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Using numerical weather prediction ensembles to distinguish urban drainage flow domains 2 days ahead

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Contingency table; Ensemble prediction system; Numerical weather prediction; Real time control; Runoff-model; Uncertainty

SUMMARY OF KEY FINDINGS

We present a method to distinguish Urban Drainage System (UDS) flow domains (dry or wet condition) over the future 48 hours using Numerical Weather Prediction (NWP) model data. Such information can be used e.g. to implement improved dry weather optimization by being able to anticipate periods with no influence from rain.

Using uncertain information, such as NWP, to optimize wastewater systems is generally challenging. Indeed, NWP is embedded with a significant uncertainty but such forecasts do however contain information that can contribute to optimization especially when utilizing multiple ensemble model runs. Therefore, we decided to create a method to extract information from NWP ensembles describing qualitatively the incoming flow domains rather than focusing on quantitative expected flow values directly.

This method is elaborated around a set of strategies handling the different source of uncertainty with the option of being more or less conservative. The skills of those strategies are assessed using a weighted contingency table. Each outcome is weighted according to its expected benefit/damages.

BACKGROUND AND RELEVANCE

Rainfall forecasts can provide valuable information to improve operational performance of Urban Drainage System (UDS) and wastewater treatment plants (WWTPs). For example, radar-based rainfall nowcast are increasingly being used within Real-Time Control (RTC) concepts (i.e. Model Predictive Control - MPC) as shown in the example presented in (Acheitner, et al., 2009), (Gaborit, et al., 2012), (Thorndahl, et al., 2013) and (Vezzaro & Grum, 2014). Nowcast rainfall extrapolates radar observations up to 2-3 hours ahead. To increase this lead time, Numerical Weather Prediction (NWP) needs to be used. For example, (Liguori et al. 2012) merged radar nowcasts with 6-hour NWP to generate a stochastic probabilistic prediction forecasting scheme. However, NWP models are embedded with significant inherent uncertainties. Those uncertainties can be characterized by generating an Ensemble Prediction System (EPS) from NWP models. This study uses the regional weather model (DMI-HIRLAM-S05 (Feddersen 2009)) which every 6 hours generates an ensemble of 25 scenarios in a 5 km grid with hourly temporal resolution (see in Figure 1).

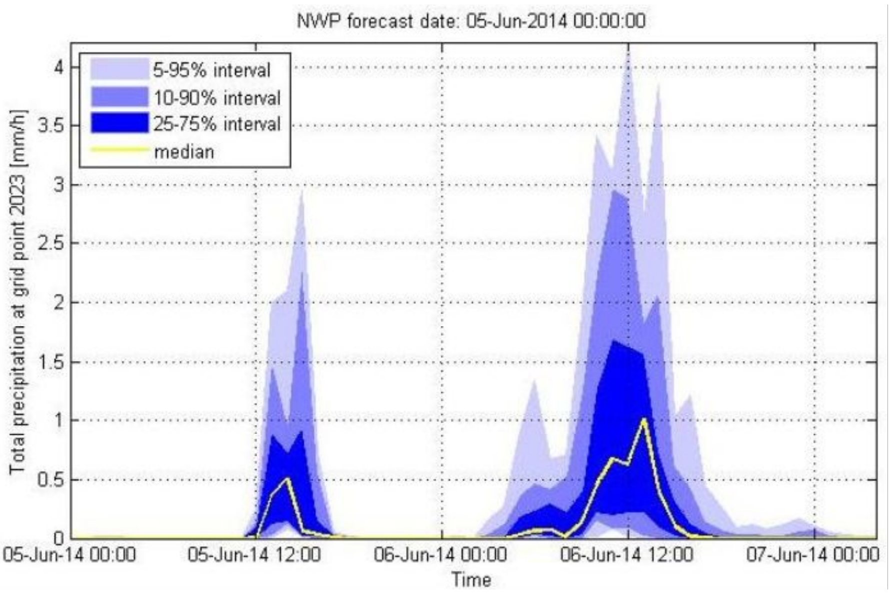

Figure 1. Hourly total precipitation prediction quantile based on the 25 scenario ensemble from the DMI-HIRLAM-S05 model (Feddersen 2009) at the 5x5km grid point 2023 (latitude 55° 42’ 02’’ Longitude 12° 25’ 42’’) generated on the 5th of June 2014 at midnight

