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Soaked or Safe?

How Soil Moisture Impacts Contingent Runoff and Flood Predictions

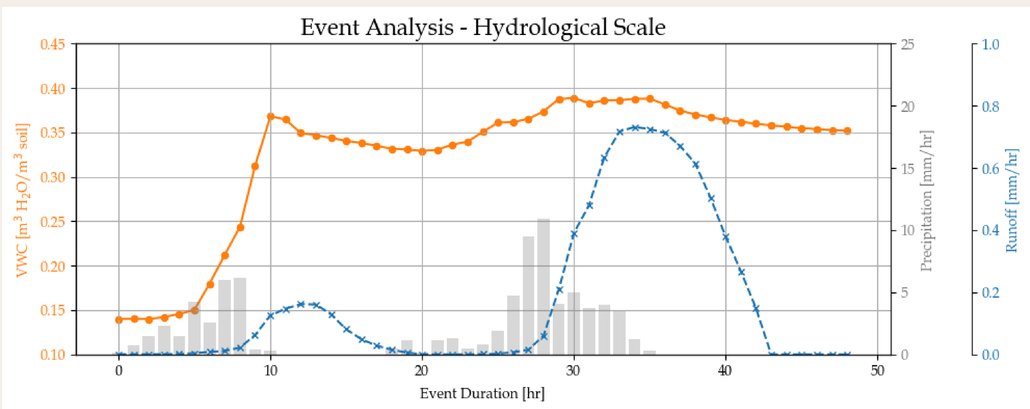
THE IMPACT OF CONTINGENT RUNOFF FROM URBAN GREEN AREAS IS OFTEN OVERLOOKED IN THE DESIGN OF URBAN DRAINAGE SYSTEMS, WHICH INCREASE THE RISK OF THESE SYSTEMS BEING UNDER-DIMENSIONED, ESPECIALLY IN LOCATIONS WITH A LARGE PERCENTAGE OF GREEN AREAS.

INTRODUCTION

Weather conditions in Denmark have changed dramatically since the 1870s, with a global temperature increase of 1.5 ℃ resulting in an approximate 100 mm rise in annual precipitation. This trend is expected to continue throughout the 21st century, with the frequency of heavy rainfall events likely to increase, affecting urban stormwater management systems and increasing the risk of urban flooding. Traditional urban drainage systems are designed to handle only 0-15% of precipitation falling on green areas, as it is assumed that most of it will infiltrate directly to the soil column. However, under certain conditions, such as when the soil is fully staturated, the soil's infiltration capacity is exceeded, resulting in runoff from permeable green areas.
This phenomenon will be defined as contingent runoff.

PROBLEM STATEMENT

To what extent does soil moisture influence surface runoff across varying spatial scales, and can incorporating volumetric water content (VWC) measurements enhance the accuracy of flow models and their application in urban flood management?



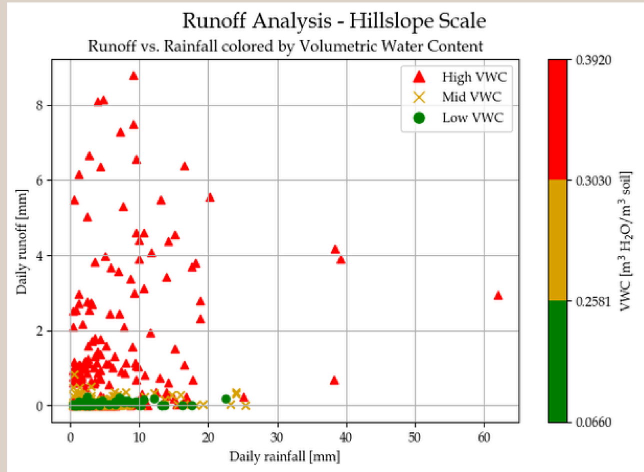
The events presented in the figure above, show that large runoff depends heavily on the VWC level. This suggests that when the initial VWC is already high, even moderate rainfall can trigger runoff with minimal delay. Moreover, rainfall intensity plays a significant role, as high-intensity rainfall can generate substantial runoff even under lower VWC conditions, if the soil's infiltration capacity is exceeded.

