Phosphorus and water quality
(beyond erosion control)

Peter Kleinman
USDA-ARS
University Park, PA

Phosphorus is essential to life!

- energy compounds (ATP, NADPH)
- nucleic acids (DNA, RNA)
- cell membranes (phospholipids regulate transport)

The British collected the bones of fallen soldiers for use as fertilizer!

Bones and teeth have > 50% $Ca_5F(PO_4)_3$

Why the concern with P?

- Eutrophication
  - Freshwaters usually P limited
  - Algal Blooms!
    - Fish kills due to hypoxia ("Dead Zone")
      - it's not just an N issue (N:P)
    - *Pfiesteria Piscicidia* and other HABs
      - acute risk
    - Chlorination of eutrophic drinking waters
      - carcinogenic risk.

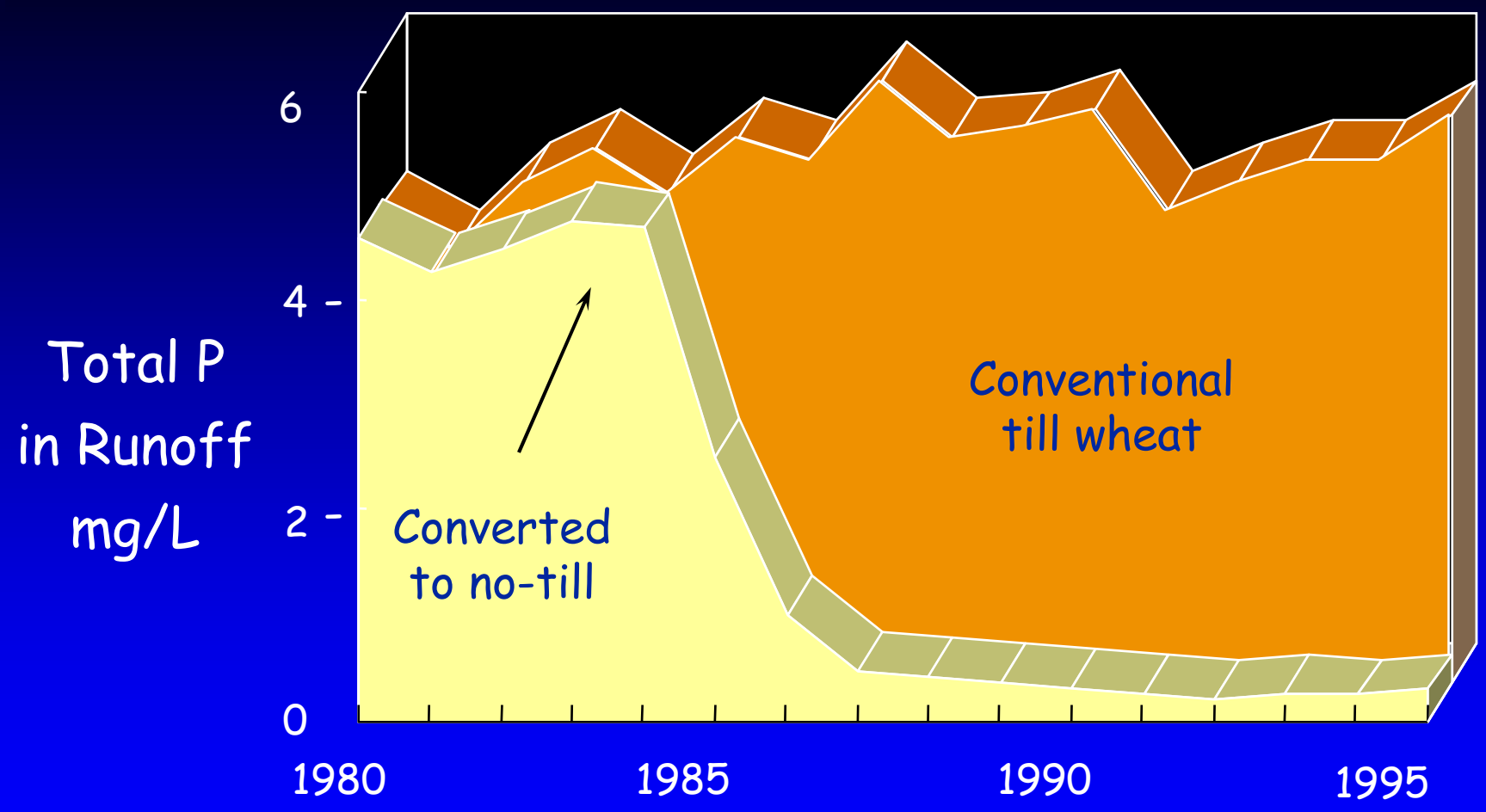
Agriculture is important, but one of a variety of sources

Sources	Area	P export
	- - - %	- - -
Nonpoint	100	64
Forest	60	3
Agriculture	30	52
Urban	10	9
Point	- -	36

Old paradigm – P is immobile…

- P reacts in the soil environment with
  - Ca, Mg, Al, Fe, Mn
- through precipitation
  - $CaH[PO_4] \cdot 2H_2O$ (brushite)
  - $Al[PO_4] \cdot 2H_2O$ (variscite)
  - $Fe[PO_4] \cdot 2H_2O$ (strengite)
- and adsorption to surfaces of clay minerals
  - aging of P compounds
    - (anion exchange --> ionic bond --> ligand bond)

The Old View
Phosphorus Loss = Soil Erosion

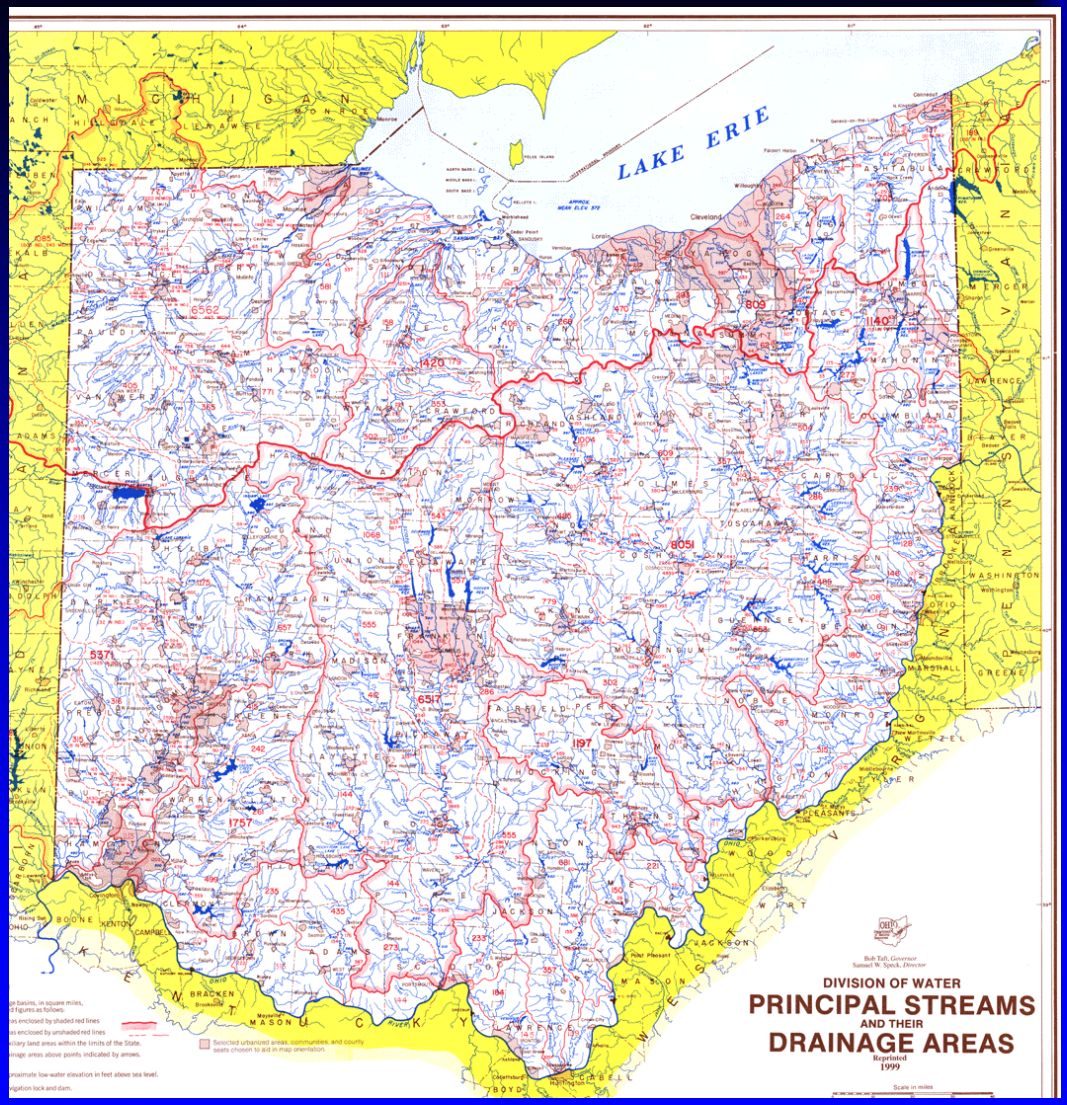


Erosion reduced 95%

Sharpley, USDA-ARS

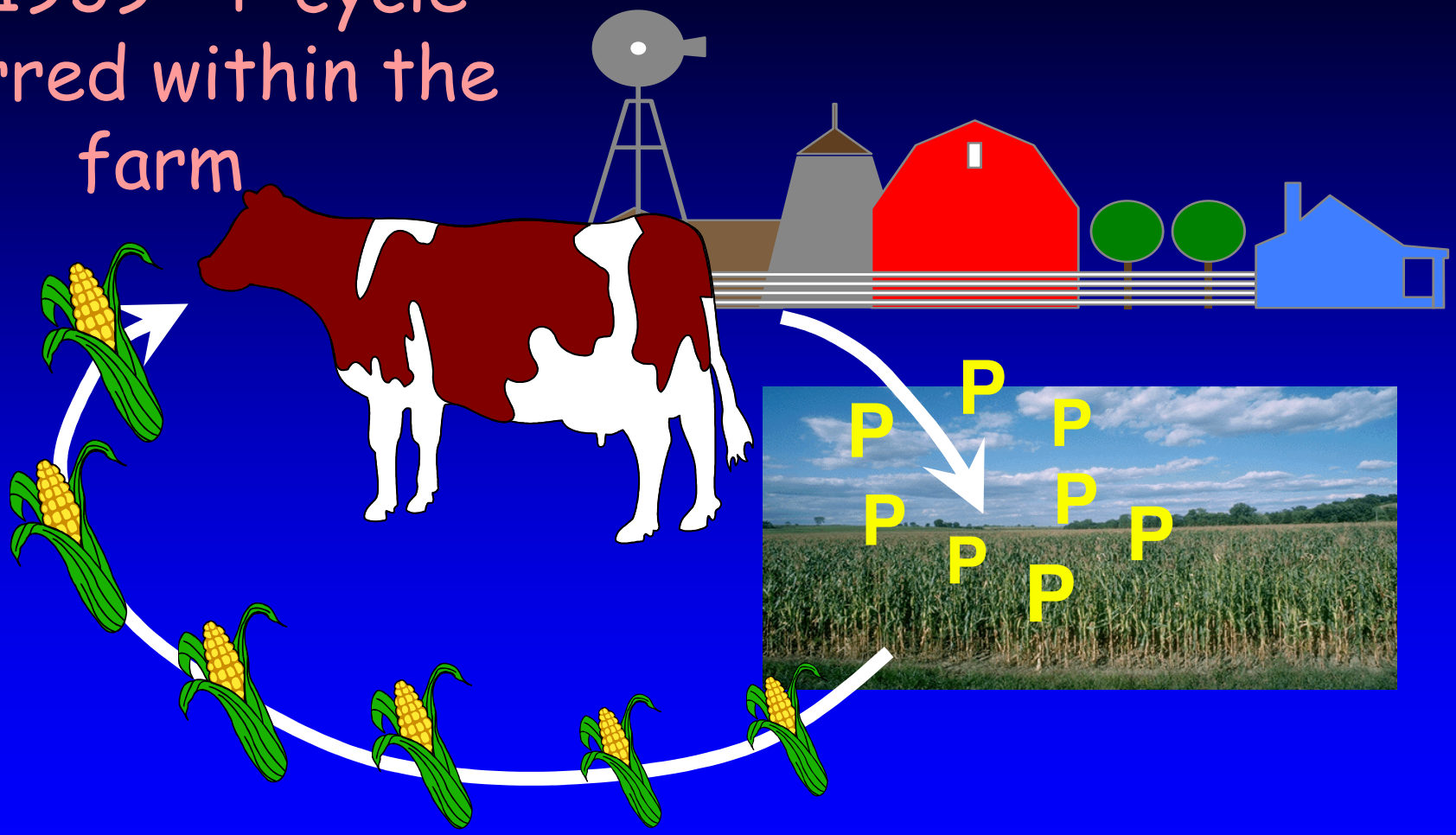
The Old View
Phosphorus Loss = Soil Erosion

