Testing the Wisconsin P Index at the Field Scale

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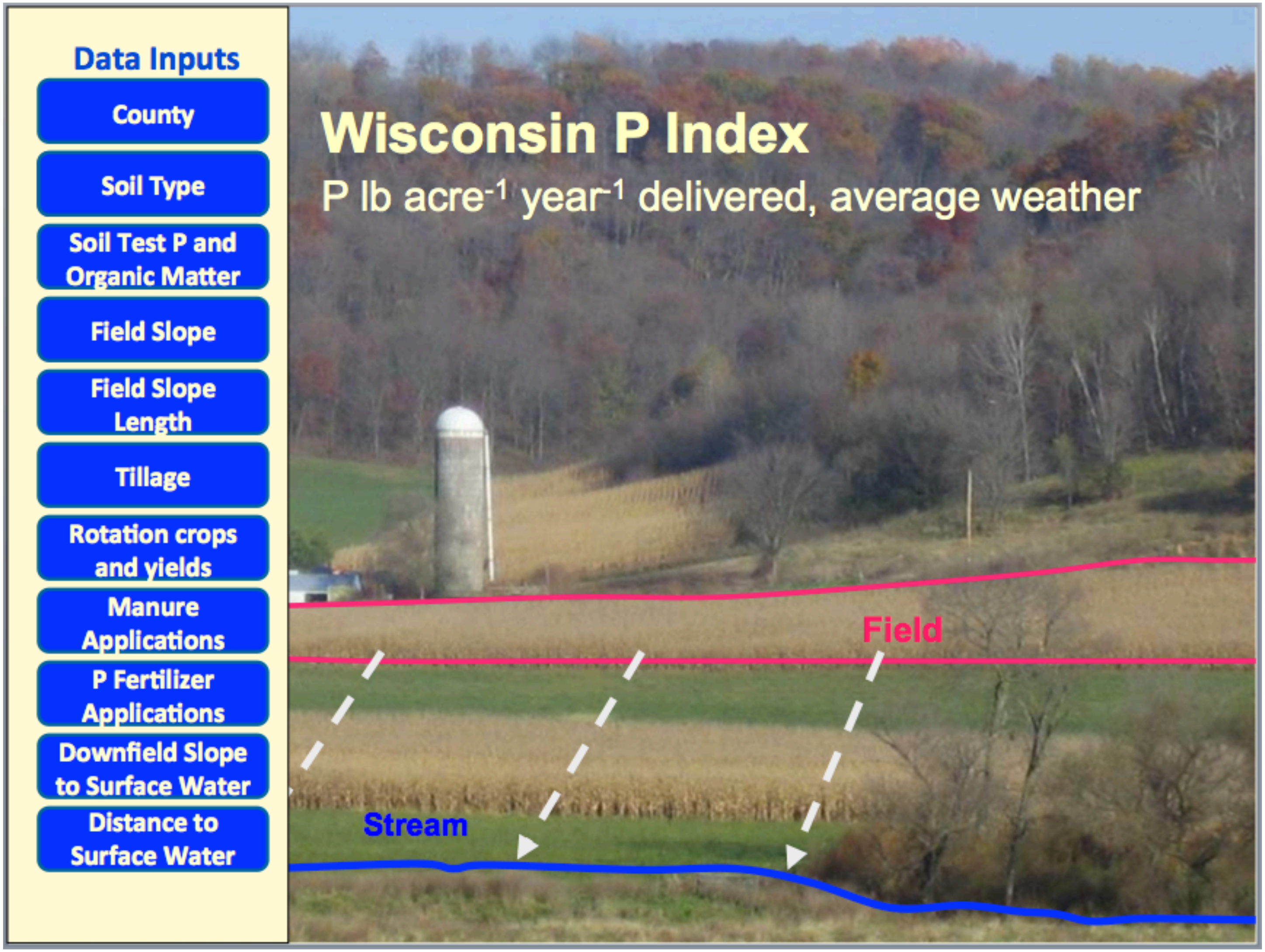
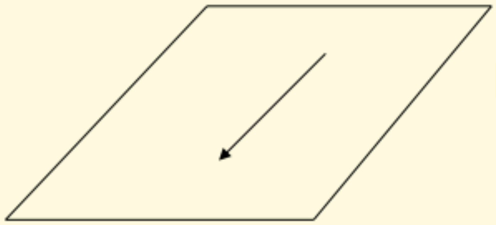
Good, L.W., P.Vadas, J.C. Panuska, C. A. Bonilla, W. E. Jokela. 2012. Testing the Wisconsin P Index with year-round, field-scale runoff monitoring. Journal of Environmental Quality.



Wisconsin's P Index was developed for use in nutrient management planning. Like those of a number of other states, it assesses a field's relative runoff P loss risk for a field under a particular management scenario by estimating the average mass of P delivered to the nearest surface water given long-term weather patterns. For making this estimate, the P Index is constrained to using information that is readily available to the farmer or planner during the course of nutrient management planning.

