A SIMPLE MANUAL OPTIMIZATION METHOD TO SELECT LOW IMPACT DEVELOPMENT PRACTICES

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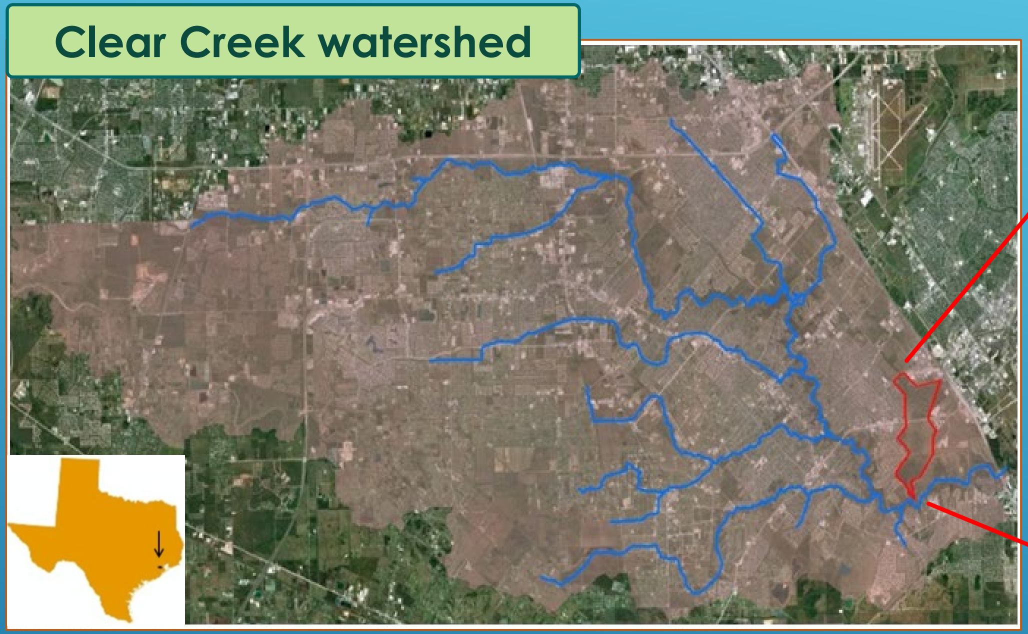
INTRODUCTION

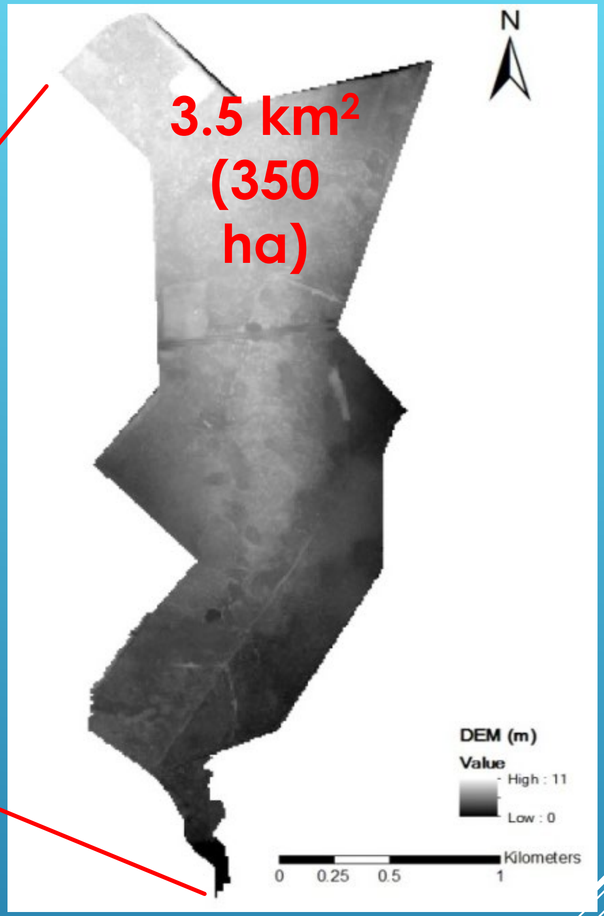
- Stormwater issues resulting from urbanization
  - change runoff patterns
  - make streams or rivers fluctuate dramatically
  - increase runoff and decrease infiltration
  - cause high peaks during a short time and fast stream velocity
  - cause deteriorated water quality
- An alternative approach for stormwater problems in urban areas
  - Low Impact Development practices (LIDs)