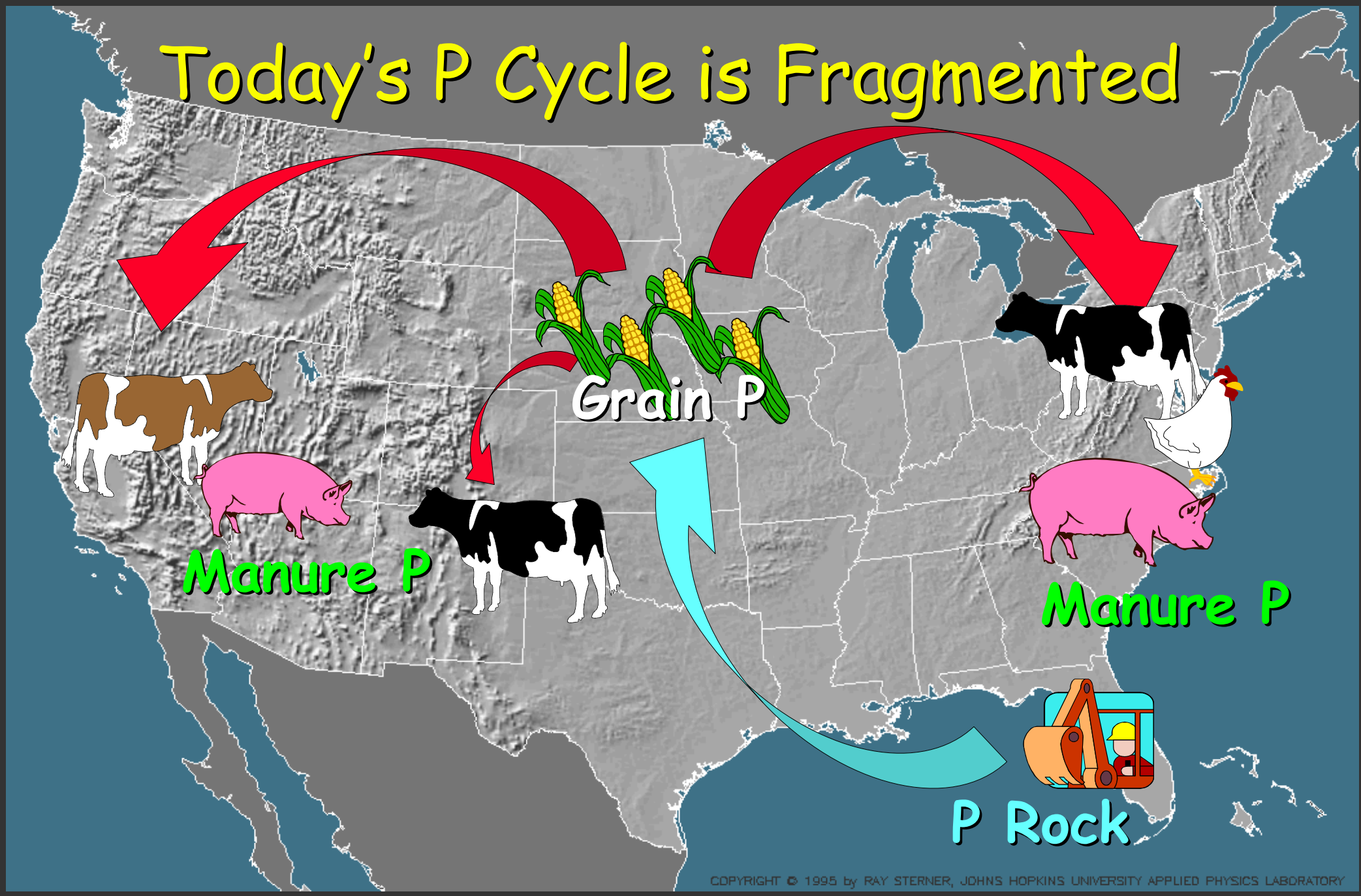
- Lake Erie Watersheds (1975-1995)
  - Non-point sources ~90% of total P loads
  - 25-40% decline in annual P export
    - Tracked suspended solids decline
    - Conservation tillage and CRP on ~90% of farms!



The New Problem: Changes in the P Cycle

Pre 1939 - P cycle occurred within the farm




Today's P Cycle is Fragmented
Grain P
Manure P
Manure P
P Rock
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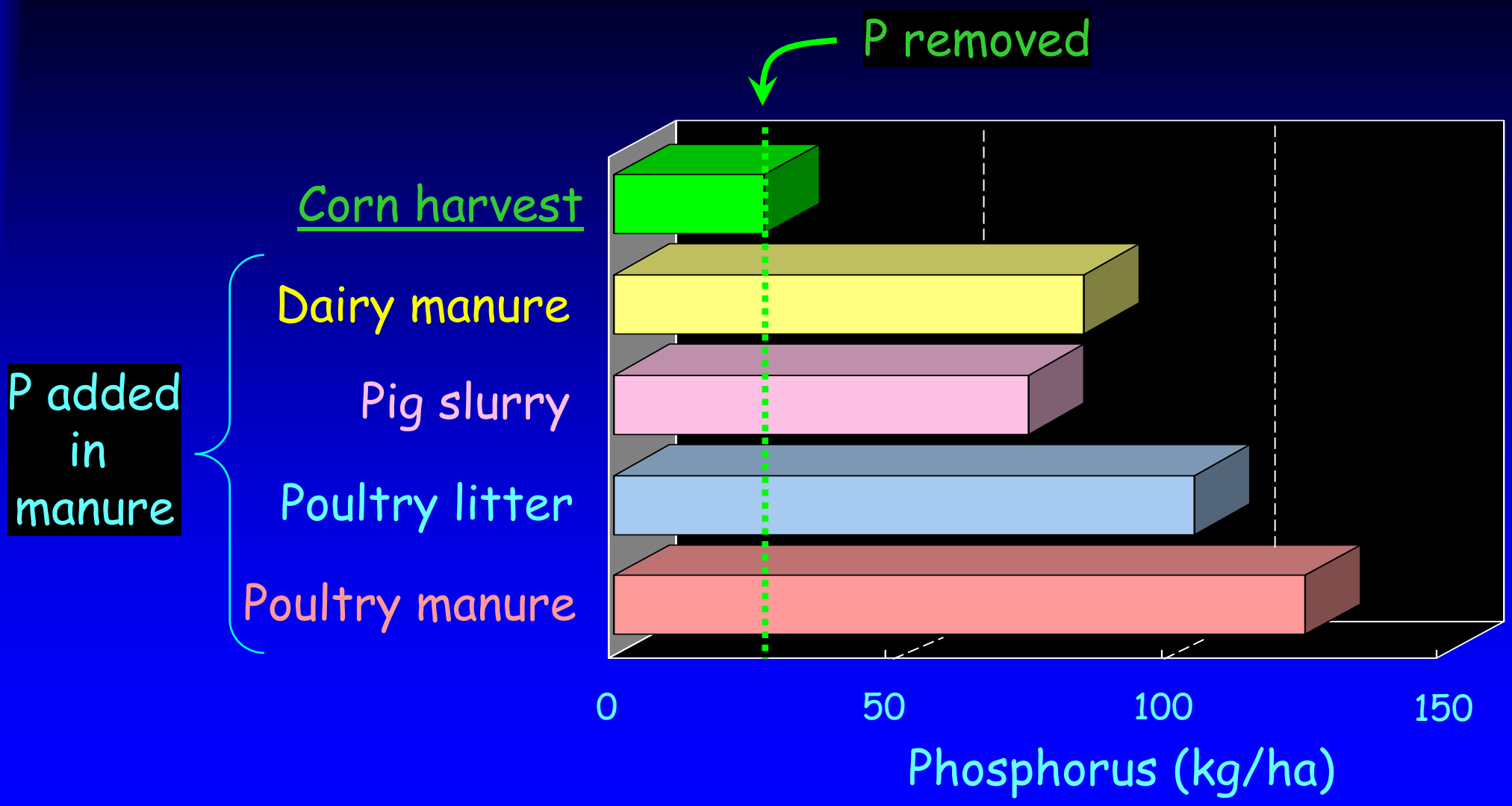
Farming System and P Balance

	Crop	Dairy	Hog	Poultry
	- - - - - - - lbs P/ac/yr - - - - - - -			
Input				
Fertilizer	18	11	--	--
Feed	--	30	104	1690
Output	16	12	20	515
Balance	2	29	84	1175
	Cash crop 75 ac	65 Holsteins 100 ac	1280 hogs 75 ac	75,000 birds 30 ac

Pennsylvania farms
(source, Lanyon, PSU)

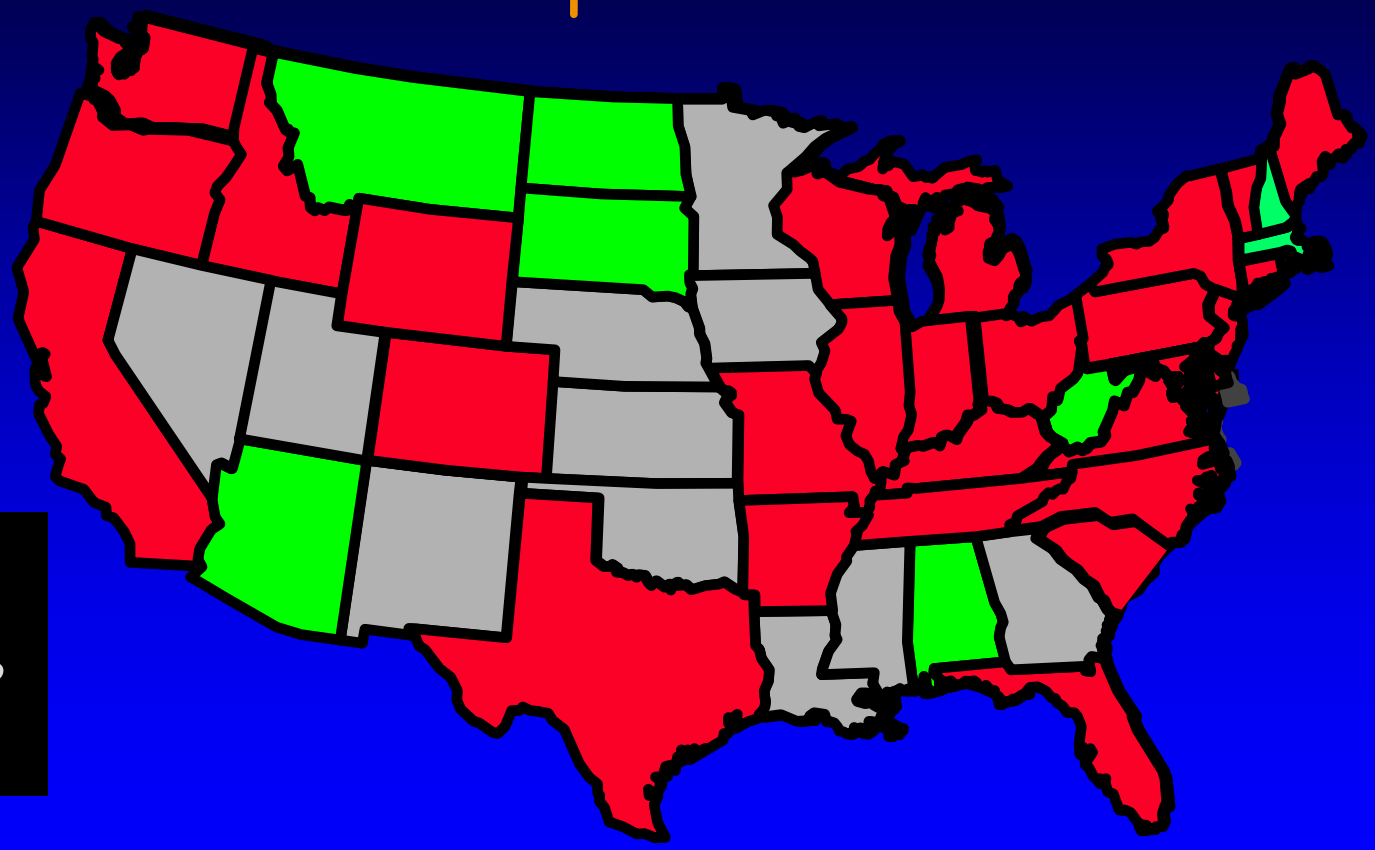
N-Based Manure Management Results in Excess P Application

