Cost-effective Allocation of Conservation Practices using Genetic Algorithm with SWAT

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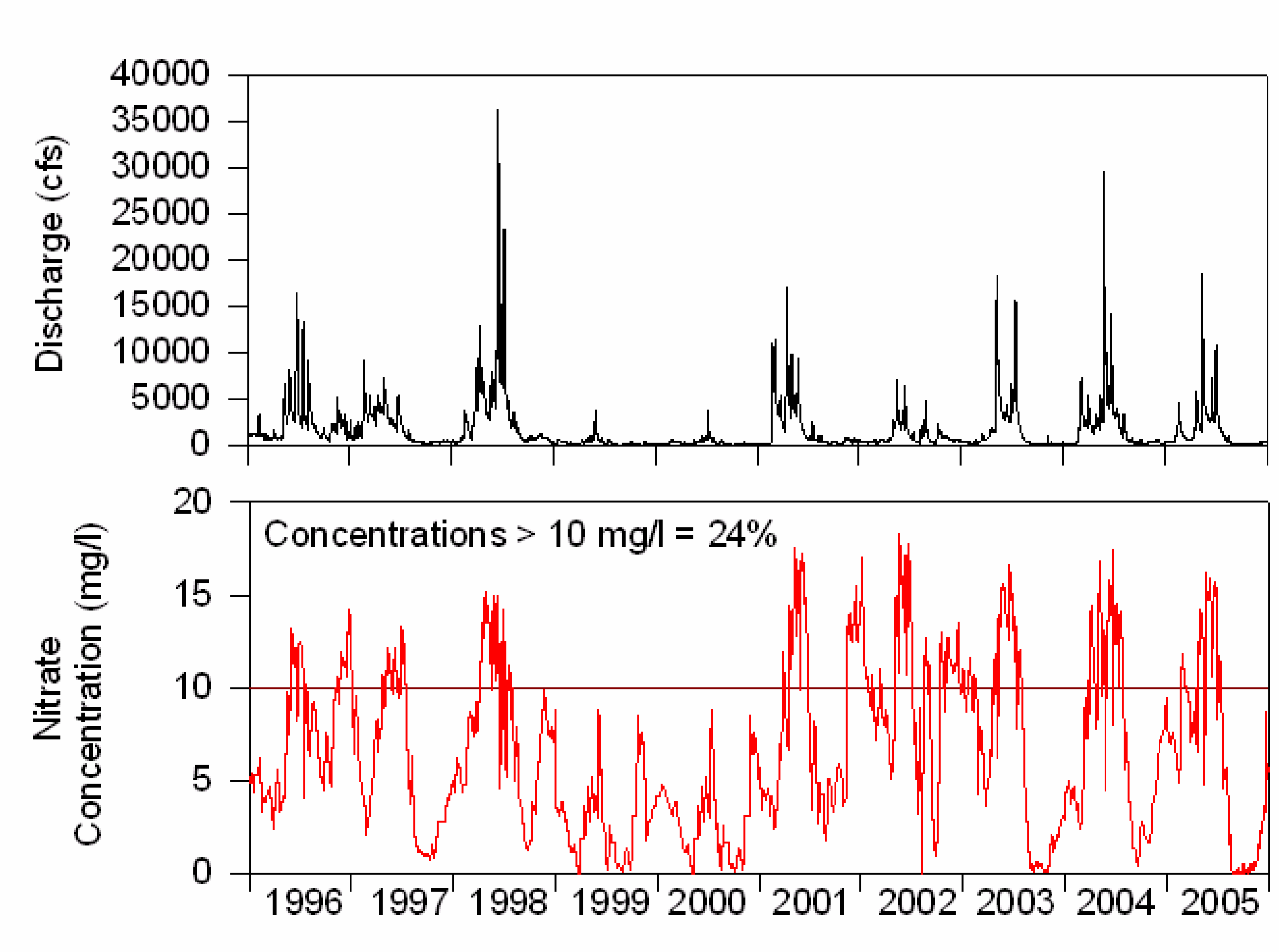
Raccoon River Watershed

Raccoon River Watershed

- Covers approximately 9,400 km^2 of West Central Iowa
- Surface water from the Raccoon River is for drinking water supply for more than 370,000 residents in Des Moines and in other central Iowa communities
- *Class C* water quality standard applies to the Raccoon River at the intake – USEPA MCL for Nitrate: 10 mg/L
- Nitrate concentration often exceeds MCL (exceeds 24% of the time from 1996-2005)



- Average concentration = 6.45 mg/L (range over 0-18.3)
- Peaked greater than 12 mg/L for 8 of the 10 monitored years
- Exceeded 10 mg/L 24% of the time from 1996-2005

Des Moines Water Works (DMWW) – World's largest nitrate removal facility (10 millions gal. of water per day)

Raccoon River Watershed

- Non Point agricultural sources are the principal contributor of the elevated nitrate concentration
- Prime agricultural area dominated by corn and soybean production in over 75% of the watershed
- Nitrate is primarily delivered to stream with subsurface flow including baseflow and tile drainage
- Baseflow contribution to nitrate loads are greater than 80% in late fall and spring

SWAT Model

- Physically based and continuous watershed scale hydrology and water quality model
- Operates on a daily time step
- Developed to predict impacts of land management practices on watershed hydrology and water quality
- Extensively used world wide; over 250 peer reviewed publications

SWAT Model

- In SWAT modeling:

  - a watershed is divided into multiple subwatershed which are further subdivided in0to lumped units called hydrologic response units (HRUs)

  - hydrology and water quality components are computed at HRU and then the resulting loadings are summed together at subwatershed level which are then routed through main channels and reservoirs to the watershed outlet.

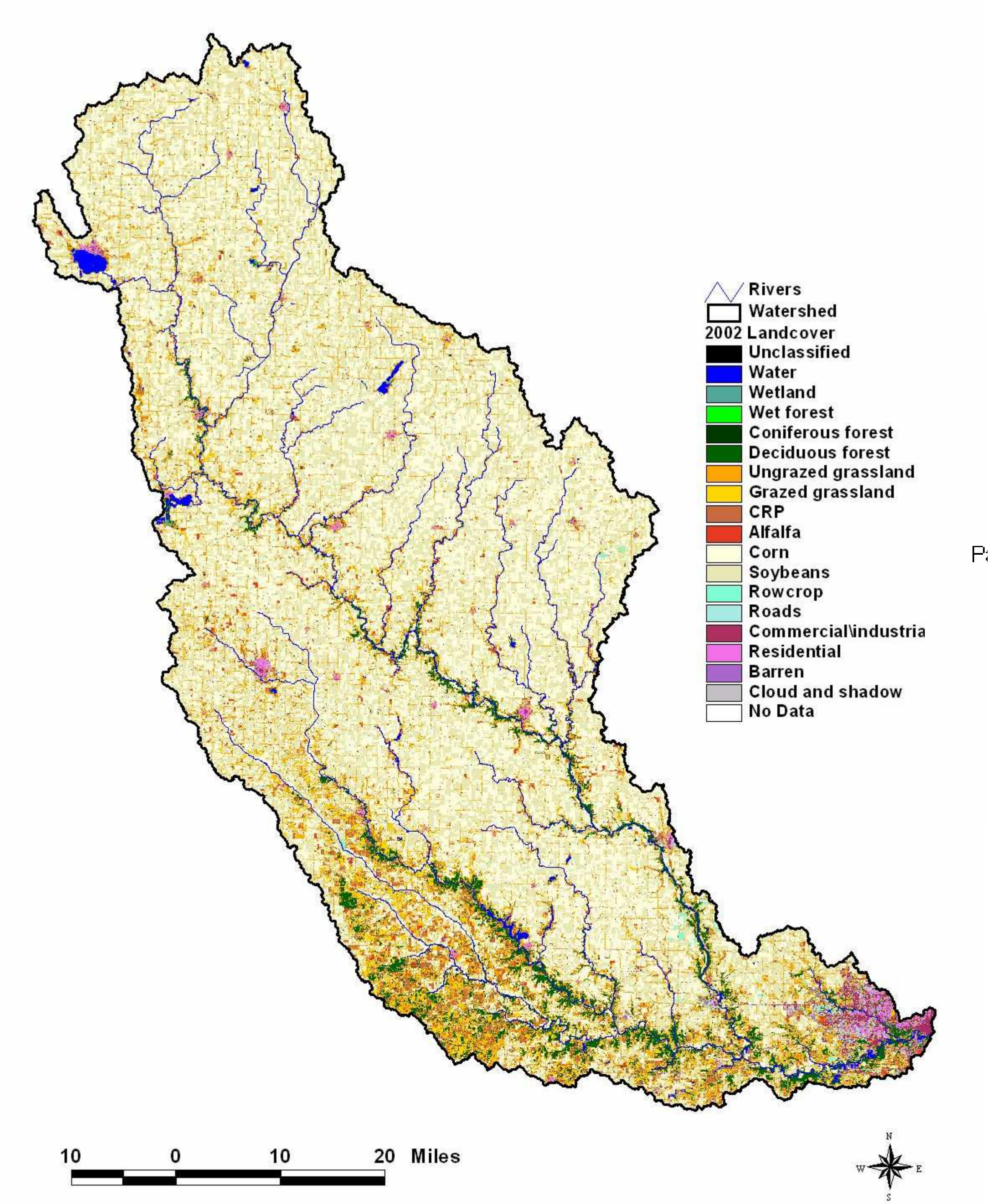
SWAT Model Setup

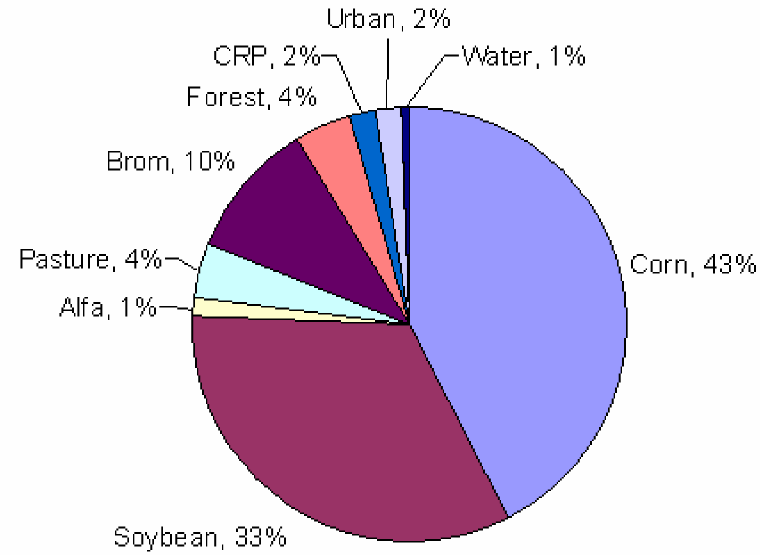
- Topography: 30m DEM
  USGS Seamless Data Distribution System
  EROS data center
  http://seamless.usgs.gov

