URBANISATION AND STORMWATER MANAGEMENT EFFECTS ON CATCHMENT-SCALE HYDROLOGY

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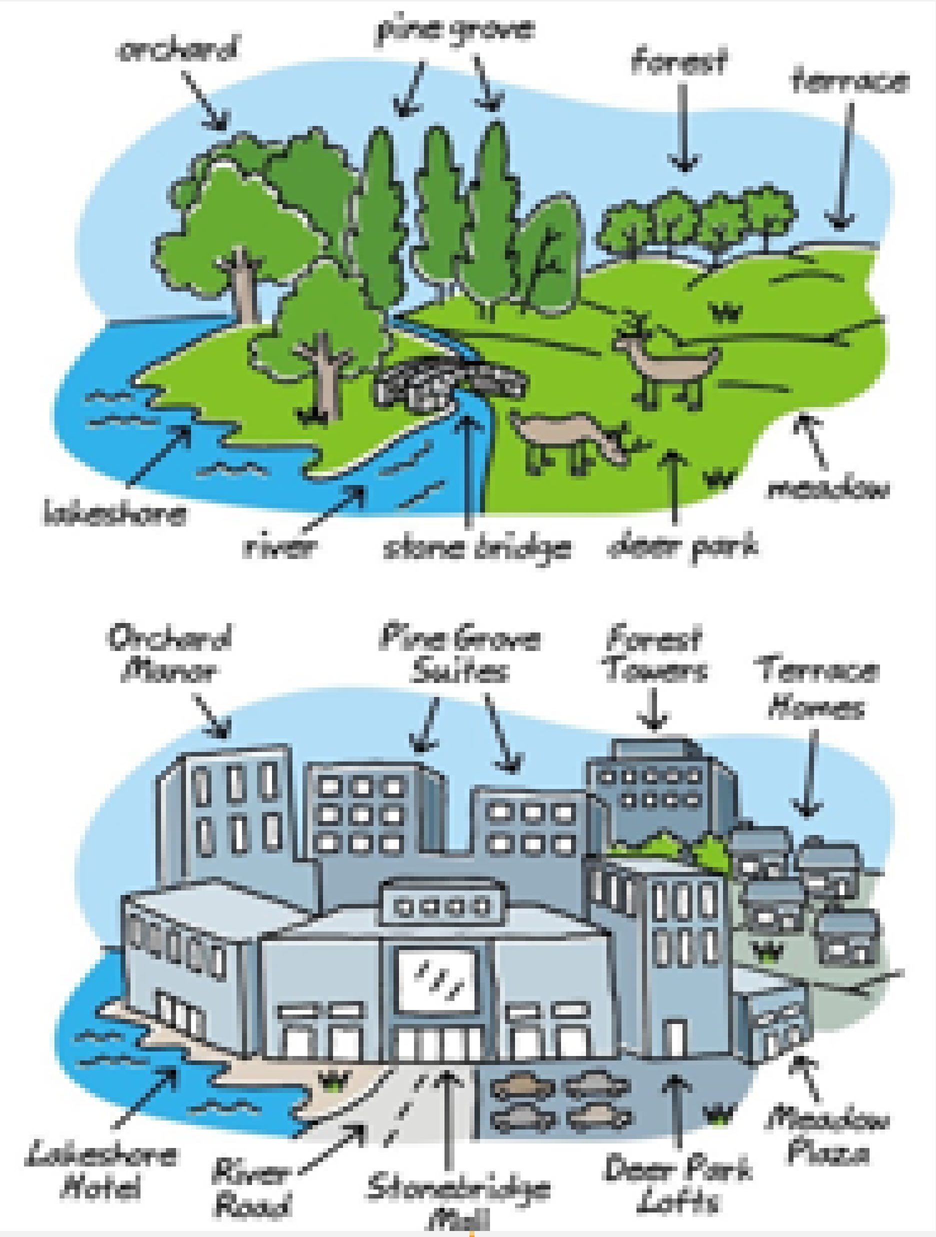
THE UNIVERSITY OF QUEENSLAND AUSTRALIA
CREATE CHANGE
Advanced Water Management Centre
CRC for Water Sensitive Cities

HYDROLOGICAL PROCESSES IMPACTED BY URBANISATION

URBAN STORMWATER STRATEGY



- Increased peak flow
- Degraded water quality
- Changes in baseflow
- Increased runoff
- Increased flooding
- Increased Urban heat

Stormwater management

Drainage-efficiency approach

- Started in mid 20 century
- Stormwater nuisance, waste rather than a resource
- Focused on rapidly conveying the flow as from urban areas to streams

Load-reduction approach

- Started in1990s
- Pollutant load reductions

Problem Statement

Problems

- Urbanization impacts on hydrology
- Stormwater management through pipe drainage and opportunistic SCMs in new developments
- Complex urban hydrology and lack of understanding of rainfall process in different surfaces
- Stormwater management objectives focus on water quality targets

current knowledge catchment scale assessment on hydrology

Knowledge and Gaps

- Lack of evidence on effectiveness of stormwater management
- Many short term empirical studies
- Few empirical long term studies
- Lack of data and difficulty in separating SCMs vs urbanisation
- Lack of catchment knowledge in setting management strategy
- How much rainfall stores in the urban catchments
- No hydrological targets for stormwater management

Some of the research gaps through Literature

1. The effectiveness of infiltration-based stormwater management, LID benefits, retrofit effectiveness poorly understood (Allison, 2014 & Fanelli, 2017 & Eckart, 2017).
2. Yet the extent of retrofit stormwater management necessary to restore healthy streams remains to be determined (D. Fletcher, 2015).
3. Lack of wholesome stormwater management objectives will result in missing out on achieving the outcome. All aspects are magnitude, frequency, timing and rate of change (Hamel, 2013).
4. There is a clear research need to quantify how LID practices affect water quantity (i.e., runoff and discharge) and quality at the scale of catchments. (H.E.Golden, 2017)
5. Contrasting scales impacts on hydrological and water quality dynamics, whilst assessing how management of water in the urban environment is occurring at increasingly local scales. Future work is required to assess the contrasting scale at which these have a demonstrable effect on the overall urban water cycle. (S.J. McGrane,2016).
6. Distribution, Connectivity, density and scale of impact of these GI is varied in different studies need to be investigated and adopted for infill development (V.McConnell, 2010).
7. Lack of watershed strategies that scientifically inform targeted green infrastructure placement (T.H.Epps, 2018).
8. Conventional approached to stormwater management for environmental protection fail because they do not address all of the changes to the flow regime caused by conventional stormwater drainage. (M.J.Burns, 2012)

Literature review

Current understanding and knowledge in cumulative impacts of stormwater strategy in the catchment scale

Over 20 imperial studies undertaken around the world mainly in USA

location and details of empirical studies that reported effects of SCMs on hydrology

Site	Study	Location		catchmen	imperviousnes	Study ti	Key Findings
1	**Fanelli et al.(2017)**	**Annapolis MD, USA**	USA	0.05-0.6	1 to 76.9		This multimetric analysis, which leveraged both discrete discharge and continuous stage-rainfall monitoring data, revealed lower watershed storage, short duration hydrographs, flashier flow regimes, and greater runoff frequency with increasing urbanization. Infiltration-based watershed restorations showed limited success in modulating the hydrological effects of urbanization
2	**Shuster and Rhea (2013)**	**Cincinnati, OH, USA**	USA	0.28-2	13-20	7	The initial analysis of discharge through a statistical model detected small but significant treatment effects. Analysis of the parameters showed a weakened correlation between precipitation and discharge, suggesting an increase in the stormwater initial loss (i.e. ET or groundwater recharge).
3	**Hamel and Fletcher(2014)**	**Melbourne, Australia**	Aus	40			SCM strategies like rainwatertanks decreased the total flow, but had no effect on the altered baseflow regime. Raingardens with a low flow underdrain also did not improve the low flow. A combination of both harvesting and infiltration is more eefective in restoring total flow and baseflow regime, but both options could not completely restore the predevelopment baseflow regime.
4	**J Kim (2018)**	**Cheongju, South Korea**	South Korea	0.14			LID is more effective in short rainfall event with significant reductions and the performance is decreased as rainfall increased
5	**B Yang (2013)**	**Houston, Texas, USA**	USA	89	32	8	Empirical evidence strongly suggests that integrated GI application can be effective in stormwater runoff reduction and water quality improvement
6	**W.K.Yau (2017)**	**Singapore**	Singapore	0.4	78-95		study found that the ABC SUDS features are effective in reducing peak flow for the 10-year design storm, by 33%,
7	**Aryal, Ashbolt, and Mcintosh (2016)**	**Brisbane, Australia**	Aus	1.4-27.9	5 to 70		By implementing stormwater harvesting options the hourly flows were reduced by up to 60 % but the maximum flow was unchanged
8	**J.V.Loperfido (2014)**	**Washington DC, USA**	USA	1.1-7.02	3 to 39	2	During rainfall events decentralised SCMs result in lower maximum discharge and stream response, higher baseflow than centralized SCMs; yet land cover caused the most of total runoff volume reduction and stream response decrease. Results suggested a combination of greater forest land cover and distributed SCMs as a solution to manage urban waterways
9	**A.S. Bhaskar (2016)**	**Maryland, USA**	USA	1.11	30	10	during development baseflow and total flow increased and after urbanization baseflow seasonality decreased and baseflow recesstion rate decreased
10	**C.J.Walch(2015), M.Burns(2016)**	**Melbourne , Australia**	Aus	4.5	13.5	8	study covers 10 catchment - The catchment that had SCMs implemented have significantly reduced the streamflow volume and runoff coefficient, which is not the case in reference and control catchments
11	**Jarden et al. (2016)**	**Ohio, USA**	USA	0.11	55.5	3	The results of this study illustrate promising effectiveness of catchment-scale green infrastructure retrofits in mitigating stormwater run-off from headwater streets by reducing peal and total flow volume and increased lag time
12	**S.Kebler (2012)**	**Palatinate,Germany**	Germany	0.4	33	2	can conclude that green infrastructure retrofits have the demonstrated potential to improve catchment-scale stormwater run-off, but they do not always perform up to that potential.
13	**R.Hale(2015)**	**Scottdale, Arizona, USA**	USA	1.2 - 5.6	49-5.6	79	infrastructure design strongly have impact on watershed hydrology and water quality(N, P, and DOC)
14	**C.D. Bell (2016)**	**North Carolina,**	USA	2.5 to 32.9	4 to 54	1	the signal produced by the distribution of SCM mitigation was insufficient to overcome the signal from imperviousness, (2) these metrics do not incorporate necessary information on spatial arrangement of both impervious surfaces and SCMs, (3) TI is actually a better predictor than EI of the suite of hydrologic behaviours studied here and (4) SCMs are unable to reverse the connection between urban surfaces and streams formed by storm drainage pipes (i.e., some mitigated impervious surfaces are still effective)
15	**J.L.Page(2015)**	**Willington, NC,USA**	USA	0.003-0.005	60	2	SCMs of limited size and application installed as retrofits within the street right-of-way can mitigate some of the water quality impacts of existing residential developments
16	**W.A.Gebret (2012)**	**Middleton WI, USA**	USA	153.2	N/A	33	Based on data collected for streamflow data collected at the Pheasant Branch at Middleton streamflow-gaging station, flood peak discharges increased 37 percent for the 2-year flood and 83 percent for the 100-year flood. And scm could reduce the sediment dicharge and total ph
17	**L.Locatelli (2016)**	**Perth Australia**	Perth	112	24	40	The simulated contribution to stream flow from the whole model area in the period 2009-2014 was 16% of the incoming rainfall.
18	**M.J.Pennino (2016)**	**Washington, MD-DC, USA**	USA	0.001-14	0.5 34.3	11	Specifically,this studyfoundthatatthewatershed scale, when stormwater green in-frastructure controls is larger than 5% of drainage area,flashy urban hydrology and nitrogen exports are reduced.
19	**D.E.Line (2015)**	**Chapel Hill, NC, USA**	USA	0.03	24	6	Monitoring results documented that the postdevelopment, runoff to rainfall ratio, and pollutant export at both stations were significantly greater than those of the predevelopment phase, during which time the land use on the site was mature woods
20	**Aulenbach (2017)**	**County, GA, USA**	USA	3 to 24	12 to 52	15	m 28.4 to 55.1 percent for WYs 2002–15, with lower runoff ratios in low precipitation years. The watersheds with the highest percentage of impervious areas had the highest runoff ratios.
21	**Selbig (2008)**	**Wisconsin, USA**	USA	0.55 to 0.77		6	The 'LID basin' retained more stormwater discharge (95% of precipitation), resulting in much lower total annual discharge volume than the 'conventional basin'; The last and largest SCM – infiltration basin retained much of the stormwater runoff, but its effectiveness decreased with increasing precipitation intensity (>0.5 inch/h).
22	**Hur(2008)**	**Carolina, USA**	USA	0.51 to 31	28	1	The developing catchments had flashier hydrographs and higher area-normalized peak flows than the relatively undisturbed catchments. Thus, the implemented SCMs failed to consistently control stormwater runoff.
23	**Hood (2007)**	**Waterford, Connecticut**	USA	0.02 to 0.055	22 to 29	3	The research focused on surface runoff. Stormwater runoff (volume, peak discharge) from the impact subdivision remained unchanged/reduced, lag times increased, compared with the control subdivisions.
24	**Wilson (2015)**	**North Carolina,**	USA	0.02		1	While both subcatchments had great reductions in peak discharge (>98%), the subcatchment with distributed SCMs had much more runoff volume reduction (98.3% median) than the other one (51.4% median).