WHAT ARE WE STUDYING?

- Previous studies have demonstrated the effectiveness of LIDs through both field experiments and modeling approaches on water quality and runoff reduction
- But, how can we select the best combination of LID practices that is cost effective and can meet target reduction goals.
- Such studies can provide decisionmakers with data to plan and design LIDs projects on a watershed scale

STUDY AREA

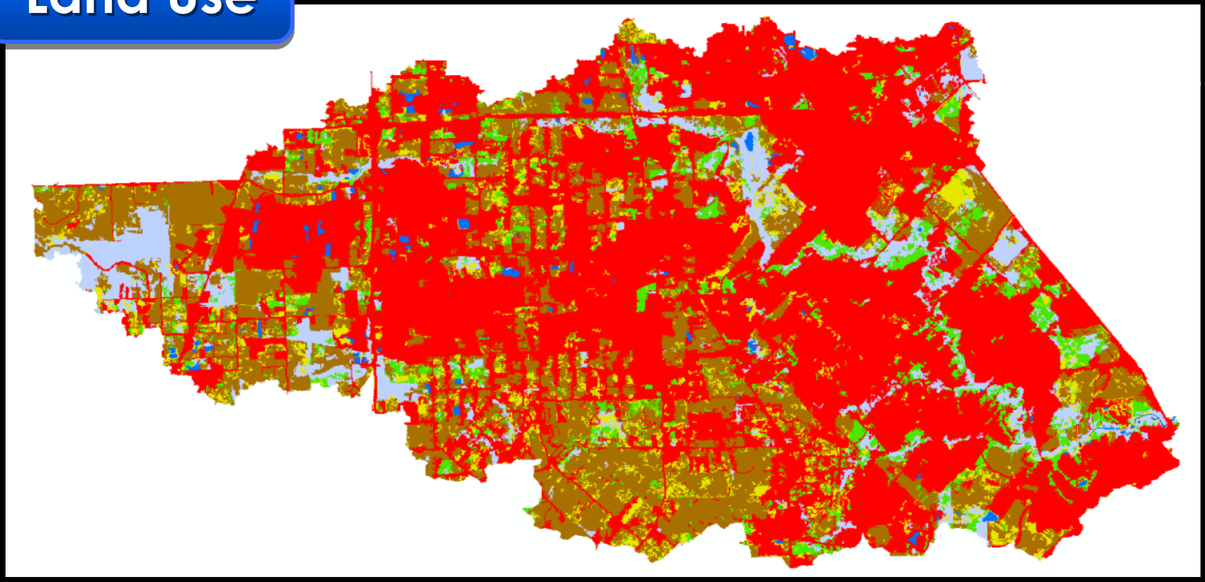




- Characteristics of the area
  - elevation: 6 to 8 meters (about 90% of the area)
  - soil: Hydrologic Soil Group (HSG) D
    - ✓ Addicks (61%; loam) and Bernard (27%; clay loam)
  - land use: wetland and hay of around 60%

