

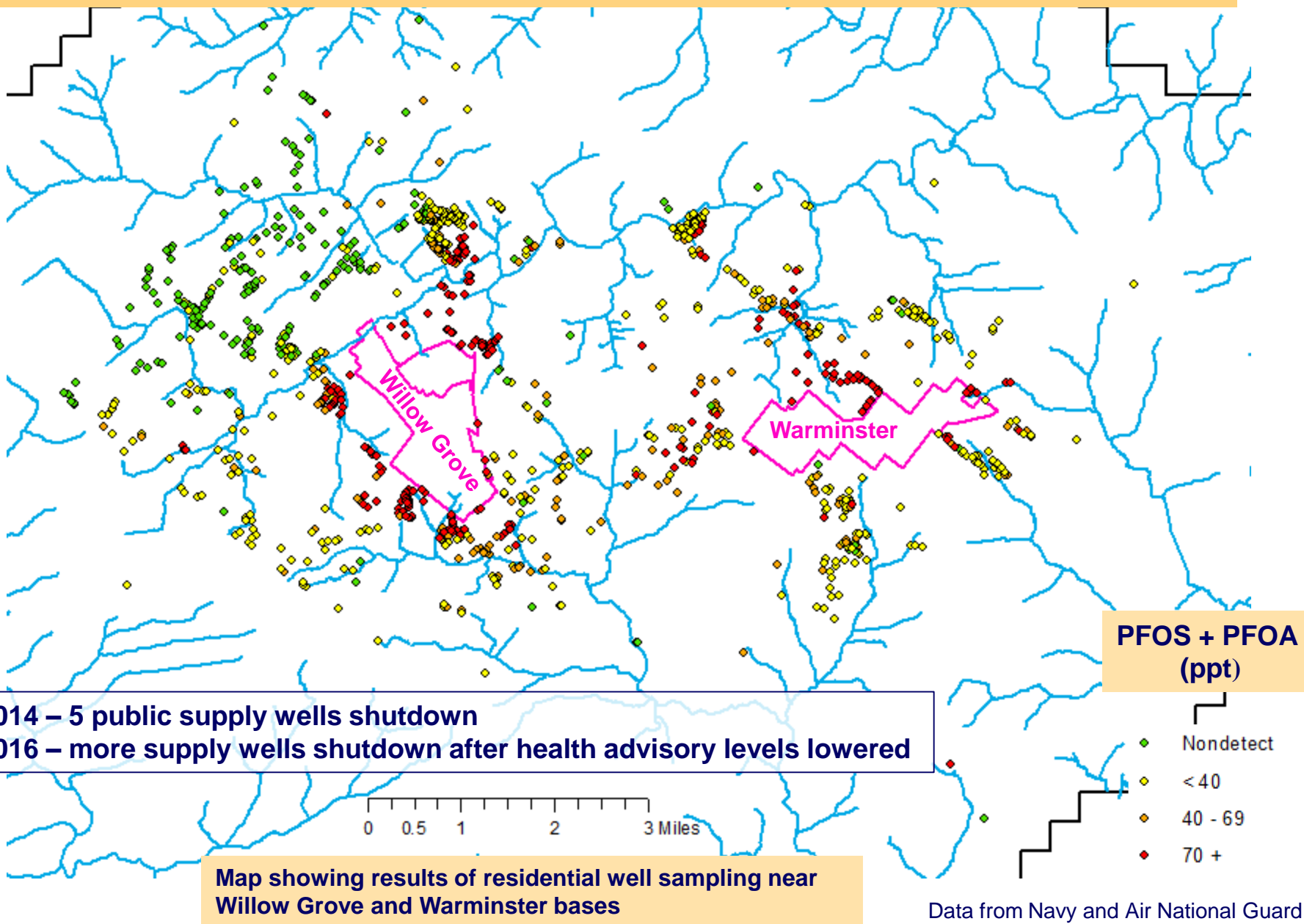
# Groundwater Withdrawals & Regional Groundwater-Flow Paths near Willow Grove & Warminster, Bucks & Montgomery Counties, Pennsylvania

02/20/2020

Dan Goode and Lisa Senior  
U.S. Geological Survey  
Pennsylvania Water Science Center

*in cooperation with U.S. Navy*

## PFAS detected in wells near Willow Grove and Warminster bases in 2014



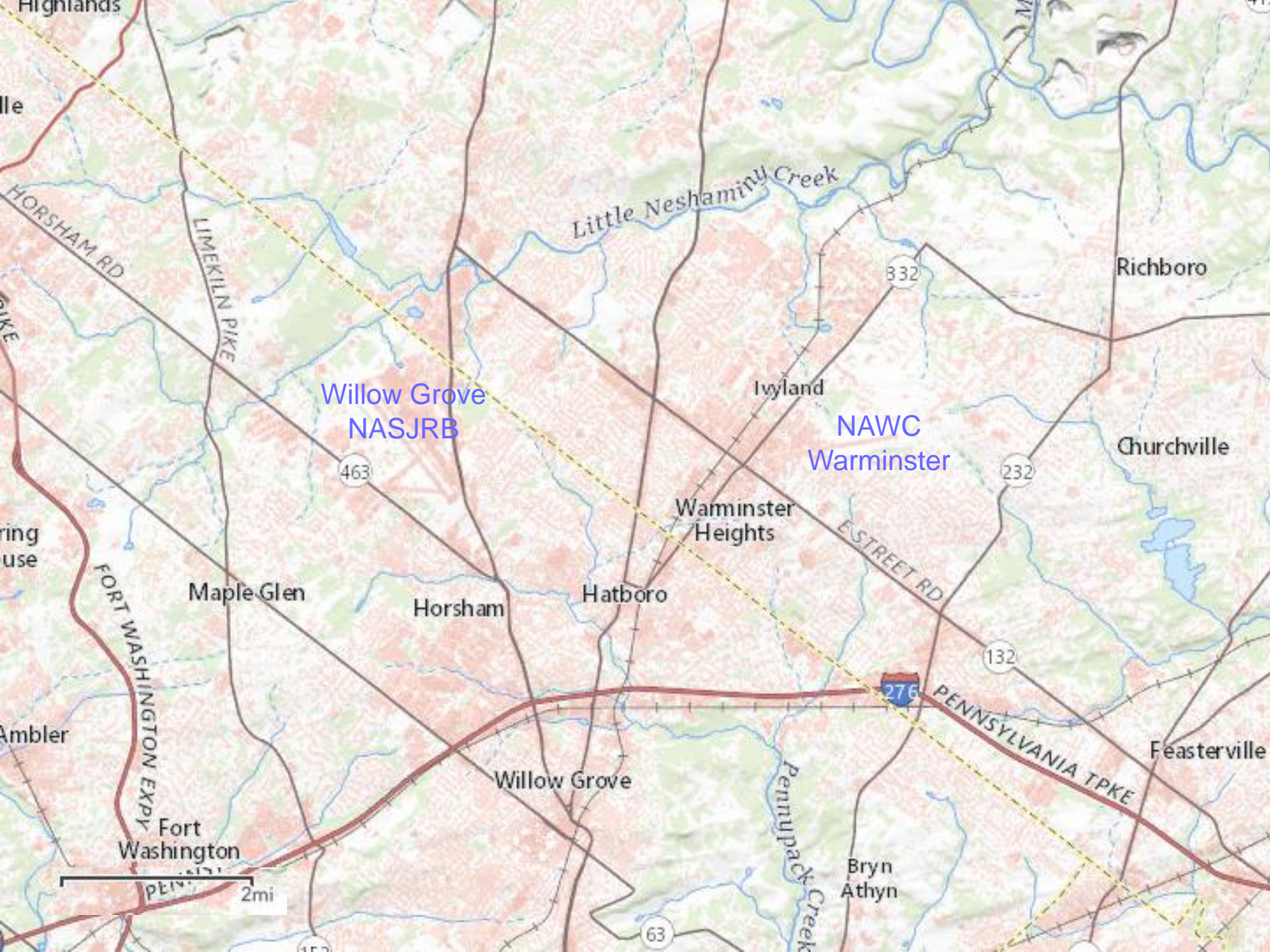
# Purpose of Current Modeling

- “To describe and improve understanding of groundwater flow rates and directions under various pumping scenarios by developing a preliminary numerical groundwater-flow model . . .”
- “The **preliminary regional-scale model** may help identify data gaps and selection of additional monitoring locations, and will form the basis for a more refined model that incorporates additional detail and data as available to further improve understanding of groundwater flow and contaminant transport in the area.”

# Regional Groundwater Flow near Willow Grove and Warminster

- Hydrogeologic setting
- Groundwater use changes
- Model description
- Model results, including:
  - Simulated flow paths from PFAS sources
  - Groundwater-surface water relations
  - Limitations







# Water-Use Analysis Program for the Neshaminy Creek Basin, Bucks and Montgomery Counties, Pennsylvania

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4127

Prepared in cooperation with the  
DELAWARE RIVER BASIN COMMISSION



## Neshaminy Study Report Prepared By U.S. Geological Survey Pennsylvania District

*Annual stream baseflow rates  
based on rock type*



**Delaware River Basin Commission**

DELAWARE • NEW JERSEY  
PENNSYLVANIA • NEW YORK  
UNITED STATES OF AMERICA

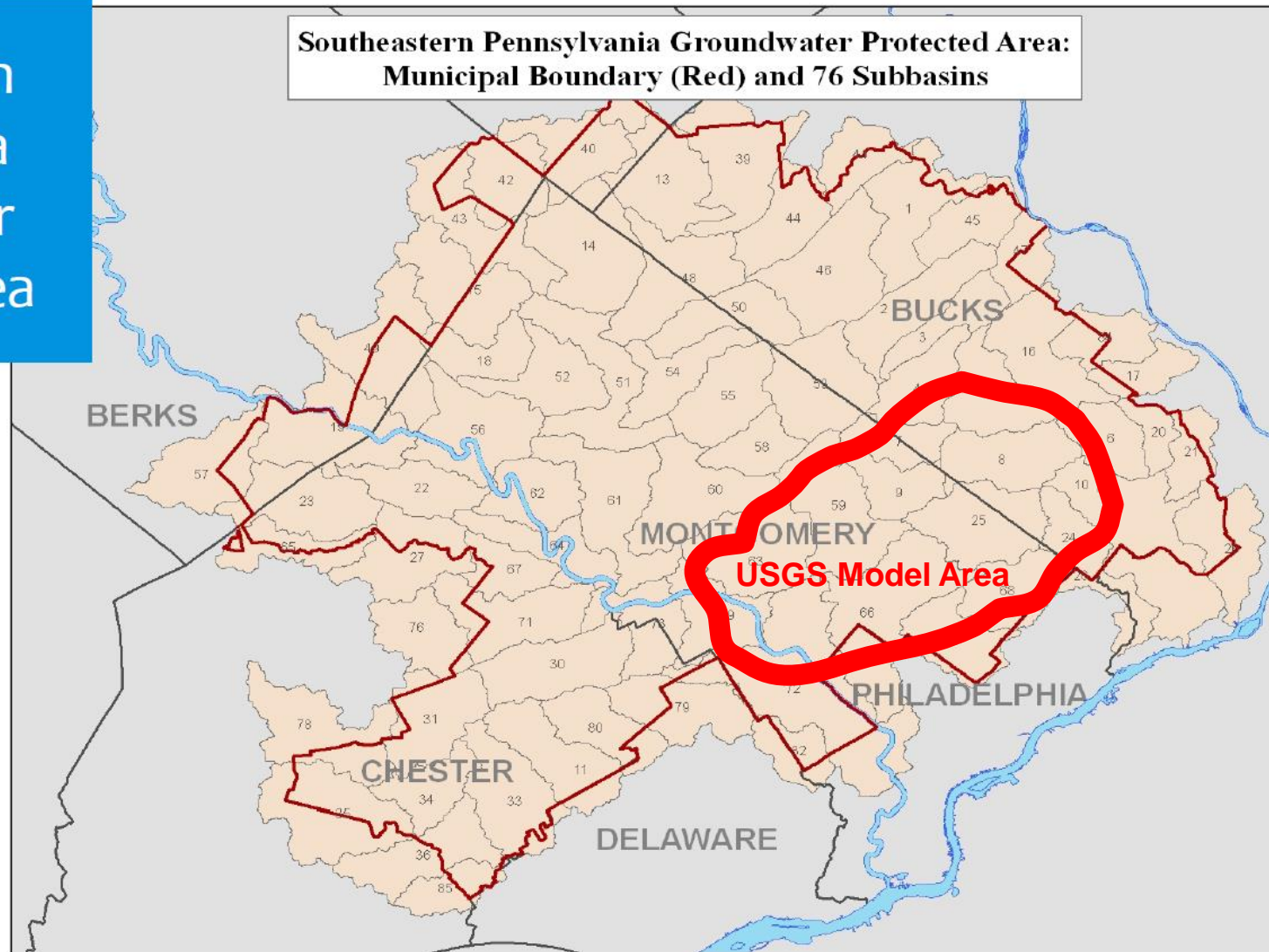
Chad Pindar, DRBC, 2019

[https://www.nj.gov/drbc/library/documents/pindar\\_SEPAGWPA\\_lafayette100219.pdf](https://www.nj.gov/drbc/library/documents/pindar_SEPAGWPA_lafayette100219.pdf)

# Southeastern Pennsylvania Groundwater Protected Area

76 subbasins associated by municipality and consisting of all of Montgomery and also parts of Berks, Bucks, Chester, and Lehigh Counties.

76 assessment units.



Chad Pindar, DRBC, 2019  
[https://www.nj.gov/drbc/library/documents/pindar\\_SEPAGWPA\\_lafayette100219.pdf](https://www.nj.gov/drbc/library/documents/pindar_SEPAGWPA_lafayette100219.pdf)



# DRBC Case Study: Southeastern PA Groundwater Protected Area

## Lafayette College

October 2, 2019

Chad Pindar, P.E.

Manager of Water Resource Planning

### Acknowledgements:

Bob Damiani, P.G., Eric Engle, P.G.,  
Evan Kwityn, Kent Barr  
David Kovach, P.G.,



GWPA established in 1980 Due to...

