MODELING A BIORETENTION BASIN AND VEGETATED SWALE WITH TRAPEZOIDAL CROSS-SECTIONAL AREAS USING SWMM'S LID CONTROL MODULE

Presented at the ICSWMM 2020 for

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Introduction

Design of LID in PCSWMM

Input Field Data

Parameter Selection

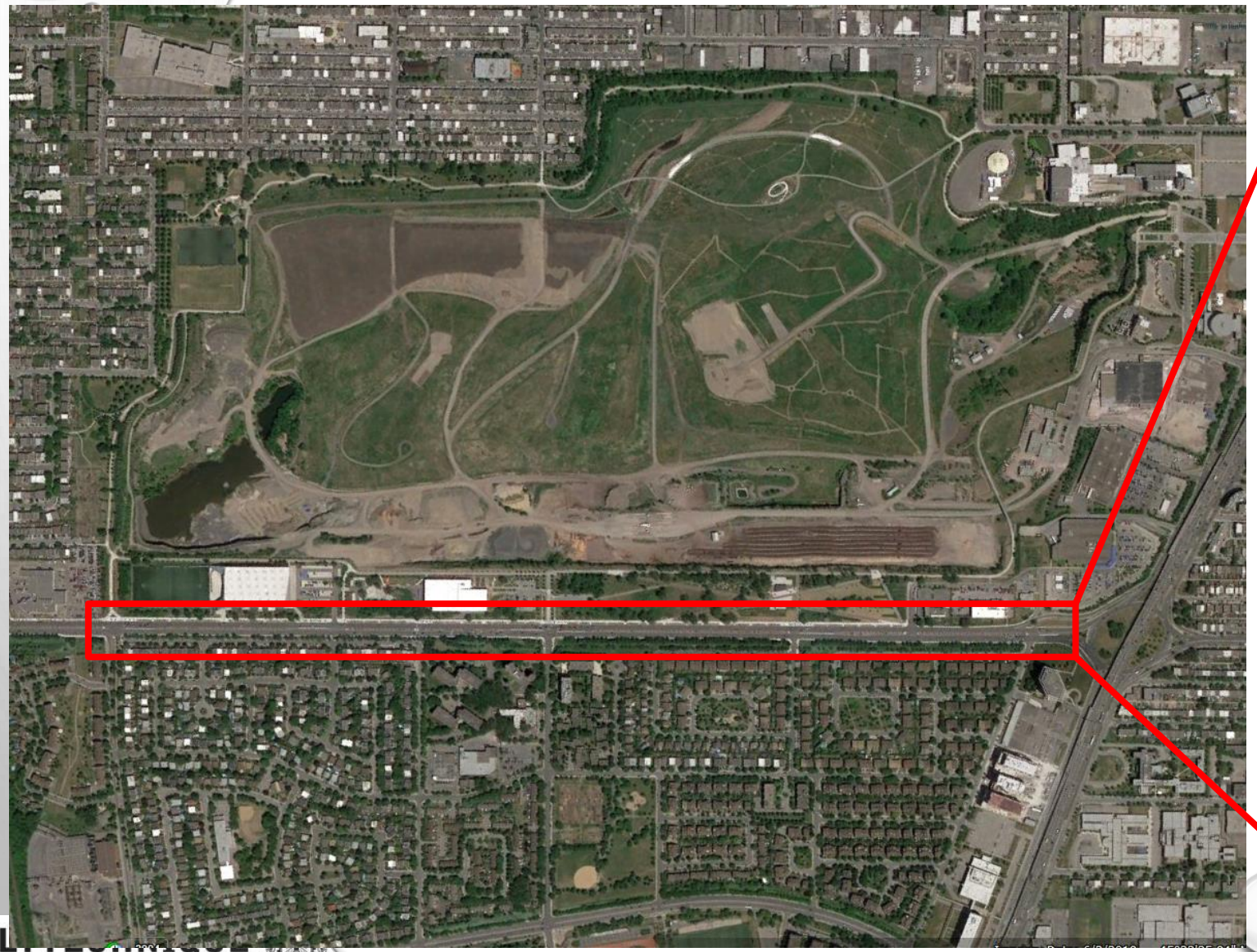
Sensitivity Analysis

Calibration

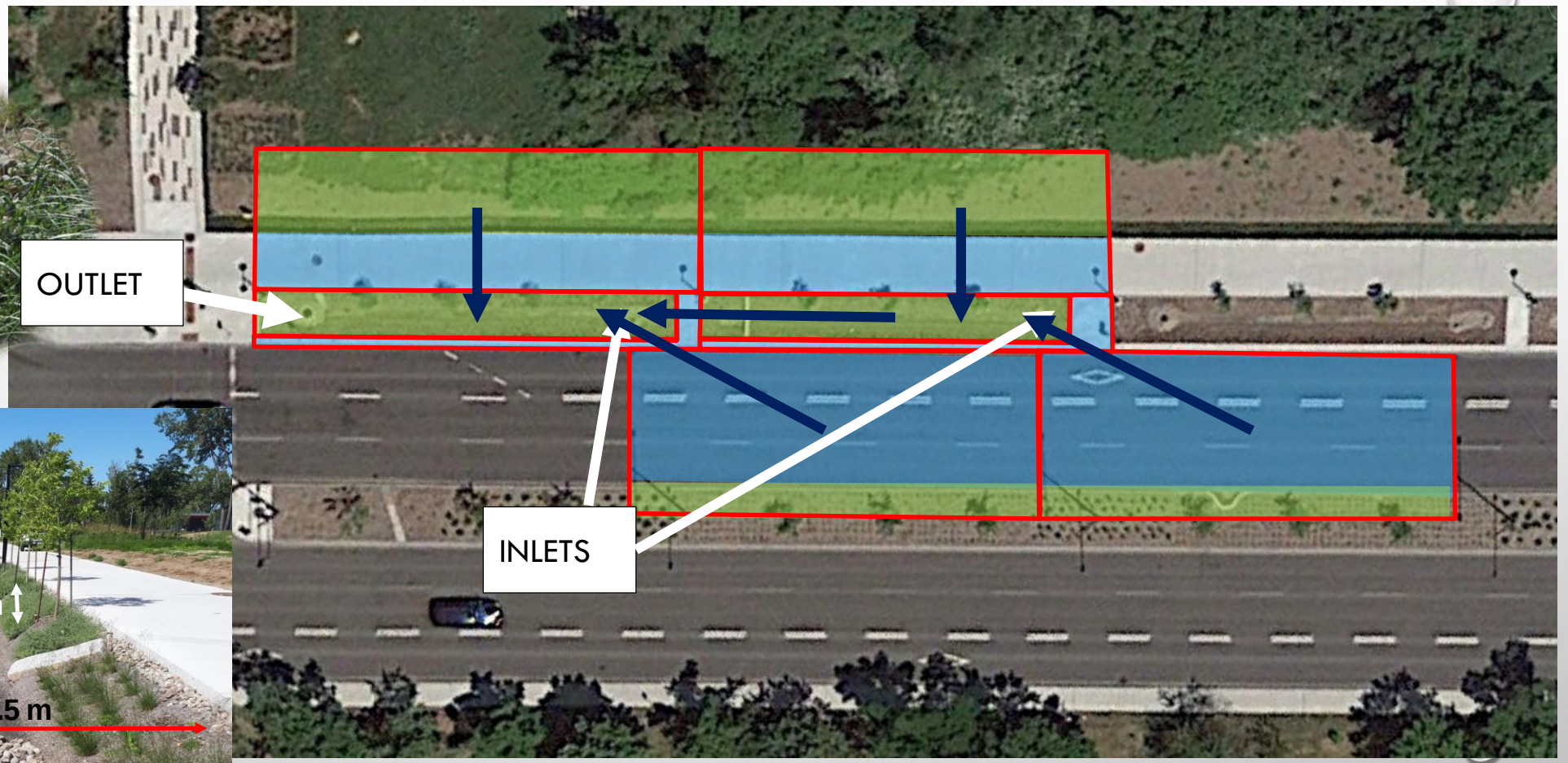
Calibration Results

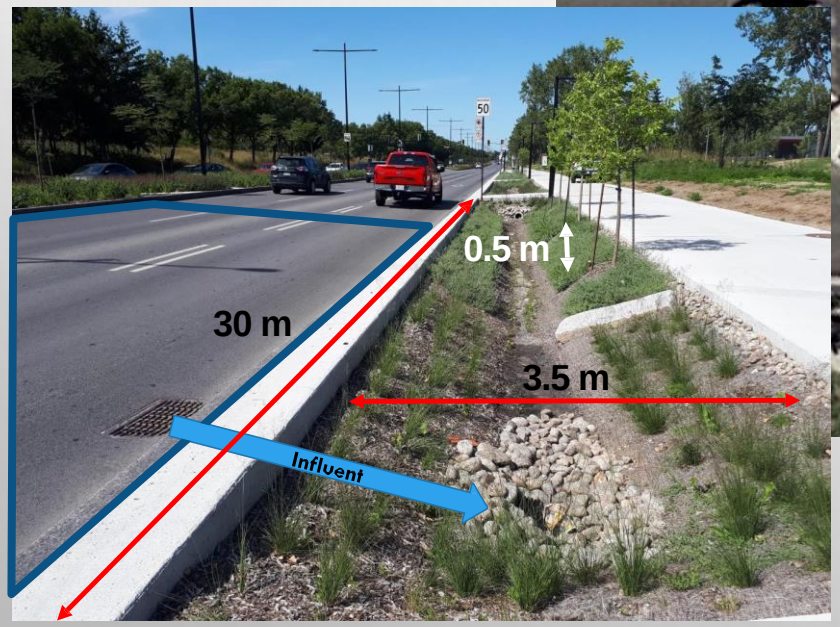
What is next? Continued troubleshooting?

