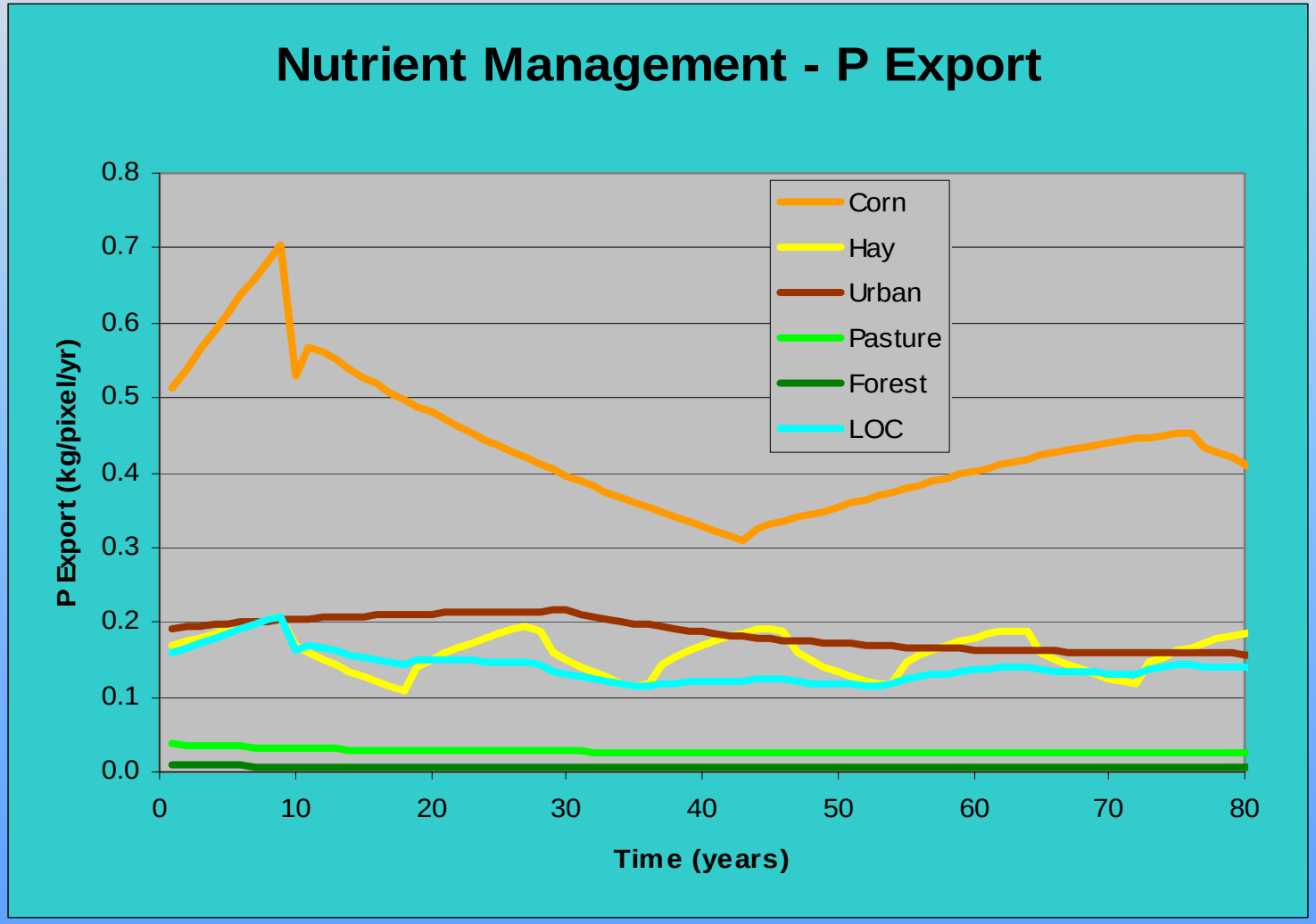
Model results
Baseline – P export



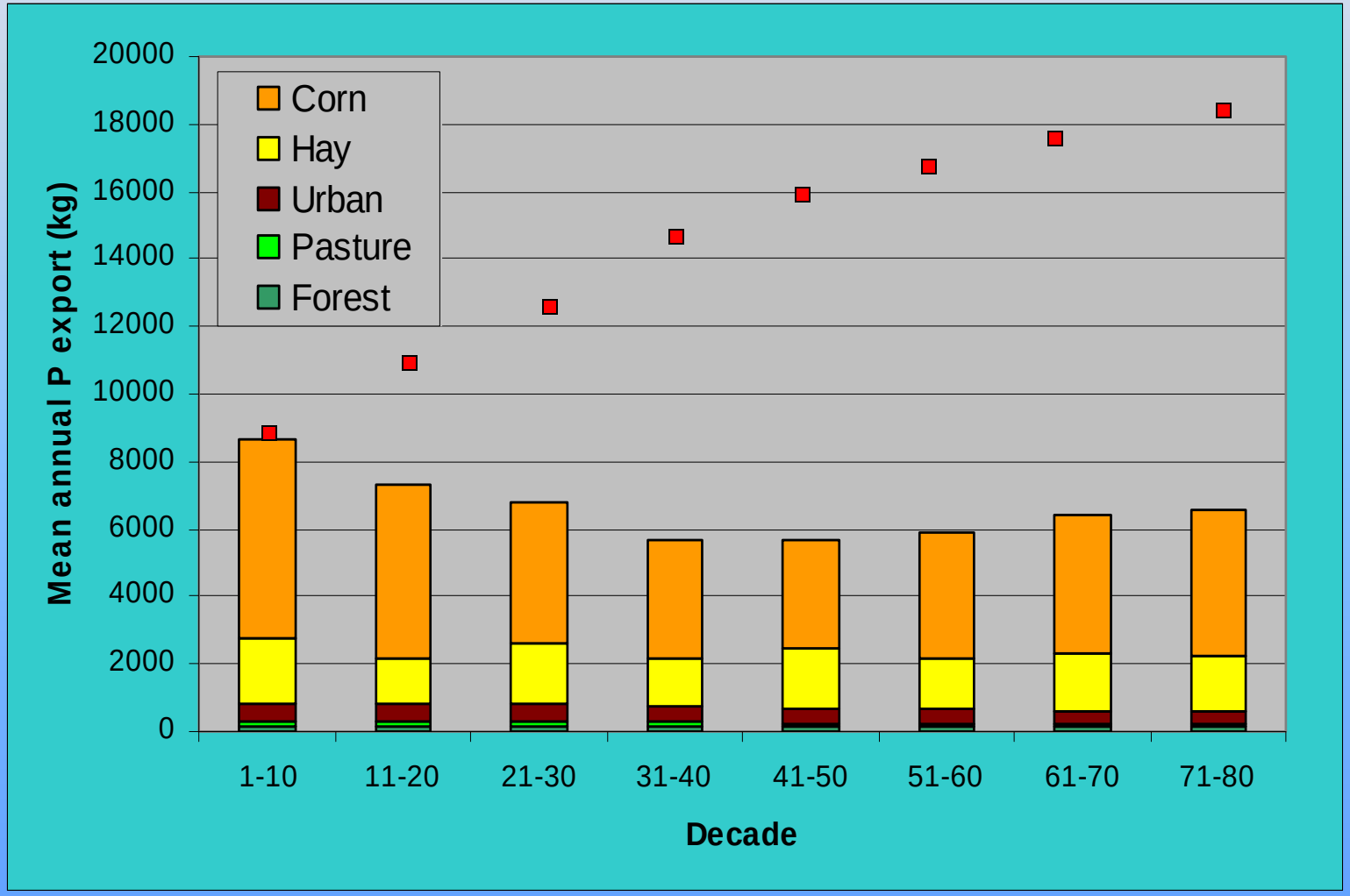
Model results
Nutrient Management



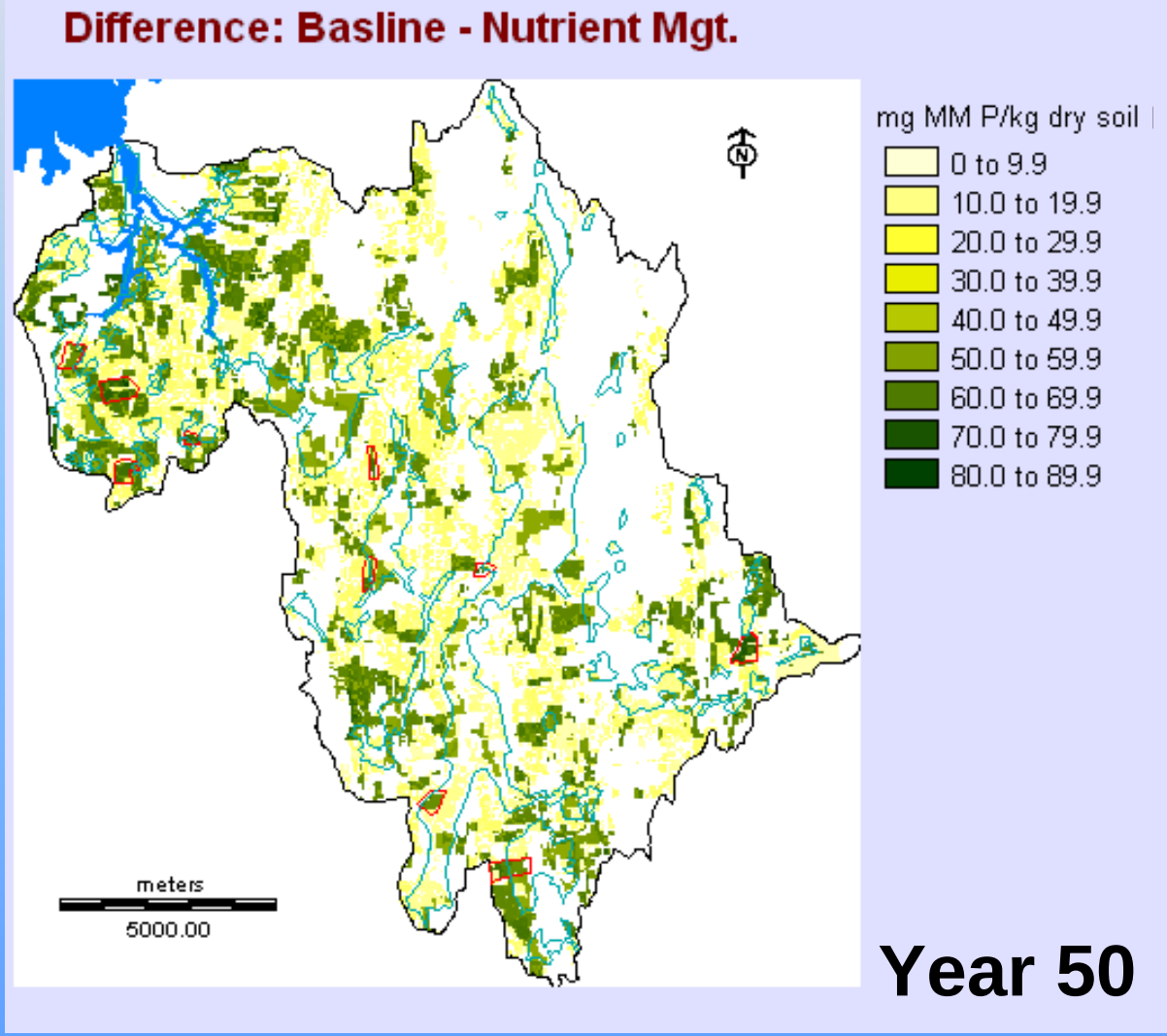
Model results
Nutrient Management



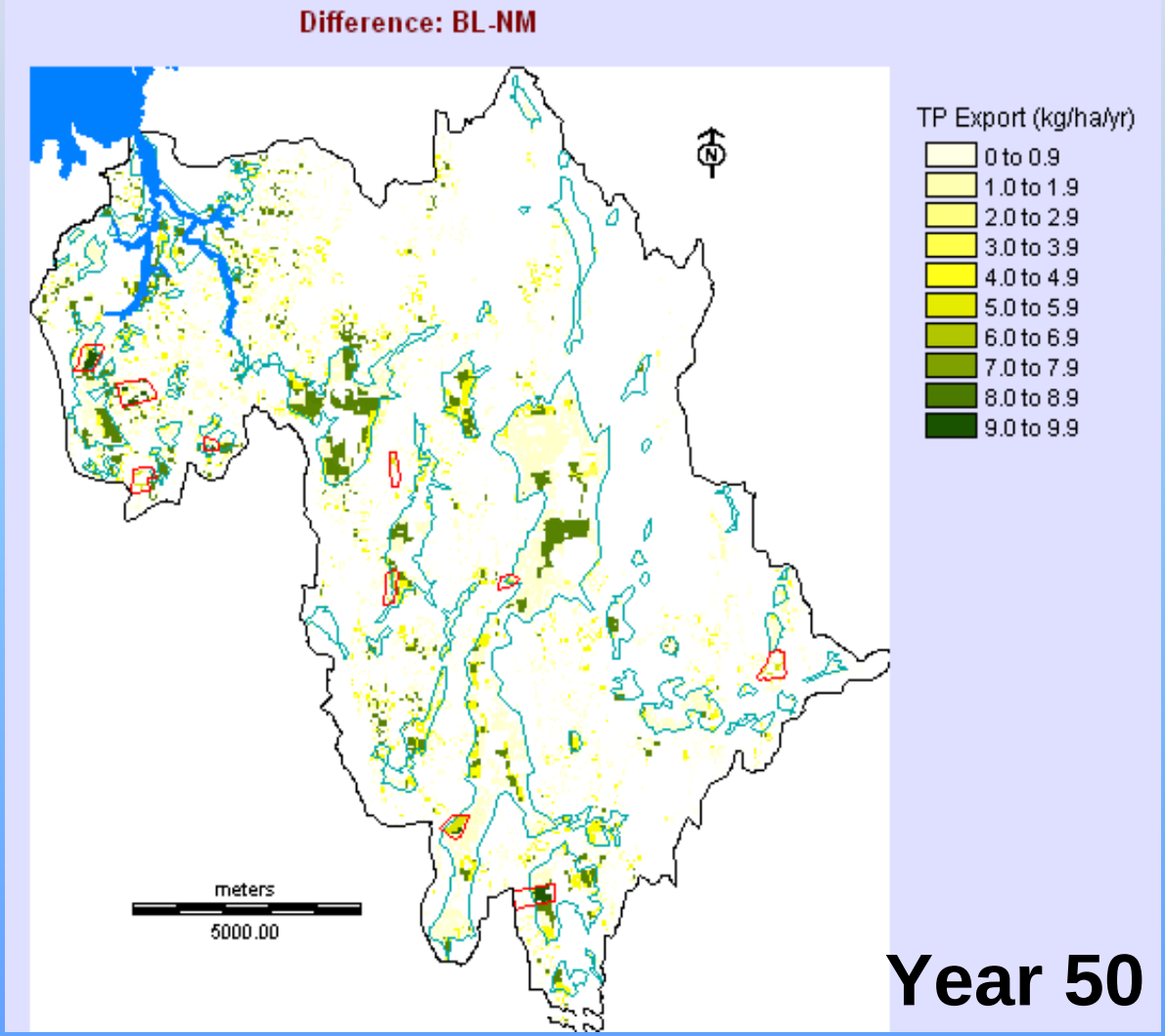
Model results
Nutrient Management



Model results
NM – soil test P difference



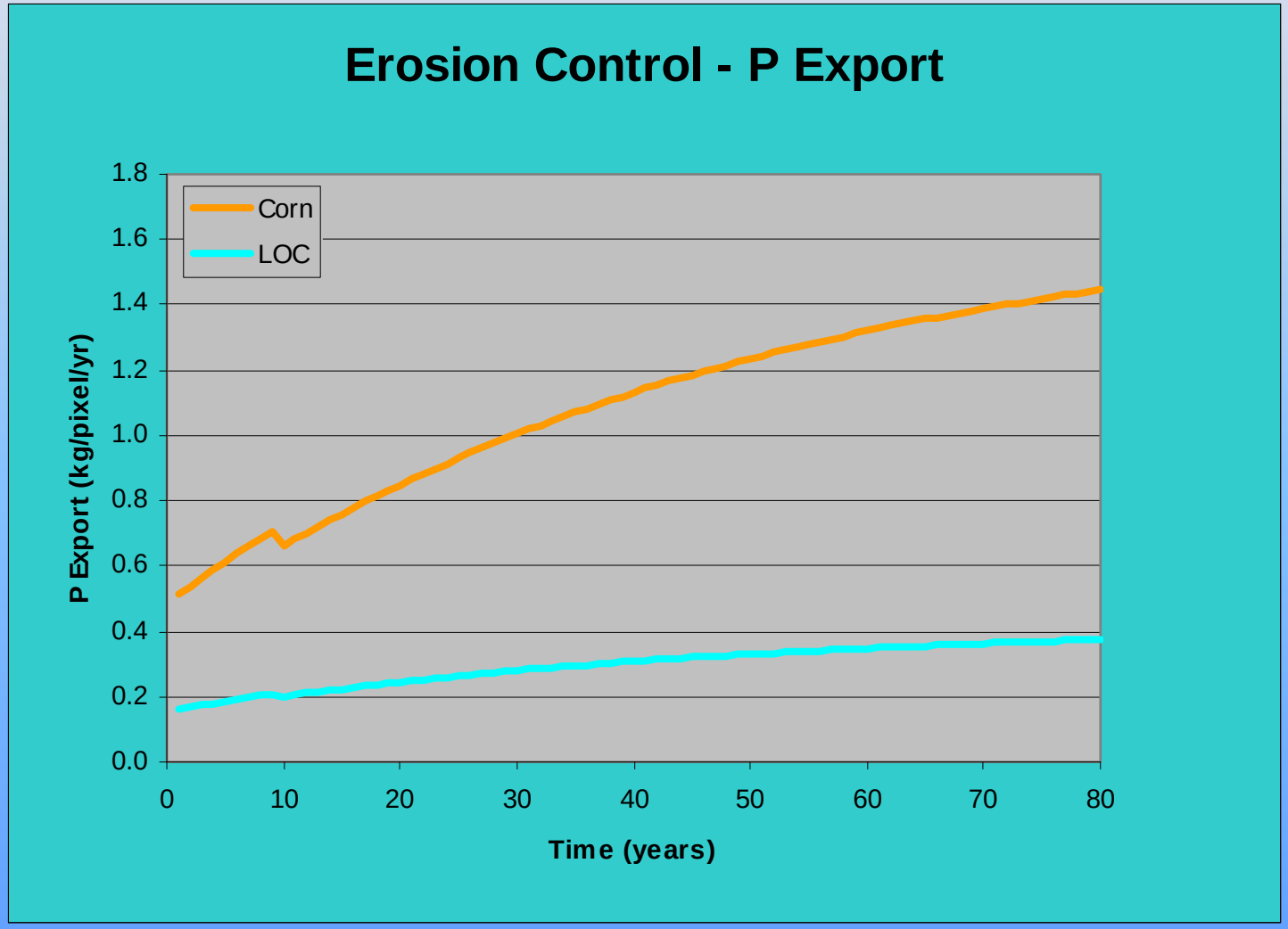
Model results
NM – P export difference



