

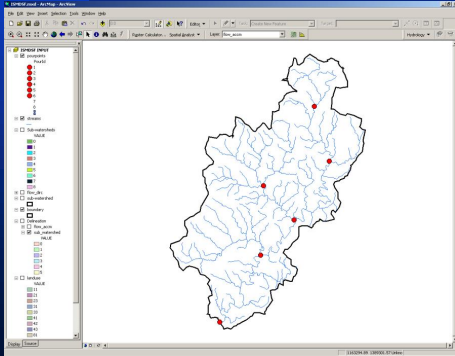
BMP-Decision Support System (BMP-DSS) Phase II

In
Prince George's County
Maryland



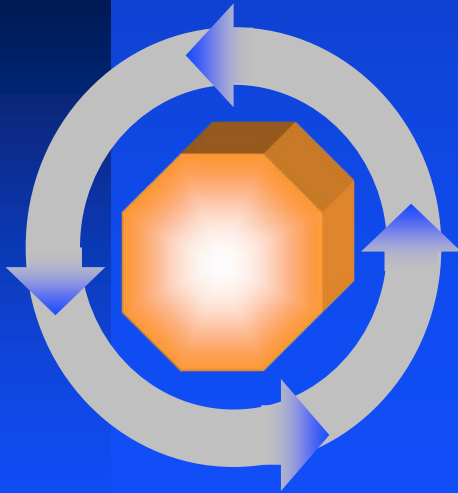
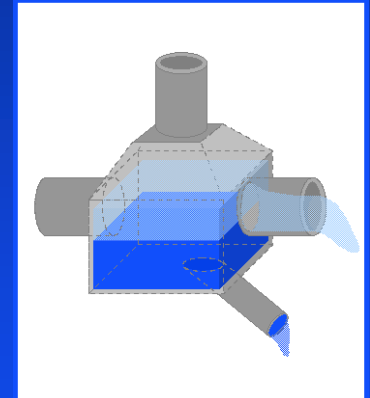
**BMP Decision Support System
for
Watershed-based Stormwater Management**

Major Module Enhancements



GIS Linkage

LID – CSO Linkage



Optimization

Project Team Members

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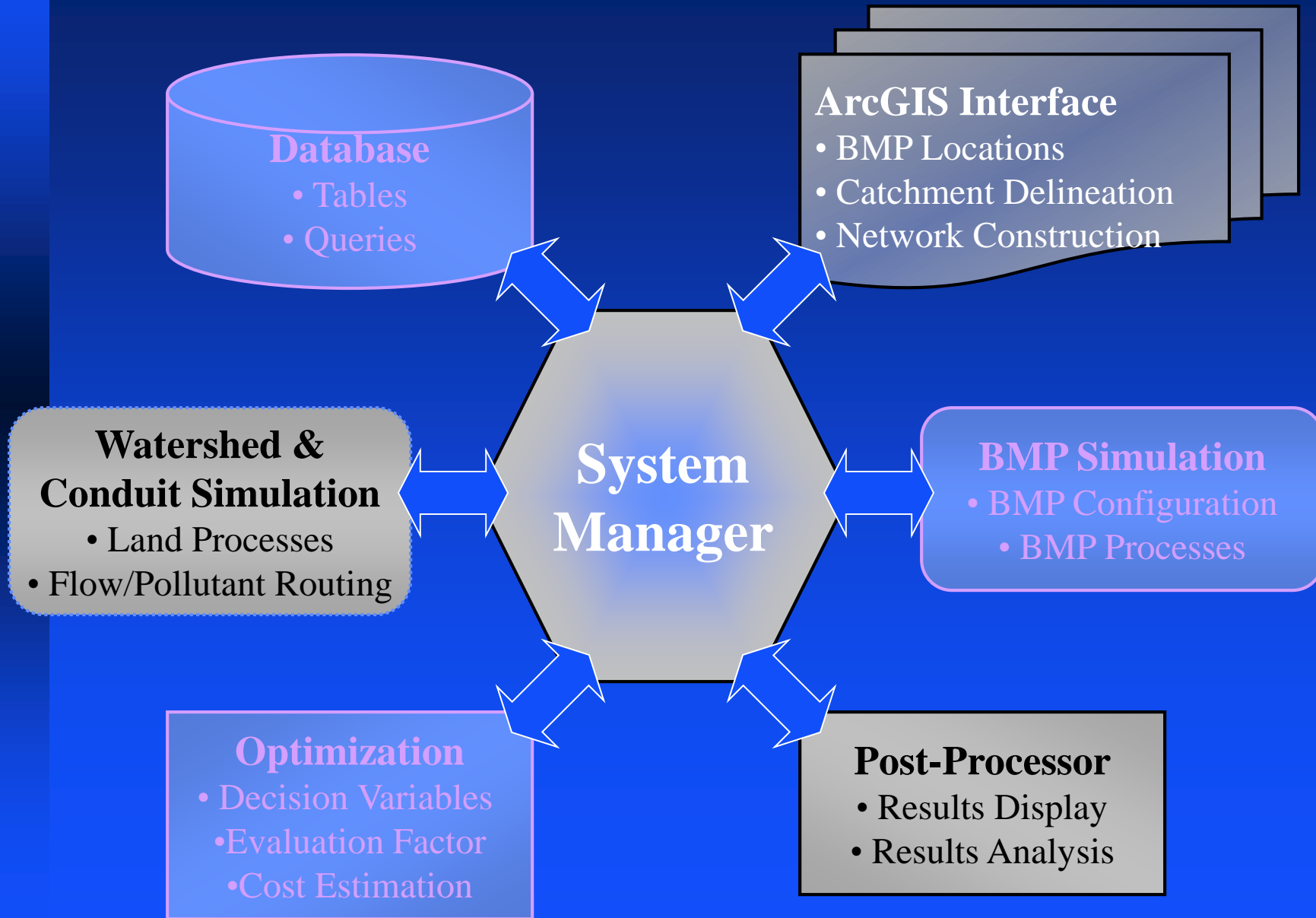
Haihong Yang

Mira Chokshi

Dr. Sabu Paul

Priya Krishnan

System Overview



ArcGIS Map Interface

BMP Model Input File

BMP Simulation/Optimization DLL

Input File Loader

Changeable Variables (C810)
(num, min, max, increment)
Control Target (C830)

Initial BMP Input Values

BMP Model Runner

Routing Sequence

BMP-A Calculation

BMP-B Calculation

Cost Calculation

Evaluation Factor Calculation

Initial Run Results:
Evaluation Factor
& Cost Values

New
changeable
variable
values

Evaluation Factor
& Cost Values

BMP Optimizer

feed new possible
solution to runner
based on previous
simulation result

Solution

Minimum Software Requirements:

Microsoft Office 2000 Professional

ArcView 9.x

ArcGIS Spatial Analyst

Watershed & Conduit Module

System uses externally generated land use-associated time series

System applies SWMM TRANSPORT algorithms for conduit routing simulation

Accesses all subroutines and functions through a DLL (dynamic link library)

BMP Module – GIS Linkage

Land use Functions

Reclassify or group land use

Time series association

BMP Functions

Add/Remove BMP

Modify existing BMP

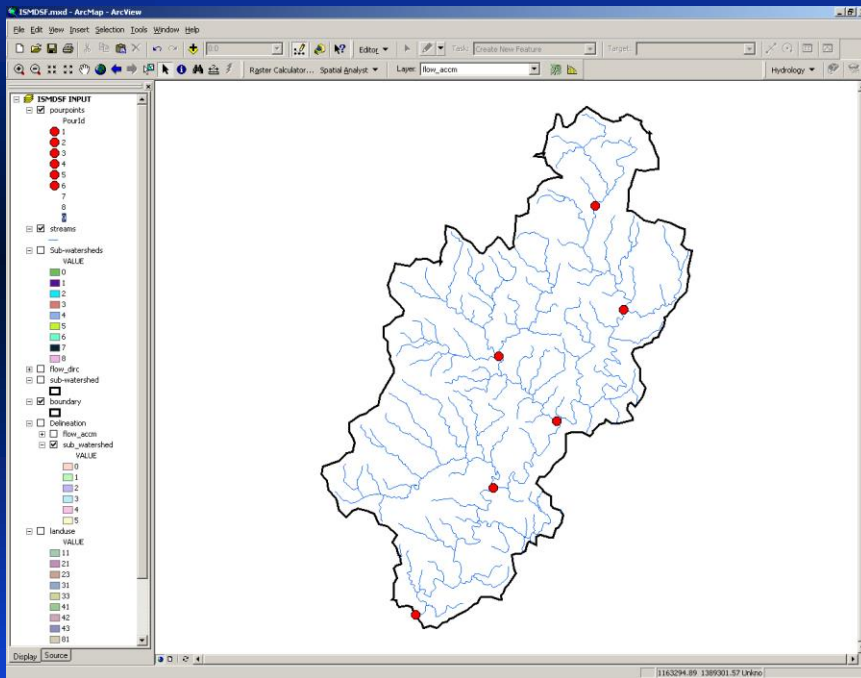
Select from list

GIS/System Functions

Delineate watershed or BMP
drainage area

Generate network

Run model scenario(s)

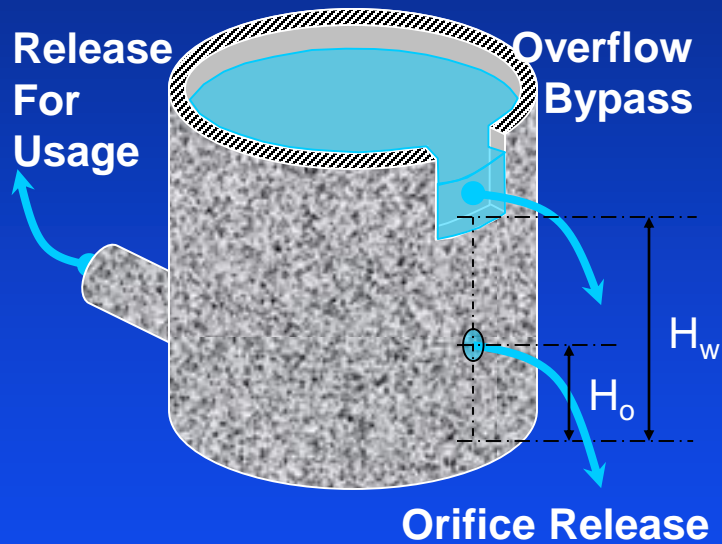


BMP Options



Additional BMPs: Cistern/Rain Barrel Functionality

- Function of stored volume, release rates, and water level
- Variable time step calculation



Output:

Weir Overflow
Orifice Release

Release For Usage

When cistern water is pumped for domestic use, the modeler can define an hourly per-capita usage rate and the number of people

Orifice Release

The modeler defines the number of dry days following a storm event, after which water from a rain-barrel is released.

ISMDSF INPUT

- pourpoints
PourId
1-8
- streams
- Sub-watersheds
VALUE
0-8
- flow_dirc
- sub-watershed
- boundary
- Delineation
- landuse
VALUE
11-92
- DEM_grd

BMP Placement

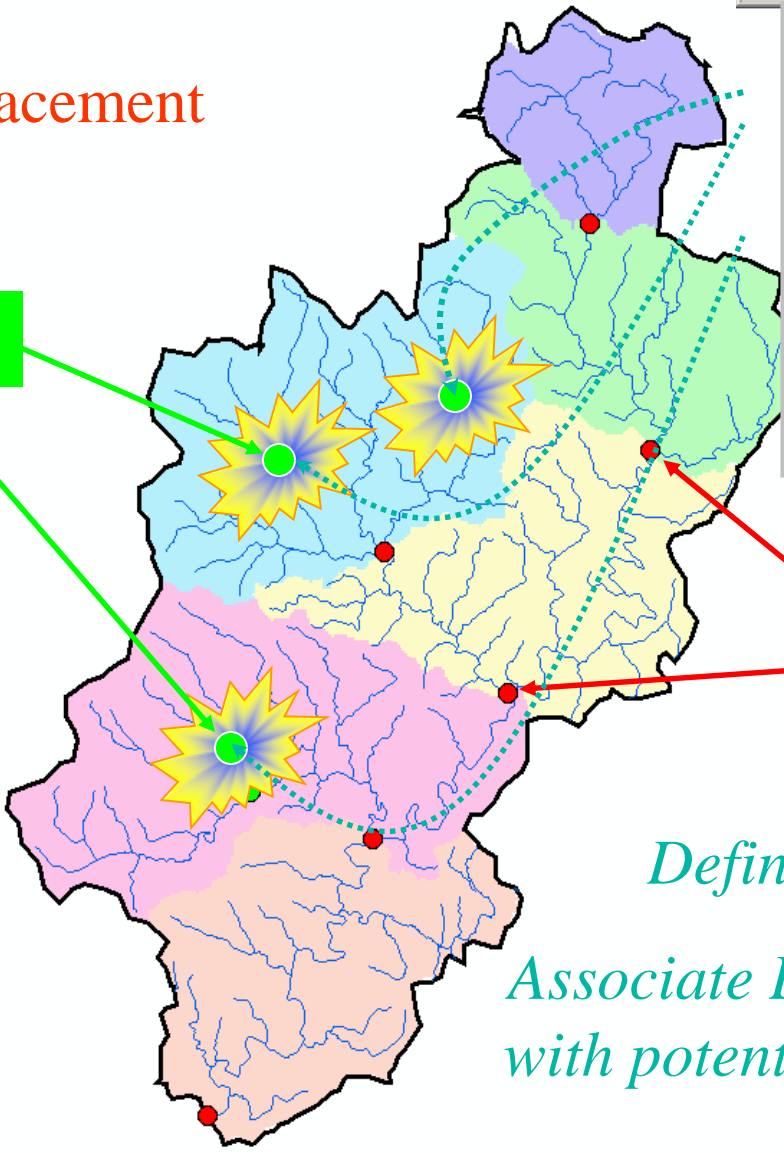
BMPs

BMPs

BMP Types:

- 1 Buffer_Zone
- 2 Bioretention_Basin
- 3 Detention_Basin
- 4 Dry_Well
- 5 Filter_Strip
- 6 Sand_Filter
- 7 Level_Spreader
- 8 Grassed_Swale
- 9 Rain_Barrels
- 10 Cistern
- 11 Infiltration_Trench

