

# Sherif Ahmed, PhD, P.Eng.

*Water Resources & Stormwater Engineer*



❖ **Kerr Wood Leidal (KWL), Engineering Consulting Firm, Canada**  
*(Edmonton / Calgary, AB, Canada)*

❖ **Education**

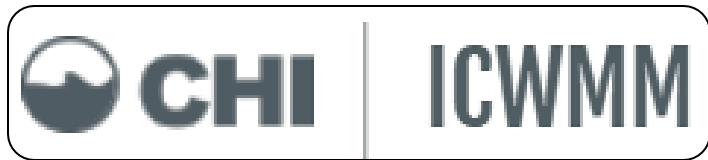
- **PhD, Civil & Environmental Engineering** — *University of Alberta, Canada*  
*3D hydrodynamic and sediment transport modelling in Stormwater ponds & wetlands*
- **MSc, Water Resources Engineering** — *Cairo University, Egypt*
- **BSc, Civil Engineering** — *Cairo University, Egypt*

❖ **Professional Background**

**13+ years of research and engineering experience as:**

- **Water Resources & Stormwater Engineer** at KWL, Canada
  - Stormwater management & LID systems
  - Hydrologic, hydraulic, and water quality modelling
  - Sediment transport & 3D hydrodynamic modelling
  - Urban drainage, ponds, wetlands, and watershed studies
- **Postdoc Scholar** at the University of Alberta, Canada
  - Stormwater ponds and wetlands Design & Operation
- **Water Resources Engineer** at Cairo University, Egypt
  - Hydrology analysis
  - Stormwater management

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# Enhancing Urban Water Balance Representation in EPA SWMM Using a Two- Layer Infiltration Approach

*Sherif Ahmed, Craig Kipkie, Tara Paradis,  
Lotte Veth, Alexa Baker and Bert van Duin*



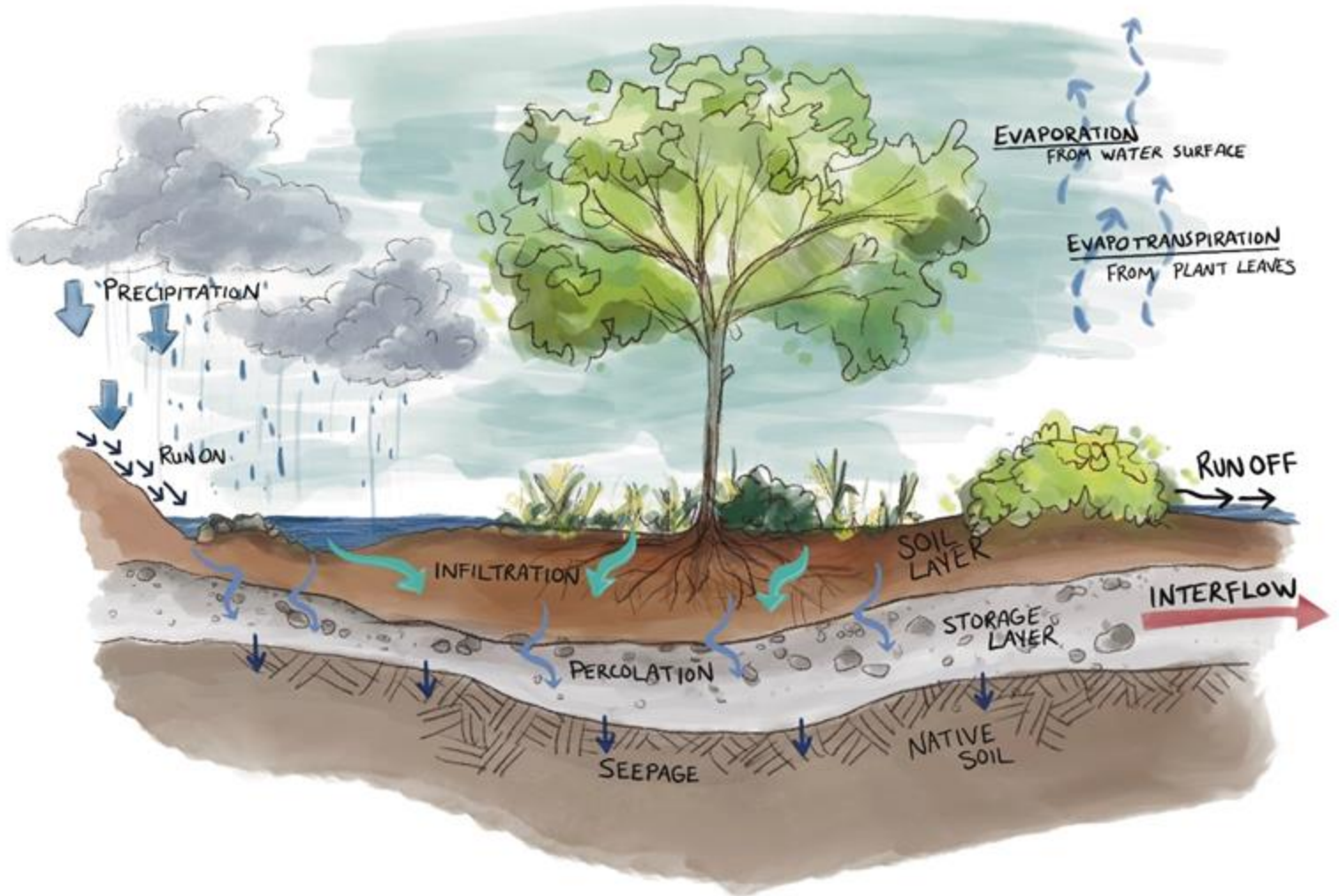
# Outlines

1. Background on the Infiltration Process on Pervious Surfaces
2. EPA SWMM Single-Layer vs Two-Layer Infiltration Modelling
3. LID Control Parameters and Methods for Two-Layer Infiltration Modelling
4. Case Study (Nose Creek Watershed Hydrological Model)
  - a. Objectives of the Two-Layer Infiltration Modelling
  - b. Study Site & Model Domain
  - c. Sensitivity Analysis
  - d. Model Calibration and Validation
  - e. Global Mass Balance Results
5. Lessons Learned about Infiltration Modelling

# Infiltration Process on Pervious Surfaces

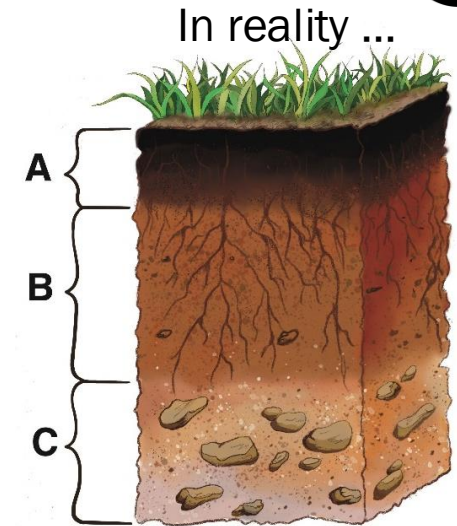
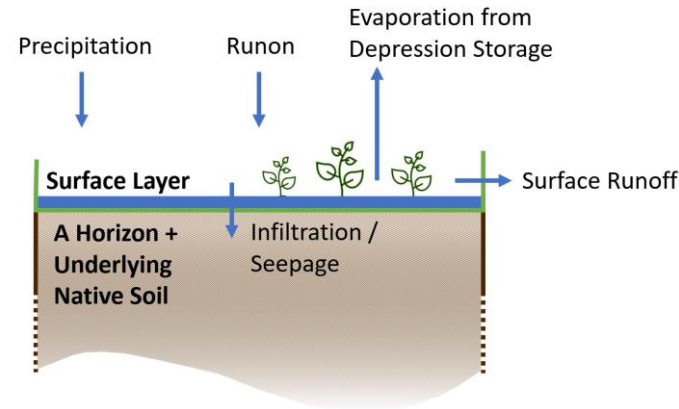


- Precipitation, irrigation, and run-on applied to pervious surfaces infiltrate into the soil.
- Infiltration capacity decreases as soil moisture content increases.
- If the applied water rate exceeds the infiltration capacity, excess water cannot infiltrate.
- The excess water either ponds on the surface or becomes surface runoff.



