City-Wide Green Stormwater Infrastructure Sizing, Siting, and Cost Effectiveness Analysis

Mike Blackhurst, PhD, PE (TX)
Research Scientist
University Center for Social and Urban Research
University of Pittsburgh

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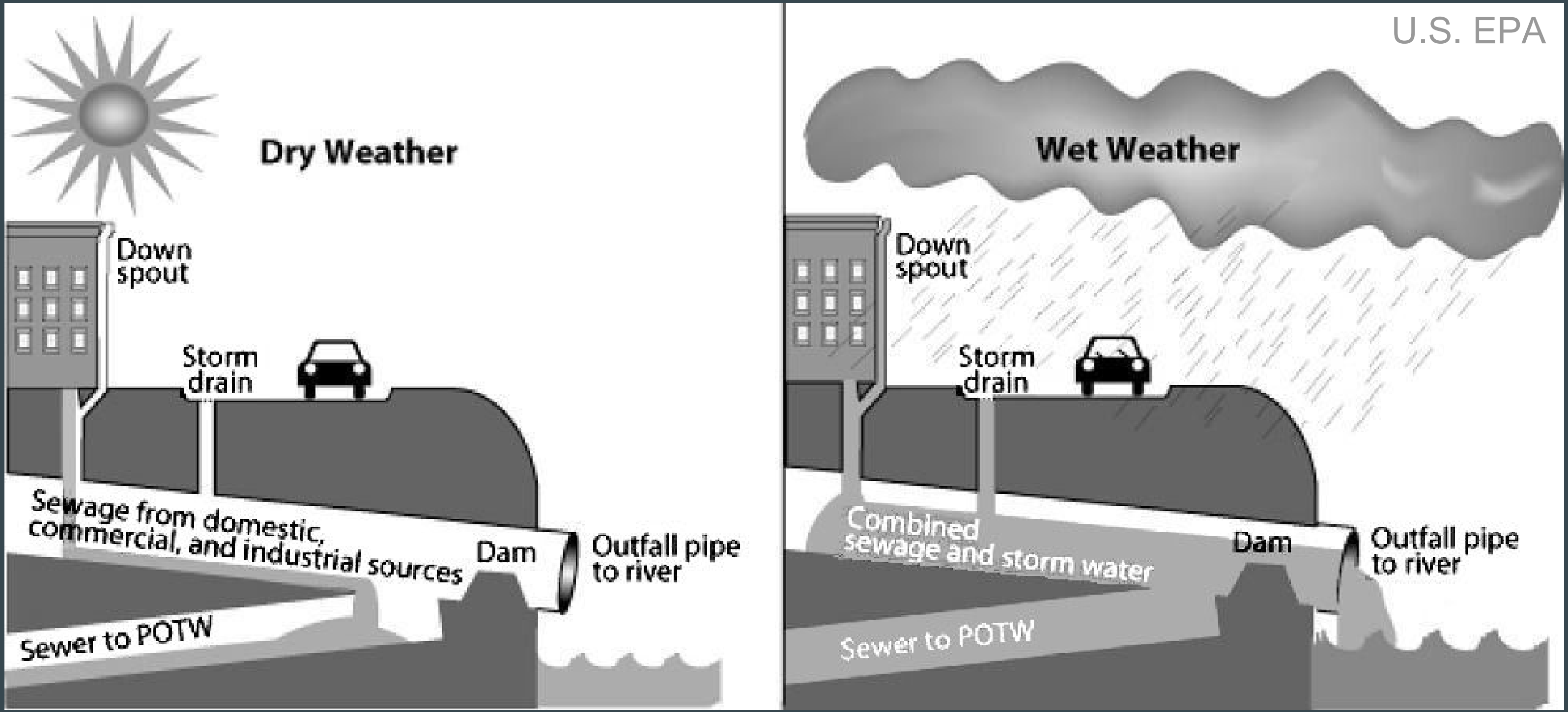
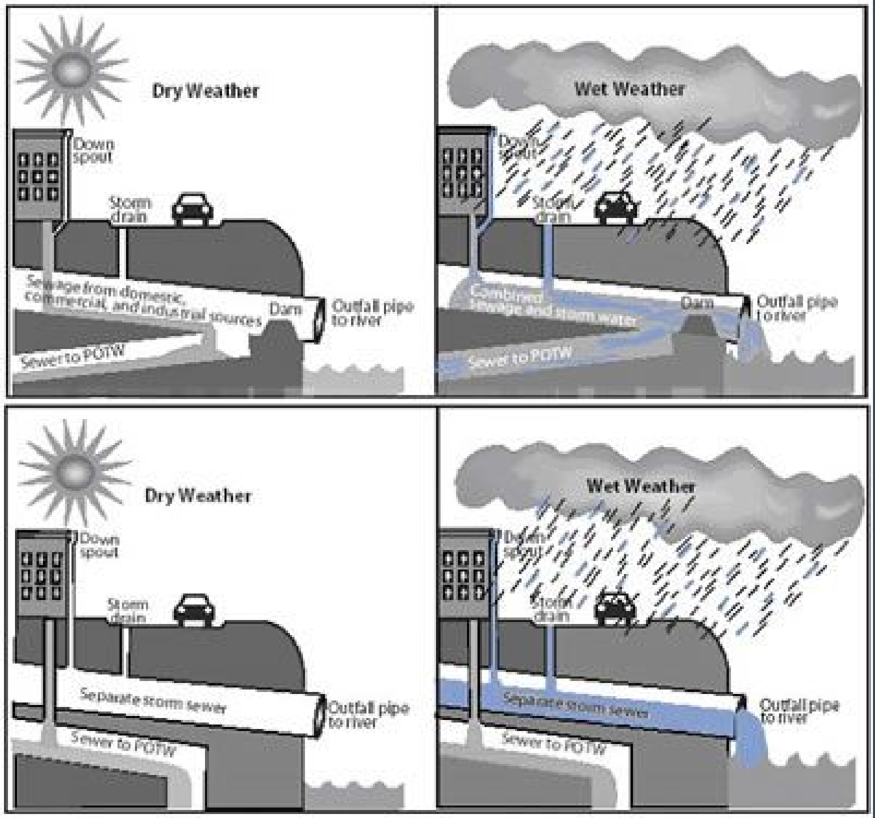
What are combined sewer overflows?