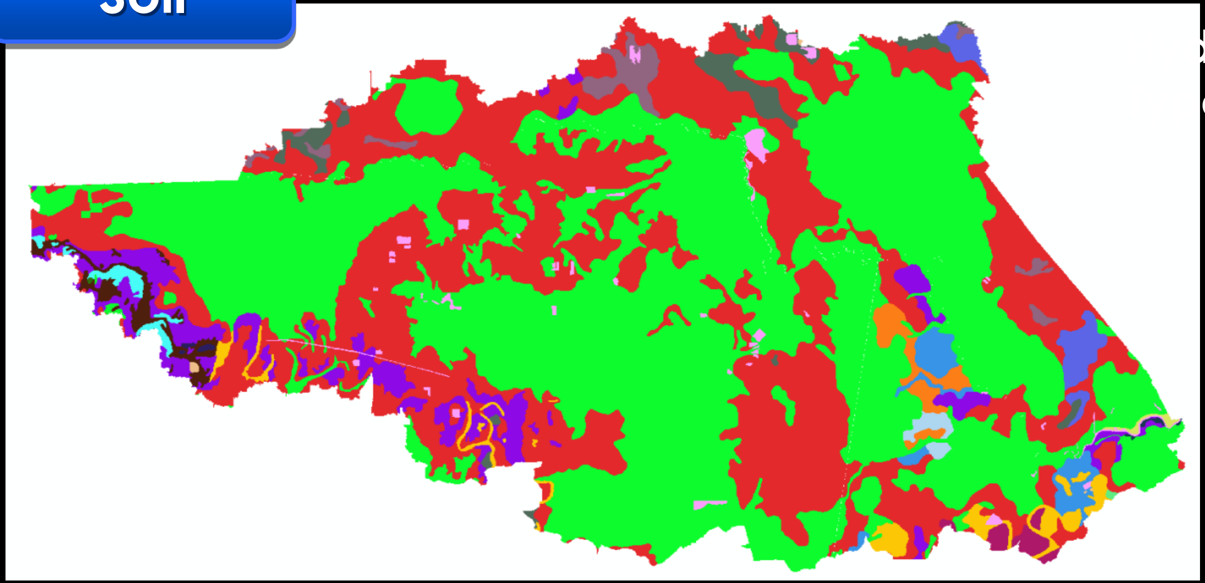
Land Use

an area: 63.23

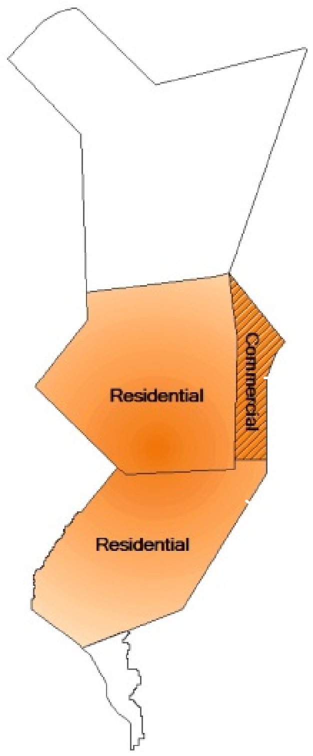


Soil

drologic Soil Group (HSG)
e D: 99.66 %



Urban Land Uses (2. UMD)



Conventional medium-density urban design

A typical pattern in the United States

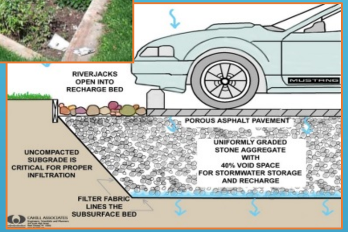
5% of total area (0.23 FAR)

51% of total area (3 units/ac)

Land use	Urban design	Urban ratio	Impervious/pervious fraction (in %)	
			Residential	Commercial
UMD	**Conventional urban form with medium density**	**56%**	**44/56**	**75/25**

Source of designs: League City, designed by Edminster, Hinshaw, Russ and Associates, Inc. (EHRA)

SPECIFICATION OF LIDS



- Three types of LIDs
  - rainwater harvesting systems (RWHs)
  - rain gardens (RGs)
  - permeable pavements (PPs)
- Each LID designed to address runoff and runoff-borne pollutants from specific sites
  - RWHs from roofs, RGs from residential areas excluding roofs, and PPs from parking lots
- Full installation and efficiency without consideration of seasonal impacts

