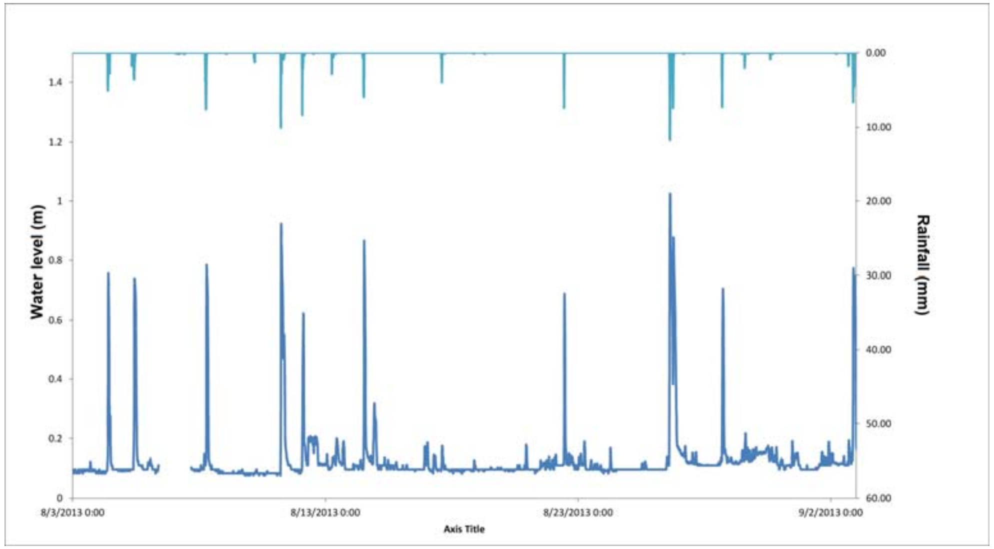
DETERMINISTIC MODELLING - Practical considerations and key takeaways

Practical Issues

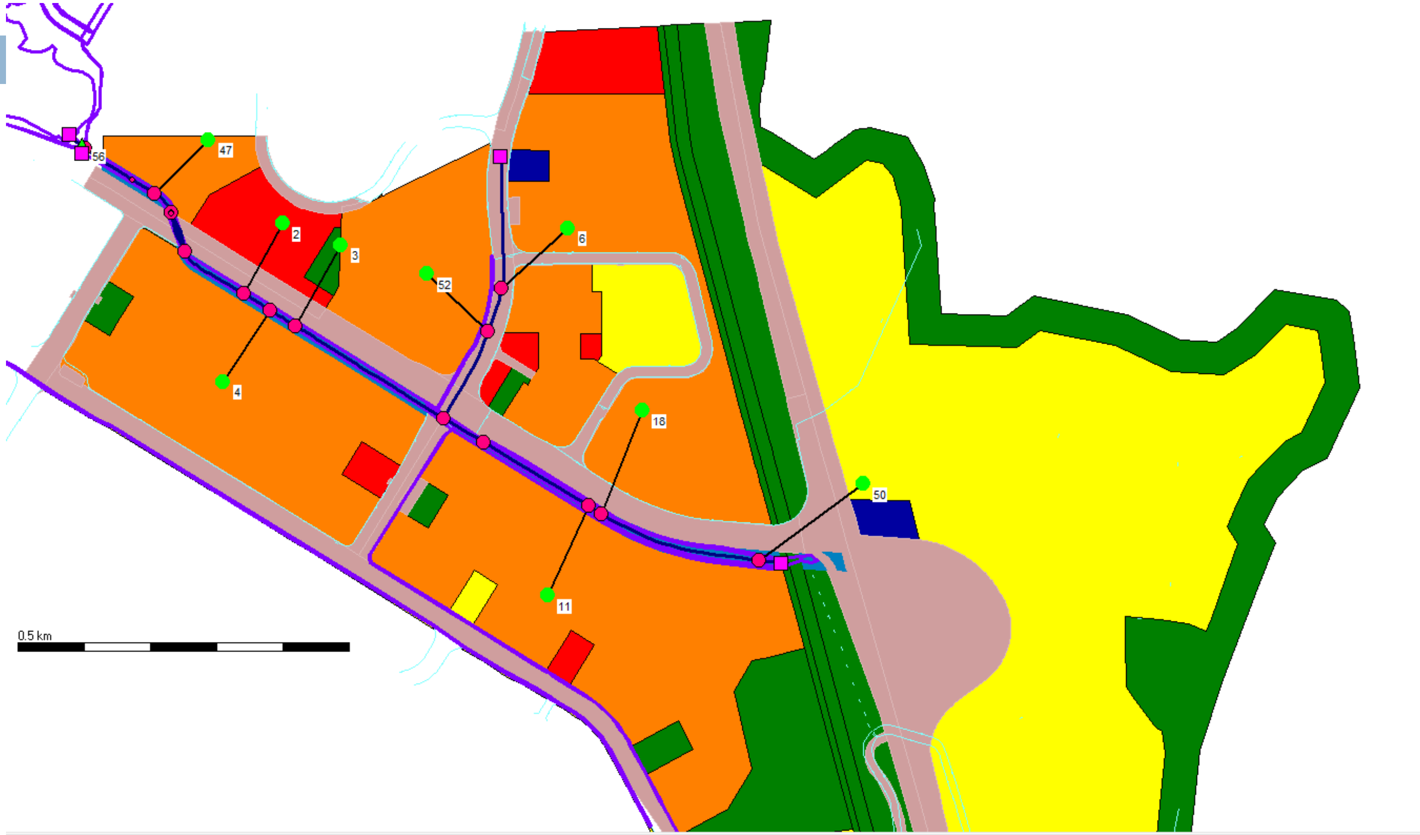
What do you do when you don't have data?

What is the issue?

- Two studies; two issues; two solutions
- Study 1- In-Stream canal
  - No rainfall gauge in the catchment
  - 4 gauges outside catchment

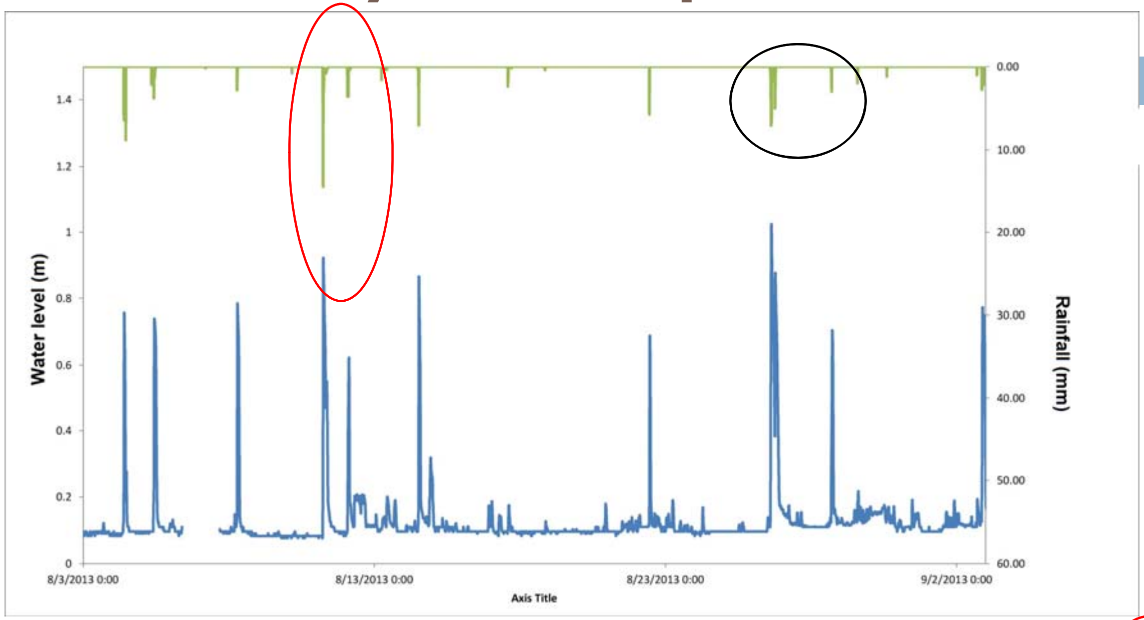


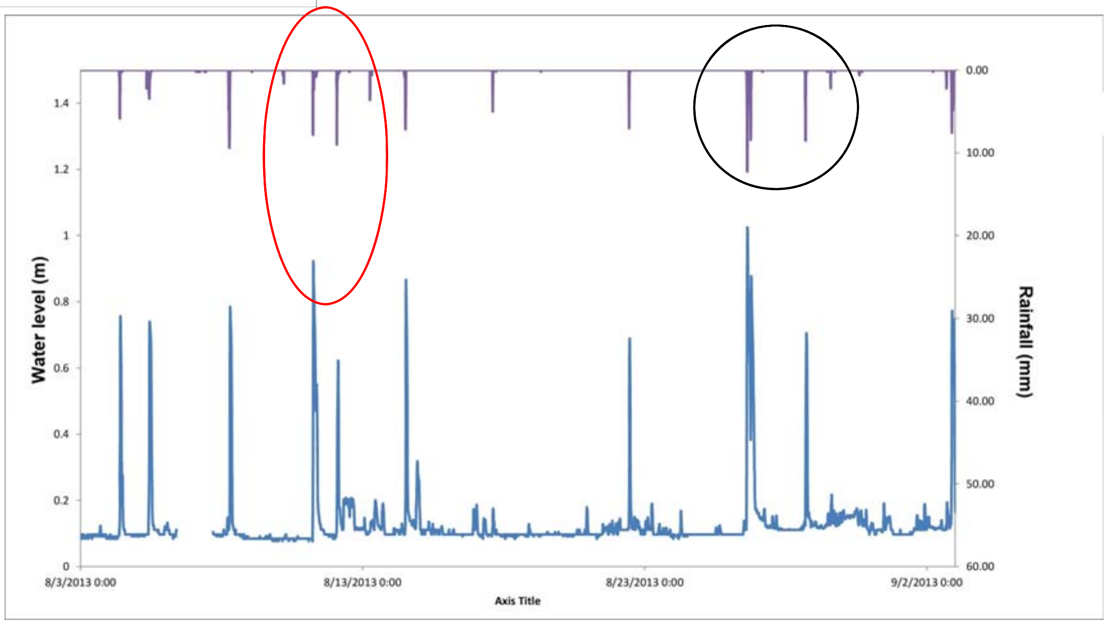
Study 1 – The Catchment



	Impervious Steep	Semi-impervious Flat	Roof	Pervious	Total
Total (m²)	112,316	272,663	317,727	777,391	1,480,097

