Surface Runoff and Groundwater Recharge Dynamics in the Human Environment

Eawag: Swiss Federal Institute of Aquatic Science and Technology

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Introduction: Groundwater Recharge

- Groundwater recharge is one of the least understood components of the water cycle
- Human land development has created additional complexity to groundwater recharge dynamics
- The rate, timing, and location of recharge are consequential for resulting groundwater quantity and quality

Burri et al., 2019: A review of threats to groundwater quality in the Anthropocene

Project Overview

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Global Objective: Explore the influence of human land development on groundwater recharge and associated flow pathways

Methods

1. Design and install a **groundwater monitoring network** at the site of investigation

2. Quantify the **annual change in groundwater storage**, accounting for changes in variables including evapotranspiration and **runoff**

3. Explore the use of **chemical and isotopic tracers** to identify anthropogenic recharge sources and associated processes

4. Combine physical and chemical data to improve the local **conceptual groundwater model** that accounts for artificial influences

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A Closer Look: Surface Runoff

- **Surface runoff** – water that runs off the land surface in response to a storm event
  - One component of stream discharge hydrograph
- Major component of a catchment water balance
- Soil compaction, impervious surfaces and agricultural drainage systems lead to increased runoff
- Acts as a carrier for chemicals from surface, soils, and atmosphere
- Stimulates ''combined sewer overflow'' (CSO) in urban areas, releasing untreated sewer water into the environment

Source: Wikimedia Commons

Fehraltorf and the Kempttal Aquifer

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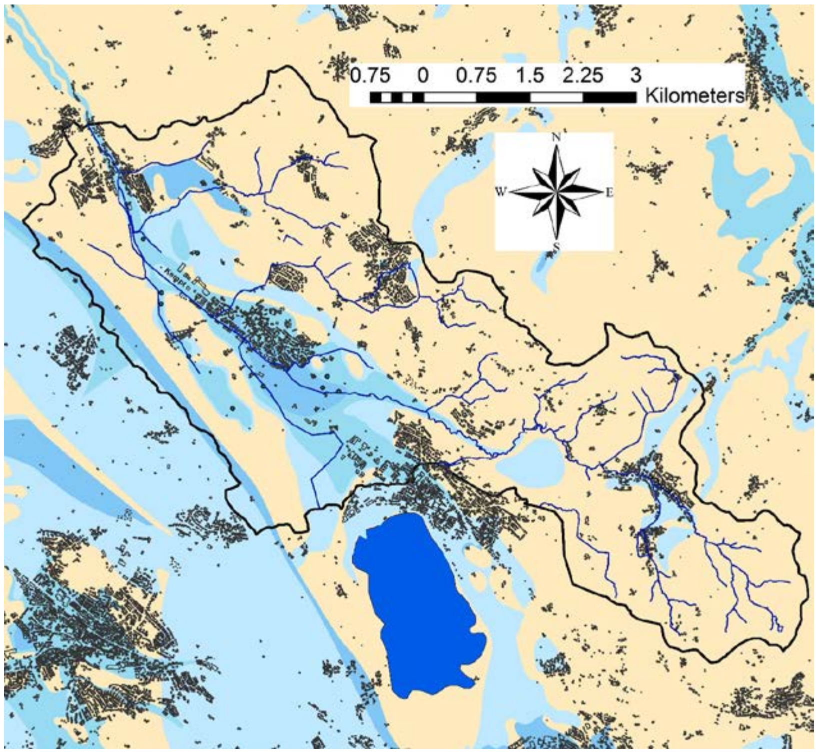

Catchment Characteristics

- **Altitude**: 500 – 900 masl
- **Climate**: average yearly rainfall of 1300 mm
- **Surface Area**: 35 km^2
- **Aquifer type and extent:** unconfined, ~15 km2, variable depth

Land Use Characteristics

- **Population**: approx. 6300
- **Land Use** 2017:
  - 19% Urban
  - 53% Agriculture
  - 2% Industrial
  - 25% Forest
- **Municipal water supply:** 80% sourced from local groundwater

