Danmarks Meteorologiske Institut

DMI Report 22-14
An open source approach for flood forecasting in Denmark – the Vejle Pilot

Final scientific report of the 2021 National Centre for Climate Research Work Package 1.2.1, Hydrology (Hydrologi)

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1. Scientific summary

Short description

Flood forecasting and warning is an important and necessary tool for mitigating the effects of extreme floods and adapting to climate change. The overall goal is to develop new knowledge and tools to support DMI's strategic efforts for forecasting of floods for coastal and inland water systems. We want to investigate and develop the capabilities of new open source hydrological modelling tools, specifically SWAT+, for modelling of lowland Danish catchments and subsequently to evaluate the value of improved spatial and temporal resolution of DMI's precipitation observation and forecast products. The specific goals for 2021 was to create and test a high resolution (in both space and time) hydrological model of the Vejle/Grejs River catchments that supports sub-daily (e.g. 15 mins - 1 hour) modelling of flooding from extreme rainfall and the application of DMI meteorological inputs down to the 1 km scale.

Overall results

The SWAT model is one of the world's most widely applied and documented hydrological models. The new, open source, SWAT+ replaces this older code and provides a more flexible spatial representation of interactions and processes within a catchment making it well-suited to our goals. This project contributes directly both to DMI's research goals and the continuous development of this open source code, in particular modelling at sub-daily time steps. The main results are:

- New code developments and code verification of the SWAT+ model for sub-daily (15min – 1hour) time steps in a collaboration between DMI, WaterITech and SWAT+ development team at USDA (U.S. Department of Agriculture), Texas and Texas A&M University. This will become part of the open source code repository available to all SWAT+ users.
- Test application, as the first in the world, of the new sub-daily capabilities of SWAT+ for the Vejle pilot catchment, including both the Vejle and Grejs rivers.
- Demonstration of the high spatial resolution capabilities using DMI's 1 x 1 km gridded rainfall data.
- A proof of concept forecasting application through the ASAP-forecast portal by WaterWebTools (www.waterwebtools.com)

Next steps

Future activities that are envisaged include the systematic investigation of impacts of different spatial and temporal resolutions on the accuracy and uncertainty of hydrological modelling and forecasting. The value and utility of DMI's high resolution radar and numerical weather models for forecasting floods from extreme rainfall will be investigated. A joint (DMI, WaterITech, USDA) journal publication is being planned around these new developments and the application to Vejle, and potentially other cases.

The results of the Vejle pilot project contribute directly to capacity building, and the research-based foundation to support DMI's ambitions of developing a national flood forecasting and warning capability.

2. Scientific reporting

Background and objectives

Flooding from extreme rainfall is a significant problem in Denmark with severe socio-economic impacts, particularly in urban areas. With climate change, more frequent and intense storms are expected, which will lead to more extreme and more frequent flooding; from extreme rainfall, cloudbursts, storm surges and extreme sea levels. Flood forecasting and warning is a cost-effective response to these risks enabling emergency services, municipalities and other public authorities, as well as the general public, to better cope and manage the risks from extreme flood events. It is also an important tool for climate adaptation.

A key focus of DMI's research strategy is to develop new knowledge regarding flooding and flood forecasting as a research foundation for DMI's ambition to act as the forecasting and warning authority for Denmark. This project contributes directly to these goals.

The research activities presented here build on the Vejle pilot case initiated under the National Center for Climate Research (NCKF) in 2020. The Vejle & Grejs Rivers and Vejle fjord system were selected for this investigation because the township of Vejle is vulnerable to flooding both from high water levels and storm surges but also from extreme rain that generates flooding in Vejle and Grejs Rivers that flow into Vejle. In other words, Vejle experiences many of the flood types that occur in many other parts of Denmark. This initial pilot study focuses on the inland, river and catchment, system. The Vejle & Grejs river catchments respond to rainfall over quite different time scales. Heavy rain in the upper part of Vejle River catchment may create a flood peak in Vejle up to 24 hours later. On the other hand, heavy rain in Grejs River will lead to flooding in just a few hours, partly because the catchment is smaller and partly because of the steep gradients.

The specific goals for our research in 2021 were to create and test a high resolution (in space and time) hydrological model of the Vejle /Grejs river catchments that enables sub-daily (e.g. 15 mins – 1 hour) modelling of flooding from extreme rainfall and the application of DMI meteorological inputs down to 1 km scale. This work has been carried out by DMI and WaterITech in collaboration with the developers of the SWAT+ model (US Department of Agriculture (USDA) and Texas A&M University.

