Local monitoring in Mahantango Creek

Examining critical source areas of phosphorus and nitrogen loss from agricultural watersheds

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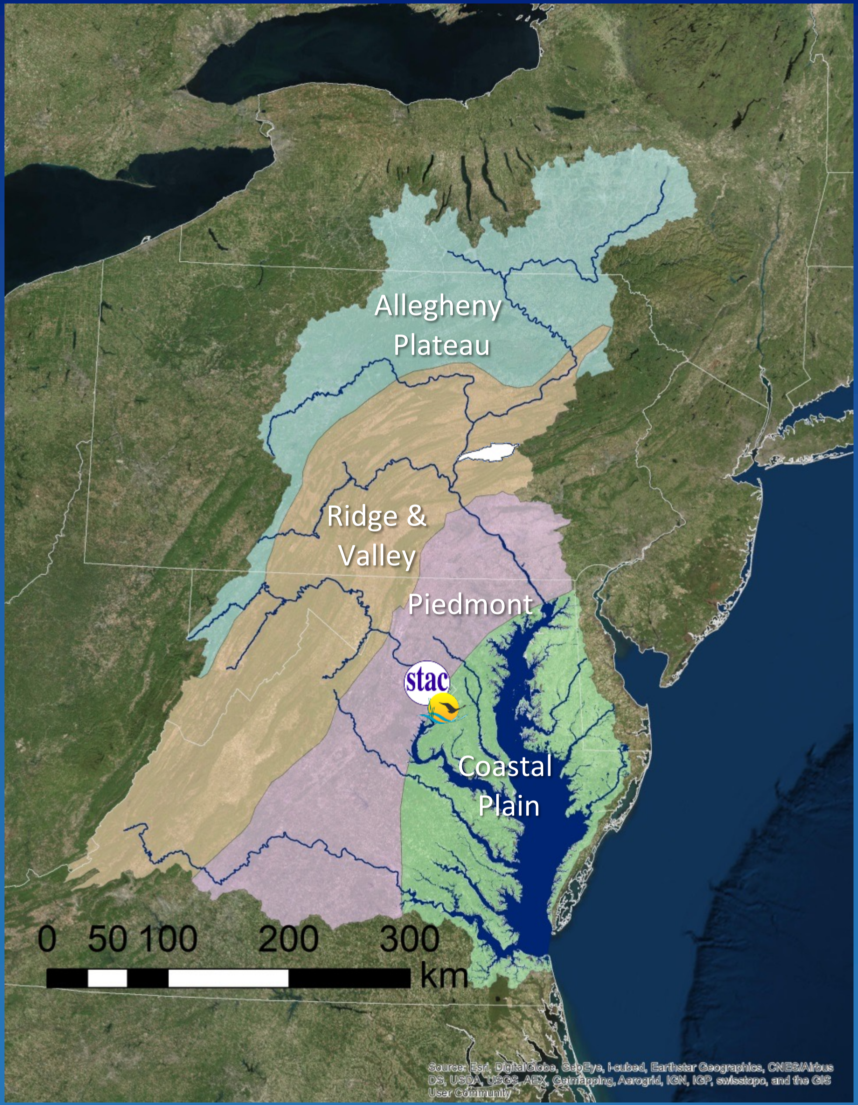
STAC Workshop

Using Local Monitoring Results to Inform the Chesapeake Bay Program’s Watershed Model

March 7-8, 2023 --- Fairfax, VA

The Mahantango Creek watershed

USDA benchmark agricultural watershed established in 1968



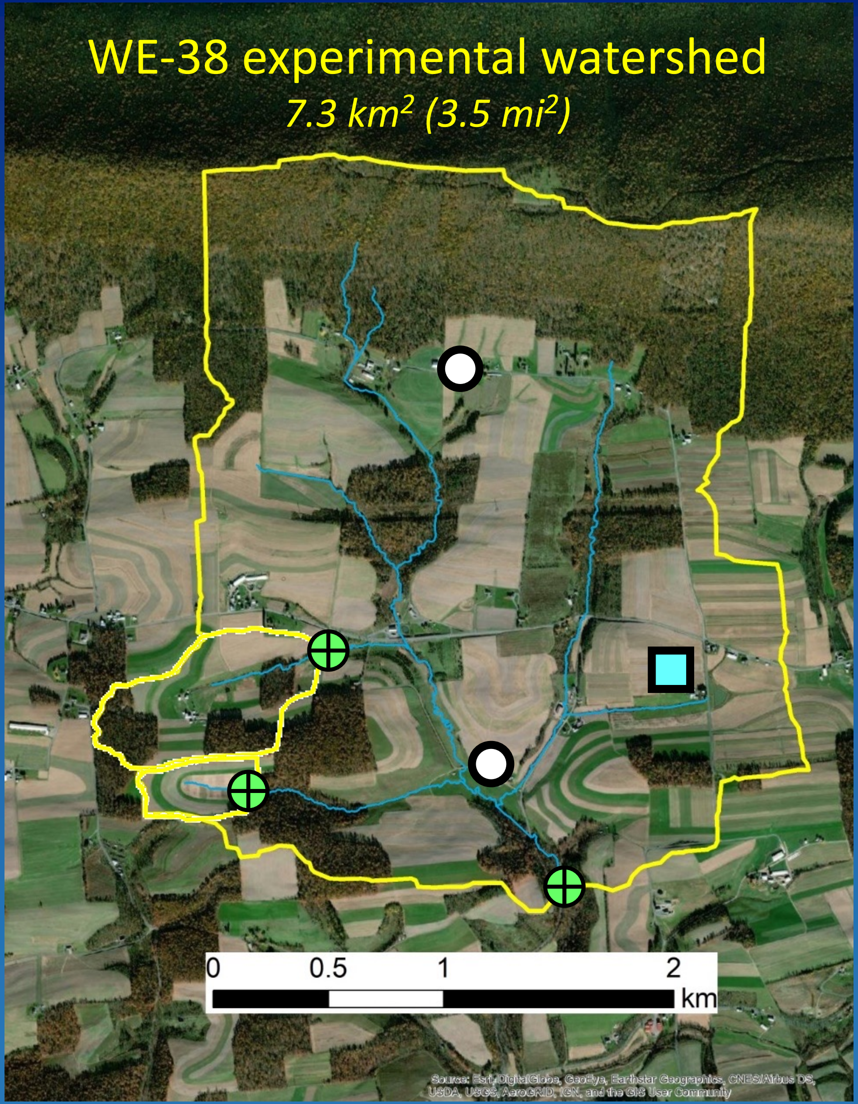
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

WE-38 weir
Area = 7.3 km^2 (3.5 mi^2)

USGS gage at Dalmatia
Area = 420 km^2 (162 mi^2)

The Mahantango Creek watershed

USDA benchmark agricultural watershed established in 1968

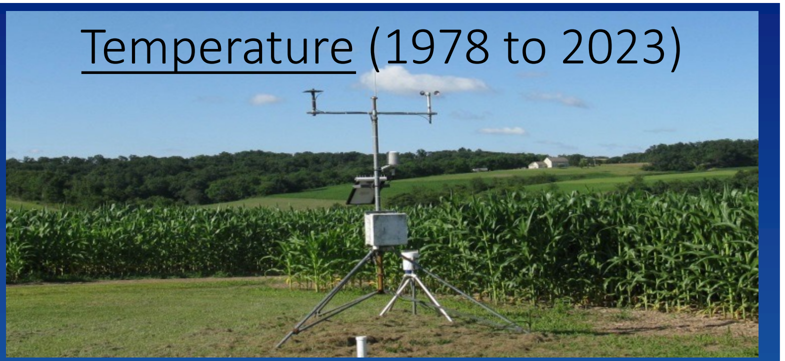


WE-38 experimental watershed

7.3 km^2 (3.5 mi^2)

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Precipitation (1968 to 2023)



Temperature (1978 to 2023)

Streamflow (1968 to 2023)

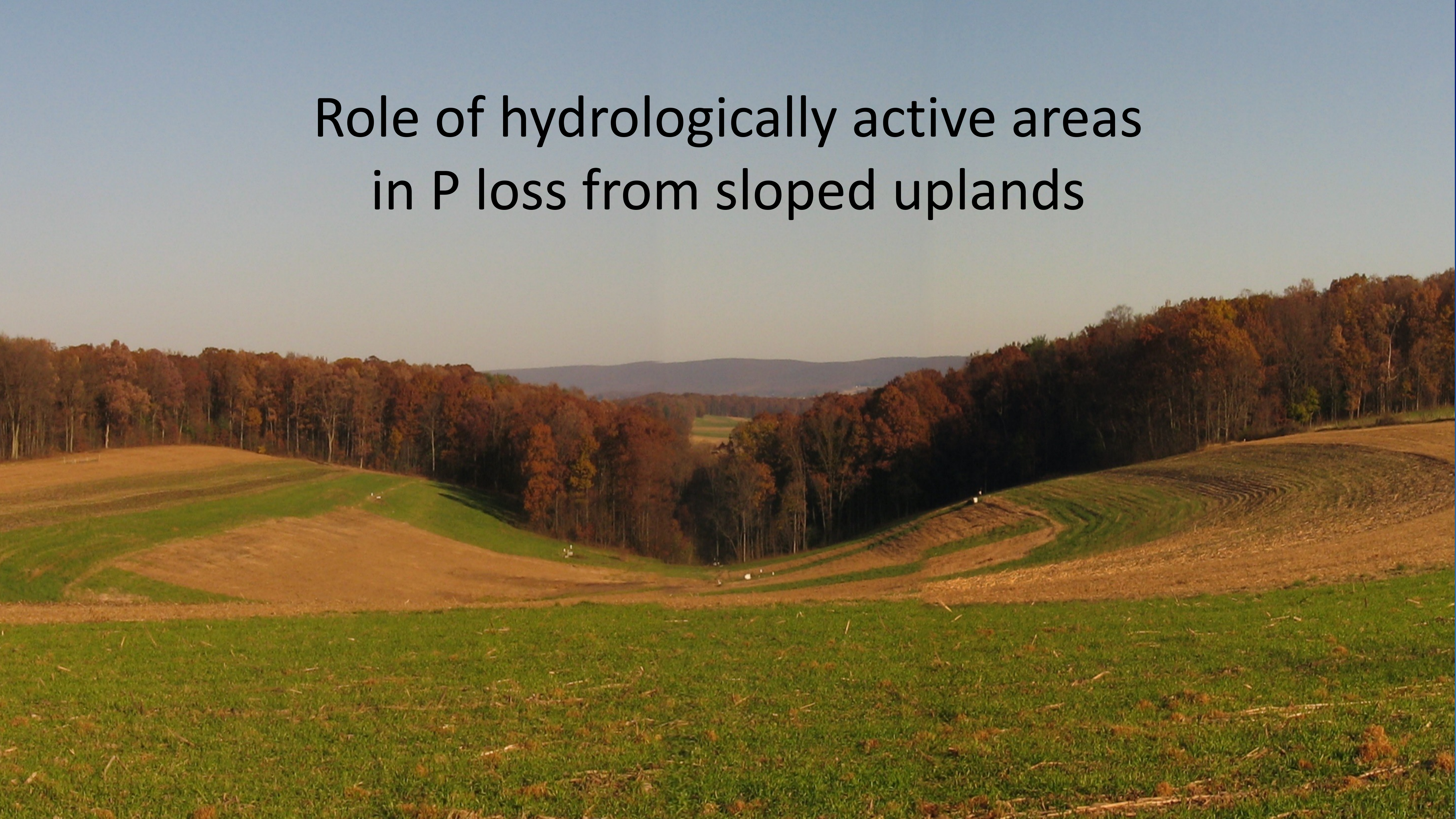
Water chemistry (1982 to 2023)

FD-36 (1997 to 2023)

Mattern (2001 to 2023)

Buda et al., 2011a, b (Water Resour. Res); Bryant et al., 2011 (Water Resour. Res.)

Role of hydrologically active areas in P loss from sloped uplands



Hydrologically active areas and hillslope P loss

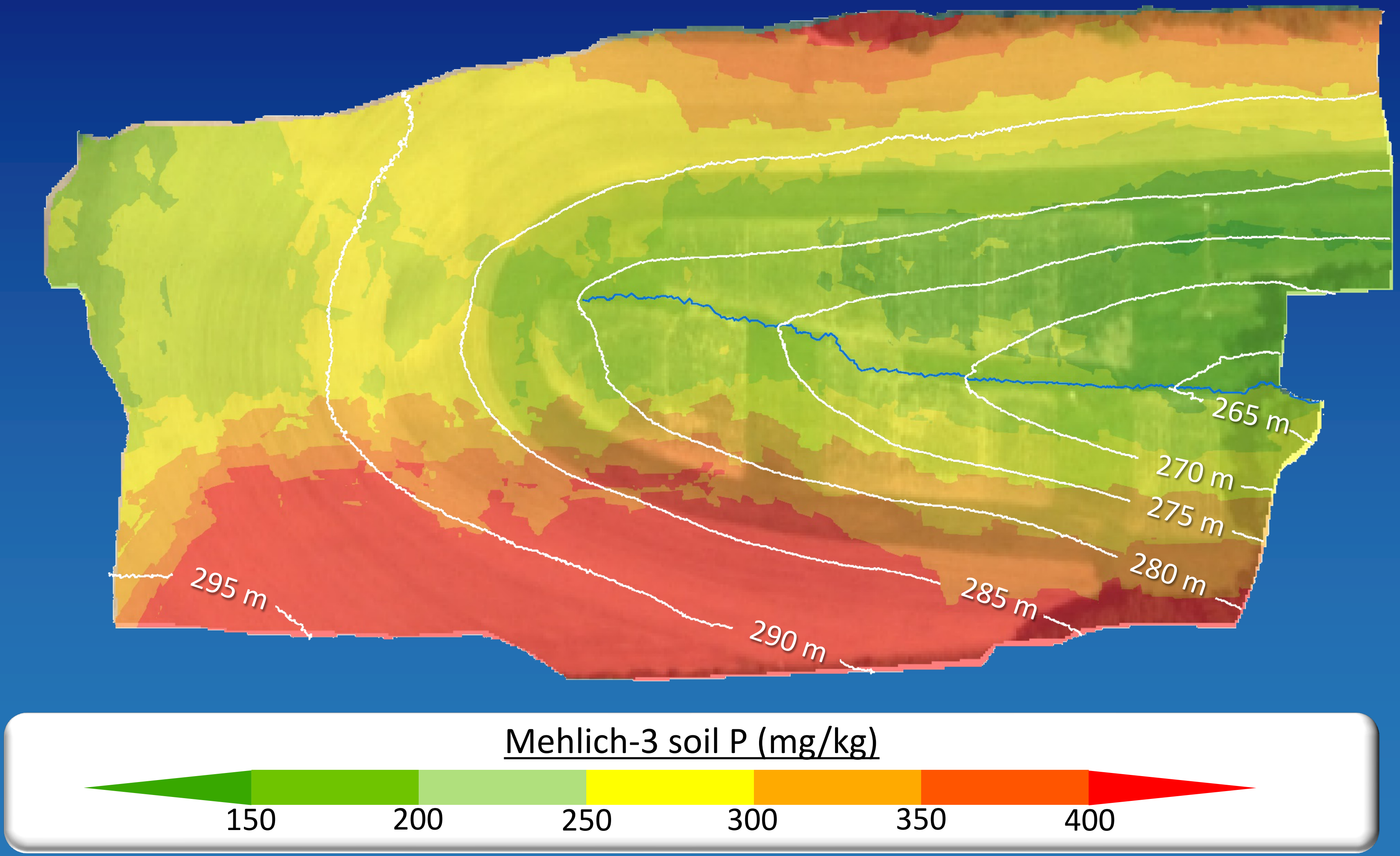
Study watershed: Mattern (11 ha)

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Buda et al., 2009 (Hydrol. Proc.)