Wisconsin P Index Equations



P delivered = Particulate P + Dissolved P

PP = Sediment [TP] x Mass

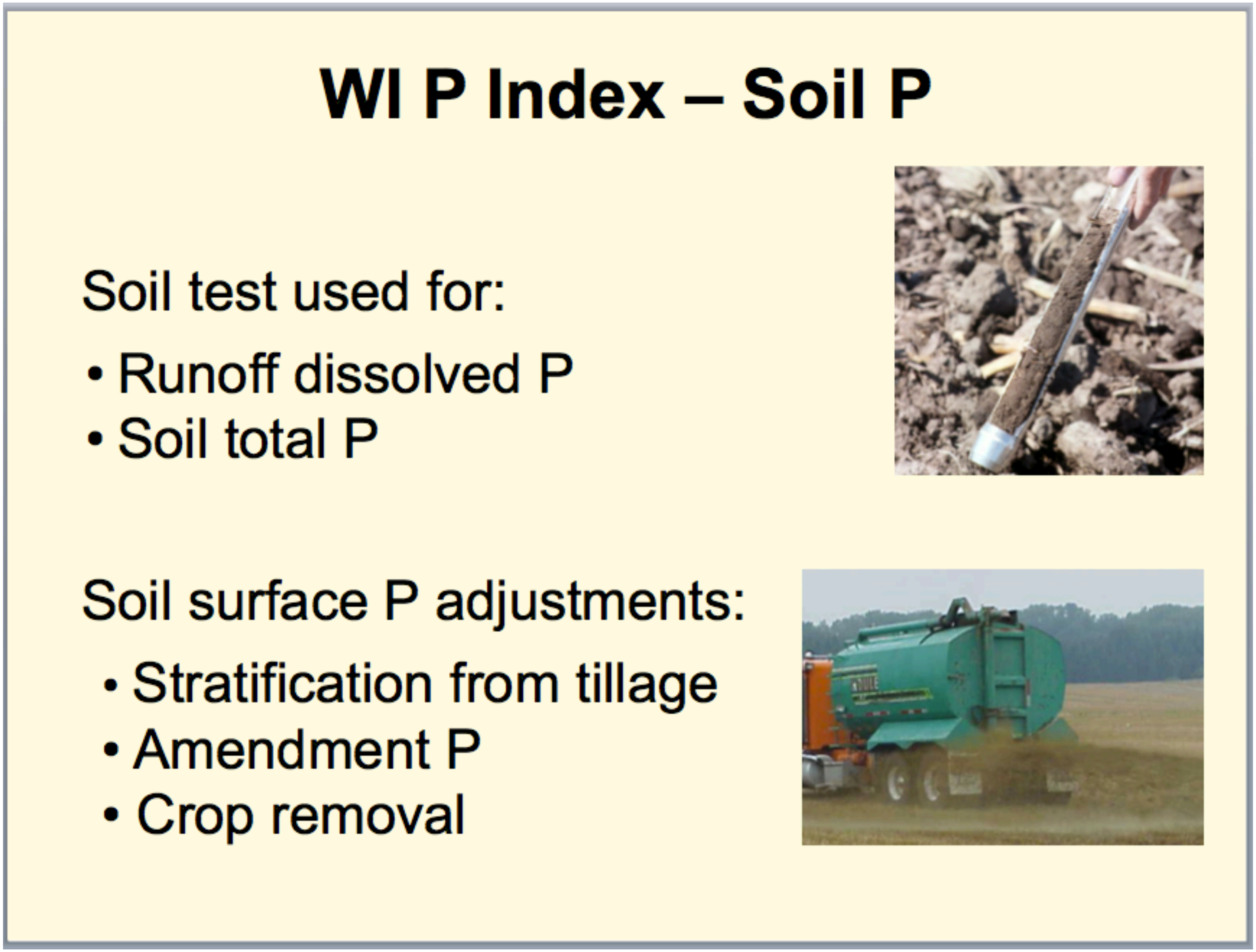
DP_{soil} = Runoff [DP] x RO Volume

DP_{manure} = Manure SP x RO/Precip x $(RO/Precip)^{0.225}$

$DP_{fertilizer}$ = Fertilizer SP x RO/Precip x 0.034 $e^{(3.4 \times RO/Precip)}$

There are a number of states that have P Indices that follow this strategy of estimating average annual P losses from a field. They have been called: process-based, quantitative, quasi-modeling, and pathway approach P Indices. We borrowed heavily from Iowa and Minnesota in developing the Wisconsin Index. All of the process-based P Indices use a format that estimates P loss in runoff from a field as a combination of dissolved P and sediment-bound P.

Dissolved P from soil is estimated as the product of runoff dissolved P and runoff (RO) volume. Sediment bound P is estimated as the product of eroded sediment mass and sediment P concentration. The equations for estimating manure and fertilizer dissolved P losses use the proportion of precipitation following application that runs off (RO/Precip) as well as the soluble P (SP) application rate.



As in many of the process-based P Indices, soil test P is used to estimate runoff dissolved P and sediment P concentrations. We use coefficients derived from research on Wisconsin soils. The Wisconsin P Index accounts for stratification from tillage and for additions and removal of P from year to year until a new soil sample is taken. Wisconsin's nutrient management planning standard requires sampling at a minimum of every four years.