1

2

3

Shuster and Rhea (2013)

Cincinnati, OH, USA

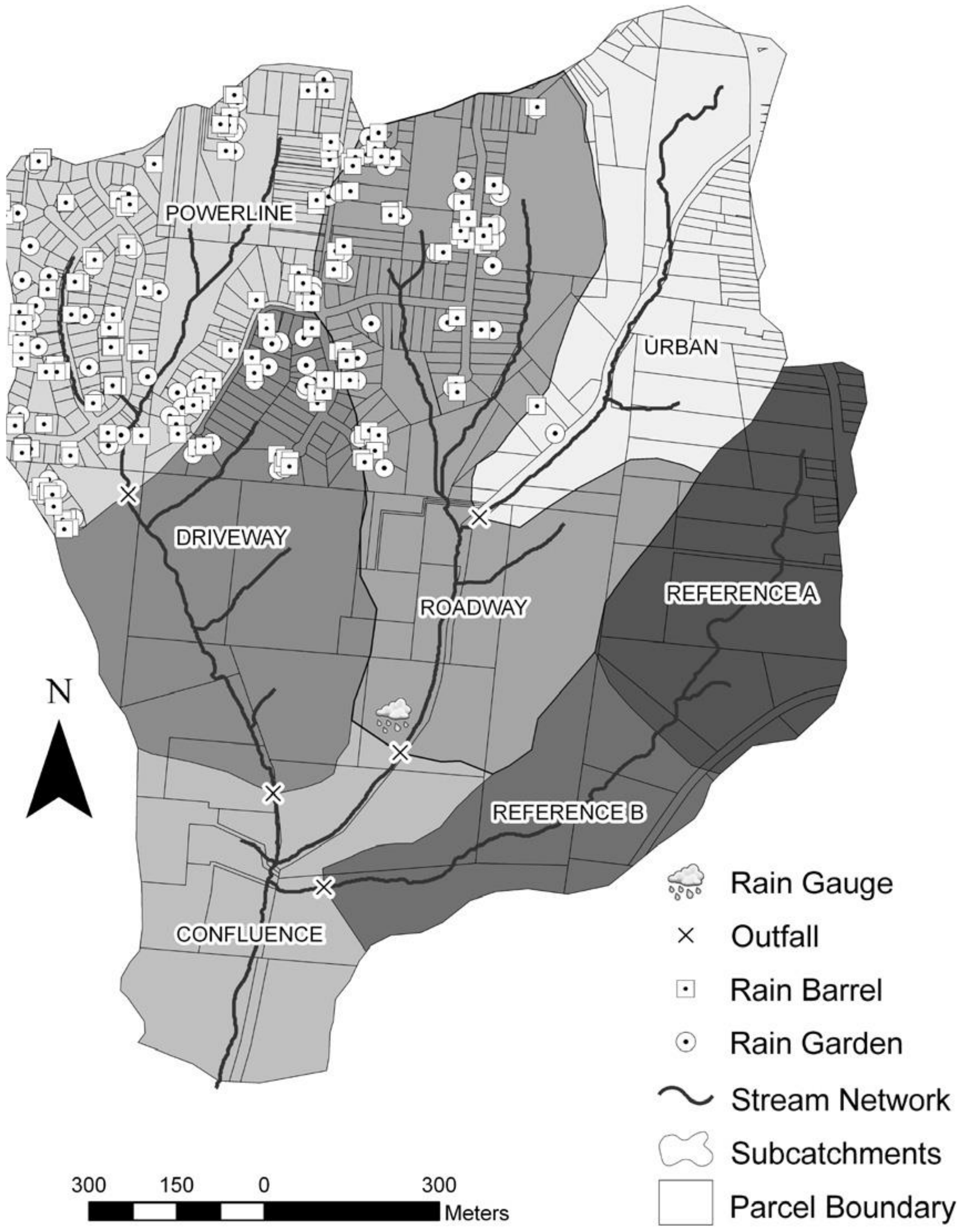
Stream discharge and precipitation were monitored 3 years before and after implementation of the stormwater management treatments

Catchment areas are 0.28 – 2.0 km^2 with 13% to 20% imperviousness

BACI design (Before After Control Impact)

The control catchment showed a weakened correlation between precipitation and discharge

Study concluded that retrofit management of stormwater runoff quantity with green infrastructure in a small suburban catchment can be successfully initiated with novel economic incentive programs, and that these measures can impart a small, but statistically significant decrease in otherwise uncontrolled runoff volume.



Loperfido (2014)

Washington DC, USA

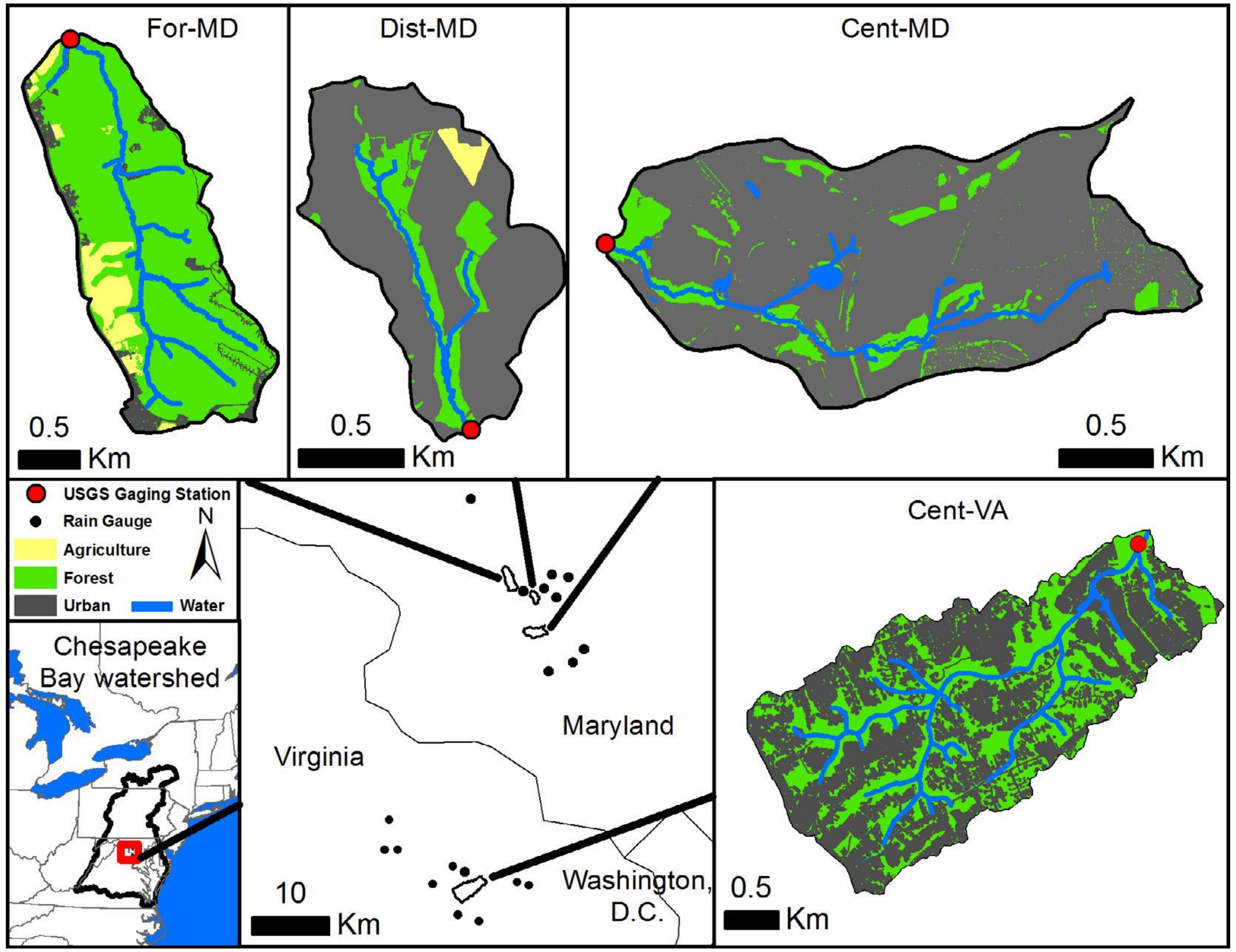
Stream hydrologic data (March, 2011–September, 2012) are evaluated in four catchments located in the Chesapeake Bay watershed

Pair Design

Catchment areas are 1.1 to 7 km^2 with 3% to 39% impervious

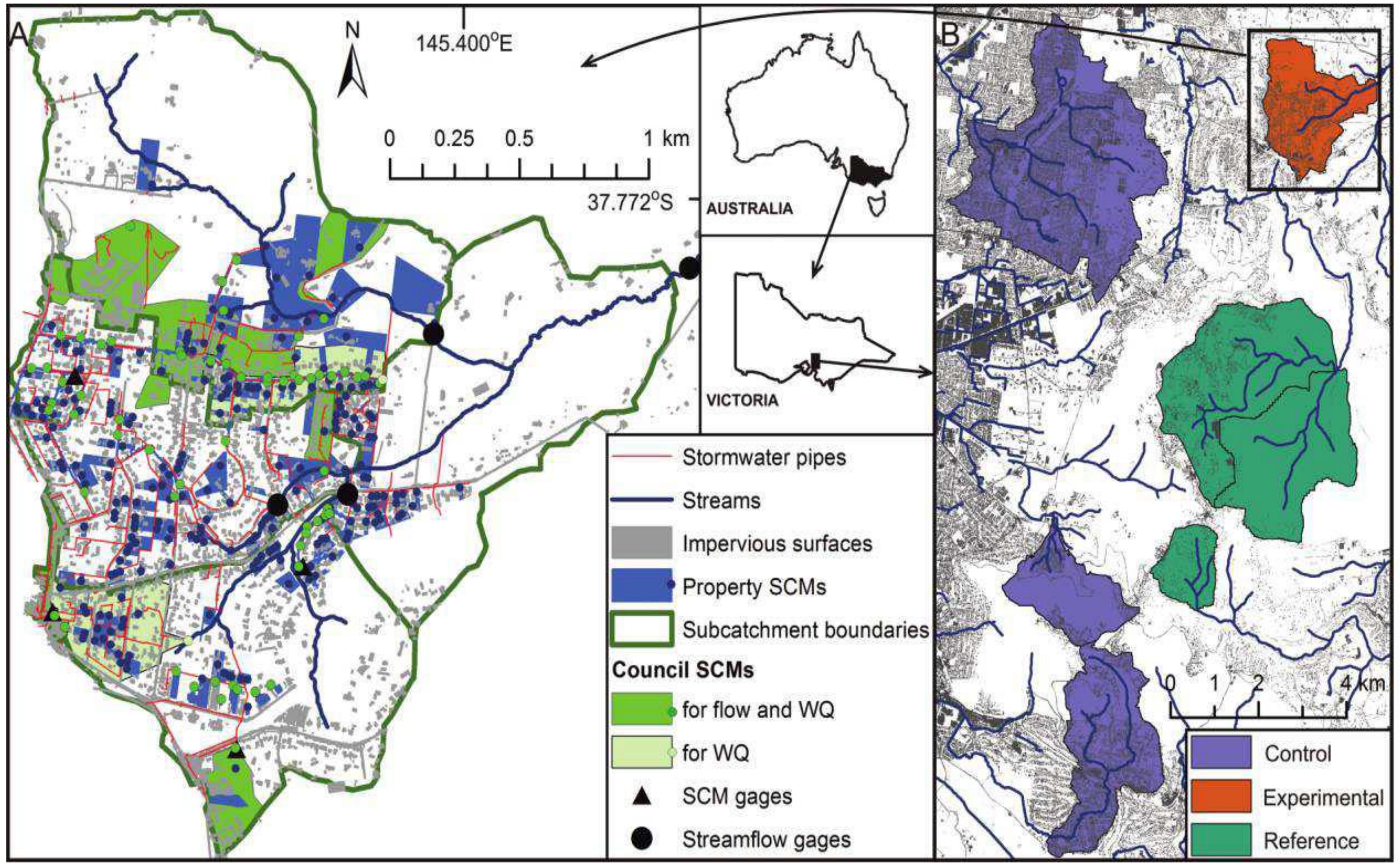
During rainfall events decentralised SCMs result in lower maximum discharge and stream response, higher baseflow than centralized SCMs; yet land cover caused the most of total runoff volume reduction and stream response decrease

Results suggested a combination of greater forest land cover and distributed SCMs as a solution to manage urban waterways



C.J.Walch(2015), M.Burns(2016)

- Melbourne Australia
- Mel Uni team worked with government authorities and the catchment community (residents and property owners) over several years to fund and implement 289 stormwater retention systems
- Catchment area of control catchment is 4.5 km^2 with 13.5% imperviousness
- BACRI design (Before After Control Reference Impact)
- Runoff coefficients for individual storm events show small but significant reductions over time



Discussion - Does stormwater management works?

In *theory* it is possible to return predevelopment hydrology if SCM network, perfectly mitigate all effects of urbanisation.

In *practice* the goal of stormwater management which is broadly around restoring the predevelopment hydrology is rarely achieved.

Most studies detected changes in small changes in hydrology such as reduction in annual runoff.

All the empirical studies attempted the open this matter to some extent, however there are still a lot of complexities still remaining.

***Catchment capacitance*, *climatic changes* and other urbanisation changes are other variables that hugely influence the runoff generated from impervious surfaces.**

Disclaimer <u>“design aim of these systems it to improve the water quality not the hydrology directly”</u>

This research method

Collect and review data for urbanised and reference catchment in subtropical climate (Brisbane)

How does the urbanization and drainage efficiency approach change the urban hydrological response in catchment?

How does cumulative stormwater control measure practices change the urban hydrological response in catchment?

What ratio of rainfall converts to runoff in subtropical urbanised catchment?

ANALYSIS – STREAMFLOW COEFFICIENT

To assess the increase of runoff volume generated by impervious surfaces the following data has been calculated

$$\text{Streamflow coefficient} = \frac{\text{Annual discharge depth (mm)}}{\text{Annual rainfall (mm)}}$$

$$\text{Annual discharge depth (mm)} = \frac{\text{Annual discharge flow } (m^3)}{\text{Catchment Area } (m^2)}$$

Annual discharge flow (m3) = Sum of Daily discharge flow (m^3/day) in 1 year

Daily discharge flow (m3/day) = Sum of all measurement in one day of stream height gauge (m) [converted to flow using flow duration curve] (m3/s]* timestep in (s) to the next reading

BASEFLOW ESTIMATE METHOD

- Baseflow is a streamflow component which reacts slowly to rainfall and is usually associated with water discharged from groundwater storage. Knowledge about baseflow is useful in the assessment of water quality and low-flow conditions.

$$y_k = f_k + b_k$$

yk: Total stream flow

fk: Runoff

bk: baseflow

K: the time step

There are two main methods

- Graphical Hydrograph separation method (GHS)
  - Recursive digital filter (RDF)
    - Lyne & Hollick

$$b_k = \frac{3a-1}{3-a} b_{k-1} + \frac{1-a}{3-a}(y_k + y_{k-1});\ b_k \le y_k$$

    - Eckhardt

$$b_k = \frac{(1 - BFI_{max}) a b_{k-1} + (1-a) BFI_{max} y_k}{1 - a BFI_{max}}$$

- Tracer Mass balance method (MB)

Bulimba Catchment Case Study

Catchment selection and Data collection

DEM (Digital Elevation Model)

Topographic survey data (LiDAR survey 1m)(supplied by BCC)

Impervious mapping for 2005 and 2014. (supplied by BCC)

Brisbane historic aerial imagery (supplied by Qimage)

Land use characteristics

Continues observed runoff (supplied by BCC and DNRM)

Continues rainfall record (supplied by BCC and BOM)

Stormwater assets database (BCC)




Bulimba Creek

Bulimba Creek catchment extending from the southern suburbs of Kuraby and Runcorn, to the confluence with the Brisbane River at Hemmant in the north. Bulimba Creek has eight major tributaries and a number of significant wetlands

Total catchment covers an area of 122 km^2. The catchment area reporting to DNRM/ BCC gauge is 57 km^2