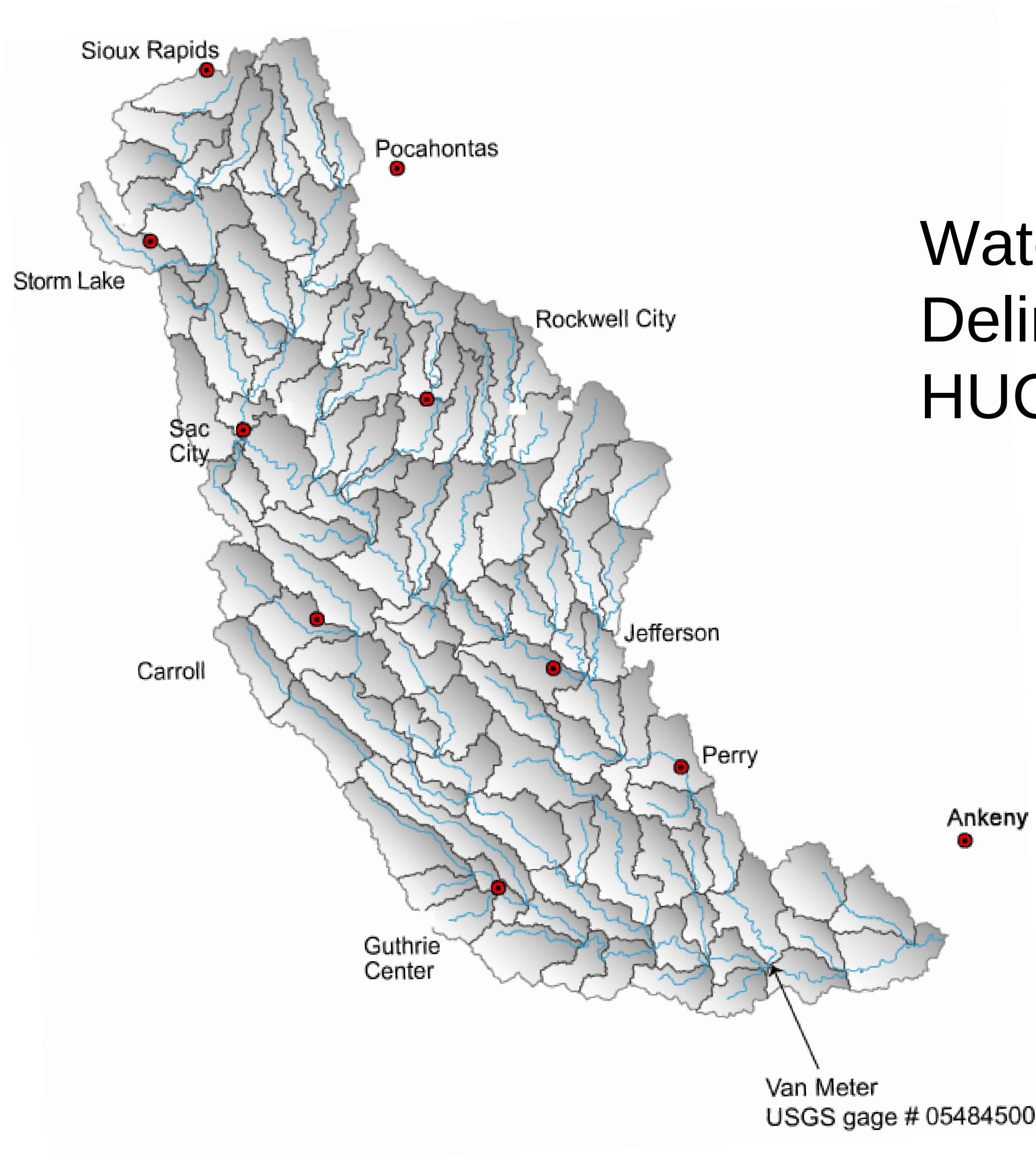
- Landuse data: 2002 Landcover
  Iowa DNR GIS Library
  http://www.igsb.uiowa.edu/nrgislibx

- Soil data: SSURGO
  NRCS Soil Data Mart
  http://soildatamart.nrcs.usda.gov

- Climate data: National Weather Service COOP
  Iowa Environmental Mesonet
  http://mesonet.agron.iastate.edu/index.phtml


Rivers
Watershed
2002 Landcover
Unclassified
Water
Wetland
Wet forest
Coniferous forest
Deciduous forest
Ungrazed grassland
Grazed grassland
CRP
Alfalfa
Corn
Soybeans
Rowcrop
Roads
Commercial\industria
Residential
Barren
Cloud and shadow
No Data
10
0
10
20
Miles


Urban, 2%
CRP, 2%
Water, 1%
Forest, 4%
Brom, 10%
Pasture, 4%
Corn, 43%
Alfa, 1%
Soybean, 33%



Watershed Delineation at HUC12 level

SWAT Model Setup

<u>Tile Drainage</u>

Classification method for soil require tile drainage:

slope ≤ 5%; drainage class > 40 (poor through very poor); and subsoil groups 1and 2 (clay < 40%)

OR

slope ≤ 2%; drainage class of poor to very poor; and hydrologic group D

SWAT Model Setup

Fertilizer Application

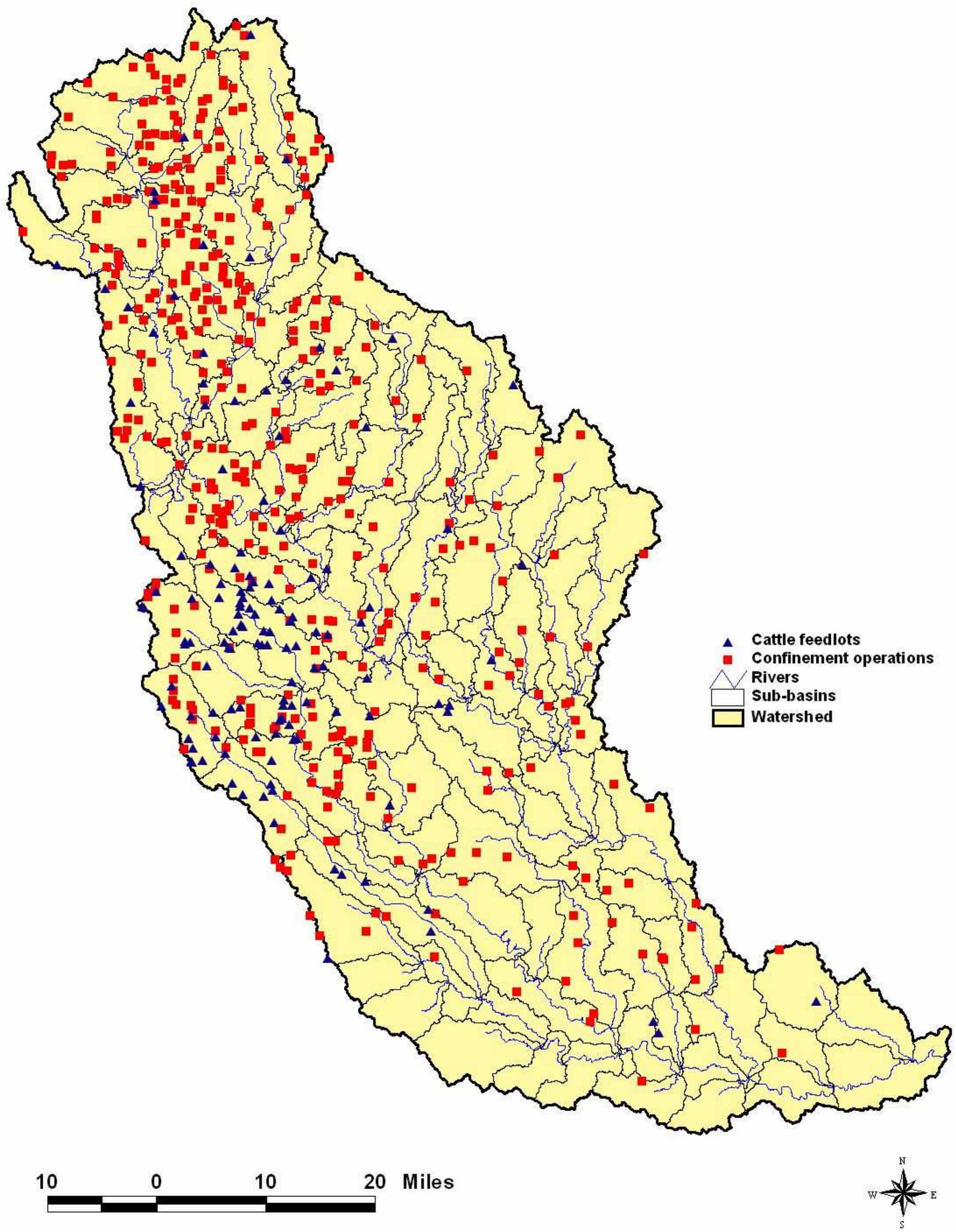
Iowa Department of Agricultural and Land Stewardship (IDALS)
Iowa Ag Census data

Manure Application

Manure from feedlots (cattle manure)
Manure from grazing operation (cattle on pasture)
Manure from CAFOs

Point Source Data

Cattle in Streams
Septic discharge (US Census data)
WWTP discharge (Iowa DNR)



Summary N Inputs (MT)

Fertilizer	57,663
Manure	31,528
Human	442
Industry	83

SWAT Model Setup

- ArcView GIS interface of the SWAT model (AVSWAT) was used for watershed delineation:
  - 108 subwatersheds
  - more than 3,500 HRUs
- SWAT model version 2005 was used in the simulation

Rainfall-runoff	: CN method
Evapotranspiration	: Penman-Monteith
Channel Routing	: Muskingum method

Modeling Results

Hydrologic balance of the watershed

(ave. annual values for 1986-2004)

