StormWISE Optimization Screening Model for Stormwater Runoff Management

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Impaired Streams

- Suspended Solids loads deposit sediment
- Excess Nutrients in runoff and sediments – Nitrogen and Phosphorous
- High flow velocities erode banks

The Cause: Urbanization & Stormwater Runoff

What Can We Do to Restore Water Quality?

- **Install** Green Stormwater Infrastructure (GSI) Technologies throughout the watershed
  - hold back the runoff from 90% of storms and infiltrate whenever possible
  - remove pollution using biological and mechanical filters
- **Restore** tree canopy and other vegetation in the *riparian buffer zone*
- **Preserve** remaining forests and wetlands by conservation easements and land purchases

Bioretention Cell

Vegetative Swale

Porous Pavement

Rain Barrel

Infiltration Trench

Green Roof

Swarthmore's Alice Paul and David Kemp Residences

Modeling Cost Effective Solutions

- “What If?” analysis: physical simulation models
- “What’s Best?” analysis: minimize costs and maximize benefits (Optimization)
- Prioritize investments across watershed by drainage zone, landuse, GSI technology, and project sites.
- Requires <u>combined use</u> of simulation models (pollutant loading, GSI performance & cost) and optimization models: <u>Watershed Systems Analysis</u>

Models for Runoff Volume & Pollutant Loading

- EPA Storm Water Management Model (SWMM) – now version 5 with graphical user interface
- GWLF/RunQual – daily precipitation data & time-steps, lumped parameter
- TMDL-2K – Tufts University, Limbrunner – also daily time steps
- Others: SWAT, HSPF, HEC-HMS, etc.

Watershed Optimization Models
Two Levels:

1. High Resolution & Site Specific

- BMP site-based watershed optimization
  - attempts to identify specific sites throughout the entire watershed to prioritize for BMP installation
  - Very detailed physical modeling: distributed or small "lumps"
  - Expensive to apply – good for engineers, consultants
  - Solution by exhaustive search or heruistic (evolutionary)

2. Low Resolution & Attribute Based

- Screening-level optimization
  - Identifies desirable attributes of potential BMP sites, but not the sites themselves
  - Moderately detailed physical modeling can potentially be automated using GIS
  - Simplified & inexpensive to apply – good for municipalities, watershed associations
  - Exact solution by classical methods or linear/nonlinear programming

