Predicting Flow and Quality Variability in Growing Urban Drainage

for managing impacts on urban ecosystems

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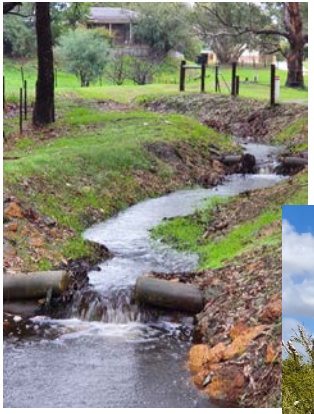
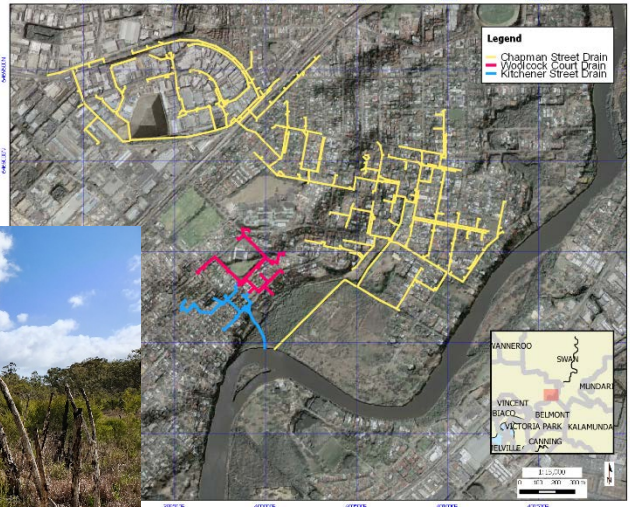
Stormwater/Drainage Impacts On Urban Ecosystems

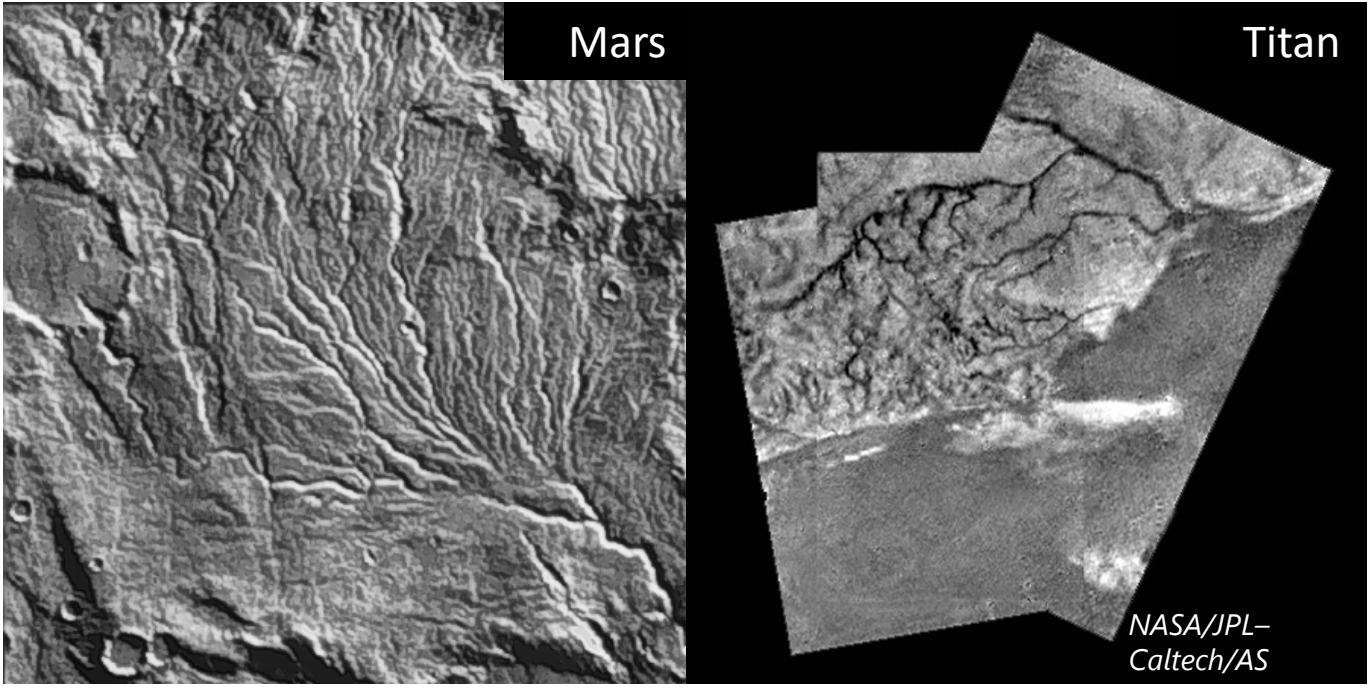




Overview

- How do stormwater networks grow?
- Can we use the network structure to predict flow variability and quality (without a complex model)?