Precipitation = 840 mm

Snowfall = 94 mm

Surface runoff = 96 mm

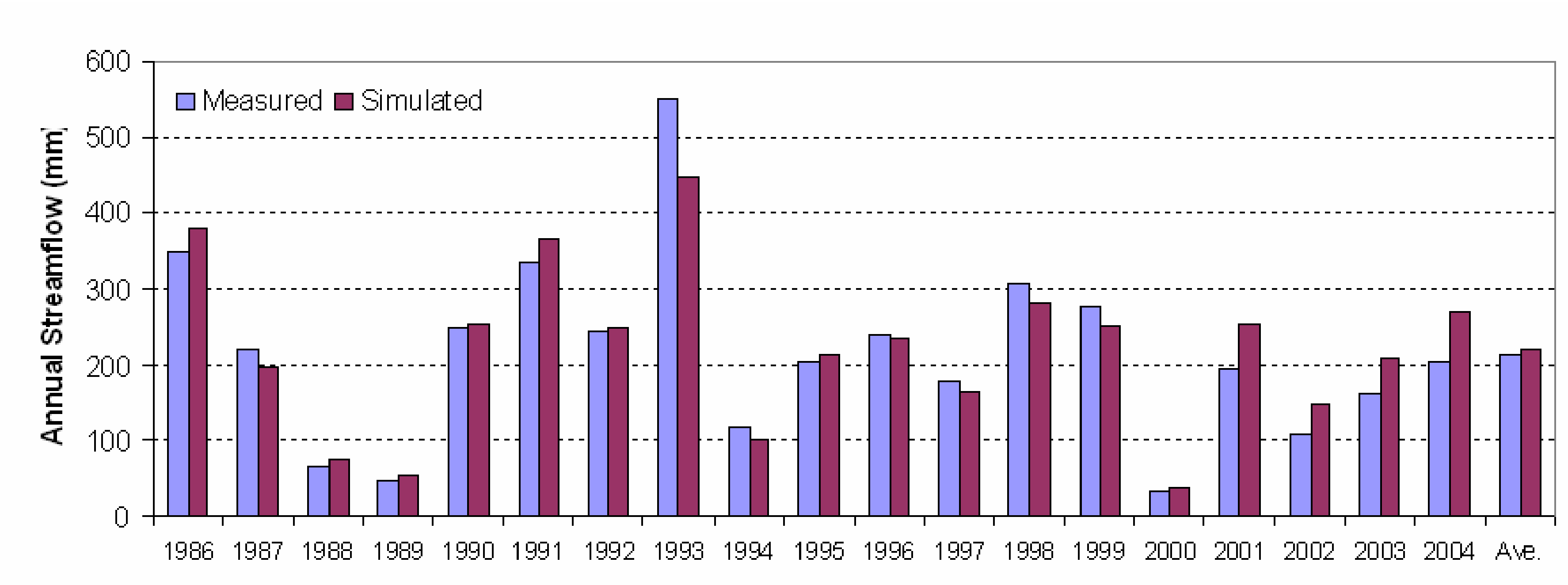
Tile flow = 56 mm

Groundwater = 78 mm

Baseflow = 134 mm (58% of streamflow)

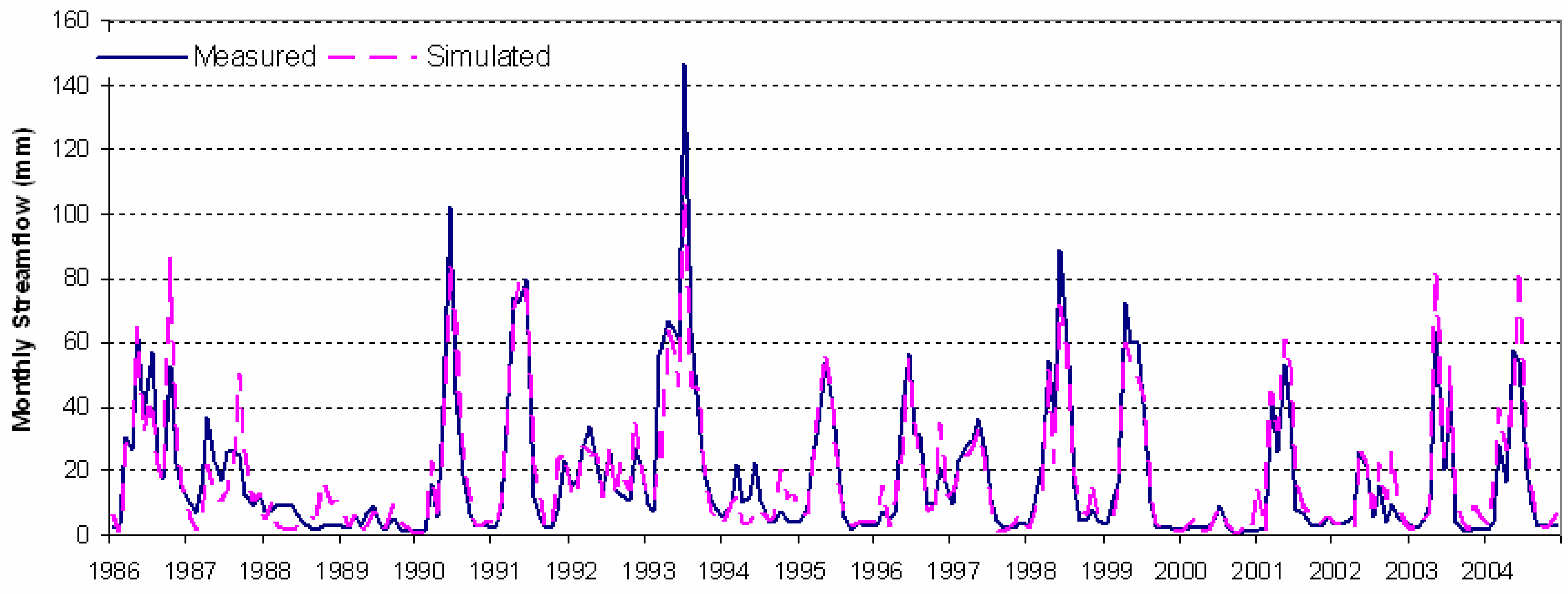
Evapotranspiration = 595 mm (71% of precipitation)

Annual Streamflow



Calibration (1986 – 1995)	Validation (1996 – 2004)
R^2 = 0.94	R^2 = 0.80
E = 0.93	E = 0.76