The catchment comprises primarily of urban residential land use

Moggill Creek

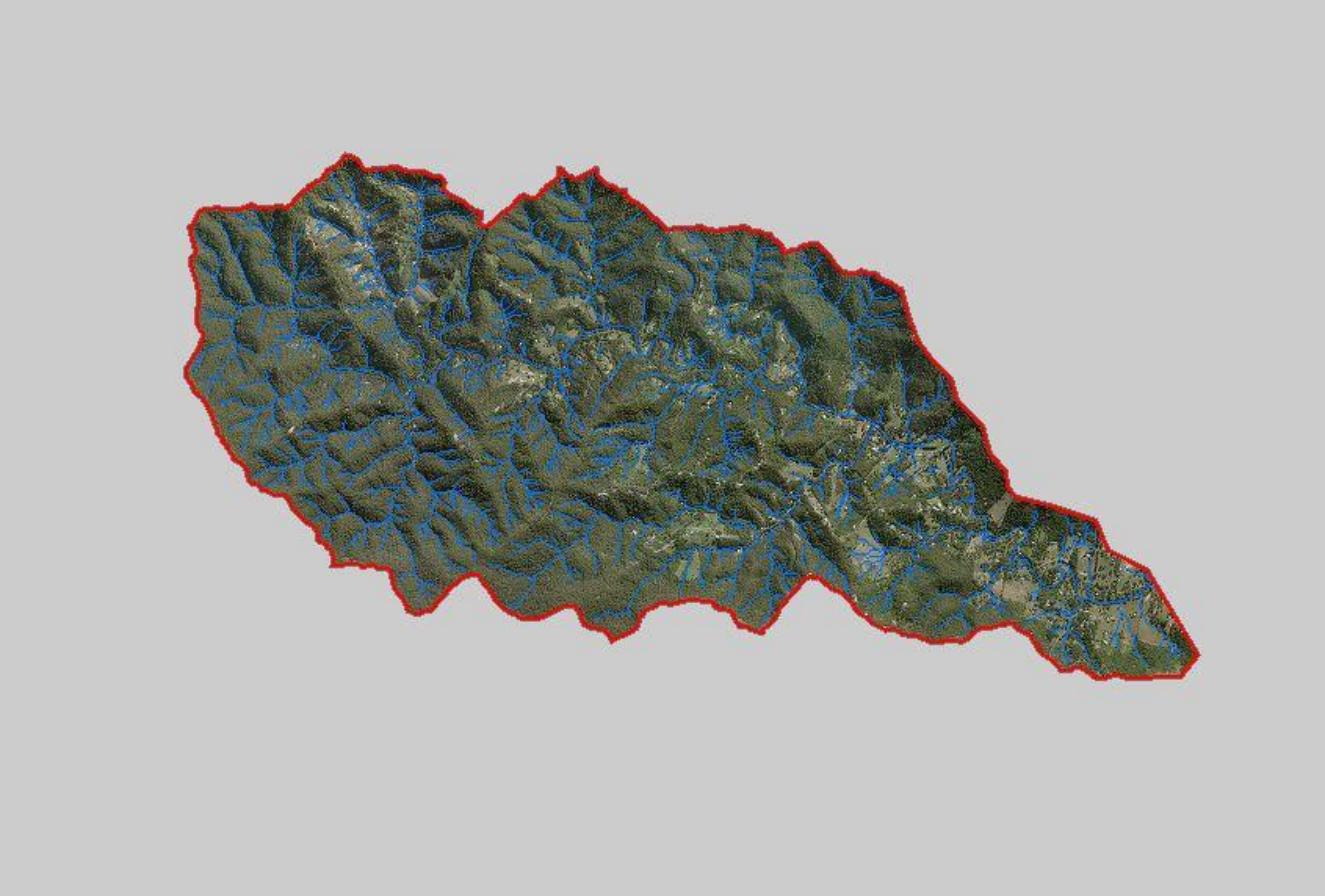
includes all or part of the suburbs of Kenmore, Kenmore Hills, Brookfield, Upper Brookfield, Mt Coot-tha, Pullenvale and Pinjarra Hills

Total catchment 57.6 km^2

The catchment area reporting to DNRM gauge is 23 km^2

catchment contains a number of land uses, including state forest and housing, comprised primarily of low density semi-rural and rural residential properties in the upper and middle catchment

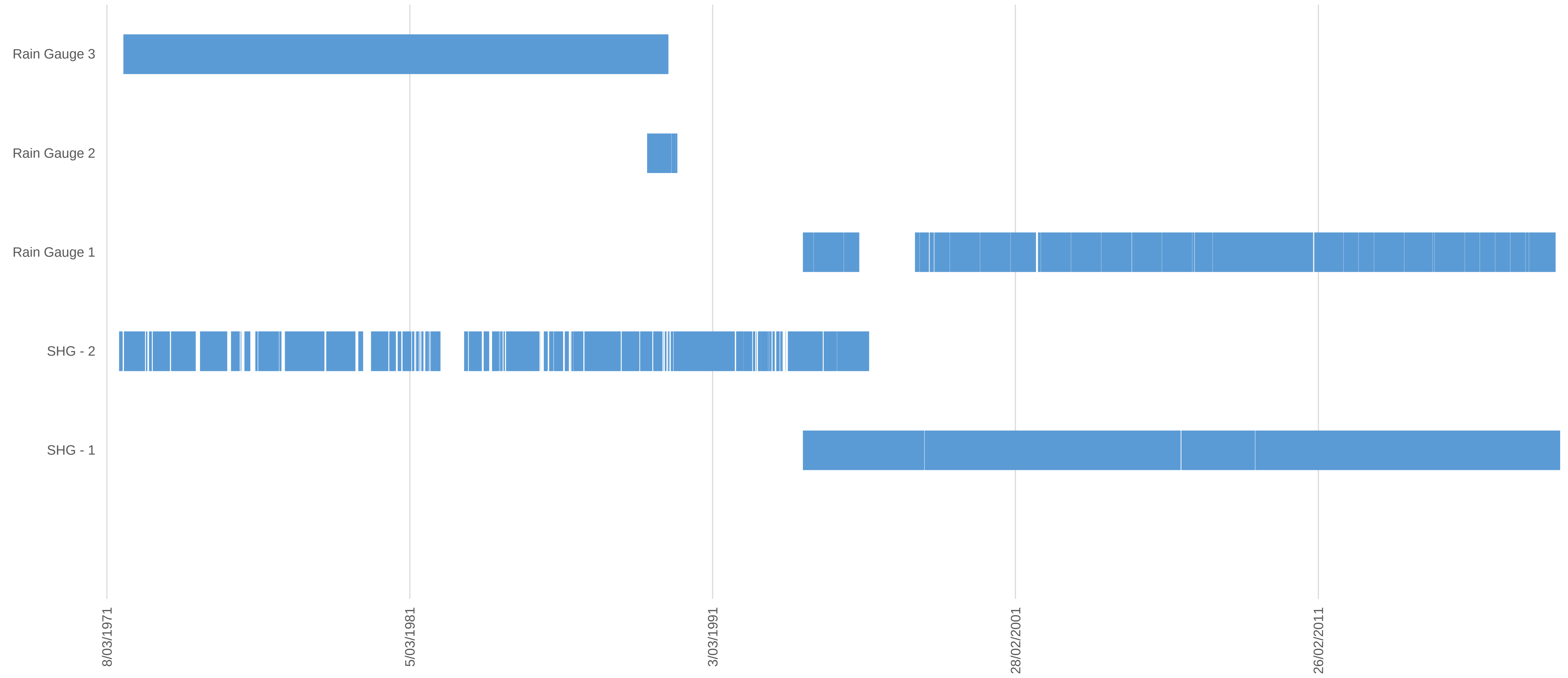
Very steep catchment

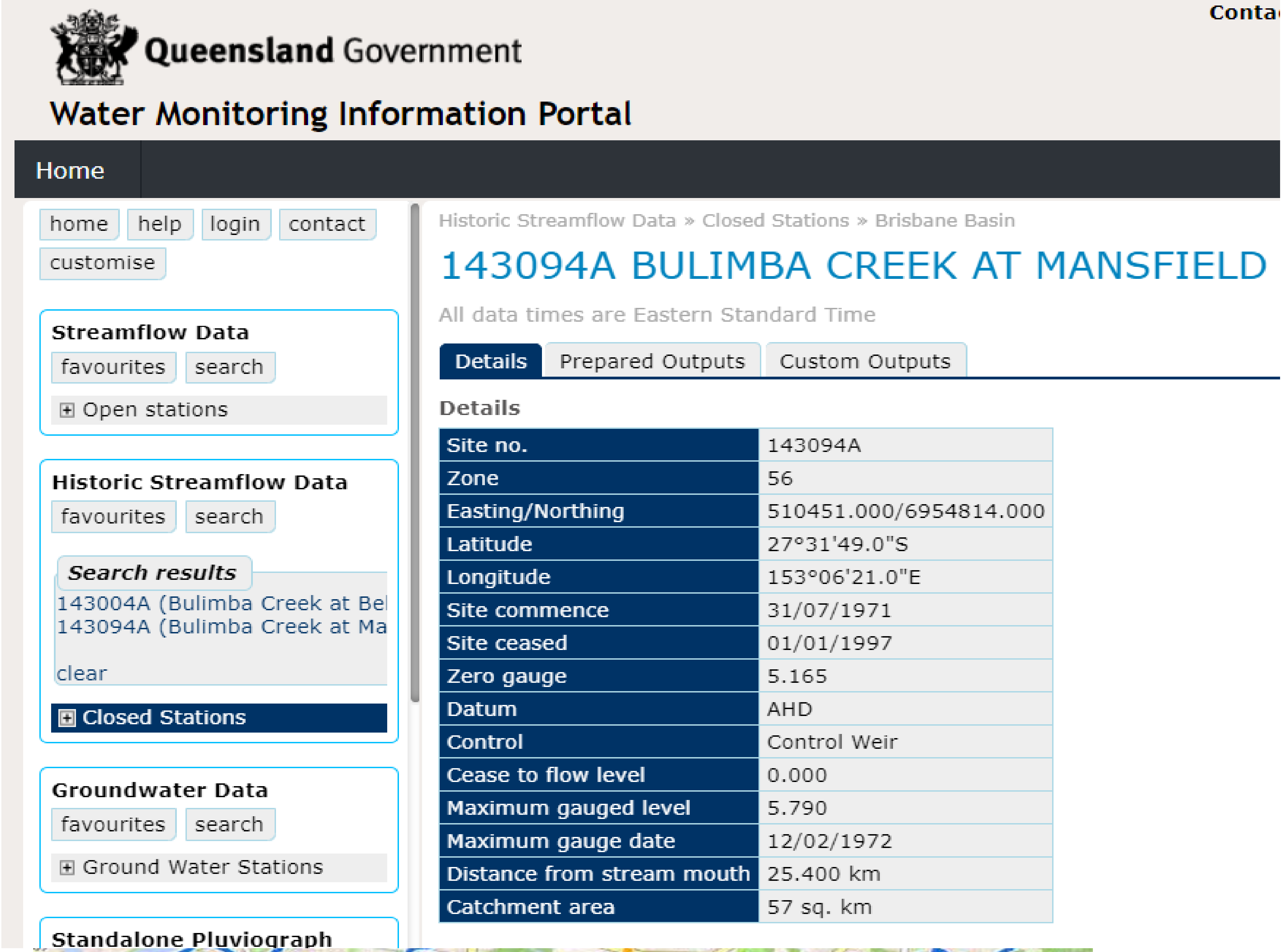


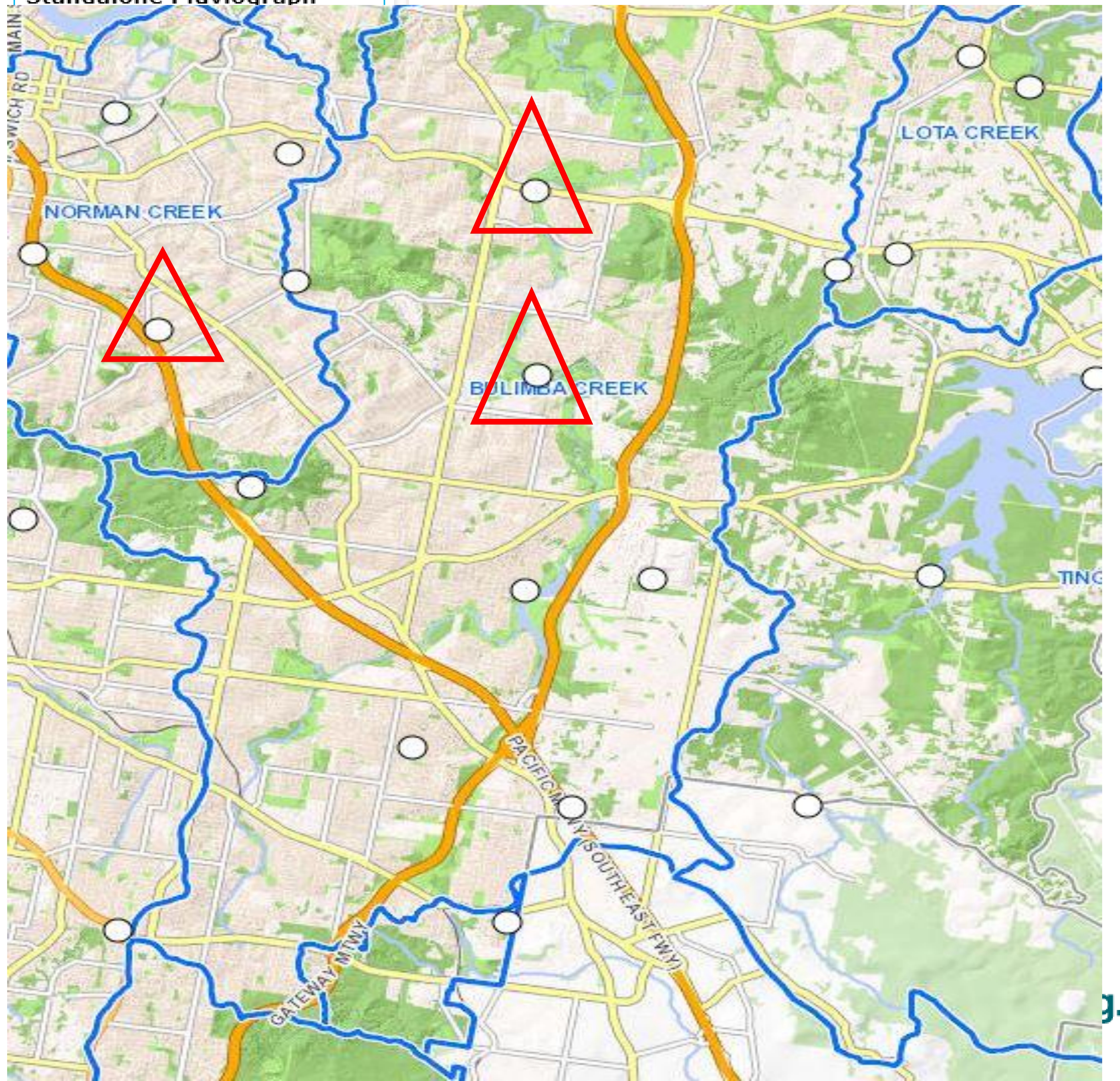
CHARACTERISTICS OF THE TWO CATCHMENTS

Items	Bulimba Creek	Moggill Creek
Gauge number	143094A/ BMA 831	
Lat. and long.	-27.5303 , 153.1058	-27.4883 , 152.8924
Control type	Weir	Weir
Years of record	47 (1971 – 2018)	42 (1976 – 2018)
Agency	BCC/DNRM	DNRM
Catchment size	57 km^2	23 km^2
Land use	Residential, industrial, commercial, open space, natural parks	Rural Residential – forested - grassland
Imperviousness	2018 (TBC) – 2014 32% - 2005 29% - 1995 (TBC)	2018 (TBC) – 2014 1% - 2005 0.8% - 1995 (TBC)
WSUD	100,000(m^2) treating 1% of catchment	NA