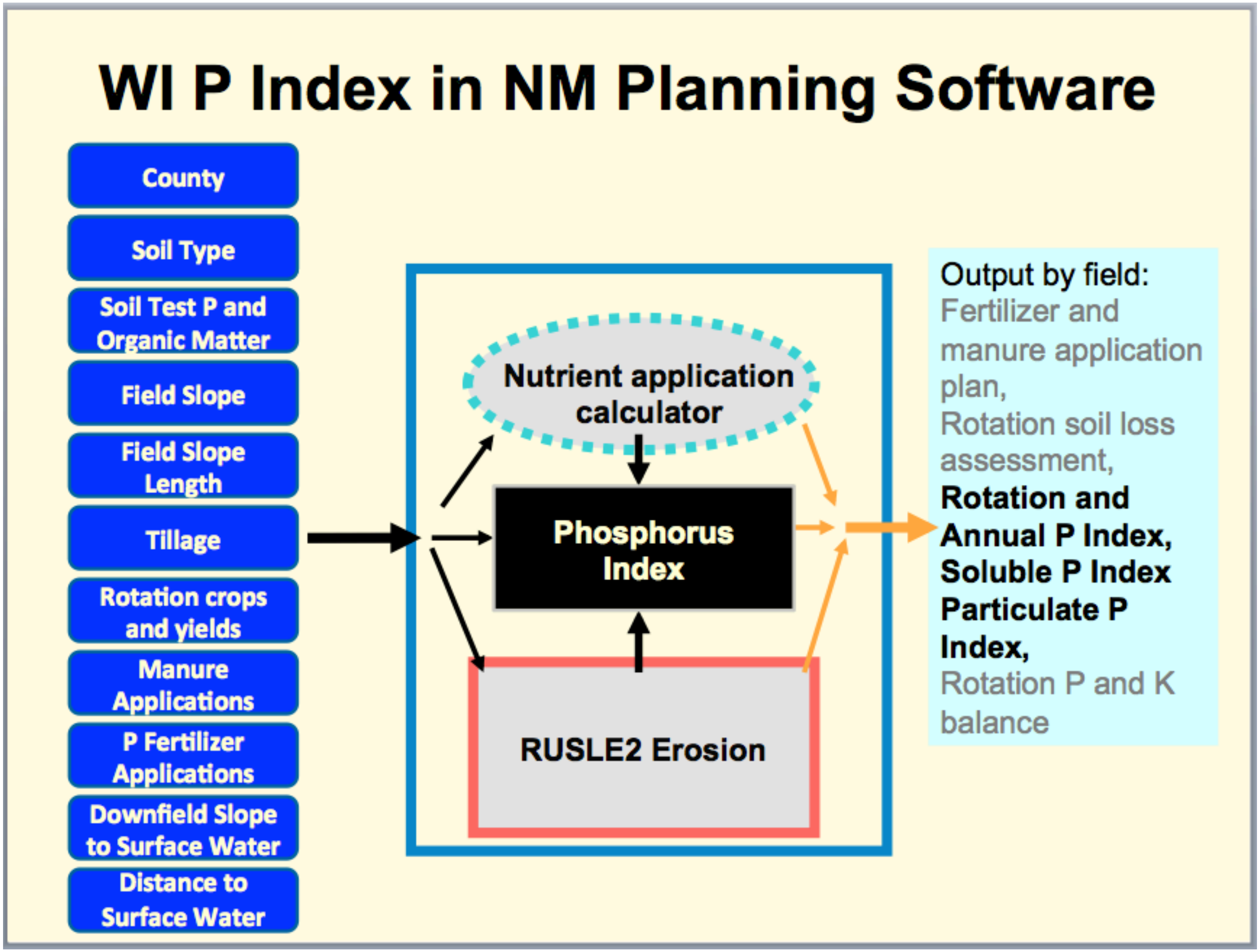
WI P Index – Transport Components

Sediment Mass: RUSLE2

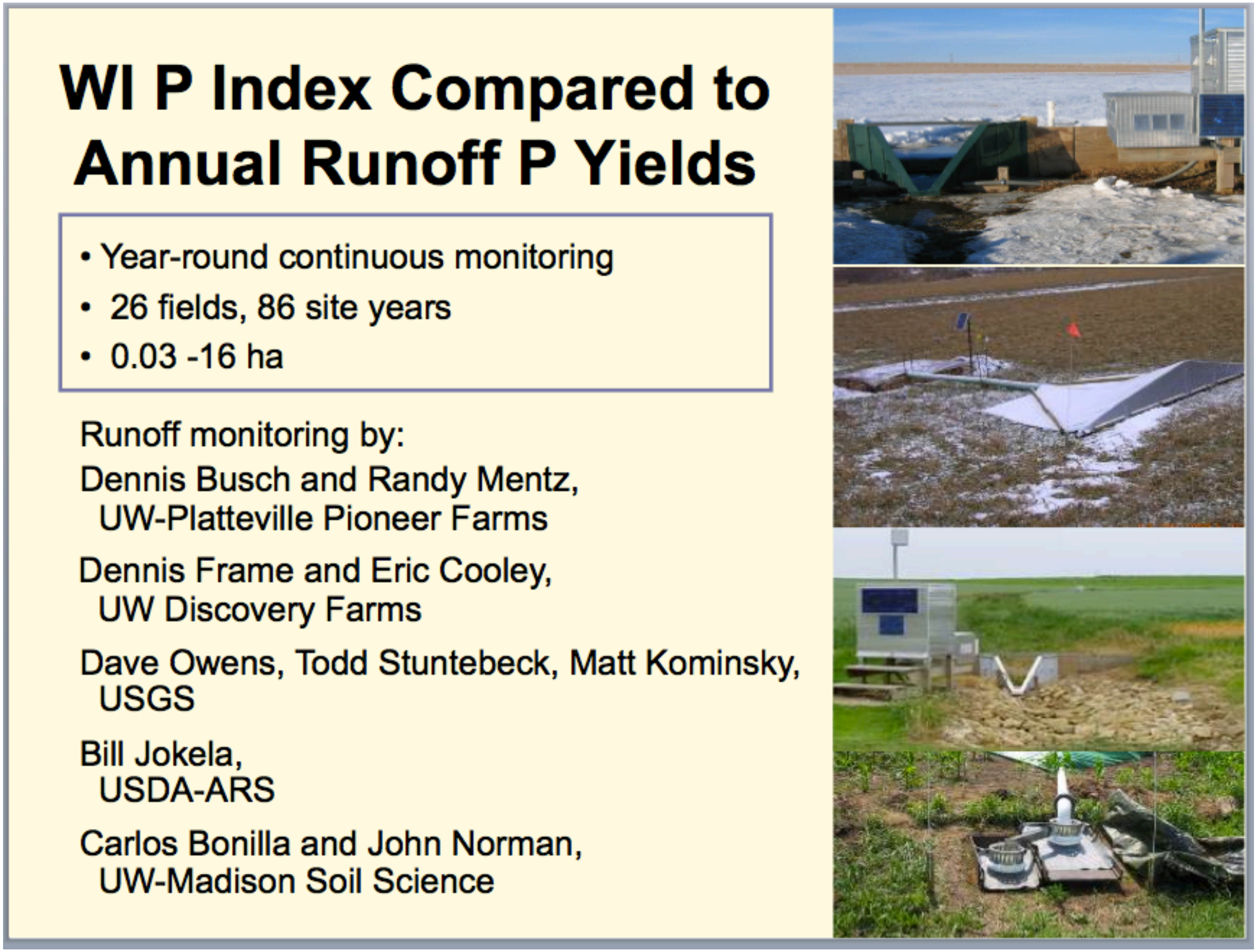
Rainfall runoff: Modified curve number method