- Increasing population and demand of groundwater resources in southeastern Pennsylvania
- More frequent interference and conflicts among users of the same groundwater resource
- Lowering water levels in streams
- Low recharge rates of the bedrock geology

- Subbasin withdrawal limits were approved for the 76-subbasins based on the 1-in-25 year average annual baseflow rate (MGY)
  - Resolution No. 98-1 – 14 Neshaminy Subbasins
  - Resolution No. 99-11 – 62 Remaining Subbasins

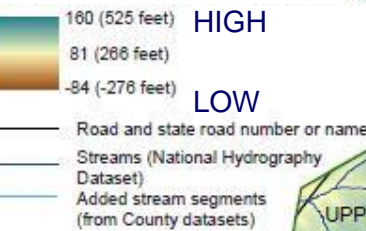


# REGIONAL MODEL AREA

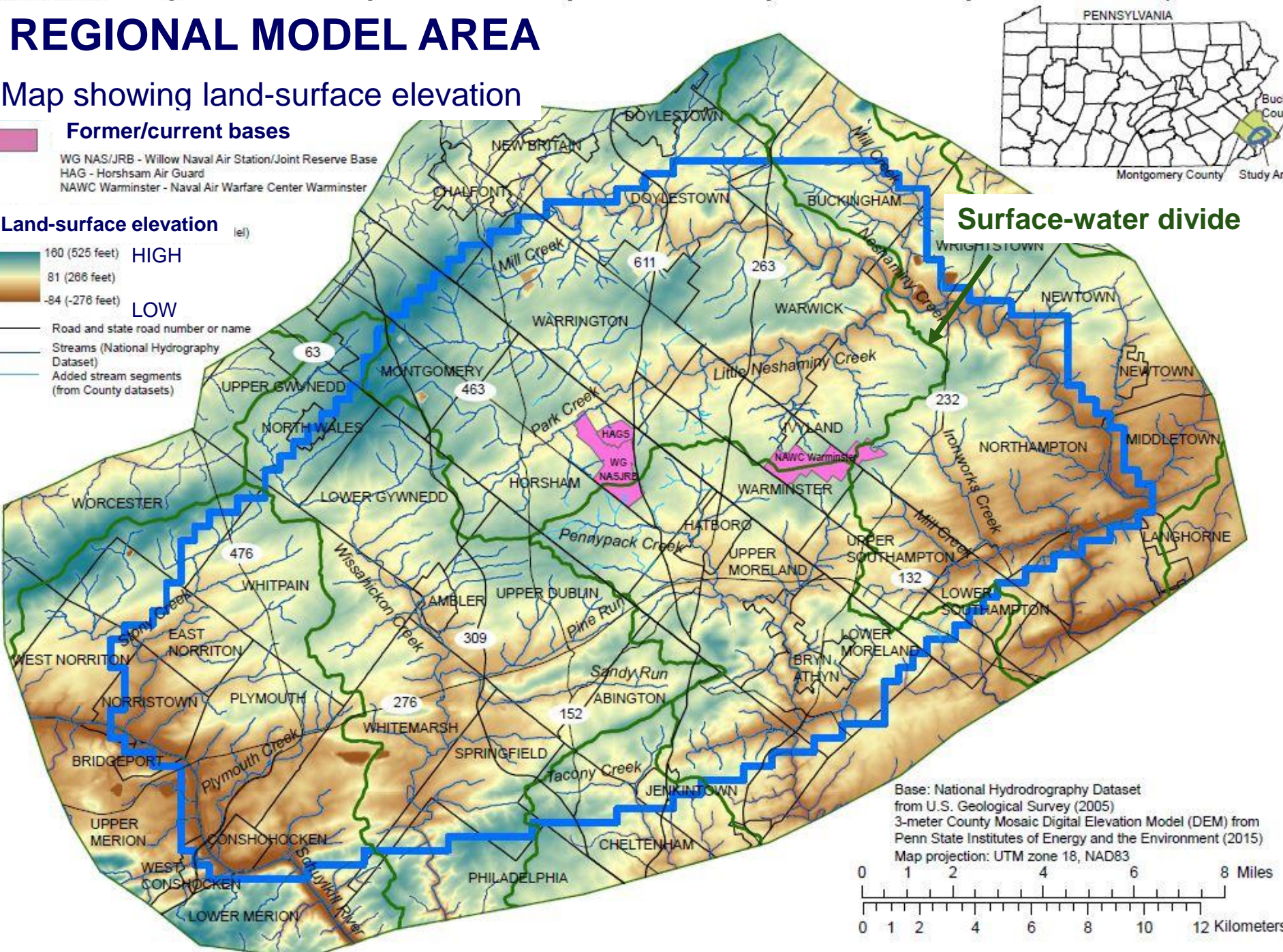
Map showing land-surface elevation

**Former/current bases**  
WG NAS/JRB - Willow Naval Air Station/Joint Reserve Base  
HAG - Horsham Air Guard  
NAWC Warminster - Naval Air Warfare Center Warminster

**Land-surface elevation**



**Surface-water divide**



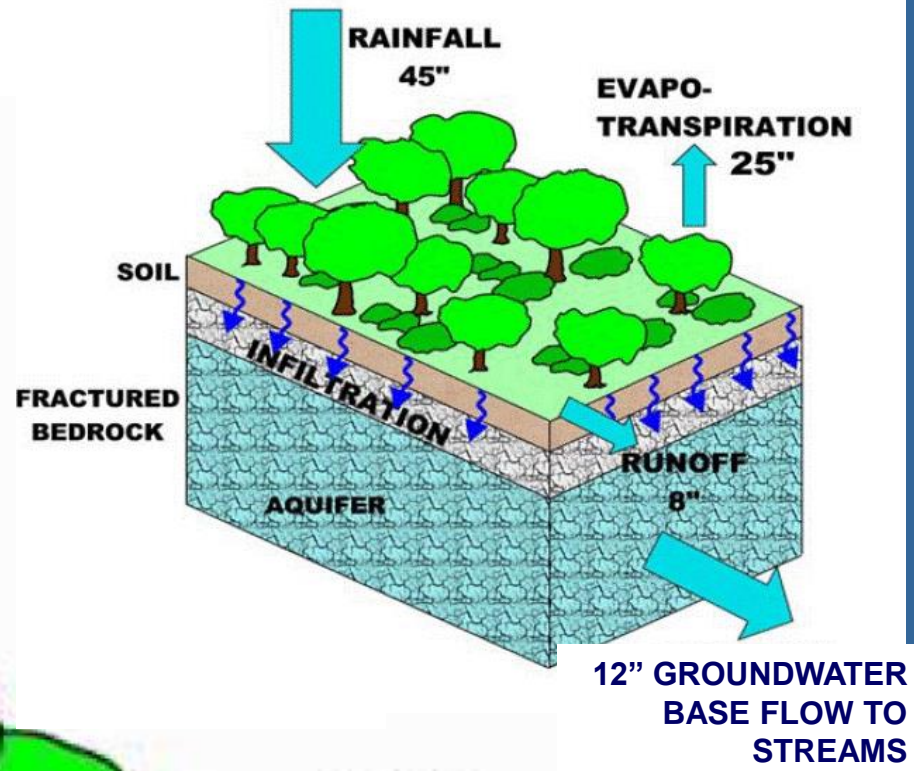
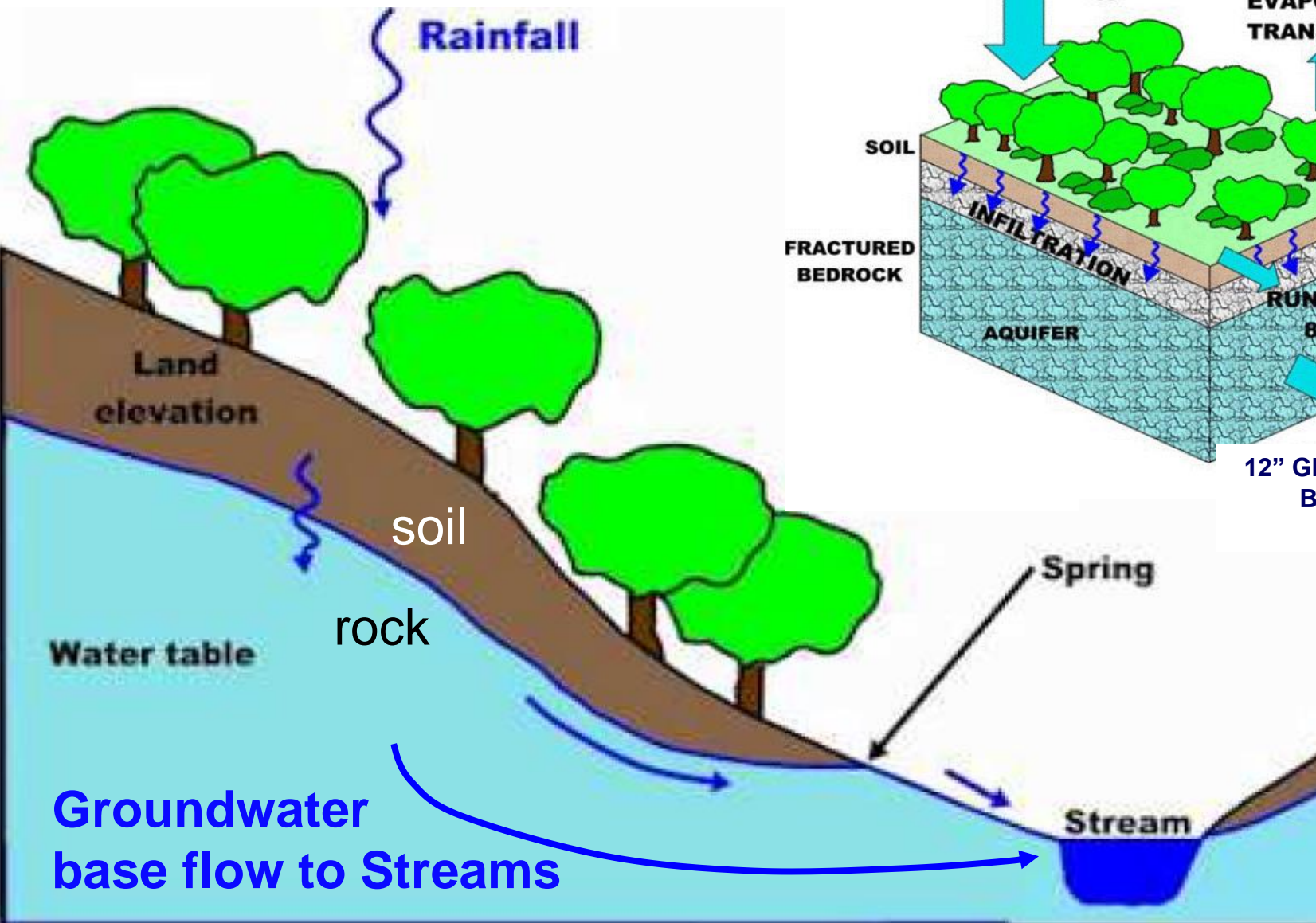
Base: National Hydrography Dataset  
from U.S. Geological Survey (2005)  
3-meter County Mosaic Digital Elevation Model (DEM) from  
Penn State Institutes of Energy and the Environment (2015)  
Map projection: UTM zone 18, NAD83

0 1 2 4 6 8 Miles  
0 1 2 4 6 8 10 12 Kilometers



Groundwater system in fractured bedrock and overlying weathered rock and soil, common in  
Piedmont of eastern United States

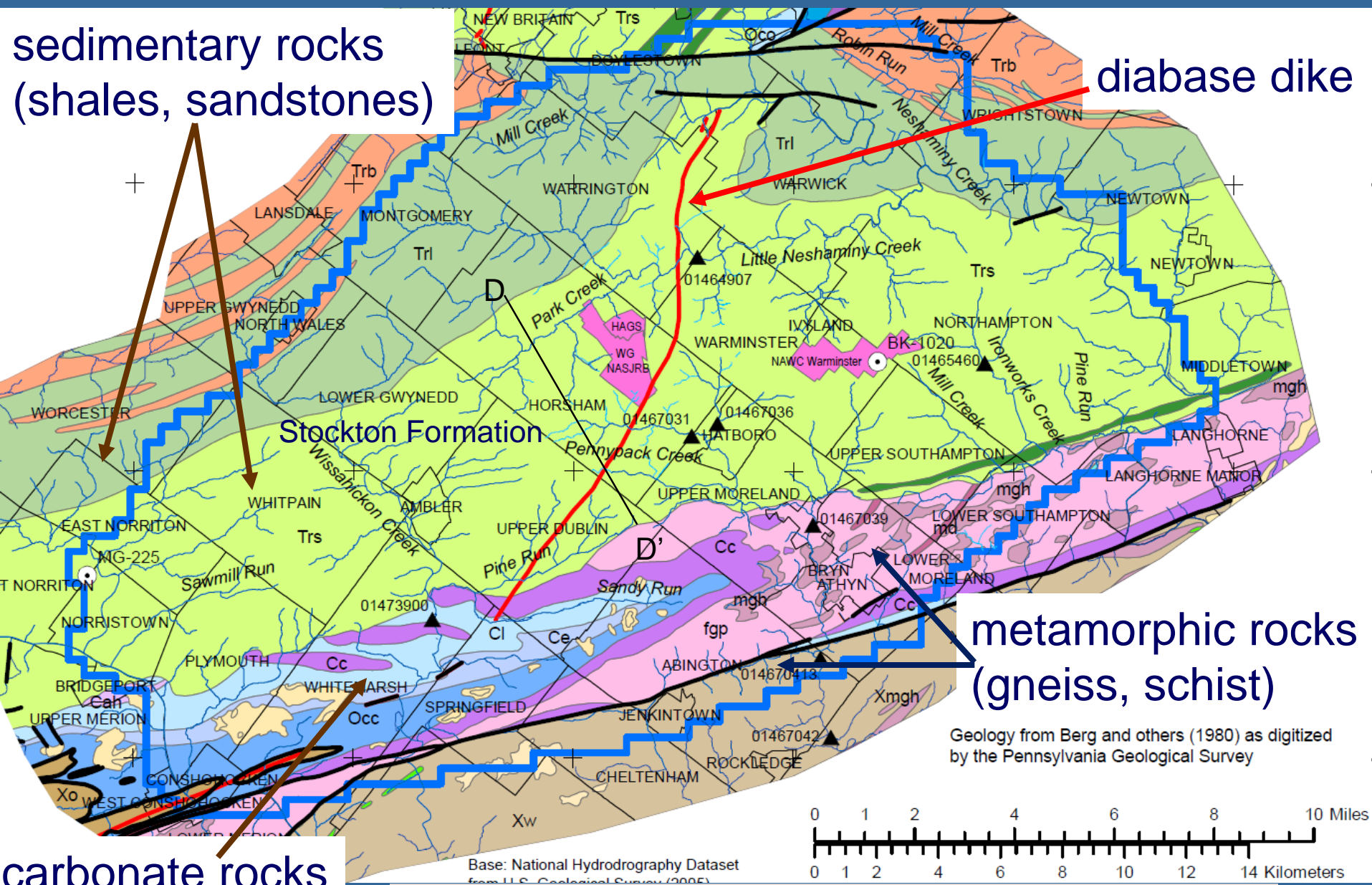
# Water budget for Piedmont Region, PA



Figures modified from Pennsylvania Department of Environmental Protection, 2006.