N-Based Manure Management



Soil Test P Survey, 1997

Percent of soils tested that had more P than crops need



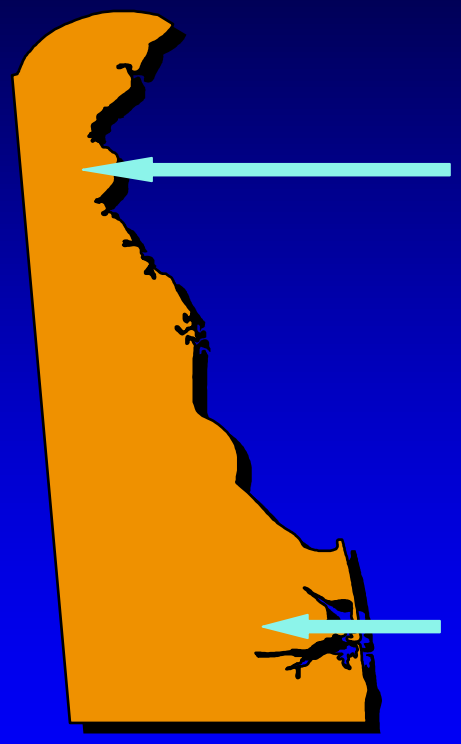
<30%

30 - 50%

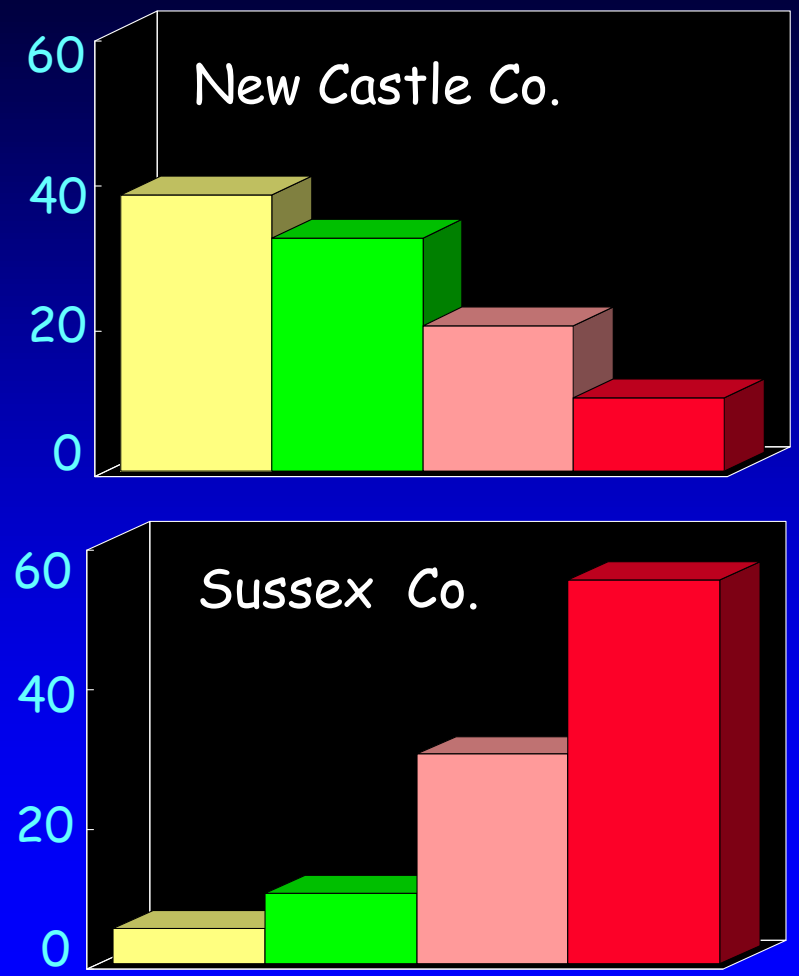
>50%

Soil P Accumulation is Localized

Percent samples in each soil test P category



Delaware



Soil test P

Mehlich-1 P, mg P/kg

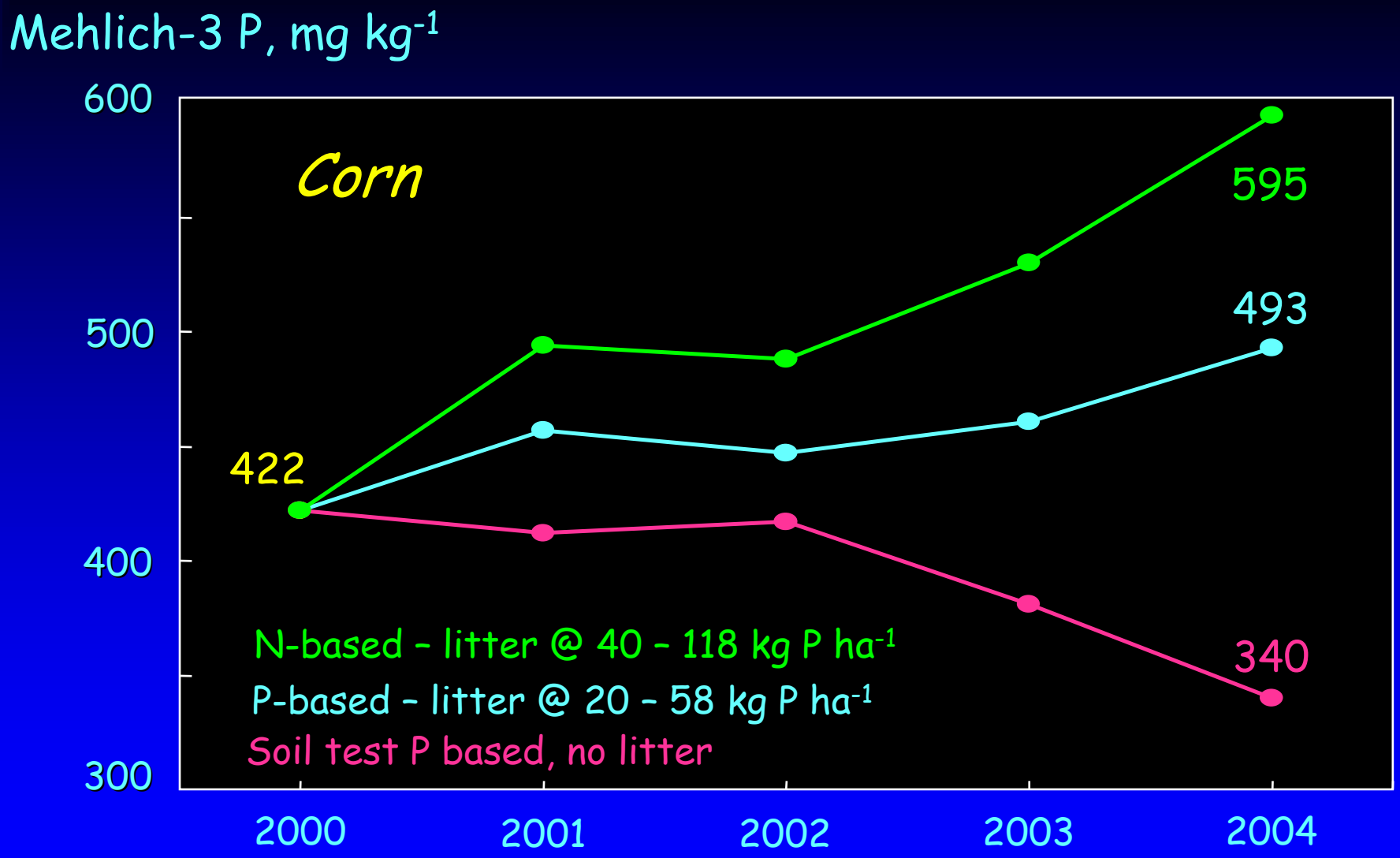
Low: <10

Medium: 10-25

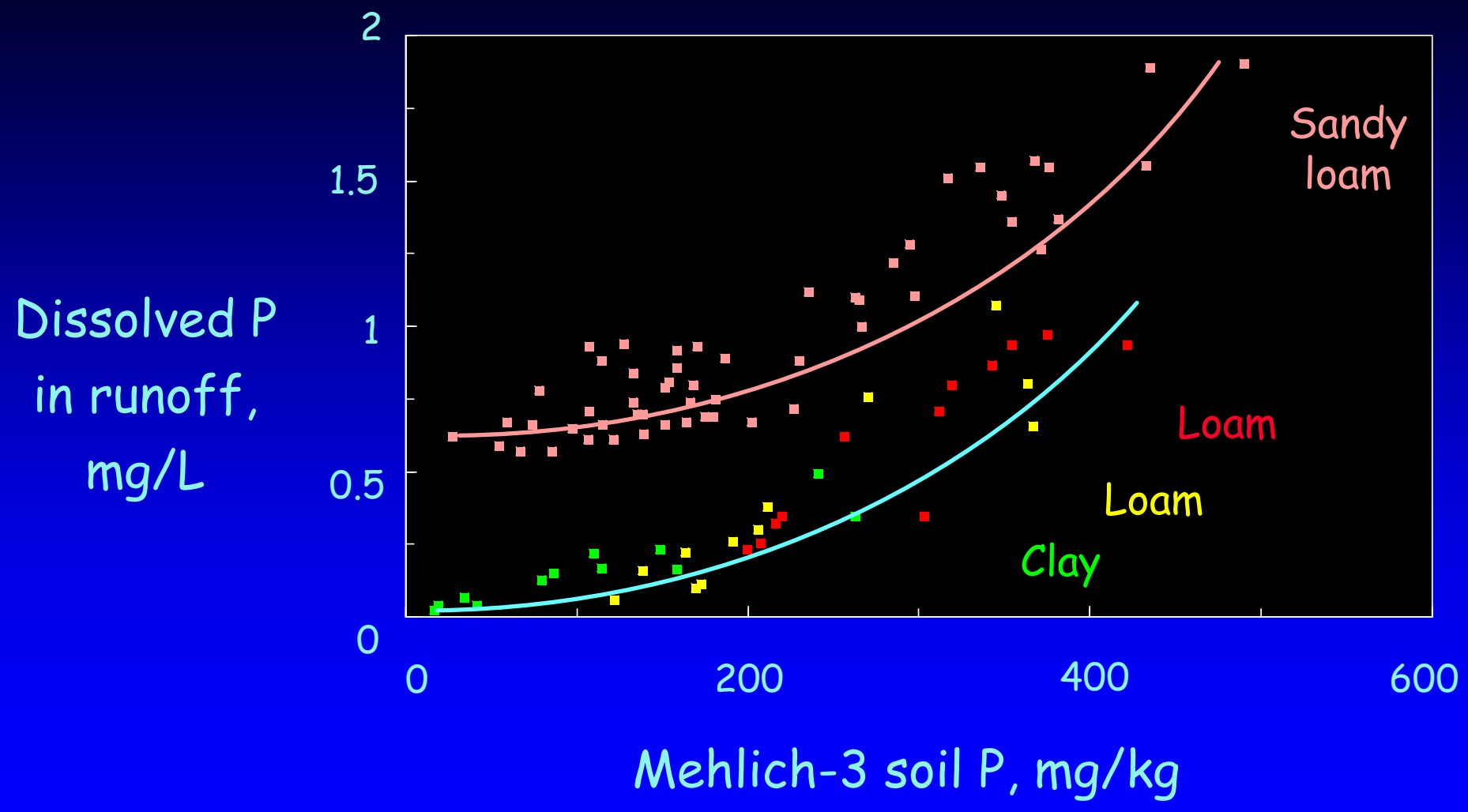
Optimum: 26-50

High: >50

Lowering soil test P is slow…



Soil as a source of dissolved P



Manokin River Watershed

Manokin River Watershed

PENNSTATE

1855

(814) 863-0841 Fax (814) 863-4540

Agricultural Analytical Services Laboratory
The Pennsylvania State University
University Park PA 16802
http://www.aasl.psu.edu

SOIL TEST REPORT FOR:	ADDITIONAL COPY TO:
LOU SAPORITO USDA-ARS 3702 CURTIN RD UNIVERSITY PARK PA 16802	11/24/03 UMES Sampling

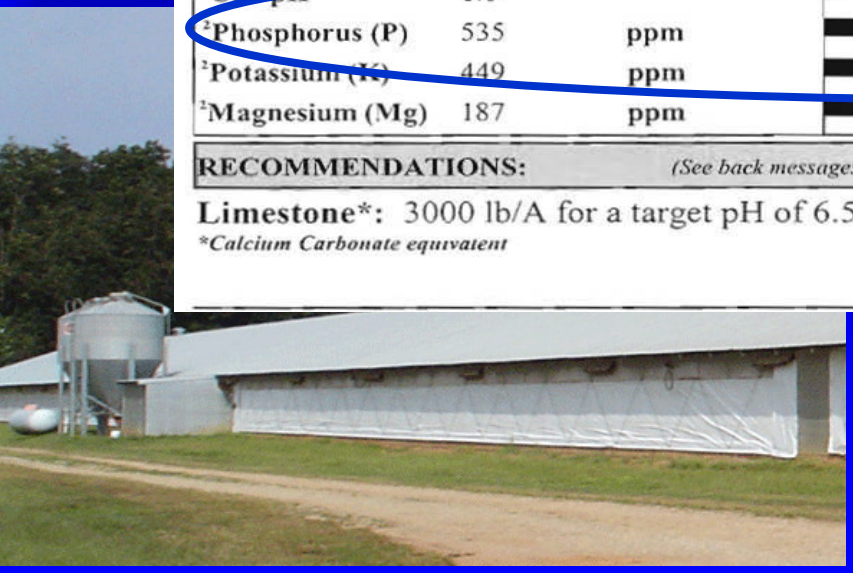
DATE	LAB #	SERIAL #	COUNTY	ACRES	ASCS ID	FIELD ID	SOIL
01/19/2004	S03-17635	113568	Centre			1 SIGMA	

SOIL NUTRIENT LEVELS			Below Optimum	Optimum	Above Optimum
[1]Soil pH	6.0				
[2]Phosphorus (P)	535	ppm			
[2]Potassium (K)	449	ppm			
[2]Magnesium (Mg)	187	ppm			

