Post-processing Hydrologic Model Output for Water Resources Studies: A Spatially-consistent, Process-based Correction Method

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Motivation and summary

- Streamflow post-processing through bias correction is used to improve model predictions and make these predictions more useful to stakeholders and water managers
- Existing bias correction methods do not take into account the river network topology, which leads to spatial inconsistency when applied to multiple locations independently
- We have developed a spatially-consistent bias correction method which can also take in information about physical processes
- We demonstrate that our method enforces spatial consistency and analyze a simple synthetic test case

Spatial consistency

An idealized channel flow network (ignoring evaporation, groundwater exchange, etc) will obey:

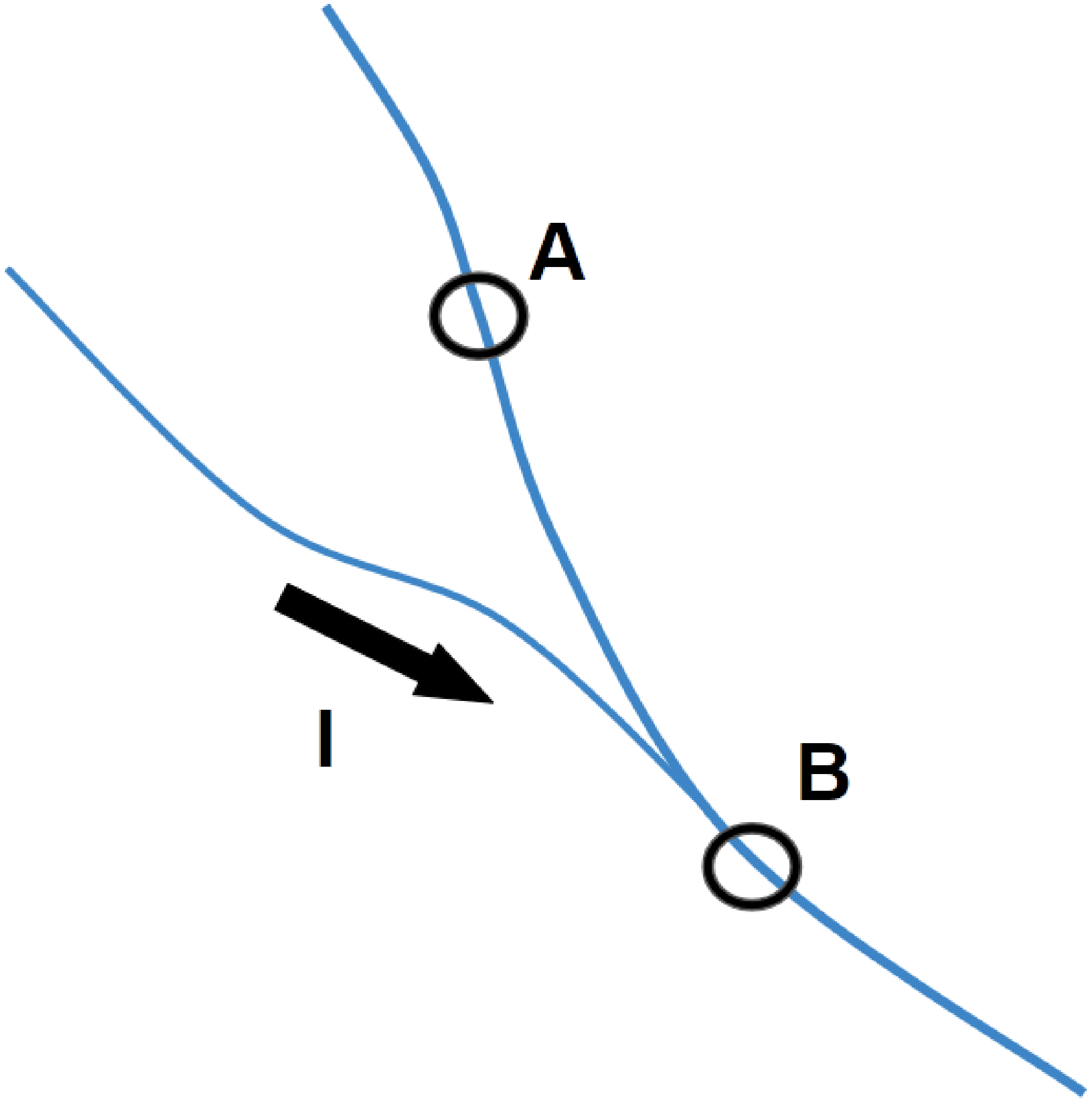
A = B - I

If we denote bias corrected flows as **BC(x)**, then a bias correction method is spatially consistent if:

BC(A) = BC(B) - I

Current bias correction techniques do not account for this inherent network topology that the river network imposes.

This can introduce artifacts in bias corrected timeseries such as negative flows, timing shifts, and will break assumptions of mass conservation.



To create a spatially consistent bias correction we bias correct local inflows

Bias correction of aggregate streamflow implicitly accounts for upstream biases

Bias correcting local flows allows us to enforce spatial consistency.

Instead of implicitly taking these corrections into account we propose to correct them directly, and then re-aggregate the flows via a routing model

This leads to 2 main questions:
1. How do we develop reference flows which are free of upstream influences?