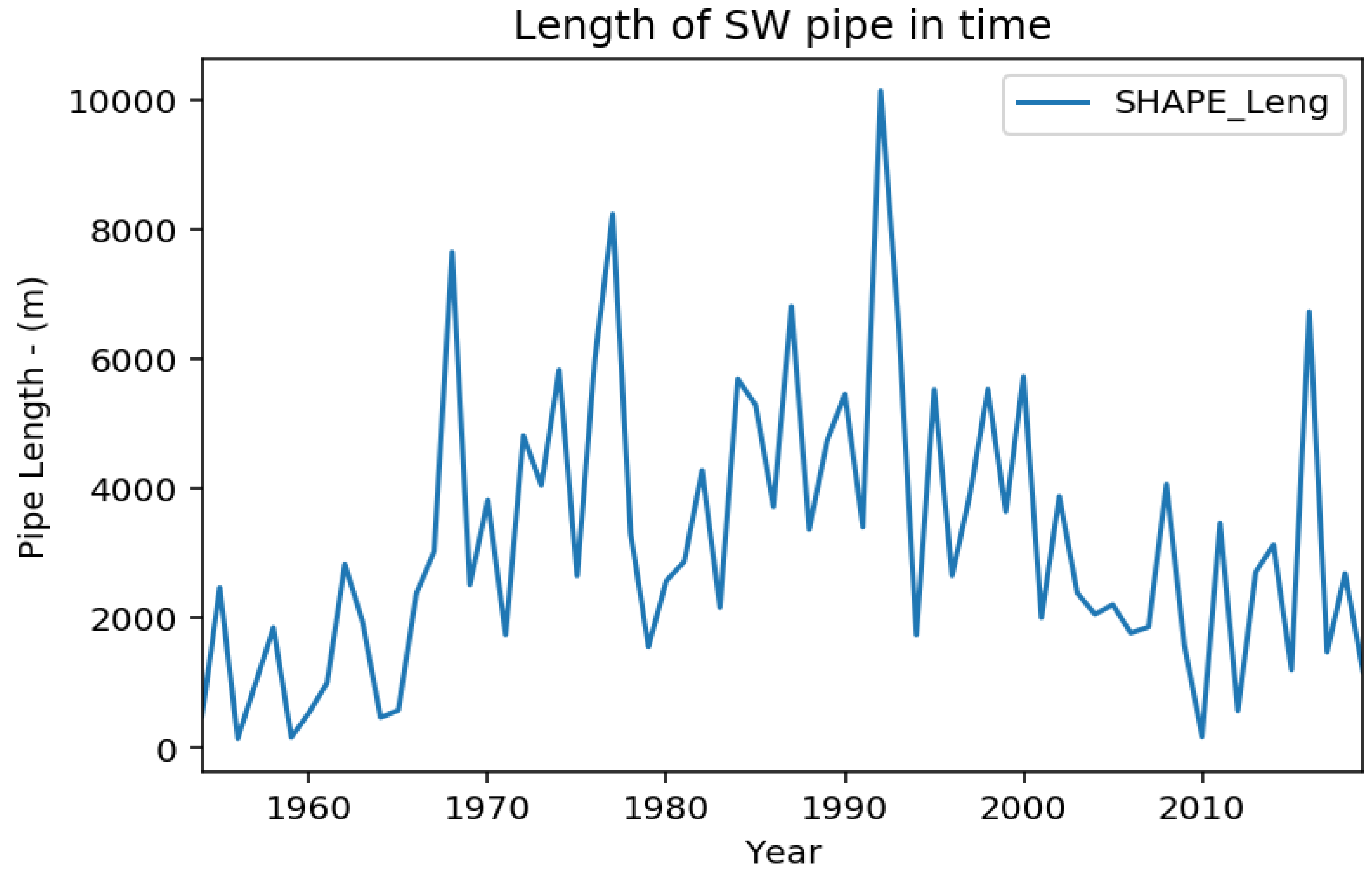
Bulimba Creek data plot

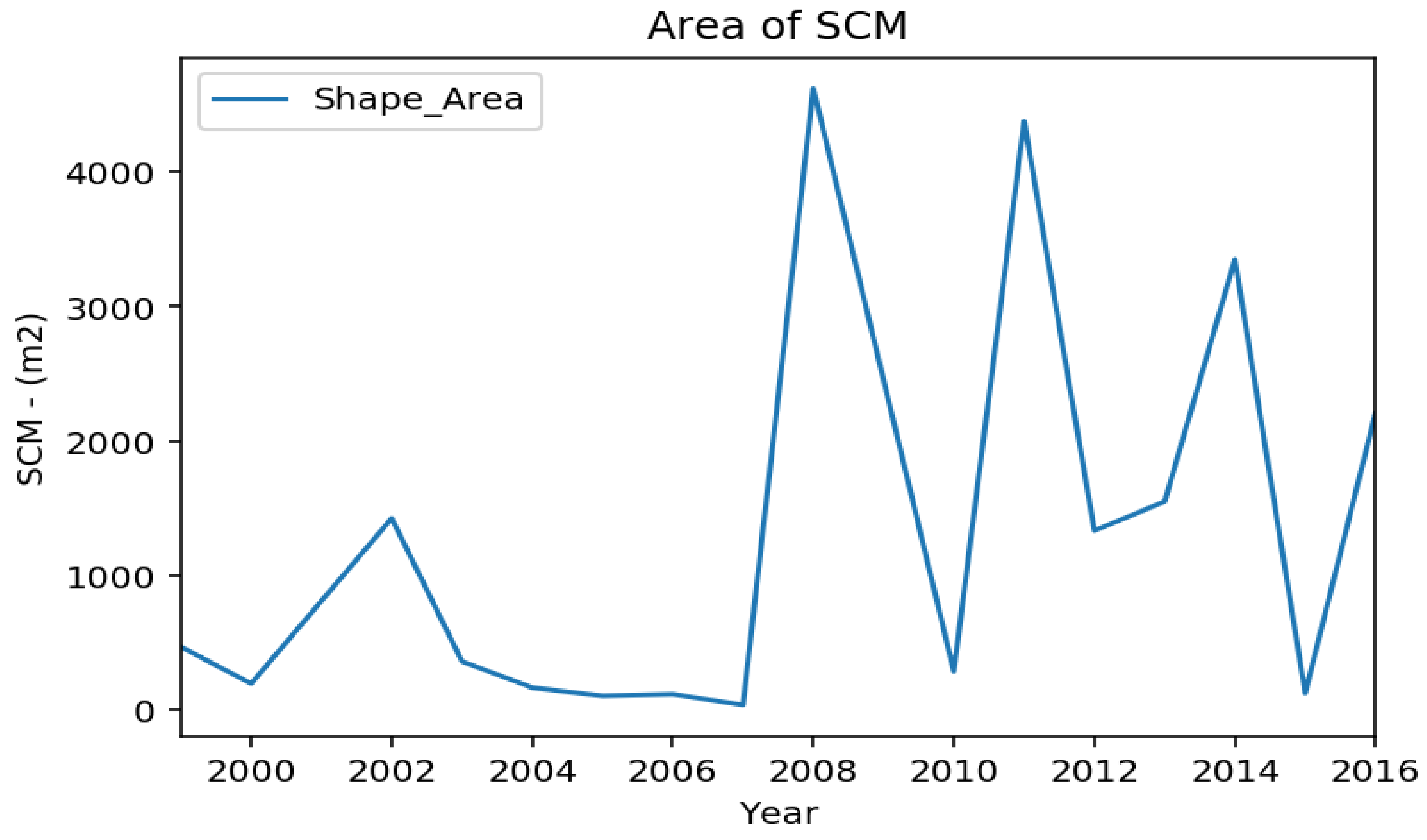


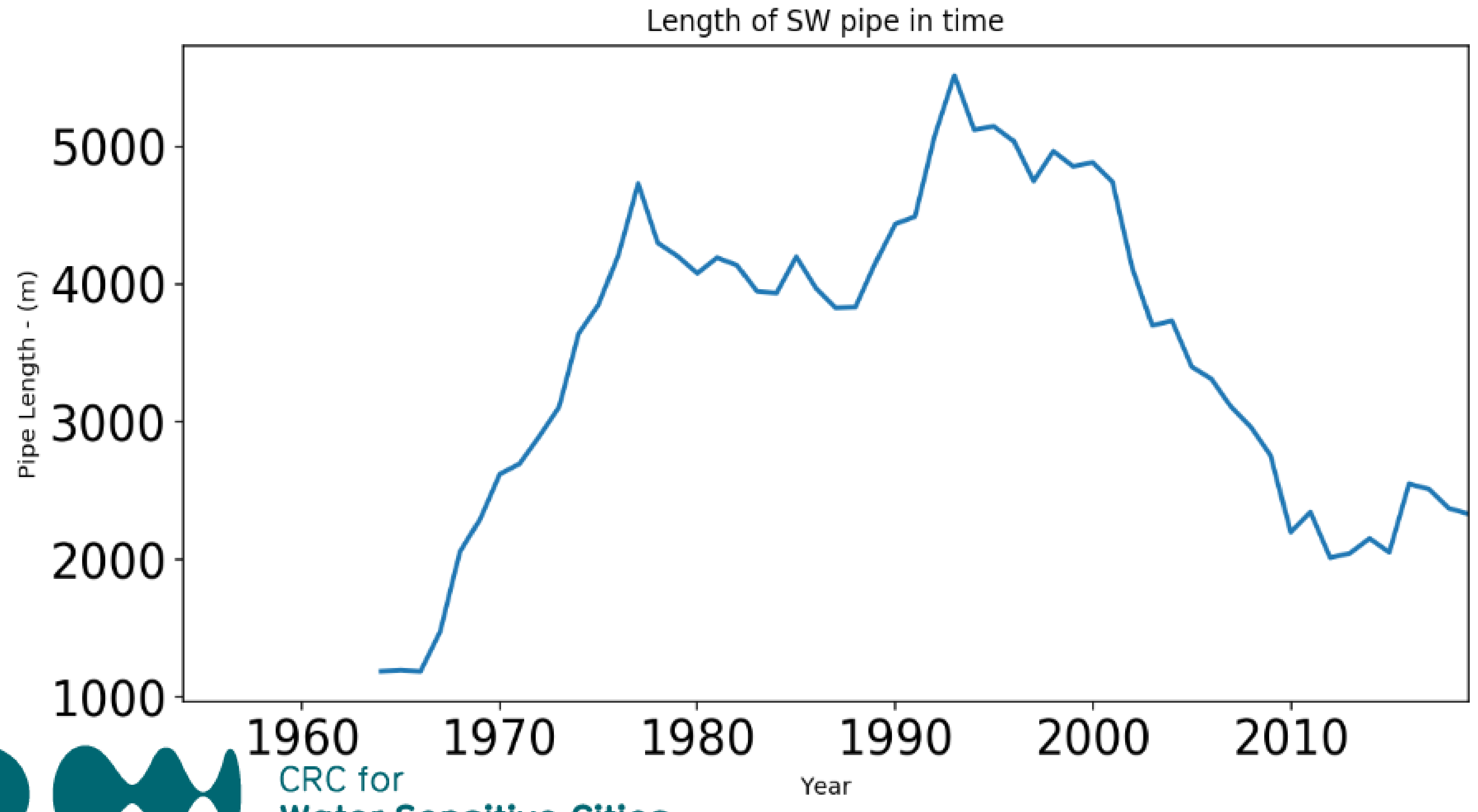


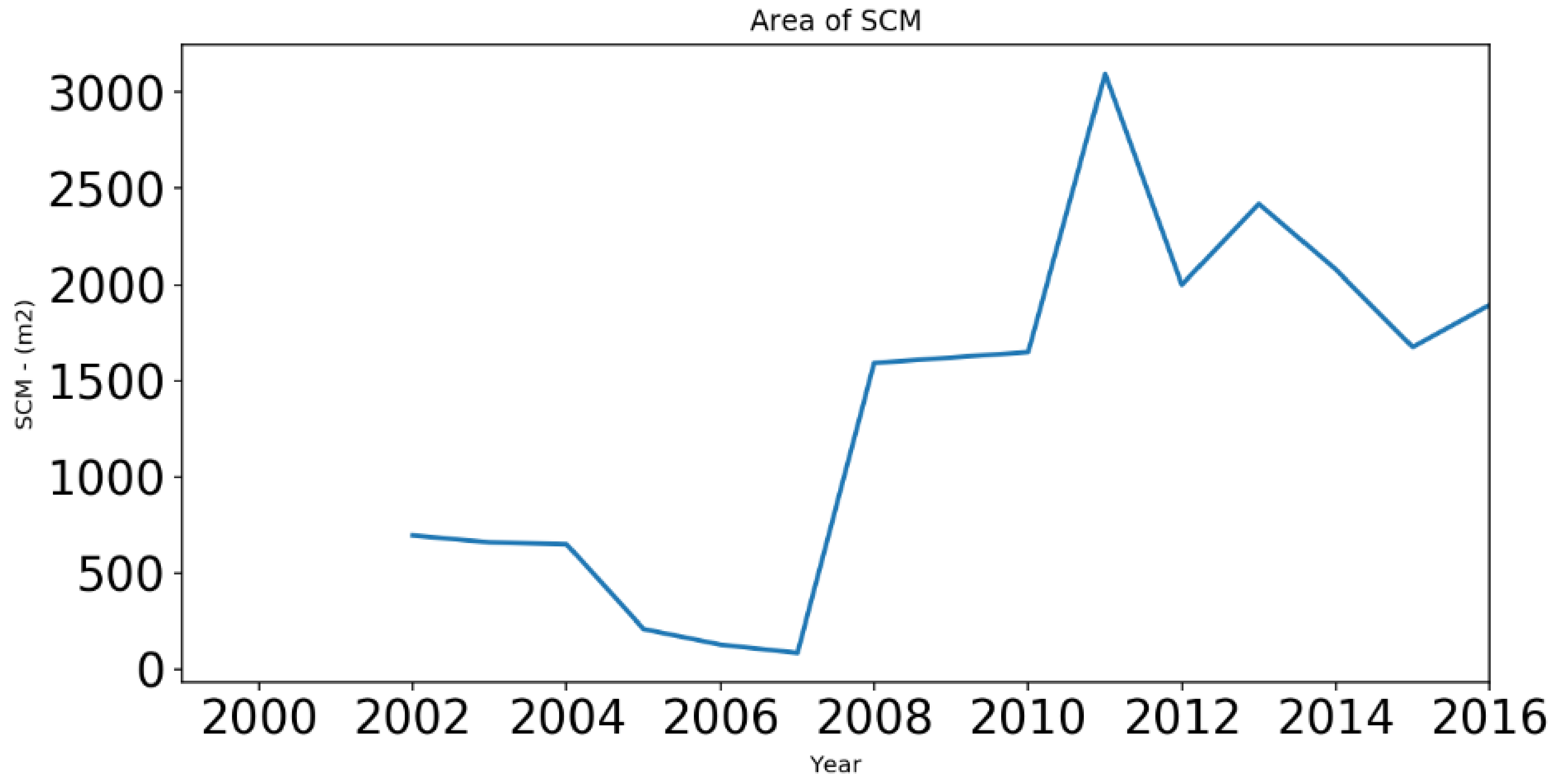


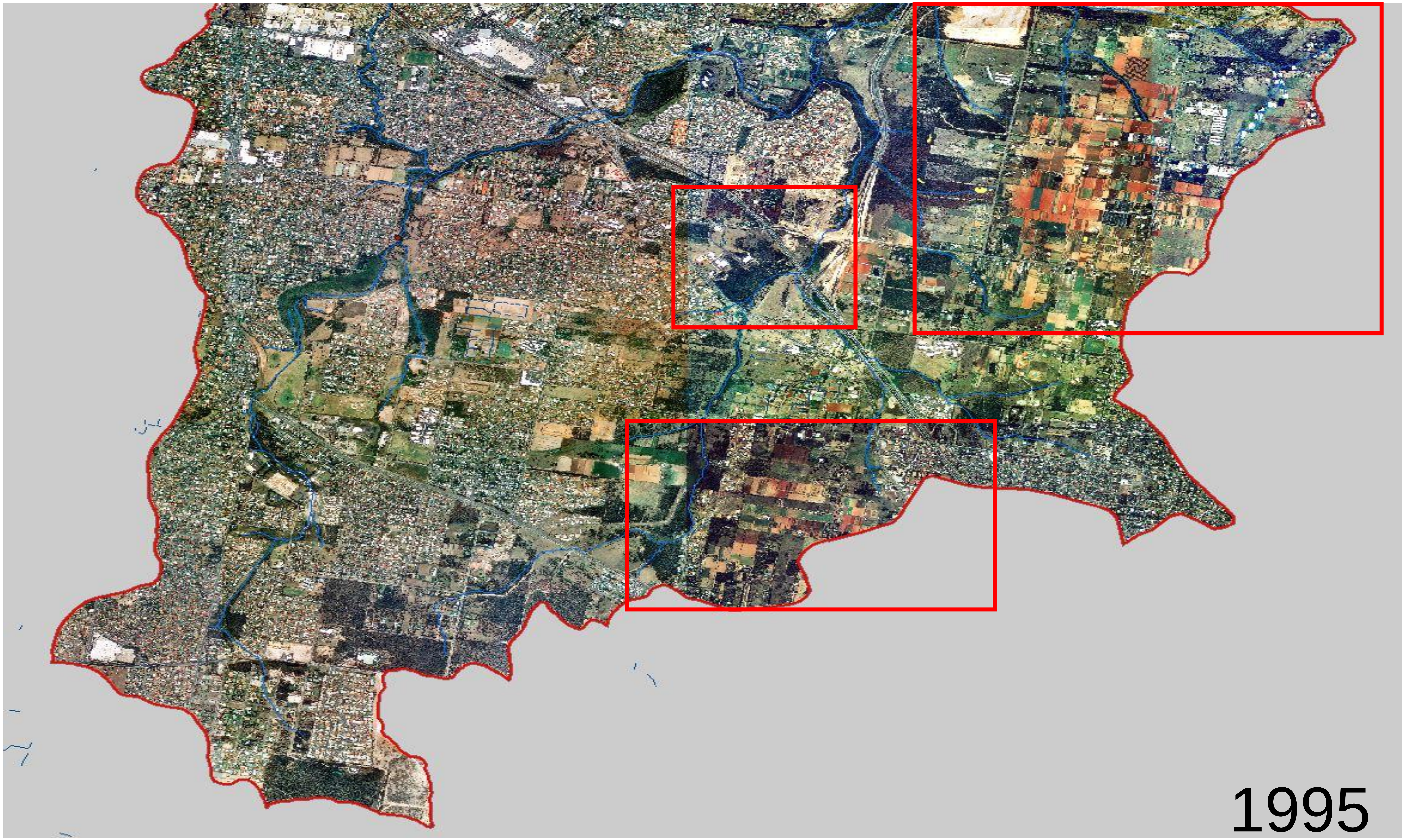
Stormwater drainage and SCM in Bulimba