PAPINEAU PROJECT– PLAN VIEW



PAPINEAU PROJECT– PLAN VIEW



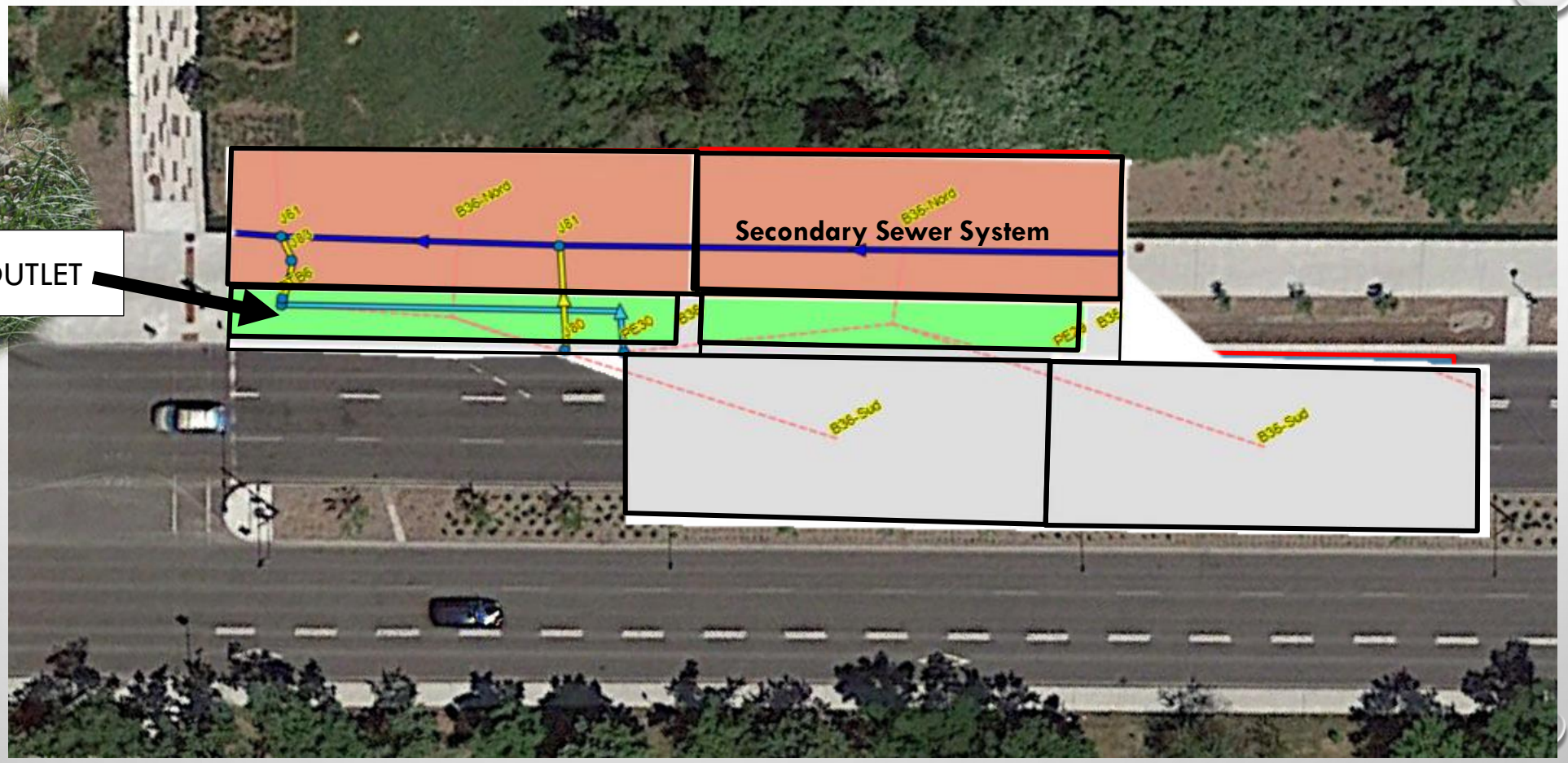


LEGEND

= IMPERVIOUS

= PERVIOUS

DESIGN OF LIDS IN PCSWMM – PLAN VIEW



- The drainage area to LID surface is approximately 4.5:1

Assumptions

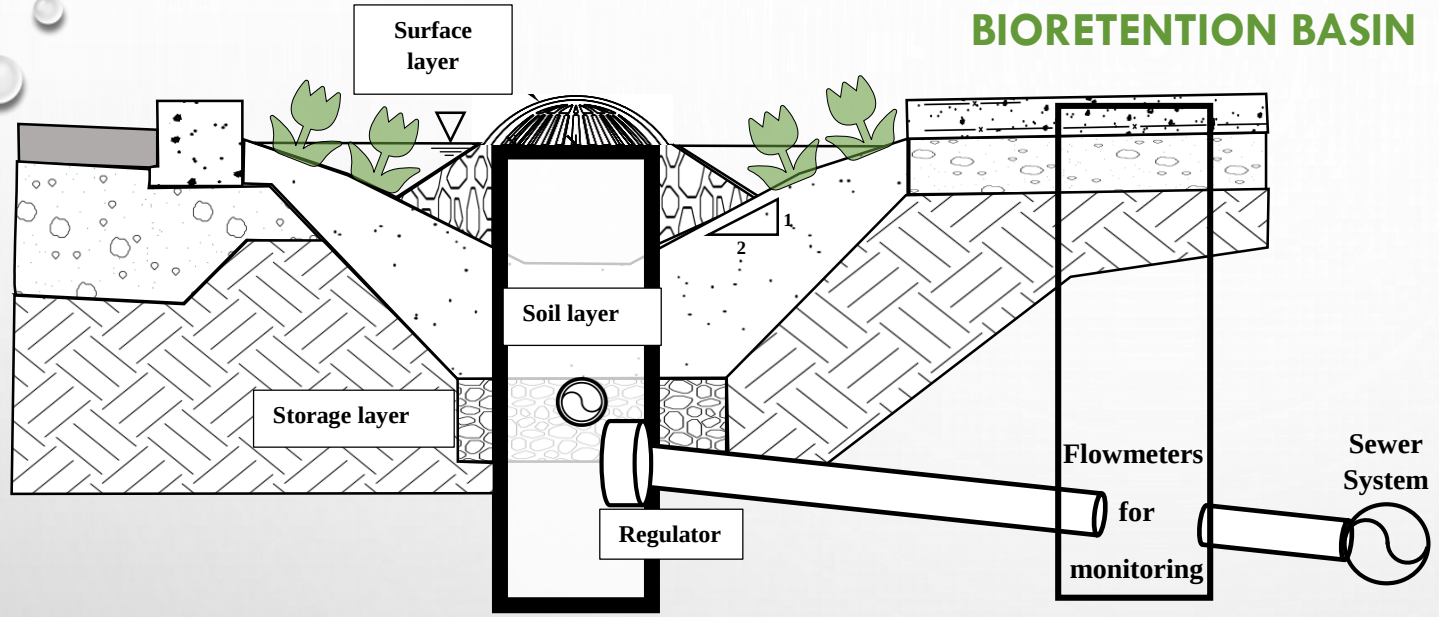
- No catch basin capacity limitations were considered

LEGEND

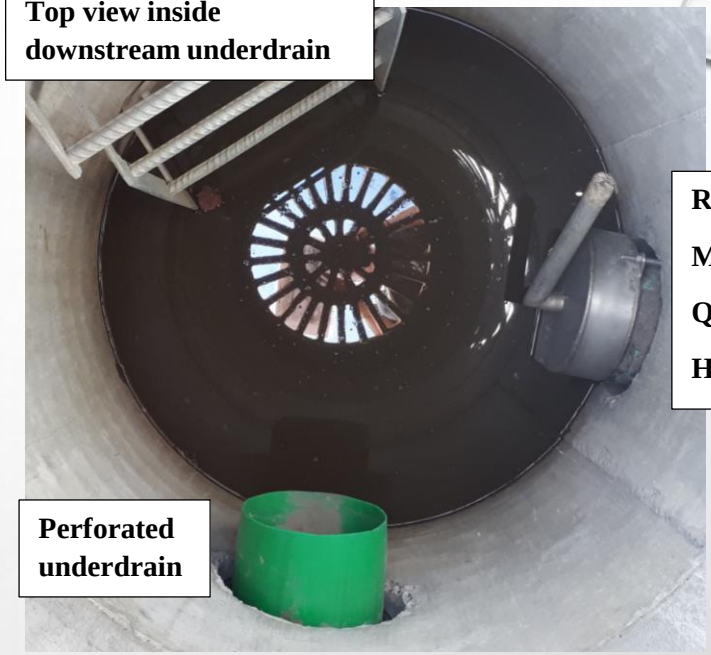
= SIDEWALK + GRASS
= LID UNITS
= STREET + MEDIAN