Source of designs: Texas AgriLife Extension, Texas Water Resources Education, Cahill and Associates, Inc. 2004

MODEL DEVELOPMENT

- SURQ in urban areas (Q_{tot}) =
  SURQ from a connected impervious area +
  SURQ from a disconnected impervious/pervious area

$$Q \text{ or } Q_{imp} = \frac{(P - 0.2S)^2}{(P + 0.2S)}$$

$$Q_{tot} = Q \cdot (1 - fcimp) + Q_{imp} \cdot fcimp$$

- To consider LIDs,

$$\mathbf{Q_{LIDs} = Q_{tot} - LIDval} \qquad \text{(MDE, 1983)}$$

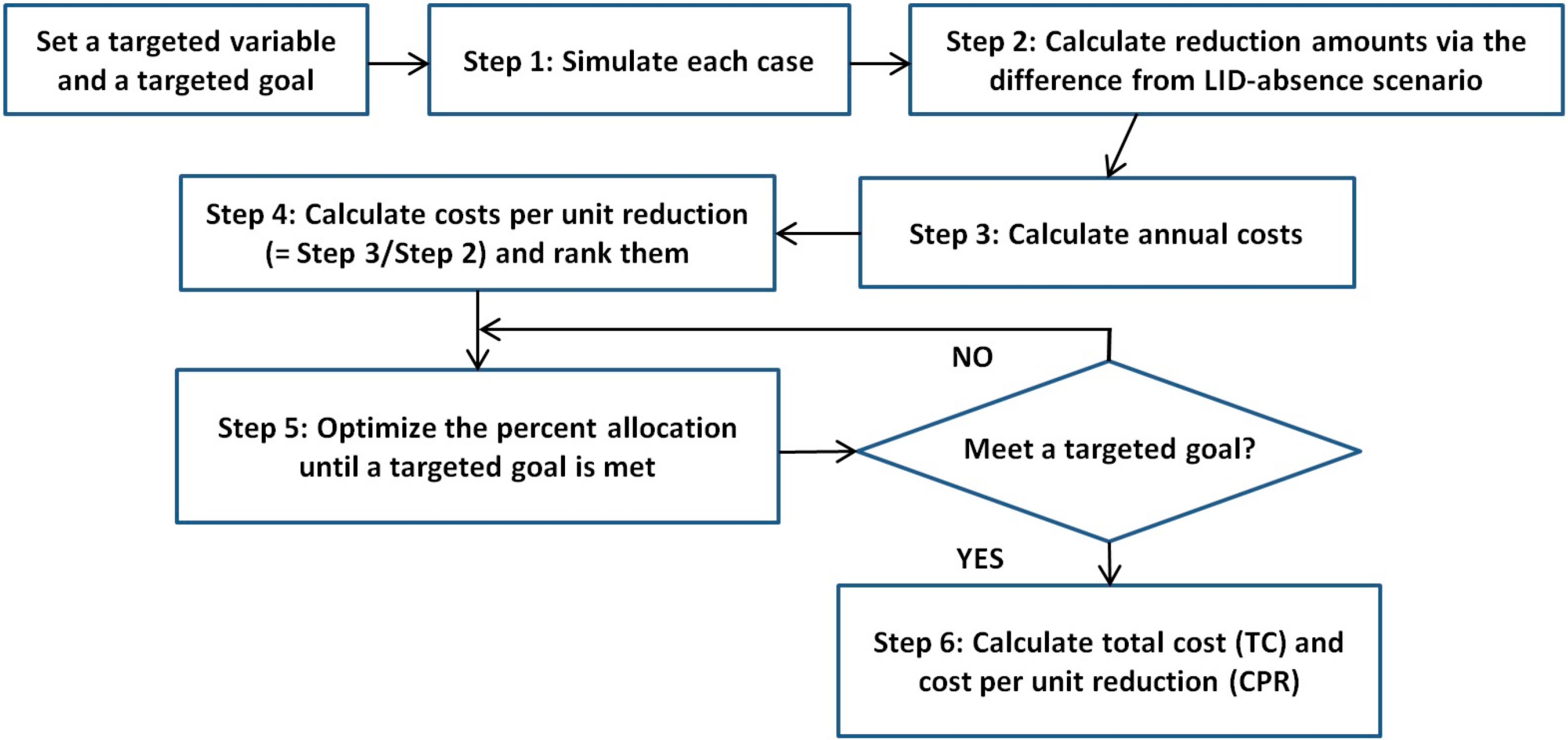
where **Q** and **Q_{imp}** are the surface runoff depths (mm) in the disconnected impervious/pervious area and in the connected impervious area, respectively, **Q_{tot}** is the total surface runoff depth in urban areas (mm), **fcimp** is the fraction of the connected impervious area, **Q_{LIDs}** is the surface runoff depth (mm) in which the impact of LIDs is considered, and **LIDval** is the surface runoff depth (mm) stored by each LID.