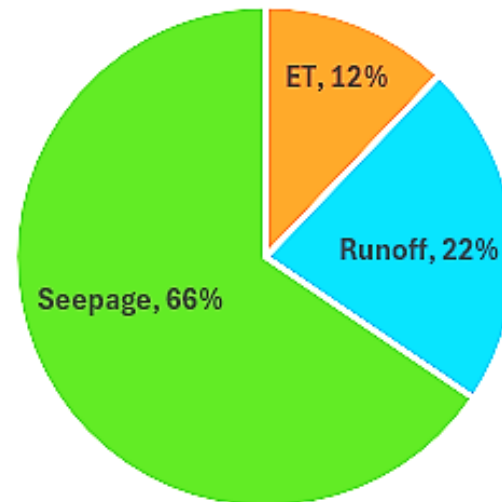
# Single-Layer Infiltration Modelling

- By default, EPA SWMM models pervious areas as one uniform soil layer in which:
  - Only one set of infiltration parameters is defined
  - No ET from the soil layer
  - No lateral flow

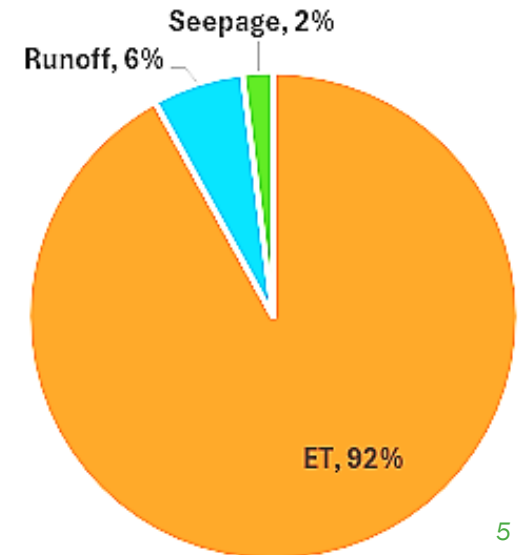


- A single-layer approach is usually acceptable when the main focus is on flood control for extreme events.
- Yet, for continuous simulation, the overall soil water balance is poorly represented by this approach

Single-Layer  
May-October 2020



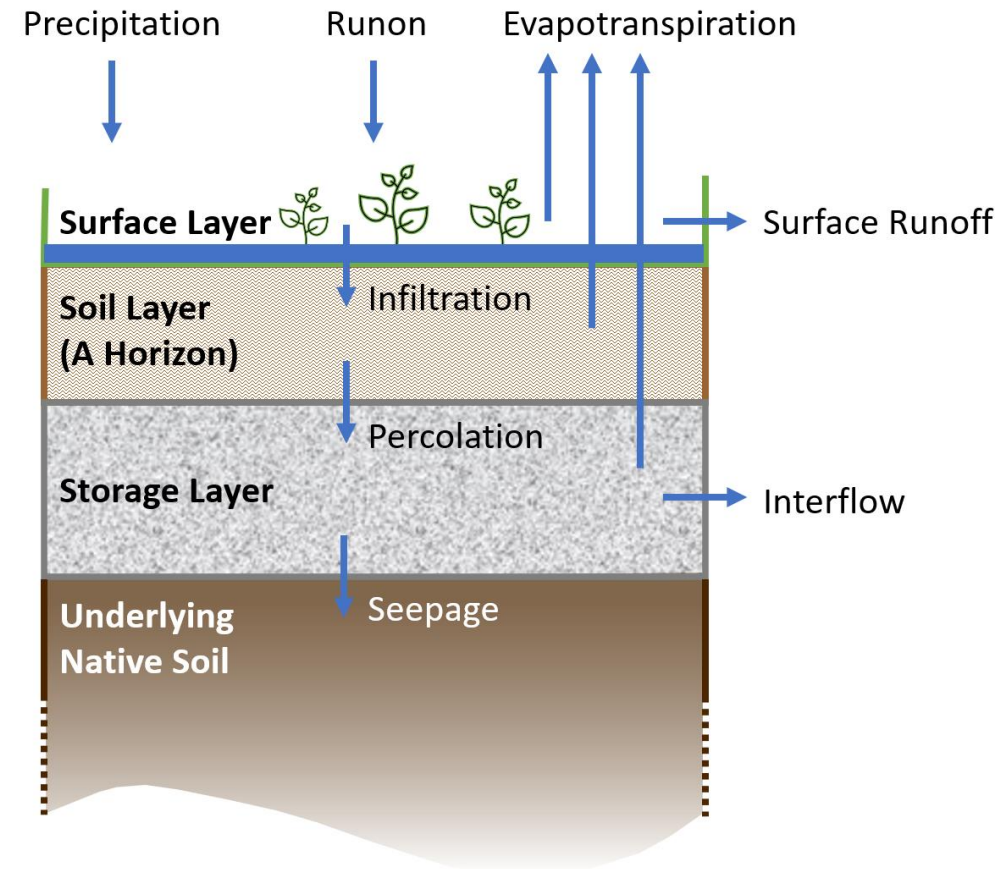
Calgary's Pre-development



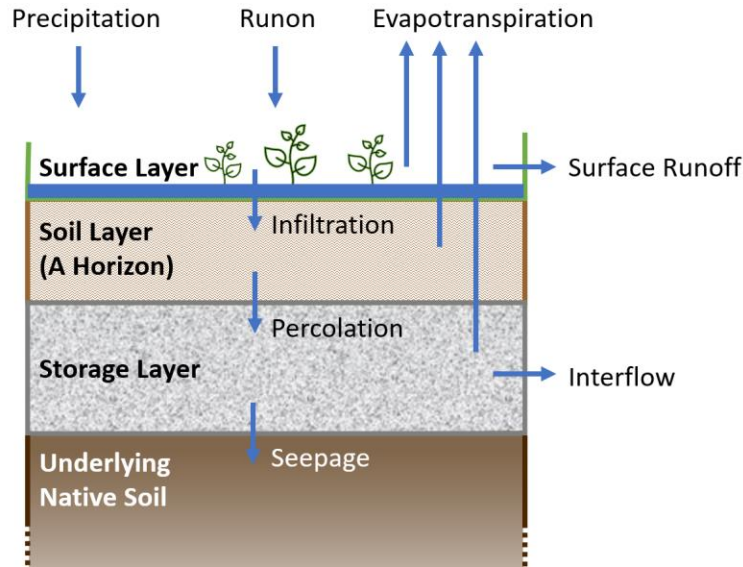
# Two-Layer Infiltration Modelling



- ❖ The soil water balance can be better represented using two-layer infiltration methods.
- ❖ One way → EPA SWMM Bioretention Cell LID control. Sounds a bit "odd", but necessary to allow the following :
  - Better control of vertical water fluxes.
  - Define thickness for infiltration control; a single-layer overlooks this option.
  - Allow ET from the soil layer.
  - Physically meaningful and defensible parameters.
- ❖ Alternative Approach → Groundwater Routine:
  - Requires additional calibration parameters.
  - Provides less transparent control over soil moisture fluxes
  - May experience numerical instability under certain configurations.



# Bioretention Cell LID Control Parameters for Two-Layer Infiltration Modelling



❖ The storage layer is not a physical layer but represents the interflow component of urban hydrology.

- 1
- 2
- 3
- 4
- 12
- 13
- 14
- 15

### LID Control Editor

Surface | Soil | Storage | Underdrain | Pollutant Removals

Bem height (mm)	5
Vegetation volume (fraction)	0.0
Surface roughness (Manning's n)	0.35
Surface slope (percent)	5.655

### LID Control Editor

Surface | Soil | Storage | Underdrain | Pollutant Removals

Thickness (mm)	200
Void ratio (voids/solids)	0.7
Seepage rate (mm/hr)	0.01
Clogging factor	0

- 5
- 6
- 7
- 8
- 9
- 10
- 11

### LID Control Editor

Surface | Soil | Storage | Underdrain | Pollutant Removals

Thickness (mm)	150
Porosity (volume fraction)	0.482
Field capacity (volume fraction)	0.321
Wilting point (volume fraction)	0.137
Conductivity (mm/hr)	12.2
Conductivity slope	27
Suction head (mm)	105

- 16
- 17
- 18

### LID Control Editor

Surface | Soil | Storage | Underdrain | Pollutant Removals

Drain coefficient (mm/hr)	0.005
Drain exponent	0.5
Drain offset height (mm)	0
Open level (mm)	0
Closed level (mm)	0
Control curve	<input type="text"/>

Note: Use a drain coefficient of 0 if the LID unit has no underdrain.