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Runoff and Recharge: Methods

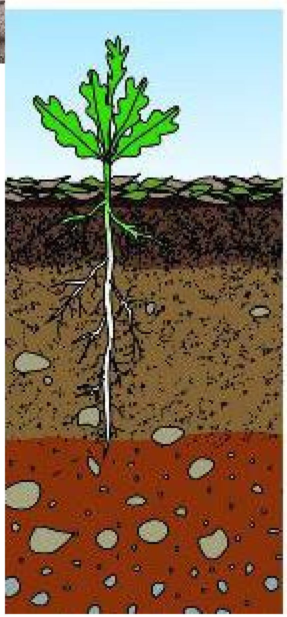
Runoff	Input	Notes
SME Method	Precipitation	With expert knowledge, model parameters account for soil type, vegetation type, and permeability
Hydrograph Separation	River discharge	Bivariate in it's simplest form. Possible to perform multivariate separation with additional data

Recharge	Input	Notes
Empirical Water Balance	Precipitation, evapotranspiration, ***surface runoff***	Accounts for soil type, vegetation type, and permeability
HBV light model	Precipitation, evapotranspiration, river discharge	Accounts for river discharge, soil moisture, and groundwater levels

Surface Runoff: Sahu-Mishra-Singh (SME) Method

$$M = \beta\left(\frac{(P_5 - \lambda S_0)S_0}{P_5 + (1-\lambda)S_0}\right) \quad when\ P_5 > \lambda S_0$$

$$R_{off} = \frac{(P - I_a)(P - I_a - M)}{(P - I_a + S_0)} \quad when\ P > I_a$$



- Antecedent soil moisture $\boldsymbol{M}$ is calculated from cumulative antecedent rainfall on a day-by-day basis (semi-continuous)
- Runoff is estimated as a function of effective precipitation $\boldsymbol{P\text{-}I_a}$, antecedent moisture, and potential maximum soil retention $\boldsymbol{S_o}$

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Estimating Groundwater Recharge

Empirical Water Balance

GWR = $P - ET - R_{off}$

- Assumes GWR as the residual of all known inputs and outputs of the watershed
- Straightforward integration of additional balance terms
- Accounting for topography, soils, land cover depends on methods used to estimate individual variables

HBV light

$$P - ET - Q = \frac{d}{dt}(SP - SM + UZ + LZ + lakes)$$

- SP = snow pack;
- SM = soil moisture;
- UZ = upper groundwater zone;
- LZ = lower groundwater zone

- Calculates groundwater recharge as the downward percolation of all remaining soil moisture after evapotranspiration
- Directly accounts for snowmelt, elevation