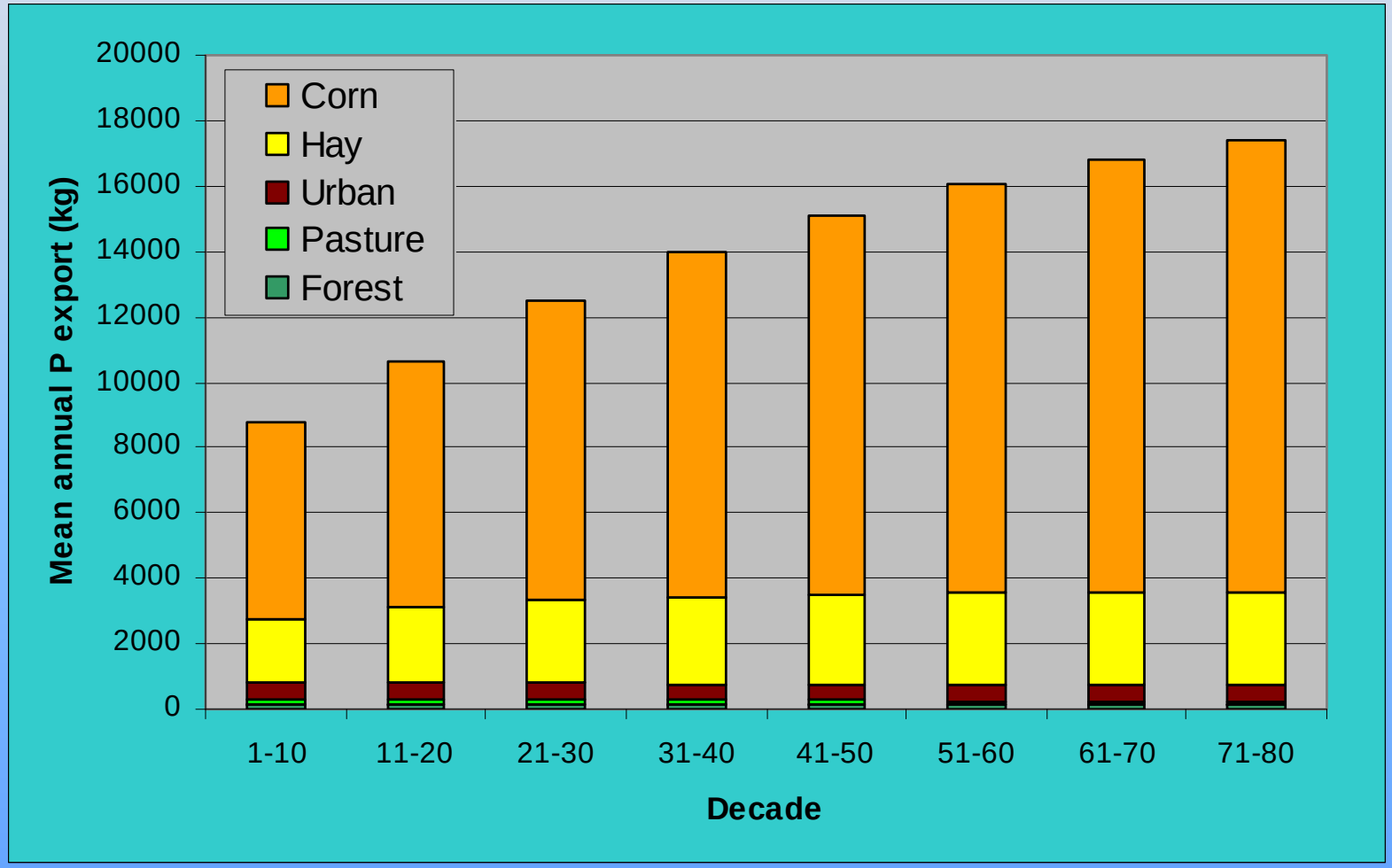
Model results
Erosion Control

No effect on soil test P

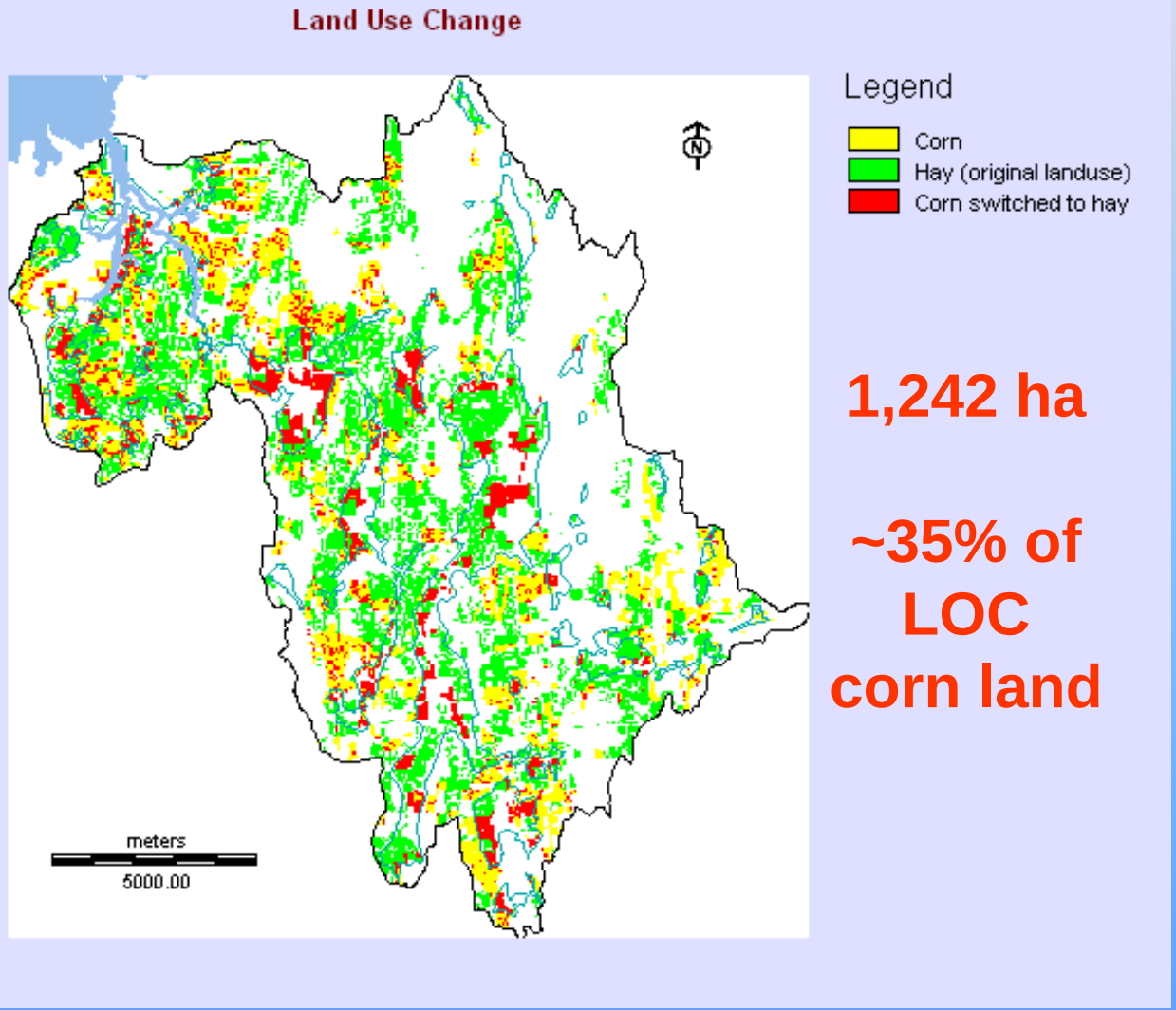
Model results
Erosion Control



Model results
Erosion Control



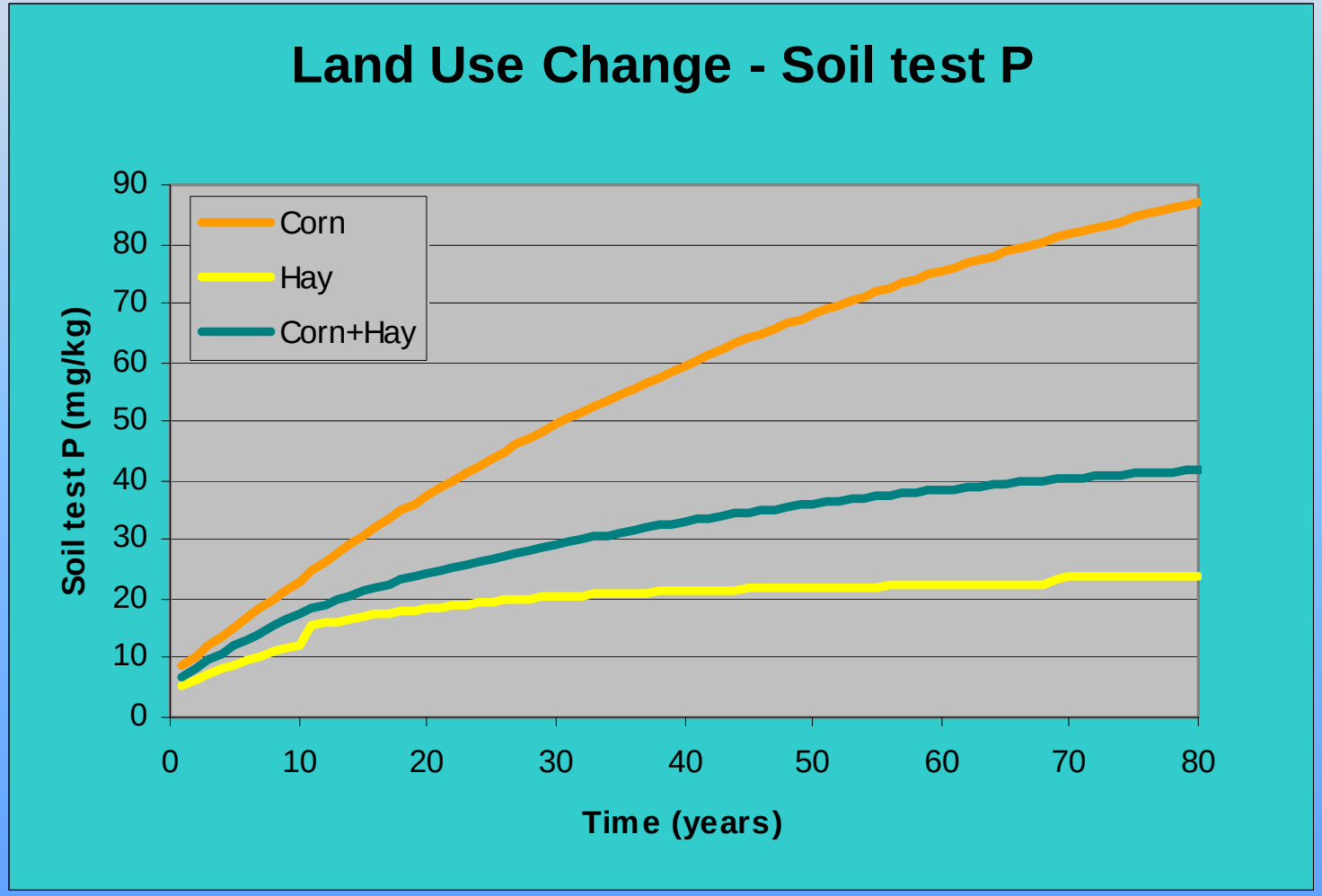
Model results
Land Use Change



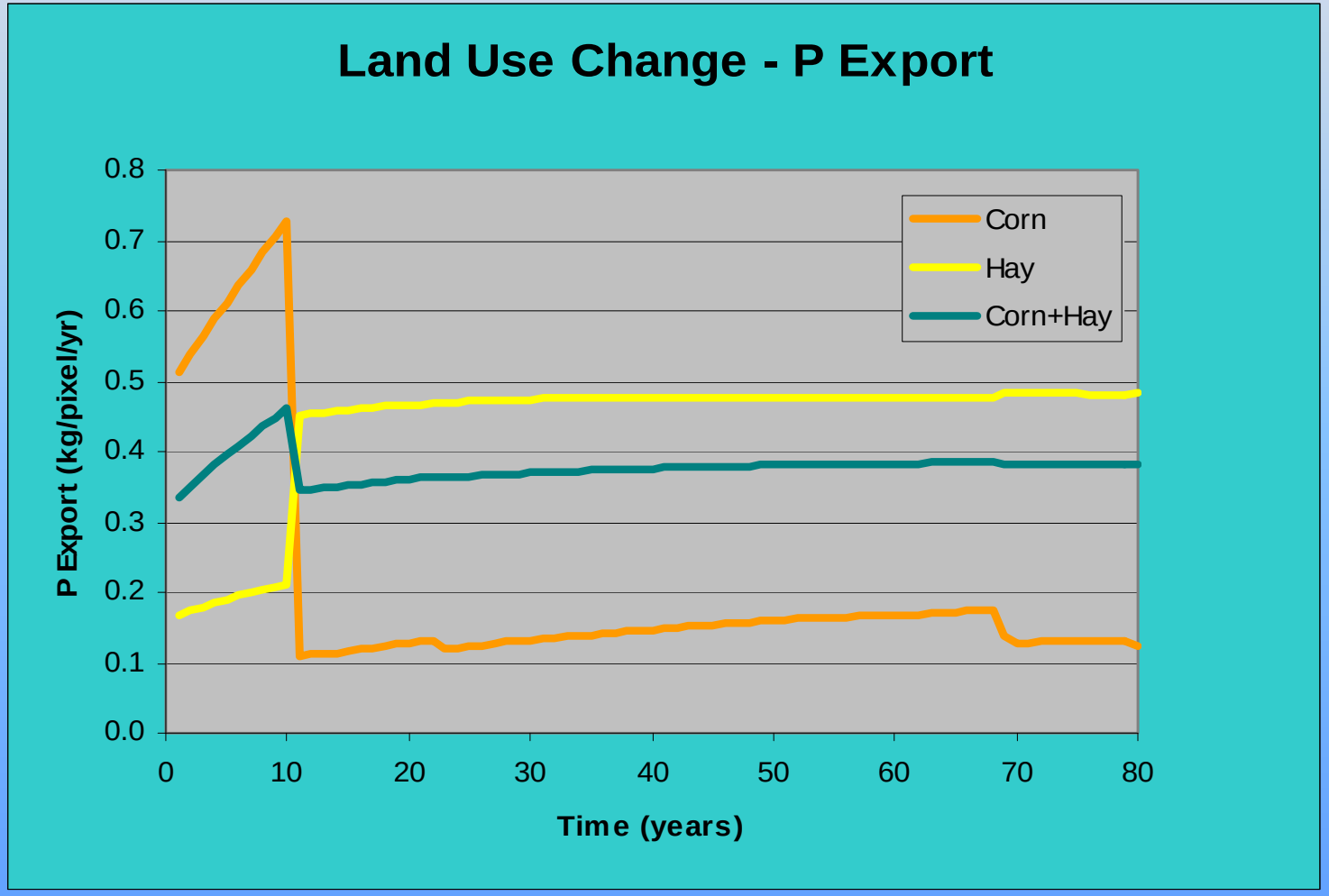
1,242 ha

~35% of LOC corn land

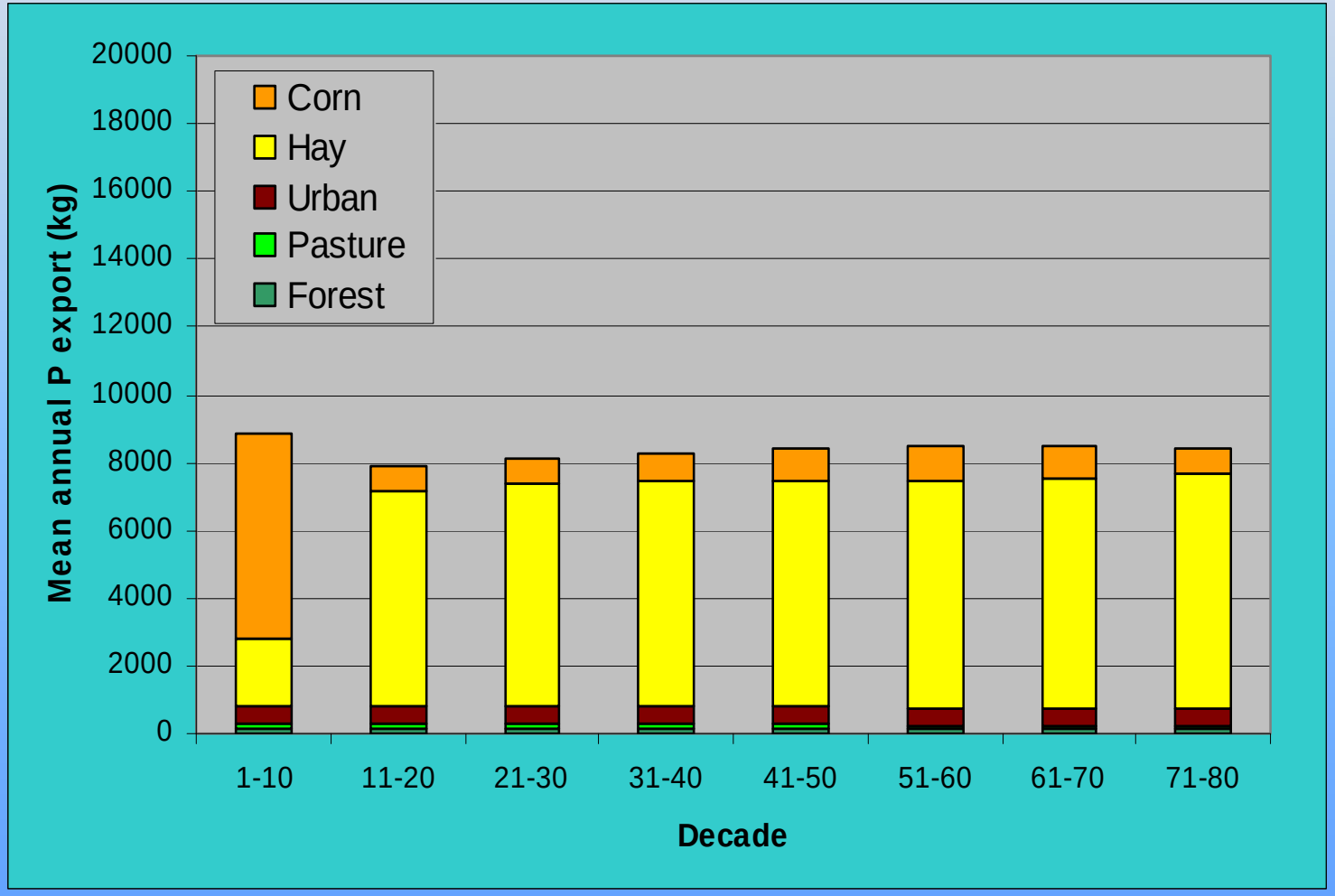
Model results
Land Use Change



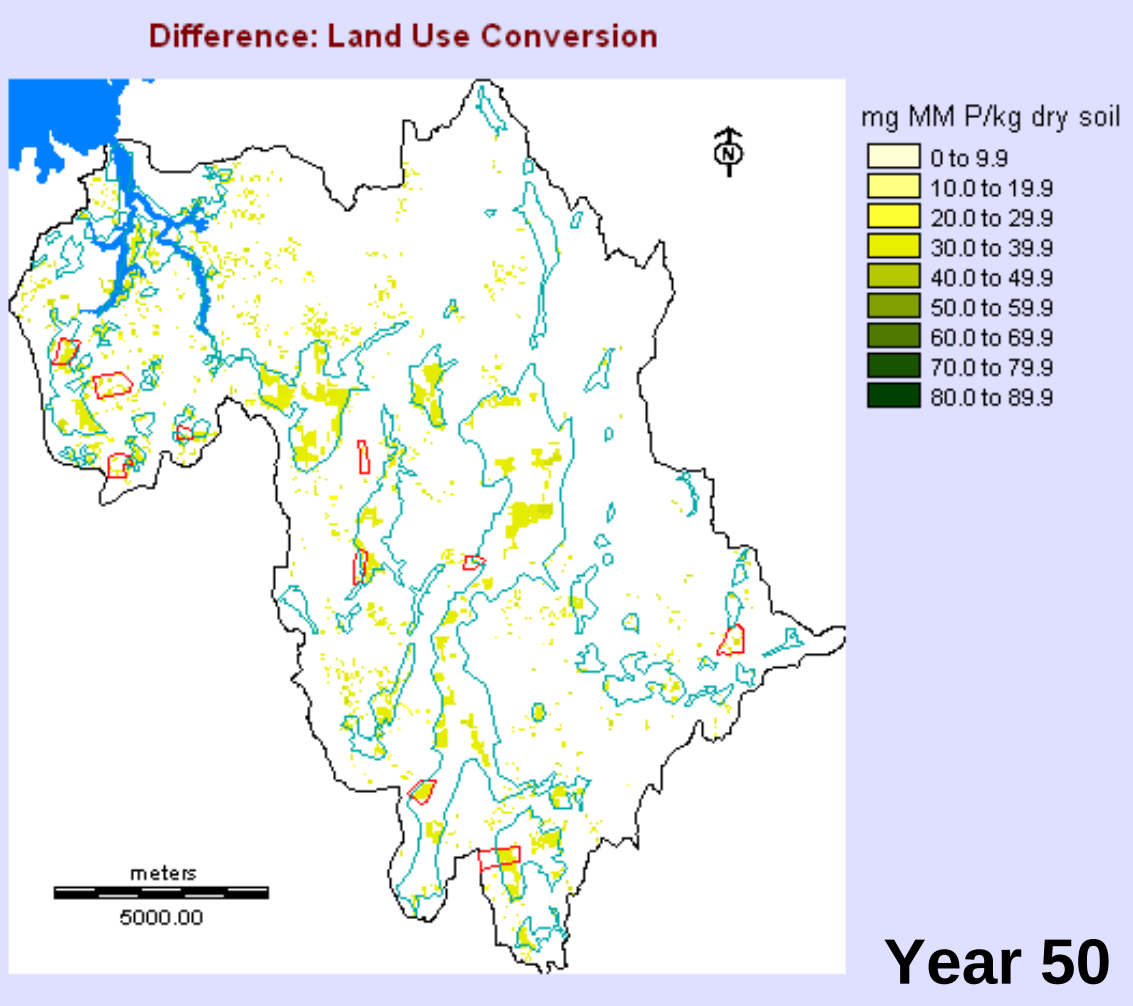