# LID Controls & Methods



❖ Because there is now no “pervious” area as known by SWMM Subcatchment, the following should be noted:

- The impervious area of each subcatchment needs to be 100% to ensure that all infiltration processes are handled solely by the LID layers.
- Pervious area parameters (Dstore Perv, N Perv) and Percent Routed to Pervious areas will not be used
- Alternative parameters to pervious area parameters (N Perv & Dstore Perv) exist in the LID control editor in the surface layer tab (Berm Height, Surface Roughness).
- Routing from impervious to pervious areas now must be done completely within the LID usage editor (% of impervious area treated)

Subcatchment: S40	
Name	S40
X-Coordinate	-10062.226
Y-Coordinate	5671749.262
Description	WNC
Tag	Res_15to70
Rain Gage	RCell246
Outlet	400068411
Area (ha)	8.1489
Width (m)	260.617
Flow Length (m)	<i>f</i> 312.677
Slope (%)	9.535
Imperv. (%)	100
N Imperv	0.015
N Perv	0.25 X
Dstore Imperv (mm)	2.9
Dstore Perv (mm)	13.6 X
Zero Imperv (%)	25
Subarea Routing	PERVIOUS
Percent Routed (%)	25 X

LID Control Editor

Surface | Soil | Storage | Underdrain | Pollutant Removals

Berm height (mm) 5

Vegetation volume (fraction) 0.0

Surface roughness (Manning's n) 0.35

Surface slope (percent) 5.655

LID Usage Editor: S40

LID usages: Two\_Layer

LID control name: Two\_Layer

LID occupies full subcatchment

Area of each unit (m<sup>2</sup>) 38496

Number of replicate units 1

% of subcatchment occupied 47.2

Surface width per unit (m) 260.617

% initially saturated 55

% of impervious area treated 25

% of pervious area treated 0

Send drain flow to:  
(Leave blank to use outlet of current subcatchment)

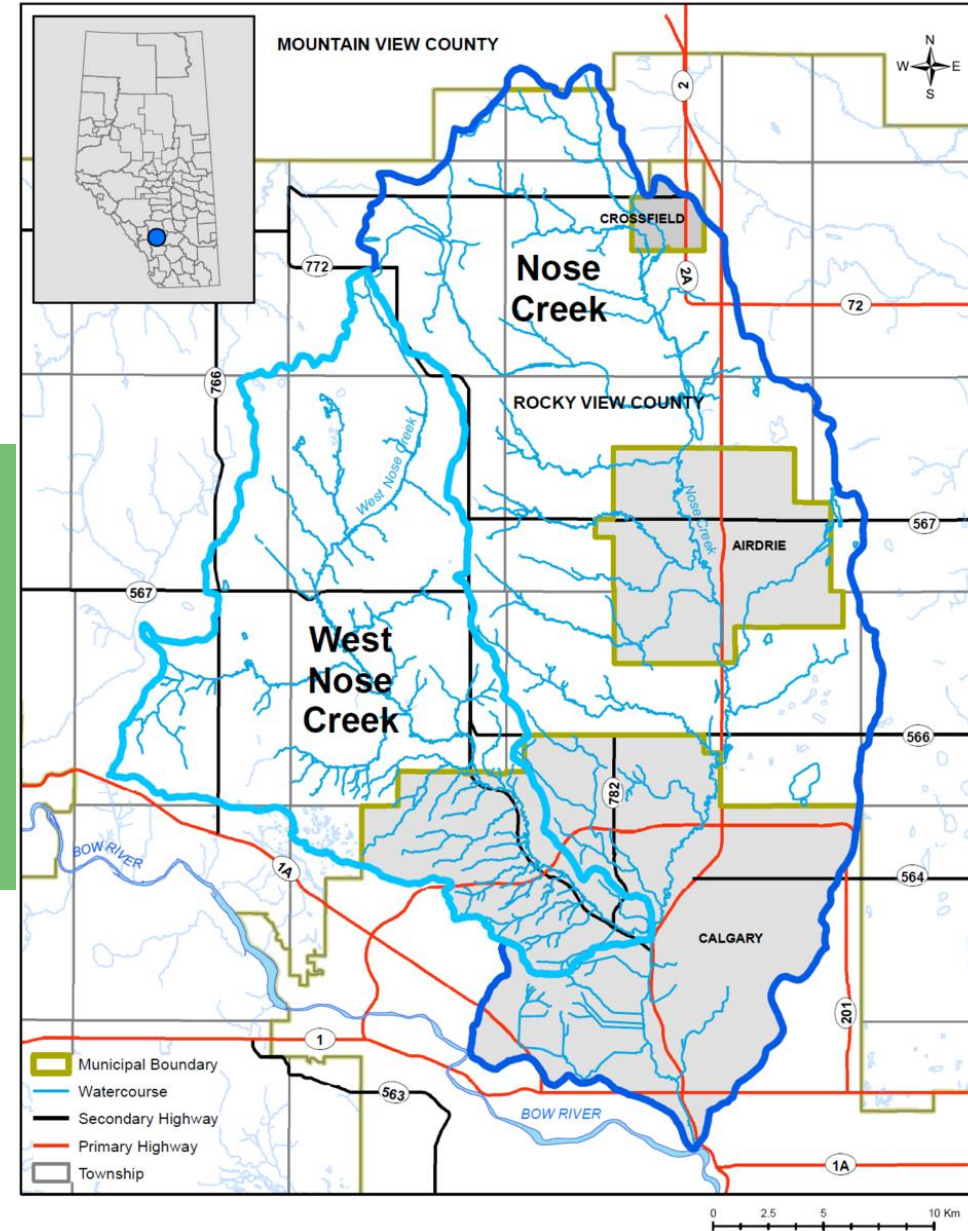
Return all outflow to pervious area

Detailed report file (optional)

