Water Quality and Phosphorus Index

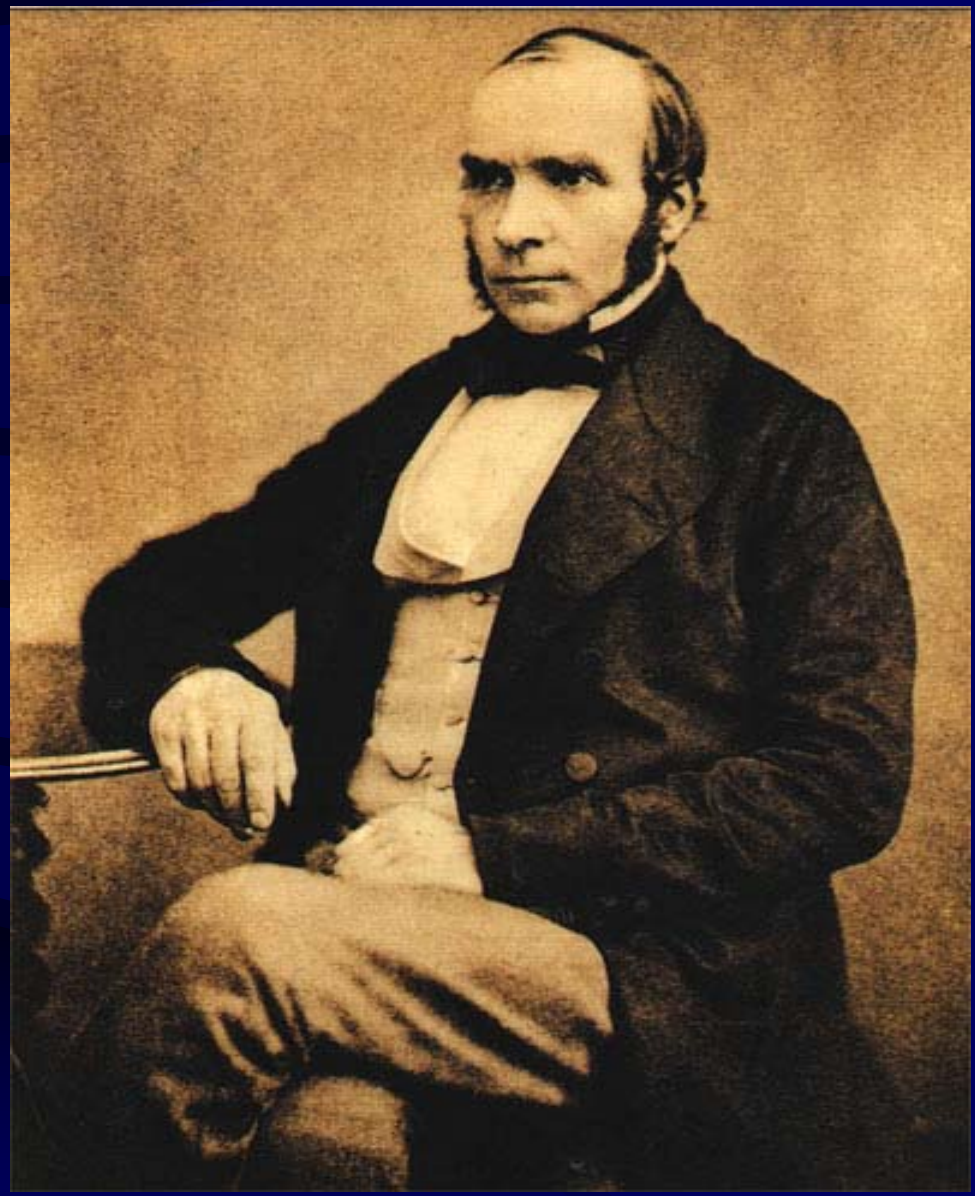
Devinder Kumar Bhumbla
West Virginia University
Morgantown

Historic Water Quality Concerns

- Taste
- Suitability for Irrigation
- Human Health
  - Roman Aqueducts

Waterborne Infectious Diseases

- Mid 19th Century
  - –Link between Cholera and Source of Water
  - –Birth of Epidemiology



John Snow

Inorganic Constituents in Water

- In the Twentieth Century
  - –Chronic Diseases

Human Health and Inorganic Constituents in Water

- Mercury Minamata
- Cadmium (Itaiitai)
- Copper
- Nickel
- Chromium

Human Health and Inorganic Constituents in Water

- Lead
- Barium
- Arsenic
- Selenium
- Nitrates

Nutrients in Water

- Essential for Health and Diversity of Surface Water

Nutrients In Water

- Nitrates
  - Blue Baby Disease
- Nitrites
  - Possible Carcinogens
- Ecological

  Eutrophication of Estuaries and Coastal Waters

  Harmful Algal Bloom

  Brown/Red Tides

Phosphates in Water

- No Direct Human Toxicity
- High Reactivity with Soil Components
- Immobile in Soils
  - No Concern about Ground Water Pollution
- Ecological Concerns
  - Algal blooms in Great Lakes
    - High Phosphate Detergents
    - Point Sources of Pollution

Excessive Phosphates

- Hypereutrophication
- Low Dissolved Oxygen
- Fish Kill
- Increased Sediment Accumulation
- Species Shift
- Pfiesteria

Nutrients and Water Quality 1990s

- Leading Cause of impairment in Lakes
- Second Leading Cause of Impairment of Rivers and Streams
- Nutrients Contributed 25 –50% of Impairment Nationally

Non-point Source of Phosphorus

- On average, inputs exceed outputs
- Excessive build-up of P in the soil

Increased loss of P through runoff

Role of agricultural production in phosphorus build-up

- Animal Feeding Operations (AFOs) or Confined Animal Feeding Operations(CAFOs).
- More than 450,000 AFOs, 85% of them have less than 250 animal units.
- Number of counties with excess manure production doubled between 1982-1997.
- Farming systems fragmented.
- Crop production and animal production regions geographically separated.

Role of agricultural production (contd.)

- Animal production systems becoming intensive due to technological changes, and domestic and export demands.
- Limited land availability for disposal of animal manures → Phosphorus surplus.

Ratio of amount of manure produced to cropland available for application of manures

USDA, 1989

High

Medium

Low

Processes of Phosphorus Export

- Surface runoff

  -forms the better part.

- Subsurface flow

  - usually negligible ,except in sandy soils, peaty soils, tile drainage, or through preferential pathways.