sedimentary rocks  
(shales, sandstones)

diabase dike



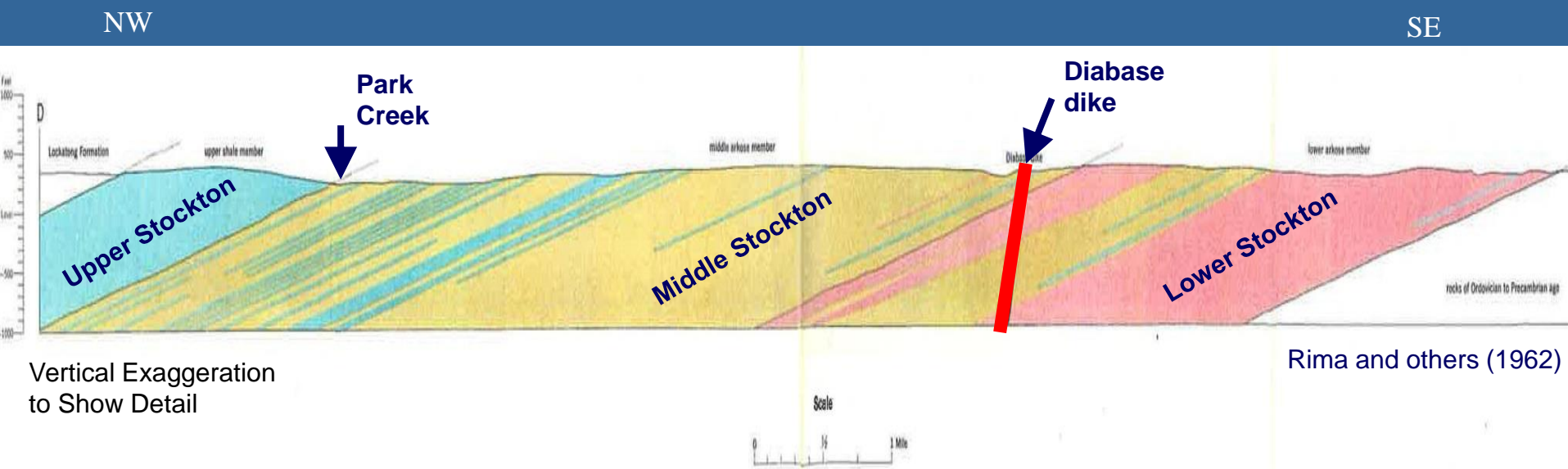
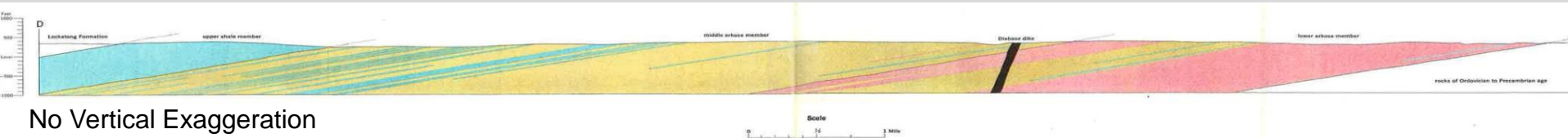
carbonate rocks  
(limestone)

metamorphic rocks  
(gneiss, schist)

## BEDROCK GEOLOGY IN MODEL AREA



# Geologic Cross Section near Willow Grove NASJRB showing dipping beds of the Stockton Formation (sandstone, siltstone, mudstone)



Geologic structure can affect groundwater flow -  
Beds of different lithologies and flow properties dip to the northwest;  
Diabase dike (magma sheet intruded into overlying strata)  
generally restricts flow across the dike.

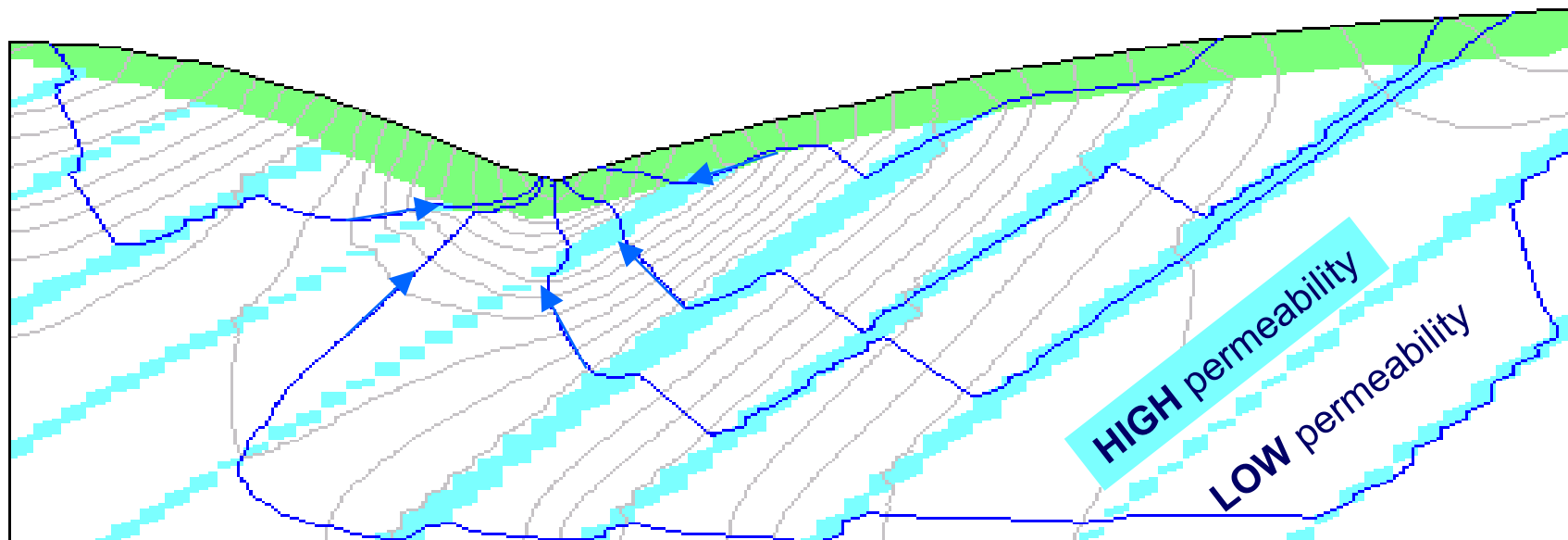


# 2018 Field Conference of Pennsylvania Geologists



Dipping beds of sandstone and shale

# Groundwater Flow in Dipping Sedimentary Rock Layers



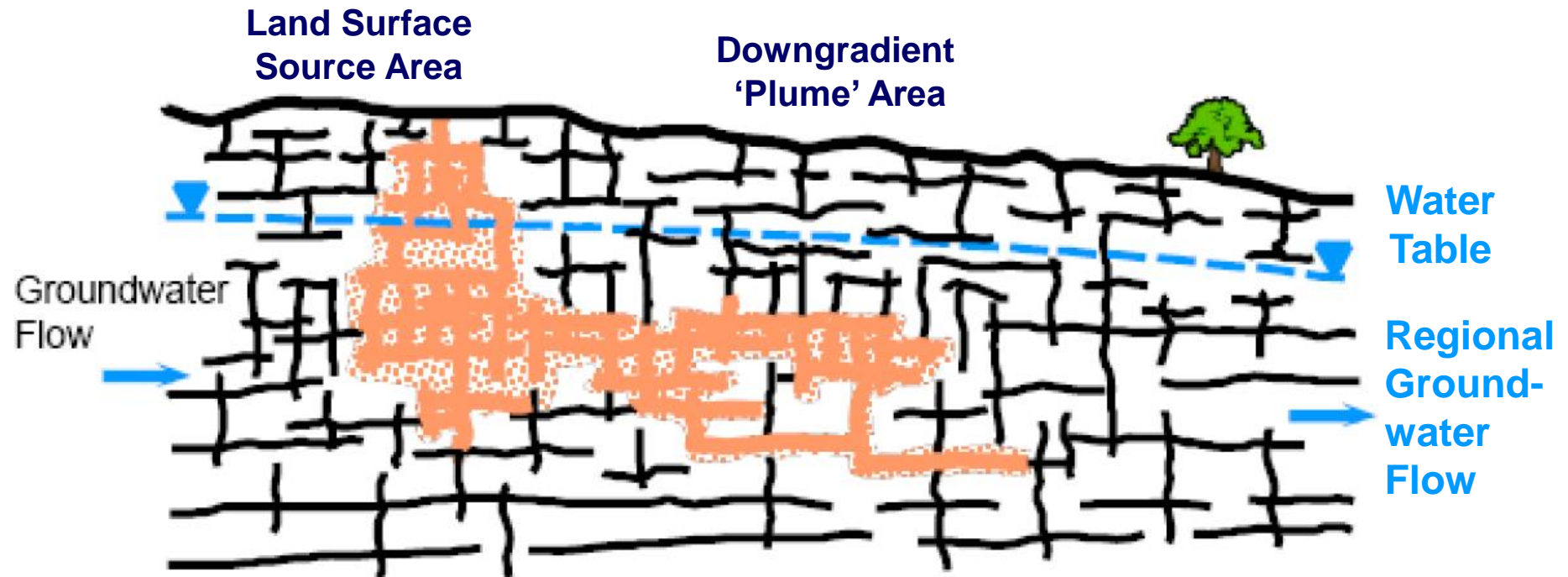
## **HIGH-** and **LOW-**permeability beds

Rapid focused flow in high-permeability beds  
Preferred regional flow in strike direction along  
bedding planes (into or out of the board)



## Non-Uniform Properties in Different Fractures Variable Connectivity Between Fractures

Flow and Contaminant Transport Mostly in Fractures,  
Limited in Unfractured Rock

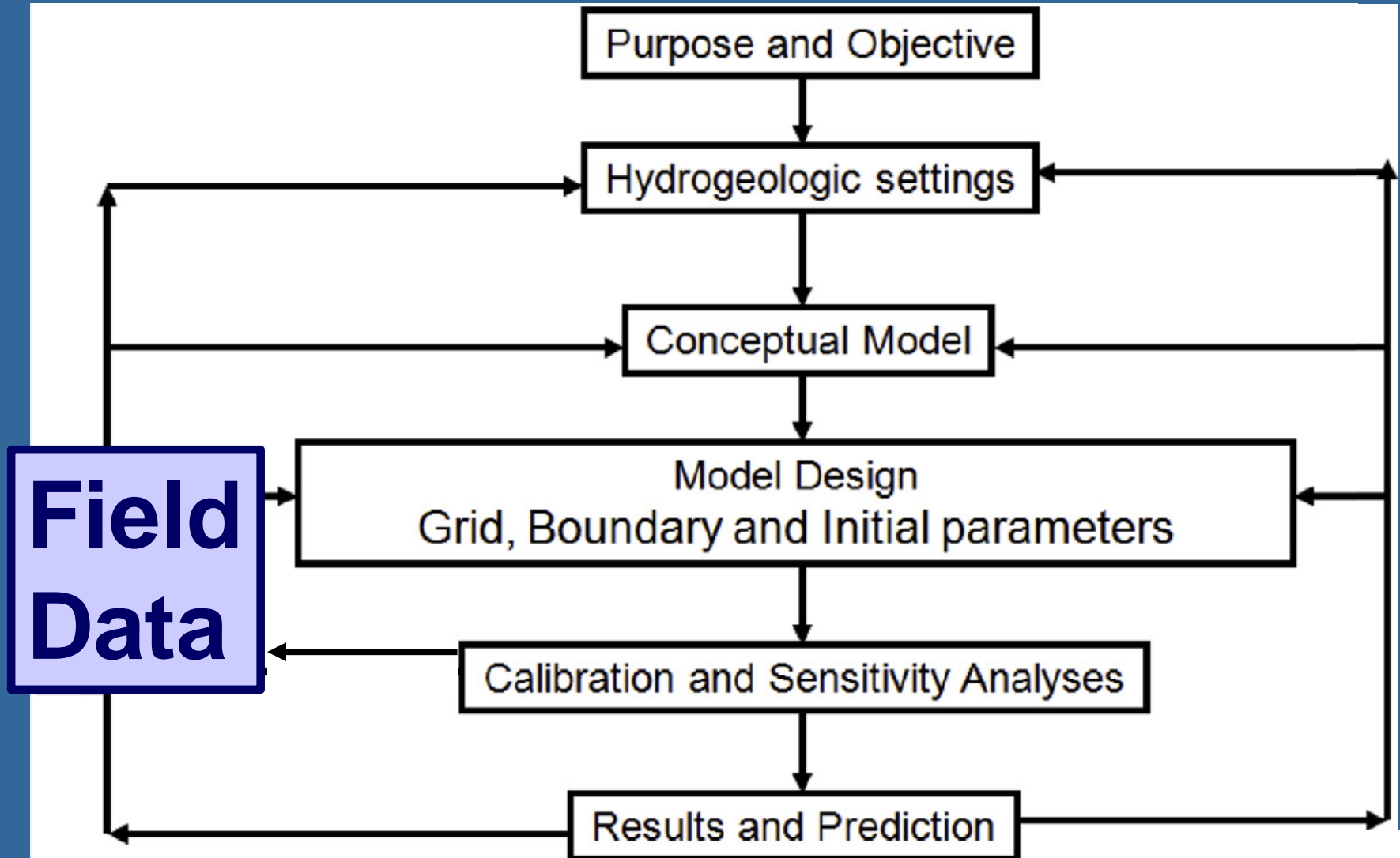


# Individual Fractures are Non-Uniform at Even Smaller Scales



**Focused groundwater discharge from isolated points along fractures in sandstone on road cut**

# MODEL DEVELOPMENT AND REFINEMENT





# Regional Groundwater Model near Willow Grove and Warminster

**Calibrate** model with 1999, 2010, 2013, 2016 data

**Simulate** directions of regional groundwater flow that can carry dissolved PFOS, PFOA, and other PFAS

Pumping scenarios near bases:

1999 – WG base active, regional pumping rates large

2010 – WG base active, pumping rates reduced

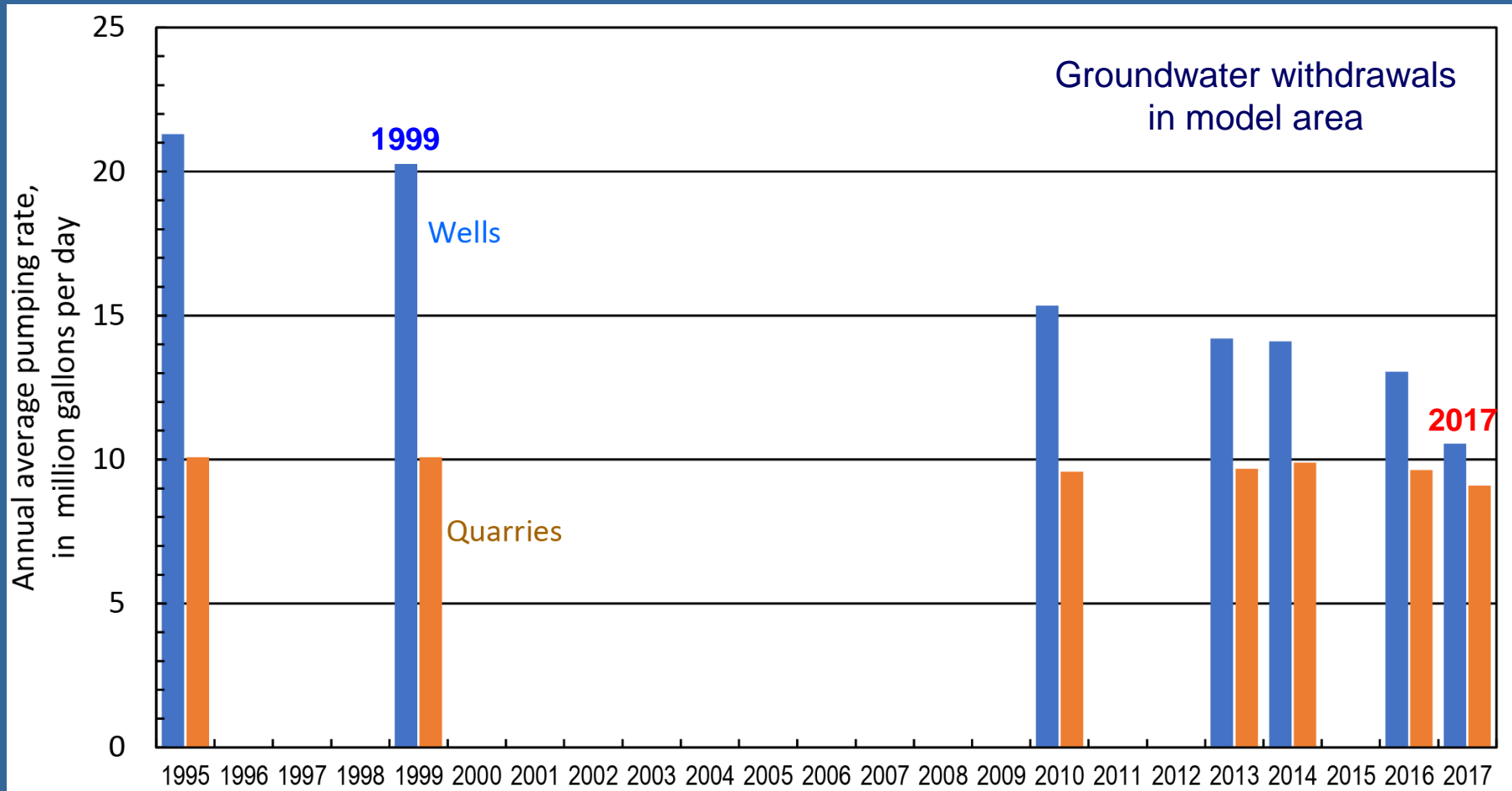
2013 – WG base closed, pumping reduced

2016 – WG base closed, >5 supply wells shutdown

2017 – WG base closed, ~13 supply wells shutdown

# Groundwater Pumping near Bases

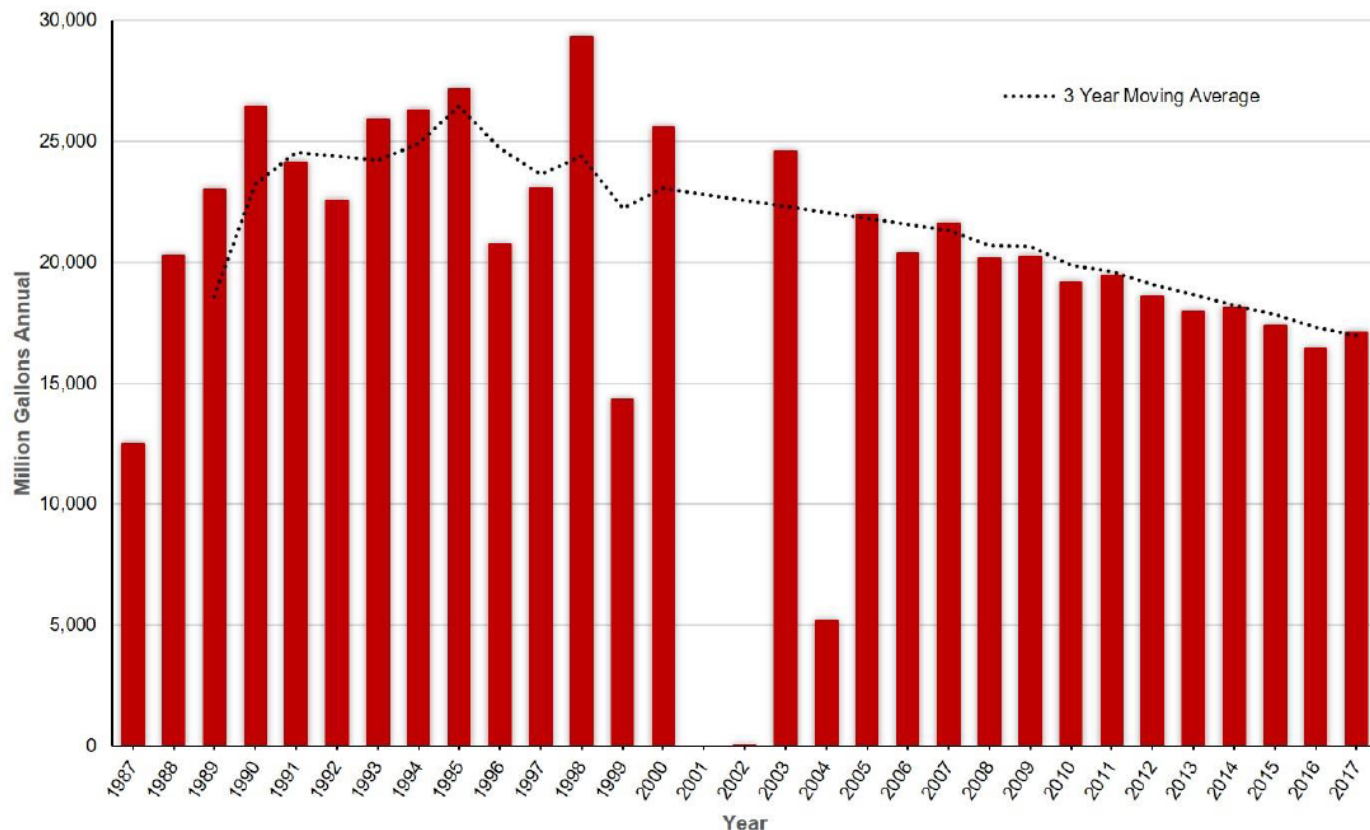
## Decreased Substantially from 1990s to 2017



# Southeastern Pennsylvania Groundwater Protected Area

- \* Cumulative groundwater withdrawals from 1987-2017

- \* Reductions since 2000

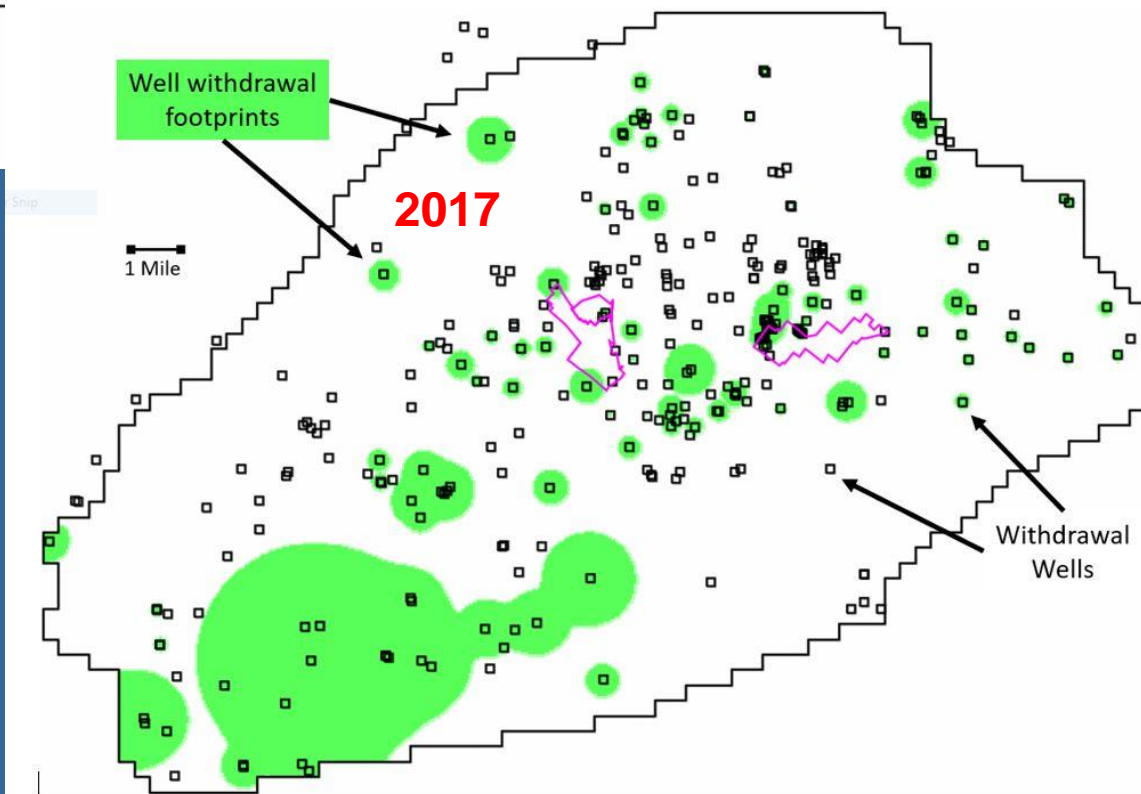
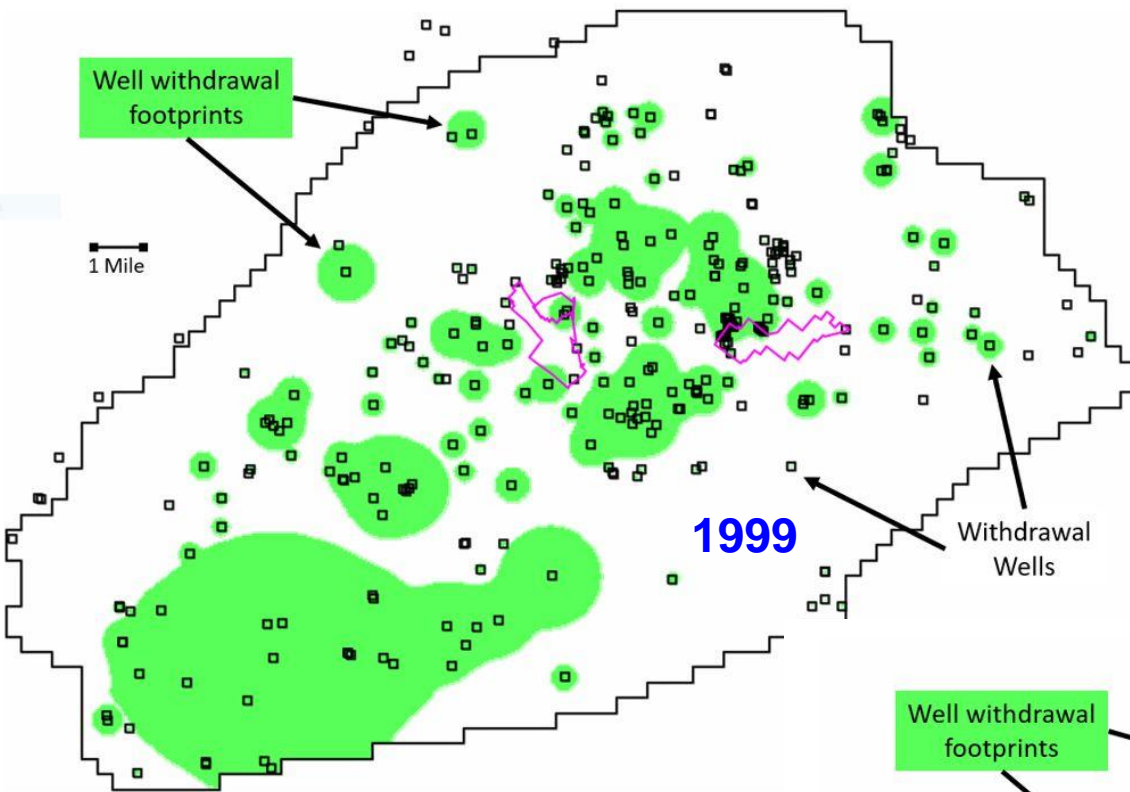


