

# Real-time Machine Learning and SWMM Automation

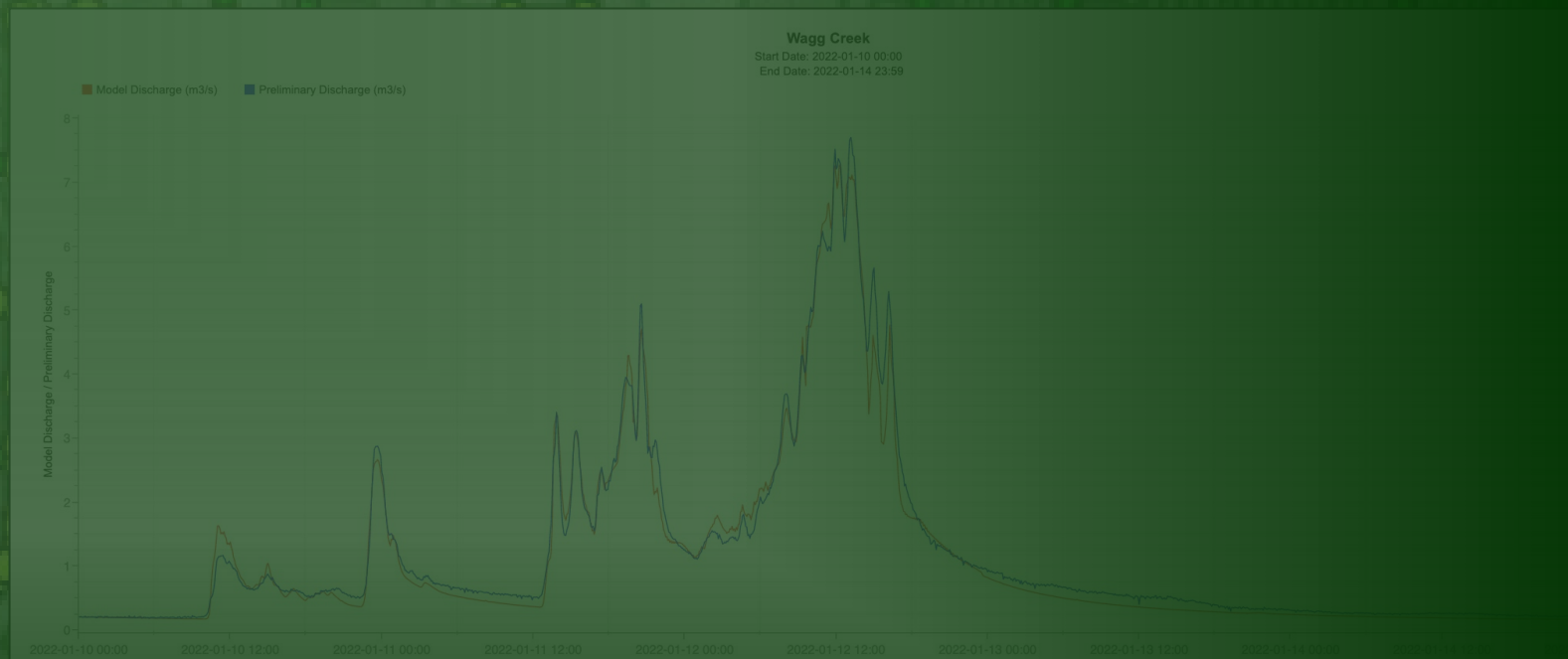
NWWC 2023 – Niagara Falls

November 14, 2023

Greg Johnston (infinittii-ai)

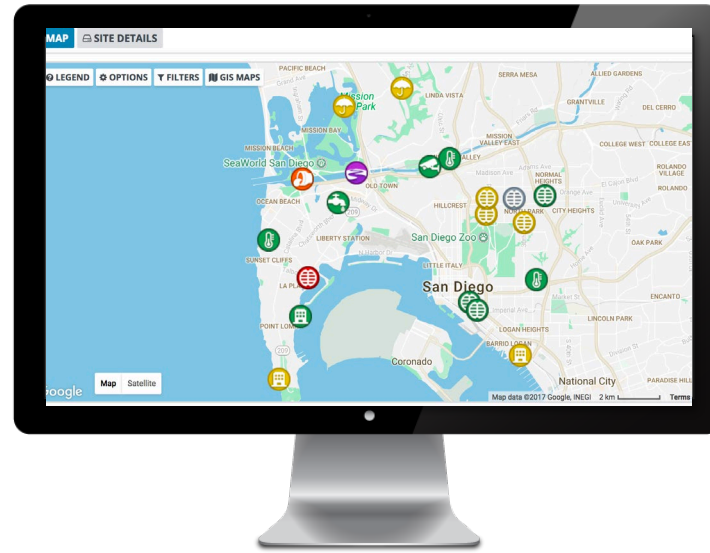
Jeff Marvin, M.A.Sc., P.Eng. (KWL)

```
FlowWorks Monitor Graph Report Analyze Manage Apps Machine Learning
Activities
Pipelines
Logs
print(newline)
continue
if line.find("END_TIME")==0:
    dateTimeToWrite=datetime.strptime(datedata[len(datedata)-1], "%Y-%m-%d %H:%M:%S")
    dateTimeToWrite=datetime.strptime(datedata[len(datedata)-1], "%Y-%m-%d %H:%M:%S")
    newline="END_TIME "+dateTimeToWrite.strftime("%Y-%m-%d %H:%M:%S")
    g.write(newline+"\n")
    print(newline)
    continue
if line.find("REPORT_STEP")==0:
    write="REPORT_STEP 00:05:00"
    print(newline)
    print(newline)
if line.find("[RAINGAGES]")!=0:
    g.write(line)
    line=f.readline()
    g.write(line)
    line=f.readline()
    g.write(line)
    line=f.readline()
    g.write(line)
    line=f.readline()
    g.write(line)
    newline="CNRain VOLUME 0:05 1.0 TIME"
    g.write(newline+"\n")
    print(newline)
    continue
```



# Infiniteii FlowWorks SaaS Based Application

## Data Collection



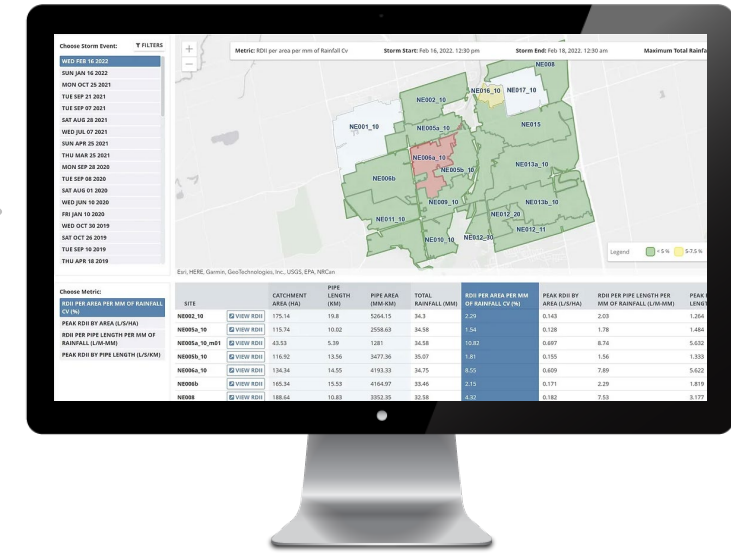
**View all network data  
in one place**

## Data Visualization



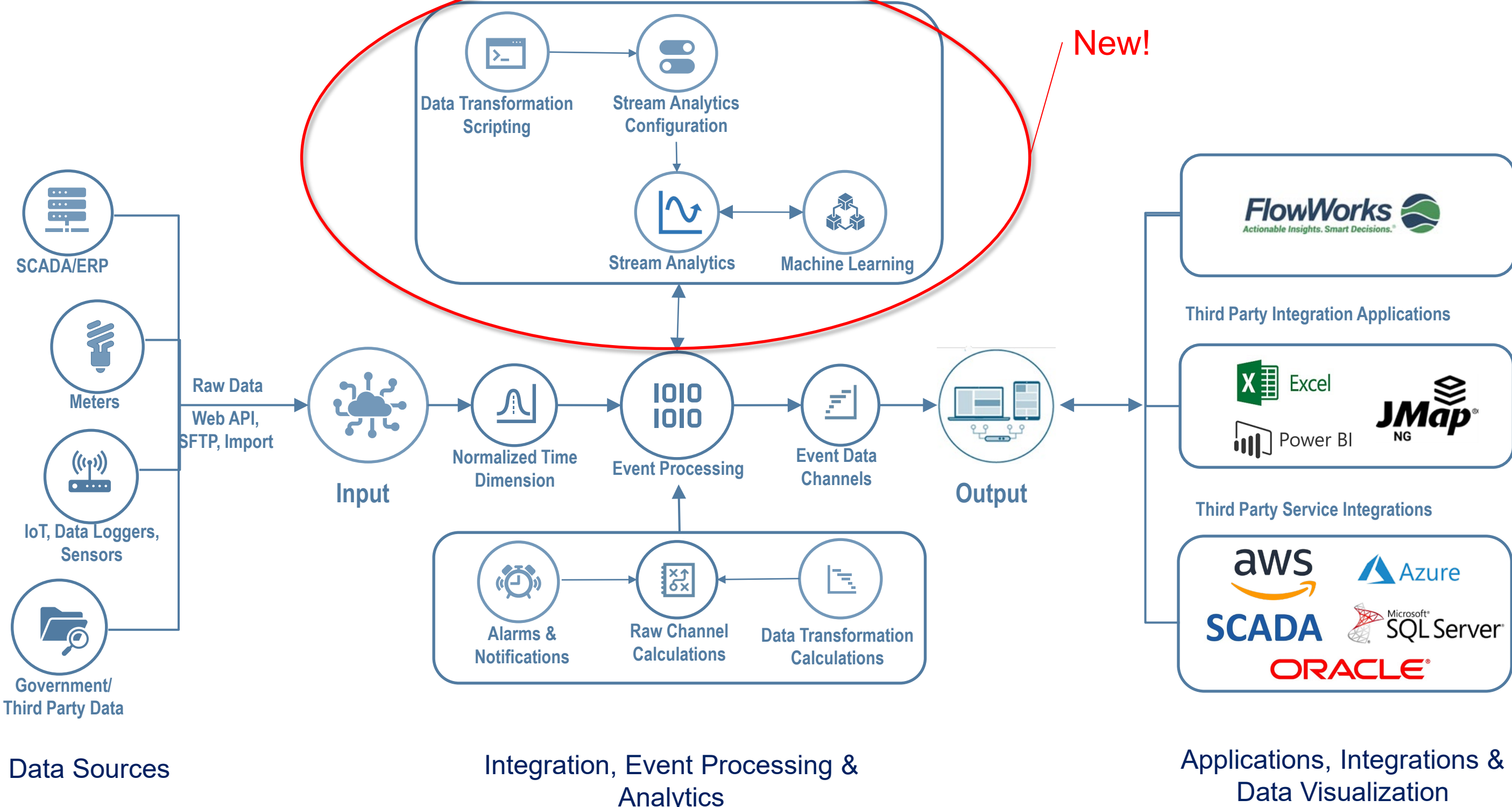
**Review and set  
alarms on channels  
of data**

## Data Analysis



**Analyze and predict  
through custom  
calculations**

# Infinintii.ai technology – ML and Advanced Analysis



# Face Pro – Feature for building and deploying advanced analytics

**FACE Pro** Transform your data in real-time with Python or R

### Pump failure alert - example

Based on 5 selected signals from the pump, the model predicts failure (failure 0, normal operation 1). The XGBoost classification model is used. Failure is predicted one hour before occurrence.

Any settings that are specified in the template cannot be modified in the bundle.

#### Input channels

Specify sites, channels, and date range for the data sets that will be available for processing in your script.

