An Erosion and Sediment Control Design Tool for Construction Sites

William Trenouth, Jennifer Thompson, and Dr. Bahram Gharabaghi

March 28, 2012

UNIVERSITY of GUELPH


Conservation
Construction Site
Stormwater Runoff

Construction Site Runoff

According to the 2000 National Water Quality Inventory, sediment runoff rates from construction sites are typically 10 to 20 times greater than those of agricultural lands (i.e. pre-development conditions); Erosion rates from construction sites range from 20-200 ton/acre/year (EPA, 2000).

Outline of the Presentation

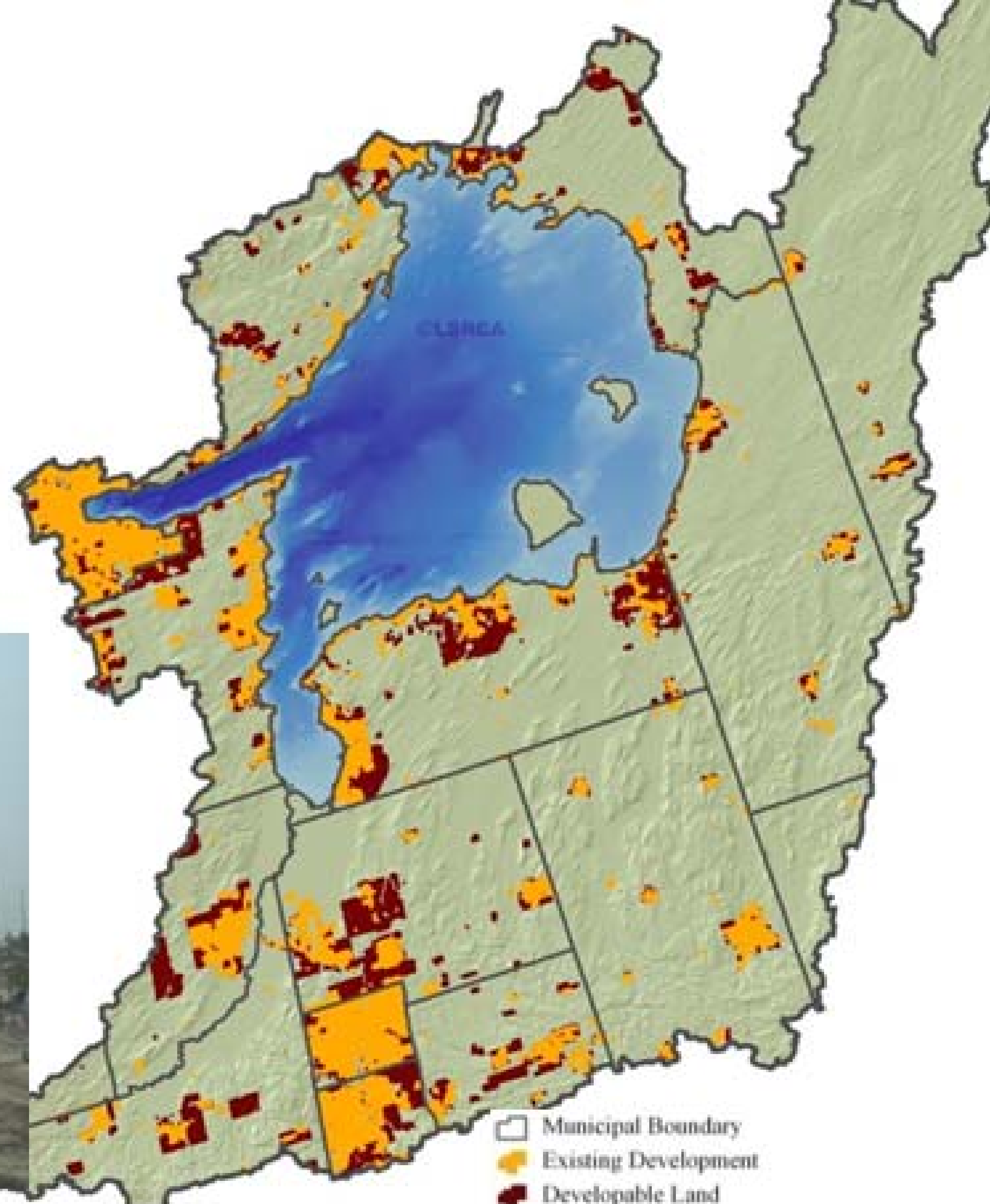
1. Overview of stormwater effluent and receiving water quality **guidelines** for construction sites.

2. **Monitoring data** on stormwater runoff from typical construction sites in the GTA.

3. Development of event-based soil loss equation combined with an **IDF** and **BMP** databases.

4. This tool has the ability to assist site planners and soil conservationists in the **design** of erosion and sediment control plans for construction sites.

Designated Growth Areas



MEDIA ROOM
- News Releases
- Charges and Convictions
- Backgrounders
- Ministerial Statements
- Speeches
- E-News
- Infocus
- Contacts
- Archives
- RSS News Feed
- Proactive Disclosure

Residential Development Company Pleads Guilty to Releasing Sediment into Marigold Creek

October 18, 2007

NEWMARKET, ONTARIO – On October 9, 2007, 589915 Ontario Limited was fined $75,000 after pleading guilty to one count of violation of Section 36(3) of the *Fisheries Act* for *"permitting the deposit of a deleterious substance in water frequented by fish"*. The offence occurred on Marigold Creek, a tributary to the East Humber River in Vaughan.

On July 29, 2004, Fisheries and Oceans Canada entered into an investigation after it was learned that large amounts of sediment were being deposited into Marigold Creek during the development of a residential subdivision. Sediment flow can be deleterious as it disrupts normal flow within a watercourse which affects fish habitat including critical spawning and nursery areas; and often renders creek water turbid and unusable by aquatic life.

At the request of Fisheries and Oceans, the court ordered that $60,000 of the fine be directed to the Toronto and Region Conservation Authority for the purpose of carrying out fish habitat improvement projects in the East Humber River Watershed.

The $75,000 fine is the largest amount ever handed down for a violation of section 36(3) in relation to a sediment release at a development site in the Province of Ontario.

CCME Guidelines

TSS	Guideline Value
Clear Flow	Max. increase of 25 mg/L over background for any periods less than 24 hrs. Max. increase of 5 mg/L over background for any periods lasting from 1 to 30 days
High Flow	Max. Increase of 25 mg/L from background levels when ambient concentration is between 25 and 250 mg/L. Should not increase by more than 10% of background when background is greater than 250 mg/L
Turbidity	
Clear Flow	Max. Increase of 8 NTUs above background levels for a short-term exposure (less than 24 hrs.). Max. average increase of 2 NTUs for any exposures lasting 1 to 30 days
High Flow	Max. Increase of 8 NTUs above background for short term exposures when ambient is between 8 and 80 NTUs. Should not increase by more than 10% above ambient when turbidity levels are greater than 80 NTU

Canadian Water Quality Guidelines for the Protection of Aquatic Life – Total Particulate Matter

The Sliding Scale Approach (Cont')

Idaho	
Natural Turbidity	**Maximum Increase**
50 NTU or less	5 NTU
Greater than 50 NTU	10% over ambient not to exceed 25 NTU
Regardless of the background level	50 NTU (instantaneous)
Regardless of the background level	25 NTU (10 or more days)

British Columbia	
Natural Turbidity	**Maximum Increase**
50 NTU or less	1 NTU
Greater than 50 NTU	10% over ambient
8 NTU or Less	For average 24 hr period
2 NTU or Less	For average 30-day period
Between 8 and 80 NTU	10% over ambient

The Sliding Scale Approach (Cont')

- **Washington State Department of Transportation Highway Runoff Manual:**
  - **25 NTU or Less** – Not likely to cause an exceedance in the receiving waters; BMP's likely working properly
  - **26-249 NTU** – Likely resulting in an exceedance; BMP's not working/installed properly. Revise ESC within 7 days and fix problem within 10
  - **250 or More NTU** – Likely resulting in an exceedance; BMP's and ESC likely failing.
    - *Notify State within 24 hrs.*
    - *Make revisions to ESC in 7 days*
    - *Implement plan within 10 days of exceedance*
    - *Sample daily until discharge is 25 NTU or less*

New US EPA Guidelines

Legal Limits - Compliance Mandatory		
Group/Legislative Body	**Standard**	**Application**
US EPA	280 NTU	Any Discharge Waters from Construction Sites

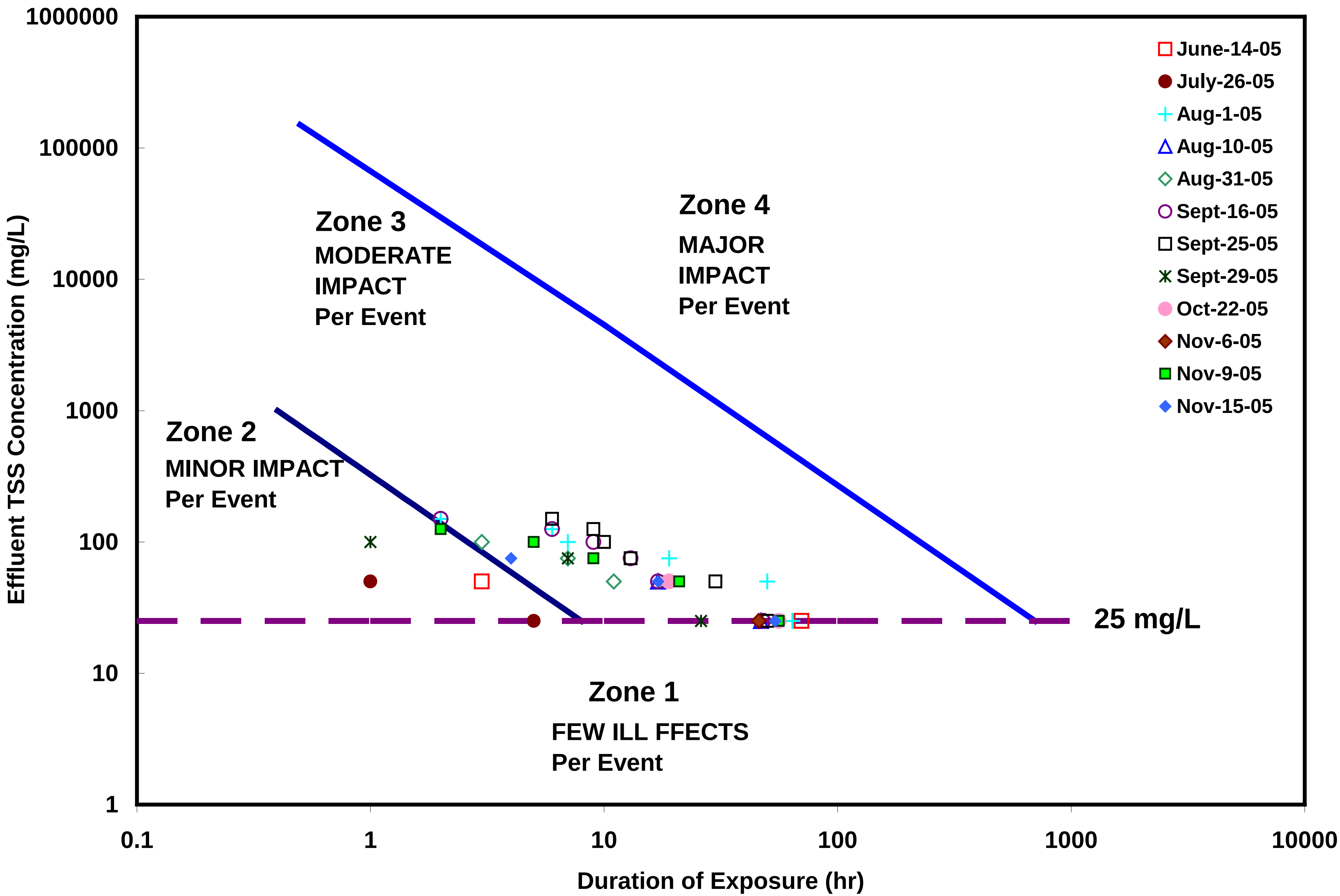
Applicable for discharges from construction sites:

- ≥ 30 acres
- rainfall erosivity factor (R factor) ≥ 50
- ≥ 10% clay content
- Applicable for discharges up to the 2-year, 24-hour storm

Ontario ESC Design Guidelines

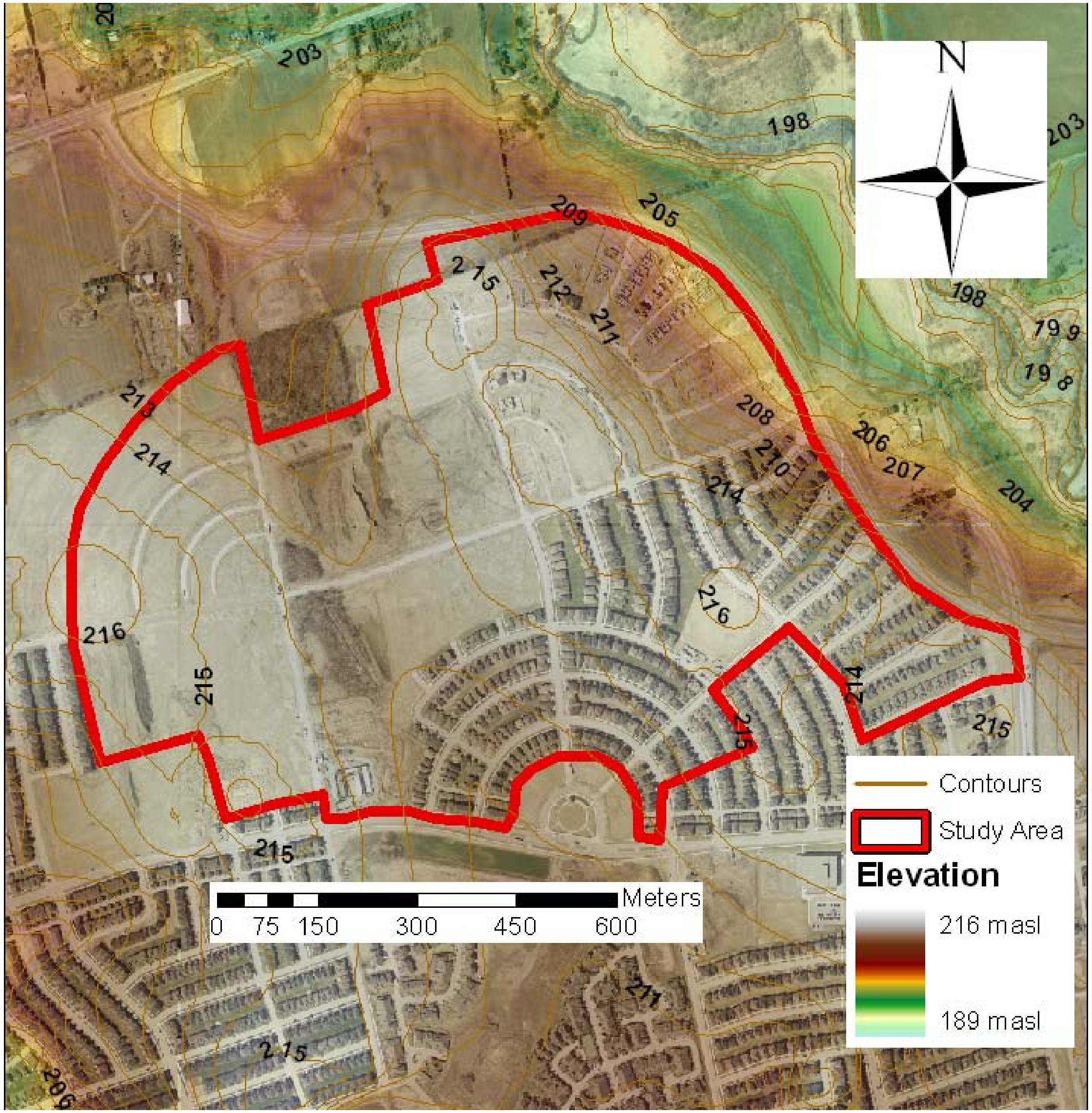
Legislative Body	Standard	Application
New York State	80% TSS Removal Efficiency	All construction site effluent. As a result, no limit on turbidity is given
City of Toronto (MNR 1989)	90% TSS Removal Efficiency	For all particles greater than 40 microns in diameter released from construction sites
Washington State	80% TSS Removal Efficiency	Applied to all construction sites discharging effluent into water bodies with background TSS between 100 and 200 mg/L
Ontario Ministry of Environment	80% TSS Removal Efficiency	Applied to all discharge effluent discharging into water bodies