Frozen soil runoff: Empirical for WI watersheds

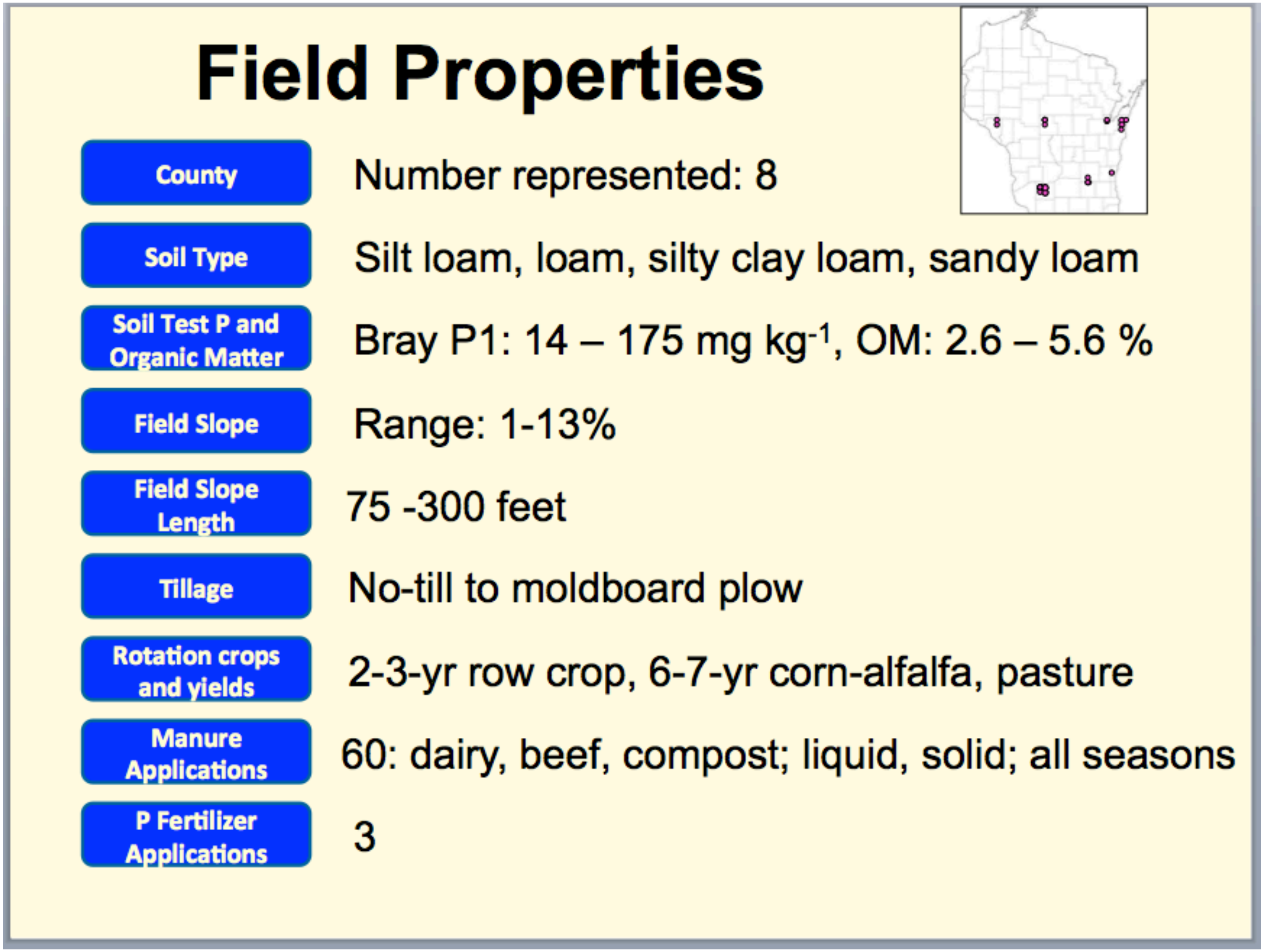
The P Index attempts to estimate how much phosphorus will be transported from a field to surface water in eroded sediment and runoff. Year-to-year weather variations can cause significant fluctuations in erosion and runoff for the same field conditions, so the P Index estimates take into account long term weather patterns. RUSLE2 is used for estimating eroded sediment, as mandated by the USDA Natural Resources Conservation Service for P Indices used for nutrient management planning. We retrieve the sediment mass from RUSLE2 for each crop year by particle size, as will be mentioned again later. Rainfall runoff volume is calculated with a modification of the runoff curve number method using curve numbers generated by RUSLE2 in combination with the frequency distributions of daily precipitation volume. Frozen soil runoff, which much of the country does not have to account for, is estimated with an empirical method developed from USGS flow monitoring in agricultural watersheds throughout Wisconsin.



As you have probably noticed by now, Wisconsin's P Index requires a lot of calculations. Its use for planning is possible because its included in nutrient management planning software along with RUSLE2. Our software, SnapPlus, is unique to WI, but other states have access to similar software called Manure Management Planner. The impetus behind SnapPlus development was a 2002 change to state law that had the intent of requiring every field that received nutrients in Wisconsin to have a nutrient management plan and have soil loss below tolerable levels. In 2011, approximately 20% of the agricultural land in WI has a current nutrient management plan, and about 85% of the planning is done with this software. Within this software, the same input information is used for the P Index, soil loss calculations and nutrient recommendations.



Starting in 2003, there were a number of year-round monitoring projects in Wisconsin within fields and on the edge-of-fields in grassed waterways. All of these projects measured runoff, sediment, flow, total P and dissolved P. Most were in production fields with managements determined by the farmers. We have compared used 86 field years of data provided by researchers at the UW-Platteville Pioneer Farm, UW Discovery Farms, UW-Madison Soil Science Department, the USDA Agricultural Research Service (ARS) and the US Geological Survey (USGS) to annual P Index values.

