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Outflow boundaries for hydrodynamic simulations at ungauged locations

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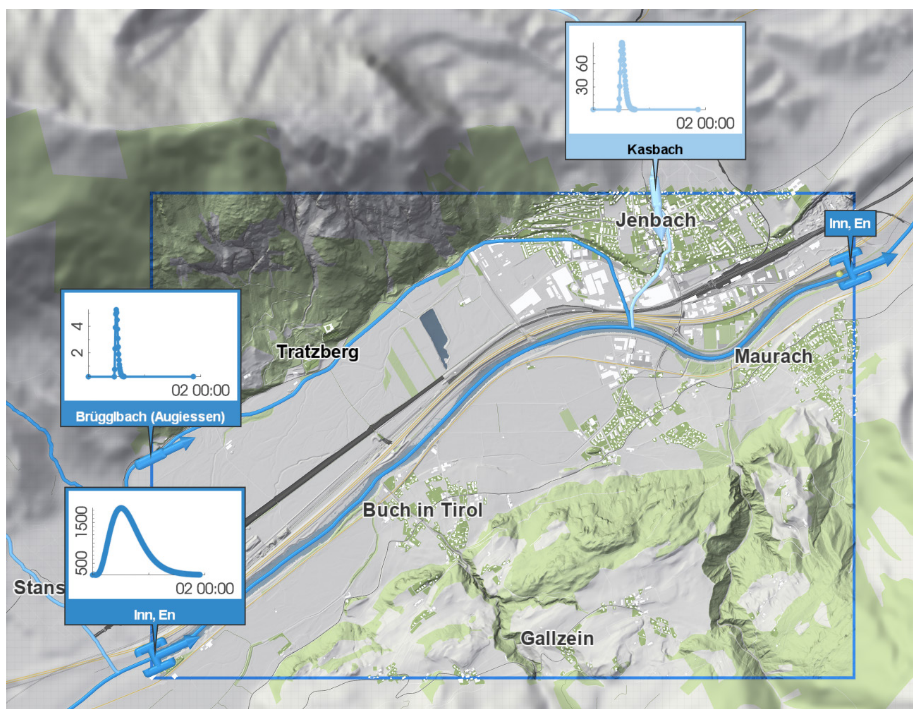
Abstract

In flood risk mapping, boundary conditions are used to prescribe design flood waves. Often, they are only given by discharge values. However, for hydrodynamic simulations both a discharge time series upstream and a water level time series downstream are typically needed as boundary conditions. Thus, discharge values need to be converted to water levels at the outflow, for example with a rating curve. At gauged locations one can simply use the measured discharge-stage relationship as a rating curve. For ungauged locations one needs to approximate this mapping. In this poster, we describe geometrical and numerical methods that improve the automatic generation of outflow boundary conditions for shallow water schemes. Our approach performs well on selected gauges in Tirol, Austria. Finally, we discuss improving the outflows by avoiding the static time dependency and we lay out future work.

Boundary conditions in flood risk mapping

The first step is to automatically create inflow and outflow boundary interfaces that prescribe boundary data to the simulation. To obtain the interfaces, we intersect river lines with the boundary of the simulation domain. Then, the boundary lines are rasterized to mark the interfaces active for the specified water level and discharge time series.

For a simulation domain as shown in the right figure, at the three inflows we set the design flood waves as discharge time series. However, we still need to derive and set one outflow boundary condition for the Inn. The difficulty lies in finding a suitable approximation of the rating curve.