Site name	Channel name	Start date	End date
FACEPRO Pumps signal example	sensor_04	2018-07-10	2018-07-28
FACEPRO Pumps signal example	sensor_06	2018-07-10	2018-07-28
FACEPRO Pumps signal example	sensor_07	2018-07-10	2018-07-28

```
predict level/script.py
1 import pandas as pd
2 from neuralprophet import NeuralProphet, set_log_level
3
4
5
6 def prepare_data(data, data_name: str):
7     """ datetime type """
8     data["time"] = pd.to_datetime(data.time)
9     """ sort values """
10    data.sort_values(by=['time'], inplace=True)
11
12    """ set index """
13    data.set_index("time", inplace=True)
14
15    """ drop duplicate time """
16    data = data[~data.index.duplicated(keep='first')]
17
18    """ resample """
19    data = data.resample('5T').pad()
20
21    """ reset index """
22    data.reset_index("time", inplace=True)
23
24    """ rename column names """
25    data.columns = ['time', data_name]
26
27    # data[data_name][data[data_name]==0] = np.nan
28    return data
29
30
31 dp = pd.read_csv("Level.csv")
32 dp = prepare_data(dp, "depth")
33
34 df = dp[["time", "depth"]]
35 df.rename(columns={"time": "ds", "depth": "y"}, inplace=True)
36
37 m = NeuralProphet(
38     n_lags=0,
39     n_forecasts=1,
40     n_changepoints=0,
41     weekly_seasonality=False,
42     daily_seasonality=True,
43     learning_rate=0.01,
44     ar_reg=0.1,
45     num_hidden_layers=0,
46     d_hidden=None,
47     epochs=10,
48 )
49
50 metrics = m.fit(df, freq='5min')
51
52 df_future = m.make_future_dataframe(df, periods=288, n_historic_predictions=864)
53 forecast = m.predict(df_future)
54 #fig_forecast = m.plot(forecast)
55 df = forecast[["ds", "yhat1"]]
56 df.rename(columns={"ds": "time", "yhat1": "value"}, inplace=True)
57
58 df.set_index("time", inplace=True)
59 print(df)
60 output_file_name = "PredLevel"
61 df.to_csv(output_file_name + ".csv")
62
```

Save file

Clone template Save template

Transform your data with Python or R Scripts

# Face Pro – Feature for building and deploying advanced analytics

The screenshot displays the FlowWorks 'FACE Pro' interface. The top navigation bar includes 'FlowWorks', 'Monitor', 'Graph', 'Report', 'Analyze', 'Manage', 'Apps', and 'Machine Learning'. The main header shows 'FACE Pro Transform your data in real-time with Python or R' and a 'SUPPORT' link. A left sidebar contains 'Activities', 'Templates', 'Pipelines', and 'Logs'. The main content area is titled 'predict level' and includes a 'Delete' button. Below this, a description reads 'predicting next 7 level values based on available level data'. A note states: 'Any settings that are specified in the template cannot be modified in the bundle.' The interface is divided into several sections: 'Input channels' (with fields for 'Site name', 'Channel name', and 'Script Reference'), 'Target channels' (with fields for 'Site name', 'Channel name', and 'Script Reference'), 'Scheduling' (with 'Enable scheduling' and 'Run in real time' toggle switches), and 'Stack' (with a 'Template stack' dropdown menu). The 'Run in real time' toggle and the 'Template stack' dropdown are circled in red.

FlowWorks Monitor - Graph - Report - Analyze - Manage - Apps - Machine Learning - fwdcdemo -

FACE Pro Transform your data in real-time with Python or R SUPPORT -

predict level Delete

Template config

Bundle list

predicting next 7 level values based on available level data

Any settings that are specified in the template cannot be modified in the bundle.

Input channels

Specify sites, channels, and date range for the data sets that will be available for processing in your script

Site name: FACEPro Demo Site Channel name: Level Script Reference\*: Level

Date  Last of  None

New input channel

Target channels

Specify sites and channels for the data sets that will be available for processing in your script

Site name: FACEPro Demo Site Channel name: Script Reference\*: PredLevel

New target channel

Scheduling

Enable scheduling  Run in real time

Stack

Template stack: Python



# Benefits Face Pro

- **Create new calculated channels of information**
- **Create advanced data transformations for prediction or pattern recognition (i.e., using ML)**
- **“Operationalize” your off-line models to run in real time as data is collected (i.e., for streaming analytics)**
- **Take advantage of open-source code to apply to your data**
- **Use third party applications and API’s within the FlowWorks application**

# Using SWMM in Face Pro: Wagg Creek Case Study

## City of North Vancouver Questions to KWL

1. Which tools are available to measure the impact of Green Infrastructure over time?
2. Can a real-time drainage model be used to set alarms at ungauged locations in the City?
3. Can a real-time drainage model be used to notify us if the flow monitoring sensors foul?
4. Can a real-time drainage model be used to predict 7-day flows based on weather models?

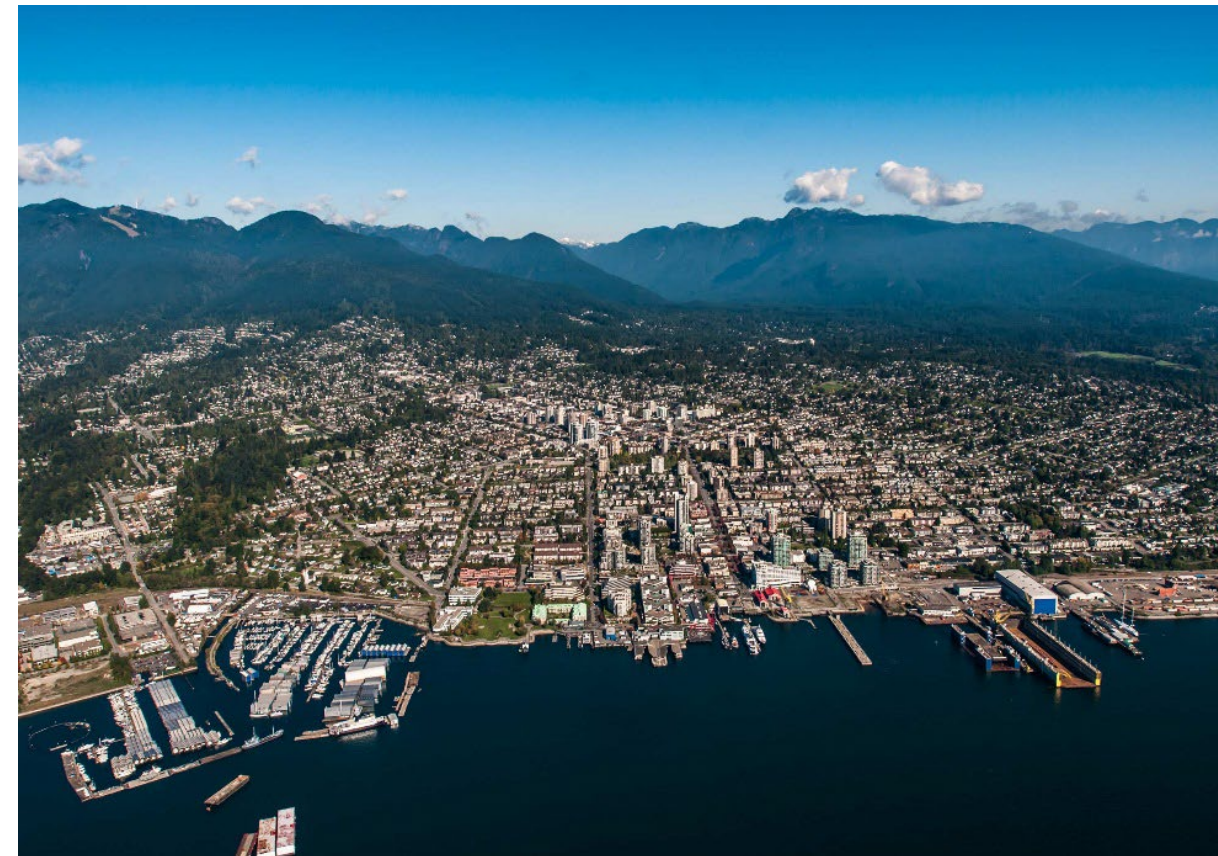
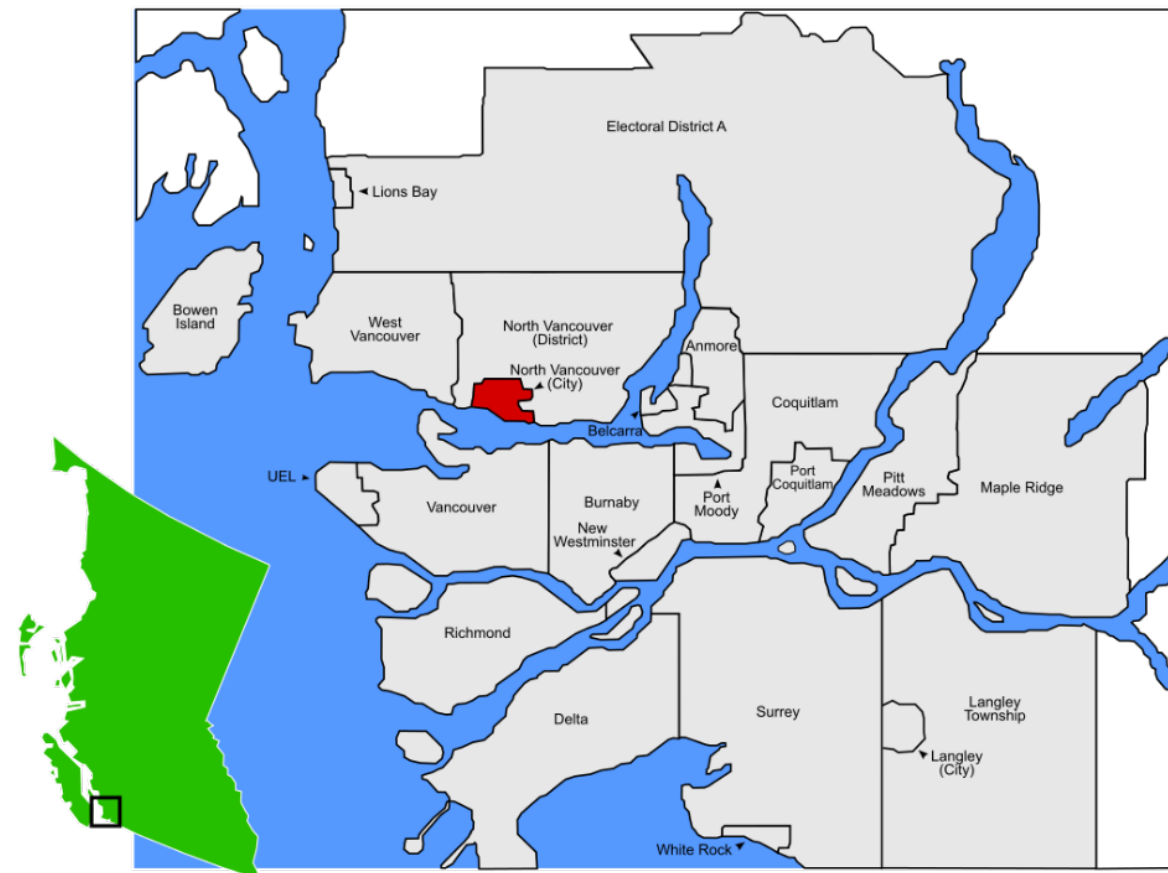


# The City of North Vancouver

Population: 58,121 (2021)