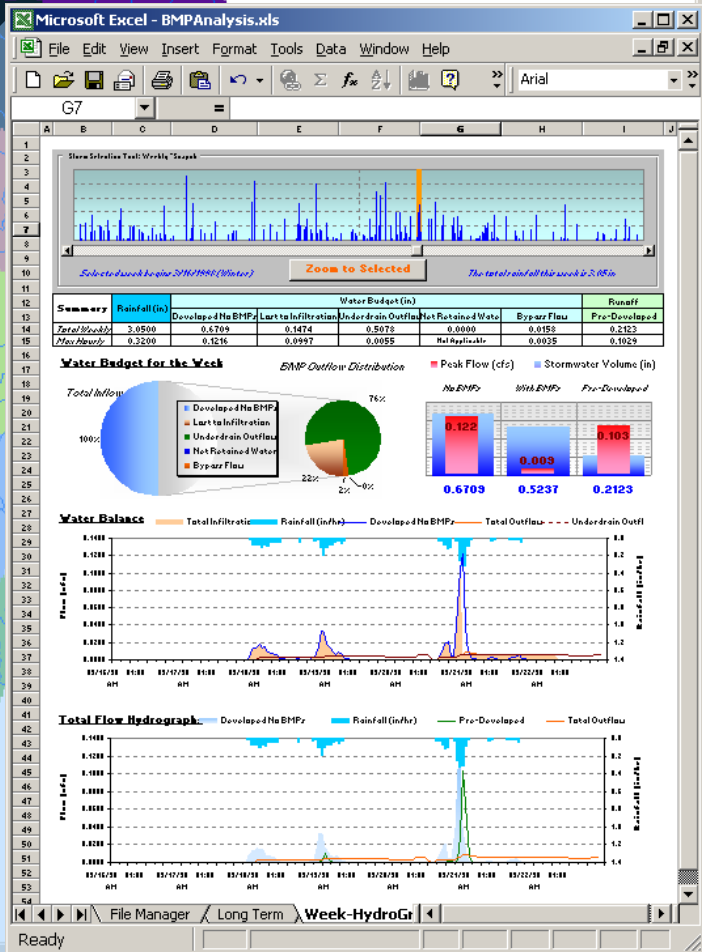
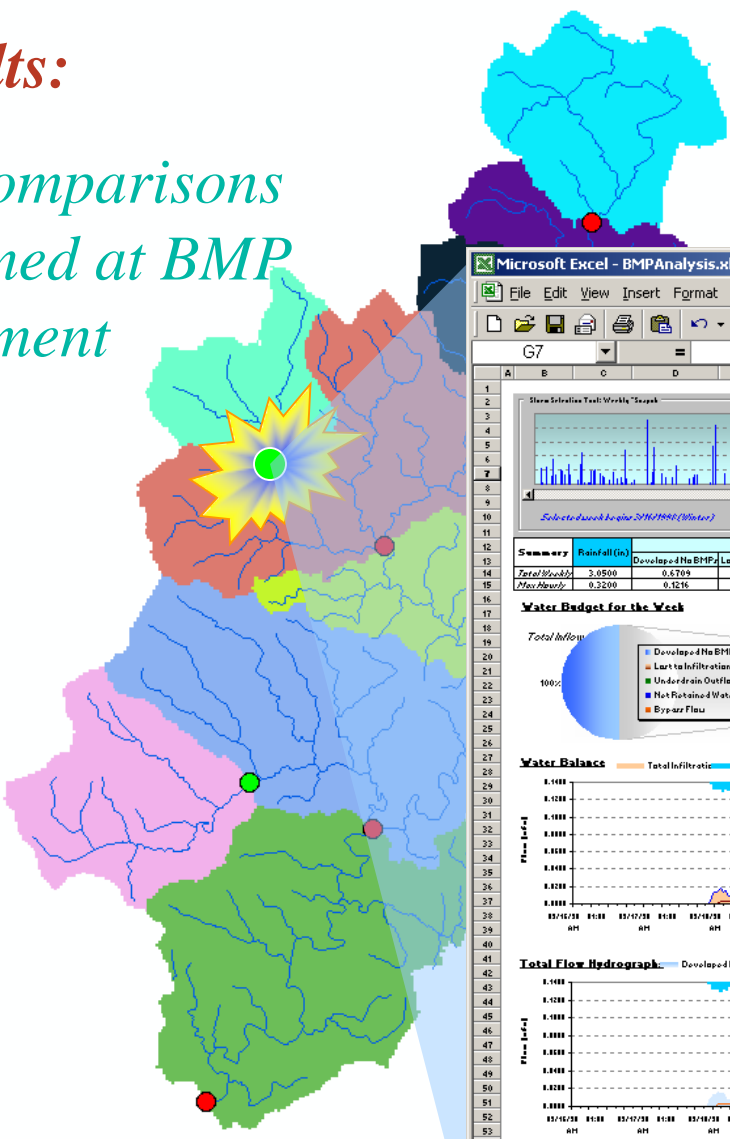
Outlets



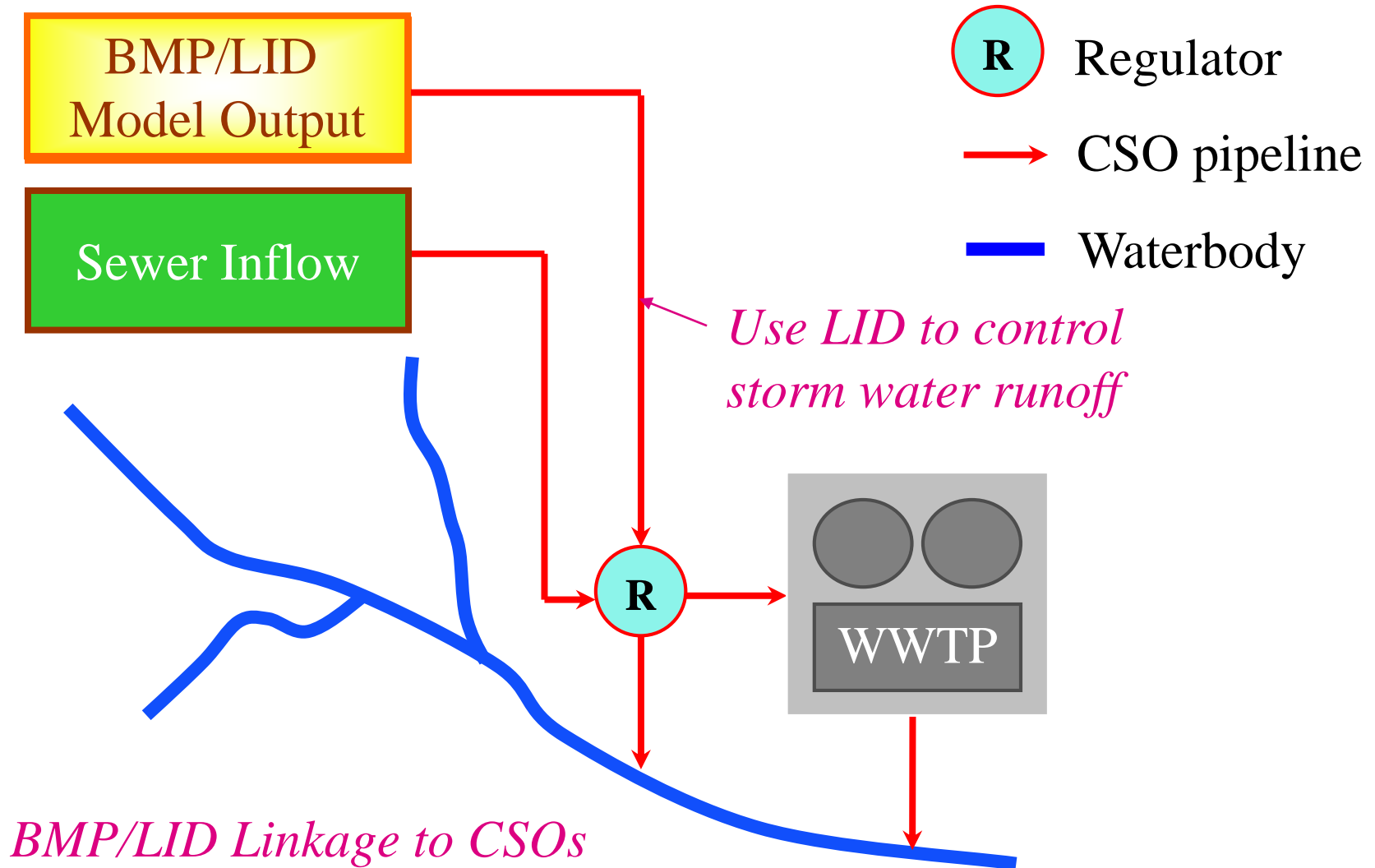
*Define Scenarios:
Associate BMP designs
with potential locations*

- ISMDSF INPUT
 - pourpoints
 - PourId
 - 1
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - 9
 - streams
 - Sub-watersheds
 - VALUE
 - 0
 - 1
 - 2
 - 3
 - 4
 - 5
 - 6
 - 7
 - 8
 - flow_dirc
 - sub-watershed
 - boundary
 - Delineation
 - flow_accm
 - sub_watershed
 - VALUE
 - 0
 - 1
 - 2
 - 3
 - 4
 - 5
 - landuse
 - VALUE
 - 11
 - 21
 - 23
 - 31
 - 33
 - 41
 - 42
 - 43
 - 61

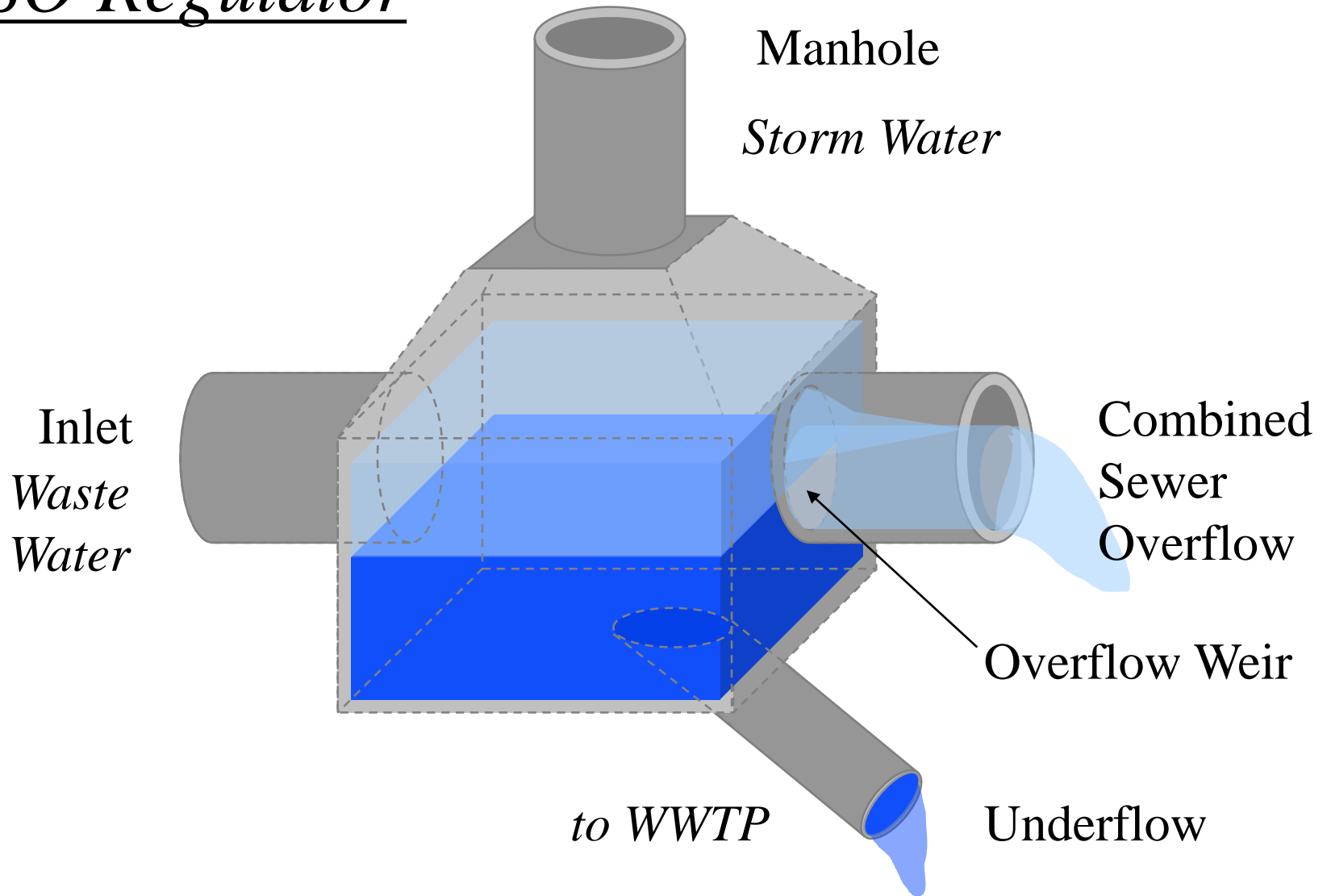
View Results:
Scenario comparisons
are performed at BMP
and assessment
locations