SME-estimated Runoff Hydrograph

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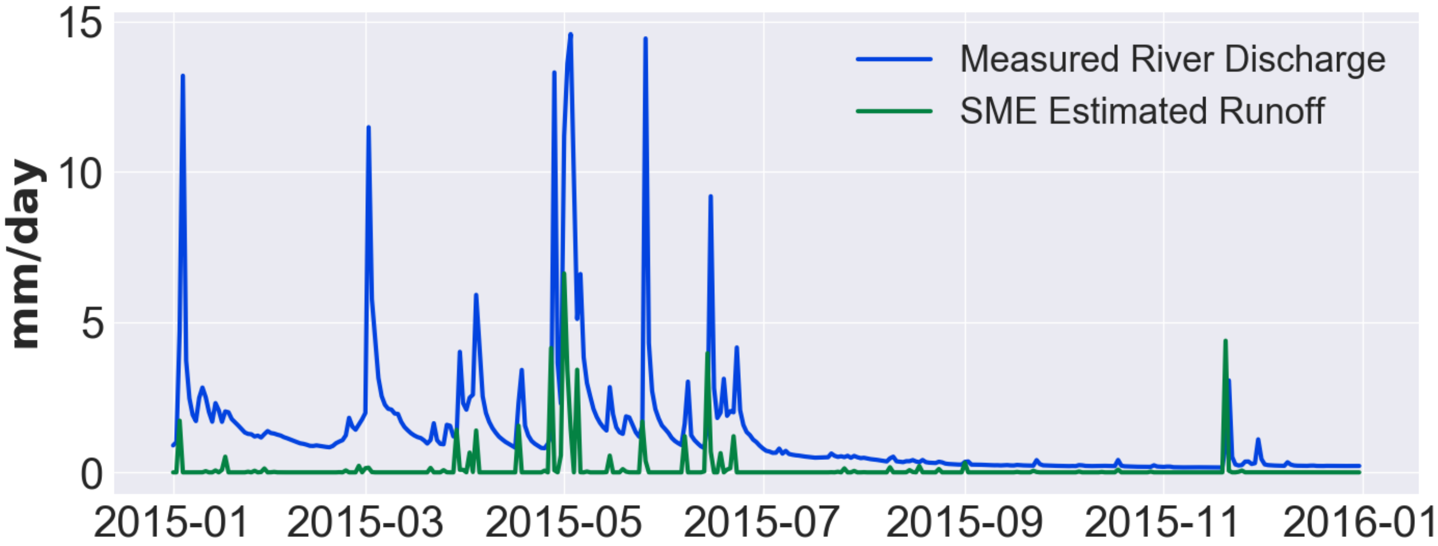

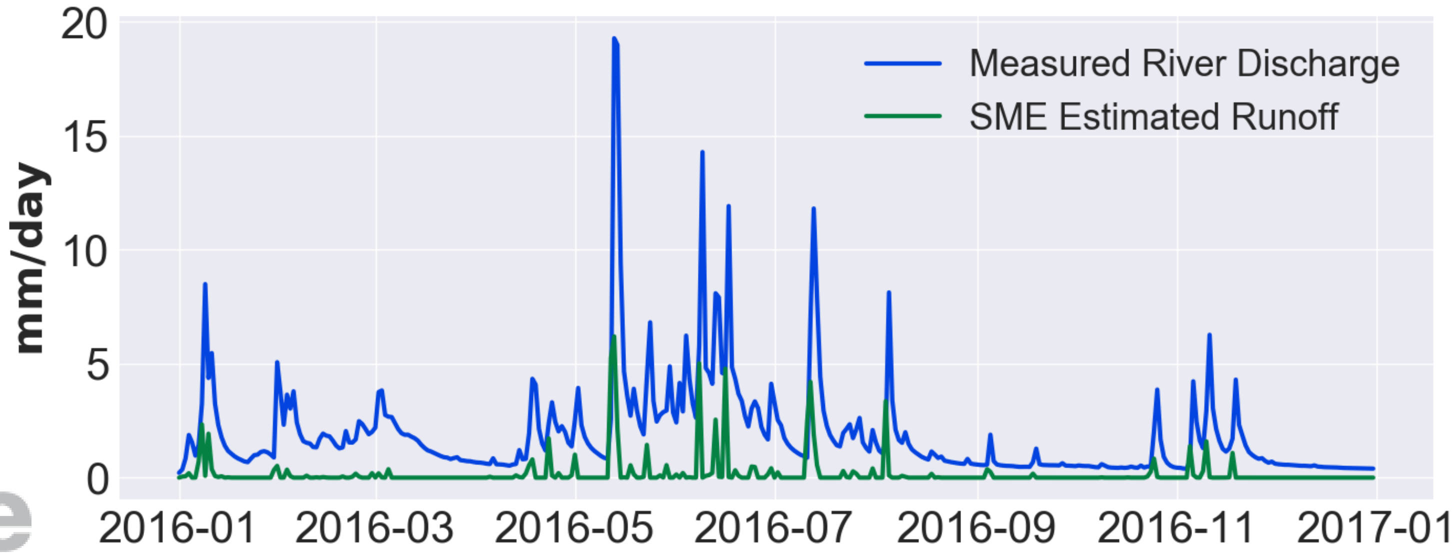

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Estimated Runoff + Baseflow = Validation ?