Methods & Results

The SWAT model is one of the world's most widely applied and documented hydrological models (> 3,000 peer reviewed publications). The new, open source, SWAT+ [1], replaces this older code and provides a more flexible spatial representation of interactions and processes within a catchment making it well-suited to our investigations of different spatial scales. SWAT+ is undergoing continuous development and since the development of the first reference model for the Vejle & Grejs River catchments in 2020 a number of new features and capabilities have been added.

New code developments and code verification of the SWAT+ model for sub-daily time steps have been carried out in a collaboration between DMI, WaterITech and SWAT+ development team at USDA, Texas and Texas A&M University. The verifications were performed using data from DMI and the Vejle/Grejs river catchments. This project contributes directly not only to DMI's research goals but also to the continuous development of this open source code for the larger global hydrological modelling community, specifically modelling at sub-daily time steps. The new code will become part of the open source code repository available to SWAT+ user community. At the time of writing, updates to the user-interfaces to support the application and calibration of sub-daily hydrological model simulations are expected in early 2022.

A completely revised hydrological model has been developed for the Vejle/Grejs River catchments to take advantage of both the new developments for sub-daily model simulations carried out here as well as some of the newer features within SWAT+. For example test models have been carried out with and without floodplain delineations. As illustrated in Figure 1. Further details regarding the model input data sources, configuration, choices made in this configuration and calibration are described elsewhere [2].

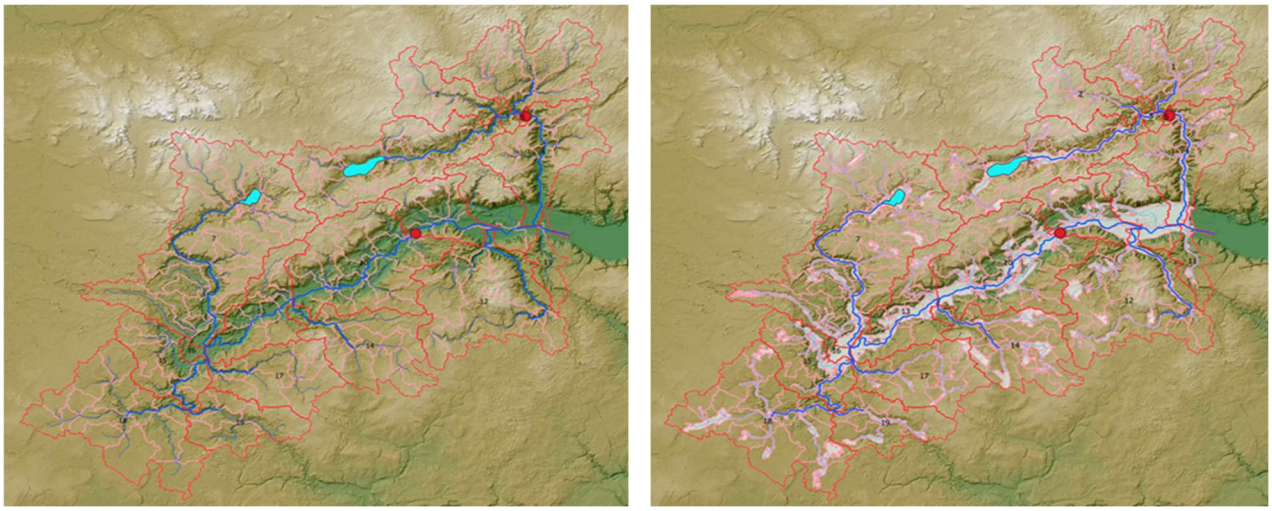

Figure 1. Watershed, subbasins and streams delineated by SWAT+ without floodplain delineation (left) and with floodplain delineation (right, areas delineated as floodplains are indicated by light shaded areas). The stream gauge stations at Grejs river (Planteskolen) and Vejle river (Haraldskær) are indicated by red points.

To demonstrate the new high resolution capabilities, in both space and time, an experimental 1 x 1 km gridded data was used as the precipitation input. These data are spatially interpolated from the national automatic rain gauge network and accumulated over 1 hour time intervals (spatial distribution is illustrated in Figure 2).The first results of the SWAT+ subdaily model are presented in Figure 3. This test application, for the Vejle pilot catchment, including both the Vejle and Grejs rivers is a world first. A proof of concept forecasting application can be found through the WaterWebTools' ASAP-forecast portal (www.waterwebtools.com), where plots are interactive and can more easily be reviewed.