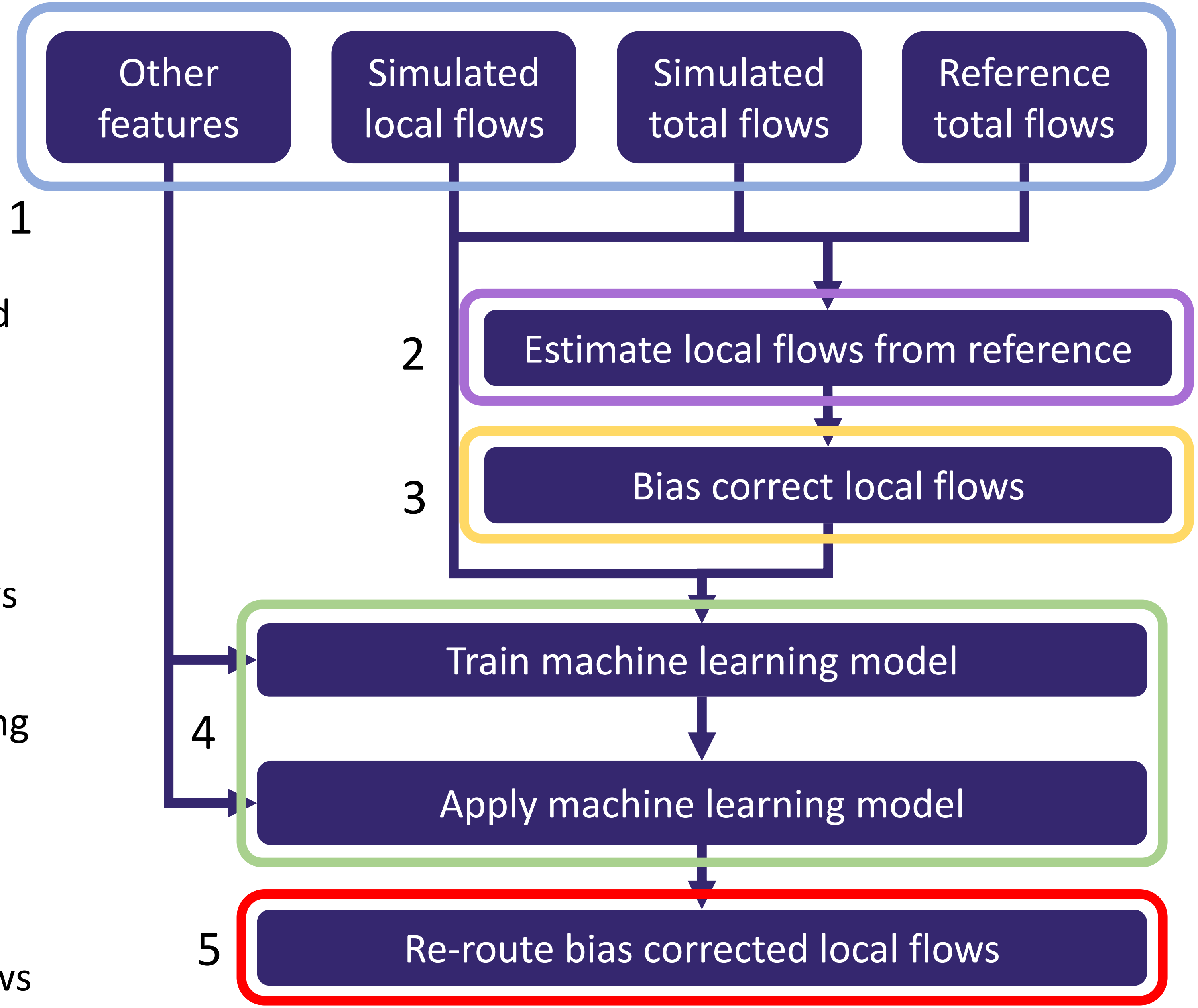
2. How can we apply this method to sub-catchments which do not have reference flows?

SCBC Workflow: overview

We refer to our method as a Spatially Consistent Bias Correction (SCBC) method

We consider 5 distinct pieces in our workflow as highlighted on the diagram

1. Input data
2. Estimation of reference local flows from reference
3. Bias correction of local flows (using reference local flows)
4. Regionalization through machine learning
5. Aggregation of bias corrected flows



SCBC Workflow: inputs

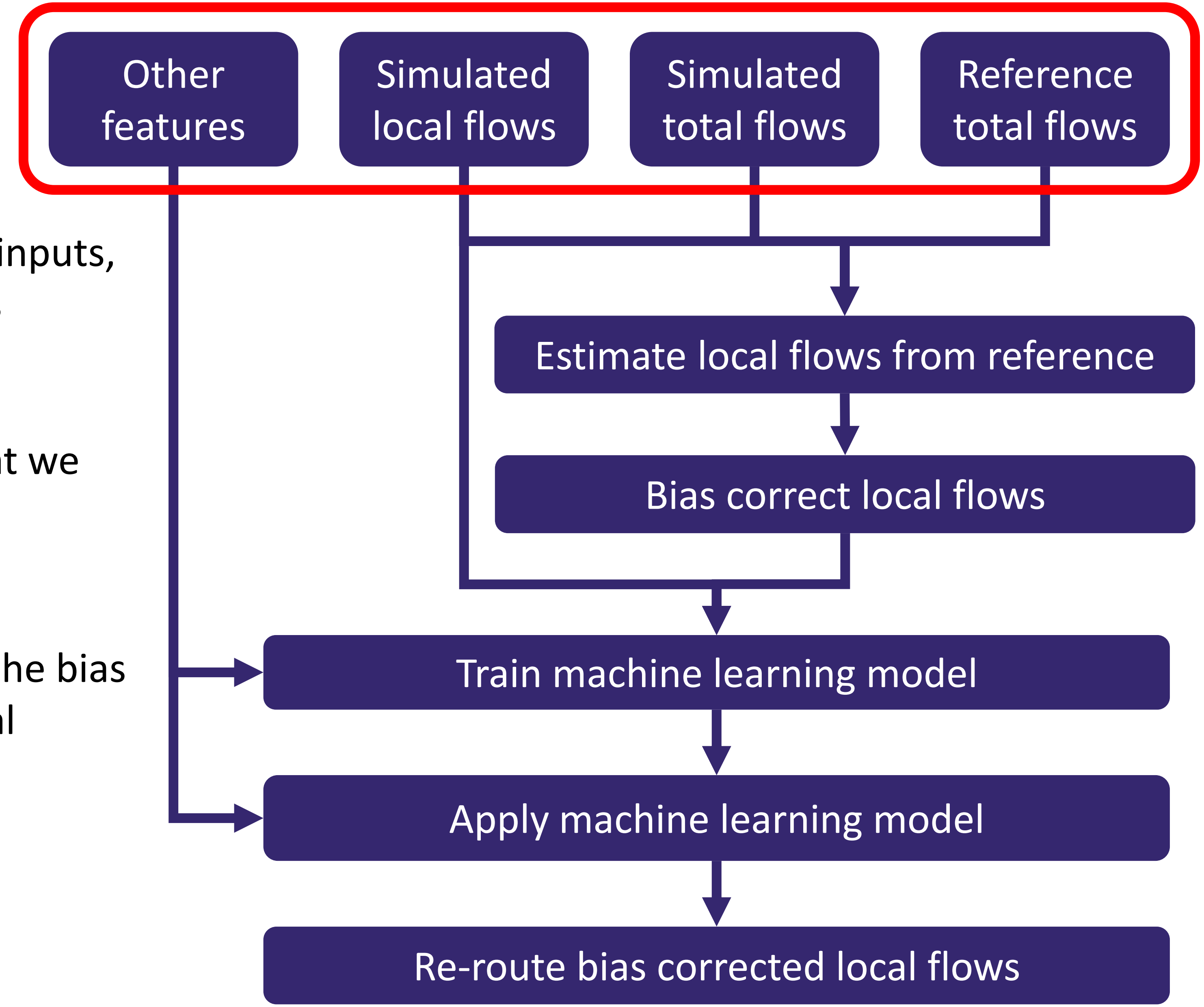
Our workflow requires a minimum of three inputs, but can be expanded to incorporate process information