CROSS-SECTIONAL VIEW OF LID STRUCTURES

BIORETENTION BASIN

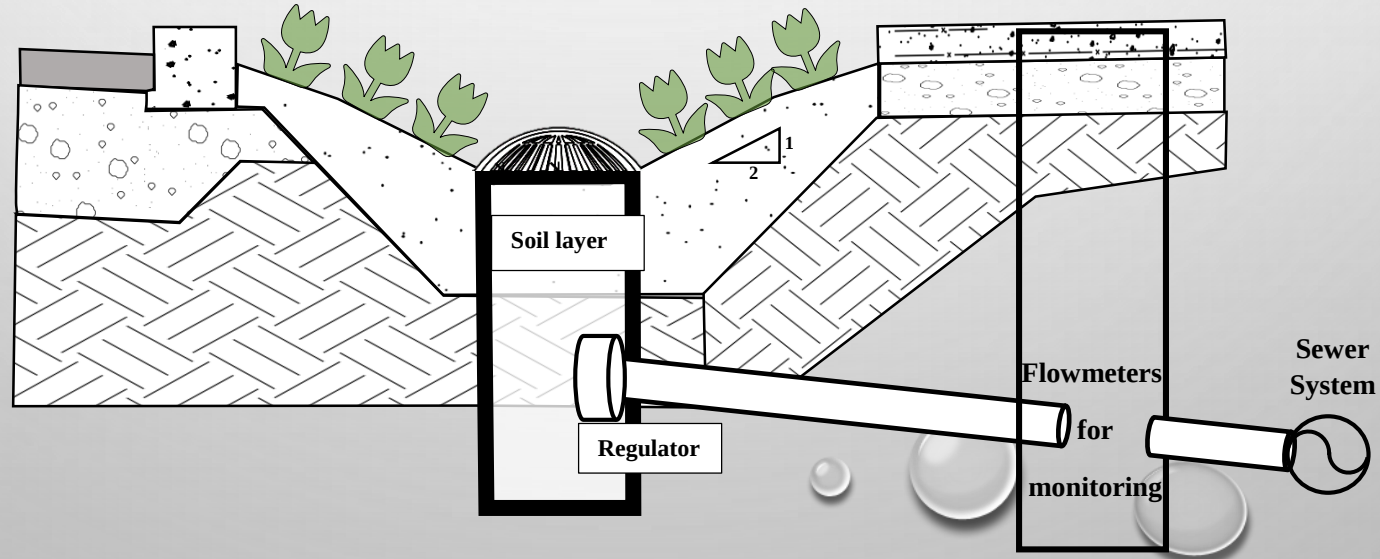


Top view inside downstream underdrain

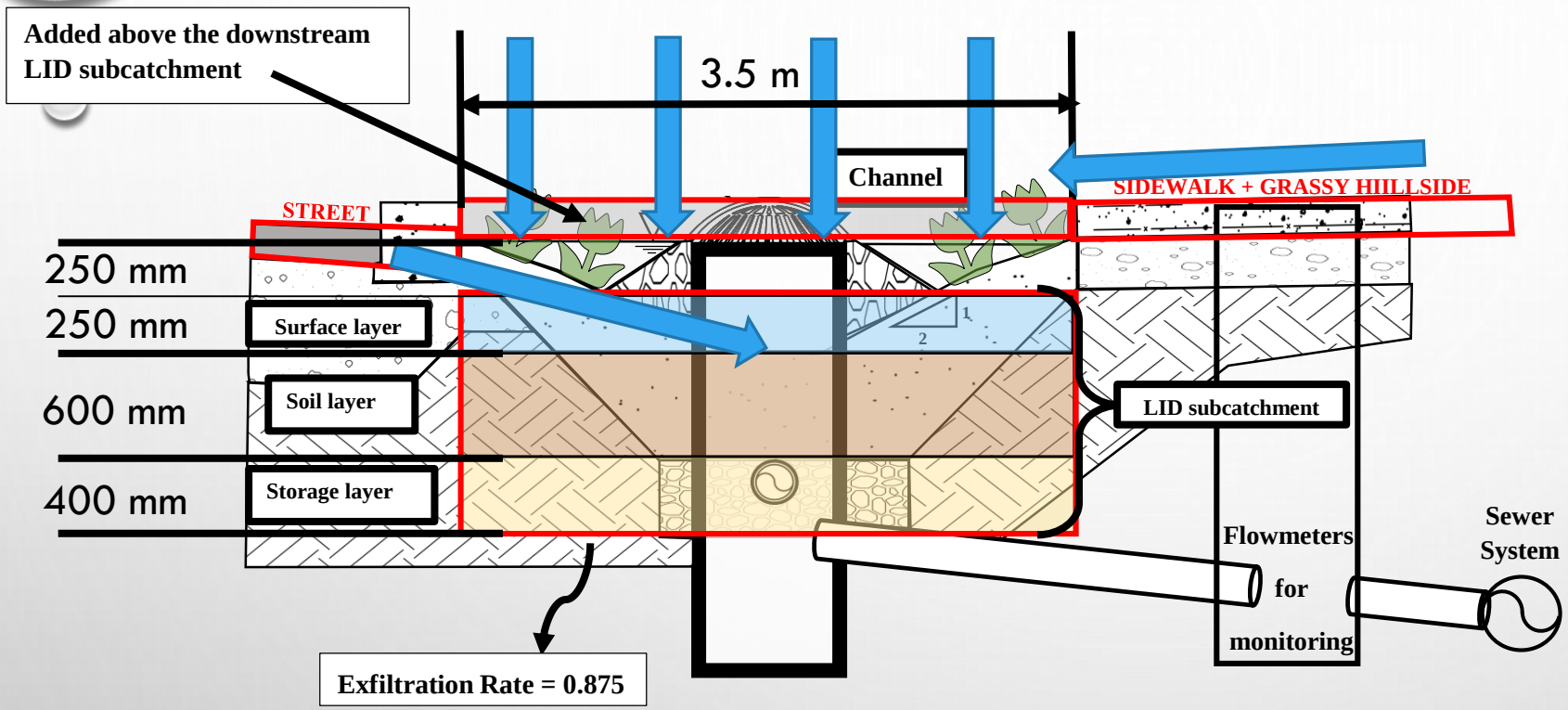


Regulator
Max
Q = 4.5 L/s
H= 1.8 m

VEGETATED SWALE



BIORETENTION BASIN AS MODELLED BY SWMM



ERRORS WHEN USING THE REAL AREA:

- Potential storage volume of **SURFACE LAYER**
  - Real = 50.26 m^3
  - SWMM = 101.84 m^3
- Volume of **STORAGE LAYER**
  - Real = 32.80 m^3
  - SWMM = 81.47 m^3

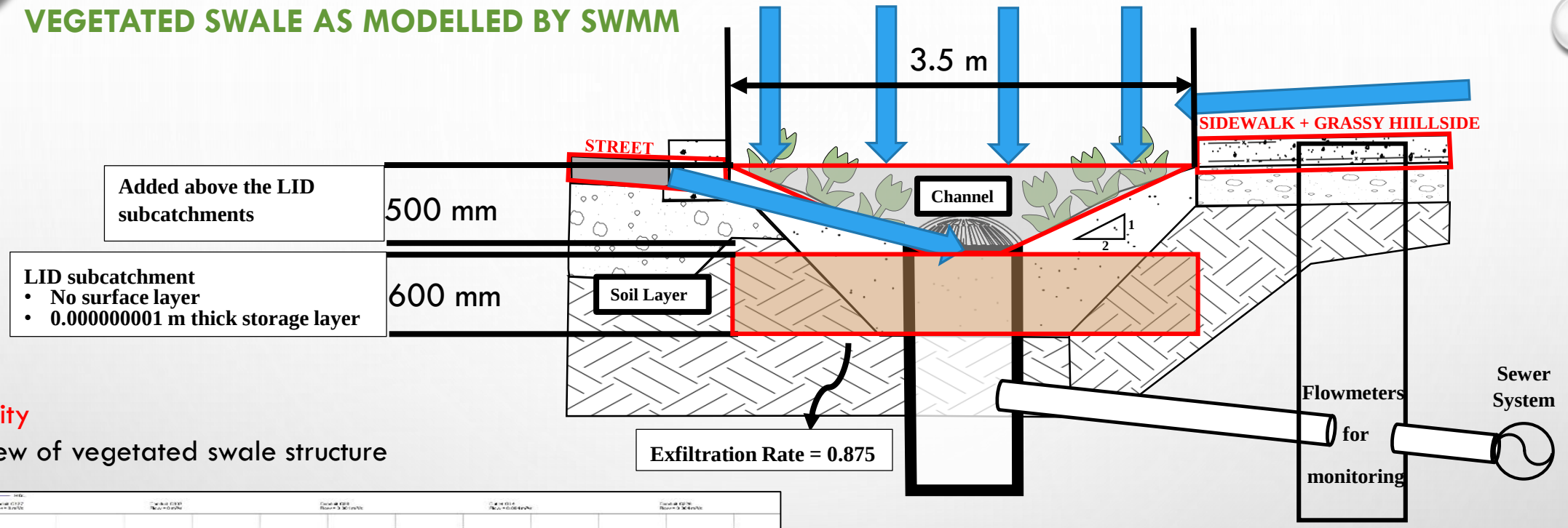
CORRECT ASPECTS USING THE REAL AREA:

- Volume of **SOIL LAYER**
  - Real = 127.94 m^3
  - SWMM = 122.21 m^3

CHANGES:

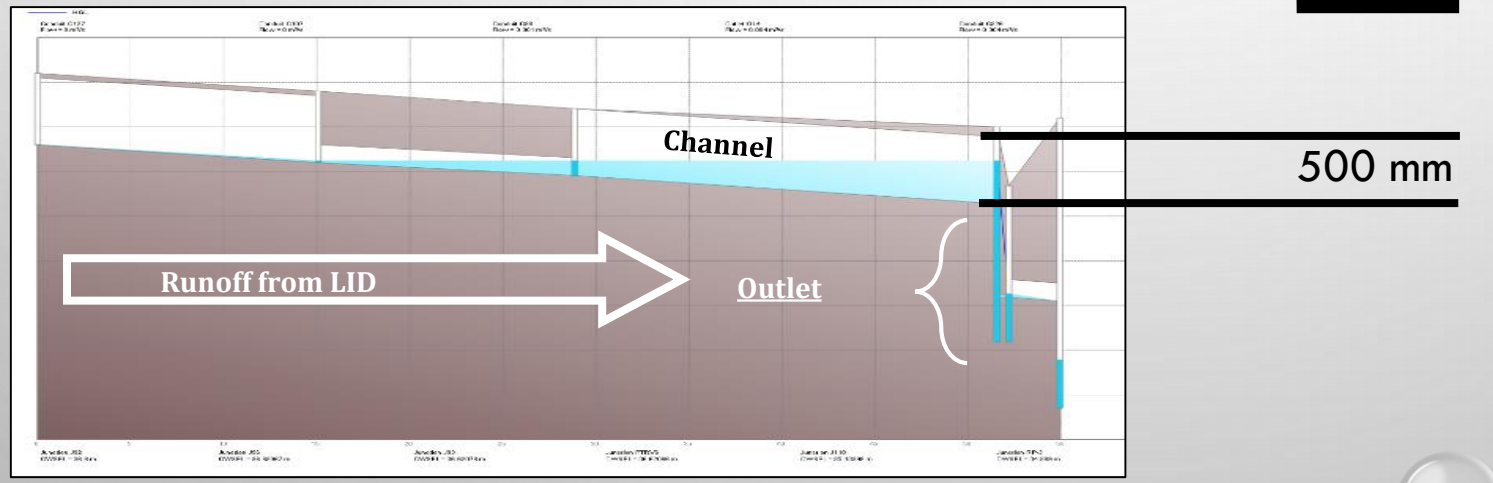
- Height of surface layer is adjusted to 250 mm so potential storage volume is accurate