Mattern watershed – soil P

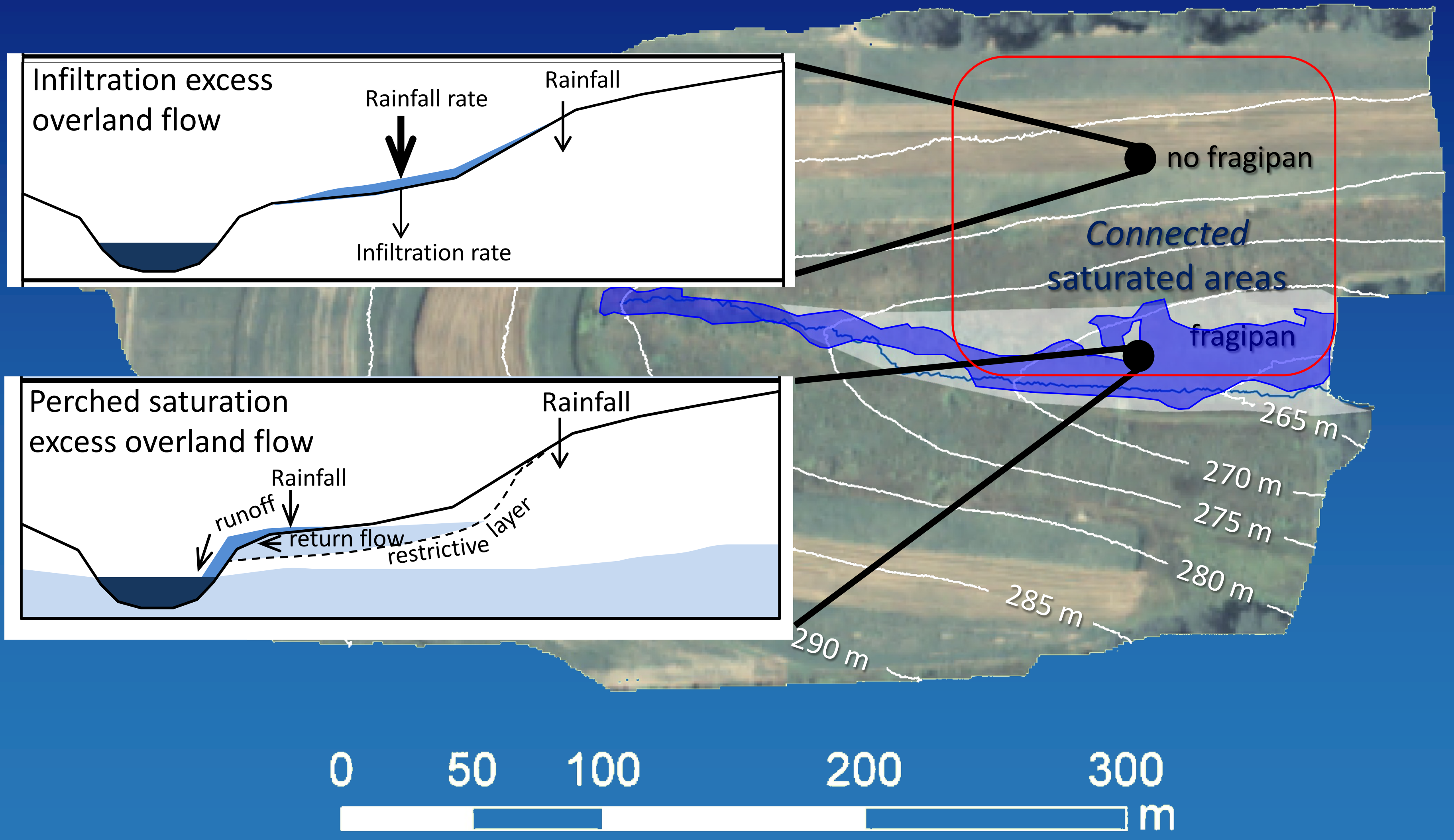
Soil P ranges from roughly 70 mg/kg near the stream to 500 mg/kg on the hilltops



Based on a grid of 172 soil sampling points

Mattern watershed – overland flow

Overland flow can be generated by infiltration and saturation excess processes



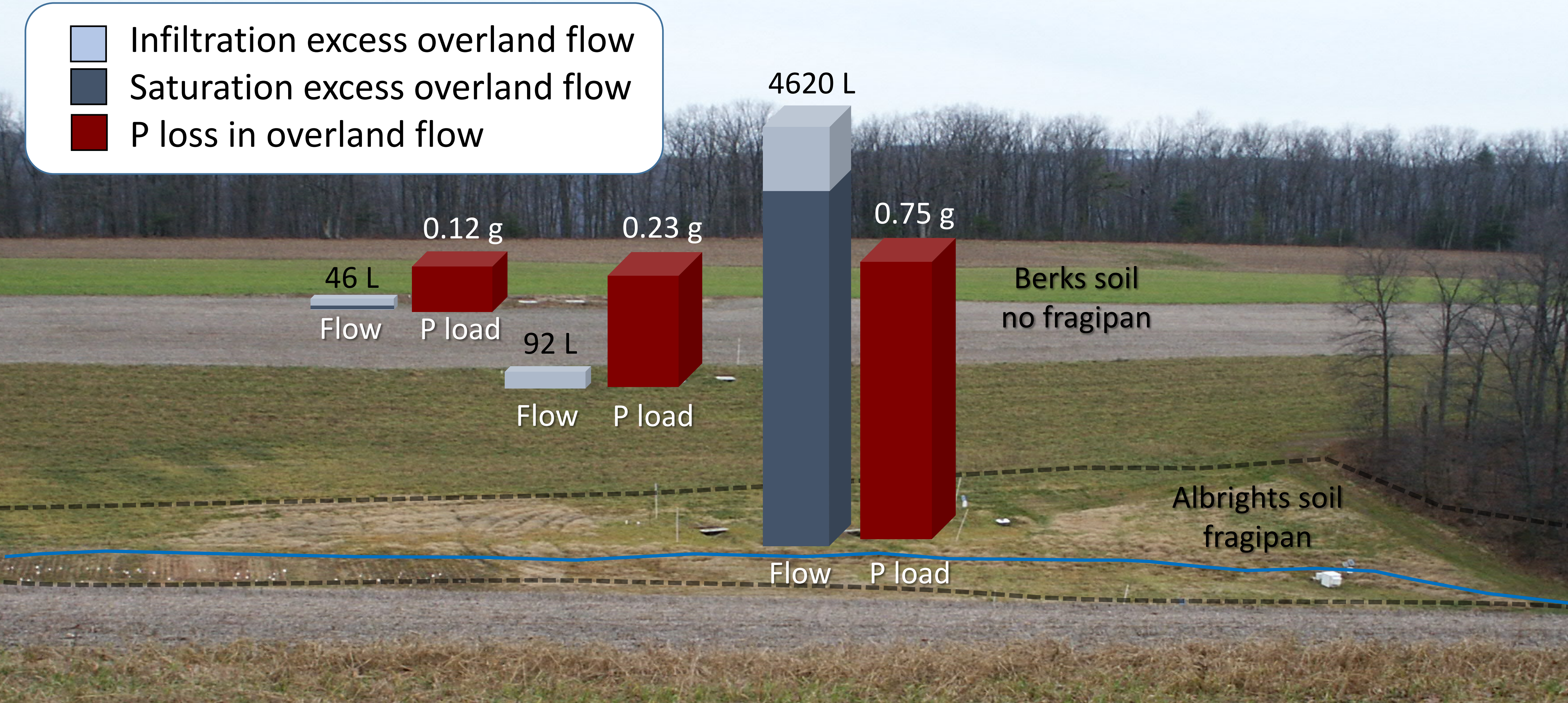
Buda et al., 2009 (Hydrol. Proc.)

Hillslope study of overland flow generation and P loss

2002 - 2004

Buda et al., 2009a (Hydrol. Proc.); Buda et al., 2009b (J. Environ. Qual.)

Data from small runoff plots suggest that fragipan soils enhance overland flow generation and P loss

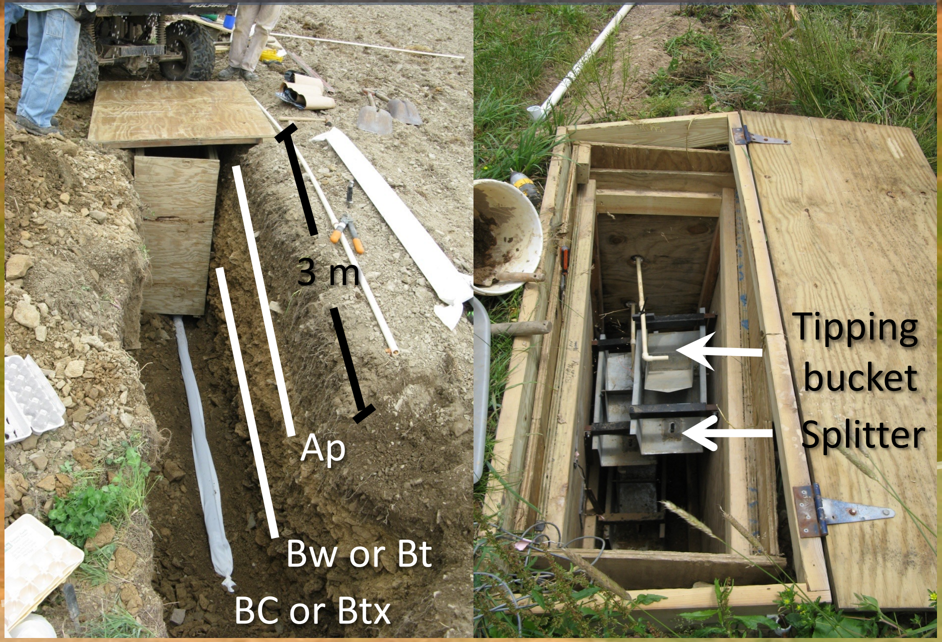


Buda et al., 2009a (Hydrol. Proc.); Buda et al., 2009b (J. Environ. Qual.)

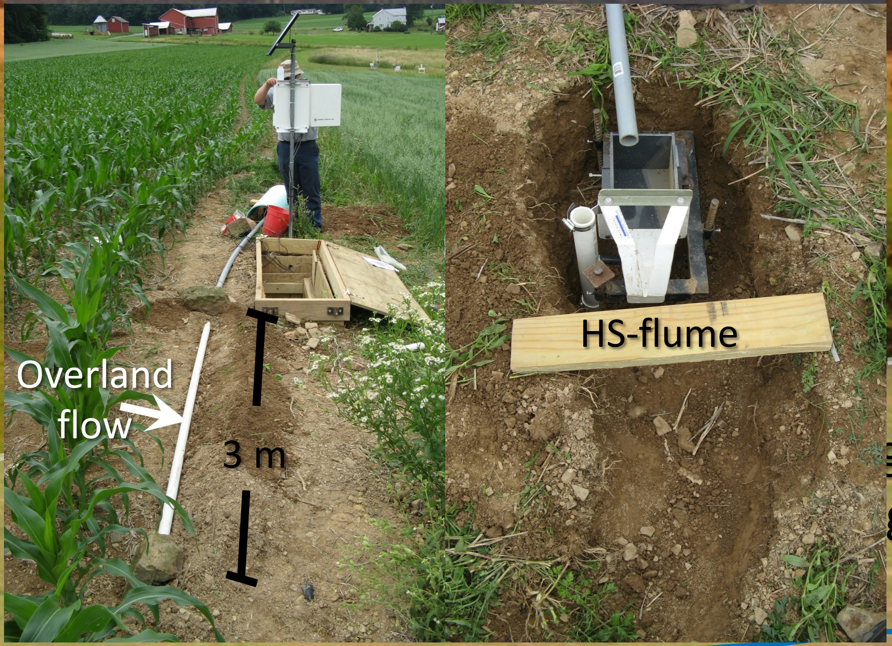
Hillslope study of P loss by overland and subsurface flows

2010 – 2015

Subsurface flow



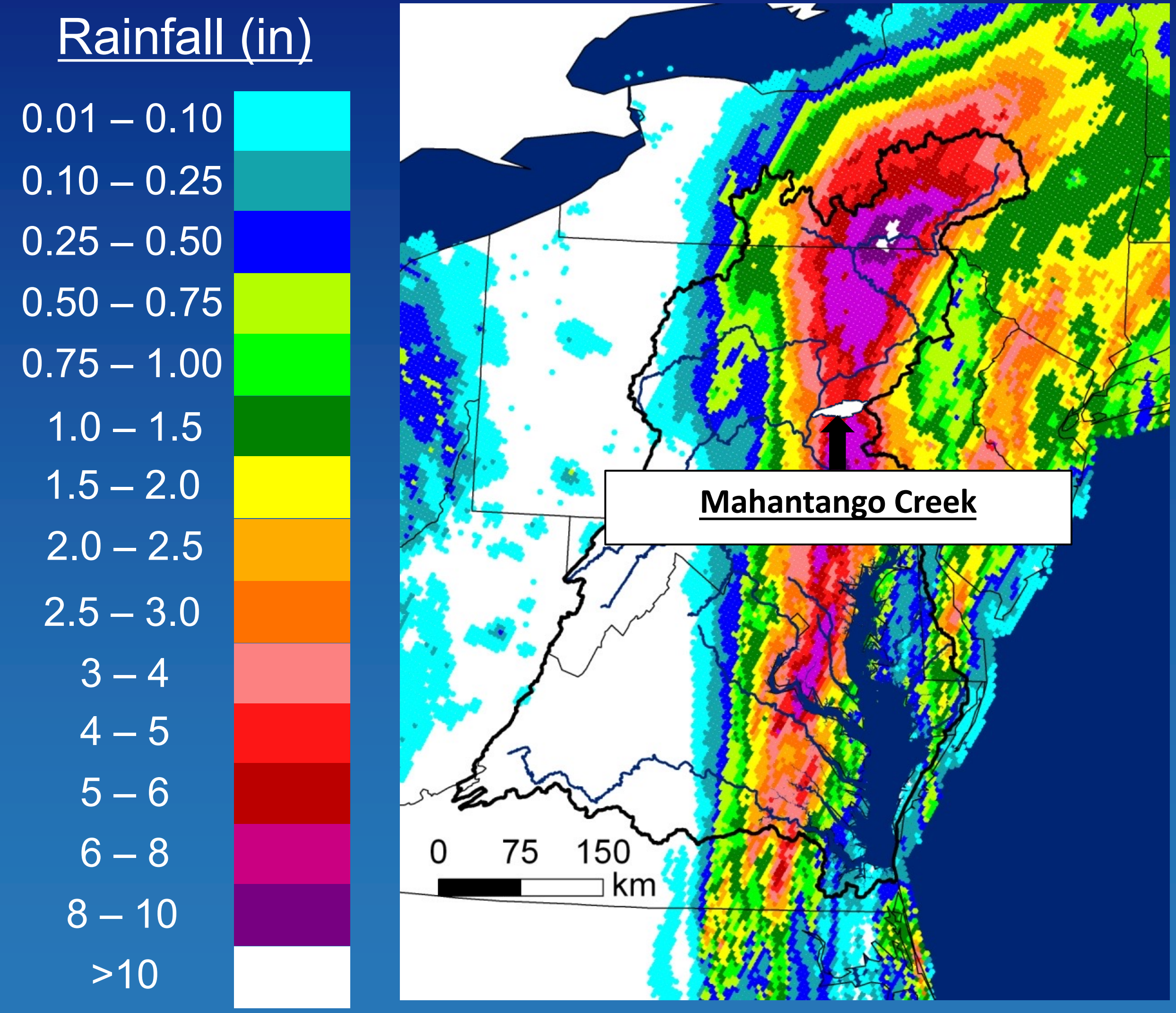
Overland flow



ghts soil
gipan

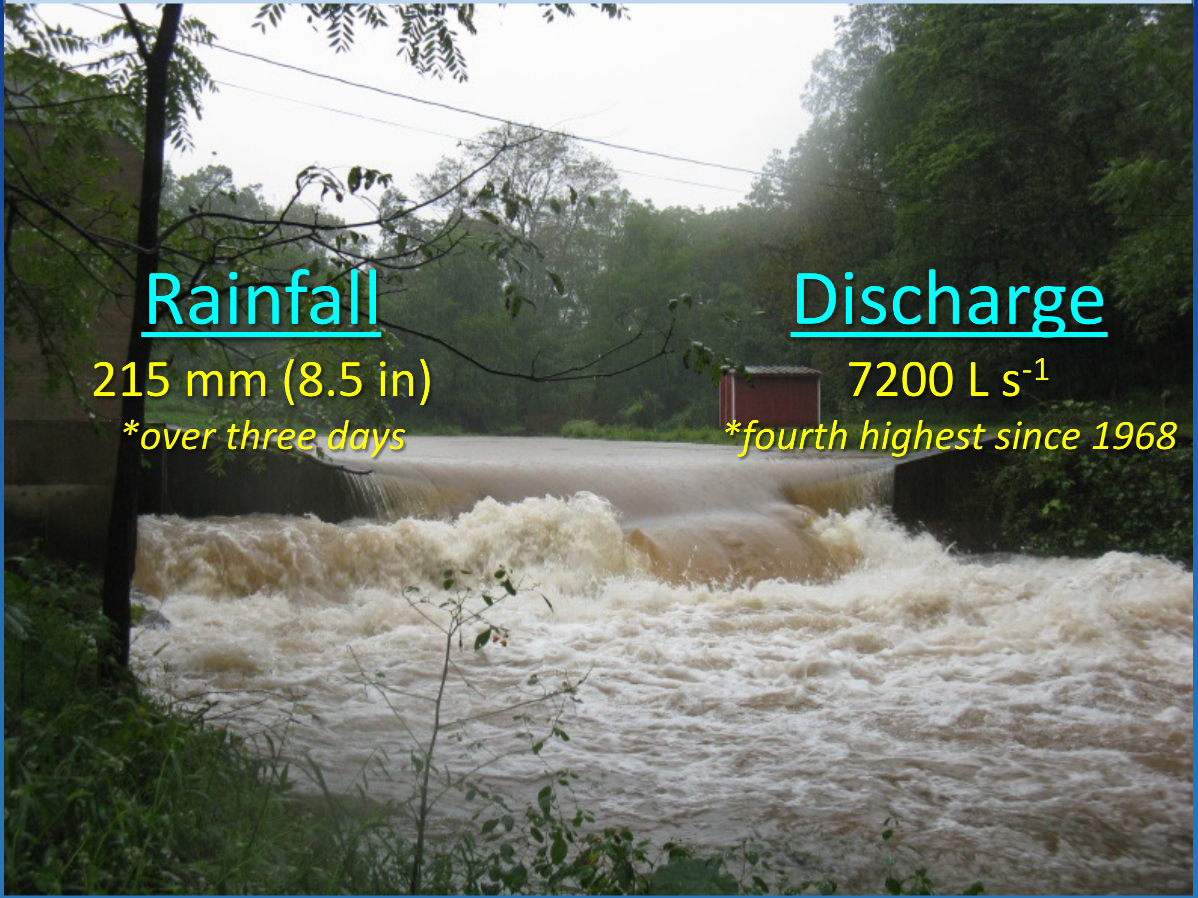
Tropical Storm Lee (September 7-8, 2011)