Modeling Work

- typical urban land use: UMD land use
- three LIDs: RWHs, RGs, and PPs
- modified SWAT model

Scenario	Surface flow (mm)	NO_3 (kg)	TP (kg)	Difference (% reduction)		
				surface flow (mm)	NO_3 (kg)	TP (kg)
UMD	473.32	591.87	449.55	**135.51**	**186.03**	**110.69**
UMDLIDs	337.81	405.85	338.86			

maximum reduction amounts


Set a targeted variable and a targeted goal
Step 1: Simulate each case
Step 2: Calculate reduction amounts via the difference from LID-absence scenario
Step 3: Calculate annual costs
Step 4: Calculate costs per unit reduction (= Step 3/Step 2) and rank them
Step 5: Optimize the percent allocation until a targeted goal is met
Meet a targeted goal?
NO
YES
Step 6: Calculate total cost (TC) and cost per unit reduction (CPR)

Targeted Reduction Amounts

	Hypothetical cases for targeted reduction amounts				
	Case 1	Case 2	Case 3	Case 4	Case 5
Surface runoff (mm)	33.88	47.43	60.98	74.53	88.08
Nitrate (kg)	46.51	65.11	83.71	102.32	120.92
Total phosphorus (kg)	27.67	38.74	49.81	60.88	71.95

- Case 1 : 25%
- Case 2 : 35%
- Case 3 : 45%
- Case 4 : 55%
- Case 5 : 65%

of maximum reduction amounts

Cost Estimation

$$C_{td} = \left[C_0 \cdot (1+s)^{td} + C_0 \cdot rm \cdot \left(\frac{(1+s)^{td}-1}{s}\right)\right] / td \quad \text{(Arabi et al., 2006)}$$

- Construction cost per unit area (**C_0**)
  - 6 (\$/ft^2) for RGs, 14 (\$/ft^2) for PPs, and 1 (\$/gal) for RWHs
- Proportion of maintenance to construction cost (**rm**)
  - 5% for RGs and PPs and 1% for RWHs
- Interest rate (**s**): 4.5%
- Lifespan of LIDs (**td**): 20 yrs
- Annual cost per unit area (**C_{td}**)

LIDs	Annual cost per unit area (\$/ft^2/yr)
RGs	1.19
PPs	2.79
RWHs	0.04

Manual Optimization

LIDs	Location	SURQ (mm)	NO_3 (kg)	TP (kg)	Differences SURQ (mm)	Differences NO_3 (kg)	Differences TP (kg)	Annual cost for LIDs ($)
None	-	473.32	591.873	449.546				
RGs	Sub 3	425.42	540.053	409.428	47.90	51.82	40.12	856,287.36
RGs	Sub 4	413.40	528.113	402.860	59.91	63.76	46.69	1,013,336.99
PPs	Sub 2	455.44	544.948	437.606	17.88	46.92	11.94	2,568,860.66
RWHs	Sub 3	468.89	578.500	448.233	4.43	13.37	1.31	69,801.00
RWHs	Sub 4	467.92	577.784	447.517	5.40	14.09	2.03	82,603.04