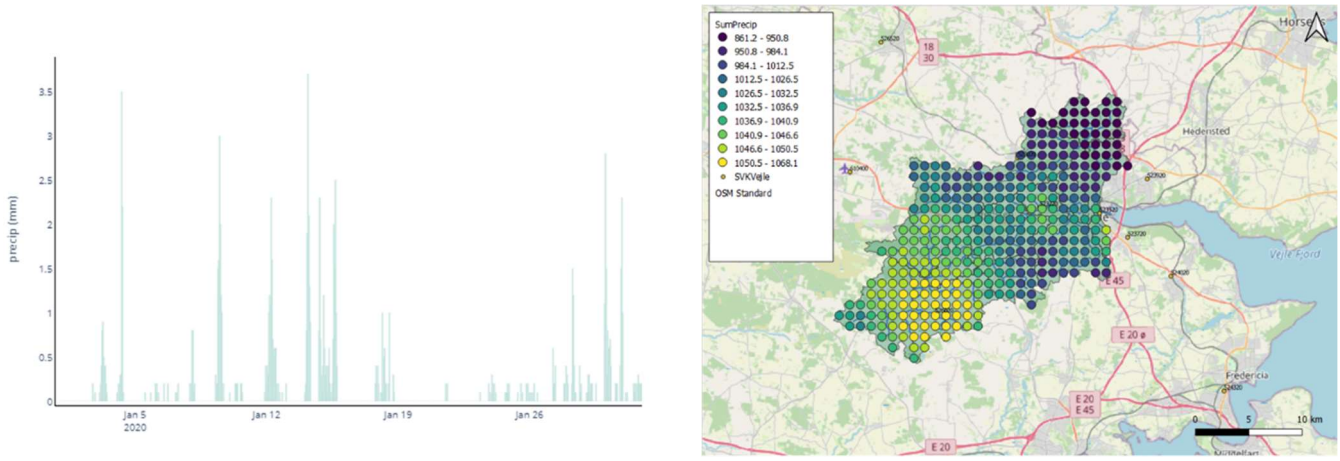

Figure 2 Example of hourly rainfall time series for January 2020 for a grid cell located centrally in the Vejle river watershed (left) and the spatial distribution of the rainfall for the entire 2020-from a 1 x 1 km gridded experimental rainfall estimate.

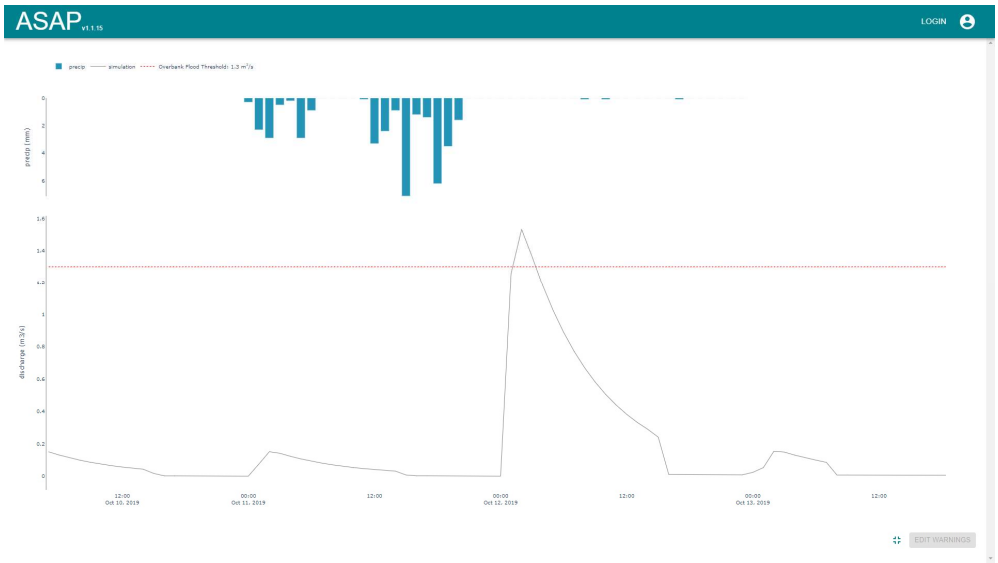

Figure 3 Example of simulated sub-daily discharge for a small ephemeral stream within the Vejle case (with clear diurnal signal).

References

[1] Bieger, Katrin, Arnold, Jeffrey G., Rathjens, Hendrik, White, Michael J., Bosch, David D., Allen, Peter M., Volk, Martin, and Srinivasan, Raghavan, 2017. Introduction to SWAT+, a Completely Restructured Version of the Soil and Water Assessment Tool. Journal of the American Water Resources Association (JAWRA) 53(1): 115– 130. doi.org/10.1111/1752-1688.12482

[2] Trolle, D. & Nielsen, A. 2022. Vejle Pilot: SWAT+ model protocol with focus on development of subdaily simulations. Model Protocol Report by WaterITech, 19p.

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