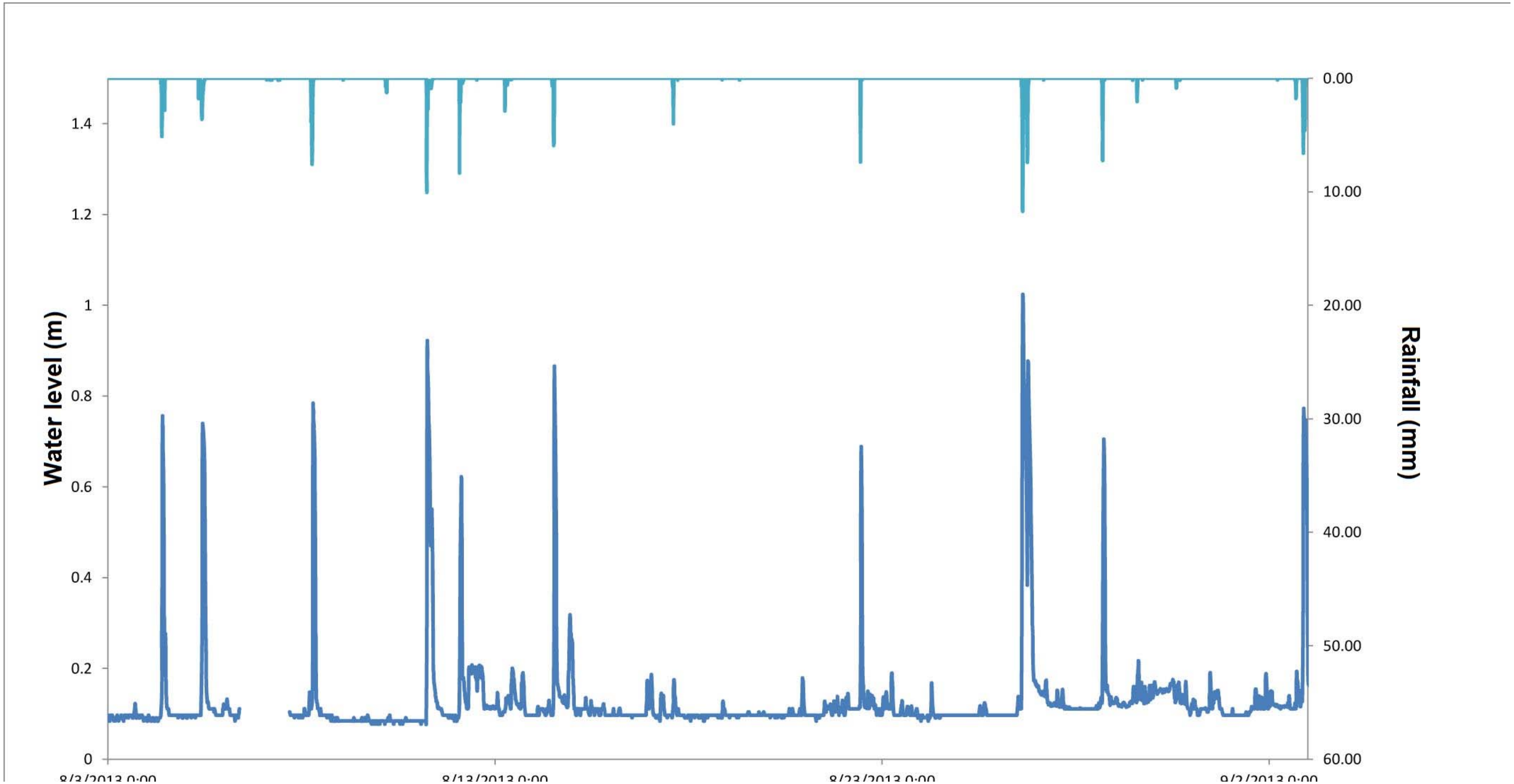
Study 1 - Spatial Variability





Study 1 - What was done?

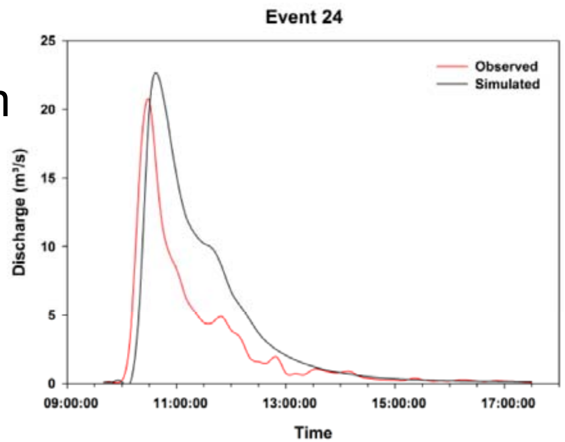
- Average it out….

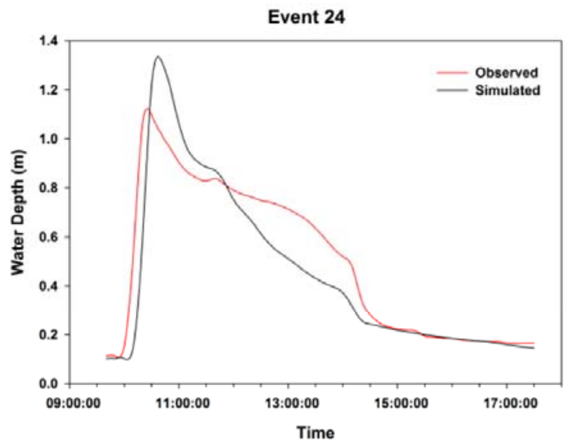


Study 1 - results in…

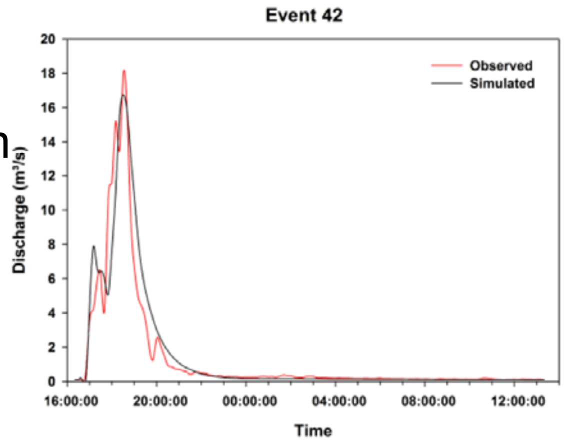
	Parameter	RMSE	MAE	R	NSE
Calibration	Discharge	1.26	0.82	0.83	0.66
	Water level	0.19	0.22	0.88	0.76
Validation	Discharge	0.87	0.48	0.85	0.72
	Water level	0.11	0.11	0.91	0.82

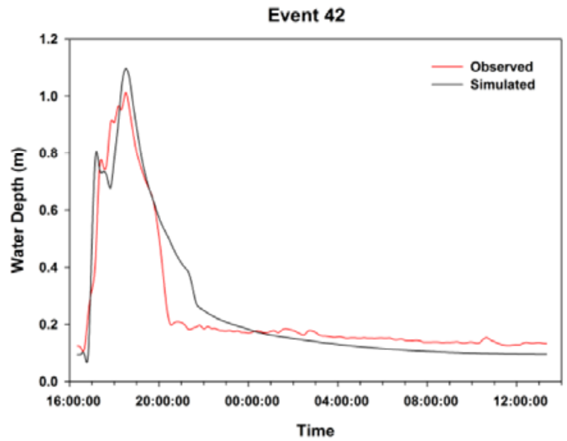
Calibration:
Rainfall: 74.1 mm





Validation
Rainfall: 74.7 mm



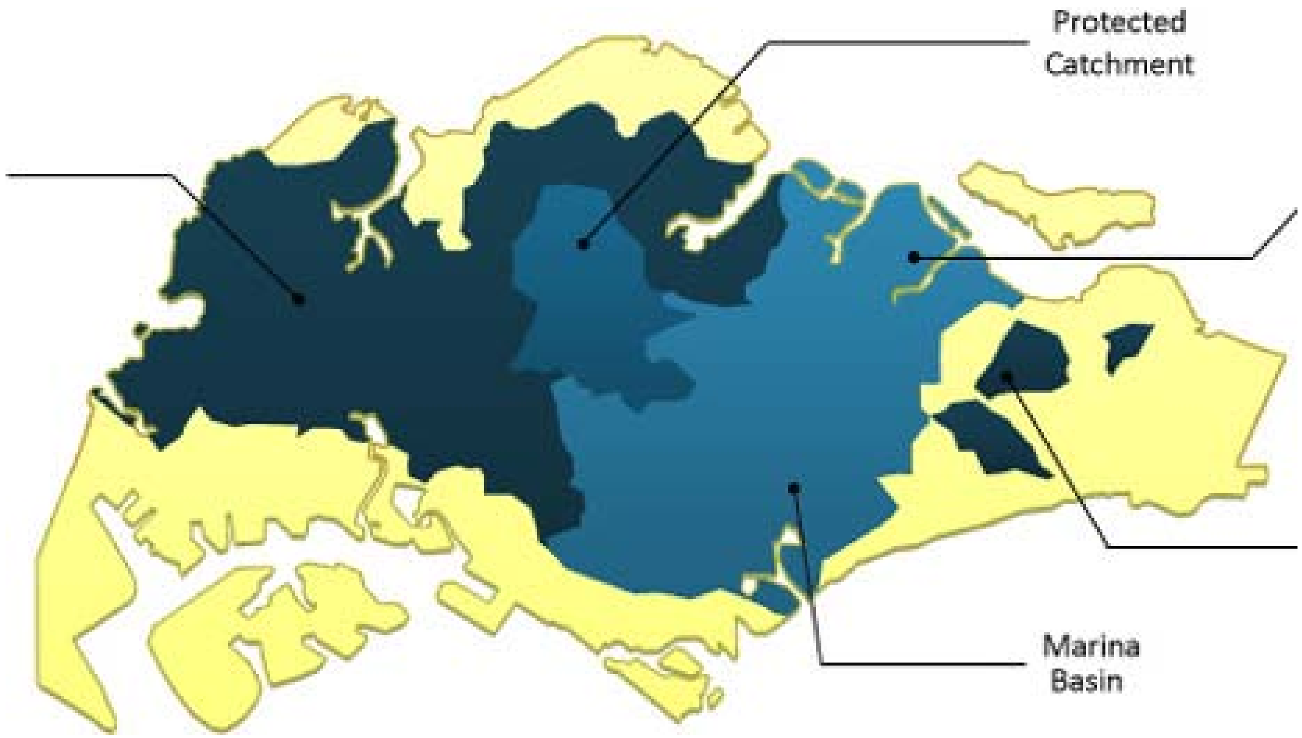


Know your Area!

Very important especially in the tropics!

Local Singapore Characteristics (1)

- Singapore is not a single watershed!



Local Singapore Characteristics (2)

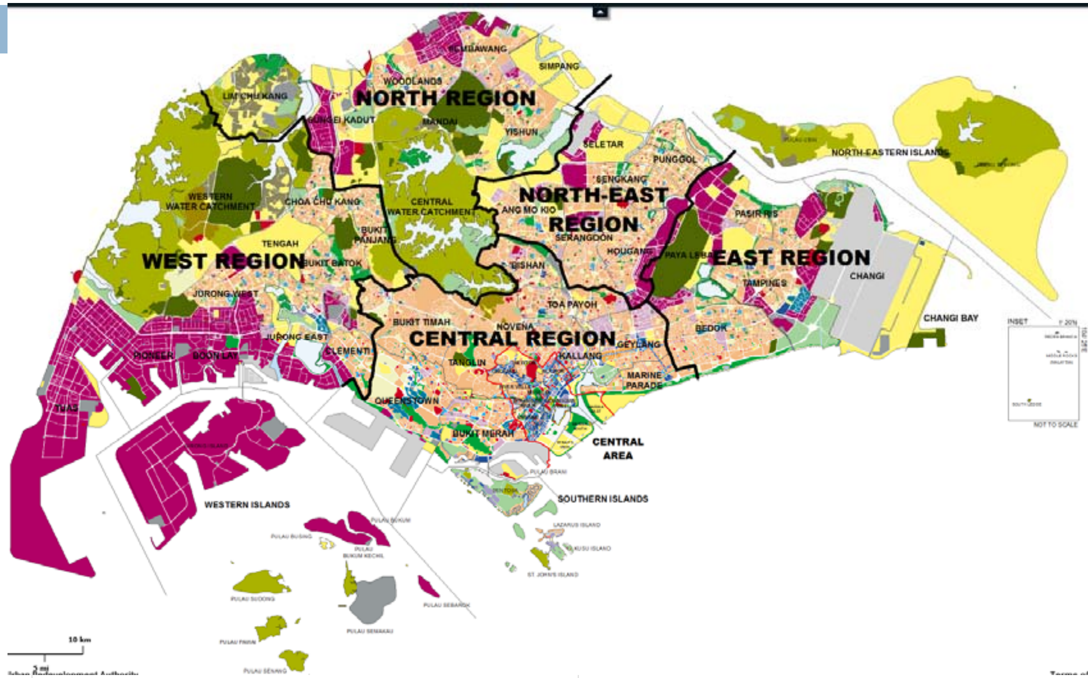
- Rainfall/runoff
  - What do you design for?