National Strategy for Nutrient Criteria

- Not to Develop a Single Value for N and P
- Base Criteria on
  - Ecological Regions
  - Types of Waters (Lakes, Rivers, Wetlands and Coastal waters)
  - Use Reference (Pristine) conditions for Setting Reference Levels

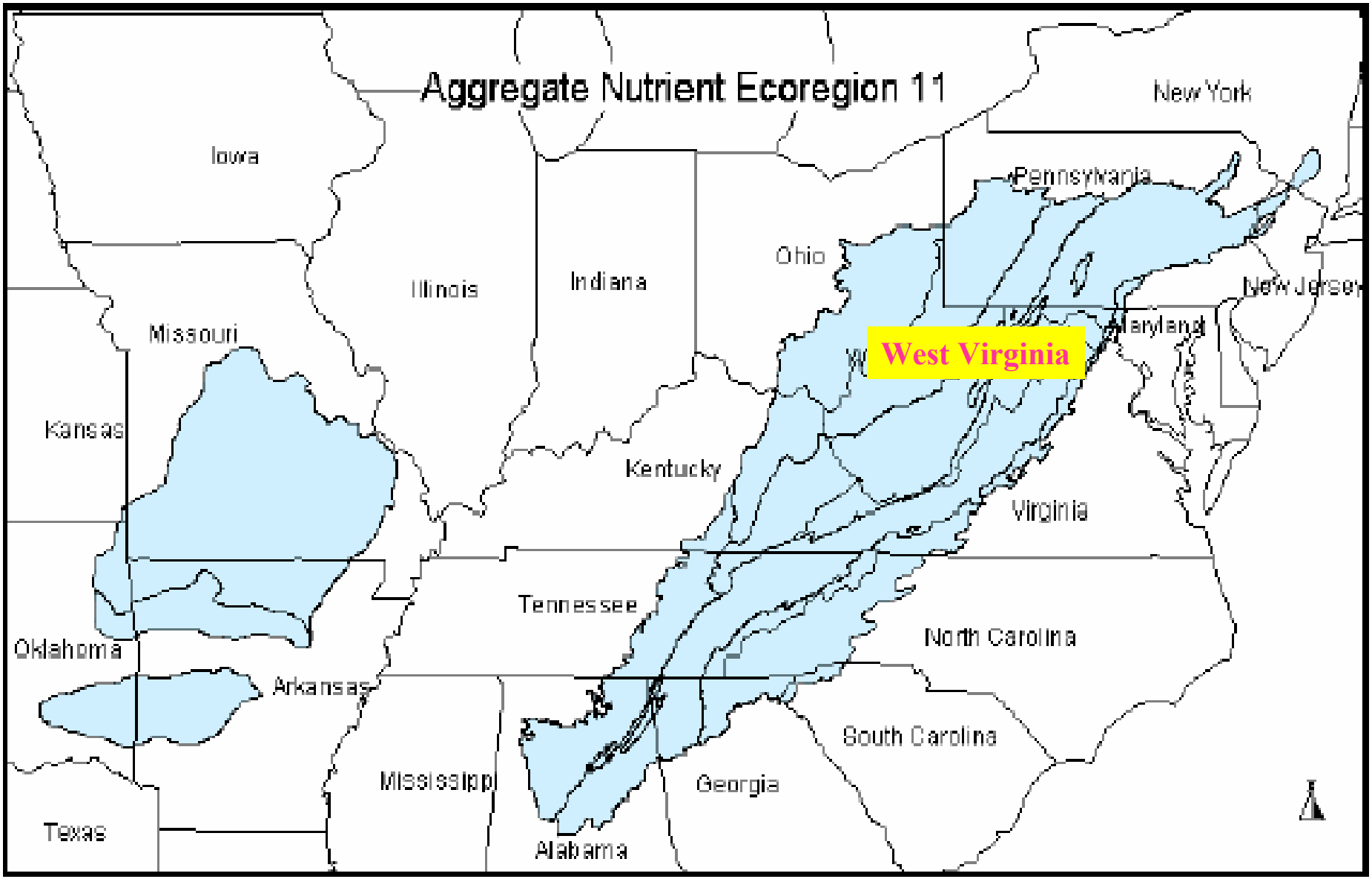


Figure 1. Aggregate Ecoregion XI.

Reference Conditions for Ecoregion XI

Parameter	Min	Max	25 th Percentile
TKN (mg/L)	0.018	3.6	0.1
Total P (ug/L)	0	2160	10

Critical Concentrations for Surface Water

Phosphorus Concentration ug/L	Comment	Source
10	Dissolve P, Lakes	Sawyer (1947) Vollenweider (1968)
100	Total P, Streams	USEPA (1986)

Critical Concentrations for Surface Water

50	Dissolved P, Florida Everglades	USA vs. South Florida Water Management District
10	Dissolved P, Florida Everglades After the Year 2000	USA vs. South Florida Water Management District
1,000	Flow Weighed Annual Dissolved P for Agricultural Runoff	USEPA(1986)

Assessing vulnerability of sites to Phosphorus loss

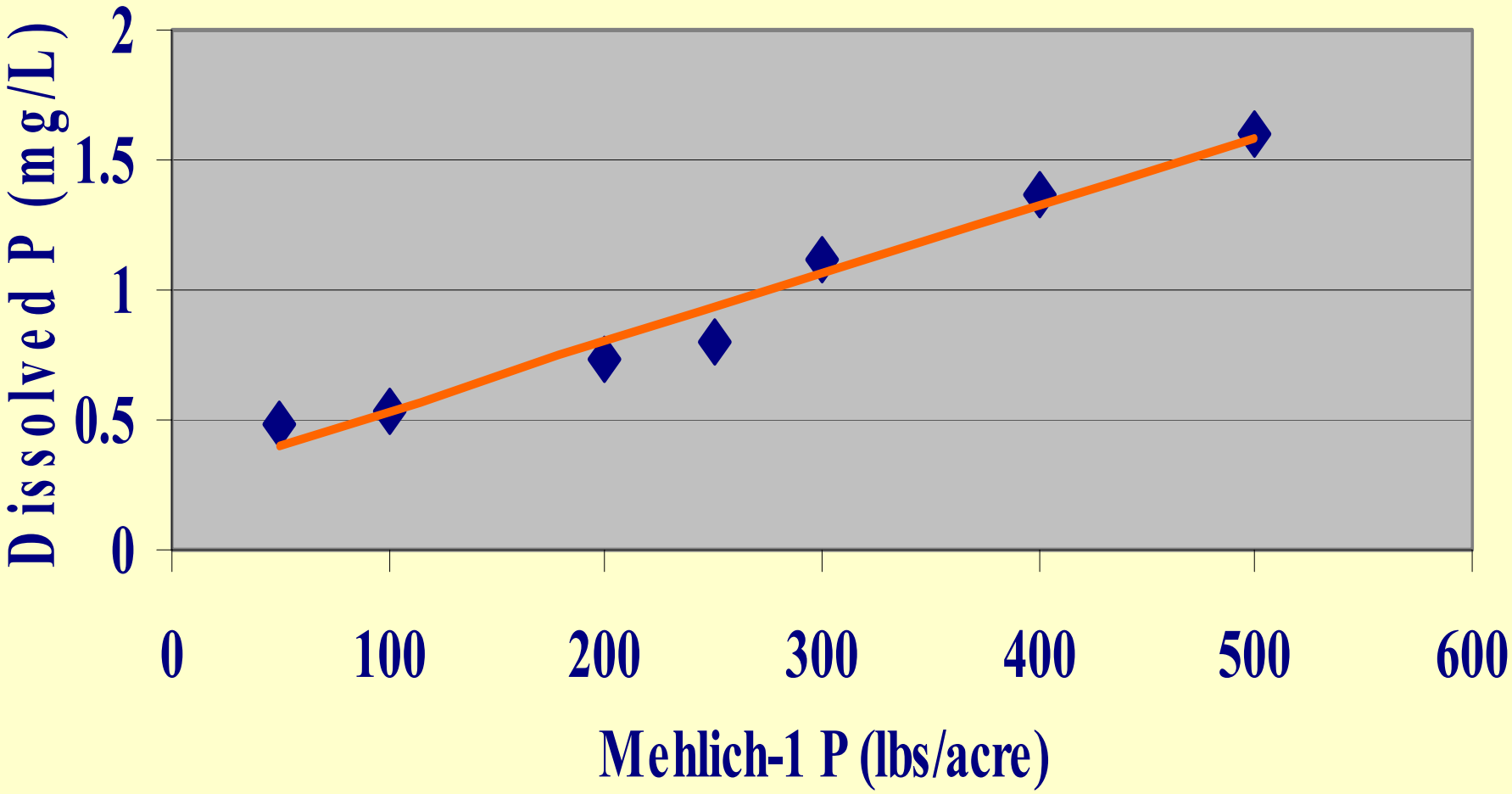
Three options:

1. Agronomic soil test P thresholds.
2. Environmental soil test P thresholds.
3. Phosphorus Index (originally proposed by Lemunyon and Gilbert(1993)).