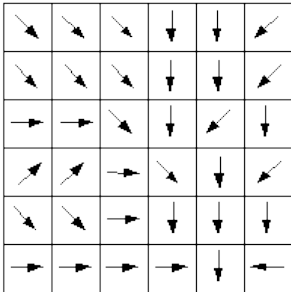
Universal River Patterns



Characterizing River (Stormwater) Networks

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

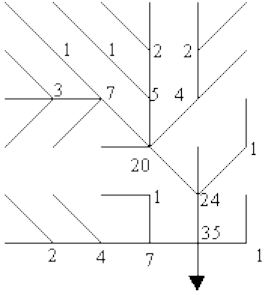
Elevation



Flow direction

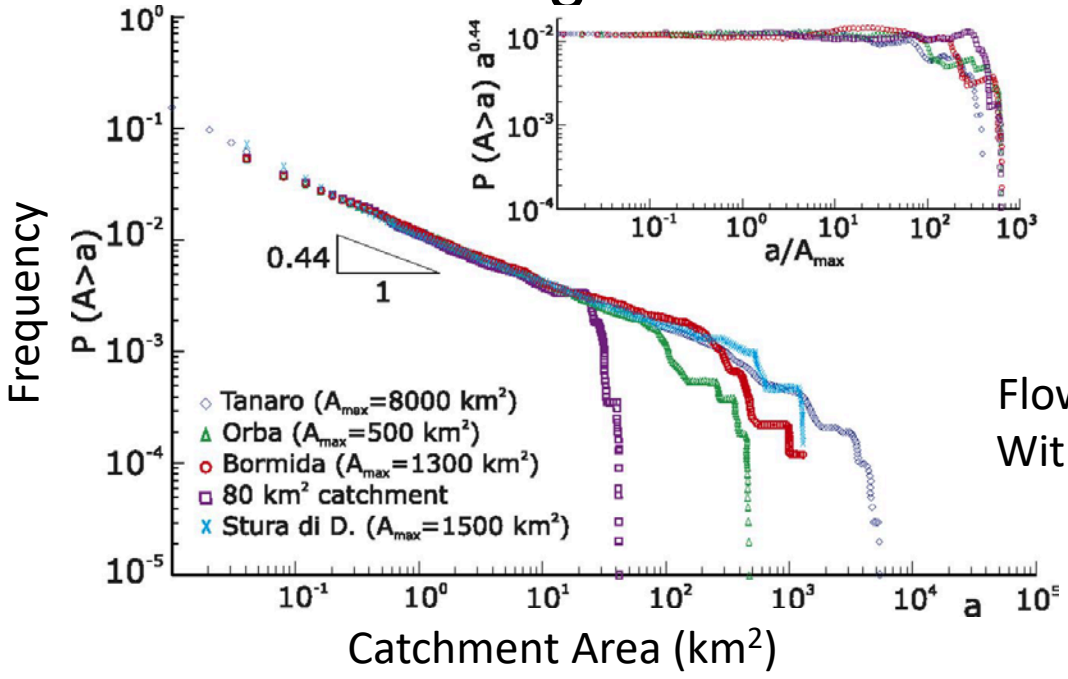
0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

Flow Accumulation



Stream Network

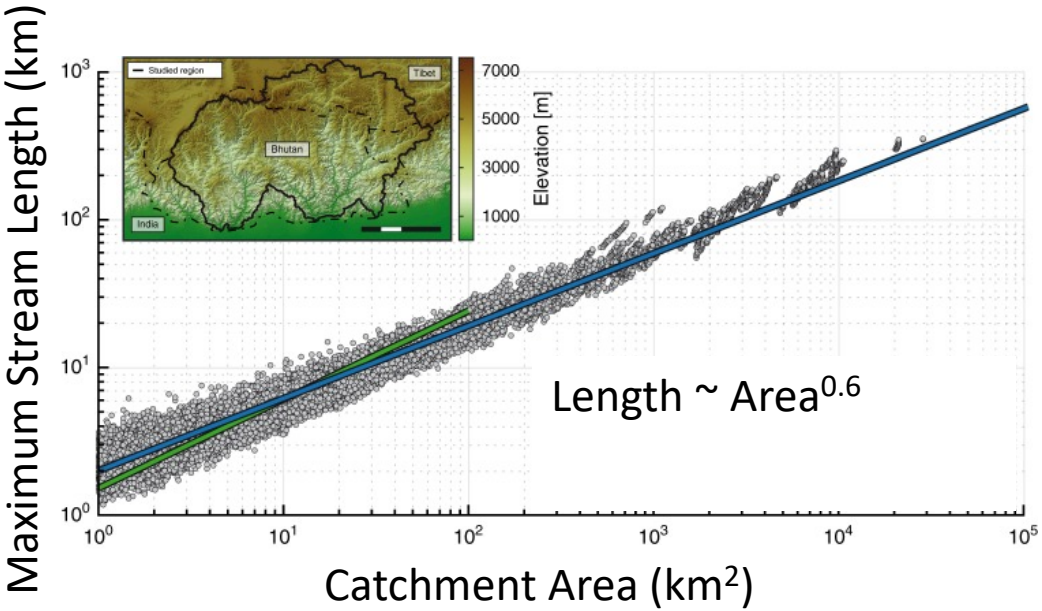
Universal Signatures of Network Organization