Greensborough Pond Performance



Greensborough Development

- ≈76 ha in size
- Rapidly-urbanizing catchment
- Monitoring from 2004 - 2005

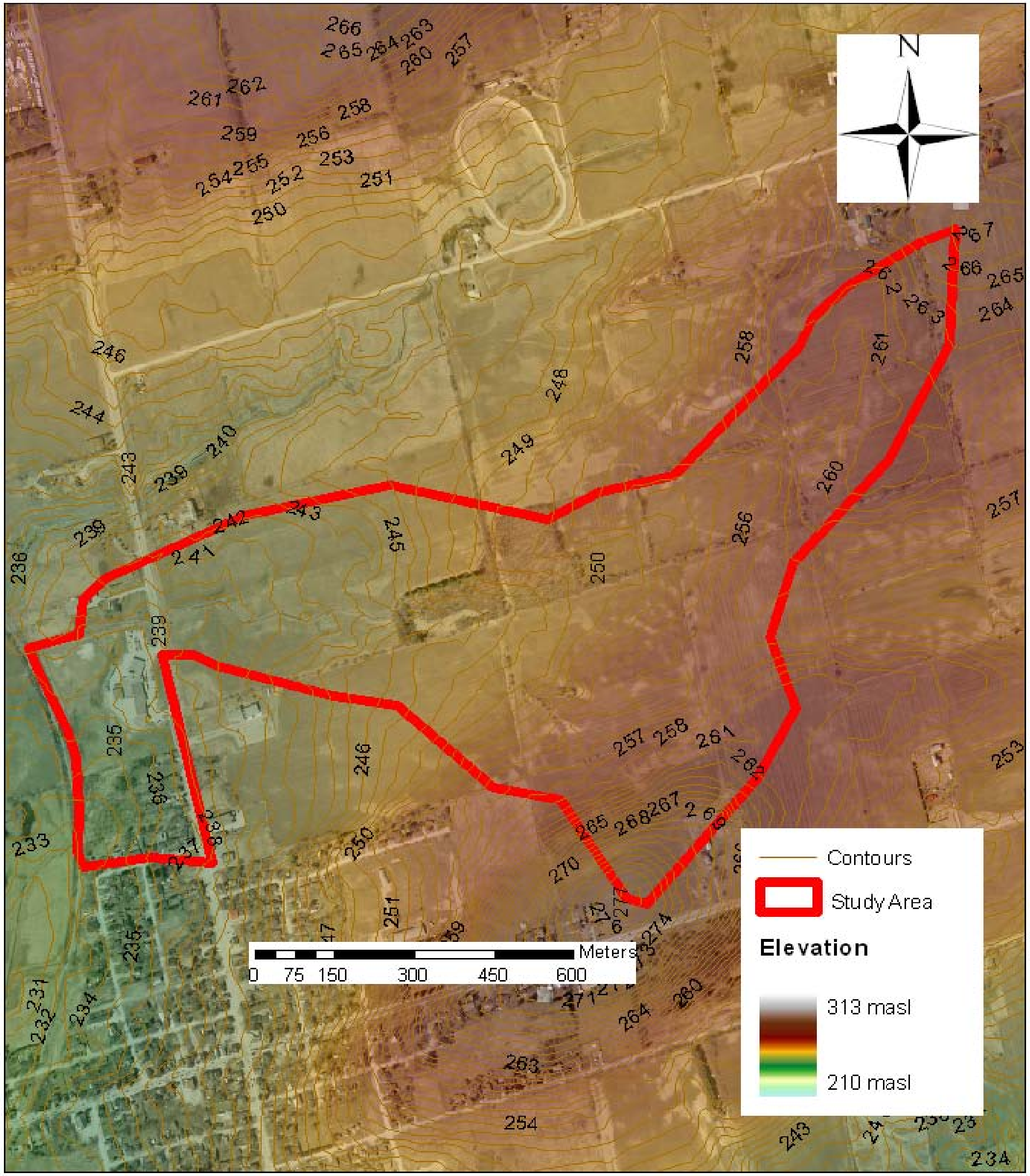


UNIVERSITY of GUELPH

CHANGING LIVES IMPROVING LIFE

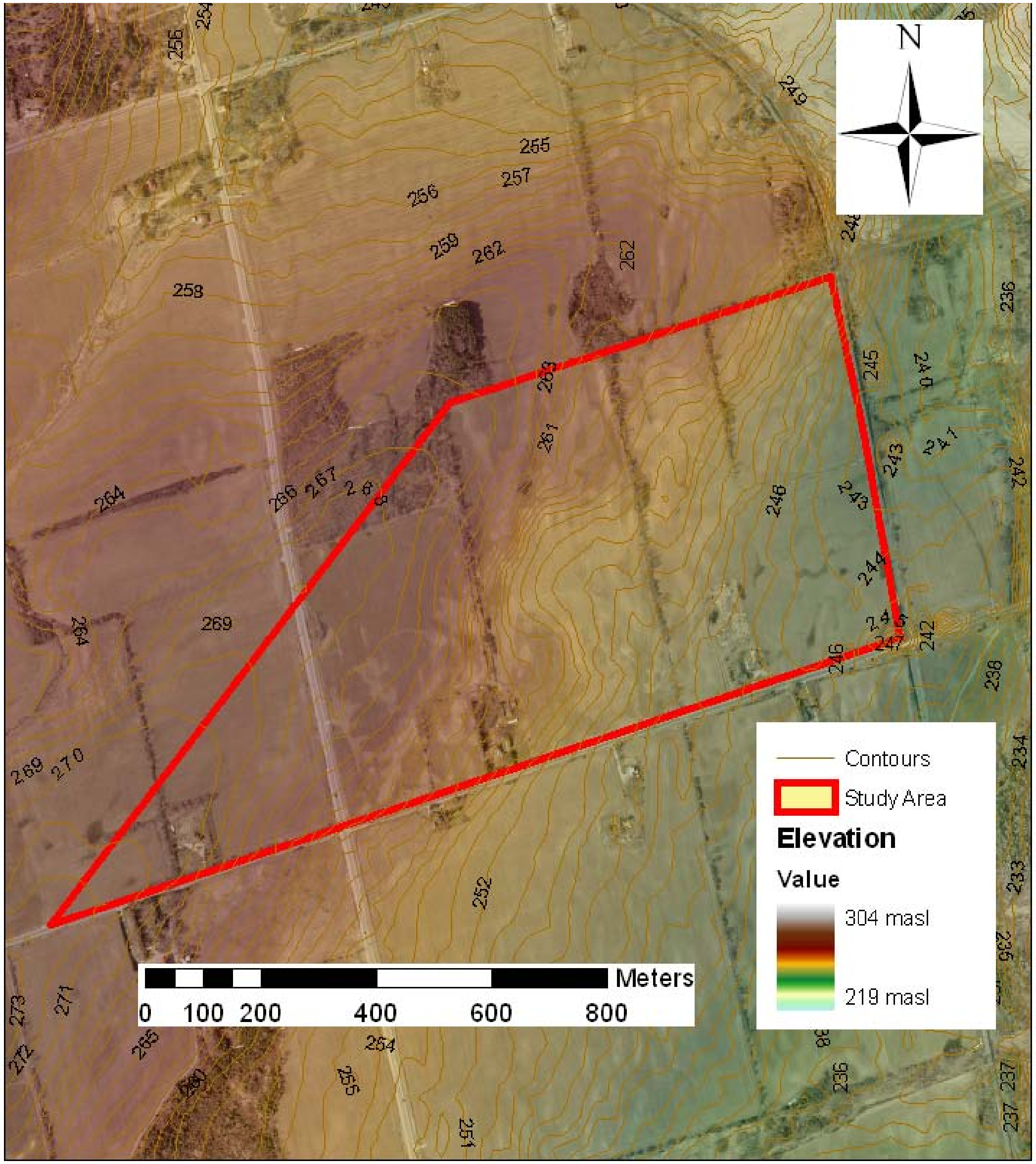
Cookstown Public School

- ≈85 ha in size
- School lot with agriculture (alfalfa) upstream

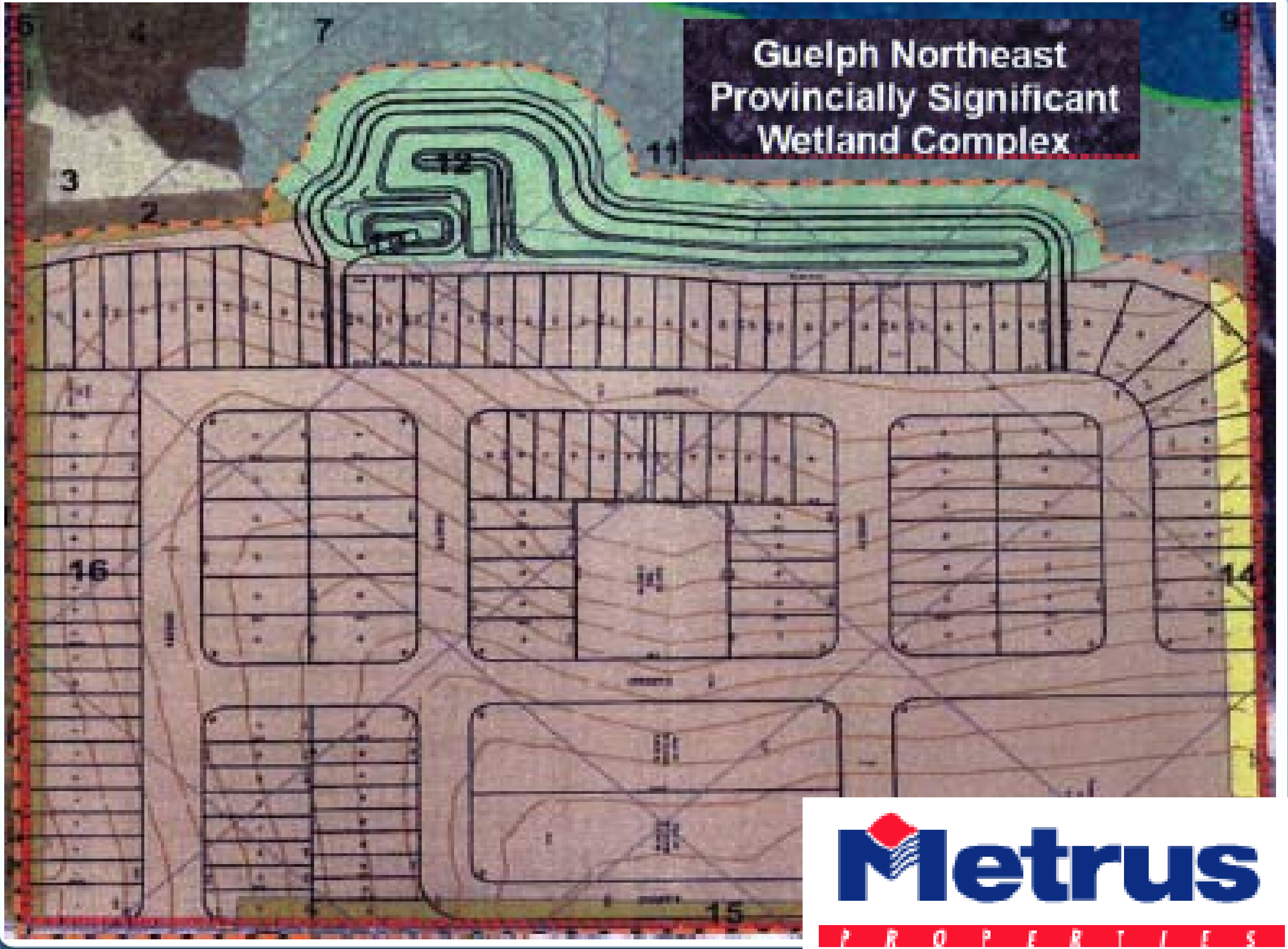


Alcona Project Site

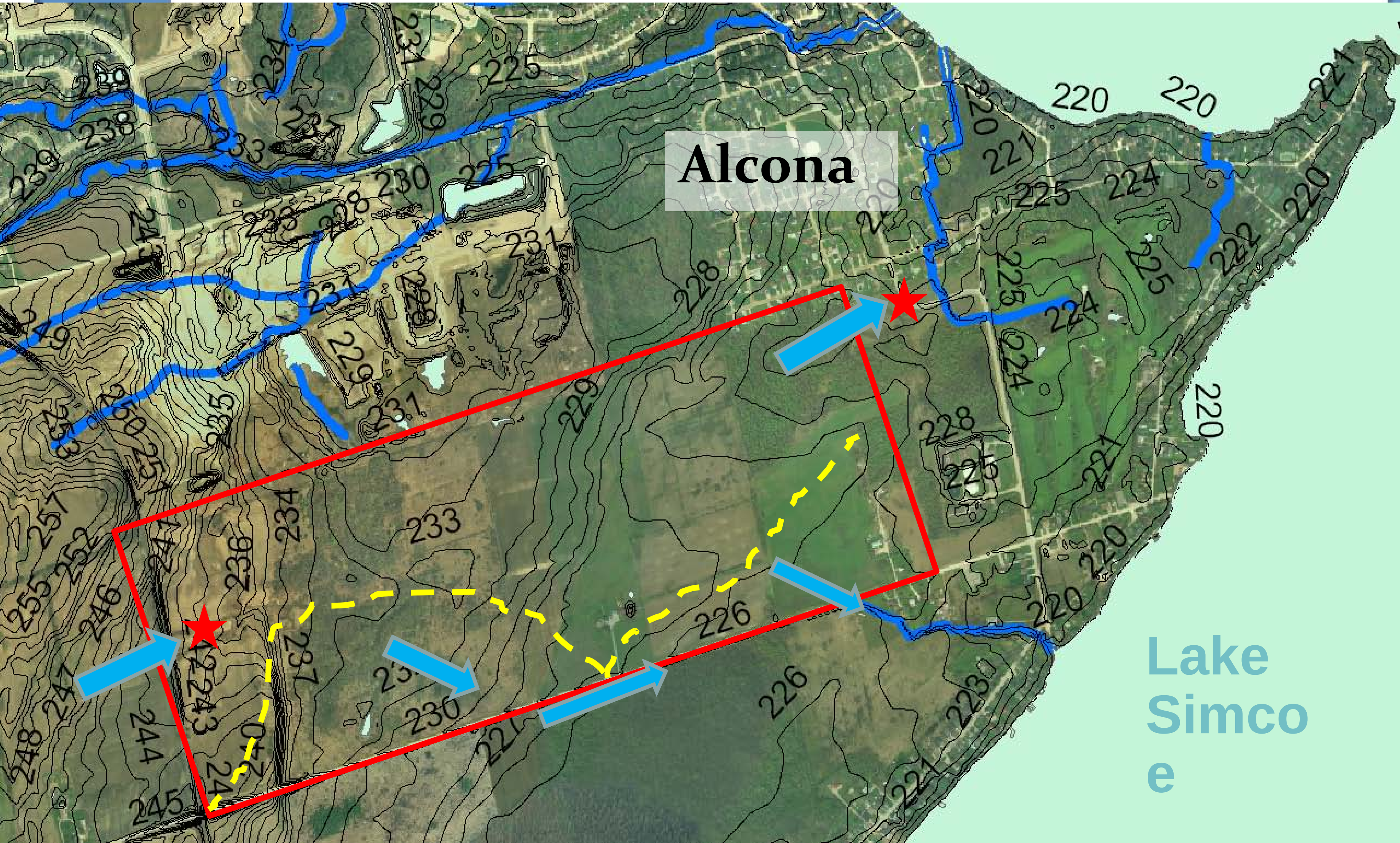
- ≈74 ha in size
- Agricultural; four separate fields identified

