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High-frequency monitoring reveals nutrient sources and transport processes in an agriculture-dominated lowland water system

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S.1 Water quality within Lage Afdeling drainage area

The low frequency dataset of almost two years with analyses from 6 locations within the Lage Afdeling drainage area showed spatial differences in water quality related to land use and subsurface characteristics. High chloride concentrations were observed at monitoring locations 1, 3 and 5, where location 1 and 3 showed higher concentrations during summer than during winter (Fig. S1). Chloride is an indicator for the contribution of deep groundwater to the surface water. Chloride concentrations above 500 mg L^{-1} were commonly observed in the deeper groundwater in the area upstream of location 3 and 5 (Fig. S3). Location 3 shows an inverse relation between the NO_3 and Cl concentrations (R^2 = -0.67) which illustrates the soil and shallow groundwater as source of NO_3 in the surface water. The Lage Vaart channel acts as a drainage channel for groundwater under the confining Holocene layer, which is often brackish/saline (Van den Eertwegh, 2002). This explains the relatively high Cl concentrations of location 1 during summer.

Low NO_3 concentrations were observed in discharge water from the nature area Oostvaardersplassen (location 6) throughout the year whereas high NO_3 concentrations were observed in water from the agricultural areas Lepelaartocht and Gruttotocht (location 3 and 4) in the winter (8.3 and 13 mg N L^{-1} in February 2014 and 2015, respectively). The NO_3 concentration in the urban area water (location 2) did not exceed 2 mg N L^{-1}. The NO_3 concentrations of the Lage Vaart channel water at the pumping station (location 1) during the winter months were lower compared to the NO_3 concentrations at the outlet of the agricultural areas. As denitrification is limited during winter time, this indicates dilution of agriculture-dominated water with water from nature areas or urban areas. This is confirmed by the SO_4 data that demonstrate some dilution of the agriculture-dominated water as well. The locations with high SO_4 concentrations exhibit an inverse pattern with the Cl concentration (R^2 = -0.45 for location 3). This shows the occurrence of pyrite oxidation in the shallow subsurface (Griffioen et al., 2013) in the Lage Afdeling drainage area except for location 6 that drains the Oostvaarderplassen which has no tube drains and high groundwater levels throughout the year. The N-Kjeldahl concentrations varied between 0.77 and 5.8 mg N L^{-1} but showed little variation over the year for the individual agriculture-dominated and urban-dominated sampling locations. The N-Kjeldahl concentration in the water from the Gruttotocht (location 3) was almost twice as high as from the Lepelaartocht (location 4).

The TP concentration of the low-frequency monitoring program varied between 0.05 and 0.72 mg P L^{-1} (Fig. S1). From all sampling locations within the Lage Afdeling, the water from the

Oostvaardersplassen (location 6) had the highest TP concentrations. The TP concentration of this water ranged between 0.37 and 0.72 mg P L^{-1} from January to July 2014. The concentration dropped to a level around 0.3 mg P L^{-1} or lower in August 2014 and stayed at this level until April 2015. From April 2015 to mid-September 2015 the TP concentration ranged between 0.35 and 0.74 mg P L^{-1}. The TP concentration at the Oostvaarderplassen and Blocq van Kuffeler were higher during the first months of 2014 compared with the same period in 2015. The long-term data series for Blocq van Kuffeler showed high TP concentrations during the first months of 2014 as well compared with concentrations in other recent years (Fig. 6.). We do not have a clear explanation for this observation. The DRP concentrations were low during the first half year of 2014 and 2015. There was an increase of the DRP concentration in July 2014 and July 2015. During the first half year of 2014 and 2015 the TP concentration was dominated (> 90 %) by particulate P while in the second half year about 50% of the TP concentration consisted of DRP.