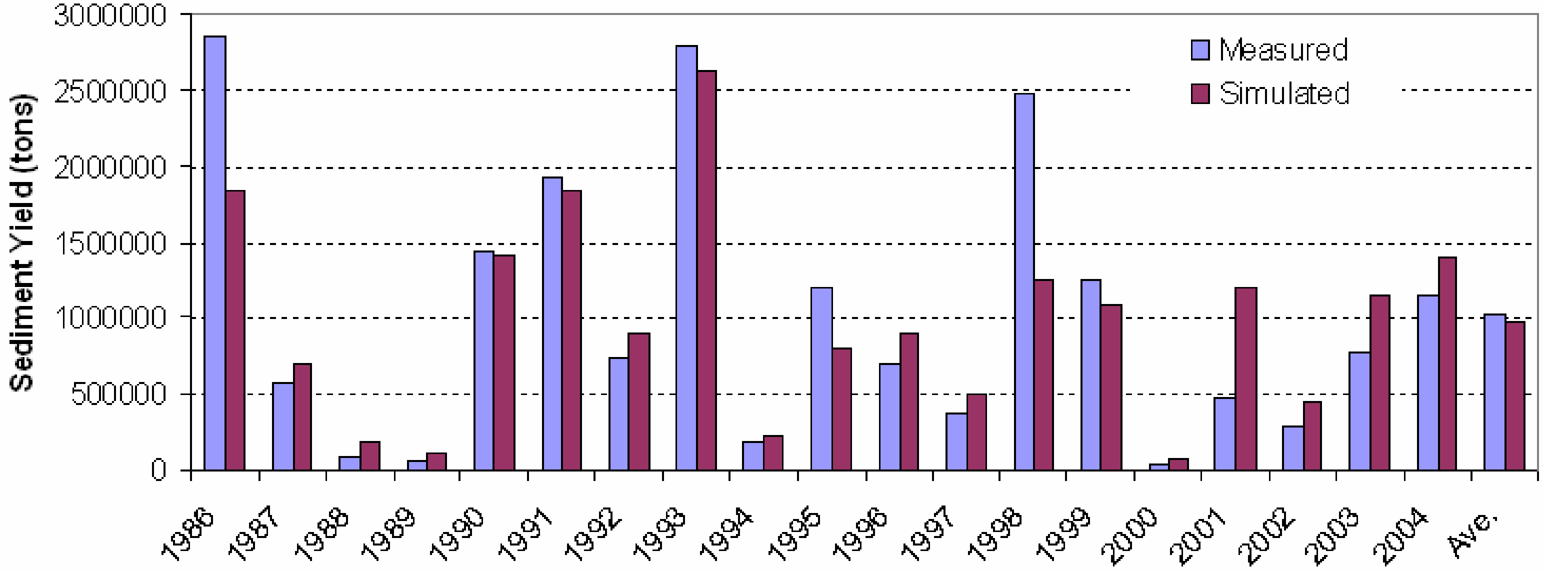
Monthly Streamflow

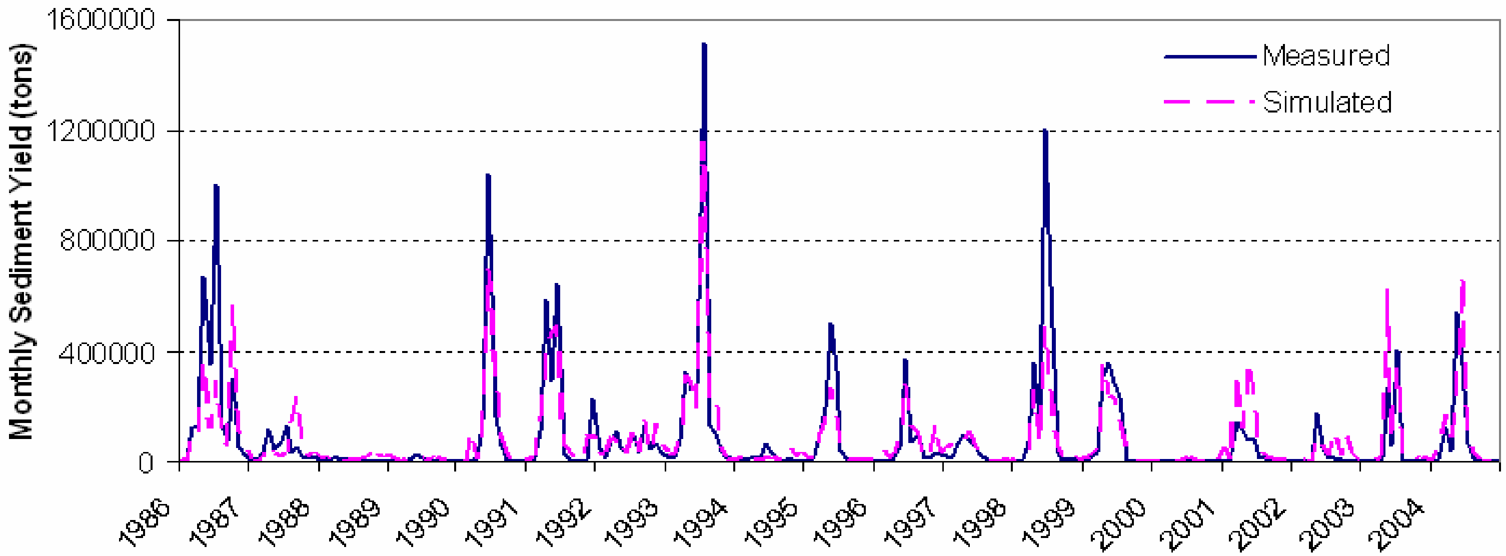


Comparison at Van Meter, IA

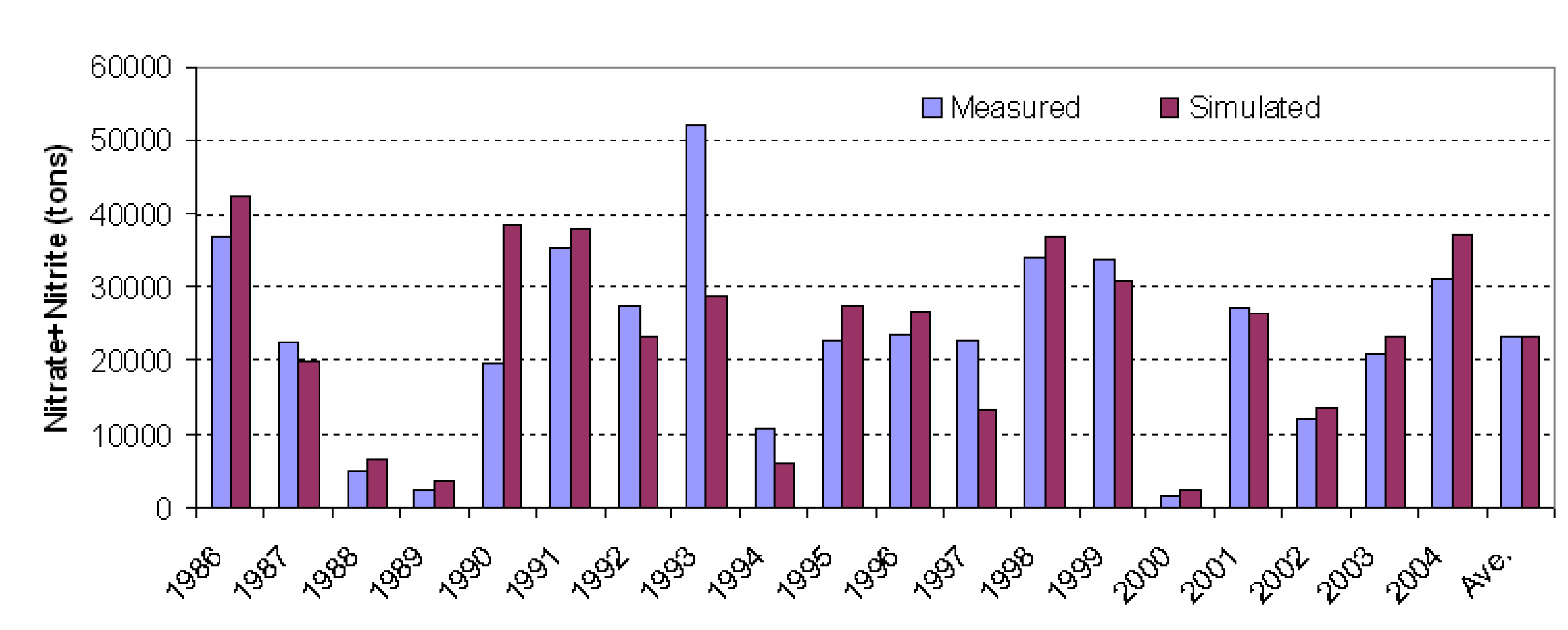
Calibration (1981 – 1992)	Validation (1993 – 2003)
$R^2 = 0.86$	$R^2 = 0.88$
E = 0.86	E = 0.87