Rainfall													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period of Record
Mean Monthly Total (mm)	241.3	160.9	185.2	178.6	171.7	161.7	159.3	176.1	169.4	193.7	255.9	287.4	1869-2010 (142yrs)
Highest Monthly Total (mm)	818.6 1893	566.7 1910	528.3 1913	454.9 1900	386.6 1892	378.7 1954	527.3 1890	526.8 1878	440.4 1988	497.1 1942	521.5 1874	765.9 2006	
Lowest Monthly Total (mm)	15.4 1997	6.3 2010	18.5 1912	16.6 1977	41.6 1997	21.8 2009	18.6 1997	18 1888	23.7 1994	10.8 2002	53.5 1981	62.5 1932	
Highest 1 day Total (mm)	194.4 31 2003	159.3 04 1995	122.8 08 2004	102.4 27 2007	153.7 04 1990	121.1 05 1984	149.1 27 1941	133.9 7 2008	187.3 21 1988	91.4 08 1952	198.6 02 1995	512.4 02 1978	
Mean Raindays	15	11	14	15	15	13	13	14	14	16	19	19	1891-2010 (120yrs)
Maximum Raindays	26 1927	24 1964	23 1945	23 1970	23 1991	26 1899	20 several	23 1936	22 1986	23 several	24 several	26 several	
Minimum Raindays	3 1976	1 1983	3 1983	3 1963	6 1997	4 1981	6 several	5 1941 1961	3 1997	5 1991	11 1998	8 1920	

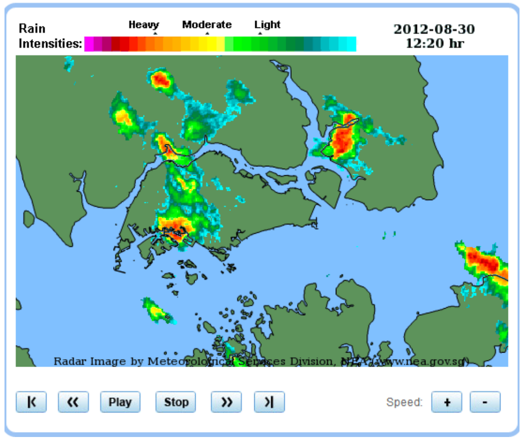
Period	Prevailing Winds	Weather Features
Northeast Monsoon Season (December – early March)	Northerly to northeasterly winds 6 – 10 km/h	◆ Monsoon Surges cause widespread continuous moderate to heavy rain, at times with 25 – 35 km/h winds in the first half of the season. ◆ Rapid development of afternoon and early evening showers. ◆ Windy and relatively dry in the later part of the season.
Inter-monsoon Period (Late March – May)	Light and variable, interacting with land and sea breezes	◆ Thunderstorms, at times severe, occur in the afternoon and early evening. ◆ Hot afternoons are common (maximum temperature above 32°C).
Southwest Monsoon Season (June – September)	Southerly to southwesterly winds 6 – 10 km/h	◆ Occasional "Sumatra Squalls" with wind gusts of 40 - 80 km/h occuring between the predawn hours and midday. ◆ Short duration showers/thunderstorms in the afternoon are common.
Inter-monsoon Period (October – November)	Light and variable, interacting with land and sea breezes	◆ Thunderstorms, at times severe, occur in the afternoon and early evening. ◆ Generally wetter than the Inter-monsoon Period earlier in the year.

Local Singapore Characteristics (3)

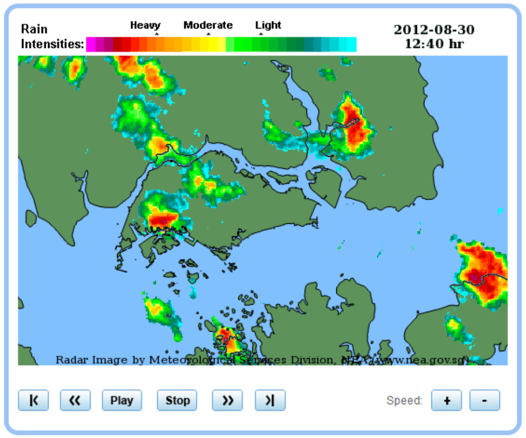
- Urban
- Green?
- Tropical



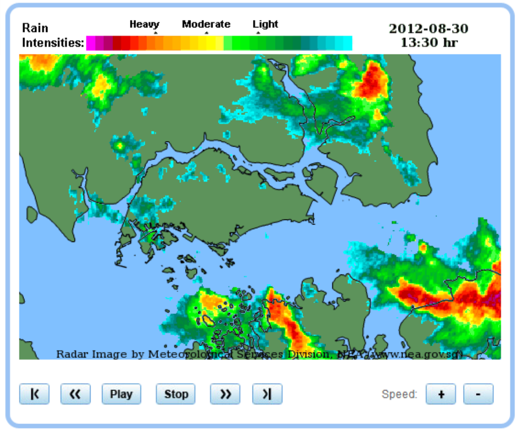
Rain Areas Animation



Rain Areas Animation



Rain Areas Animation

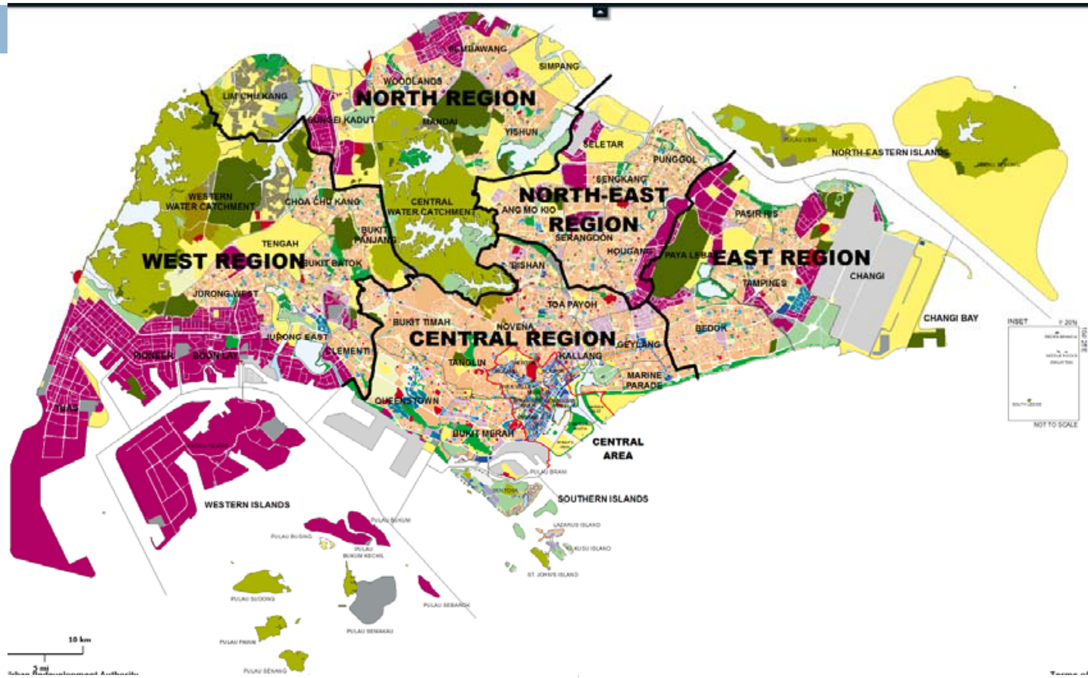


Kent Ridge Catchment

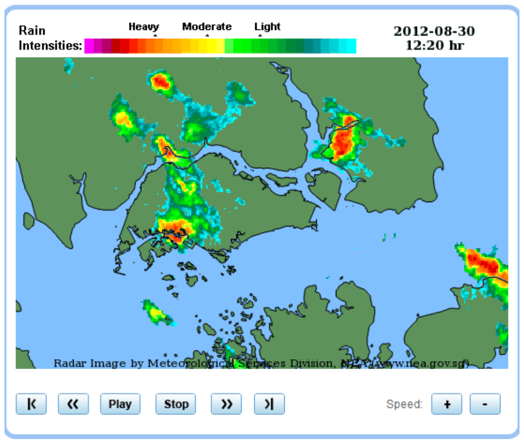
PUTTING IT ALL TOGETHER

Local Singapore Characteristics (3)

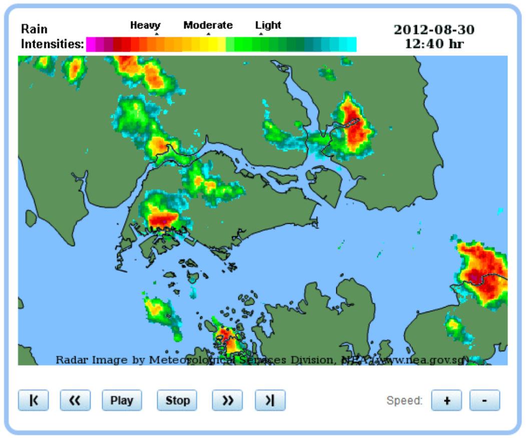
- Urban
- Green?
- Tropical



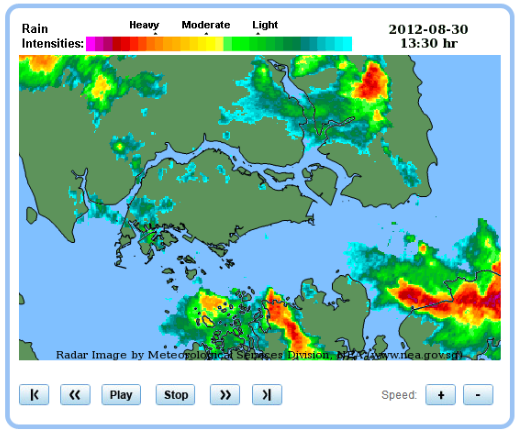
Rain Areas Animation



Rain Areas Animation



Rain Areas Animation



Project Objectives

- Improve understanding of the hydrological responses on urban areas in Singapore →

Improve rainfall-runoff simulations for the region

How?