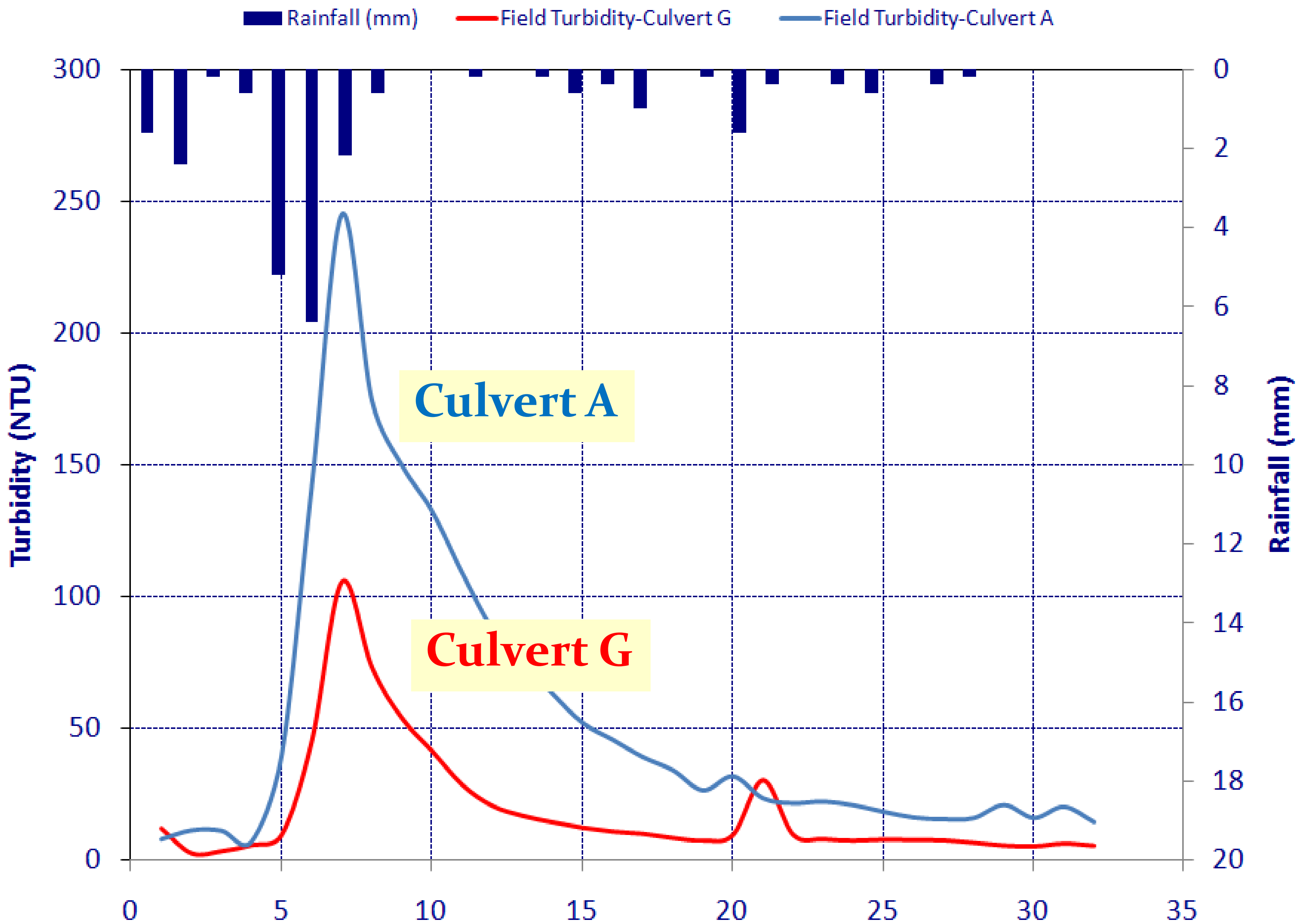


Grangehill Phase 7 - Guelph



Stormwater Monitoring





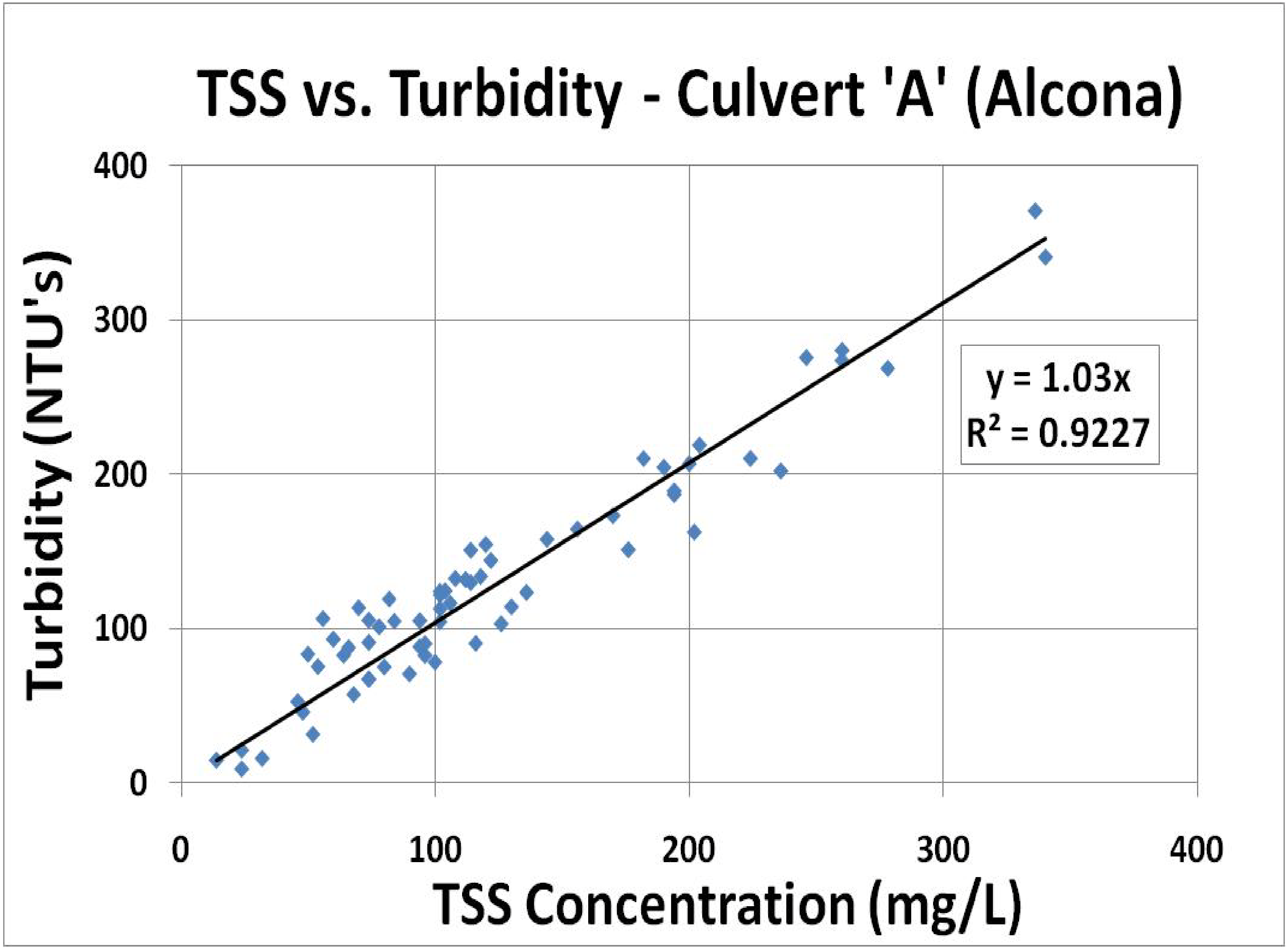
Rainfall (mm)
Field Turbidity-Culvert G
Field Turbidity-Culvert A
Turbidity (NTU)
Rainfall (mm)
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30
35
Culvert A
Culvert G

