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Modeling of Low Impact Development Nutrient Reduction Performance in the Lake Simcoe Watershed

James Li

May 5, 2020 08:30-10:15 HS7.3
EGU General Assembly 2020 Online

Agenda

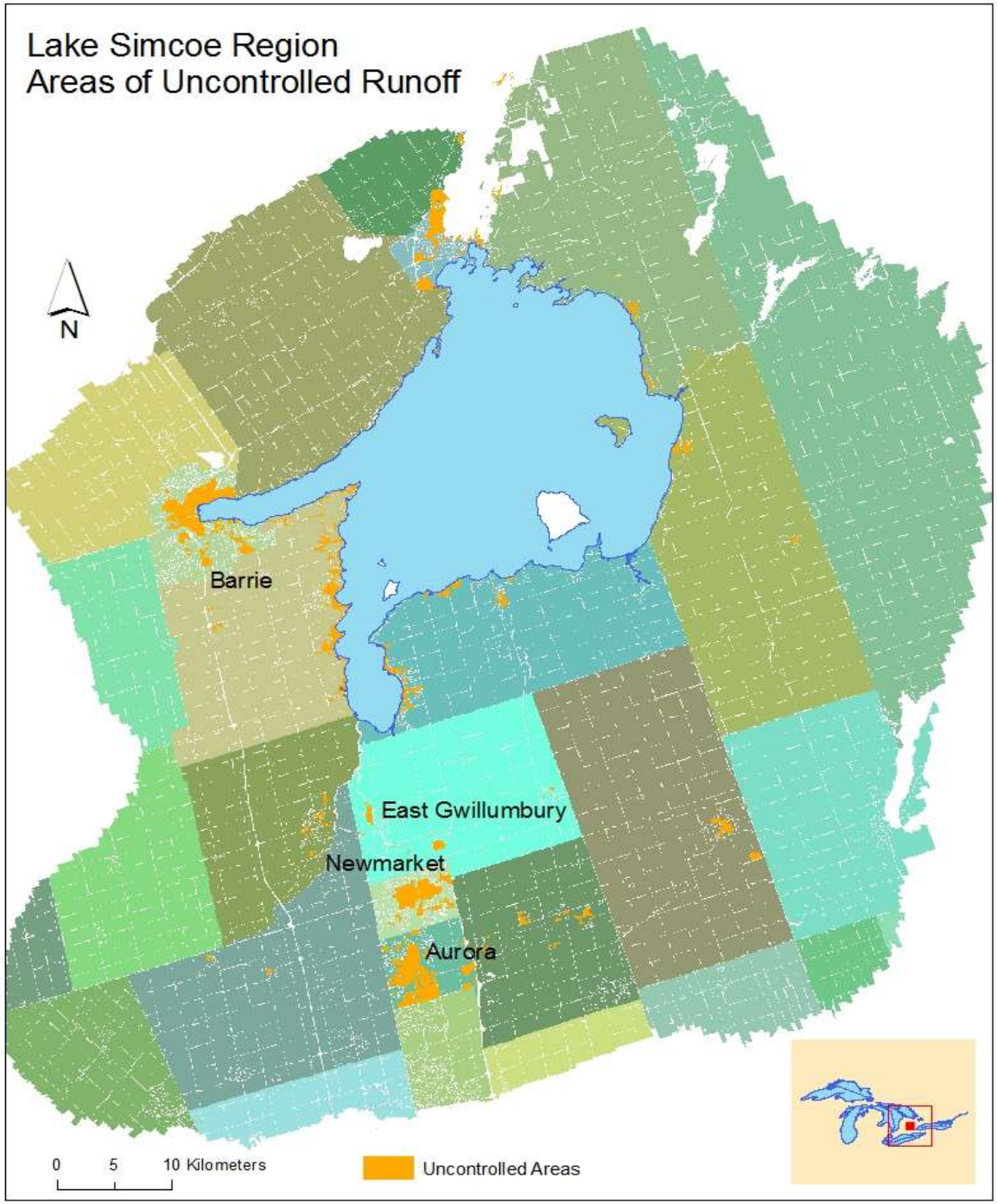
1. Project Description – Lake Simcoe watershed
2. GIS in Screening of Low Impact Development (LID) Opportunities
3. GIS in Development of Hydrologic Response Funcations (HRUs)
4. Development of HRU Hydrologic Models
5. Results of Application of HRU Models for all municipalities

Master Plan of LIDs for in the watershed (3400 km^2 and 20 municipalities)

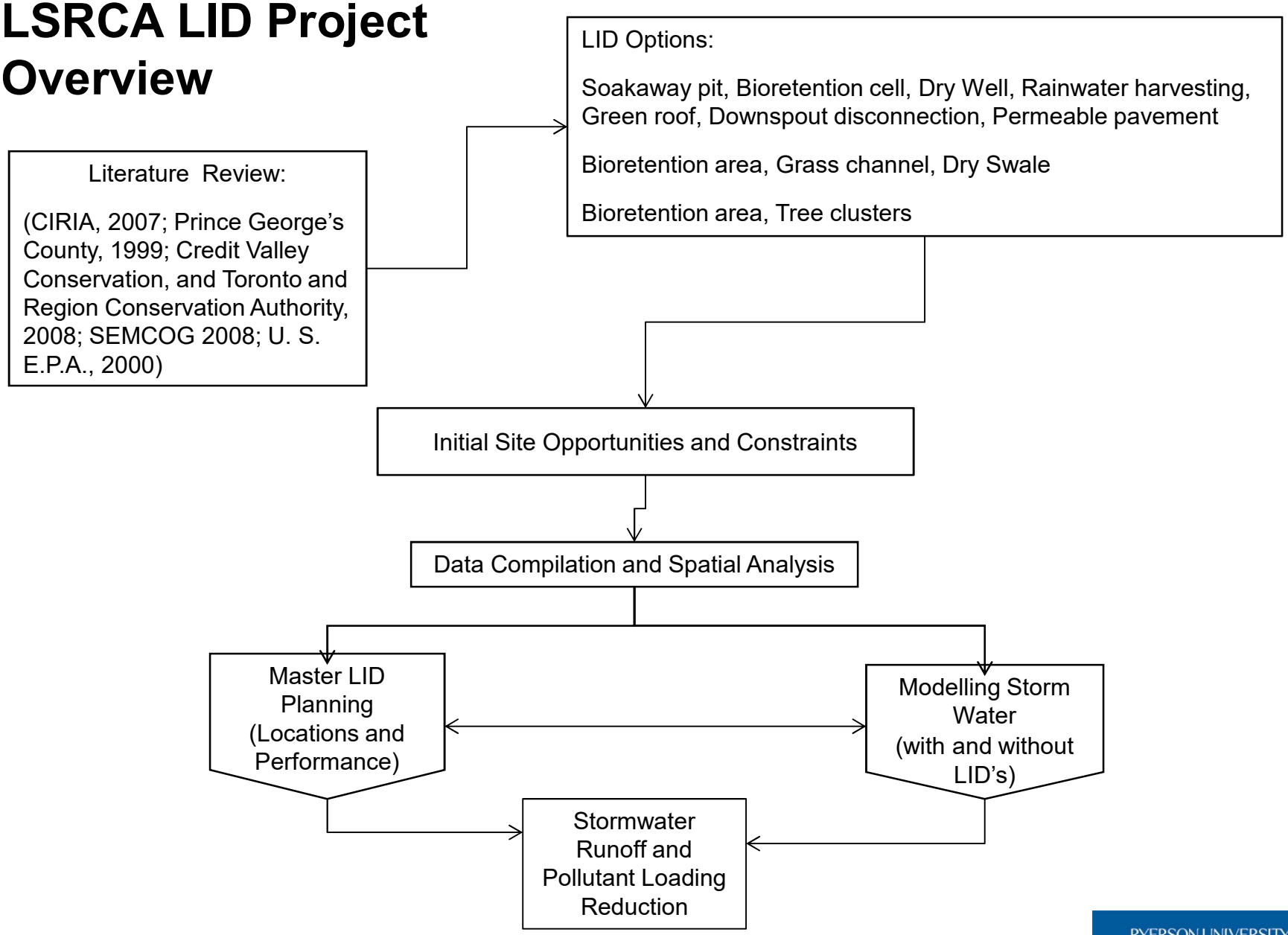
- What and Where?

- What is the overall performance?

- What is the total Phosphorus reduction?



LSRCA LID Project Overview



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Lot Level LID Practices

Source: Li, J. et al. 2010 Evaluation of Low Impact Development Stormwater Technologies for the Uncontrolled Urban Areas in the Lake Simcoe Regions

Soakaway pit, dry well, rain harvesting, downspout disconnection, greenroof, bioretention cell, porous pavement, 17 combinations

Along ROW LID Practices

Source: Li, J. et al. 2010 Evaluation of Low Impact Development Stormwater Technologies for the Uncontrolled Urban Areas in the Lake Simcoe Regions

Bioretention area, grass channel, dry swale

Multiple-lot/Area LID Practices

Source: Li, J. et al. 2010 Evaluation of Low Impact Development Stormwater Technologies for the Uncontrolled Urban Areas in the Lake Simcoe Regions

Bioretention area, tree clusters

GIS in Screening of LID

Lot-based LID Opportunities

- Essential criteria for identifying potentially appropriate LID procedures for any particular lot:
  - soil depth
  - soil infiltration rate
  - slope steepness
  - land use
  - typical drainage area beyond setbacks
  - building sizes and other building-attribute details
  - land use categories
  - public land ownership

GIS in Screening of LID

ROW LID Opportunities

- Essential criteria for identifying potentially appropriate LID procedures for road allowances:
  - off the travelled portion and parking lanes
  - beyond assessment lot frontages
  - off sidewalks and parking lots
  - away from trees
  - in spaces between driveways
  - with sufficient width available to accommodate LIDs
  - with sufficient depth above bedrock and groundwater table
  - below slope steepness criteria along roadside
  - linked to the category of adjacent land use / road width