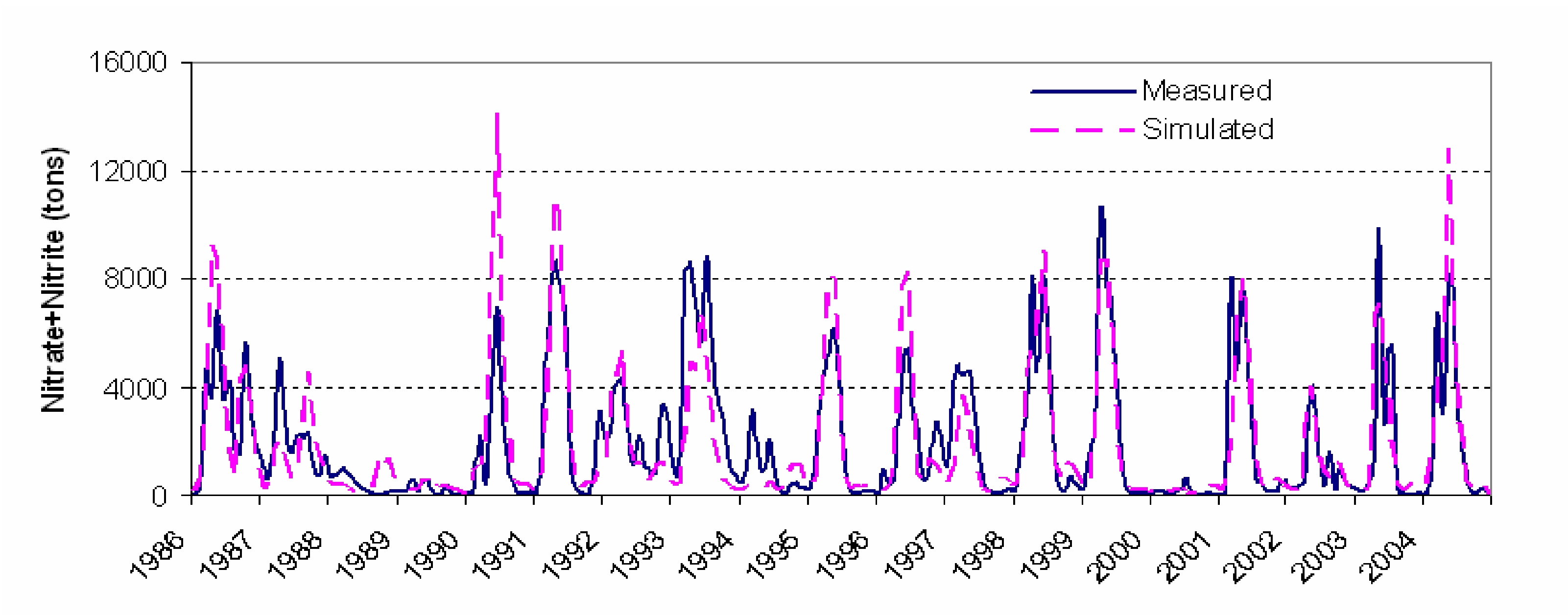
Sediment Yield

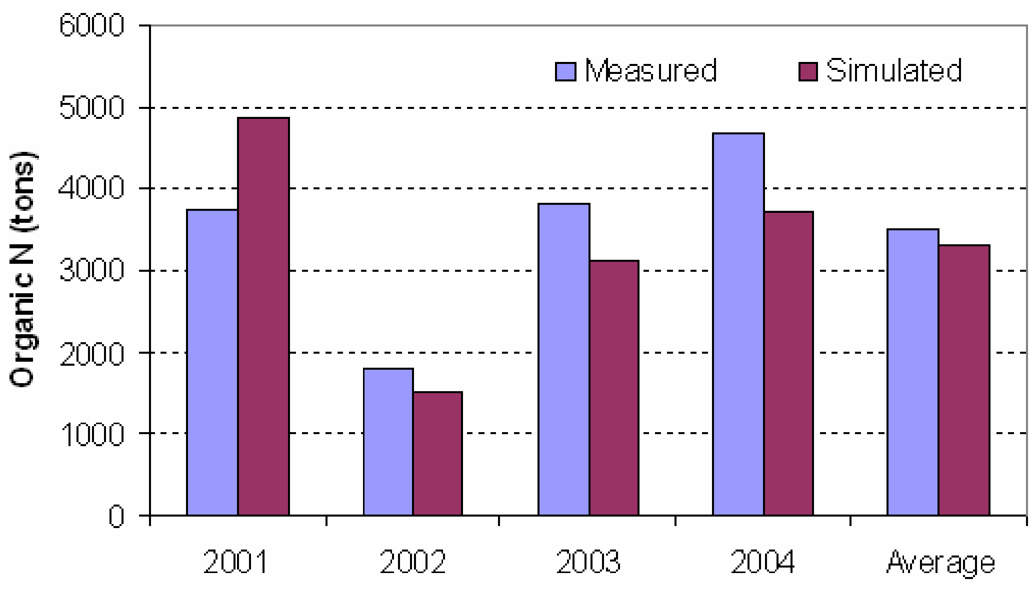


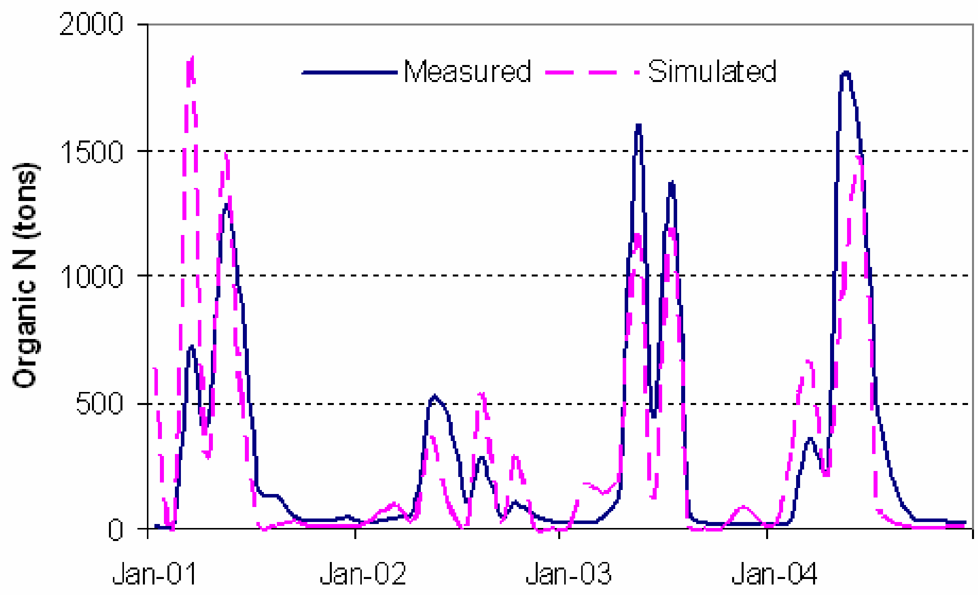


Nitrate+Nitrite

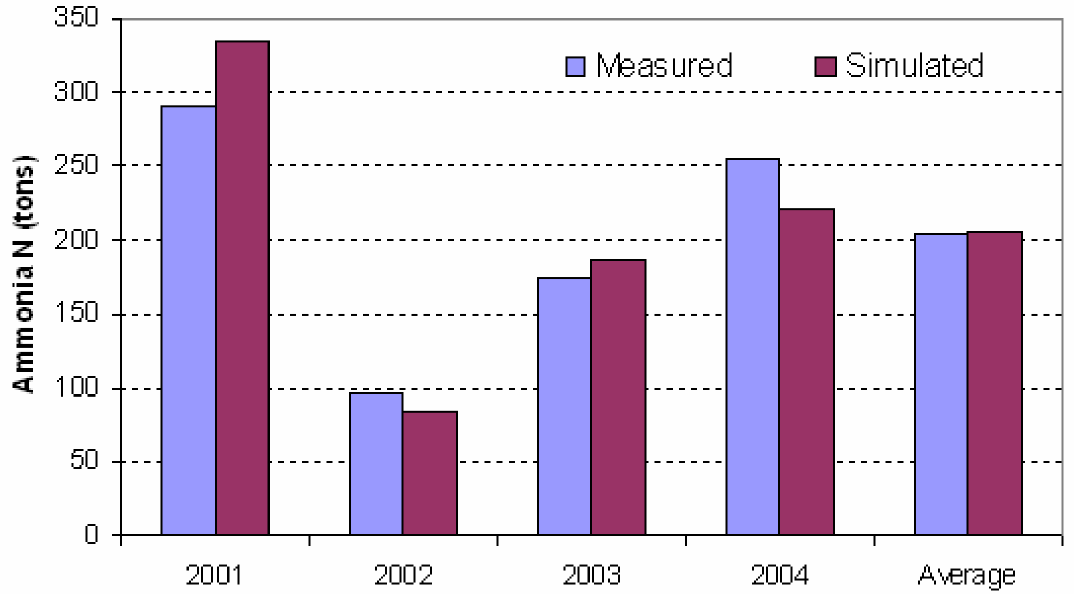


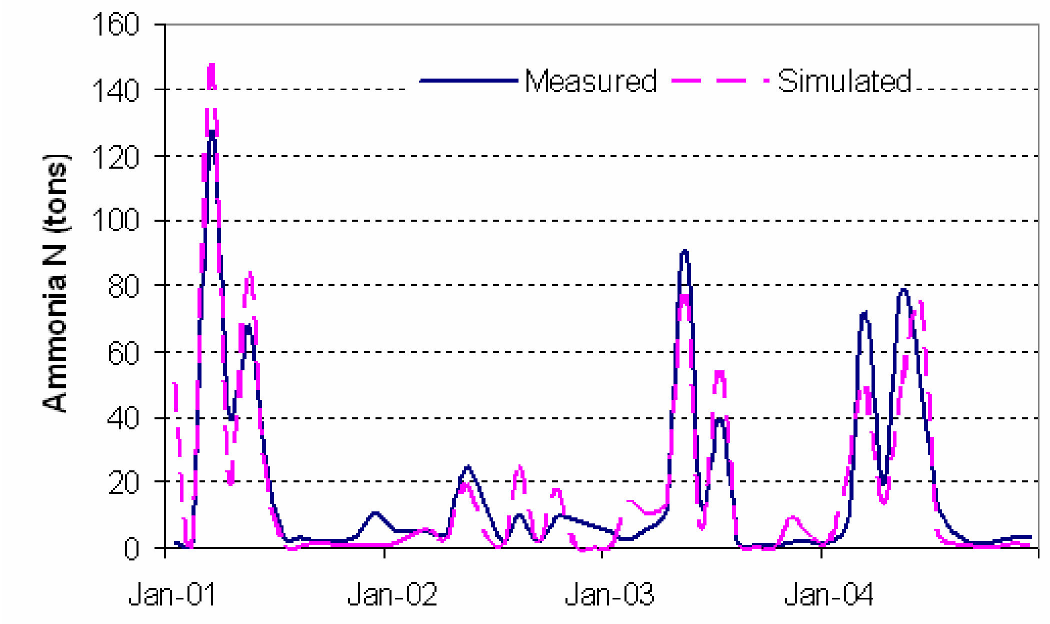




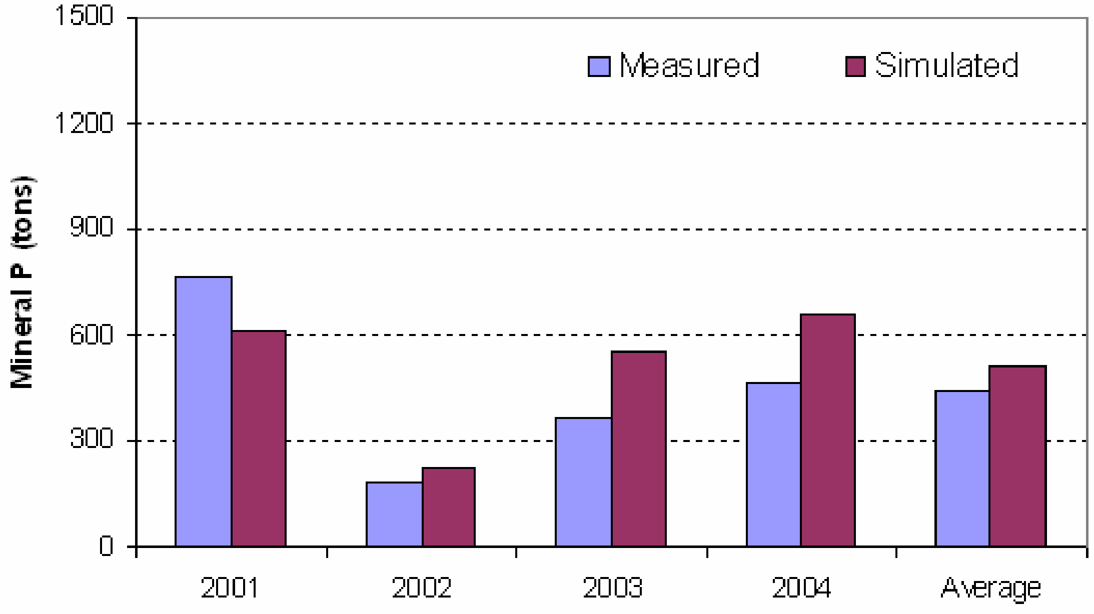


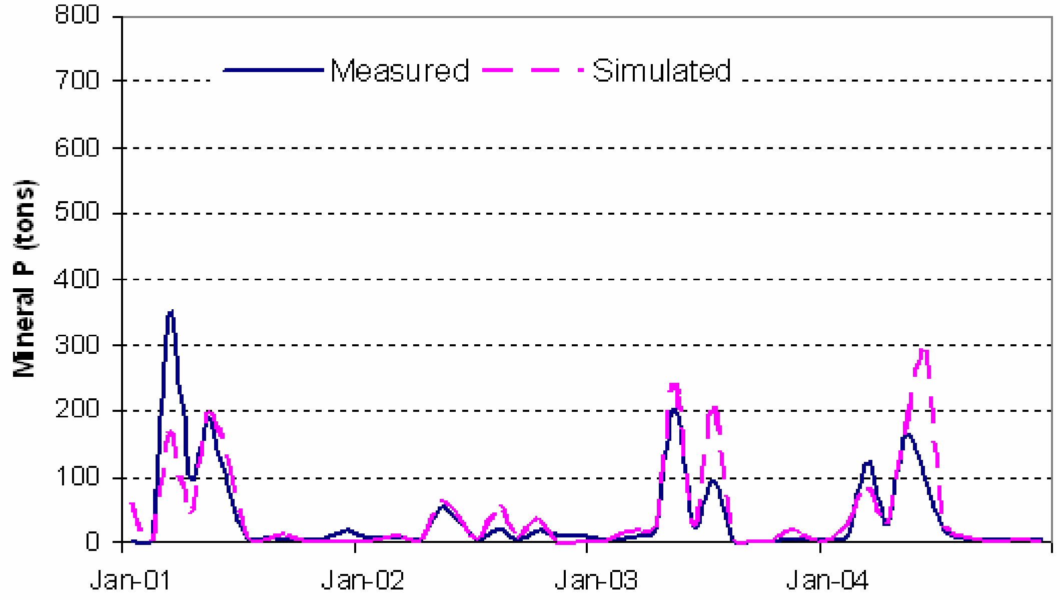
Organic Nitrogen



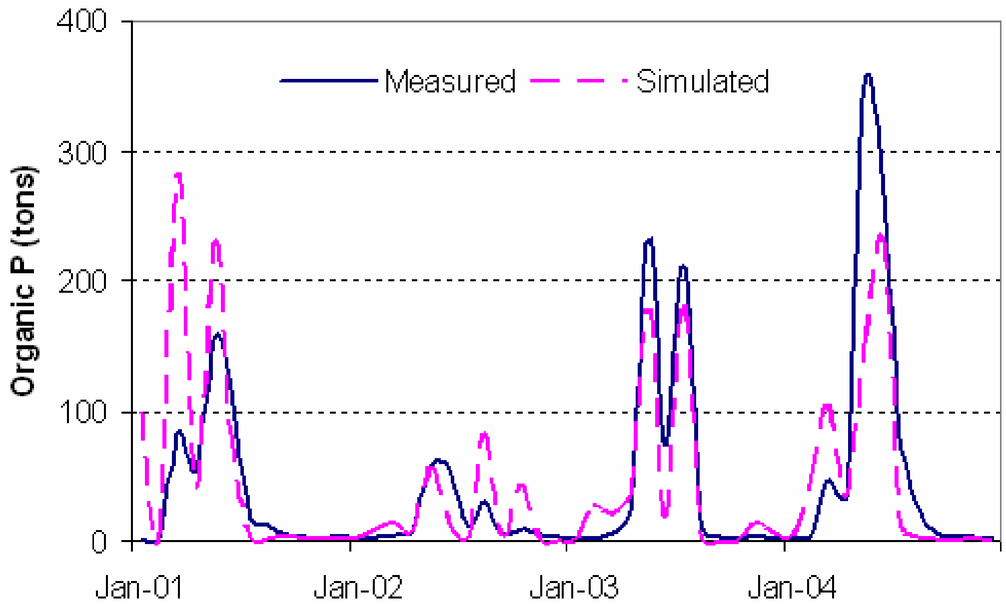


Ammonia Nitrogen





Mineral Phosphorus



Organic Phosphorus

Genetic Algorithm

- Optimal placement of conservation practices is required for cost-effective water quality benefits

- If, N: conservation practices (CPs) for possible adoption
  F: total number of fields (HRUs) in a watershed

  posssible combinatios = N^F

- Genetic algorithm provides a solution strategy of this sort of problems.