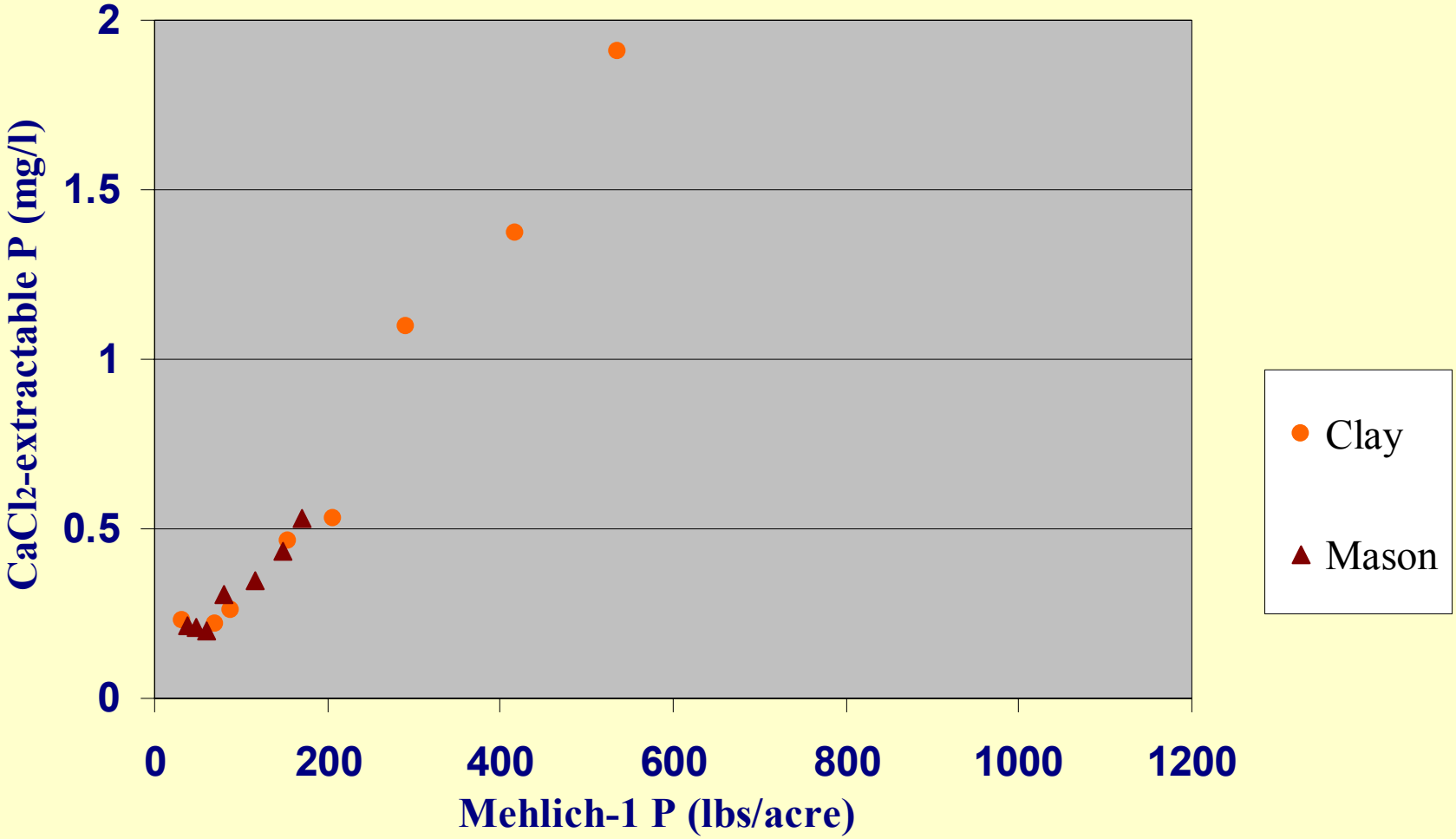
Threshold Phosphorus Values

Soil Test Cut off

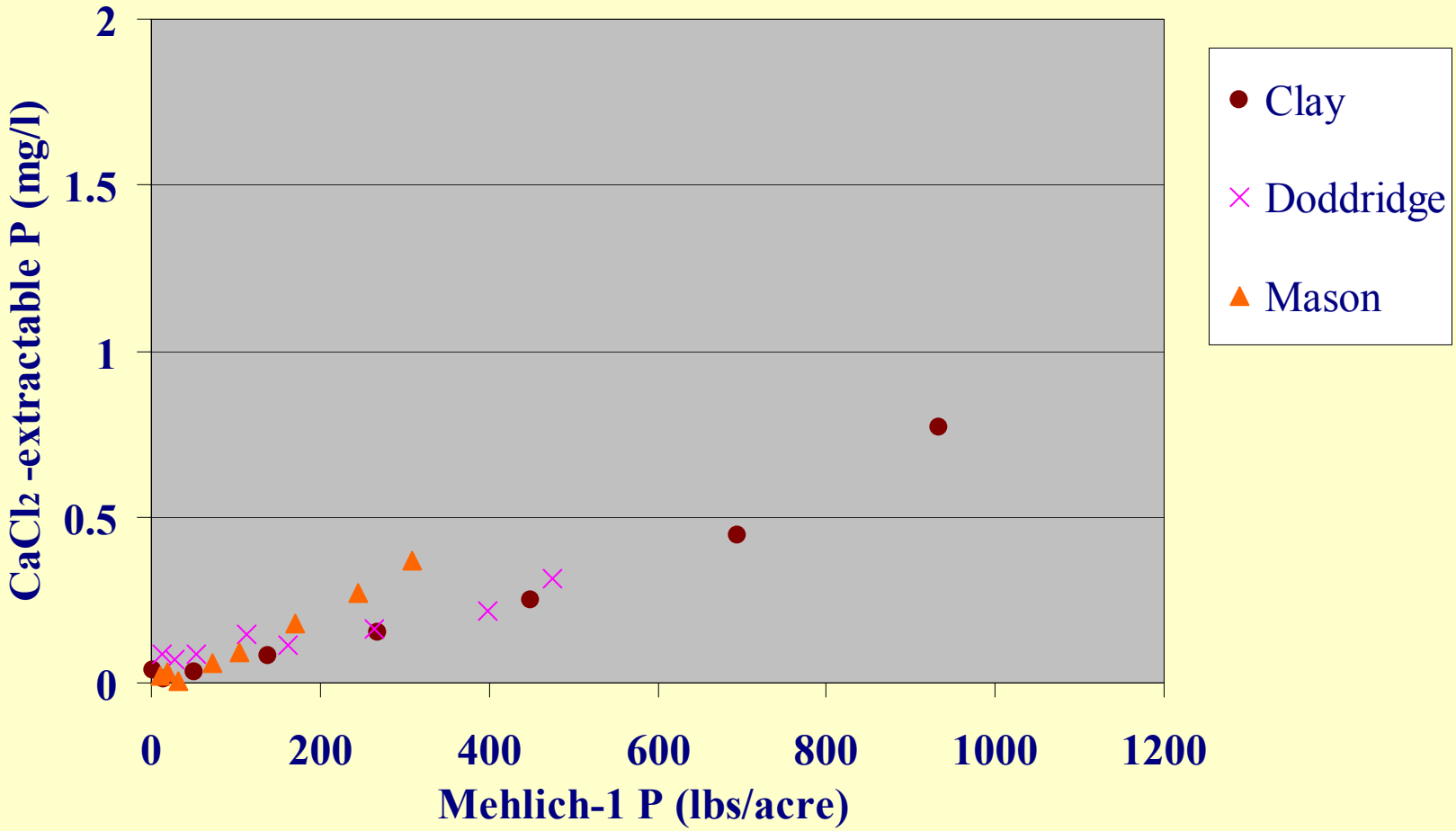
Relationship between Soil-test Phosphorus and Phosphorus in Runoff Water