GIS in Screening of LID

Area-based LID Opportunities

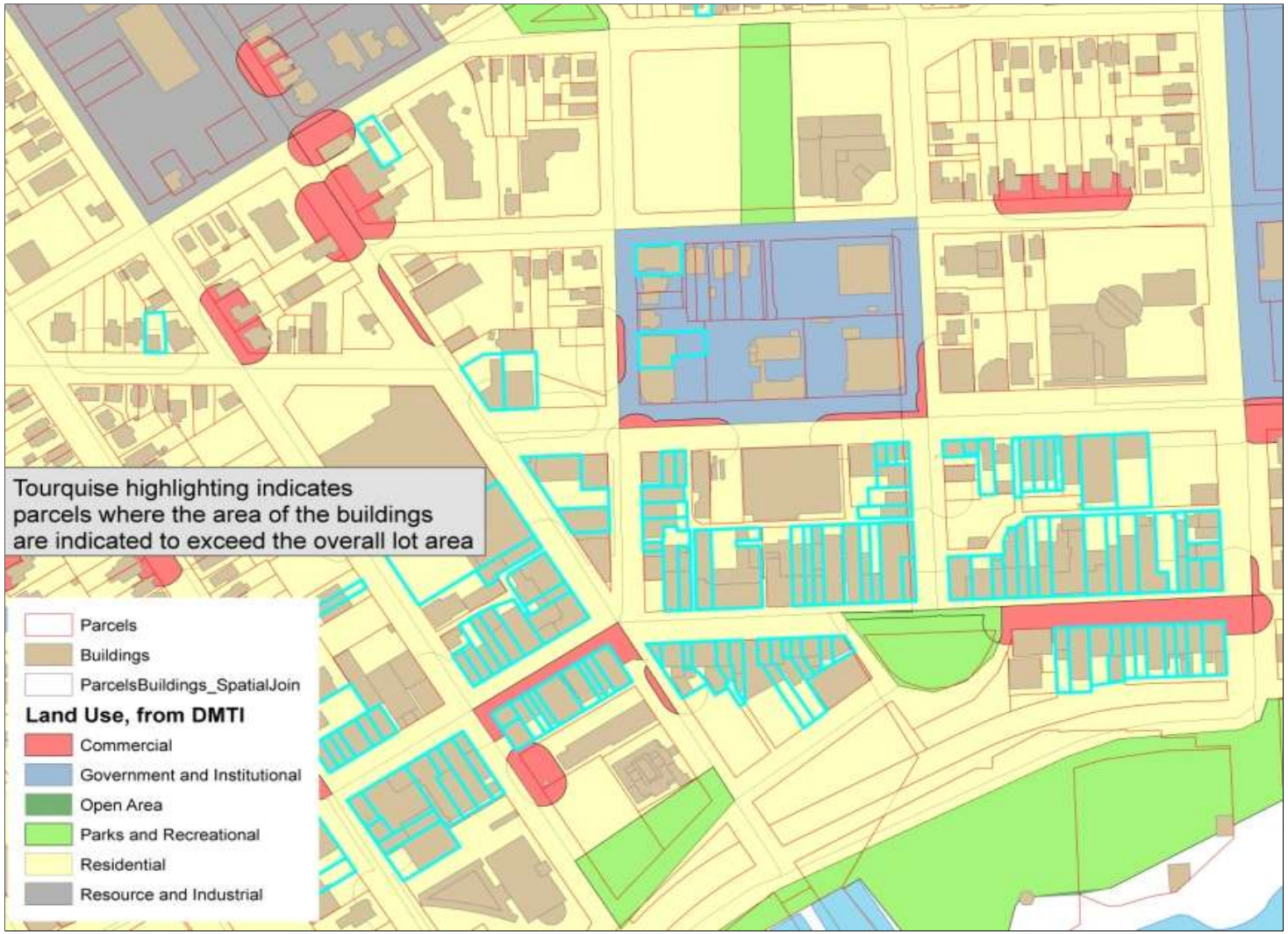
- Inventory review
  - on public open space (parks, gores and natural areas)
  - off buildings, driveways and parking areas
  - on appropriate soils
  - away from treed areas
  - in acceptable slope range
  - with sufficient depth to bedrock and the water table
  - with soil of the appropriate hydrographic class

GIS in Screening of LID Opportunities

Data Issues

- Geographic resolution and registration
- Used GIS tools (selection by attributes, table join, selection by location/intersection, area calculation) to consolidate features into a consistent and coherent geodatabase

Buildings identified as being larger than their lots were clipped to lot bundaries

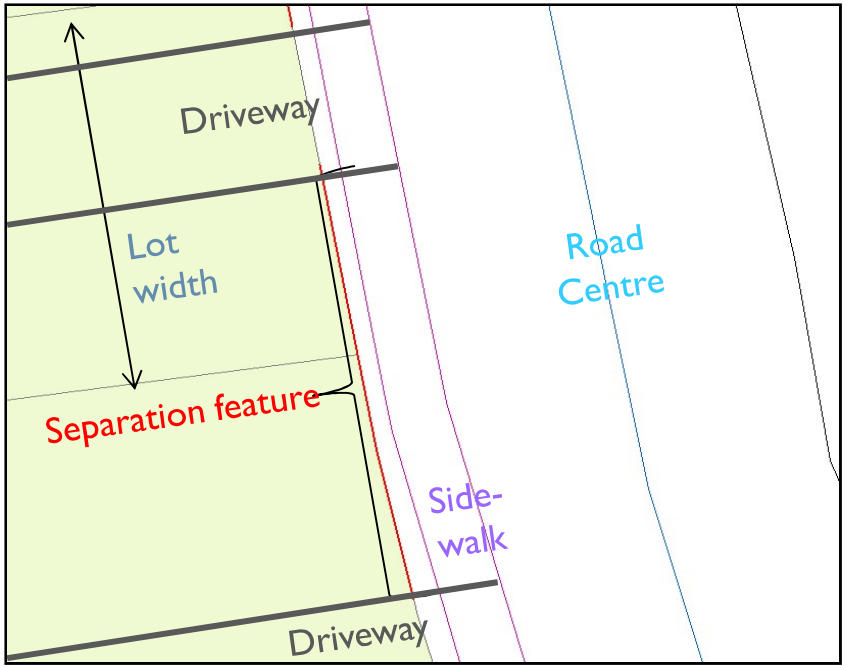


Parking lots (turquoise) were largely unclosed polygons which are unsuited for calculating impermeable portions of lots.

GIS in Screening of LID Opportunities

Data Issues continued

- **Details of Roads' Rights of Way**
  Used additional GIS tools (projection of polylines, assignment of topology rules to features, derivation of new polygon features by assembling polylines) for LID screening of roads and their rights of way:



GIS in Screening of LID Opportunities

Data Issues

- **Roads and Rights of Way Data**

  New features that were generated:

  - road segments by surface material (paved/unpaved)
  - presence or absence of ditches
  - presence or absence of trees
  - and sufficient right-of-way space available to accommodate LIDs

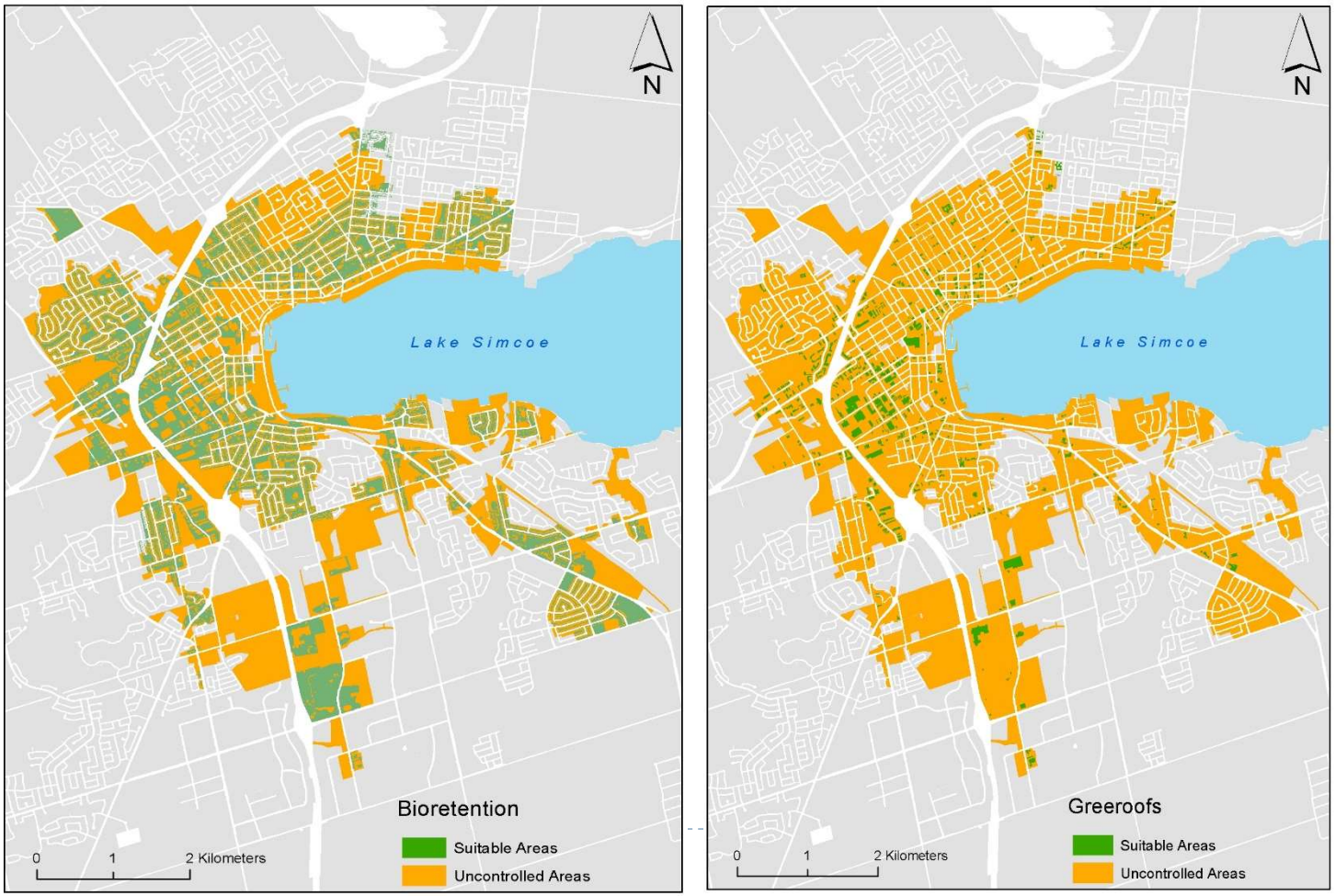
GIS in Screening of LID Opportunities

Layers	Barrie	Newmarket	East Gwillimbury	Aurora
Parcels	Comprehensive (from LSRCA/Teranet)			
Parking	Completed	Present	None	None
Driveways	Present	None	None	None
Buildings	Comprehensive (except attributes)	Comprehensive (except attributes)	None	None
Land Use	Satisfactory (from LSRCA and DMTI)			Comprehensive
Sidewalks	Present	Require restructuring (lines)	None	Incomplete, lines
Soils	Complete (Hydrographic Classes and Depths, from LSRCA)			
Roads	Completed (lines)	Require restructuring (lines)	Present (lines)	Present (lines)
Storm Drainage System	Present (lines)	Comprehensive	Present	Present
Ditches	Present	None	None	None
Parks	Present	Present	from LSRCA	Present
DEM/DTM	from LSRCA			