How do combined sewers contrast with separate sewers?



How common are combined sewers?

- 860 communities served by combined sewers
- 40 million people (about 12% of population)
- Located in 32 states

EPA 2016;
Tibbets 2005

Why do we care about combined sewers?

- In U.S. combined sewers discharge 850 billion gal of untreated wastewater (year 2004)
- Discharges contain a host of pollutants that threaten public health and environment

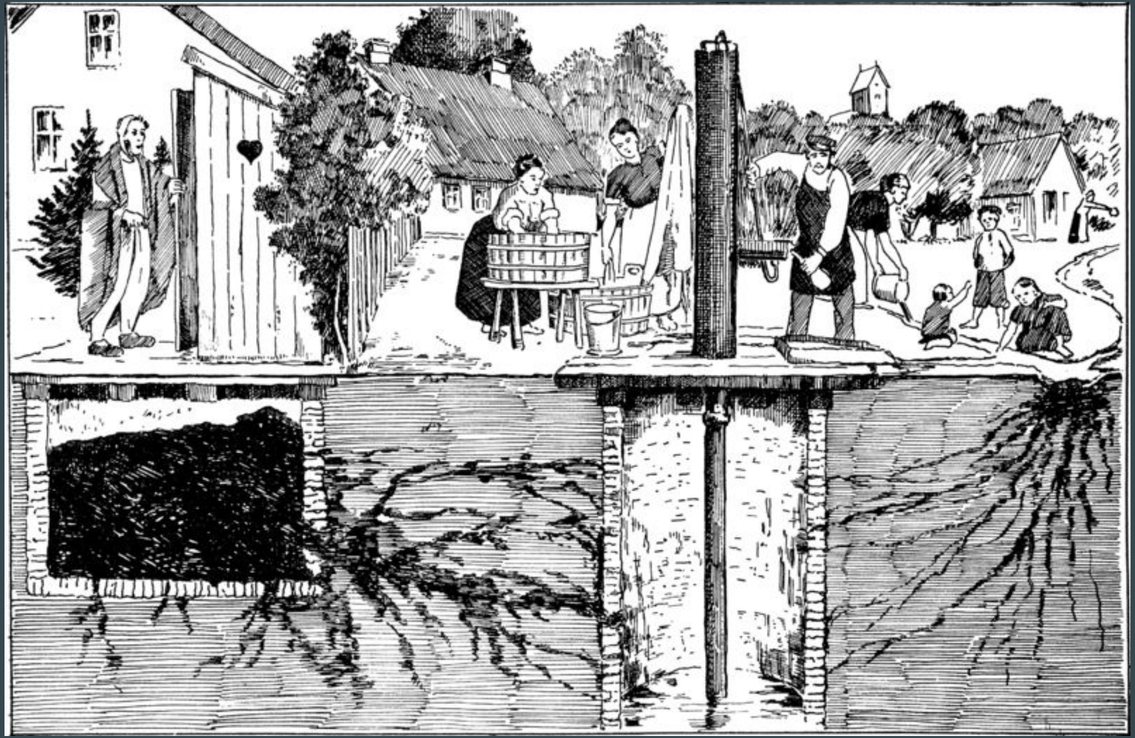
EPA

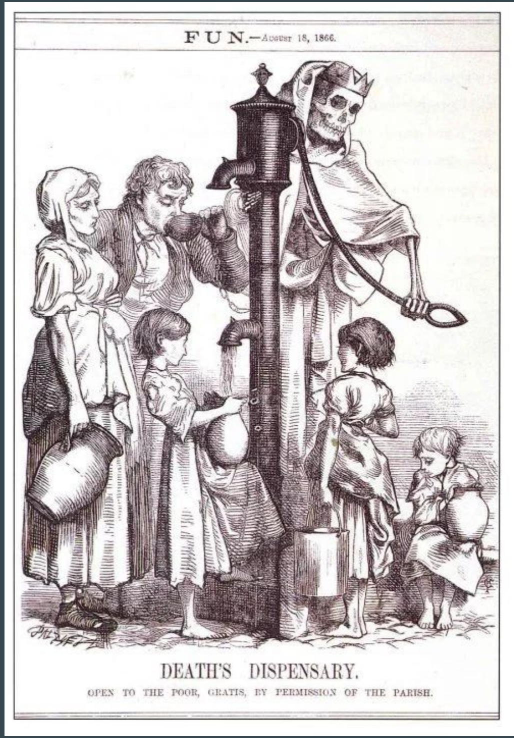
Why do we even use combined sewers?

It’s a long story...

... but it’s relevant.

We used to store sewage with our water supply.





A messy search for sanitation brought about combined sewers.

Co-locating water and sewage led to public health problems (< 1850)

Shift to piped, untreated water (mid 1800's)

Piped water overwhelms cesspits, contaminating urban water supplies (1850 - 1900)

Drinking water treatment (~1900)
+
Shift to sewers, mostly combined (1900 - 1920)

Contamination of downstream surface water supplies (1930 -)

Wastewater treatment (1930 -)
+
Sanitary sewers (1930 -)
+
Advanced water treatment (1930 -)

Transition to combined sewers bears relevance to current decisions.

Technological uncertainty….

> “Extensive debates and discussions concerning ***water-carriage technology*** were held by professional associations, municipal officials, and citizens' groups. These debates often dragged on for years and involved the preparation of a number of engineering reports that addressed the comparative advantages of various forms or designs of waste disposal technology.”

Cost uncertainty…

> “Proponents argued the capital and maintenance costs of building sewerage systems would represent a savings for municipalities over the annual costs of collection under the cesspool-privy vault-scavenger system.”