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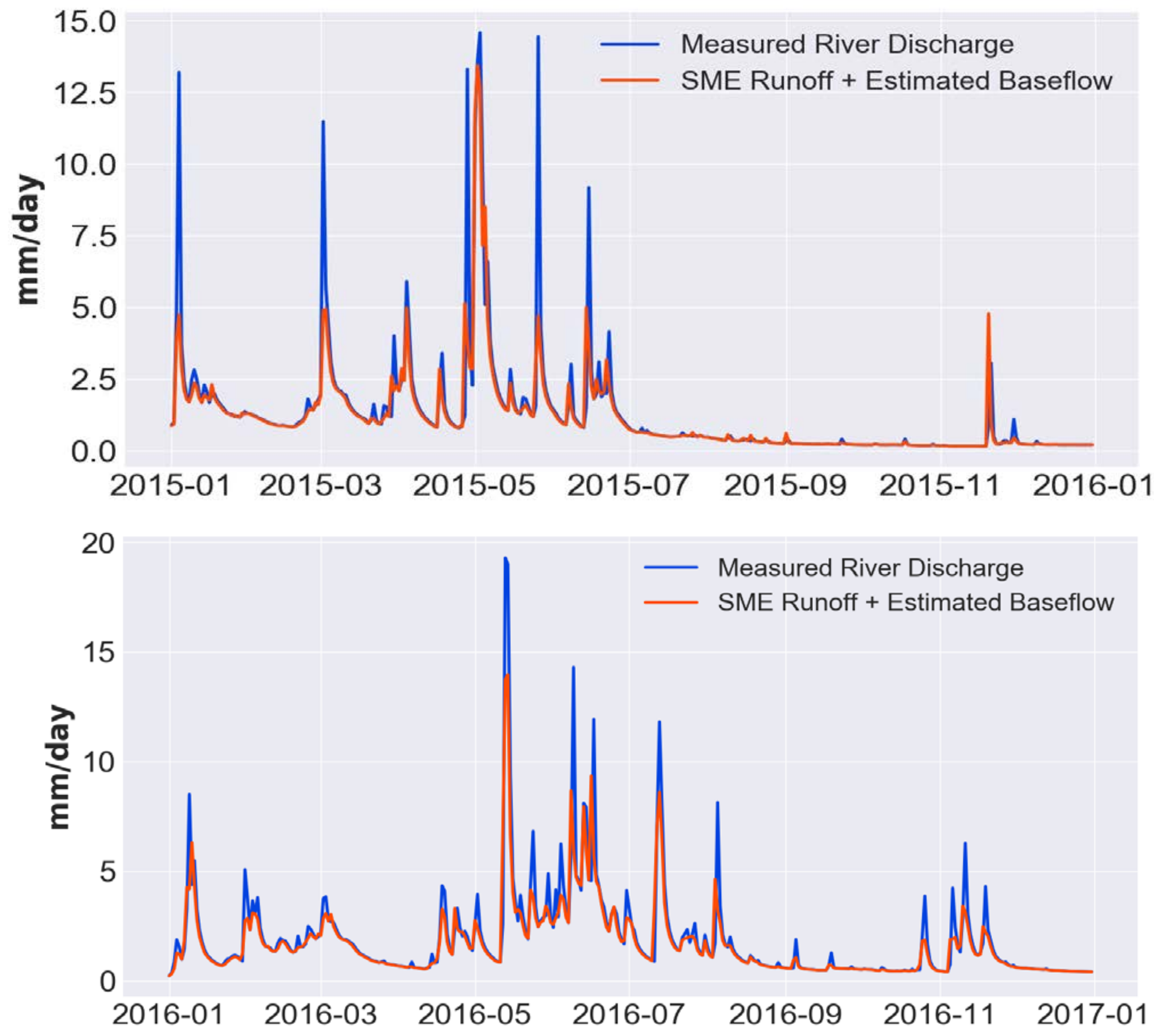