Model results
Land Use Change



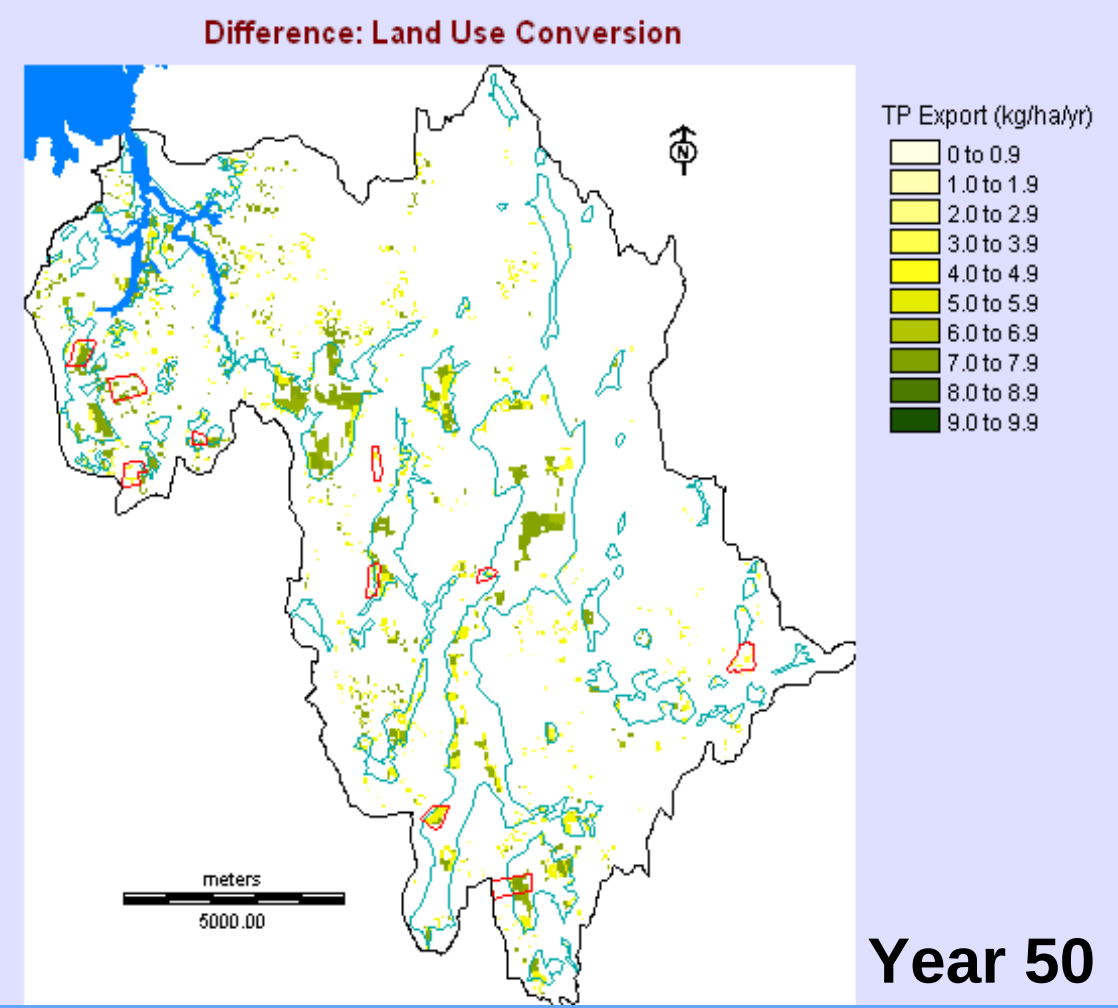
Model results
Land Use Change



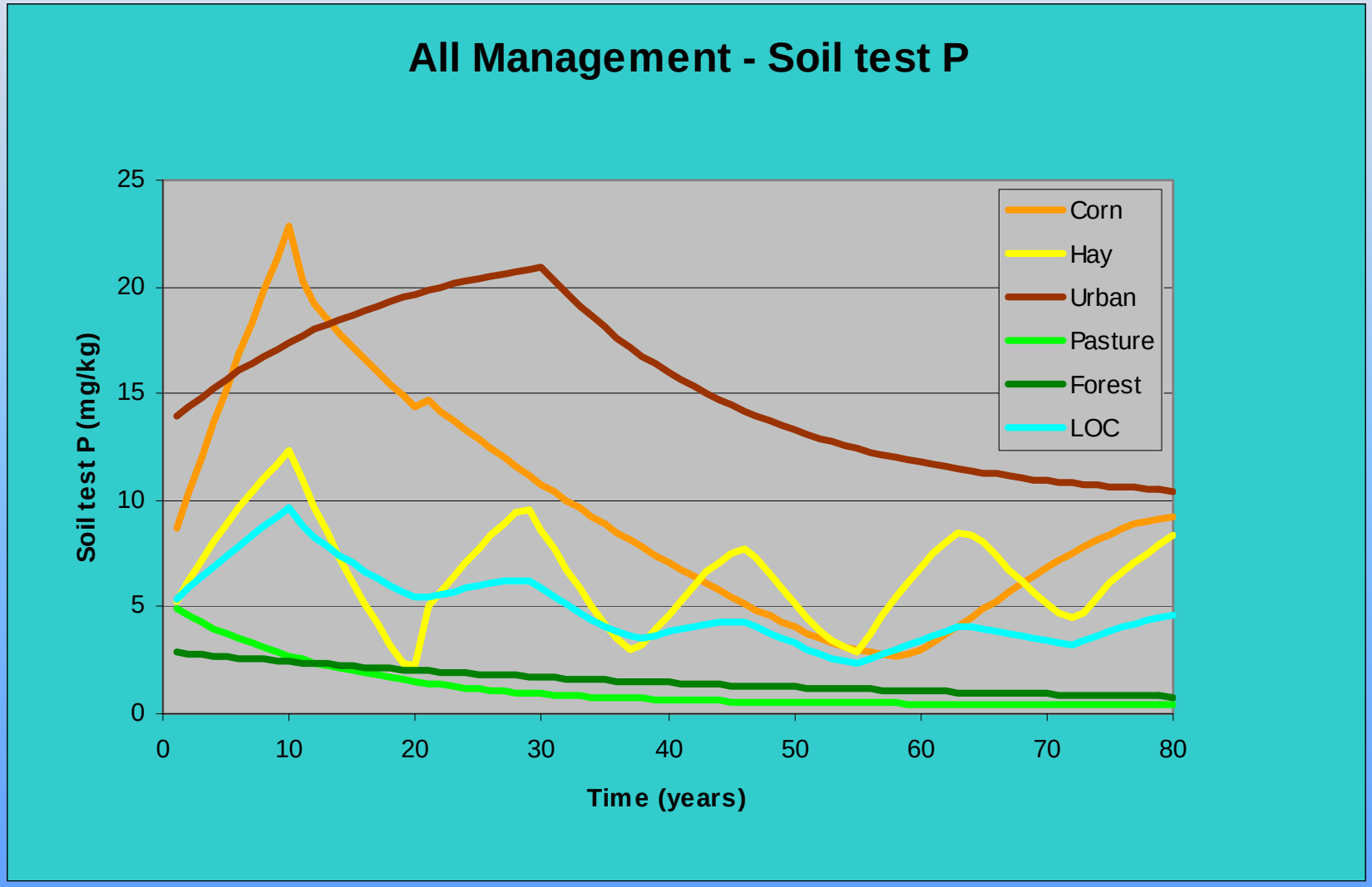
Model results
LU Change – soil test P



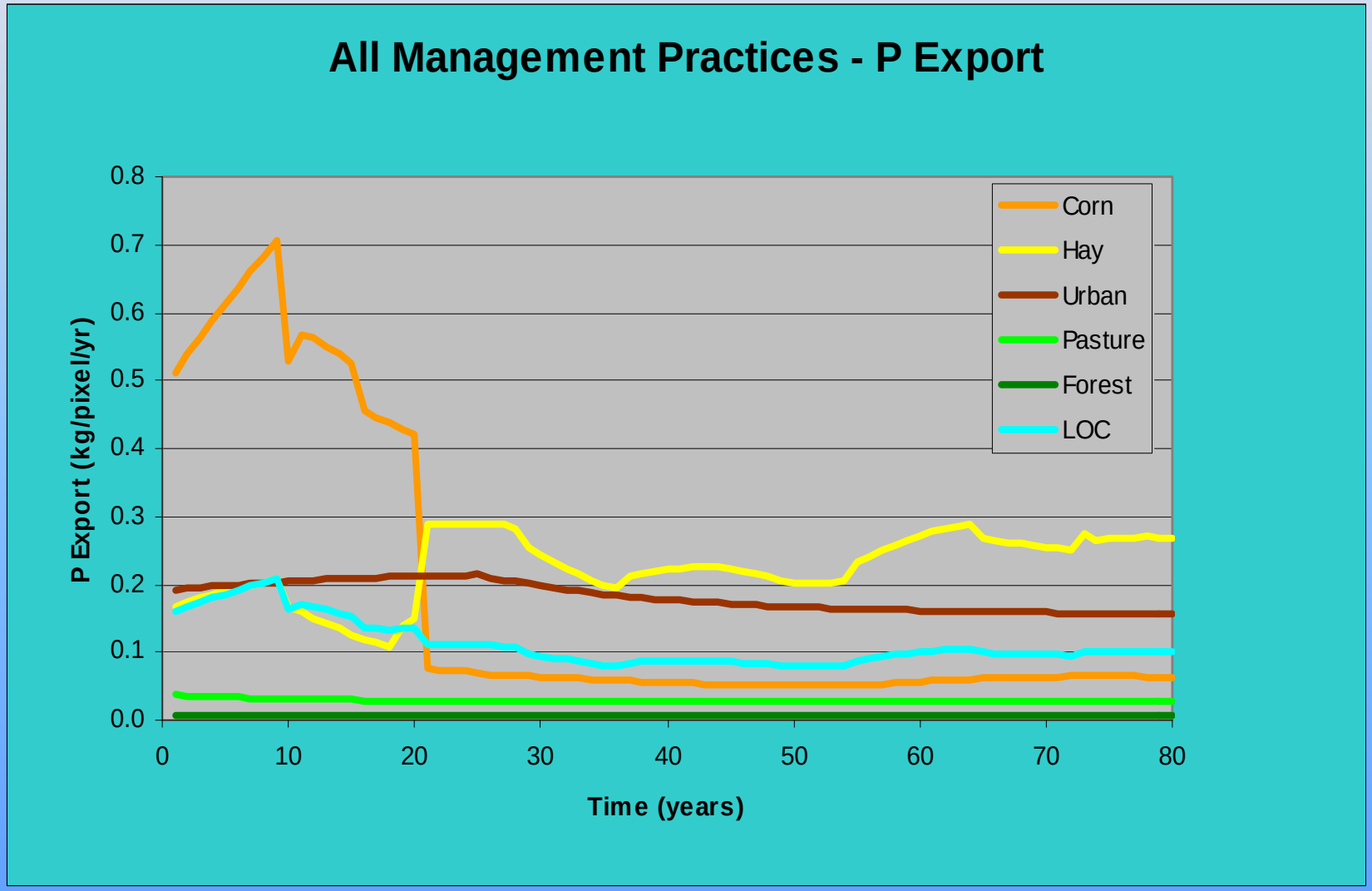
Model results
LU Change – P export



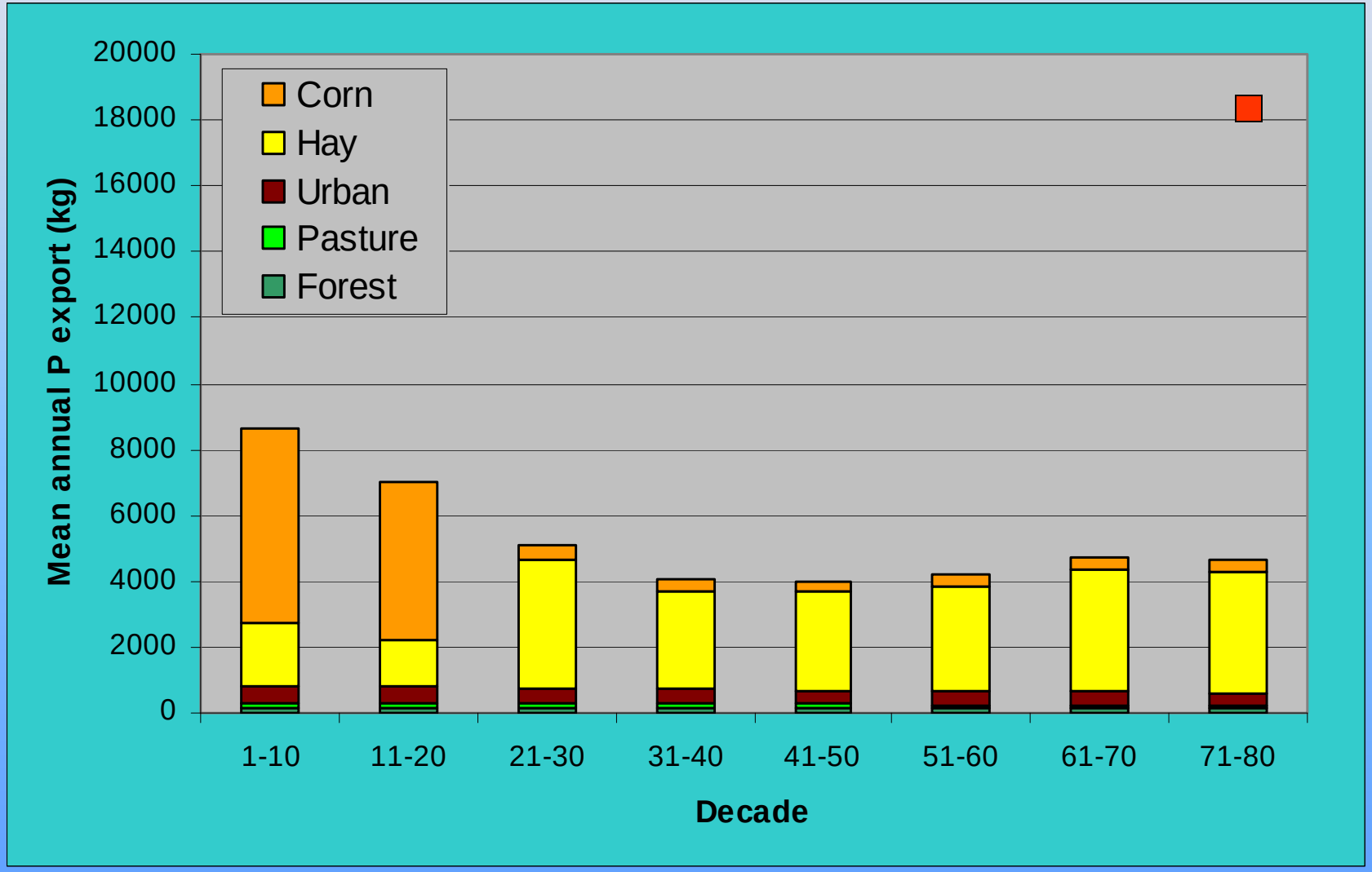
Model results
All Management



Model results
All Management



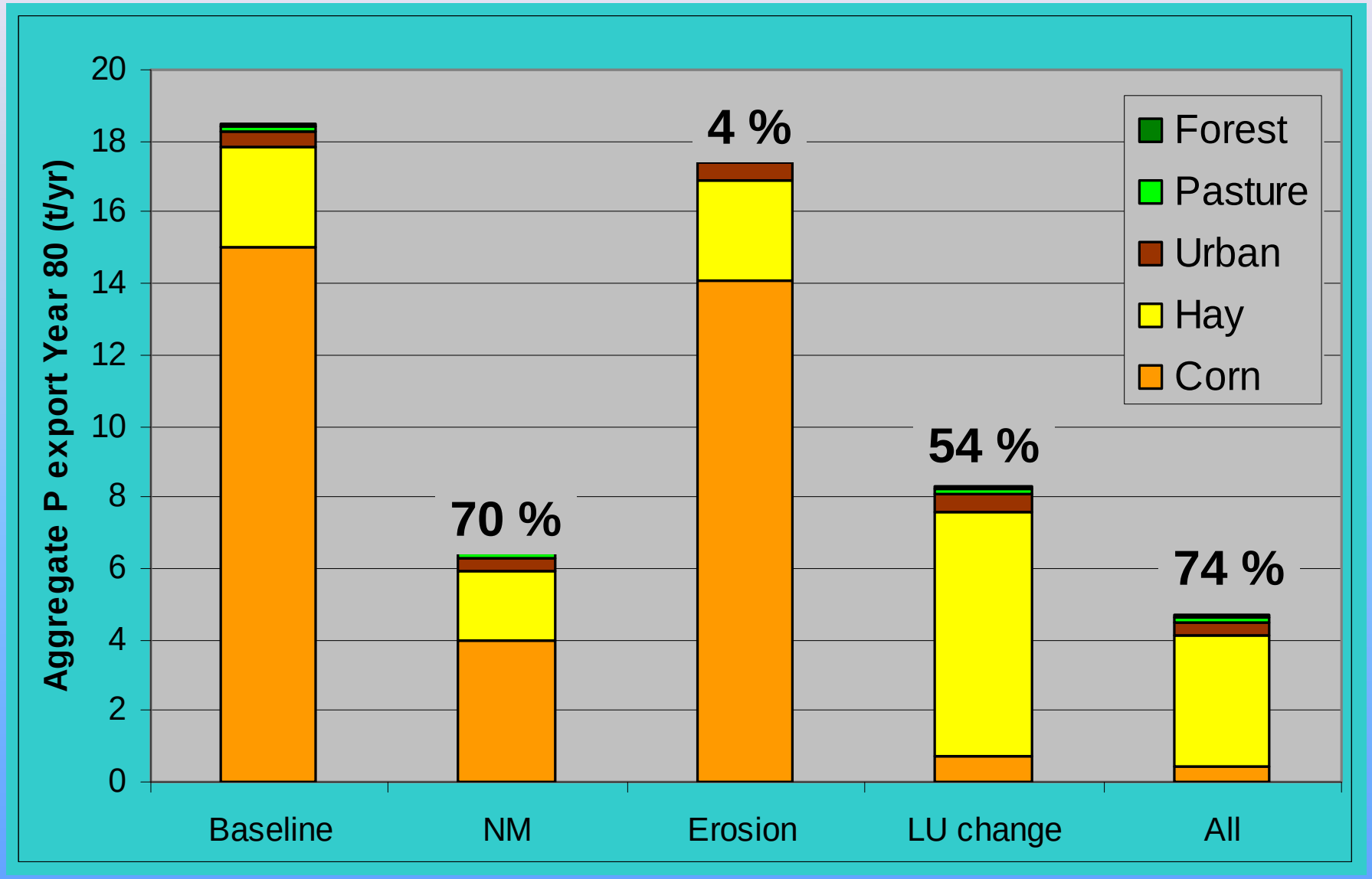
Model results
All Management



Conclusions