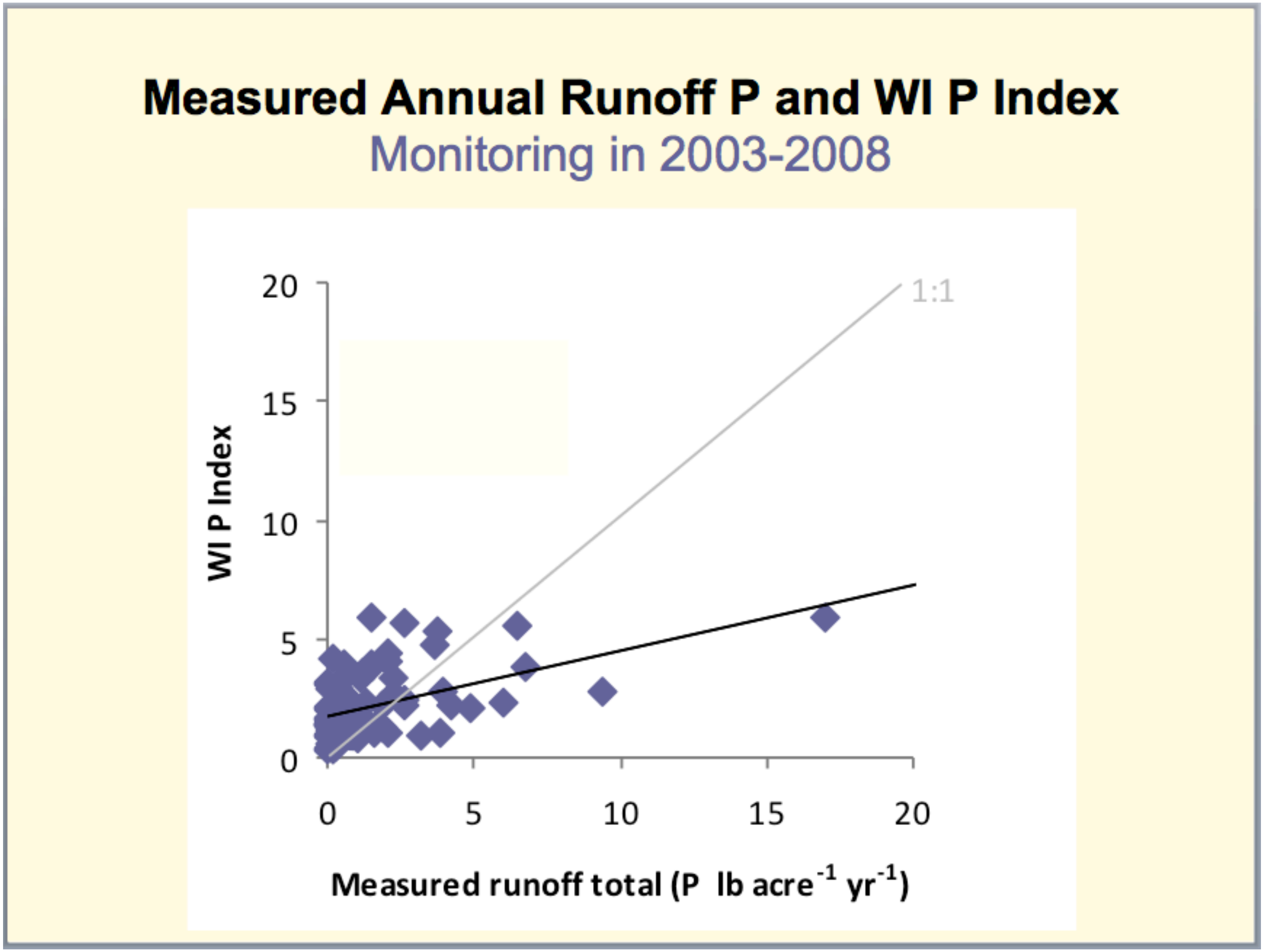


The monitored fields were located across Wisconsin. Most were silt loams, the coarsest was a sandy loam and the finest was a silty clay loam. Soil tests were from 14-175 ppm. Slopes ranged from 1 to 13%. Some of the fields were in corn and soybeans, but most were in corn and alfalfa hay rotations. Sixty of the field years had some kind of manure application. Most applications were in the fall and winter, though there were some spring and summer applications too. Not very many of these fields had P fertilizer applications.

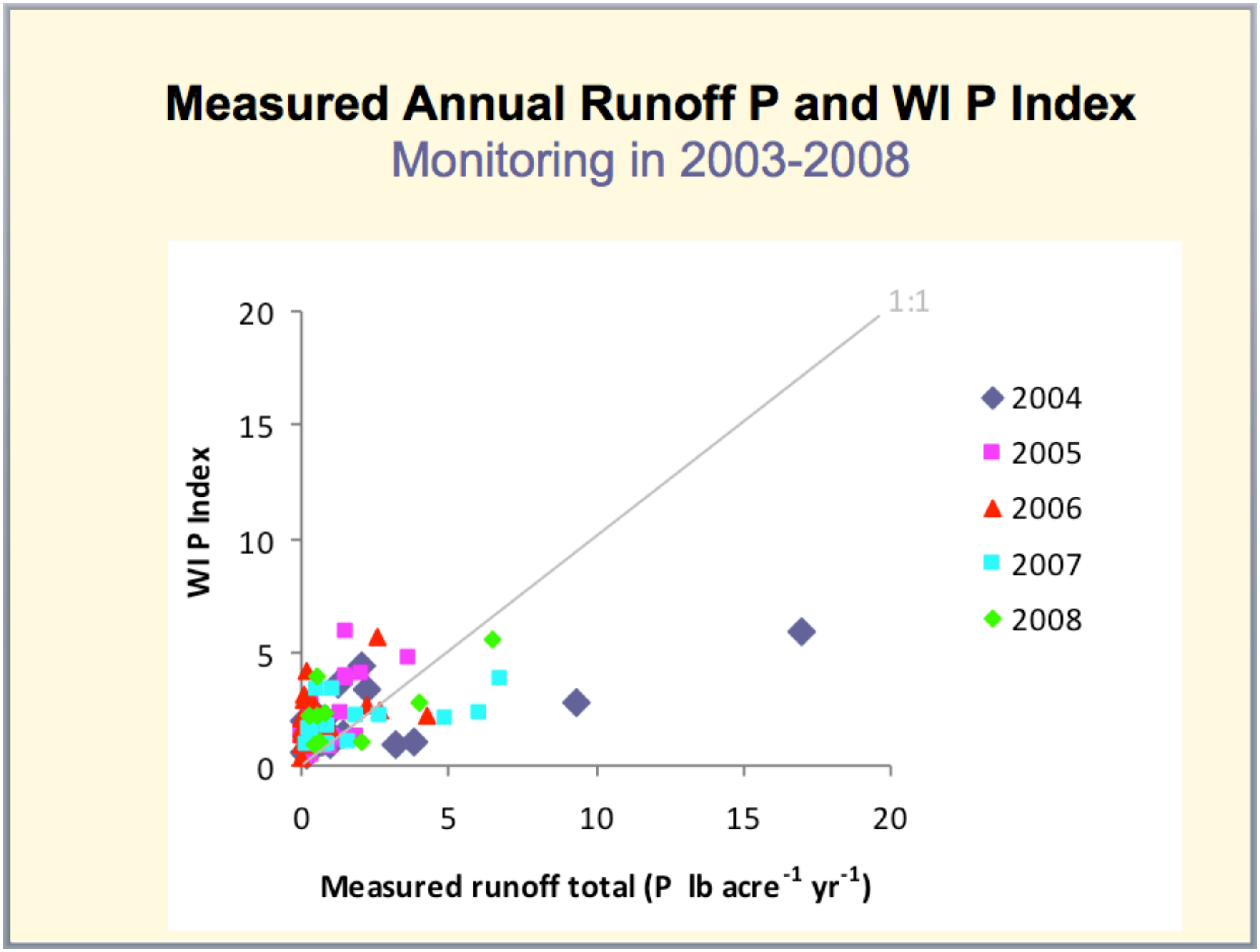
Non-research farm nutrient management information:

- Inexact, uneven application rates
- No manure analysis
- Routine soil tests

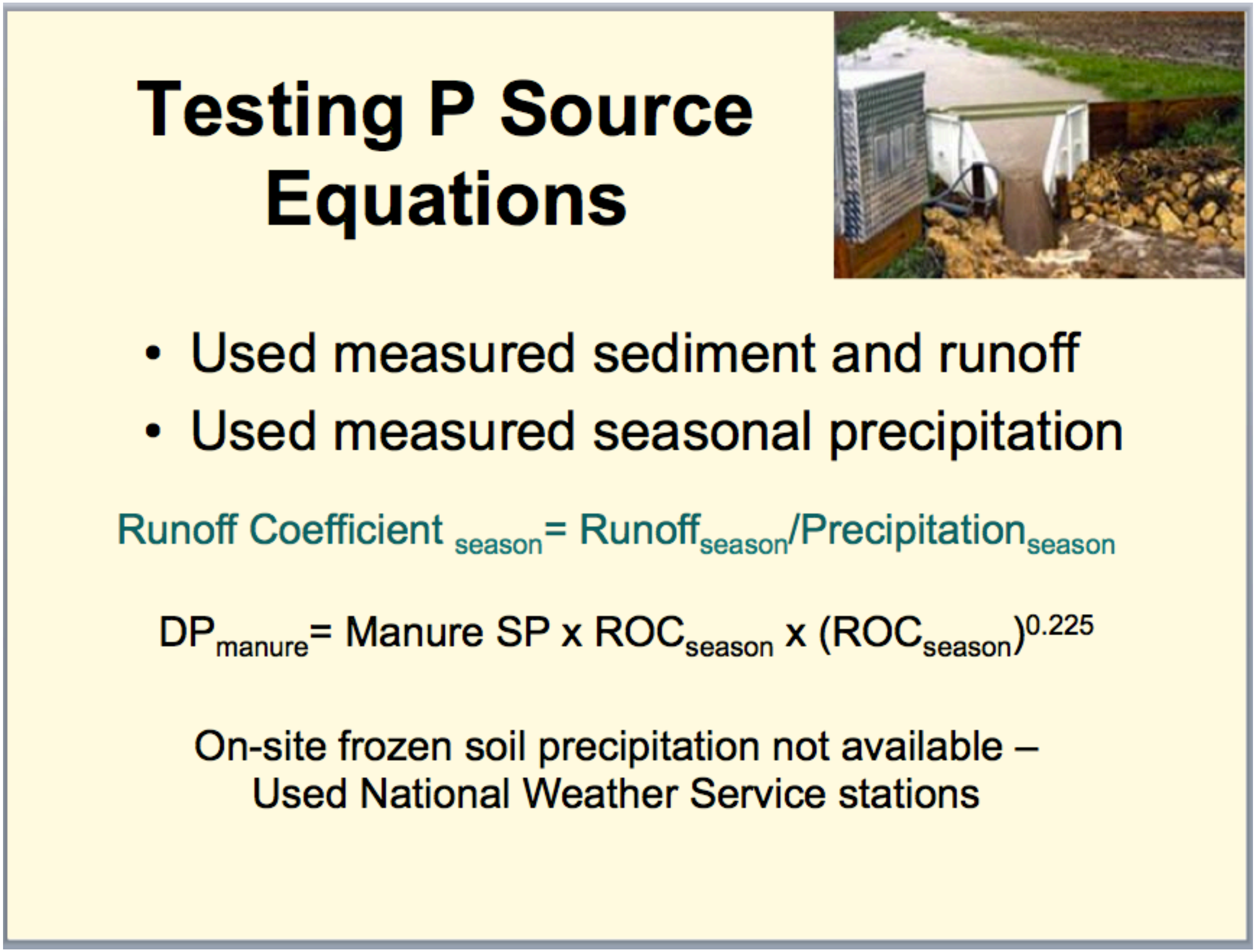
While calculating the P Index on these fields, we encountered some input information issues that are common for nutrient management planning on real fields. In some cases manure was not applied to the whole field or records on application rates were not clear, often there was no manure analysis, and only routine soil P analysis were available (one sample per 5 acres every 4 years). Also, some of the fields' managements did not exactly match the general tillage categories available in the SnapPlus software so we had to use the most representative choices.



When we compare the P Index to monitored annual runoff P loads, you get some correlation but it is not very good. That is because these are not really comparisons of the same conditions. The P Index is an estimate of P loss under long-term average weather, the real weather on each site was very variable from year-to-year. Each field's monitored P loads were a result of runoff and erosion occurring as a result of the precipitation in that year.



To better illustrate the effects of annual weather variations on runoff P losses, the measured P loads are shown with different colored symbols for each weather year. In 2006 (red triangles that are clustered on the y-axis), much of the state was really dry so there was little to no rainfall runoff and P losses were very low. In 2004 (blue diamonds), rains in May and early June were more erosive than average, leading to loads that were higher than the WI P Index estimated average on some fields with low residue cover.



To remove the weather-induced variability in the transport parts of the equations and to test how well the equations that relate soil P and P application rates to losses work, we recalculated the P Index using measured sediment and runoff for each of the monitored site years. In the equations for manure and fertilizer P losses, we used measured precipitation to get a seasonal runoff coefficient (ROC). One problem was that while rainfall was measured at each field site, snowfall was not. For frozen precipitation, we used records from National Weather Service stations within the region for each site.

Measured Dissolved P and Soluble P Index

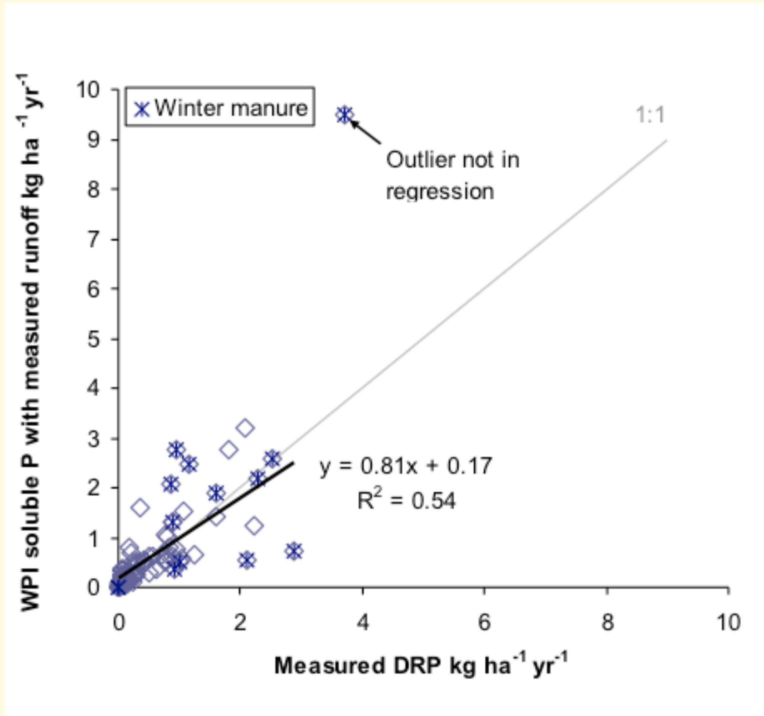
Soluble P Index calculated with measured runoff and seasonal precipitation