LIDs cost in handling unit reduction					
SURQ ($/mm)	Ranking	NO_3 ($/kg)	Ranking	TP ($/kg)	Ranking
17,876.44	4	16,524.19	4	21,343.75	1
16,913.66	3	15,892.90	3	21,705.39	2
143,685.69	5	54,744.24	5	215,144.88	5
15,757.62	2	5,219.56	1	53,144.64	4
15,298.75	1	5,862.79	2	40,694.67	3

ex) Case 5 for surface flow

targeted amount		88.08						
Ranking	**Type**	**Location**	Reduction		**Allocation**		Reduction	
1	RWHs	Sub 4	5.40	X	100.00	=	5.40	5.40
2	RWHs	Sub 3	4.43	X	100.00	=	4.43	9.83
3	RGs	Sub 4	59.91	X	100.00	=	59.91	69.74
4	RGs	Sub 3	47.90	X	38.28	=	18.34	88.08
5	PPs	Sub 2	17.88		0.00			

X

Cost per reduction	Cost
15,298.75	82,603.04
15,757.62	69,801.00
16,913.66	1,013,336.99
17,876.44	327,786.80
143,685.69	0.00
total cost ($) =	1,493,527.83
cost per unit reduction ($/mm) =	16,956.54

Manual Optimization

- Optimization of percent allocation: 3 constraint conditions
  - **ultimate adoption**: to allow 100% allocation

	Area (ha)	
	Commercial area	Residential area
Subbasin area	18.22	181.83
RGs	-	**14.55 (8%)**
RWHs	-	**36.37 (20%)**
PPs	**8.57 (47%)**	-

  - **maximum adoption**: to restrict the potential allocation of LIDs up to a maximum of 75% for RGs and RWHs and 50% for PPs
  - **minimum adoption**: to require at least 20% allocation of LIDs but not to exceed 75% for RGs and RWHs and 50% for PPs

Results of Optimization (surface flow)

Difference between each case: 13.55 mm   +100%   +200%   +300%

(a) Ultimate adoption			Case 1	Case 2	Case 3	Case 4	Case 5
Targeted reduction amount			33.88	47.43	60.98	74.53	88.08
Ranking	Type	Location	↑	% allocation			
1	RWHs	Sub 4	100.00	100.00	100.00	100.00	100.00
2	RWHs	Sub 3	100.00	100.00	100.00	100.00	100.00
3	RGs	Sub 4	40.14	62.76	85.38	100.00	100.00
4	RGs	Sub 3	0.00	0.00	0.00	9.99	38.28
5	PPs	Sub 2	0.00	0.00	0.00	0.00	0.00
(b) Maximum adoption							
1	RWHs	Sub 4	75.00	75.00	75.00	75.00	75.00
2	RWHs	Sub 3	75.00	75.00	75.00	75.00	75.00
3	RGs	Sub 4	44.24	66.86	75.00	75.00	75.00
4	RGs	Sub 3	0.00	0.00	18.10	46.39	74.68
5	PPs	Sub 2	0.00	0.00	0.00	0.00	0.00
(c) Minimum adoption							
1	RWHs	Sub 4	75.00	75.00	75.00	75.00	75.00
2	RWHs	Sub 3	75.00	75.00	75.00	75.00	75.00
3	RGs	Sub 4	22.28	44.90	67.52	75.00	75.00
4	RGs	Sub 3	20.00	20.00	20.00	38.93	67.21
5	PPs	Sub 2	20.00	20.00	20.00	20.00	20.00

22.62%   45.24%   59.86%   59.86%

Results of Optimization (NO_3 & TP)