VEGETATED SWALE AS MODELLED BY SWMM



Particularity

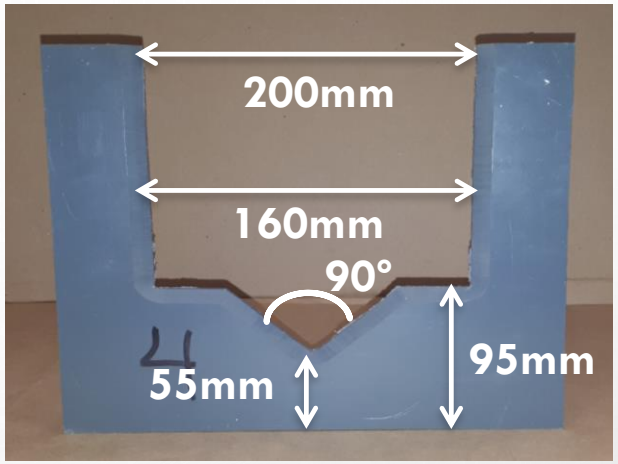
Profile view of vegetated swale structure



INPUT FIELD DATA

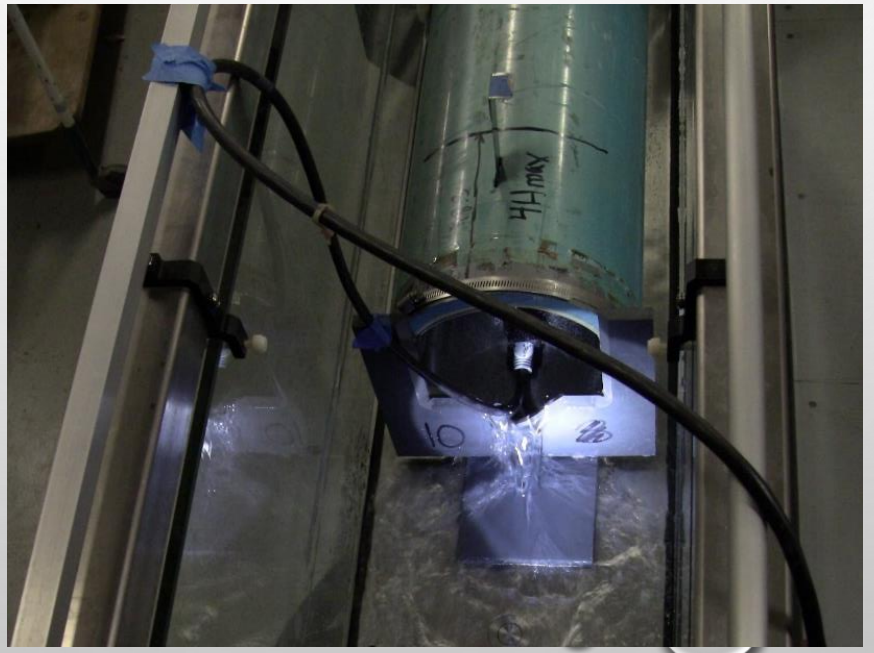
WEATHER STATION:

- 79.2 cm from 47 precipitation events (April 18th – nov 5th 2019)
- Max and min daily Temperature data for climate file (evaporation calculations)



FLOWMETERS AND WEIRS:

- Compound weirs (90° v-notch and rectangular)
- Standard calibration completed in the laboratory and verified in-situ
- Second measurement system = probe with a pressure transducer



MOISTURE CONTENT PROBES

GENERAL PARAMETERS

Parameter	Value	Source
Manning coefficient – impervious	0.01	(James et al., 2011)
Manning coefficient – pervious	0.1	(James et al., 2011)
D store imperv (mm)	1	(James et al., 2011)
D store perv (mm)	5	(James et al., 2011)
Zero Imperv (%)	25%	Default
Infiltration Model	Green-Ampt	--
Suction Head (mm)	166.8	Silt Loam (based upon geotechnical analysis of bore holes) (MDDEFP, 2014)
Conductivity (mm/hr)	6.6	
Moisture Deficit	0.501	

LID PARAMETERS

Parameter	Value		Source
Surface Layer			
Berm Height (mm)	Swale 0	Bio 250	Project construction plans
Vegetation Volume (fraction)	0.1		(James et al., 2011)
Surface Roughness	0.3		(James et al., 2011)
Soil Layer			
Soil Thickness (mm)	600		Project construction plans
Soil Classification	Silty Sand		(García-Gaines & Frankenstein, 2015)
Hydraulic Conducivity K_s (mm/hr)	91		(Rossman & Huber, January 2016)
Suction Head (mm)	50		(Rossman & Huber, January 2016)
Porosity (fraction)	Swale 0.467	Bio 0.54	Laboratory tests
Field Capacity	0.121		(Rossman & Huber, January 2016)
Wilting Point	0.057		(Rossman & Huber, January 2016)
Conductivity Slope (HCO)	44		(Rossman & Huber, July 2016)
Storage Layer			
Thickness (mm)	Swale 0	Bio 400	Project construction plans
Seepage Rate (mm/hr)	0.875		Field Tests
Underdrain (Bio only)			
Underdrain coefficient	152		Calculated
Drain exponent	0.5		(Rossman & Huber, July 2016)
Offset Height (mm)	200		Project construction plans

SENSITIVITY ANALYSIS

The sensitivity of parameters was quantified using the relative sensitivity (James, 2005):

$$Relative\ Sensitivity = \frac{\partial COF / COF}{\partial p / p}$$

Where COF = computed objective function;

p = parameter value.

The total outflow volume and peak flow were used as objective functions.

Results:

Parameters influencing detention (peak flow):

- Hydraulic conductivity

Parameters influencing retention (total volume):

- Conductivity slope, evaporation and porosity

Values of Relative Sensitivity

% change	+25%				+50%			
Basin	Swale		Bioretention		Swale		Bioretention	
Parameter	Total Volume	Peak Flow	Total Volume	Peak Flow	Total Volume	Peak Flow	Total Volume	Peak Flow
Manning Coefficient	-0.8%	-0.9%	-0.6%	-1.4%	0	0	0	0
Surface Slope	-1.0%	-1.9%	-0.4%	-0.5%	0	0	0	0
Porosity	-18.4%	0	-30.8%	0	-18.4%	0	-29.0%	0
Wilting Point	1.8%	0	0	0	1.9%	0	0	0
Conductivity	-3.8%	0	2.1%	102.6%	-3.4%	0	1.7%	86.5%
Conductivity Slope	24.7%	2.8%	9.9%	0	22.1%	1.9%	9.1%	0
Seepage Rate	-9.4%	-0.9%	-8.6%	0	-7.3%	-0.5%	-8.2%	-0.6%
Evaporation Rates	-20.7%	-0.9%	-30.5%	0	-20.7%	-1.4%	28.4%	0

CALIBRATION TO SENSITIVE PARAMETERS

$$\text{Soil percolation speed} = \frac{K_{rs}}{e^{HCO(\emptyset_2 - \theta_2)}}$$

VEGETATED SWALE:

- Outflow volume overestimation (retention metric);
  - Increase percolation speed to increase infiltration of runoff;
    - (+) hydraulic conductivity (K_s) and (-) conductivity slope (HCO);
  - (+) porosity and (+) evaporation;

BIORETENTION BASIN:

- Time to start of runoff dis-alignment and peak flow overestimation (detention metrics);
  - Increase percolation speed to align observed and simulated hydrographs;
    - (+) K_s and (-) conductivity slope
- Outflow volume overestimation (retention metric);
  - (+) porosity and (+) evaporation

Evaporation rates				
Source	April	May	June	July
Environment Canada averages from 1981 to 2010	0	4.2	4.6	4.6
Simulated in SWMM from climate file	0.5	2.9	3.7	4.7

Evaluation of model efficiency

- NSE = The Nash-Sutcliffe coefficient used to assess specifically the predictive power of hydrological models (Nash & Sutcliffe, 1970). Performance required is $NSE > 0.5$
- Error in effluent volume and peak flow < 25 %

Optimal values (SWMM reference manual Vol 3 pg 127)

- K_s =increased from 91 to 140 mm/hr
- Conductivity Slope (HCO) = reduced from 44 to 30