Chad Pindar, DRBC, 2019

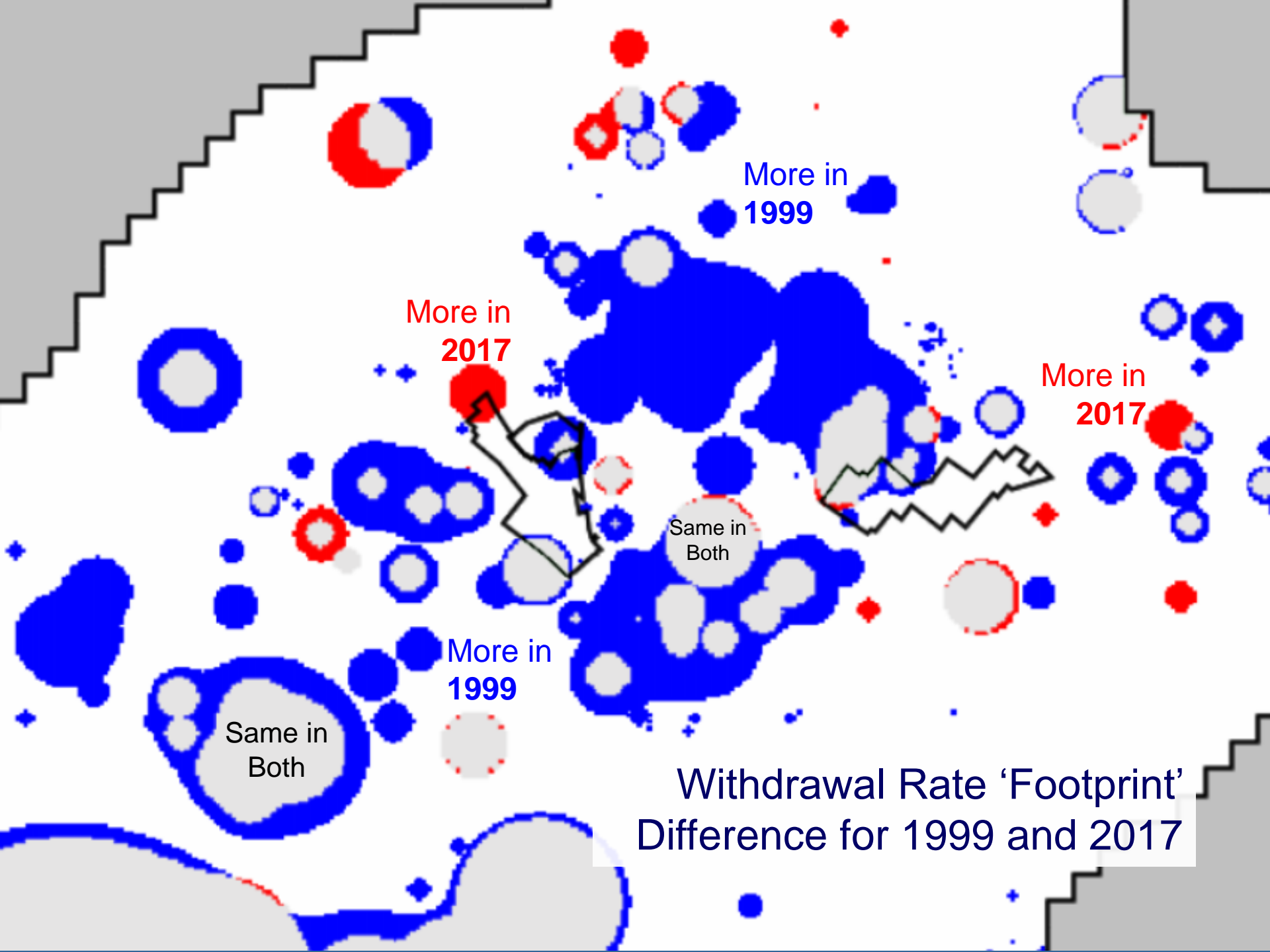
[https://www.nj.gov/drbc/library/documents/pindar\\_SEPAGWPA\\_lafayette100219.pdf](https://www.nj.gov/drbc/library/documents/pindar_SEPAGWPA_lafayette100219.pdf)



# Withdrawal Rate 'Footprints'



Data from Pennsylvania Dept. of Environmental  
Protection and USGS (1998)  
Map method after Goode (2016)



Withdrawal Rate 'Footprint'  
Difference for 1999 and 2017



**Point-source discharge to streams, in cfs**

- >0.1 to 1.0
- >1.0 to 2.0
- >2.0 to 4.0
- >4.0 to 7.3

**Locations of model calibration data (stream gages, groundwater levels) and Specified discharges, withdrawals other than wells**

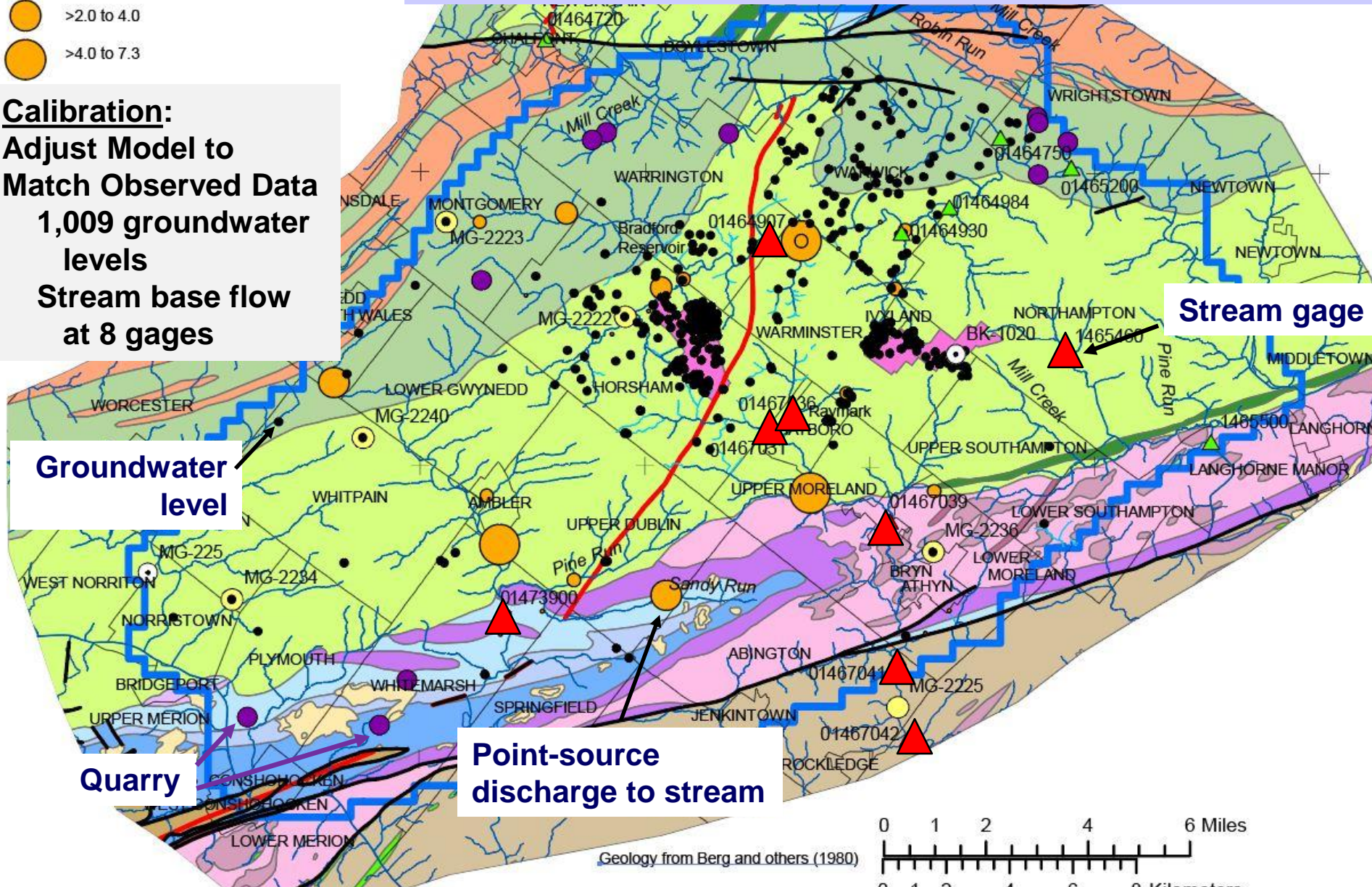
**Calibration:**  
Adjust Model to Match Observed Data  
1,009 groundwater levels  
Stream base flow at 8 gages