Scaling of Flow Accumulation Within Catchments

PNAS 2014;111:7:2417-2424

Universal Signatures of Network Organization

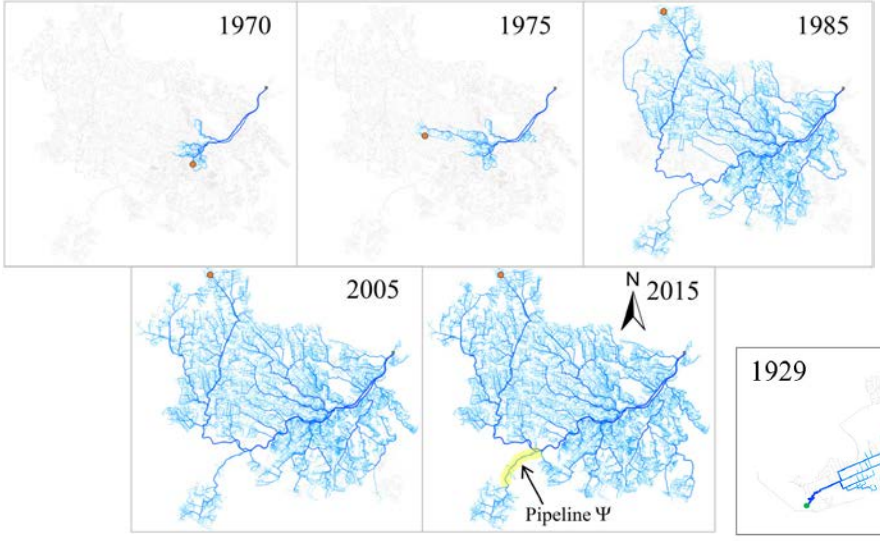


Scaling of Length of Stream vs Catchment Area

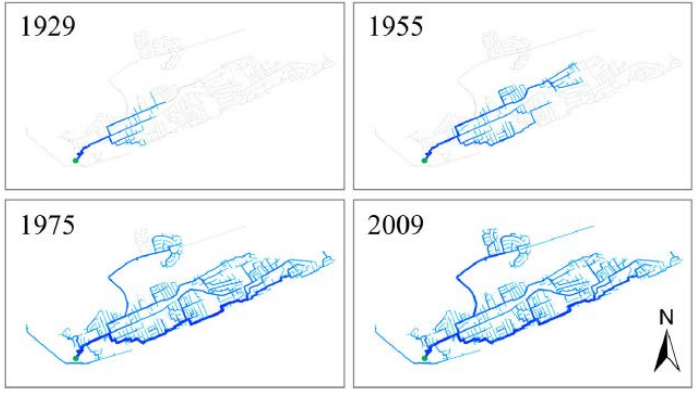
Sassolas-Serrayet, Cattin, and Ferry, Nature Communications, 2018