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Annual Estimations of Surface Runoff

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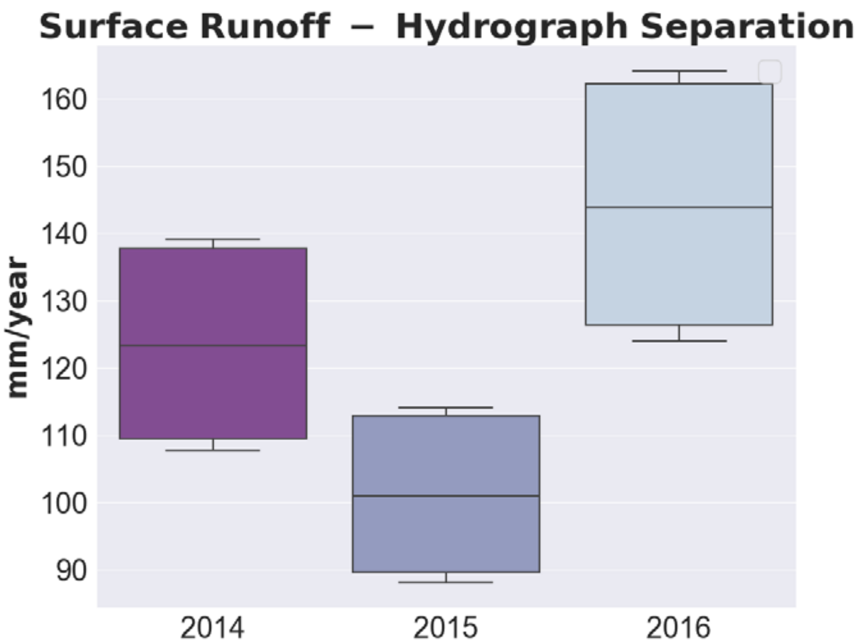
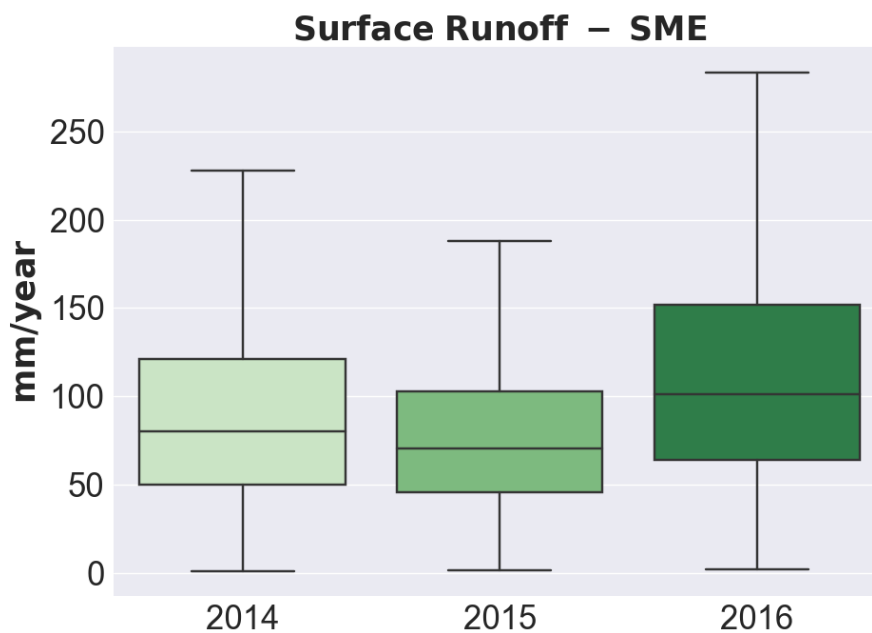