Effect of soil-test (Mehlich-1) P on dissolved P ($CaCl_2$ - extractable) in 'A' horizons of Gilpin soils



Effect of soil-test (Mehlich-1) P on dissolved P ($CaCl_2$-extractable) in Bt1 horizons of Gilpin soils

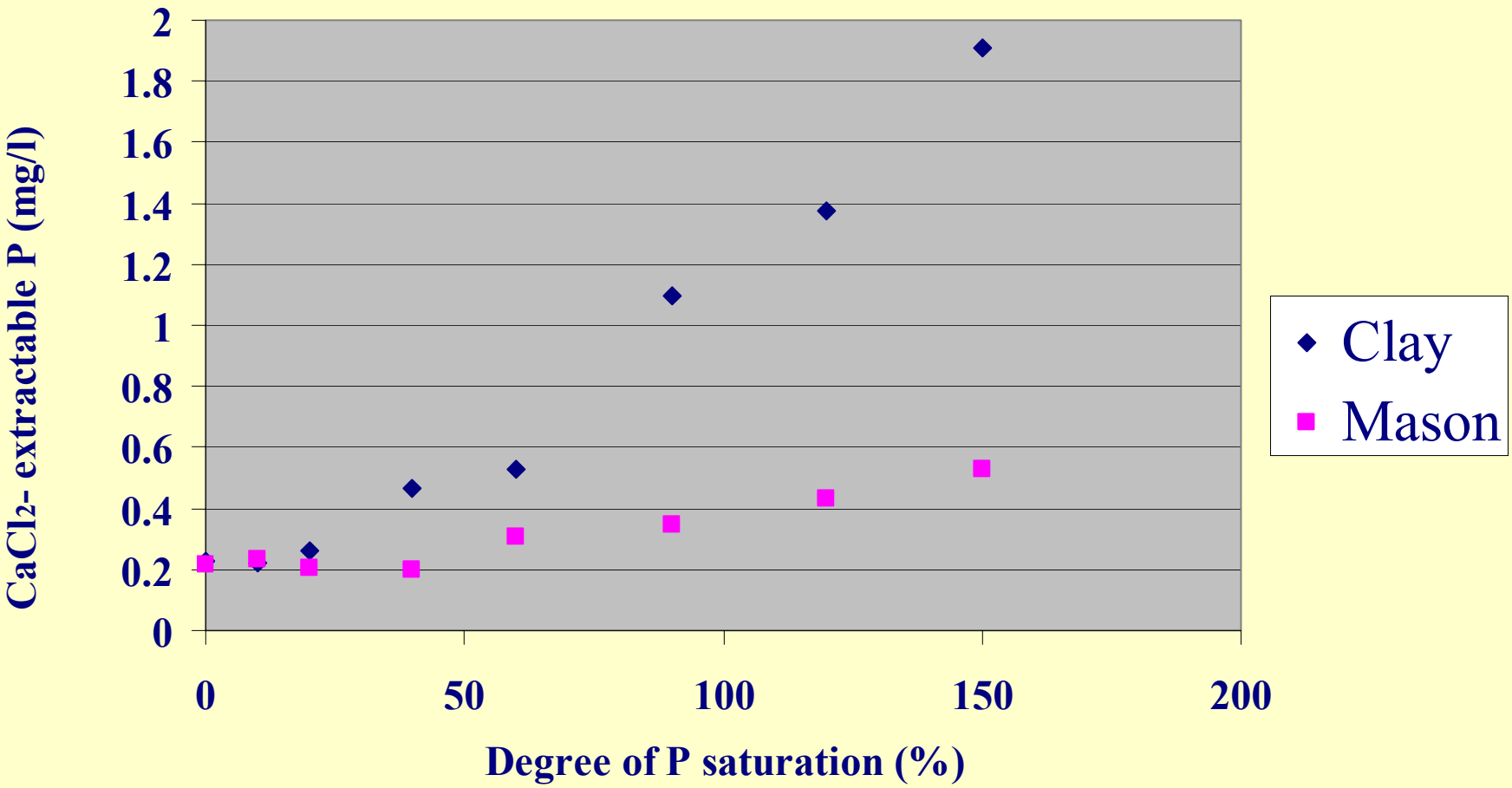