> “In regard to financial costs, perhaps the most crucial change was the transference of maintenance expenses from the individual householder to the municipality.”

> “Opponents argued… the costs of sewerage systems would create a heavy tax burden. If financed with bonds, they would impose costs on future generations with no voice in the decision.”

Tarr et al. 1984

The legacy of overconfidence in combined sewers is still with us.

“While there were a few critics who warned about the health hazards of water-carriage technology, they were largely ignored because of the belief that ‘running water purifies itself.’ ”

“Engineering News maintained that questions involving water supply and sewage disposal should be decided by engineers rather than by physicians, because engineers had a superior conception of the "relative needs and values" of municipalities.“

Tarr et al. 1984

The history of combined sewers is salient.

- Demonstrates the longstanding influence of uncertainty in innovation
- Underscores the importance of interdisciplinarity in innovation
- Reminds us that the unintended consequences of technical change matter
- Emphasizes the importance of long-term planning
- Demonstrates importance of “systems level” thinking

What are engineering solutions to combined sewers?

1. “Gray infrastructure” that increases the capacity of conveyance, treatment, and/or storage for combined stormwater + wastewater
2. “Green infrastructure” that reduces stormwater inflow into the combined system
3. Separate storm and sanitary sewers (often too expensive at scale)

How does green infrastructure work?

Green infrastructure can either retain, divert, or delay the flow of stormwater.

University of Nebraska, 2013

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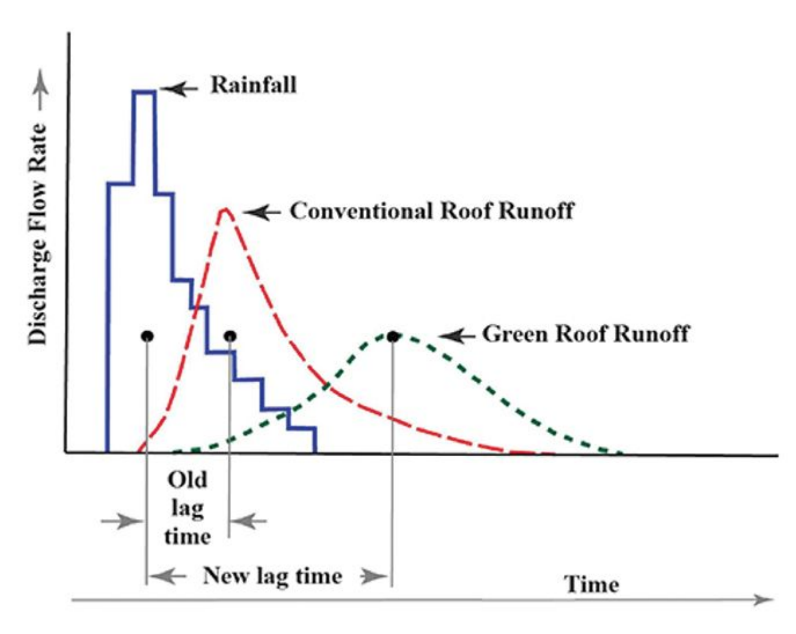


University of Nebraska, 2013

What is the regulatory context for combined sewers?