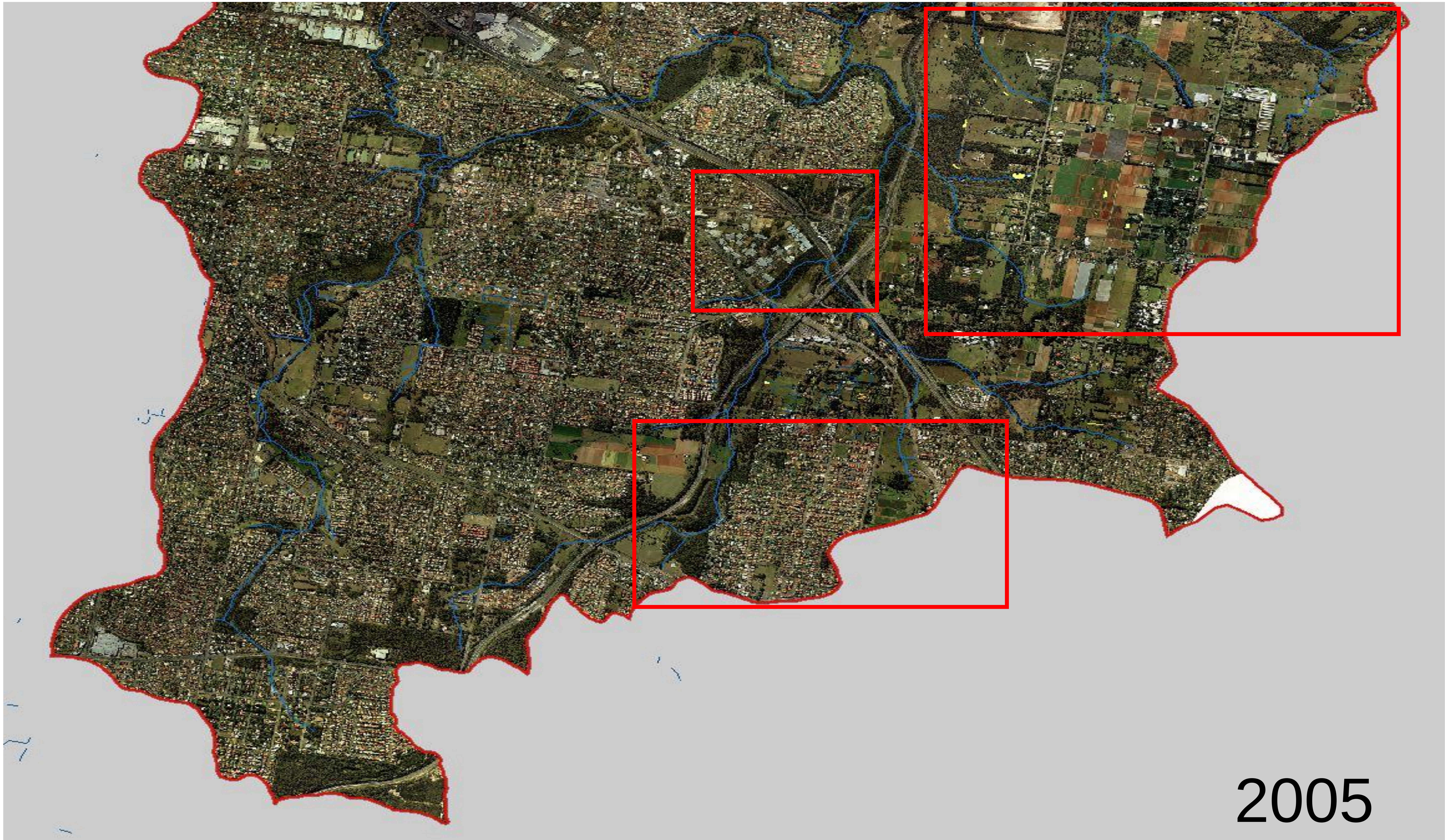


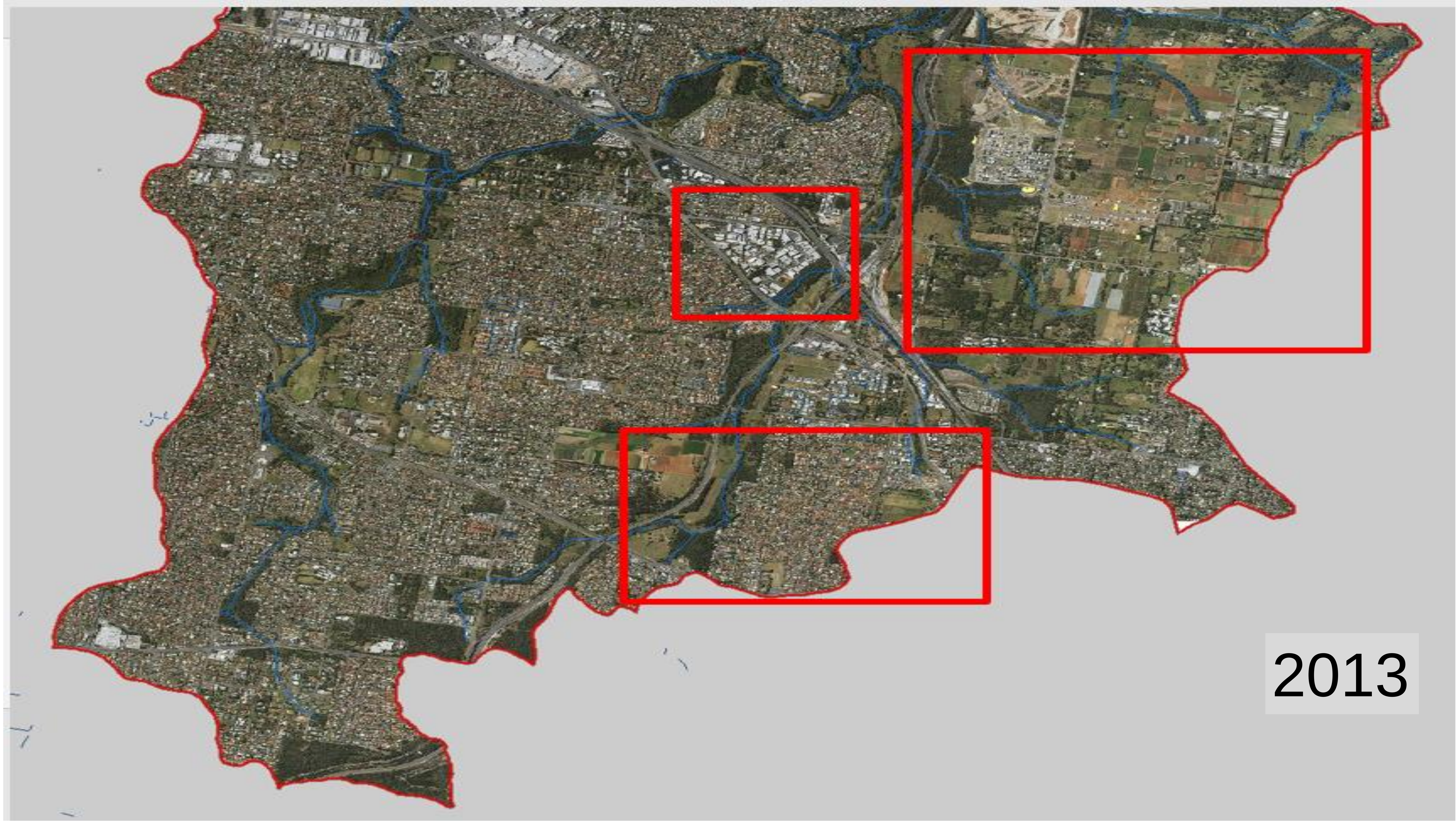






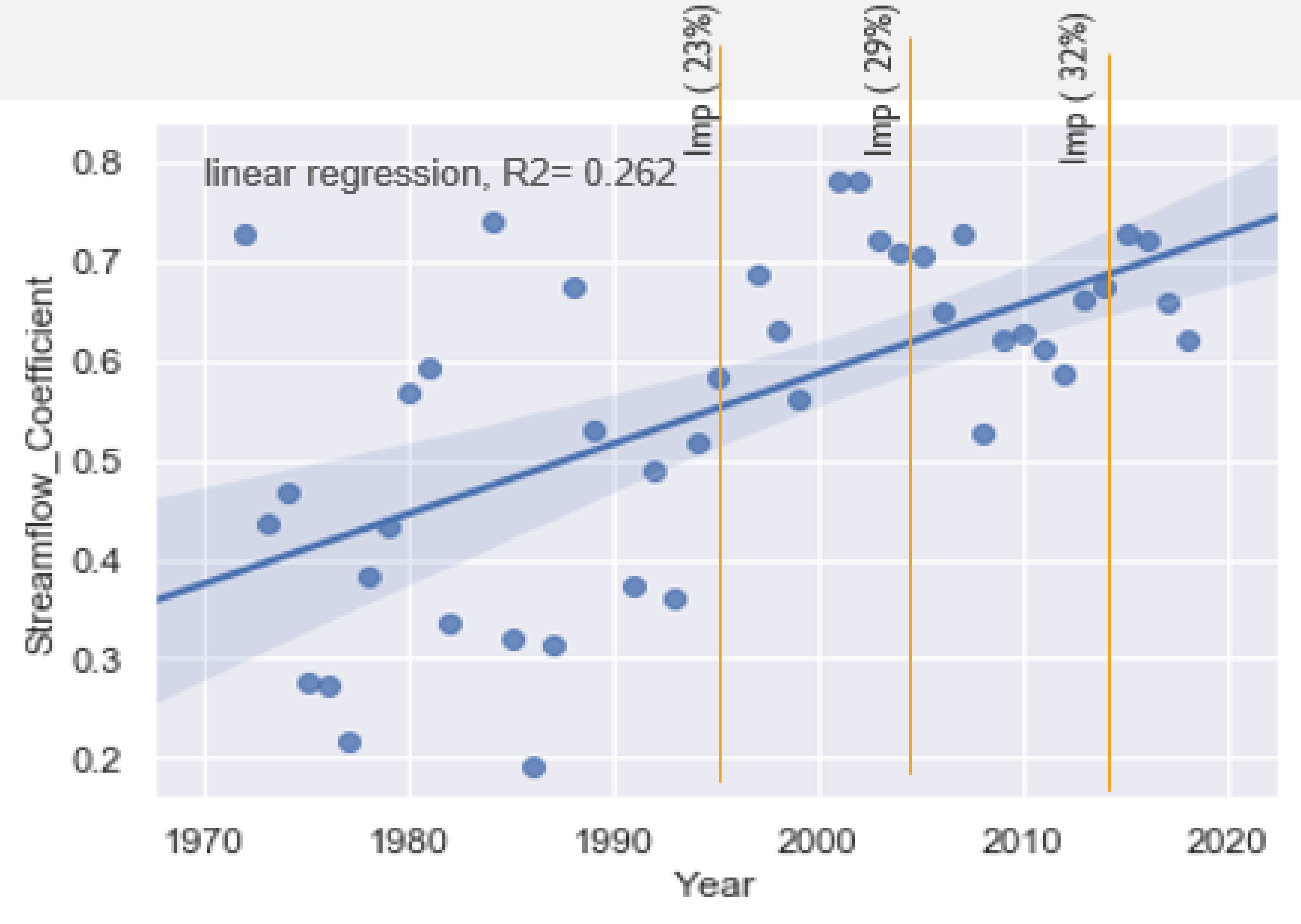

1995

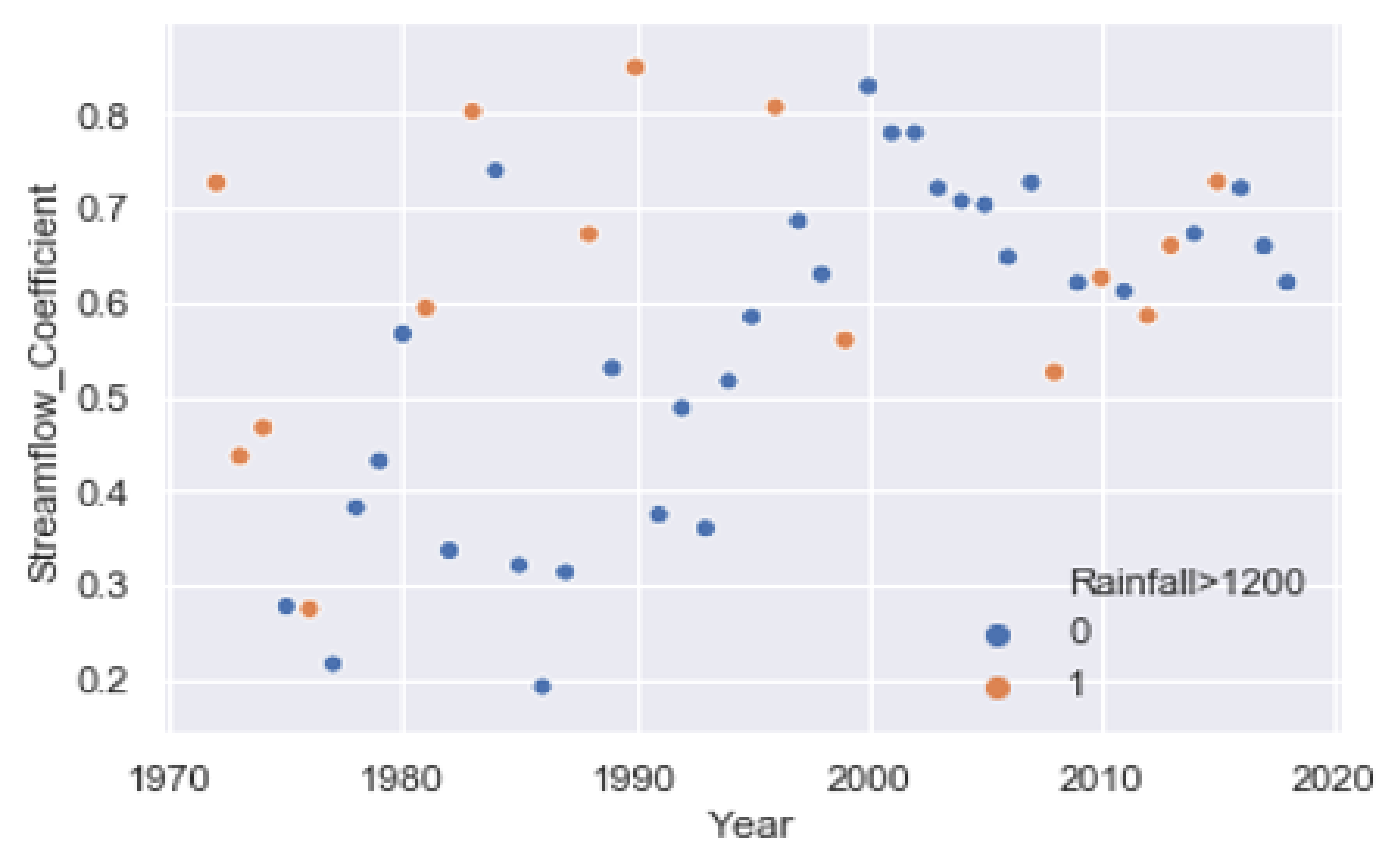

2005


2013


2018

BULIMBA CREEK CATCHMENT ANALYSIS

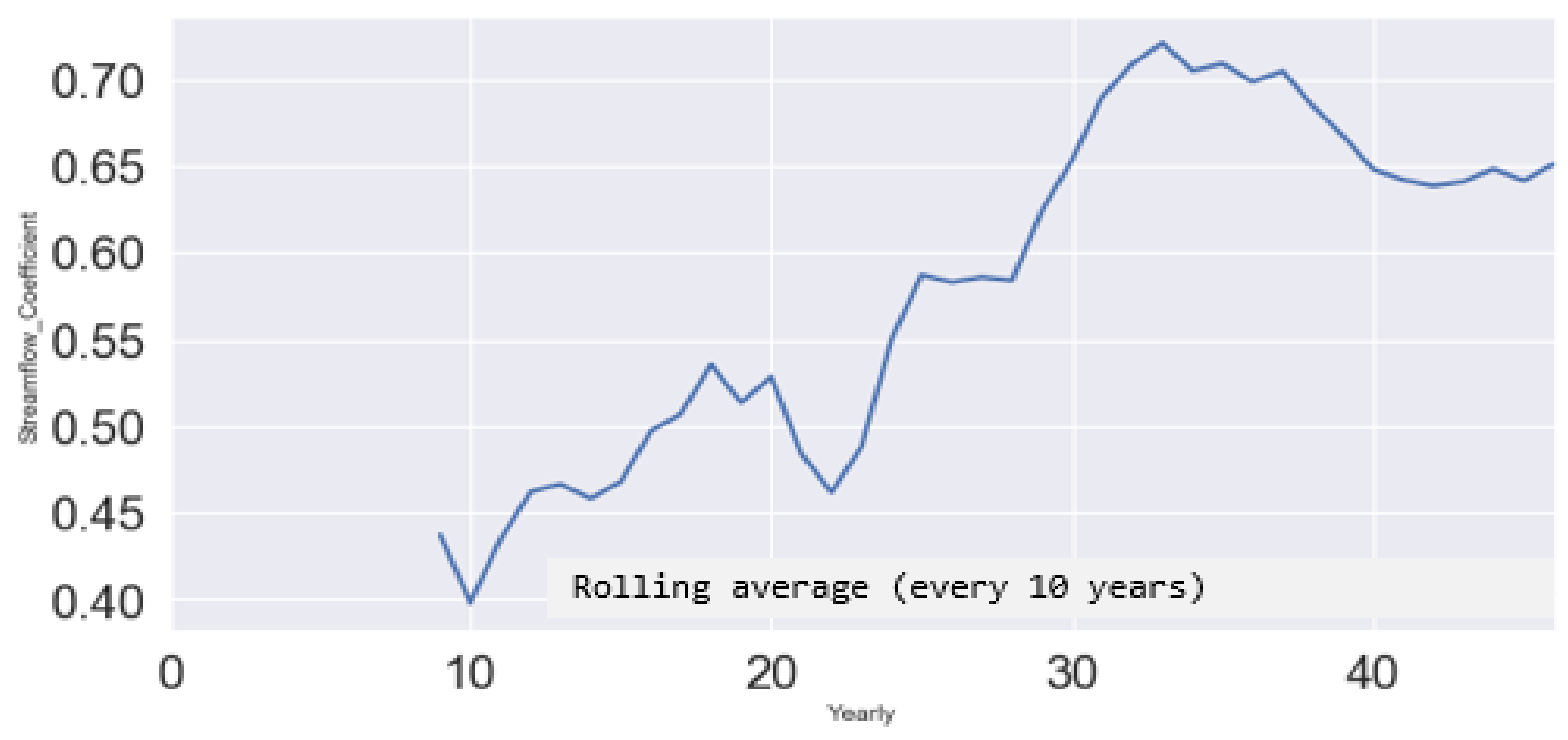


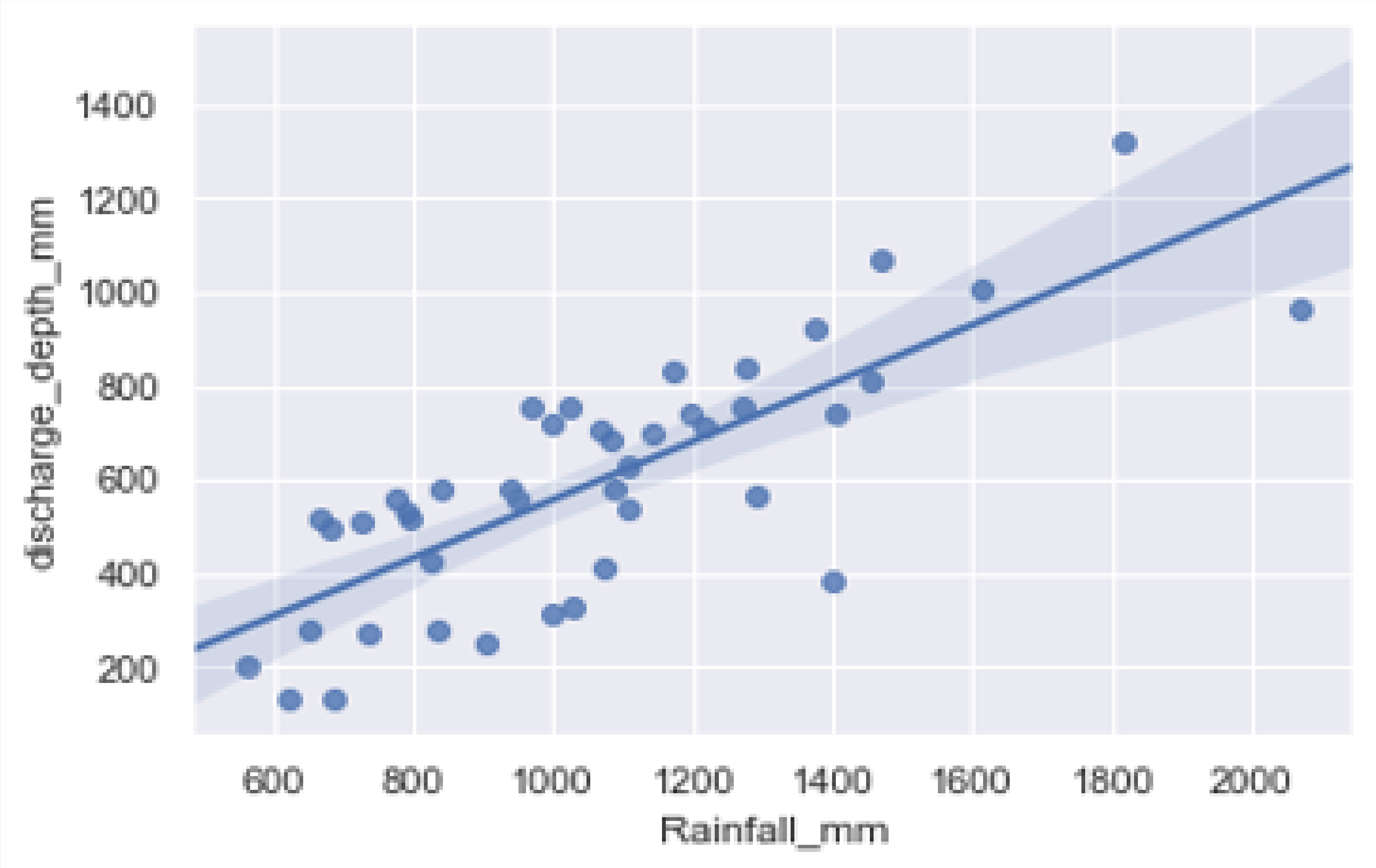