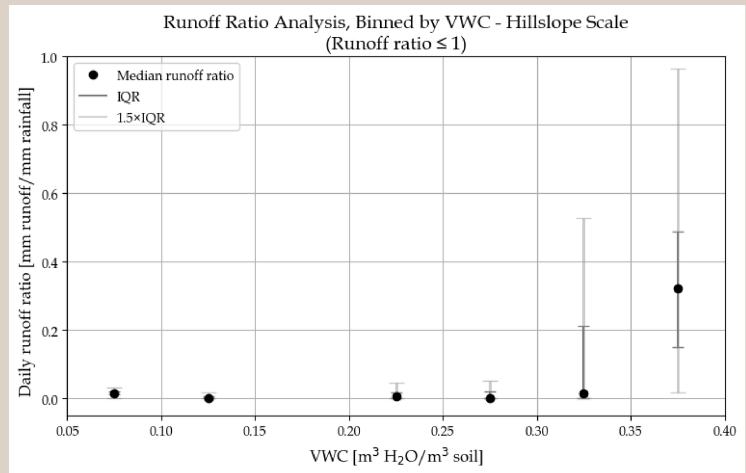
FACTORS THAT IMPACT CONTINGENT RUNOFF

- High rainfall intensities
- Long rainfall durations
- Volumetric water content
- The saturated hydraulic conductivity
- Soil texture
- Soil compaction
- Topography

Runoff Analysis

Hillslope Scale



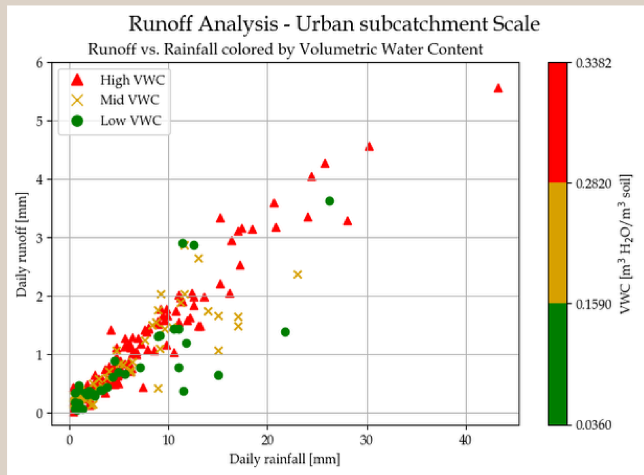


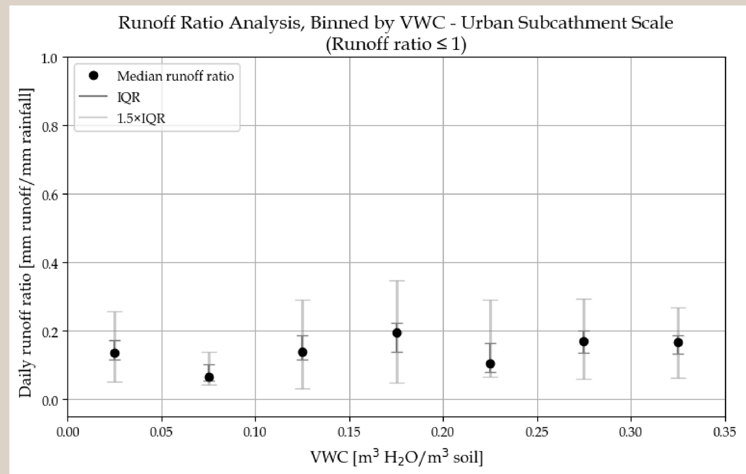
Runoff at the hillslope scale generally exhibits a high response to VWC, with daily runoff values ranging from 0.00 to 9.00 mm. This is particularly evident in the high VWC category, which displays a broad distribution of runoff values. The median runoff ratio is ~0.00 mm/mm until a threshold of 0.30 m^3/m^3, where the runoff ratio increases significantly.

FINDING 1.

A statistically significant relationship is observed between VWC and runoff at the hillslope scale.