- The Clean Water Act gives the U.S. EPA authority to regulate CSOs.
- Clean Water Act includes *minimum* compliance requirements and more flexible principles
- Compliance is documented in a “Wet Weather Plan”
  - Prepared by the local municipality
  - Approved by relevant higher level state (DEP) and federal (EPA) authorities

Clean Water Act *minimum* compliance standards include amongst others

- Prohibiting dry weather discharges
- Requiring maintenance and monitoring
- Requiring public reporting of overflows

Four additional Clean Water Act compliance “principles”

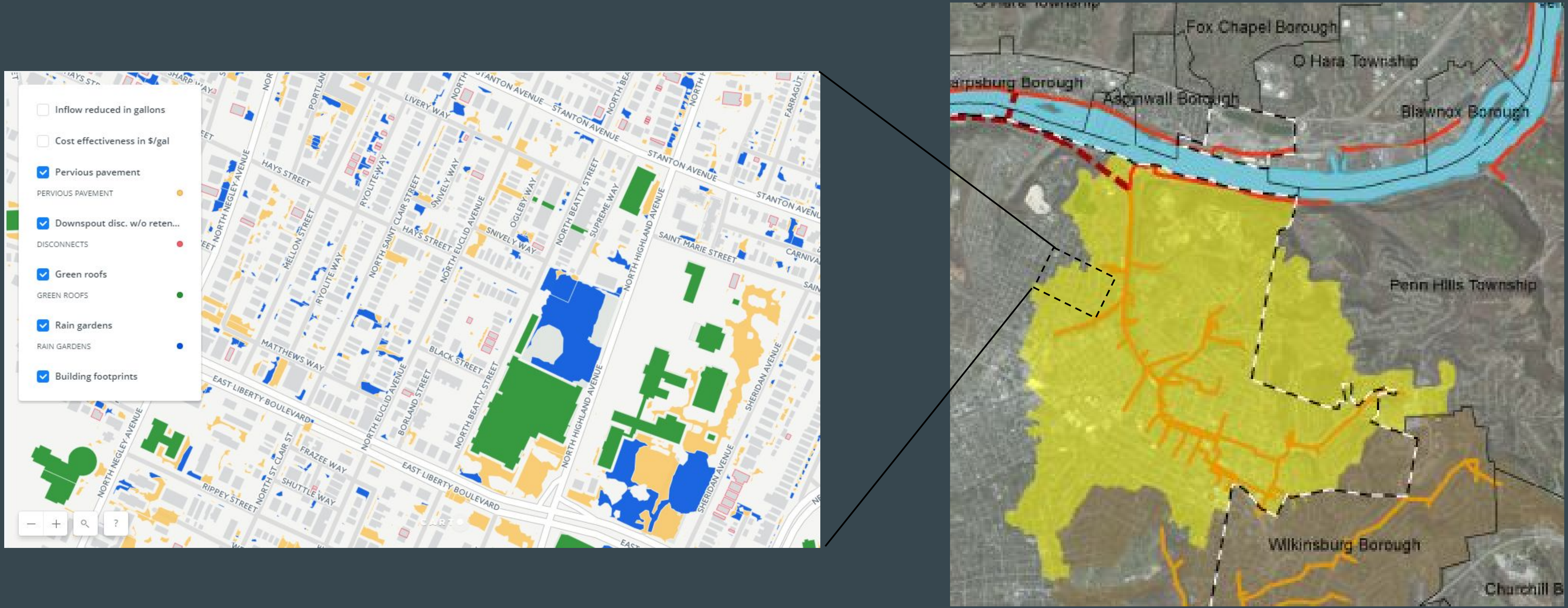
1. Provide clear levels of control… presumed to meet health and environmental objectives
2. Provide sufficient flexibility to consider the site-specific nature of CSOs and to determine the most cost effective means of reducing pollutants
3. Allow a phased approach to implementation of CSO controls considering a community's financial capability
4. Review and revise water quality standards and overflow control implementation

What is the status of compliance in Pittsburgh?