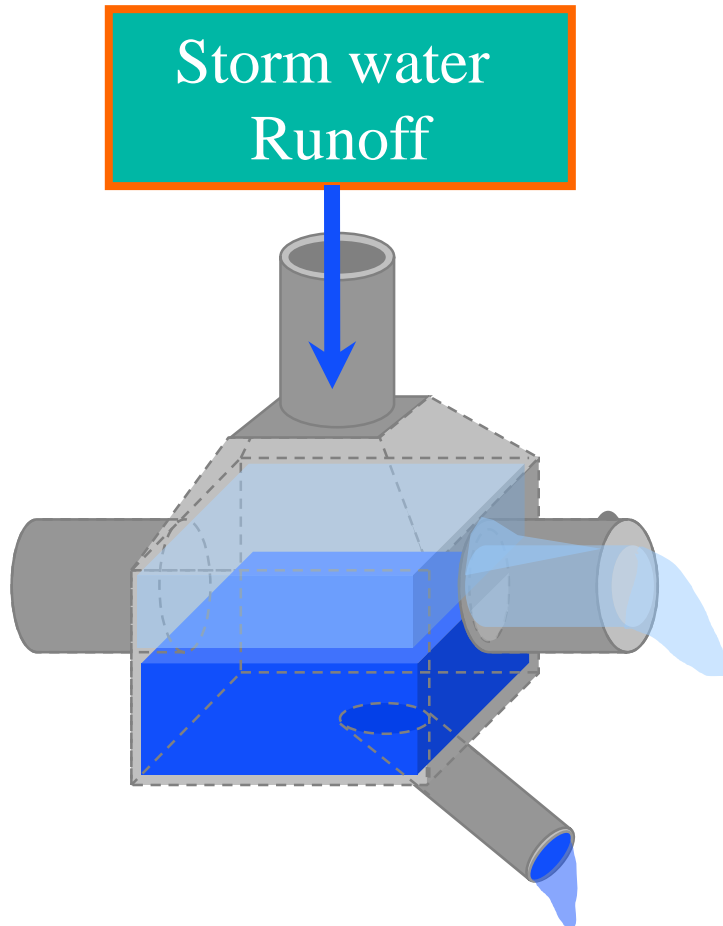
The Effects of LID on CSOs



CSO Regulator

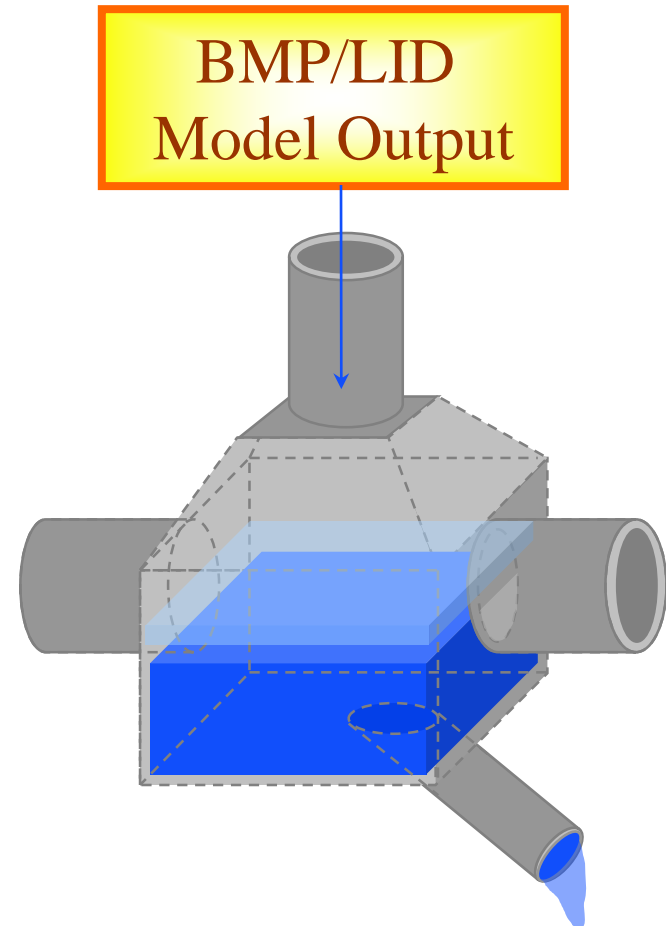


Existing CSO Model



Sewer Overflows Observed

BMP/LID Linkage to CSOs



CSOs Reduced or Eliminated



Optimization

Problem Formulation

Objectives & constraints

Evaluation factors & assessment points

Potential BMP types and locations

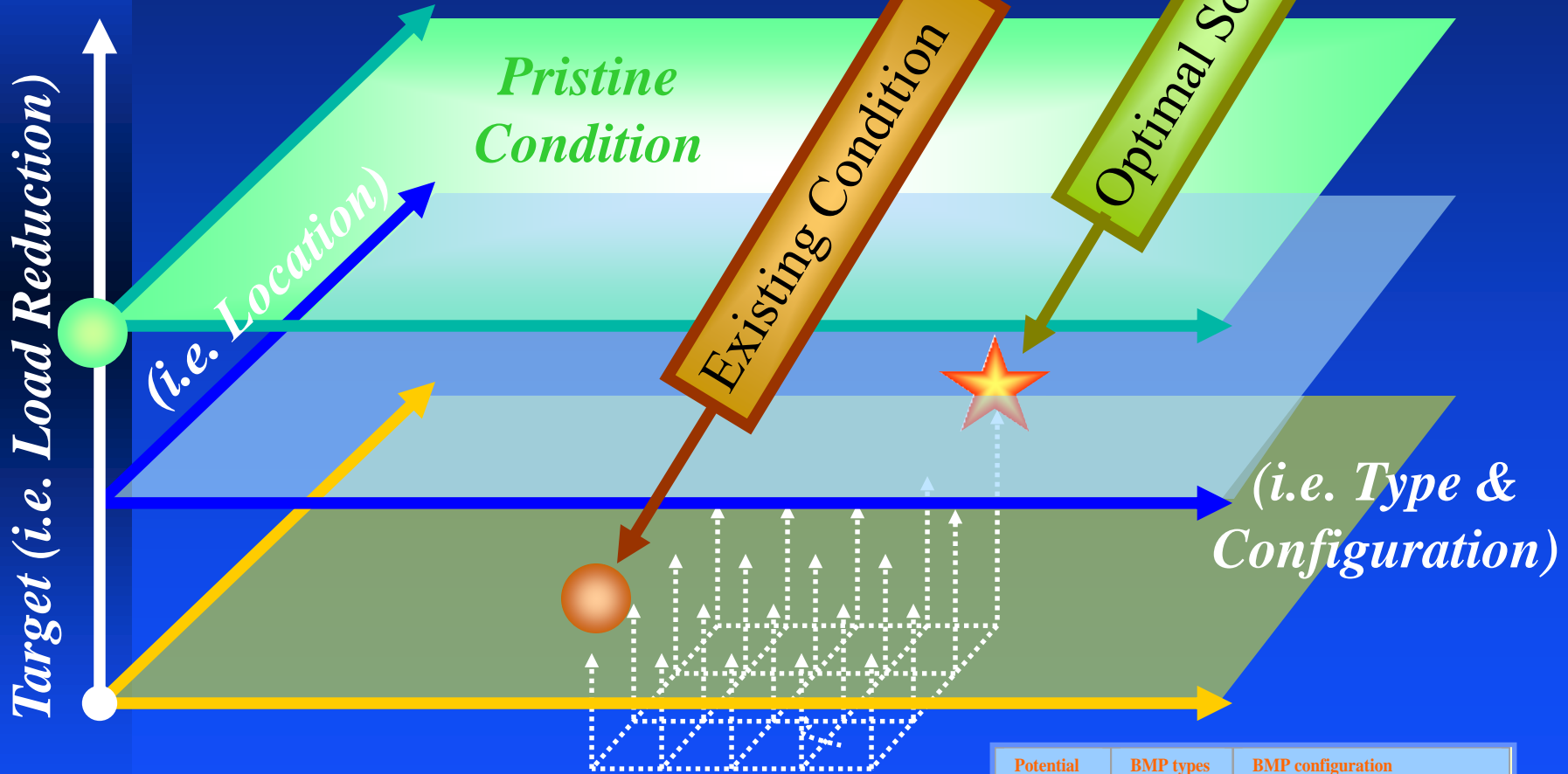
Solution Techniques

Scatter search

Genetic algorithm



Optimization



Feasible Alternatives

Potential Location	BMP types	BMP configuration		
1 (0-1)	A, B, C...	Depth	Surface area	...
2 (0-1)	A, B, C...	Depth	Surface area	...



Defining BMP Optimization

Find *optimum* BMP placement and selection strategies based on pre-selected potential sites and applicable BMP types.

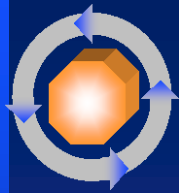
What is optimum? (Problem Formulation)

- Minimize water quantity and pollutant load (same cost)
- Minimize total cost (same load reduction)

How does one measure optimum?

Evaluation Criteria: (using continuous simulation)

- Minimum long-term flows and pollutant loads with an pre-defined budget
- Lowest cost among various alternatives to yield the same load reductions



Optimization Procedure

Two common methods, **Genetic Algorithms** and **Scatter Search**, are both **population-based** approaches that select alternatives from within a set range of attributes present within the population.

Genetic Algorithm – *Stochastic Method*

Uses **probabilistic** rather than **deterministic** search rules.

Uses **randomization** to select which “elements” of “parent” alternatives are combined to generate “offspring.”

Strongest “offspring” elements are used in the “next generation”

Scatter Search – *Strategic Method*

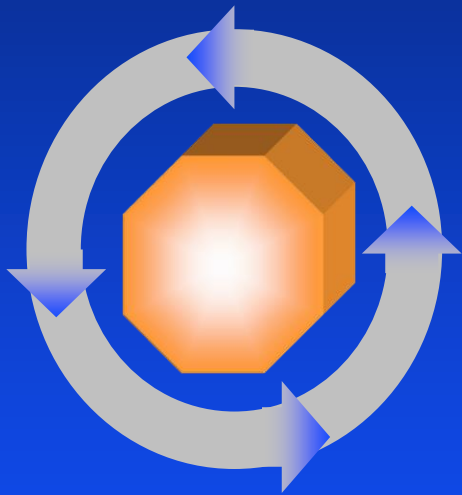
Uses both deterministic and probabilistic search rules

Not **randomized** – treats all alternatives equal at the start

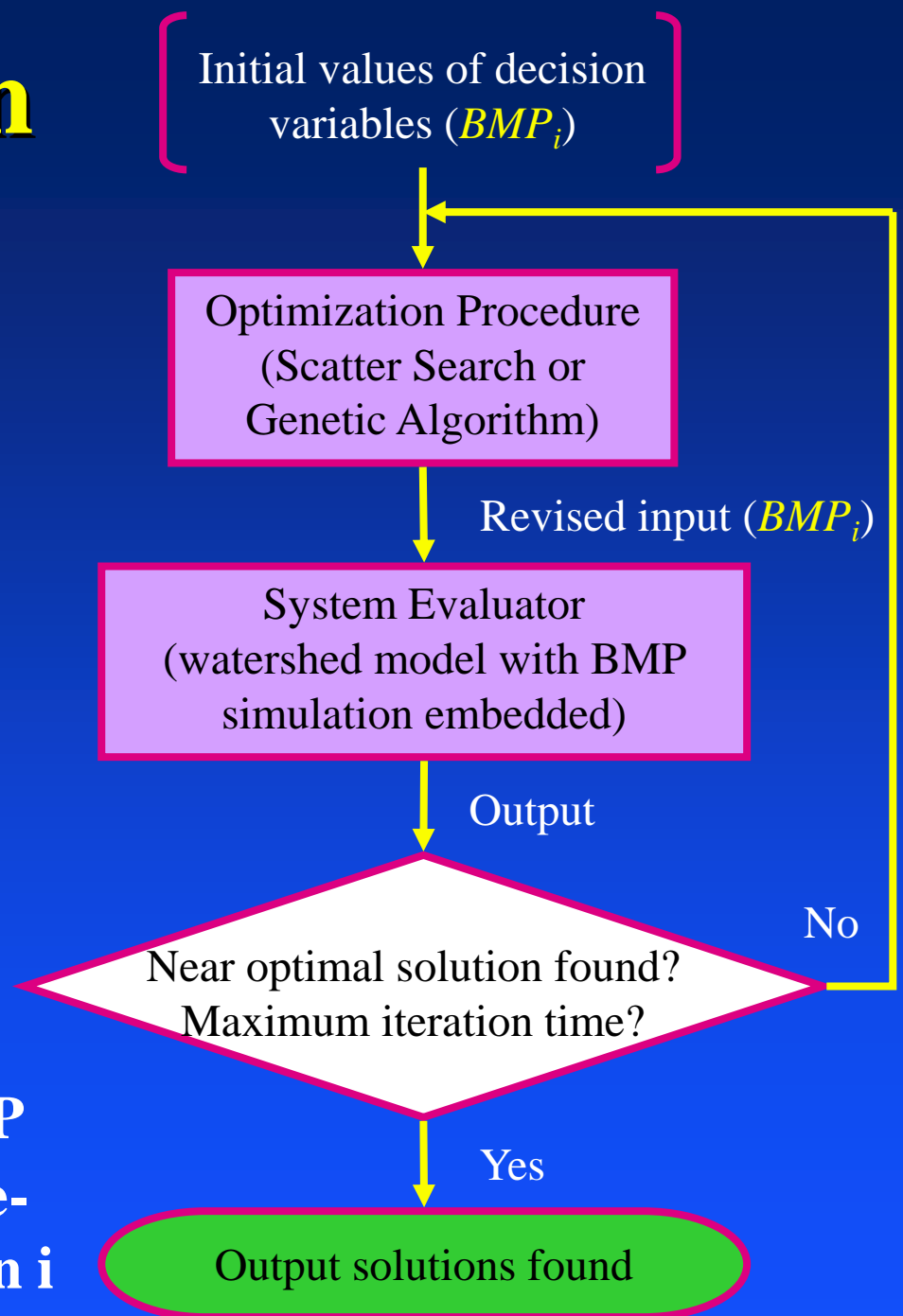
Narrows search based on system response and history

Optimization Flow Chart

For BMP_i^*



* BMP_i is a set of BMP decision variables for pre-selected potential location i



Optimization Decision Matrix

A group of BMP_i ($i = 1, \dots, n$) forms the decision matrix, which defines the optimization engine's search domain:

Potential Location	BMP Type	BMP Configuration Parameters				
		1	2	3	...	m
1	A1 (wet pond)	Surface area	Pool depth	Outlet structure		
	A2 (Bio-retention)	Surface area	Outlet structure	Soil column depth	Surface infiltration rate	Final infiltration rate
2	C (buffer strip)	Length	Width	Slope	Vegetation height	Overland manning's n
...						
n	B1 (swale)	Length	Width	Slope	Manning's n	

GIS Interface

The screenshot displays the ArcMap - ArcView interface for the BMP Decision Support System. The main window shows a map of a watershed with various features and junctions. The menu is open, listing several options for data management and simulation.