NO_3: Difference between each case, 18.60 kg

(a) Ultimate			Case 1	Case 2	Case 3	Case 4	Case 5
Targeted amount			46.51	65.11	83.71	102.32	120.92
Ranking	Type	Loc.	% allocation				
1	RWHs	Sub 3	100.00	100.00	100.00	100.00	100.00
2	RWHs	Sub 4	100.00	100.00	100.00	100.00	100.00
3	RGs	Sub 4	29.87	59.04	88.21	100.00	100.00
4	RGs	Sub 3	0.00	0.00	0.00	21.41	57.30
5	PPs	Sub 2	0.00	0.00	0.00	0.00	0.00
(b) Maximum							
1	RWHs	Sub 3	75.00	75.00	75.00	75.00	75.00
2	RWHs	Sub 4	75.00	75.00	75.00	75.00	75.00
3	RGs	Sub 4	40.64	69.81	75.00	75.00	75.00
4	RGs	Sub 3	0.00	0.00	29.51	65.42	75.00
5	PPs	Sub 2	0.00	0.00	0.00	0.00	29.06
(c) Minimum							
1	RWHs	Sub 3	75.00	75.00	75.00	75.00	75.00
2	RWHs	Sub 4	28.21	75.00	75.00	75.00	75.00
3	RGs	Sub 4	20.00	38.84	68.01	75.00	75.00
4	RGs	Sub 3	20.00	20.00	20.00	47.31	75.00
5	PPs	Sub 2	20.00	20.00	20.00	20.00	29.06

TP: Difference between each case, 11.07 kg

(a) Ultimate			Case 1	Case 2	Case 3	Case 4	Case 5
Targeted amount			27.67	38.74	49.81	60.88	71.95
Ranking	Type	Loc.	% allocation				
1	RGs	Sub 3	68.96	96.57	100.00	100.00	100.00
2	RGs	Sub 4	0.00	0.00	20.76	44.47	68.18
3	RWHs	Sub 4	0.00	0.00	0.00	0.00	0.00
4	RWHs	Sub 3	0.00	0.00	0.00	0.00	0.00
5	PPs	Sub 2	0.00	0.00	0.00	0.00	0.00
(b) Maximum							
1	RGs	Sub 3	68.96	75.00	75.00	75.00	75.00
2	RGs	Sub 4	0.00	18.53	42.24	65.95	75.00
3	RWHs	Sub 4	0.00	0.00	0.00	0.00	75.00
4	RWHs	Sub 3	0.00	0.00	0.00	0.00	75.00
5	PPs	Sub 2	0.00	0.00	0.00	0.00	36.30
(c) Minimum							
1	RGs	Sub 3	38.07	65.68	75.00	75.00	75.00
2	RGs	Sub 4	20.00	20.00	35.70	59.40	75.00
3	RWHs	Sub 4	20.00	20.00	20.00	20.00	75.00
4	RWHs	Sub 3	20.00	20.00	20.00	20.00	75.00
5	PPs	Sub 2	20.00	20.00	20.00	20.00	36.30

Results of Cost

Case	Variable	Ultimate adoption		Maximum adoption		Minimum adoption	
		Cost ($)	Cost per unit reduction*	Cost ($)	Cost per unit reduction*	Cost ($)	Cost per unit reduction*
5	Runoff	1,493,527.83	16,956.54	1,513,759.76	17,186.24	1,963,588.64	**22,293.30**
4		1,251,284.14	16,789.22	1,271,516.07	17,060.68	1,721,430.57	23,097.45
3		1,017,591.16	16,687.76	1,029,336.60	16,880.38	1,483,537.77	24,328.95
2		788,374.34	16,622.70	791,769.48	16,694.29	1,254,320.94	26,447.09
1		559,157.51	**16,505.60**	562,628.65	**16,608.06**	1,025,104.12	30,259.74
5	NO_3	1,656,393.69	13,698.51	2,263,032.20	18,715.45	2,263,032.20	18,715.45
4		1,349,072.15	13,185.47	1,434,446.15	14,019.89	1,793,187.45	**17,526.13**
3		1,046,268.60	12,498.38	1,126,953.36	13,462.21	1,488,503.12	17,781.17
2		750,678.20	11,529.45	821,713.58	12,620.47	1,192,912.72	18,321.61
1		455,087.80	**9,785.39**	526,072.52	**11,311.72**	963,350.07	20,714.15
5	TP	1,547,180.52	21,504.95	2,449,017.71	34,039.98	2,449,017.71	34,039.98
4		1,306,918.32	21,468.24	1,310,485.93	21,526.85	1,788,390.63	**29,377.20**
3		1,066,656.12	21,415.22	1,070,249.06	21,487.36	1,548,229.76	31,083.77
2		826,916.70	21,345.41	829,936.20	21,423.35	1,309,329.87	33,798.06
1		590,495.76	**21,339.66**	590,517.17	**21,340.43**	1,072,908.94	38,773.37