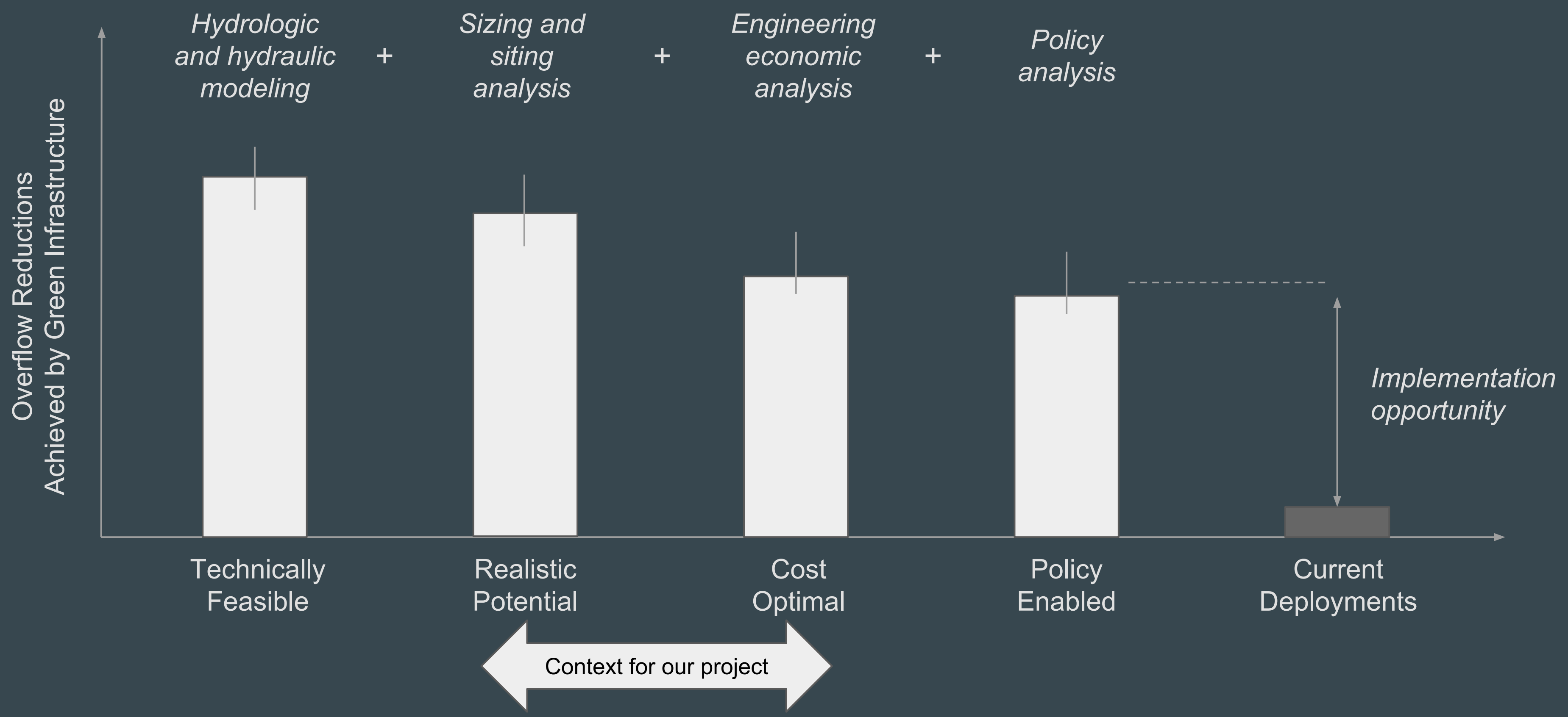
What is the engineering role in compliance?

- Apply hydrologic principles to simulate runoff (land use + topography + precipitation)
- Apply hydraulic principles to simulate conveyance
- Using engineering economics for cost (and sometimes benefit) estimation