As displayed in Figure 1**Figure** , the ensemble spread can be significant, from 0 to 4 mm/h in this case. Furthermore, this EPS doesn’t express the full NWP model uncertainty, the spatial NWP uncertainty in capturing storm tracks should for example be considered as well. Hence, quantifying absolute flow values from NWP remains rather uncertain. Nevertheless, qualitative UDS status, differentiating low flows and high flows, can be determined.

First, a runoff model was used to process rainfall intensity data to catchment discharge data (for the case study presented below a Nash linear reservoir model (Nash 1957) was implemented). Then, different uncertainty handling strategies were applied, both on the rain selection and the post-processing. For example, to predict low flow status with accuracy, the rain input can account for spatial and temporal uncertainty, forecast consistency, etc. Therefore high flow will be wrongly predicted more often (more false alarm) but the low flow prediction accuracy will increase (less miss hit). The prediction outputs are assessed using a weighted contingency table (Table 1) accounting for the potential benefit or loss for each outcome.

Table 1. Contingency table comparing predicted and observed hourly flows and distinguishing low- and high-flow domains. Positive outcomes are displayed in green and negative outcomes in orange.

		High flow predicted		**Total**
		Yes	**No**	
High flow Observed	**Yes**	Hit	Miss Hit	Observed Yes
	No	False Alarm	Correct Negative	Observed No
Total		Predicted yes	Predicted No	Total

Among the parameters adjustable for the NWP uncertainty handling we considered:

- **Inclusion area (upscaling strategy):** To cope with NWP spatial uncertainty, high intensity predicted in neighboring grid cells can be considered in the predicted rainfall. The size of the area considered can be adjusted.
- **Forecast consistency:** New NWP data are generated every 6 hours covering the incoming 54 hours. Hence, successive forecast are overlapping and previous predictions can be used to assess forecast consistency.
- **Proportion of scenario:** DMI-HIRLAM produces an ensemble of 25 members. The number of members required to trigger high flow prediction can be adjusted.

RESULTS AND DISCUSSION

This approach was applied to the Damhuså catchment (Copenhagen, Denmark), **Figure 2**Figure 2, for dry weather optimization. If low flows are predicted, actions can be taken to optimize the system (pumping strategy, WWTP inflow smoothing, energy consumption, etc.). Catchment and flow data was obtained from the utility company HOFOR and rainfall data was obtained from the Danish Meteorological Institute.

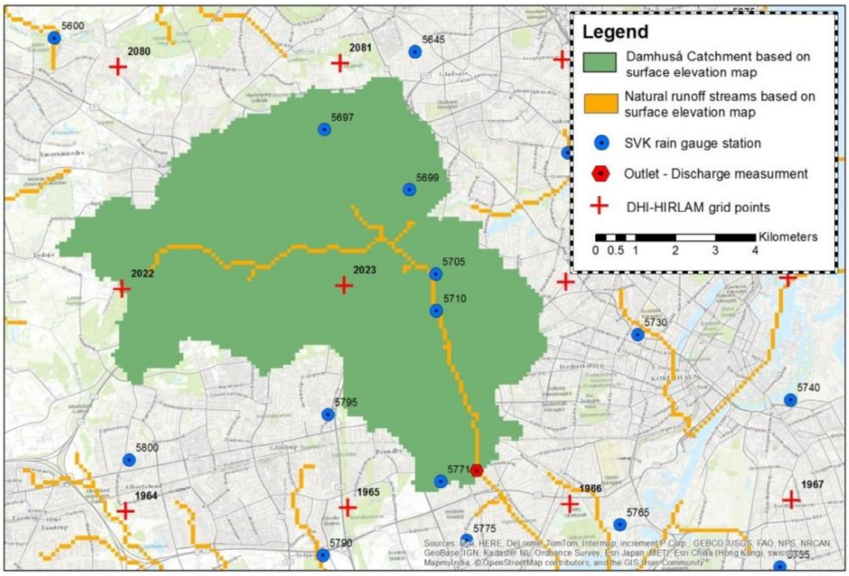

Figure 2: Study case area Damhuså catchment, Copenhagen, Denmark (contributing area, green area on the map, 67 km2)