Growth and Scaling of Stormwater

Amann, Jordan

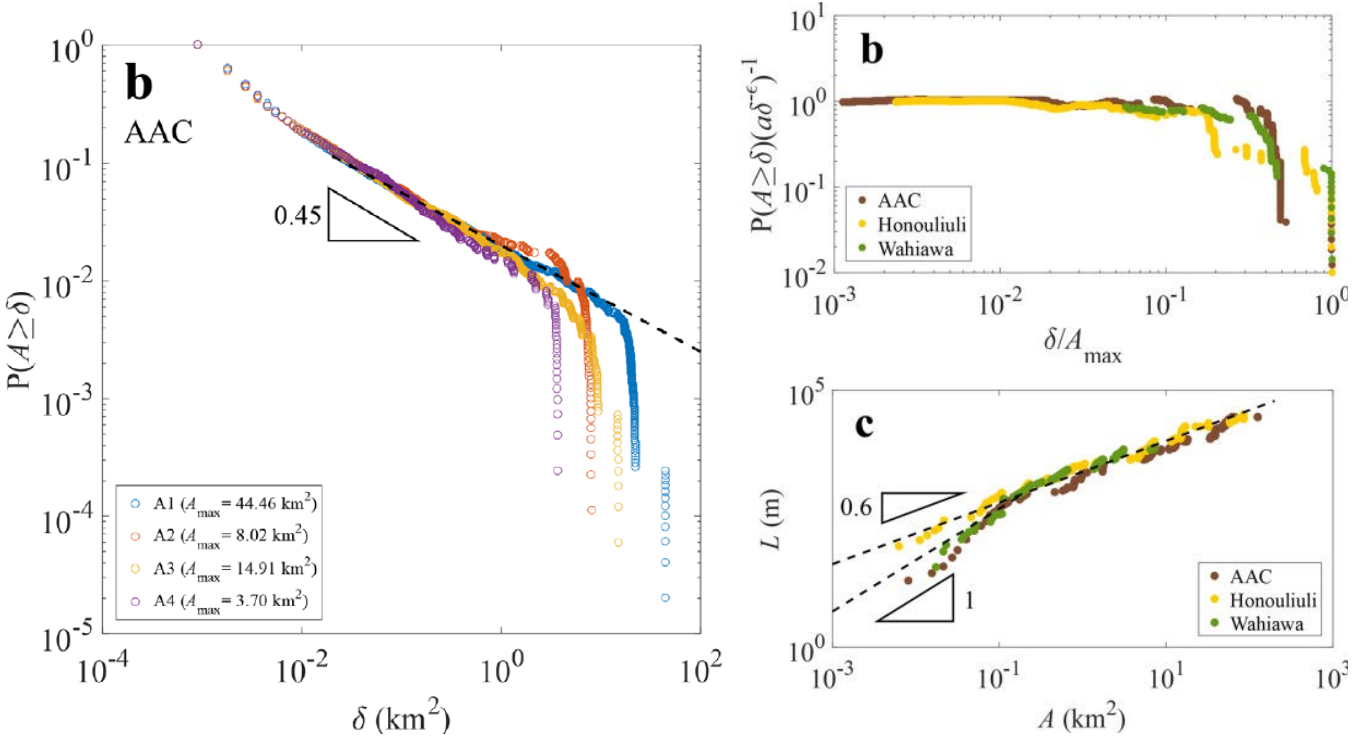


Oahu, Hawaii



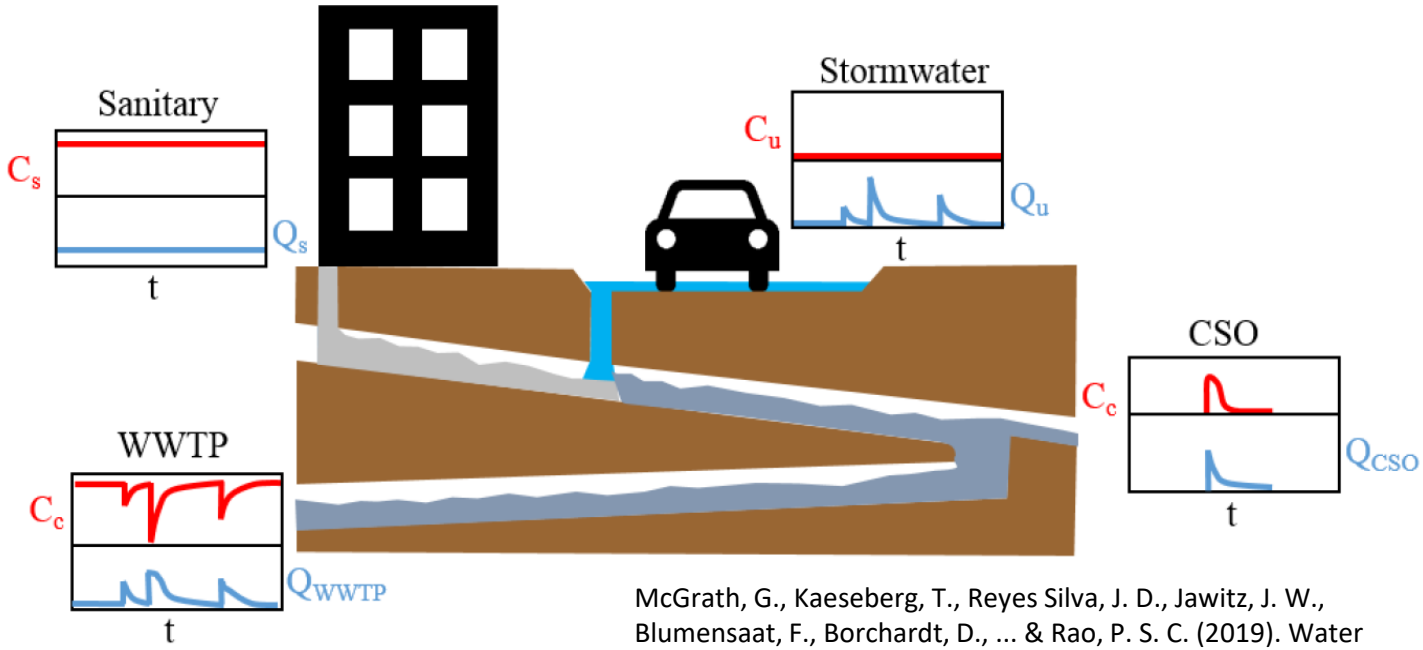
Yang, S., Paik, K., McGrath, G. S., Urich, C., Krueger, E., Kumar, P., & Rao, P. S. C. (2017). Water Resources Research, 53(11), 8966-8979.

Stormwater Networks Scale Like Rivers!