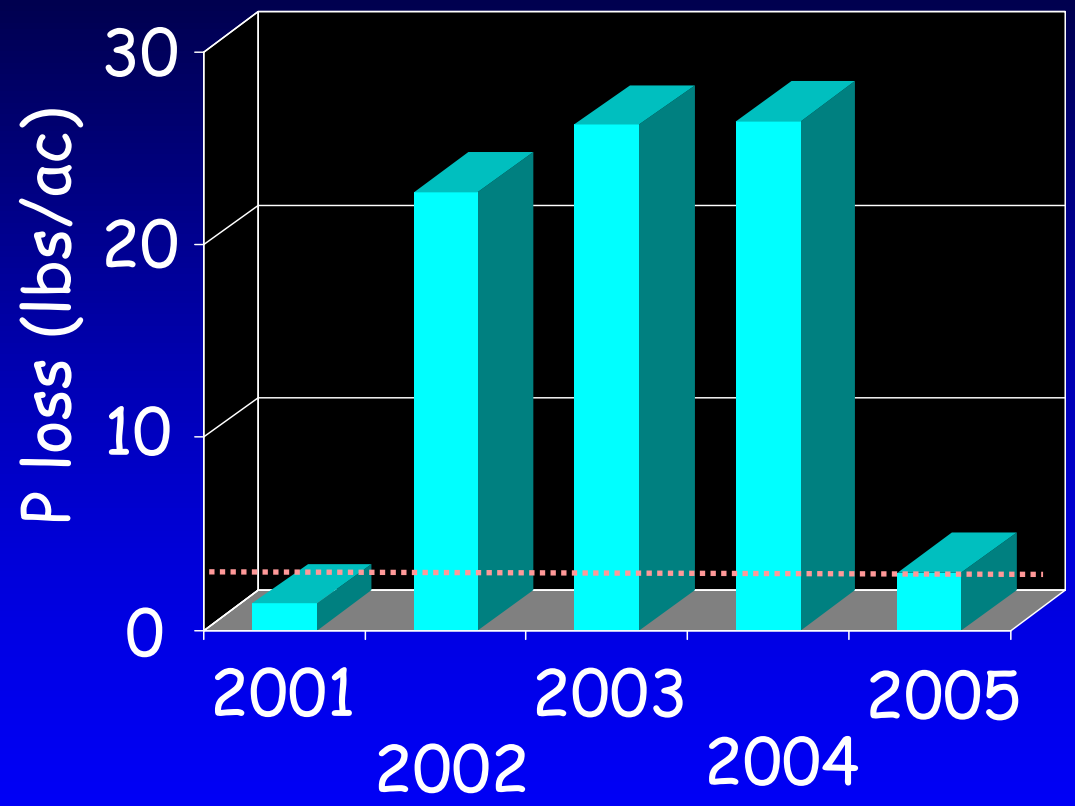
RECOMMENDATIONS: *(See back messages for important information)*

Limestone*: 3000 lb/A for a target pH of 6.5. **Magnesium (Mg):** NONE

**Calcium Carbonate equivalent*



Ditch P losses – soil P desorption

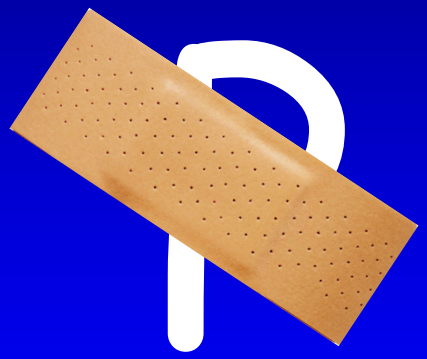


Mehlich-3 P ~ 400 mg/kg

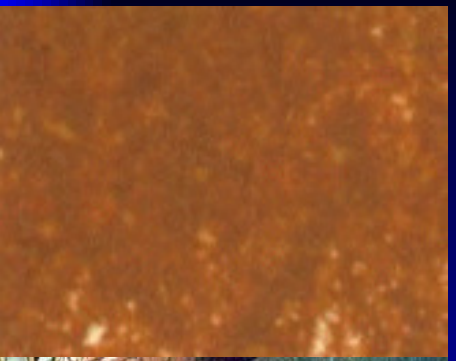
> 80% of P in ditches is from sub-surface flow!

What to do when the system is saturated with P?

- Cease P applications to soils and export yields
- Deep tillage
- Filters
  - Filter strips
  - Riparian buffers
  - Chemical traps…



P sorbing materials



Acid mine drainage treatment residuals

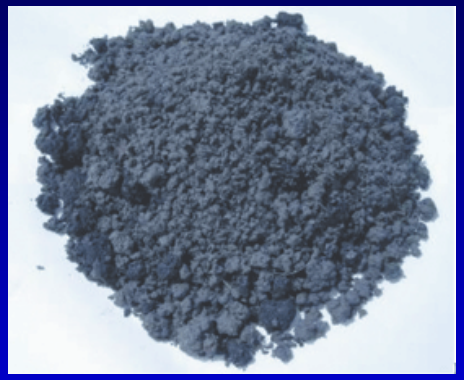
Bauxite mining and production waste (red mud)

Steel slag waste

Drinking water treatment residuals

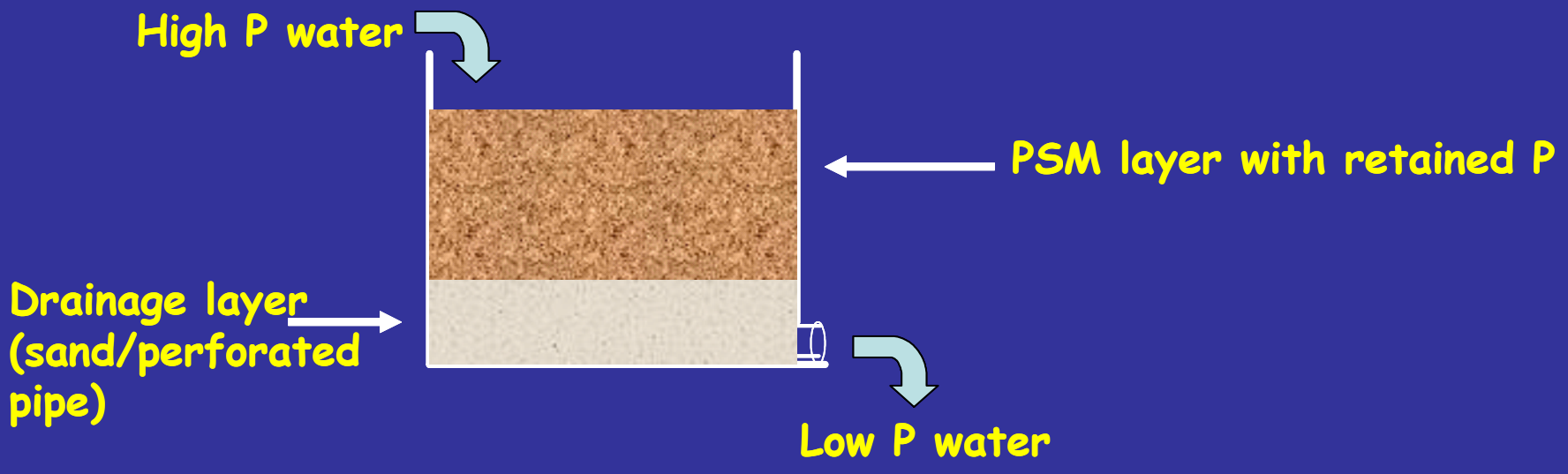
Fly ash

Waste recycled gypsum



Paper mill waste

Ditch filters



Ditch filter

High P water

layer with retained P

Drainage lay
(sand/perfor
pipe)

Treated water piped to adjacent collection ditch

Ray Bryant,
Chad Penn

Ditch filter

High P water

layer with retained P

Drainage lay
(sand/perfor
pipe)

Ray Bryant, Chad Penn

Ditch filter

High P water

Draina
(sand/
pipe)