The benefit of each strategy be can assessed using the weighted contingency table, and results through the forecast horizon for different uncertainty handling strategies are shown on Figure 3. The conservative strategy denoted “Large Upscale” and even more utilizing information about forecast consistency improves the high flow prediction skill but at the expense of a lower accuracy for low flow prediction. Figure 3 illustrates the capacity of NWP uncertainty strategies to improve high flow prediction accuracy. However, using conservative strategies increases the false alarms. Hence, those methods could be further developed to improve their skills.

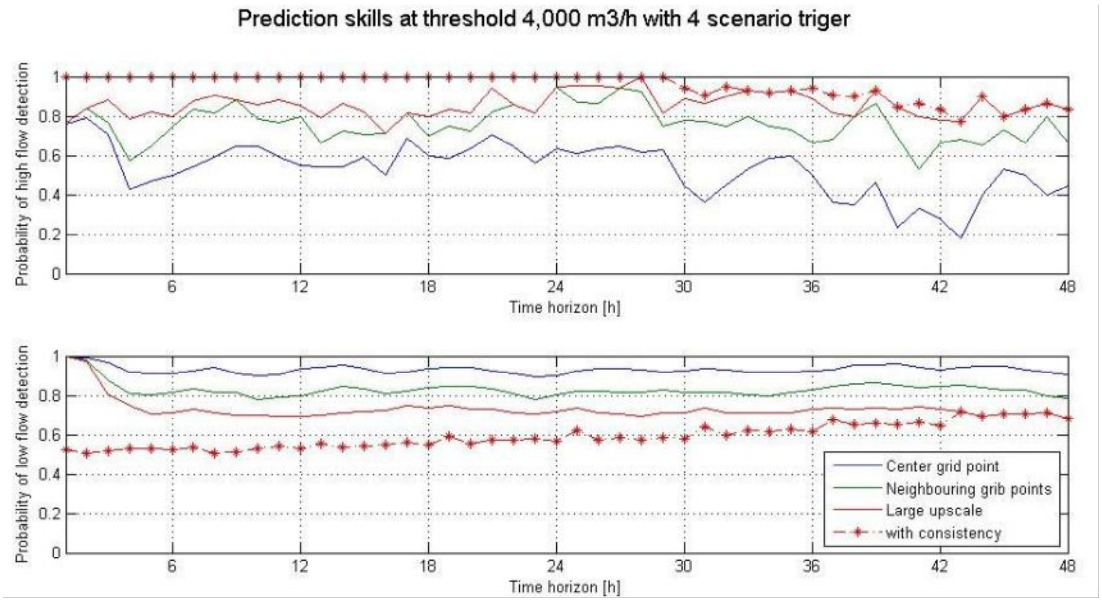

Figure 3: Top: Probability to correctly predict high flow (i.e. Hits/(Hits+Misses)); Bottom: Probability to correctly predict low flow (i.e. Correct negative / (Correct negative + False alarm)). The 3 full lines represent upscaling strategy and dashed line represents the large upscaling strategy with a consistency criteria (if a previous forecast has predicted a high flow, this prediction is kept). 4 scenarios (over 25) should predict high flow to trigger the prediction.

Furthermore, the runoff model could also be improved. Indeed, using rain gauge measurements as input, the high flow detection is only 80% (initial point on Figure 3a – Rain gauge data are used to hot start the runoff model). These preliminary results are run on 3 months, from June to August 2014. Longer time series will be used to build stronger statistics.

Another potential development could be to run different NWP uncertainty strategies, more or less conservative, in parallel to draw a better picture of the probability of different future UDS flow domains.

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