Getting Function from Structure

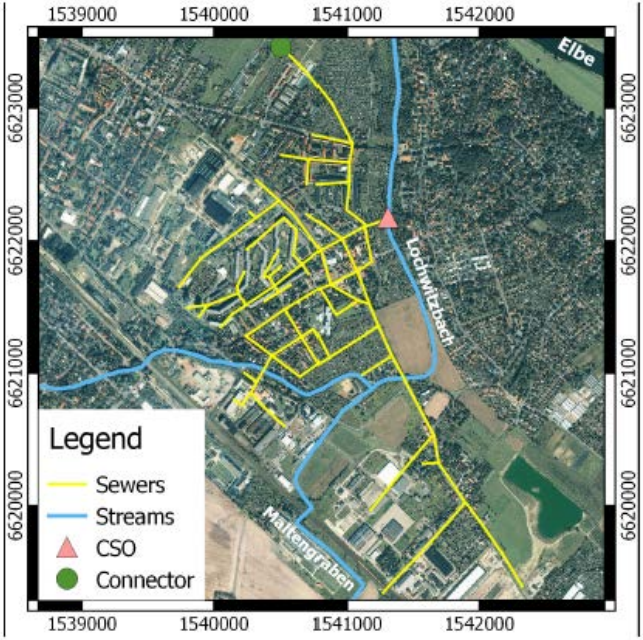
Example for Combined Sewer Overflows



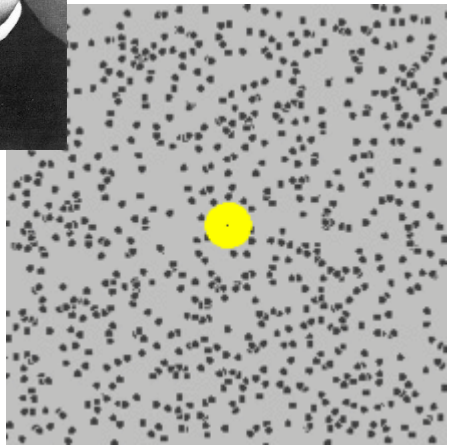
McGrath, G., Kaeseberg, T., Reyes Silva, J. D., Jawitz, J. W., Blumensaat, F., Borchardt, D., ... & Rao, P. S. C. (2019). Water Resources Research, 55(11), 9578-9591.