GIS in Screening of LID Opportunities

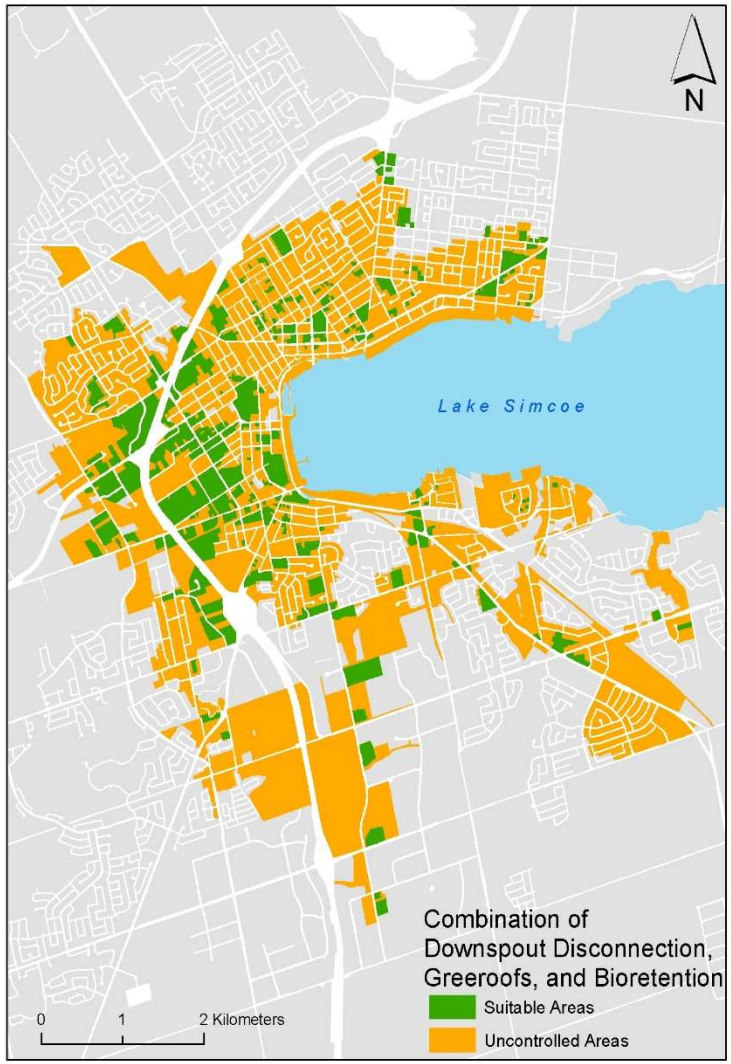
LID Screening

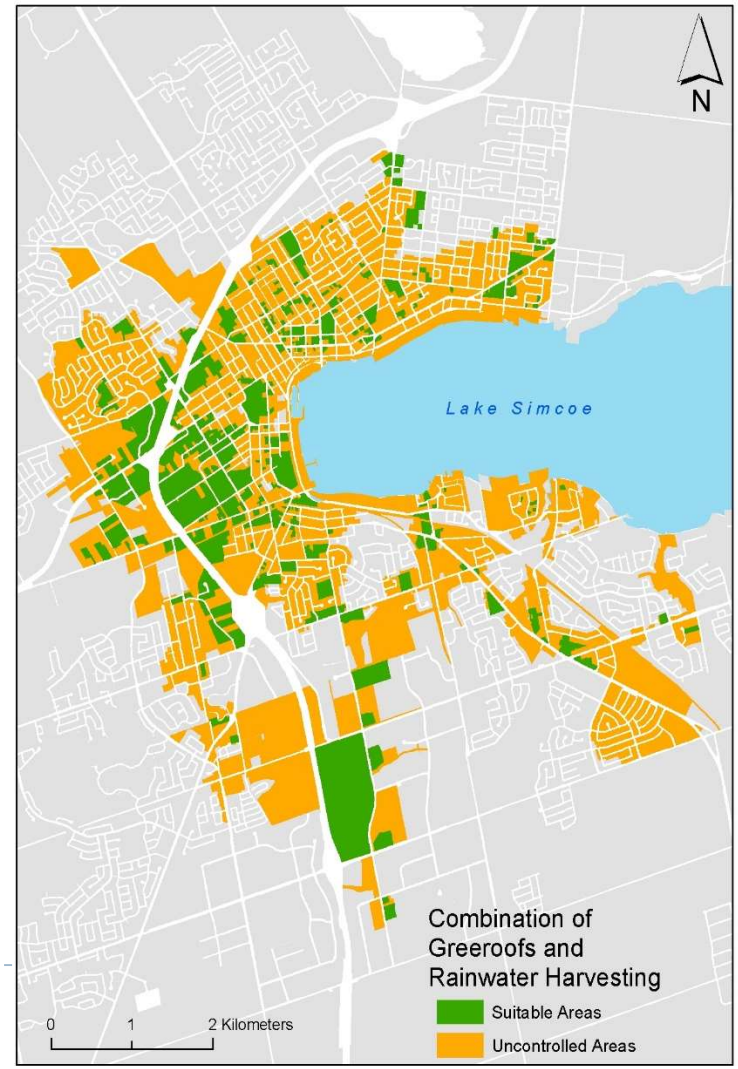
Screening of sites suited to each individual lot-based LID have been mapped, demonstrating that conditions are appropriate and choices exist



GIS in Screening of LID Opportunities

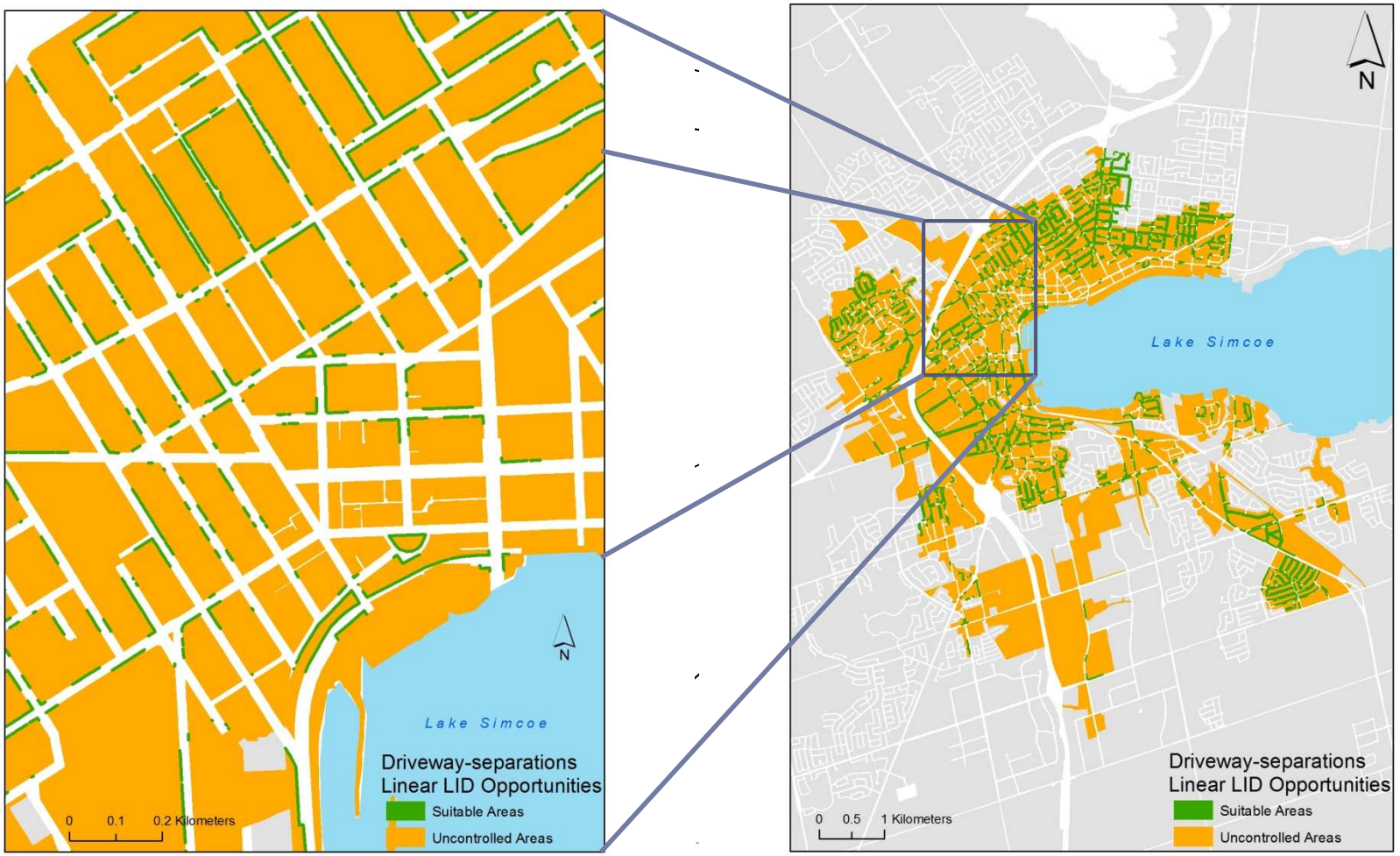
LID Screening sites for combinations of lot-based LIDs have now been demonstrated to be appropriate:





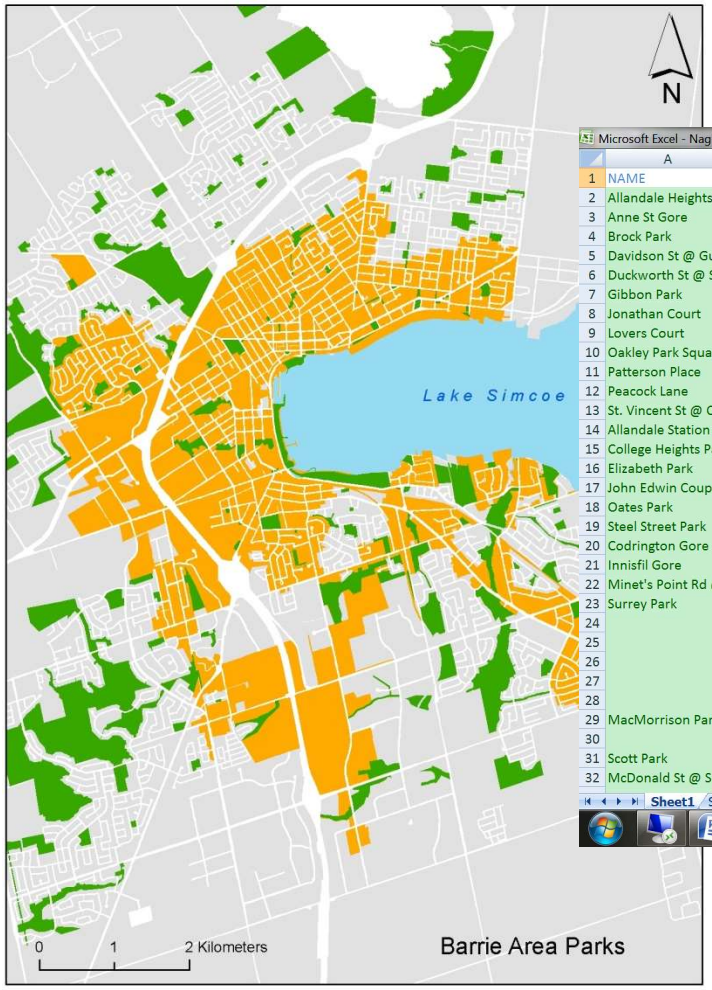
GIS in Screening of LID Opportunities

LID Screening of rights-of-way based LIDs have now also been demonstrated to be appropriate:



GIS in Screening of LID Opportunities

LID Screening of area-based LIDs have now also been demonstrated to be available:



Microsoft Excel - Naglaa Screening table for Barrie parks 110.xlsx

	A	B	C	D	E	F	G	H	I	J
1	NAME	UNOFFICIAL	TYPE	LTMUNICIPA	Park_Area	UnTreeArea	Available Space	% of Available area	Nearest intersection	comments
2	Allandale Heights Park		Park	CITY OF BARRIE	12146.03	12146.03	12146.03	100.00	Glenridge& Bayview	
3	Anne St Gore		Gore	CITY OF BARRIE	1128.17	1128.17		100.00	campbell Ave & Anne St	
4	Brock Park		Park	CITY OF BARRIE	15157.15	15157.15		100.00	Brock and Sanford	
5	Davidson St @ Gunn St		Gore	CITY OF BARRIE	389.86	389.86		100.00	Davidson and gunn	
6	Duckworth St @ St. Vincent St		Gore	CITY OF BARRIE	855.88	855.88		100.00	Eugenia and Duckworth	
7	Gibbon Park		Park	CITY OF BARRIE	6967.42	6967.42		100.00	Gibbon and Anne	
8	Jonathan Court		Gore	CITY OF BARRIE	146.91	146.91		100.00	bothwell and davidson	
9	Lovers Court		Gore	CITY OF BARRIE	146.91	146.91		100.00	Lovers and Royal oak	
10	Oakley Park Square		Gore	CITY OF BARRIE	146.91	146.91		100.00	oak and grove	
11	Patterson Place		Park	CITY OF BARRIE	4588.25	4588.25		100.00	Moon and Patterson	
12	Peacock Lane		Gore	CITY OF BARRIE	146.91	146.91		100.00	Peacock and thorncrest	
13	St. Vincent St @ Orchard Dr		Gore	CITY OF BARRIE	146.91	146.91		100.00	St Vincent and Orchad	
14	Allandale Station Park		Park	CITY OF BARRIE	68580.71	68513.93		95.00	tiffin & lakeshore	
15	College Heights Park		Park	CITY OF BARRIE	12482.73	12482.73		95.00	Rose and Bernick	
16	Elizabeth Park		Park	CITY OF BARRIE	9117.02	9117.02		95.00	Elizabeth and James	
17	John Edwin Coupe Park		Park	CITY OF BARRIE	2399.71	2399.71		95.00	Mcdonald and Owen	
18	Oates Park		Park	CITY OF BARRIE	4692.81	3883.61		95.00	Edgehill and ferndale	
19	Steel Street Park		Park	CITY OF BARRIE	9868.27	9868.27		95.00	Steel and cook	
20	Codrington Gore		Gore	CITY OF BARRIE	1743.52	1743.52		90.00	Codring and Lakeview	
21	Innisfil Gore		Gore	CITY OF BARRIE	834.18	834.18		90.00	treed area	
22	Minet's Point Rd @ Lakeshore Dr		Gore	CITY OF BARRIE	1261.56	1261.56		90.00	Foster and yonge	
23	Surrey Park		Park	CITY OF BARRIE	23475.46	20096.08		90.00	Edgehill and ferndale	
24		Irwin Natural Area	Natural Area	CITY OF BARRIE	7505.17	5.40		90.00	Cundles and Anne	
25		Strabane Park South	Park	CITY OF BARRIE	2020.61	2020.61		90.00	Cook and Straban	
26		Lovers Creek Ravine	Natural Area	CITY OF BARRIE	27506.34	1221.63		90.00	Yonge and Big Bay Point	
27		Willoughby Natural	Natural Area	CITY OF BARRIE	33437.69	33437.69	30000.00	89.72	Big bay Point and Yonge	
28		Whiskey Creek Soutl	Natural Area	CITY OF BARRIE	50525.57	4911.07	30000.00	89.72	Mapleview and Huronia	
29	MacMorrison Park		Park	CITY OF BARRIE	26416.56	26416.56	23416.00	88.64	Grove and St vincent	
30		Dyments Creek East	Natural Area	CITY OF BARRIE	17057.89	10866.47	15000.00	87.94	Brock and Lorena	
31	Scott Park		Park	CITY OF BARRIE	7511.55	7511.55	6250.00	83.21		
32	McDonald St @ Sophia St		Gore	CITY OF BARRIE	293.03	293.03		80.00	Sophia and Mcdonald	