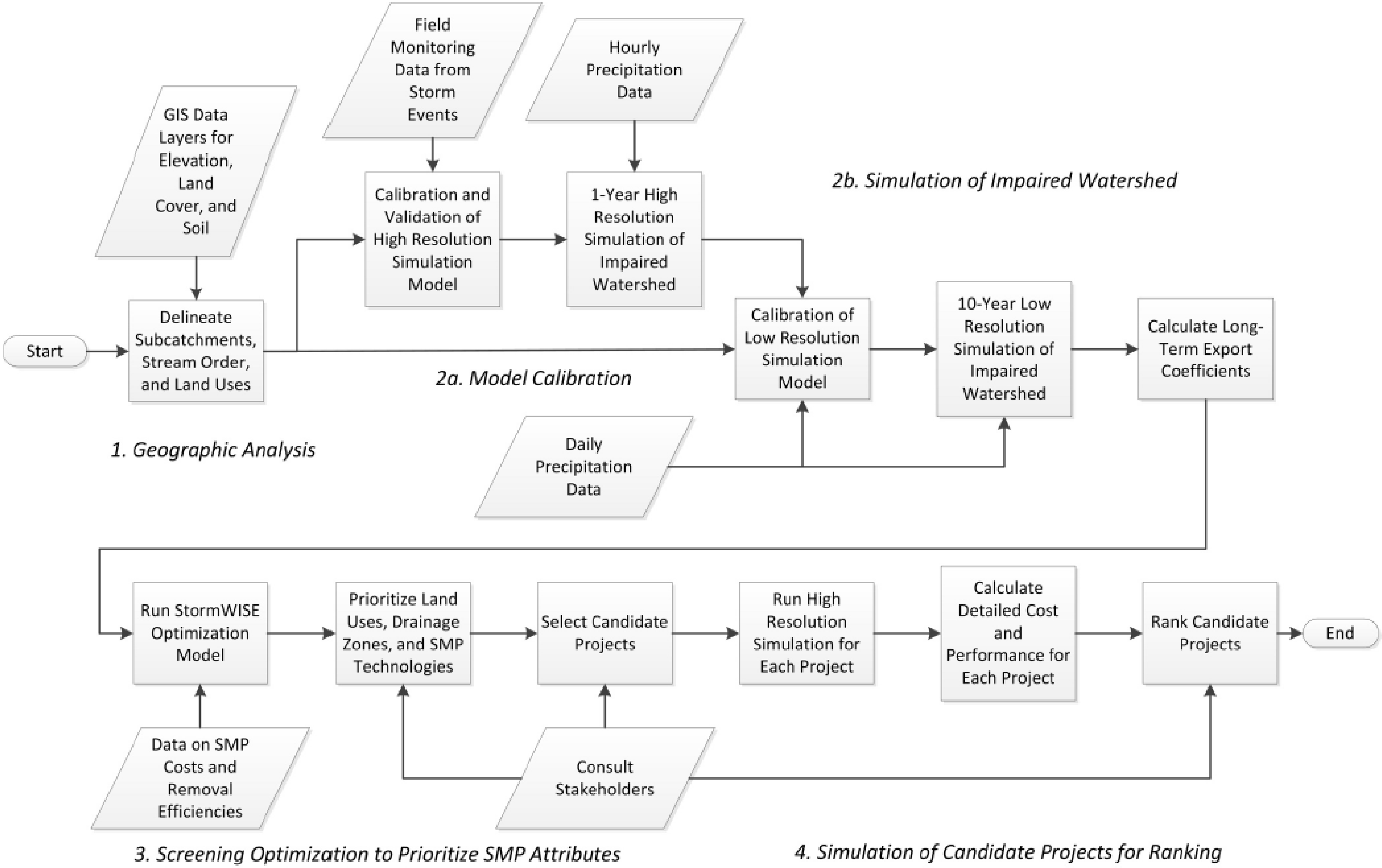
Screening: StormWISE

- **Storm W**ater **I**nvestment **S**trategy **E**valuator
- Screening Model: high level, guidance for early stages of watershed management process
- Prioritizes drainage zones, land uses, and GSI technologies for funding of implementation projects
- Identifies opportunities to reduce runoff volume and pollutant loads while maximizing effectiveness of available funds
- Extends pollutant loading models to include GSI cost minimization over entire watershed

Methodology for an Ideal and Complete Watershed Systems Analysis

1. Geographic Analysis
2. Watershed simulation modeling and calibration with field data
3. Screening Optimization to prioritize attributes of potential GSI sites
4. GSI site selection, post-optimization simulation modeling and ranking

Watershed Systems Analysis



Primary StormWISE Assumptions

1. Separate benefit functions can be specified for each combination of drainage zone and land use.
2. Upper limits can be specified for how much can be invested on each BMP technology in each combination of drainage zone and land use.

StormWISE TMDL Model Formulation

- **Minimize:** (total cost of BMP's over entire watershed)
- **Subject to:**

1. Watershed-scale benefit functions for each landuse category within each subwatershed drainage area
2. User specified pollutant reduction levels for sediment and nutrients

- (Solved using AMPL optimization software) or Excel Solver)

StormWISE-TMDL Mathematics

$$\text{Minimize} \quad Z = \sum_{i \in I} \sum_{j \in J} x_{ij}$$

subject to:

$$\sum_{i \in I} \sum_{j \in J} b_{ijt}(x_{ij}) \geq B_t^{\min} \qquad \text{for} \quad t \in T$$