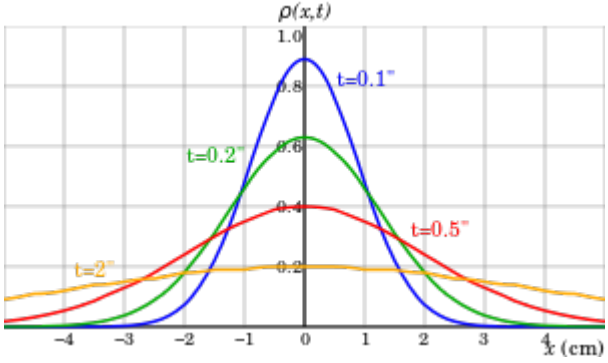
Linking Network Structure to Function

- Urban Observatory Dresden
- 665 mm/year
- 7,600 population
- River outfall



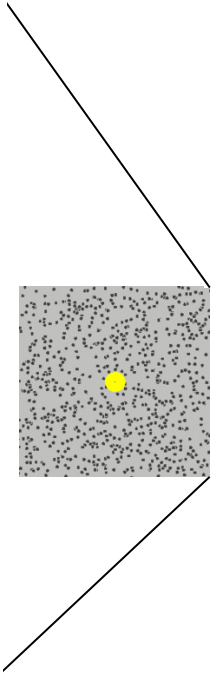
From Einstein to Hydrologic Variability



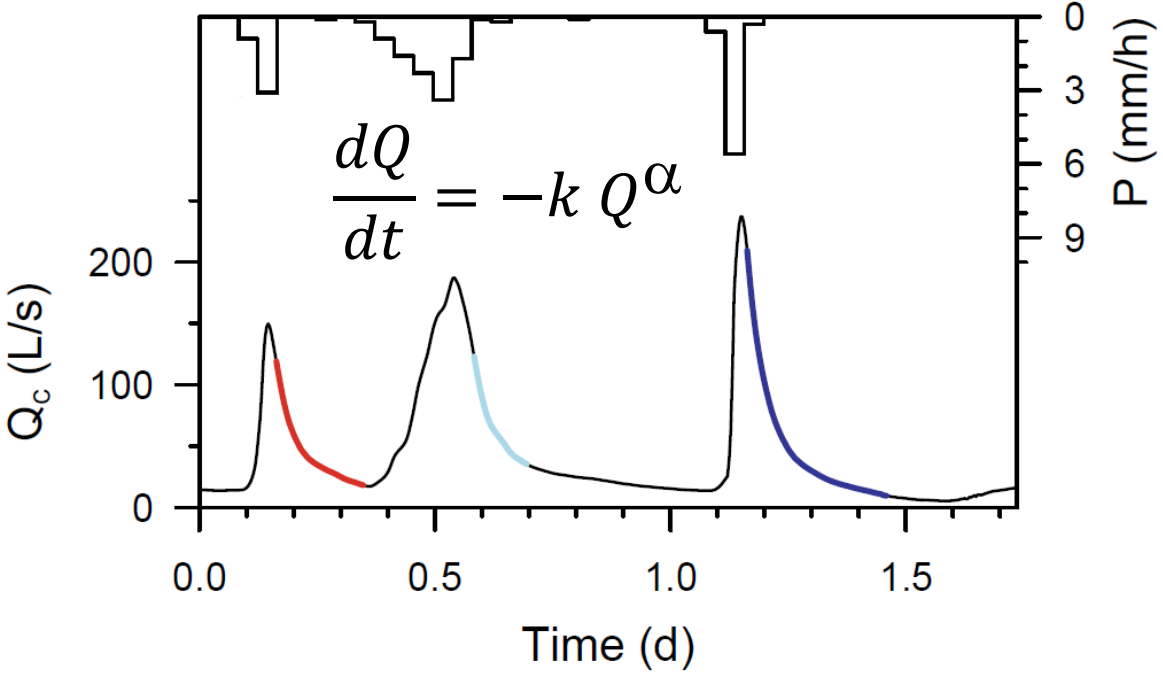


Histogram of positions

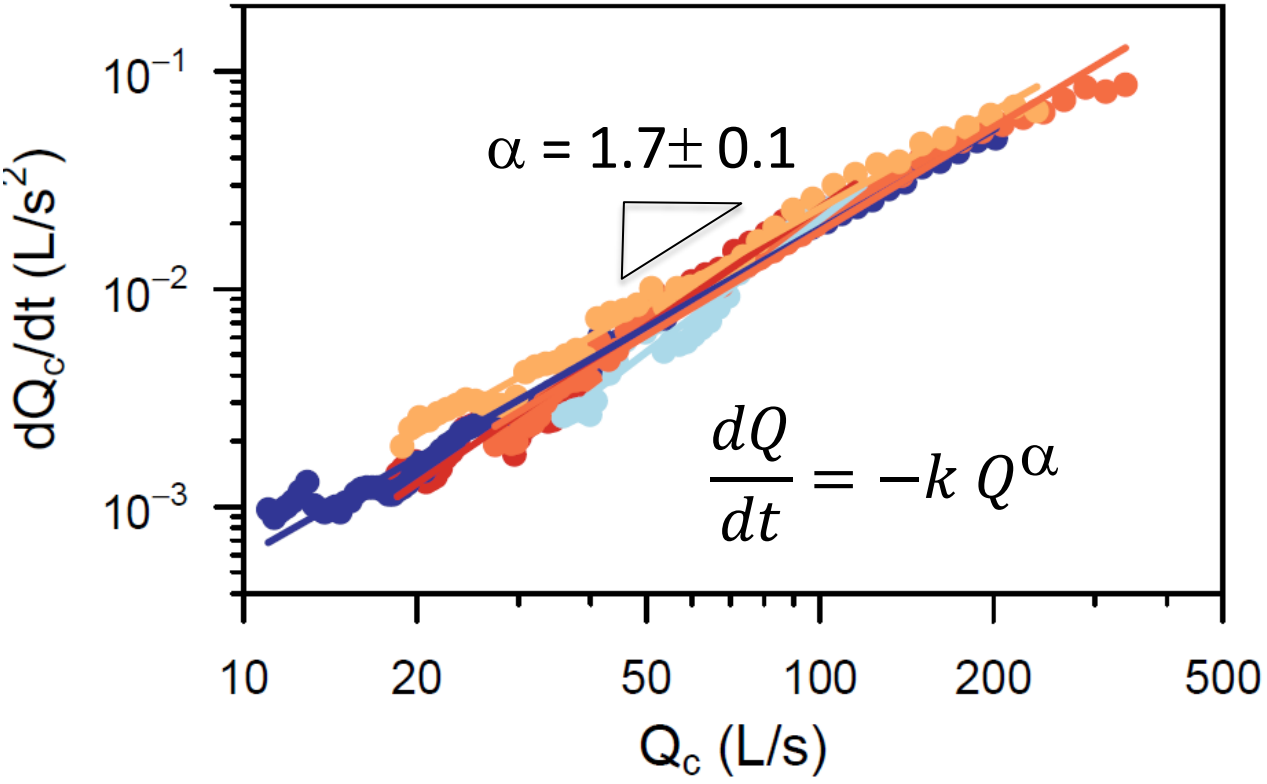
https://en.wikipedia.org/wiki/Brownian_motion