Sheet1 Sheet2 Sheet3

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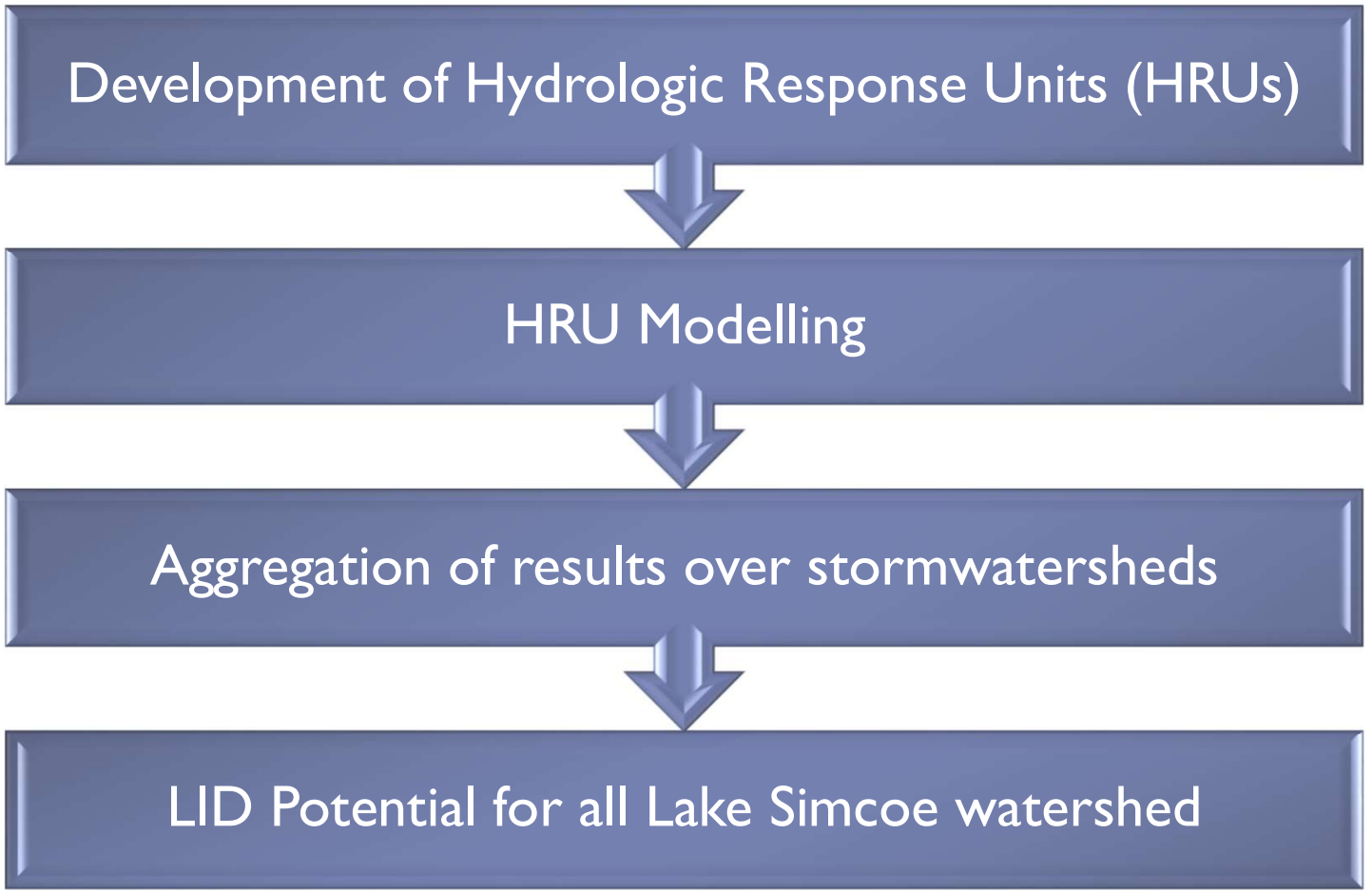
13/09/2010

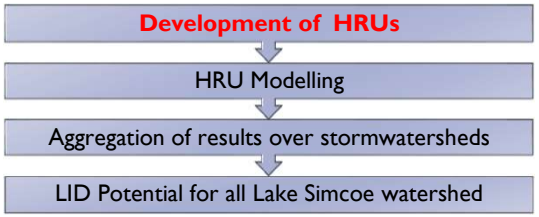
GIS in Development of HRUs

Data Compilation: Records Needed for HRU development

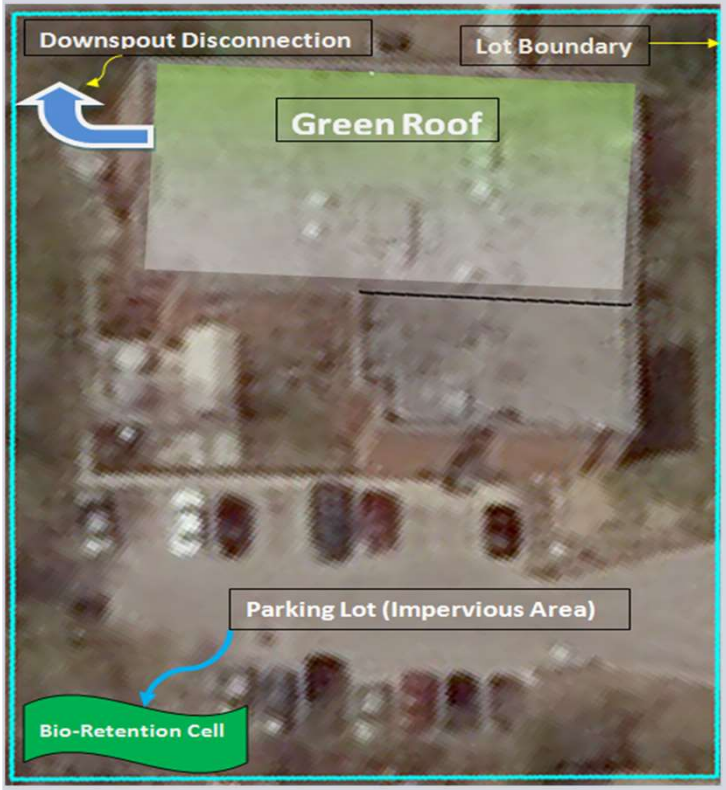
- storm sewer networks including outfalls
- buildings:
  - roof area as a proportion of its land parcel
  - building height
  - building age
  - roof age
  - material
  - type (flat or sloping)
  - storm-sewer connectivity
- roads and their attributes:
  - presence or absence of ditches
  - surface material
  - paved area
  - right-of-way extent
- aerial photography
- precipitation records
- runoff data

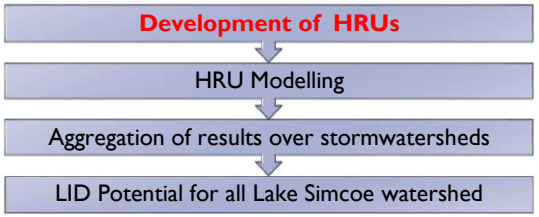
Computational Approach





LID Combinations

LID Combination	LID Placement	Connectivity Assumptions
Green Roof + Bio-Retention Cell + Downspout Disconnection (GR + BR + DD)		**GR:** • 75 % of roof area • Draining to pervious area **BR:** • Treating parking and driveway runoff only



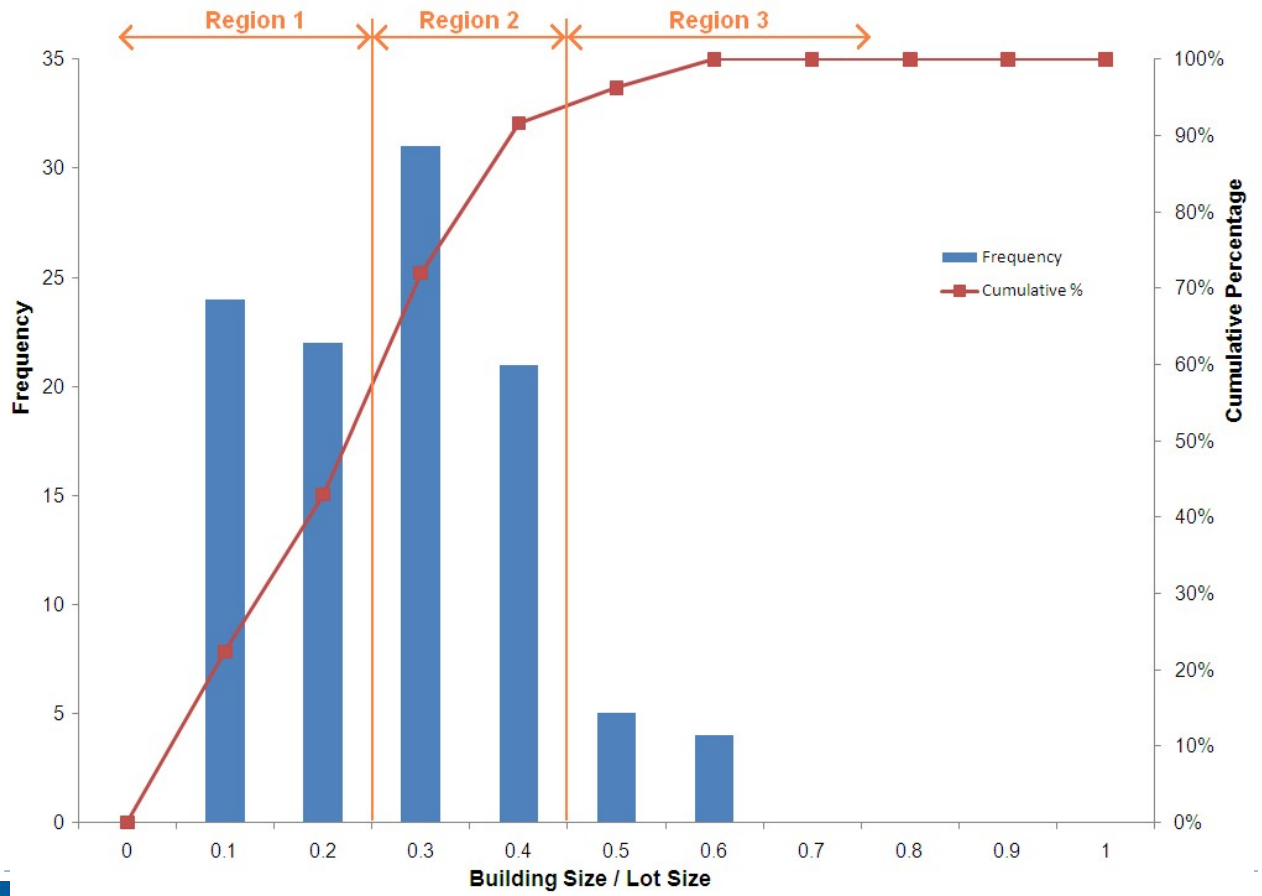
Lot-Based HRUs

- Lot as a basic unit
- Use of GIS screening results
  - Hydrologic similarity
  - LID opportunities
- Procedure
  - Examine the distribution of lots produced by screening
  - Select three regions
  - Select one lot to be modeled from each region (orthophotos)
  - Model selected lots (existing and with LID)
  - Develop HRU performance curves
    - Runoff reduction
    - Pollutant loading reduction