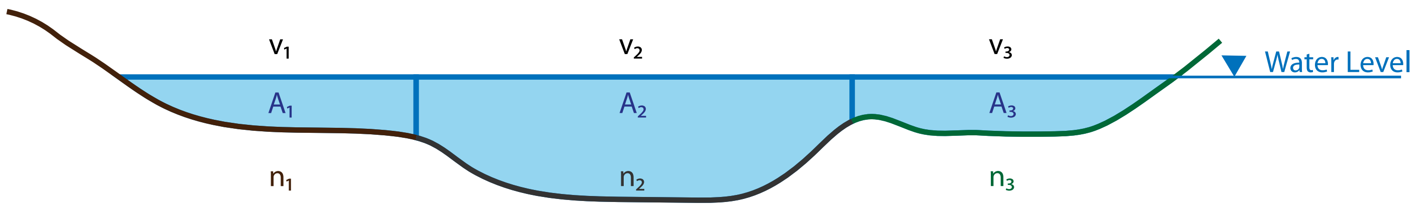


Deriving the rating curve at ungauged locations

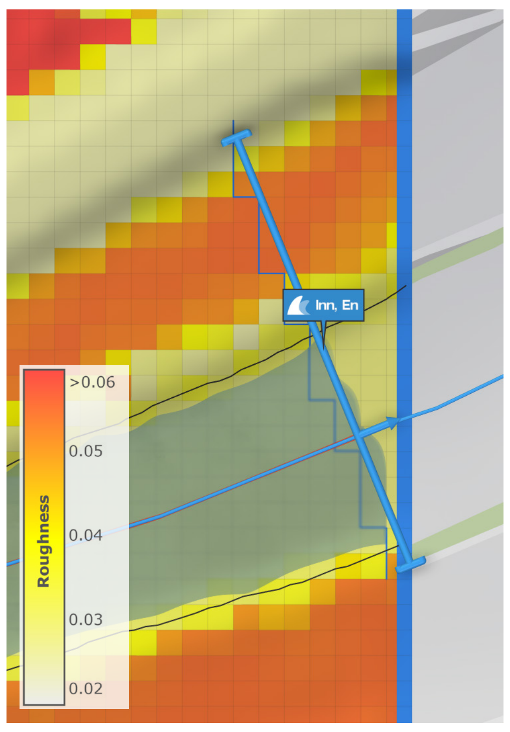
At gauges, the relationship between discharge and water level, the rating curve, is obtained by measuring the flow velocities to estimate the total discharge. At ungauged locations, we approximate rating curves based on Manning's equation for the mean velocities

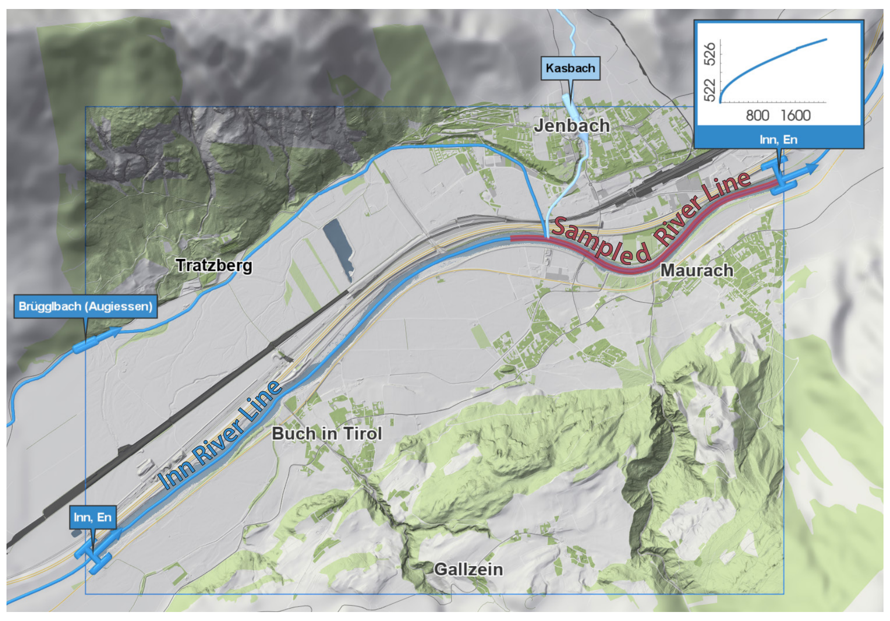
$$v_i = R_i^{2/3} S^{1/2} / n_i,$$

where *n* and *R* is the roughness and hydraulic radius, resp., along the segment *i* of the cross-section. The energy slope *S* is usually not available, thus we are approximating it with the terrain slope. The hydraulic radius are computed via the wet perimeter and the flow area of the polygon between water level and river bed. The total discharge *Q* is then computed via the sum of the products of the cross-sectional area A and the mean velocity v of a segment, as shown in the schematic cross-section below. For lack of a better solution, we assume that Manning's equation is also a good approximation for non-uniform flow.



Manning's roughness value *n* might vary a lot along the cross-section, as we can see in the left figure below. By dividing the cross-sectional line into sections of approximately the same roughness, we are able to improve the accuracy of the rating curve. The roughness value is a a parameter controlling the energy loss due to friction. For the energy slope, we compute a least-squares approximation of the terrain slope along the river line. We sample from the outflow boundary upstream inside the domain, as is shown in the righ figure below. Altogether, we are finally able to compute the discharges for different water levels to obtain the rating curve.