Required inputs:

- Simulated local flows: These are what we will bias correct
- Simulated total flows: Used in the estimation of reference local flows
- Reference total flows: Used to train the bias correction as well as to estimate local reference flows

We add other features for regionalization:

- Daily minimum temperature
- Precipitation
- Basin area
- Basin elevation



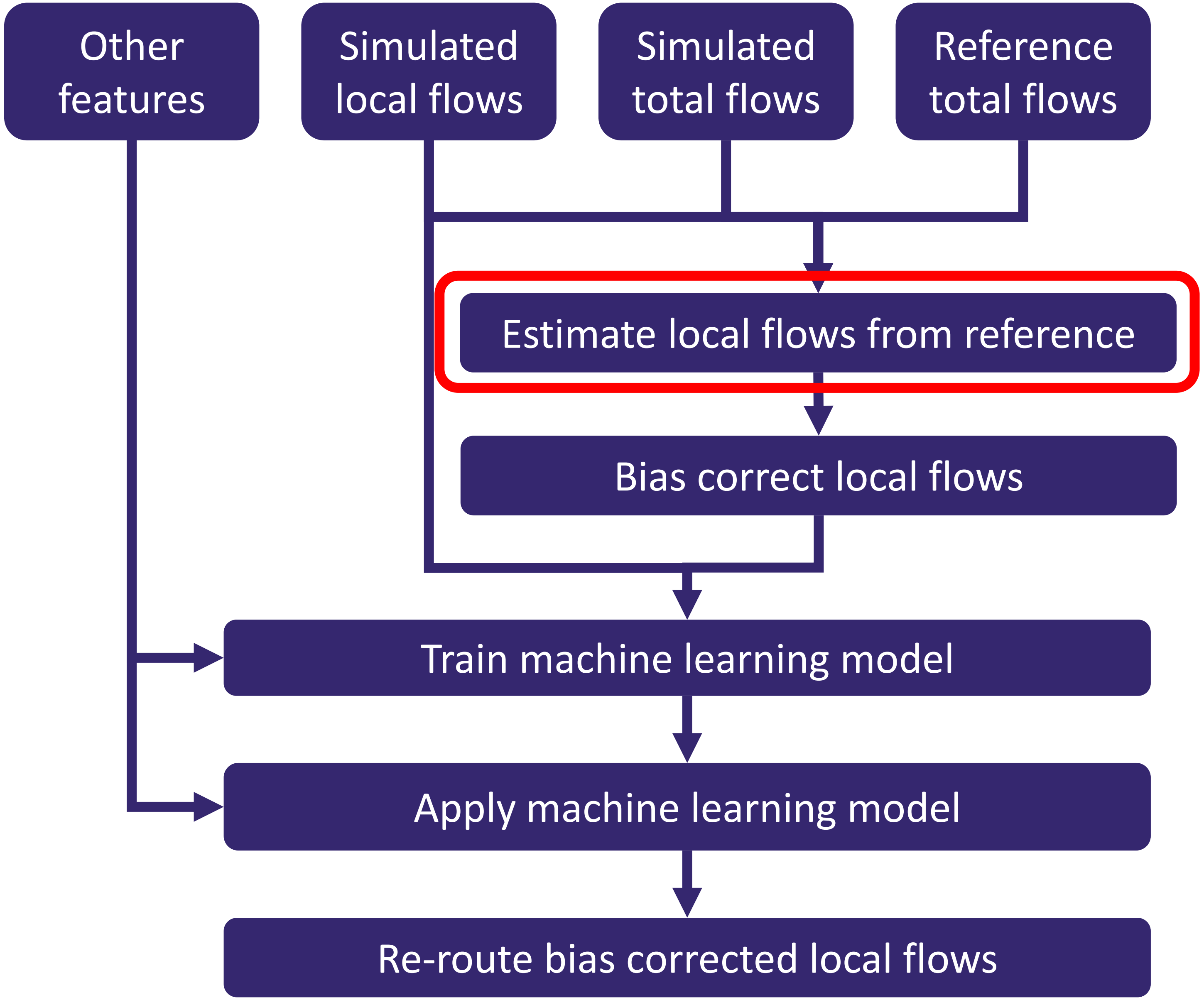
SCBC Workflow: estimating reference local flows

Bias correction requires mapping of a source variable onto a target variable

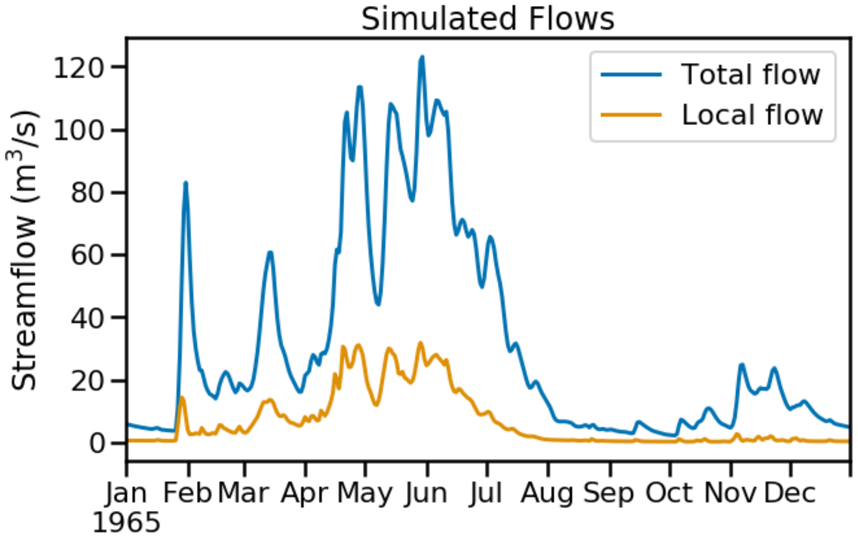
Generally we don't have observations of local flows to use to train our bias corrections

