Response to Referee 4

We are thankful for Referee 4's constructive and valuable feedback. We have assessed the Referee's concerns in the manuscript and detail our individual responses in the following. The Referee's comments are in a yellow background, and our responses are beneath.

This paper presents a hydrological-hydraulic modelling framework aimed at simulating the effect of culvert blockage in minor drainage networks. the main component is a modified version of TELEMAC-2D model that can handle dynamic blockage conditions. The modelling framework is applied to a drainage basin in Germany to simulate different scenarios of rainfall intensity and culvert blockage conditions.

Overall this is an interesting work. It addresses an important problem that is often underestimated both in scientific literature and in operational flood risk management.

We thank the referee for his valuable feedback and for reviewing our manuscript.

Main comments

1) My feeling is that the focus of the work is too narrow, resembling a technical report rather than a scientific paper. There is little reference to importance of the problem on a bigger scale, and little attention is given to the applicability of the proposed approach to other case studies. For instance, would the TELEMAC 2D work well also for larger river networks, or under more complex hydraulic conditions such as bifurcating culverts, underground confluences etc? Can it be coupled with stormwater models? These are all issues that should be discussed by the authors.

Our study has shown that blocked culverts do not have significant impacts on a bigger scale, as the outlet hydrographs of the catchment showed only little sensitivity to blockage. This is in agreement with the study from Al-Whoane et al. (2025). Within our limitations section, however, we state that blocked culverts can lead to failure of the culvert structure, which in turn can cause a catastrophic event on a large scale. We have further elaborated this in the limitations section.

It would be premature to make generalizable statements from our specific case study, which may not hold for other catchments. In this sense, yes, there is a rather narrow scope. Nevertheless, we argue that our proposed approach can be directly applied to other case studies and also bigger catchments. By applying a scenario-based modeling approach with varying degrees and timings of blockages, critical culverts within a catchment can be identified. Additionally, targeted mitigation measures can be assessed by modeling scenarios with some culverts prevented from blockage. We do agree though that this was not strongly enough stated in the manuscript and have stressed this point more in the introduction and the conclusion.

A coupling of TELEMAC-2D with a drainage network is currently under development. This does open up new possibilities in modeling culverts, especially with bifurcations. A small section on this within Limitations has been added to the manuscript.

Furthermore, we have rephrased statements in the introduction and the conclusion to provide more context on the relevance of the study and the ability to transfer the methods on other study cases.

2) The reliability of the modelling framework is not sufficiently discussed in the manuscript. The authors state that discharge measurements are not available for the study area, and therefore they carried out a plausibility check using data from a reference flood event. However, the authors should discuss if and how modelled flood extent and depth agrees with observations.

Furthermore, the plausibility of model results could be assessed by comparing the frequency of simulated flooding due to culvert blockages with reported frequency of flooding. For instance, results at cross-section 4 (figure 7) indicate that the study area is likely to be flooded at least once every 10 years, or more frequently in case of culvert blockage. Is this in agreement with reported flood frequency, or is the model overestimating the occurrence of flood events?

We have revised the previous section "Model Validation" and renamed it "Model Plausibilisation", as we cannot fully validate the model. This should now further clarify that the model in fact cannot be validated, but the results at least match the observations from the photographs. The precipitation scenarios for the culvert blockages exceed the threshold for experienced flooding from past events. Therefore, flooding is expected for these scenarios, which is reproduced by the model. There is no specific flood frequency data available for the catchment, and therefore we could only assess floods based on reports by the fire department.

3) L116 "Without these culverts, the sub-catchments upstream of the culverts are disconnected from the overall flood" and Lines 273-274: "Omitting culverts in hydrodynamic models can cause parts of the catchment to become artificially disconnected from the flood dynamics,..." these two sentences are not clear, do you mean that there is no hydrological connectivity? My understanding is that the model can simulate surface runoff, so channel continuity is not a requisite to convey water downstream. Can you please clarify and expand the description of the modelling framework on this?