Flow Recession at Lochwitzbach



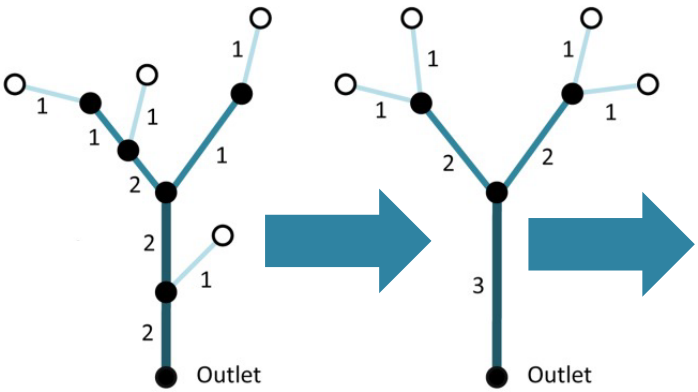
Flow Recession Analysis

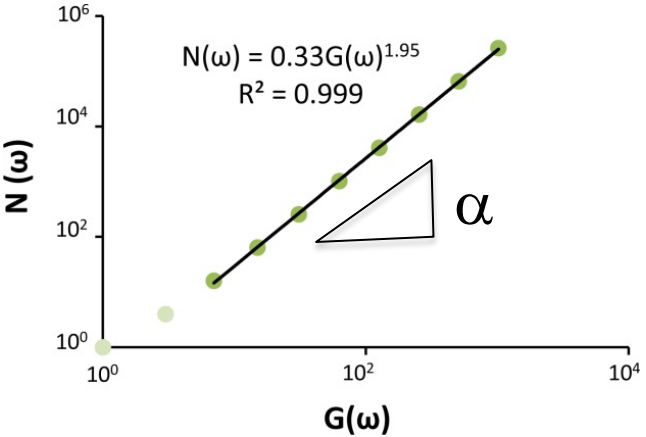


From a Network To Flow Dynamics

Actual Network Shape

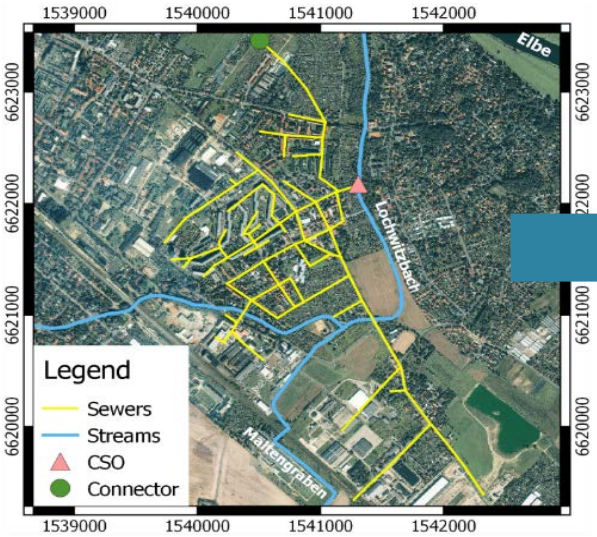
"Functional" Network Shape

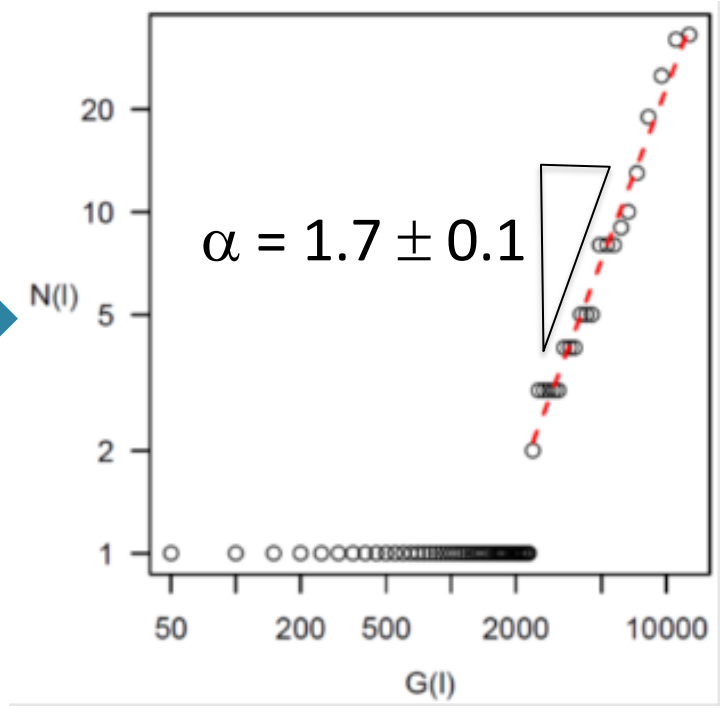




Water Resources Research, Volume: 49, Issue: 8, Pages: 4900-4906, First published: 24 June 2013, DOI: (10.1002/wrcr.20379)