Year	Mean	Max	Min
2014	**122**	139	108
2015	**102**	115	88
2016	**144**	164	124



Year	Mean	Max	Min
2014	**77**	230	0
2015	**75**	188	0
2016	**101**	286	0

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Improving Hydrograph Separation

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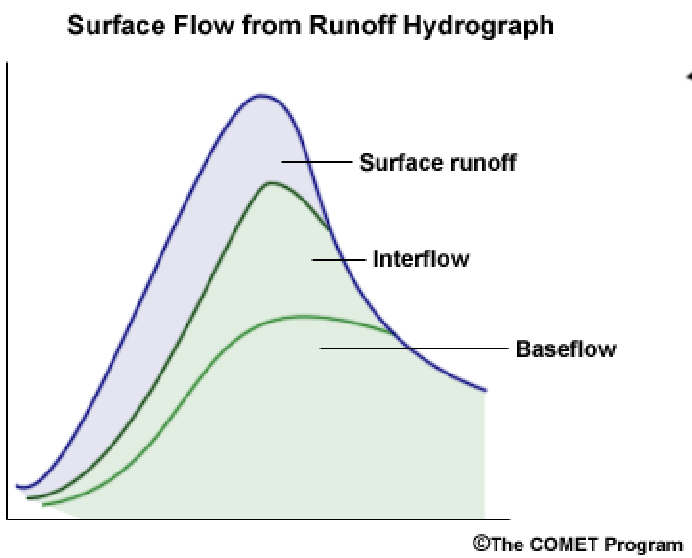
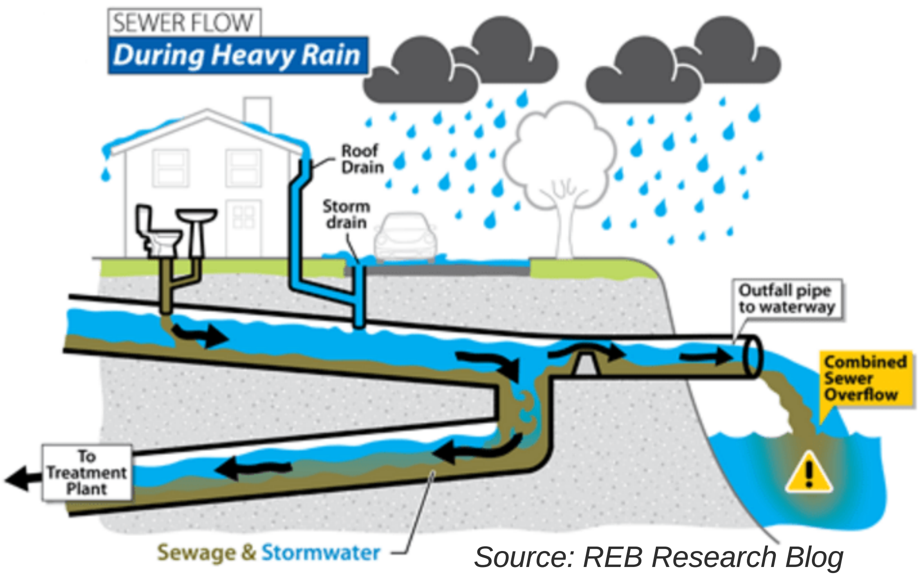
Hydrograph separation – a bivariate model is not enough!

What other elements might be present?

- Soil moisture / interflow
- Combined sewer overflow
- ... ?





Source: REB Research Blog

How to identify them?