Extratropical storm that generated substantial overland and subsurface flow



National Weather Service GIS Portal

Storm characteristics



Rainfall

215 mm (8.5 in)

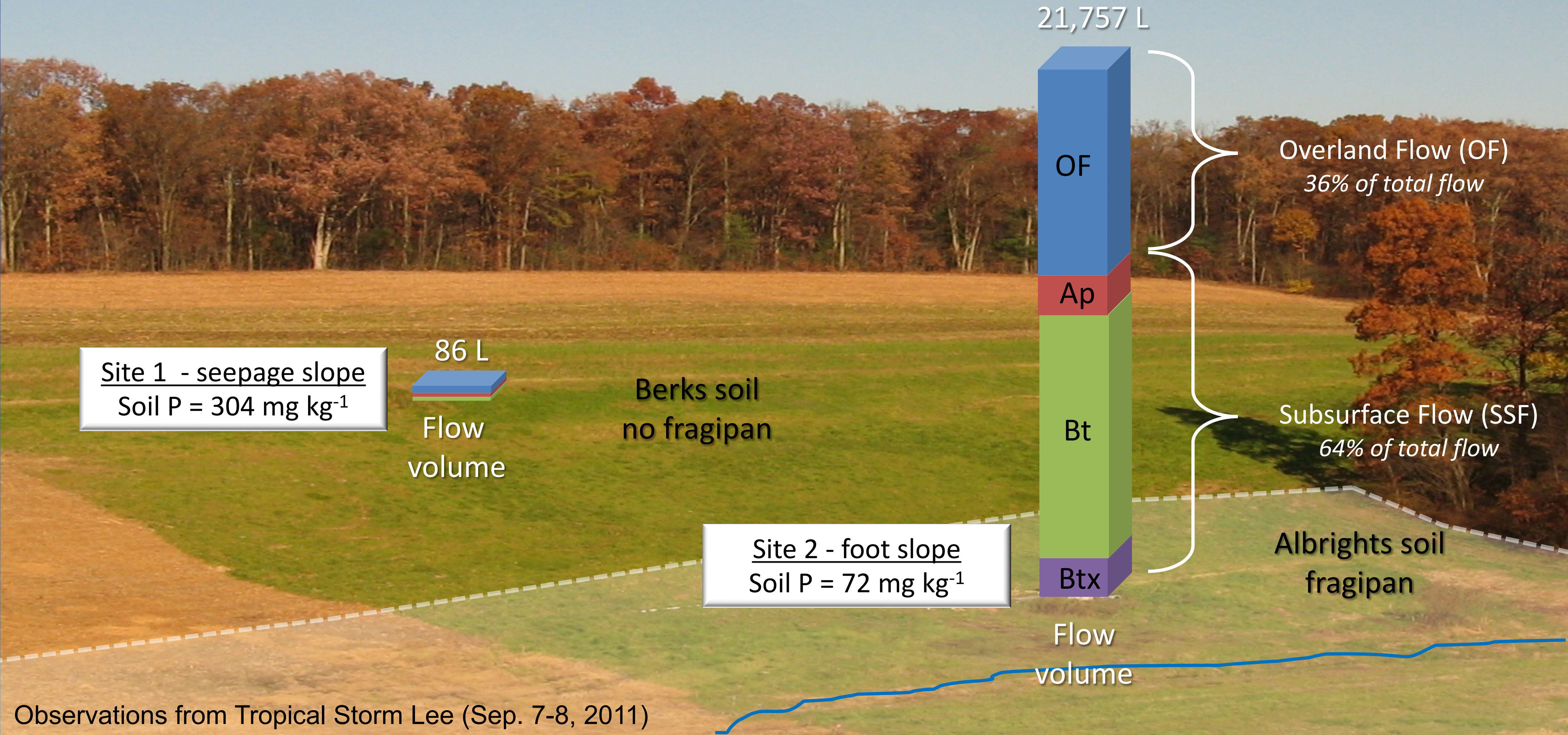
**over three days*

Discharge

7200 L s^{-1}

**fourth highest since 1968*

Data from hillslope trenches show that fragipan soils generate substantially more overland and subsurface flow than upland soils



Site 1 - seepage slope
Soil P = 304 mg kg^{-1}

Flow volume

Berks soil
no fragipan

Site 2 - foot slope
Soil P = 72 mg kg^{-1}

Flow volume

Overland Flow (OF)
36% of total flow

Subsurface Flow (SSF)
64% of total flow

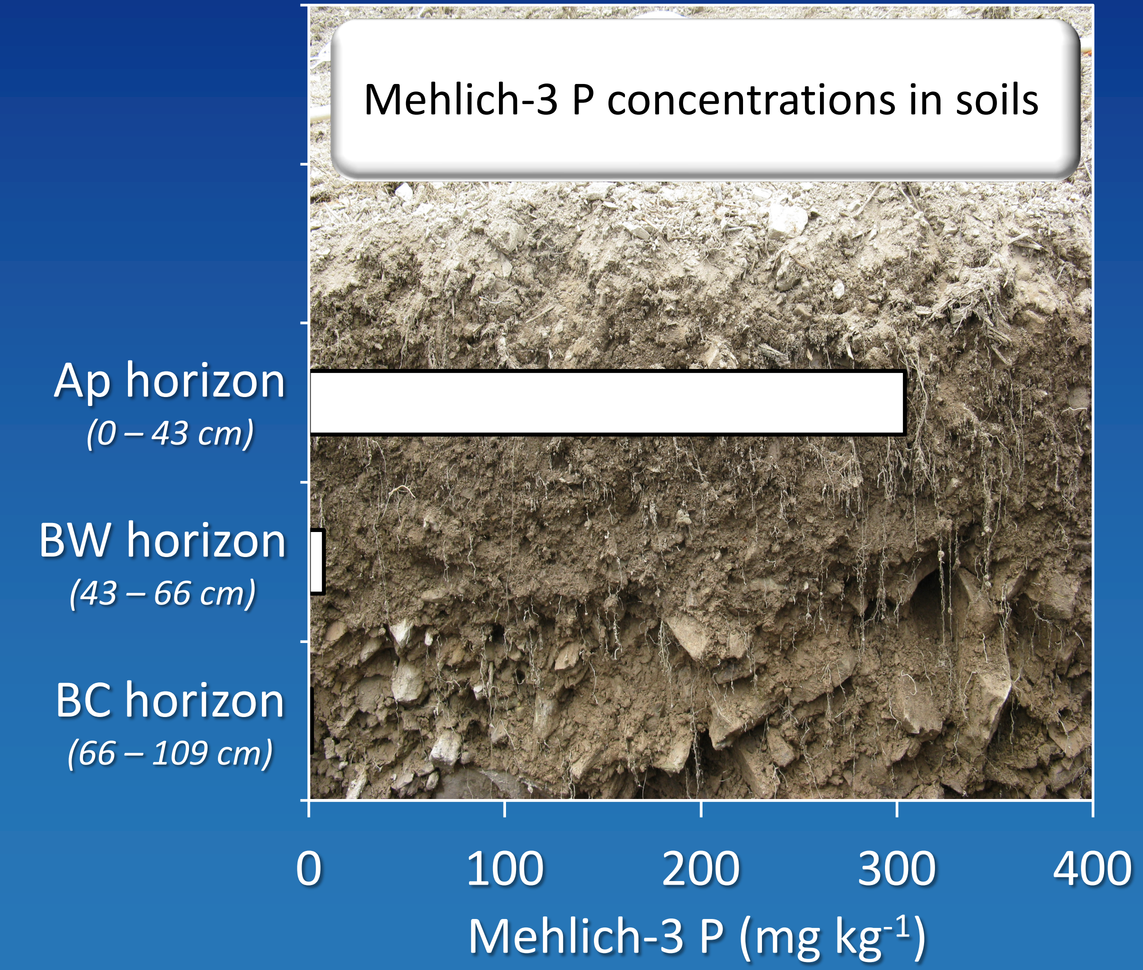
Albrights soil
fragipan

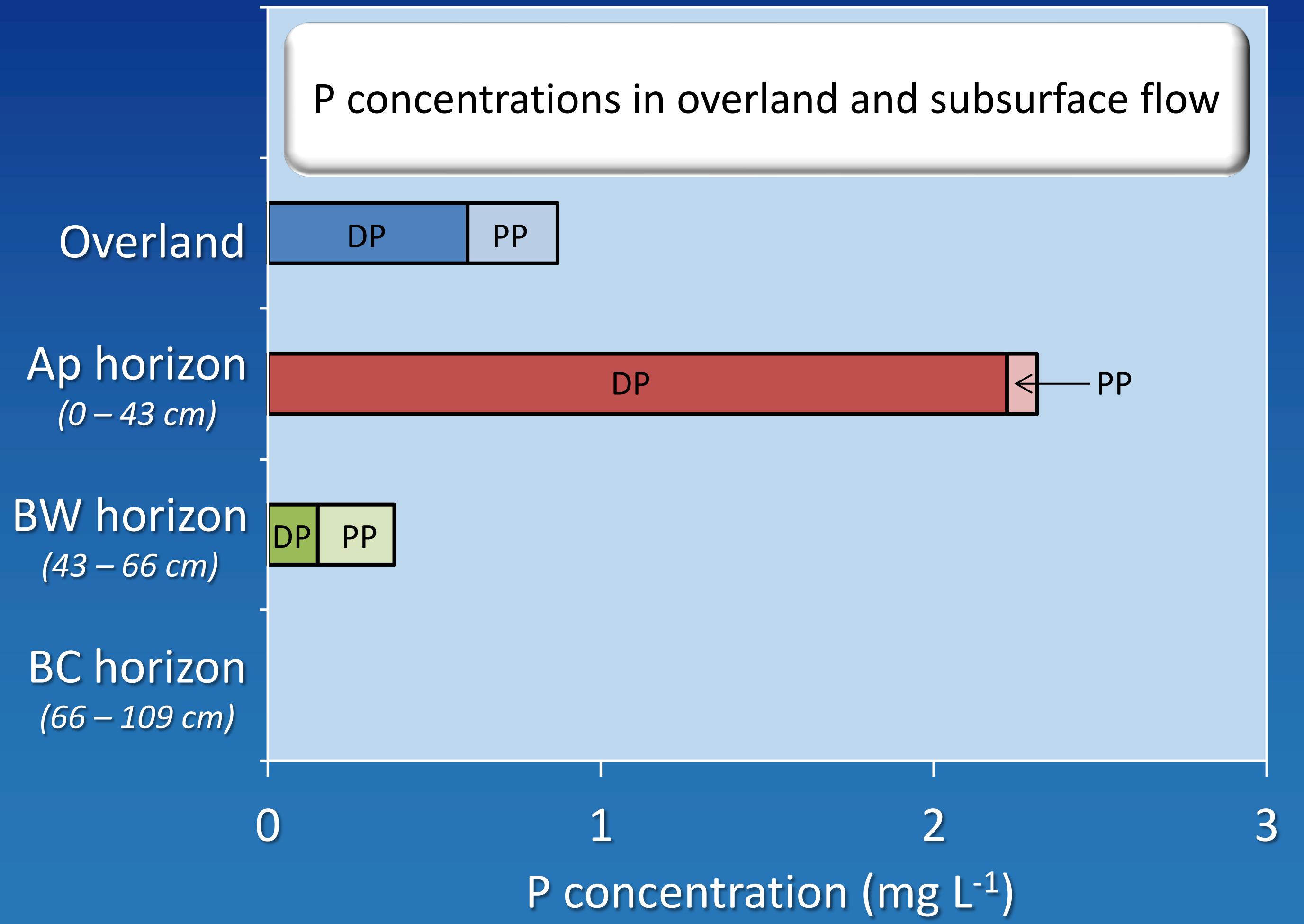
Observations from Tropical Storm Lee (Sep. 7-8, 2011)

Site 1 – P concentrations in runoff tracked soil P

Highest P concentrations in overland flow and drainage from Ap horizon

Site 1 – Seepage Slope (No Fragipan)



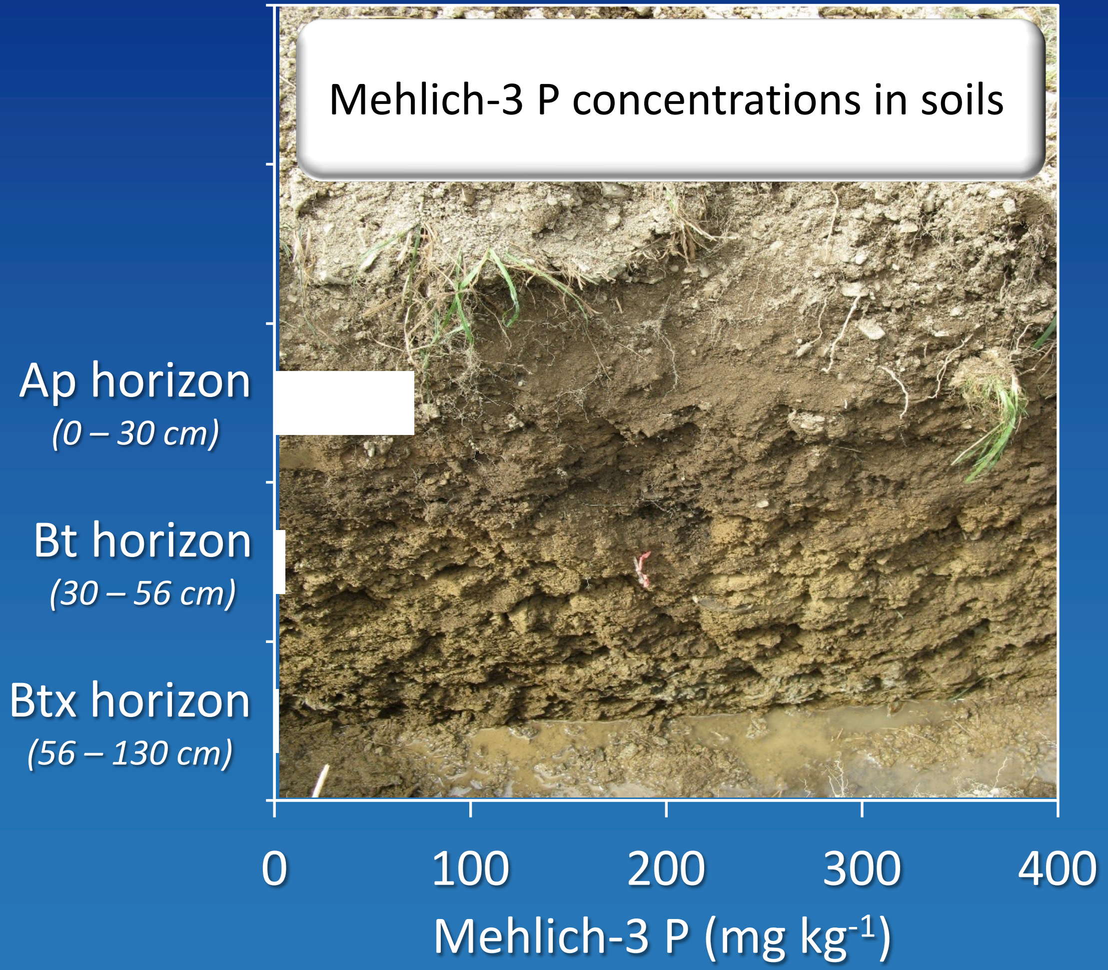


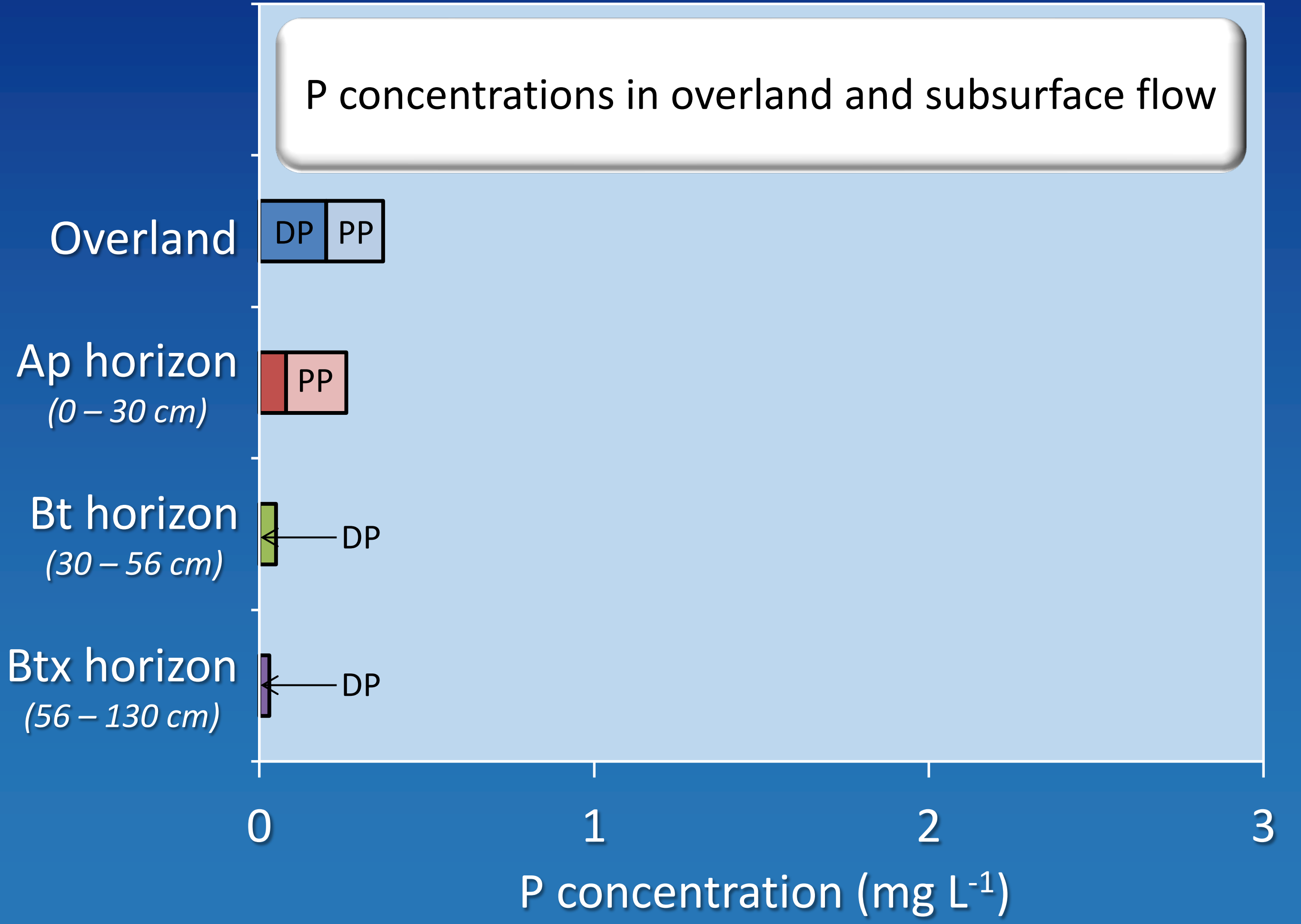
Observations from Tropical Storm Lee (Sep. 7-8, 2011)