Parametric Calibration Results

VEGETATED SWALE:
NSE = 0.206
33.9% ERROR VOL
25.3% ERROR PEAK

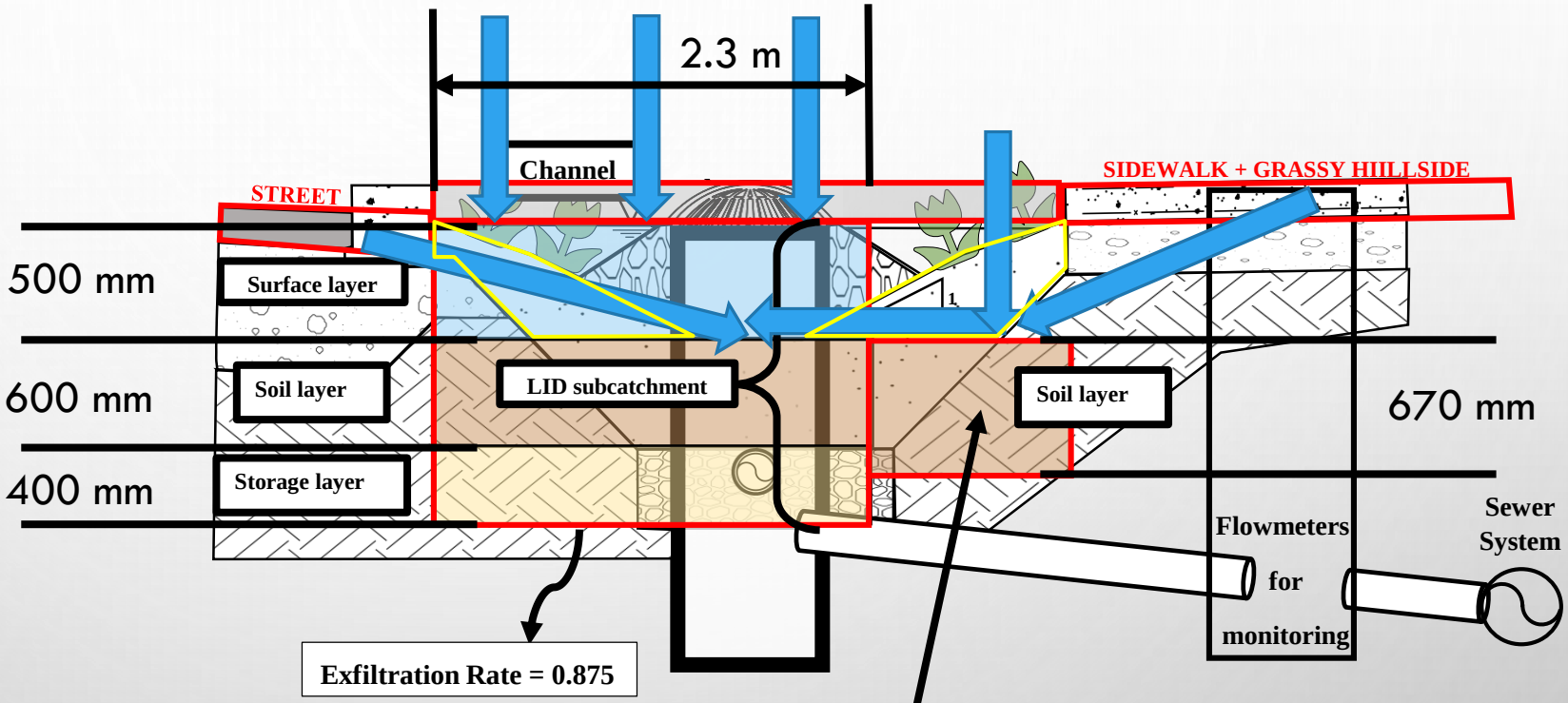
BIORETENTION BASSIN:
NSE = -0.686
96.6% ERROR VOL
25.4% ERROR PEAK

REDESIGN OPTIONS: CASE 1

CHANGES:

- KEEP REAL SURFACE LAYER HEIGHT 500 MM;
- ADJUST WIDTH TO MAKE SURFACE LAYER VOLUME ACCURATE BUT MORE TO SIMULATE FORM OF SOIL LAYER MORE ACCURATELY;
- ADDED A SEPARATE LID TO REPRESENT THE TOP SIDE SOIL (HIGHLIGHTED IN YELLOW);

BIORETENTION BASIN

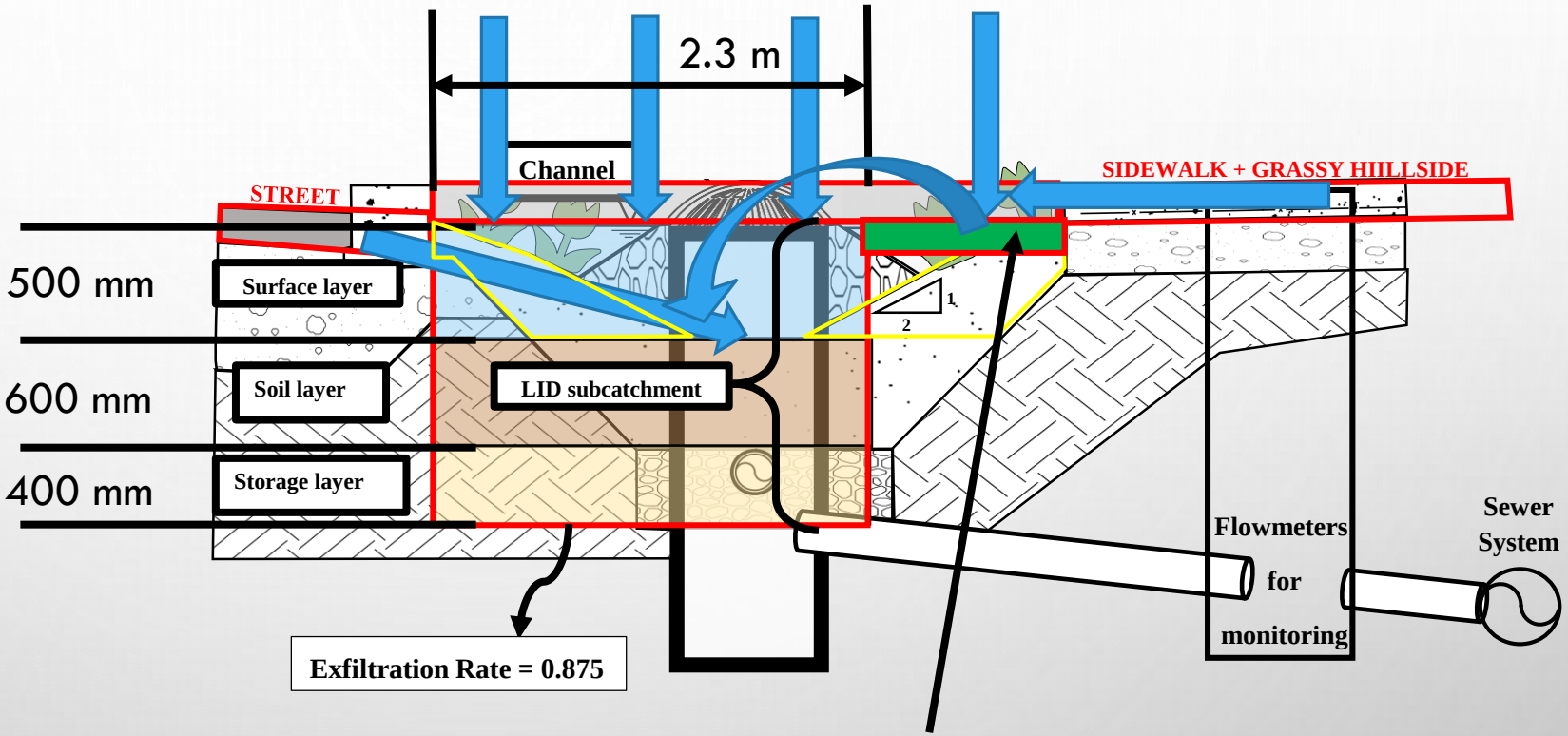


REDESIGN OPTIONS: CASE 2

CHANGES:

- KEEP REAL SURFACE LAYER HEIGHT 500 MM;
- ADJUST WIDTH TO MAKE SURFACE LAYER VOLUME ACCURATE BUT MORE TO SIMULATE FORM OF SOIL LAYER MORE ACCURATELY;
- ADDED A SEPARATE SUBCATCHEMENT TO REPRESENT THE TOP SIDE SOIL (HIGHLIGHTED IN YELLOW);