No, we do not mean that there is no hydrological connectivity in the general sense. As the referee points out, channel continuity is NOT a requisite to simulate a connected water volume downstream, as the model is 2D and does not distinguish streams from the rest of the terrain. We do not mean that the model simply disconnects upstream from downstream forever (as it would be in a 1D , or a network model).

What these lines mean is that missing culverts in the model break the connectivity of water that would flow through the stream if the culvert were present in the model. Connectivity may re-establish itself after water ponds and finds some drainage direction or simply overtops. The reviewer is right in that the model doesn't care, since water will flow wherever the gradients lead.

Whether this connectivity is re-established or not is an outcome of the simulation. As we wrote in the manuscript, this incorrect and artificial disconnectivity can be expected to underestimate flow and flooding downstream, or at the very least delays due to the artifical retention.

Other comments

Line 48-49: "However, these logjams at bridges usually show larger impacts at larger bridges, which are present at large rivers and therefore not directly an issue for flash floods at smaller streams." I do not agree here: also bridges over minor rivers are prone to debris jams, and the determine backwater effects and consequent overflow upstream, especially in steep areas. I would say that such events can be highly dangerous becasue of the quick onset of flood waves.

The referee is correct to point out that this statement neglects the danger that bridges can also play an important role during flash floods. We have rephrased the lines that culverts play an important role alongside bridges.

L118: "the Reichenberger Bach lies in a comparatively dry region with a mean annual precipitation of 712mm..." comparatively dry to what? To the rest of Germany?

We thank the referee for pointing out the lack of context. The area is only comparatively dry for the state of Bavaria, and not for Germany. We have rephrased that the region is frequently affected by droughts, but still the catchment experienced several minor flash floods in recent years.

Figure 1: please add the two water courses in the map

We have added the water courses to the map.

L120-125: what does NH means?

We have added context to the abbreviation HN.

L128: is KOSTRA 2020 a dataset of measurements, or something different? Is it at national scale? Please explain

We have added more context about the KOSTRA 2020 dataset in the manuscript.

L193-194: "The flow types can be further grouped into inlet (flow types 1 and 5) and outlet control (flow types 2, 3, 4, and 6)." If these flow types are relevant for the study you should provide at least a short description of each. Otherwise, this can be omitted

The description of the different flow types of culverts has been done in multiple studies. Therefore, we argue it is not necessary to detail this again in our study. We agree though, that these flow types should not be stated in this context then and have omitted this now in the manuscript

Figure 10: the graph shows many simulations and most of them look similar, consider omitting some of them

We agree that most of the blockage scenarios are rather similar, besides the TR=1.5 scenario, and the TR=0 scenario. However, we prefer to keep the other blockage scenarios as well, to stress the argument that the trigger point itself is only important, if triggering is either close to the flood peak or triggering is prevented by a large TR. We have added some context on this in section 3.4.

Section 3.5 I would rename it as "Simulation of mitigation measures", there are no indications for the design

We have renamed the section to “Simulation of mitigation measures”.

L513: "backwater effects tend to be constrained by the bridge thickness." not fully clear: do you mean that the bridge decks are relatively thin in the study areas and hence cannot block substantial amount of floating debris?

Yes, the bridge decks in the study area are relatively thin and we have replaced “bridge thickness” to “thickness of the bridge decks”.

L526: "The results show that certain culverts can exert an large influence on flood dynamics,..." This is perhaps an overstatement given the results, culvert blockage can increase flood depths and extent at certain locations, but the effect is not so large

We have rephrased the statement to “can impact local flood dynamics”.

L533-534: "Future research should further investigate the processes driving culvert blockage formation. Laboratory experiments can provide insight into blockage mechanisms and thresholds, which could then be translated into dynamic numerical models." Even though this might be useful, I would first prioritize the installation of water level/discharge gauges in strategic points of the drainage network. This would allow to measure the response of the basin to different rainfall events and relate it with culvert blockages. Having real-time measurements could also allow for more timely interventions to remove blockages

We agree that gauges throughout the catchment and within drainage infrastructure could provide valuable insights into the mechanisms of culvert blockages and flood responses. We have added this to the conclusion.