The seasonal variation of the DRP concentrations of the Lage Vaart channel water at the pumping station (location 1) followed the trend of the Oostvaardersplassen. Although less pronounced, this seasonal variation applied as well for the agriculture-dominated water (location 3 and 4) and the urban water (location 2). The TP concentrations were higher during the summer months than during winter months. The groundwater within the Lage Afdeling drainage area has relatively high dissolved P concentrations (Fig. S3)

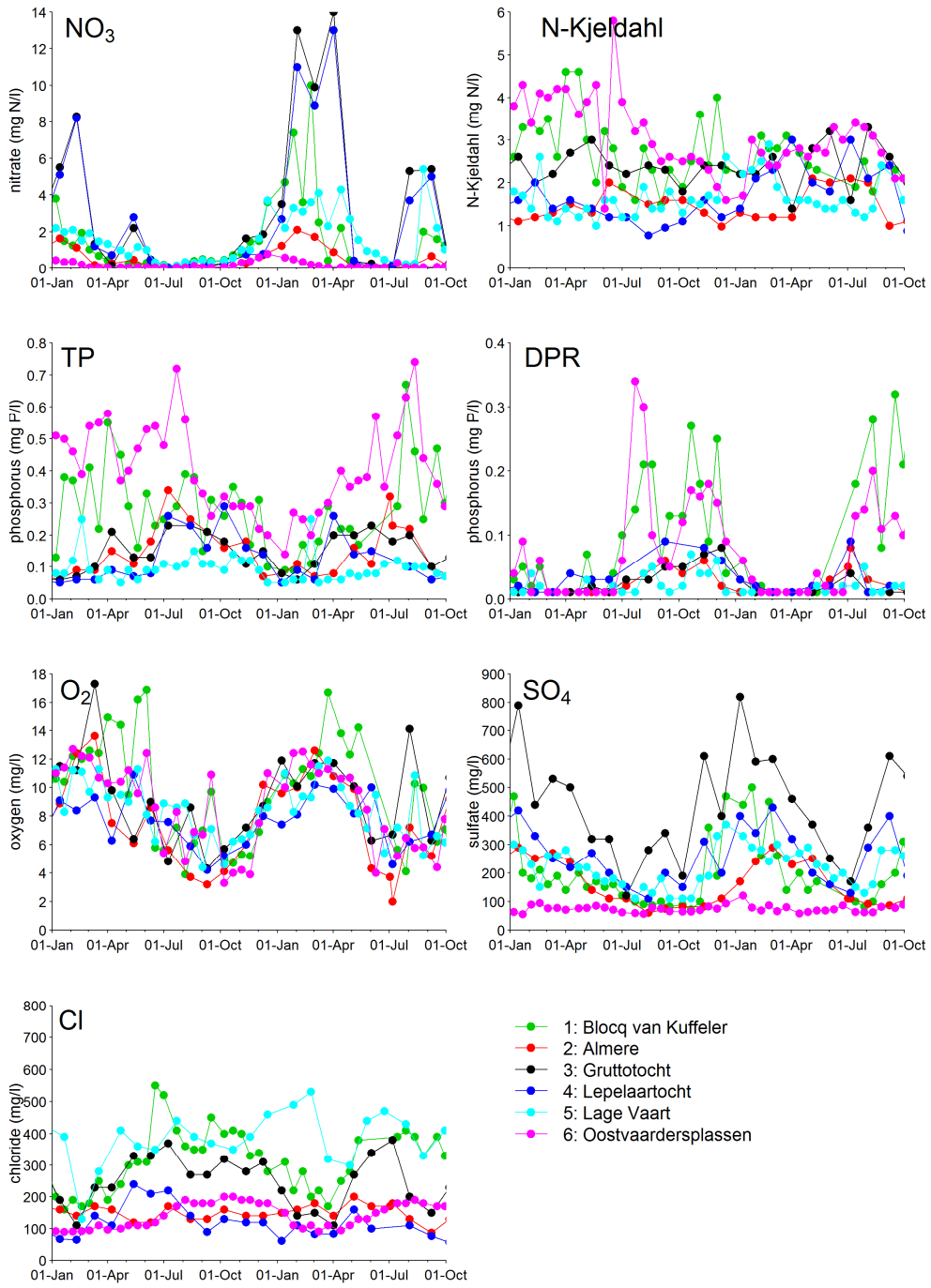


Figure S1. Low-frequency time series of NO_3, N-kjeldahl, TP, DRP, O_2, SO_4 and Cl concentration at surface water sampling location in the Lage Afdeling drainage area during the period January 2014 to October 2015. Fig. 1 shows the positions of the monitoring locations.