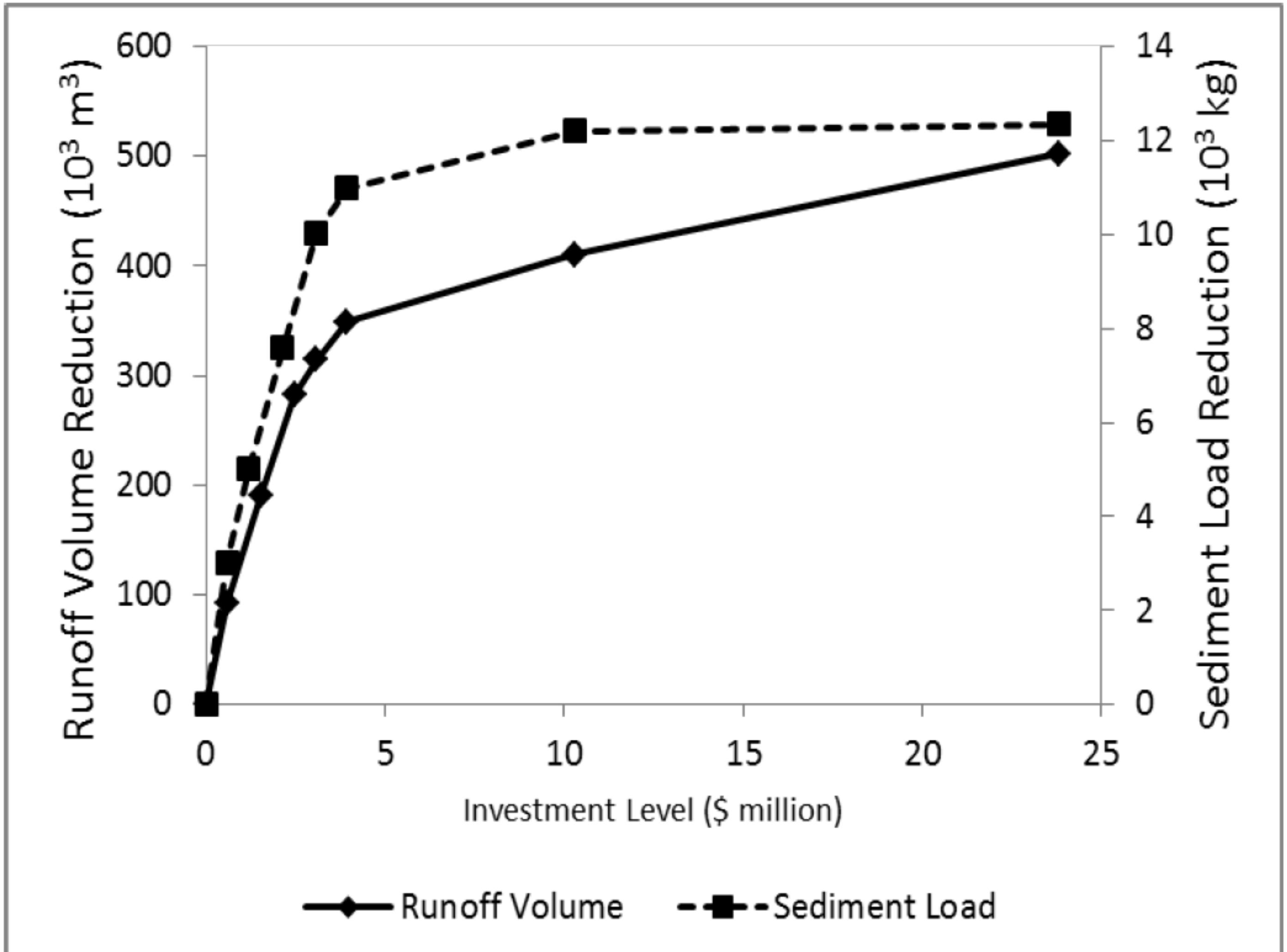
Piecewise Linear Benefit Functions

$$b_{ijt}(x_{ij}) = \sum_{k \in K} s_{ijkt} x_{ijk} \qquad \text{for} \quad \mathrm{i} \in \mathrm{I}, \mathrm{j} \in \mathrm{J}, \mathrm{t} \in \mathrm{T}$$