- Isotopic mixing models
- Mass balance of organic micropollutants from different sources

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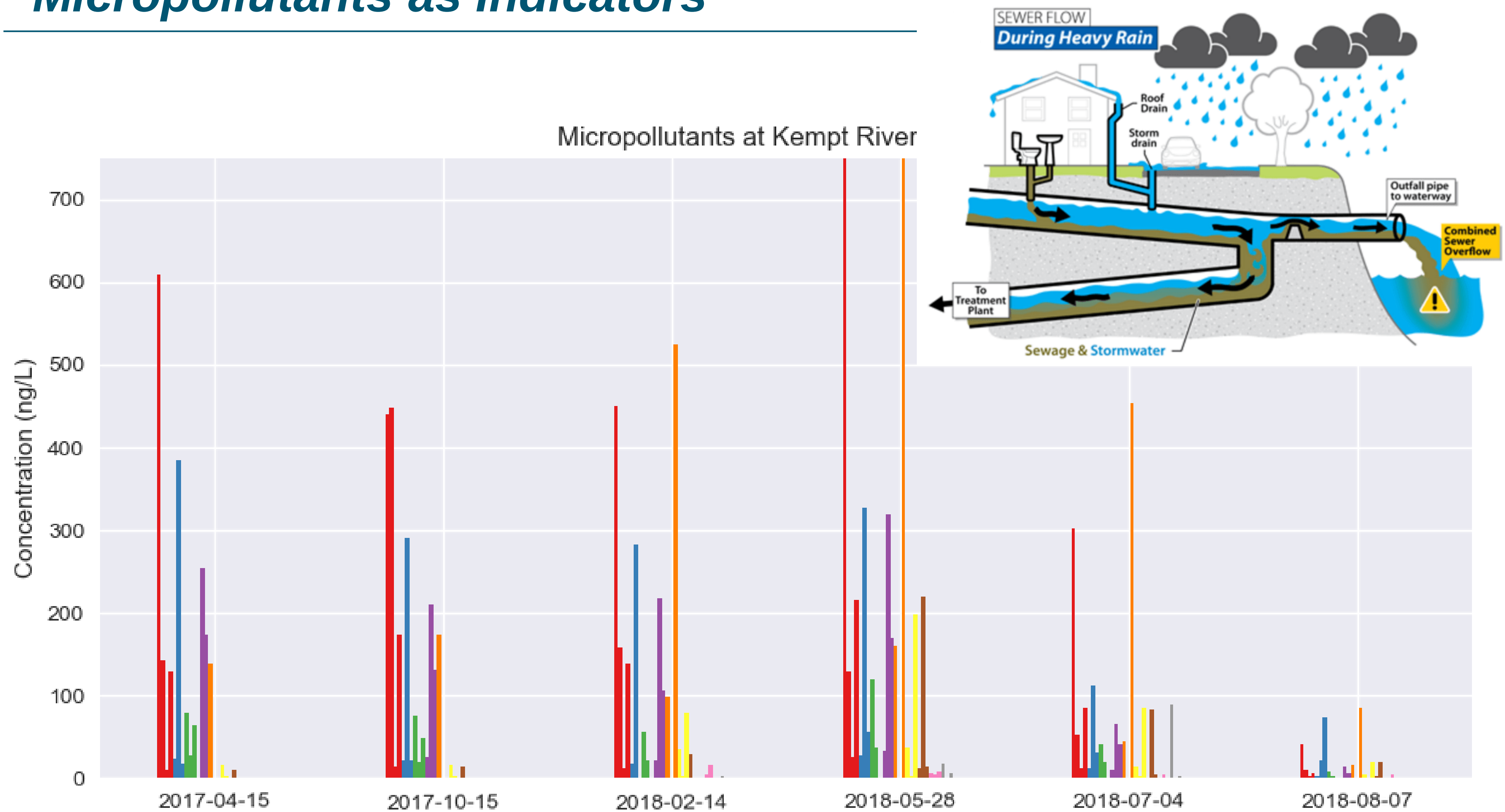
Improving Hydrograph Separation

Micropollutants as Indicators



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Comparing Estimates of Groundwater Recharge