So, we will need some estimate of local flows to use as reference

To estimate these we will consider the ratio of our simulated local flows to simulated total flows

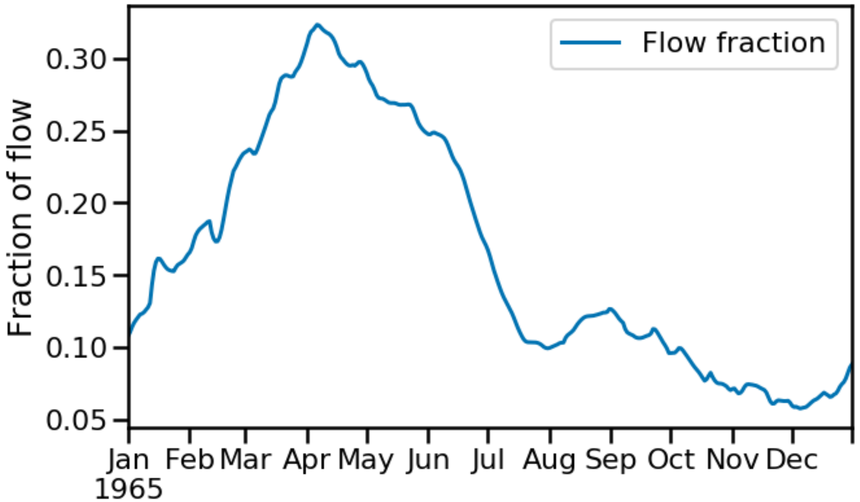


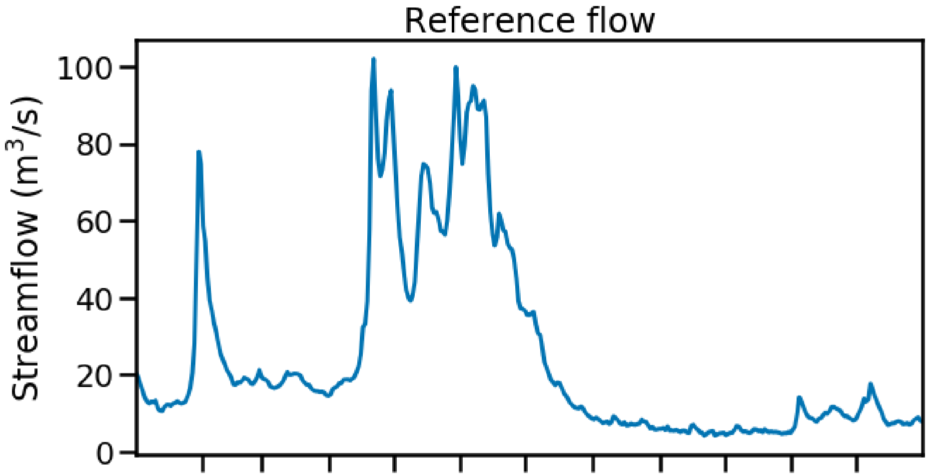
SCBC Workflow: estimating reference local flows



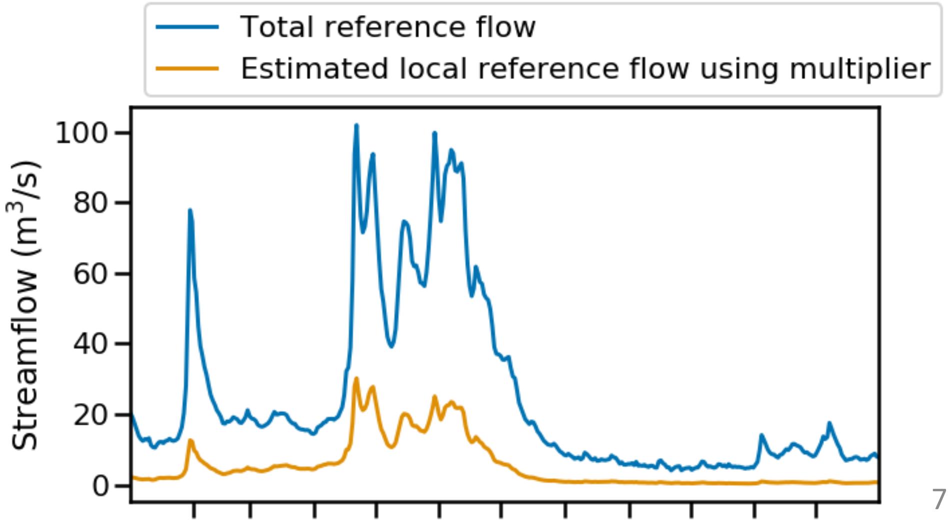
The first step is to calculate a flow fraction index

We use the 30 day rolling mean of the ratio of simulated local to total flow





The flow fraction index is multiplied by the reference flow to create the estimate of the local reference flow