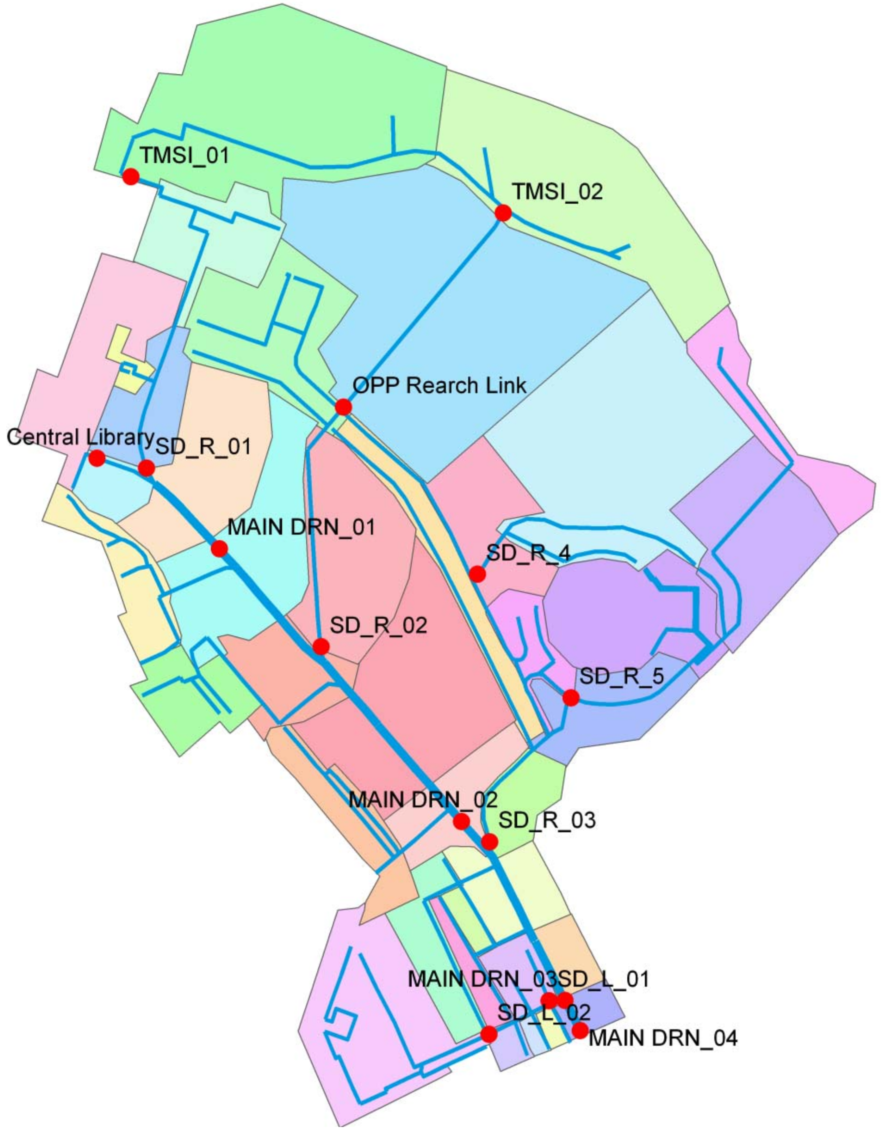
- Setup model and dense monitoring network
  - Why this catchment?
  - Why this combination?

- What did we hope to achieve?
  - Increase RF forecast lead time
  - Improve RF-RO simulation
  - Model emulation to provide alternatives
  - Integrated control

Issues in Tropical Urban RF-RO

- Besides interception, depression, infiltration, seepage → Rapid runoff!
- Other issues:
  - Hydrological processes not well understood
  - And changing trend from rapid release to storage (4 TAPS)

Moving from reality → model



Designing the monitoring network

- Computer model support

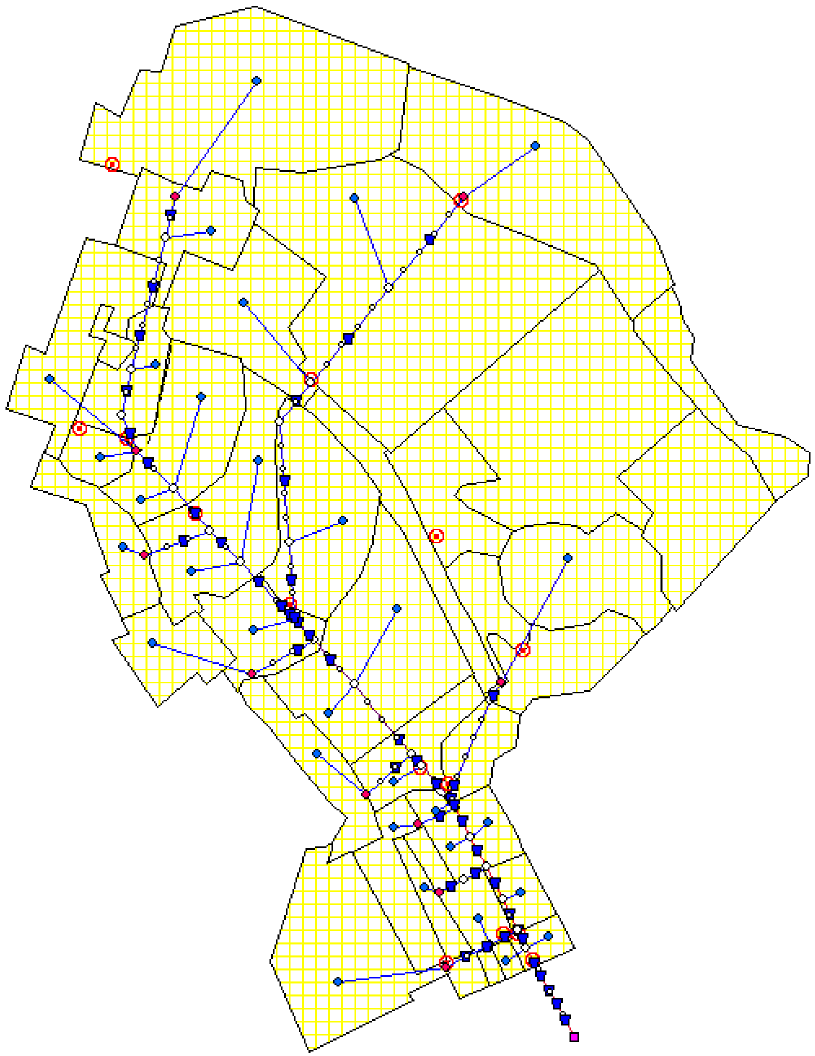
- Regional Frequency Flow Curve
  - Uses Rational Method:

  $Q\ (L/s) = C\ I\ (mm/hr)\ A\ (ha)\ /\ 0.36$

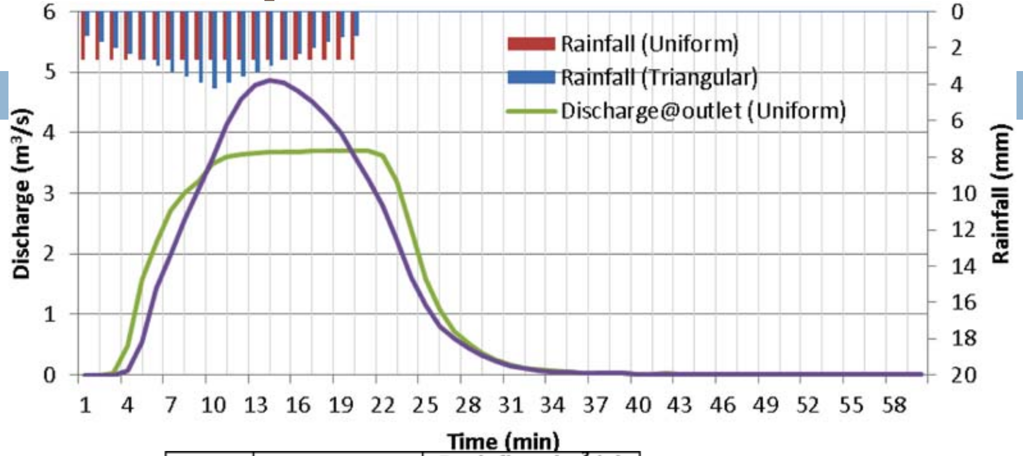
  - Used AR&R formula for $Tc = 0.76A^{0.38}$

1D RF-RO Model

- Support Monitoring Equipment Design
- Triangular and Uniform Distribution
- Horton Infiltration



Inputs and Outputs



Sl. No	Location Name	Peak flow (m^3/s) for 1 in 10 year event
1	Central Library	0.136
2	SD_R_01	0.502
3	TMSI_01	0.328
4	TMSI_02	0.291
5	OPP Research Link	0.805
6	MAIN DRN_01	0.803*
7	SD_R_02	1.106
8	SD_R_03	1.052
9	MAIN DRN_02	2.512*
10	MAIN DRN_04	3.992
11	SD_L_01	0.047**
12	MAIN DRN_03	3.942*
13	SD_L_02	0.183
14	SD_R_4	0.440**
15	SD_R_5	0.612**

Kent ridge catchment (8.5 ha)

<u>Main land cover:</u>

16% Roofs (R) (1.4 ha)

9% Parking and roads (P) (0.8 ha)

75% Steep unpaved areas (U) (6.3 ha)

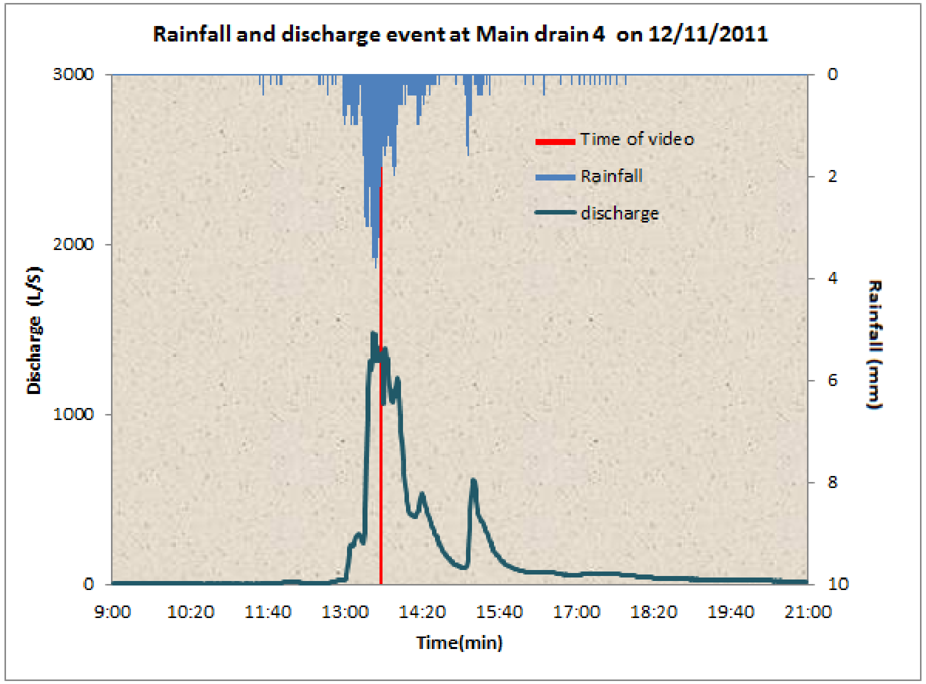
<u>Monitoring network:</u>

- 5 rainfall stations
- 14 water level stations
  (3 include flow velocity)
- Infiltration measurements