Scenario	Average pixel soil test P (mg/kg) – Year 71-80				
	Corn	Hay	Urban	Pasture	Forest
Baseline	80.9	22.7	22.5	0.4	0.8
NM	9.0	8.6	10.6	0.4	0.8
Erosion control	80.9	22.7	22.5	0.4	0.8
Land use change	86.9	23.8	22.5	0.4	0.8
All management	9.2	8.5	10.5	0.4	0.8

Conclusions



Conclusions

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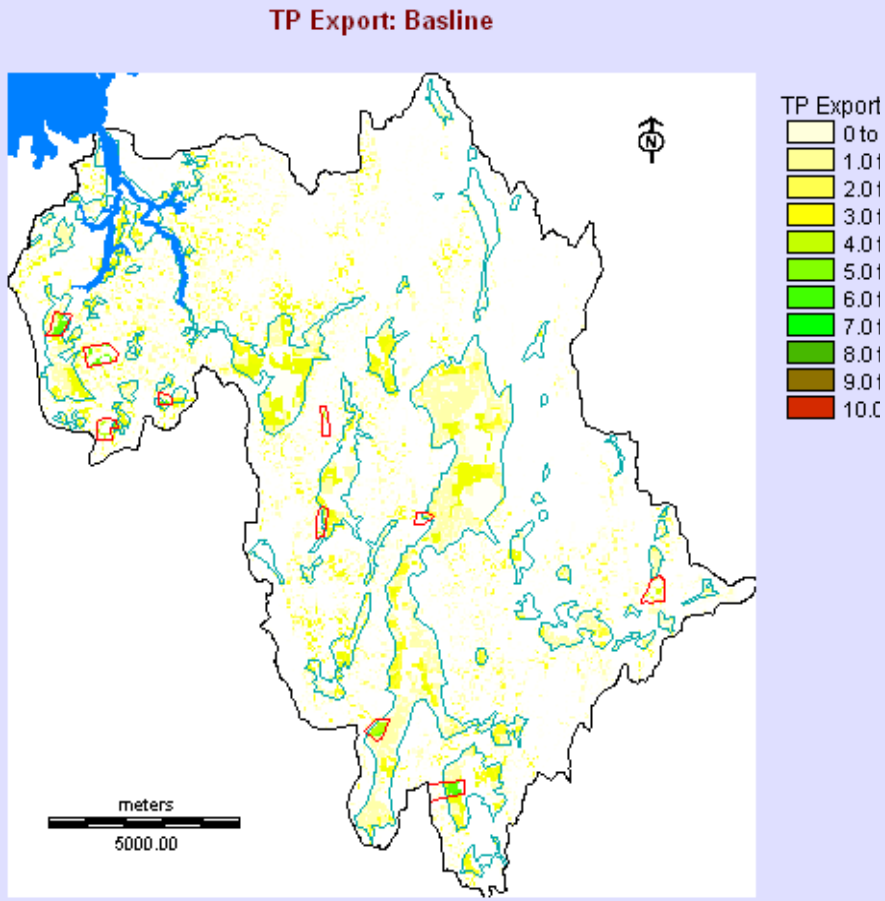
- **Areas of P accumulation and high risk of P export not uniformly distributed across a watershed or even within a land use**