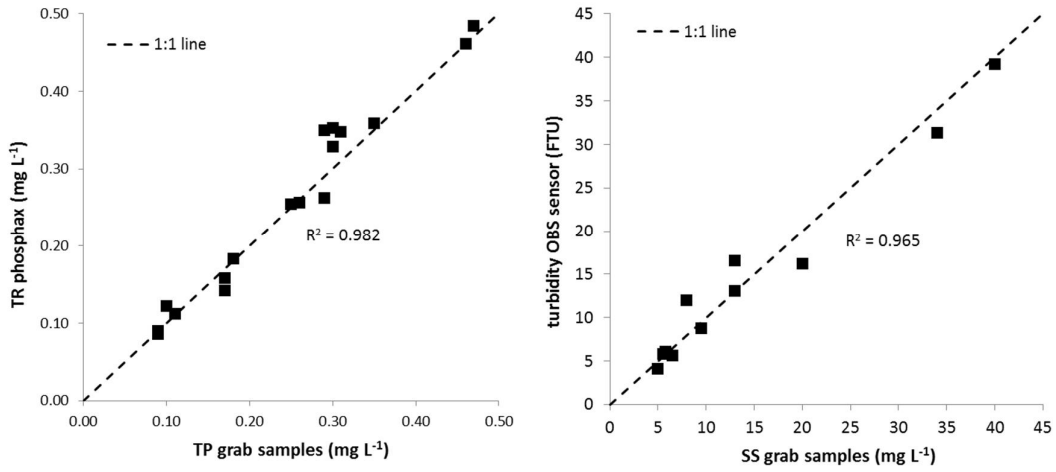


Figure S2. Total phosphorus (TP) and suspended sediment (SS) concentration from grab samples vs. the concentration measured by the continuous monitoring devices.