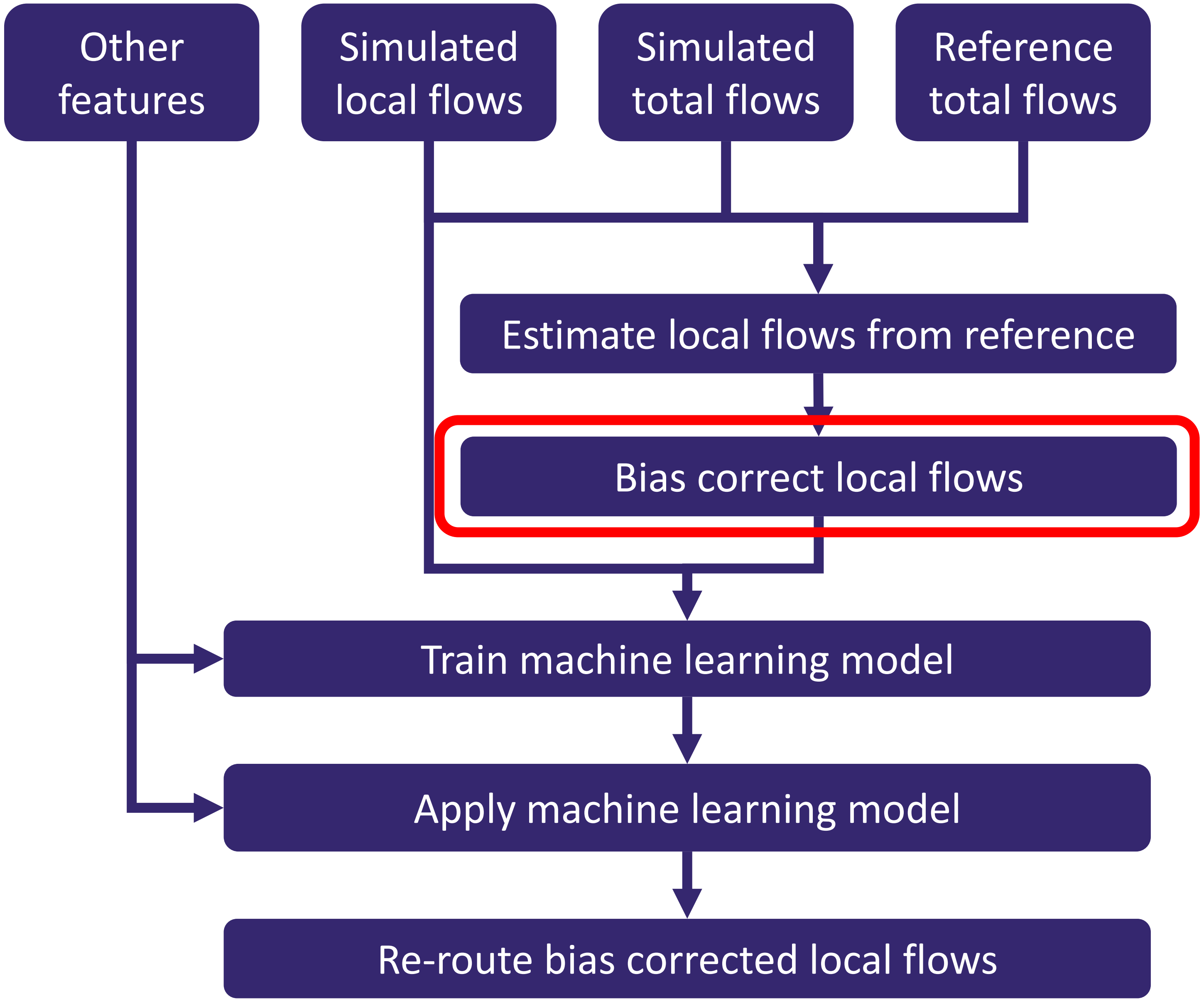
SCBC Workflow: Bias correction

With an estimate of the reference local flows we can now bias correct sites where we have reference flows

We use a variant of quantile mapping to do our bias corrections currently

However, there are still many river reaches without reference flows

So we use these bias corrections at reference flows sites to train a regionalization model