Development of HRUs
HRU Modelling
Aggregation of results over stormwatersheds
LID Potential for all Lake Simcoe watershed

Areas for Modeling

- Example: Soakaway pits in residential areas
  - Distribution and selection of regions



Development of HRUs
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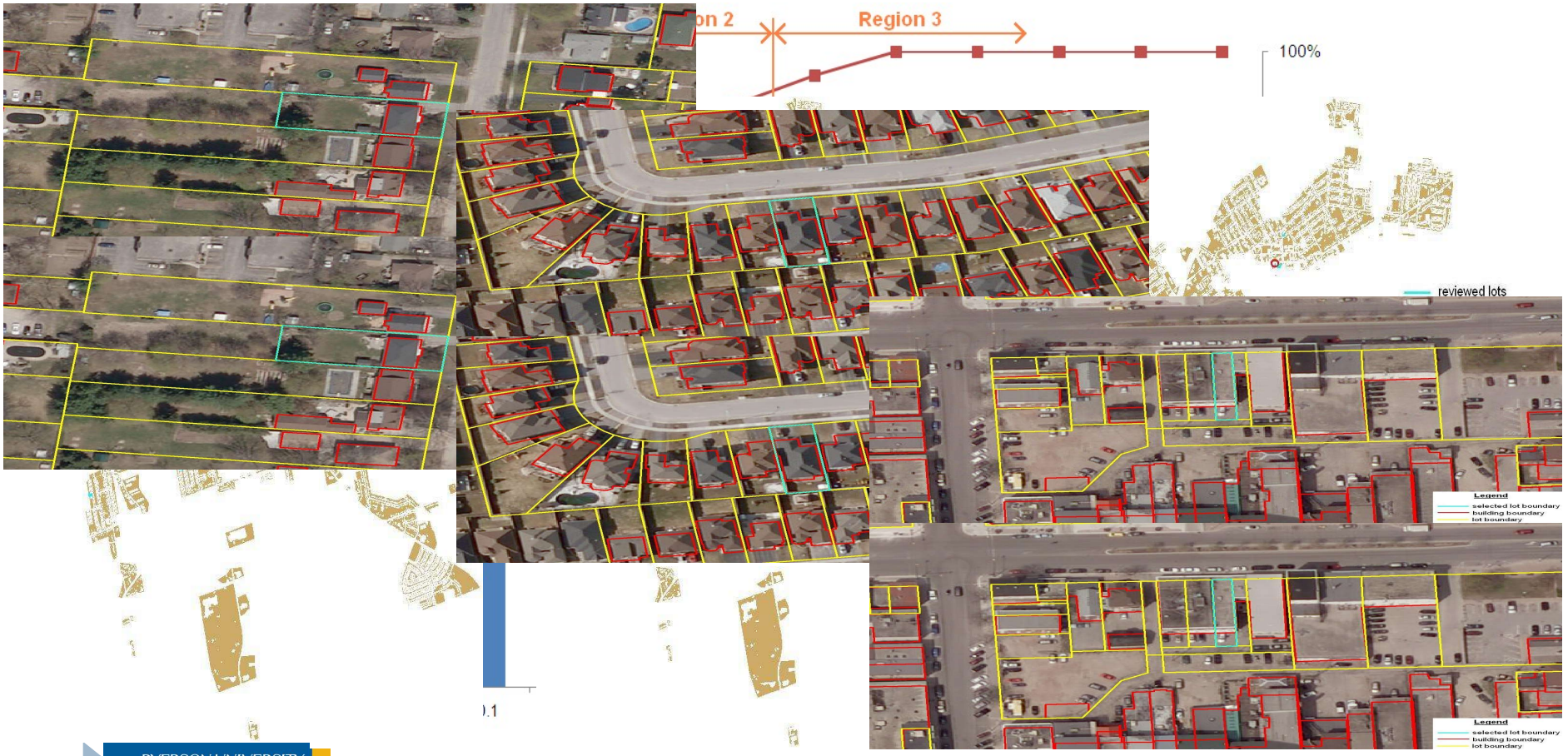
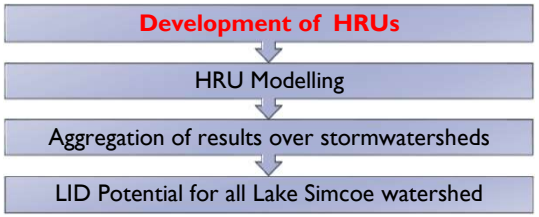
Areas for Modeling

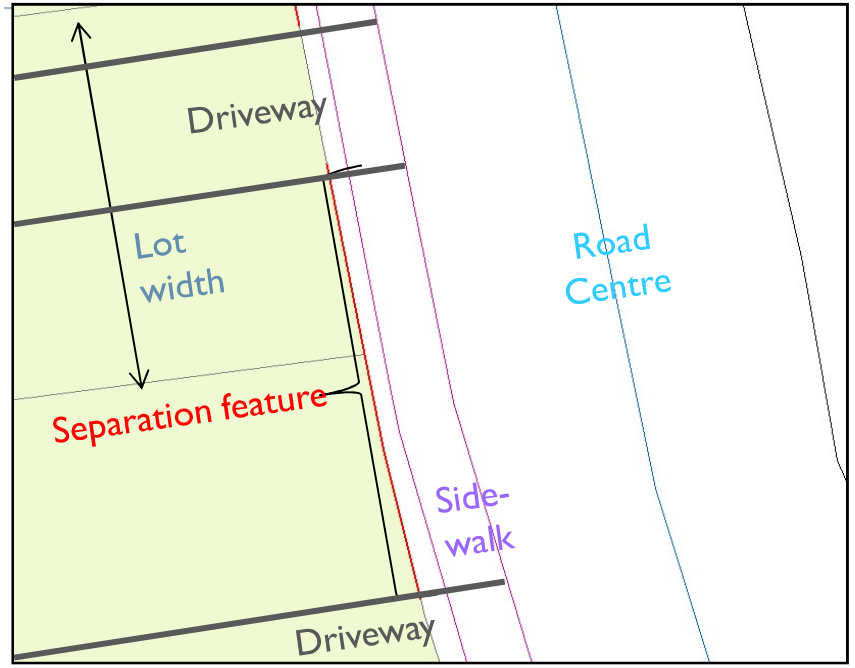
- Example: Soakaway pits in residential areas
  - Examining and selection of lots in each region

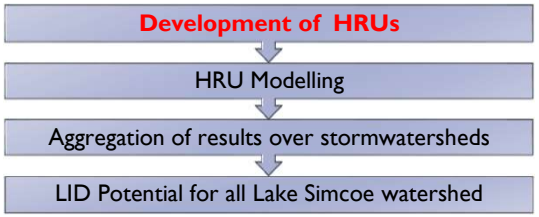


ROW HRUs



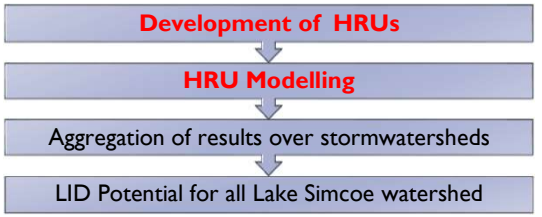
- ROW length as a basic unit
- Use of GIS screening results
  - Drainage area (road width)
  - LID opportunities
- Procedure
  - Examine the distribution of roads of different width
  - Model unit lengths of selected roads
    - Existing
    - With LID implementation
  - Develop HRU performance curves





Development of Area ~~HRUs~~

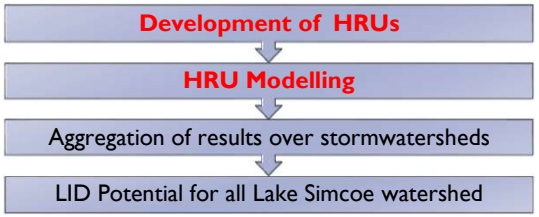
- Manual screening of opportunities
  - Open spaces
  - Paved areas
  - Tree cover
  - Presence of sports facilities
  - Soil type
  - GW table
  - Drainage area
- Model individual areas



HRU Modelling in Barrie

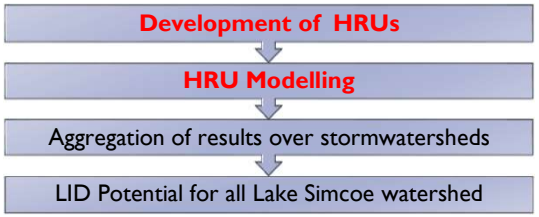
- Population 177,061
- Total area 898 km^2
- Uncontrolled drainage area
  - 24 km^2 (1/5 of total uncontrolled area)
  - 136 stormwatersheds
  - 11,135 lots

Location	Total Number of Catchments	Total Urban Area (ha)	Uncontrolled		
			#	Area (ha)	% (area)
Aurora	210	2930.15	153	1941.49	66
Ballantrae	51	725.93	33	277.31	38
Barrie	198	3957.42	136	2446.64	62
Beaverton	38	254.34	38	254.34	100
Bradford	38	581.82	32	413.29	71
Cannington	17	106.96	15	94.69	89
Holland Landing	50	450.68	38	351.63	78
Innisfil	181	2116.87	150	1417.92	67
Keswick	96	899.54	83	602.38	71
Mount Albert	18	163.17	15	108.12	66
Newmarket	108	3104.03	51	1040.88	33.5
Orillia – Lake Simcoe	27	1468.13	27	1468.13	100
Pottageville	13	88.26	12	76.88	87
Schomberg/Lloydtown	27	149.40	23	113.43	76
Sharon	10	248.41	8	130.49	52.5
Sutton	49	306.58	48	269.44	88
Uxbridge	43	677.74	30	337.54	50
Totals	**1174**	**18,229.43**	**892**	**11,344.60**	**62.2**
Orillia – Lake Couchiching*	49	799.64	49	799.64	100



Modelling Inputs

- Rainfall Data
  - Barrie WPCP
  - Hourly records 1968-2003 analyzed
  - Average year (1985) precipitation used
- Evapotranspiration
  - Provided by LSRCA
  - Barrie Creek Watershed used
- Pollutant concentrations
  - EMC based on Toronto WWFMMP Study
  - Use of local data in the future



LID Sizing Assumptions

- Usually target-based (e.g. design events)
- LID Sizing assumptions
  - Lot-based - Existing 2003 MOE guidelines
  - ROW - TRCA/CVC LID Manual
  - Area - TRCA/CVC LID Manual
- Typical pollutant removal assumed (literature)