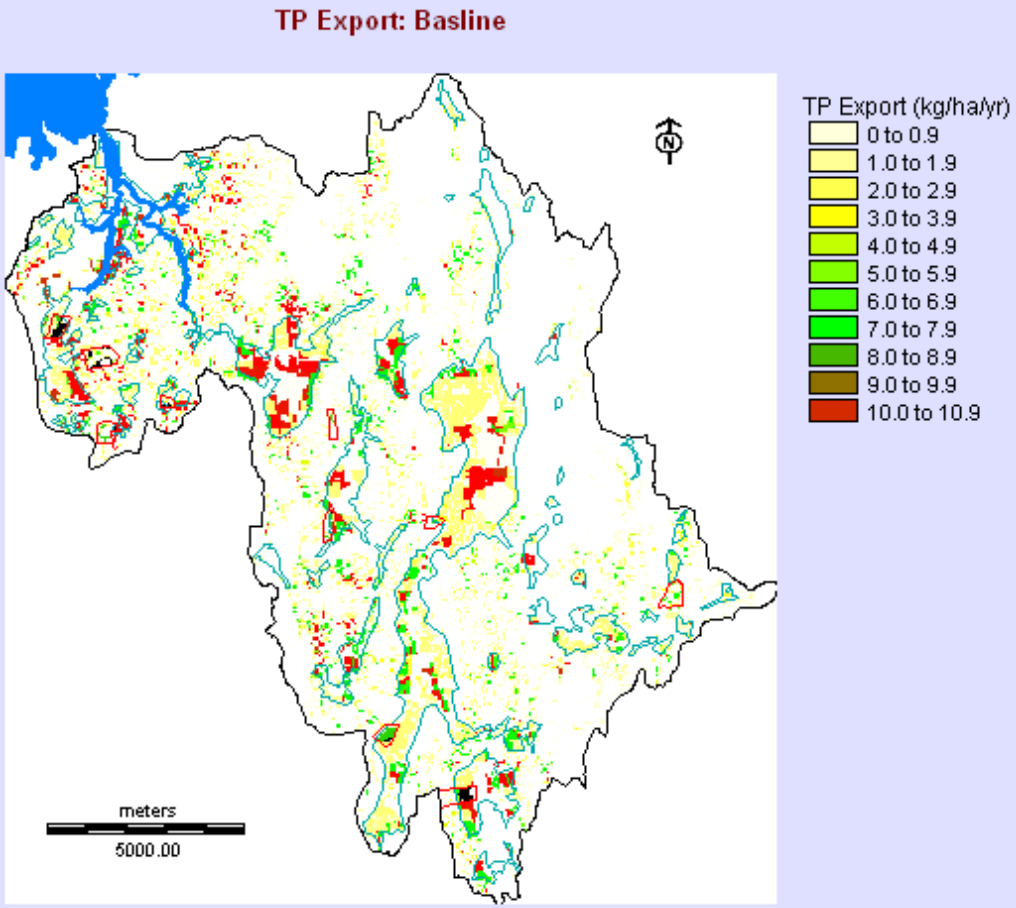
- **Hotspots reflect combinations of geophysical and management characteristics that change through time and can change in response to management**

- **Targeted application of management measures, even acting on only a fraction of watershed land, can significantly reduce the accumulation of P in watershed soils and significantly reduce P export.**