Validation of the presented method at gauged locations

We show an evaluation of our method on three gauges at the Inn and the Ziller. On the right, measured rating curves and computed ones for the gauges at

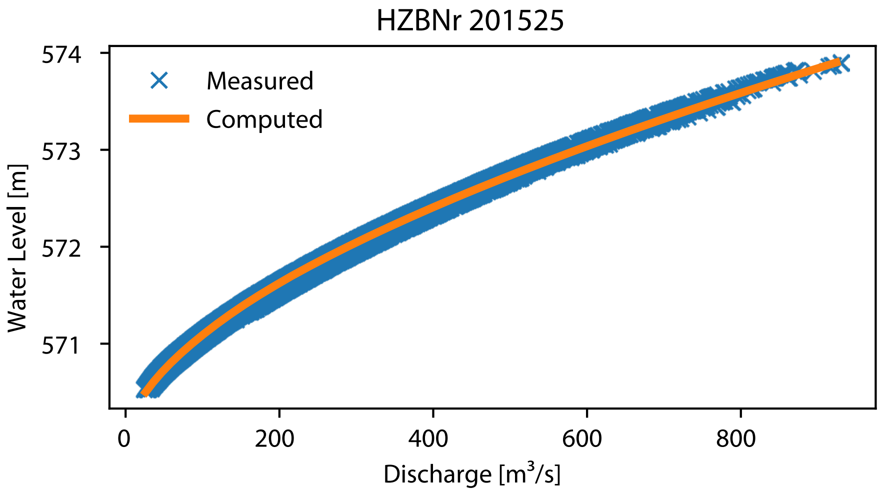
- Innsbruck (Inn, HZBNr 201525),
- Jenbach (Inn, HZBNr 201681), and
- Hart (Ziller, HZBNr 201780)

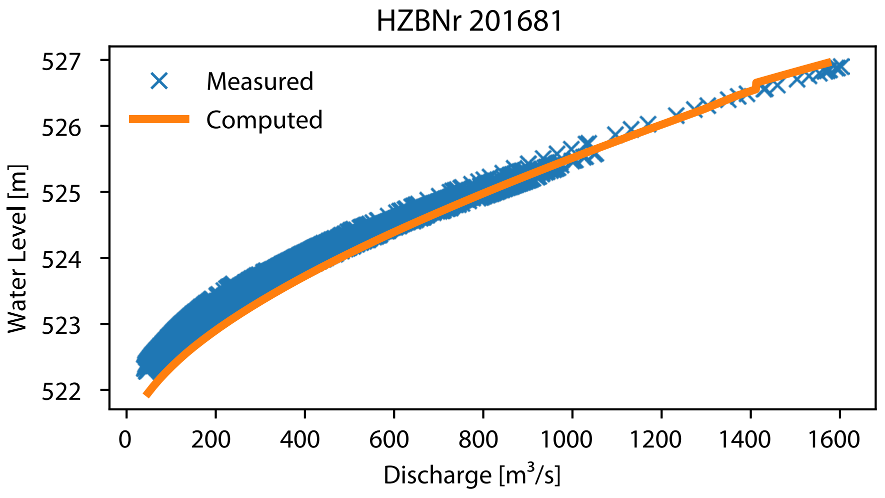
are plotted.

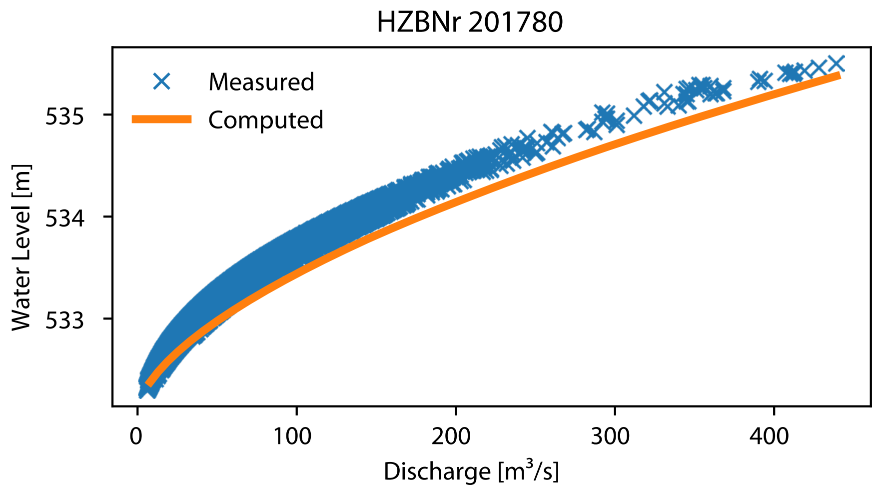
The gauge at Innsbruck has discharge and water level data from 2006 to 2015, since the gauge was relocated in August 2006. The Jenbach gauge has data from 2003 to 2015. The gauge at Hart has the most complete data including nearly 20 years, i.e., from 1997 to 2015. Except for Innsbruck, the gauges include the large flood event of 2005, note the different scalings in the plots.