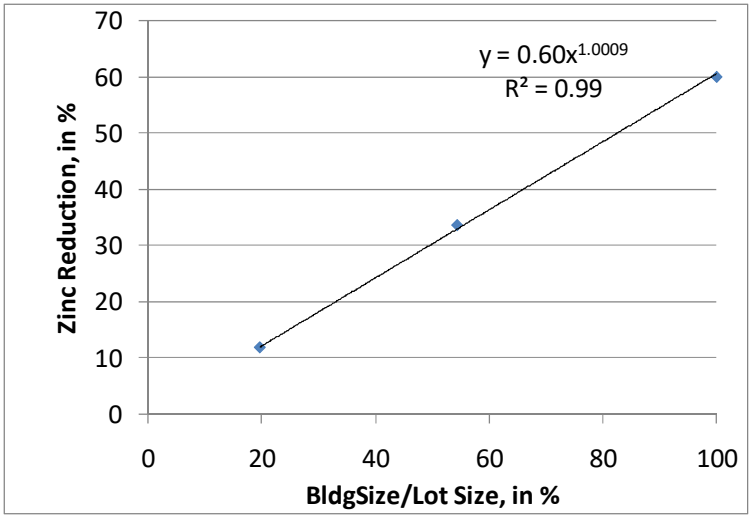
Practice	TSS	TP	Zinc
Bioretention	60 (15 to 75)	60 (-75 to 85)	65 (40 to 95)
Dry Well	90 (80 to 100)	50 (40 to 60)	90 (80 to 100)
Downspout Disconnection	100	100	100
Rainwater Harvesting	100	100	100
Permeable Pavement	75 (60 to 95)	65	75 (65 to 85)
Soakaway Pit	90 (60 to 95)	65 (50 to 95)	65 (65 to 85)
Green Roof	88	-80 (-242 to -69)	69
Grass Channel	45 (30 to 65)	15 (10 to 25)	35 (20 to 50)
Dry Swale	80 (75 to 90)	83 (-45 to 60)	75 (60 to 85)

Development of HRUs
HRU Modelling
Aggregation of results over stormwatersheds
LID Potential for all Lake Simcoe watershed

Aggregation of Results

- Spreadsheet model
  - LID performance on stormwatershed basis (e.g. greenroof)

Stormsewershed ID	Stormsewershed Area, in m^2	Applicable Area of LIDs	
		in m^2	in %
BAR-C1	1,071,533	257,125	24.0

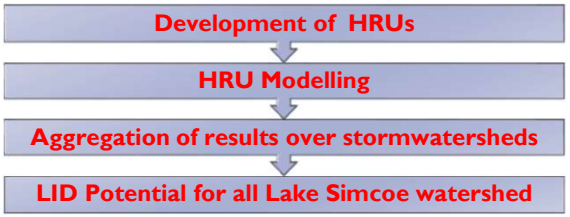


RUNOFF VOLUME CALCULATION				
Total Runoff per Stormsewershed, in m^3	Runoff of Applicable Area, in m^3		Runoff Reduction	
	(no LID)	(with LID)	in m^3	in %
157,130	64,963	58,275	6,688	4.3

TOTAL PHOSPHORUS (TP) LOADING				
TP per Stormsewershed, in kg/yr	TP of Applicable Area, in kg/yr		TP Loading Increasing	
	(no LID)	(with LID)	in kg/yr	in %
108.1	35.9	36.4	-0.48	-0.44

TOTAL SUSPENDED SOLID (TSS) LOADING				
TSS per Stormsewershed, in kg/yr	TSS of Applicable Area, in kg/yr		TSS Loading Reduction	
	(no LID)	(with LID)	in kg/yr	in %
24,572	4,779	3,596	1,184	4.8

ZINC LOADING				
Zinc per Stormsewershed, in kg/yr	Zinc of Applicable Area, in kg/yr		Zinc Loading Reduction	
	(no LID)	(with LID)	in kg/yr	in %
43.2	26.0	20.7	5.2	12.1



Watershed Municipalities

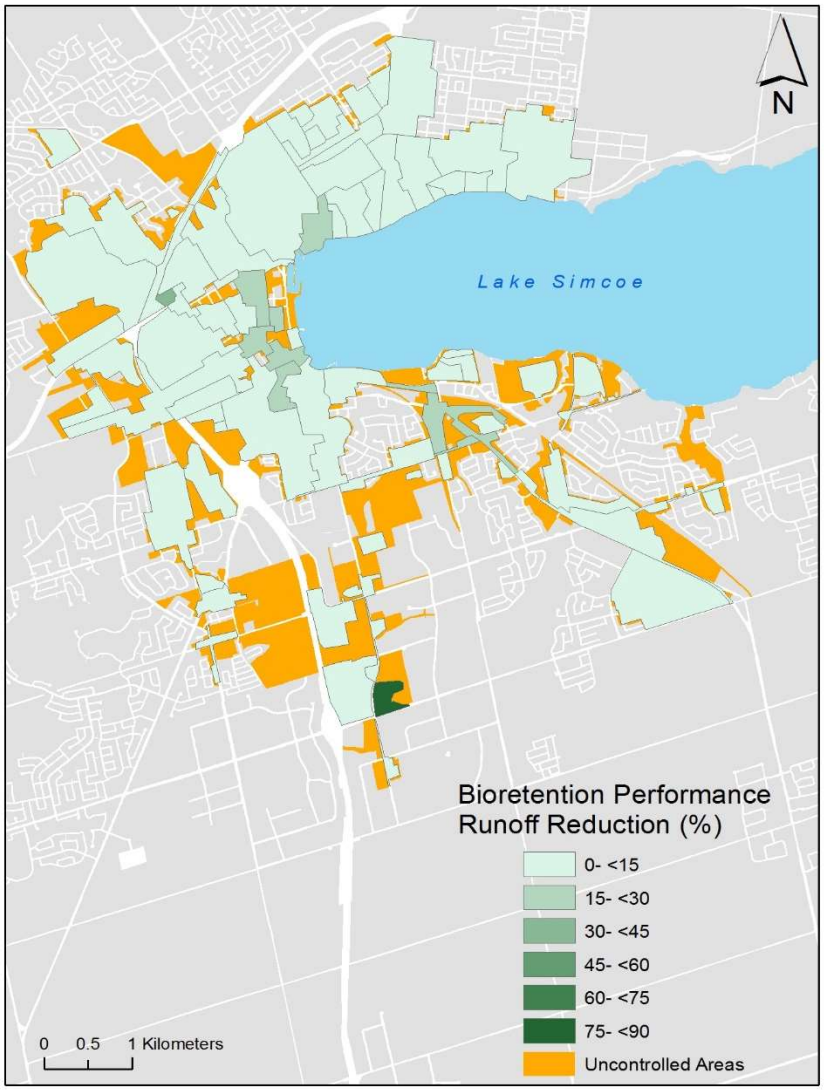
- Analyze Barrie results by land use
  - Loading rates for runoff and phosphorus
  - Reduction factors

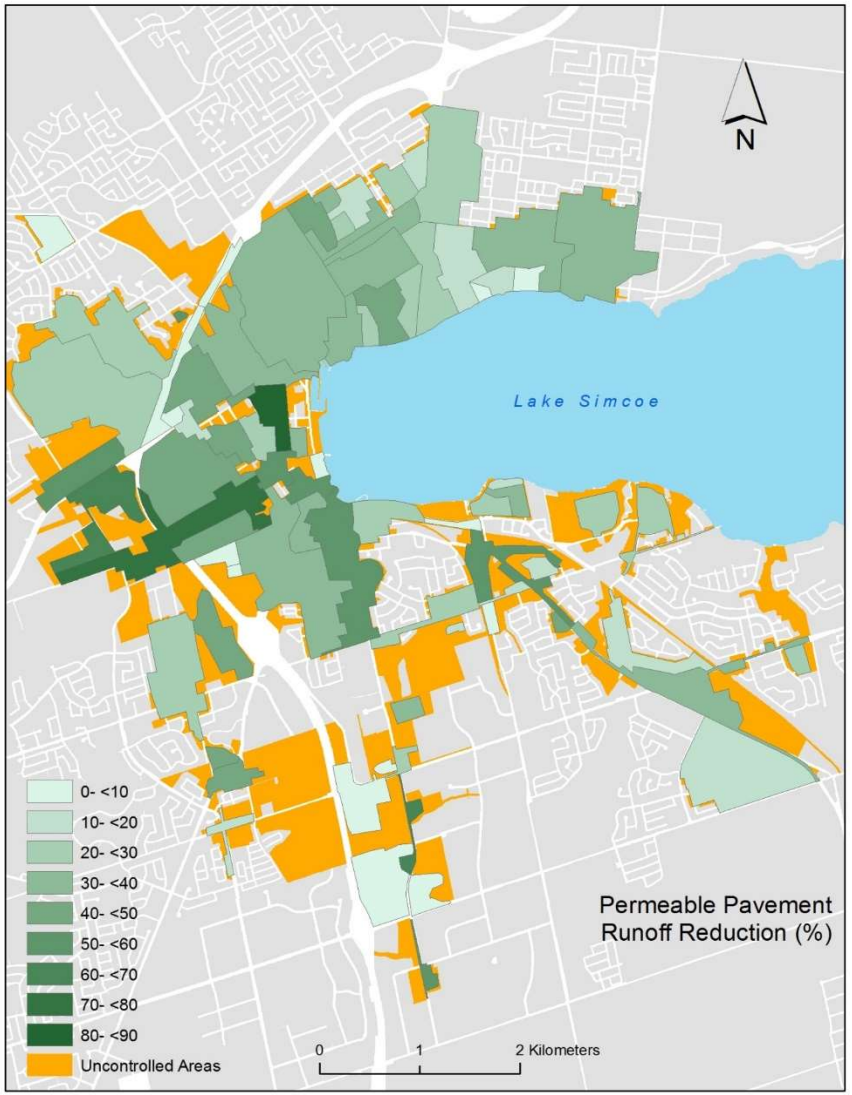
	Land Use Types			
	Residential	**Commercial**	**Resource and Industrial**	**Government and Institutional**
All Lots in City of Barrie				
Total Area, in ha	837.3	29.94	252.6	45.48
Without LID				
Total Runoff Volume, in m3	1,406,226	93,825	679,459	85,535
TP, in kg/yr	1,153	49	353	44
TSS, in kg/yr	333,697	5,038	36,487	4,593
Zinc, in kg/yr	215	40	292	37
Lots after GIS Screening				
Reduction Factors				

- Assemble land use distribution in all municipalities
- Apply loading and reduction factors