Menu Options:

- Data Management
- Assign Time Series
- Define BMP Template
- Add Off-stream BMP
- Add On-stream BMP
- Delineate Drainage Area
- Define Drainage Area to BMP Connection
- Define Routing Network
- Create Schematic Layer
- Define Assessment Point
- Optimization Setup
- Create Input File
- Edit/View Input File
- Run Simulation
- View Simulation Results
- About BMPDSS

Layers Panel:

- SubWatershed
- Conduits
 - OUTLETTYPE
 - Total
- BasinRouting
- BMPs
 - Type
 - PorousPaveme
 - GreenRoof
 - RainBarrel
 - BioRetentionBa
 - JunctionX
 - Junction
- Watershed
 - ID
- landuse
 - 1
 - 3
 - 4
 - 5
 - 20
- streams

GIS Interface Functions

BMP Decision Support System

Data Management

Assign Time Series

Define BMP Template



Add Off-stream BMP



Add On-stream BMP

Delineate Drainage Area



Define Drainage Area to BMP Connection



Define Routing Network

Create Schematic Layer

Define Assessment Point

Optimization Setup

Create Input File

Edit/View Input File

Run Simulation

View Simulation Results

About BMPDSS

Data Management

The image shows the ArcMap interface with the 'Data Management' menu open. An orange arrow points from the menu item to the 'Data Management' dialog box. The dialog box contains the following settings:

Category	Field	Value	Action
Datasets	Define landuse layer	landuse	Folder icon
	Define landuse lookup table	LULOOKUP	Folder icon
	Define project workspace directory	C:\BMPDSS\TempSBS_sp1	Folder icon
Datasets (required for automatic delineation only)	Define DEM layer	dem2	Folder icon
	Define stream layer	streams	Folder icon

Buttons: OK, Cancel

Assign Time Series

SBStest - ArcMap - ArcView

File Edit View Insert Selection Tools Window

BMP Decision Support System

Data Management

Assign Time Series

Define BMP Template

Add Off-stream BMP

Add On-stream BMP

Delineate Drainage Area

Define Drainage Area to BMP Connection

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View Simulation Results

About BMPDSS

Time Series Assignment for Landuse

① Select Input Landuse Types

Landuse Code	Landuse Description
1	Building
20	Grassland
3	Roads
4	Sidewalk
5	Woods

OK

Cancel

② Landuse Group

Forest

③ Percentage Imperviousness

0

④ Pervious Time Series File

...

⑤ Impervious Time Series File

...

⑥ Add New or Remove Existing Landuse Groups

Add ↓↓

Remove ↑↑

Landuse...	Landuse Description	Impervious ?	Percentage	Time Series File
------------	---------------------	--------------	------------	------------------

LAND SIMULATION

✓ External time series generated using HSPF

Time Series Assignment for Landuse

① Select Input Landuse Types

Landuse Code	Landuse Description
5	Woods

OK
Cancel

② Landuse Group: Forest

③ Percentage Imperviousness: 2

④ Pervious Time Series File: C:\BMPDSS\data\Dataset1\Timeseries\forest.out

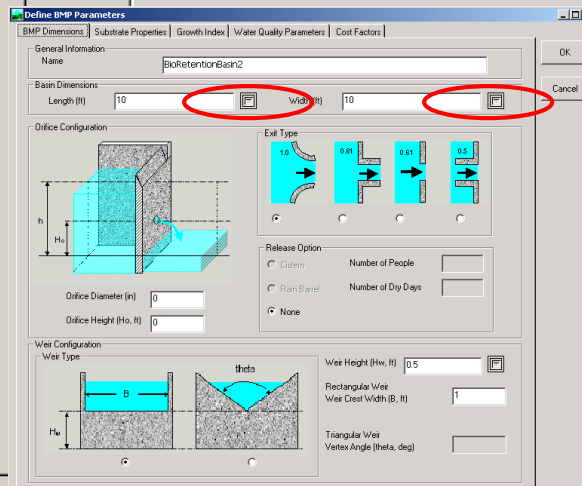
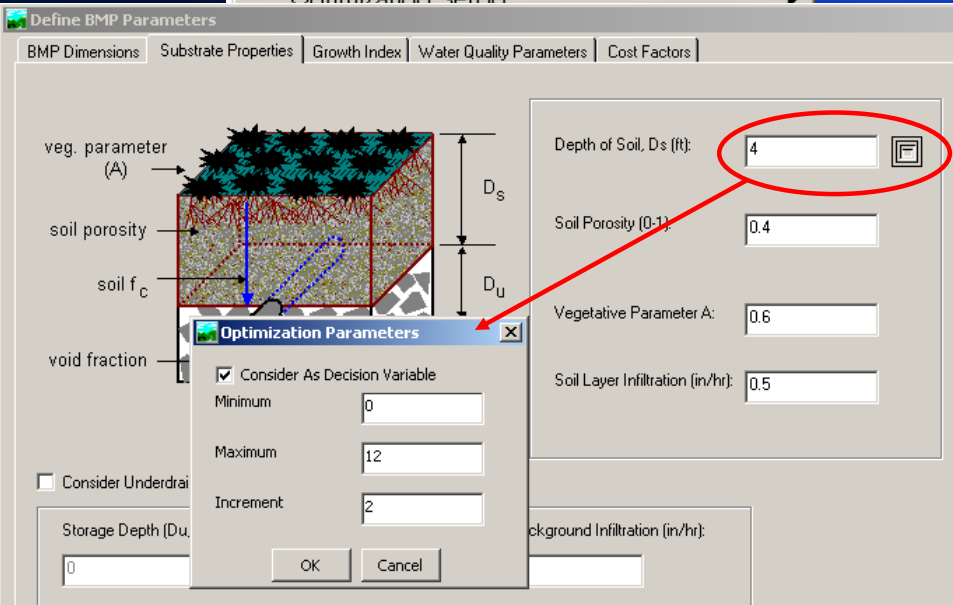
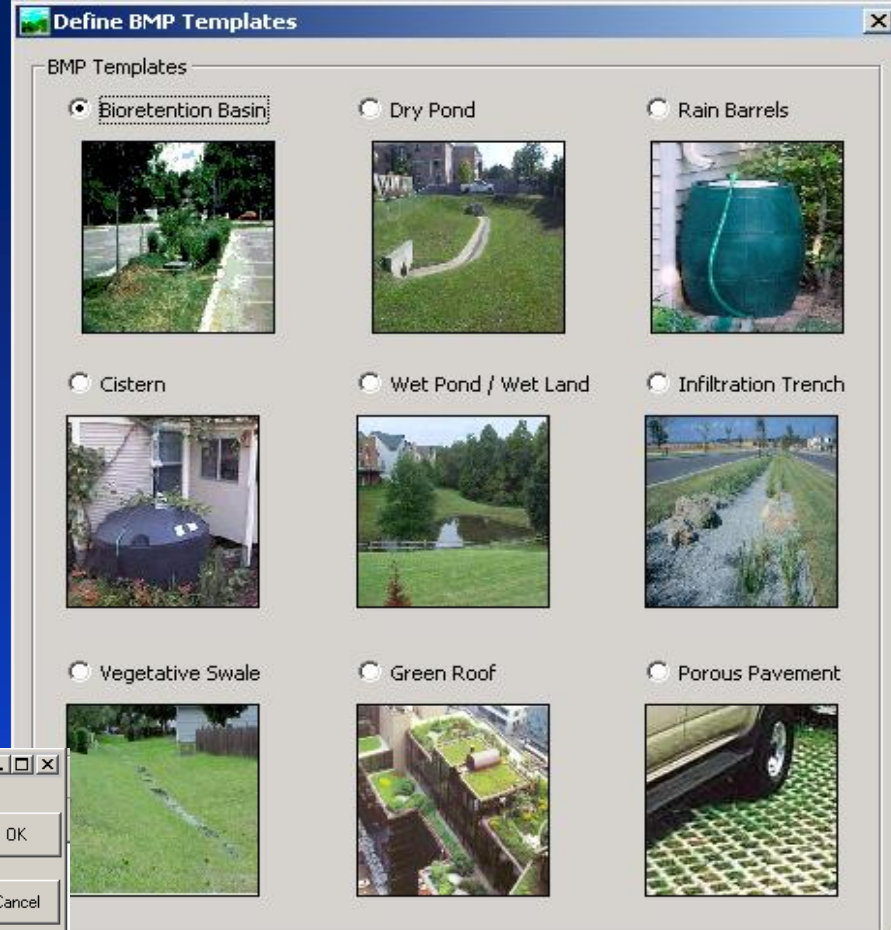
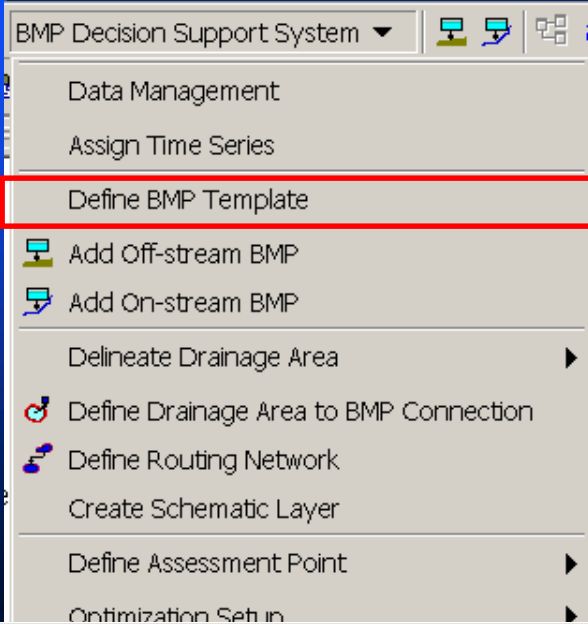
⑤ Impervious Time Series File: C:\BMPDSS\data\Dataset1\Timeseries\ldr-i.out

⑥ Add New or Remove Existing Landuse Groups

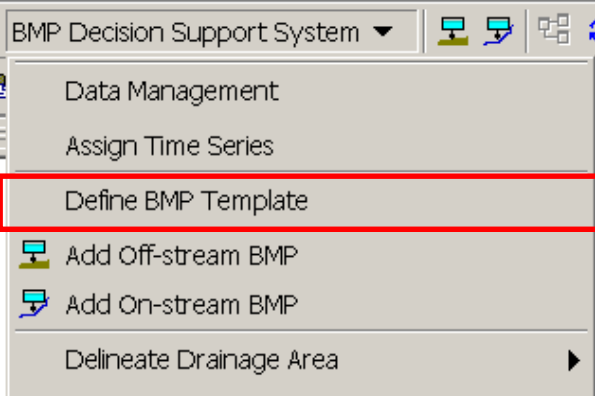
Add ↓↓ Remove ↑↑

Landus...	Landuse Description	Impervious ?	Percentage	Time Series File
Rooftop	Building	1	100	C:\BMPDSS\data\Dataset1\Timeser...
Agricult...	Grassland	1	2	C:\BMPDSS\data\Dataset1\Timeser...
Agricult...	Grassland	0	98	C:\BMPDSS\data\Dataset1\Timeser...
Road	Roads	1	95	C:\BMPDSS\data\Dataset1\Timeser...
Road	Sidewalk	1	100	C:\BMPDSS\data\Dataset1\Timeser...
Road	Roads	0	5	C:\BMPDSS\data\Dataset1\Timeser...

Define BMP Template



Optimization Parameters



Define BMP Template (Cont)

(Define Growth Index, Water Quality, and Cost Parameters)

Define BMP Parameters

BMP Dimensions | Substrate Properties | Growth Index | Water Quality Parameters | **Cost Factors**

Define BMP Cost Function

$$\text{Cost} = (Aa \times \text{Area}^{Ab}) \times (Da \times \text{Depth}^{Db}) + \text{Land Cost} \times \text{Area} + \text{Fixed Cost}$$

where

- Area = area excavated for BMP site (ft²),
- Depth = average depth of soil excavated (ft),
- Land Cost = unit cost of land (\$/ft),
- Fixed Cost = fixed cost (\$), and

Aa, Ab, Da, Db are coefficients of the cost function

Cost Parameters

Aa	<input type="text" value="5"/>	Ab	<input type="text" value="1"/>
Da	<input type="text" value="1"/>	Db	<input type="text" value="1"/>
Land Cost (\$/ft ²)	<input type="text" value="10"/>	Fixed Cost (\$)	<input type="text" value="1000"/>

Total Cost (\$)

OK
Cancel

BMP Decision Support System Toolbar

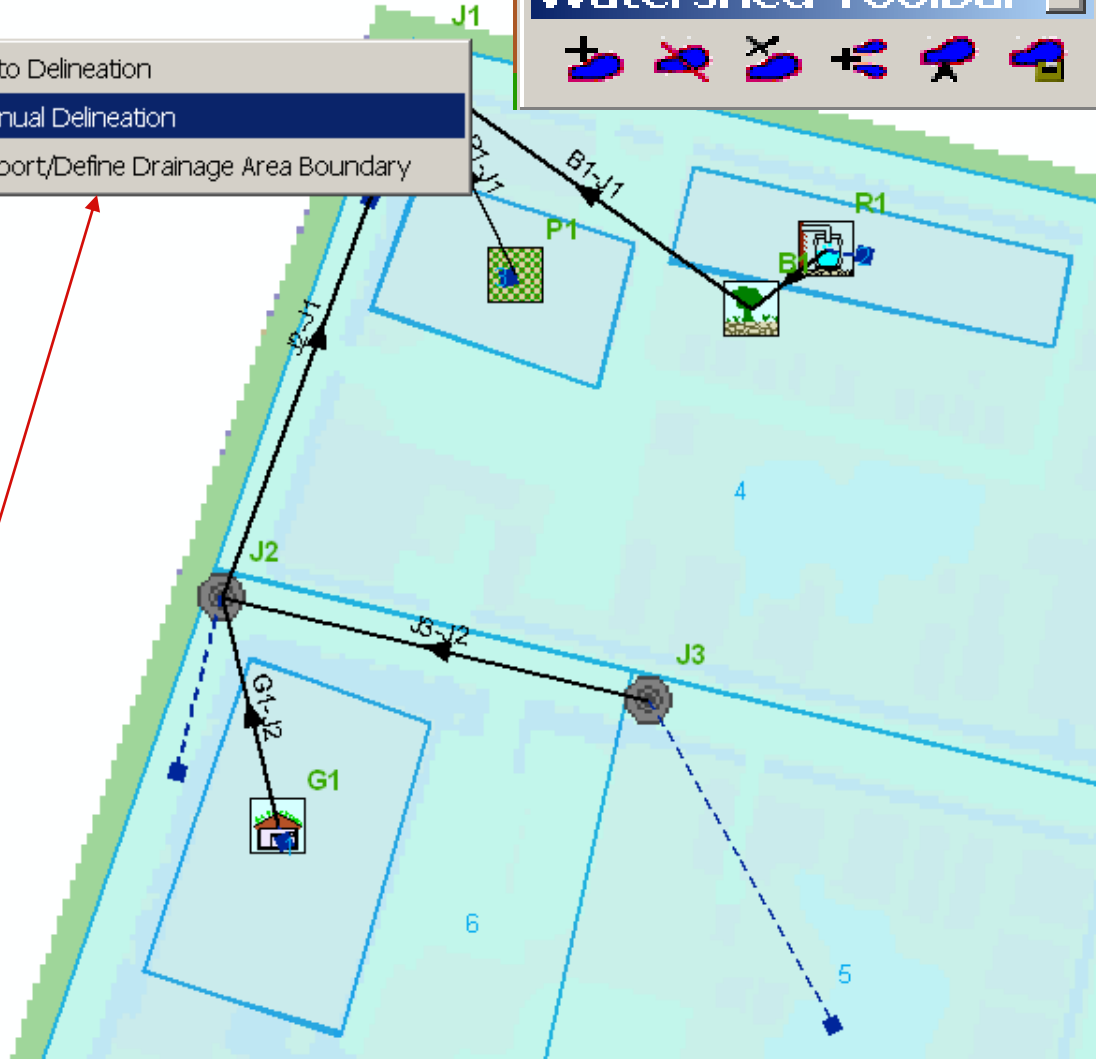
BMP Decision Support System

- Data Management
- Assign Time Series
- Define BMP Template
- Add Off-stream BMP
- Add On-stream BMP
- Delineate Drainage Area**
- Define Drainage Area to BMP Connection
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- About BMPDSS