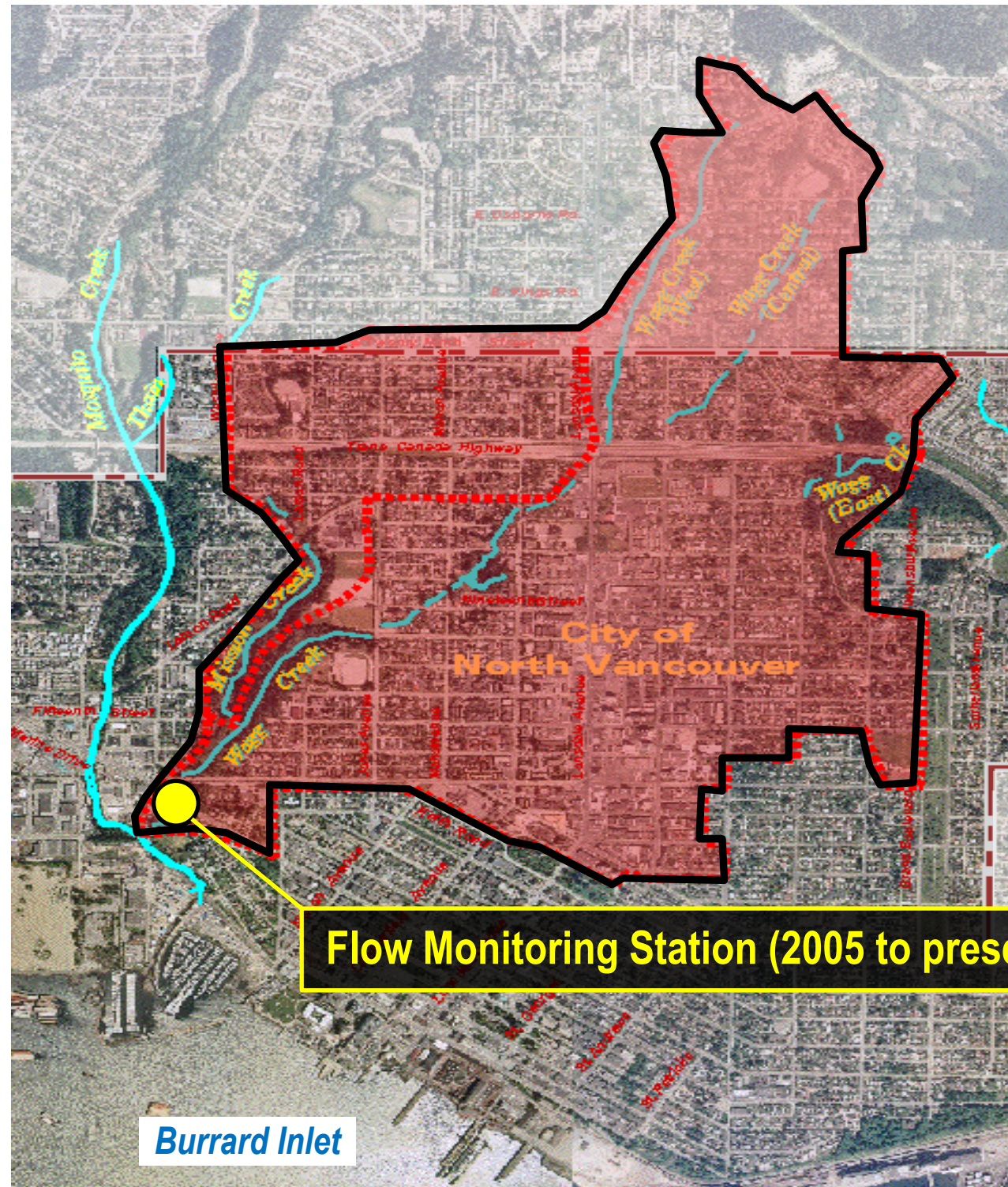
Area: 11.83 km<sup>2</sup>

Density: 4,913 people/km<sup>2</sup>





# Wagg Creek Watershed



- 100% Urban, Fully Developed Watershed
- Total Impervious Area (TIA) = 50%
- Drainage Area = 5 km<sup>2</sup>

# Wagg Creek Watershed Planning History

- **1996 – Master Drainage Plan (MDP):**
  - Identified conveyance system upgrades to meet future development needs.
- **1999 – Integrated Stormwater Management Plan (ISMP):**
  - Identified impacts of increased densification & impervious area on stream erosion & aquatic habitat.
  - *New Drainage Criteria (2005 guidelines & 2014 bylaw):*
    - *56 mm rainfall capture by stormwater source controls (Green Infrastructure)*
    - *Impervious disconnection to pervious areas*



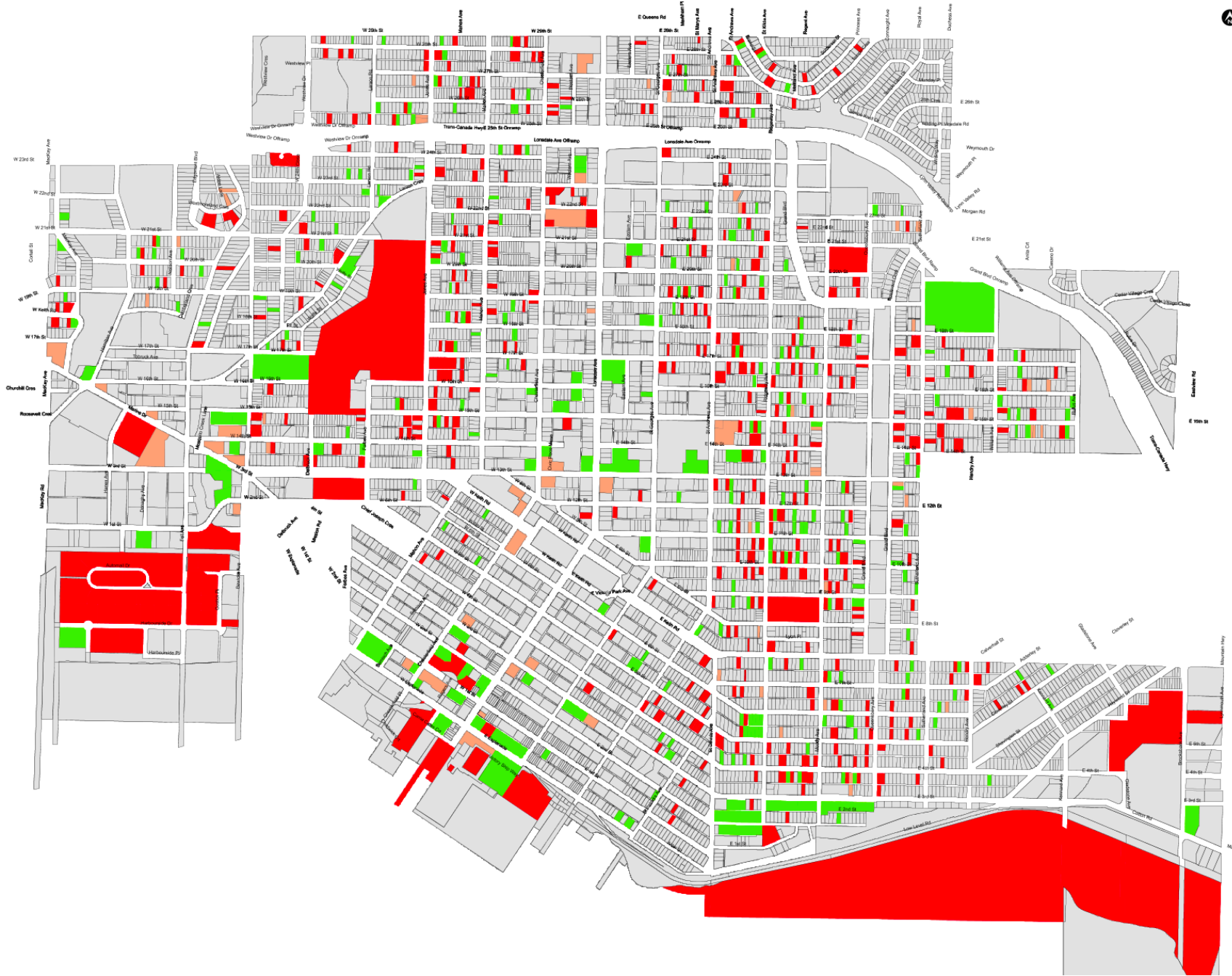
# Examples of Wagg Creek Erosion – 1999



Important note: This erosion was not caused by a “flood event”, but by the continuous impact of a “flashier” hydrograph.