**Groundwater level**

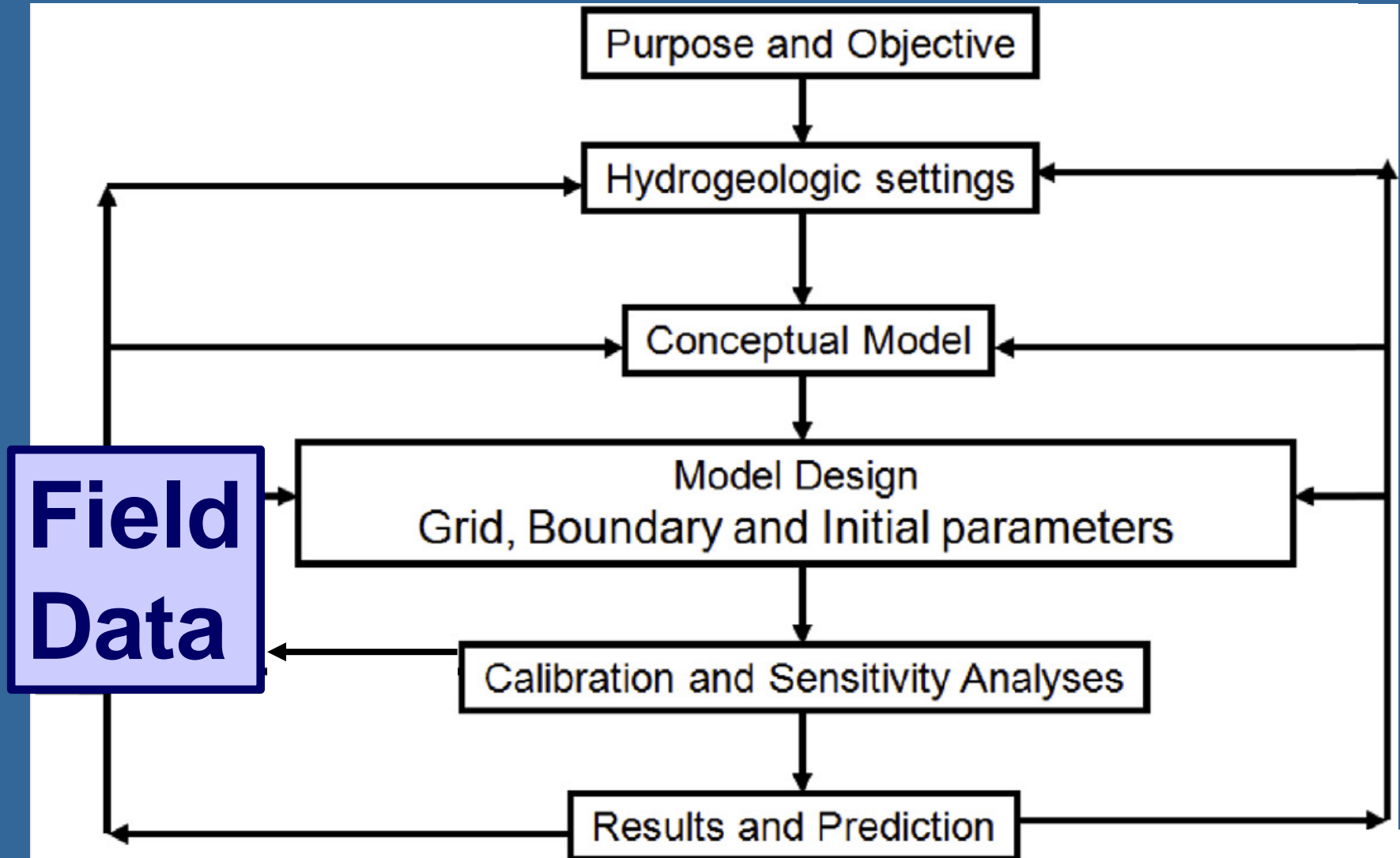
**Stream gage**

**Quarry**

**Point-source discharge to stream**



# MODEL DEVELOPMENT AND REFINEMENT

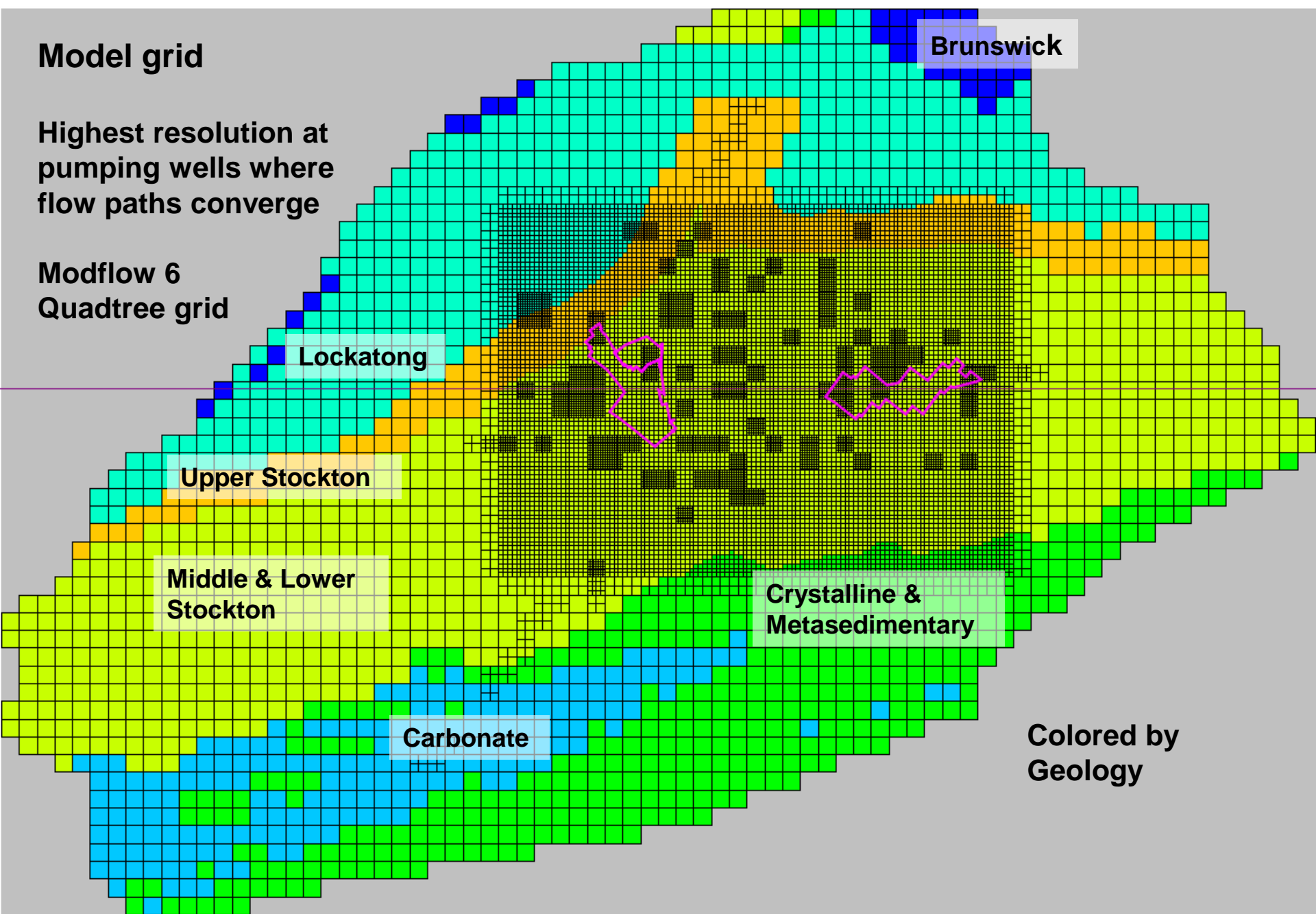


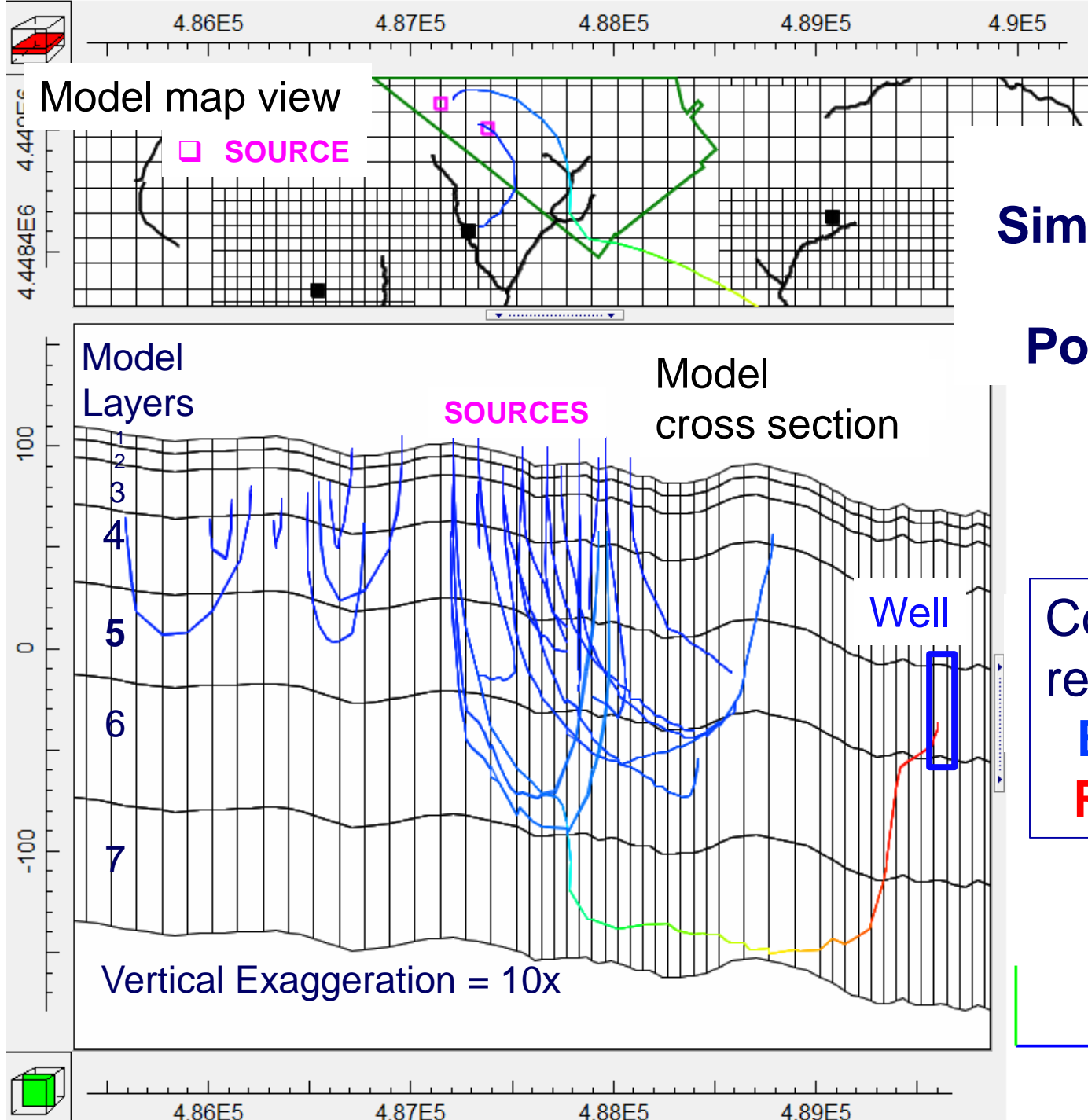


## Model grid

Highest resolution at  
pumping wells where  
flow paths converge

Modflow 6  
Quadtree grid

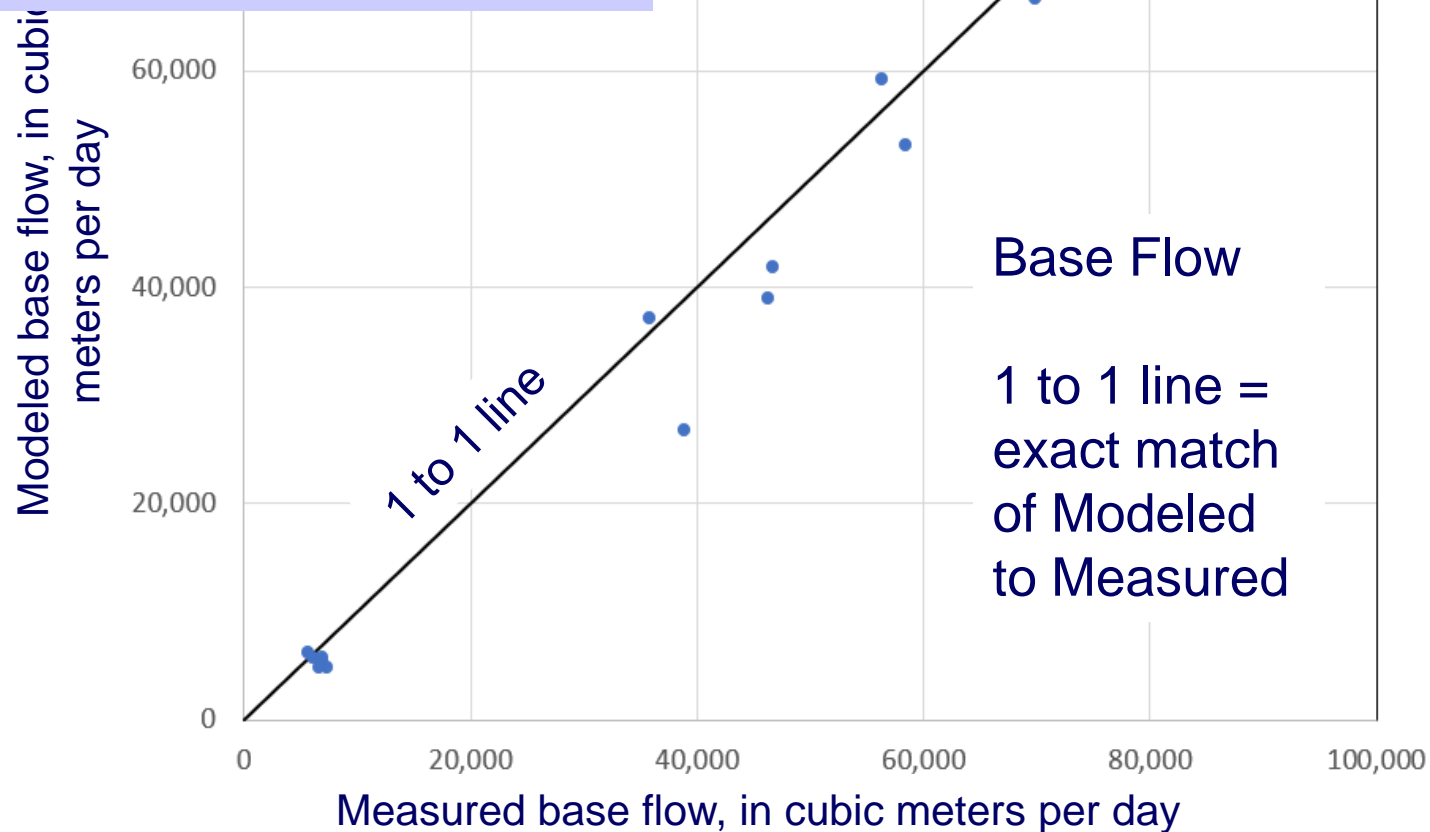


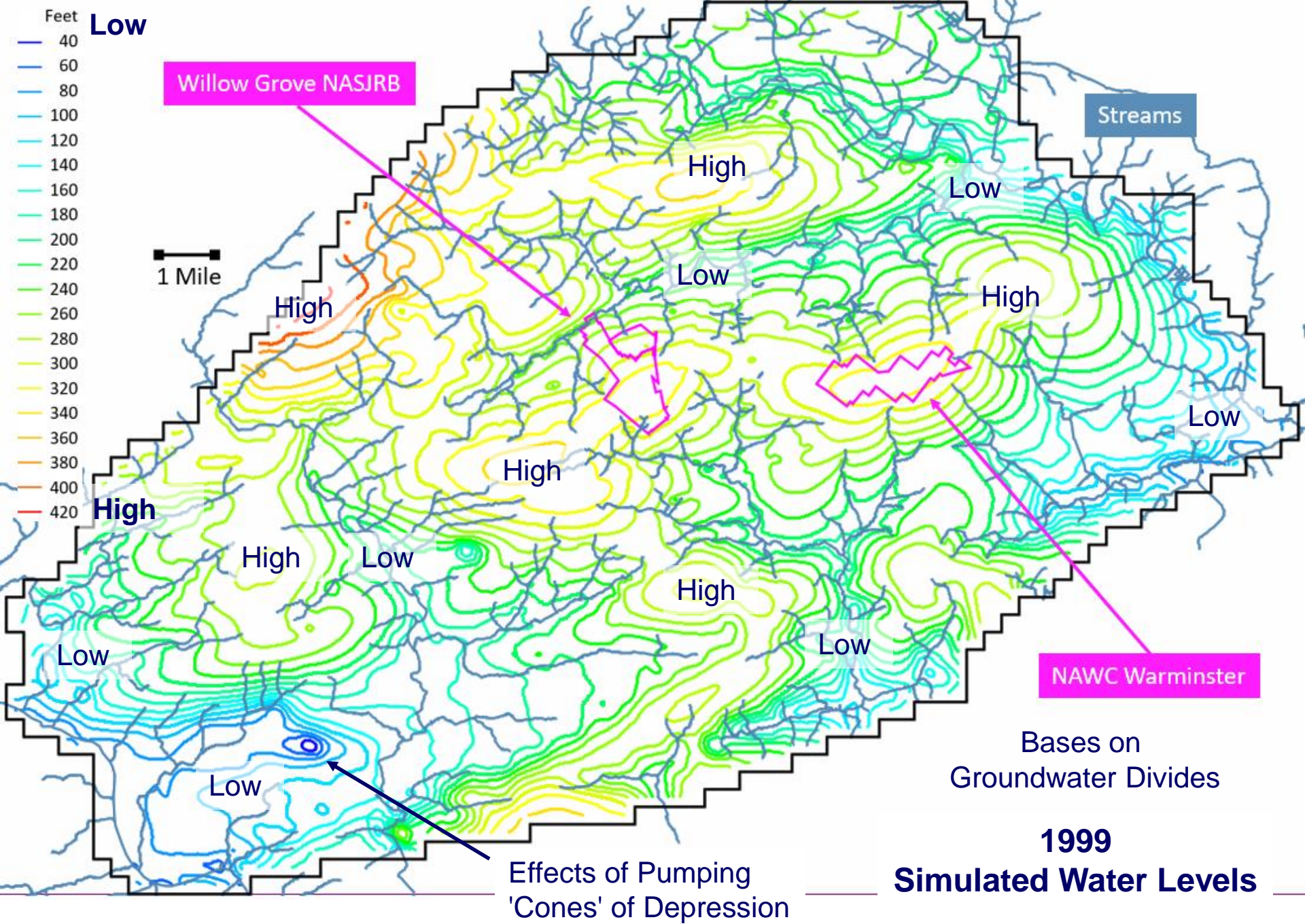




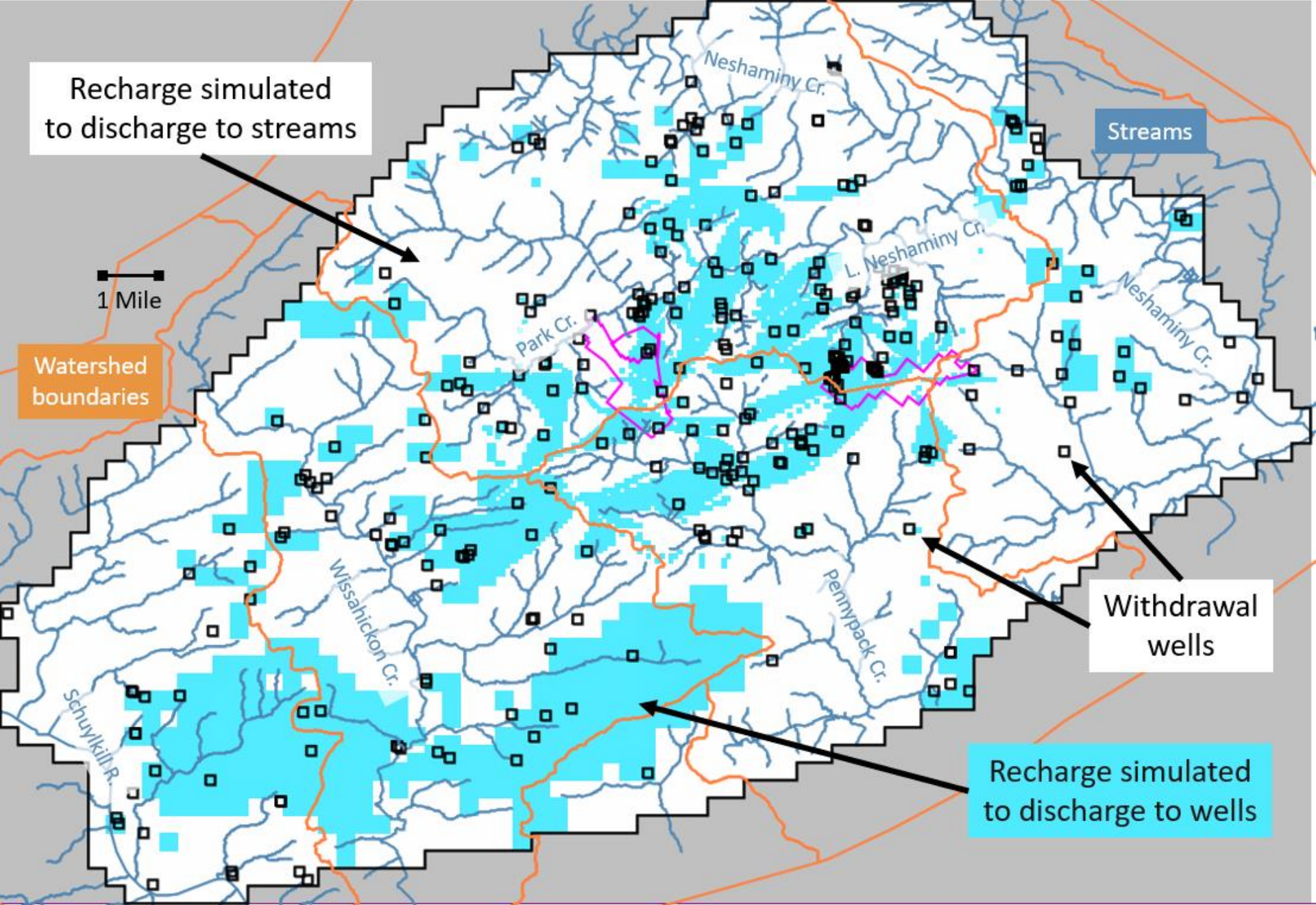
## Calibration

Change Parameters  