$$SPI = DP_{soil} + DP_{manure} + Dp_{fertilizer}$$

$$DP_{soil} = [DP] \times RO$$

$$DP_{manure} = \text{Man. SP} \times ROC \times (ROC)^{0.225}$$

$$DP_{fertilizer} = \text{Fert SP} \times ROC \times 0.034\, e^{(3.4\, ROC)}$$



Using measured runoff (RO) and seasonal precipitation in the Soluble P Index (SPI), we tested the equations that relate soil test P to runoff dissolved P, as well as the equations that relate runoff coefficient (ROC) to manure and fertilizer P losses from a given application rate. The measured Dissolved P (DP) yields were strongly related to the SPI. Note this DP is dissolved reactive P (DRP) because that was what was measured at all sites.

There was one outlier. This was where the SPI predicted a very high P loss following a frozen soil manure application. In this case the runoff coefficient, or runoff over precipitation, was calculated using the National Weather Service (NWS) snowfall for a station within the region because snow was not measured on site. It is possible that the NWS snowfall was less than true snow accumulation at this site, resulting in an overestimate of the runoff coefficient. It is also possible the manure P application rate used for this site is not accurate. Note also that the measured DP yields did not exceed 3 lb/acre for any site year, except for the outlier.

Measured Particulate P and Particulate P Index

Particulate P Index calculated with measured sediment yields

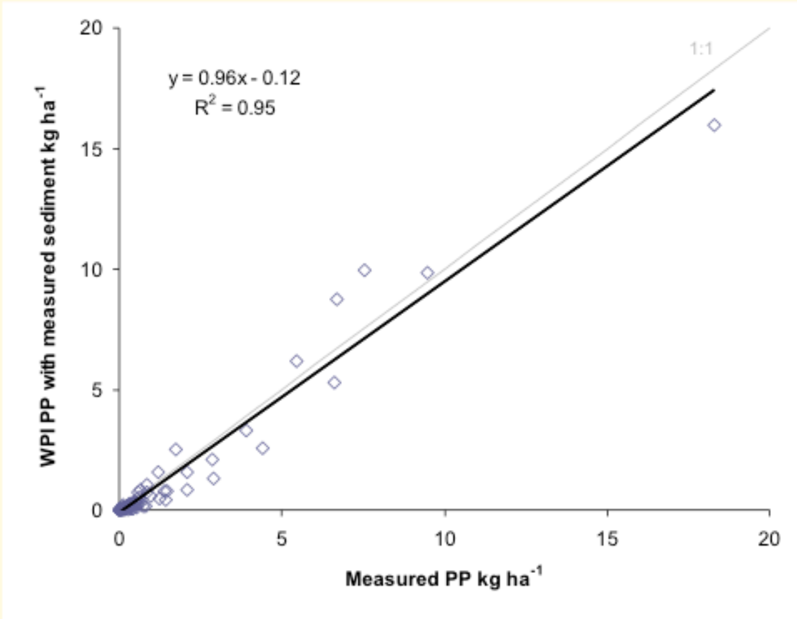
Measured Particulate P = Total P - DP

PP = Sediment [TP] x Sediment mass

Sediment [TP]= Soil TP x PER

PER=
(clay/sediment x 3)
+
(silt/sediment x 1.8)
+
(large particles/sediment x 0.8)

Particle size mass ratios from RUSLE2 with large particles = small aggregates, sand, large aggregates.

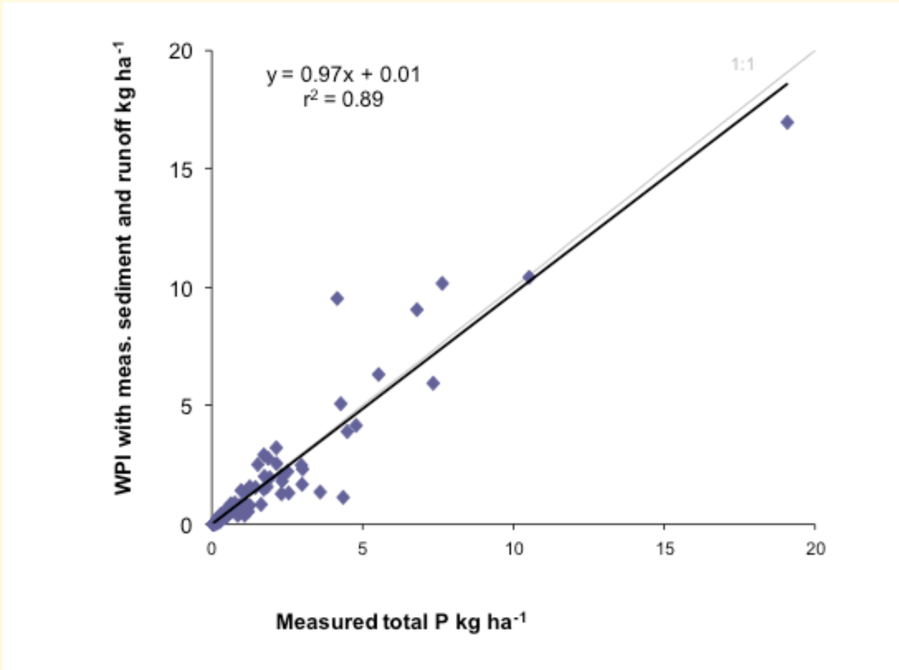


Using measured sediment mass in the Particulate P Index (PPI) calculation, we tested the equations that estimate sediment P concentration. Soil total P (TP) is calculated from soil test P and organic matter percent. Runoff sediment is generally enriched in P compared to the soil. The PPI accounts for enrichment by taking advantage of RUSLE2's routing of eroded sediment by particle size. RUSLE2 provides sediment delivery by clay, silt, small aggregate, sand and large aggregate classes. Based on field research, we assign a P Enrichment Ratio (PER) of 3 to clay, 1.8 to silt, and 0.8 to the larger particles. With this method, the relationship between measured and predicted particulate P (PP) was good. I need to point out that these PER are an improvement over the current publicly available WI PPI version. In the current version, the PER is the same for clay but only 1 for silt and 0.7 for the larger particles, and this underestimates PP losses (PPI = 0.78 measured PP - 0.09, $r^2 = 0.94$).