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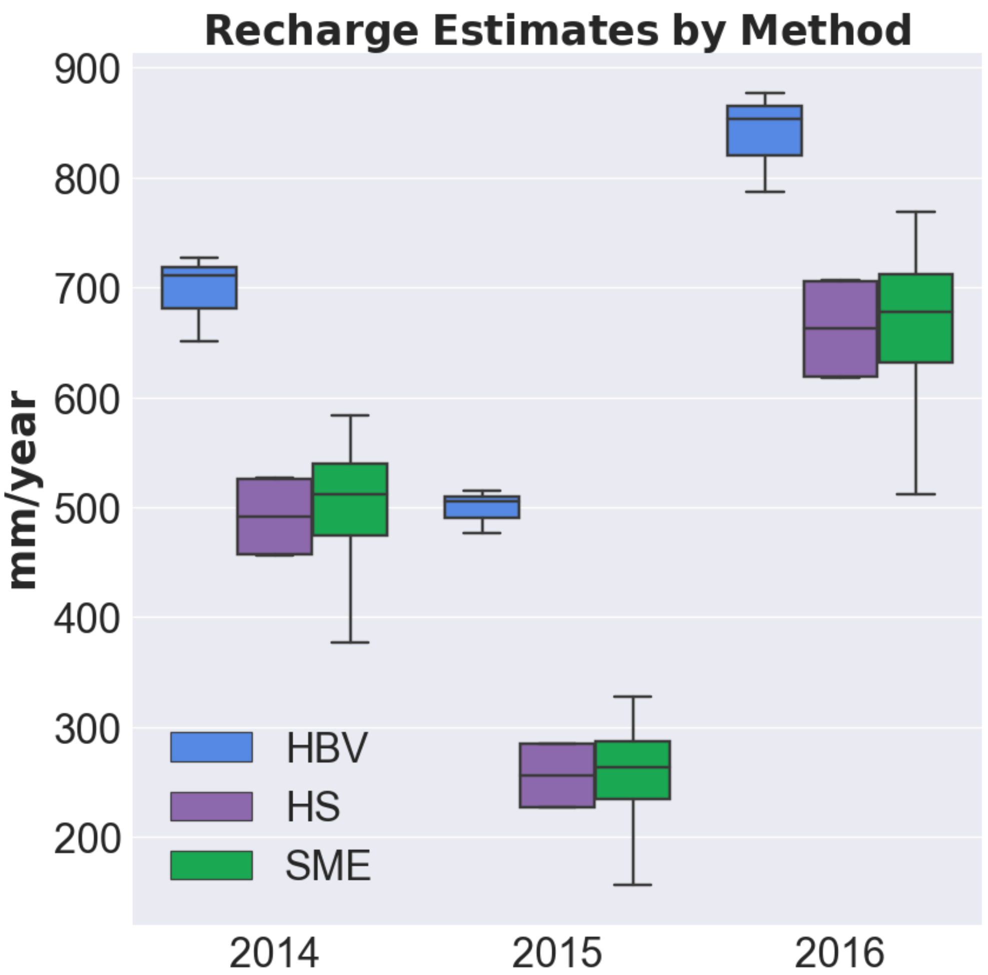
Estimates – Average Values

Year	HBV	SME	HS
2014	696	502	491
2015	498	258	255
2016	838	665	662

Uncertainties

- **Hydrograph separation** may overestimate runoff and **underestimates recharge**
- **HBV model** assumes infiltration = recharge – likely **overestimate recharge**
- No method explicitly accounts for interflow!



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Next Steps

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Improving Runoff Estimates with SME

- Explore the application of a continuous index for soil moisture accounting
  - Option: antecedent precipitation index

$$API_d = kP_{d-1} + k^2 P_{d-2} + \ \dots$$

- Validate SME model values with hydrograph quickflow

Improvements on Hydrograph Separation

- Multivariate hydrograph separation accounting for interflow, sewer overflow
- Construct an isotopic mixing model (3+ components) for more precise hydrograph separation
- Mass balance of organic micropollutants to evaluate their utility as a tracer for individual hydrograph components

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Thank You !