Aggregation of Modeling Results in Barrie

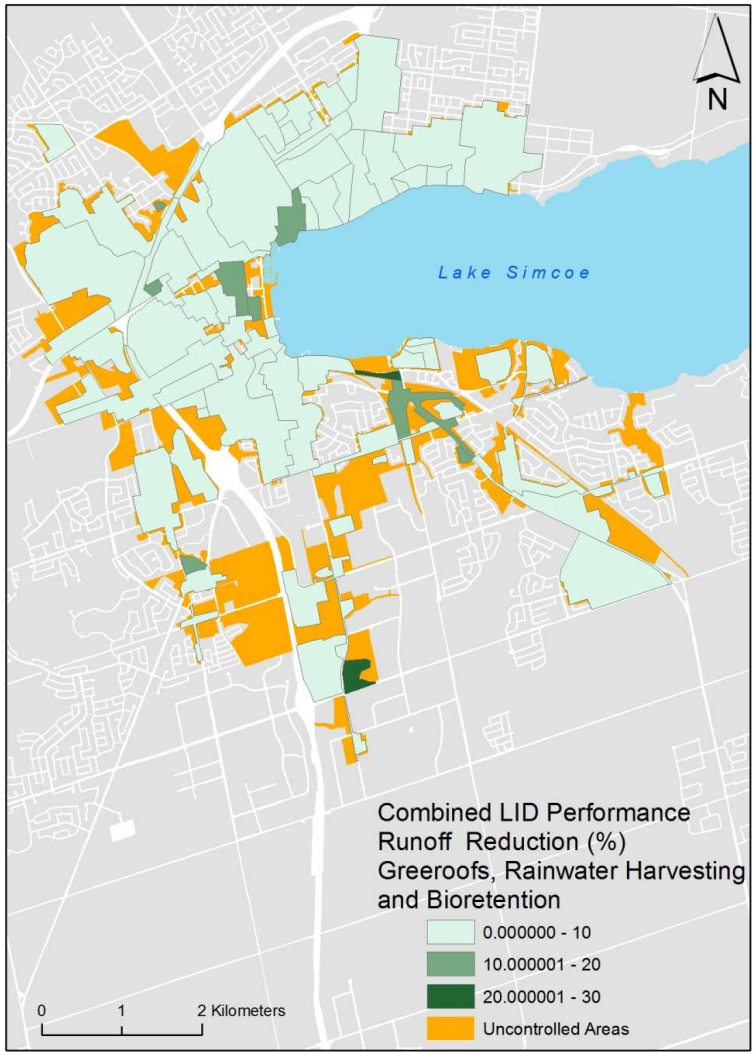
- Performance Maps: Lot-based: Individual LIDs

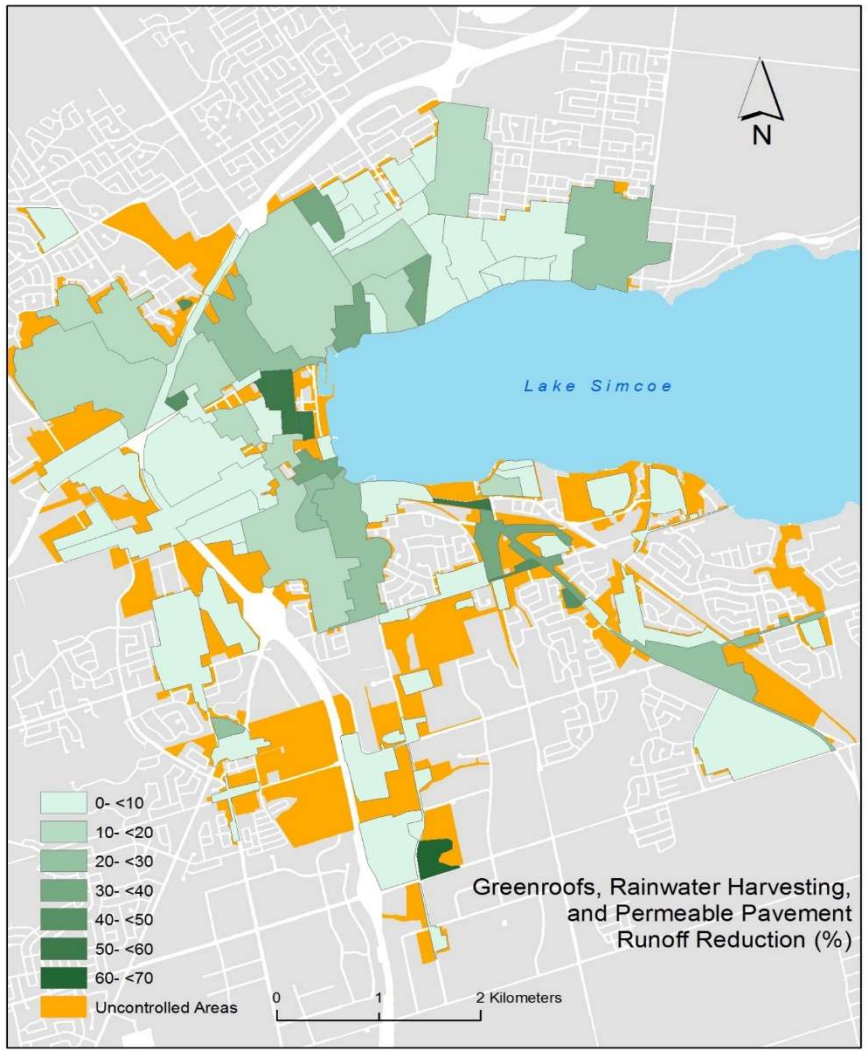




Aggregation of Modeling Results in Barrie

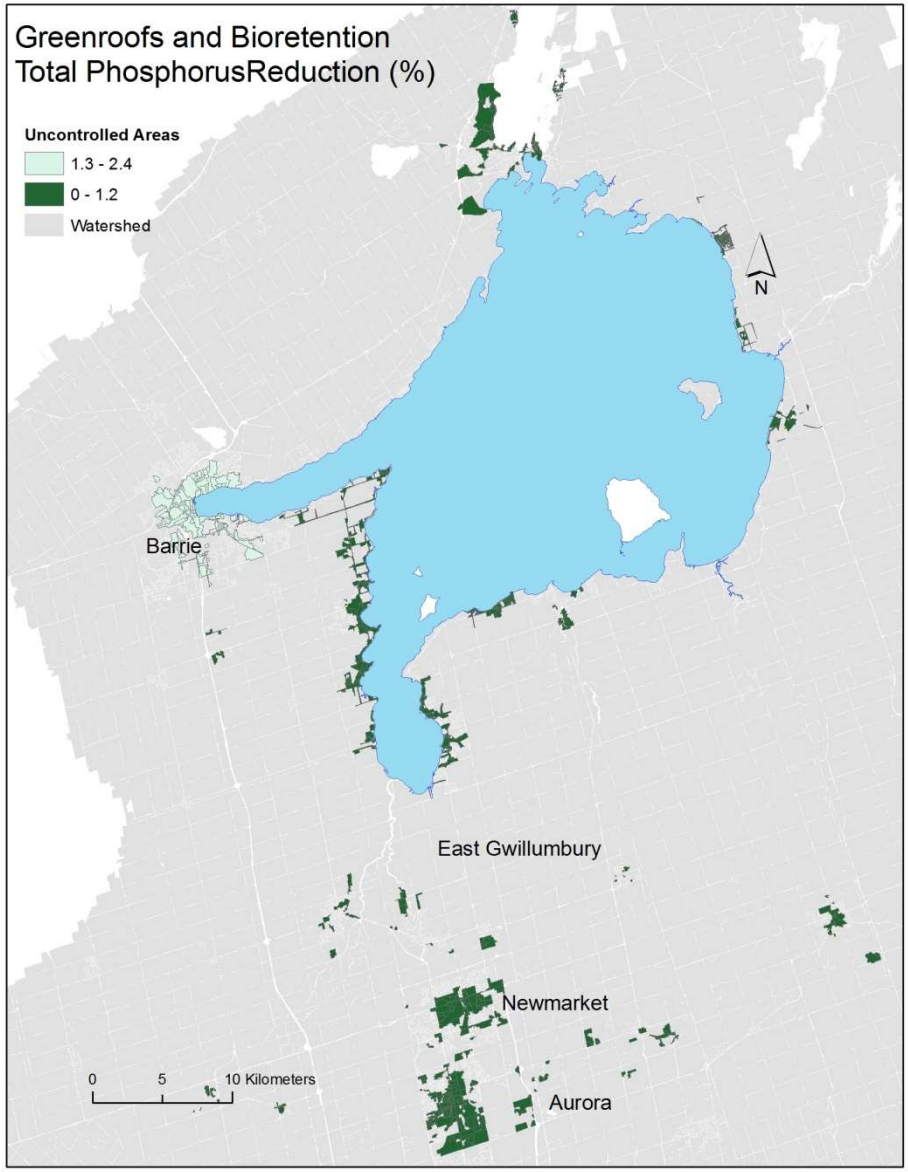
- Performance Maps: Combinations of lot-based LIDs

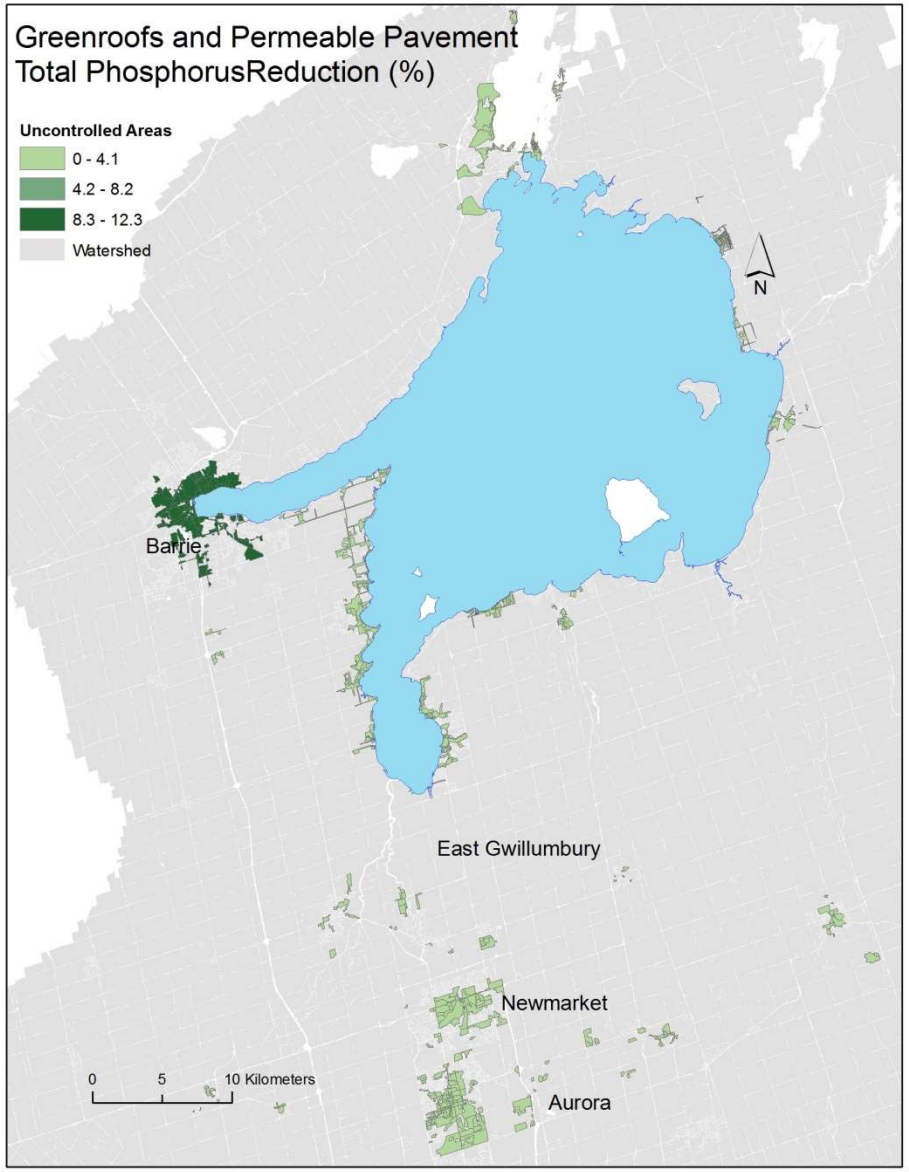




Aggregation of Results in Lake Simcoe

- Performance Maps: Combinations of lot-based LIDs





Potential Loading Benefits of Lot-level LIDs in Lake Simcoe

Names of Cities/Townships	TP Loading of Existing Condition (without LID), in t/yr	TP Loading, in t/yr			
		PP	BR+PP	DD	DW+PP
CITY OF ORILLIA	0.65	0.23	0.22	0.19	0.30
TOWN OF AURORA	1.18	0.49	0.35	0.36	0.46
TOWN OF BRADFORD-WEST GWILLIMBURY	0.06	0.02	0.02	0.02	0.03
TOWN OF EAST GWILLIMBURY	0.17	0.06	0.06	0.05	0.08
TOWN OF GEORGINA	0.46	0.17	0.17	0.14	0.22
TOWN OF INNISFIL	0.95	0.33	0.32	0.28	0.44
TOWN OF NEWMARKET	0.98	0.39	0.34	0.30	0.44
TOWN OF WHITCHURCH-STOUFFVILLE	0.09	0.03	0.03	0.03	0.04
TOWNSHIP OF BROCK	0.12	0.04	0.04	0.03	0.05
TOWNSHIP OF KING	0.03	0.01	0.01	0.01	0.01
TOWNSHIP OF RAMARA	0.00	-	-	-	-
TOWNSHIP OF SEVERN	0.04	0.01	0.01	0.01	0.02
TOWNSHIP OF UXBRIDGE	0.22	0.08	0.08	0.07	0.10
CITY OF BARRIE	2.08	0.66	0.45	0.50	0.60
Total	7.04	2.53	2.11	1.99	2.79