Delineate Drainage Areas

Watershed Toolbar

- Auto Delineation
- Manual Delineation**
- Import/Define Drainage Area Boundary



Three Options

Add Off-Stream BMPs

Add On-stream BMPs

BMP Toolbar



- Building
- Road
- SideWalk
- Woods
- GrassyArea

BMP Decision Support System



Data Management

Assign Time Series

Define BMP Template

Add Off-stream BMP

Add On-stream BMP

Delineate Drainage Area

Define Drainage Area to BMP Connection

Define Routing Network

Create Schematic Layer

Define Assessment Point

Optimization Setup

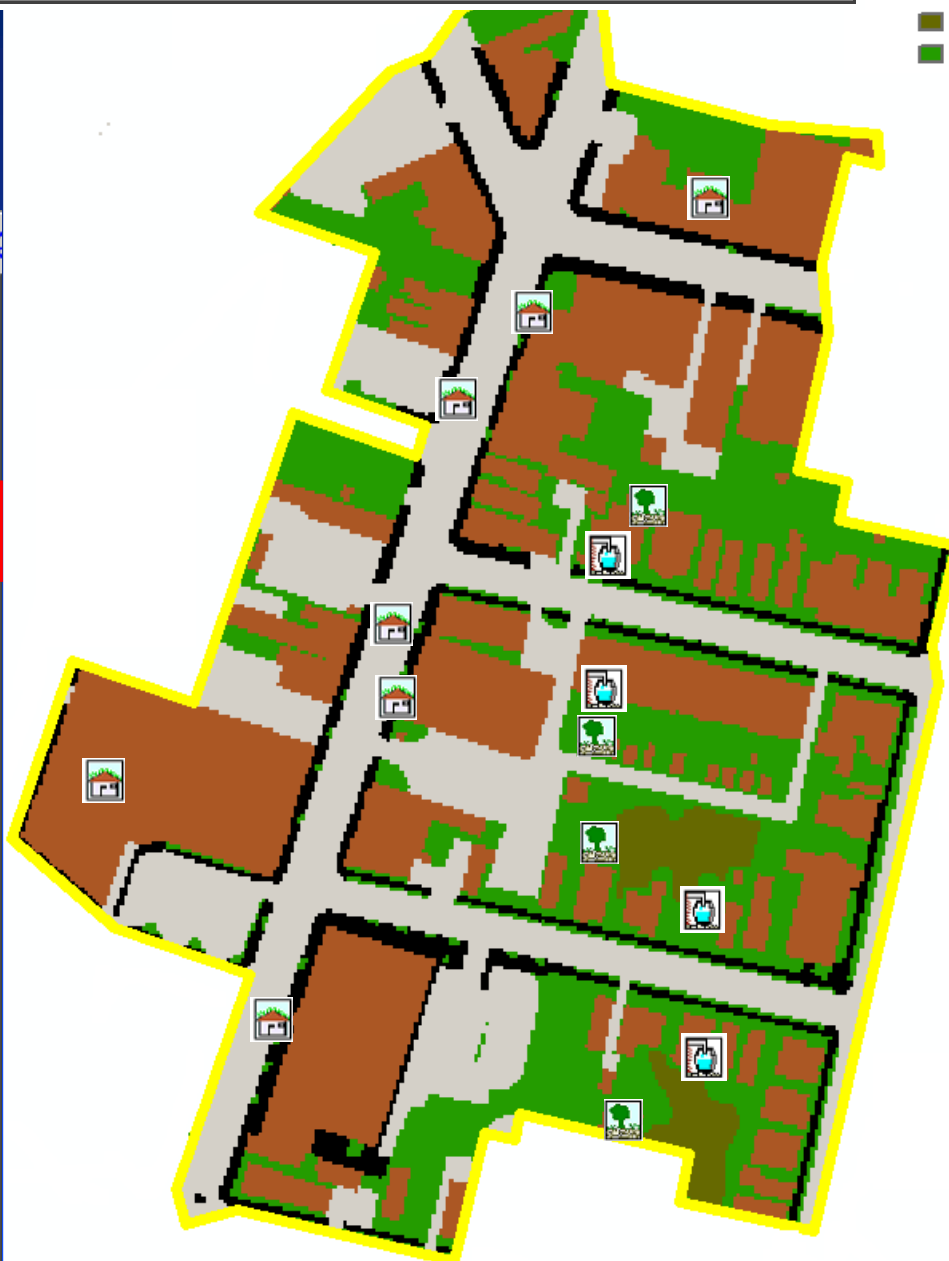
Create Input File

Edit/View Input File

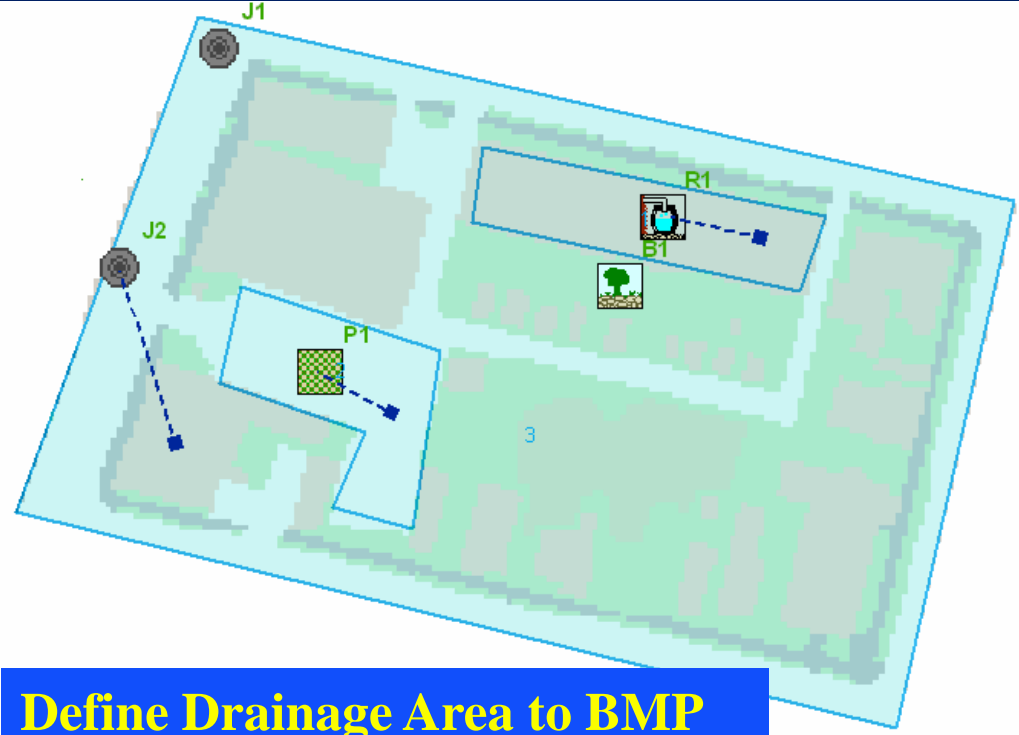
Run Simulation

View Simulation Results

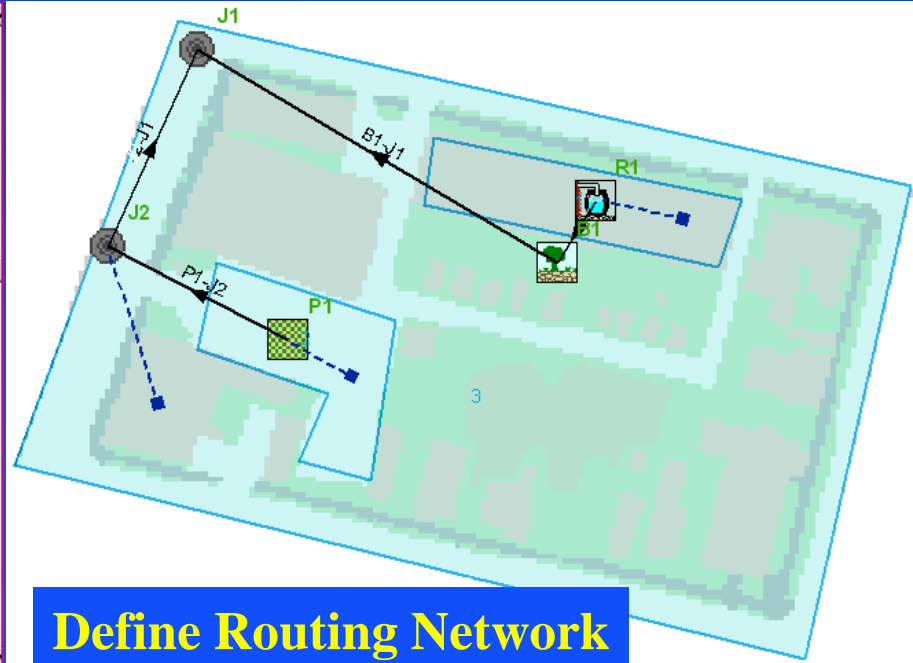
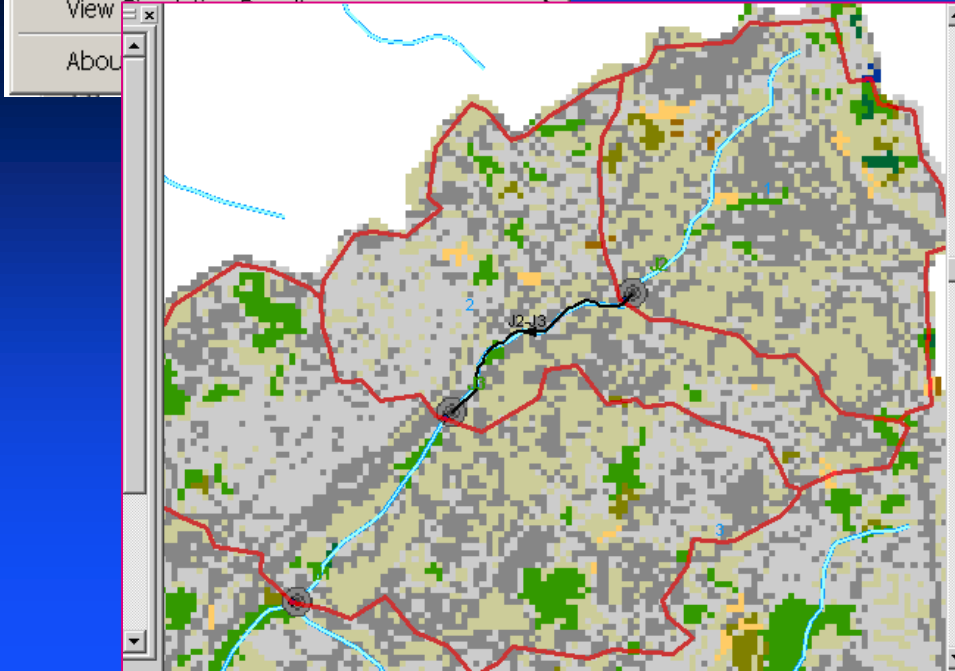
About BMPDSS



- BMP Decision Support System
- Data Management
 - Assign Time Series
 - Define BMP Template
 - Add Off-stream BMP
 - Add On-stream BMP
 - Delineate Drainage Area
 - Define Drainage Area to BMP Connection**
 - Define Routing Network**
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 - Optimization Setup
 - Create Input File
 - Edit/View Input File
 - Run Simulation