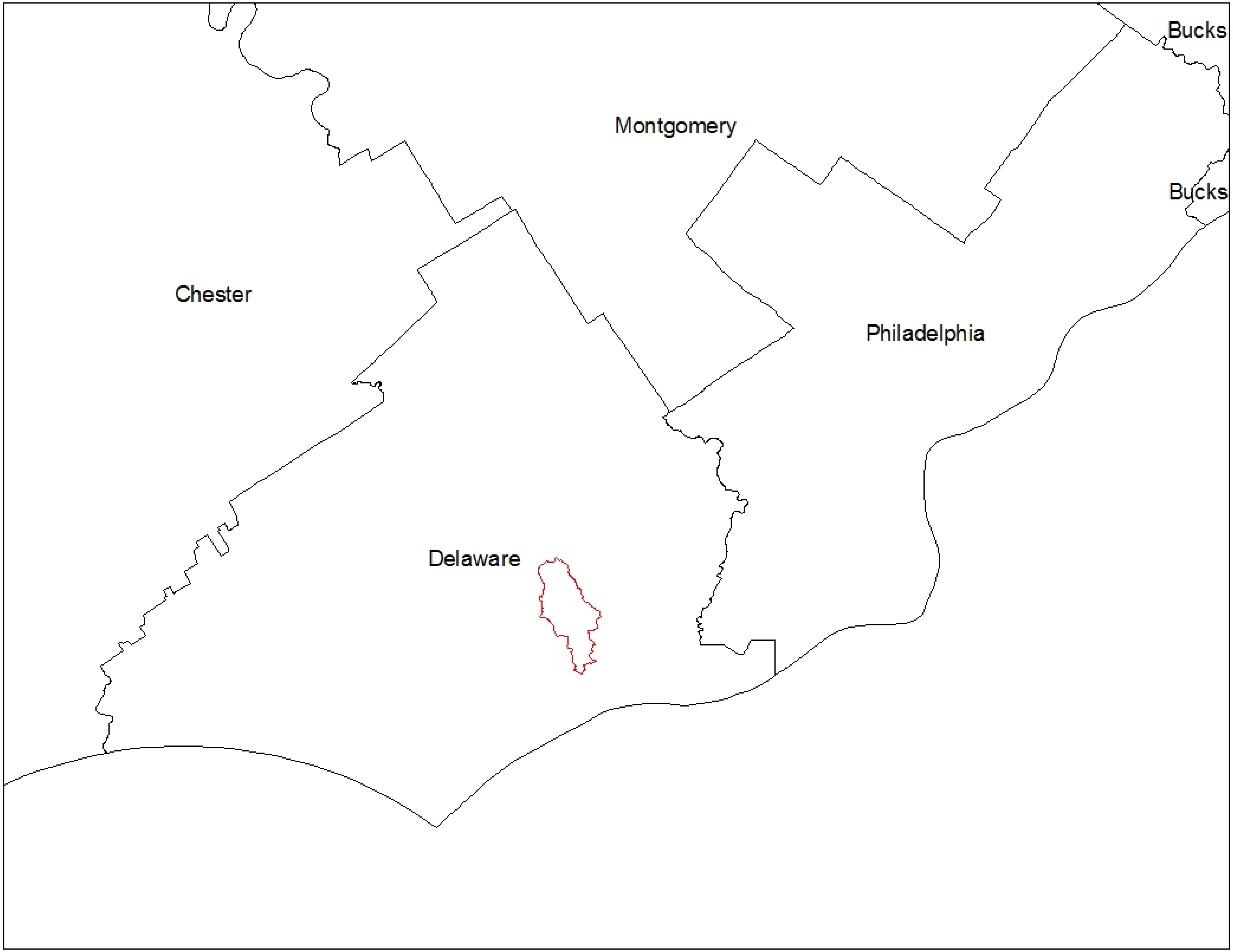
$$0 \le x_{ijk} \le u_{ijk} \qquad \text{for} \quad i \in I, j \in J, k \in K$$

With a <u>single benefit</u> function constraint (eg. Runoff volume only), StormWISE can be solved using a simple