The digital terrain model is given on a raster with 1 m resolution.
The terrain slope is sampled along the river line for 2 km on the Inn and for 500 m on the Ziller. The cross- section used for Manning's formula is extending the river width by 20 per cent.The computed rating curves are fitting the measured data quite well.

Since the proposed approach can not detect local flow control, the results are surprisingly satisfying. Nevertheless, the selection of the roughness coefficient is an art, and the sampled roughness field is specified by hydraulic engineers and estimated through geological river bed properties and land use.





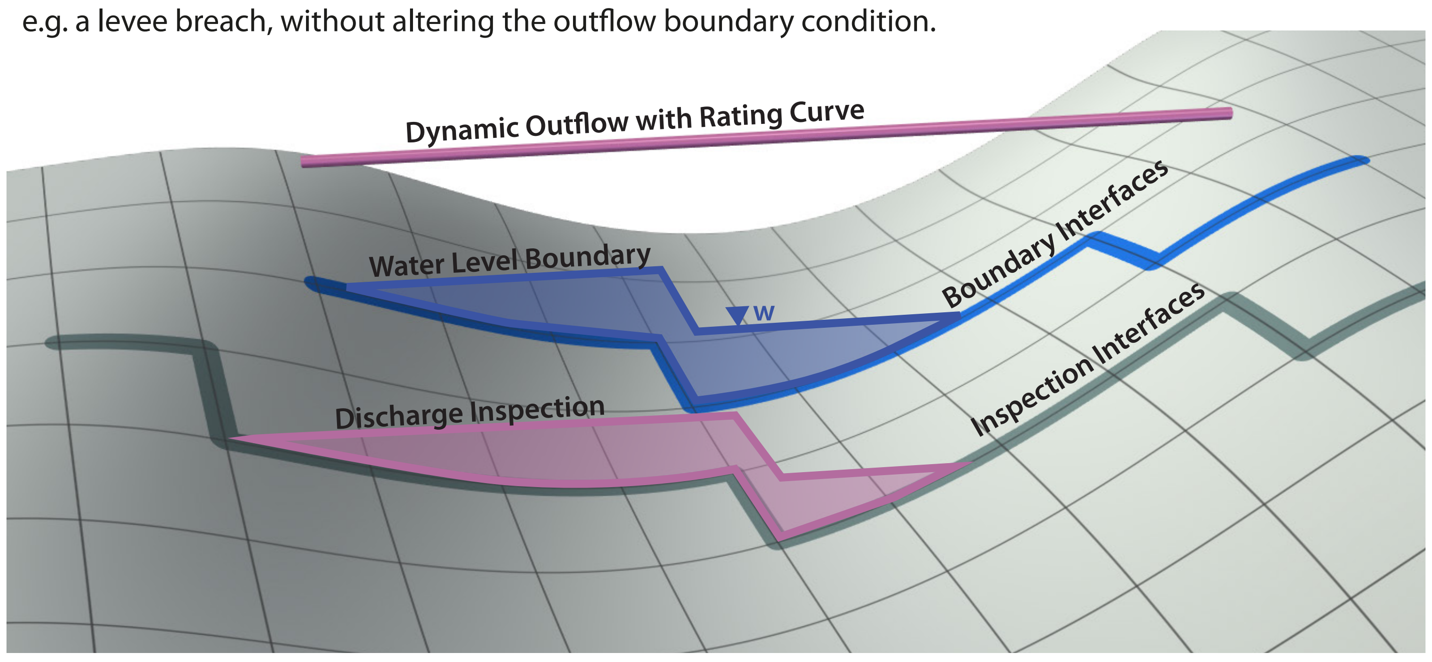


Dynamic outflow boundary conditions

To avoid problematic effects coming from outflow time values not correctly accounting for the travel time shifts for the design flood waves, we propose dynamic outflow conditions. These boundary conditions work directly on the given rating curve, instead of using a precomputed water level time series. Rather than depending explicitly on time values, at each time step

- the discharge at the outflow is recorded,
- the recorded discharge is subsequently mapped to a water level via a rating curve,
- the boundary fluxes prescribe the mapped water level at the boundary interfaces.

Importantly, the dynamic outflows allows us to modify the flow behavior inside the simulation domain, e.g. a levee breach, without altering the outflow boundary condition.



Summary and Future Work

We present methods to improve outflow boundary conditions for flood risk mapping. The methods for obtaining rating curves validate for a selected set of gauges. In the future, we plan to assess the uncertainty and quality of our approach systematically for nearly a hundred gauging stations throughout Austria. Also, the application and evaluation of the dynamic outflow boundary conditions in real-world cases is currently in progress.

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