*Unit is $/mm for runoff and $/kg for nitrate and total phosphorus

Alternative Analysis

- A considerable amount of water generated as surface runoff
- An alternative strategy to consider the water that is not treated by LIDs: Detention ponds
  - assumption: 100-year 24 hour rainfall (13 in.)
  - estimation of required detention volume (0.1538 ac-ft/ac)
  - detention vol. = required detention vol. – vol. detained by LIDs
  - cost calculation: $C = 24.5V^{0.705}$ (Brown and Schueler, 1997)

where C is the establishment cost including construction, design, and authorization ($) and V is the pond volume (ft^3)

Case	Variable	Volume detained by LIDs (ac-ft/ac)	Volume detained by detention ponds (ac-ft/ac)	Cost ($)	Savings ($)
(b) Maximum adoption					
5	Runoff	0.0092	0.1446	245,482.09	10,908.07
4		0.0086	0.1452	246,188.43	10,201.73
3		0.0080	0.1458	246,893.92	9,496.23
2		0.0074	0.1464	247,584.71	8,805.45
1		0.0069	0.1470	248,250.71	8,139.45
5	NO_3	0.0105	0.1433	243,883.47	12,506.69
4		0.0090	0.1448	245,713.38	10,676.77
3		0.0083	0.1456	246,609.48	9,780.67
2		0.0075	0.1463	247,497.80	8,892.36
1		0.0068	0.1470	248,356.64	8,033.52
5	TP	0.0109	0.1430	243,486.50	12,903.66
4		0.0032	0.1506	252,623.95	3,766.21
3		0.0026	0.1512	253,316.18	3,073.98
2		0.0020	0.1518	254,007.62	2,382.54
1		0.0014	0.1524	254,696.05	1,694.11
(c) Minimum adoption					
5	Runoff	0.0100	0.1439	244,574.79	11,815.37
4		0.0094	0.1445	245,281.97	11,108.18
3		0.0088	0.1451	245,975.87	10,414.29
2		0.0082	0.1456	246,643.69	9,746.47
1		0.0077	0.1462	247,310.75	9,079.40
5	NO_3	0.0105	0.1433	243,883.47	12,506.69
4		0.0095	0.1443	245,072.51	11,317.65
3		0.0088	0.1450	245,961.40	10,428.76
2		0.0081	0.1458	246,822.47	9,567.68
1		0.0057	0.1482	249,707.61	6,682.55
5	TP	0.0109	0.1430	243,486.50	12,903.66
4		0.0055	0.1483	249,904.20	6,485.96
3		0.0049	0.1489	250,599.27	5,790.89
2		0.0043	0.1495	251,289.89	5,100.27
1		0.0037	0.1501	251,972.56	4,417.59

CONCLUSIONS

- An excel based tool was developed to optimize LID selection and adoption rate to meet a targeted pollution reduction at a minimal cost
- The tool is easy to modify to tailor to specific developments
- Can be used at watershed or development scale to guide decision makers/developers
- Plans to upgrade to a simple online tool/app to be more user friendly