TREND ANALYSIS

Mann-Kendall test

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically assess if there is a monotonic upward or downward trend exists but trend may or may not be linear.





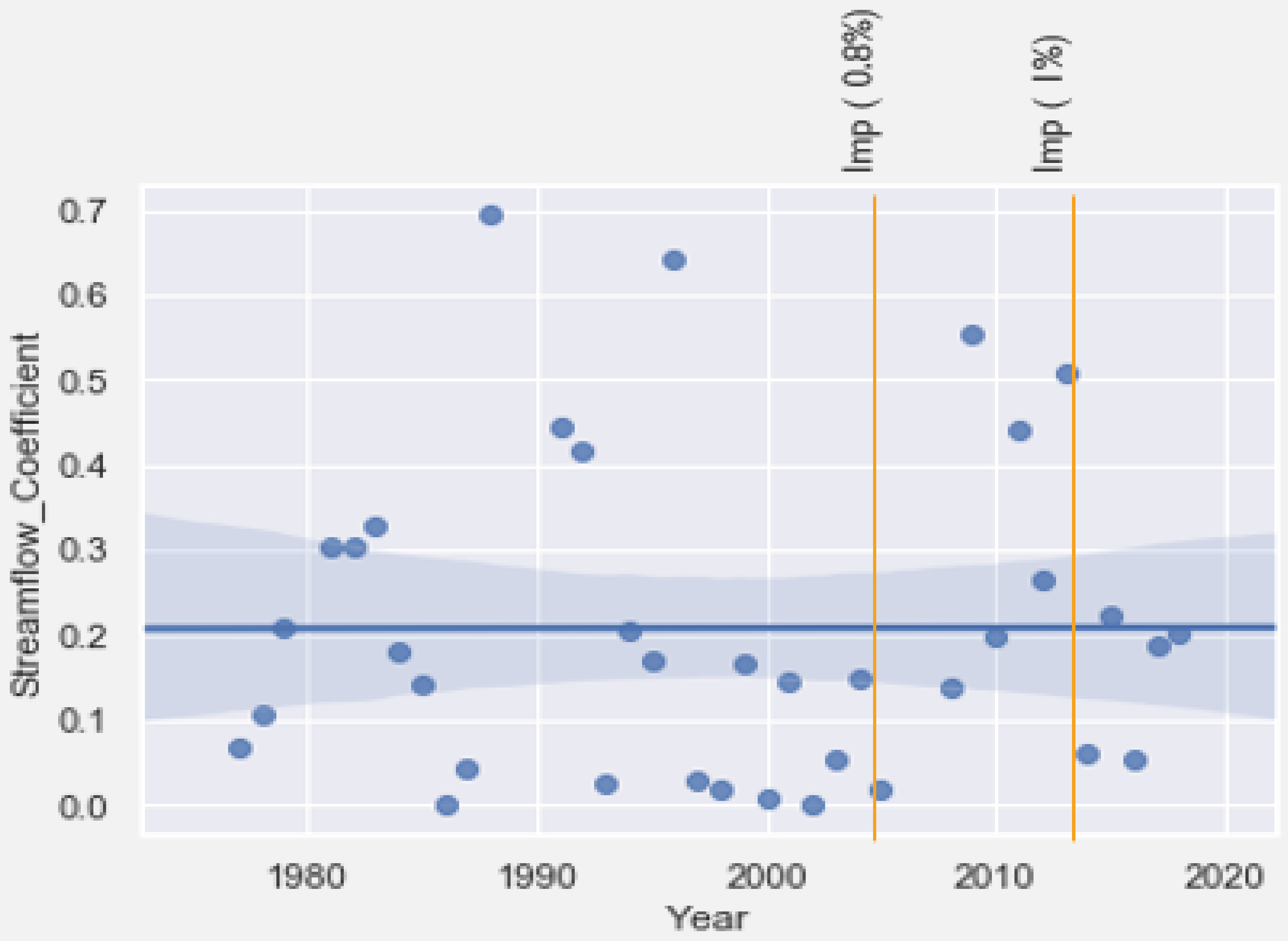

```
x = df.Streamflow_Coefficient.values
```