d P

>90% dissolved P removal efficiency

Designed to work for 1-2 years before replacing P sorbing materials

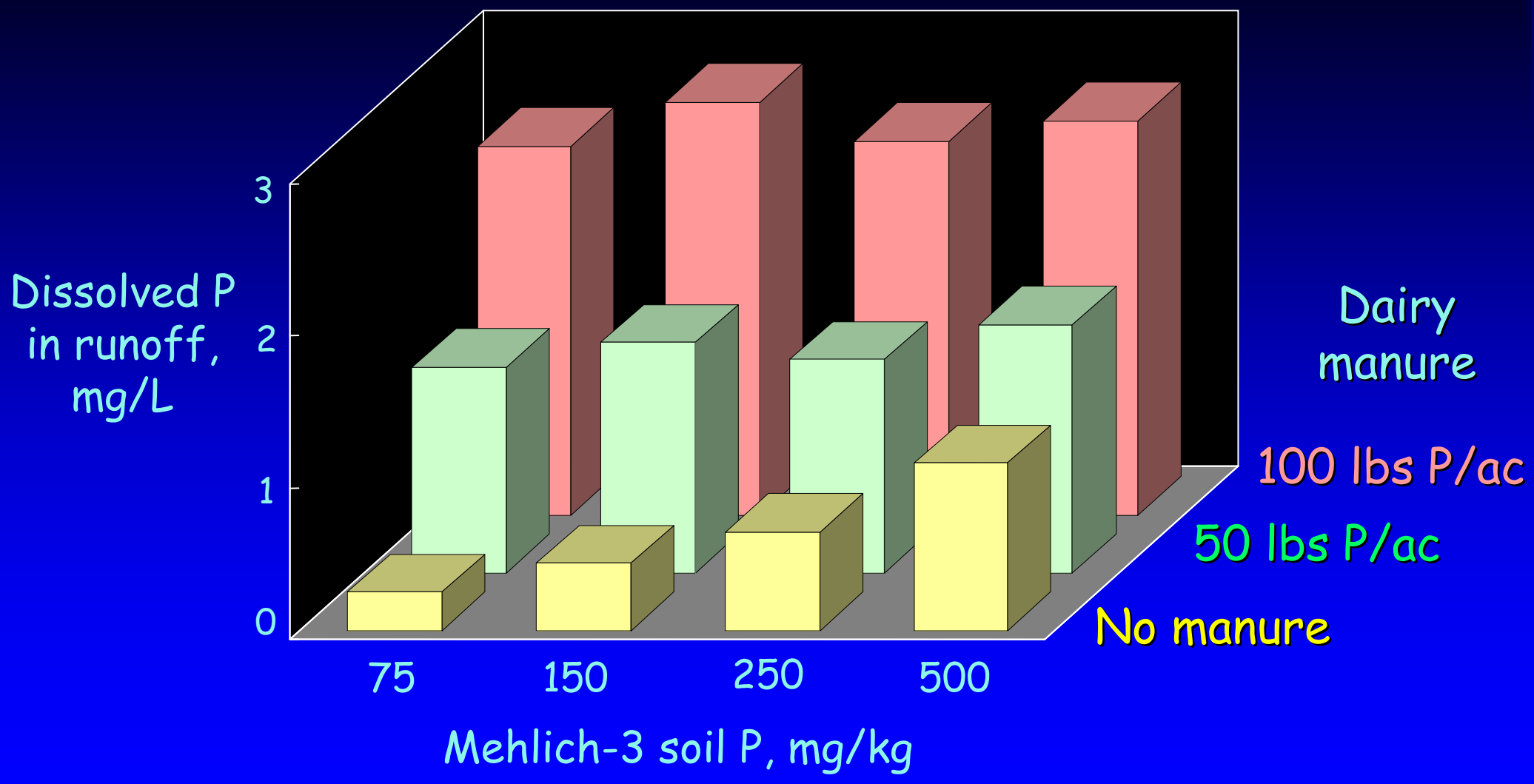
P sorbing materials can be land applied

Ray Bryant, Chad Penn

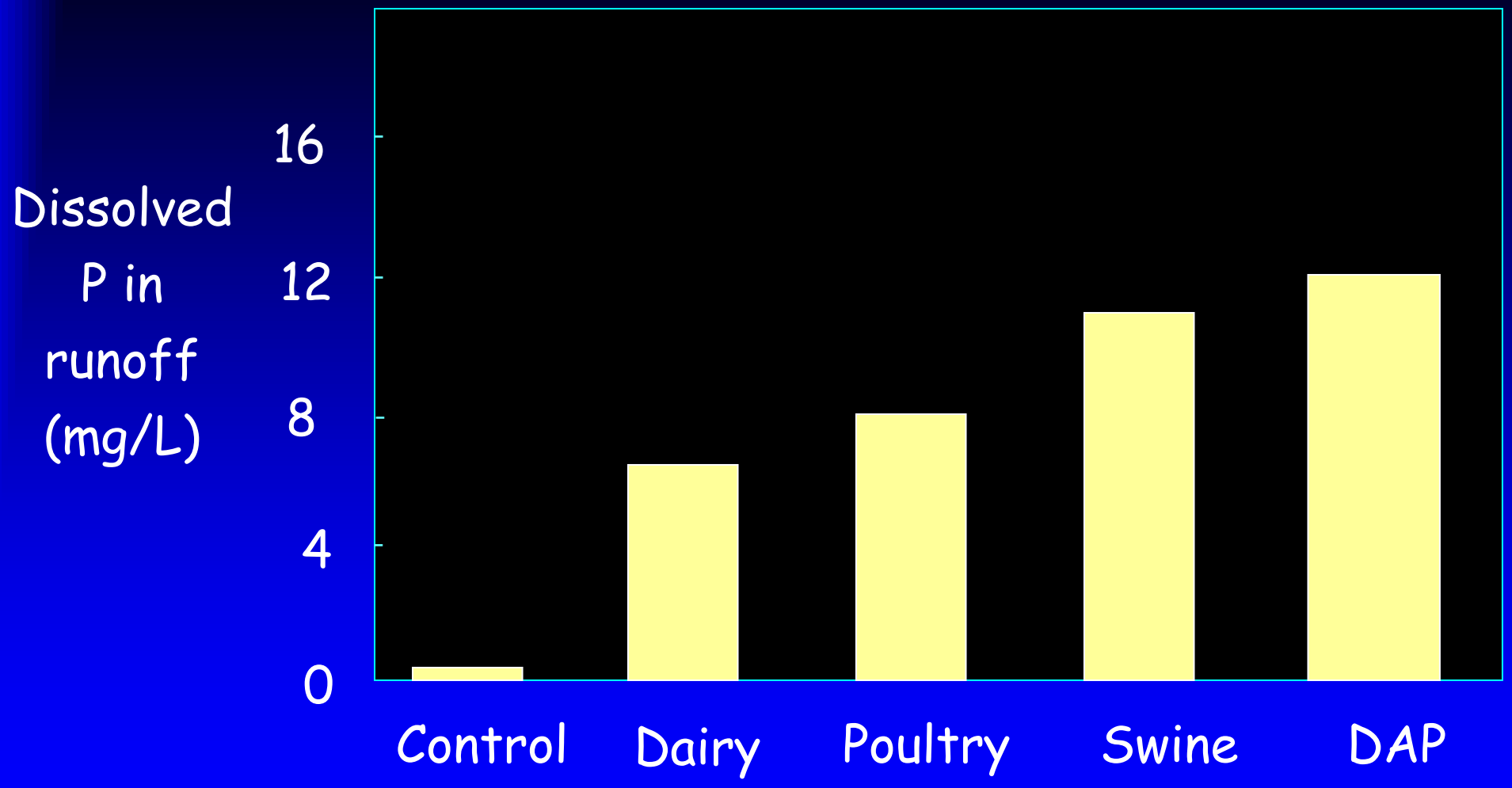
Managing incidental transfers

- ✓ If it rains 5 inches some time in the next week…

Manure as a Source of P – Application Rate and Soil Test P



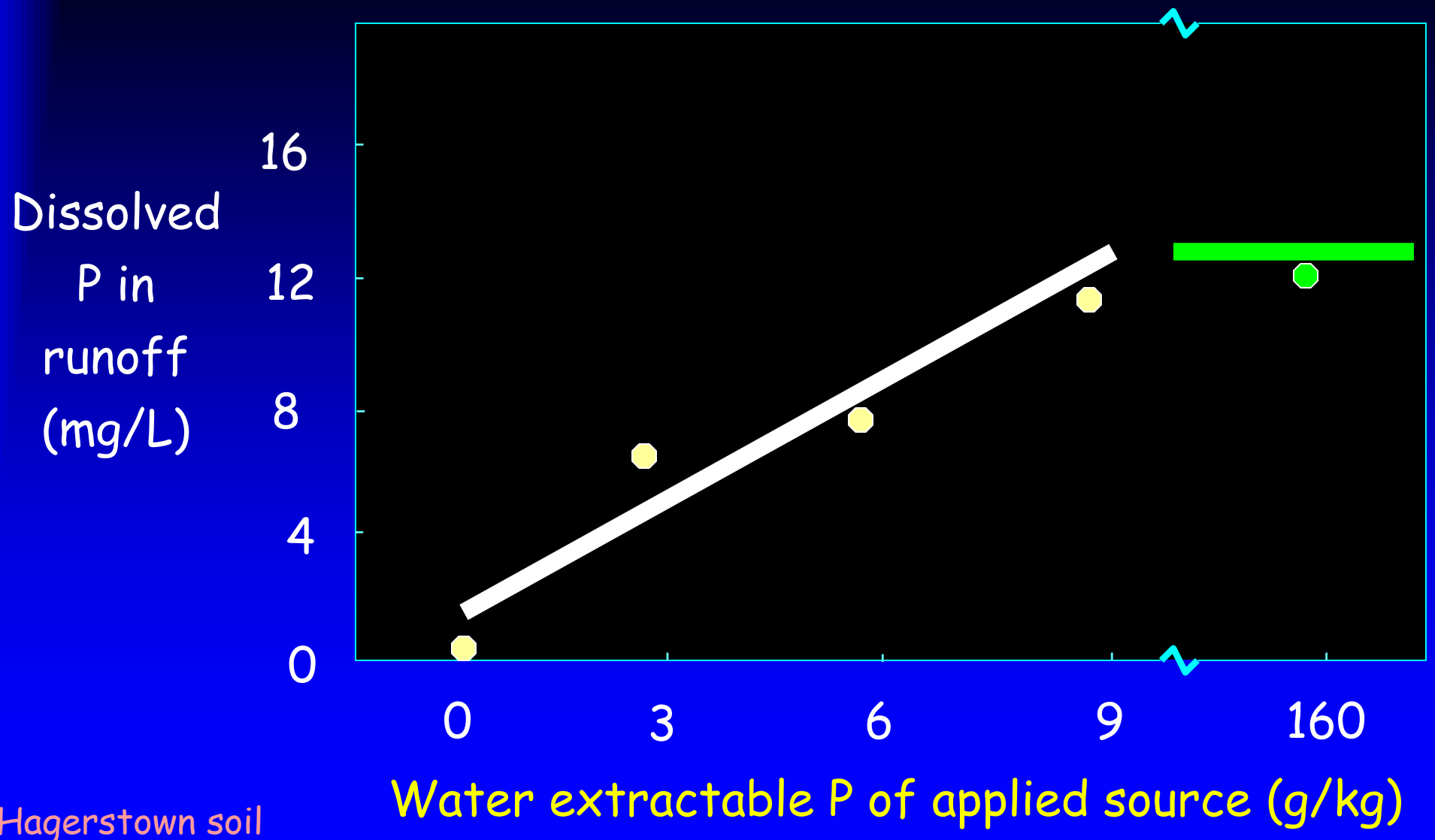
Development of P Availability Coefficients