so that  
Model Outputs  
are similar to  
Field Data









Model simulates where recharge discharges to streams or to wells



1999

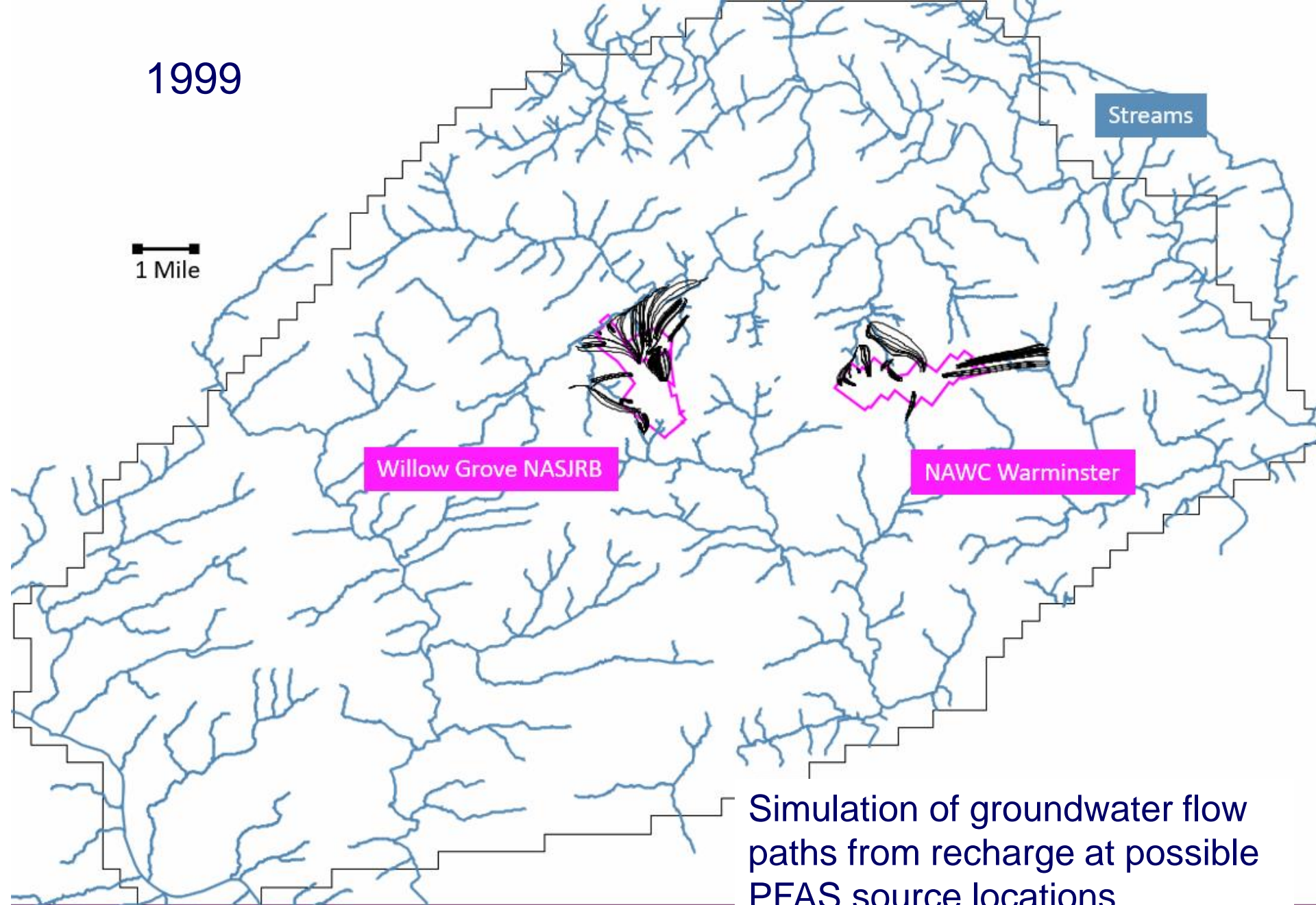
1 Mile

Streams

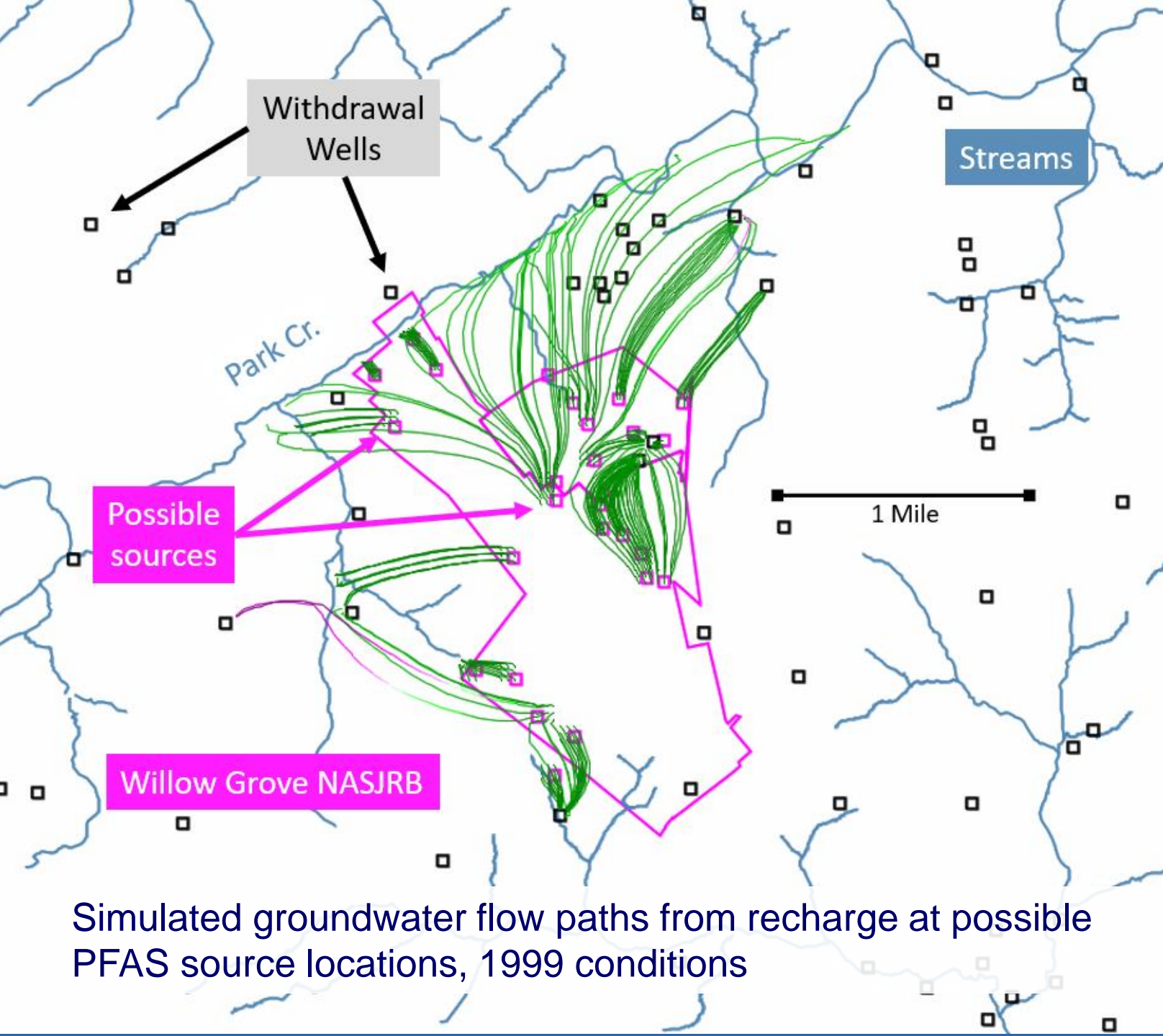
Willow Grove NASJRB

NAWC Warminster

Simulation of groundwater flow paths from recharge at possible PFAS source locations



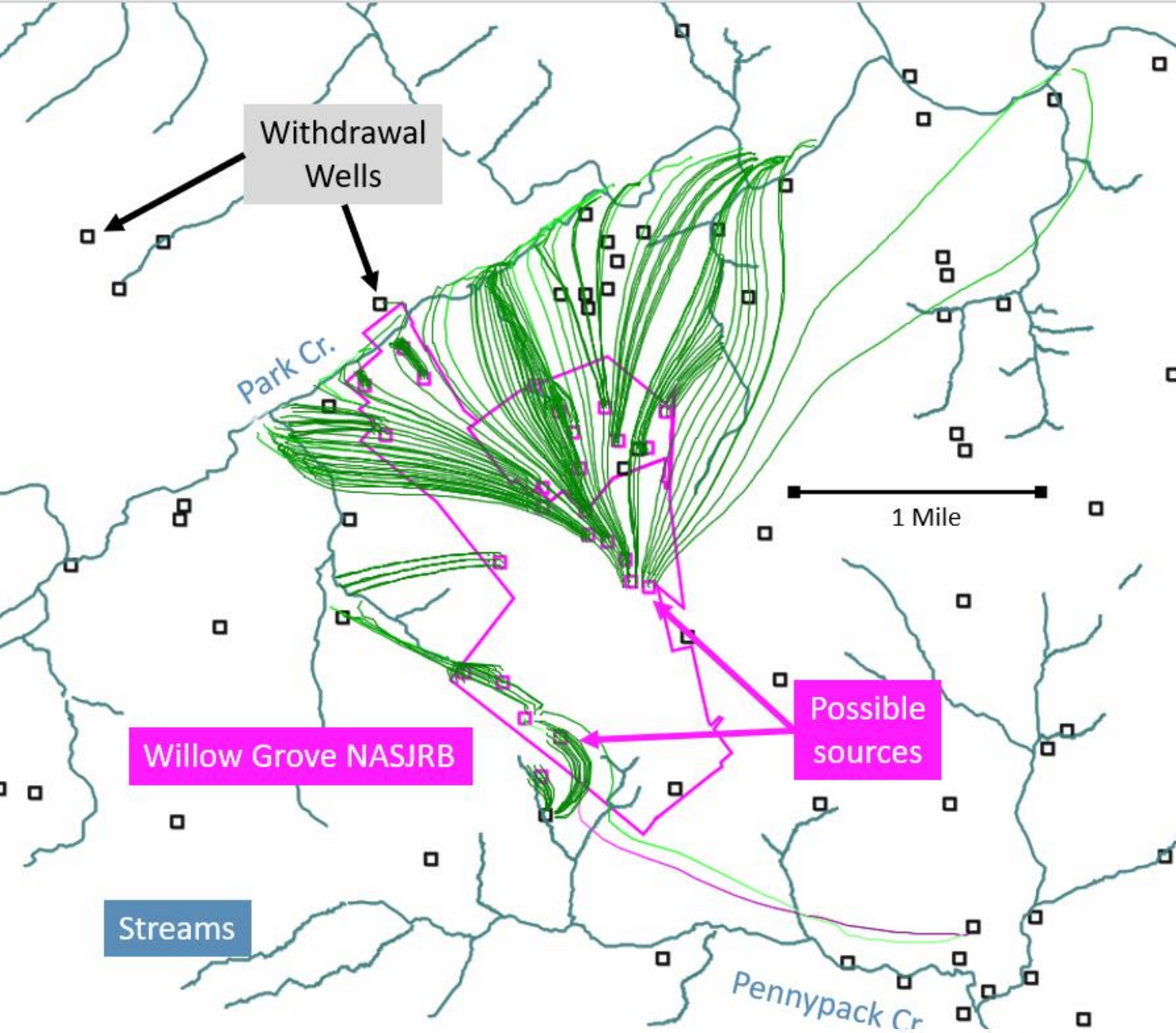
1999



Simulated groundwater flow paths from recharge at possible PFAS source locations, 1999 conditions