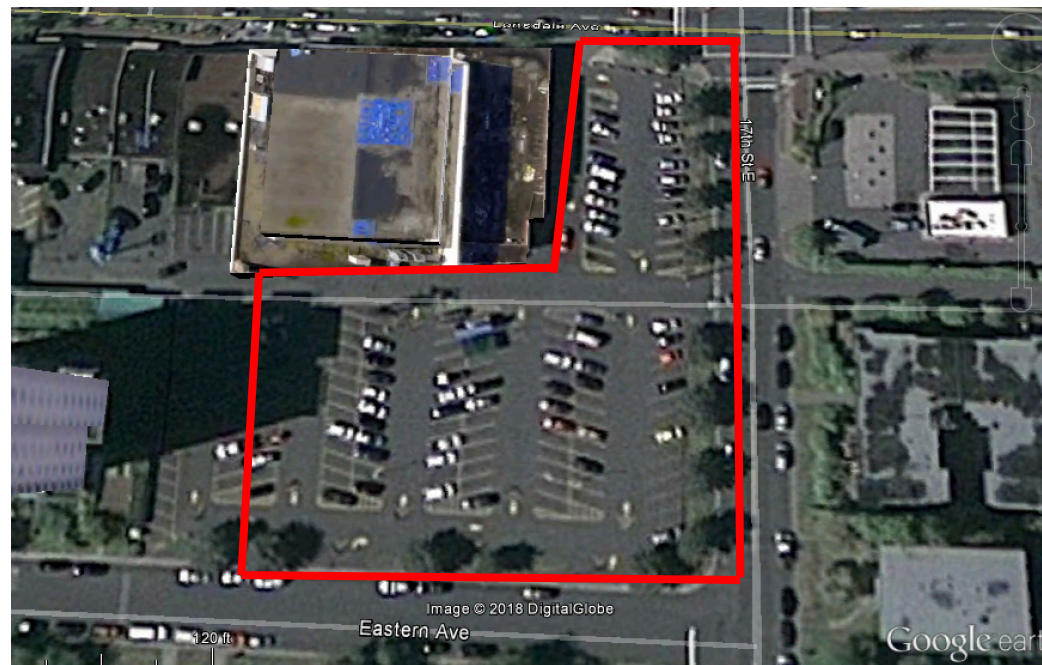


# Stormwater Source Control Implementation (2010 to 2018)

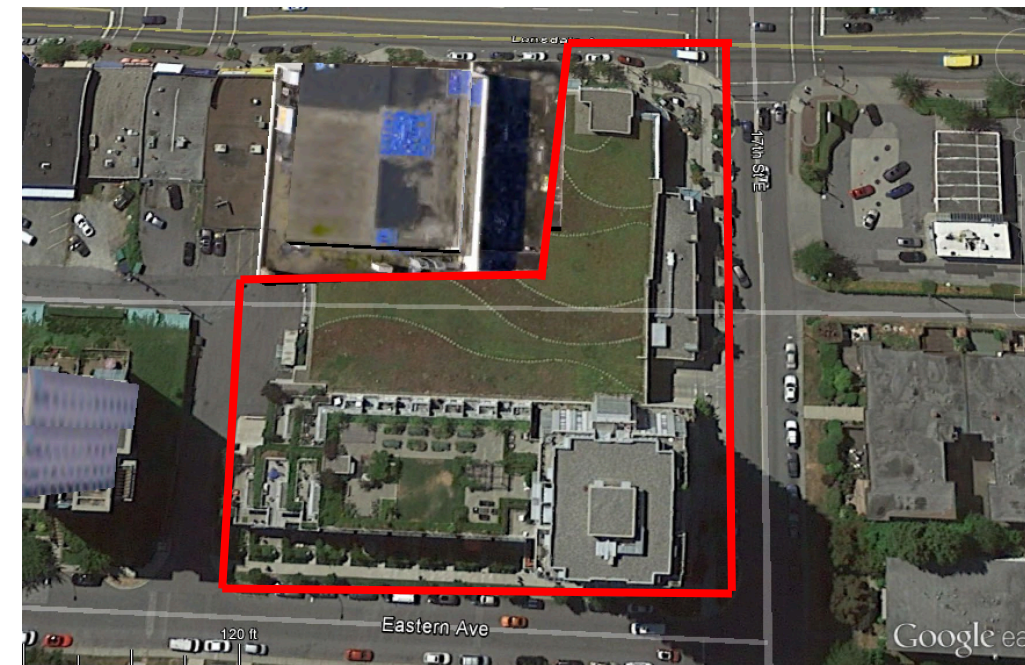


# Stormwater Source Control Implementation: Lots

2003 – Parking Lot



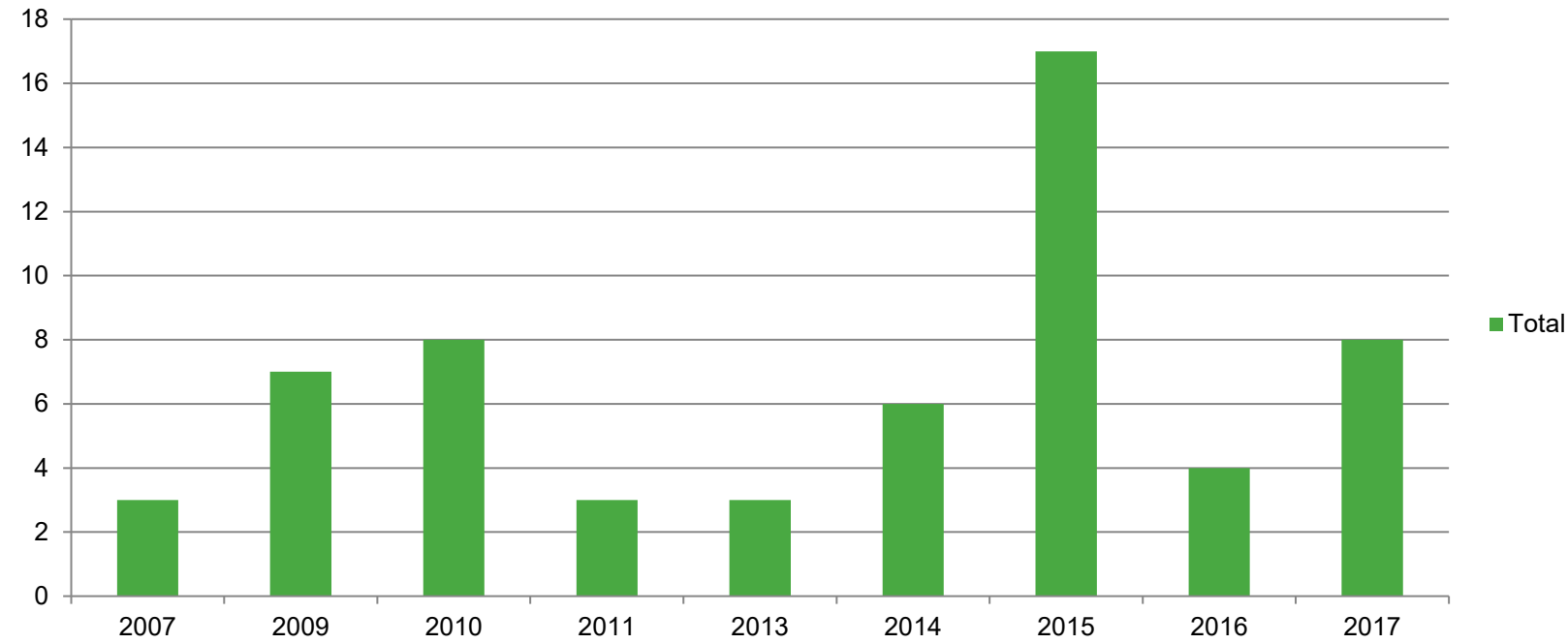
2017 – Green Roof





# Examples of City-Owned Rain Gardens in Public ROW

## History of Rain Garden Construction





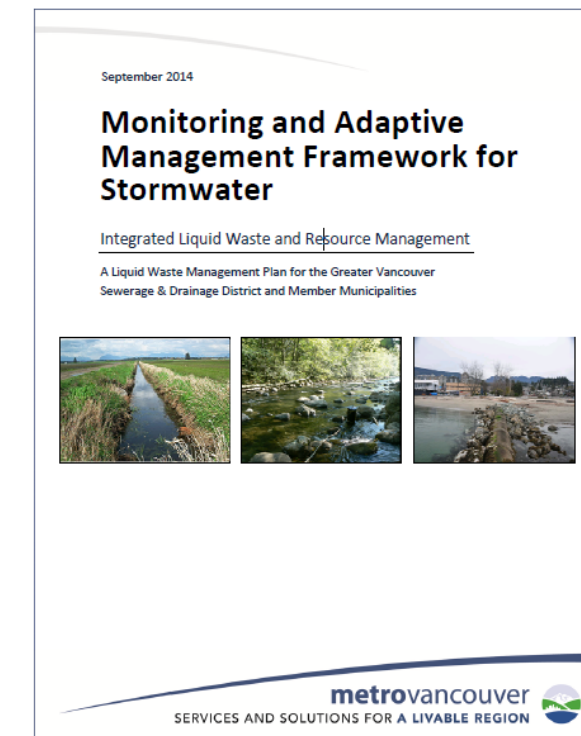
# Methods to Measure Changes in Wagg Creek Watershed Health

## 1. Metro Vancouver's Management and Adaptive Monitoring Framework (MAMF):











- Trends from flow monitoring data
- Benthic Index of Biotic Integrity (B-IBI)

## 2. Measure impervious surface “disconnection”:

- “Effective” Impervious Area (EIA)
- Updated model calibration



# Wagg Creek MAMF Trending (2005 – 2017)

MAMF Trending	Target	Result
Flashiness (TQMean)	Stable or Increasing	
Low Flow Pulse count (number)	stable or decreasing	
Low Flow Pulse duration (days)	Stable or Increasing	 
Summer baseflow (7 day)	Stable	 
Winter baseflow (7 day)	Stable or Increasing	
High flow Pulse count (number)	stable or decreasing	
High flow Pulse duration (days)	Stable or Increasing	 

- **Decreased flashiness**
- **Stable Low & High Flow Pulse Durations**
- **Increasing Summer Baseflows**
- **More frequent high flows, but less flashy**



# Summary of Benthic Index of Biotic Integrity (B-IBI)

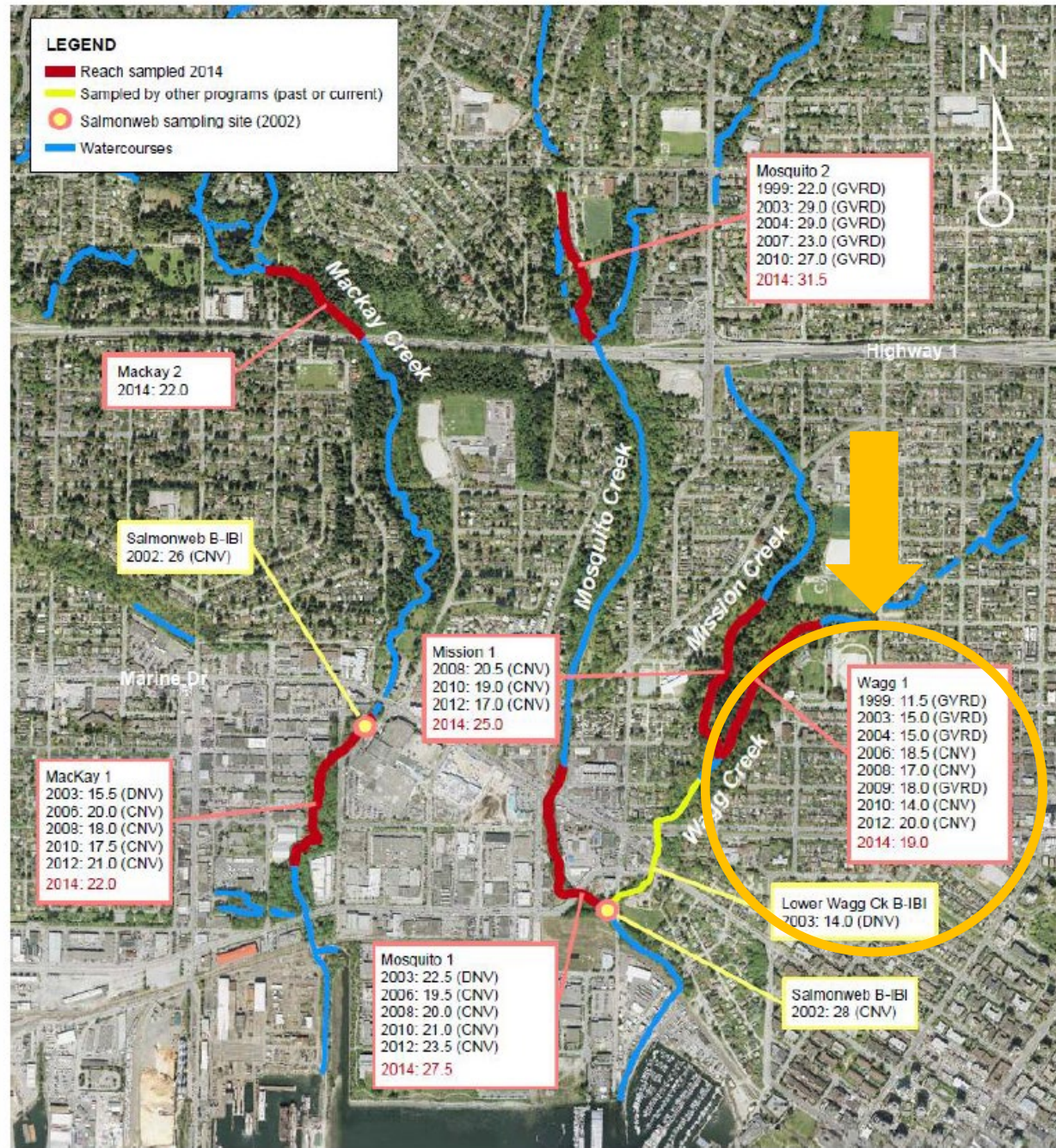
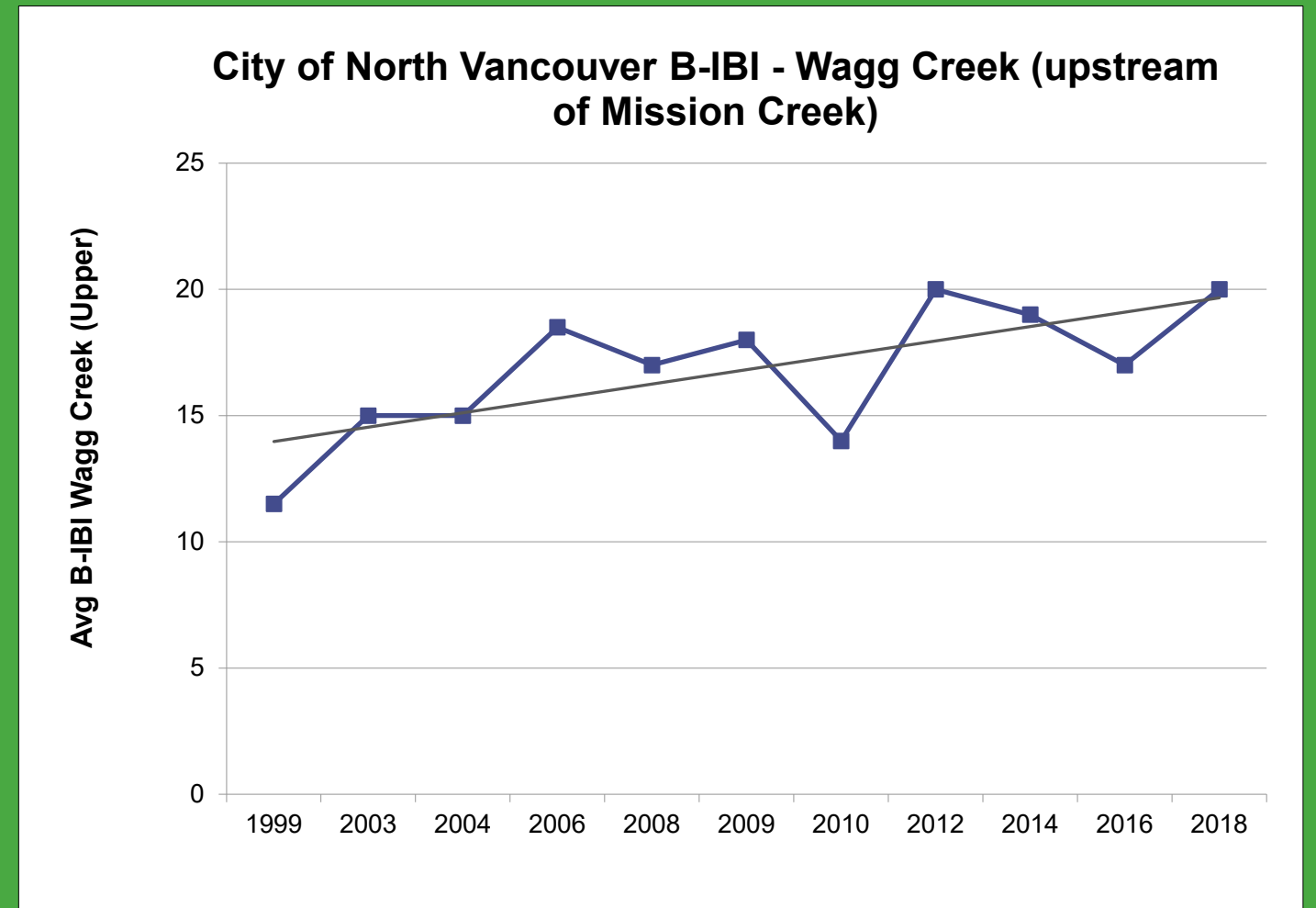