- Genetic algorithm is an evolutionary algorithm, which searches for solutions among an enormous amount of possibilities

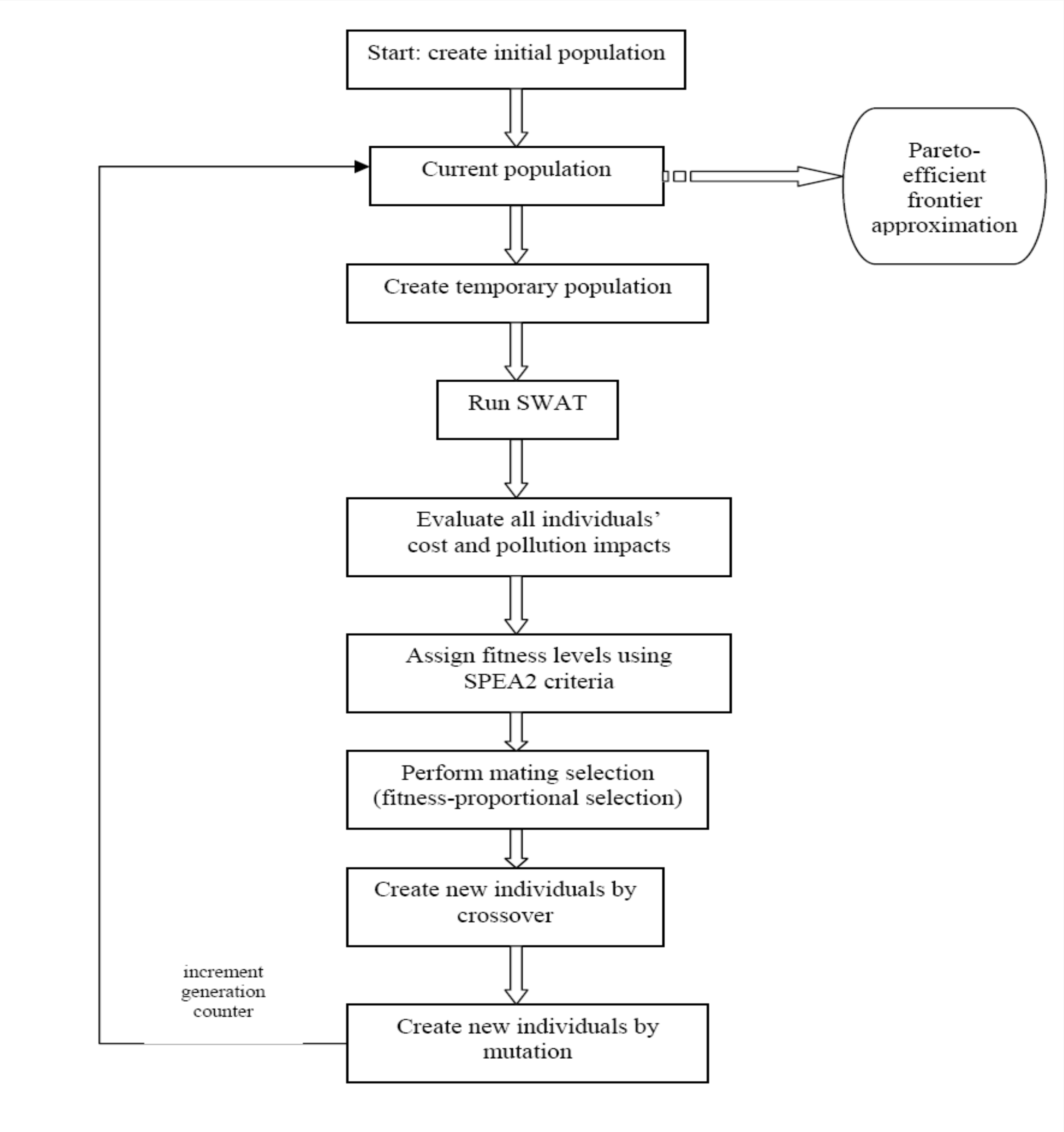
Genetic Algorithm and SWAT

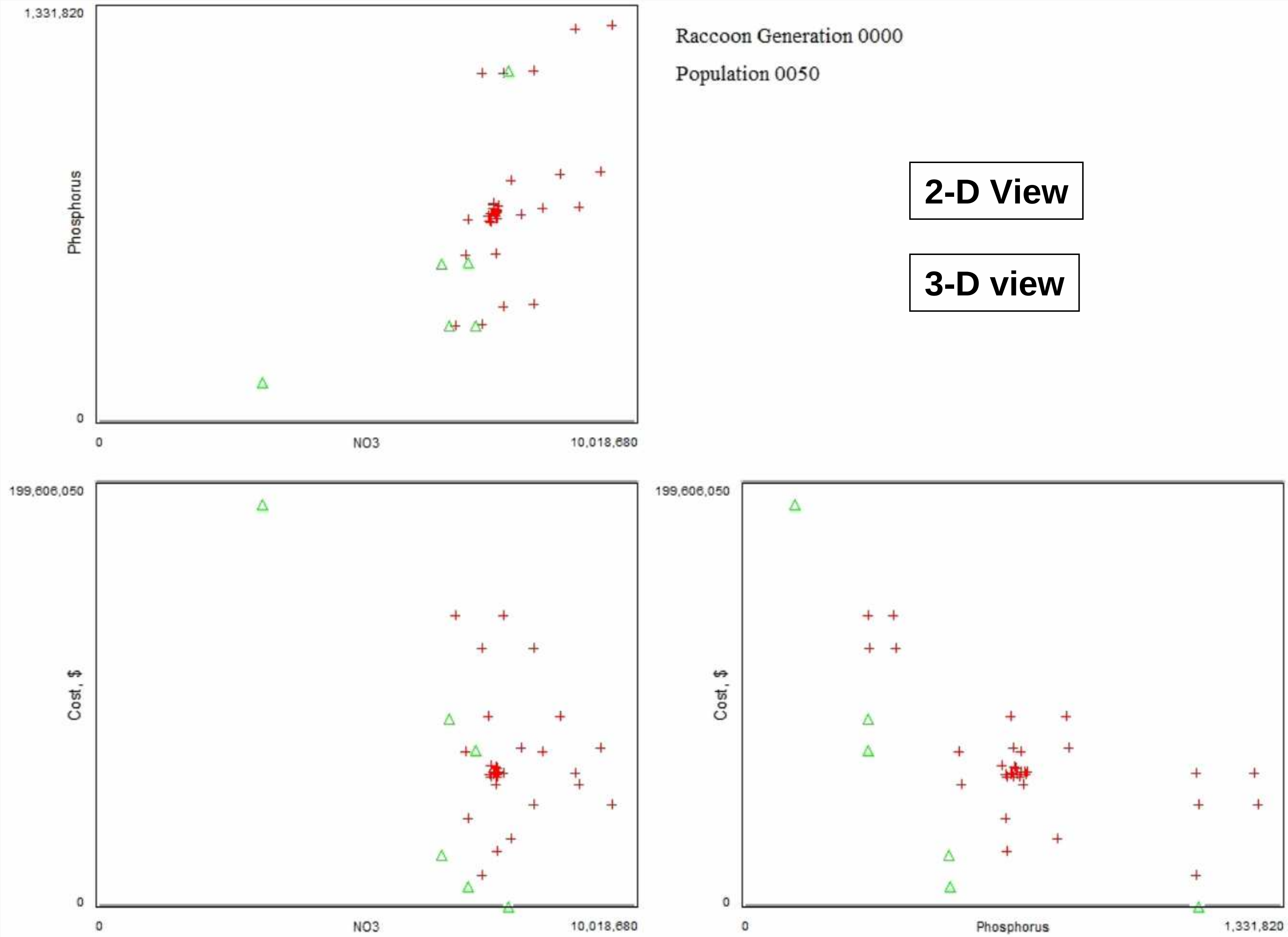
- ➢ We integrate modern evolutionary algorithm (SPEA2) with SWAT model to search for a frontier of cost-effective nutrient pollution reduction solutions for a watershed

  Similar attempts: Srivastava et al. (2002), Veith et al. (2003), Muleta and Nicklow (2005), Lant et al. (2005) and Arabi et al. (2006)

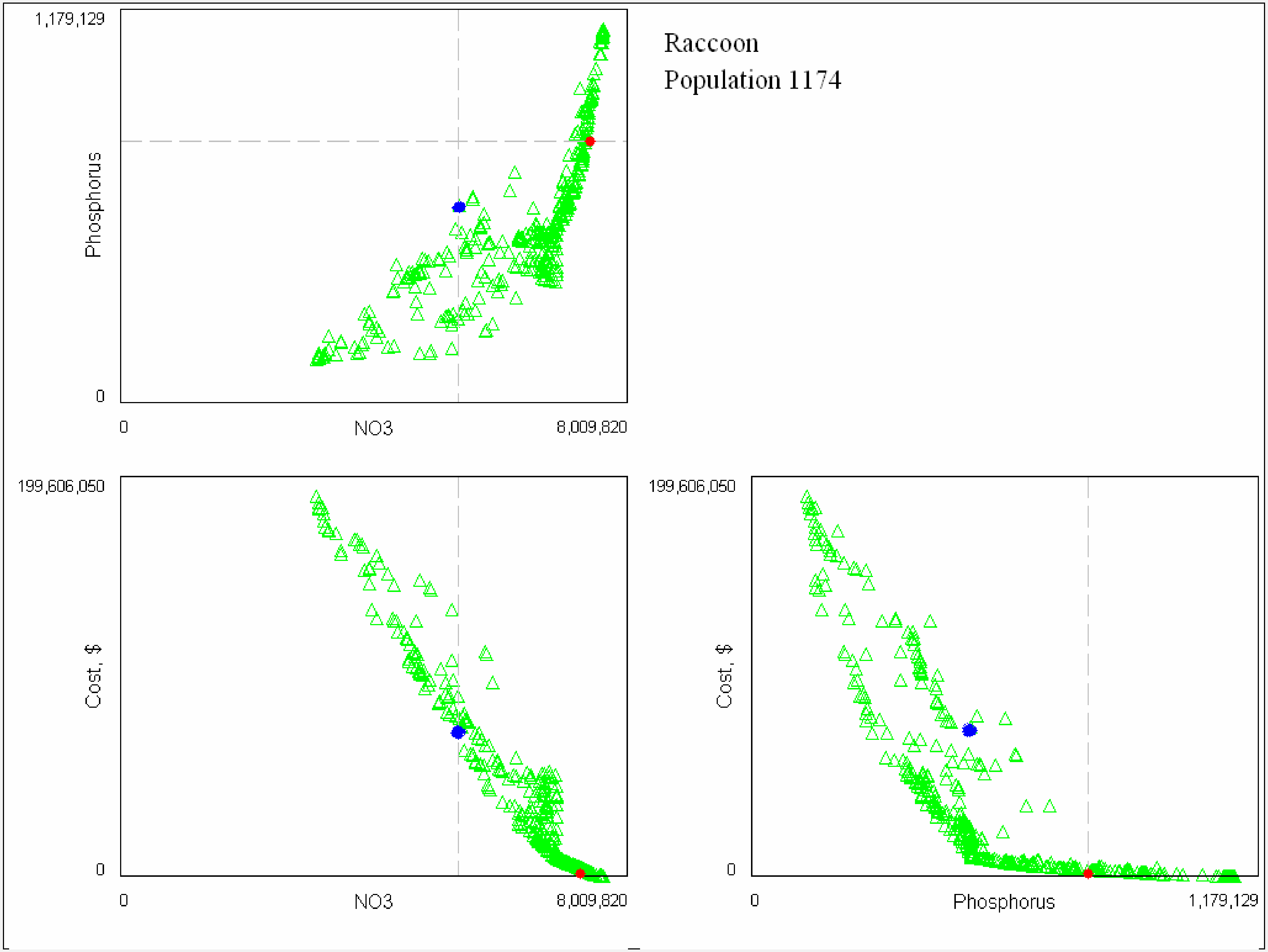
- ➢ For each HRU, there are 33 mutually exclusive options:
  - land retirement, and
  - interacting 4 tillage types (CT, RT, MT, NT) with conservation practices (terraces, contouring, grassed waterways) and 20% N fertilizer reduction