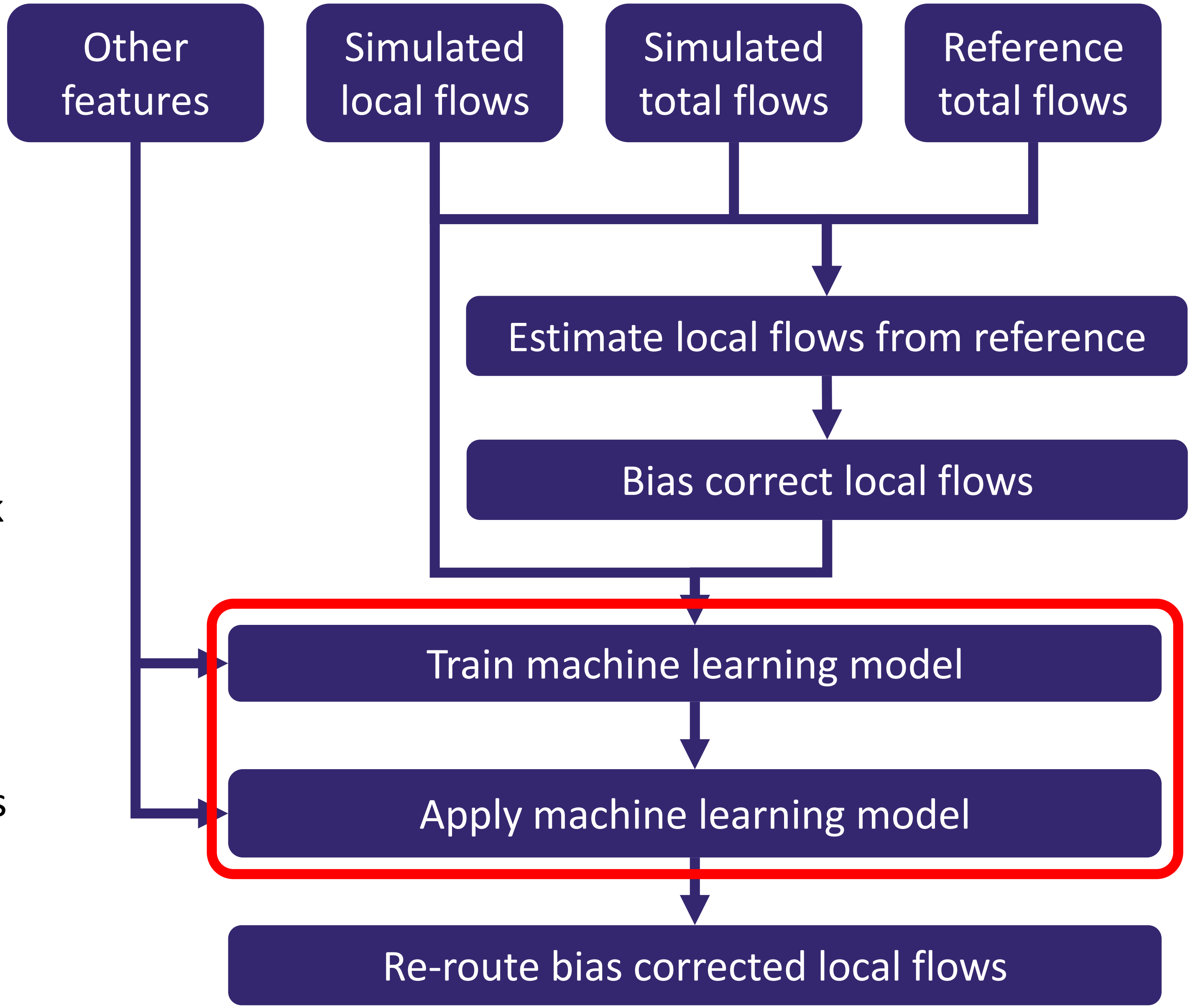
SCBC Workflow: Regionalization

To apply our method across all river reaches we train a neural network using all locations where we have reference flows

We additionally feed the neural network features that contain process information such as, temperature, precipitation, elevation, and basin area

This allows the neural network to find patterns in what drives the model biases

Currently we use a bidirectional LSTM but are exploring other architectures

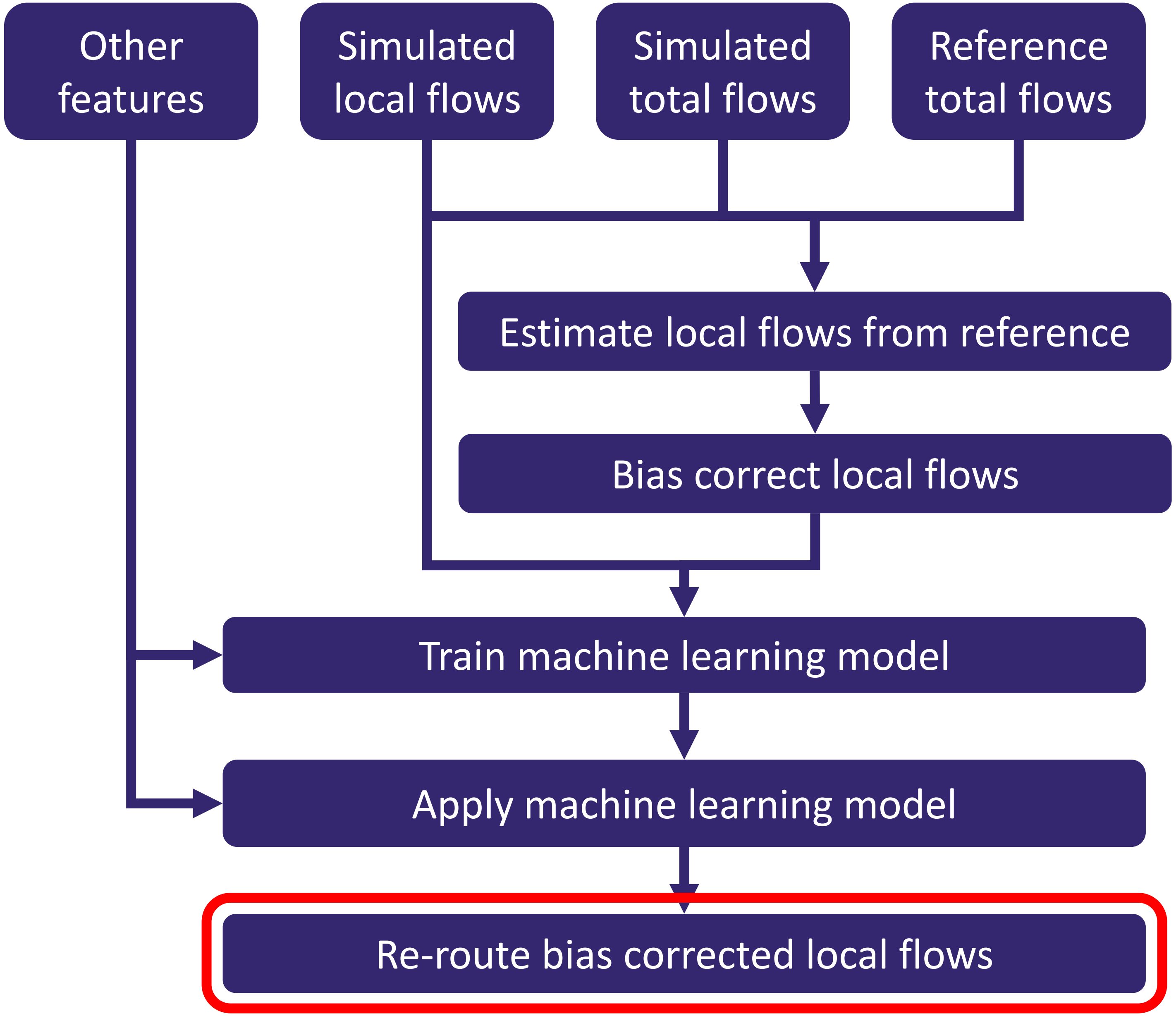


SCBC Workflow: Reaggregating flows

After training and applying the machine learning regionalization model we have produced bias corrected local flows at each river reach in the basin

We then re-route these flows through the mizuRoute river routing model

By re-routing we produce the total flows which have integrated all the local bias corrections



Test cases

To better understand methodological decisions we are analyzing our method on several test cases

We present results of two test cases for the Yakima river basin, located in Washington state in the northwestern United States

We use a larger set of points, 277 gauge locations throughout the northwestern United states, for training the neural network for regionalization

Our model of the Yakima river basin consists of 143 river reaches and has 14 gauge locations

