Clean Water Act
have
have  

want
have do want
have → do → want
“There are no mistakes"
Pond

Bioswale
Time

Water level, erosion, etc.

Pre-construction

Post-construction
Site 1

Water level, erosion, etc.

Time

Pre-construction

Post-construction
Site 1

Site 2

Water level, erosion, etc.

Time

Pre-construction

Post-construction
Site 1
Site 2

Time

Water level, erosion, etc.

Better

Pre-construction
Post-construction
Site 1

Site 2

Water level, erosion, etc.

Time

Better

Better

Pre-construction

Post-construction

1

2

D

Ann Arbor

Huron River at Gallop Park

Wrightenaw
Site 1
Site 2
Downstream

Water level, erosion, etc.

Time

Better
Better

Pre-construction
Post-construction
Site 1

Site 2

Downstream

Water level, erosion, etc.

Time

Better

Better

Worse?

Pre-construction

Post-construction
Water level, erosion, etc.

Site 1: Pre-construction - Better
Post-construction - Better

Site 2: Pre-construction - Better
Post-construction - Worse?

Downstream

Time
do
have do measure want
have → do → measure → want

adapt
have → do → measure → want
2x sediment capture
6x dissolved nutrient capture
Downstream point

Neighborhood 1

Neighborhood 2

Water level

Time

Flooding/Erosion
Downstream point

Neighborhood 1

Controller

Neighborhood 2

Time

Water level

With Control

Without Control

Flooding/Erosion

With and Without Control

Downstream point

Neighborhood 1

Controller

Neighborhood 2

Water level

Time

With Control

Without Control

Flooding/Erosion

With and Without Control

Downstream point
Downstream
Downstream

Upstream

Downstream
Before
• 15 Million Gallons Storage
• $22/gal
• 600 lb/yr Total P

After
• 22.5 million Gallons
• $16/gal
• 800 lb/yr Total P
Sheehan estimated that prior to installing Open Storm, it cost Ann Arbor $22 per gallon to drain storm water. That cost has dropped to $16 per gallon, roughly saving the city $1 million in infrastructure costs thanks primarily to the water valve, which costs only a few thousand dollars.
Outlet

Mary Beth Doyle (ARB018)

10 sq. mi.
scale?
100+ Sensors

20+ Control Points
Reprogram the System

400 ML sewer Overflow Reduction

VS

Build More

400 ML storage $500 Million
Storm Duration

Storm Intensity

Breaking point
AI = Math

\[ F_{1,1} \quad \Psi_{1,2} \quad 0 \quad 0 \quad 0 \quad 0 \]
\[ \Phi_{2,1} \quad F_{2,2} \quad \Psi_{2,3} \quad 0 \quad \Psi_{2,5} \quad 0 \]
\[ 0 \quad \Phi_{3,2} \quad F_{3,3} \quad \Psi_{3,4} \quad \Phi_{3,5} \quad 0 \]
\[ 0 \quad 0 \quad 0 \quad 1 \quad 0 \quad 0 \]
\[ 0 \quad 0 \quad \Phi_{5,2} \quad \Psi_{5,3} \quad 0 \quad F_{4,4} \quad \Psi_{5,6} \]
\[ 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1 \]

\[ H_{t+\Delta t} \]

\[ \begin{bmatrix} H_{1}^{t+\Delta t} \\ H_{2}^{t+\Delta t} \\ H_{3}^{t+\Delta t} \\ H_{4}^{t+\Delta t} \\ H_{5}^{t+\Delta t} \\ H_{6}^{t+\Delta t} \end{bmatrix} \]

\[ G_{1} \\ G_{2} \\ G_{3} \\ G_{4} \\ G_{5} \\ G_{6} \]

System control outflows:

\[ Q(k) = -Kx(k) \]

\[ J = \rho \cdot x^T(N)Qx(N) + \sum_{k=0}^{K-1}(\rho \cdot x^T(k)Qx(k) + u^T(k)Ru(k)) \]

\[ K = (R + B_u^T P B_u)^{-1} B_u^T PA \]

\[ Q = Q^T = \begin{bmatrix} I_{11} & 0 \\ 0 & 0 \end{bmatrix} \geq 0, R = R^T = I \# valvess > 0 \]

\[ \rho = 3500 \]

Algorithm 1 Load balancing control

**Inputs:** \( S_i \) (states), \( S^i_t \) (setpoints), \( a_i \) (system importances), \( \rho \) (instantaneous importance weight), \( I_C \) (controlled assets), \( I_U \) (uncontrolled assets)

1. for \( t \in T \) do
2.     for \( i \in (I_C \cup I_U) \) do
3.         if \( i \in I_C \) then
4.             \( \gamma_i(t) = \frac{a_i}{\sum a_i} \frac{S_i(t) - S^i_t}{S^i_t - S_i(t)} \)
5.         else
6.             \( \gamma_i(t) = 1 \)
7.     \( \beta_i(t) = a_i \cdot \gamma_i(t) \)
8.     \( \bar{C}(t) = \frac{1}{n} \sum_{i=1}^{n} \beta_i(t) \cdot (S_i(t) - S^i_t) \)
9.     if \( i \in I_C \) and \( \bar{C}(t) > \bar{C}^i(t) \) then
10.        \( J \leftarrow J \cup \{i\} \)
11.     end for
12. end for
13. end for