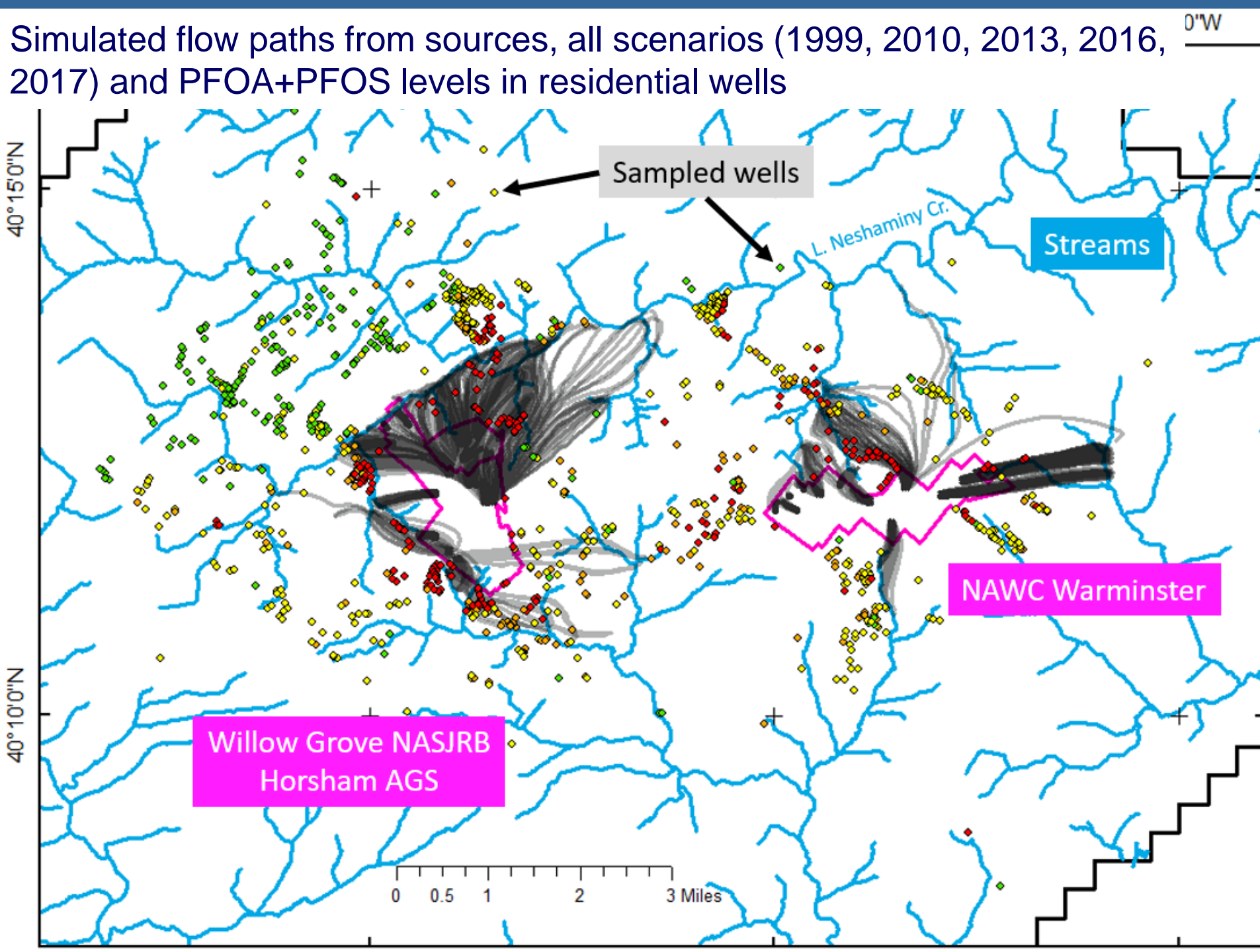
2017

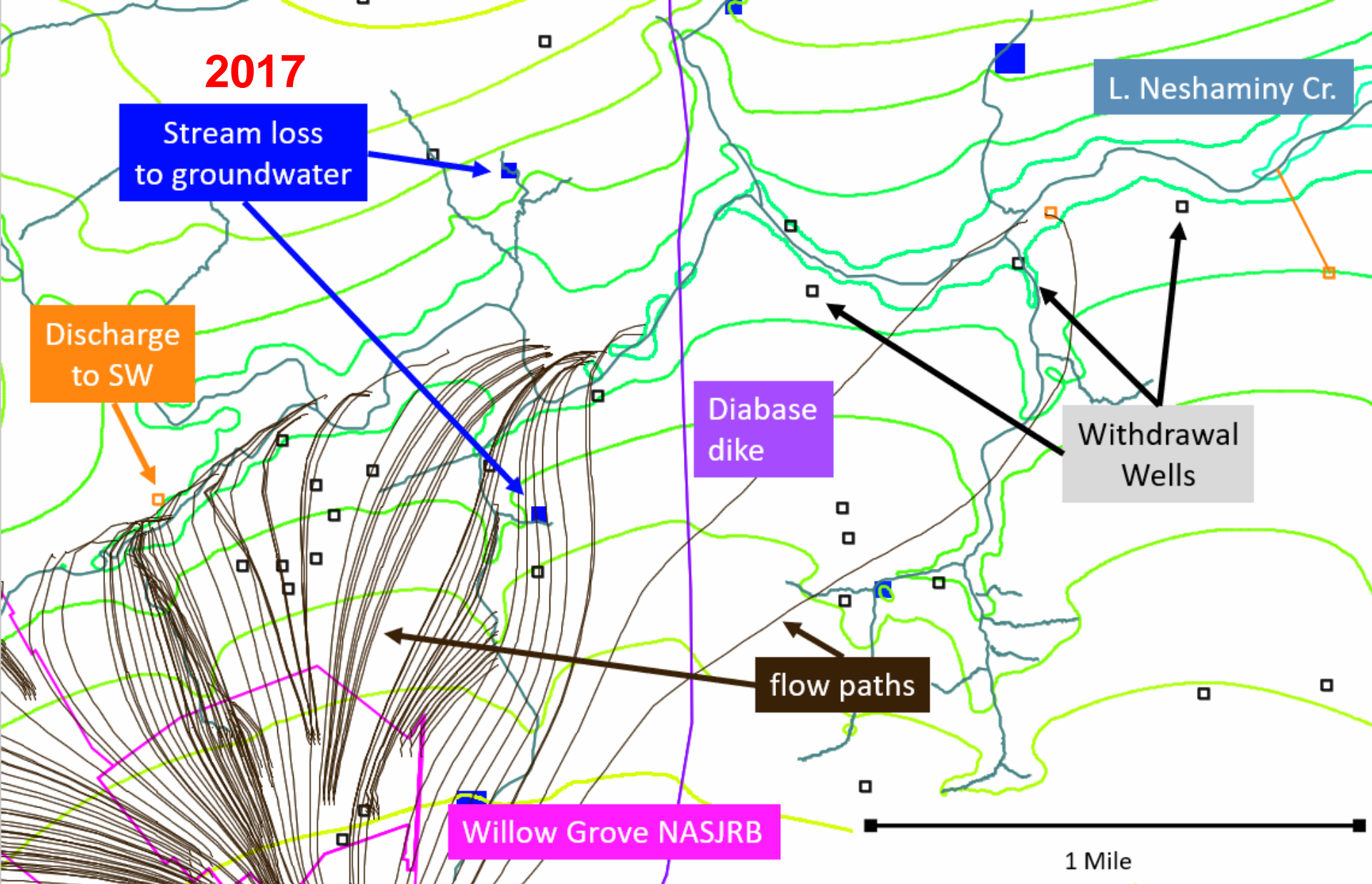


Simulated groundwater flow paths from recharge at possible PFAS source locations, 2017 conditions



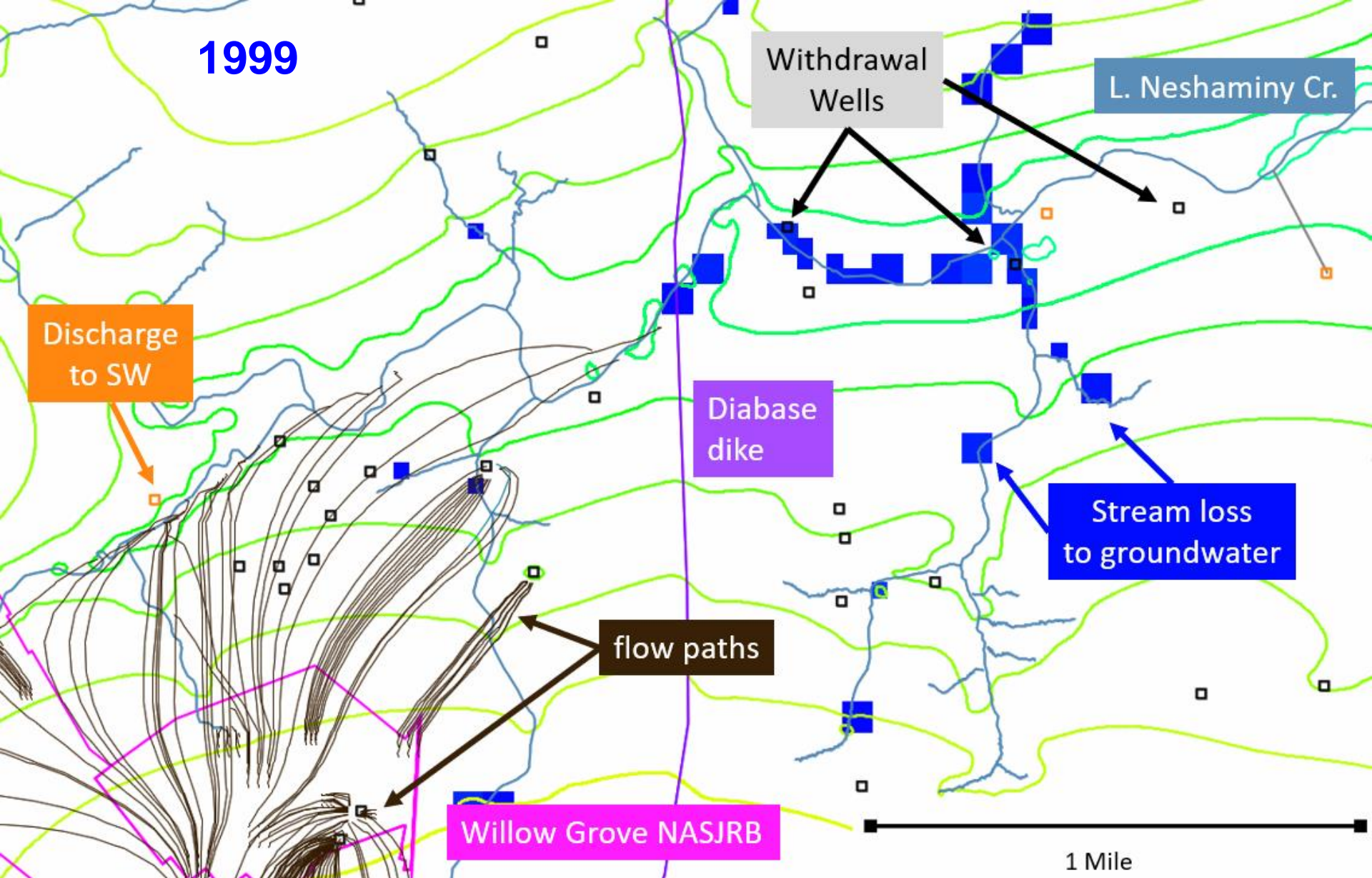
Simulated flow paths from sources, all scenarios (1999, 2010, 2013, 2016, 2017) and PFOA+PFOS levels in residential wells







1999





## SUMMARY OF FINDINGS

"Simulations showed that recharge at the bases discharged to withdrawal wells and local streams, generally within a mile or two of the bases."

"Locations of many residential wells near the bases identified by the Navy and Air National Guard as having elevated PFAS concentrations are generally consistent with the simulated flow paths from possible sources at the bases."

"However, there are some areas of observed PFAS contamination where no flow paths from base sources were simulated, indicating presence of unknown PFAS sources, unidentified transport processes, and (or) model limitations."

Groundwater pumping results in depletion of base flow and, under some conditions, losing stream reaches, especially under reduced recharge conditions.

Reductions in pumping have reduced the proportion of recharge discharging to wells since the 1990s.

Uncertainty – regional scale model, limited data, transient flow conditions, etc.

# Report, Data, & Model Online

- ❖ USGS Report OFR 2019-1137 published 6 Feb 2020  
*Groundwater Withdrawals and Regional Flow Paths at and near Willow Grove and Warminster, Pennsylvania—Data Compilation and Preliminary Simulations for Conditions in 1999, 2010, 2013, 2016, and 2017*
- ❖ USGS Data Releases published 6 Feb 2020  
Model -- Can be re-run and modified  
Datasets  
    Withdrawals  
    Streamflow (including base flow)
- ❖ Available online @ [usgs.gov](https://usgs.gov)

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- U.S. Geological Survey, 1998, Southeastern Pennsylvania Ground Water Protected Area: U.S. Geological Survey Open-File Report 98-571, 1 CD.
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