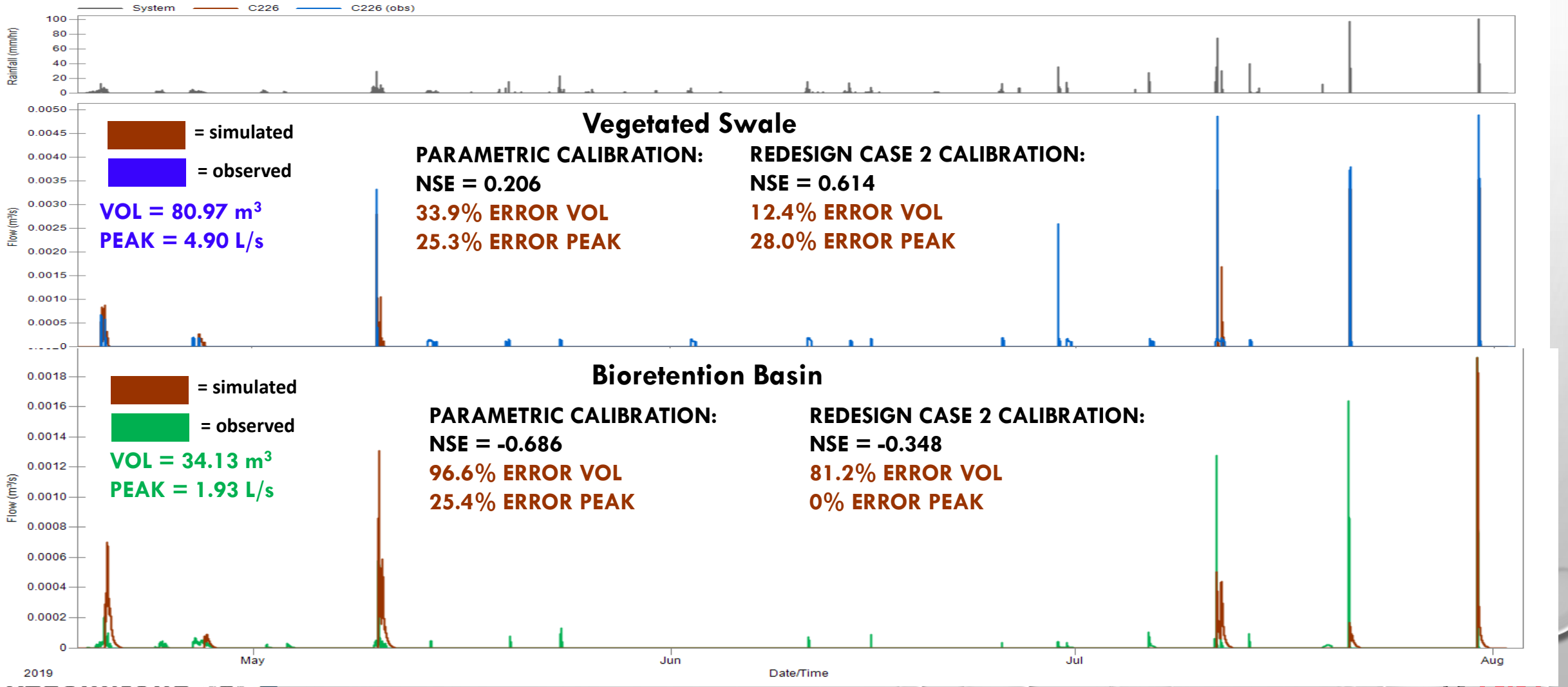
BIORETENTION BASIN



Additional subcatchment to represent the top soil (completely pervious with green-ampt parameters of suction head 50; conductivity 140 and initial deficit of 0.463)

CALIBRATED RESULTS – REDESIGN CASE 2

CONTINUOUSLY FROM APRIL 18TH – JULY 30TH



CALIBRATED RESULTS – REDESIGN CASE 2 – VEGETATED SWALE

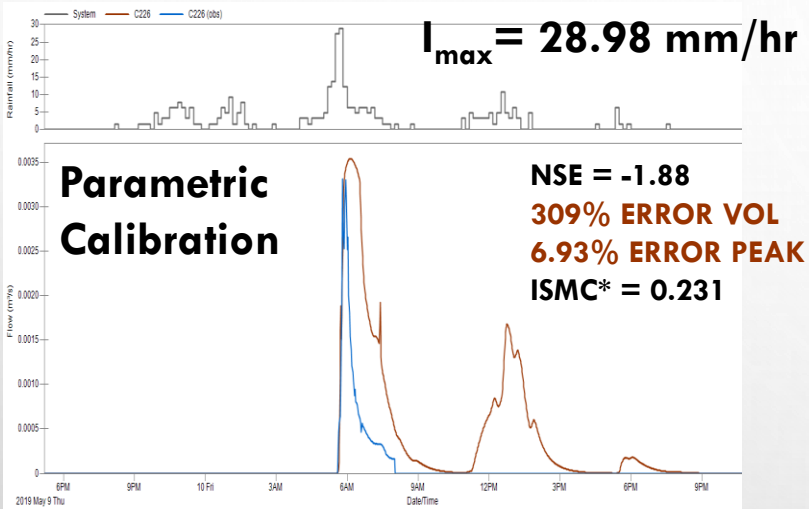
MAY 9TH : 57.12 mm in 24 hrs with 6.29 antecedent dry days

