The functioning of water-storing roads in relation to groundwater

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Highlights

- Using groundwater monitoring well transects, the functioning of water-storing roads in relation to groundwater was researched at eight case studies.
- Water-storing roads widely differ in design and design principles, but can generally be assigned to one of four categories: with an infiltrating drain, with a draining drain, with a (draining) drain and additional storage units or without a drain.
- Most of the researched water-storing roads function as designed, where the drainage system plays a major role in the functioning of the water-storing road, but the effects of the water-storing road on groundwater are still uncertain.

Introduction

As a result of climate change, winters in the Netherlands are expected to become wetter, rainfall events will increase in intensity and frequency, and drought events will occur more often (KNMI, 2023). To deal with a changing climate, municipalities have implemented a number of climate adaptive measures. One such measure is the so-called water-storing road (WSR). In a WSR, collected rainfall can (temporarily) be stored directly beneath the road in storage units or a sandy road bed. Stored water can then, through drainage, either be released to a connected sewer system or directly infiltrate from the storage units to the soil.

Municipalities in the Netherlands manage around 123.000 km of public roads (SWOV, n.d.). A WSR can therefore be an ideal climate change adaptation measure, especially in areas that are limited in unoccupied, aboveground space. A WSR can in theory be used not only to temporarily store water, but possibly also to mitigate the effects of drought by increasing the amount of infiltration. Moreover, several WSRs have been used in areas with high groundwater levels and soils with a poor infiltration capacity.

While the WSR is a promising blue adaptation measure, it is not yet widely implemented and the water dynamics occurring around WSRs are still not fully understood, especially within the wide variety of different WSR designs. Furthermore, little is known about the effects these roads really have on groundwater. As such, this research aims to improve knowledge on the functioning and interaction of WSRs in relation to groundwater and precipitation events, better structure water-storing roads on the basis of their functioning and to provide insights on optimization of the design of WSRs for successful use in practice.

Methodology

Eight different WSRs were studied as part of this research. For these eight different roads, water levels in the storage were measured using a diver at the bottom of the storage unit. At six of these roads, monitoring wells were placed perpendicular to the road to measure groundwater levels. An example of a case study site (Margrietstraat, Zoeterwoude) with a transect of monitoring wells is visualised in figure 1, with a schematic representation of the WSR and the positioning of the monitoring wells. All roads were measured for a maximum of 2 years and with an interval of 5 to 10 minutes.

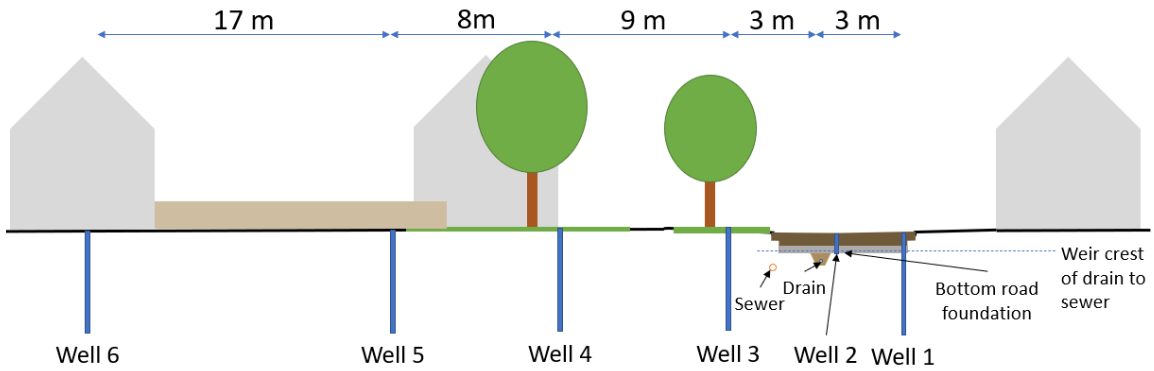

Figure 1. Schematic overview of the case study at the Margrietstraat (Zoeterwoude), with the positioning of the monitoring wells. Well 6 is located in an alley between two buildings.

In order to quantify interactions between storage capacity of these WSRs and ground water levels with (extreme) precipitation events, precipitation measurements of nearby weather stations were collected from nearby private weather stations or, in absence of proper measurements, from official KNMI weather stations. Furthermore, multiple soil profiles and design drawings of each case study were collected as well. Table 1 presents all measurement locations.

Table 1. Description of the measured WSRs.