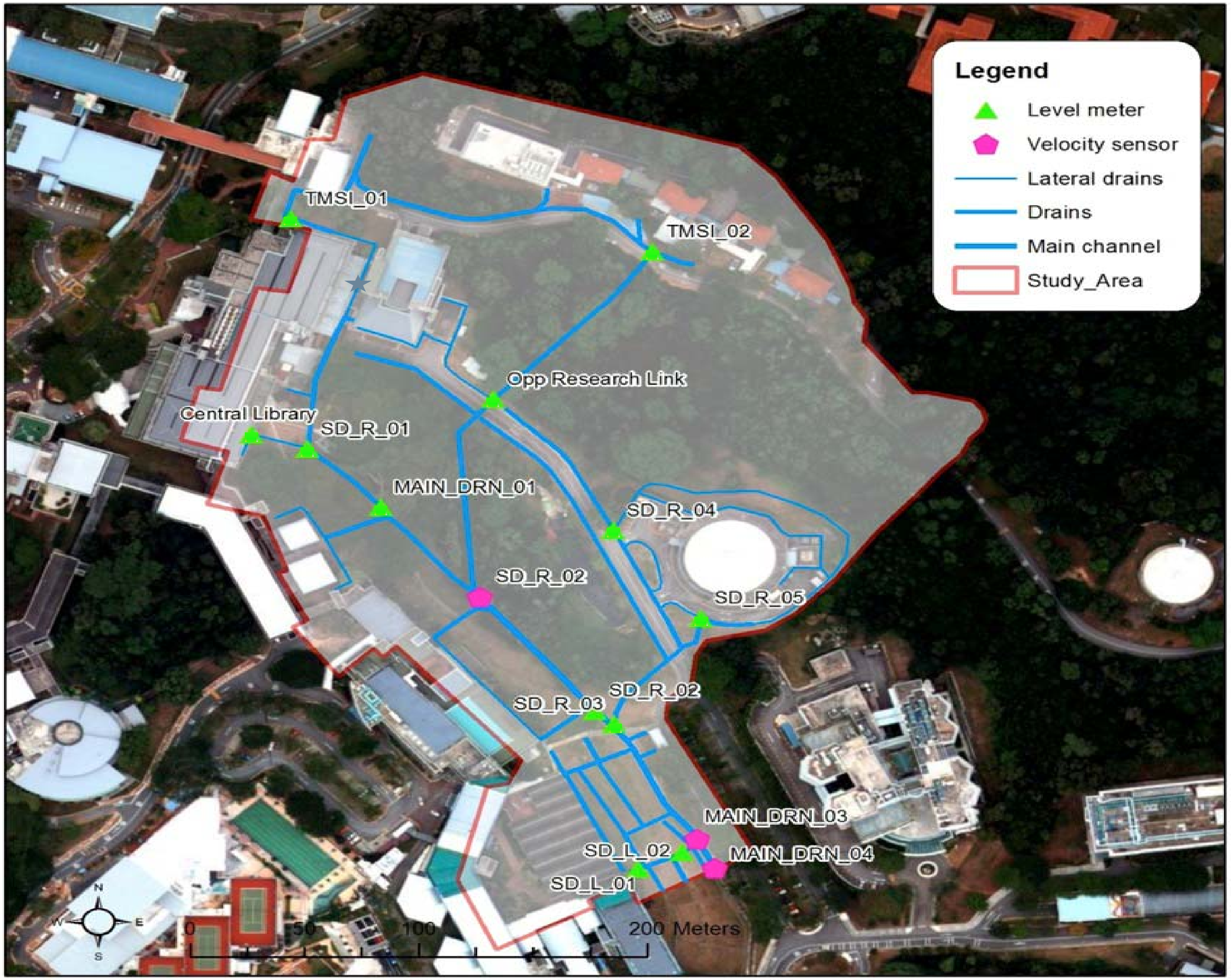
1D RF-RO Changes in preparation for network data

- Thiessen Polygon to distribute rainfall
- Change infiltration if necessary (Sacramento/HBV)
- Realign subcatchments based on instrument
- Properly accounting for cascades

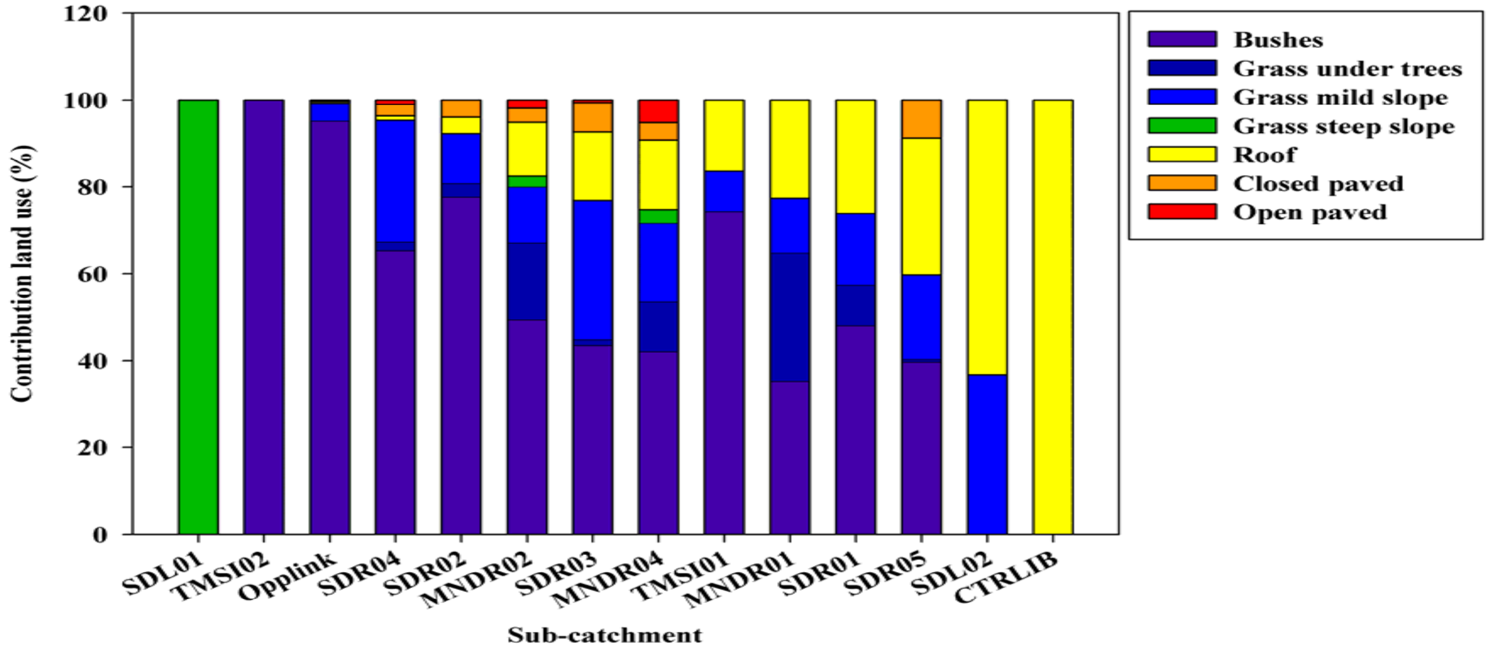
A storm event with a return period > 100 years



Kent Ridge Catchment as a study case



Deciphering land cover contribution with regards to peak runoff



Sub-catchment delineation allows for a detailed analysis during model calibration and validation