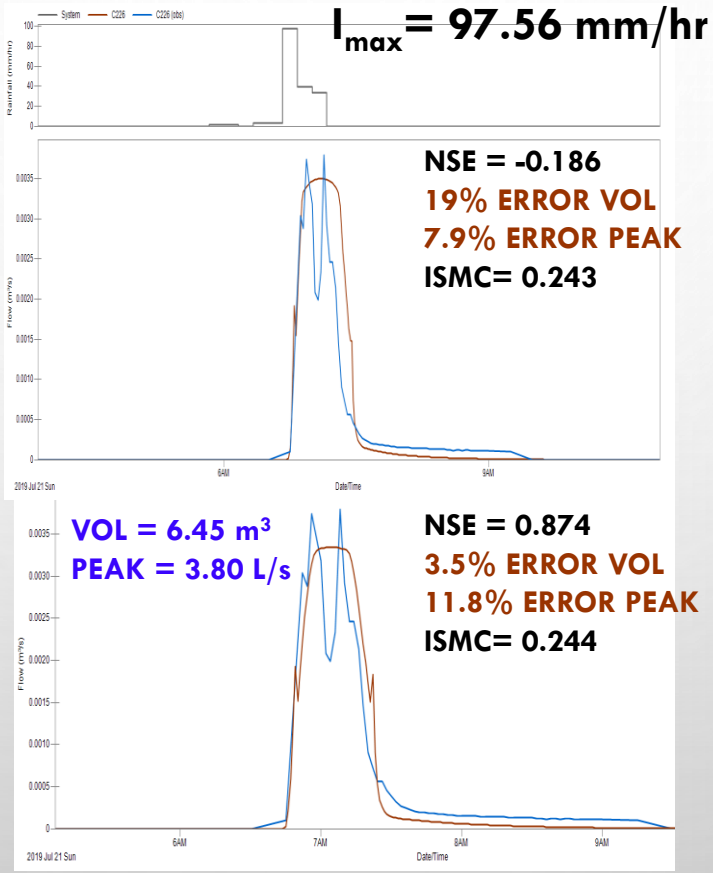
= simulated

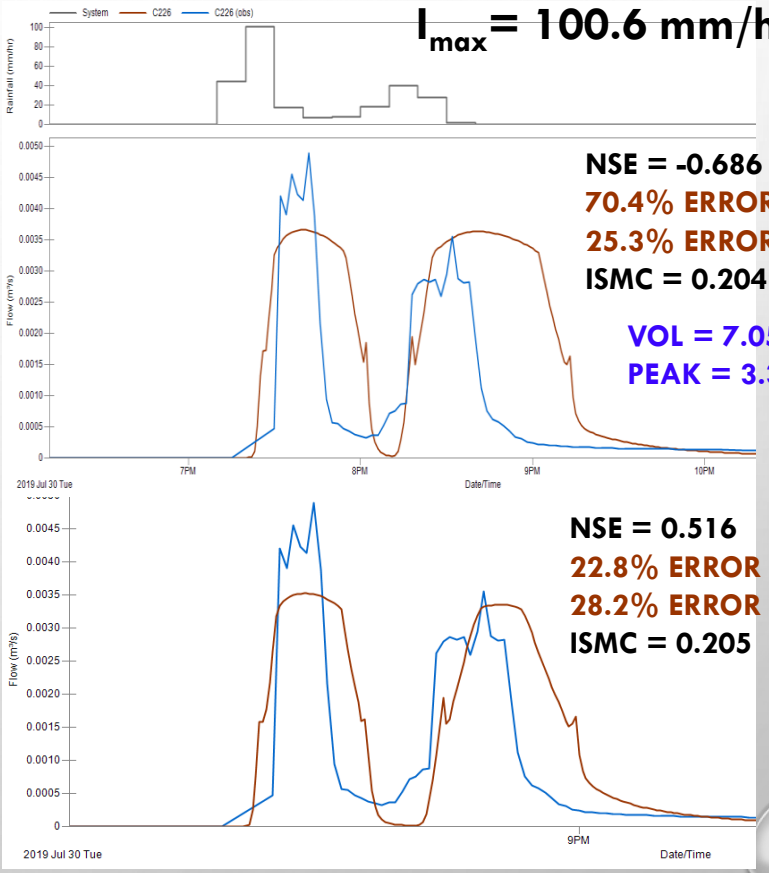
= observed

JULY 21ST : 29.97 mm in 1h20min with 2.70 antecedent dry days

JULY 30TH : 43.68 mm in 1h30min with 9.50 antecedent dry days







*ISMC = Initial Soil Moisture Content

CALIBRATED RESULTS – REDESIGN CASE 2 – BIORETENTION BASIN

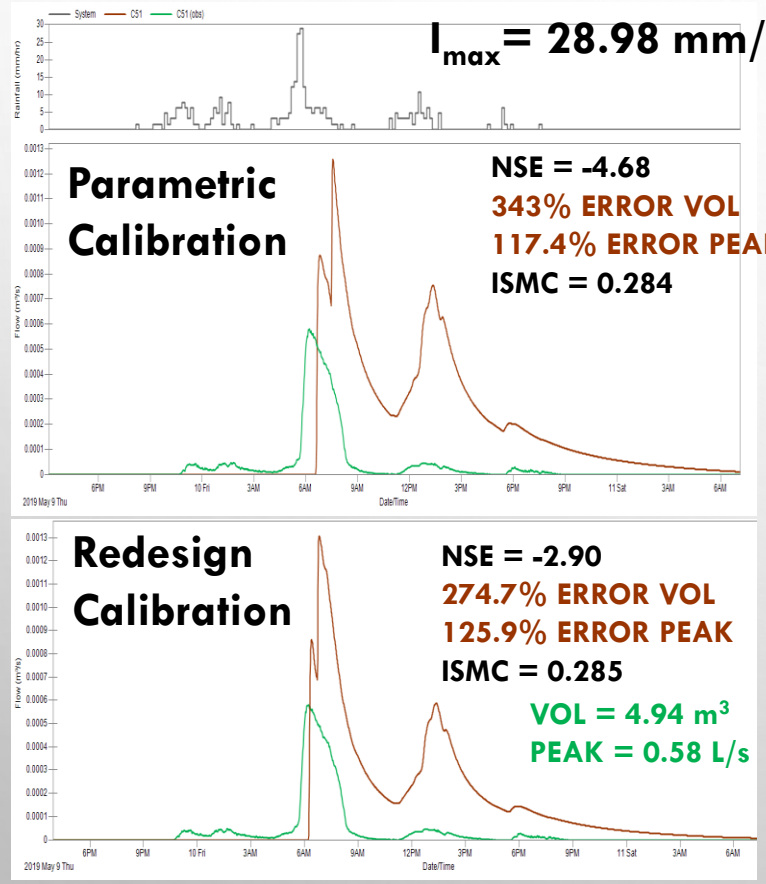
= simulated

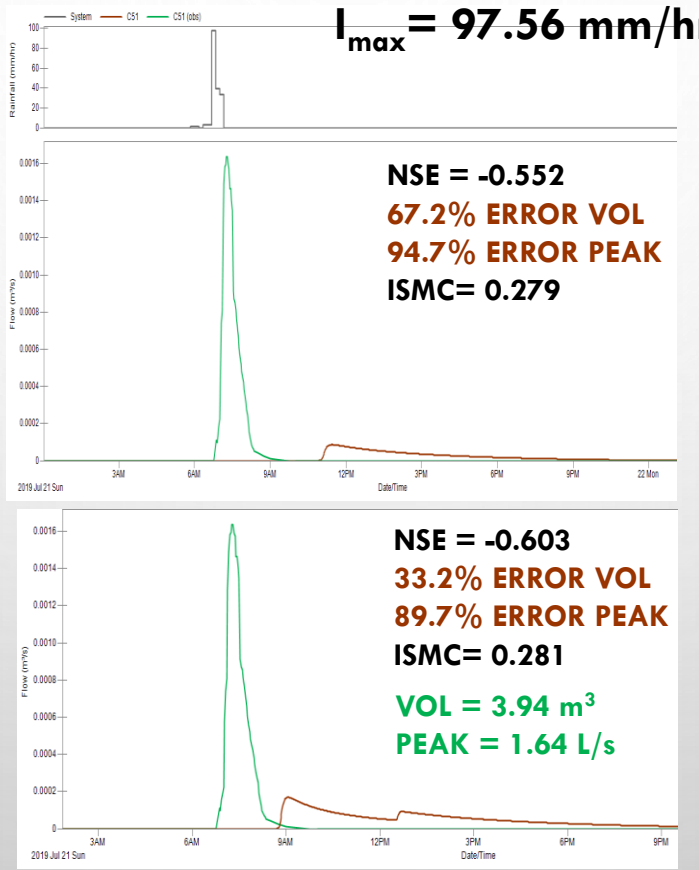
= observed

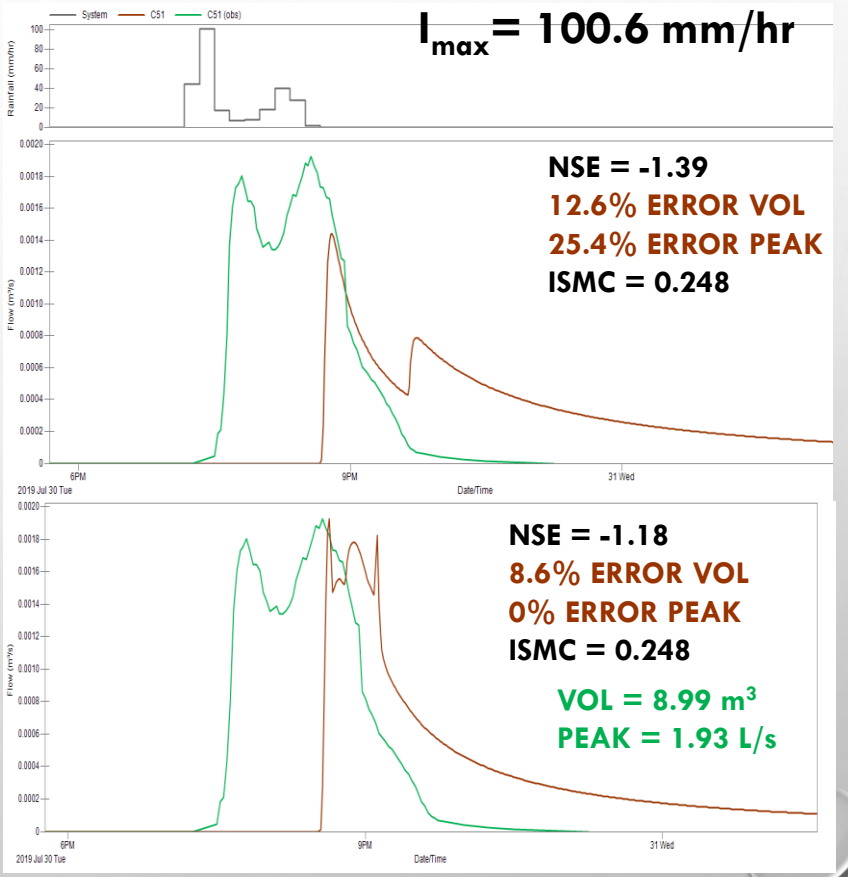
MAY 9TH : 57.12 mm in 24 hrs with 6.29 antecedent dry days

JULY 21ST : 29.97 mm in 1h20min with 2.70 antecedent dry days

JULY 30TH : 43.68 mm in 1h30min with 9.50 antecedent dry days





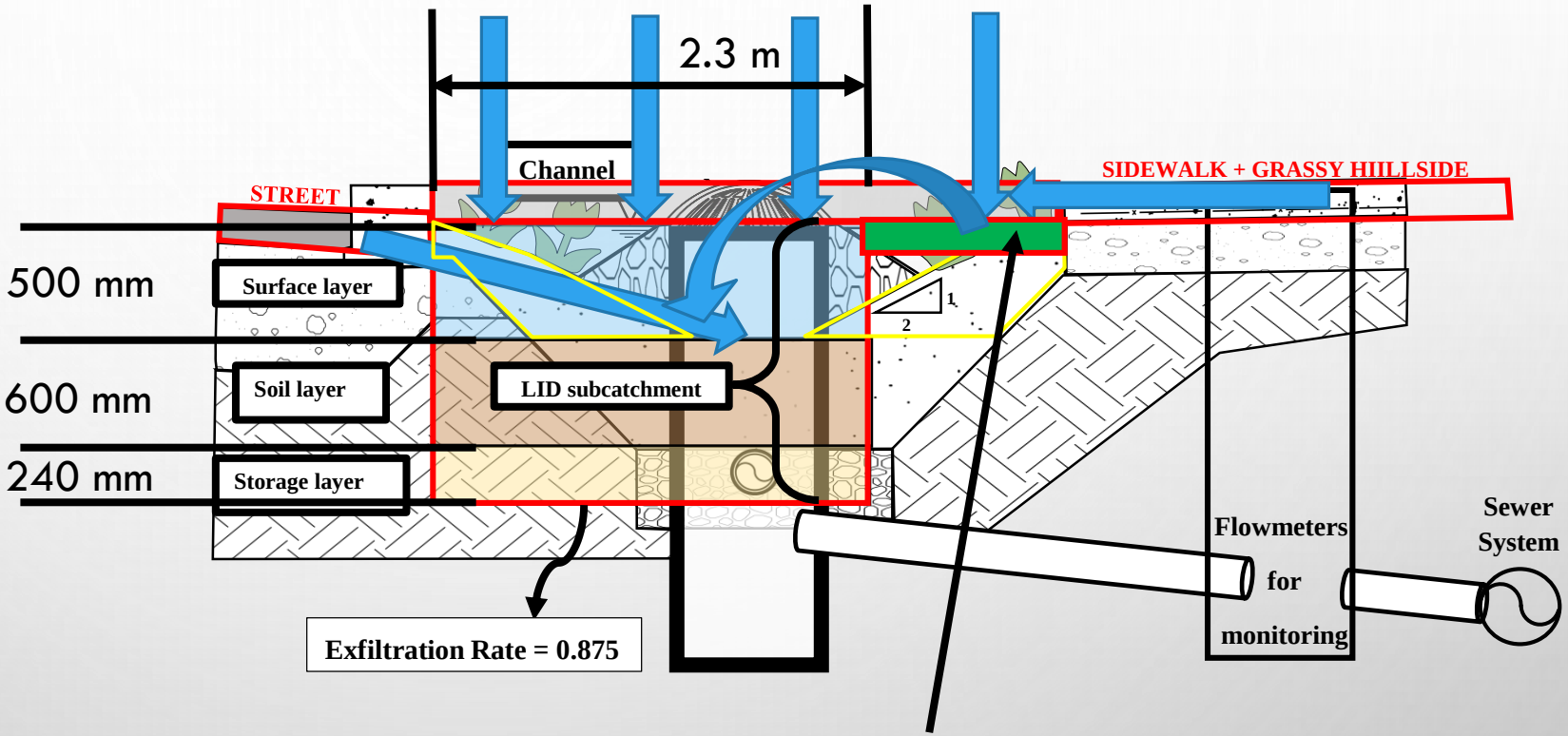


REDESIGN OPTIONS: CASE 3

CHANGES:

- KEEP REAL SURFACE LAYER HEIGHT 500 MM;
- ADJUST WIDTH TO MAKE SURFACE LAYER VOLUME ACCURATE BUT MORE TO SIMULATE FORM OF SOIL LAYER MORE ACCURATELY;
- ADDED A SEPARATE SUBCATCHEMENT TO REPRESENT THE TOP SIDE SOIL (HIGHLIGHTED IN YELLOW);
- MAKE STORAGE VOLUME CORRECT BY REDUCING HEIGHT TO 240 MM;

BIORETENTION BASIN



Additional subcatchment to represent the top soil (completely pervious with green-ampt parameters of suction head 50; conductivity 140 and initial deficit of 0.463)