Site 2 – lower soil P than Site 1; similar trends with depth

As with Site 1, highest P levels in overland flow and drainage from Ap horizon

Site 2 – Footslope (Fragipan)

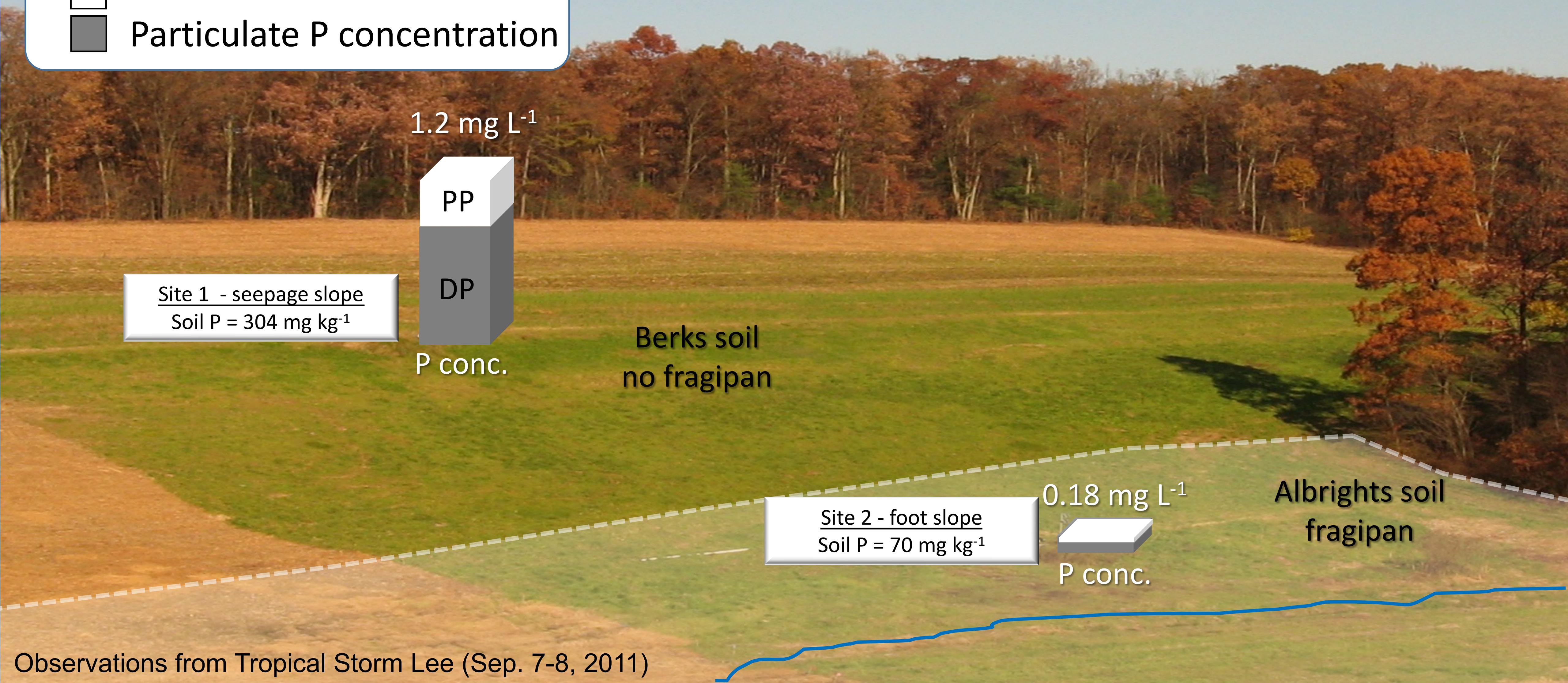




Observations from Tropical Storm Lee (Sep. 7-8, 2011)

Overall, highest P concentrations in runoff occurred in upslope soils where highest P reserves were found

☐ Dissolved P concentration
▨ Particulate P concentration



Site 1 - seepage slope
Soil P = 304 mg kg^{-1}

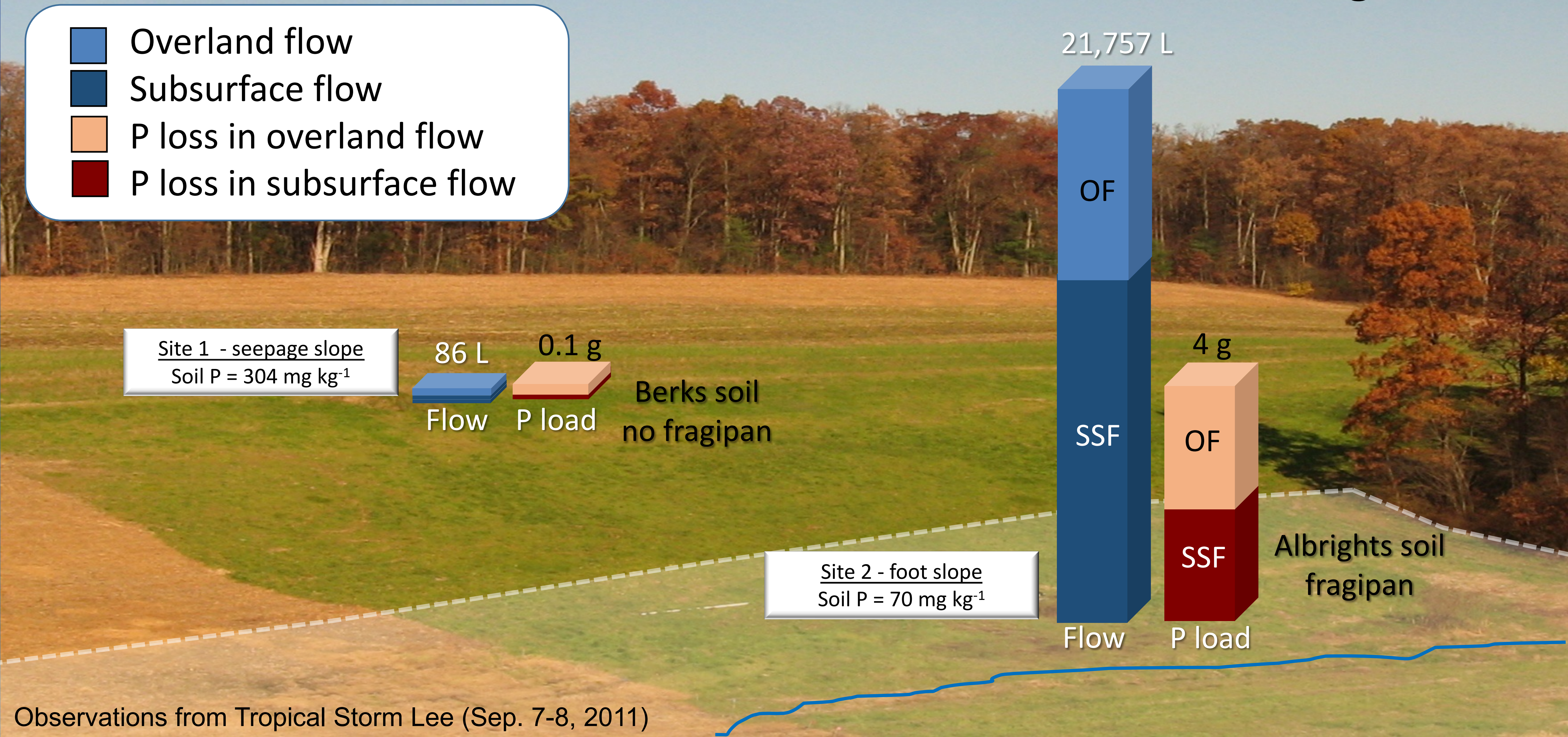
Berks soil
no fragipan

Site 2 - foot slope
Soil P = 70 mg kg^{-1}

Albrights soil
fragipan

Observations from Tropical Storm Lee (Sep. 7-8, 2011)

As with the plot-scale study of overland flow, largest P losses occurred near the stream where runoff volumes were highest



Site 1 - seepage slope
Soil P = 304 mg kg^{-1}

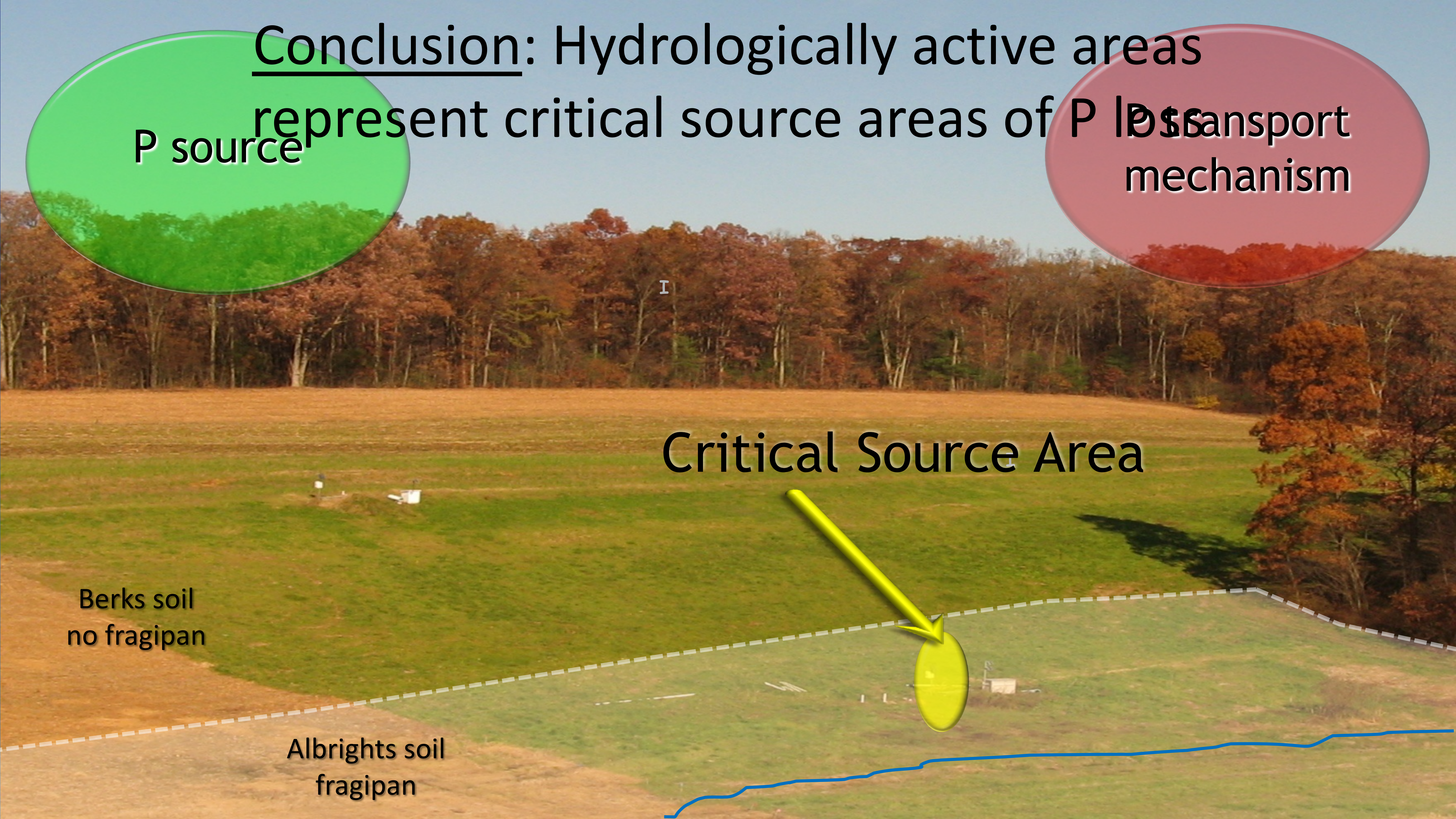
Berks soil
no fragipan

Site 2 - foot slope
Soil P = 70 mg kg^{-1}

Albrights soil
fragipan

Observations from Tropical Storm Lee (Sep. 7-8, 2011)

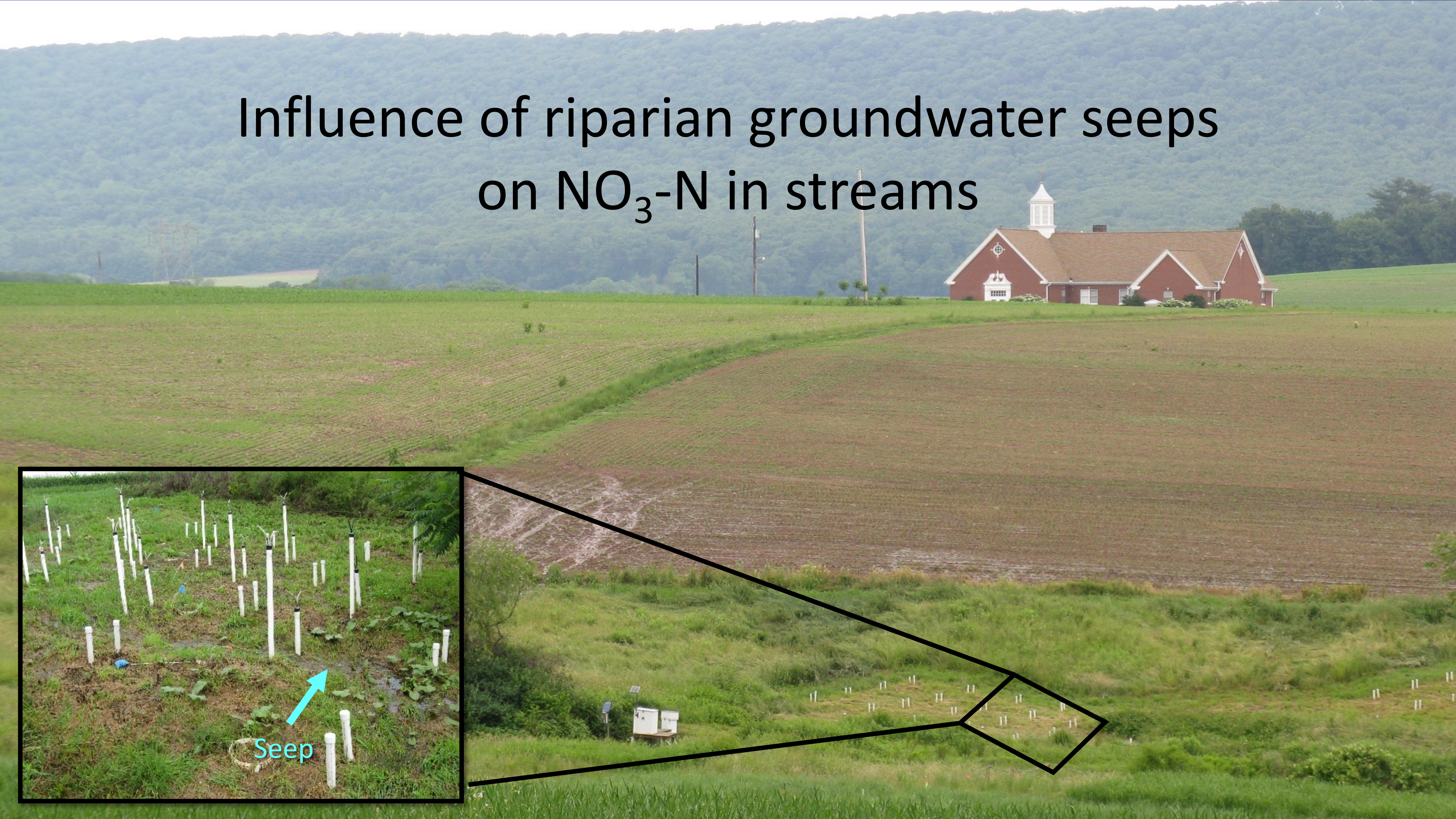
Conclusion: Hydrologically active areas represent critical source areas of P loss