Location	System definition	No. monitoring wells	Soil type	Measurement period	Weather station
Margrietstraat (Zoeterwoude)	Waterpassing pavement, Rockflow, drain	5	Clay	02-01-2022 t/m 12-11-2023	Private station
Julianapark (Zoeterwoude)	Urban Rain Shell, drain	2	Clay	01-04-2022 t/m 24-03-2023	Private station
Solferinostraat (Diemen)	Sand, Drain	5	Sand (on clay)	01-03-2022 t/m 31-12-2022	Schiphol (KNMI)
Frans Halslaan (Amstelveen)	Water passing pavement, Bufferblocks, drain	5	Clay	04-03-2022 t/m 14-11-2022	Private station
Boekenrode (Rotterdam)	Water passing pavement, sand, drain	5	Clay	01-02-2021 t/m 24-01-2022	Zestienhoven (KNMI)
Ellemare (no WPV) (Rotterdam)	Sand, drain	4	Clay	01-05-2018 t/m 12-11-2019	Zestienhoven (KNMI)
De Velst (Heemskerk)	Water passing pavement, Bluestone granulate, drain	2	Clay	17-06-2021 t/m 12-04-2022	Wijk aan Zee (KNMI)
Maarten van Heemskerckstraat (Heemskerk)	Bluestone granulate, no drain	2	Sand	25-03-2021 t/m 19-12-2022	Wijk aan Zee (KNMI)

As the case studies vary considerably in design and design principles, the WSRs were first categorized in relation to their drainage design (e.g. with or without drain) and groundwater characteristics (e.g. situated in areas with high or low groundwater levels) to make a better comparison between cases. Next, the (ground)water levels at and around each of the measured WSRs were analysed descriptively.

Furthermore, for each of the case studies a first analysis on rainfall-recharge relationships was carried out for the water levels in the storage unit. Individual rainfall events were selected by hand, when a clear rise and fall of water levels as a result of a precipitation event could be observed. For the selected events, the water level rise and fall (mm) and the speed of water level rise (mm/hour) was calculated.

Results and discussion

Analysis of the 8 WSRs indicate that the case studies can generally be divided in 4 categories: a WSR with an infiltrating drain, with a draining drain, with a (draining) drain and an additional storage unit, or without drain.

Water-storing road with a (draining) drain and an additional storage unit

The WSRs of this category are the locations at the Margrietstraat and Julianapark (Zoeterwoude), Velst (Heemskerk) and at the Frans Halslaan (Amstelveen). Only the case of the Margrietstraat will be discussed.

Figure 2 shows a slice of the measurements (y-axis) of monitoring wells (corresponding to the well numbers in figure 1) at or near the WSR in the Margrietstraat (Zoeterwoude) at the mean sea level (msl). The 2nd y-axis shows precipitation (mm/day) of a weather station located nearby. The WSR can be emptied through infiltration or through a drainage system below the storage unit. This drain is connected with a weir to a sewage system (weir level at 1meter-msl), as indicated by the dotted line with label “crest weir”.