All sources broadcast at 100 lbs TP/ac

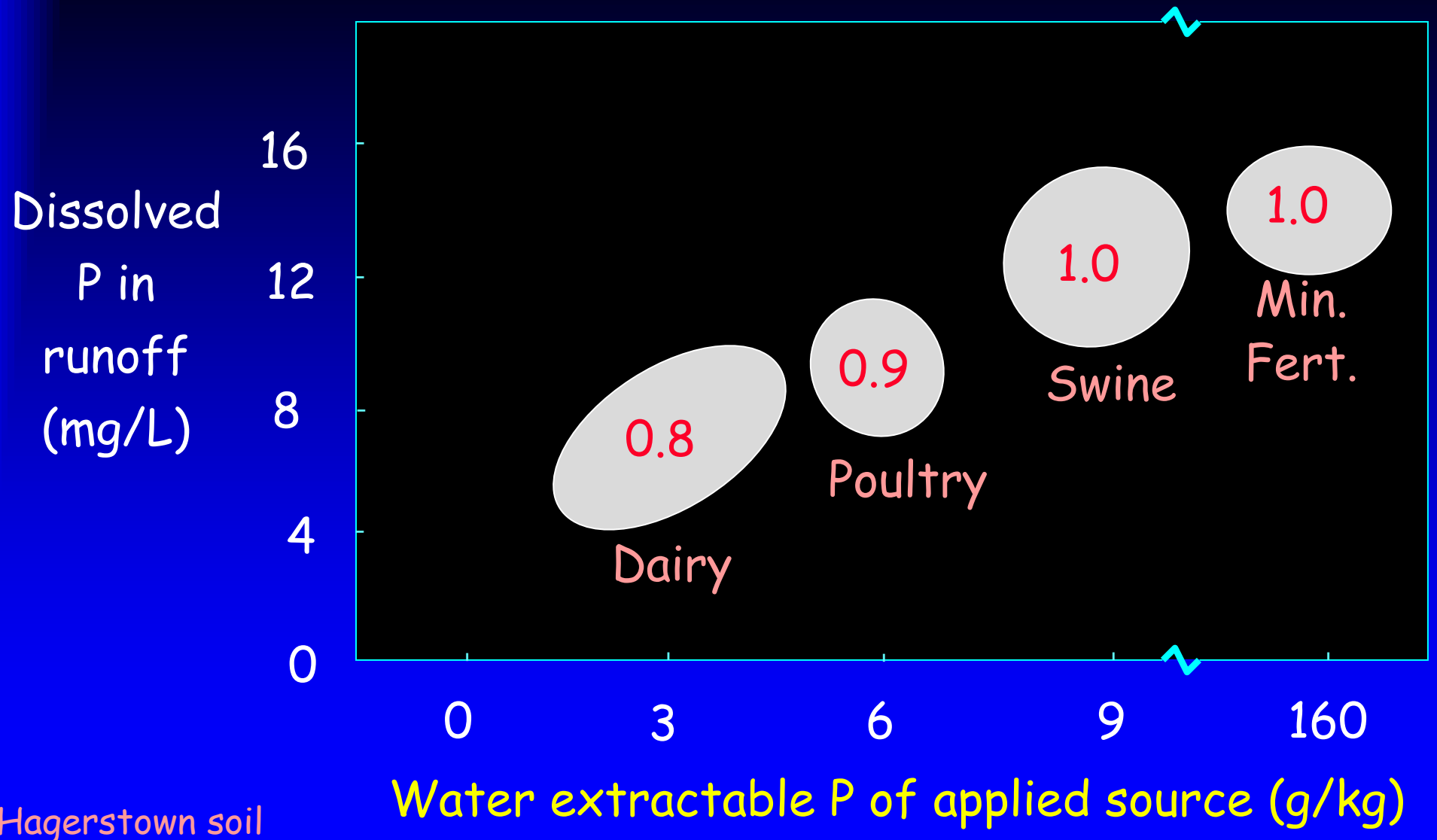
Hagerstown soil

Development of P Availability Coefficients



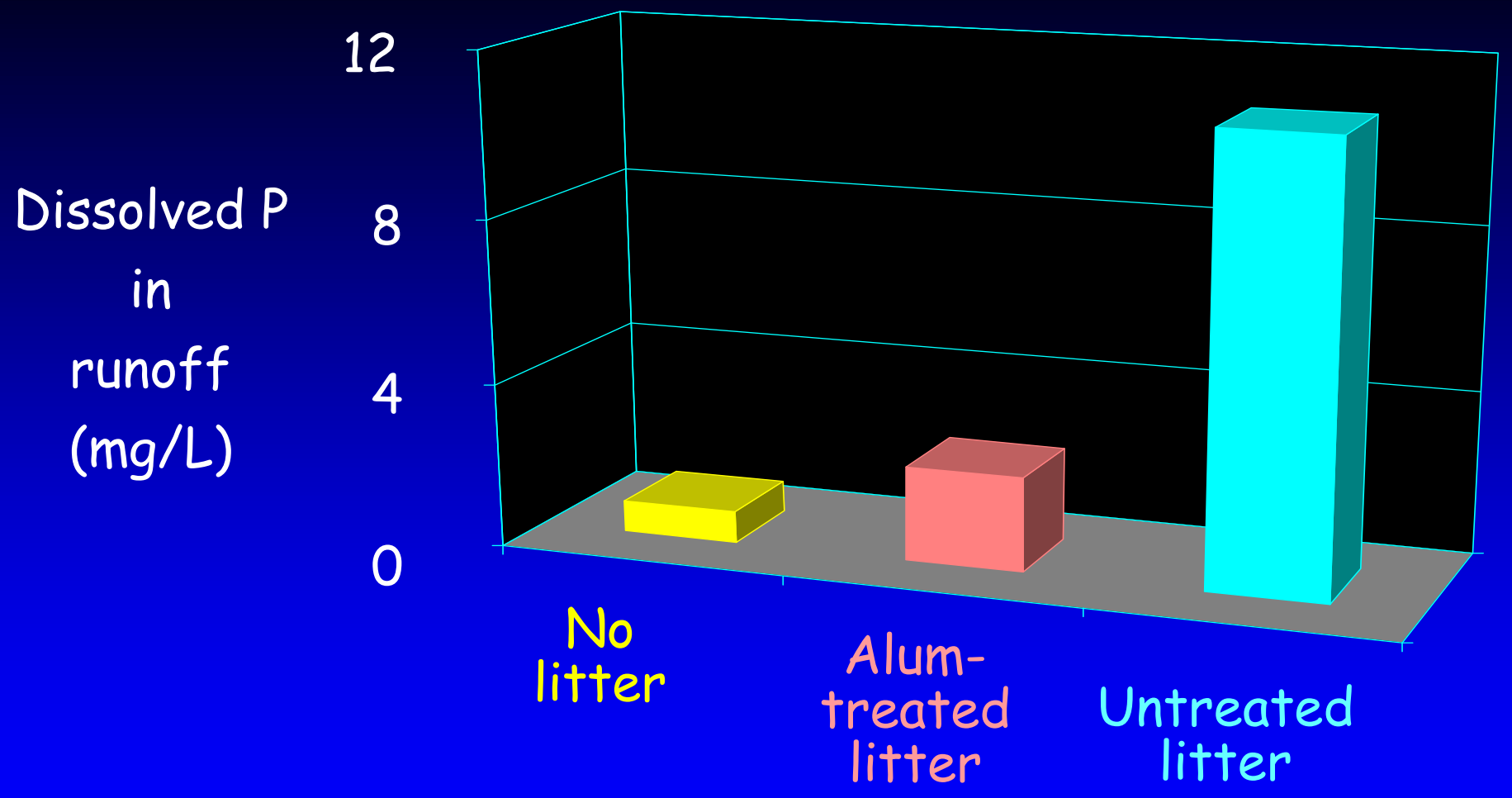
Hagerstown soil

Development of P Availability Coefficients



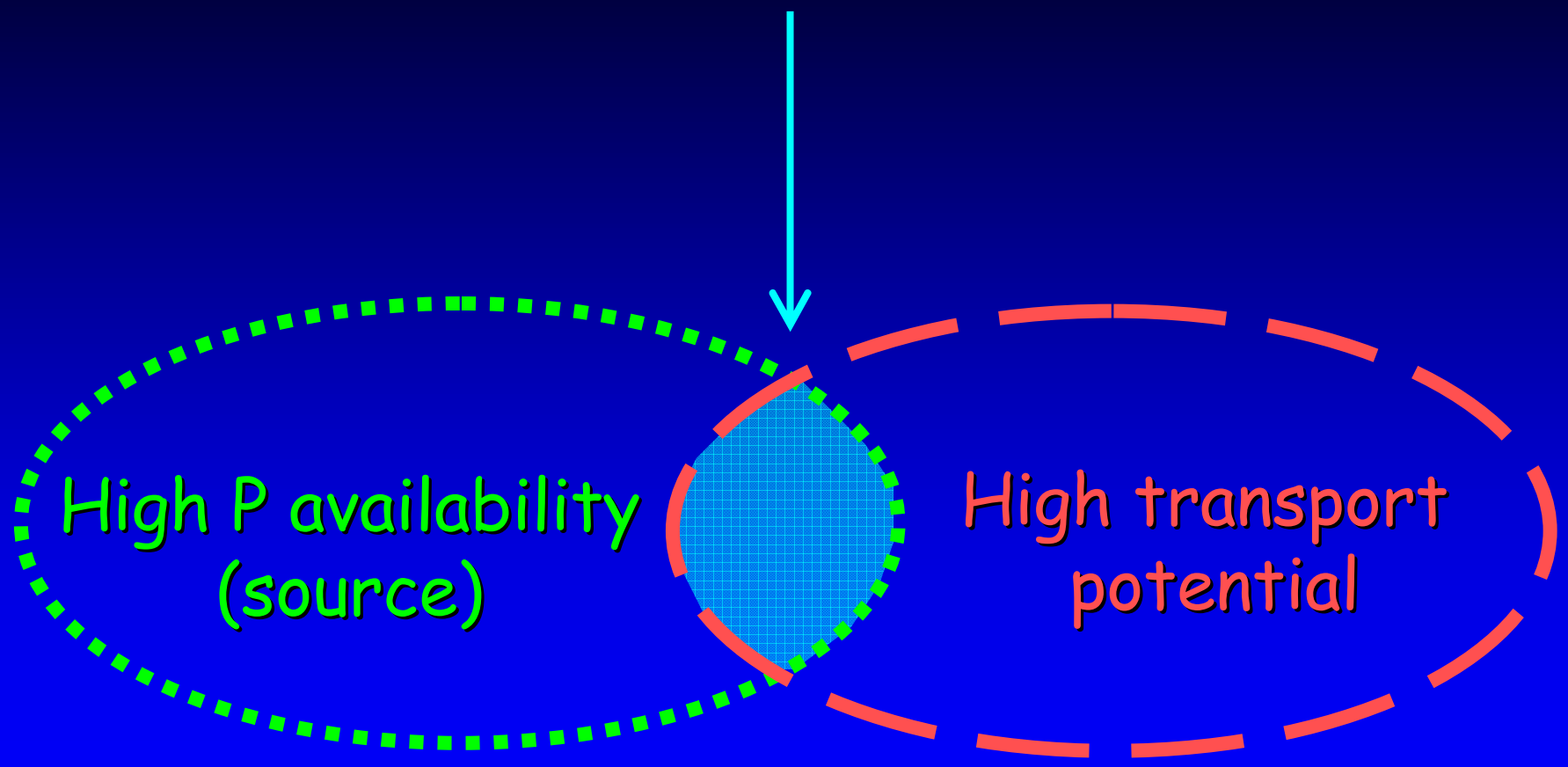
Hagerstown soil

Managing solubility in applied sources

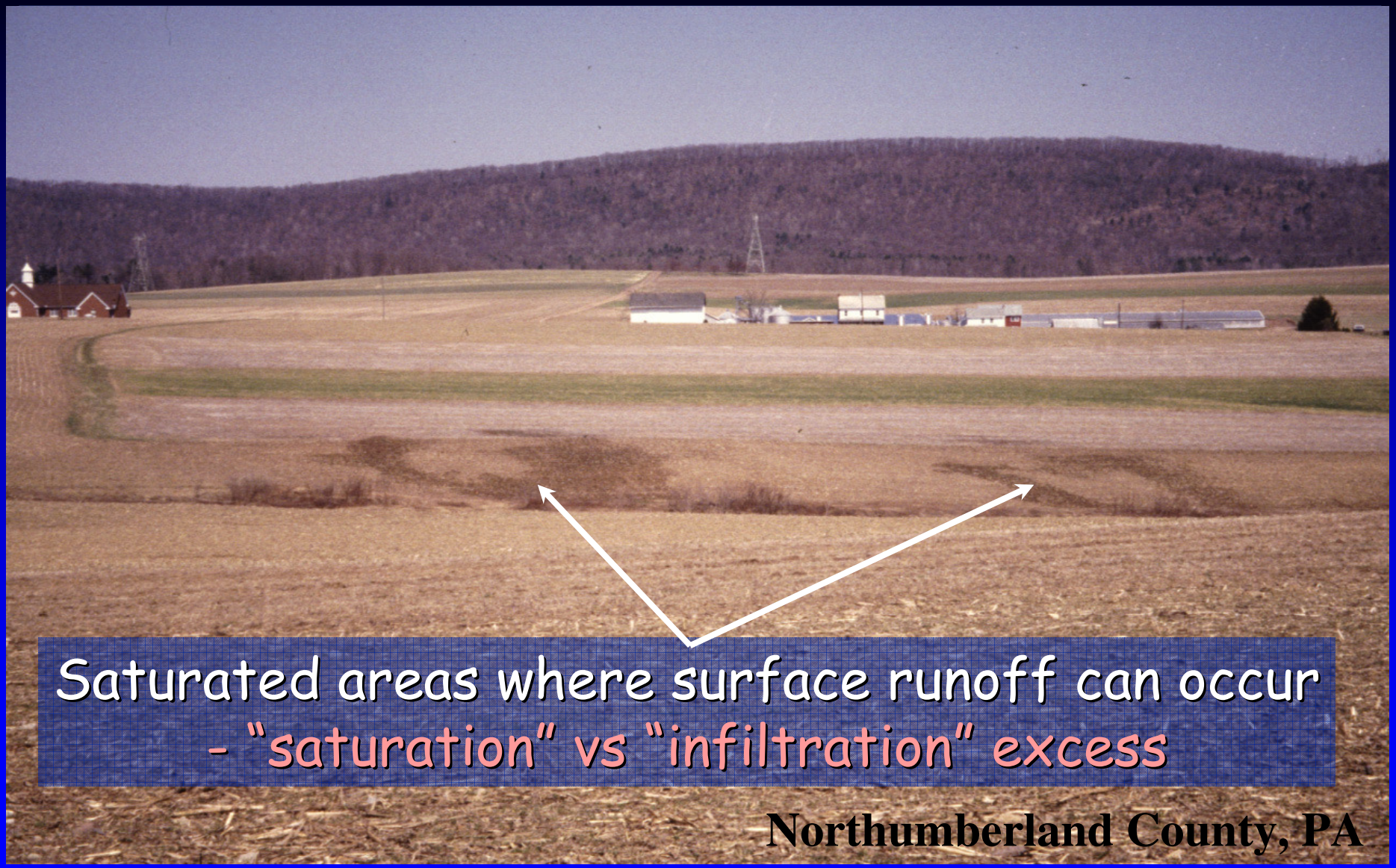


Poultry litter applied to pasture soil (Moore et al., 2000)