P source

P transport mechanism

Influence of riparian groundwater seeps on NO_3-N in streams

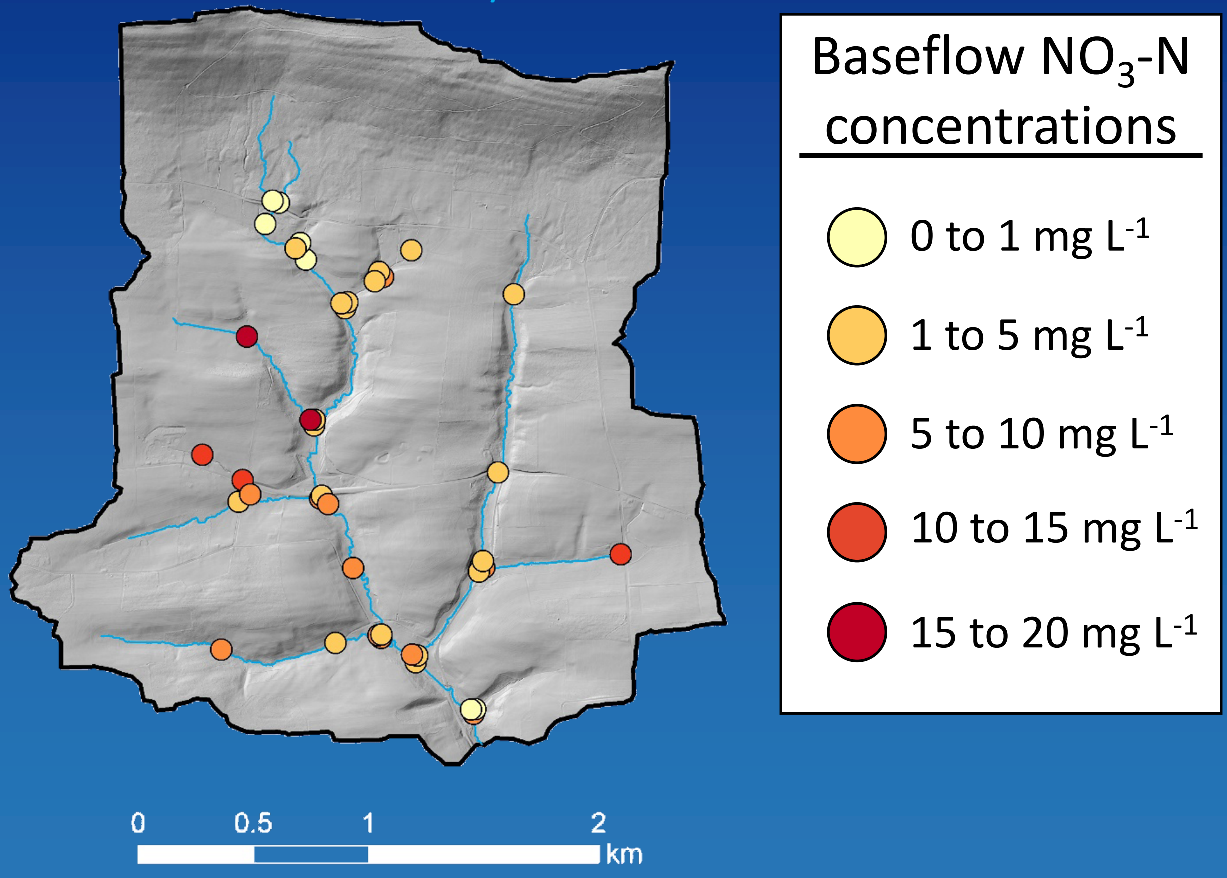


Agricultural streams in WE-38 have elevated NO_3-N levels

Sampling during baseflow offers insight into NO_3-N contributions from groundwater

Baseflow survey of 41 stream locations

September 1990



Journal of Hydrology 217 (1999) 1–18

Flow and chemical contributions to streamflow in an upland watershed: a baseflow survey

W.J. Gburek*, G.J. Folmar

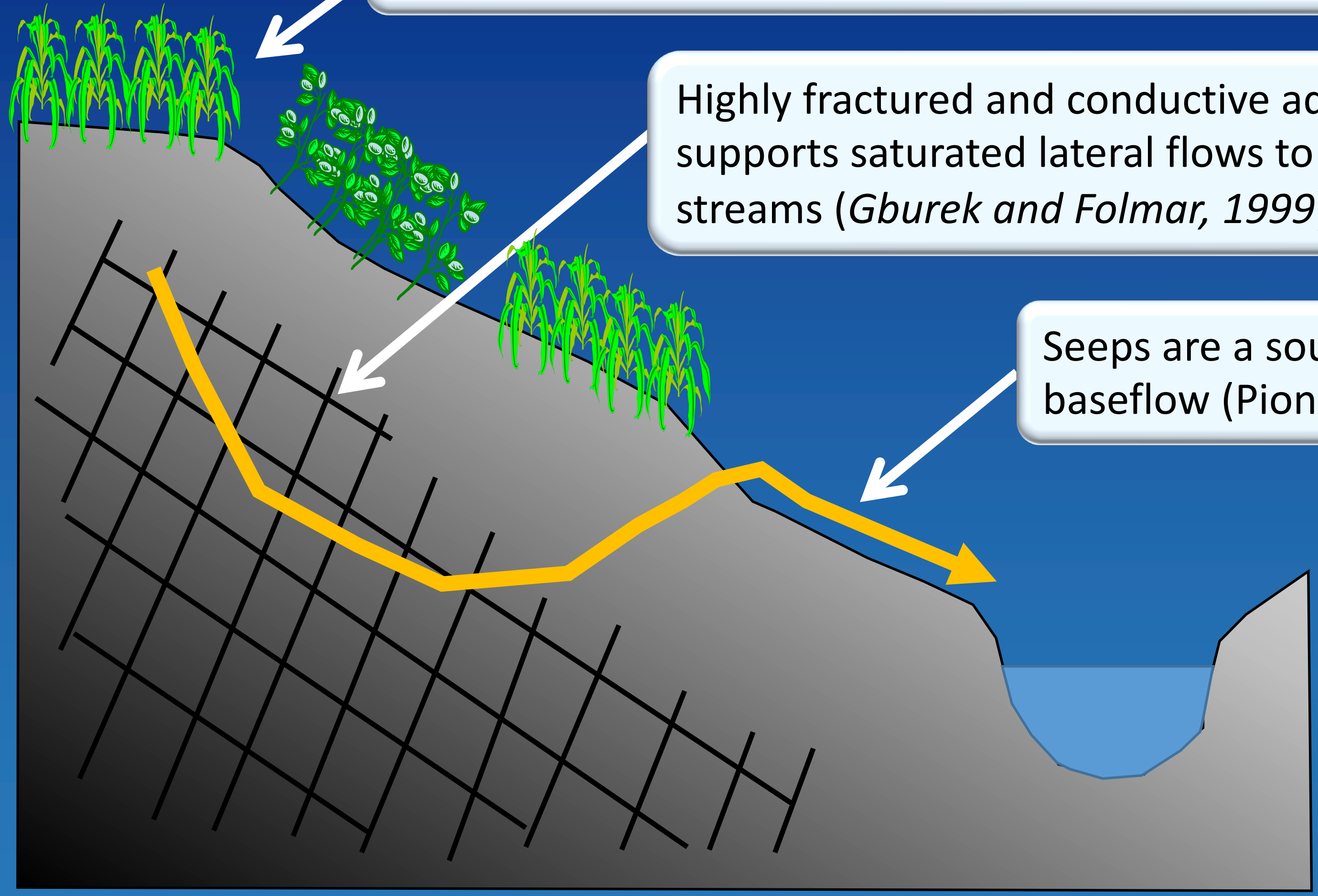
Abstract

1. Introduction

Gburek and Folmar, 1999 (J. Hydrol.)

Groundwater discharge via seeps is common in WE-38

Understanding the connection between seeps and NO_3-N in streams is important



Water quality of the fractured aquifer is affected by the overlying land use (Pionke and Urban, 1985)

Highly fractured and conductive aquifer that supports saturated lateral flows to seeps and streams (*Gburek and Folmar, 1999*)

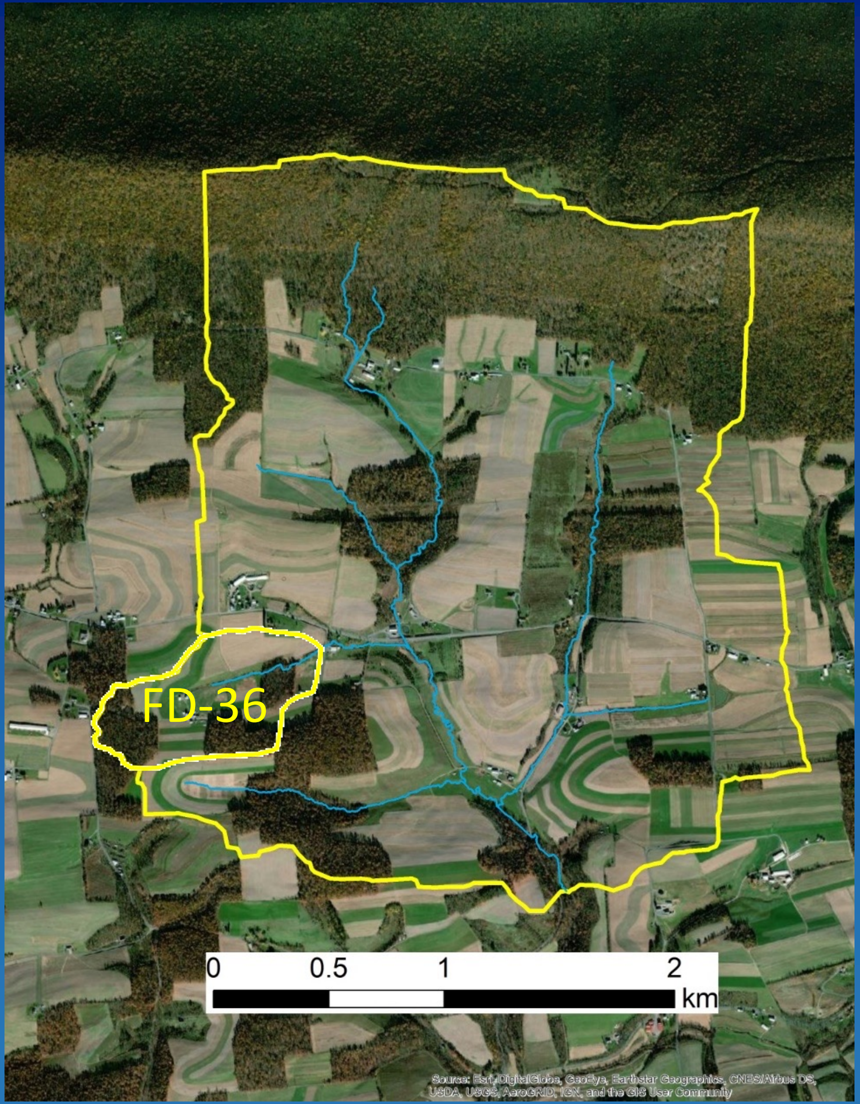
Seeps are a source of stream baseflow (Pionke et al., 1988)

Riparian seep

Williams et al., 2014 (J. Hydrol.); Williams et al., 2016 (Groundwater)

Riparian groundwater seeps and NO3-N in streams

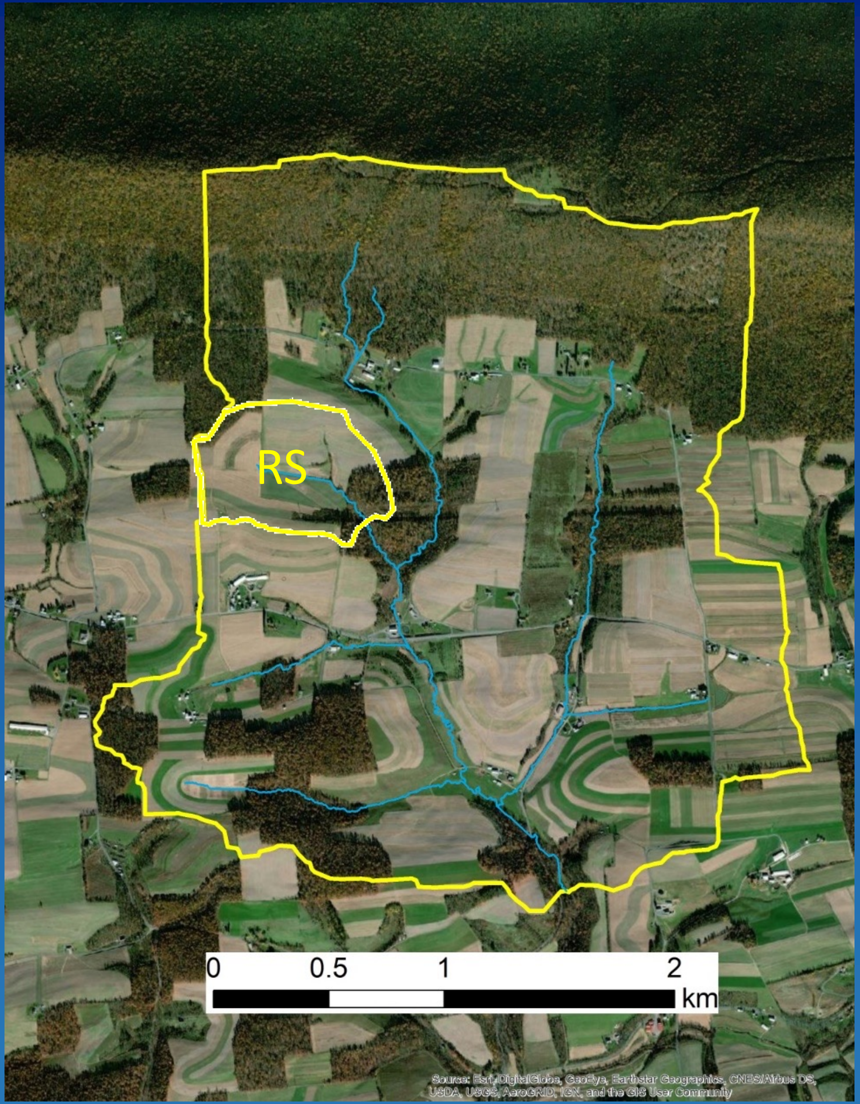
Study watersheds: <u>FD-36 (40 ha)</u> and RS (45 ha)



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Riparian groundwater seeps and NO3-N in streams

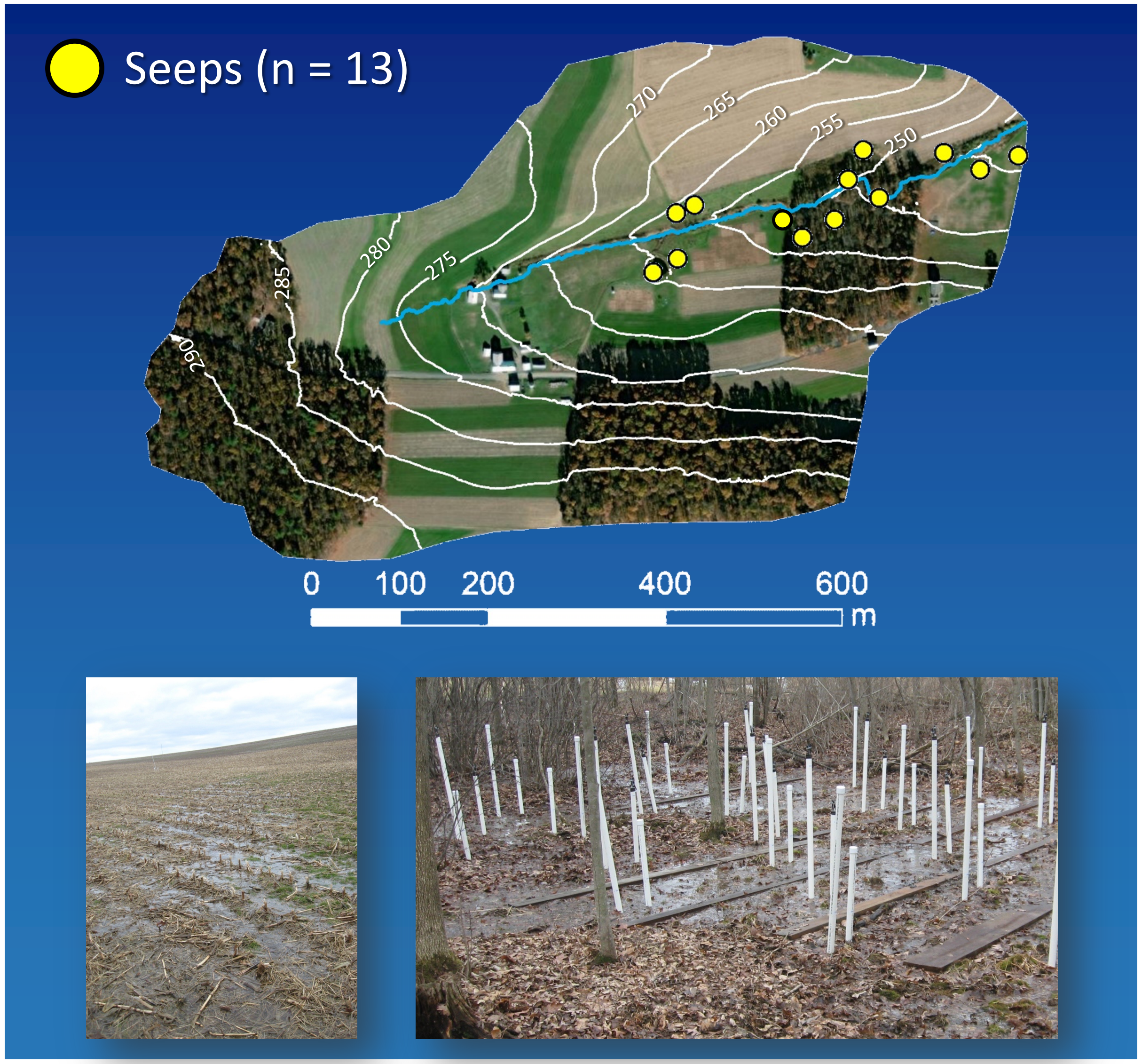
Study watersheds: FD-36 (40 ha) and RS (45 ha)