Change Point Concept
Degree of P Saturation

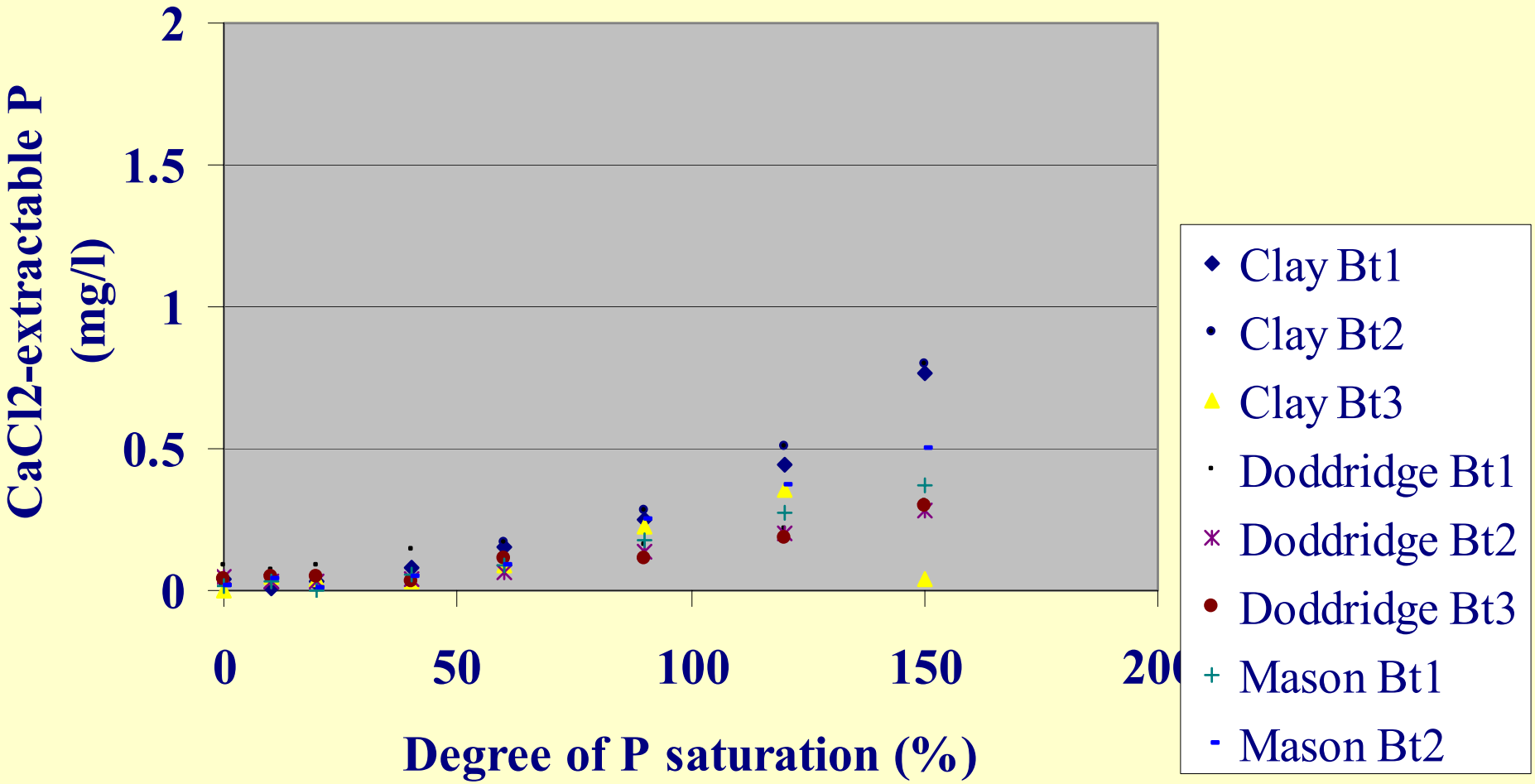
Degree of P Saturation

$$= [P/(Fe + Al)] * 100$$

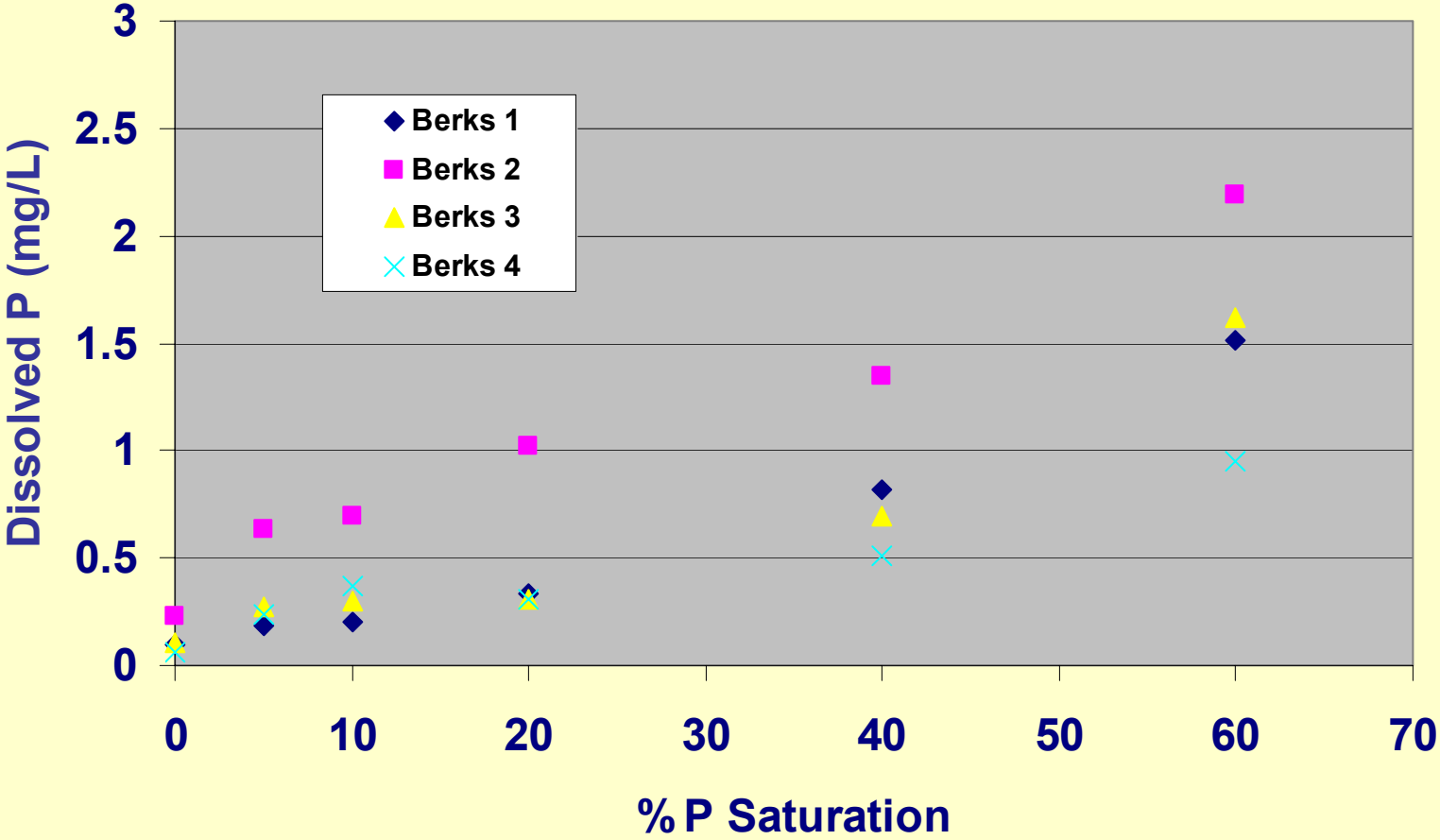
Effect of degree of P saturation on dissolved P ($CaCl_2$-extractable) P in Gilpin 'A' horizons