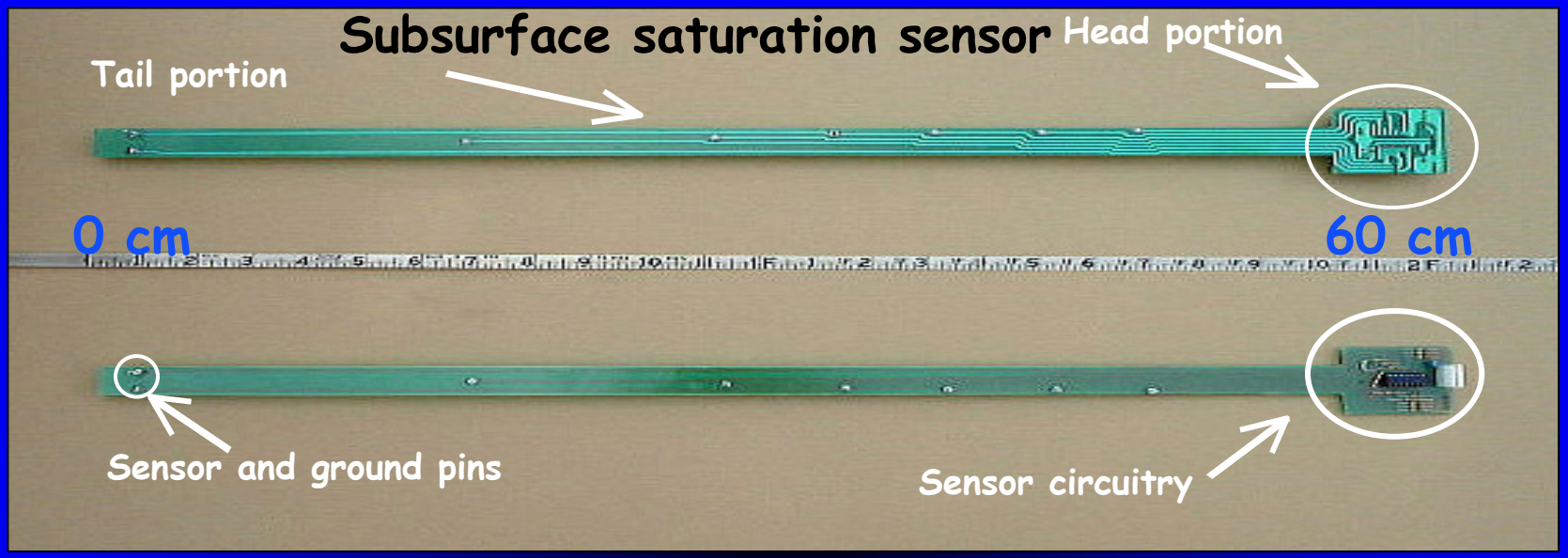
Critical Source Areas

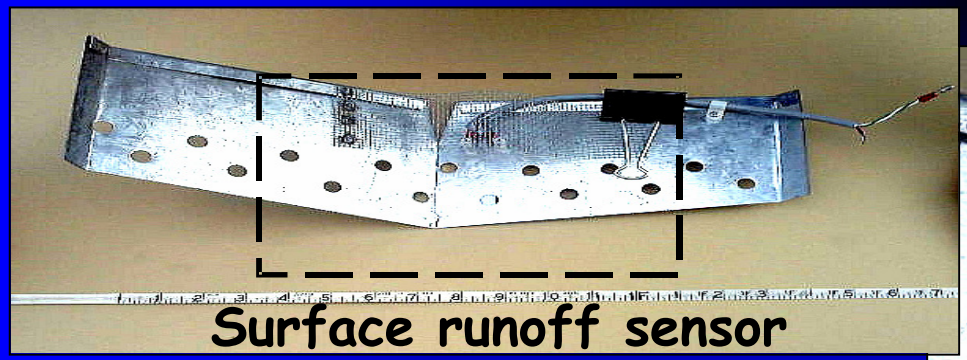


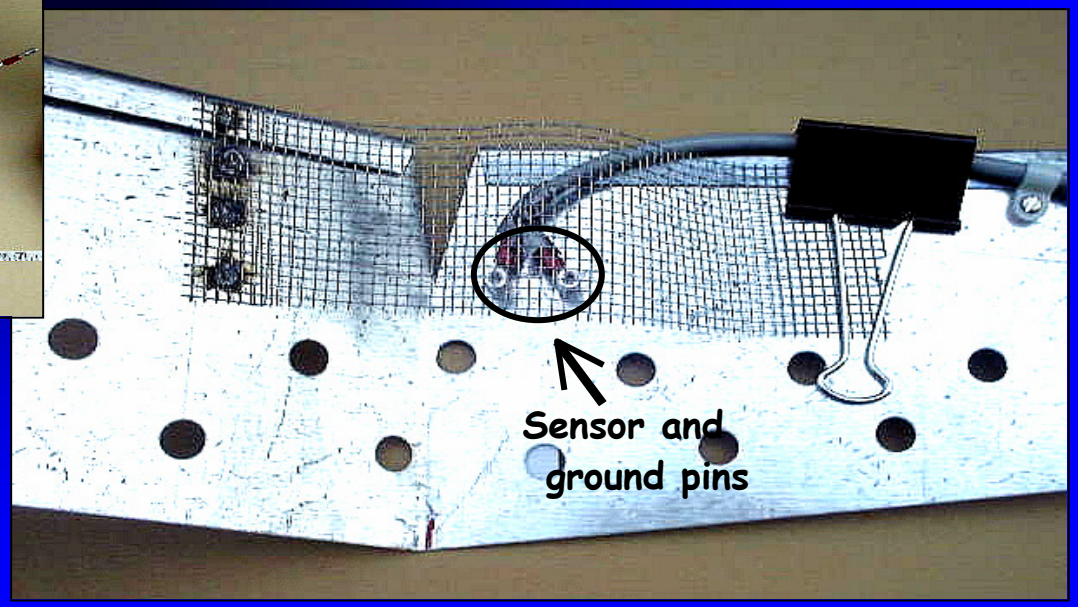
Variable source area hydrology



Getting a handle on runoff sources

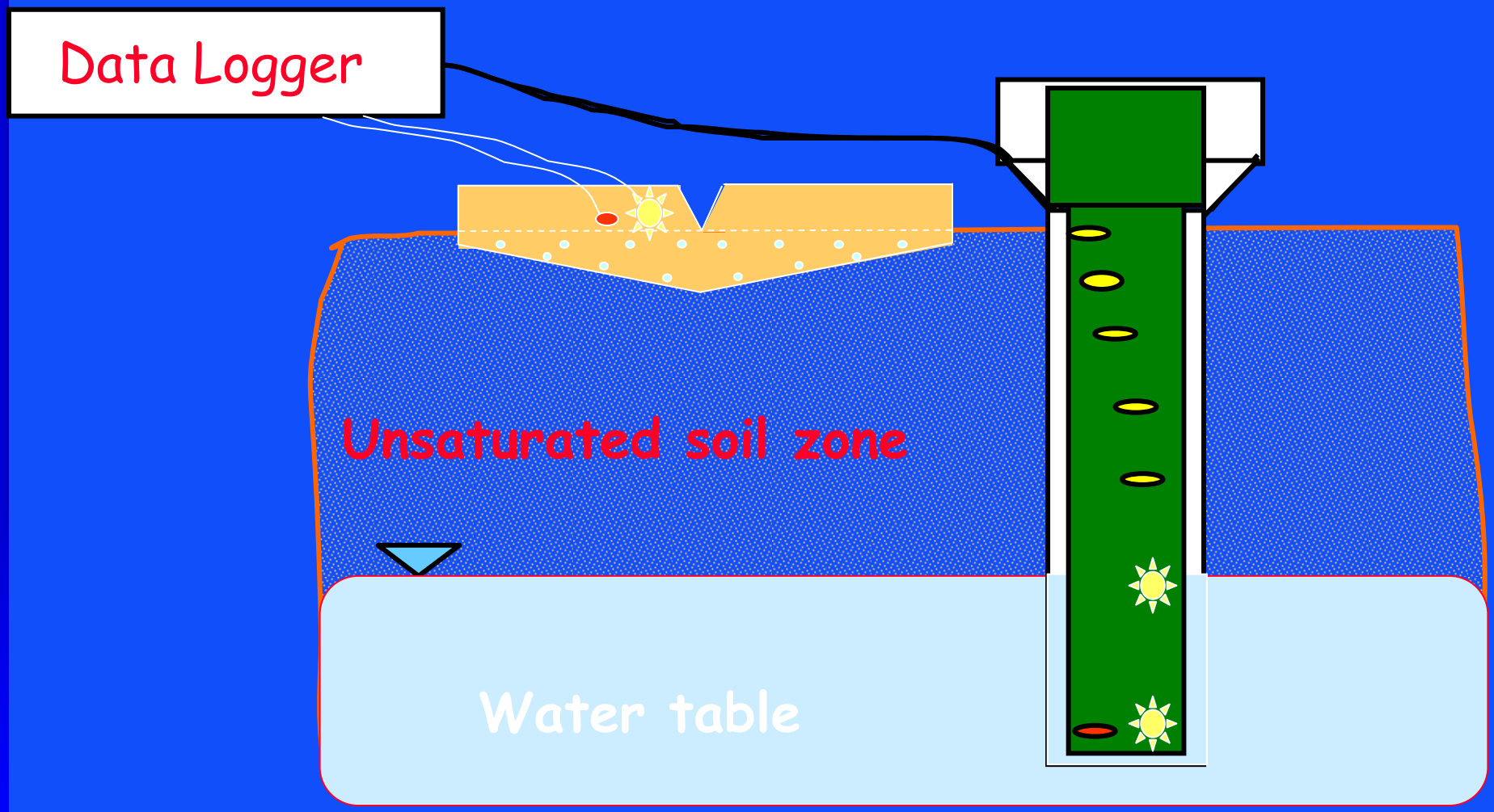

Subsurface saturation sensor
Tail portion
Head portion
0 cm
60 cm
Sensor and ground pins
Sensor circuitry


Surface runoff sensor

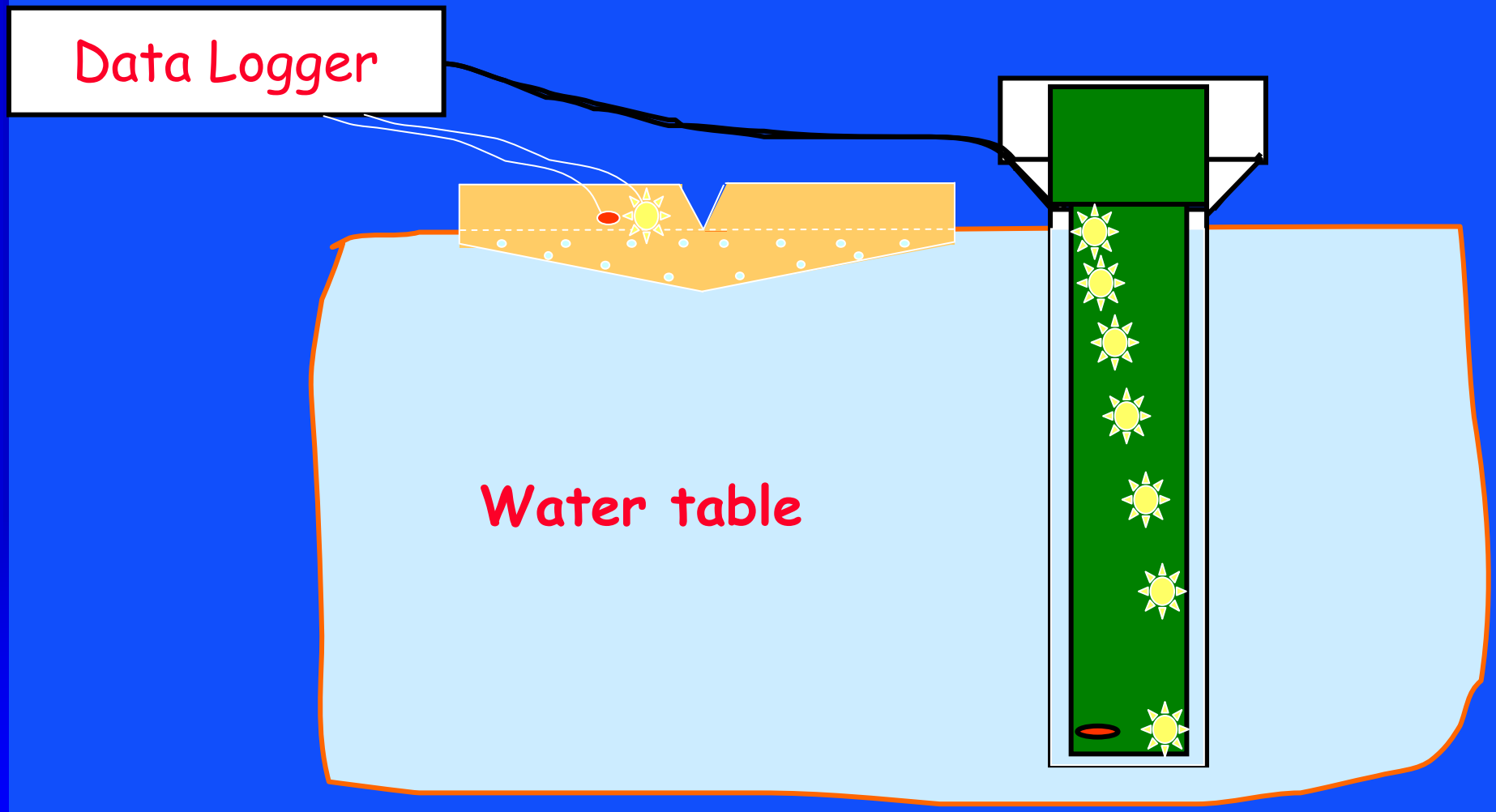

Sensor and
ground pins

Water flowing through the surface runoff sensor

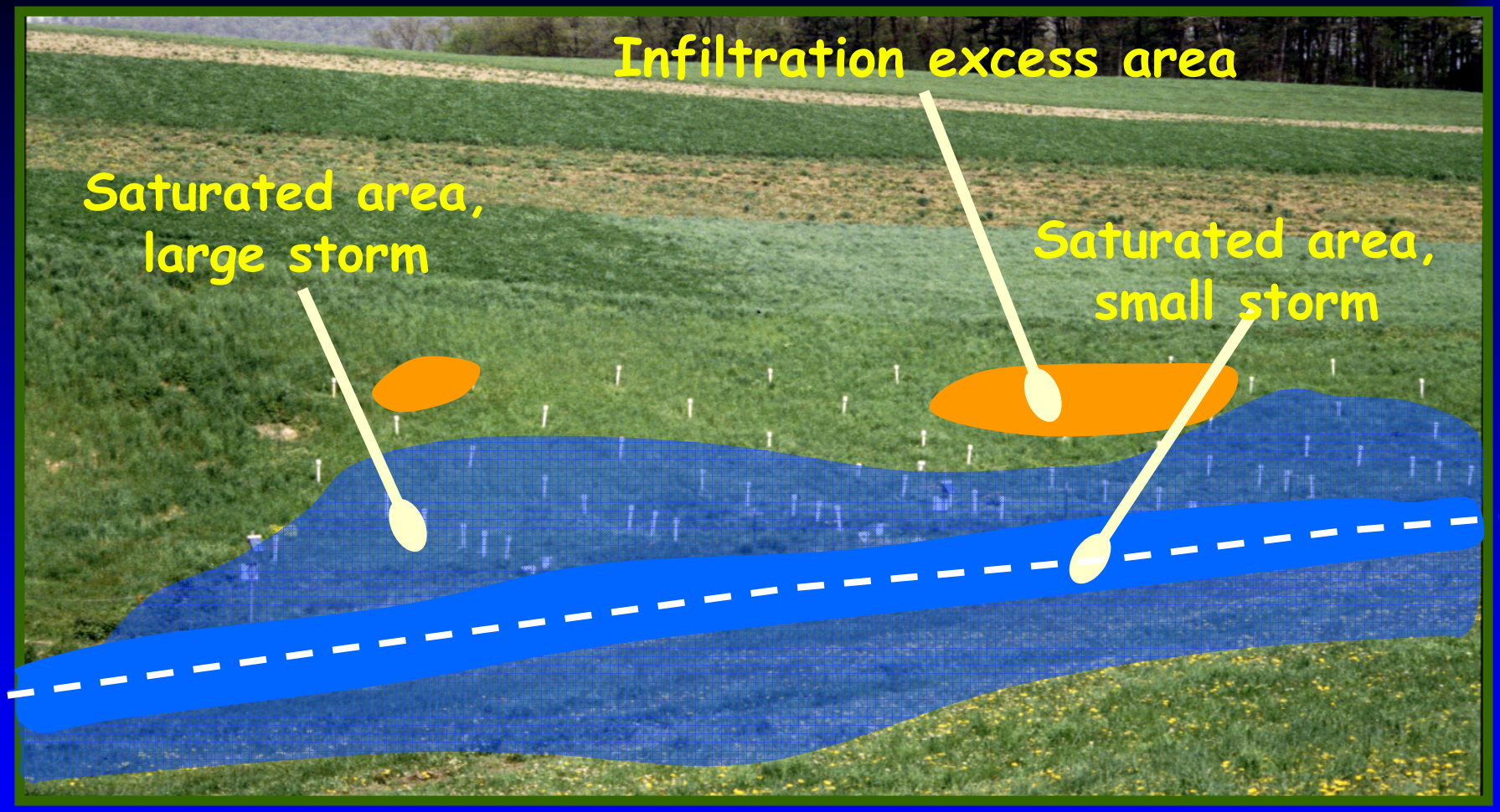
Infiltration excess runoff



Saturation excess runoff

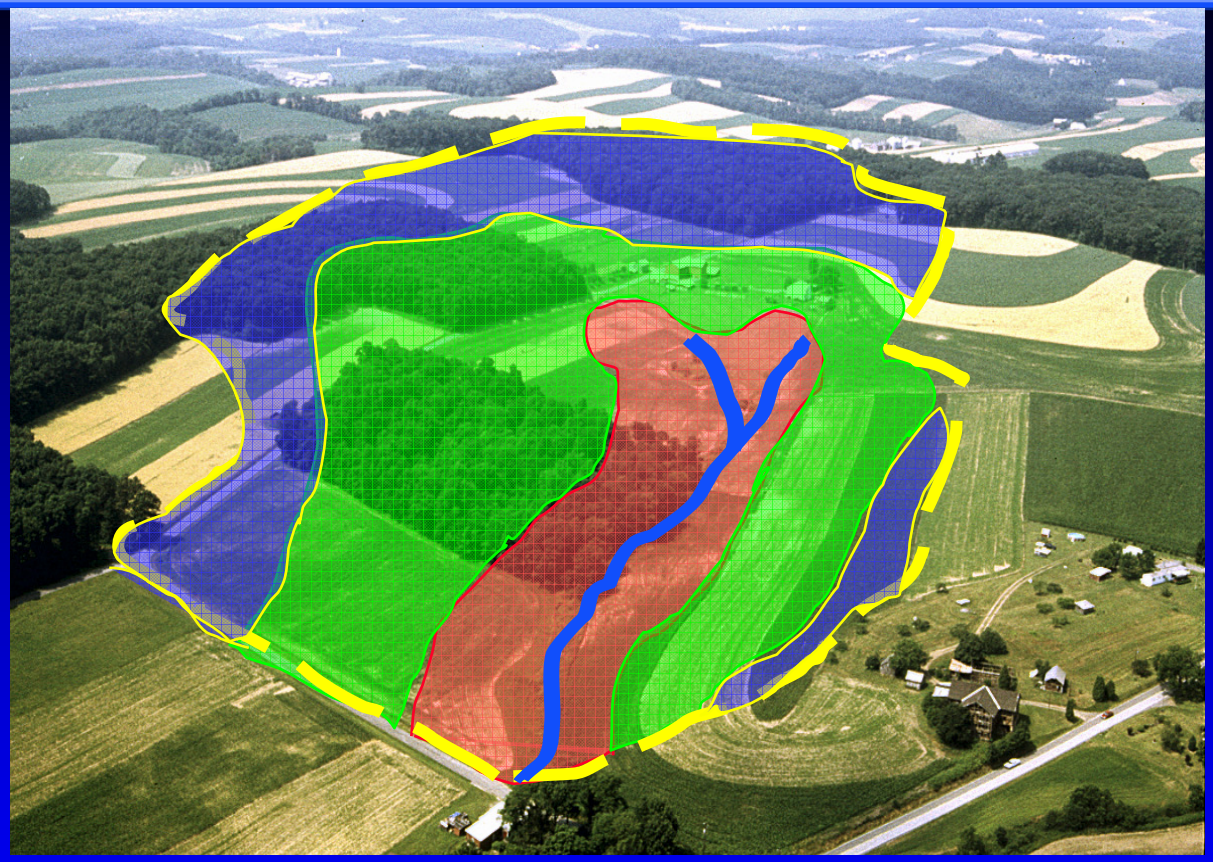


Characterizing and mapping runoff



Small storm < 0.5” Large storm > 0.5”