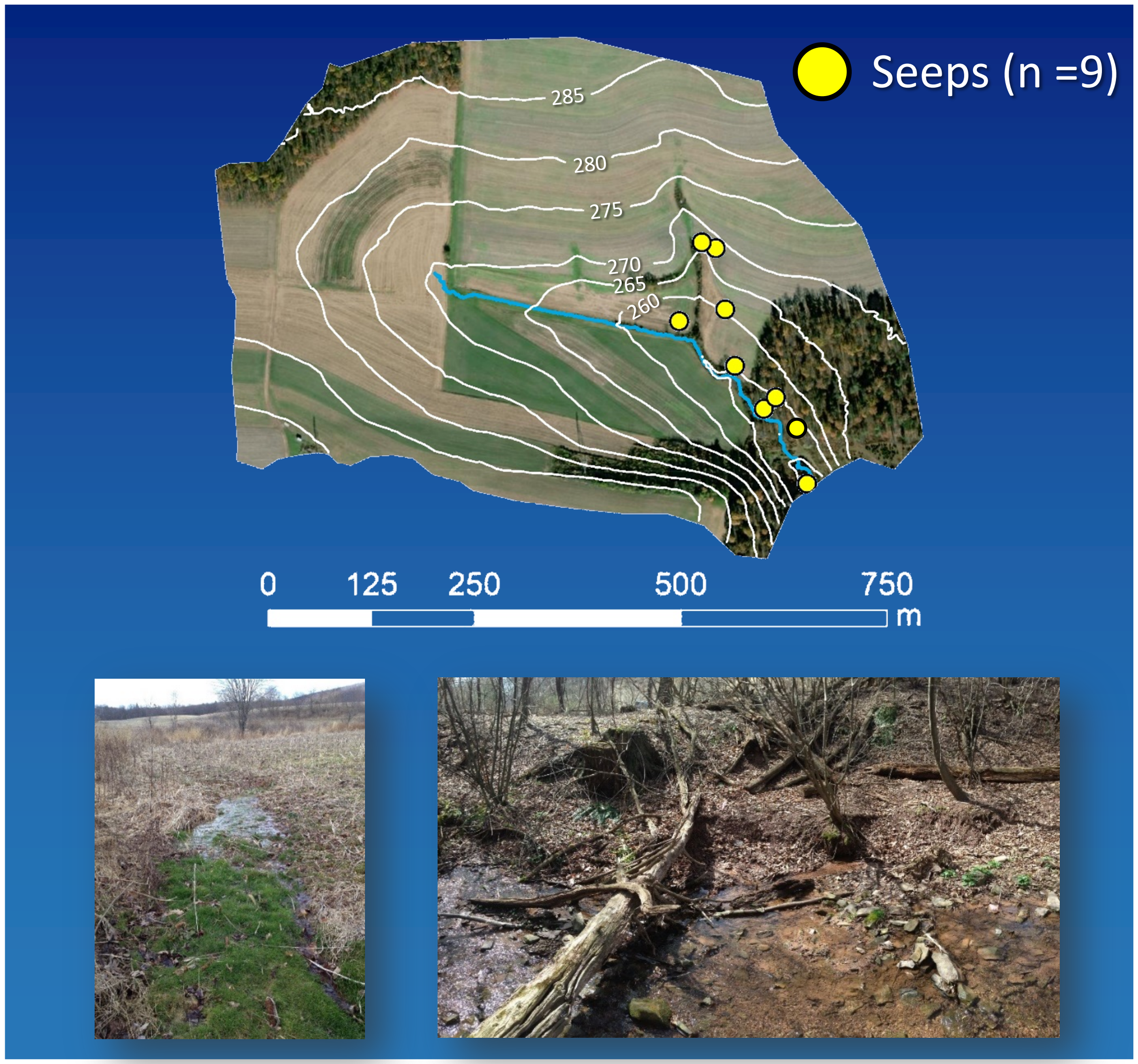


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Riparian groundwater seeps and NO_3-N in streams

Seeps in FD-36 and RS were sampled every two weeks from May 2010 to April 2012

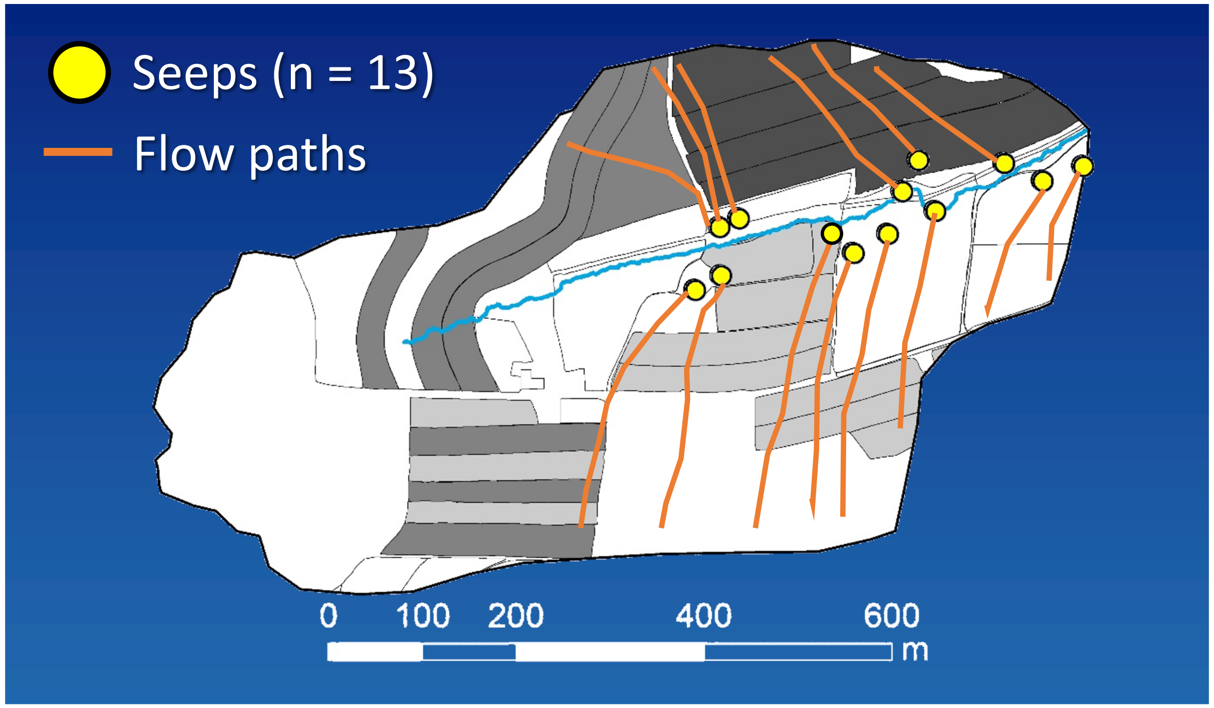


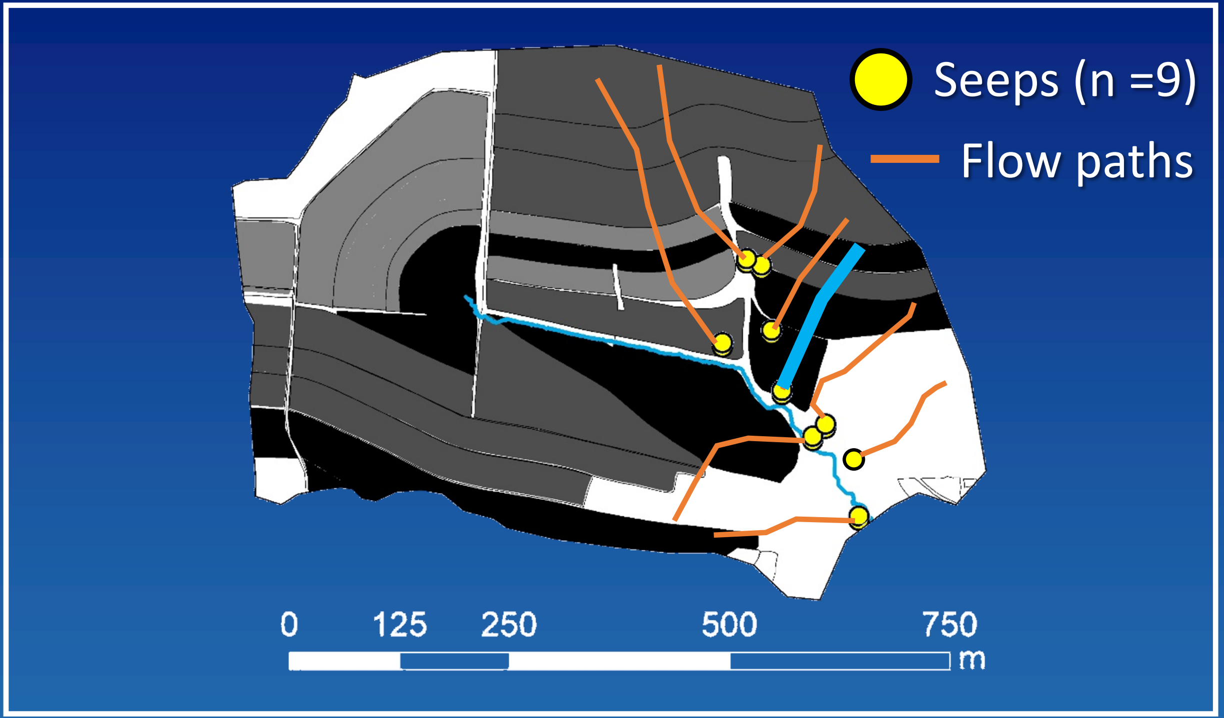


Williams et al., 2015 (J. Environ. Qual.)

Seep flow pathways and N management

LiDAR DEMs used to extend flow paths from seep emergence to watershed divide





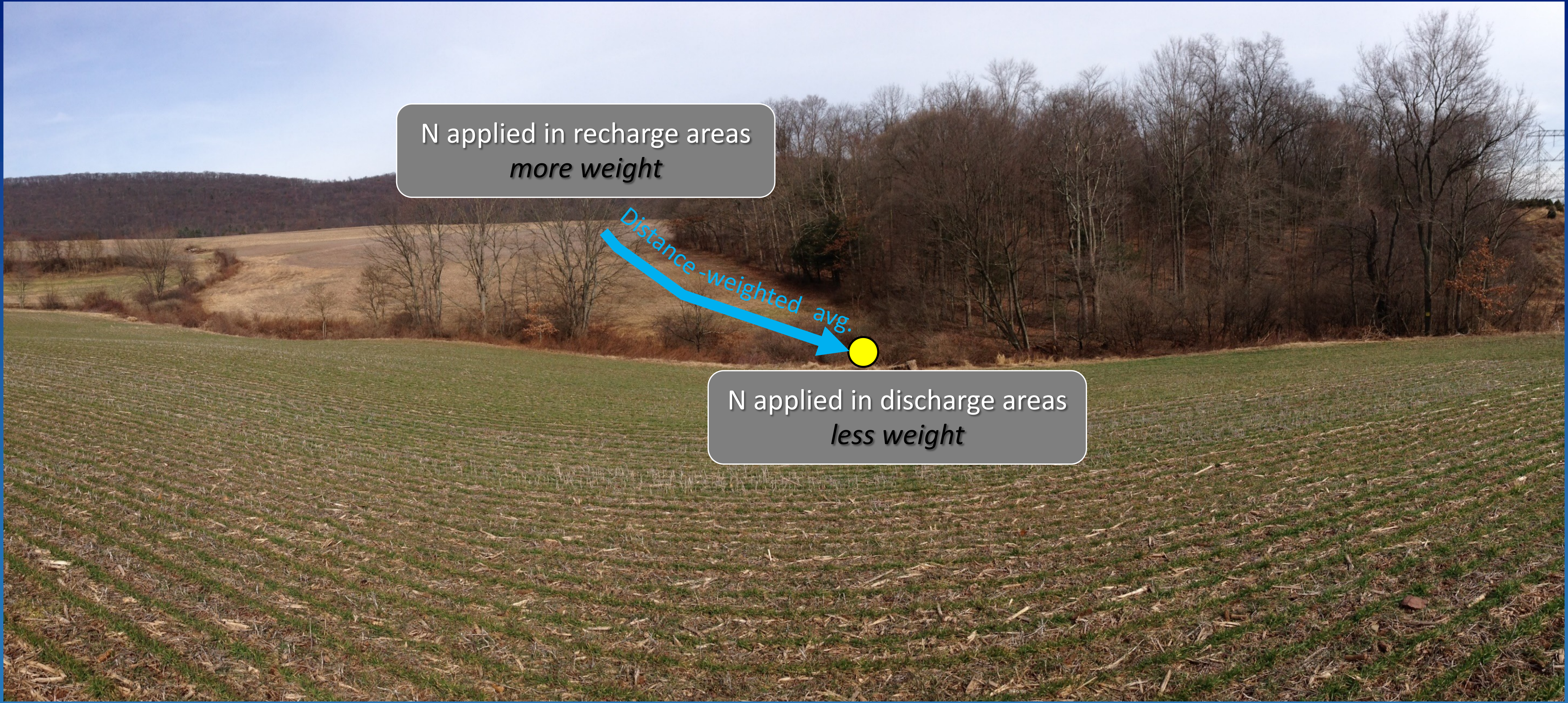
Nitrogen application rate (kg ha^{-1} yr^{-1})

0 to 50	50 to 100	100 to 150	150 to 200	200 to 250
⬜	░	▒	▓	⬛

Williams et al., 2015 (J. Environ. Qual.)

Calculating N application rates along seep flow paths

Distance weighting function that gave more weight to N applied in recharge areas



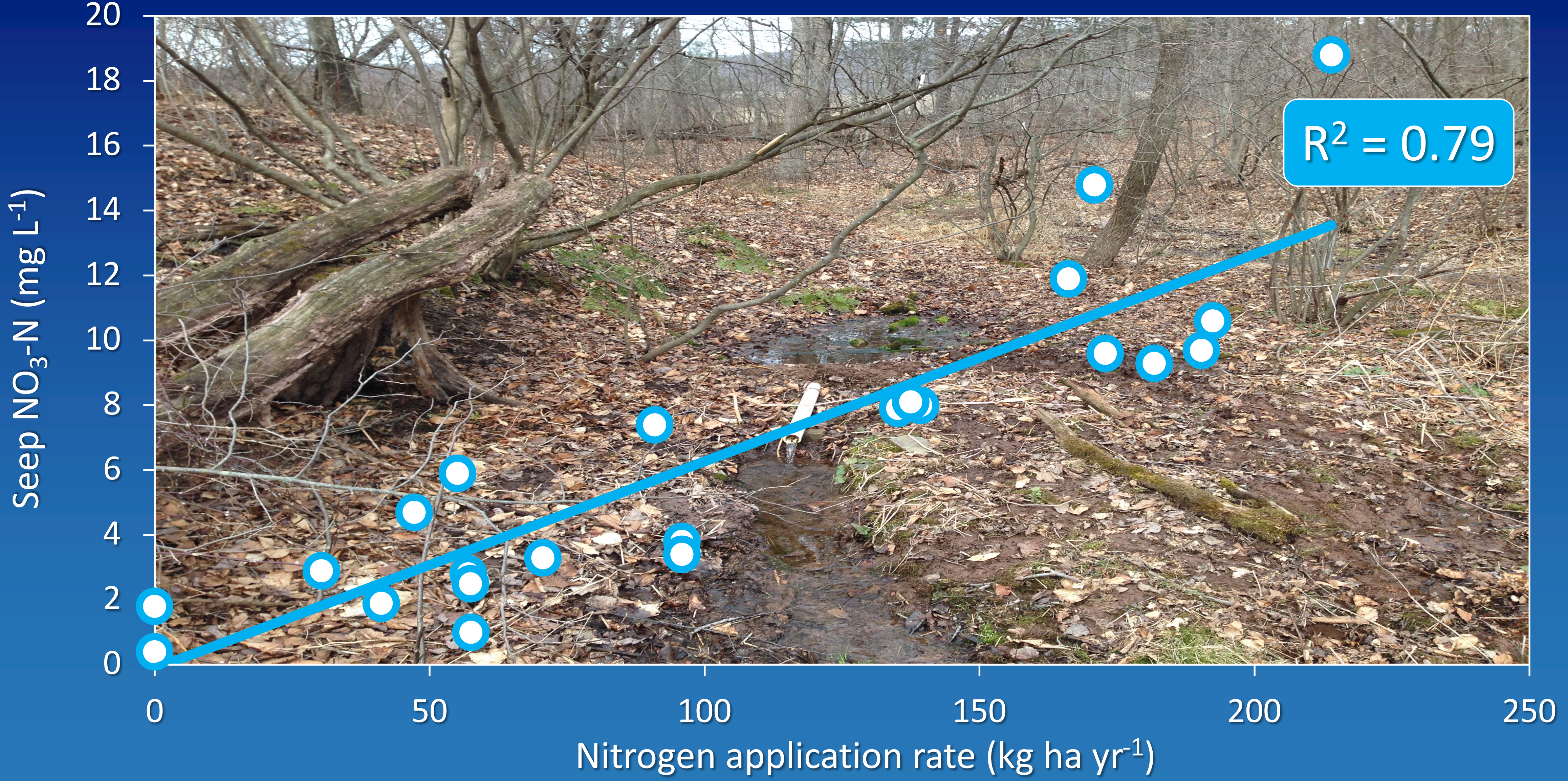
N applied in recharge areas
more weight

N applied in discharge areas
less weight

Williams et al., 2015 (J. Environ. Qual.)