sorting algorithm. For <u>multiple benefits</u> solved simultaneously, Linear Programming is used.

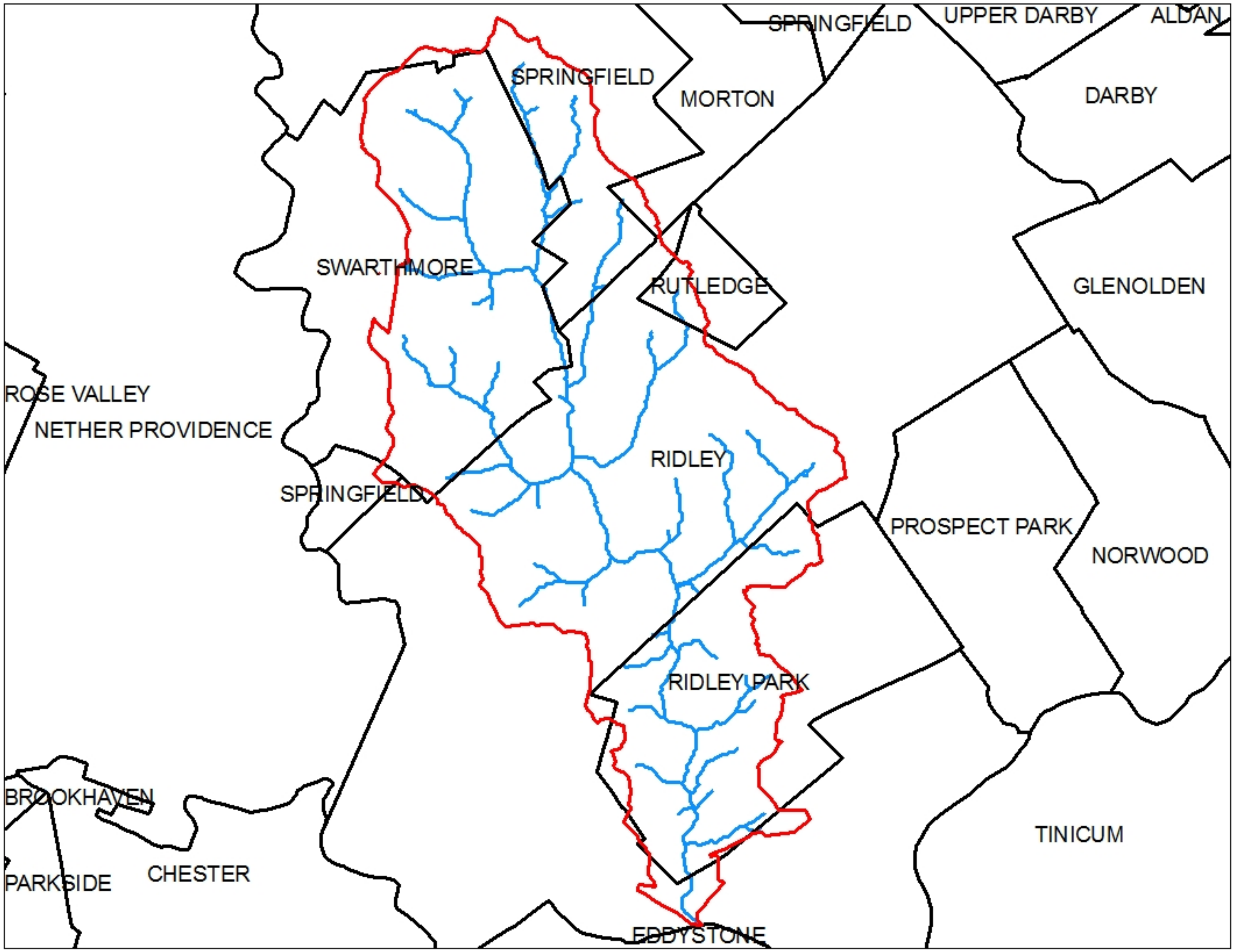
Piecewise linear benefit functions for medium-density residential land use in the headwaters