Conclusions

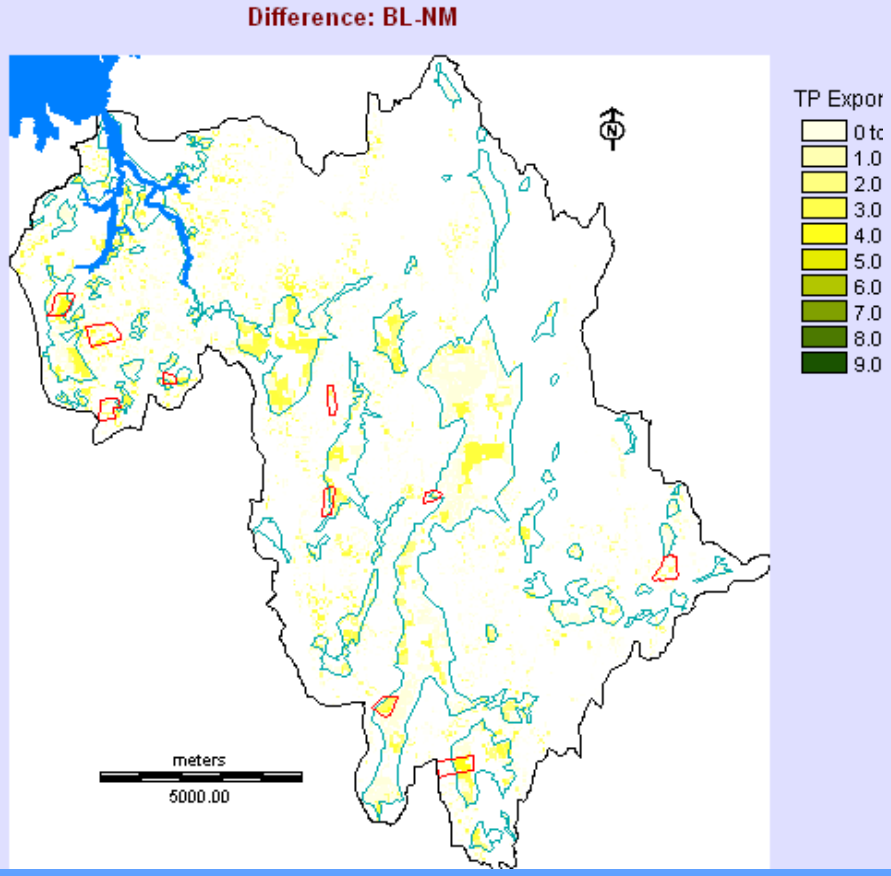
- If present-day management continues, soil test P and P export will inevitably increase

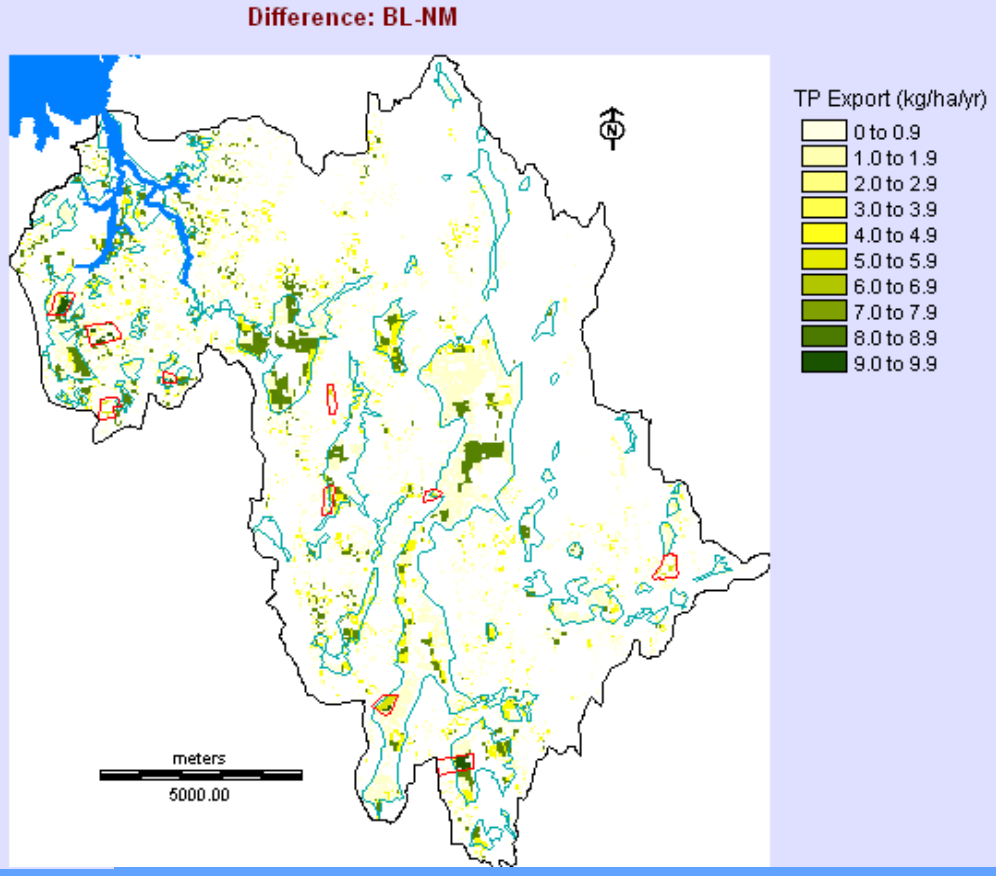




Conclusions

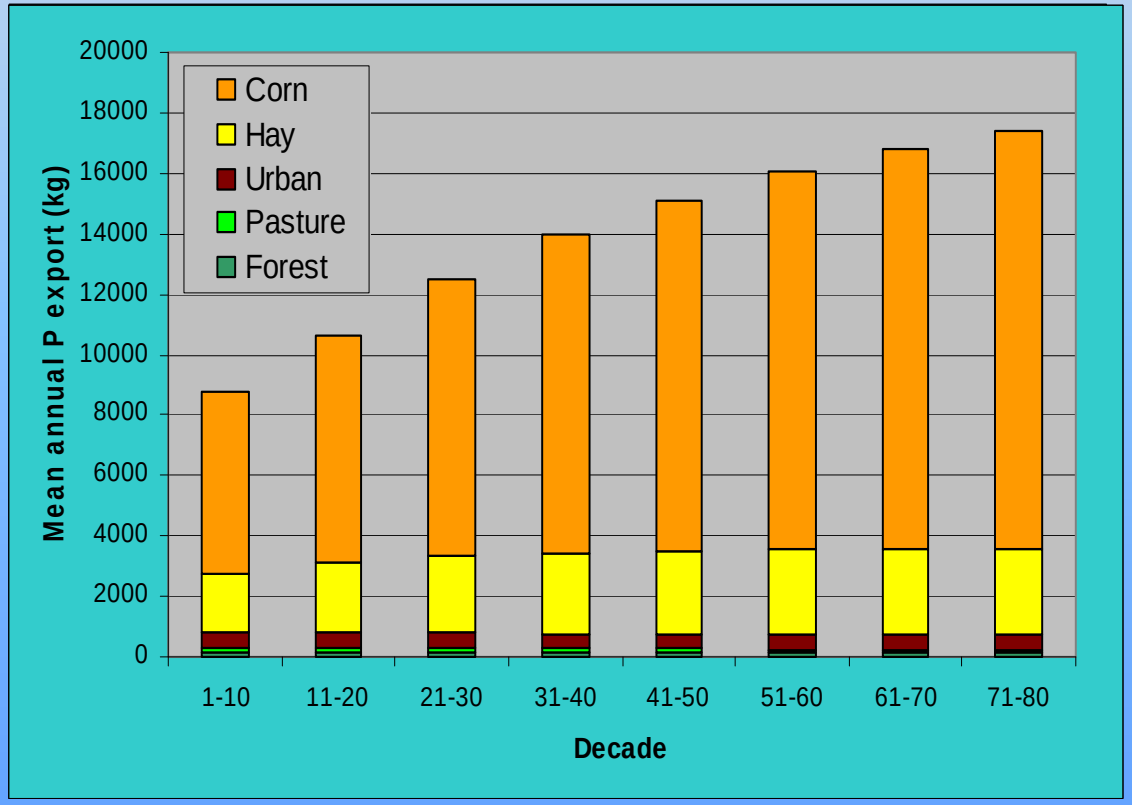
- The only way to affect soil test P is to achieve a better P balance; the only effective measure was nutrient management.





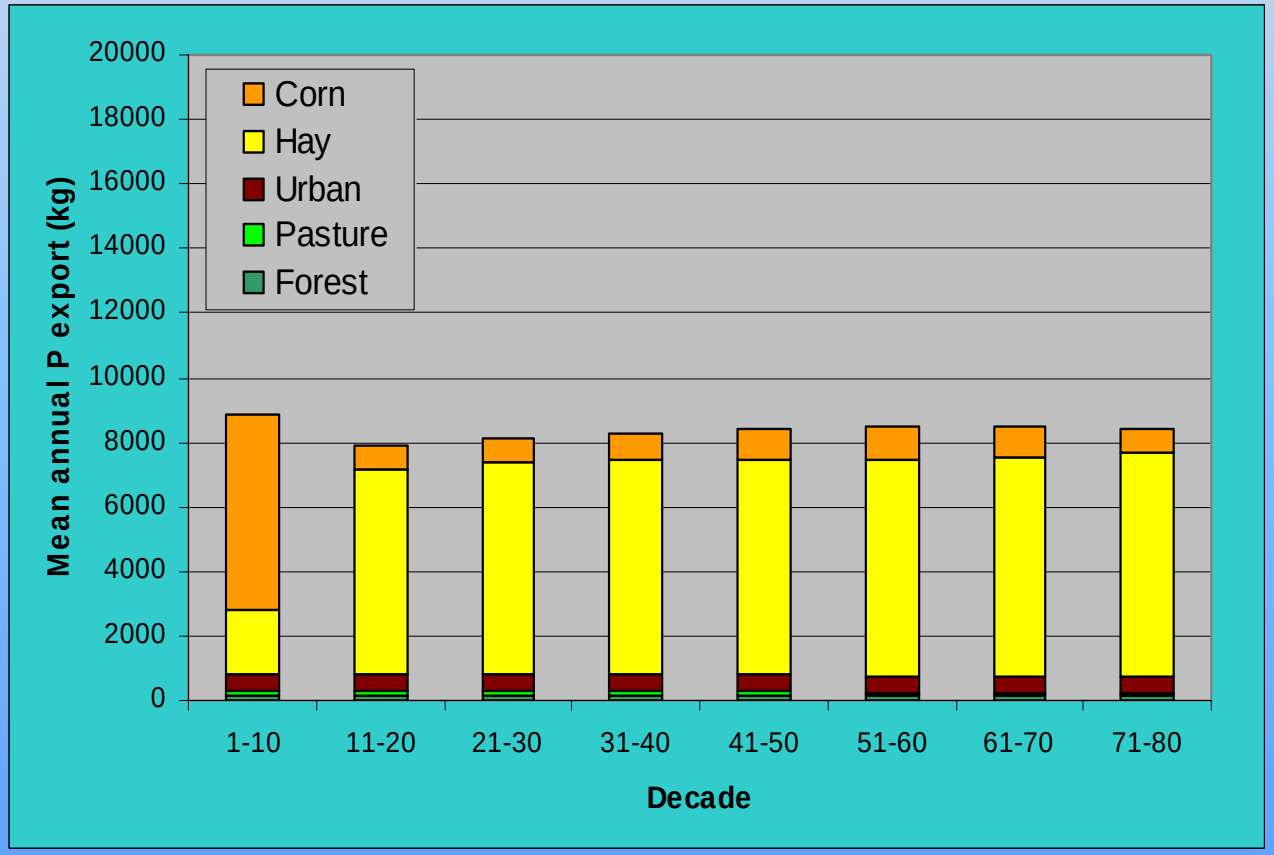
Conclusions

- **Erosion control has little or no effect on soil test P and only a transitory reduction in P export**



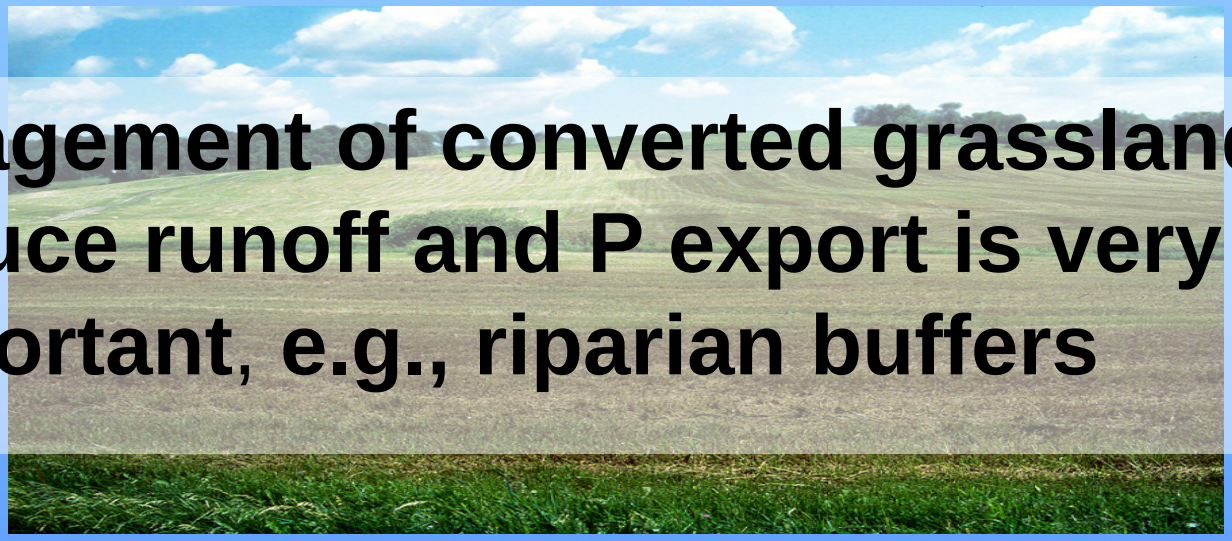
Conclusions

- **Conversion of row crop land to permanent grass land can reduce P export, but not soil test P.**