N application versus seep NO_3-N concentrations

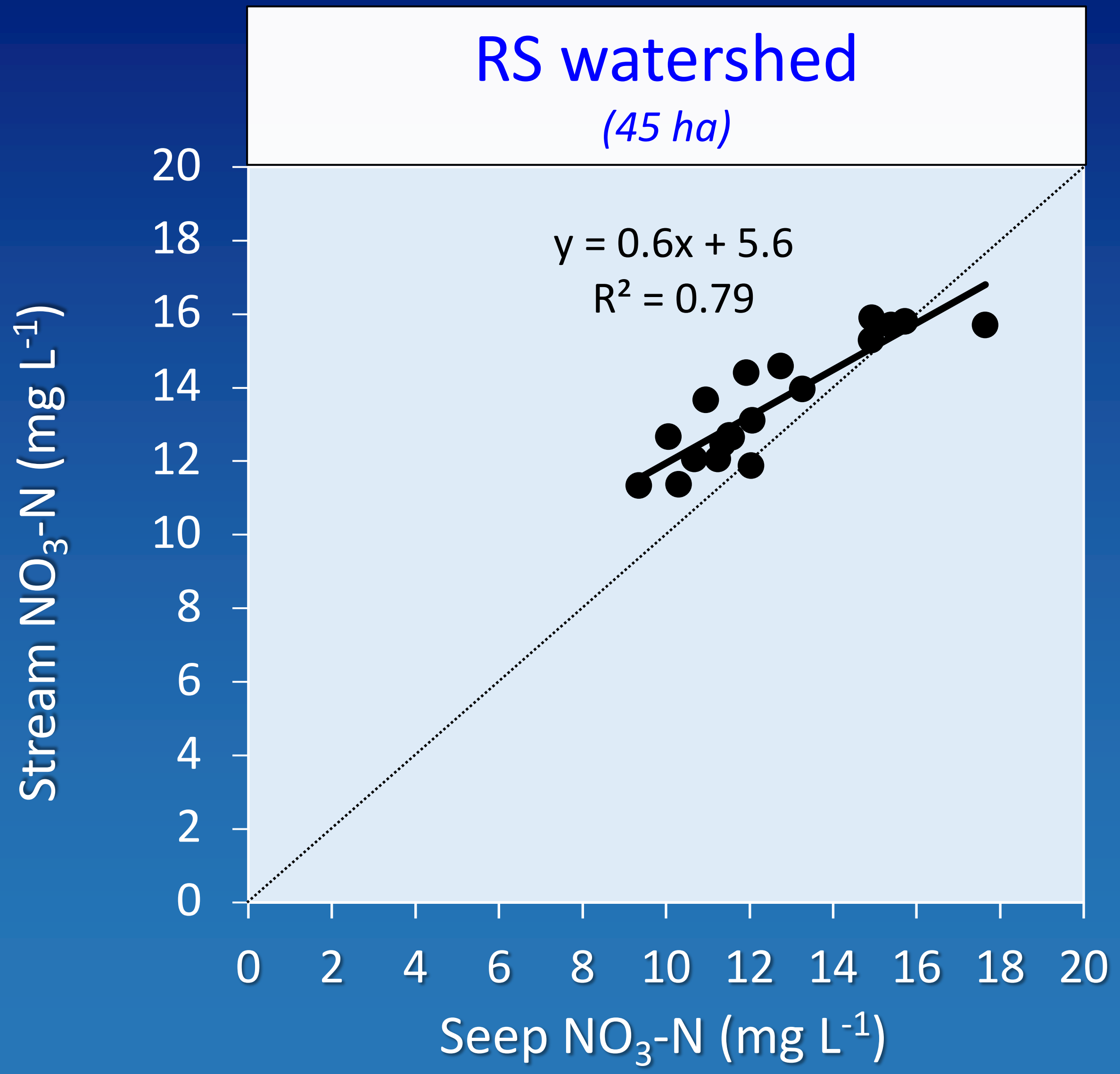
N leaching from upper landscape positions is a key driver of NO_3-N losses from seeps

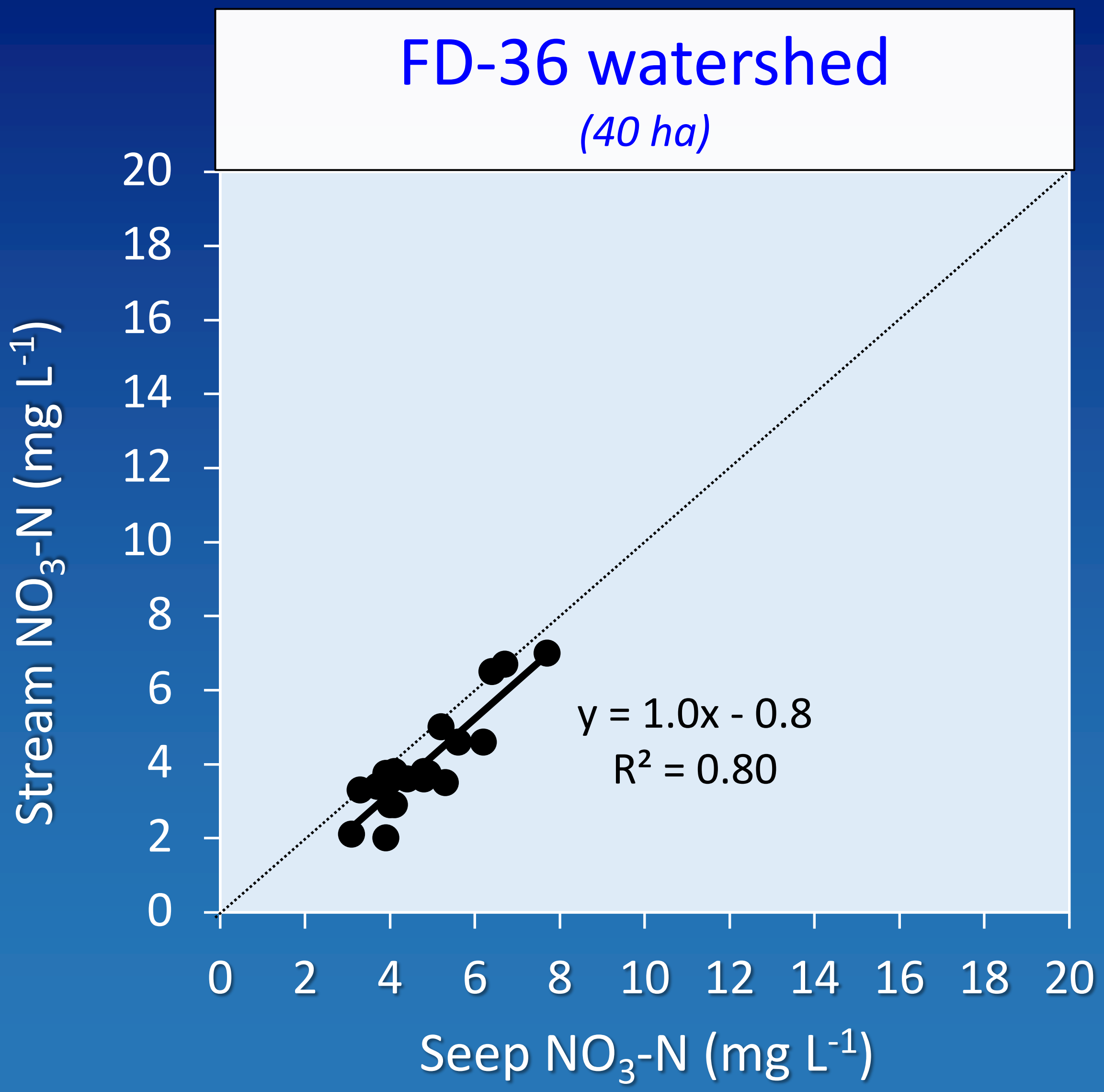


Williams et al., 2015 (J. Environ. Qual.)

Monthly mean seep NO_3-N vs. monthly mean stream NO_3-N

NO_3-N losses from seeps strongly influenced NO_3-N in headwater streams





Williams et al., 2015 (J. Environ. Qual.)

Chemical-hydrologic interactions in the near-stream zone

In 1988, Harry Pionke hypothesized similar controls on seep and stream chemistry

WATER RESOURCES RESEARCH, VOL. 24, NO. 7, PAGES 1101–1110, JULY 1988

Chemical-Hydrologic Interactions in the Near-Stream Zone

H. B. Pionke, J. R. Hoover, R. R. Schnabel, W. J. Gburek, J. B. Urban, and A. S. Rogowski

U.S. Department of Agriculture, Agricultural Research Service, Northeast Watershed Research Center, University Park, Pennsylvania

The chemical and hydrologic responses of a 9.9-ha Pennsylvania hill-land watershed to a typical summer storm event were determined and compared. Patterns and the relative magnitudes of NO_3, NH_4, total phosphorus (P), and orthophosphate (PO_4) concentrations observed in seepage, surface runoff, storm flow, base flow, and rainfall fit those hypothesized from the storm hydrograph and associated water table responses observed in the near-stream zone. Nitrate concentrations in seepage and base flow were similar and, typically, exceeded those in surface runoff, rainfall, and peak storm flow by 5–20 times. Conversely, NH_4, total P, and PO_4 concentrations in surface runoff from the seep zone and in peak storm flows exceeded those in seepage and base flow by 2–20 times. The findings, presented in a hydrologically based framework for this watershed, provide a conceptual model of how the near-storm zone operates during and following storm events.

INTRODUCTION

Watersheds with seep zones constitute much of the landscape in many areas of the United States. Seep zones not only discharge subsurface waters to the land surface, which then drain to streams, but can also be major surface runoff producers during rainstorm events. These zones can be dynamic and responsive during single storms, both expanding and then shrinking quite rapidly. The expanding seep zone causes increased seepage, part of which may originate from previously unsaturated or chemically different zones. Also, the ratio of surface runoff to seepage can change substantially and quickly throughout the storm, causing concomitant changes in streamflow chemistry. The chemistry of subsurface discharge is usually much different from that of surface runoff, which may approach the chemistry of precipitation. The chemical-hydrologic interactions of the surface runoff and subsurface-discharge zones need to be better understood if the chemical dynamics of streamflow are to be established.

Seep zone formation in the near-stream zone is usually most important in watersheds where substantial percolation occurs annually or seasonally, and the downslope transmission capacity of the subsurface flow system is restricted due to geologic, geometric, or hydrologic properties. These properties establish a large-scale control on the extent and locations of seep zones. Within this large-scale control, individual or short series of storms generate or expand seep zones temporarily and locally. The geologic, geometric, and hydrologic properties include low or decreased downslope water table gradients (e.g., decreasing land slope without increased storage), decreased cross section (e.g., slope break or reduced aquifer thickness), and decreased permeability (e.g., downgradient shifts from coarser- to finer-textured soils or geologic deposits). A 7.4-km^2 research subwatershed of the Mahantango Creek Watershed located in east central Pennsylvania has these properties and exhibits seep zones [*Pionke and Urban*, 1985].

The seep zone portion of the surface runoff generating area has long been recognized as important on this watershed [*Engman and Rogowski*, 1974; *Gburek*, 1978], but the relationship between the surface runoff generating area, surface runoff from the seep zone, and subsurface discharge, particularly as it affects the chemistry of streamflow, has not been examined. The objectives of this paper are to (1) describe specific chemical-hydrologic interactions observed in seep zone and stream, (2) examine these interactions in the context of observed subsurface hydrologic responses in the near-stream zone, and (3) generalize these observations into a conceptual model of how this near-stream zone operates.

DEFINITION OF COMMONLY USED HYDROLOGIC TERMS

Surface runoff: Precipitation excess or rainfall that does not infiltrate at any point but runs over the land surface to the stream.

Surface storm flow: Surface runoff plus channel precipitation (precipitation falling directly on the stream surface).

Seepage: Subsurface water (soilwater, groundwater, perched water) discharged to the land surface irrespective of residence time or travel distance in the subsurface.

Subsurface discharge: Seepage plus discharge of groundwater and perched water directly to the stream channel.

Groundwater: Subsurface water occupying the saturation zone.

Water table: The surface of unconfined groundwater at which the water pressure relative to atmospheric pressure equals zero. The point where it intersects the land surface defines the upper boundary of the seepage face.

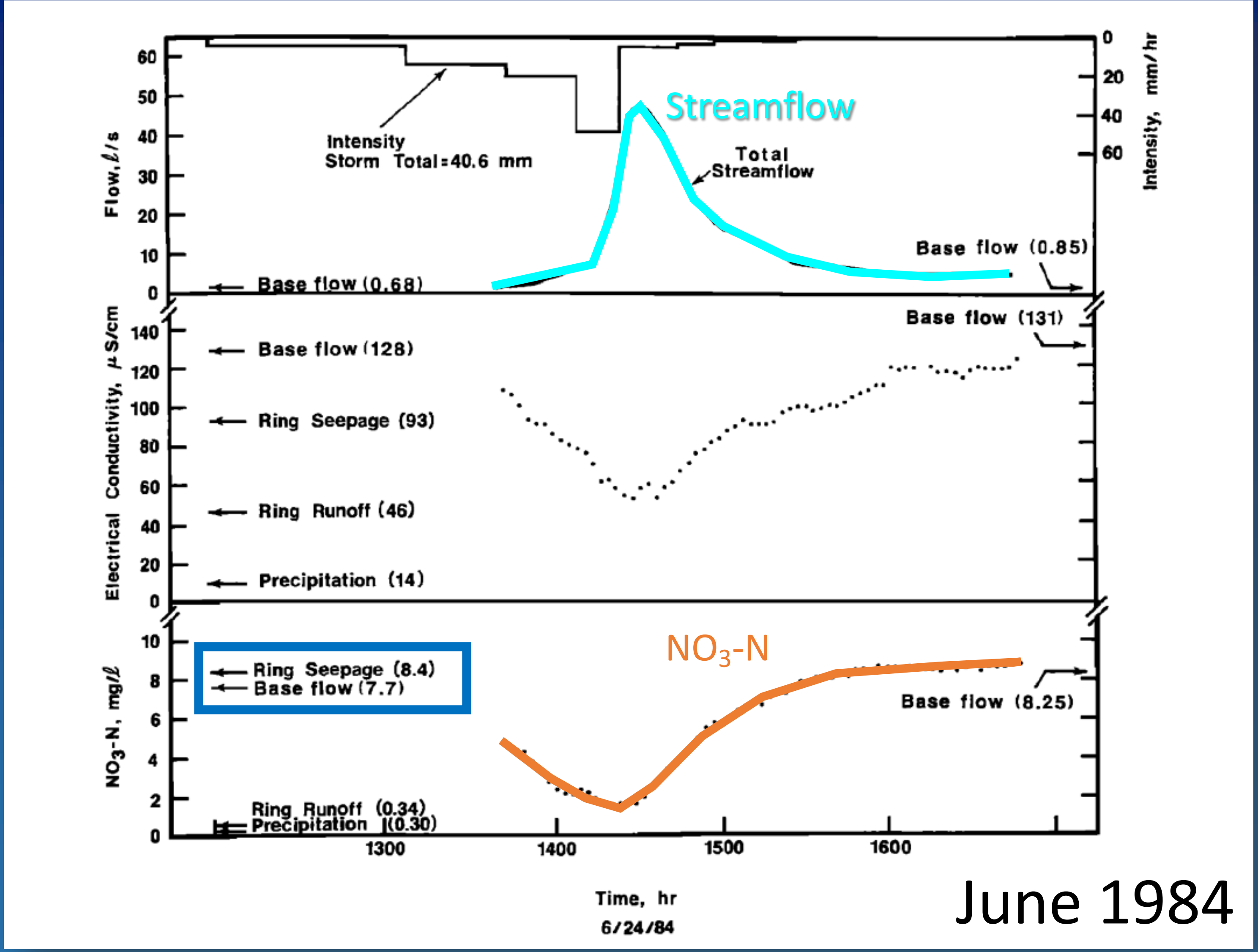
Base flow: Streamflow (subsurface discharge) between storm events.