Add Del OK Cancel

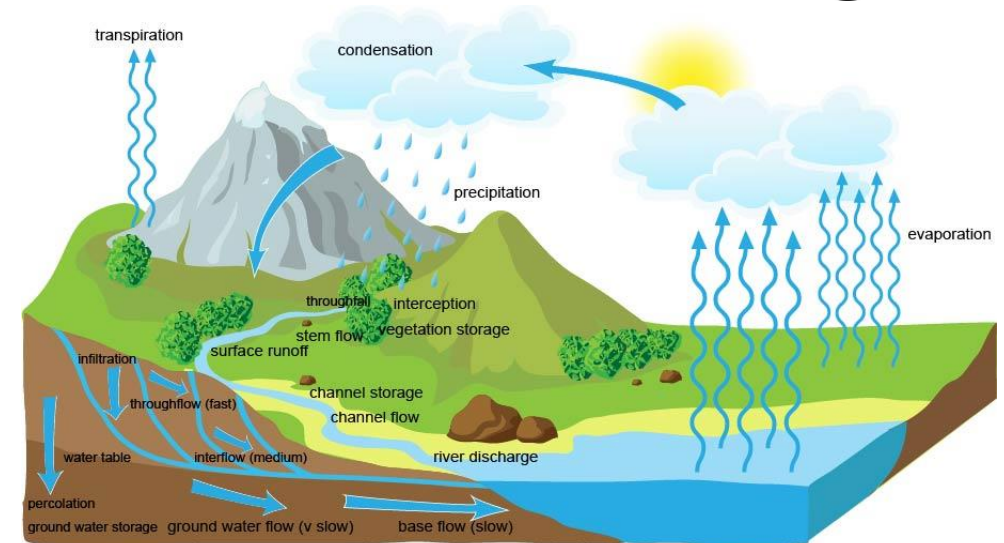
# Case Study

## Nose Creek Watershed Hydrological PCSWMM Model

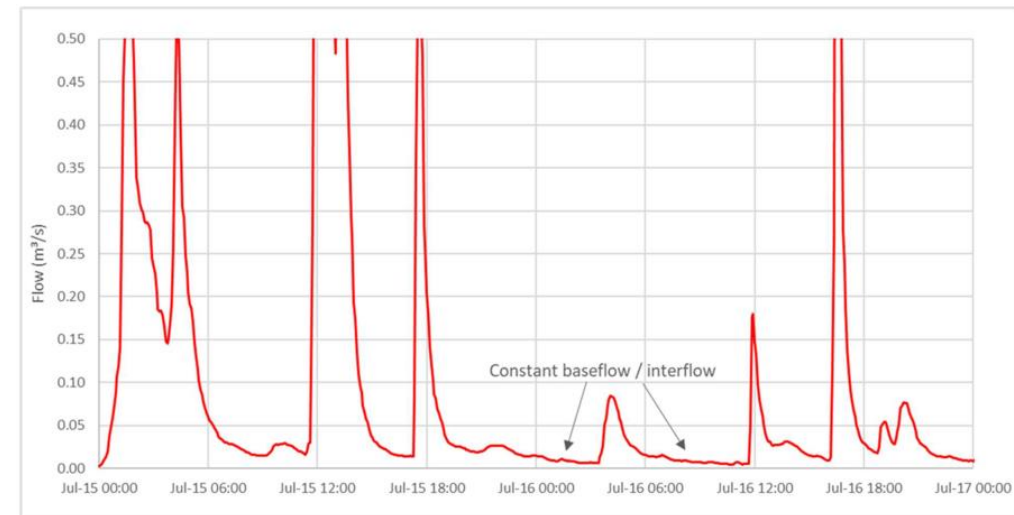


# Objectives of the Two-Layer Infiltration Modelling

- ❖ To make the soil water balance representative of Nose Creek's condition.
  - Semi-arid climate and tight glacial tills
  - Calgary's pre-development mass balance is as follows:
    - ET = 92%
    - Seepage = 2%
    - Runoff = 6%
- ❖ To account for the Interflow or the lateral movement of infiltrated water within the unsaturated soil zone
  - In urban areas, interflow can make its way into weeping tiles and utility trenches and eventually enter the stormwater system, resulting in a slow, continuous flow response, which has been observed in monitoring data collected in Calgary.

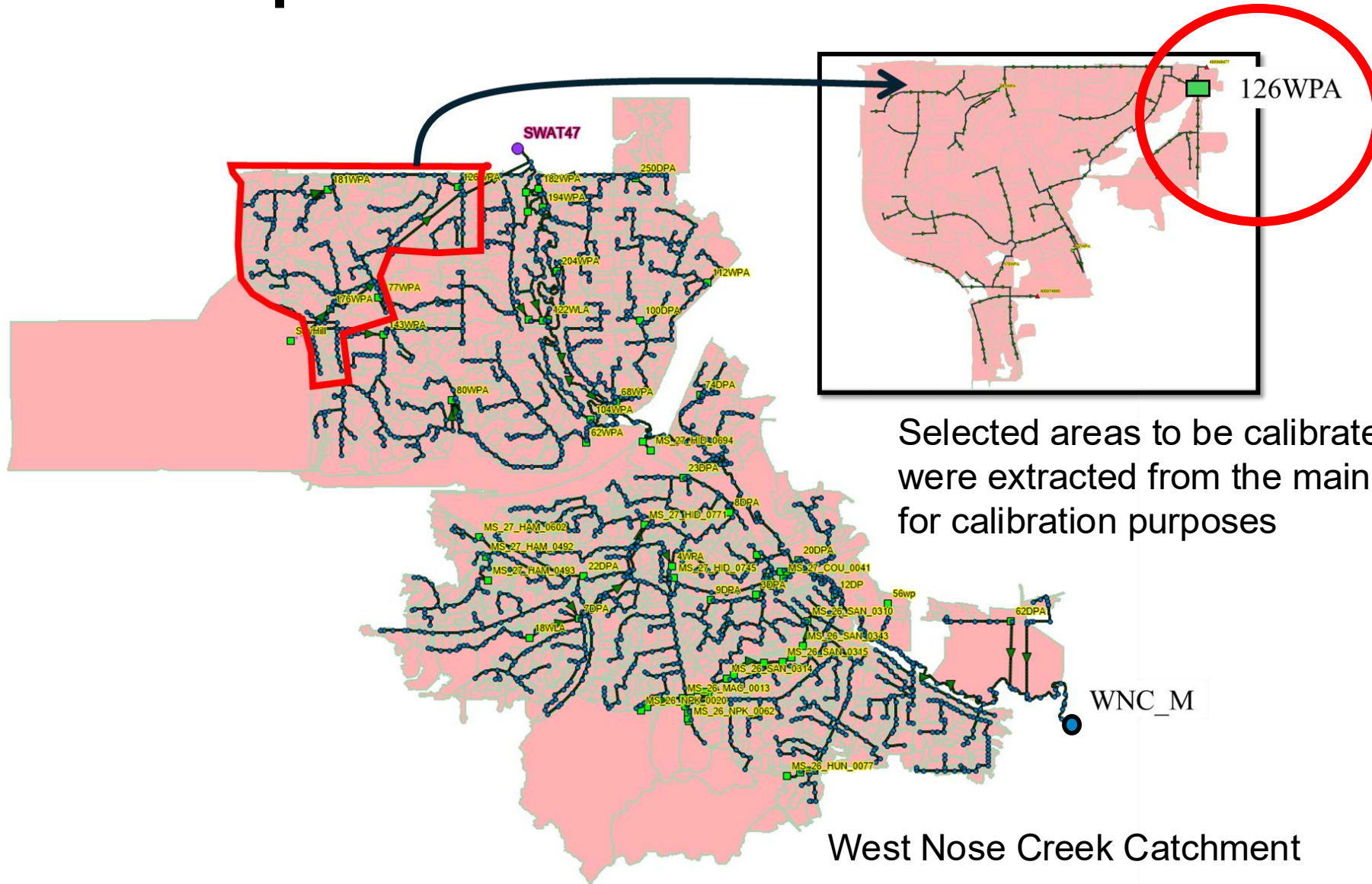


<https://www.alevelgeography.com/drainage-basin-hydrological-system/>





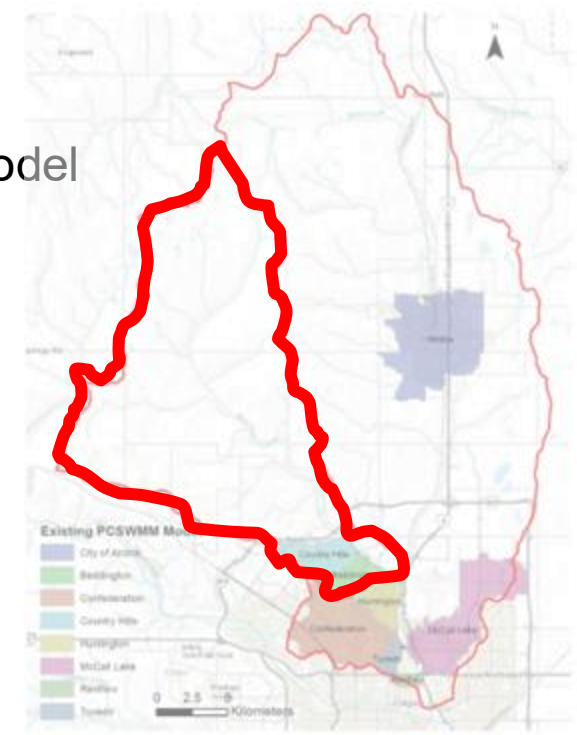
# Example of a Model Domain for Calibration



The model was calibrated and validated against observed pond water depths  
May-October 2020 for Calibration  
May-October 2019 for validation

Selected areas to be calibrated were extracted from the main model for calibration purposes