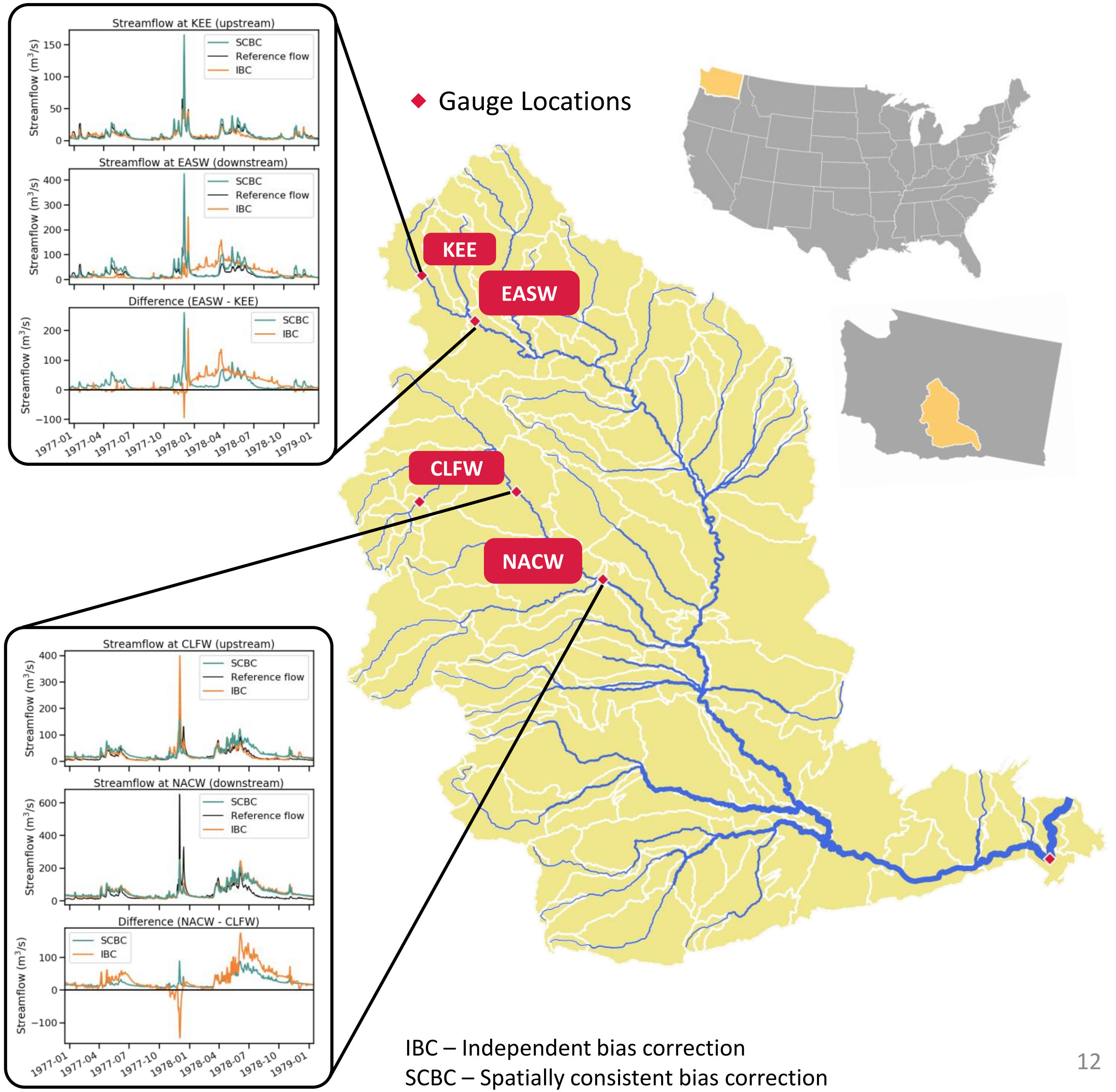
Test case 1: spatial consistency

We first demonstrate that our method preserves spatial consistency across the river network

We applied SCBC to the Yakima river basin as well as applying a traditional bias correction method (IBC) independently at the gauge locations

We look at 2 upstream-downstream site pairs (CLFW-NACW and KEE-EASW) to demonstrate that SCBC preserves spatial consistency while IBC does not

In the difference plots of both site pairs we see that IBC introduces artificial negative flows while SCBC does not



Test case 2: synthetic flows

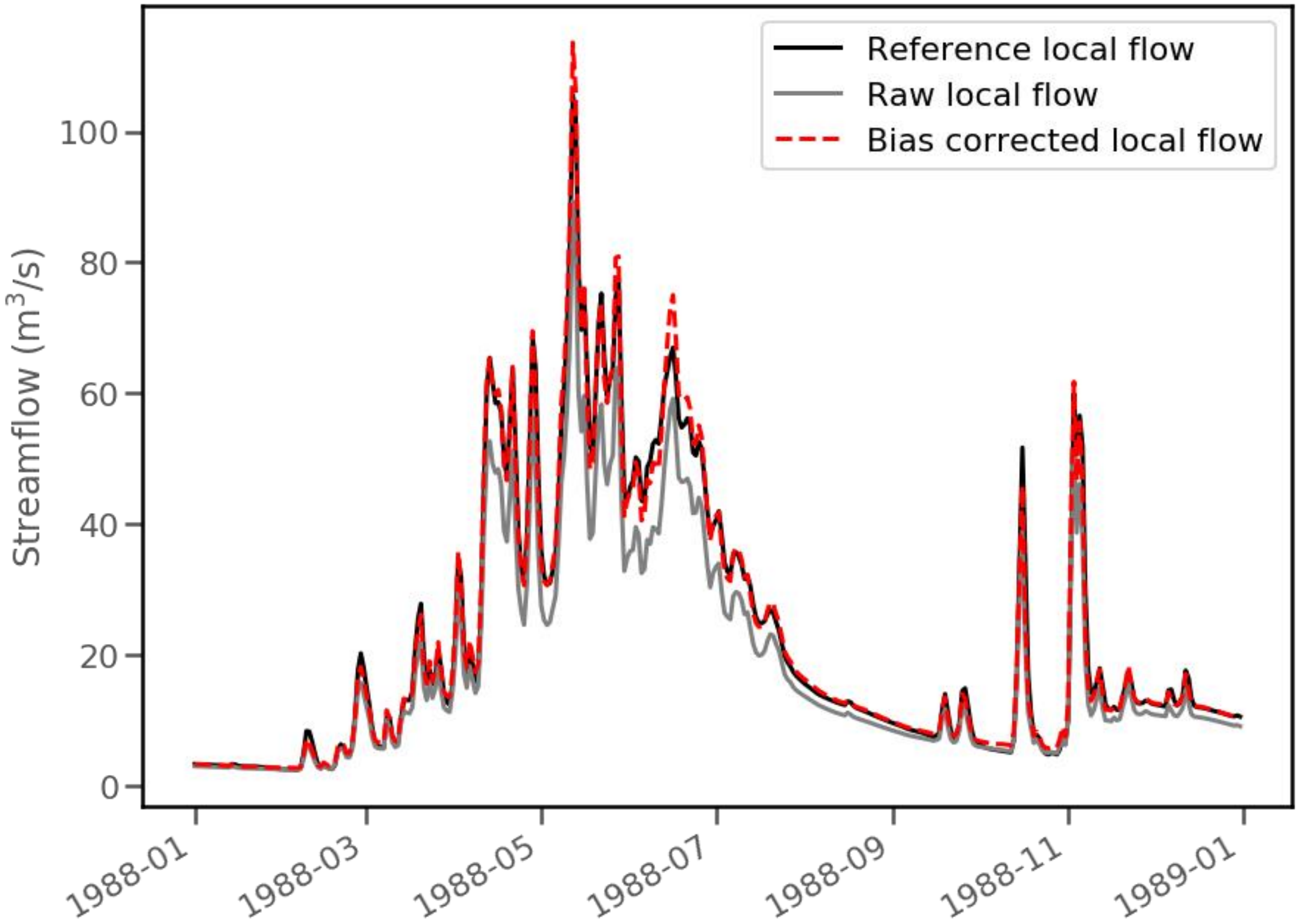
Instead of using gauge observations to train our regionalization we use a transformation of our raw simulated flows