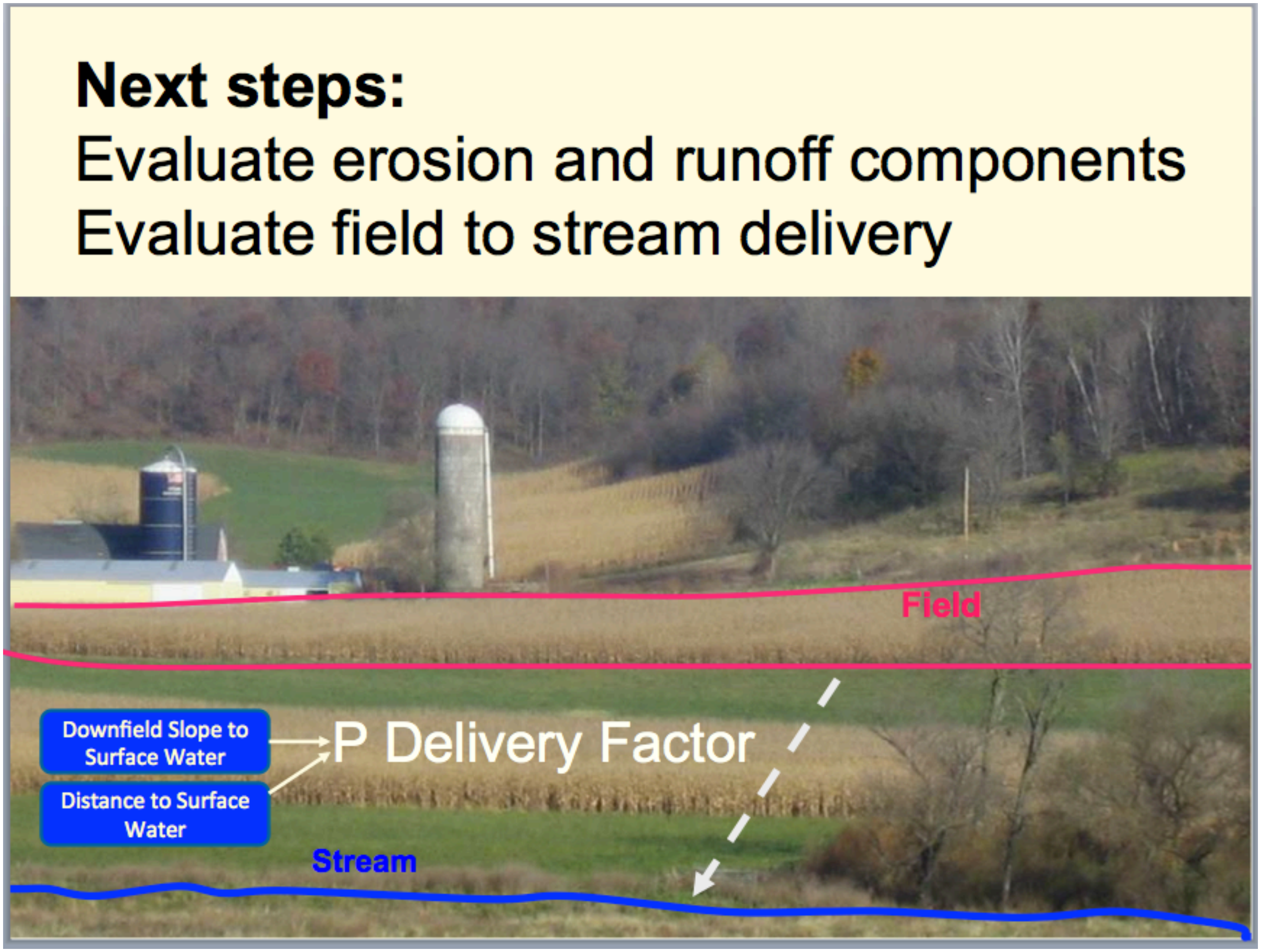
Note that the highest PP delivery was much higher at almost 18 lb/acre than the max of 3 lb/acre for DP shown in the previous slide.

Measured Total P and the Wisconsin P Index

Revised WI P Index compared to measured runoff losses for 86 site years using measured sediment and runoff volume in the equations



The SPI and PPI are combined for the total WI P Index (WPI). When measured sediment and runoff are used in the WPI equations, there is a strong relationship between WPI P loss estimates and measured runoff losses that is almost 1:1. Therefore, if RUSLE2 erosion and the WPI runoff calculations accurately reflect the effects of field management on average annual erosion and runoff, then the WI P Index is accurately assessing the effects of management on field P losses.



One obvious next step is to evaluate the erosion and runoff components of the WPI. At this point, it looks like the effects of management on rainfall runoff, frozen soil runoff and erosion are directionally correct for each of these transport pathways, but it is not possible to ascertain whether they are correct in relation to each other; in other words, is a lb of P in the frozen soil runoff calculations equivalent to a lb of P in rainfall runoff or erosion? This is important because some management practices can increase P losses through one pathway while decreasing those through another. Due to this lack of assurance about the equivalency, it may be useful for planners to report and explain the P Index by each component pathway.

In addition, we are working to evaluate and improve the method used to estimate field-to-stream delivery. This evaluation will use existing runoff monitoring data and mechanistic models to gain greater understanding of the significant processes governing transport through various WI landscapes. Simplified assessment tools can then be developed for use with the WPI.

WI P Index

- Inputs same as other P Indices
- Accurate representation of P management effects on runoff P losses from real fields
- Quantification allows testing

In summary, the WI P Index uses the same data inputs as many other P Indices and provides an accurate representation of management effects on runoff P losses from real fields. The quantification of dissolved P and particulate P yields in the WI P Index has allowed us to test it at the field scale.