CALIBRATED RESULTS – REDESIGN CASE 3 – BIORETENTION BASIN

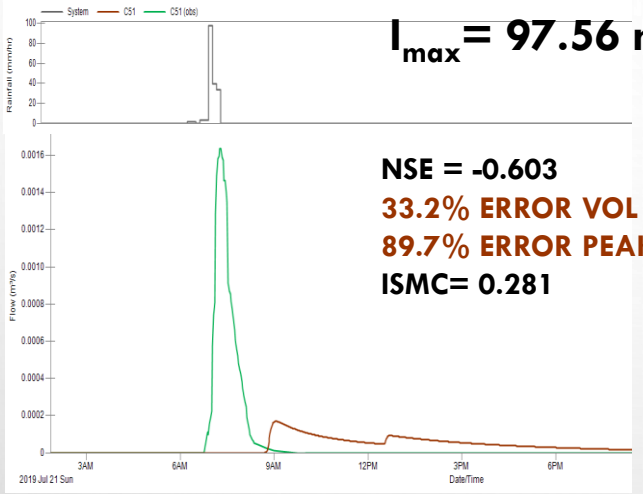
JULY 21ST : 29.97 mm in 1h20min with 2.70 antecedent dry days

= simulated

= observed

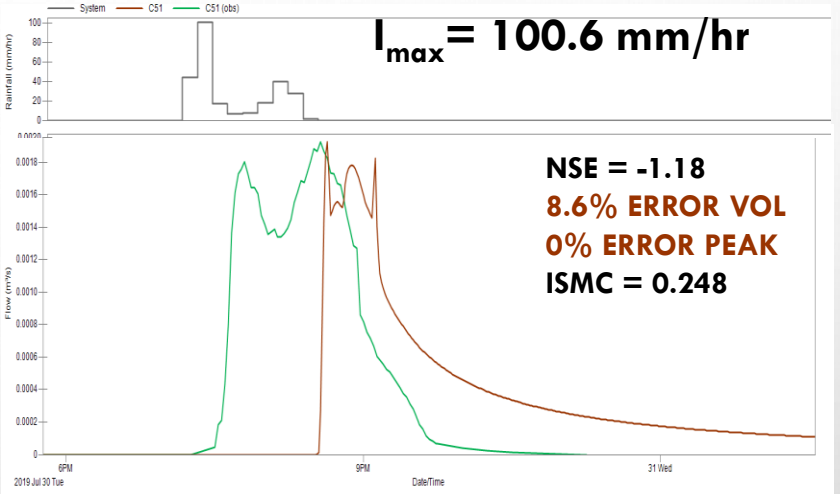
JULY 30TH : 43.68 mm in 1h30min with 9.50 antecedent dry days

Redesign Calibration Case 2



I_{max}= 97.56 mm/hr

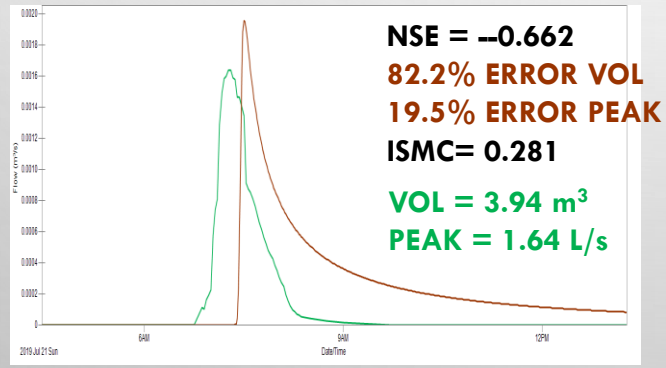
NSE = -0.603
33.2% ERROR VOL
89.7% ERROR PEAK
ISMC= 0.281



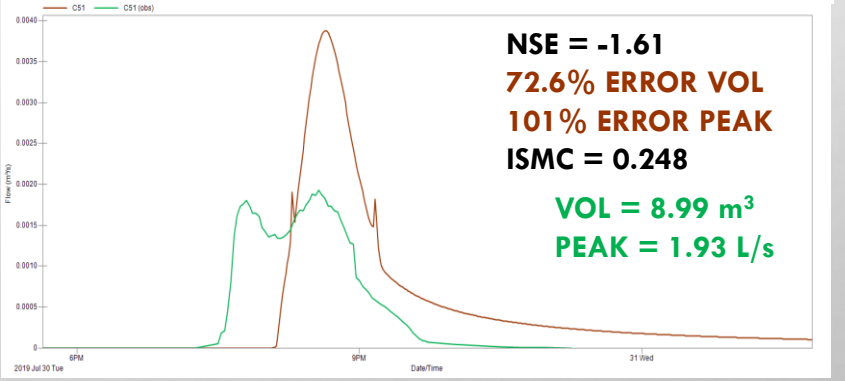
I_{max}= 100.6 mm/hr

NSE = -1.18
8.6% ERROR VOL
0% ERROR PEAK
ISMC = 0.248

Redesign Calibration Case 3



NSE = --0.662
82.2% ERROR VOL
19.5% ERROR PEAK
ISMC= 0.281
VOL = 3.94 m³
PEAK = 1.64 L/s



NSE = -1.61
72.6% ERROR VOL
101% ERROR PEAK
ISMC = 0.248
VOL = 8.99 m³
PEAK = 1.93 L/s

CONCLUSIONS

- Vegetated swale vs bioretention performance
- Model vs observed data performance
- Contradiction in timing of outflow hydrographs and volume ejected
- Complex nature of the soil

Assuming observed data is correct

➢ The complexity of soil behaviour is not completely captured by SWMM LID bioretention control

➢ The SWMM bioretention cell is accurate and it is the inflow that is being overestimated

➢ Liberation of soil retention capacity due to evaporation is not fully capture by SWMM

Assuming the model results are correct

➢ Error in flow values derived from the weir calibration curves and the height of runoff measured by the probes

Note: It is unlikely that the timing of the observed exit hydrographs is incorrect

REFERENCES

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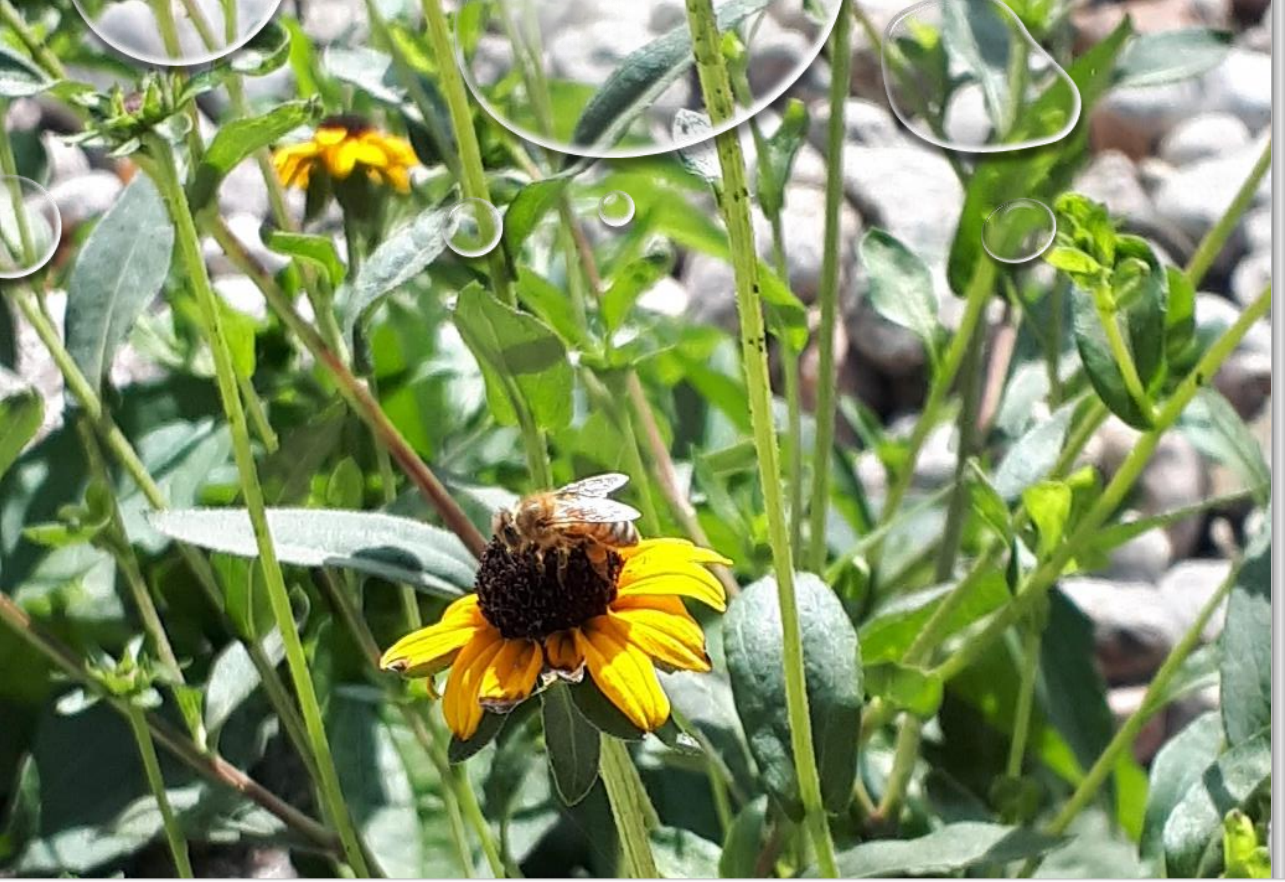

THANK YOU FOR LISTENING!

QUESTIONS ? SUGGESTIONS?

CONCLUSIONS

Based on the model results, the bio-retention basin performance is superior to the vegetated swale however both basins performance's are inferior to the results from the observed data. Based on the observed data, the bio-retention basin reacts quickly to the rainfall event however is still able to retain a large amount of volume which seems contradictory. In the case of the model, it is not able to simulate both behaviors. This means that if the outflow is to be reduced, the alignment of the hydrographs will be lost and if the latter is prioritized, this leads to an overestimation of the volume. It is possible the model is too simple a representation of the complex nature of the soil and it not able to capture both penomenon simulatenously.