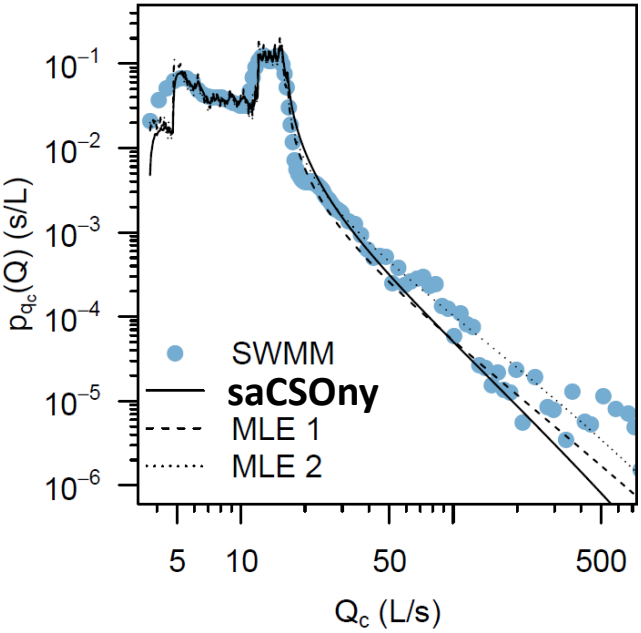
From a Network To Flow Dynamics



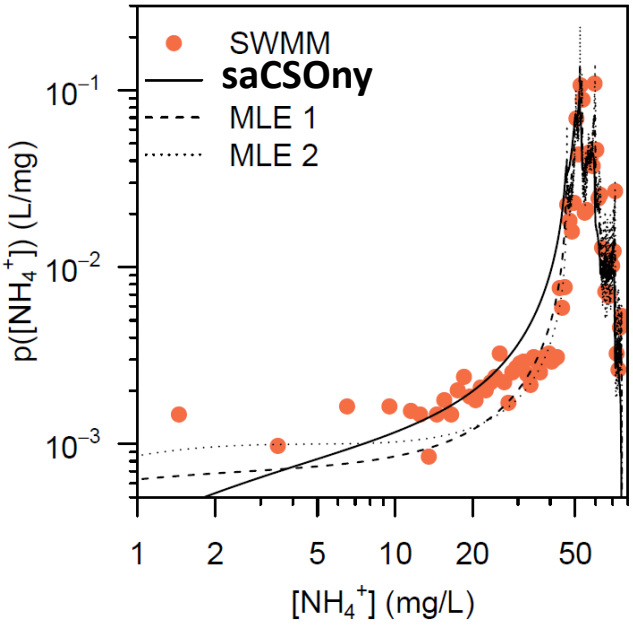


Observed vs Modelled Variability

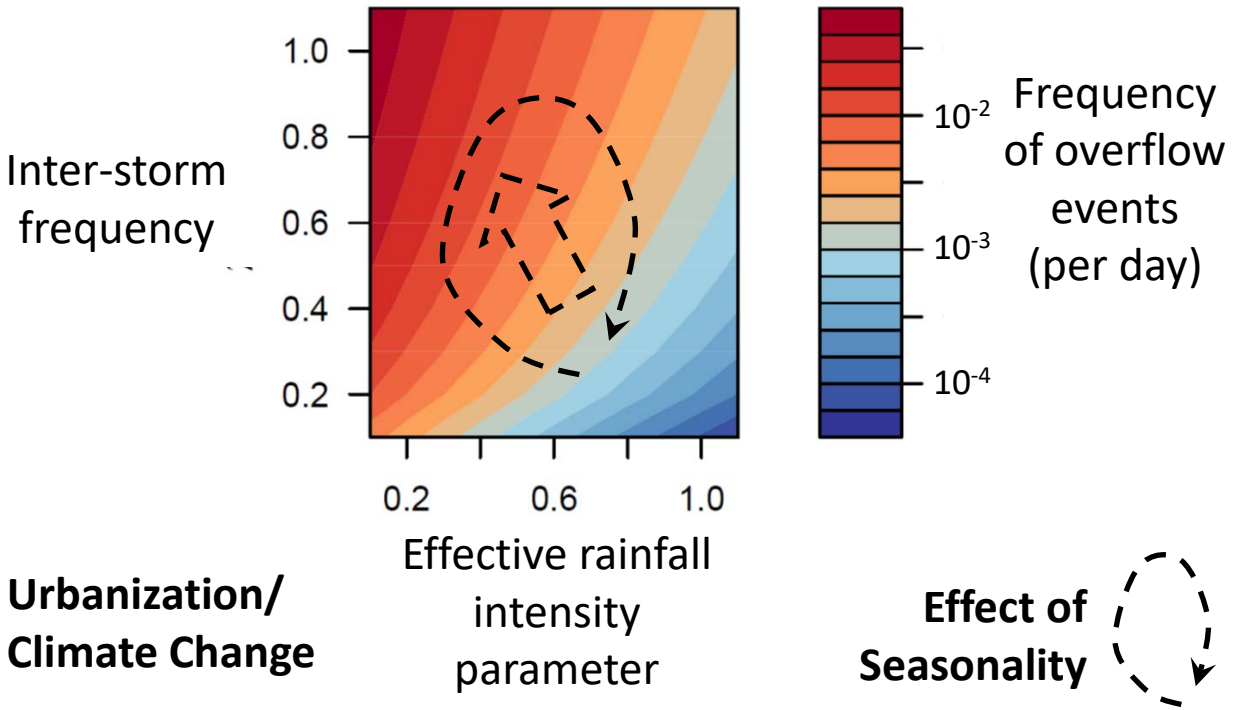
Histogram of Flow



Histogram of Ammonia Concentration



Rapid Scenario Assessment



Summary

- Stormwater networks have a characteristic structure – like rivers
  - Cross-cultural
  - More similar to rivers as they grow
  - Are engineers really in control?
- Stormwater network structure predicts function
  - Without calibration
  - Function grows with network
  - Variability predictable

Vision

Urban Observatories

- Innovation
- Training
- Collaboration

Use of saCSOny

- Change scenarios
- Sustainability planning
- Conservation

https://blogs.worldbank.org

Acknowledgements

- TU Dresden
  - P. Krebs
    T. Kasebeburg
    F. Blumesaat
  - J. D. Reyas-Silva
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  - D. Borchardt
- Collaborators on Hydrological Synthesis
  - K. Paik
    J. Jawitz
    P.S.C. Rao
    S. Yang

Einstein-like approach

Hydrology $\left\{ \frac{dQ}{dt} = -k\,Q^{\alpha} + \xi(t) \right.$

Flow Recession

Random (weather) forcing

Equations for Histograms

Flow, Water Quality, Overflows, UWWTP Loads, etc.

$$p_{q_c}(Q_c) = K\left\{(Q_c - Q_s)^{-\alpha}\exp\left[-\frac{\gamma}{k}\frac{(Q_c - Q_s)^{2-\alpha}}{(2-\alpha)} + \frac{\lambda}{k}\frac{(Q_c - Q_s)^{1-\alpha}}{(1-\alpha)}\right] + \frac{k}{\lambda}\delta(Q_c - Q_s)\right\}$$

Rainfall Variability + Sanitary Baseflow