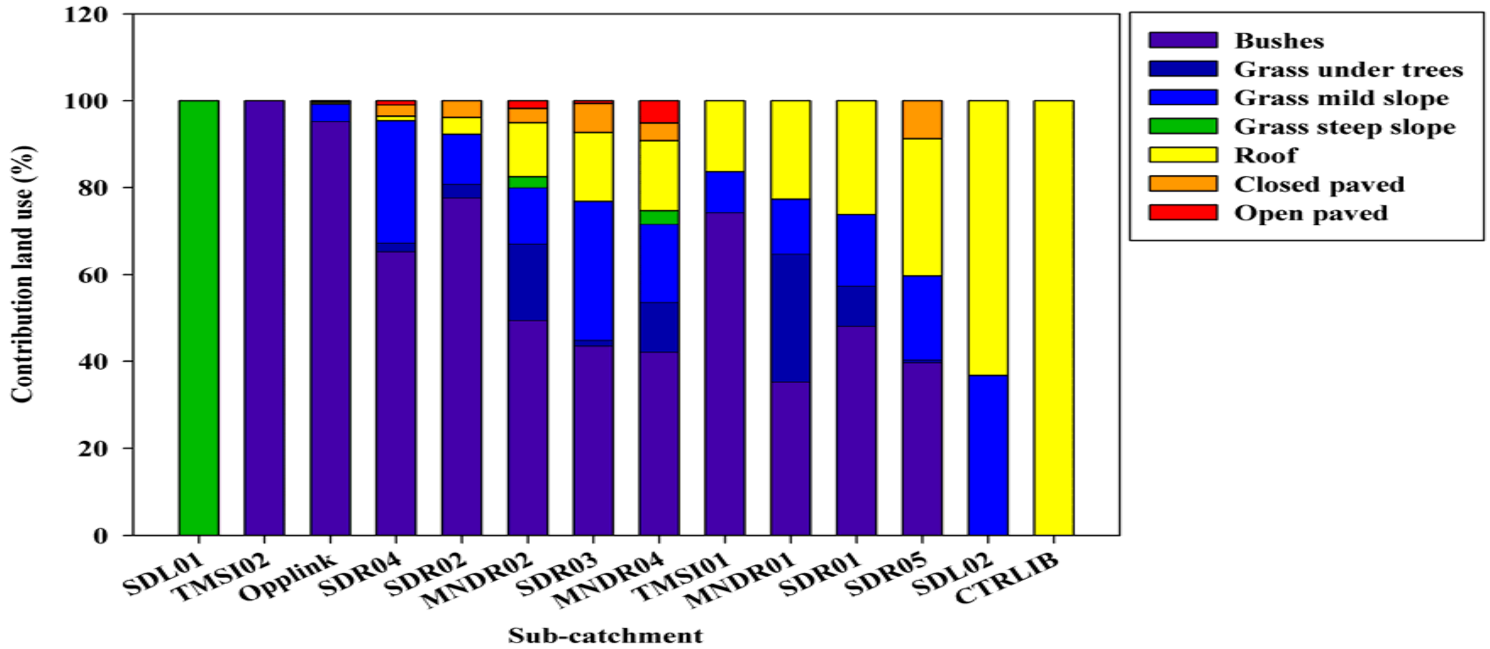
MNDRN01

MNDRN04

SDR02

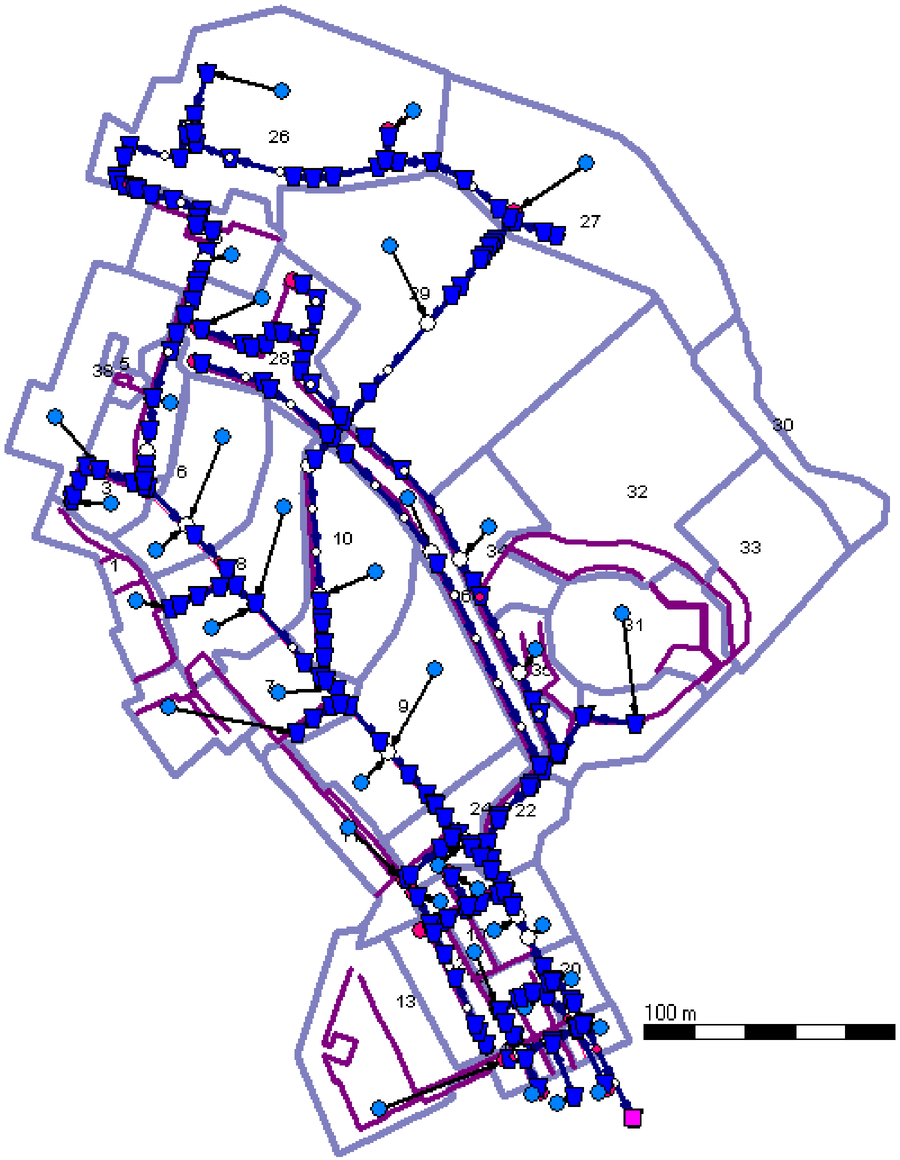
OPPRLINK

14 monitoring locations and their distinctive land use characteristics



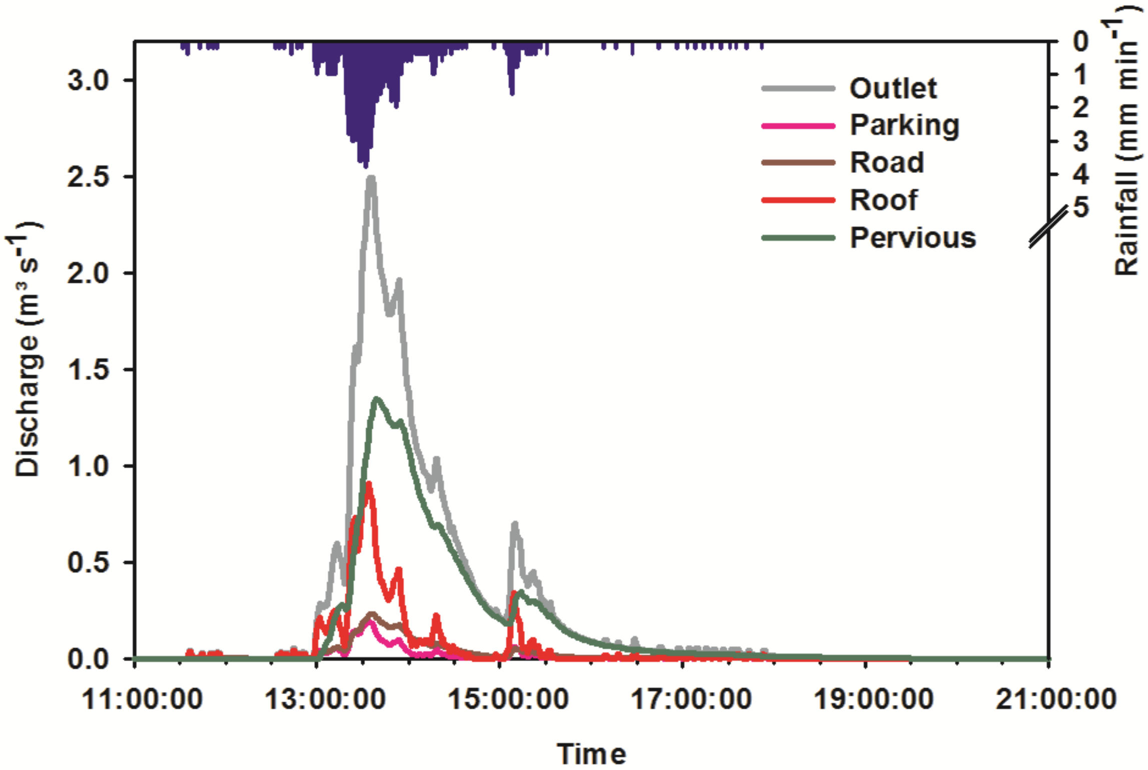
=> Improved understanding of land use specific runoff contribution at catchment level

Schematization of Kent Ridge catchment:



- Runoff at sub-catchment level
  - Runoff delay is a function of landuse
  - Infiltration of land uses
- 1D-Flow through the system:
  - Implementation of cross section of drainage channels
  - Roughness of channel bed (friction)

- Evaluation of land cover towards peak runoff at the outlet:
  - When pavement takes up to 25 % its runoff contribution is 35-40% of the actual peak discharge
  - Unpaved land uses have a delay of 2-5 min to peak discharge at catchment outlet

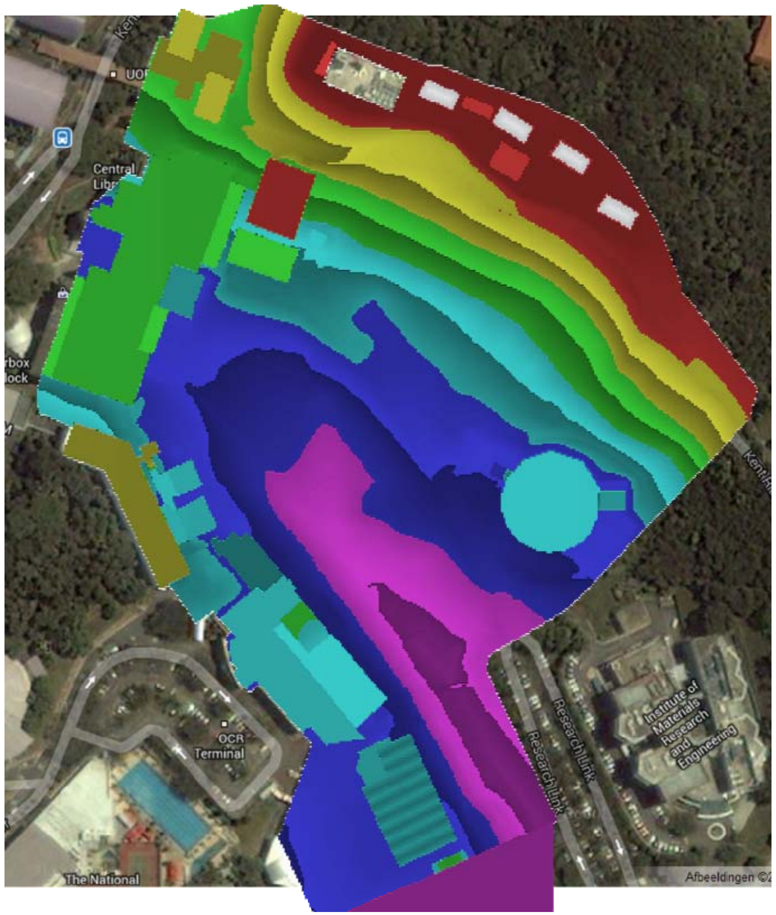


A new paradigm

A shift – brought upon a reconsideration of the physical problem

Data

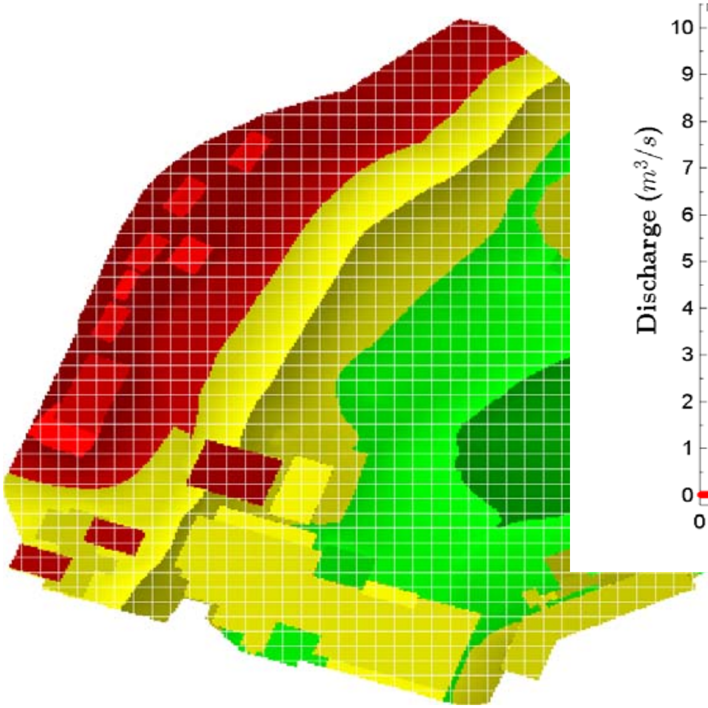
- Can we use it differently?

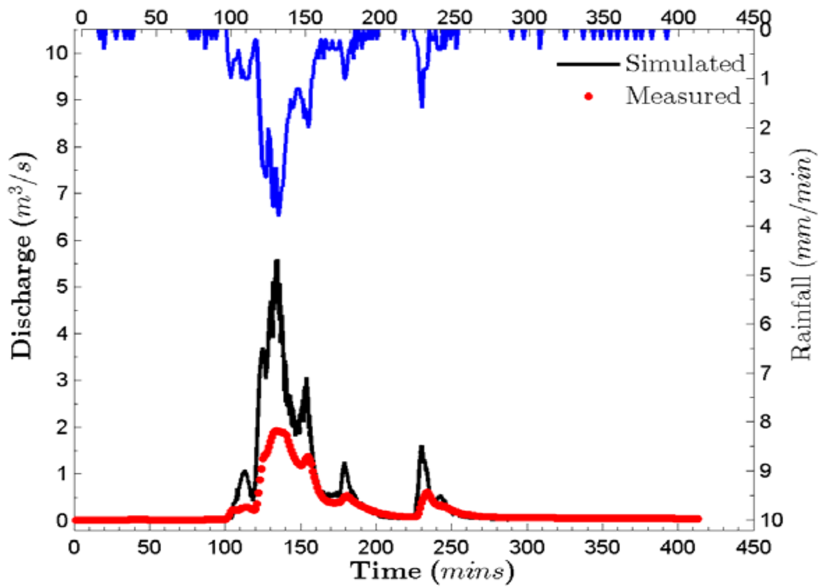


A new model

- Schematize the whole catchment just using rectangles!