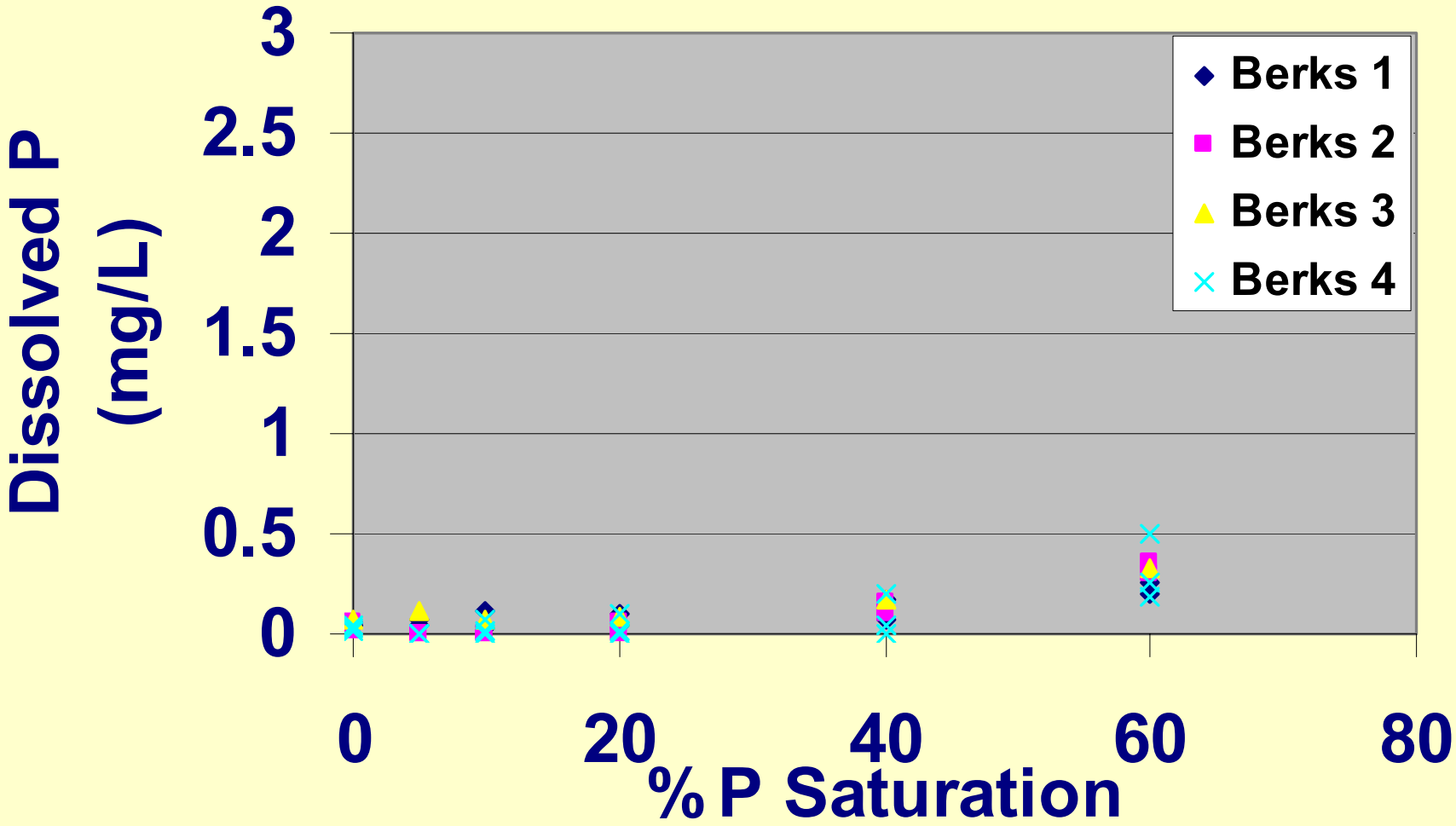
Effect of degree of P saturation on dissolved ($CaCl_2$-extractable) P in Bt horizons of Gilpin soils



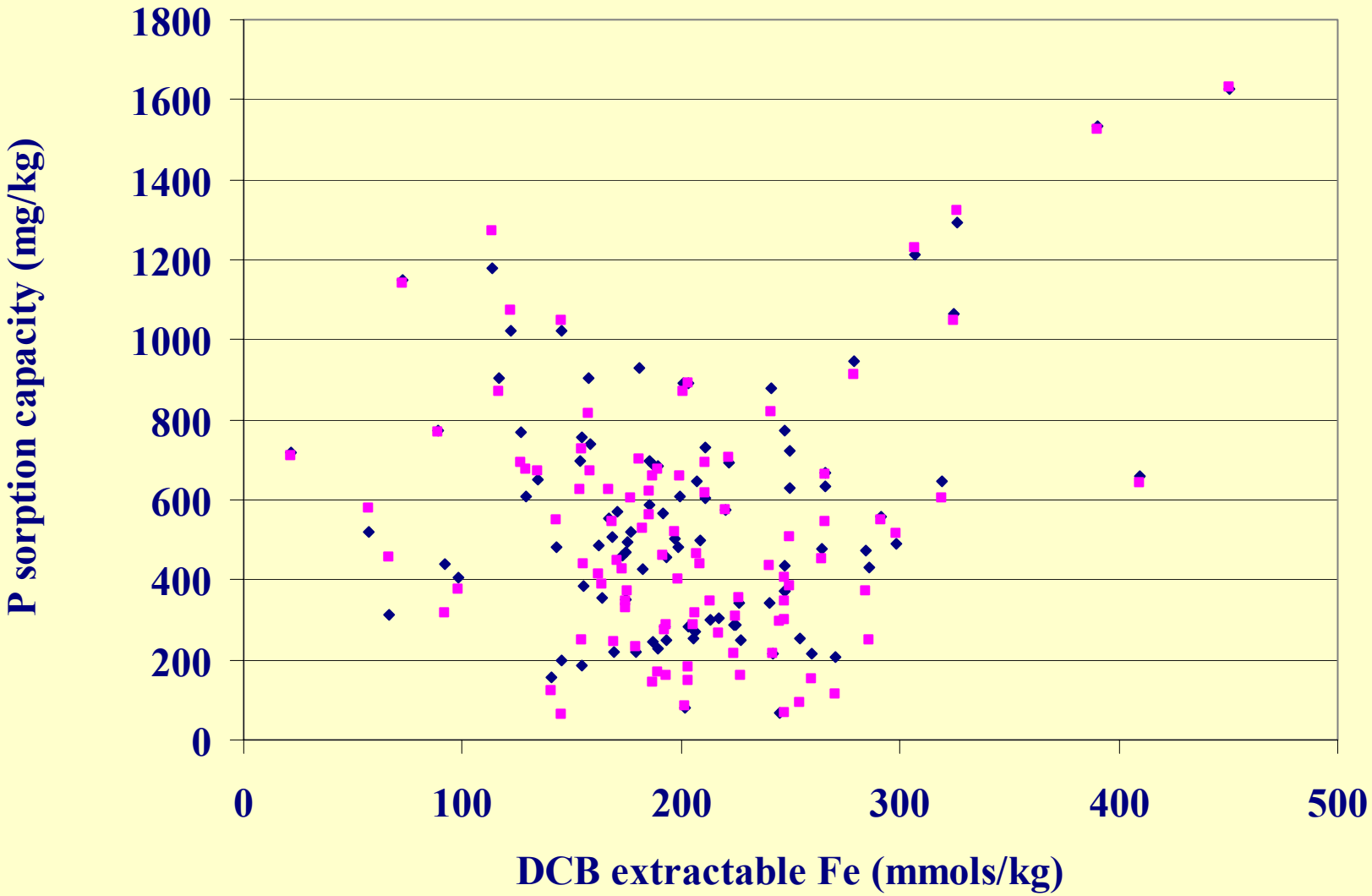
Dissolved P at different P saturations in Berks A horizons