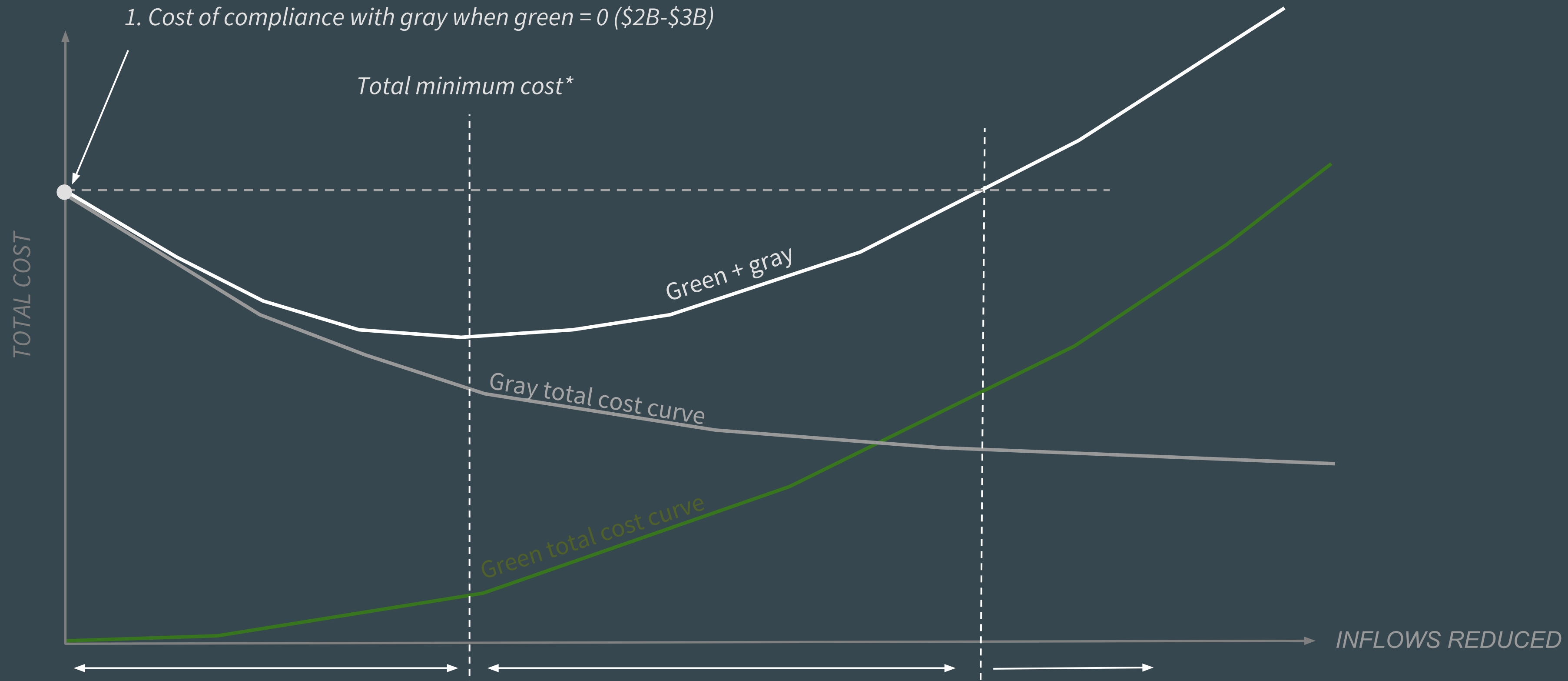
Models sanctioned for policy misalign with the green infrastructure context.



Integrating sewershed and GI modeling contexts involved interdisciplinarity.



Gray and green model results can be integrated using total cost curves.



2. Cost of compliance less than total minimum technology cost. Significant cost efficiencies realized by green infrastructure.

3. Cost of compliance exceeds total minimum technology. Moderate cost efficiencies realized by green infrastructure.

4. Compliance met with all gray solution because cost of gray + green exceeds cost of gray when green = 0

Our approach is

- Estimate the cost and inflow performance of select GI for each parcel in Pittsburgh, PA
- Prepare total cost curve for GI
- Develop extensible methods to accommodate future changes
- Publish the results in an open and extensible format
- See what happens next...

A summary of methods

(1) Characterize land use by parcel using best available data

(2) Apply sizing and siting criteria to identify all feasible installations of
   (a) Rain gardens
   (b) Downspout disconnects
   (c) Green roofs
   (d) Pervious pavement

(3) Run hydrologic models for each feasible installations

(4) Estimate cost effectiveness of each installation

(5) (Publish results and hope for more!)

Step 1. Characterize land use by parcel using best available data

Provide GIS demo

Step 2. Apply sizing and siting criteria to identify all feasible installations of GI

Summarized on project website.

http://sb.ucsur.pitt.edu/green-infrastructure/

Step 3. Run hydrologic models for each feasible installations

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Step 4. Estimate cost effectiveness of each installation