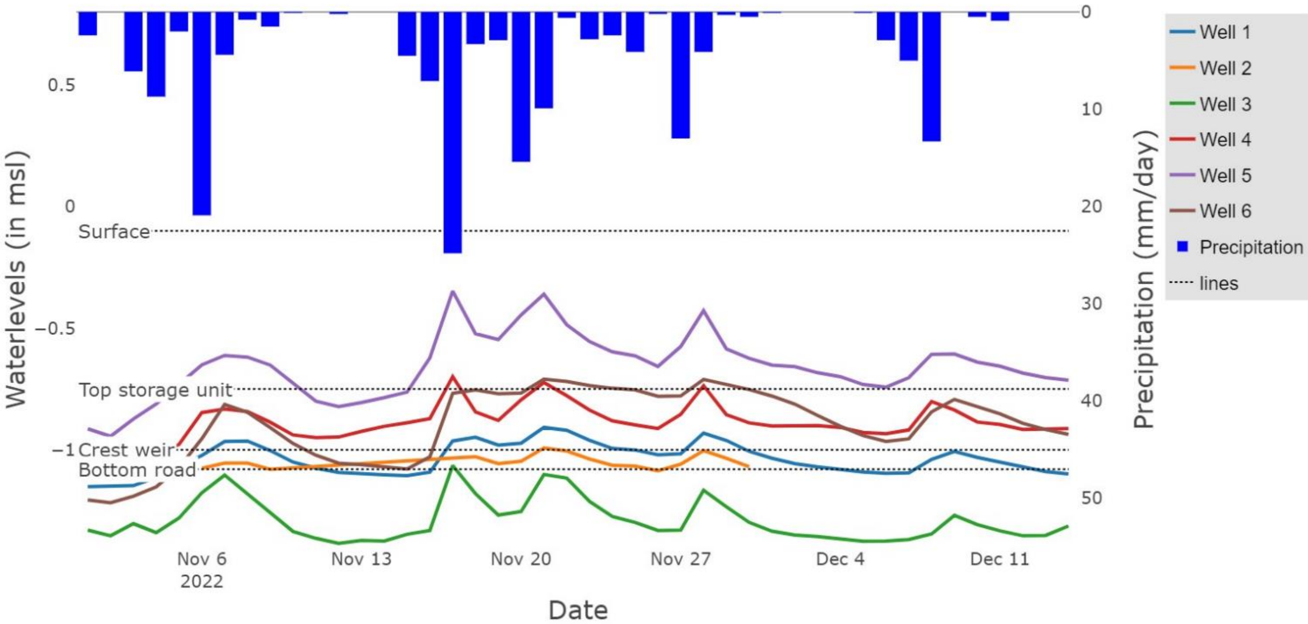

Figure 2. Water level measurements at or near the WSR in the Margrietstraat (Zoeterwoude) at the y-axis. The 2nd y-axis shows precipitation, measured at a nearby weather station (at 600 m distance). The dotted horizontal lines indicate heights related to the functioning of the WSR, as indicated by the labels on the left. To keep the graph clear, only measurements between 01-11-2022 and 15-12-2022 are shown. No data at well 2 (orange) indicate no measured water levels above the bottom of the storage unit.

The measurements at the bottom of the storage unit (Well 2, orange) indicate that relatively little water can be stored, as the weir level is only 7cm above the bottom of the storage unit. Furthermore, water level in the storage unit as a result of precipitation rarely occurs. When water levels do rise within the storage unit, the groundwater levels near the WSR (well 1 and 3, blue and green respectively) next to the storage unit show a rise as well, to a level above the bottom of the storage unit. This indicates that the water level rise measured in the storage unit is at least partly the result of groundwater inflow, and not purely rainwater.

Monitoring wells next to the WSR show large differences in response after a precipitation event. A number of unusually high peaks are visible at well 5 (purple), in comparison to the peaks observed at well 6 (brown) and 4 (red). This may be attributed to surface runoff directly into the well. Well 3 and 1 show strong differences in groundwater level peaks. The water level gradually increases and then gradually decreases in well 1, while well 3 shows sharper peaks but also faster declines. Well 6 descends and rises much more gradually and hardly shows the peaks present at well 3, 4 and 5.

Between the monitoring wells 3 till 6, bulging can be observed, with the highest groundwater levels at well 4 and 5. Local groundwater extraction may take place near well 3, possibly due to a leaking sewer or drainage. Local extraction at well 3, but also at well 6, may also explain why the differences in average groundwater level between summer (01-04 to 30-09) and winter (01-10 to 31-03) decreases in the direction from well 5 to well 3, as the extraction keeps the groundwater at a constant level.

Analysis the rainfall-recharge-discharge relationship, obtained by selecting 5 individual rainfall events (precipitation event, followed by >48 hours of no precipitation) during summer, yielded no meaningful results.

Other water-storing roads
Due to a page limitation, the results of the other water storing roads are only described briefly.

WSRs with an infiltrating drain are situated in areas where seepage flows are generally larger then precipitation or groundwater recharge. The Solferinostraat (Diemen) can be assigned to this category. As the drain in in this case study is directly connected to a surface water body, the drainage system in the WSR infiltrates year round and water level fluctuations within the drain can mostly be attributed to surface water level fluctuations.

WSRs with a draining drain are situated in areas with groundwater levels above the drain level and where the drainage system is connected directly to a surface water. The cases in Rotterdam can be assigned to this category. Water in these roads is stored in sandy areas of the road foundation. In these case studies the drain in the WSR is draining around 80% of the year. Groundwater fluctuations in the storage of these roads can be explained by the low infiltration capacity of the natural soil (clay).

WSRs without a drain, with a storage unit, are situated in areas where groundwater levels are lower than the WSR, and where the infiltration capacity has a high enough permeability, such that the storage is emptied before the next precipitation event occurs. Of the researched cases only the Maarten van Heemskerckstraat (Heemskerk) could be assigned to this category.

Conclusions and future work

Early results indicate that most of the researched WSRs function as designed. Water level fluctuations in the storage unit only attributed to precipitation were either small or of very short duration, indicating discharge through the drainage instead of infiltration as the main sink of water from the WSRs. In the WSRs where a drain had been installed, groundwater levels were either lowered around the WSR in cases with high groundwater levels, or the drainage system lead to raised groundwater levels in the surrounding area as a result of the infiltration of surface water in areas where the groundwater levels were generally lower. In WSRs with drainage limited by a weir, the weir levels were either designed too low, minimising the storage capacity of the WSR, or the high weir level subsequently lead to a nearly permanently filled WSR. The design of WSRs without weir could potentially be improved by implementing a weir with an orifice, to store water longer and allowing for more infiltration, while still reducing the risk of groundwater nuisance.

The measurements further highlight the complexity of groundwater-recharge relationships in urban areas. While the transects of monitoring wells provide a first indication of different processes influencing (ground)water in and around the researched WSRs, the quantitative influence of WSRs on water infiltration and groundwater drainage could not yet be determined. With longer measurements, statistical time-series analyses can be applied to gain insights in rainfall-recharge relationships in and around the WSRs.

In future work, measurements on WSRs with a drain must be expanded with discharge measurements and high quality precipitation measurements to determine a water balance of a WSR, which could provide better insights in the effects of WSRs on groundwater recharge, especially during periods of drought.

References

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