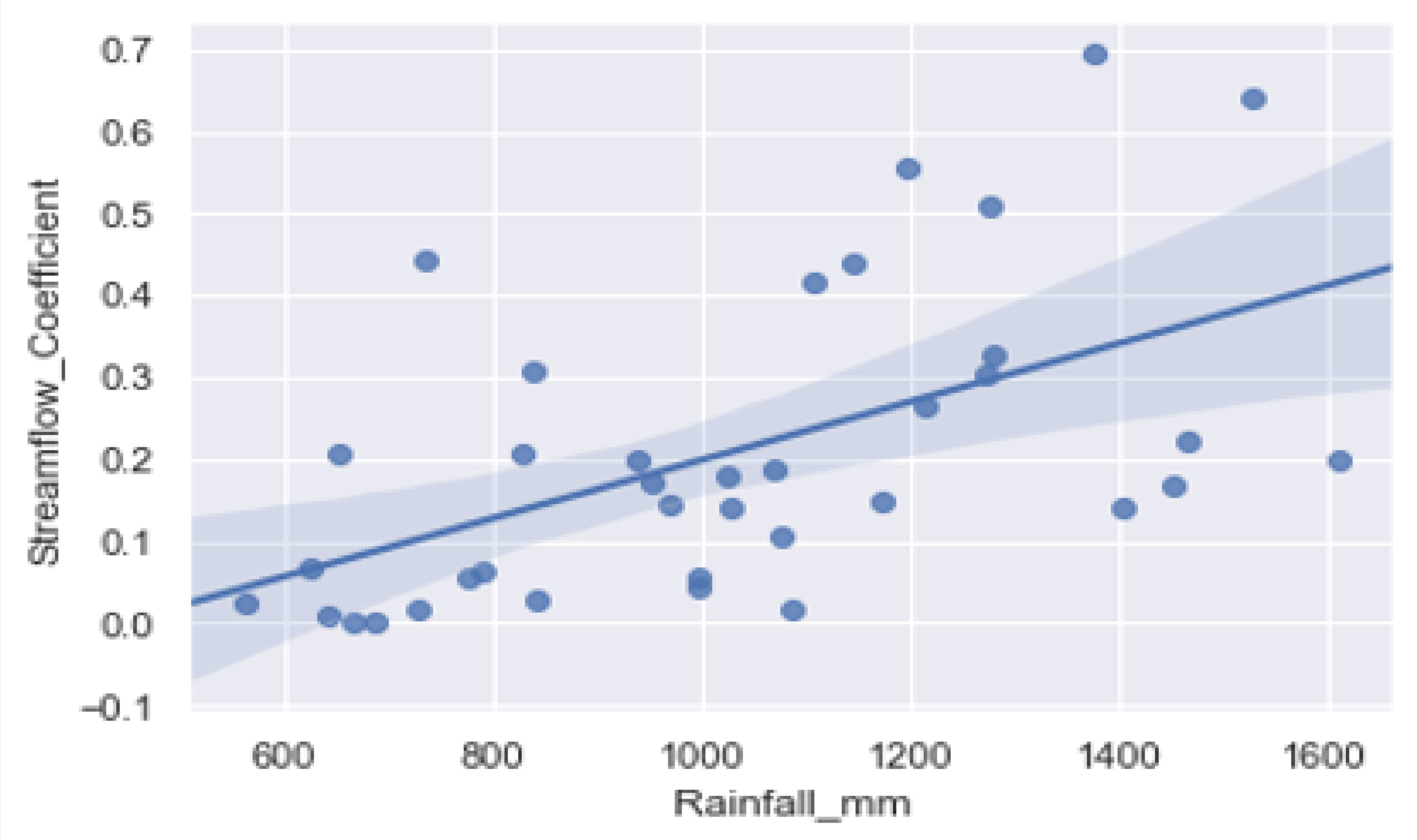
```
mk_test.mk_test(x)
```

```
('increasing', True, 0.0002398661470286445, 3.672843765918688)
```

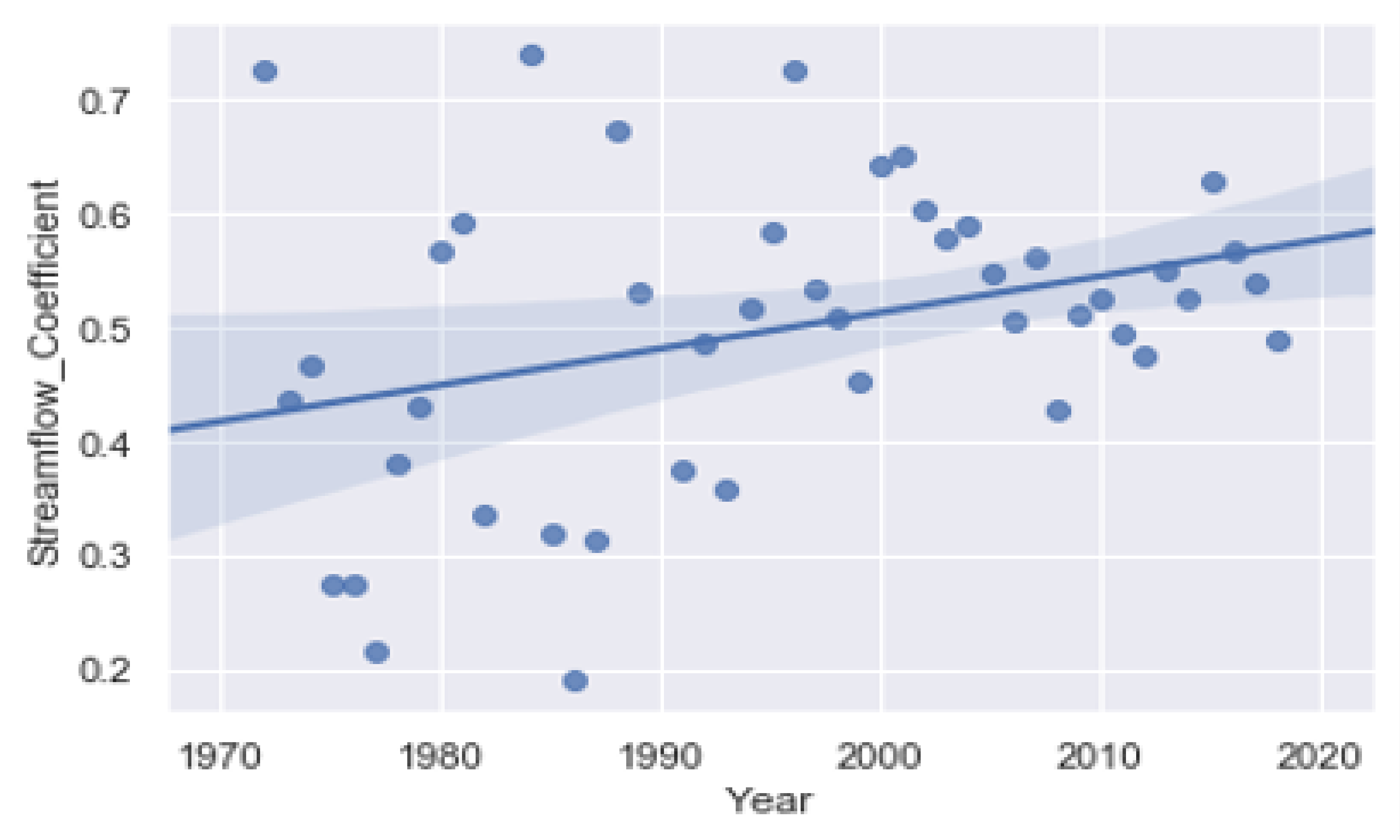
Monotonic trend exist   Monotonic trend significance