Innisfil Monitoring Locations

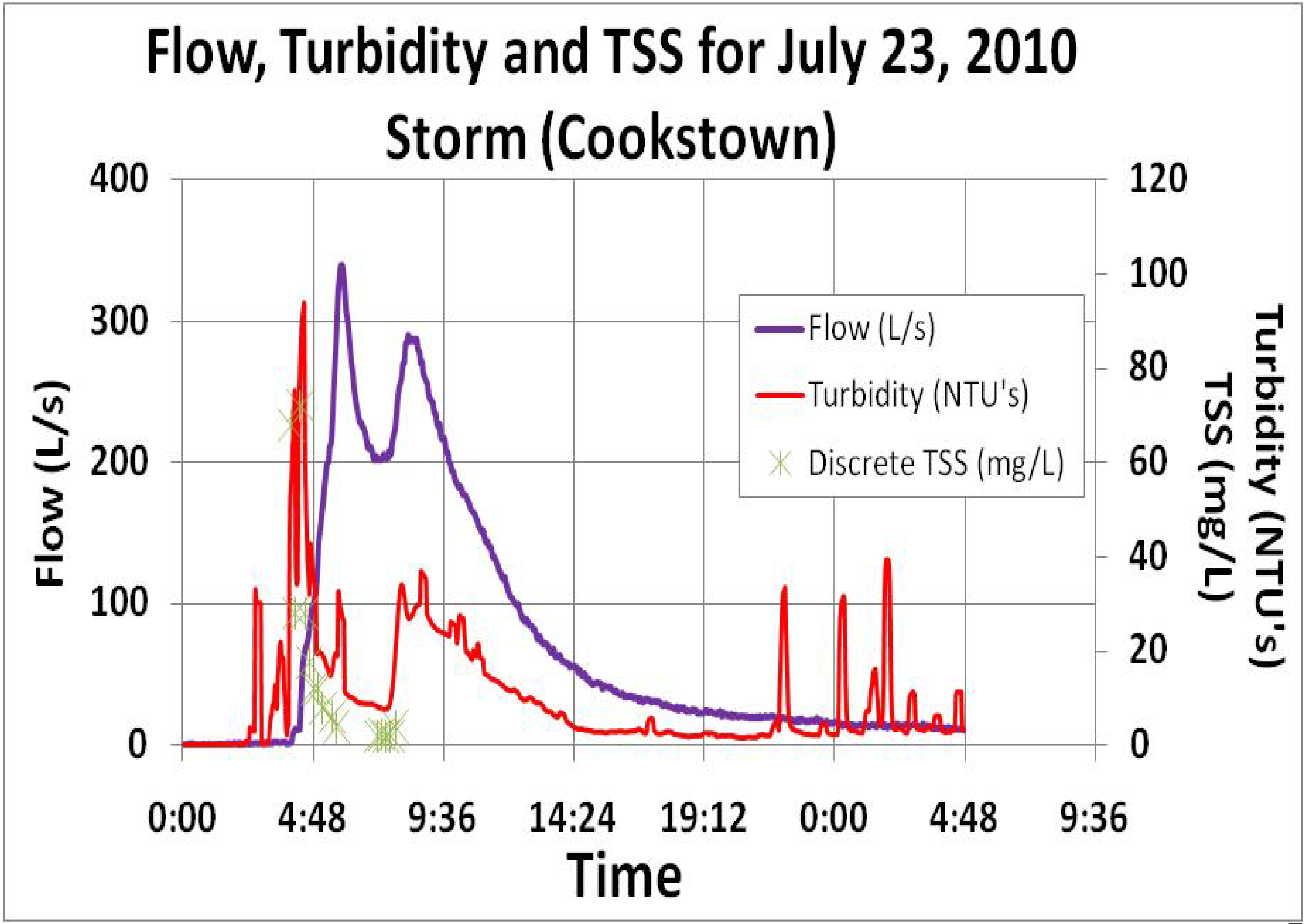
TSS vs. Turbidity

UNIVERSITY of GUELPH

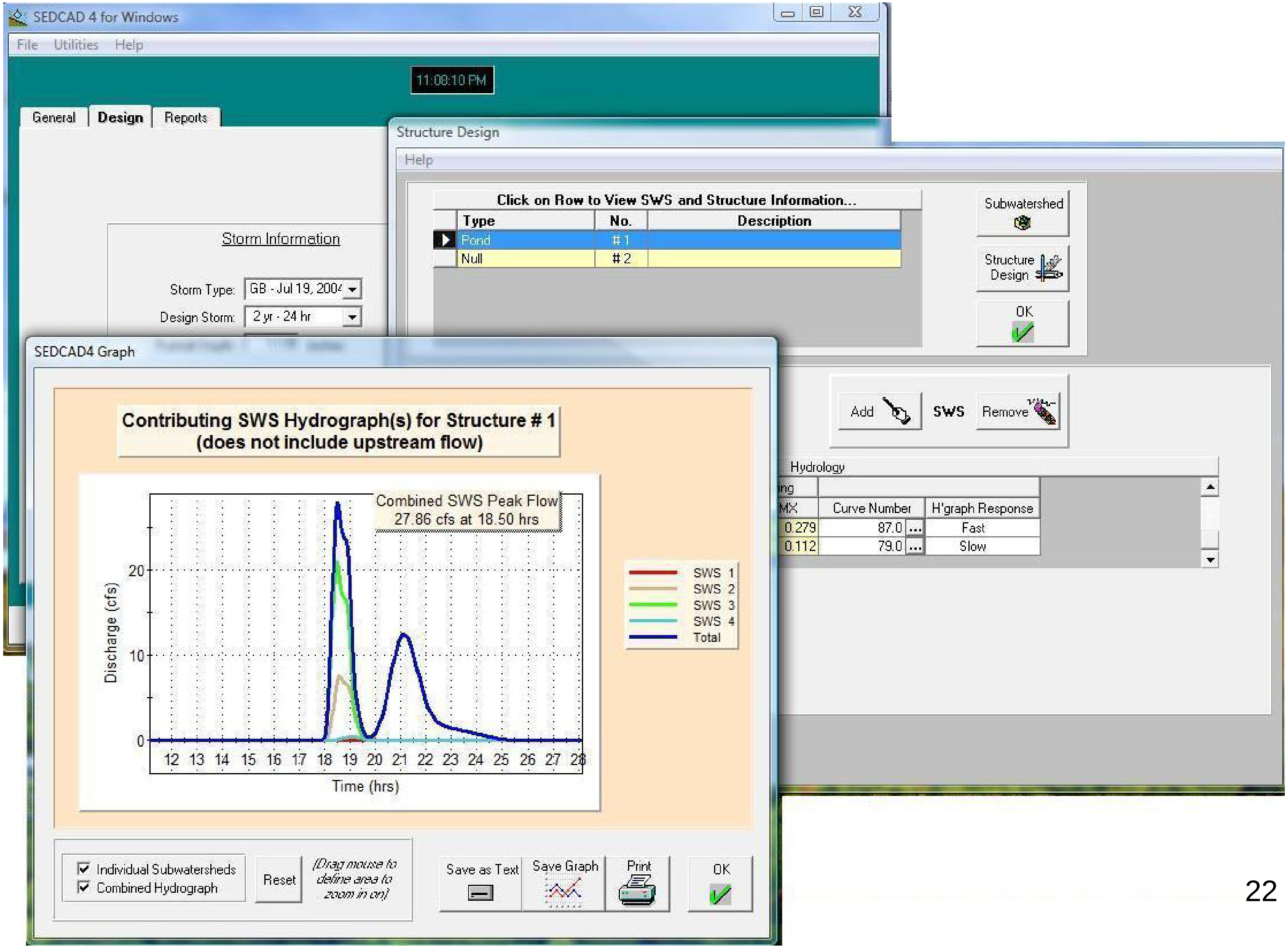
CHANGING LIVES IMPROVING LIFE



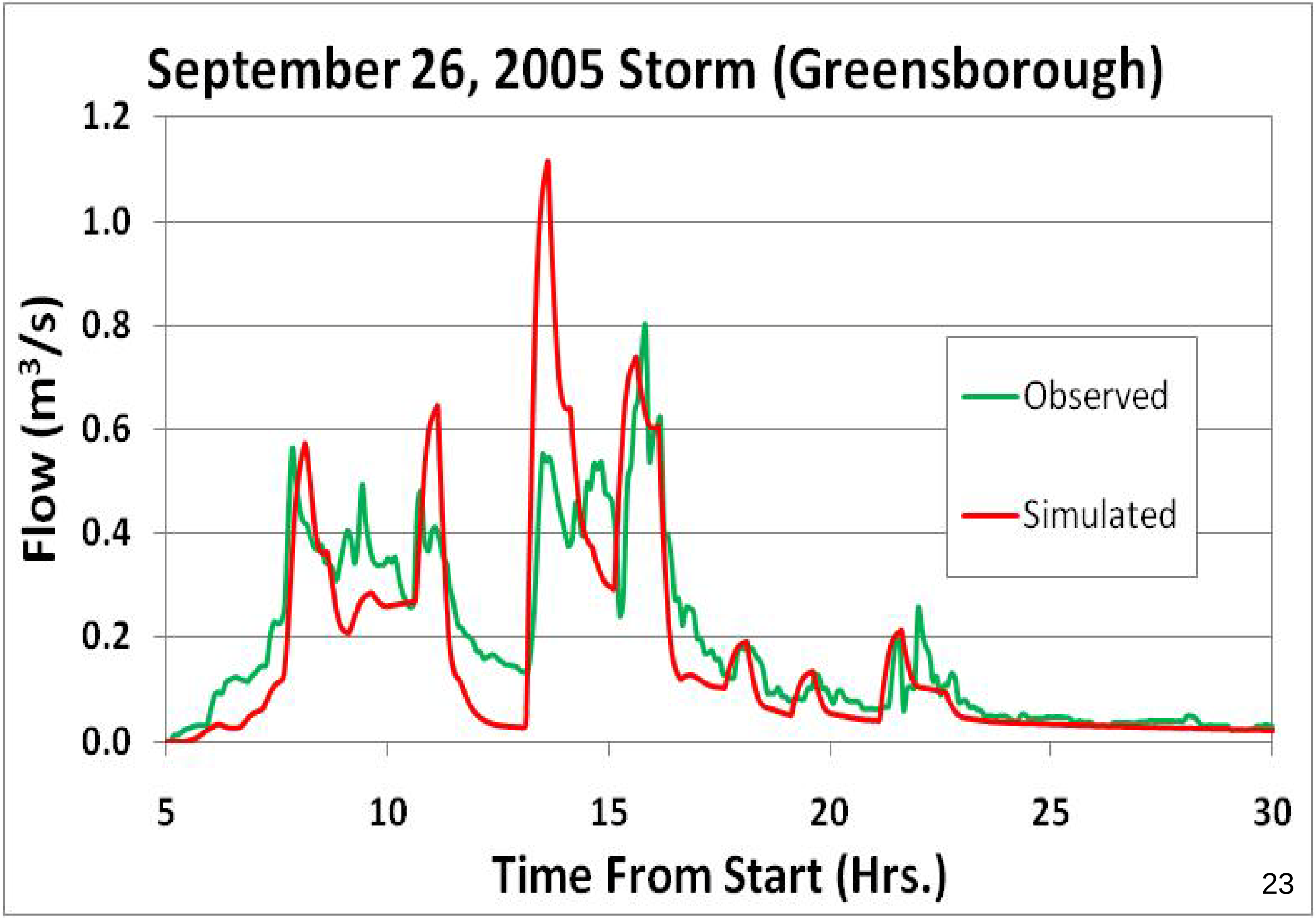
Results – ‘First Flush’ Effects



SEDCAD Modeling



Results – SEDCAD Modeling



Methodology

- 4 ISCO 6712 Autosamplers
- 4 ISCO 1640 Liquid Level Actuators
- 4 DTS1200 Continuous Turbidity Sensors
- 20 Hobo Level Loggers
- 1 RG6000 Wireless Rain Gage
- 3 Onset Soil Moisture Sensors



Sample Analysis

- Samples were analyzed at the UofG SOE
  - Samples also sent to the MOE lab in Etobicoke for QA/QC purposes
  - TP and nutrient analysis at the UofG/OMAFRA Lab

Ballymore Pond Study, Richmond Hill (2002-2003)

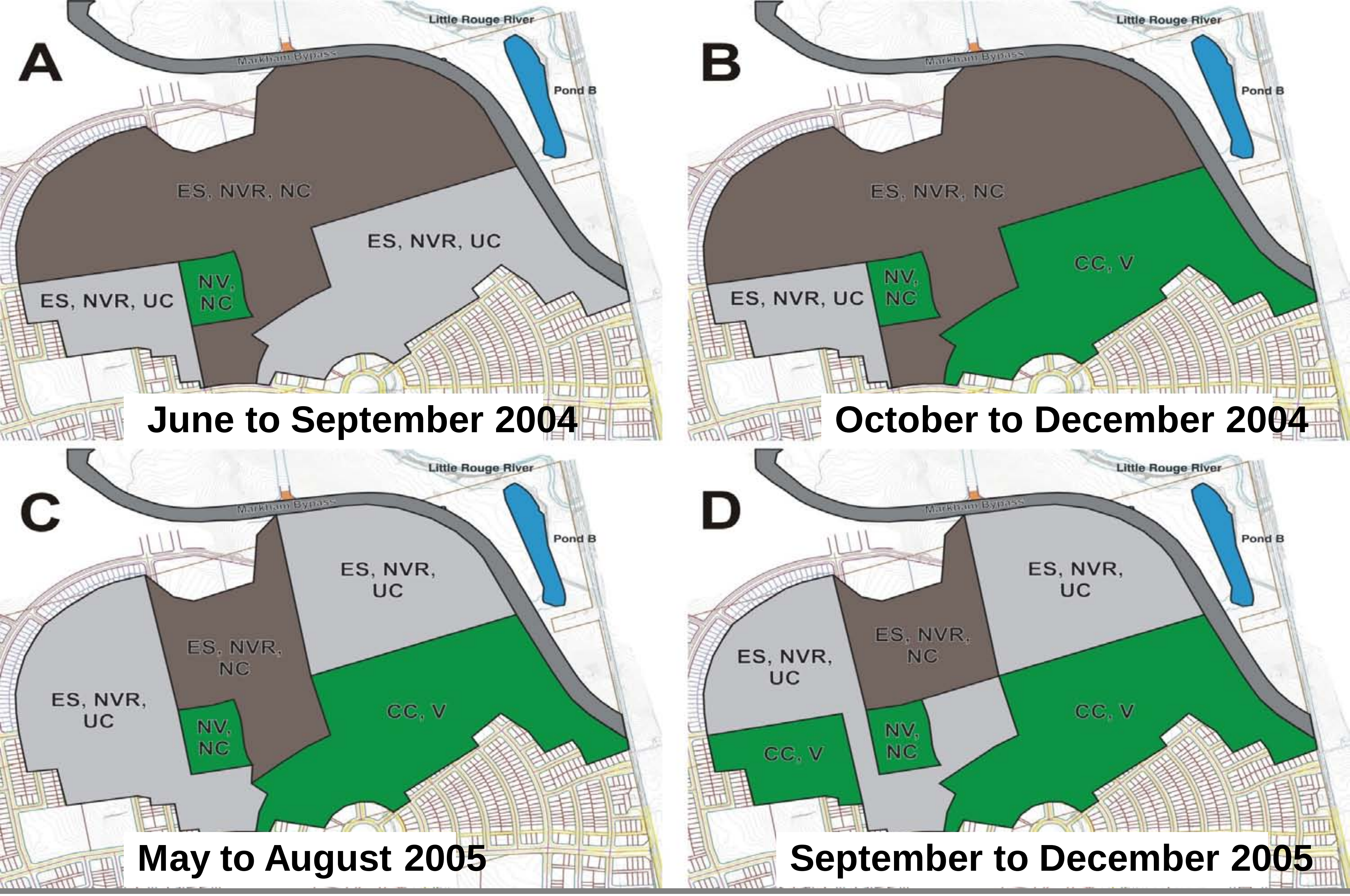
Sustainable Technologies Evaluation Program