Conclusions

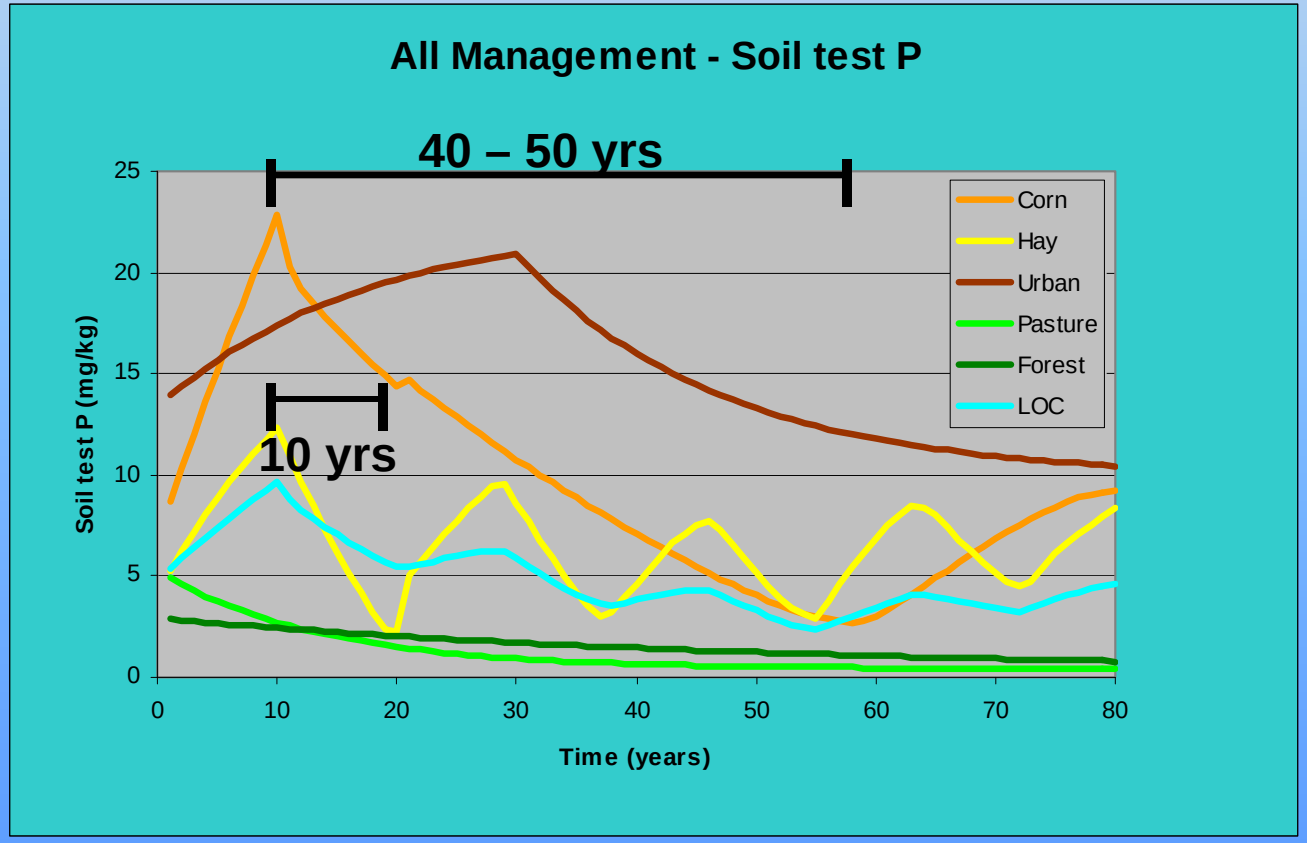
- **Important implications of conversion of row crop land to grassland**
  - **New hay land inherits high soil P**
  - **P export from new hay land higher than "old" hay land**



★ **Management of converted grassland to reduce runoff and P export is very important, e.g., riparian buffers**

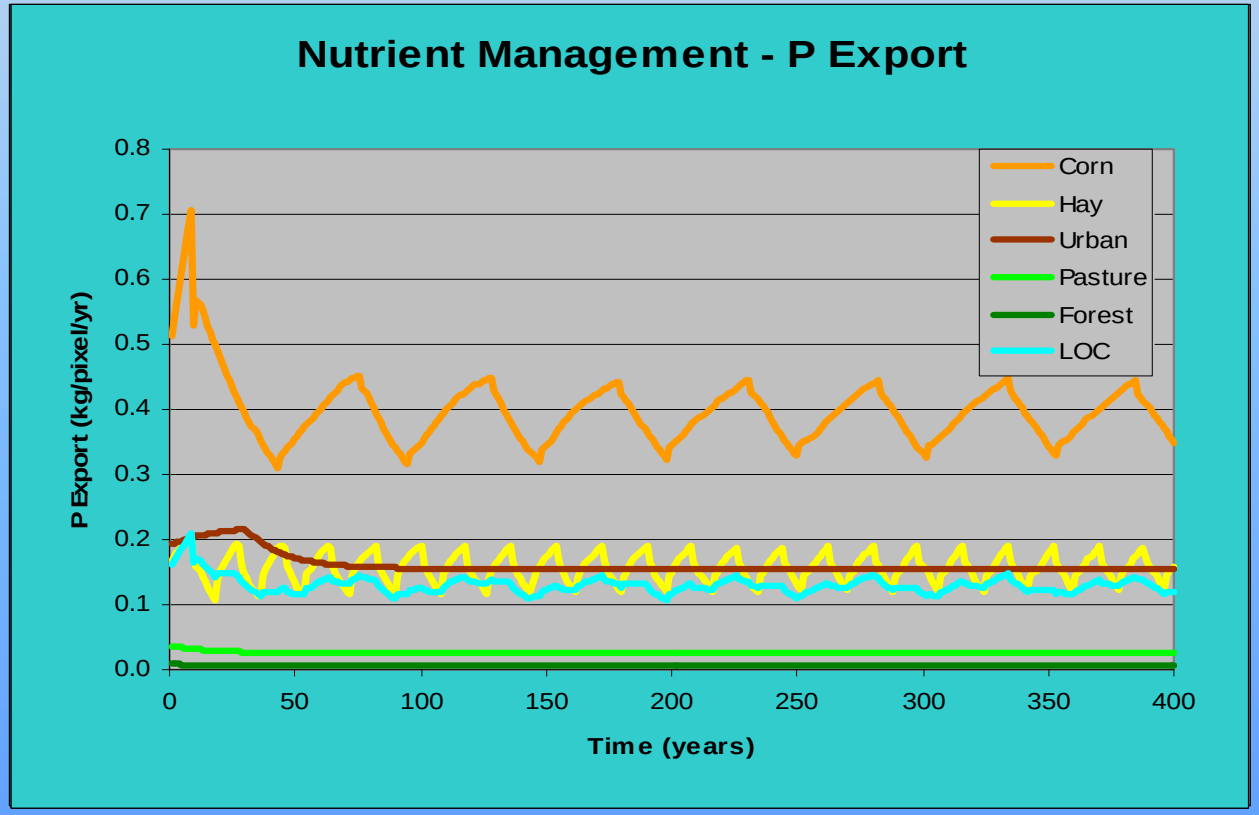
Conclusions

- **Even after P inputs are drastically reduced there will be a substantial lag-time before soil test P and P export decline to sustainable levels**



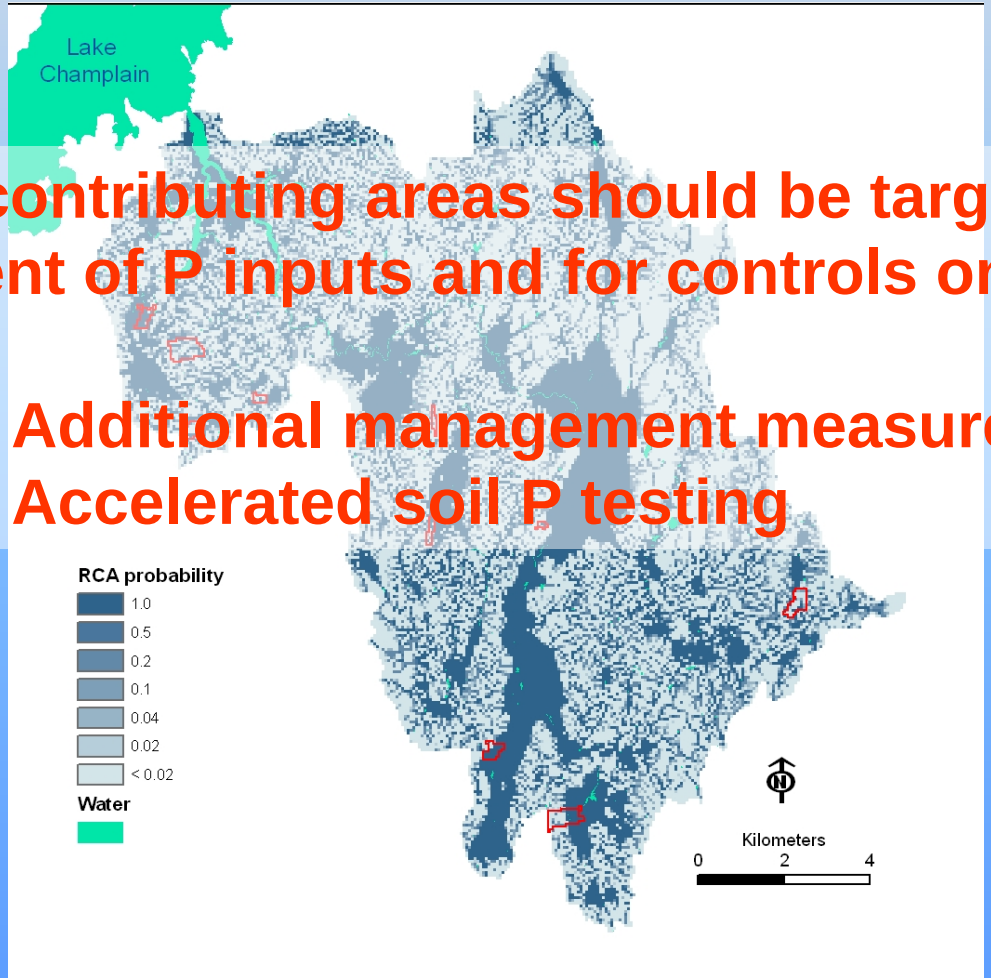
Conclusions

- **Even with very stringent management, neither soil test P nor P export achieve a constant level over time.**



Conclusions

- **Regardless of land use, runoff contributing areas are critical to P export**



Runoff contributing areas should be targeted for management of P inputs and for controls on P export.

Additional management measures
Accelerated soil P testing

Curve Number selection

Land Use	Hydrologic Soil Group			
	A	B	C	D
Corn	70	80	86	90
Hay	58	72	81	85
Pasture	39	61	74	80
Urban	72	77	84	87
Forest	25	55	70	77
Undefined	49	69	79	84

Design storms and estimated runoff

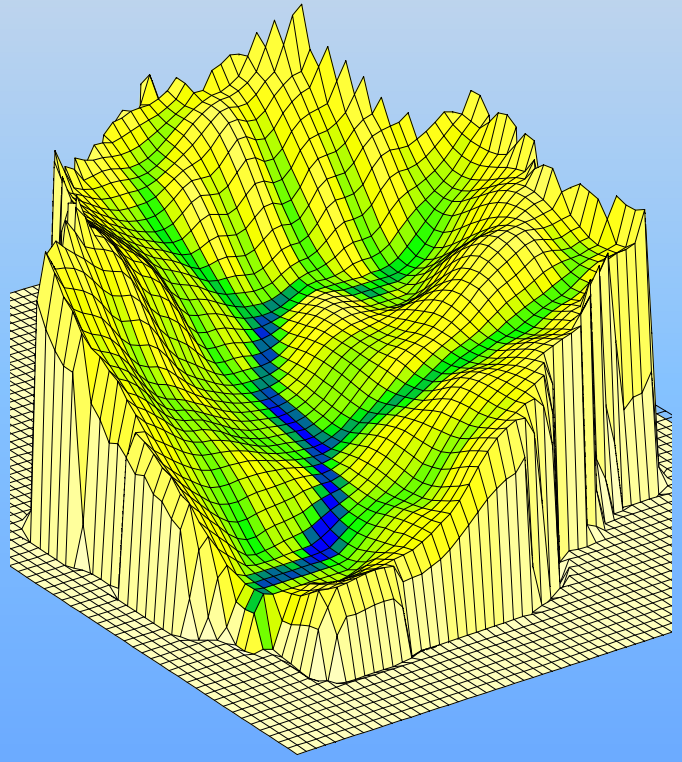
Storm (24 hr)	Precipitation (in.)	Runoff (in.)	% RCA	RCA Probability
1 yr	2.1	0.58	27%	1.00
2 yr	2.5	0.81	32%	0.50
5 yr	3.4	1.42	41%	0.20
10 yr	3.8	1.71	45%	0.10
25 yr	4.5	2.25	50%	0.04
50 yr	4.9	2.57	52%	0.02
>50 yr	>4.9	> 2.57	48%	0.001

- Identify probable runoff contributing areas

Wetness Index

(D.G. Tarboton, Utah State)