Figure C2-4: Results of 2014 Benthic Invertebrate Sampling in Comparison to Historical Data (all values as mean B-IBI)

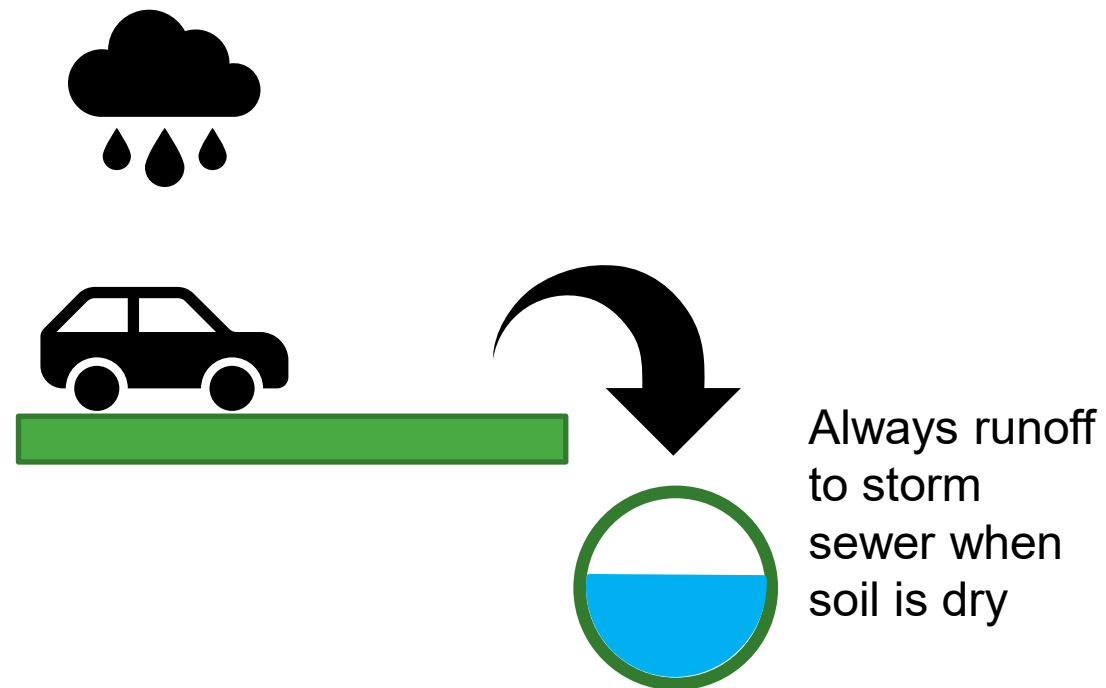
## Wagg Creek B-IBI Results:

- 1999: 11.5
- Significant trend since 2012
- Still significant increase in 2018

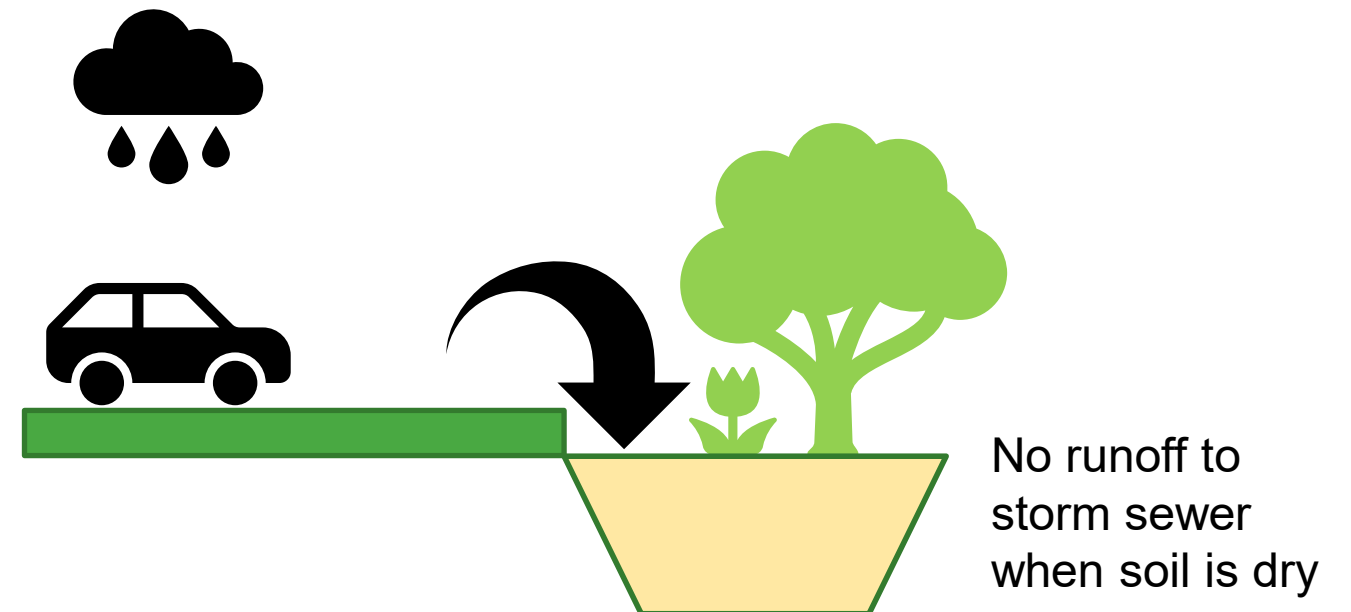


# Effective Impervious Area (EIA) Calculation

Connected Impervious Area = EIA



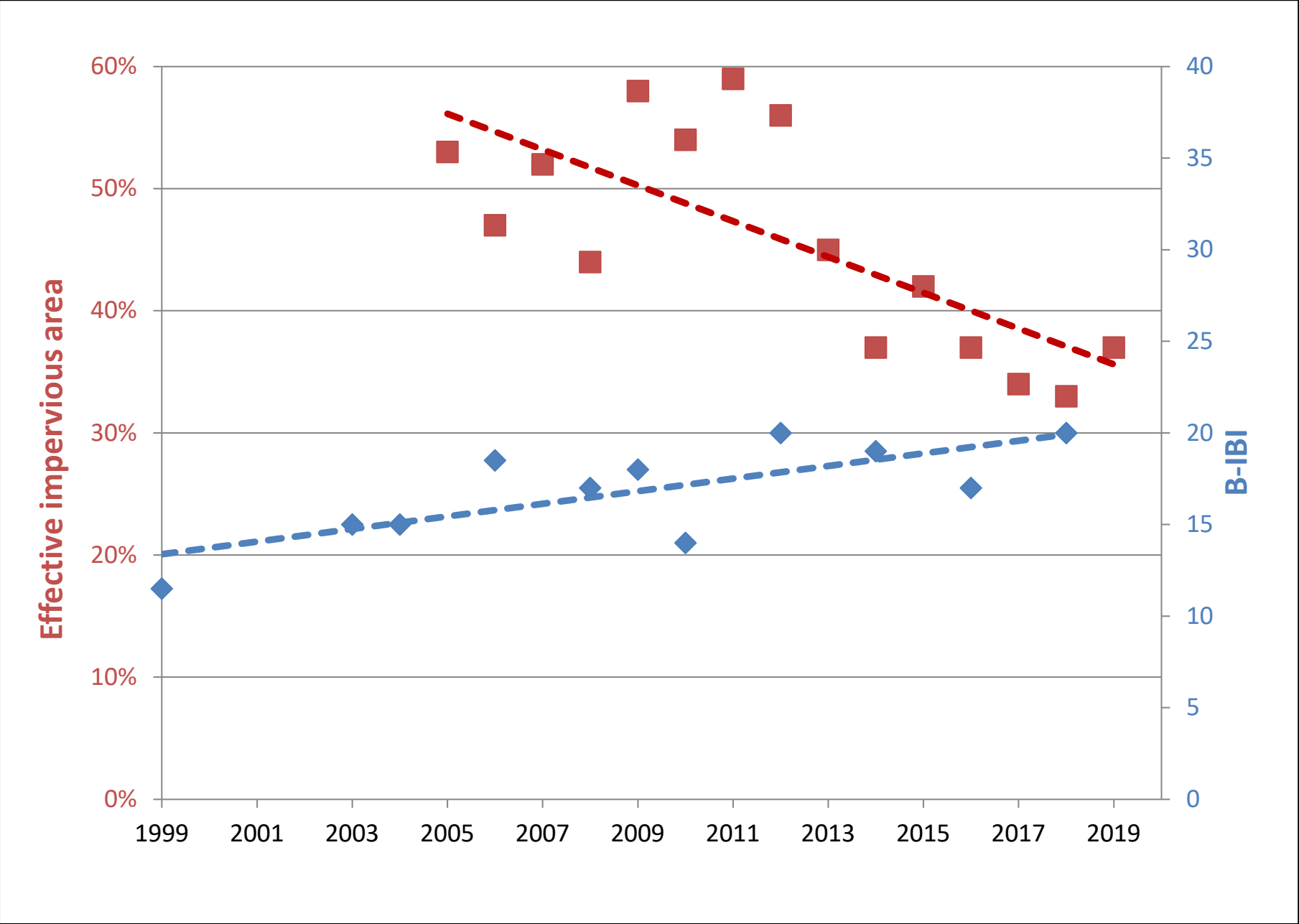
Disconnected Impervious Area = (TIA - EIA)



Is there a way to use summer flow monitoring data to determine the level of disconnection in the watershed?



