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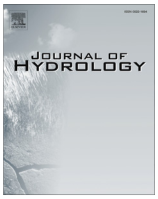

Surface runoff in flat terrain: How field topography and runoff generating processes control hydrological connectivity

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SUMMARY

In flat lowland agricultural catchments in temperate climate zones with highly permeable sandy soils, surface runoff is a rare process with a large impact on the redistribution of sediments and solutes and stream water quality. We examine hydrological data obtained on two field sites in the Netherlands for a period of 1.5 years to give an integrated narrative of surface runoff in this type of catchment. In the monitoring period, seven surface runoff events were observed with a magnitude of 9.8–975 L runoff. Four of these events were classified as saturation excess events, due to a shallow water table. Three of the events occurred under infiltration excess conditions due to rainfall in combination with snowmelt. Though the microtopography of the fields was quite different, they were identical in terms of topographical indicators. Therefore, we analyzed the dynamics of hydrological connectivity on these fields with a numerical model that takes into account routing variability through microtopography and calculated simplified hydrographs and Relative Surface Connection functions from the results. The connectivity dynamics of the fields were different as quantified by these indicators. We found that the dynamics of hydrological connectivity in this low-angle terrain are not just a function of the soil surface meso- and microtopography, but also of the type of surface runoff generating process. This is an important factor to consider when using connectivity functions as an upscaling tool in catchment scale modeling.

1. Introduction

The amounts and dynamics of surface runoff generation in flat lowland agricultural catchments in temperate climate zones, such as the Netherlands, are poorly understood. Surface runoff is a rare and erratic process in such areas, because environmental characteristics favor flowroutes through the shallow and deep soil above routes over the land surface (Brutsaert, 2005). The prevalence of low-intensity precipitation events (Lenderink and Van Meijgaard, 2008) inhibits infiltration excess runoff, while extensive artificial drainage inhibits saturation excess runoff (van der Velde et al., 2009; Vidon et al., 2012). Also, low-gradient fields have a larger water storage capacity in their microtopography than fields with the same microtopography, but a larger surface gradient (Onstad, 1984; Borselli and Torri, 2010).

Though the contribution of surface runoff to the regional water balance in these catchments is often small compared to that of other flow routes, incidental surface runoff can have a severe impact on stream water quality, because of the relatively large quantity of sediments and associated nutrients and pesticides it transports (Withers et al., 2003; Leistra and Boesten, 2010). In experimental studies in the Netherlands, up to 56% of annual phosphorus loss has been reported to occur in a single runoff event (Salm et al., 2012).

Surface runoff generation is not uniform within a field, for instance due to the presence of compacted tracks (Deasy et al., 2008) or drain pipes (Augeard et al., 2005). The amplitude and spatial organization of the microtopography in a field play a key role in connecting or obstructing these source areas with the catchment ditches and streams (Chu et al., 2015; Dunne et al., 1991). As a result, the nature of the contribution of surface runoff to the catchment hydrograph is more incidental and erratic than that of subsurface flowpaths (Deasy et al., 2009). This makes it difficult to predict the effects and impact of surface runoff across locations and scales of time and space.

The concept of hydrological connectivity has the potential to allow comparisons of runoff measurements across various spatial

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scales as well as to identify general controls underlying runoff generation (McDonnell et al., 2007; Michaelides and Chappell, 2009; Ali and Roy, 2010; Bracken et al., 2013). Indeed, surface runoff through microtopography has been shown to serve as a dynamic metric of connectivity of a small landscape unit to a stream (Antoine et al., 2009; Appels et al., 2011; Peñuela et al., 2013). The use of dynamic metrics has the benefit of addressing process connectivity, i.e. considering the processes that produce runoff as well as the static landscape components that affect storage and routing (Bracken et al., 2013). Most current research efforts have focused on these processes at the plot scale or partial field scale, considering impermeable surfaces or infiltration excess runoff generation (Peñuela et al., 2013; Yang and Chu, 2013, 2015).

Here, we present new measurements and new model results from two agricultural fields in the Netherlands to examine the generation and dynamics of surface runoff in flat, permeable areas. Considering the climate and soil characteristics in the region, saturation excess conditions are a more probable driver of runoff generation than infiltration excess. Furthermore, due to the general lack of topographic gradient, microtopography plays an important role in storing and routing water at the soil surface. In the field, we monitored the forcing and soil moisture conditions and the amount of surface runoff that entered the surrounding ditches. We then used a custom-made model to investigate how these variables affect the ponding dynamics and evolution of flowpaths within the meso- and microtopography of the fields. We address the following questions:

- What are the conditions under which surface runoff occurs in this and similar low-relief sandy landscapes in the Netherlands?
- How does hydrological connectivity develop in the meso- and microtopography of the fields during surface runoff events?
- Can quantitative measures of hydrological connectivity be used to explain surface runoff dynamics at various locations?