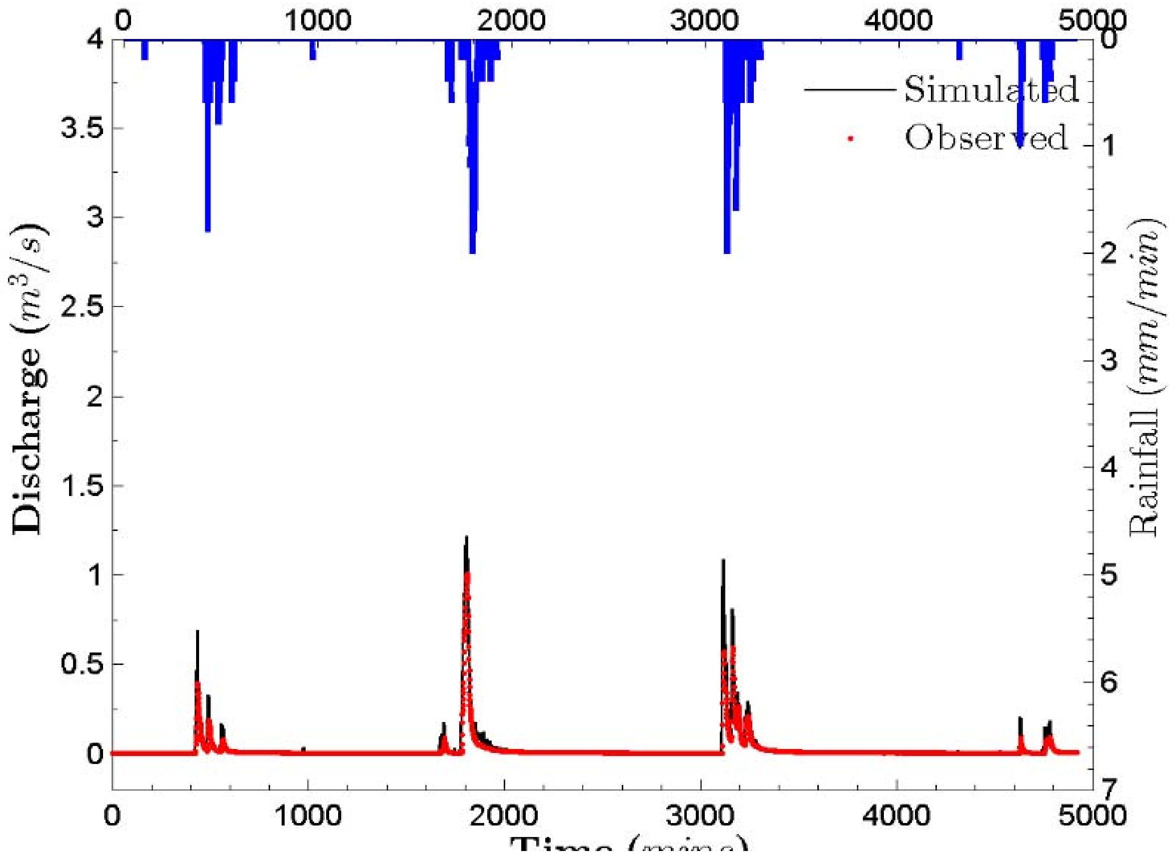
2D grid with coarse grid size dx = 8 m





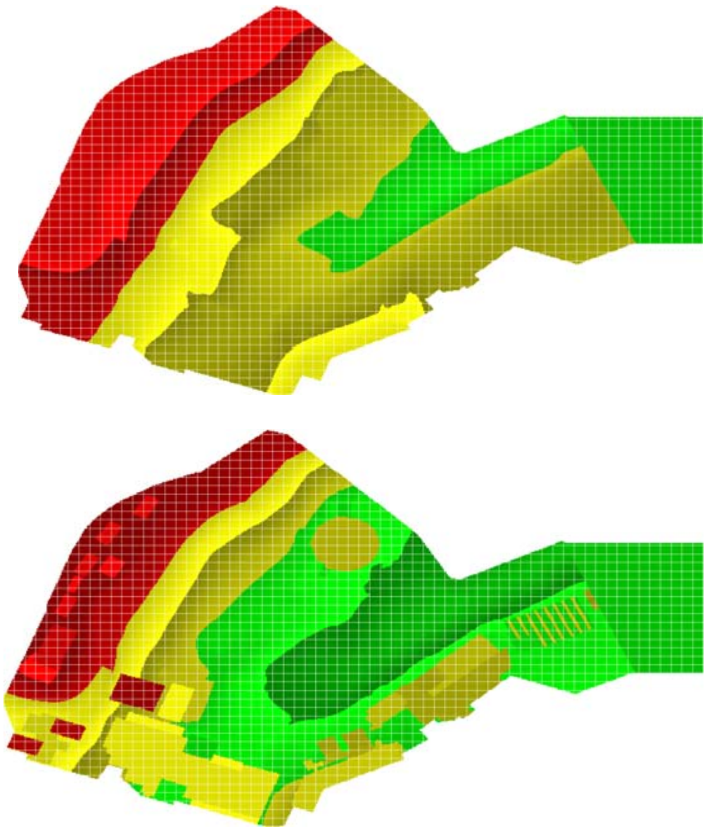
Same data set

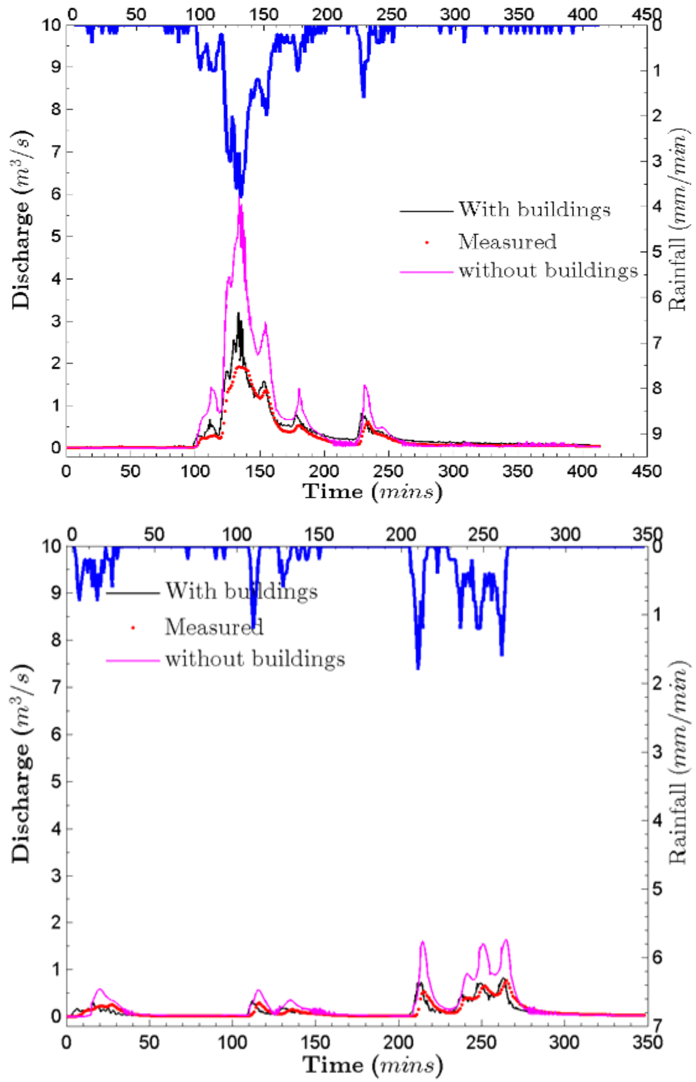
- Test and validate – boundary conditions; friction factor; porosity



What else can you test with this type of model?

- Impact of buildings…





Conclusions (Kent Ridge Model)

- Mixed success in prediction of runoff
- 2D model performs better overall than 1D coupled
- Improvement in channel/network description required
- Removal of uncertainty in boundary conditions
- Possibility of measurement errors for certain locations and events

Summary and Conclusions

- Present sub-grid based method is capable of fast, conservative simulations of rainfall-runoff problems with high resolution topography information
- Slope-limiters, Linearized friction, and Porosity provides a set of stabilization and calibration tools
- It is a work in progress. Gridded information regarding soil, land cover could be used as pixel based input. A full sub-surface model is also being developed.

Key Points for Deterministic Models!

What can a deterministic model give you

- A tool to base well-founded decisions on
- Higher-quality basis-data
- Better knowledge of the basic processes
- Insight in the physical system

Steps in numerical model development

- definition of the objectives of model use
- schematisation of the modelled area
- equations, conditions and solution algorithms
- the modelling environment
- model data
- model calibration and verification
- simulations

How do we get good model results?

- learn through the model applications
- critical assessment of results
- check sensitivity of numerical parameters
- check sensitivity of physical parameters
- be aware of effects of extrapolation

Error sources in numerical modelling, quality of the model

- Data errors
- Errors in the model equations
- Discretisation errors
- Measurement errors

Model error

Differences between simulation and measurements

Points for attention when calibrating

- Schematisation
- Data quality
- Influence of storage
- Influence of discharge capacity
  $K = C * A * R^{1/2}$ using Chezy,
  $K = (1/n) * A * R^{2/3}$ using Manning)
- Can parameters be extrapolated?
- Lateral discharges
- Measurement errors

Stamford Canal

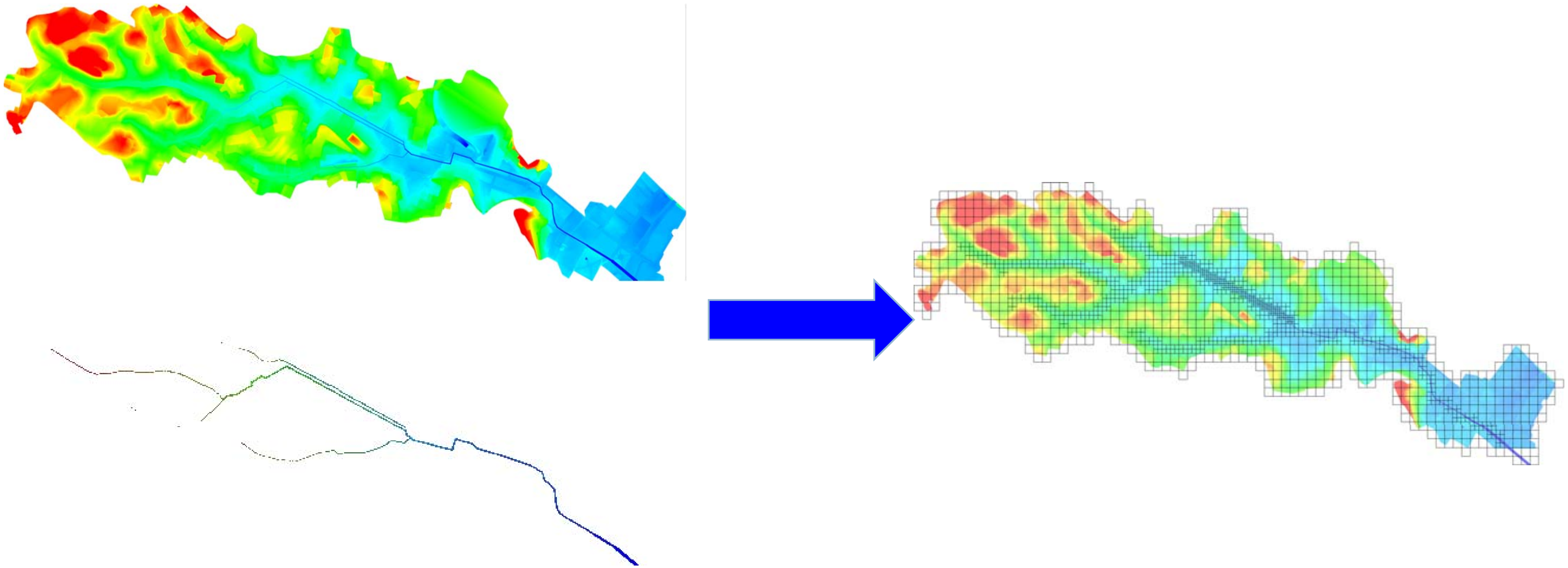
Real-world application

What is the issue (2)?