# Effective Impervious Area (EIA) Results

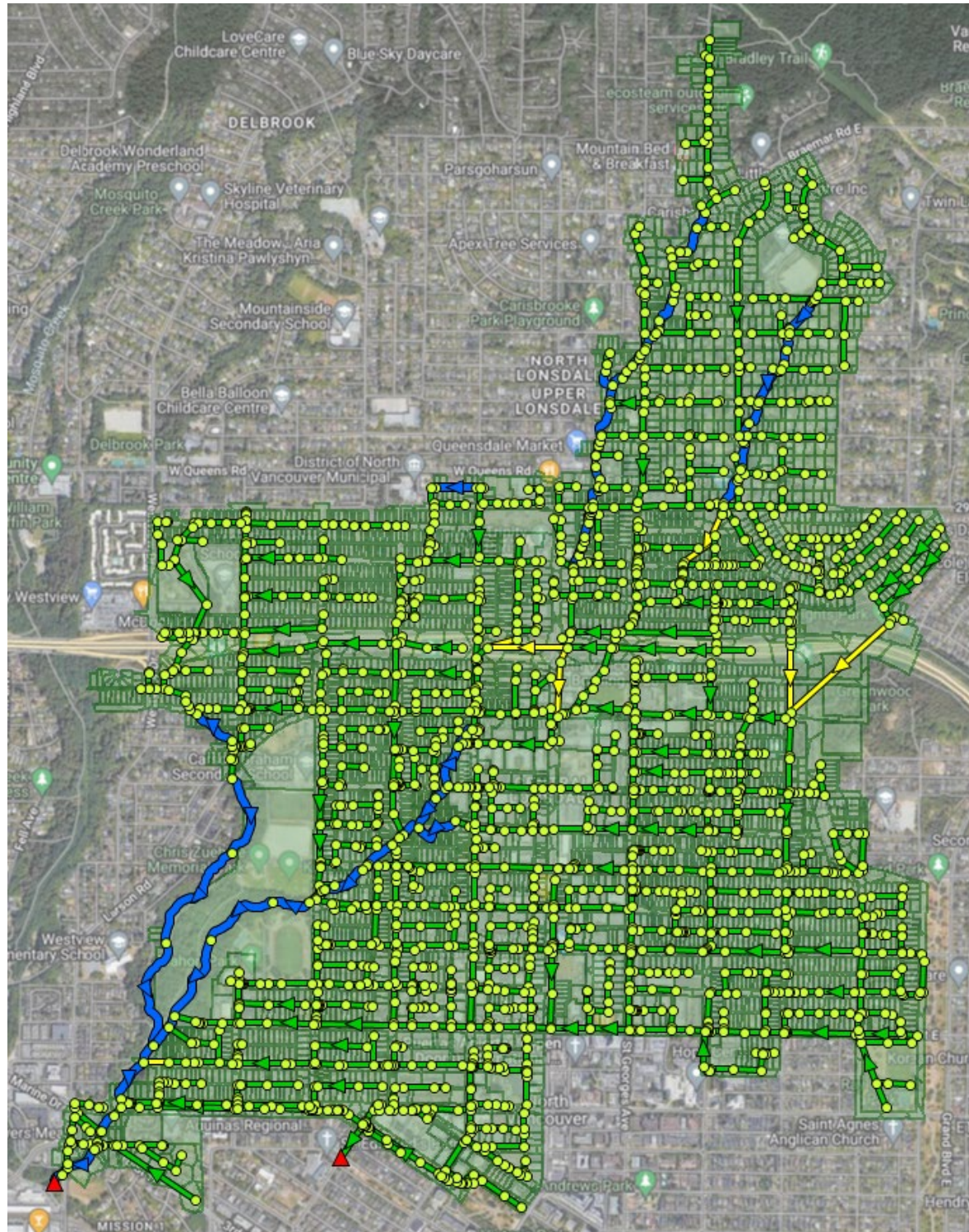


Evaluated summer rainfall events where:

- 2-Day Rainfall < Cumulative ET
- 2-Day Rainfall > 10 mm

$$EIA = \frac{\text{streamflow volume (event)} - \text{baseflow}}{\text{watershed area} \times (\text{event rainfall} - 5\text{mm})}$$

# Wagg Creek SWMM Model



- Citywide model originally developed & calibrated following 1996 MDP
- Model has been kept up to date while remaining calibrated to older flow monitoring data
- Wagg Creek “sub-model” running with real-time & forecasted climate data inputs in FlowWorks through Face Pro



# Wagg Creek SWMM Model & Face Pro Integration

```
FlowWorks Monitor Graph Report Analyze Manage Apps Machine Learning
<
Activities
Templates
Pipelines
Logs
202 print(newline)
203 continue
204
205 if line.find("END_TIME")==0:
206 # dateTimeToWrite=datetime.strptime(datedata[len(datedata)-1],"%Y-%m-%d %H:%M:%S")
207 dateTimeToWrite=datetime.strptime(datedata[len(datedata)-1],"%m/%d/%Y %H:%M")
208 newline="END_TIME "+dateTimeToWrite.strftime("%H:%M:%S")
209 # newline="END_TIME "+apiDateTimeEnd.strftime("%H:%M:%S")
210 g.write(newline+"\n")
211 print(newline)
212 continue
213
214 if line.find("REPORT_STEP")==0:
215 newline="REPORT_STEP 00:05:00"
216 g.write(newline+"\n")
217 print(newline)
218
219 if line.find("[RAINGAGES])==0:
220 g.write(line)
221 line=f.readline()
222 g.write(line)
223 line=f.readline()
224 g.write(line)
225 line=f.readline()
226 g.write(line)
227 newline="CNVRain VOLUME 0:05 1.0 TIMESERIES CNVRain"
228 g.write(newline+"\n")
229 # print(newline)
230 continue
231
232 if line.find("[TIMESERIES])==0:
233 g.write(line)
234 line=f.readline()
235 g.write(line)
236 line=f.readline()
237 g.write(line)
238 for n in range(0,len(datedata)):
239 # dateTimeToWrite=datetime.strptime(datedata[n],"%Y-%m-%d %H:%M:%S")
240 dateTimeToWrite=datetime.strptime(datedata[n],"%m/%d/%Y %H:%M")
241 dateTimeToWriteStr=datetime.strptime(dateTimeToWrite,"%m/%d/%Y %H:%M")
242 newline="CNVRain "+str(dateTimeToWriteStr)+" "+str(precipdata[n])+"\n"
243 g.write(newline)
244 for n in range(0,len(et.tsDate)):
245 newline="CNV_ET "+str(et.tsDate[n])+" "+str(et.tsEvap[n])[0:6)+"\n"
246 g.write(newline)
247 continue
248
249 newline=line
250 g.write(newline)
251 f.close()
252 g.close()
253
254 if ((simEndDateTime-simStartDateTime).total_seconds())<1800:
255 print("Not enough new data to bother")
256 sys.exit()
257
258 print("Copying Hot Start File")
259 ostxt="cp hotstart.out hotstart.inp"
260 os.system(ostxt)
261
262 print("Running SWMM5")
263 ostxt="./runswmm5 "+inpSWMMFile+" "+outSWMMFile
264 os.system(ostxt)
265
266 print("Processing Output File")
267 f=open(outSWMMFile,'r')
268 g=open(outFTPFile,'w')
269
270 # a.write("Database: CNV\n")
```

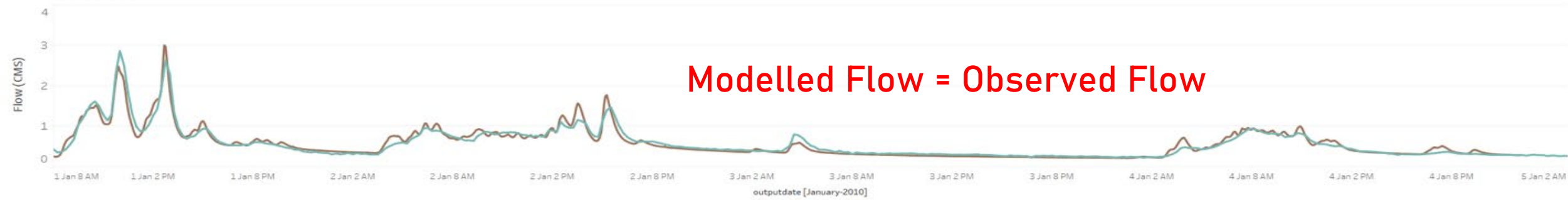
- Developed python code to:
  1. Download real-time/forecasted climate data
  2. Run SWMM model
  3. Push output data into FlowWorks
- Python code uploaded to Infinitii-ai's Face Pro to continuously run the SWMM model online
- PySWMM could also be used