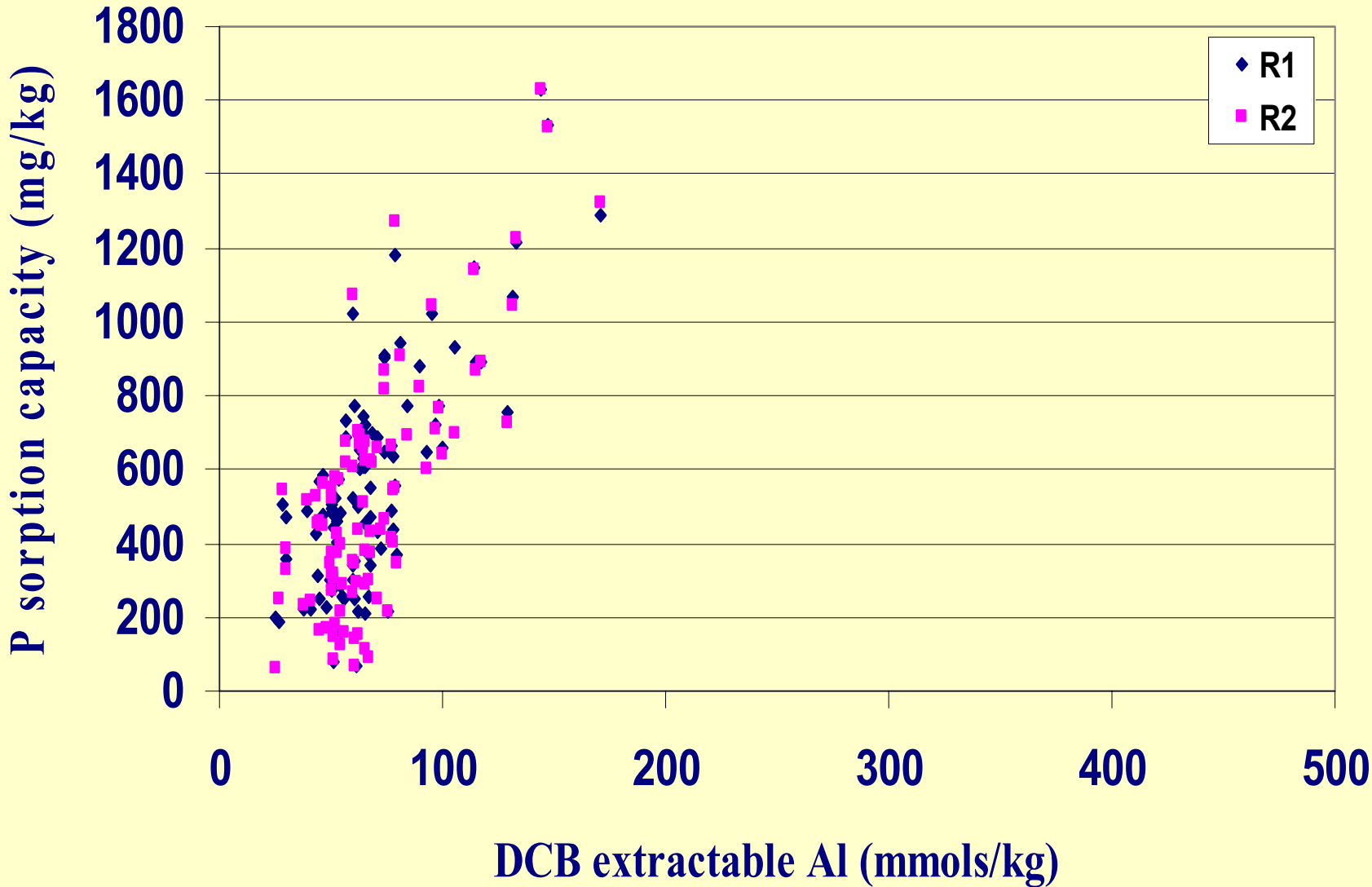
Dissolved P at different P saturations in Berks B horizons



Effect of DCB extractable Fe on P sorption capacity



Effect of DCB extractable Al on P sorption capacity



Factors of P Export

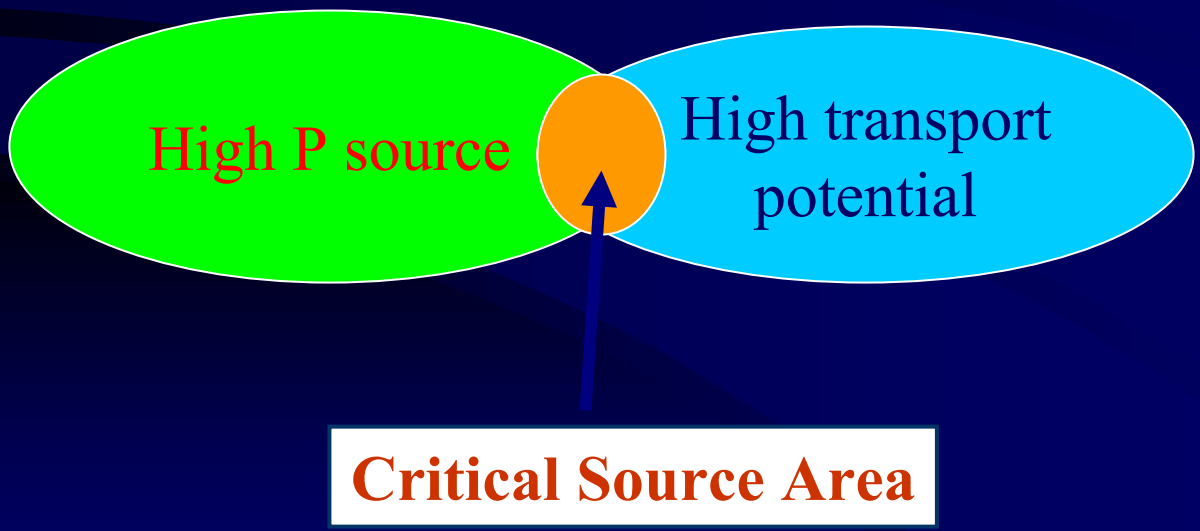
- Source Factors:
  - soil test phosphorus

  Management Factors:
  - manure or fertilizer applications

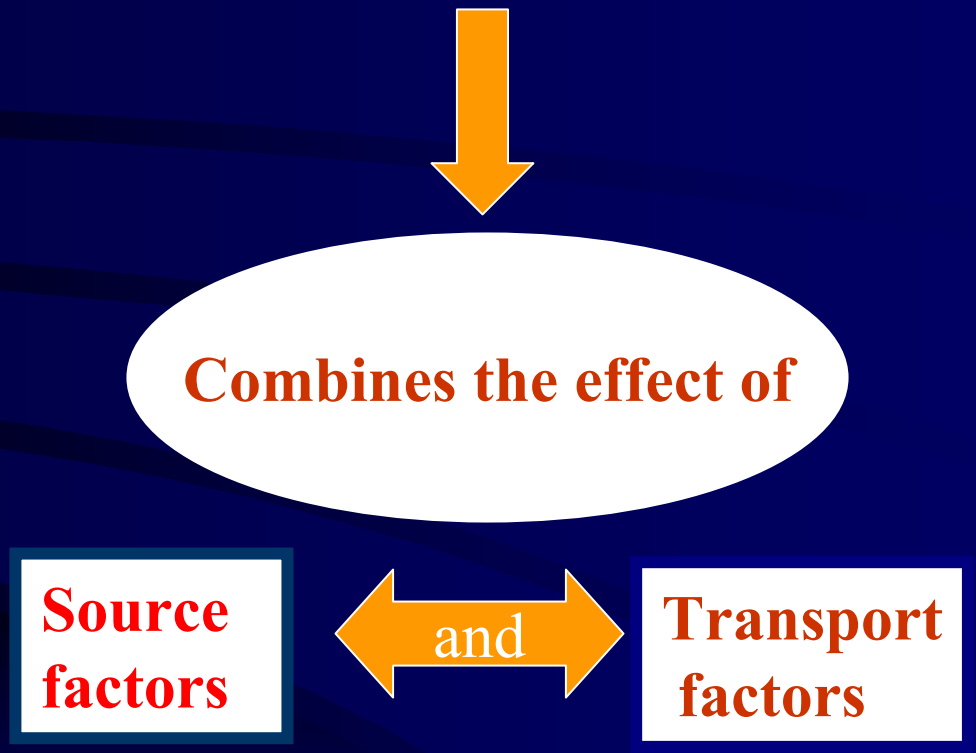
  Transport Factors:
  - runoff, leaching, erosion,etc.