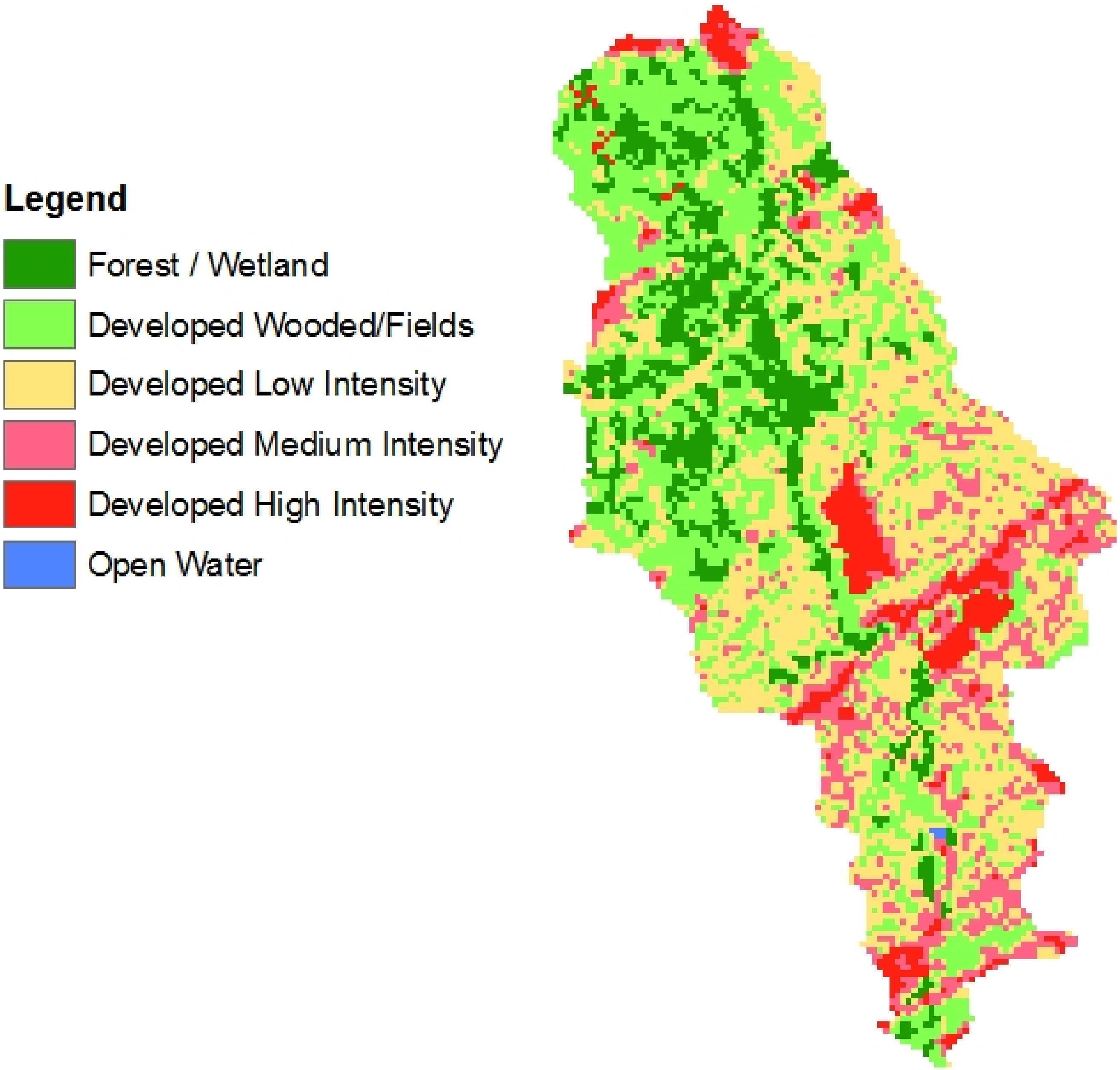


Case Study: Little Crum Creek Watershed in Suburban Philadelphia

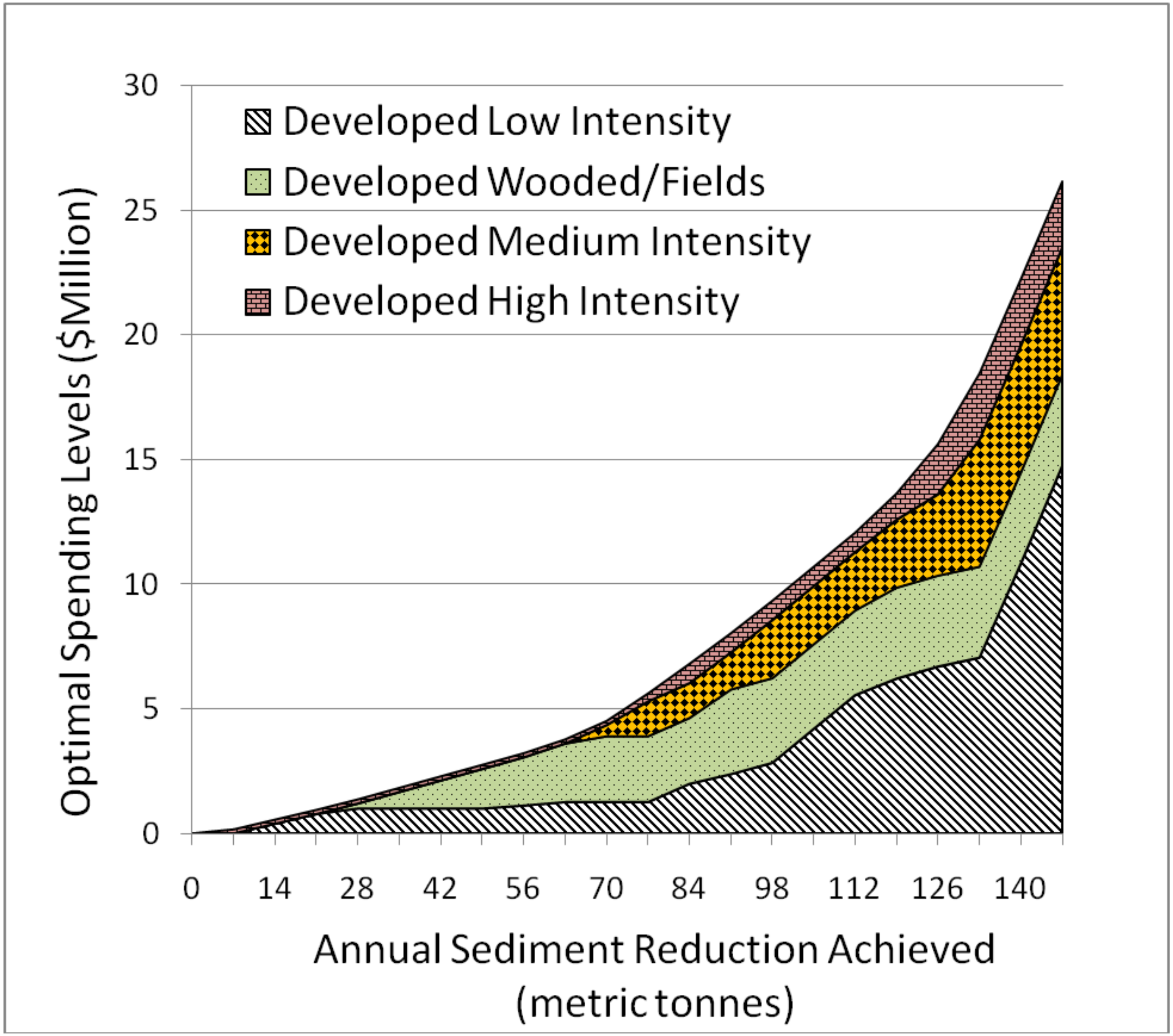


Watershed drains four Pennsylvania municipalities