- Study 2 : Stamford Canal
  - Rainfall in the catchment → runoff into the drains
  - How to make it work better?

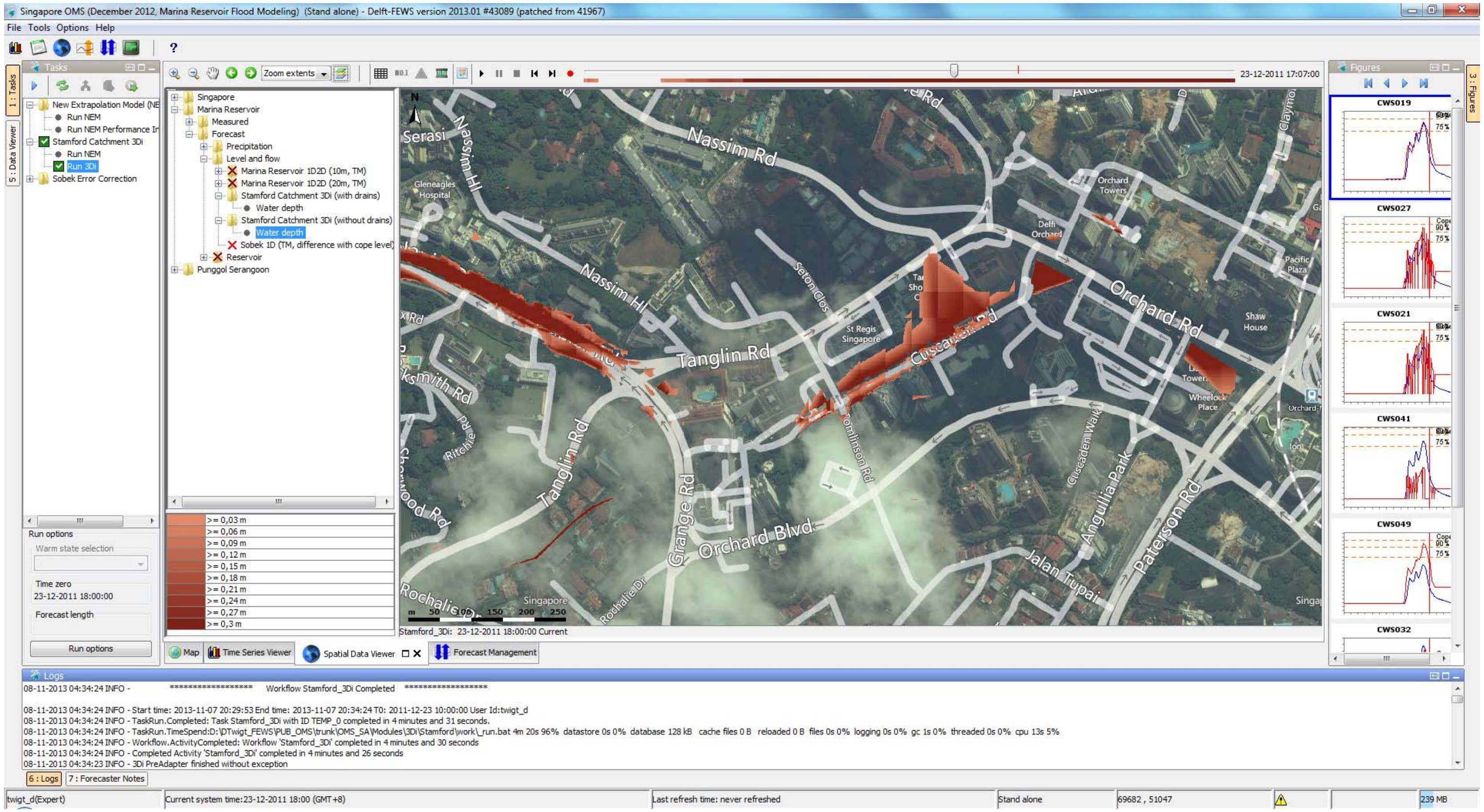
Can we solve it?

- Making use of data and new modeling techniques!



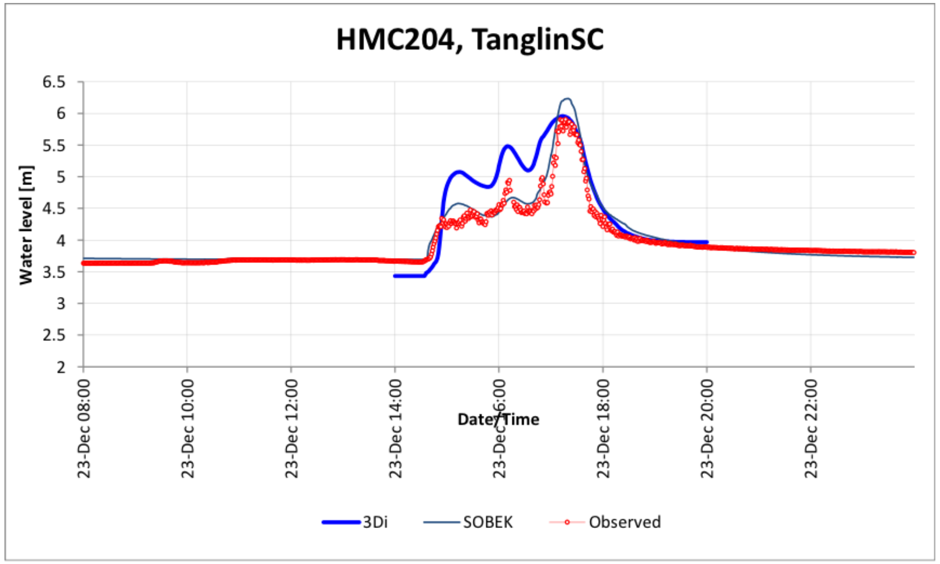
The end result....

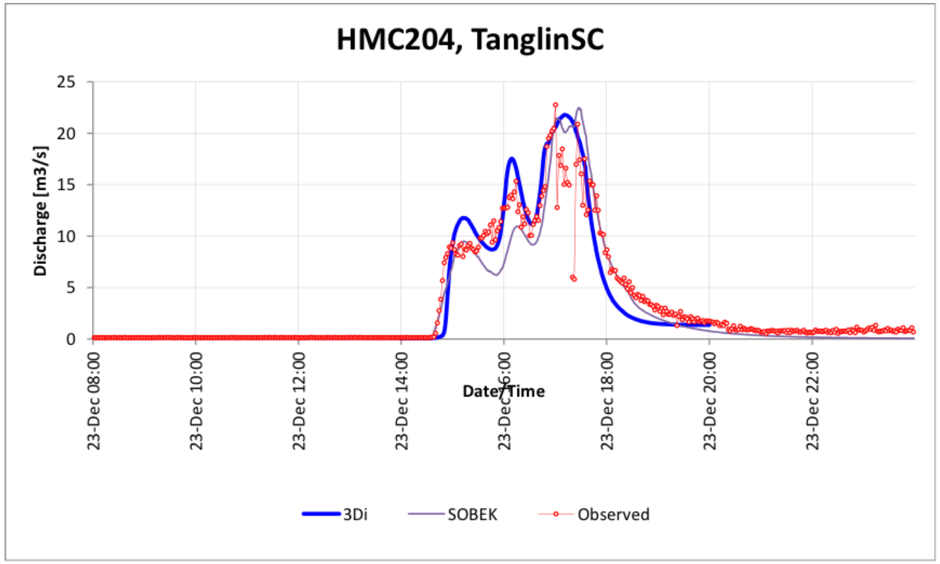
- Nov 2011



Results (1)

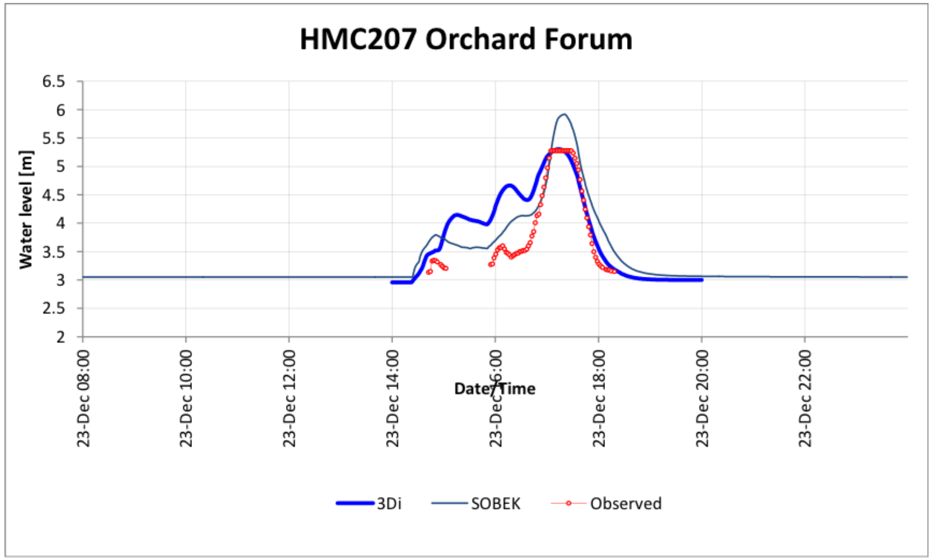
- Upstream

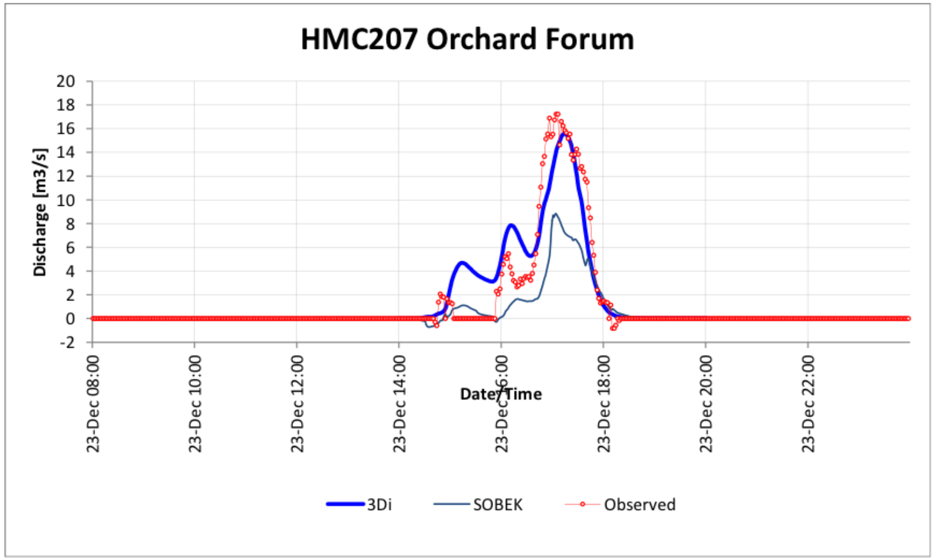




Results (2)

- Mid





Results (3)

- Downstream