Define Drainage Area to BMP



Define Routing Network

CONVEYANCE SIMULATION

✓ SWMM TRANSPORT Module

Conduit Cross Section

Conduit Cross-section | Conduit Dimension Group | Decay Factors

Shape: RECT_TRIANGULAR

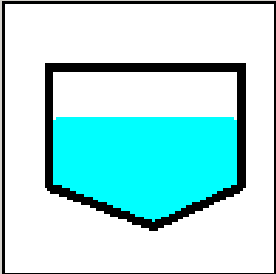
Barrels: 1

Dimensions: Feet

Max. Depth (ft.): 1

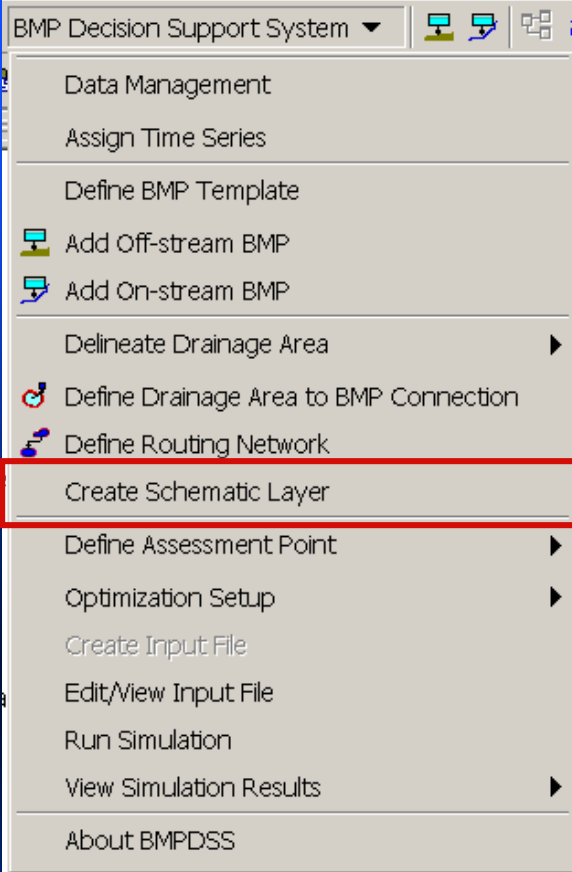
Top Width (ft.): 0

Triangle Height (ft.): 0

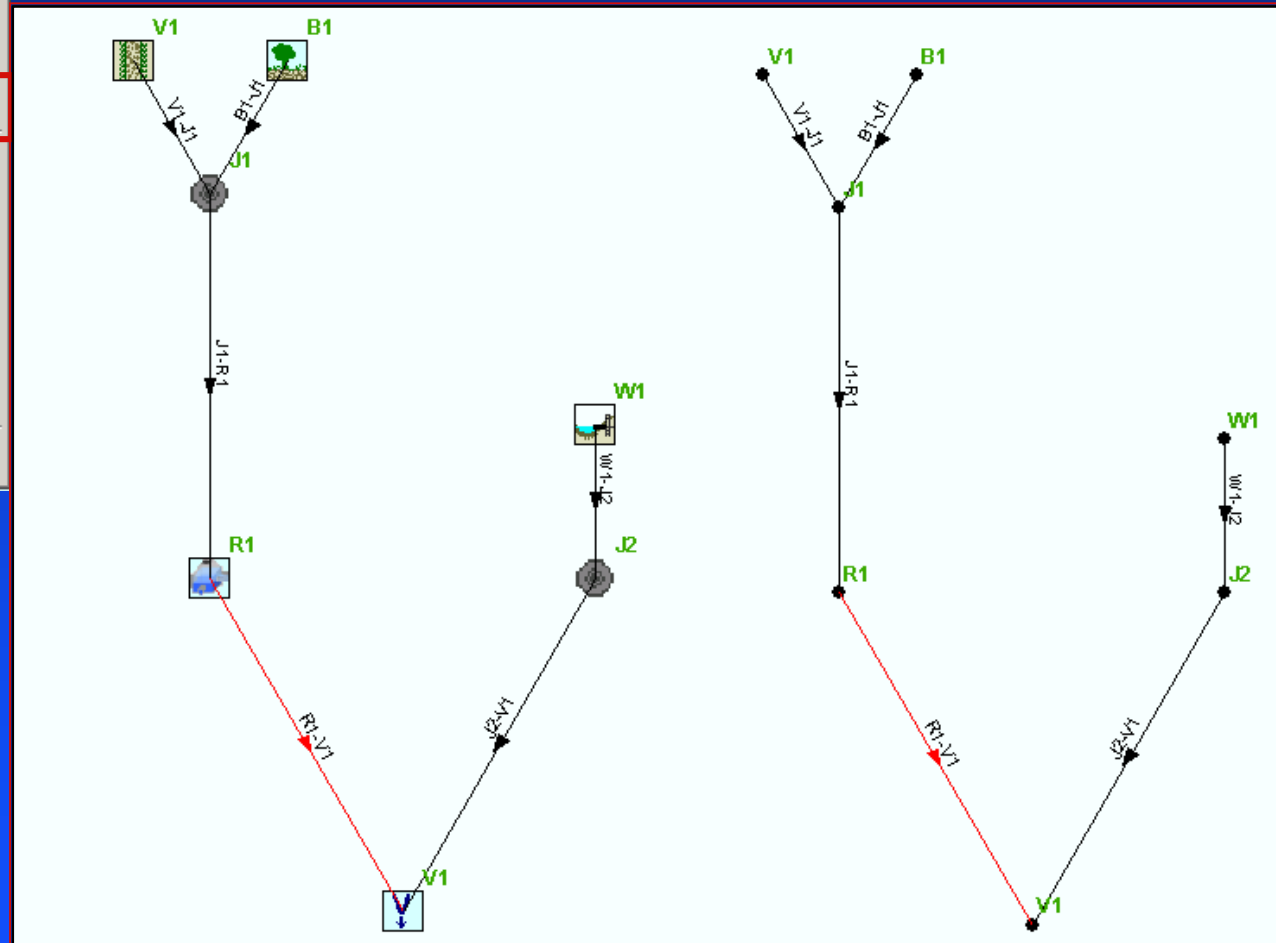


OK Cancel

The image shows a software window titled "Conduit Cross Section" with three tabs: "Conduit Cross-section", "Conduit Dimension Group", and "Decay Factors". The "Conduit Cross-section" tab is active. It contains a "Shape" dropdown menu set to "RECT_TRIANGULAR", a "Barrels" spinner set to "1", a "Dimensions" dropdown set to "Feet", a "Max. Depth (ft.)" spinner set to "1", a "Top Width (ft.)" spinner set to "0", and a "Triangle Height (ft.)" spinner set to "0". A diagram of a rectangular conduit cross-section is shown with a blue water level. The window has "OK" and "Cancel" buttons at the bottom.



Create Schematic Layer



Define Assessment Points

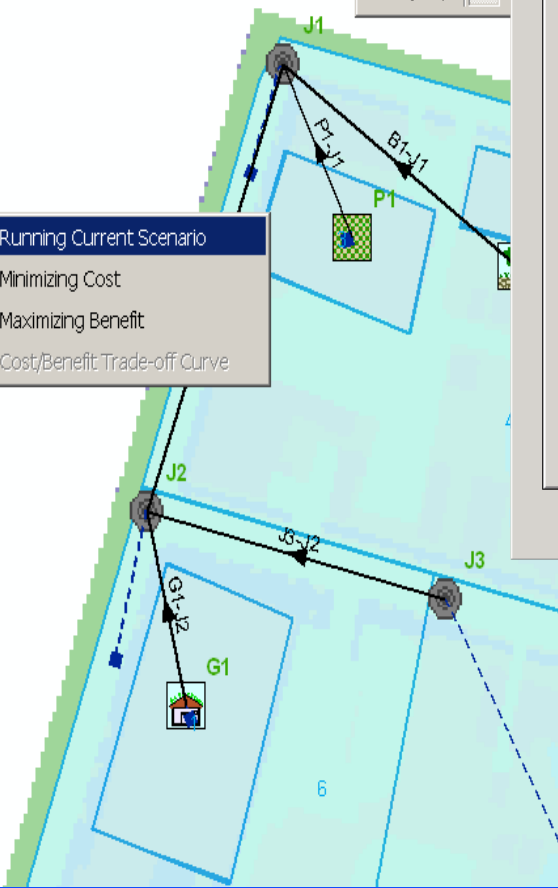
BMP Decision Support System Toolbar

BMP Decision Support System

- Data Management
- Assign Time Series
- Define BMP Template
- Add Off-stream BMP
- Add On-stream BMP
- Delineate Drainage Area
- Define Drainage Area to BMP Connection
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- Create Input File
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- About BMPDSS

Edit BMP Toolb..

- For Running Current Scenario
- For Minimizing Cost
- For Maximizing Benefit
- For Cost/Benefit Trade-off Curve



Existing Condition

Select the evaluation factor.

Flow | BOD, 5 D | NITROGEN | PHOSPHOR | ZINC, TO

Flow

- Average annual flow volume
- peak discharge flow
- Exceeding Frequency (times per yr) Threshold [] (cfs)

Done Cancel

Minimize Cost

Select the evaluation factor and input control target.

Flow | BOD, 5 D | NITROGEN | PHOSPHOR | ZINC, TO

Annual Average Flow Volume

- Percent of the value under existing condition (0-100) [75]
- Between pre-development and existing condition (0-1) []
- Specified value [(R3/yr)] []

Peak Discharge Flow

- Percent of the value under existing condition (0-100) []
- Between pre-development and existing condition (0-1) []
- Specified value [(cfs)] []

Exceeding Frequency (times per yr)

Threshold(cfs) []

- Percent of the value under existing condition (0-100) []
- Between pre-development and existing condition (0-1) []
- Specified value [(times per yr)] []

Done Cancel

Select evaluation factor and input priority factor.

Flow | BOD, 5 D | NITROGEN | PHOSPHOR | ZINC, TO

Flow

- Average annual flow volume [] Priority Factor(1-10) []
- 2-yr storm peak discharge flow [] []
- Exceeding Frequency (times per yr); Threshold [] (cfs) []






* 10 = most important
1 = least important

Done Cancel

Optimization Setup

SUSTAIN Toolbar

SUSTAIN ▾

- Data Management
- Assign Timeseries for Landuses
- Simulate Timeseries for Subwatersheds ▶
- Define BMP Template
-  Add Off-stream BMP
-  Add On-stream BMP
- Define Buffer Strip Template
-  Buffer Strip
- Delineate Drainage Area ▶
-  Define Drainage Area to BMP Connection
-  Define Routing Network
- Create Schematic Layer
- Define Assessment Point ▶
- Optimization Setup ▶**
- Create Input File
- Edit/View Input File
- Run Simulation
- View Simulation Results ▶
- About SUSTAIN

Minimize Cost

Number of Near Optimal Solutions

Number of near optimal solutions for output

Set Search Stopping Criteria

Stop the search and output near optimal solutions when the total cost has NOT been reduced by

\$

Maximum search time allowed

hour

Minimize Cost

Maximize Control Benefit

Cost Limit

Input cost limit

\$

Number of Near Optimal Solutions

Number of near optimal solutions for output

Set Search Stopping Criteria

Stop the search and output near optimal solutions when the control benefit has NOT been improved by

%

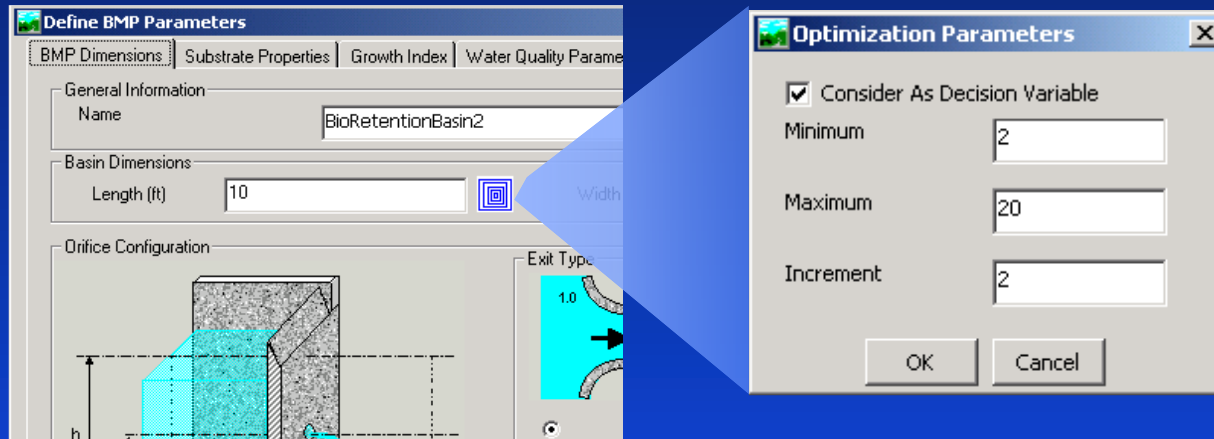
Maximum search time allowed

hour

Max Control Benefit

BMP OPTIMIZATION

✓ BMP Decision Variables







✓ Assessment Point(s)



✓ Objective and Constraints

Create Input Files

- BMP Decision Support System ▾
 - Data Management
 - Assign Time Series
 - Define BMP Template
 -  Add Off-stream BMP
 -  Add On-stream BMP
 - Delineate Drainage Area
 -  Define Drainage Area to BMP C
 -  Define Routing Network
 - Create Schematic Layer
 - Define Assessment Point ▶
 - Optimization Setup ▶
 - Create Input File**
 - Edit/View Input File
 - Run Simulation
 - View Simulation Results ▶
 - About BMPDSS

Define Simulation Option

Start Date: 1997/01/01 End Date: 1998/12/31

BMP Simulation Time Step (Minutes, 1-60): 5

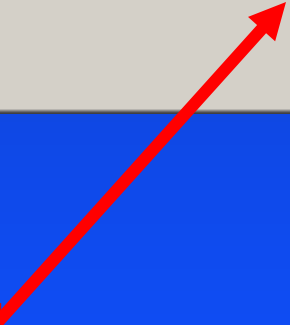
Output Time Step: Hourly

Define Pre-development Landuse Type: Forest

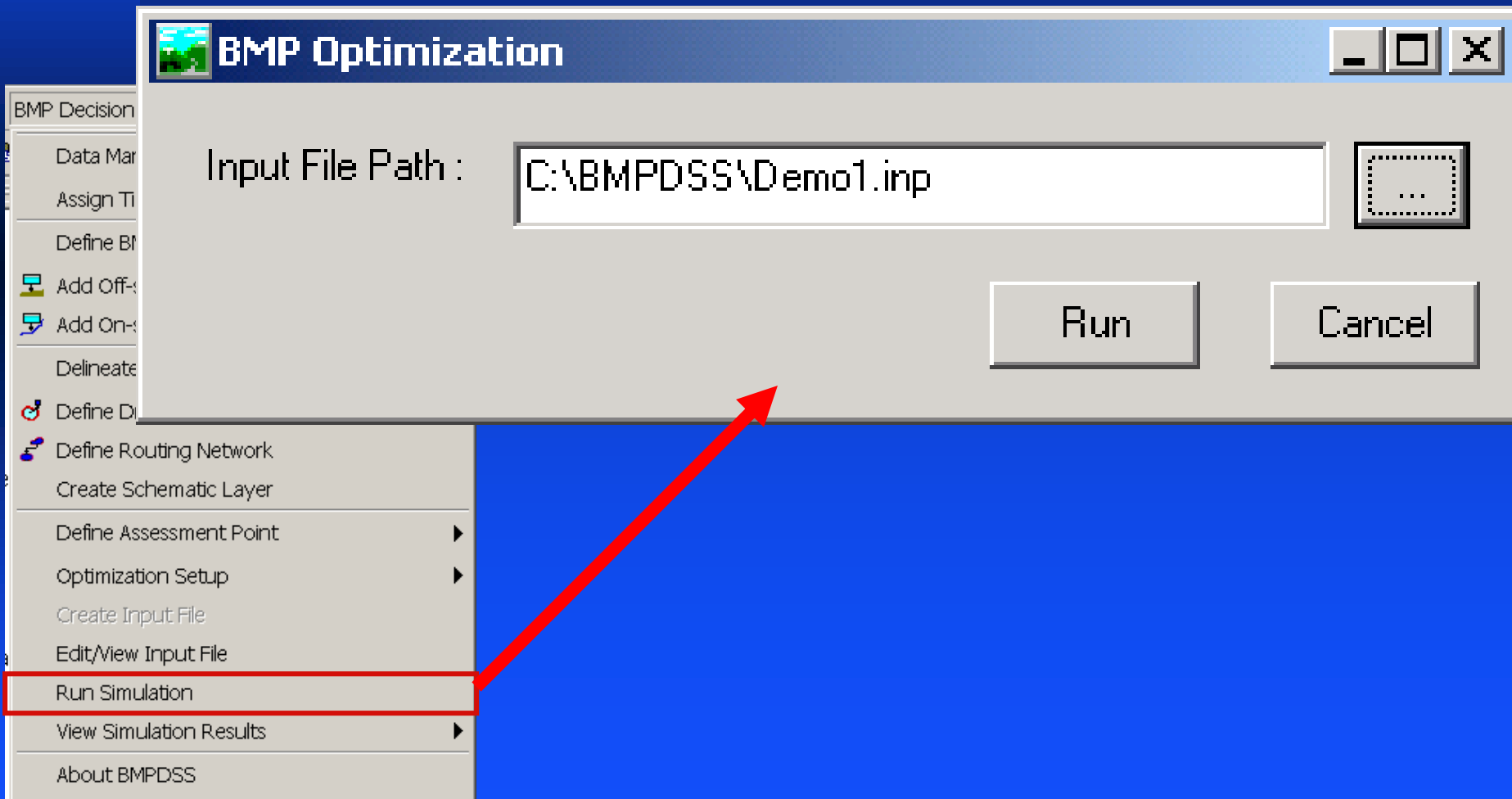
Define Input File: ...