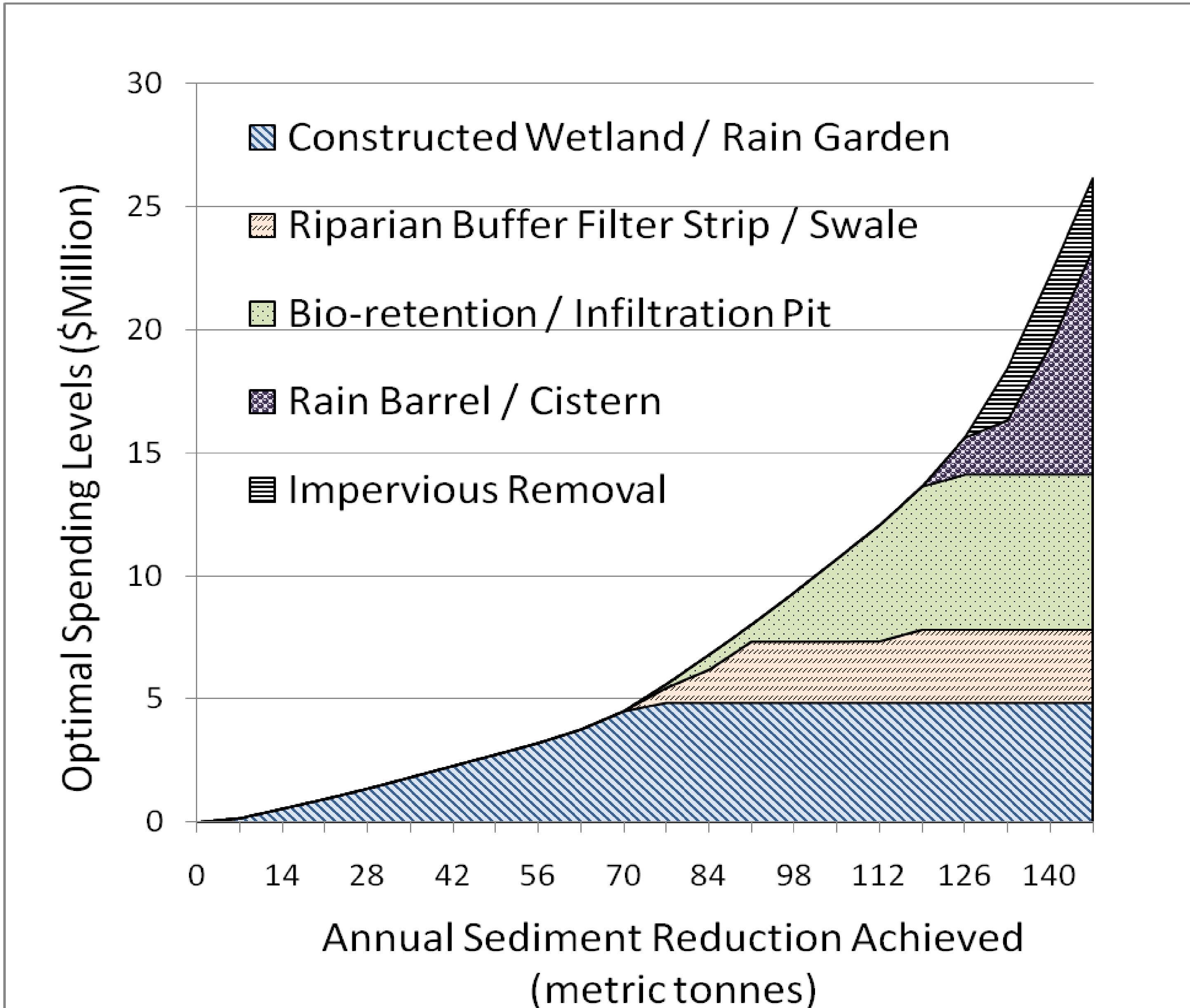



Legend
Forest / Wetland
Developed Wooded/Fields
Developed Low Intensity
Developed Medium Intensity
Developed High Intensity
Open Water