We apply the transformation:

$$Q_{ref} = (Q_{sim})^{1.05}$$

We produced these synthetic reference flows for all 277 training gauge locations, and used them as the basis for our regionalization model which is applied in the Yakima river basin

The right plot shows the raw flows, reference flows, and the bias corrections that are produced by the regionalization model



Test case 2: synthetic flows

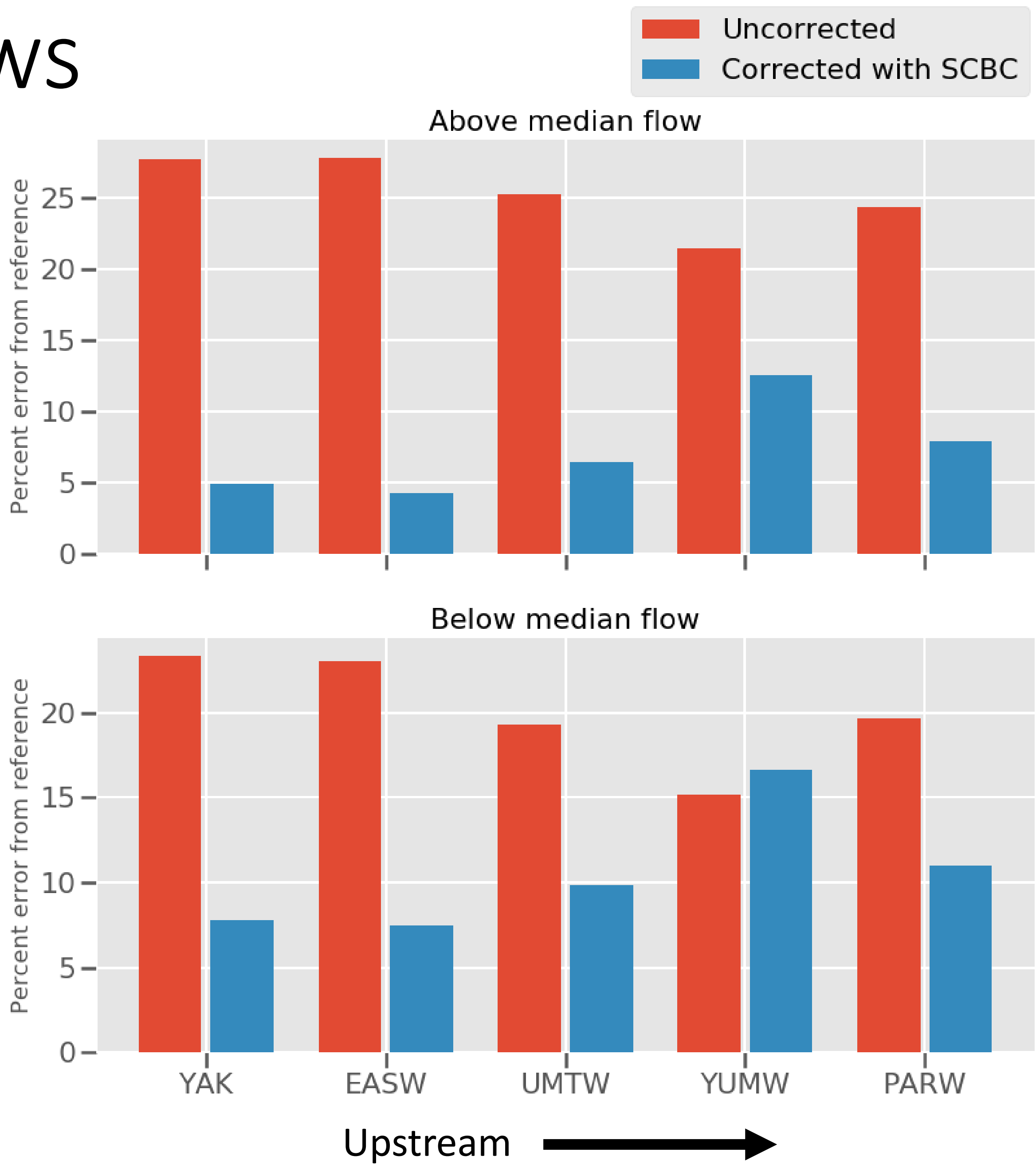
We compute the percent error from the reference flows for 5 sites along the main stem of the Yakima river

We separate the analysis into flows that are above the median value and below the median value within each site

For flows above the median value we see large improvements in percent error at all sites

For flows below the median value we generally reduce the percent error, with the exception being at YUMW

SCBC works better at downstream locations than upstream



Discussion and ongoing work

We have demonstrated our initial workflow for the SCBC method. Much of the work so far has been setting up the workflow pipeline

We will continue to explore different methods for

- estimating reference local flows
- bias correcting training local flows
- building regionalization models with different approaches

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