Define Output Folder: ...

OK Cancel



Run Simulation



The image shows a software interface for BMP Optimization. On the left, a menu is open with the following items: BMP Decision, Data Mar, Assign TI, Define BF, Add Off-s, Add On-s, Delineate, Define D, Define Routing Network, Create Schematic Layer, Define Assessment Point, Optimization Setup, Create Input File, Edit/View Input File, Run Simulation (highlighted with a red box), View Simulation Results, and About BMPDSS. A red arrow points from the 'Run Simulation' menu item to a dialog box titled 'BMP Optimization'. The dialog box has a title bar with a small landscape icon and standard window controls. It contains an 'Input File Path' label and a text field with the path 'C:\BMPDSS\Demo1.inp'. To the right of the text field is a browse button (represented by a dotted rectangle with an ellipsis). At the bottom of the dialog are 'Run' and 'Cancel' buttons.

BMP Optimization

Input File Path : C:\BMPDSS\Demo1.inp

Run Cancel

BMP Decision
Data Mar
Assign TI
Define BF
Add Off-s
Add On-s
Delineate
Define D
Define Routing Network
Create Schematic Layer
Define Assessment Point
Optimization Setup
Create Input File
Edit/View Input File
Run Simulation
View Simulation Results
About BMPDSS

View Simulation Results

SBS_sp1 - ArcMap - ArcView

File Edit View Insert Selection Tools Window Help

BMP Decision Support System

- Data Management
- Assign Time Series
- Define BMP Template
- Add Off-stream BMP
- Add On-stream BMP
- Delineate Drainage Area
- Define Drainage Area to BMP Connection
- Define Routing Network
- Create Schematic Layer
- Define Assessment Point
- Optimization Setup
- Create Input File
- Edit/View Input File
- Run Simulation
- View Simulation Results**
- About BMPDSS

Microsoft Excel - BMPAnalysis.xls

File Edit View Insert Format Tools Data Window Help

G7

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Show Selected Tool: Weekly "Stopp"

Selected Week: Higher 2/16/2009 (Winter) Zoom to Selected The total rainfall this week is 2.05in

Summary	Rainfall (in)	Water Budget (in)	Runoff
Developed No BMPs	3.0500	0.6709	0.1474
Zero BMPs	0.3200	0.1216	0.0997
Underdrain Outflow		0.5078	0.0000
Net Retained Water		0.0005	0.0158
By-pass Flow		0.0035	0.2123
Pre-Developed			0.1629

Water Budget for the Week

BMP Outflow Distribution

Peak Flow (cfs)

Stormwater Volume (in)

	No BMPs	With BMPs	Pre-Developed
Peak Flow (cfs)	0.122	0.009	0.103
Stormwater Volume (in)	0.6709	0.5237	0.2123

Water Balance

Total Flow Hydrograph

Ready

File Manager | Long Term | Week-HydroGr

View Results In MS Excel

View Results On Chart



What can the system be used for

Area of Interest: Control Objectives

Potential BMP Sites

Cost Concerns

What is the benefit of management?

What is the difference between management options/scenarios including one or more practices?

Are they cost effective?

Case Study Application

Incorporate data from existing D.C. WASA CSS Model for a few city blocks in Anacostia Watershed.

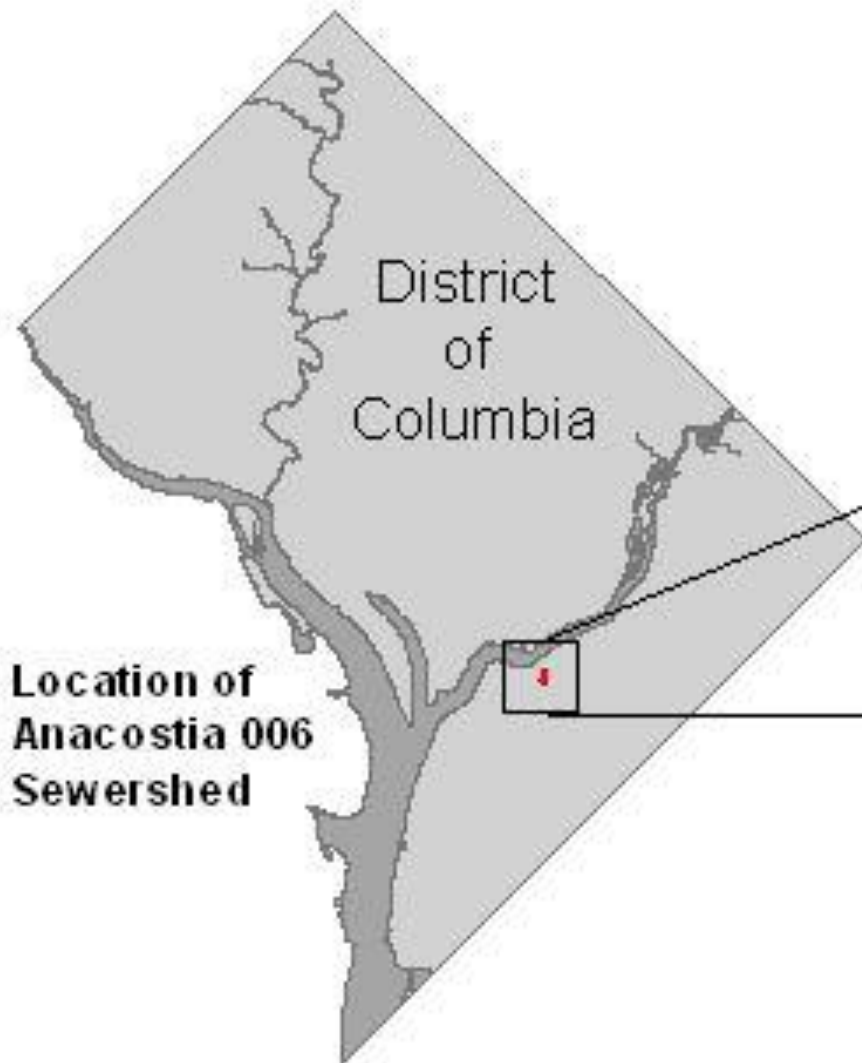
Develop potential LID configuration scenarios

Test BMP selection and placement optimization

Summarize effect of potential LID configurations on runoff volume and CSO inflow reduction

CSO storm water inflow reduction is associated with reduction of CSO overflow frequency

Case Study



Anacostia 006 Sewershed

Problem Formulation

Objectives

Minimize CSO
volume

Minimize cost

Decision Variables

Porous Paving

Size

Location

Rain Barrel

Sizes

Location

Bioretention

Size

Soil Depth

Location

Green Roof

Size

Depth of Soils

Locations

Cost Function

$$\text{Cost} = (Aa \times \text{Area}^{Ab}) \times (Da \times \text{Depth}^{Db}) + \text{Land Cost} \times \text{Area} + \text{Fixed Cost}$$

where

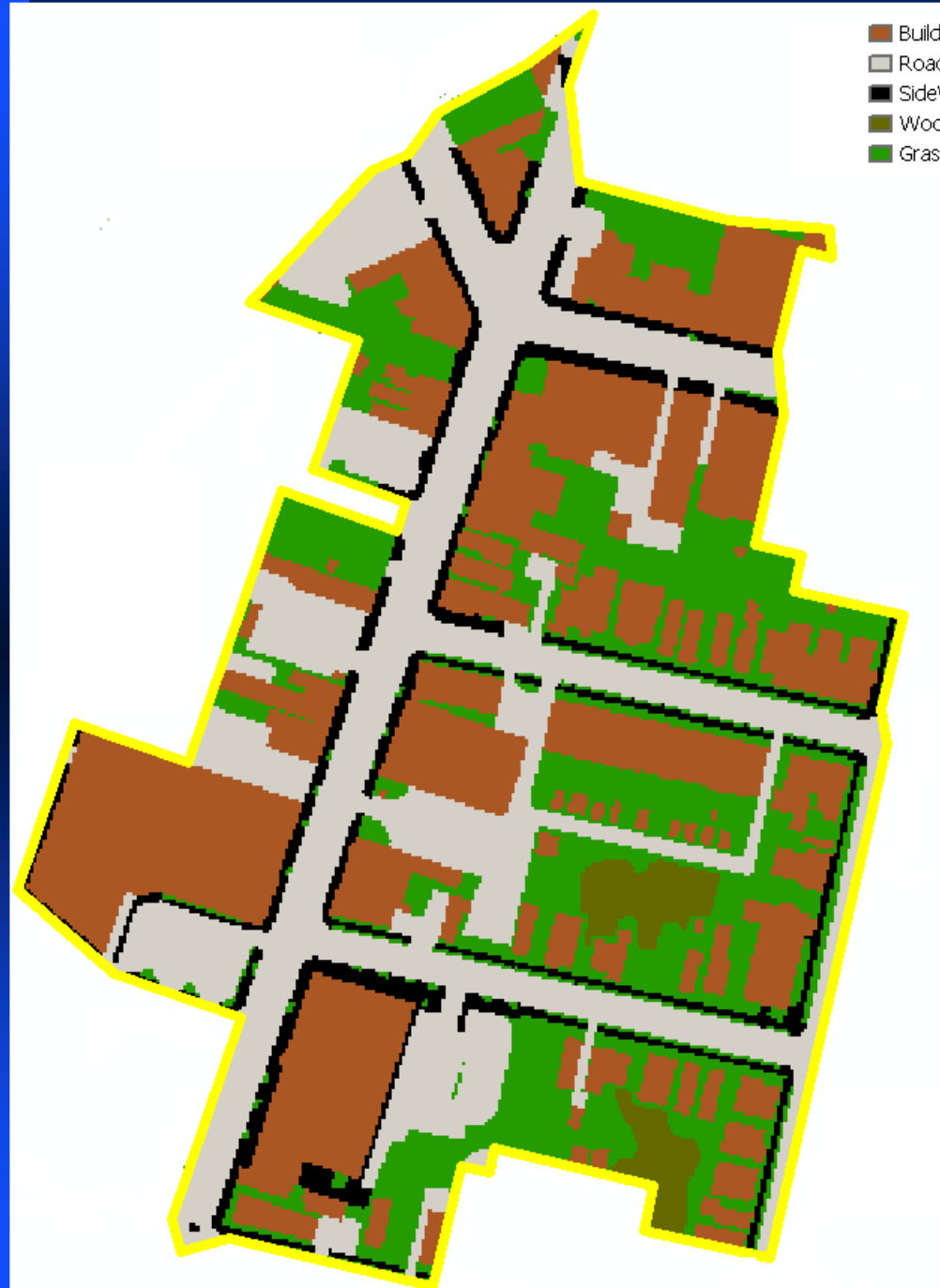
Area = area excavated for BMP site (ft^2),

Depth = averaged depth of soil excavated (ft),

Land Cost = unit cost of land (\$/ft),

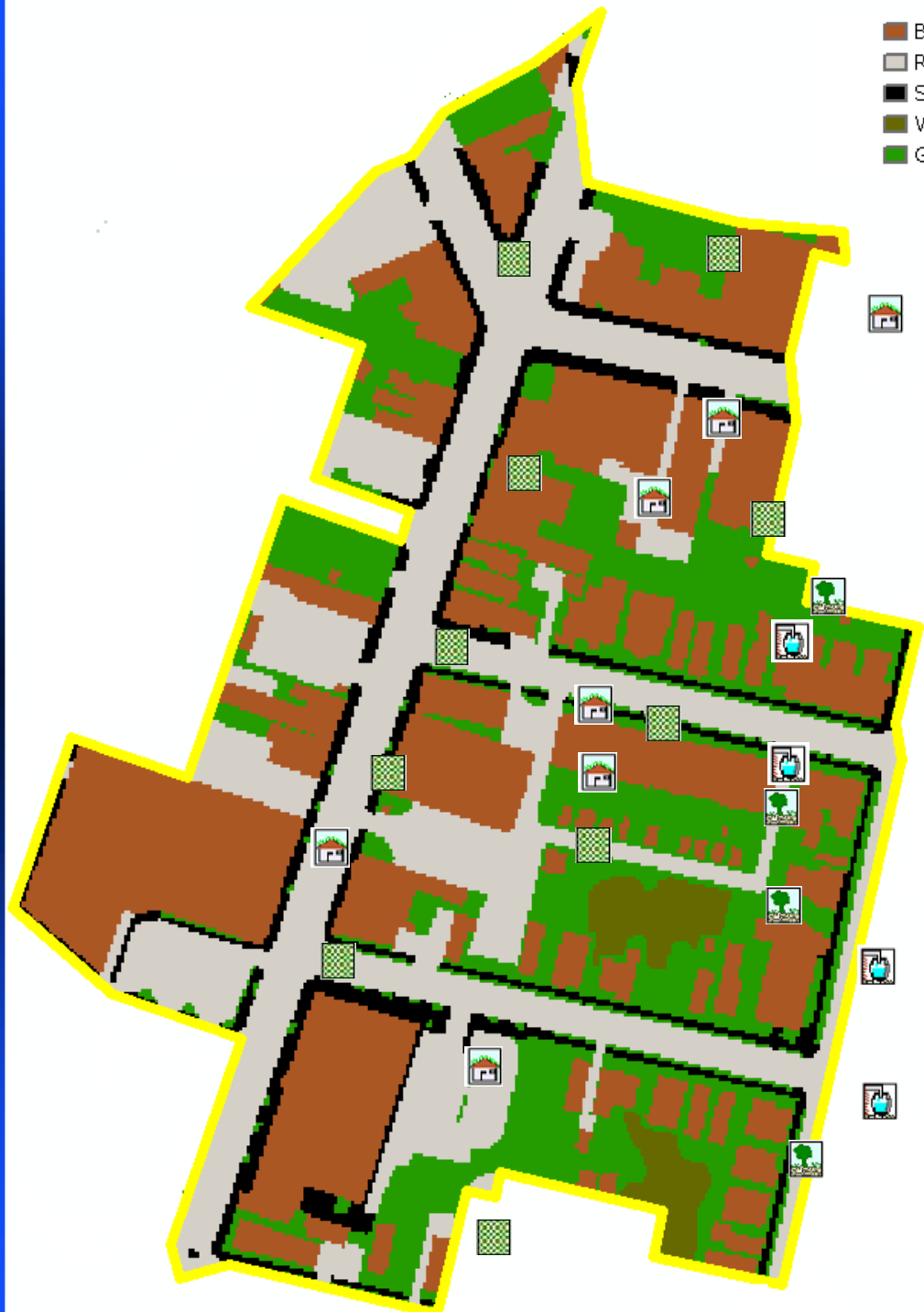
Fixed Cost = fixed cost (\$), and

Aa, Ab, Da, Db are coefficients of the cost function



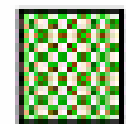
- Building
- Road
- SideWalk
- Woods
- GrassyArea