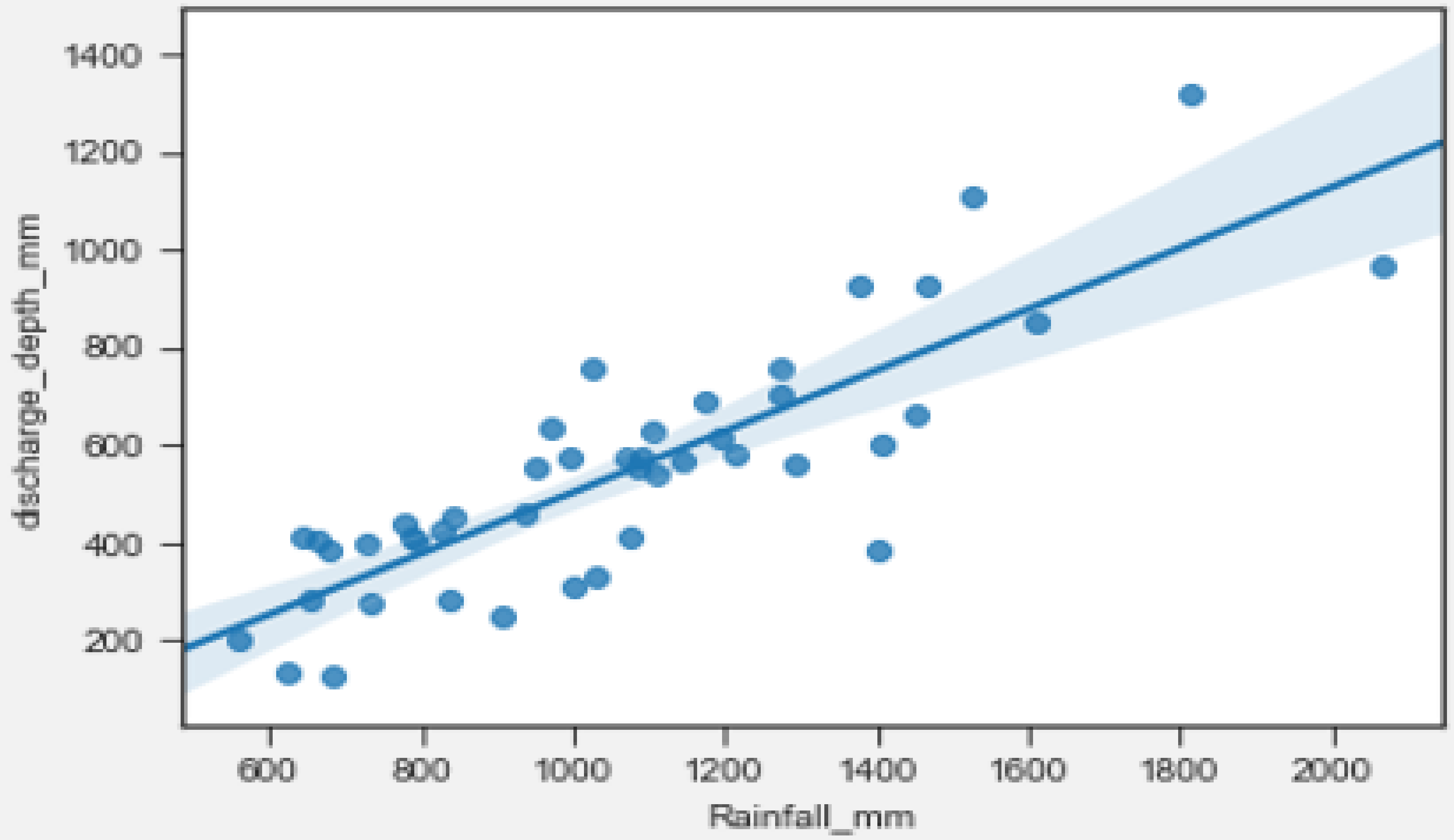
MOGGILL CREEK CATCHMENT



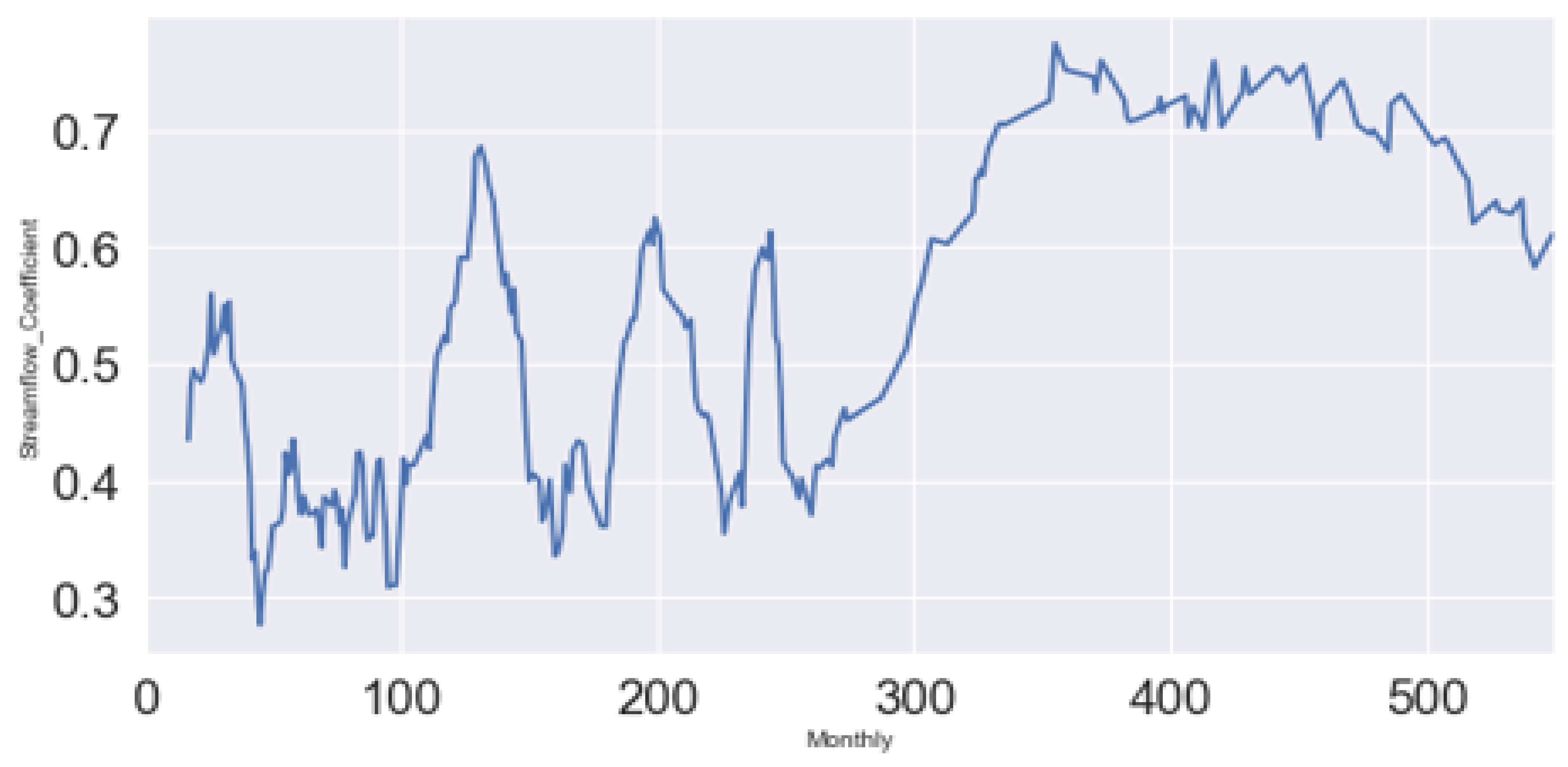


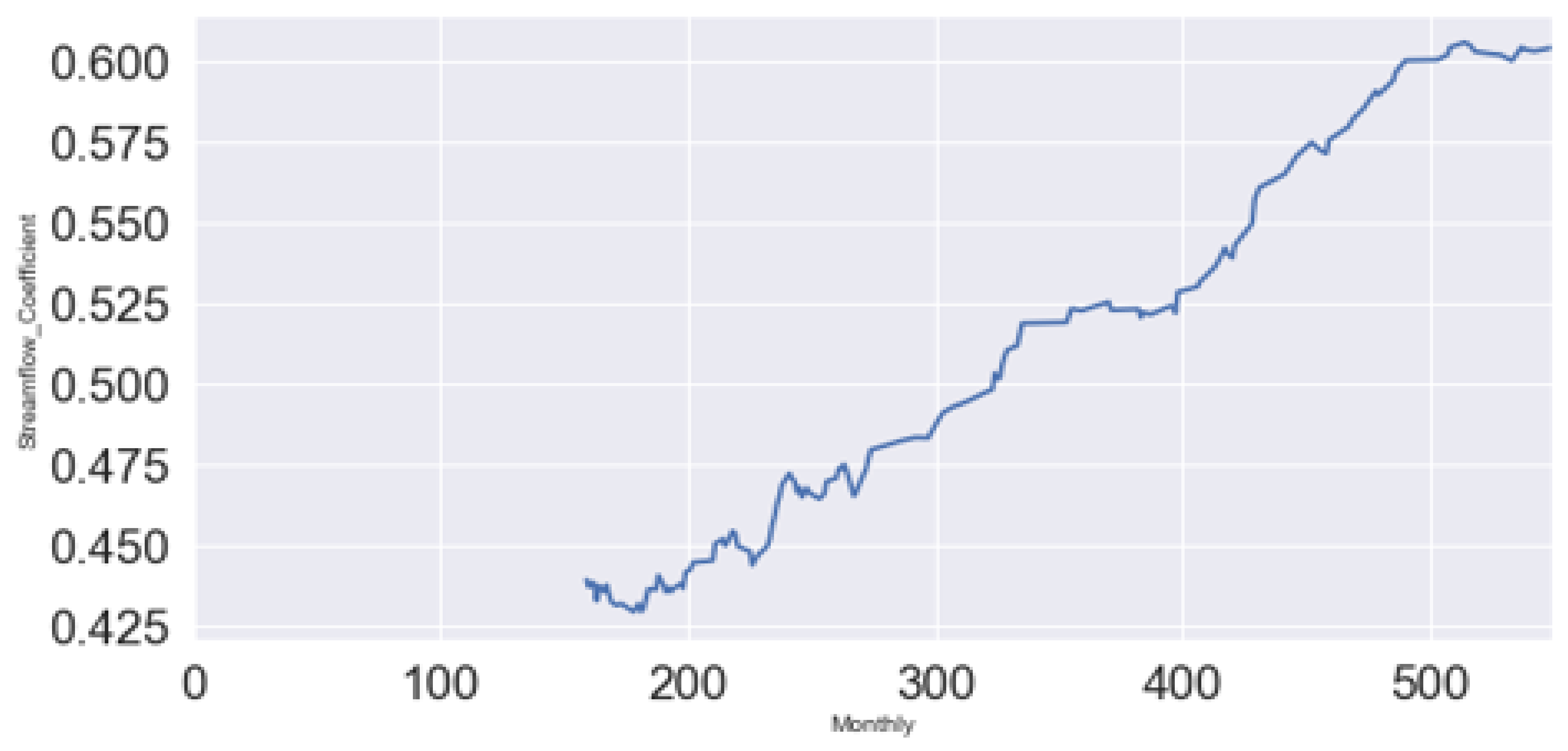
SENSITIVITY TESTING BULIMBA CREEK



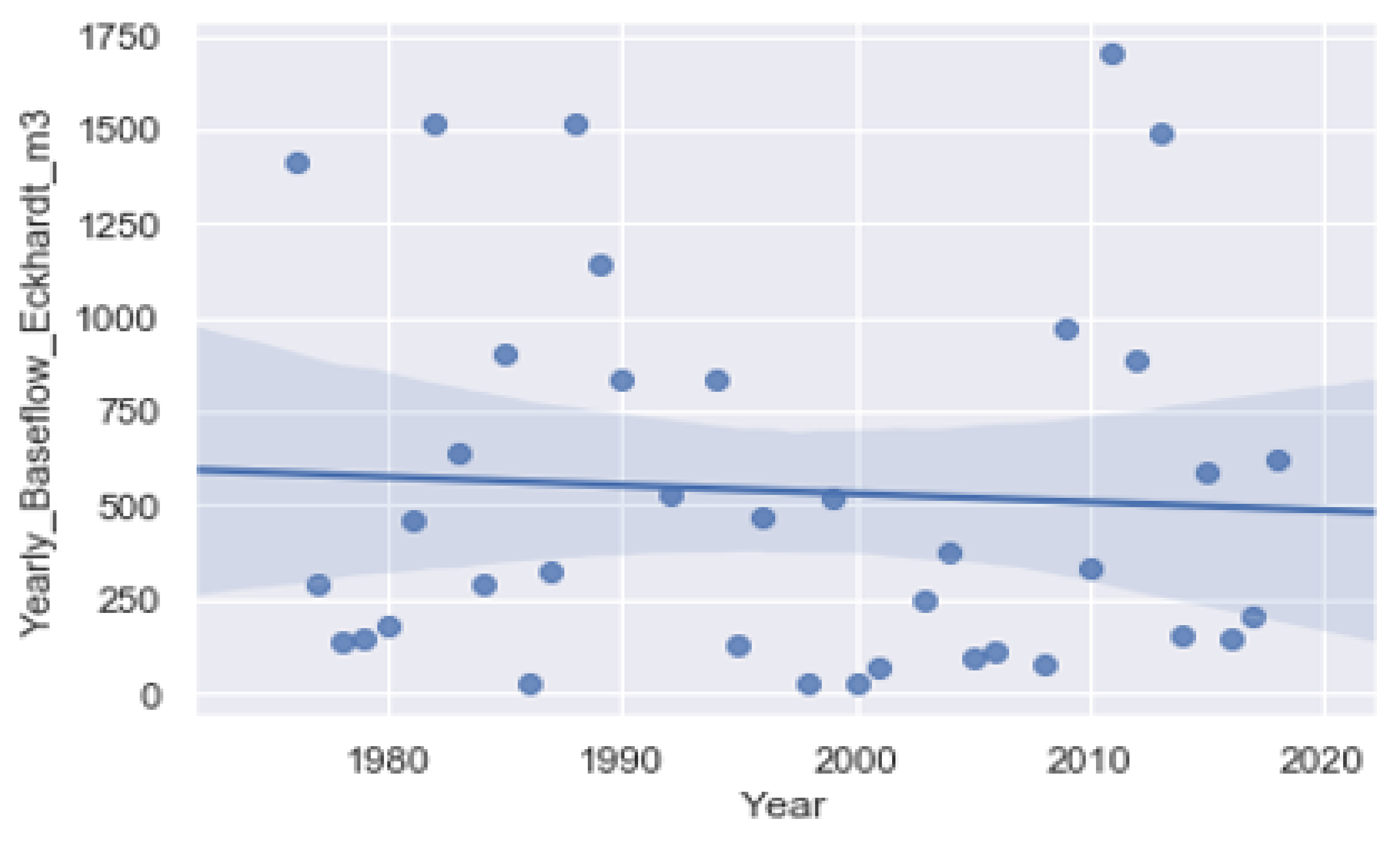


MONTHLY ANALYSIS BULIMBA

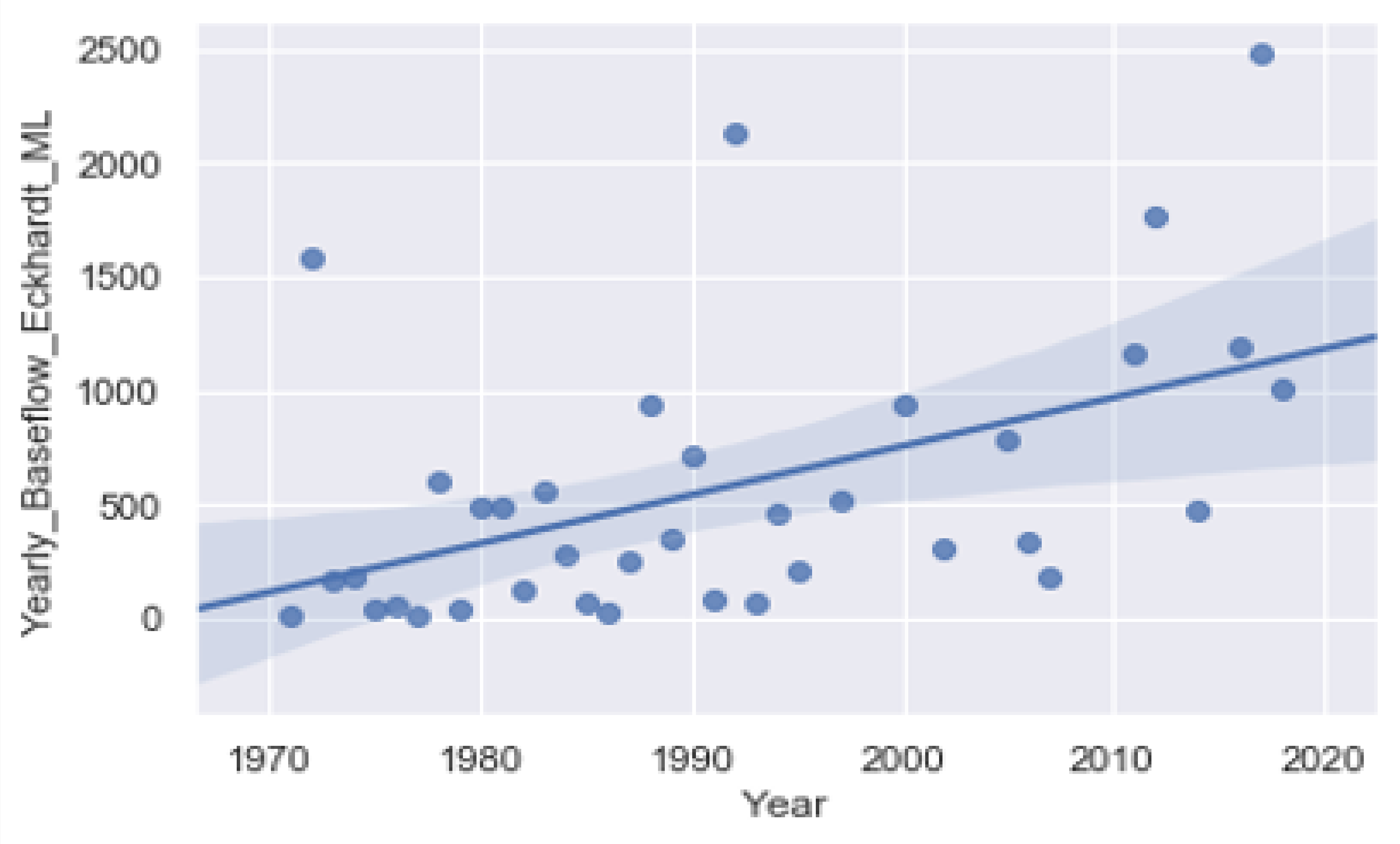




BASEFLOW ANALYSIS
[RECURSIVE DIGITAL FILTERING OF HYDROGRAPHS –ECKHART METHOD]



Moggill Creek



Bulimba Creek

not for citation/ publication

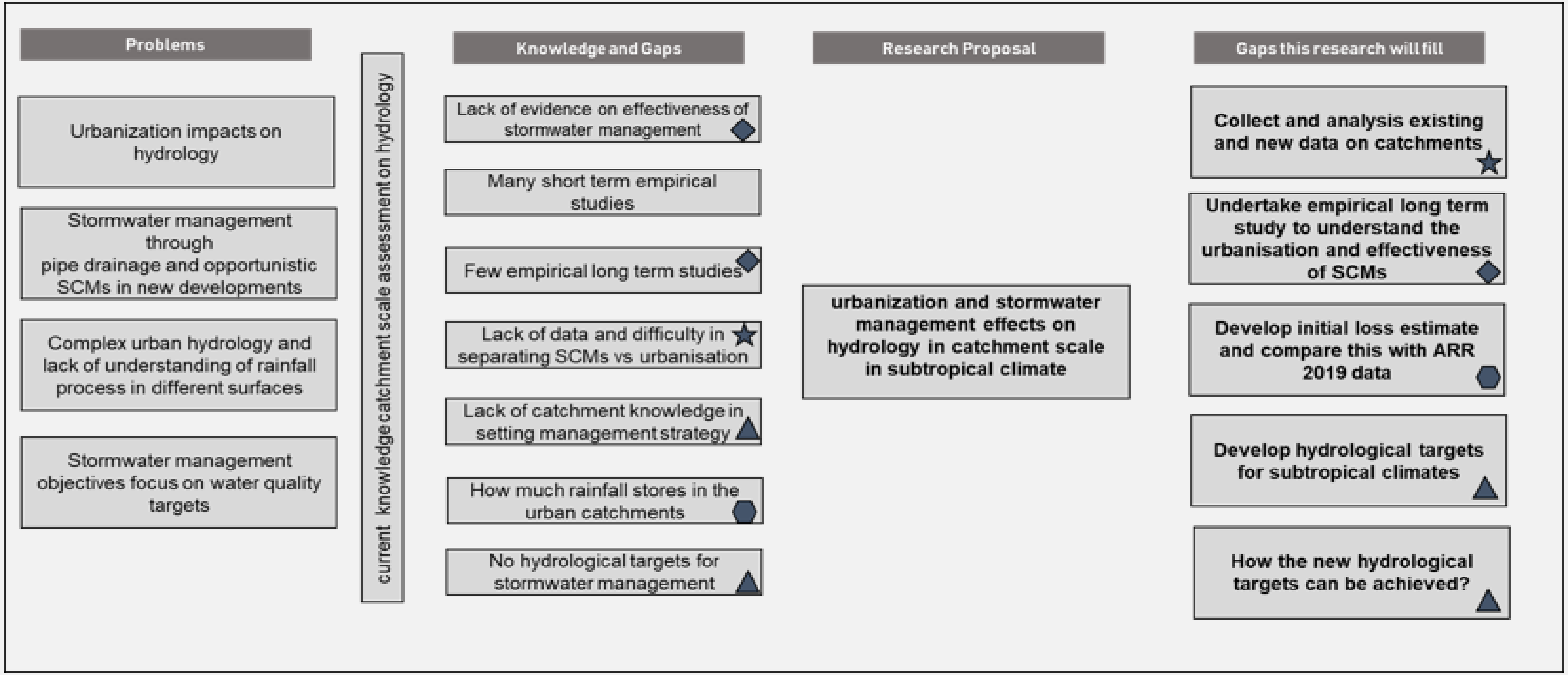
CONCLUSIONS

- Surface runoff is increasing
- Increase in imperviousness increase the stream flow discharge
- The pervious areas generating a considerable amount of runoff
- Big gap in mimicking natural behaviour of the entire flow regime
- Conventional drainage system has major impact on flow regime.
- Catchment capacitance and rainfall pattern are important factors for developing stormwater strategy

FUTURE WORK

- Rating curve update
- Continue analysis and separating urbanisation and SCM impact
- Define initial loss
- Develop hydrological targets
- Develop solutions for the targets

GRAPHICAL ABSTRACT



THANK YOU

The University of Queensland Australia
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