Algorithm Flow Diagram





Raccoon Generation 0000
Population 0050
2-D View
3-D view
1,331,820
Phosphorus
0
0
NO3
10,018,680
199,606,050
Cost, $
0
0
NO3
10,018,680
199,606,050
Cost, $
0
0
Phosphorus
1,331,820

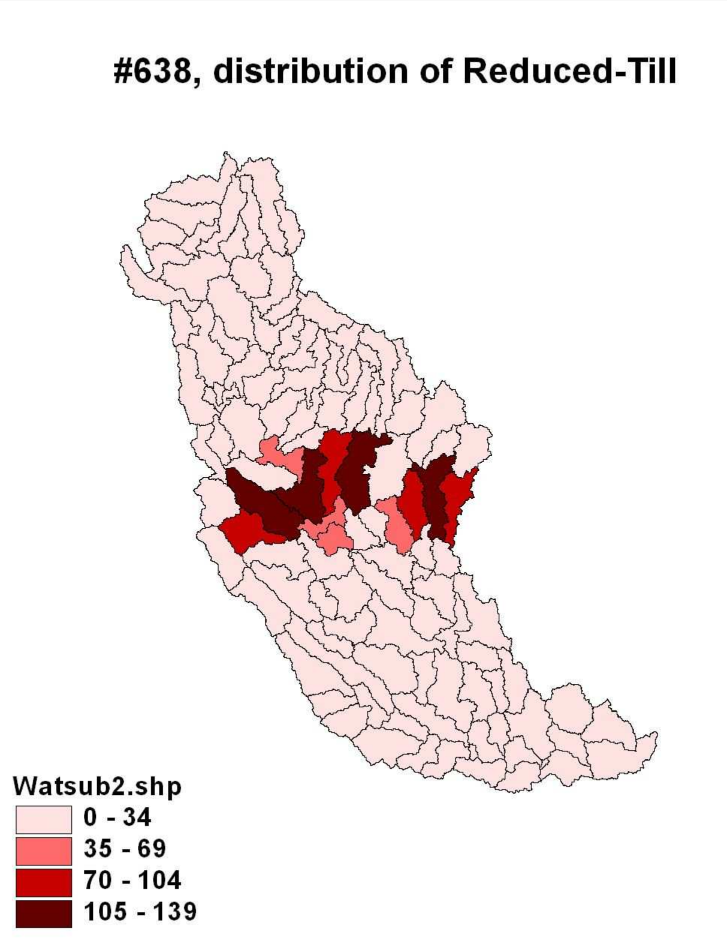


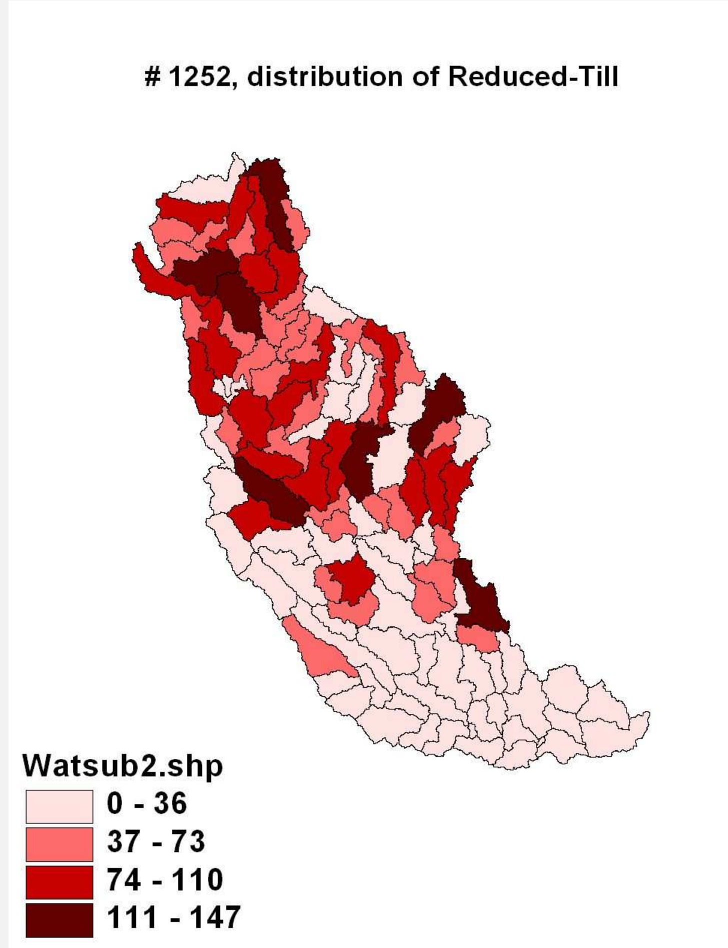
Raccoon
Population 1174
1,179,129
Phosphorus
0
0
NO3
8,009,820
199,606,050
Cost, $
0
0
NO3
8,009,820
199,606,050
Cost, $
0
0
Phosphorus
1,179,129

Cost and Pollution Outcome

Point #	*Nitrate Reduction*	*Phosphorus Reduction*	*Cost of achieving reductions, M$/year*
	% from baseline		
638	**30.5**	53.2	80.1
1252	3.9	**30.2**	3.6
1146	**15.4**	**54.6**	22.9

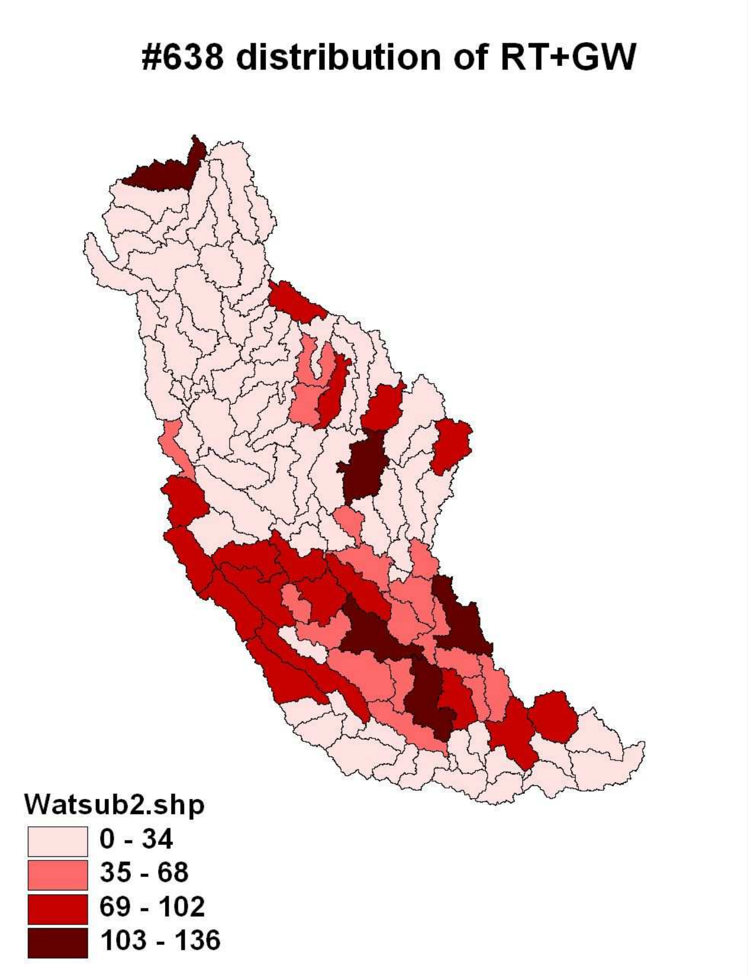
Land allocation for selected scenarios, km^2