Results by Land-use



Results by BMP Technology

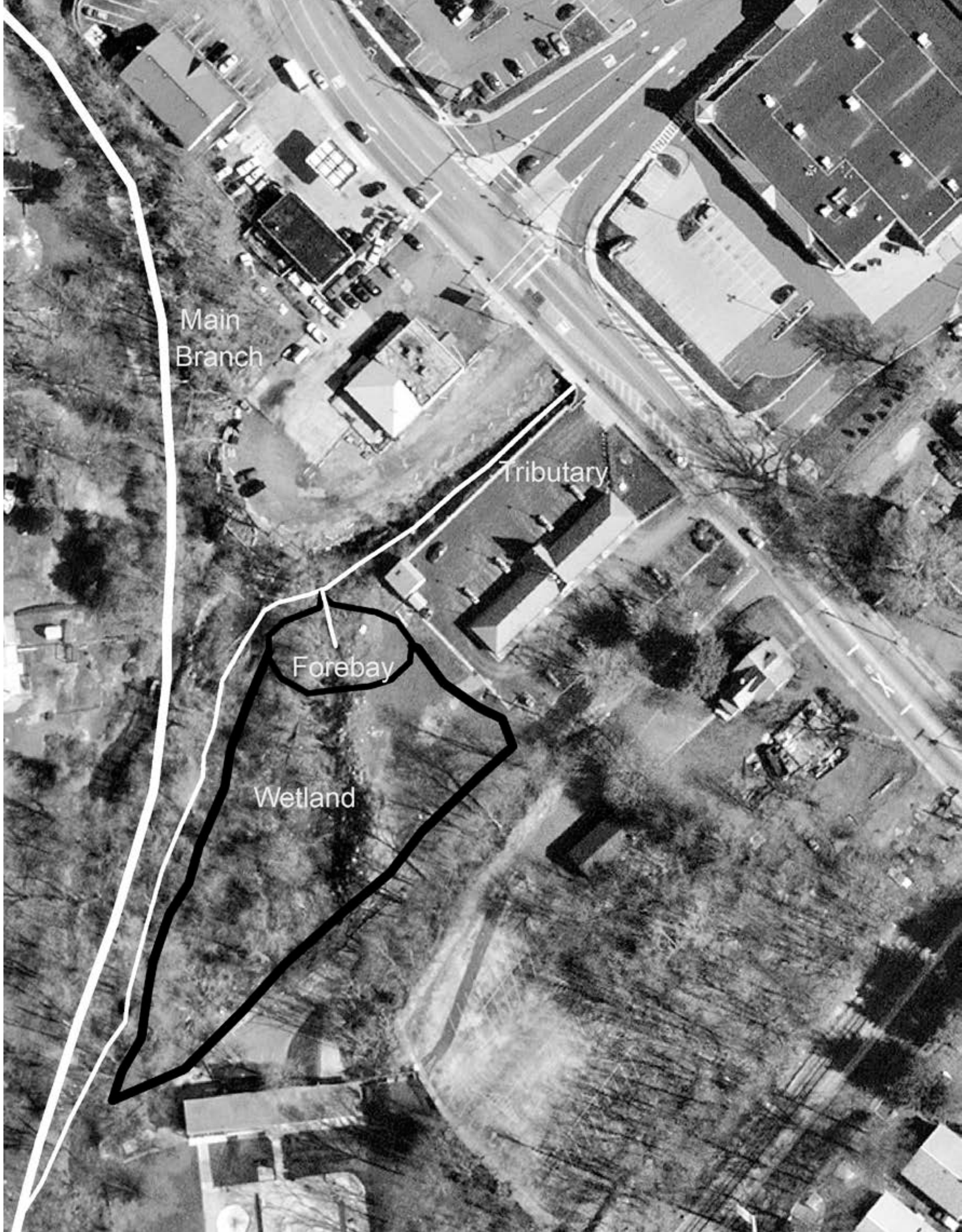


Example BMP Project

Site: new construction of a Super-Wawa convenience store in Ridley Township, PA

Project: constructed wetland with sediment forebay designed to capture and treat existing upstream runoff as well as new runoff.

Little Crum Creek Action Plan: http://watershed.swarthmore.edu



Current Research

- Couple an evolutionary algorithm solver to SWMM simulation for StormWISE calibration
- Statistical analysis of simulation results to obtain generalized benefit functions for different types of watersheds
- StormWISE application to combined sewer overflow (CSO) for evaluating Philadelphia's "Green Cities – Clean Water" Green Infrastructure Program.
- Multidisciplinary Consortium: Swarthmore, Temple, UMBC, Johns Hopkins http://www.greenphilly.net
- Philadelphia StormWISE demo: http://stormwise.greenphilly.net