Existing Site Condition Land Uses



-  Building
-  Road
-  SideWalk
-  Woods
-  GrassyArea

Selected BMP Alternatives



PorousPavement



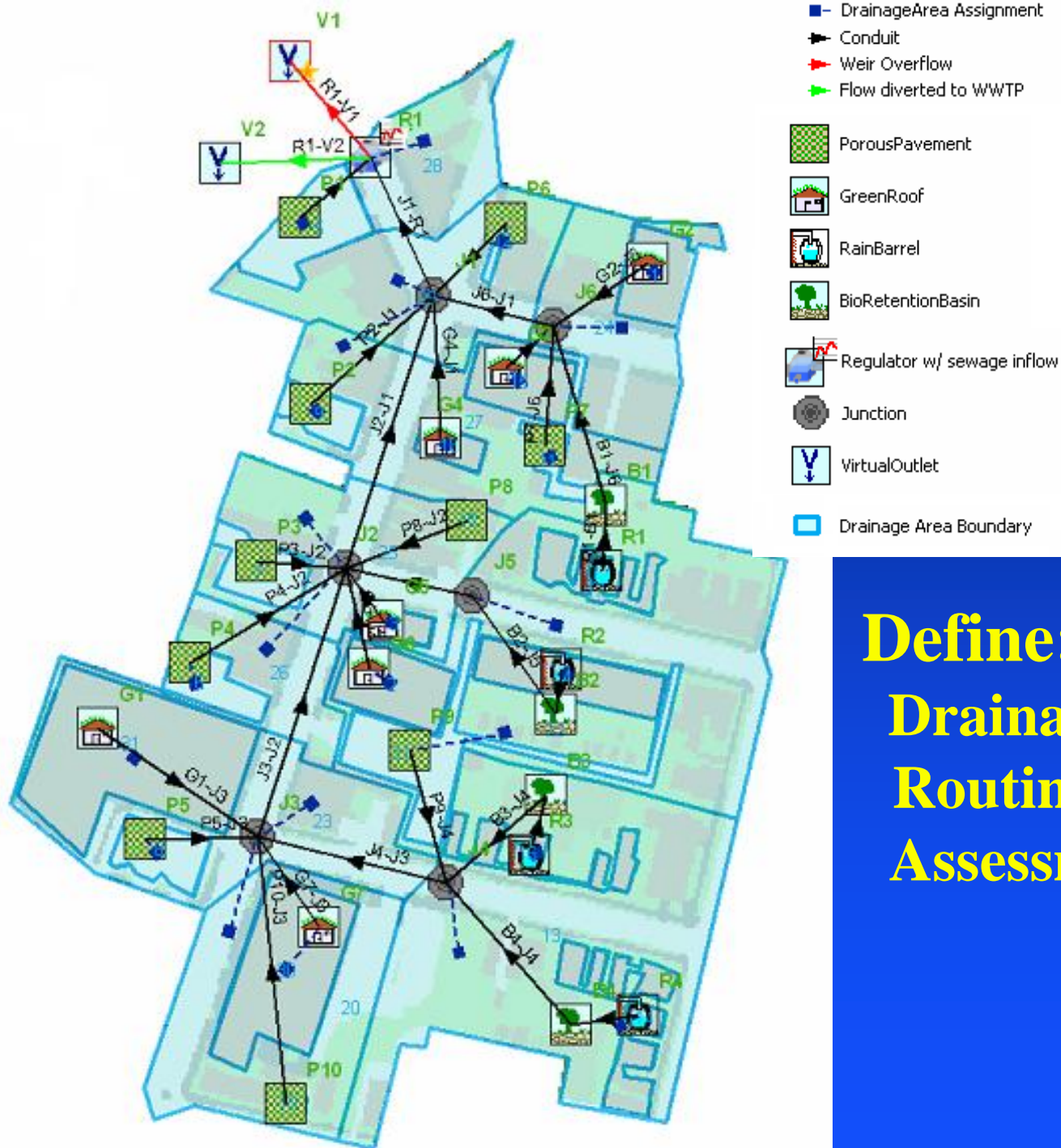
GreenRoof



RainBarrel

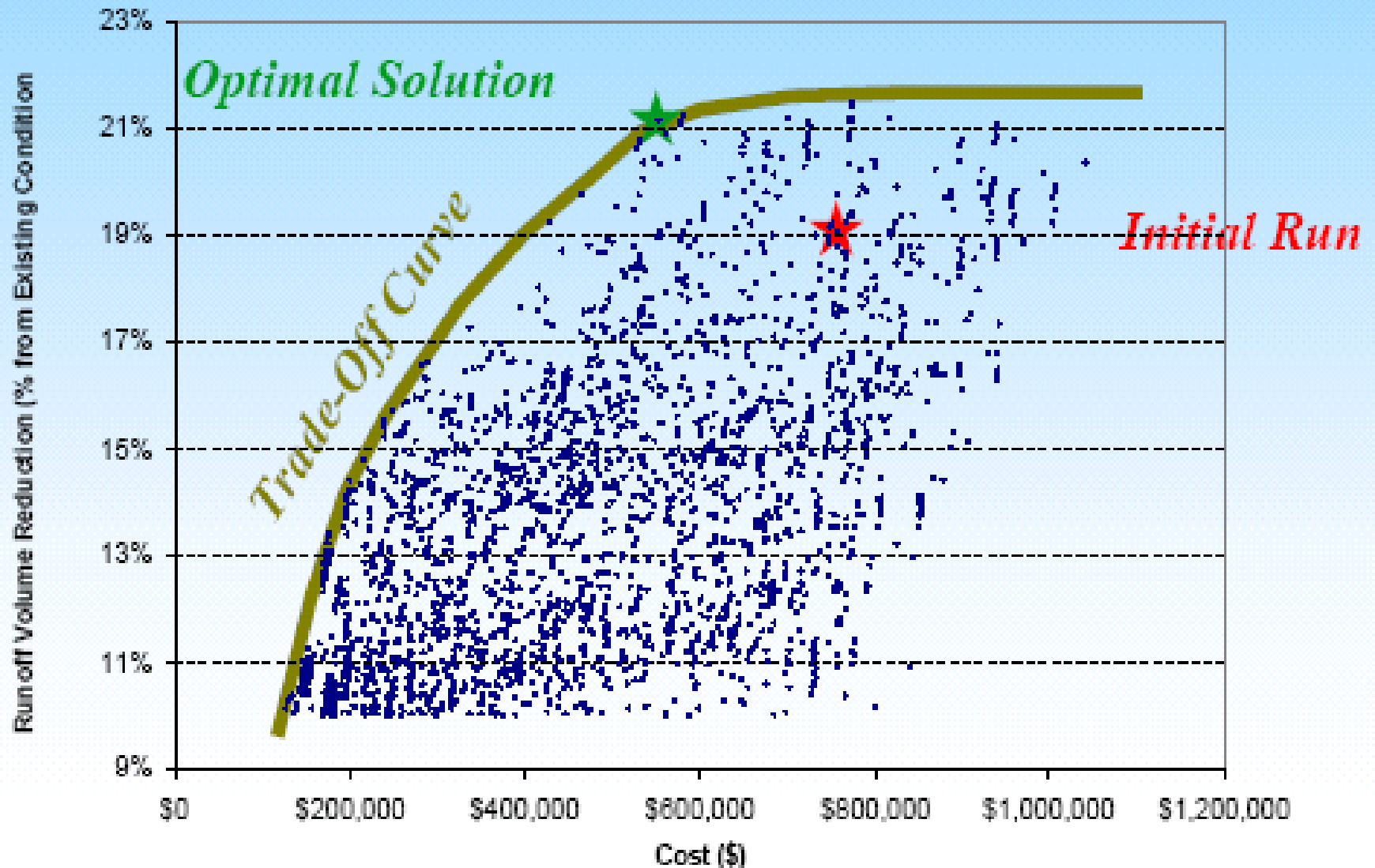


BioRetentionBasin

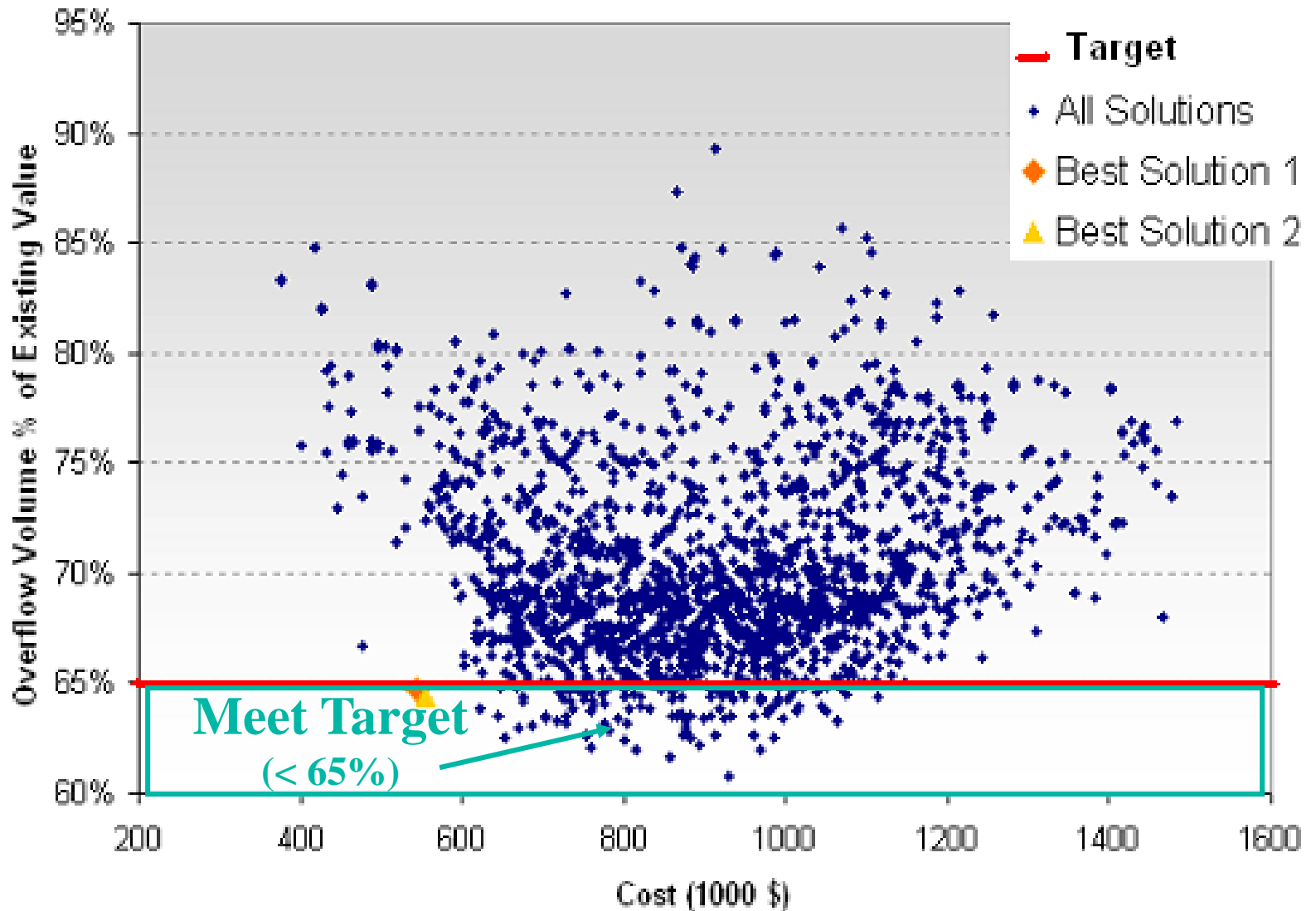


Define:
Drainage areas
Routing network
Assessment points

Optimization Solutions



Optimization Solutions



Optimization Solution Details

BMP Type	BMP ID	Decision Variable Upper Limit	Best Solution 1 Overflow volume reduction = 35.3% cost = \$544,124	Best Solution 1 Overflow volume reduction = 35.7% cost = \$555,904
		Surface area (ft ²) or Rain Barrel Count	Surface area (ft ²) or Rain Barrel Count	Surface area (ft ²) or Rain Barrel Count
Bio-retention	B1	1800	1200	1200
	B2	900	675	675
	B3	2250	1500	1500
	B4	2700	1800	1800
Rain Barrel	R1	6	6	6
	R2	12	12	12
	R3	10	8	8
	R4	12	8	8
Porous Pavement	P1	8118	2706	2706
	P2	3534	2356	3534
	P3	5505	1835	1835
	P4	4343	1447.6	1447.6
	P5	5205	1735	1735
	P6	981	490.5	490.5
	P7	2310	1155	1155
	P8	380	0	0
	P9	11400	5705	5705
	P10	801	801	801
Green Roof	G1	26400	6596	6596
	G2	6144	0	0
	G3	6400	0	0
	G4	2340	2340	2340
	G5	2400	1200	1200
	G6	7812	0	0
	G7	15408	0	0



Discussions and Conclusions

(from the case study)

Green Roofs

Relatively high-cost alternative when only runoff reduction is the primary objective

Rain Barrels

Are a cost-effective alternative for controlling runoff when open land is limited

Are less cost-effective than bioretention when sufficient open land is available for bioretention

Discussions and Conclusions

This is a TOOL for selecting and evaluating alternatives

This tool can be customized for local uses.