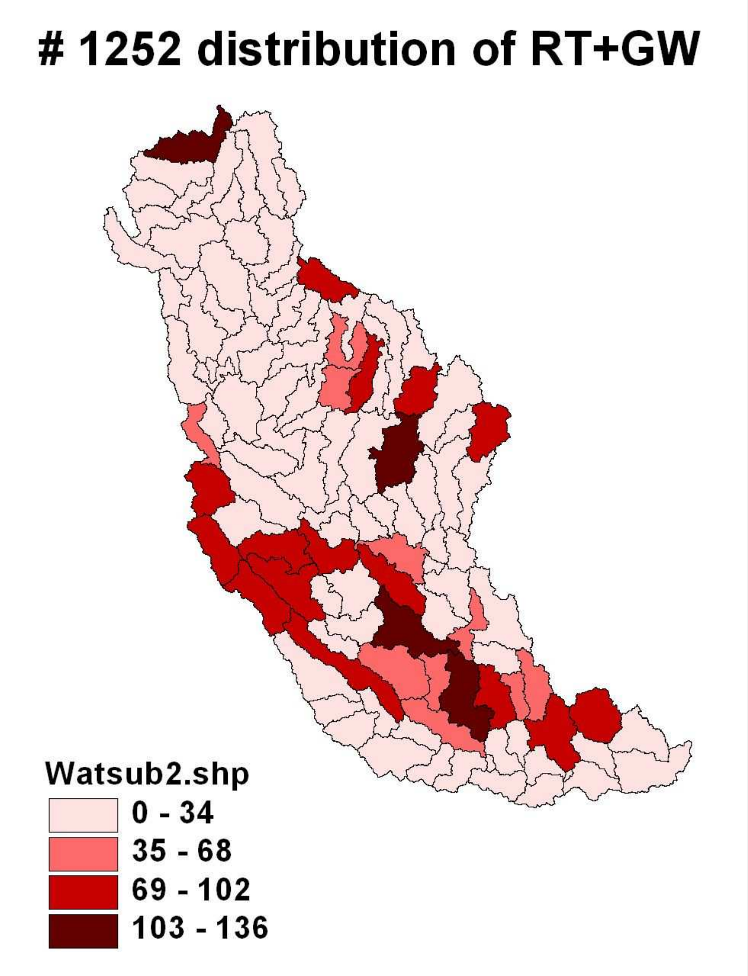




<u>Reduced Tillage</u>

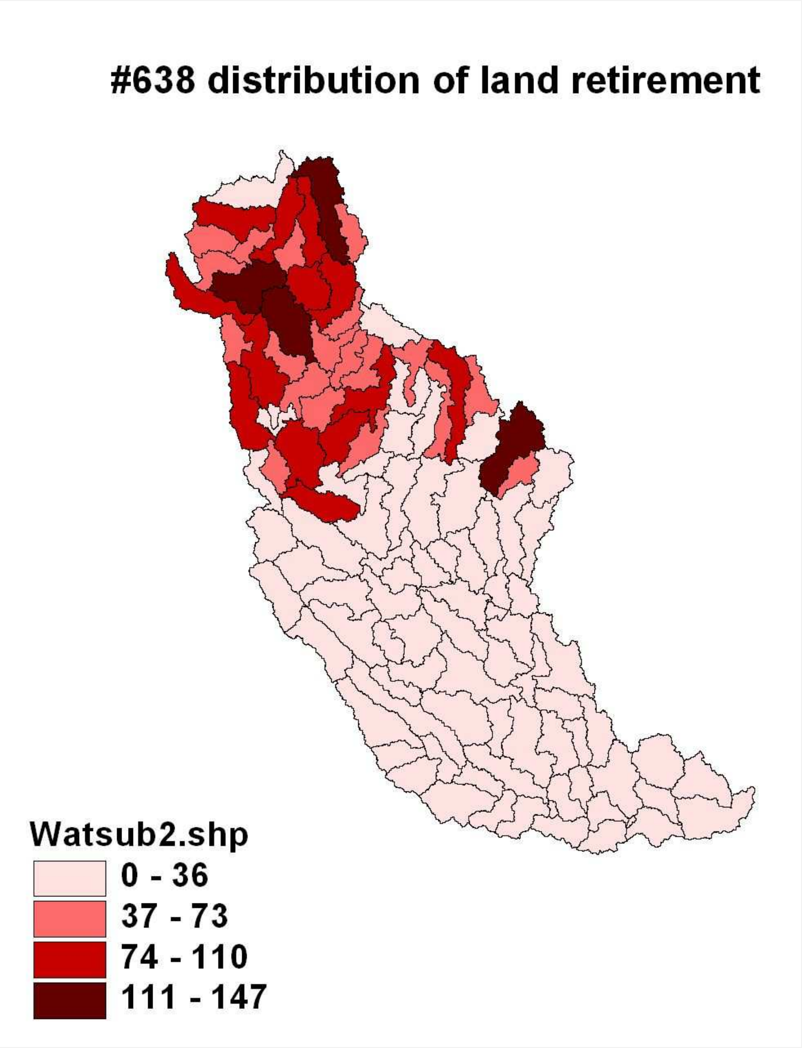
Land allocation for selected scenarios, km^2





Reduced Tillage + Grassed Waterways

Land allocation for selected scenarios, km^2



Land Retirement

Some Implications

- Algorithm favors:
  - "Grassed Waterways" as a P reduction practice
  - "N fertilizer reductions" for small reduction in nitrate loadings
  - "land retirement" for medium to large reductions in nitrate loadings

- Cost of nitrate control rise dramatically once land retirement has to be utilized

Conclusions

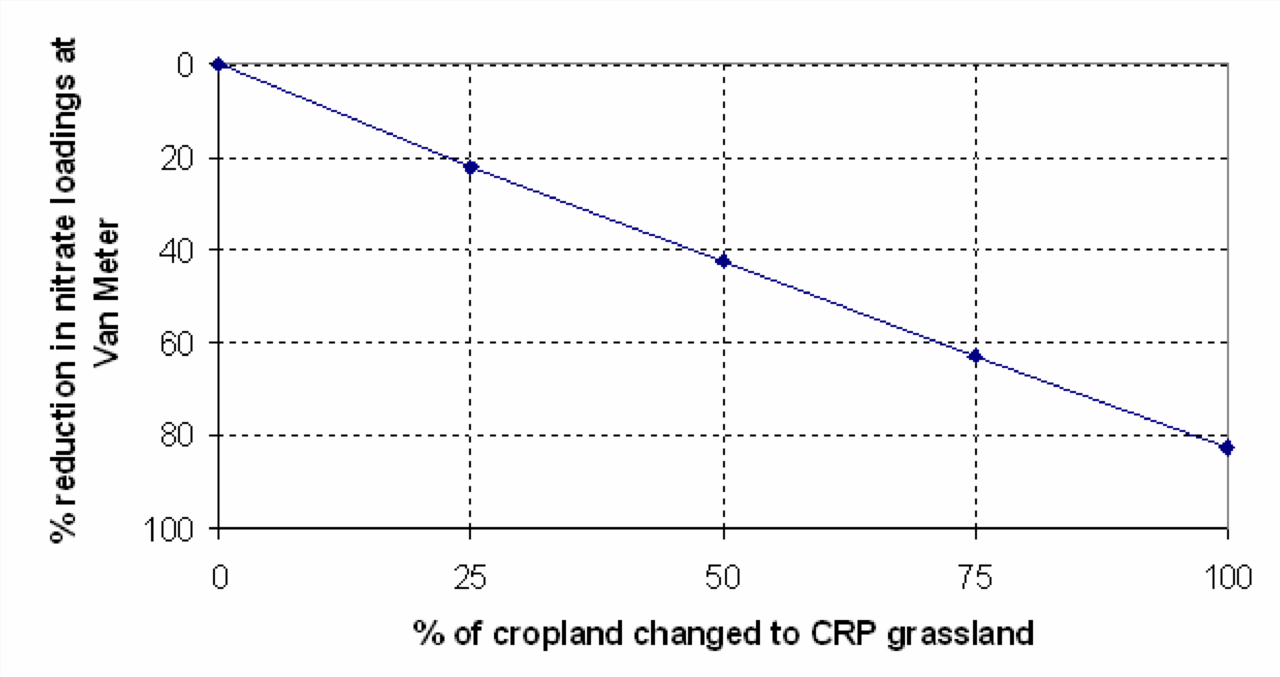
- SWAT modeling framework is set up for the Raccoon River Watershed with detailed land management information.
- Raccoon SWAT setup is calibrated and validated for watershed hydrology, streamflow, and nitrogen and phosphorus constituents.
- Genetic Algorithm is an useful optimization tool in assessing cost-effective allocation of conservation practices for pollution reductions.
- Conservation practices selected by algorithm for 15% nitrate reduction also reduces phosphorus automatically by more than 50% for Raccoon River Watershed.
- GA in combination with SWAT is very useful in providing a frontier of cost-effective allocations of selected conservation practices for improved water quality.

Thank You!

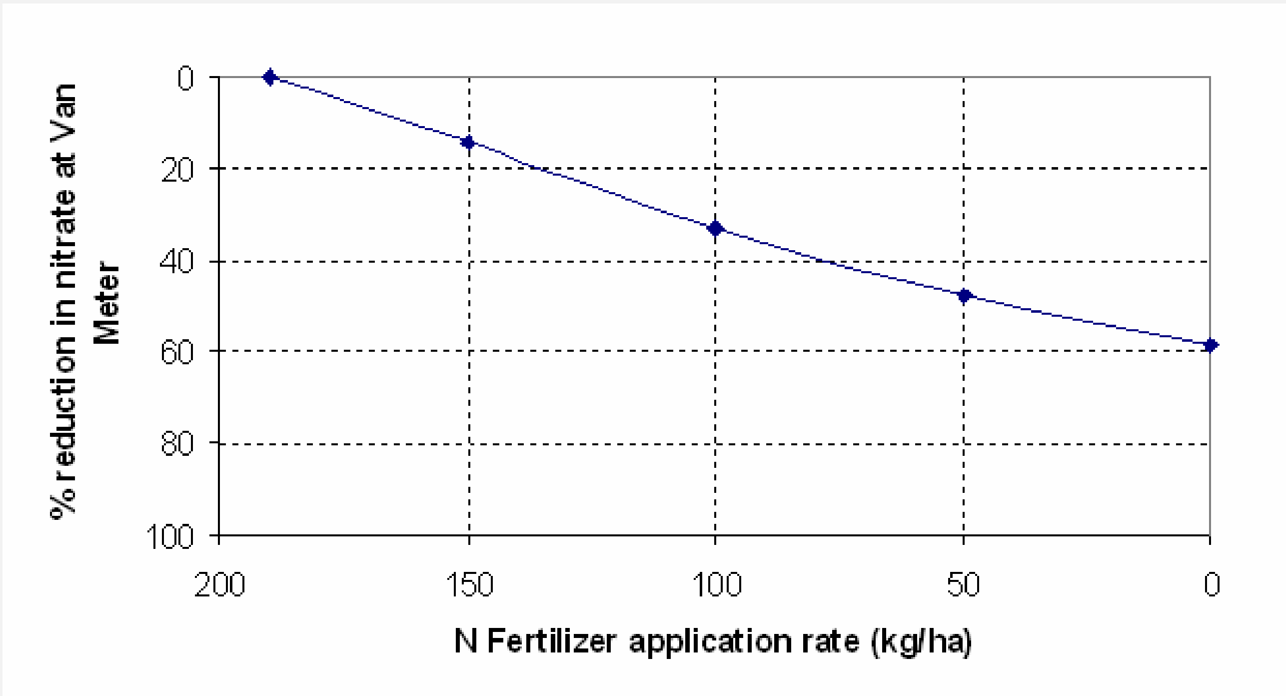
Convert all perennial grasslands to corn-corn

	Area converted km^2 (% of wat.)	Nitrate loading (Tons)	% Change
Baseline	-	23,501	-
Convert only CRP to corn-corn	192 (2%)	24,313	+ 3.5
Convert all grasslands (CRP, Alfa, Brom, Pasture) to corn- corn	1682 (18%)	26,265	+ 11.8

Convert row crops to CRP grasslands



Decrease N fertilization rates on corn ground



Remove all point sources

	Nitrate loading (Tons)	% Change
Baseline	23,501	-
Remove all human waste sources (septic and WWTPs)	21,692	- 7.7
Remove all cattles from the streams	23,489	- 0.1

Change livestock patterns in the watershed

	Nitrate loading (Tons)	% Change
Baseline	23,501	-
Remove all pastured cattle (no grazing)	23,413	- 0.4
Remove cattle from feedlots	22,944	- 2.4
Remove CAFOs	18,535	- 21.1
Remove all livestocks	17,888	- 23.9

Conclusions

- SWAT modeling framework is set up for the Raccoon River Watershed with detailed land management information.
- Raccoon SWAT setup is calibrated and validated for watershed hydrology, streamflow, and nitrogen and phosphorus constituents.
- Converting all grasslands to continuous corn may increase nitrate loadings by 12%.
- Converting all croplands to grasslands may reduce nitrate loadings by more than 80%.
- Point sources pollutants are responsible for around 8% of nitrate loadings.
- Total livestock manure including CAFOs and feedlots are responsible for around 24% of the total nitrate loadings.

Future Direction

- Validate the Raccoon SWAT modeling setup at several locations within the watershed.
- Develop more management scenarios for better understanding of the watershed response to various possible situations including different climatic conditions.
- Develop a Bacteria TMDL – another parameter recognized significantly for the Raccoon River.