Modeling Areas of High Runoff Probability

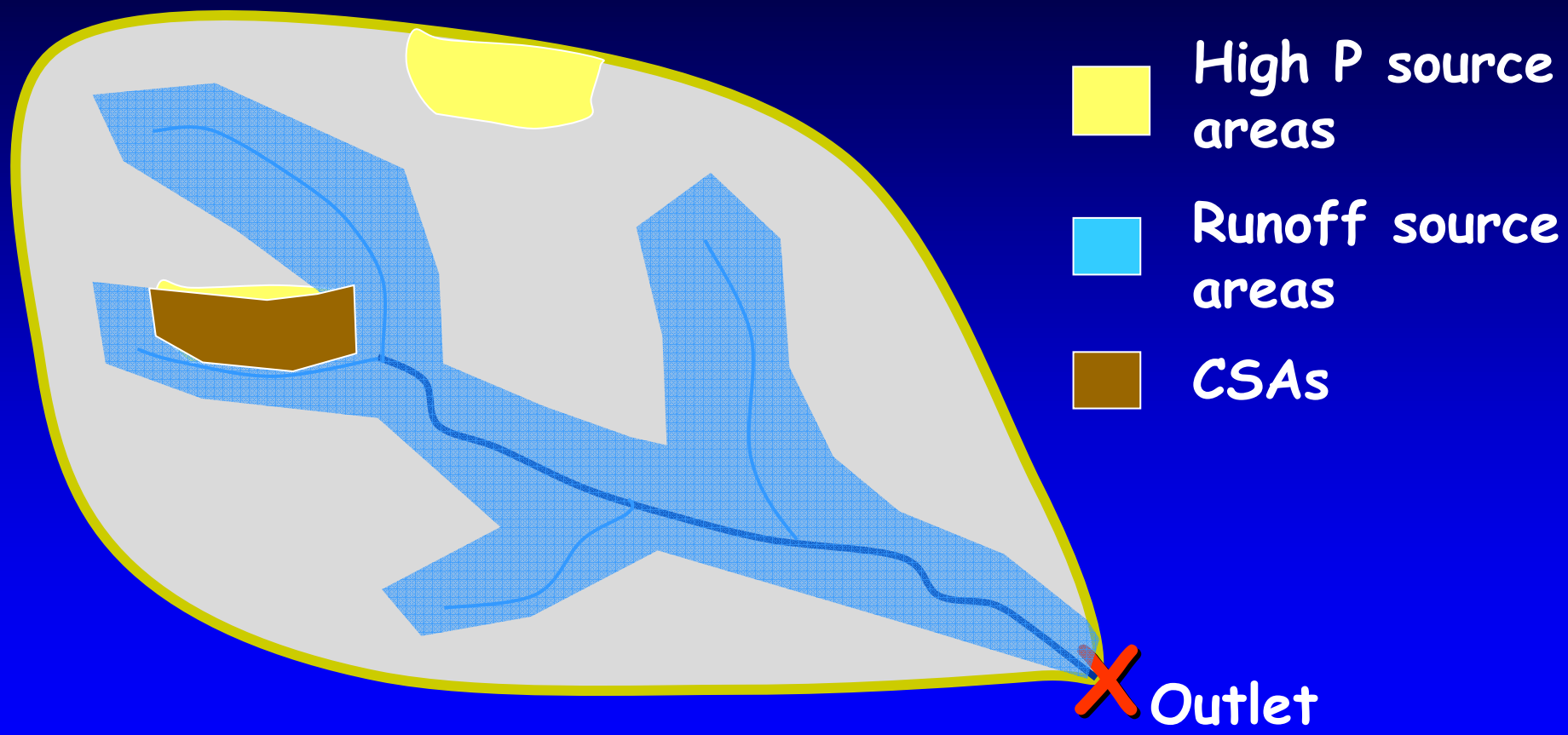


Rainfall Return Periods

2 years 5 years 10 years

(Gburek et al., 1999)

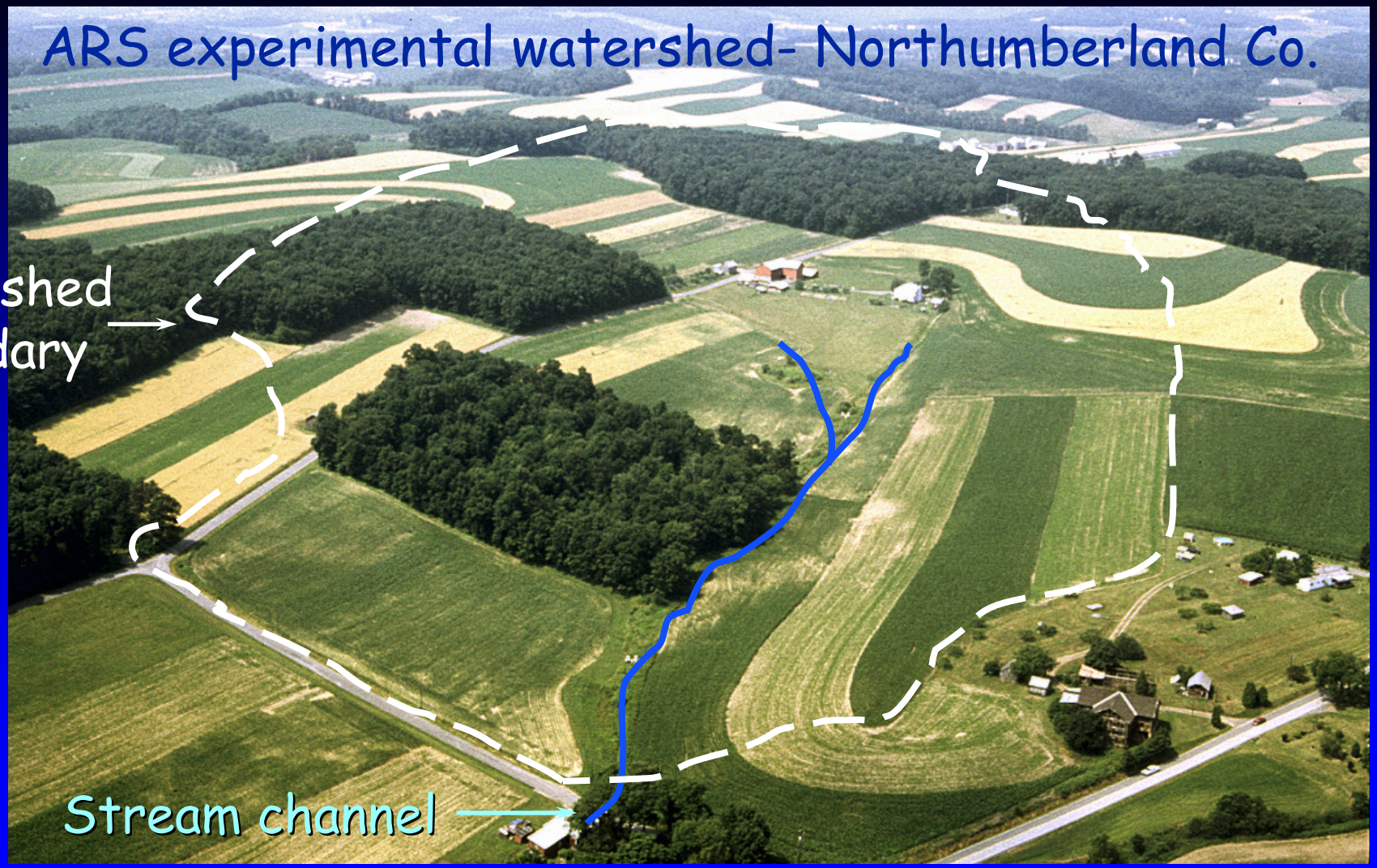
Critical Source Areas



EPA-NRCS: P Management Options

- Crop P requirements
- Threshold soil P levels
- Site vulnerability assessment
  - P Index

Assessing Site Vulnerability



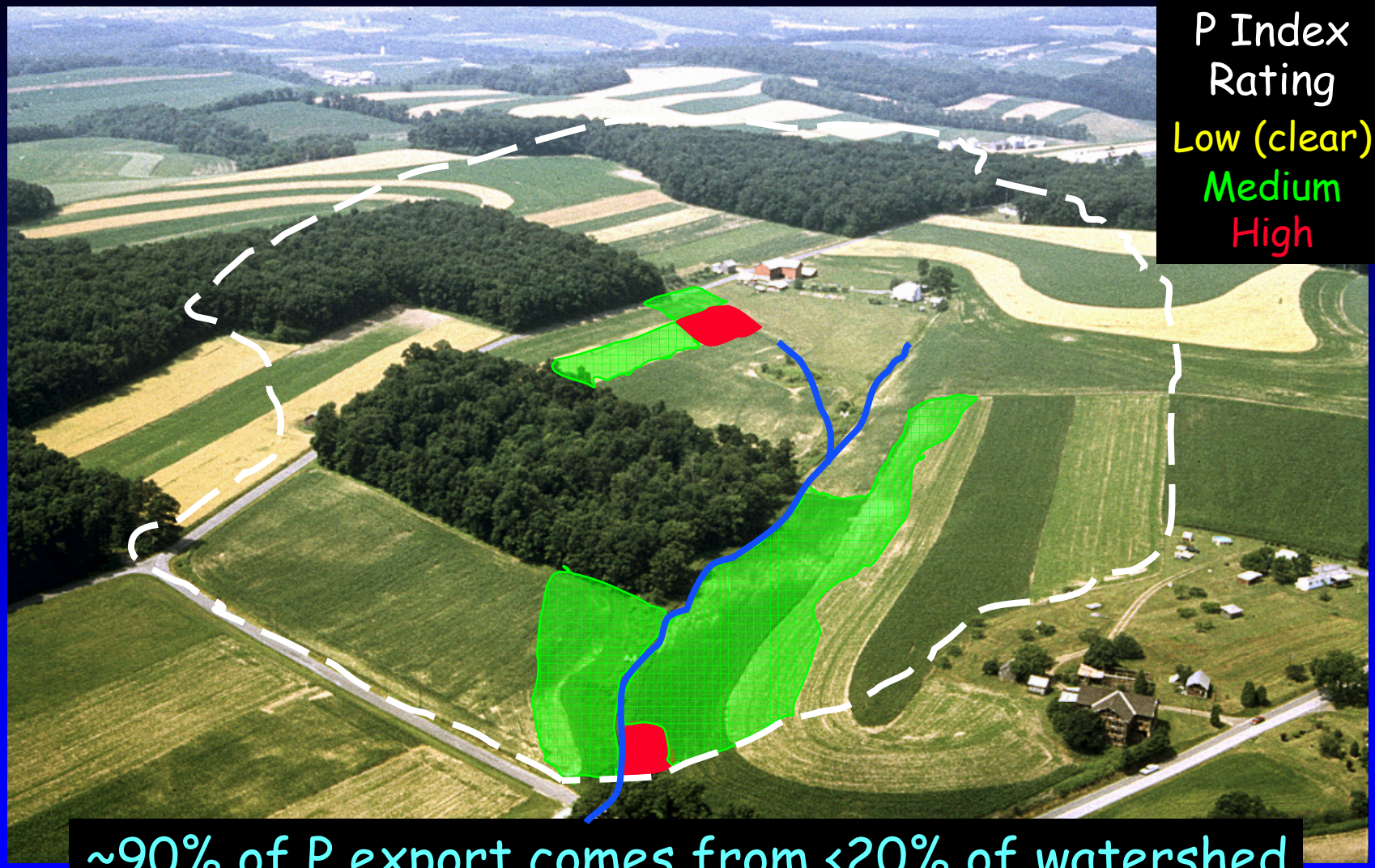
Crop P Requirement

85% of the watershed would receive no P

Soil Environmental P Threshold

40% of the watershed would receive no P

The P Index



~90% of P export comes from <20% of watershed

P Index Summary

- Source
  - Soil P
  - Manure Fertilizer P (rate, method, timing)
- Transport
  - Runoff
  - Erosion
  - Leaching

Conclusions

- Science of P transport rapidly advancing
- Long-term problem = imbalance
- A lot of temporary fixes
  - P Index fits critical source area concept and is first step