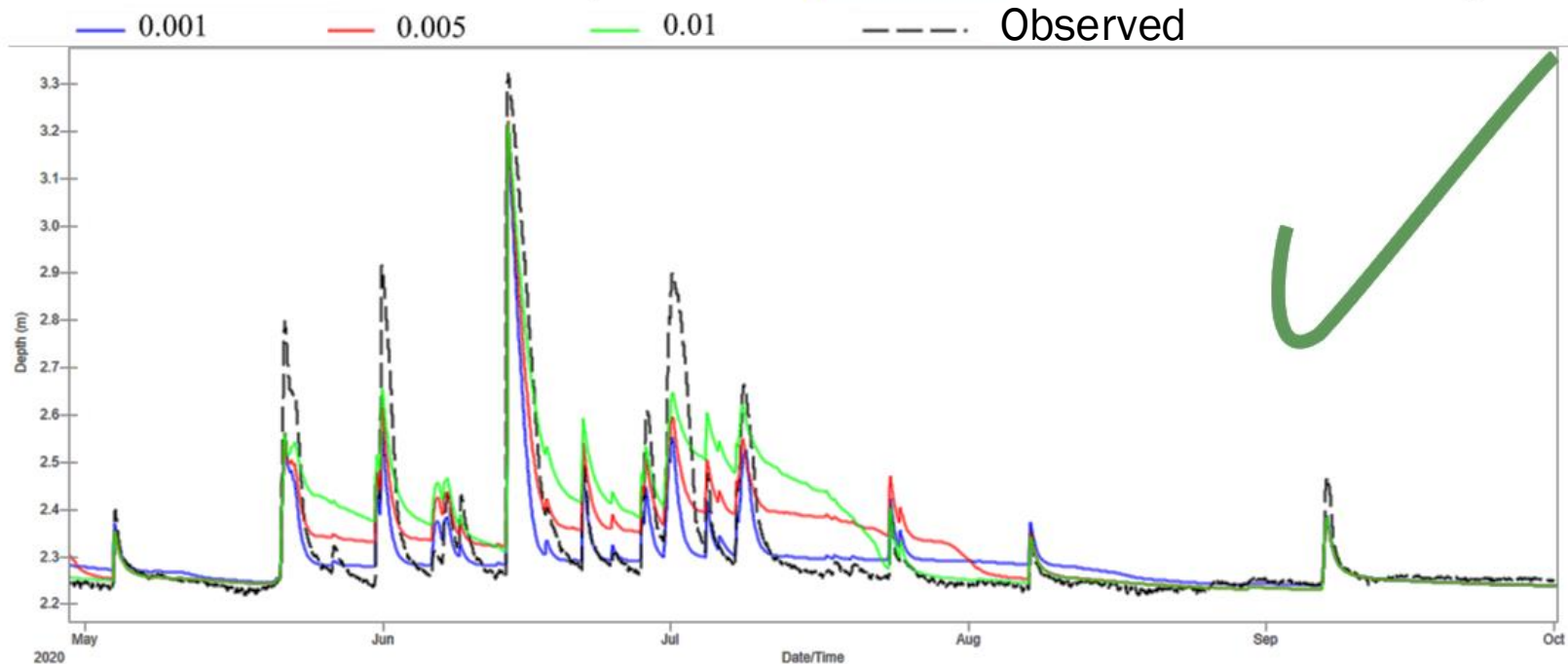
West Nose Creek Catchment



# Parameters Sensitivity Analysis

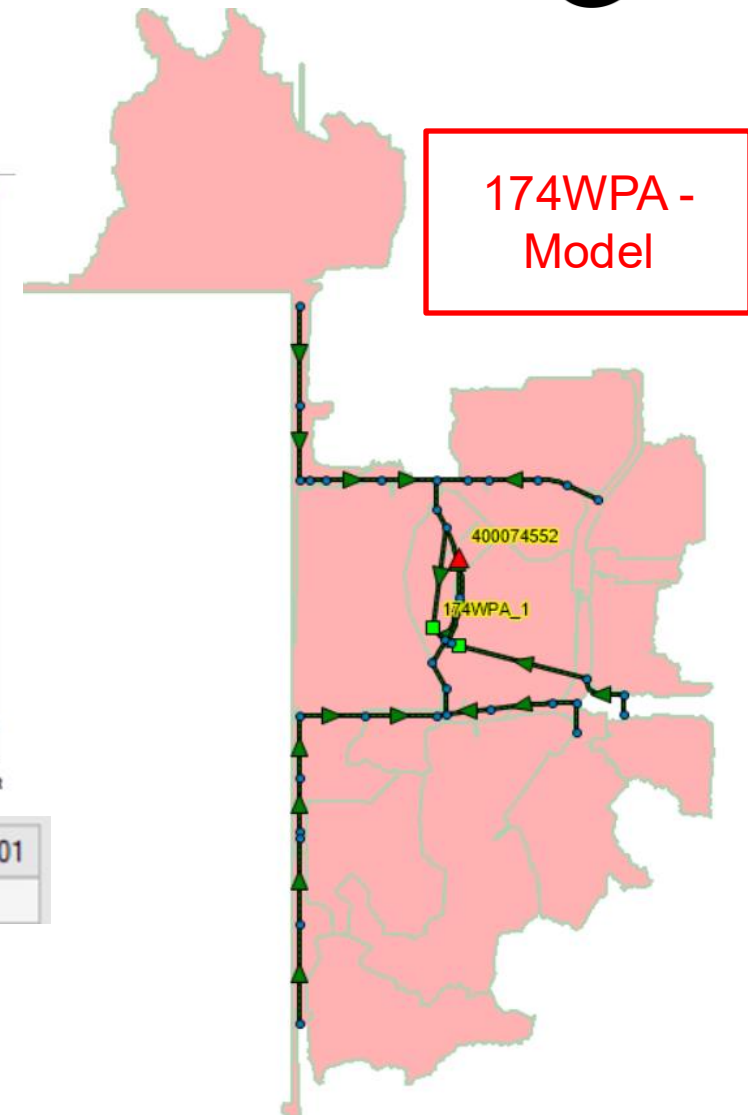


Drain Coefficient (0.001, **0.005**, 0.010 mm/hr)



	174WPA_1 DrainCoeff0.001	174WPA_1 DrainCoeff0.005	174WPA_1 DrainCoeff0.01
Nash-Sutcliffe efficiency (NSE; R <sup>2</sup> )	0.701	0.754	0.68

← Sensitive if relative change in NSE is ≥ 10% →



# Parameters Sensitivity Analysis (cont.)



The most sensitive parameters are:

LID Control Editor

Surface Soil Storage Underdrain Pollutant Removals

1 **Bem height (mm)**

Vegetation volume (fraction)

Surface roughness (Manning's n)

Surface slope (percent)

LID Control Editor

Surface Soil Storage Underdrain Pollutant Removals

2 **Thickness (mm)**

3 **Porosity (volume fraction)**

4 **Wilting point (volume fraction)**

5 **Conductivity (mm/hr)**

Conductivity slope

6 **Suction head (mm)**

LID Control Editor

Surface Soil Storage Underdrain Pollutant Removals

7 **Drain coefficient (mm/hr)**

8 **Drain exponent**

Drain offset height (mm)

Open level (mm)

Closed level (mm)

Control curve

Note: Use a drain coefficient of 0 if the LID unit has no underdrain.