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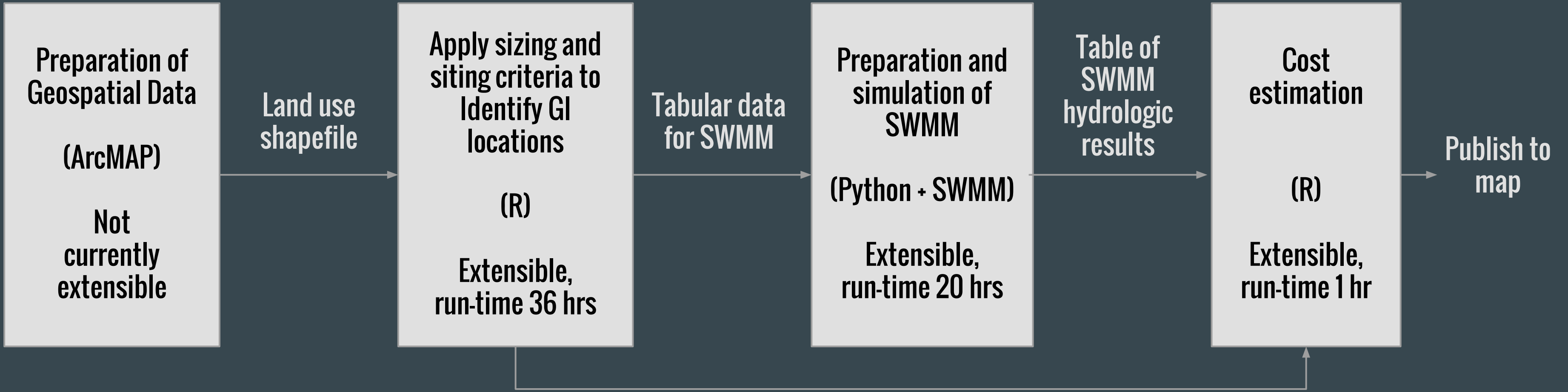
Process Flow



Summary statistics of results

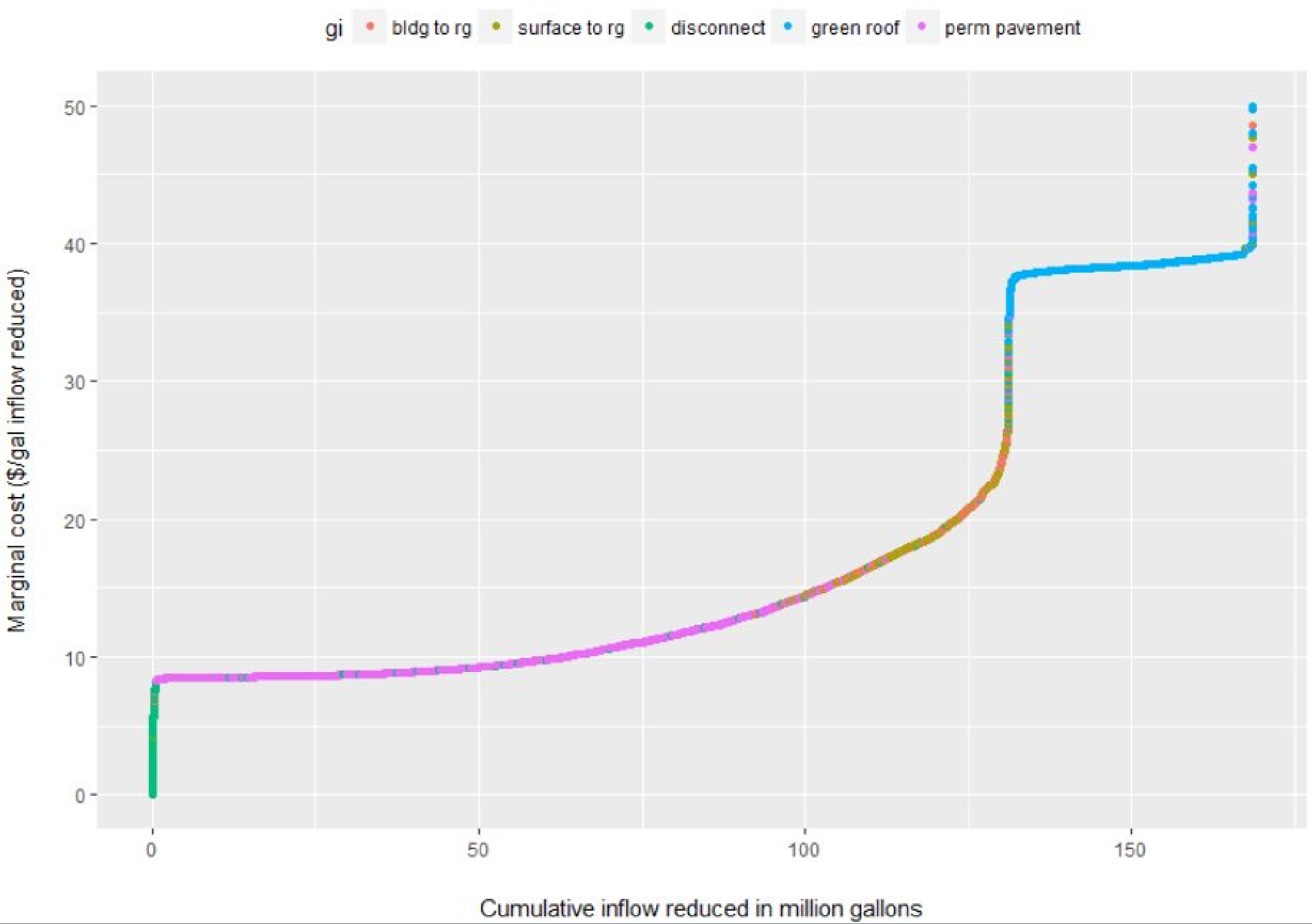
Identified approximately 138,000 GI projects