Ballymore Pond, Richmond Hill						
Event Date	Rainfall (mm)	Inlfuent Peak TSS Conc.	Influent TSS Conc. (mg/L)[+]	Effluent Peak TSS Conc.	Effluent TSS Conc. (mg/L)[§]	Rem. Eff. (%)
14-Sep-02	28.8	20050	7404	415	277	96.3
20-Sep-02	13.3	34000	1427	59	27	98.1
27-Sep-02	18.4	12200	4655	189	75	98.4
2-Oct-02	10	19100	8557	10	7	99.9
19-Oct-02	13	3800	1059	67	29	97.3
25-Oct-02	9.4	3800	1129	62	17	98.5
2-May-03	6.8	979	360	52	30	91.7
5-May-03	17.4	2350	879	60	36	95.9
11-May-03	17.8	6110	-	470	224	-
20-May-03	10.8	4100	1499	192	100	93.3
4-Jun-03	13.4	3380	1299	202	49	96.2
8-Jun-03	23.6	8560	4547	2640	1630	64.2
13-Jun-03	14	4190	1020	144	82	92.0
15-Sep-03	9.8	3030	598	213	121	79.8
19-Sep-03	38	538	317	259	93	70.6
22-Sep-03	25	1100	229	46	28	87.8
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
Average	**16.8**	**7955**	**2332**	**318**	**177**	**91**
Median	**13.7**	**3950**	**1129**	**167**	**62**	**96**

Sustainable Technologies Evaluation Program

Greensborough Pond Study, Markham (2004-2005)

Greensborough Pond, Markham						
Event Date	Rainfall (mm)	Influent Peak TSS Conc.	Influent TSS EMC (mg/L)	Effluent Peak TSS Conc.	Effluent TSS EMC (mg/L)	Rem. Eff. (%)
7-Jul-04	13.2	-	1880*	-	12.8*	99.4
19-Jul-04	36.2	19900	13028	246	92.8	99.3
9-Sep-04	17.2	5250	2607	45	34.8	98.7
15-Oct-04	4.1	-	5610*	-	22.9*	99.7
30-Oct-04	8.8	-	9920*	76	38.5	99.7
2-Nov-04	8.2	1790	892	22	19.2	97.8
24-Nov-04	8.7	-	595*	-	16.5*	88.7
14-Jun-05	19.2	12500	9308	64	30.5	99.7
17-Jul-05	10.8	6580	2401*	20	16.9	99.3
26-Jul-05	9	2930	2633	68	24.1	99.1
1-Aug-05	18	14500	5490	196	71.6	98.7
10-Aug-05	11.2	6380	3692	62	48.5	98.7
31-Aug-05	21.8	2160	854	120	48.5	94.3
8-Sep-05	15.4	10200	3580	23	14.5	99.6
16-Sep-05	32.8	11700	2897	163	57.2	98.0
25-Sep-05	43.6	8040	971	191	63.0	93.5
29-Sep-05	9.4	3310	962	102	39.9	95.9
22-Oct-05	23.8	5890	830	70	42.8	94.8
6-Nov-05	5.6	8000	3797	41	20.5*	99.5
9-Nov-05	19.2	9480	1925	150	56.7	97.1
15-Nov-05	25.6	2880	970	95	44.2	95.4
	17.2	**7735**	**3564**	**98**	**39**	**98**
	15.4	**6580**	**2607**	**73**	**39**	**99**



ES exposed soil, NV natural vegetation, NVR natural vegetation removed, NC no construction, UC under construction, CC construction complete, and V vegetated.

Greensborough Pond

Event Date	Rainfall (mm)	Inlet SS EMC (mg/L)	Load (kg)	Outlet SS EMC (mg/L)	Load (kg)
19-Jul-2004	36.2	13,027	173,088	109.0	1,391.1
9-Sep-2004	17.2	2,607	18,837	34.8	240.2
14-Jun-2005	19.2	6,744	44,067	30.5	254.1
17-Jul-2005	10.8	1,830	2,962	16.9	25.9
10-Aug-2005	11.2	3,691	20,123	48.5	137.2
31-Aug-2005	21.8	852	852	48.5	366.4
8-Sep-2005	15.4	2,355	5,881	14.5	34.3
16-Sep-2005	32.8	2,896	46,874	57.2	861.7
25-Sep-2005	43.6	432	12,499	63.0	1,475.6
29-Sep-2005	9.4	962	6,859	39.9	360.8
22-Oct-2005	23.8	831	7,948	42.8	450.8
6-Nov-2005	5.6	770	2,480	20.5	28.9
9-Nov-2005	19.2	817	7,240	56.7	468.9
15-Nov-2005	25.6	519	30,695	44.2	2,520.6
Average:	**17.2**	**2,901**	**22,512**	**39.6**	**456.9**
Median:	**15.4**	**1,830**	**7240**	**38.5**	**240.2**

Modified Universal Soil Loss Equation

Williams (1972)

$$A = 95(Q * q_p)^{0.56} * K * LS * C * P$$

Where,

A = Soil loss

q_p = Peak runoff rate

Q = Runoff volume

K, LS, C, P = As defined in the USLE

Modified Universal Soil Loss Equation

Onstad and Foster (1975)

$$A = (0.5 * R_{st} + Q * q_p^{\frac{1}{3}}) * K * LS * C * P$$

Where,

A = Soil loss
q_p = Peak runoff rate
Q = Runoff volume
R_{st} = Rainfall erosivity
K, LS, C, P = As defined in the USLE

Event-Based Soil Loss Equation

Equation Number	Erosivity Factor	Term Value					
		a	b	c	d	e	f
1	$EI_{30} + a$	10					
2	$a * EI_{30} + b$	106.76	22.09				
3	$a * EI_{30}^{b}$	14.36	1.33				
4	$a * EI_{30} + b * RO + c$	3.07	139.57	-36.76			
5	$a * ((EI_{30}^{b} + RO^{c}) * Qp)^{d}$	73	1.31	2.19	0.55		
6	$a * ((EI_{30}^{b} + RO^{c}) * Qp^{d})^{e}$	180	1.15	-0.01	1.51	0.42	
7	$a * (EI_{30}^{b} * RC^{c} * Qp^{d})^{e}$	6.63	1.04	-0.49	1.09	0.78	
8	$a * (EI_{30}^{b} + RO^{c} + Qp^{d})^{e}$	9.78	104.6	227.57	130.7	0.01	
9	$a * (EI_{30}^{b} + RC^{d})Qp^{e}$	7.25	0.87	42.21	0.06	0.52	
10	$a * ((EI_{30}^{b} * Qp^{c}) + (RO^{d} * Qp^{e}))^{f}$	165.5	1.25	1.56	1.2	1.86	0.4

EI_{30} = Rainfall Erosivity ($MJ*mm*ha^{-1}*h^{-1}$); RO = Runoff (mm); Qp = Peak Runoff Rate ($L*s^{-1}*h^{-1}$); RC = Runoff Coefficient (dimensionless); a, b, c, d, e & f = fitting parameters

MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS FACTSHEET
ISSN 1198-712X

Table 2. K Factor Data (Organic Matter Content)

Textural Class	Average	Less than 2 %	More than 2 %
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	--	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	-	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

ISSN 1198-712X

Table 3A. LS Factor Calculation

Slope Length ft (m)	Slope (%)	LS Factor
100 ft (31 m)	10	1.3800
	8	0.9964
	6	0.6742
	5	0.5362
	4	0.4004
	3	0.2965
	2	0.2008
	1	0.1290
	0	0.0693
200 ft (61 m)	10	1.9517
	8	1.4092
	6	0.9535
	5	0.7582
	4	0.5283
	3	0.3912
	2	0.2473
	1	0.1588
	0	0.0796

Equation for Calculation of LS (if not using Table 3A above)

$$LS = [0.065 + 0.0456(\text{slope}) + 0.006541(\text{slope})^2] \times (\text{slope\_length} \div \text{const})^{NN}$$

USLE – C Factor

Table 4A. Crop Type Factor

Crop Type	Factor
Grain Corn	0.40
Silage Corn, Beans & Canola	0.50
Cereals (Spring & Winter)	0.35
Seasonal Horticultural Crops	0.50
Fruit Trees	0.10
Hay and Pasture	0.02

Table 4B. Tillage Method Factor

Tillage Method	Factor
Fall Plow	1.0
Spring Plow	0.90
Mulch Tillage	0.60
Ridge Tillage	0.35
Zone Tillage	0.25
No-Till	0.25

Crop Residue C-factor

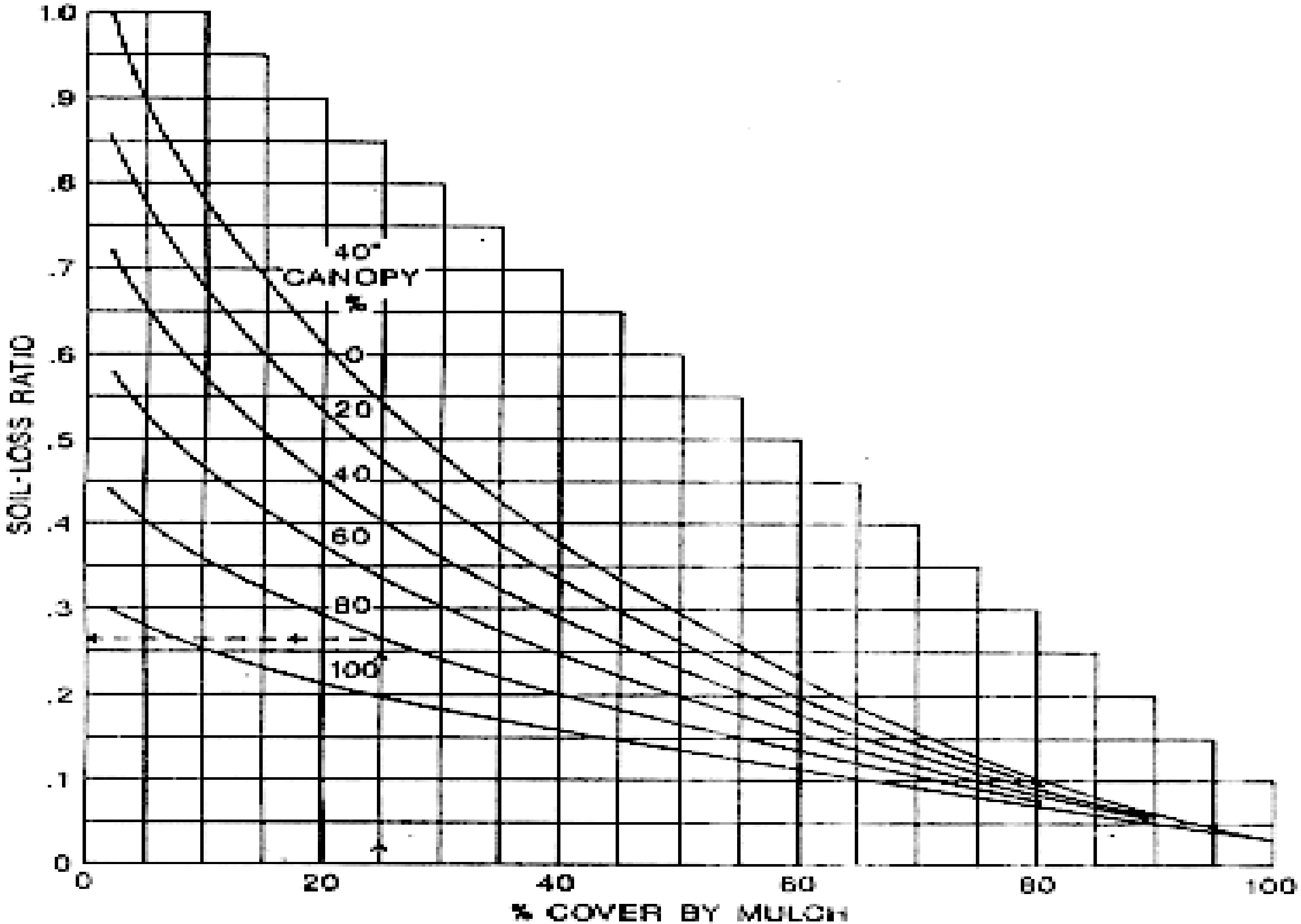


FIGURE 6.—Combined mulch and canopy effects when average fall distance of drops from canopy to the ground is about 40 inches (1 m).