- **DEM**



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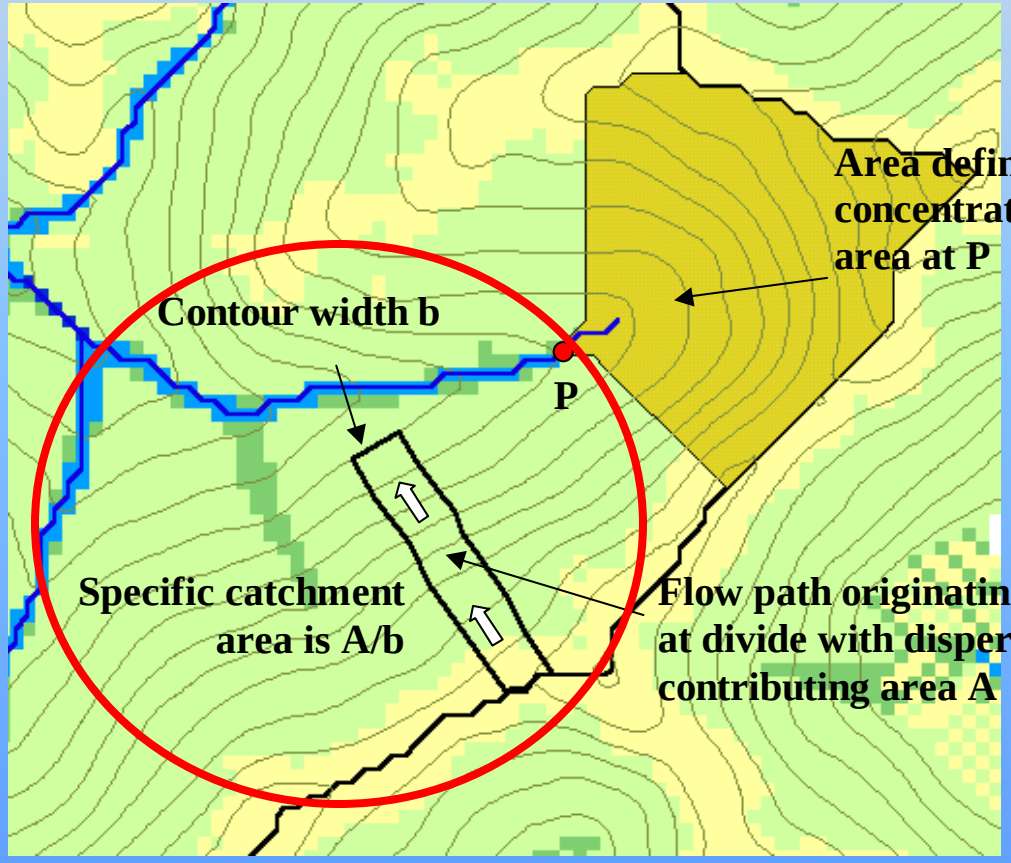
- DEM
- **Flow path analysis**



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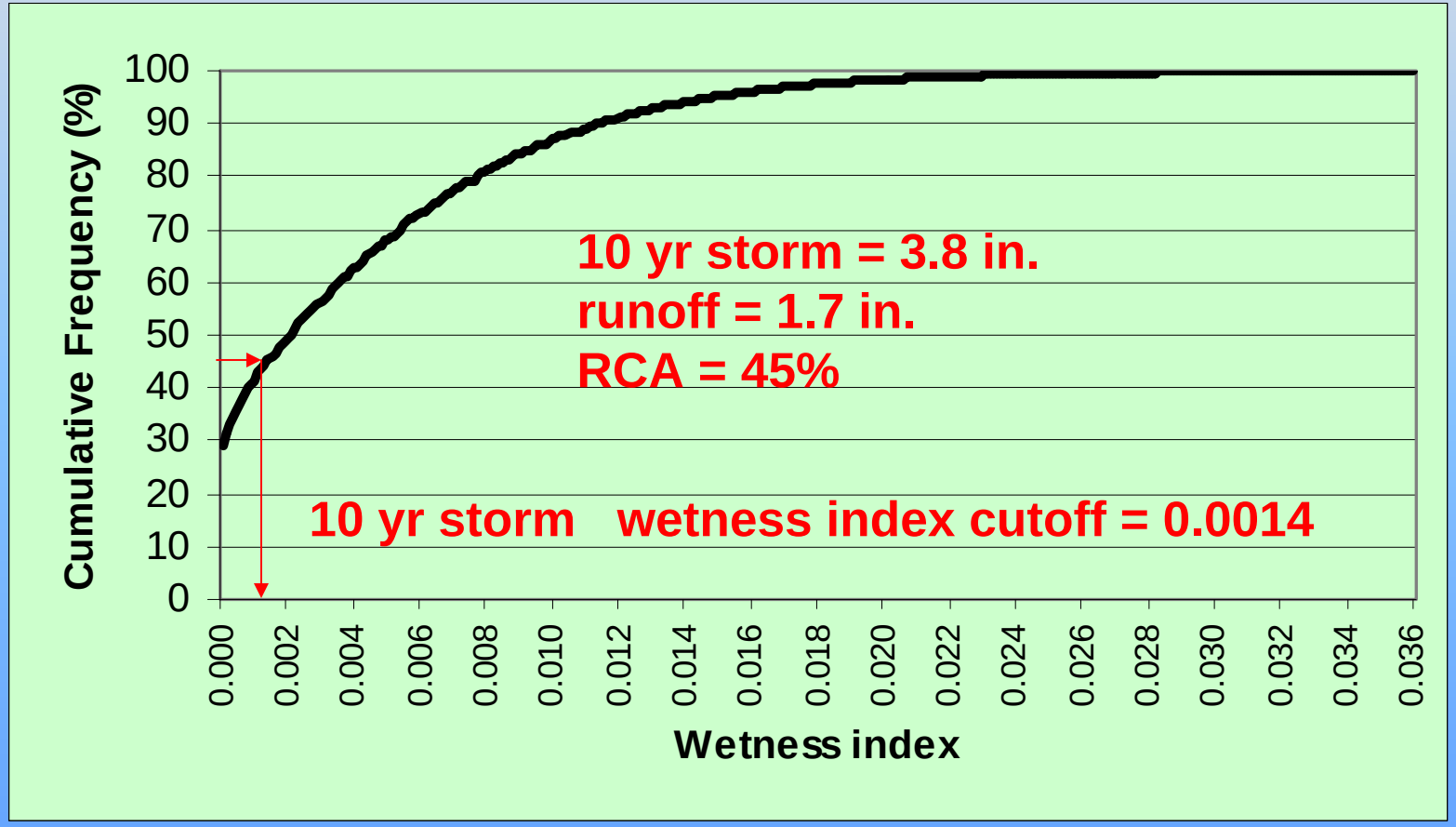
<u>Slope (b)</u>
Catchment area (a)

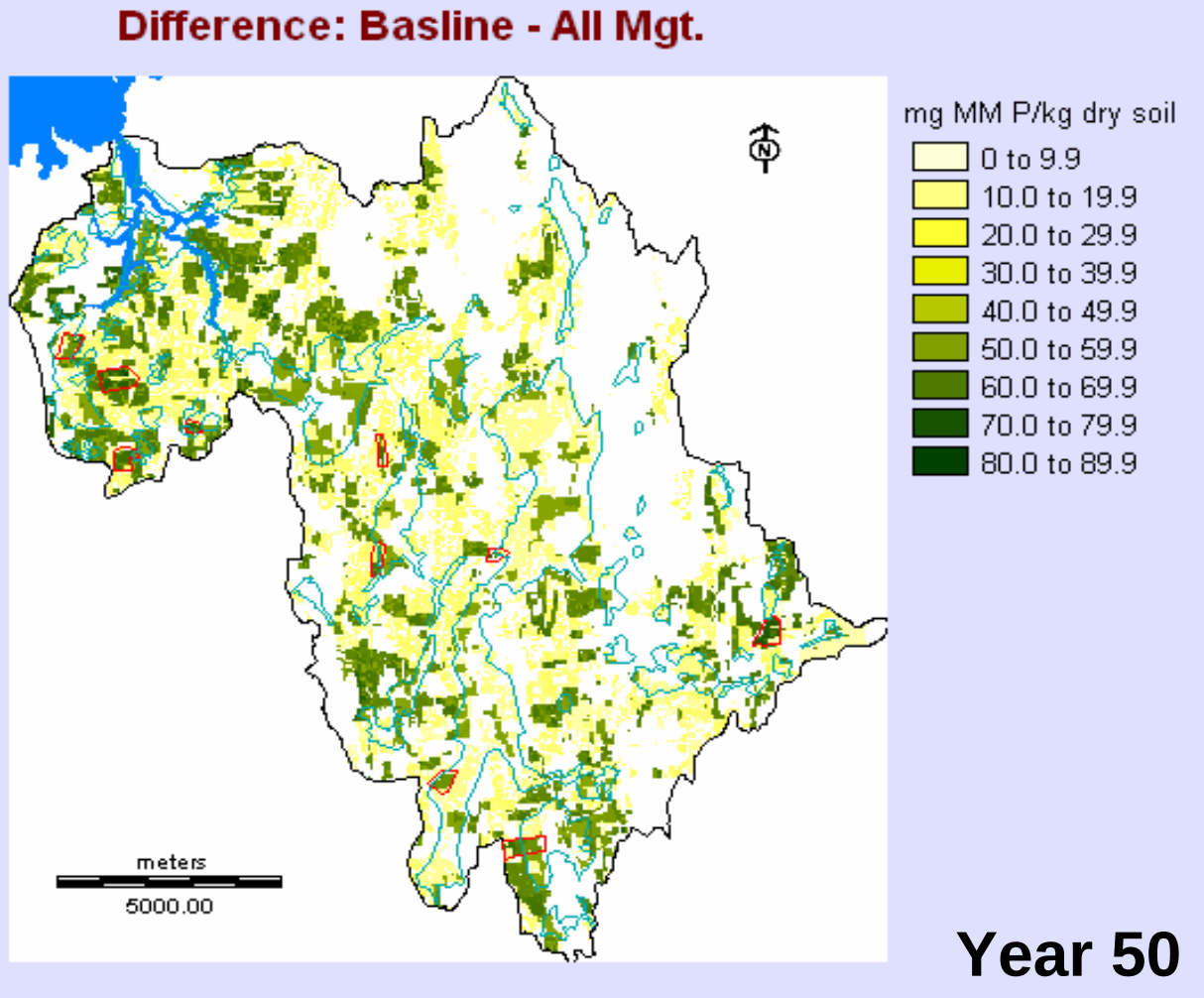
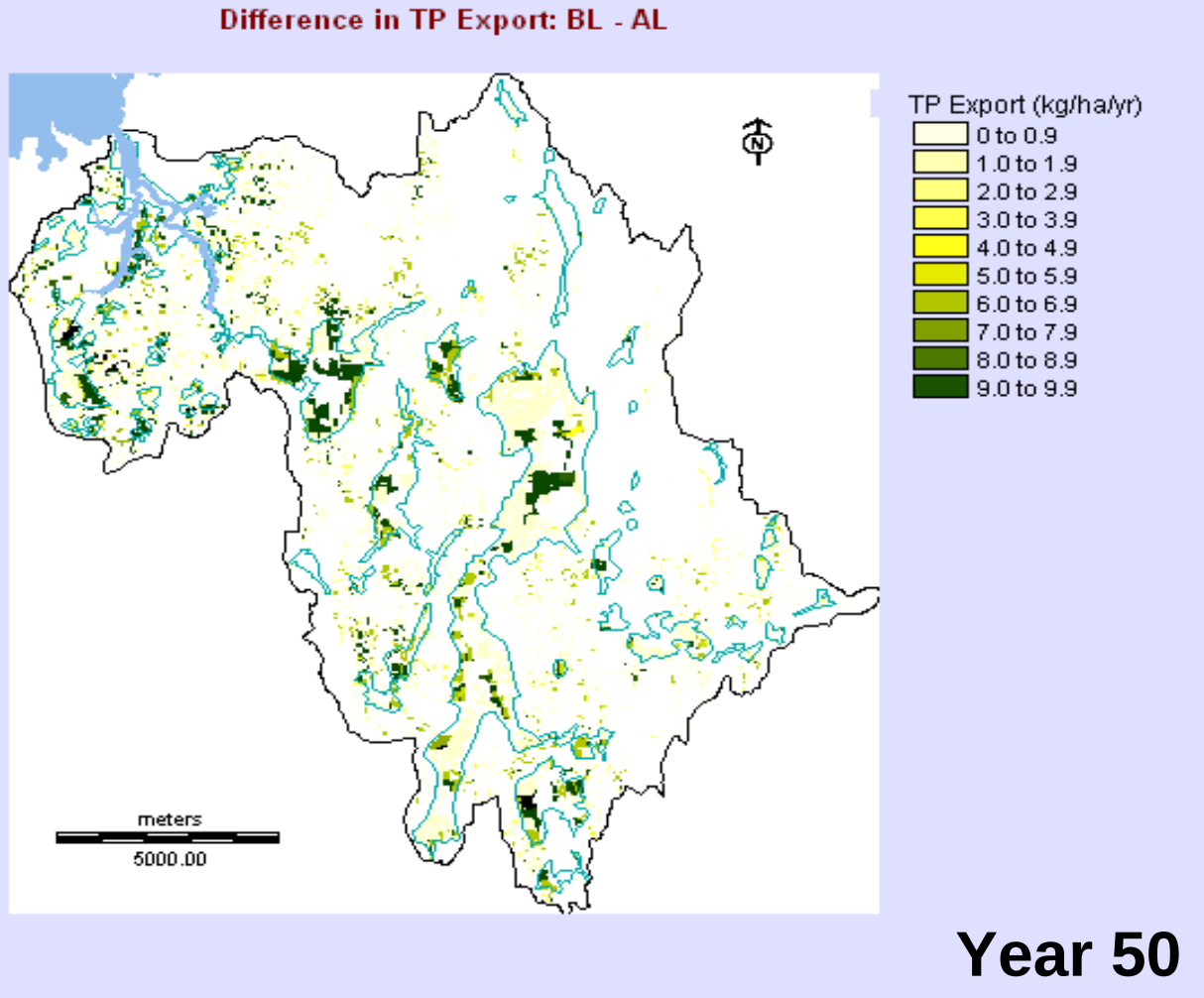
ln (tanb/a)

Inverse of topographic index (TOPMODEL) to avoid division by zero in areas of zero slope

- Identify probable runoff contributing areas



Model results
All Management – soil test P



Model results
All Management –P export