Urban Subcathment Scale



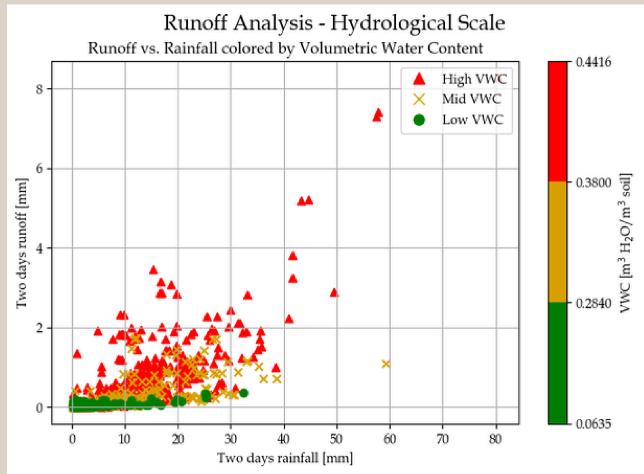


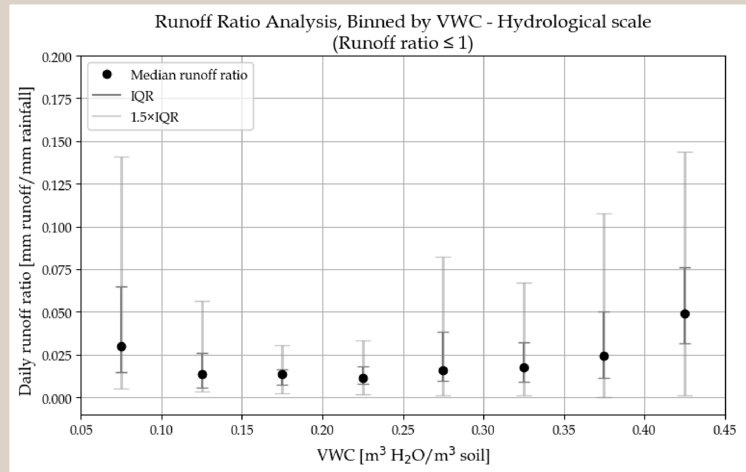
Runoff at urban subcatchment scale responds strongly to rainfall, with daily runoff values ranging from 0.00 to ~5.50 mm. The relationship between rainfall and runoff is quite linear, indicating that VWC has a limited influence on runoff generation. The median runoff ratio primarily remains constant, independent of VWC level.

FINDING 2.

A statistically significant relationship is observed between VWC and runoff at the urban subcatchment scale, however, the visual effect is limited, likely due to the dominant hydrological influence of the impervious surfaces.

Hydrological Scale



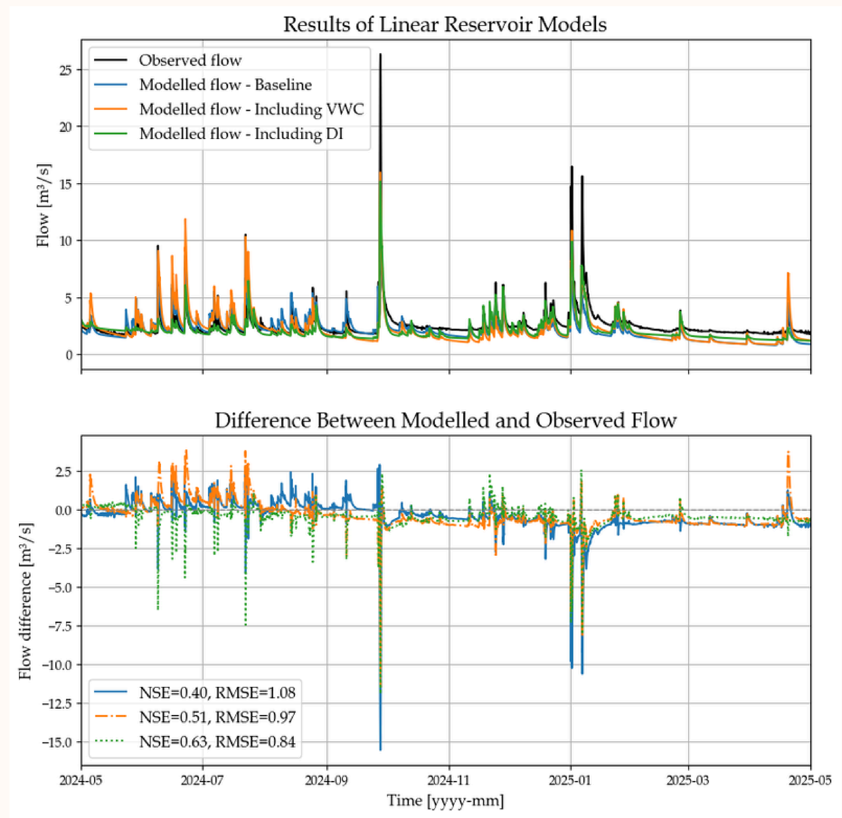


Runoff at the hydrological scale generally exhibits a strong response to rainfall, with two-day runoff values ranging from 0.00 to 8.20 mm. This is particularly pronounced in the high VWC category. The median runoff ratio is ~0.01 mm/mm until the VWC descends a threshold of 0.15 m^3/m^3 or exceeds a threshold of 0.35 m^3/m^3, where the runoff ratio increases.

FINDING 3.

A statistically significant relationship is observed between VWC and runoff at the hydrological scale.

Implementation of VWC and DI in Flow modelling



Three Linear Reservoir Models: baseline, including VWC, and including drought index (DI), are developed to simulate the flow in Grejs Å. The lower plot of the figure presents the difference between the modelled and observed flow, where positive values indicate overestimations and negative values indicate underestimations.

FINDING 5.

Prediction performance of simple flow models improves significantly when either VWC or DI is incorporated.

FINDING 4.

Across all three scales, there is a general tendency for long-duration winter precipitation to generate the largest runoff volumes, primarily due to elevated soil moisture levels.

CONCLUSION

In summary, it can be concluded that VWC does influence contingent runoff. However, it is not the only controlling factor. Runoff is the result of a complex interaction of multiple variables, including rainfall intensity, previous conditions, and soil properties.
Moreover, the implementation of VWC and DI enhances the accuracy of simple flow models.

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