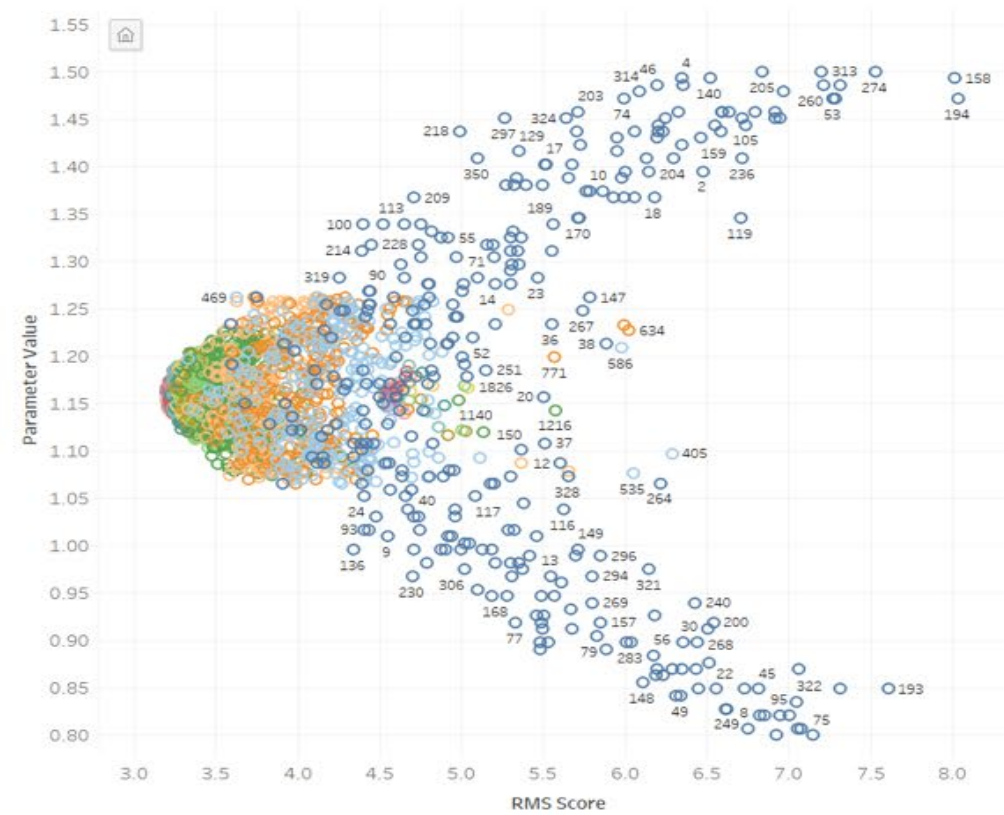
# Model Calibration to 2010 Flow Data

## Parallax (KWL's auto-calibration tool)

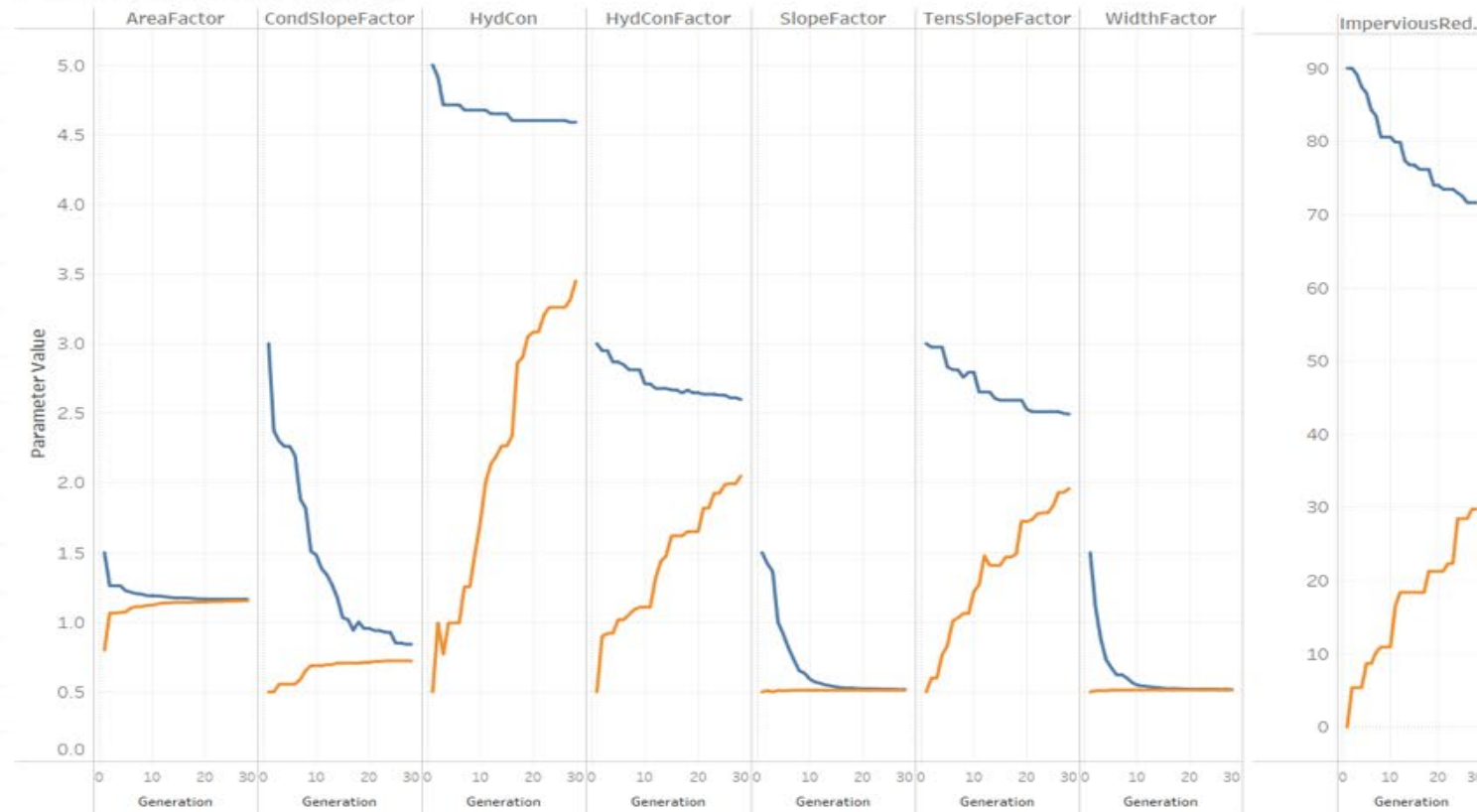
Hydrograph



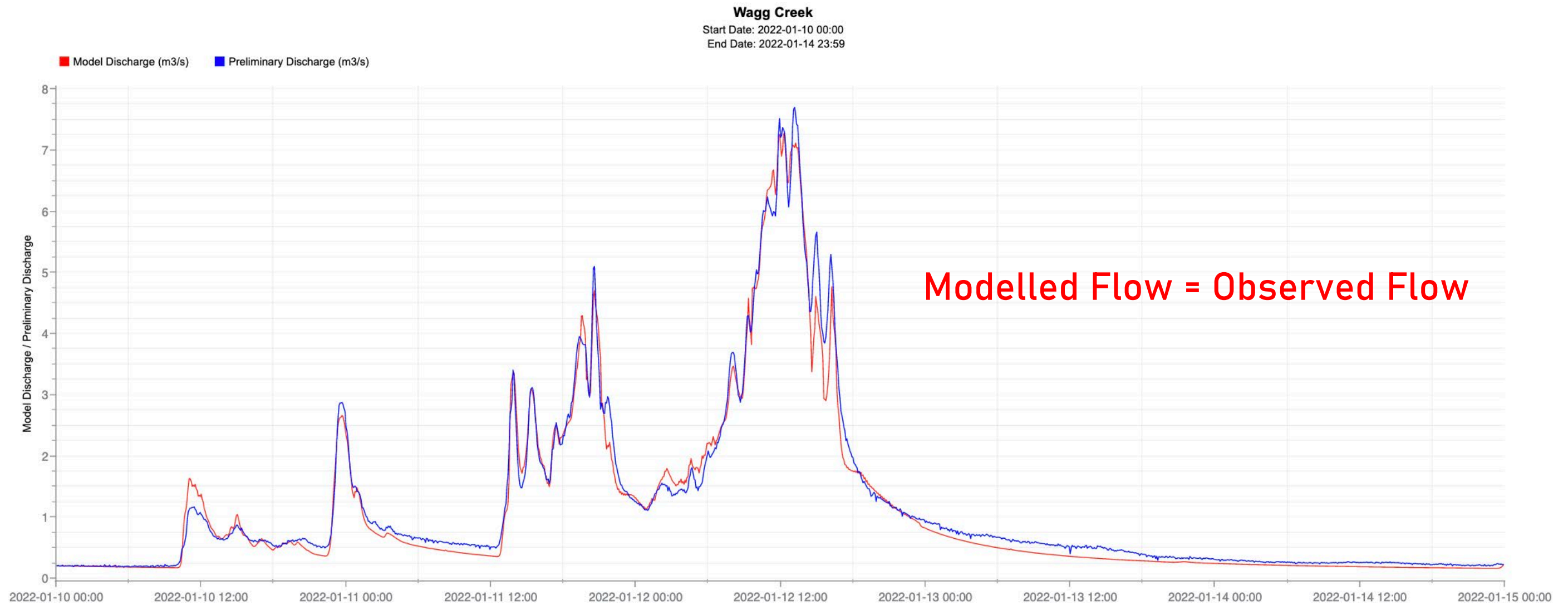
Parameter Scoring



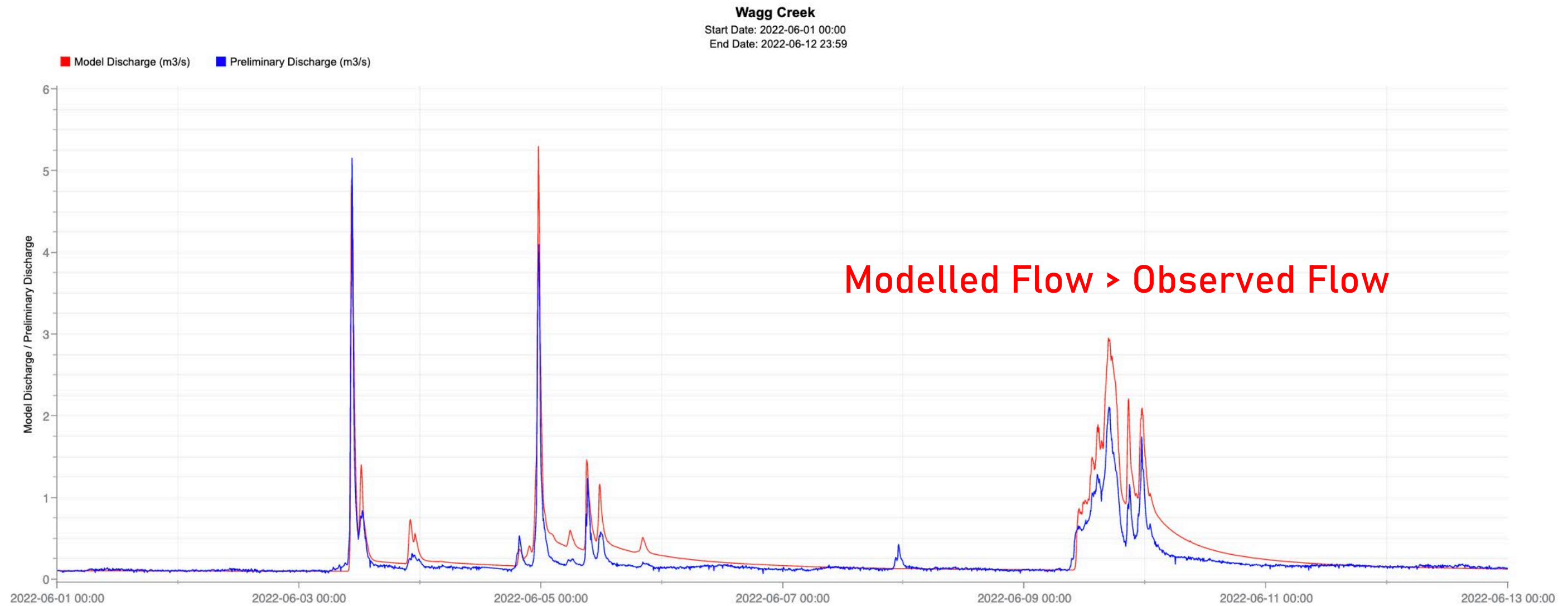
Parameter Convergence



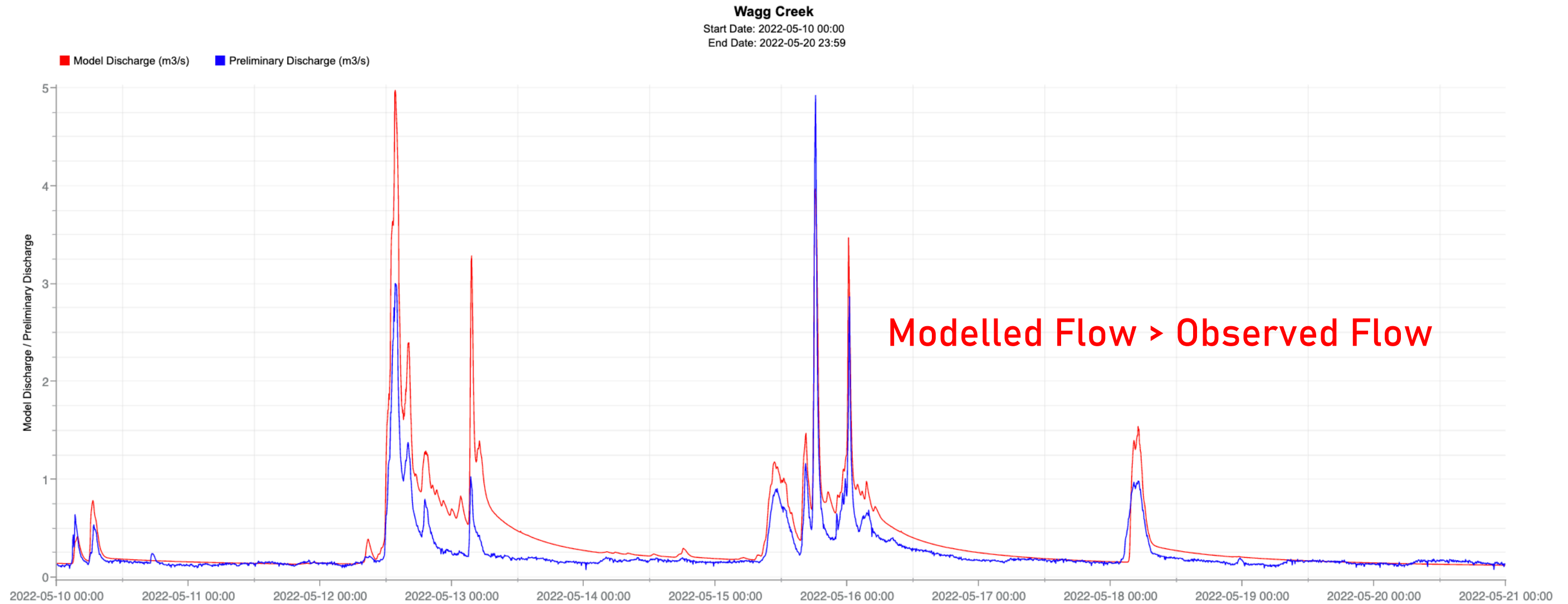
# Modelled vs. Observed Flow in FlowWorks – Winter 2022