Conservation Practice Factor

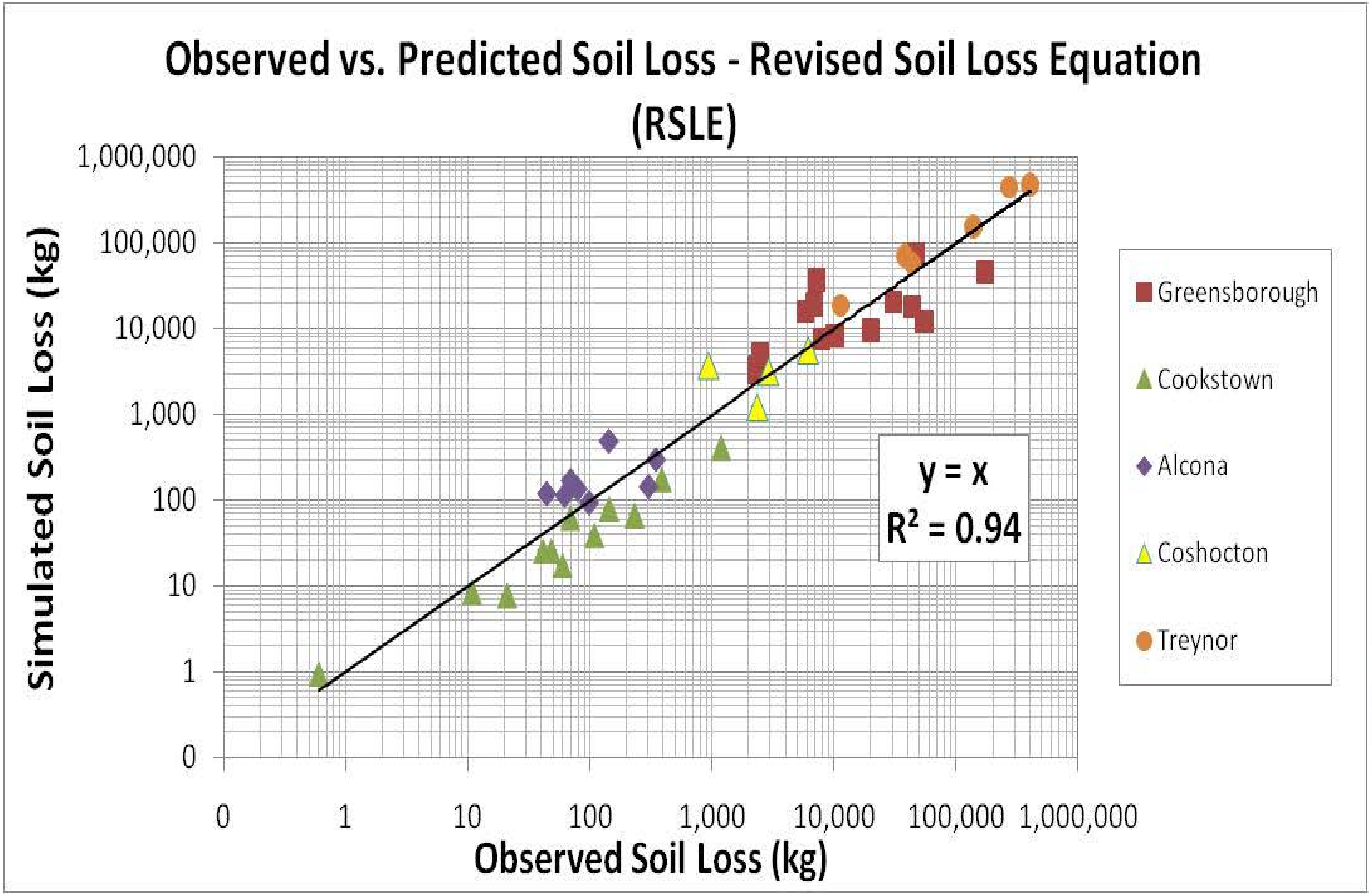
- The P-factor is the ratio of soil loss under the given condition to soil loss from up-and-down-slope farming. Therefore it is a value between 0 and 1

Table 5. P Factor Data

Support Practice	P Factor
Up & Down Slope	1.0
Cross Slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

Revised Soil Loss Equation

$$A = 165.5 * \left(\left(RO^{1.2} * Q_p^{\ 1.86}\right) + \left(EI_{30}^{\ 1.25} * Q_p^{\ 1.56}\right)\right)^{0.4} * K * LS * C * P$$



UNIVERSITY of GUELPH
CHANGING LIVES IMPROVING LIFE

Design Storm Development

- Optimized RSLE, SEDCAD Model and MTO IDF Database were used produce design storms for each site:

12-Hour, Type-II Design Storm EI30 Calculations (MJ mm ha^{-1} h^{-1})

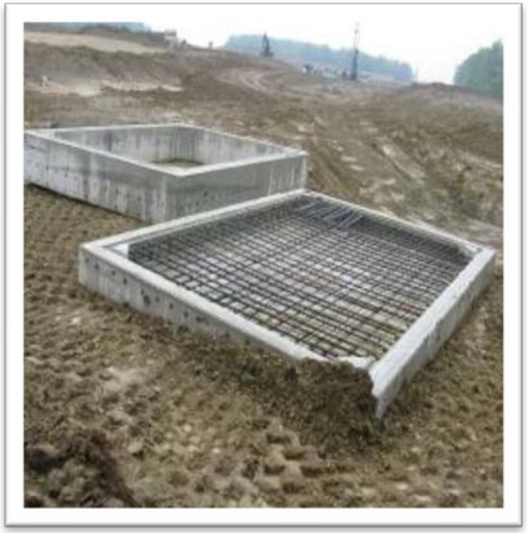
Location	Return Period					
	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr
Cookstown	282.1	382.8	722.6	1062.7	1385.5	1713.8
Alcona	300.9	405.0	753.5	1025.6	1259.1	1571.6
Greensborough	300.9	451.2	785.1	1259.1	1610.5	2018.0



Staged ESC Planning

- The dynamic nature of the construction process and the importance of having the most appropriate and effective controls in place requires separate ESC Plans showing measures that must be in place prior to each stage of construction

1) Earthworks



2) Servicing

3) Building construction

Construction Phase BMPs

- Soil erosion prevention – use of vegetative cover, mulches and fibre blankets to protect exposed soils.
- Phasing of site activities, strategic grading and minimizing soil loss from vehicle traffic leaving site.
- Detention/sedimentation ponds.
- Flow control structures (e.g. check dams, silt fences)
- Filtration systems (e.g. compost biofilters)
- Infiltration systems (e.g. swales, weep berm)

A REVIEW OF CONSTRUCTION SITE BEST MANAGEMENT PRACTICES FOR EROSION CONTROL

Tyner et al. (2011) **Transactions of the ASABE** Vol. 54(2): 441-450

We found that erosion control mats reduced erosion most, followed in descending order by mulches, composts, hydromulches and bonded fiber matrixes (BFMs), polyacrylamides (PAMs), and lastly compaction methods. Excluding compaction, all of the methods relied on surface cover for erosion control and exhibited average ***soil erosion reductions of 62% to 79%*** *from what would be expected for bare loose soil.*

Agricultural BMPs

BMP	Sediment	TP	Source Material
No-Tillage	92 (85)	69 (62)	(Merriman et al, 2009; Dinnes, 2004; Wagow et al, 2002; Bryant et al, 2008; Schnepf and Cox, 2006)
Vegetative Buffer Strips	74 (69)	61 (57)	(Schnepf and Cox, 2006; Mikkelsen and Gilliam, SEPA, 2010; Ghebremichael and Watzin, 2008; Gitau et al, 2005; Boyer, 2006; Melcher and Skagen, 2005)
Ditch Bank Stabilization	70 (59)	38 (37)	(Merriman et al, 2009; Cook, 1999; DPRA Inc, 1989; SEPA, 2010; SWCS, 2008; Yagow et al, 2002)
Conservation Tillage	55 (56)	45 (42)	(SERA 17, 2009; Yagow et al, 2002; Bryant et al, 2008; Gitau et al, 2005; Schenepf and Cox, 2006)
Streambank Fencing	40 (47)	30 (30)	(Schnepf, 2006; Cook, 1999; SWCS, 2008; Merriman et al, 2009)
Cover Crops	35 (44)	48 (37)	(Merriman et al, 2009; Dinnes, 2004; Yagow et al, 2002; SEPA, 2010; SWCS, 2008; Schnepf and Cox, 2006)
Reforestation	14 (27)	10 (27)	(Merriman et al, 2009; SWCS, 2008)

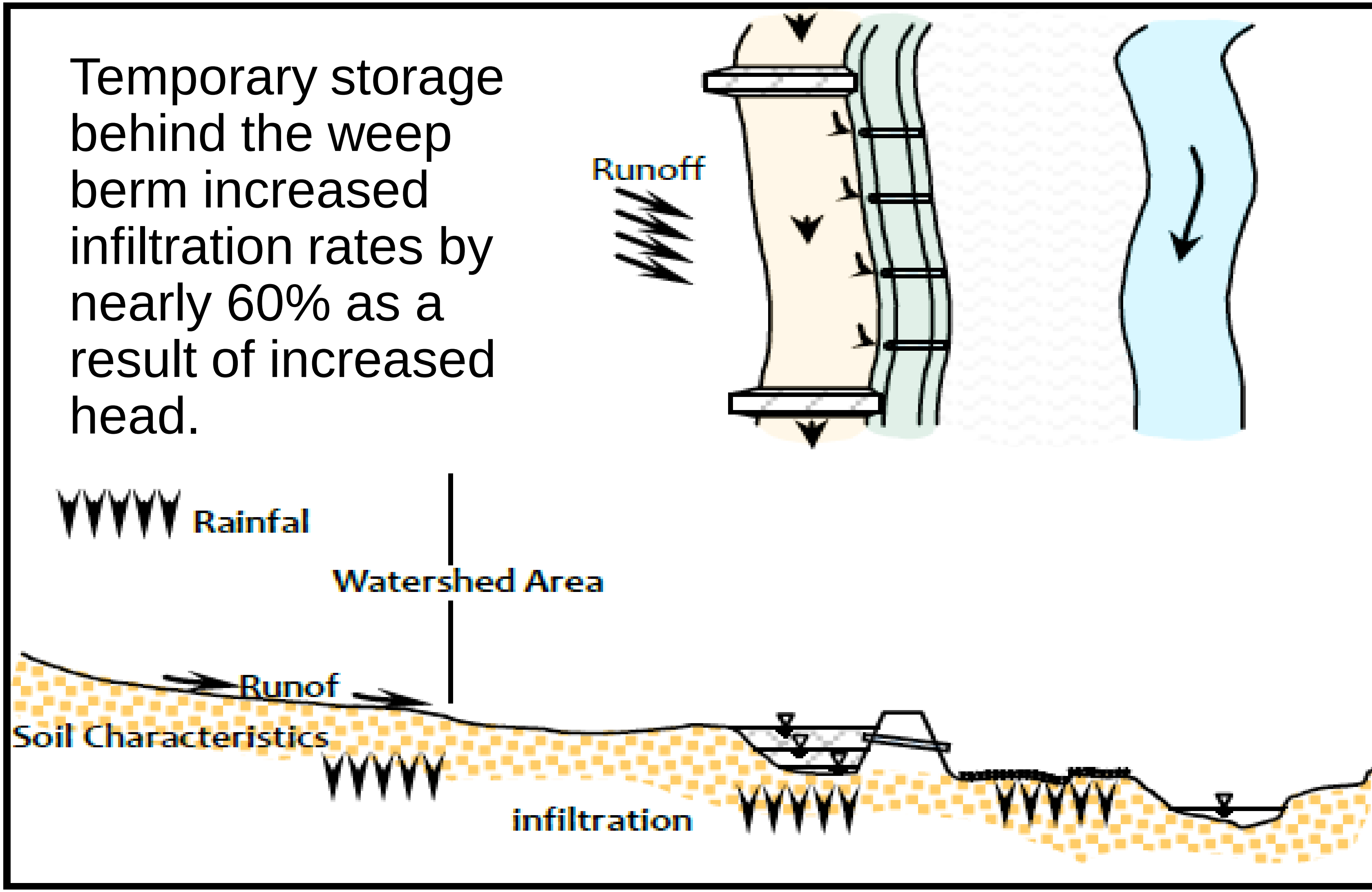


Fig 1. Schematic of a Weep Berm-Grass Filter System. Adapted from Warner et al. (2007).