# Local Calibration - 62 WPA pond

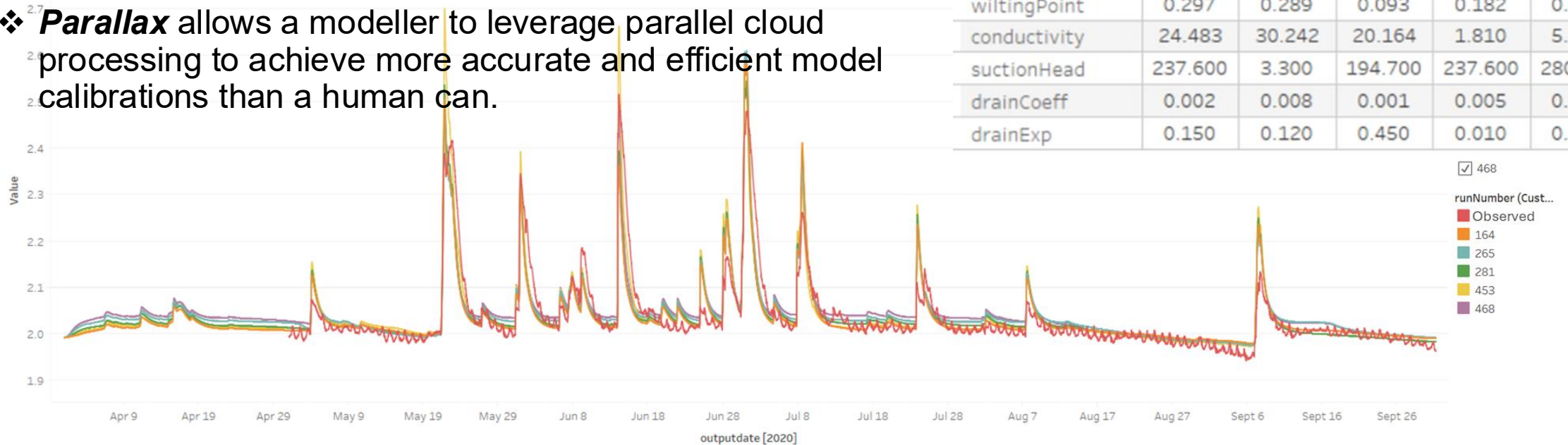


62 WPA - Best 5 Parallax Runs

Run #

Run #	164	265	281	453	468
NSE	0.792	0.808	0.801	0.820	0.828
variableName					
bermHeight	2.750	13.750	3.500	2.250	0.000
soilThickness	182.000	174.000	154.000	126.000	184.000
porosity	0.563	0.455	0.368	0.644	0.542
wiltingPoint	0.297	0.289	0.093	0.182	0.286
conductivity	24.483	30.242	20.164	1.810	5.768
suctionHead	237.600	3.300	194.700	237.600	280.500
drainCoeff	0.002	0.008	0.001	0.005	0.005
drainExp	0.150	0.120	0.450	0.010	0.280

- ❖ Calibration of 2020 water depth in the ponds
- ❖ Model calibration aims to maximize the Nash–Sutcliffe Efficiency (NSE) for simulated versus observed pond water depths.
- ❖ Calibration is done using KWL’s machine learning calibration tool for open-source models called **Parallax**.
- ❖ **Parallax** allows a modeller to leverage parallel cloud processing to achieve more accurate and efficient model calibrations than a human can.

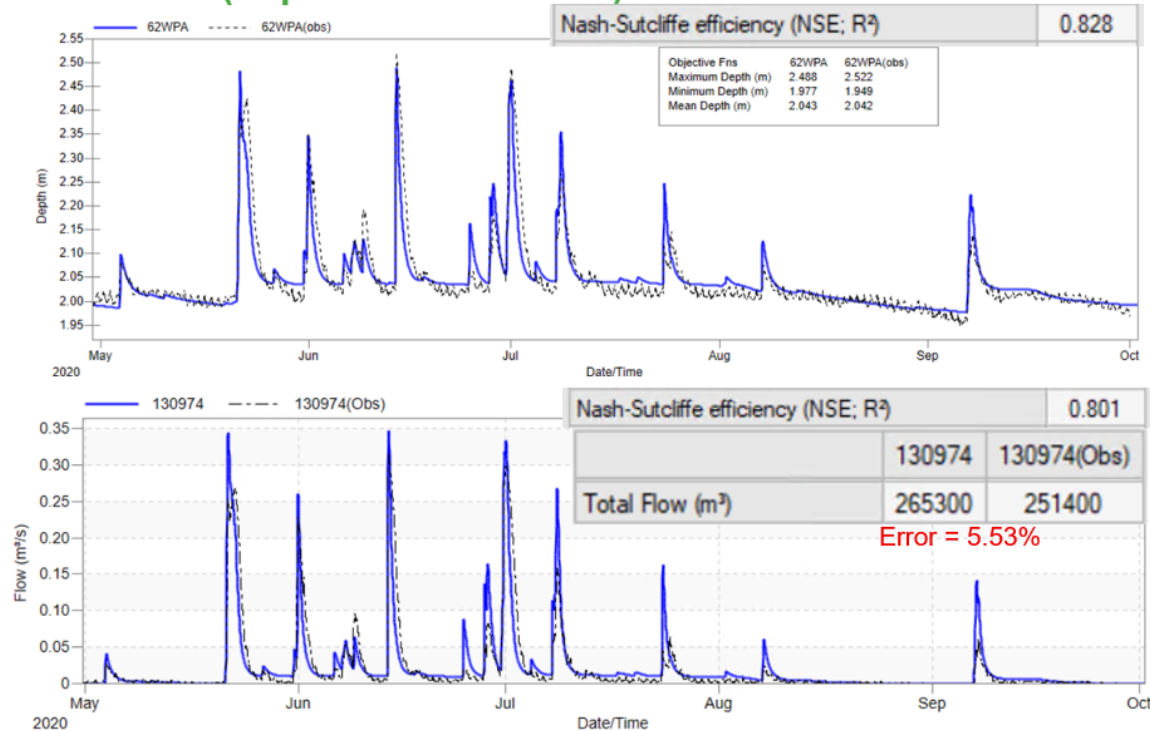


# Local Validation - 62 WPA pond

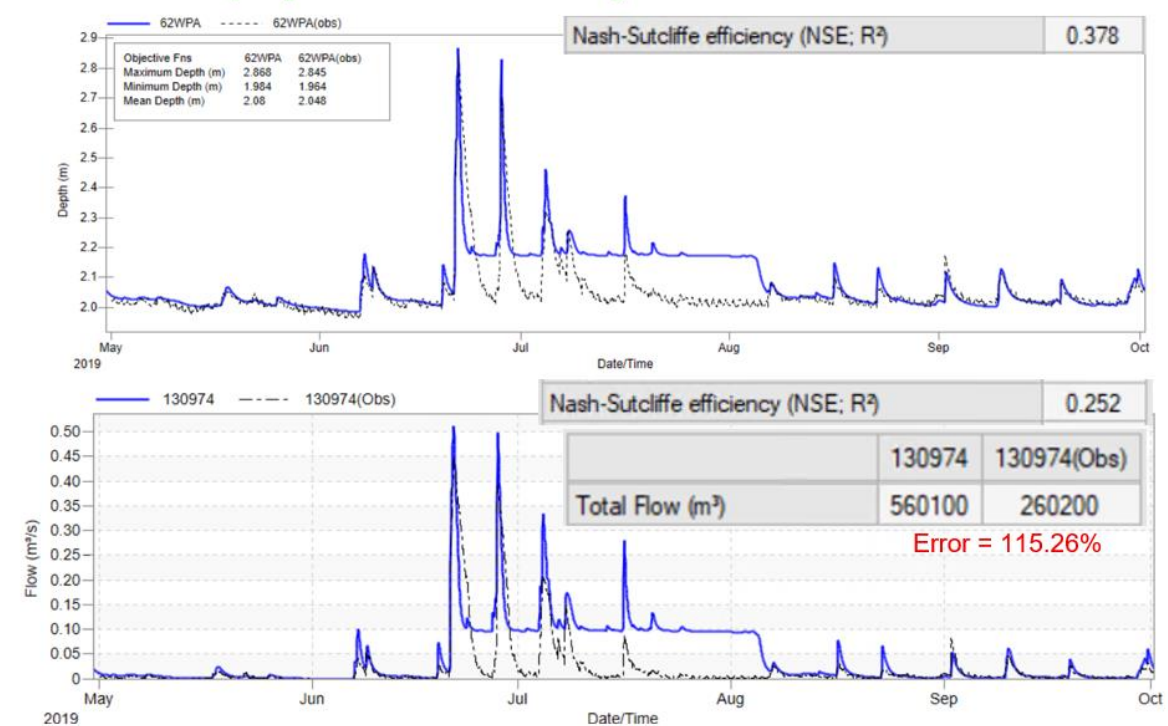
- ❖ The top five calibration parameter sets, ranked by maximum NSE in 2020, were selected for validation between May and October 2019 to evaluate reliability and parameter transferability.
- ❖ Validation performance is assessed using NSE for pond water depths and relative error in outlet flow volumes derived from rating curves.