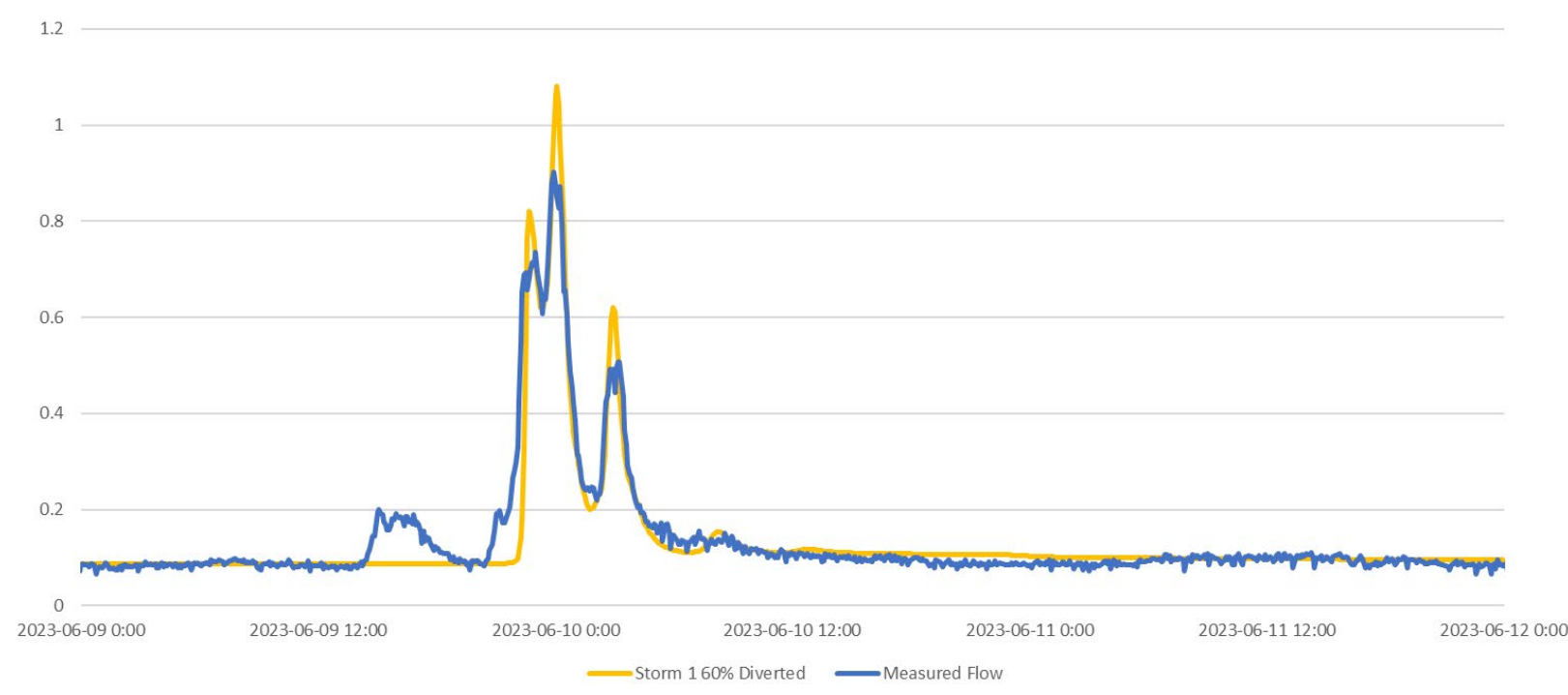
# Modelled vs. Observed Flow in FlowWorks – Spring 2021



# Modelled vs. Observed Flow in FlowWorks – Spring 2022



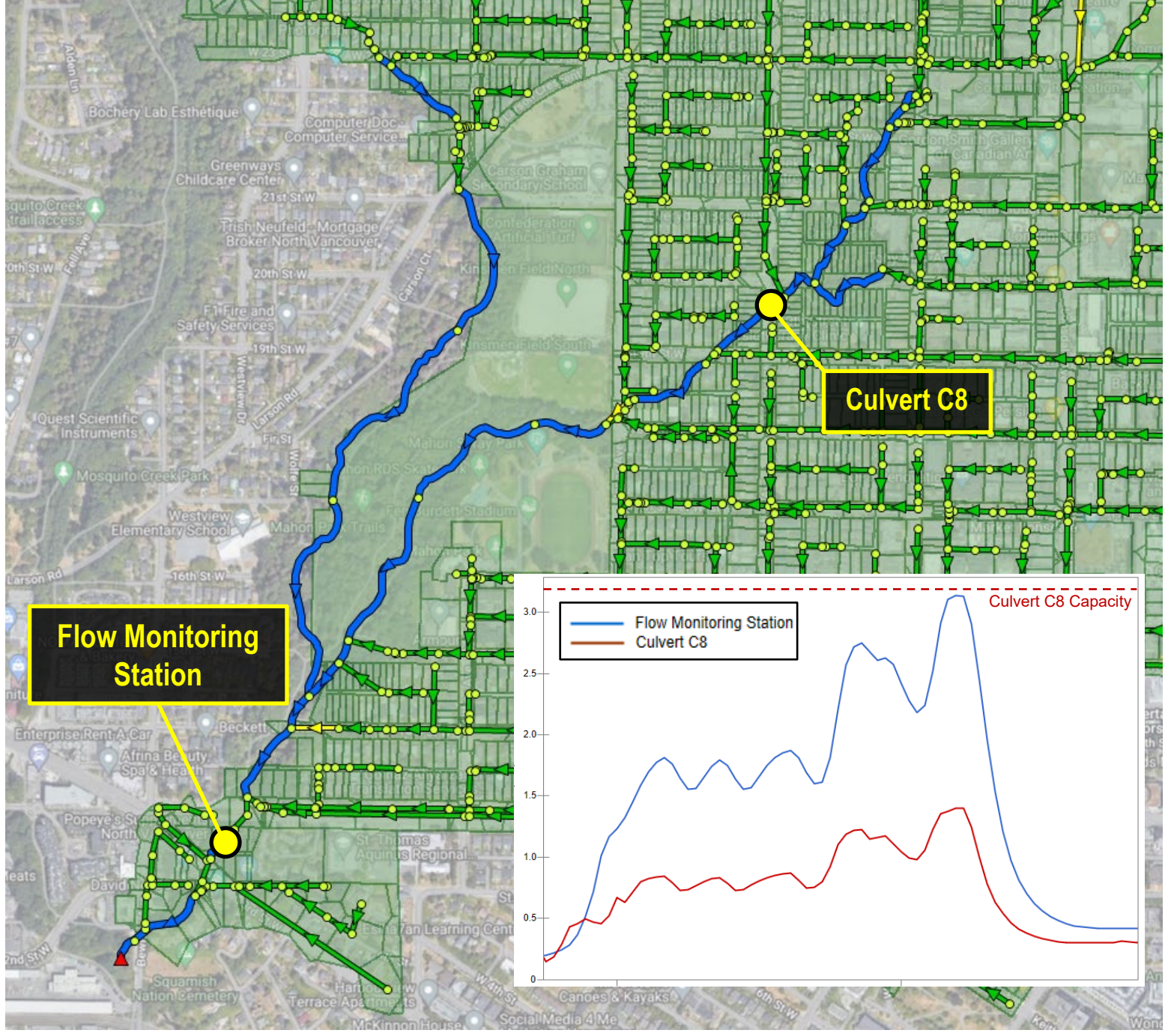
# Wagg Creek SWMM Model Updated 2023 Calibration



- Calibration to 2000's data no longer valid – model flows are higher than monitored flows
- Updated calibration using 2023 data by increasing impervious disconnection in model



# City of North Vancouver Benefits



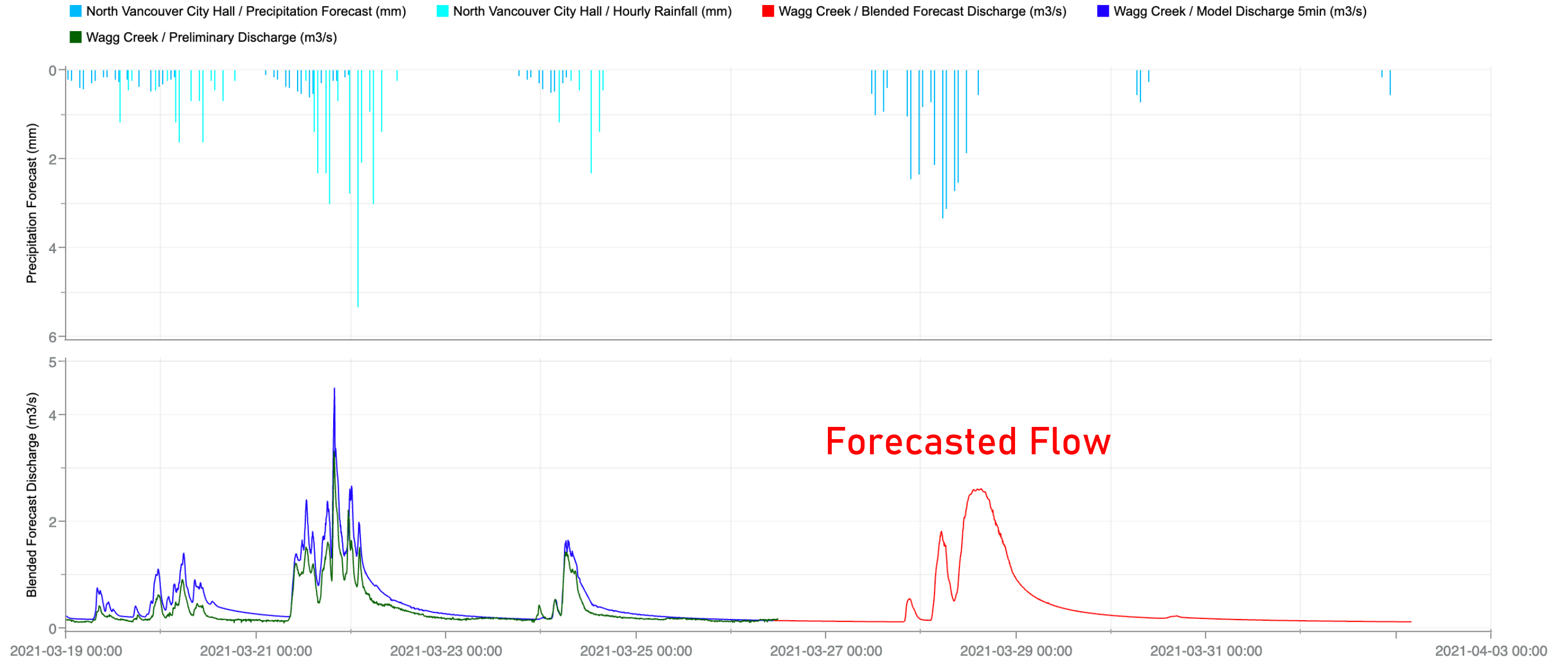
- Alarm when flow monitoring differs from model
- Provides more accurate/detailed flood estimates compared to flow monitoring alarms
- Alarm when flow at culvert location is greater than capacity or design flow.

# Flood Forecasting in FlowWorks

## North Vancouver City Hall / Wagg Creek

Start Date: 2021-03-19 00:00

End Date: 2021-04-02 23:59







## Conclusions

1. The potential stream health benefits of impervious area disconnection and Green Infrastructure can be evaluated with long-term flow and B-IBI monitoring.
2. Real-time modelling can also be used to identify changes in rainfall responses as watershed characteristics change over time.
3. Face Pro can be used to run SWMM (or other models) online with output in FlowWorks for flood forecasting and real-time flow alarming purposes.

## Questions?

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consulting engineers

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**infinitii ai**  
make your data smarter

Work completed for City of North Vancouver