A Multi-Barrier Approach

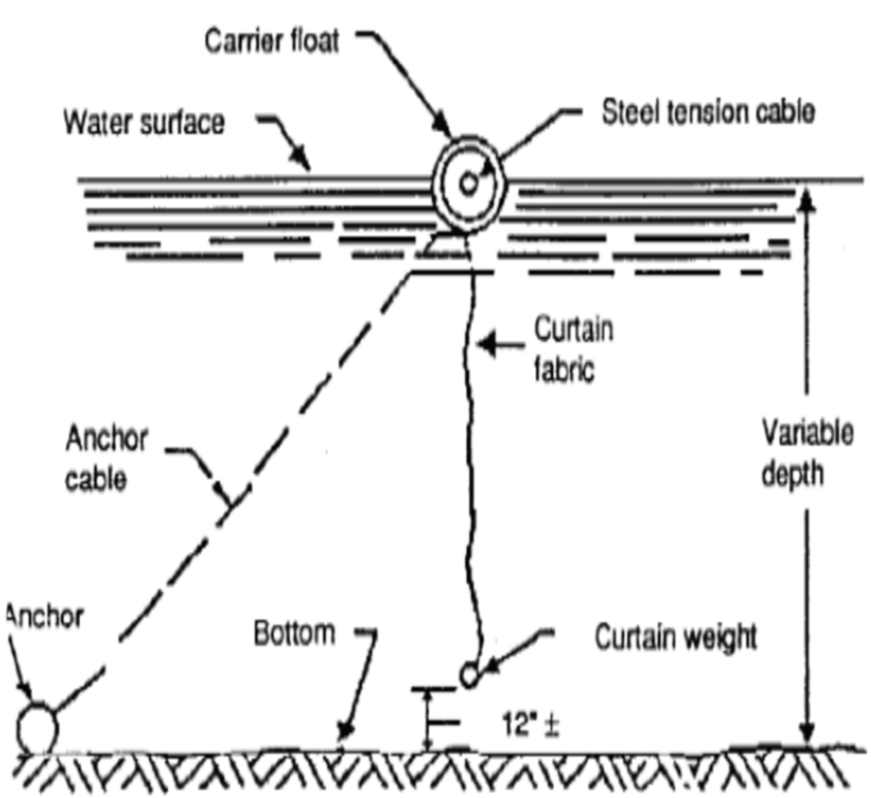
Rolled Erosion Control Products

- We have access to free RECP's for research purposes

Sustainable Technologies
Evaluation Program

Enhanced Sediment Ponds

- Flotation silt curtain within ponds (to limit and control the migration of suspended



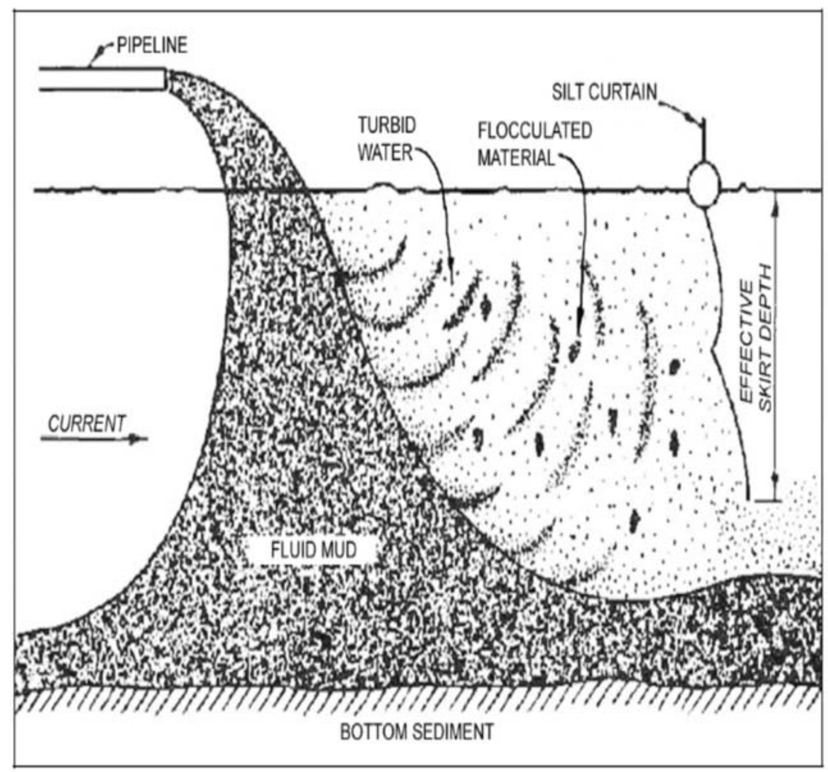


Figure 2. Processes affecting silt curtain performance (JBF Scientific Corporation (1978))

Floating Siphon

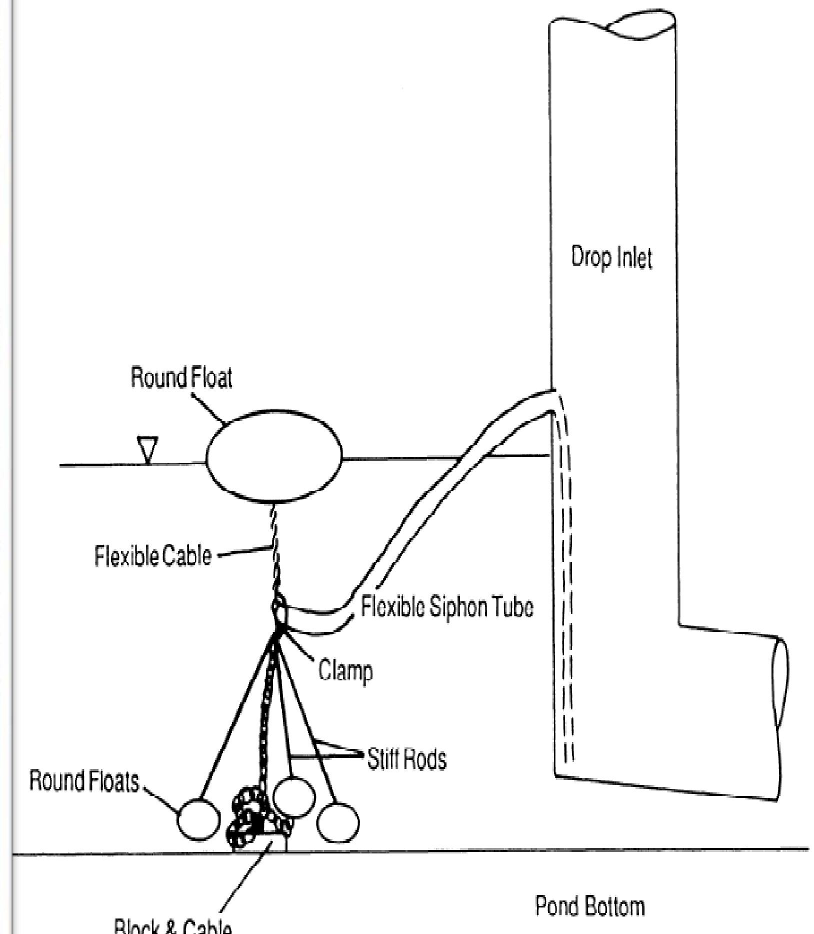


Fig. 12.1.5. Schematic of floating siphon tube used for dewatering.

Anionic Polymers

- **TRCA 2010**

Sustainable Technologies Evaluation Program

Table 1: Main Reason for Construction Practice Failure as Identified by North Carolina Administrators (reported in percentage response), N = 22-29

Erosion and sediment control measure	Technically deficient (%)	Poor installation (%)	Poor maintenance (%)
Brush barriers	58	29	13
Straw bales	64	20	16
Filter strip	23	41	36
Pre-fabricated silt fence	23	54	23
Silt fence	7	57	36
Sediment trap	0	38	62
Sediment basin	11	29	60
Inlet protection	16	40	44
Slope drain	0	76	24
Vegetated channel	27	57	15
Riprap channel	15	74	11

Technical Note #88 from Watershed Protection Techniques. 2(3): 413-417

UNIVERSITY of GUELPH

CHANGING LIVES IMPROVING LIFE

Conclusions

- The RSLE performed slightly better than other soil loss equations
- Using the soils, grading plans, IDF and BMP databases, design storms can be used to estimate event-based soil loss under development scenarios
- Using this simple tool erosion and sediment control plans can be designed and evaluated quantitatively

Conclusions

- Erosion and sediment control plans are designed to reflect the dynamic nature of construction sites
- Everything hinges on the monitoring, assessment and reporting of onsite erosion and sediment controls
- To enable a timely response to design deficiencies, the online, real-time reporting of ESC performance is essential for regulators, developers, and contractors

Research Webdatabase

Monitoring of Phosphorus Load in Stormwater Runoff

UNIVERSITY of GUELPH

CHANGING LIVES IMPROVING LIFE

Home | About Us | Monitoring | Contact Us

http://dev.web.uoguelph.ca/engineering/swm/

View | Edit | Revisions | Track

Research Summary

Design of Erosion and Sediment Controls for construction sites in Ontario are rapidly evolving; particularly in the Lake Simcoe region, which is experiencing rapid growth, the Ontario Regulation 60/08 under the Ontario Water Resources Act, seek to reduce the phosphorus entering Lake Simcoe by making stormwater management facilities serving new development meet the highest design standards. The Lake Simcoe Protection Plan (2009) requires municipalities to incorporate into their official plans policies related to

MONITORING DATA

- Monitoring Stations Location
- Rainfall Data
- Soil Moisture Data
- Water Level Data
- Rating Curves
- Lab Turbidity Data
- Field Turbidity Data

Acknowledgements

- Environment Canada
- Ontario Centres for Excellence
- Ontario Ministry of the Environment
- Lake Simcoe Region Conservation Authority
- Toronto and Region Conservation Authority
- Simcoe County District School Board
- Town of Innisfil and City of Guelph
- The Cortel Group and Greenland Consulting
- Metrus Development and Exp Consulting
- Pratt Development and EXP Consulting
- Alcona Downs Development and Stantec Consulting
- Filtrexxx Canada

UNIVERSITY of GUELPH

CHANGING LIVES
IMPROVING LIFE