Run #	164	265	281	453	468
	NSE 0.792	NSE 0.808	NSE 0.801	NSE 0.820	NSE 0.828
variableName					
bermHeight	2.750	13.750	3.500	2.250	0.000
soilThickness	182.000	174.000	154.000	126.000	184.000
porosity	0.563	0.455	0.368	0.644	0.542
wiltingPoint	0.297	0.289	0.093	0.182	0.286
conductivity	24.483	30.242	20.164	1.810	5.768
suctionHead	237.600	3.300	194.700	237.600	280.500
drainCoeff	0.002	0.008	0.001	0.005	0.005
drainExp	0.150	0.120	0.450	0.010	0.280

## 468. Calibration (Depth & Outflow 2020)



## 468. Validation (Depth & Outflow 2019)



# Multi-objective rescoring – Pond 62 WPA



- ❖ The top five calibrated parameter sets were re-scored for both calibration and validation using a multi-objective framework based on NSE for pond water depths and relative error in outlet flow volumes.

Run		164	265	281	453	468
<b>Calibration YR 2020</b>	Depth NSE	0.792	0.808	0.801	0.82	0.828
	Volume Relative Error %	-15.31%	-2.11%	-7.72%	3.26%	5.53%
<b>Validation YR 2019</b>	Depth NSE	0.787	0.796	0.813	0.303	0.378
	Volume Relative Error %	-12.10%	-0.73%	-5.57%	44.78%	115.26%

Multi-Objective	164	265	281	453	468
<b>Avg (Depth NSE) / Avg (Volume Abs Error)</b>	5.761	56.479	12.144	2.338	0.998

# Multi-objective rescoring – All ponds



Pond	62 WPA	126 WPA	174 WPA	176 WPA	246 WPA
Optimum RUN ID	265	995	10481	212	202
Berm Height	13.750	18.563	15.000	5.500	11.750
Soil Thickness	174.000	268.560	129.206	182.000	178.000
Porosity	0.455	0.471	0.415	0.551	0.449
Wilting Point	0.289	0.132	0.267	0.054	0.275
Conductivity	30.242	8.421	6.176	6.848	1.810
Suction Head	3.300	168.432	125.491	115.500	204.600
Drain Coefficient	0.008	0.013	0.003	0.002	0.004
Drain Exponent	0.120	0.010	0.124	0.060	0.180

# Global Set Infiltration Parameters



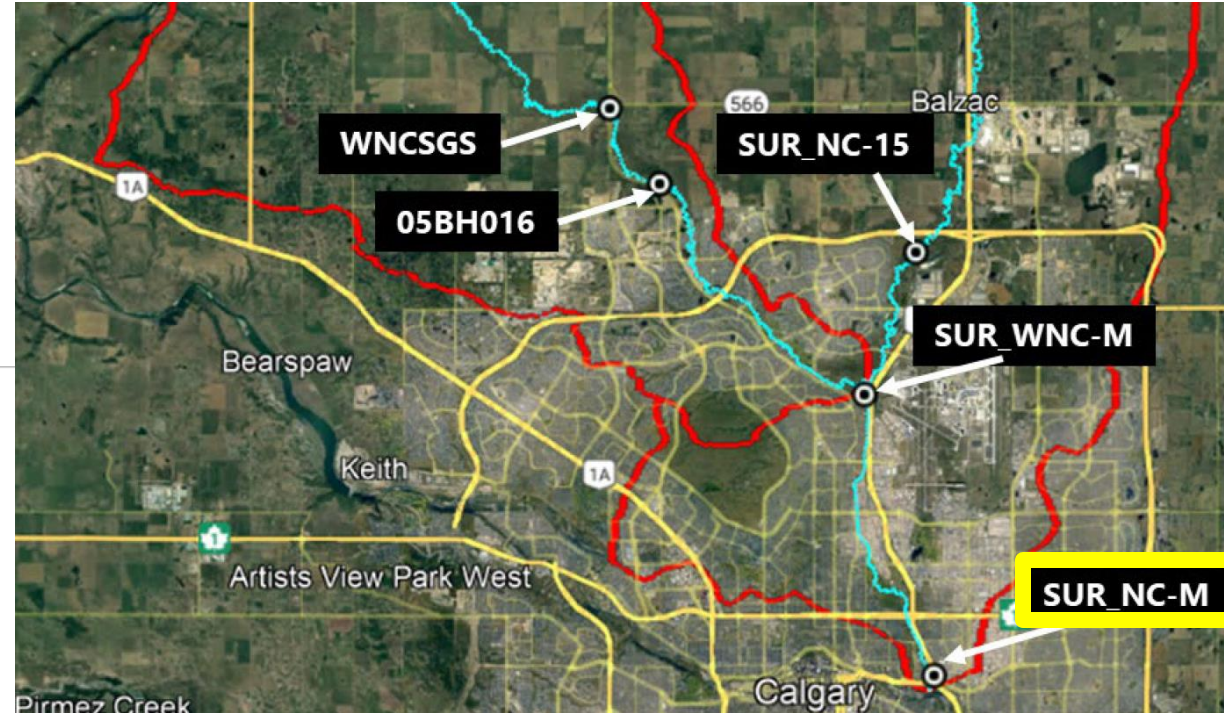
Pond	62 WPA	126 WPA	174 WPA	176 WPA	246 WPA	<b>Global Set (All ponds avg)</b>
<b>Berm Height</b>	14	19	15	6	12	13
<b>Soil Thickness</b>	174	269	129	182	178	186
<b>Porosity</b>	0.455	0.471	0.415	0.551	0.449	0.468
<b>Wilting Point</b>	0.289	0.132	0.267	0.054	0.275	0.203
<b>Conductivity</b>	30.24	8.42	6.18	6.85	1.81	10.7
<b>Suction Head</b>	3	168	126	116	205	124
<b>Drain Coefficient</b>	0.008	0.013	0.003	0.002	0.004	0.006
<b>Drain Exponent</b>	0.120	0.010	0.124	0.060	0.180	0.1

# Global Parameters Validation – Storm Drain Flows (N27)

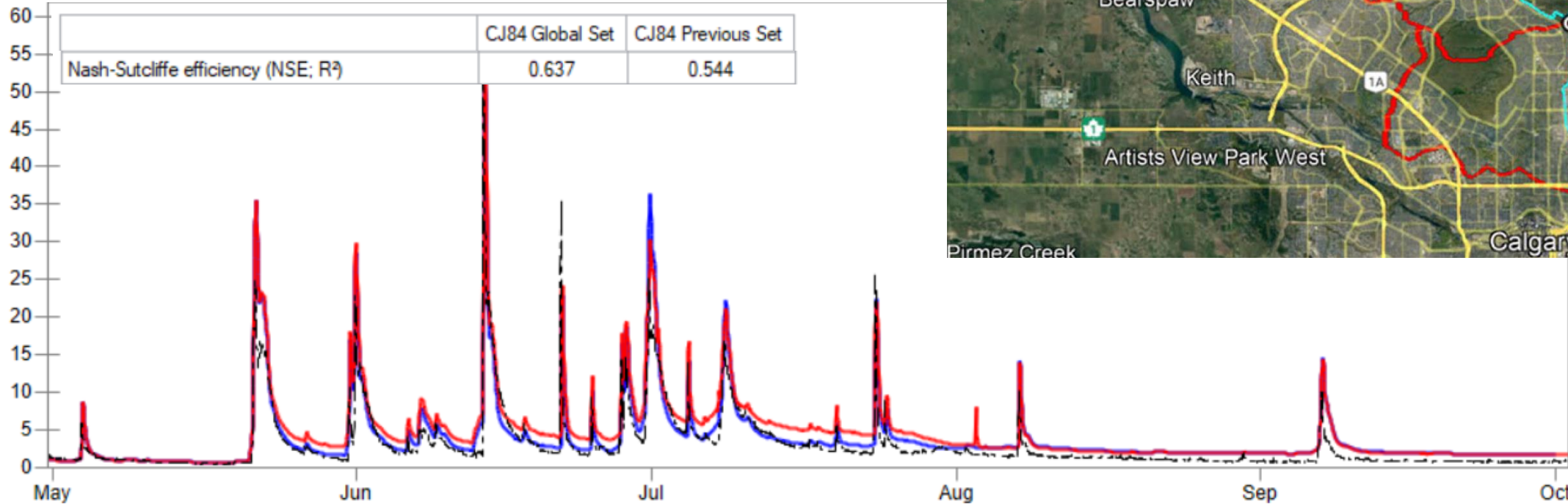


	CJ84 Global Set	CJ84 Previous Set	CJ84(obs)
Total Flow (m <sup>3</sup> )	49639600	58201200	38184500