GI	million sq ft	count	Inflow reduced (mil gal)	Construction cost ($M)
Building to rain garden	13.3	22,500	13.2	245
Surface to rain garden	14.9	30,200	14.6	267
Disconnect	10.7	16,500	0.4	3.2
Green roof	57.5	3,800	37.4	1,440
Permeable pavement	88.2	65,400	103.0	1,060

About 24% of rainfall for 5-year, 24-hr design storm “controlled” by GI

About 13% reduction in inflows for 5-year, 24-hr design storm

Variation in technology cost and performance primarily influences cost effectiveness.



Published in an open, extensible manner

Explore resources on project website.

http://sb.ucsur.pitt.edu/green-infrastructure/

Potential future work

Include operating and maintenance cost

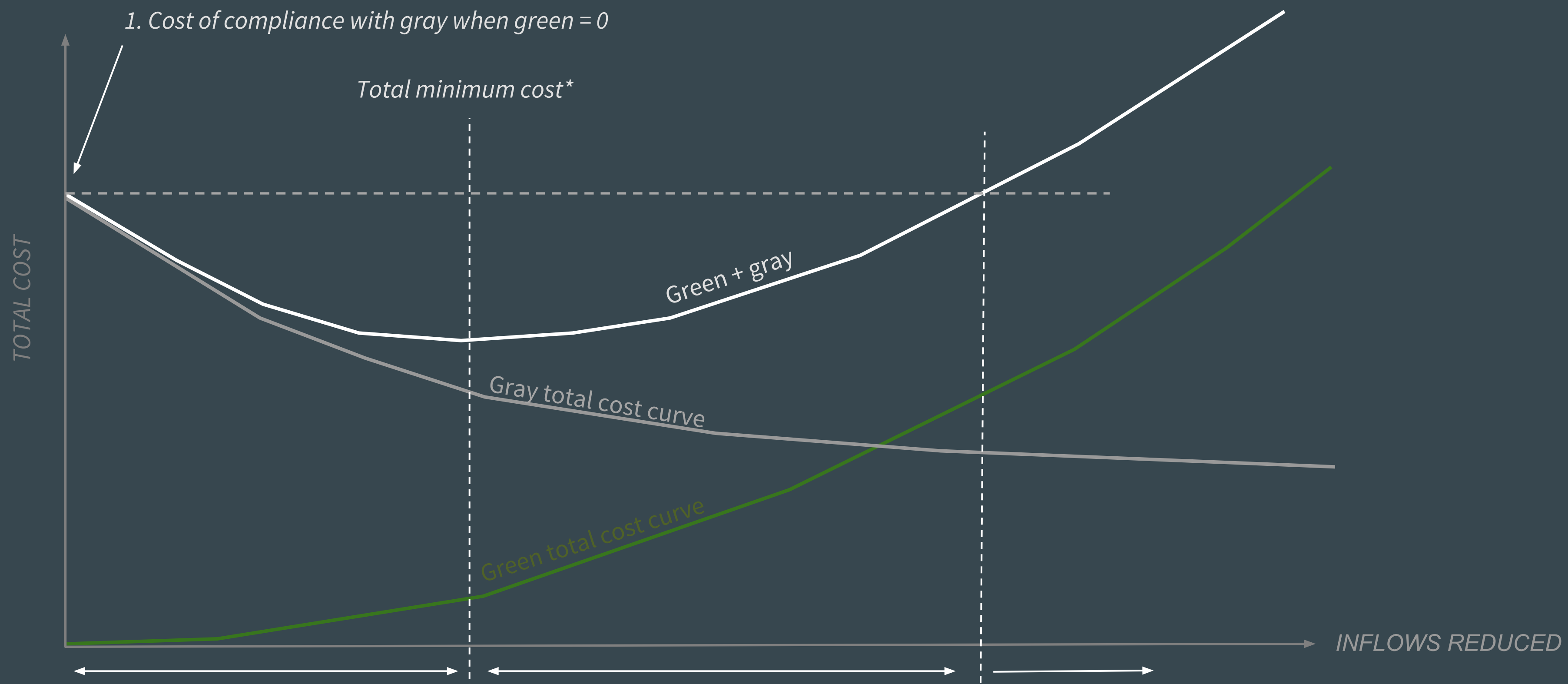
Model ranges (very limited uncertainty / variability modeling)

Include other GI interventions

- Right-of-way green infrastructure retrofits (e.g., complete streets)
- Trees

Collaborate with others to complete the “total cost” curve

Gray and green model results can be integrated using total cost curves.



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Advisory board members for phase I