2. Study site

The data were obtained at two fields in the eastern part of the Netherlands. This region has a semi-humid sea climate with 750–800 mm annual rainfall. The annual evaporation is 525–540 mm resulting in an annual recharge of 210–275 mm. Both sites are agricultural sites surrounded by ditches (Fig. 1).

Site A is located in Beltrum, (52.082°N, 6.538°E). The field has an area of 4 ha. The soil consists of a thick deposit of Pleistocene Coversand. The upper 0.25–0.3 m consist of loamy fine sand with an organic matter content of 5%. The lower part of the profile is poor in organic matter and consists of the same loamy fine sand to a depth of at least 12 m. The groundwater level increases from the ditches surrounding the field towards its center. Through the year the average groundwater depth fluctuates between 0.5 and 1.5 m below the soil surface. The ditches surrounding the field run dry in summer. The site has been used for agriculture for centuries and is currently cropped with maize. The surface elevation ranges from 16.7 to 17.2 m above Ordnance Datum.

Site B is located in Winterswijk, (51.915°N, 6.723°E, at some 25 km southeast of site A). The field has an area of 2.7 ha. The soil consists of a fine loamy sand with some gravel underlain by a thick layer of Tertiary heavy clay. The level of the top of this layer varies throughout the field from 0.40 to 1.2 m below the surface. The groundwater level mainly follows the macrotopography, peaking in the center of the field. The average groundwater depth fluctuates throughout the year between 0.25 and 2.0 m below the soil surface and is therefore located in the clay layer during the summer. The ditches surrounding the field run dry in summer. Agricultural use is based on a rotation scheme of maize and pasture, and during the experimental period was cattle grazed grassland. The surface elevation ranges from 42 to 45 m above Ordnance Datum. The site slopes with a gentle 2% down to the ditch north of the field.

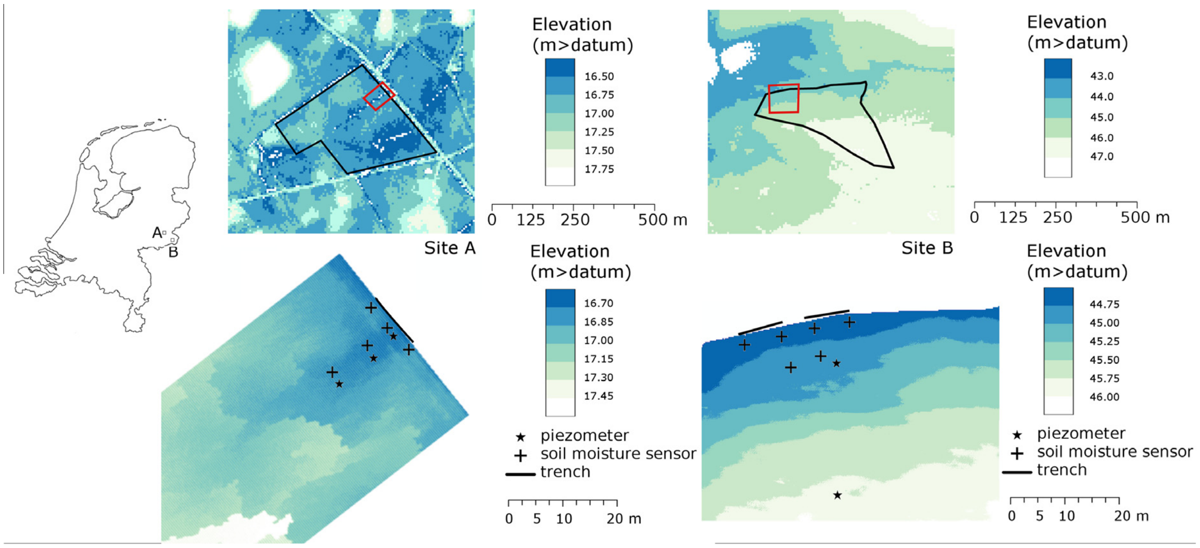

Fig. 1. Location of field sites in the Netherlands and surface elevation (m) of site A (left) and B (right). Black lines indicate the position of ditches surrounding the fields, red rectangles indicate the extent of the DEMs in the lower row and the maps of Fig. 10. Lower row: position of measurement devices at field site A and B. At site B, a third piezometer was installed some 50 m further South, outside the scope of this map. The 0.1 m DEMs in the lower row were constructed from the 0.5 m AHN2 data and the microtopograhy measurements (Section 3.4). The microtopography is difficult to discern as it is masked by the larger mesotopography, even in flat fields. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)