Relative Error      30%      52%

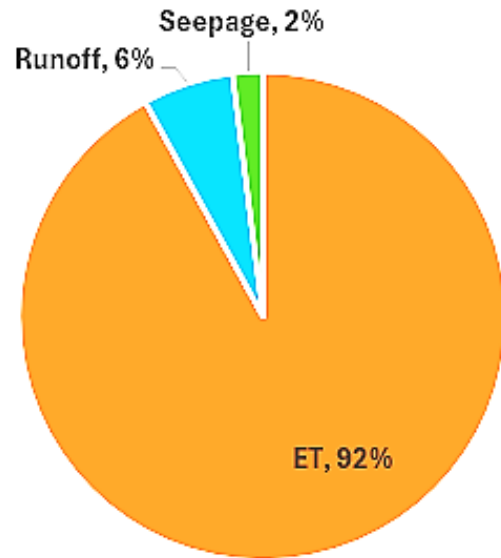


— Parallax – Global Set      — Previous set      - - - Observed Data

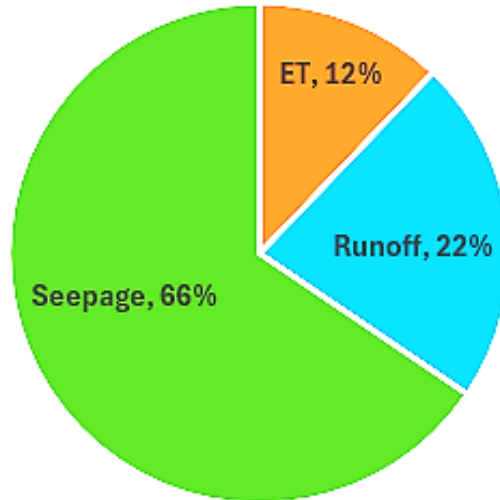


# Water Balance Results

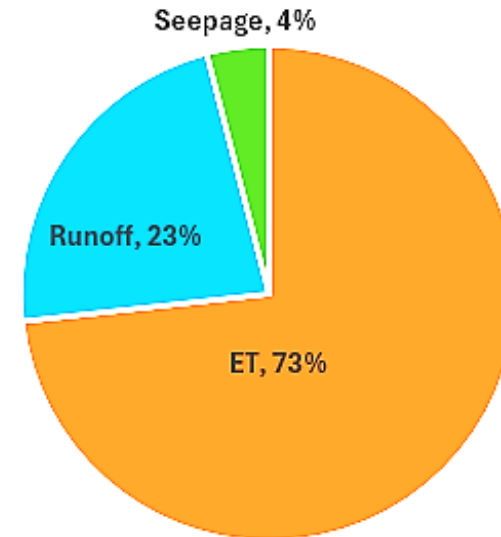
## Calgary's Pre-development



## One Layer May-October 2020



## Two Layer May-October 2020

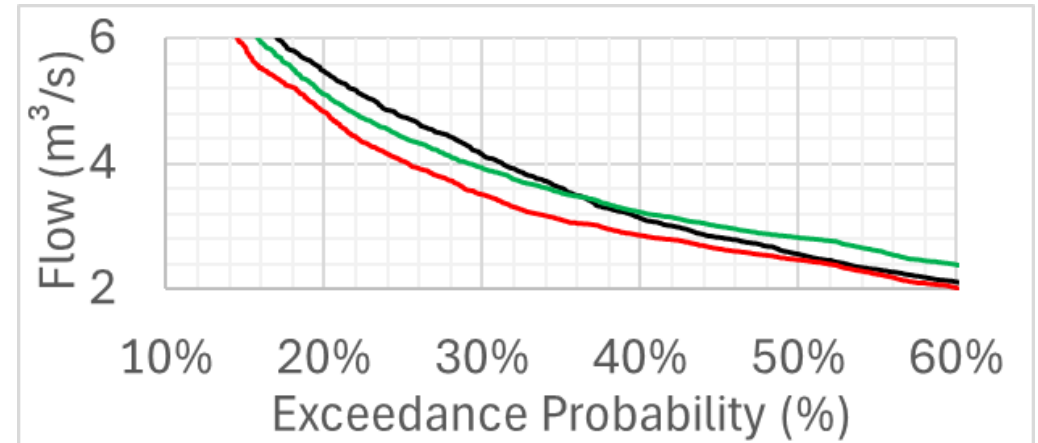
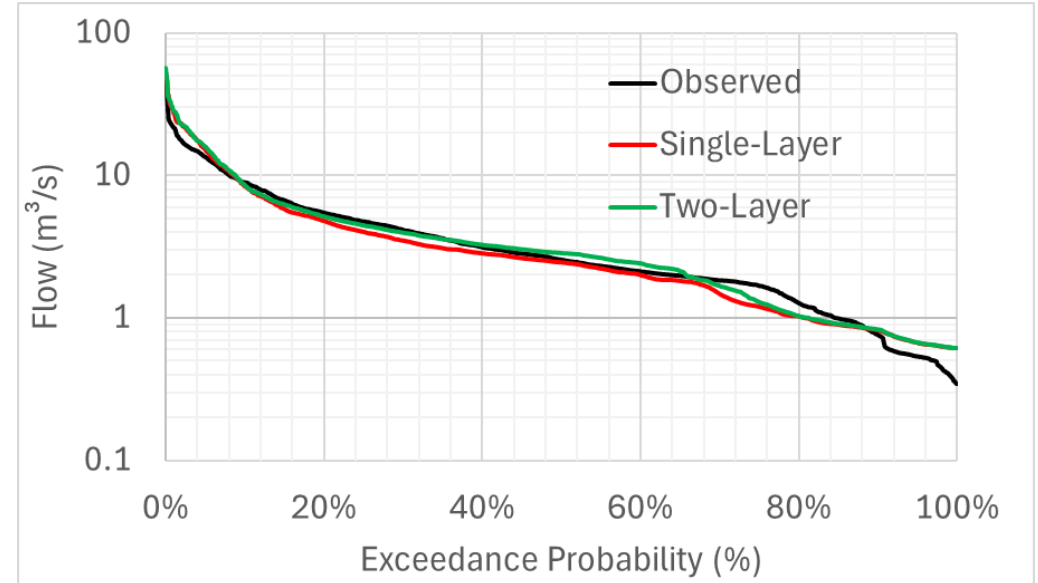


## Why internal process representation matters (even if runoff is similar):

- Models with incorrect internal fluxes may match current runoff but respond unrealistically to future scenarios (climate change, land use change, LID usage).
- A physically consistent model is more defensible, transferable, and robust for scenario analysis and design.

# Evidence from Flow Duration Curves:

- The distribution of the middle part of the flow duration curve is mainly controlled by the permeability, extent, and distribution of the subsurface materials.
- In the Single-Layer model, underestimation of mid-range flows indicates infiltrated water is drained or lost too quickly rather than being stored and slowly released.
- In the two-layer model, sustained mid-range flows indicate more realistic soil moisture storage and gradual release, improving baseflow representation.



# Conclusion



- ❖ The default EPA SWMM single-layer infiltration approach is usually acceptable when the main focus is on flood control for extreme events.
- ❖ In continuous simulation, single-layer infiltration poorly represents the overall soil water balance.
- ❖ Two-layer infiltration approach improved the water balance results for continuous simulations, compared to the single-layer approach.
- ❖ In our case study, the two-layer infiltration method decreased seepage and increased ET, yielding an overall water balance that is more representative of typical Nose Creek Watershed conditions.



# Sherif Ahmed

sahmed@kwl.ca