Storm flow: Surface storm flow plus subsurface discharge during the storm period.

BACKGROUND

Surface storm flow in the Mahantango Creek Watershed has been extensively studied in context of the variable source area concept. This concept, which proposes that most surface runoff occurs from small areas within the watershed where precipitation excess is generated [*Betson and Marius*, 1969; *Ragan*, 1968], applies here [*Engman and Rogowski*, 1974; *Gburek*, 1978, 1983]. These hydrologic source areas are generally located near the stream [*Gburek*, 1978; *Engman and Rogowski*, 1974; *Gburek and Pionke*, 1983] or have direct surface water connection to the stream [*Engman and Rogowski*, 1974]. In addition to the seep zone which acts as a impervious surface to rainfall input, the variable source area includes bordering areas prone to seep zone development or characterized by low infiltration rates and/or storage capacities. The bordering

Paper number 7W4911.

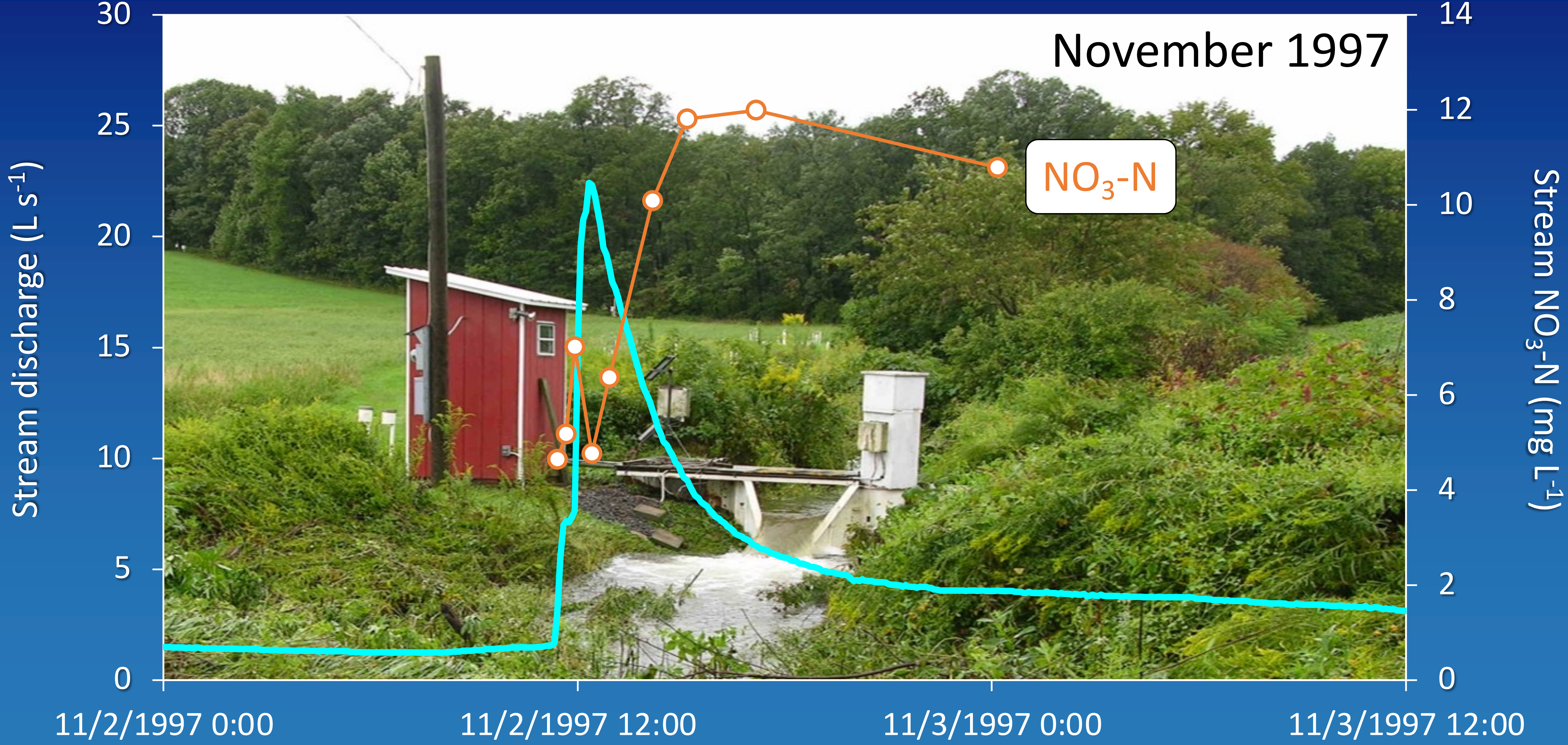


June 1984

Pionke et al., 1988 (Water Resour. Res.)

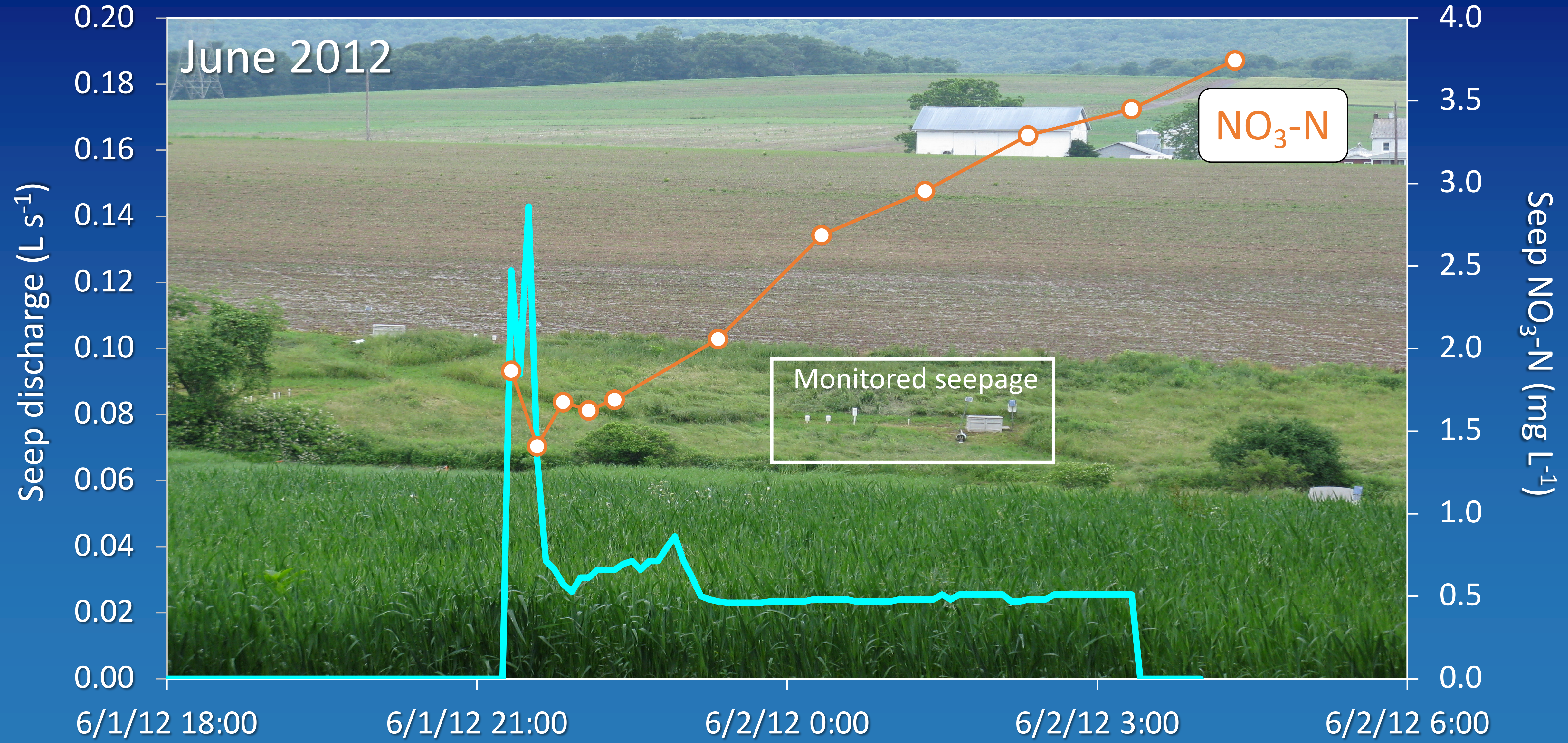
Chemical-hydrologic interactions in the near-stream zone

Sampling in FD-36 shows a similar relation between discharge and NO_3-N



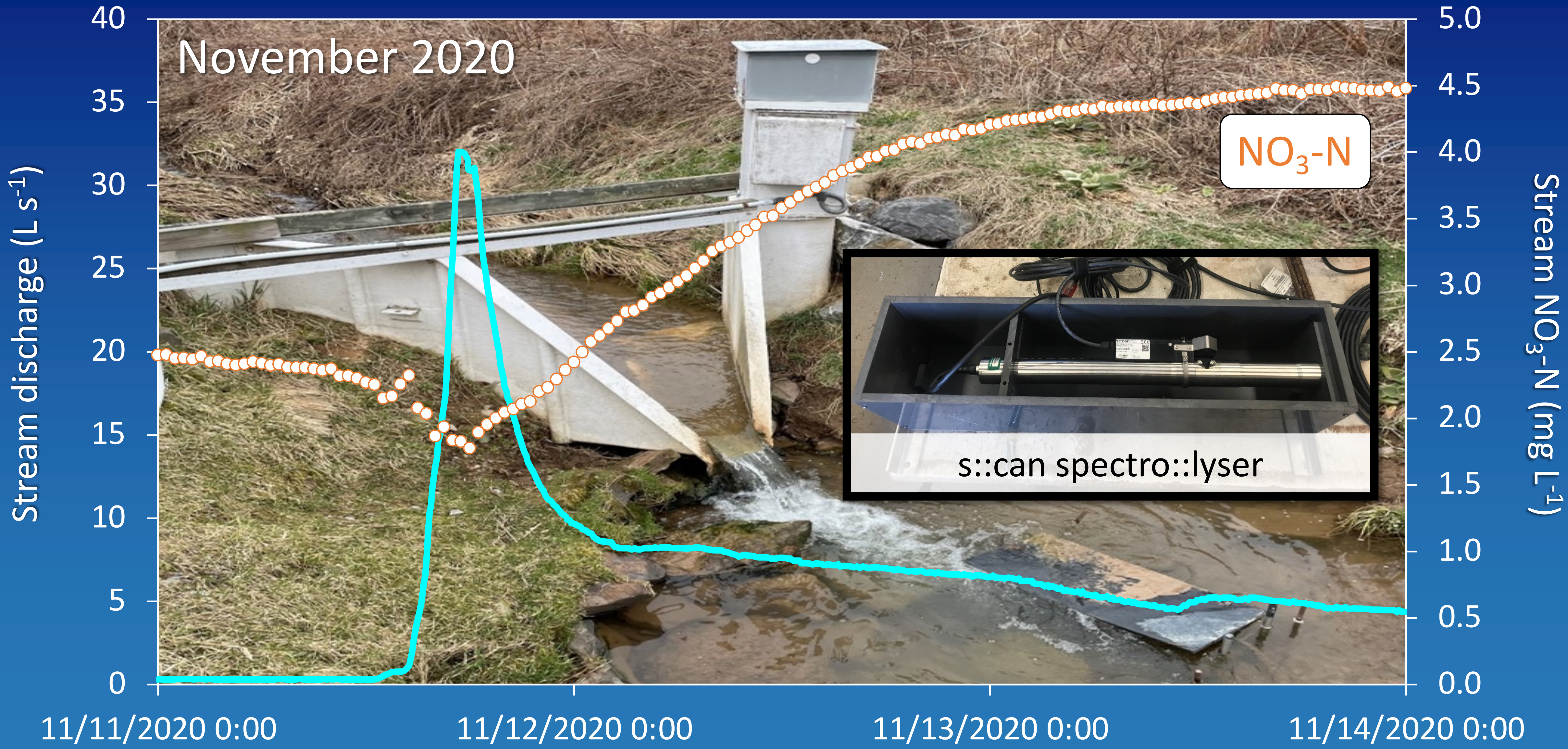
Chemical-hydrologic interactions in the near-stream zone

Sampling of groundwater seepage also revealed the same NO_3-N behavior

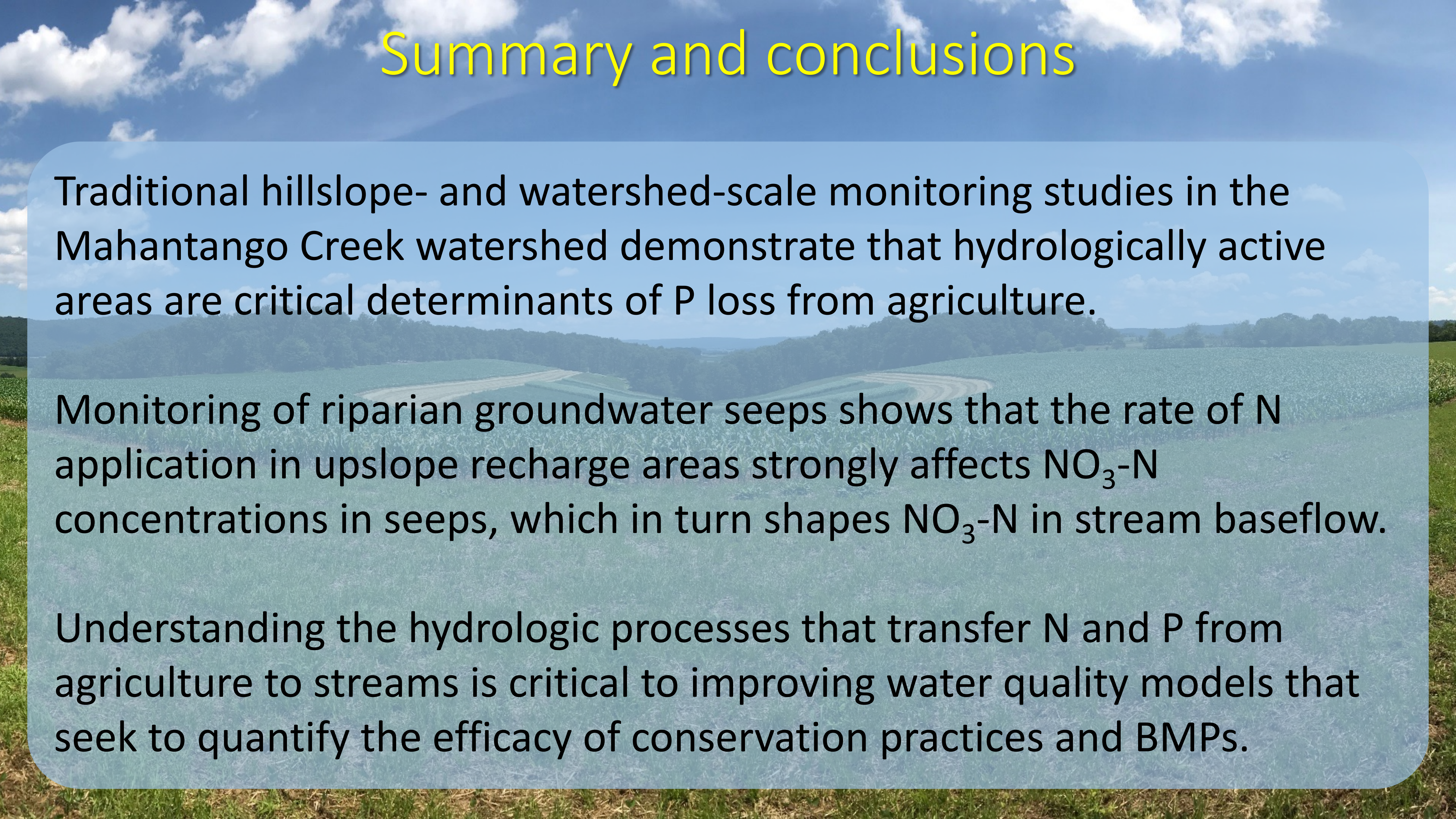


Chemical-hydrologic interactions in the near-stream zone

Recent data from s::can sensors show that these NO_3-N patterns are recurrent



Summary and conclusions



Traditional hillslope- and watershed-scale monitoring studies in the Mahantango Creek watershed demonstrate that hydrologically active areas are critical determinants of P loss from agriculture.

Monitoring of riparian groundwater seeps shows that the rate of N application in upslope recharge areas strongly affects NO_3-N concentrations in seeps, which in turn shapes NO_3-N in stream baseflow.

Understanding the hydrologic processes that transfer N and P from agriculture to streams is critical to improving water quality models that seek to quantify the efficacy of conservation practices and BMPs.