Potential % Reduction of Lot-level LIDs in Lake Simcoe

Names of Cities/Townships	Runoff reduction(%)		TP reduction(%)	
	PP	BR+PP	DD	DW+PP
CITY OF ORILLIA	36	38	30	46
TOWN OF AURORA	44	30	31	39
TOWN OF BRADFORD-WEST GWILLIMBURY	45	38	31	46
TOWN OF EAST GWILLIMBURY	34	38	30	46
TOWN OF GEORGINA	38	41	30	48
TOWN OF INNISFIL	35	38	30	46
TOWN OF NEWMARKET	42	37	30	45
TOWN OF WHITCHURCH-STOUFFVILLE	37	35	30	44
TOWNSHIP OF BROCK	35	39	30	47
TOWNSHIP OF KING	34	38	30	46
TOWNSHIP OF RAMARA	0	0	0	0
TOWNSHIP OF SEVERN	34	38	30	46
TOWNSHIP OF UXBRIDGE	37	37	30	45
CITY OF BARRIE	33	21	24	29

Costs of Lot-level LIDs in Lake Simcoe

Names of Cities/Townships	Capital & 20 year O&M Cost ($M)			
	PP	BR+PP	DD	DW+PP
CITY OF ORILLIA	17.8	94.2	1.2	24.3
TOWN OF AURORA	46.7	134.7	1.8	58.9
TOWN OF BRADFORD-WEST GWILLIMBURY	2.3	6.7	0.1	4.3
TOWN OF EAST GWILLIMBURY	4.2	25.2	0.3	5.1
TOWN OF GEORGINA	14.2	65.8	0.8	24.7
TOWN OF INNISFIL	24.4	142.0	1.8	28.8
TOWN OF NEWMARKET	35.9	124.0	1.6	60.7
TOWN OF WHITCHURCH-STOUFFVILLE	2.7	13.4	0.2	2.7
TOWNSHIP OF BROCK	3.0	17.1	0.2	4.2
TOWNSHIP OF KING	0.7	4.0	0.1	0.8
TOWNSHIP OF RAMARA	0.0	0.0	0.0	0.0
TOWNSHIP OF SEVERN	1.1	6.6	0.1	1.3
TOWNSHIP OF UXBRIDGE	6.4	31.8	0.4	8.4
CITY OF BARRIE	61.6	181.9	2.5	60.1

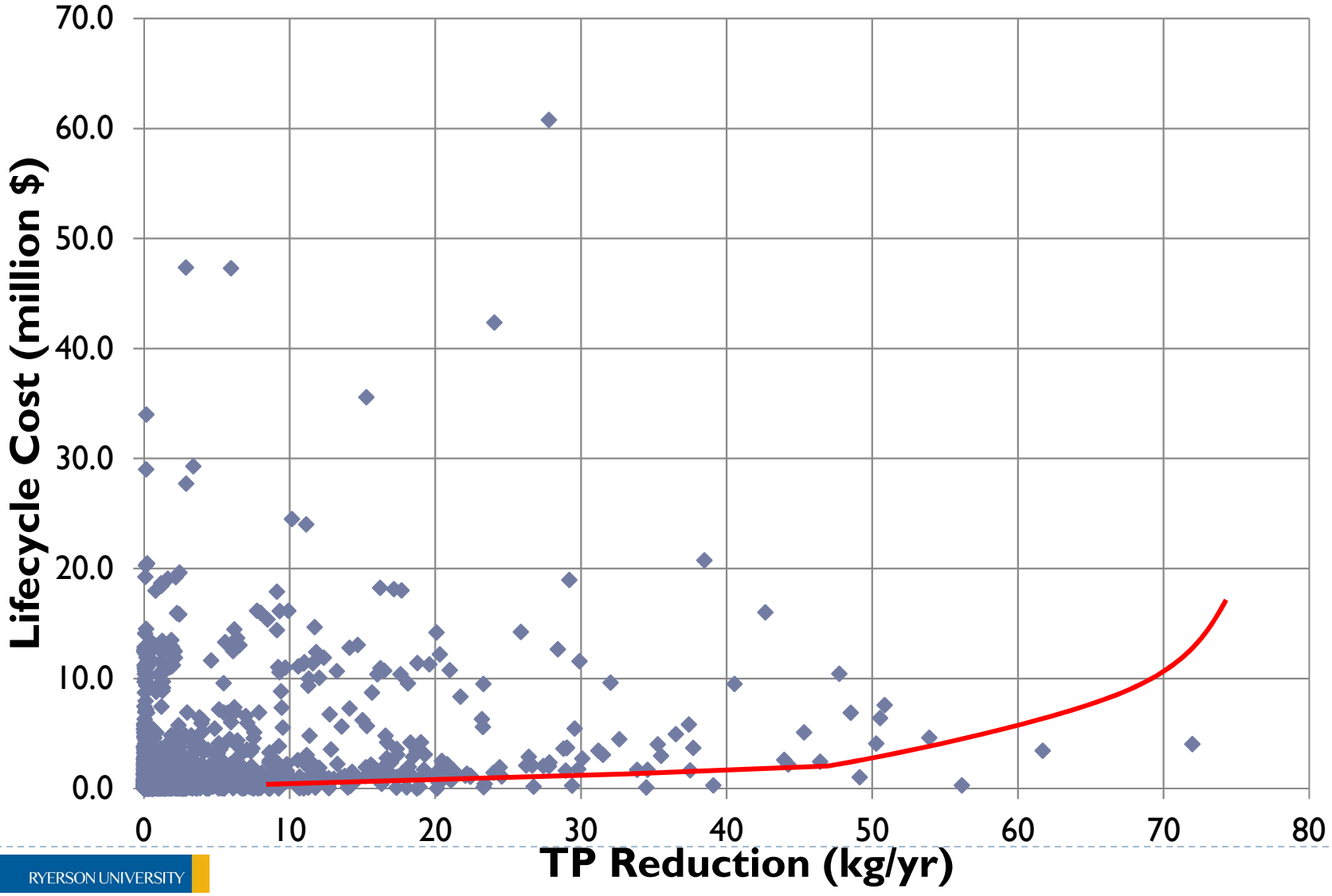
ROW LIDs in the City of Barrie

ROW LID	Overall Reduction								Cost($M)
	Runoff		TP		TSS		Zinc		
	m^3/yr	%	t/yr	%	t/yr	%	t/yr	%	
BR	43,821	5.3	0.1	16.4	44.6	16.4	0.043	17.3	55.6
GC	2,800	0.3	0.002	0.6	3.2	1.2	0.002	1.0	1.5

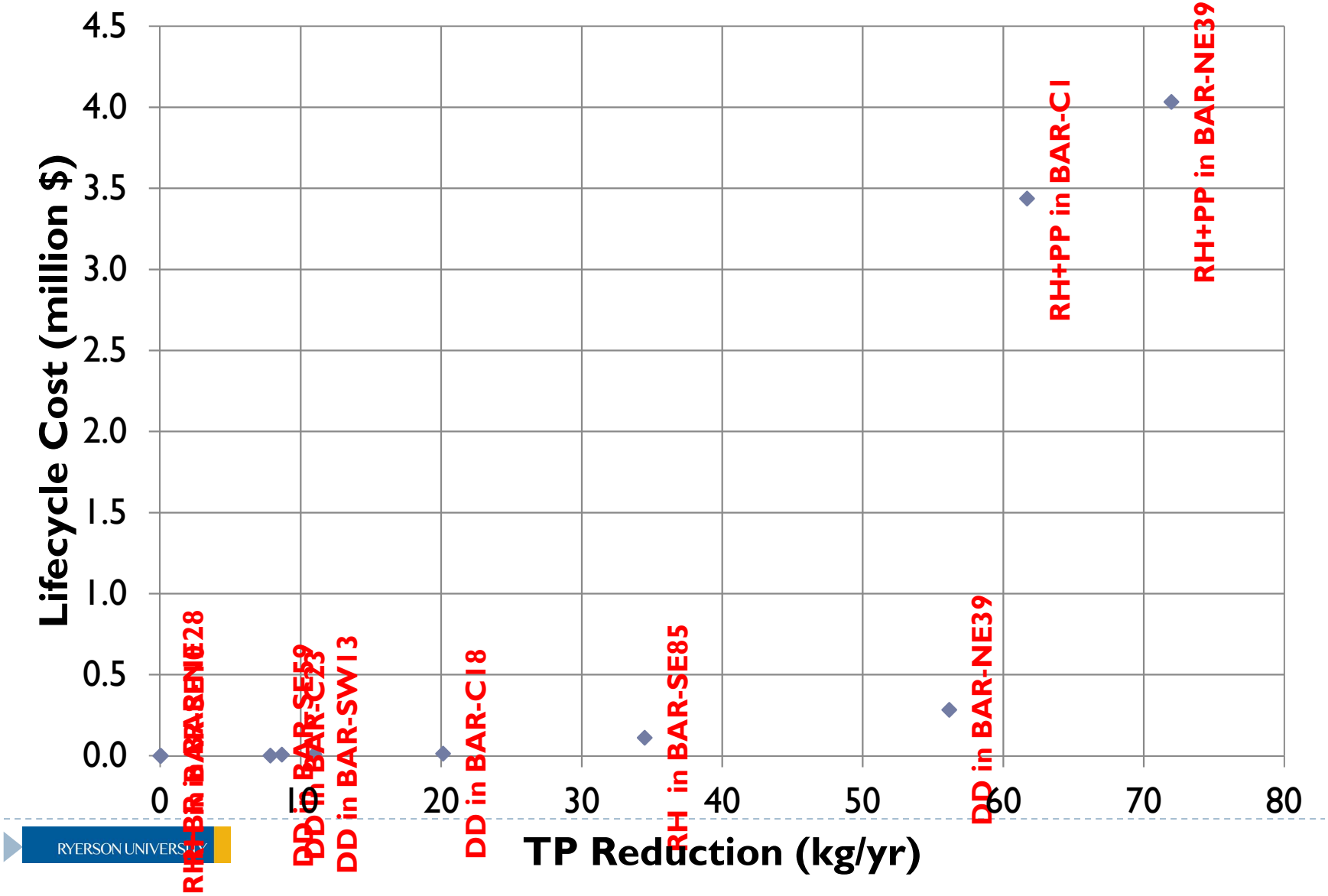
Marginal Costs of LIDs

Lot LID	$/m³	$/kg
PP	3	4,115
BR+PP	14	20,154
DD	0.3	251
DW+PP	4	5,037

Prioritization of Potential LID Areas



Prioritization of Potential LID Areas



Summary and Conclusions

- GIS analysis of LID feasibility requires high quality, good resolution, and consistent digital data throughout the study area.
- HRU approach
  - Allows watershed evaluation of implementation of small scale practices
  - Flexible
    - LID practices
    - Detailed modeling – performance curves
  - Prioritization and ranking of future efforts