Critical Source Areas

- Areas where high soil P areas and high transport potential areas overlap:



Phosphorus Index



First Version of P Index

8 Site Characteristics
(weighting factor)

X

5 Loss ratings
(value)

Three Transport Factors:

1. Soil erosion (1.5)
2. Irrigation erosion(1.5)
3. Runoff class (1.5)

Five Source Factors:

1. **Soil Test P (1.0)**
2. **P Fertilizer application rate (0.75)**
3. **P Fertilizer application method (0.5)**
4. **Organic P source application rate (1.0)**
5. **Organic P application method (1.0)**

1. **None (0)**
2. **Low (1)**
3. **Medium (2)**
4. **High (4)**
5. **Very High (8)**

http://www.nhq.nrcs.usda.gov/BCS/nutri/phosphor.html

Transport Factors in P Index

Site characteristic (weighting factor)	Loss Rating (value)				
	None (0)	Low (1)	Medium (2)	High (4)	Very High (8)
Soil Erosion (1.5)	N/A	<5 tons/acre	5-10 tons/acre	10-15 tons/acre	>15 tons/ acre

Factor of Soil Erosion

- Actual Soil Erosion.
- Universal Soil Loss Equation (USLE).
- Revised USLE (RUSLE)

$$A = R\ K\ LS\ C\ P$$

Average annual soil loss tons/acre/year

Supporting practices factor

Soil erodibility factor

Slope length and steepness factors

Erosivity by climate at a particular location

Cover-management factor

Transport factors in P-Index

Site characteristic (weighting factor)	Loss Rating (value)				
	None (0)	Low (1)	Medium (2)	High (4)	Very High (8)
Runoff Class (0.5)	Negligible	V.low or low	Medium	High	Very High

Source Factors in P-Index

Site Characteristic (weighting factor)	Loss Rating (value)				
	None (0)	Low (1)	Medium (2)	High (4)	Very High (8)
Soil Test P (1.0)	N/A	Low	Medium	High	Excessive
P- Fertilizer application rate (0.75)	None Applied	1-30 lbs P_2O_5 /acre	31-90 lbs P_2O_5 /acre	91-150 lbs P_2O_5 /acre	>150 lbs P_2O_5 /acre
P-Fertilizer application method (0.5)	None Applied	Placed with planter deeper than 2”	Incorporated immediately before crop	Incorporated > 3 months before crop or surface applied <3months before crop	Surface applied > 3 months before crop

Source Factors in P-Index (contd.)

Site Characteristic (weighting factor)	Loss Rating (value)				
	None (0)	Low (1)	Medium (2)	High (4)	Very High (8)
Organic P source application rate (1.0)	None Applied	1-30 lbs P_2O_5 /acre	31-60 lbs P_2O_5 /acre	61-90 lbs P_2O_5 /acre	> 90 lbs P_2O_5 /acre
Organic P source application method (1.0)	None Applied	Injected deeper than 2 inches	Incorporated immediately before crop	Incorporated >3 months before crop or surface applied < 3 months before crop	Surface applied to pasture or applied > 3 months before crop

Generalized Interpretation of P-Index

P-Index = Total of weighted rating values
= ∑(weighting factor* rating value)

P-Index	Vulnerability to P loss
<8	Low
8-14	Medium
15-32	High
>32	Very High

Modifications to P-Index

- Sharpley et al.(1999):
  - **Distance from watercourse added to transport factors.**

	None (0)	Low (1)	Medium (2)	High (4)	Very high (8)
Distance from watercourse (1.0)	**>1000ft**	**1000-500ft**	**500-200ft**	**200-30ft.**	**<30ft.**

Modifications to P-Index (contd.)

- Gburek et al.(2000):
  - **Pointed out the basic flaw of P-Index: effect of source and transport factors can not be additive; should be multiplicative so as to account for the lack of potential for surface runoff in some areas.**
  - **incorporated the effect of contributing distance.**

An example that illustrates flaw in P-index due to its additive nature

Factor	Level	Weighting * Rating		Value
Soil Test P	Excessive	1 X 8	=	8
Fert-P rate	160 lbs P_2O_5/acre	0.75 X 8	=	6
Fert-P method	Surface-applied >3months before planting	0.5 X 8	=	4
Manure-P rate	100 lbs P_2O_5/acre	1 X 8	=	8
Manure-P method	Surface-applied > 3months before planting	1 X8	=	8
Erosion	*None*	*1.5 X 0*	=	*0*
Irrigation erosion	*None*	*1.5 X 0*	=	*0*
Runoff class	*Negligible*	*0.5 X 0*	=	*0*
P-Index	P – Index > 32 : Very High !!!!			Total=34

Major modifications in P-Index suggested by Gburek et al. (2000)

Transport factor	P loss rating (value)				
	None (0.6)	Low (0.7)	Medium (0.8)	High (0.9)	Very high (1.0)
Soil Erosion (1.0)	N/A	<10 Mg/ha	10-20 Mg/ha	20-30 Mg/ha	>30 Mg/ha
Runoff Class(1.0)	Negligible	Very low or low	Medium	High	Very High
Return period/distance (1.0)	(0.2) >10yr >170m	(0.4) 6-10yr 130-170m	(0.6) 3-5 yr. 80-130m	(0.8) 1-2yr. 30-80m	(1.0) <30m

Modified P-Index (Gburek et al.,2000) Calculations

PI = (*Erosion rating* Runoff rating*Return period rating)* * ∑ (Source factor rating*weighting factor)

Transport factor less than one.

PI	P Loss vulnerability
<5	Low
5-9	Medium
9-22	High
>22	Very high

Concept of modifications(by Gburek et al.,2000) of PI

- Transport factor scales source factor: If transport factor is unity, PI equals the sum of source factors ⟹ full potential of the source is being realized.
- Effect of return period: shorter the return period, smaller the contributing area.

Other modifications

- Pennsylvania P-Index:
  - **Used by Sharpley et al.(2001) to assess quantitatively vulnerability of a soil to P loss.**
  - **Normalizes both transport and source factors with respect to the full potential of these factors.**

P loss potential due to transport factors in P-Index (Sharpley et al., 2001)

Transport factor	Relative ranking					
Soil erosion	_____Soil loss (Mg/ha/year)_____					Value
Surface runoff class (1.0)	Very low (0)	Low (1)	Medium (2)	High (4)	Very High (8)	____
Leaching potential	Very low (0)	Low (1)	Medium (2)	High (4)	Very High (8)	____
Connectivity	Not connected (0)	(1)	Partly connected (2)	(4)	Connected (8)	_____
Total site value Transport potential (site value/max. possible value e.g.(7+8+0+8= 23)						____ _____

P loss potential due to source factors (Sharpley et al., 2001)

Factor	Relative ranking					Value
STP	Mehlich-3 P (mg/kg soil)					
STP rating	STP*0.2					_____
Fertilizer P rate	Fertilizer P rate (kg P /ha)					_____
Fertilizer P method and timing	>5cm deep				Surface	
Fert. Rating	0.2	0.4	0.6	0.8	1.0	_____
	Fertilizer P application rate*loss rating					_____
Manure P rate	Manure application (kg P/ha					
Manure P method and timing	> 5cm deep				Surface	
Manure rating value	0.2	0.4	0.6	0.8	1.0	_____
	Manure P application rate*loss rating value					_____
	Total source value					_____

P-Index rating for a site = (transport potential value* source value)

P-Index	Site vulnerability to P loss
<35	Low
35-70	Medium
71-100	High
>100	Very High

Conclusions

- P-Index provides a basic pattern of an assessment method .
- It can be modified for local adaptations: ***algorithmic in nature***.
- Modified P-index should be evaluated for its effectiveness.
- P-Index should not be a mere edge-of-field tool.
- Validation data are not available.
- P-Index is more of an educational tool than a planning tool. It facilitates interaction between planners and land-users.