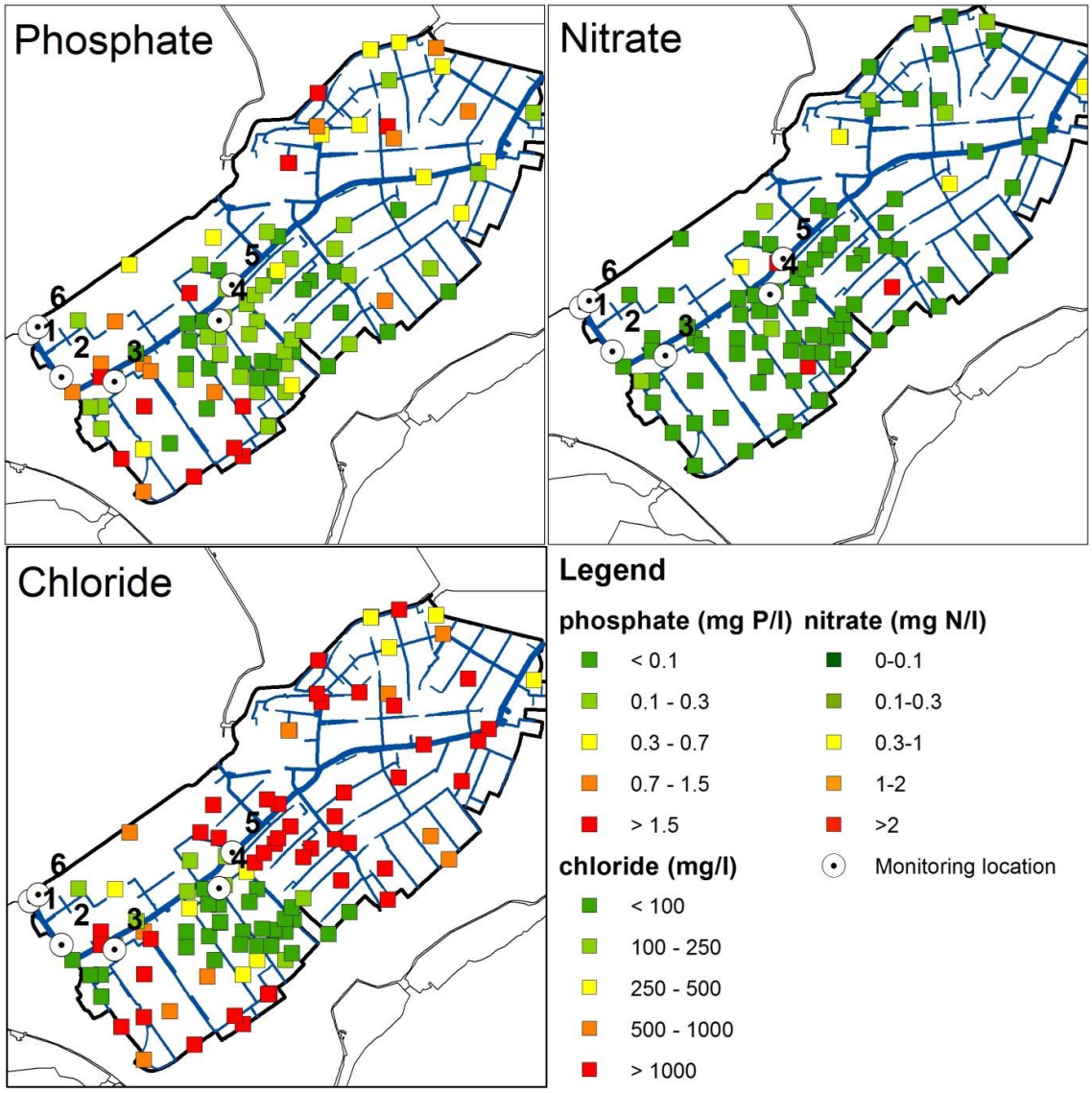


Figure S3. Phosphate, nitrate and chloride concentrations in groundwater down to 30 m depth (data from Griffioen et al., 2013).

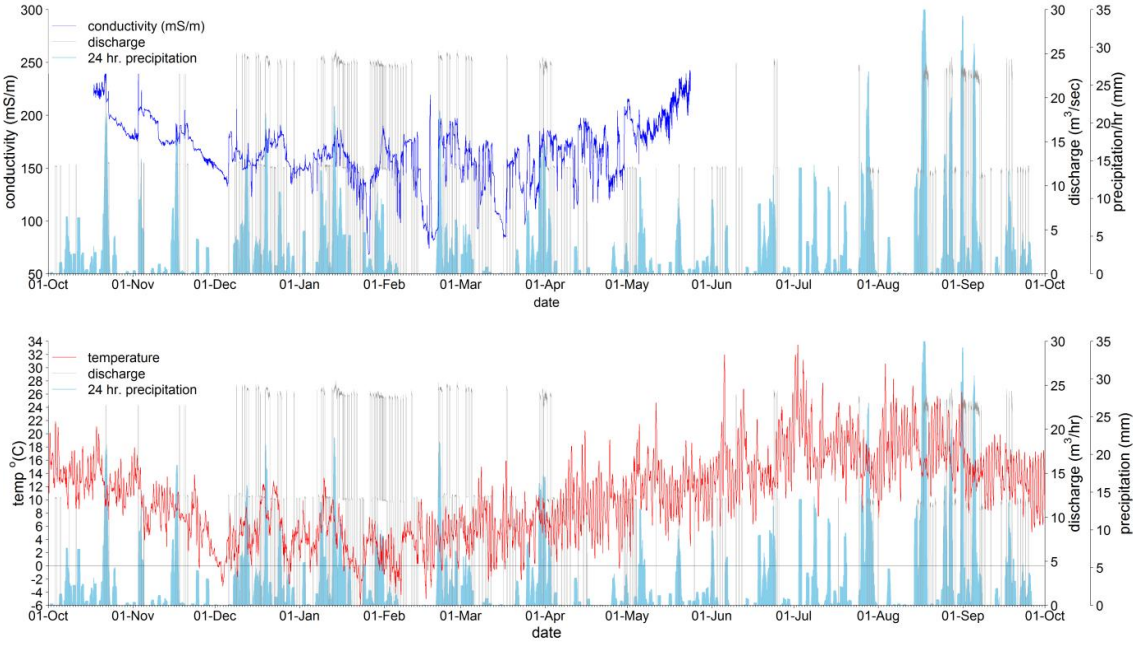


Figure S4. Conductivity, air temperature (from KNMI weather station Lelystad). Due to malfunctioning of the CTD divers, conductivity measurements from June 2015 were lost.

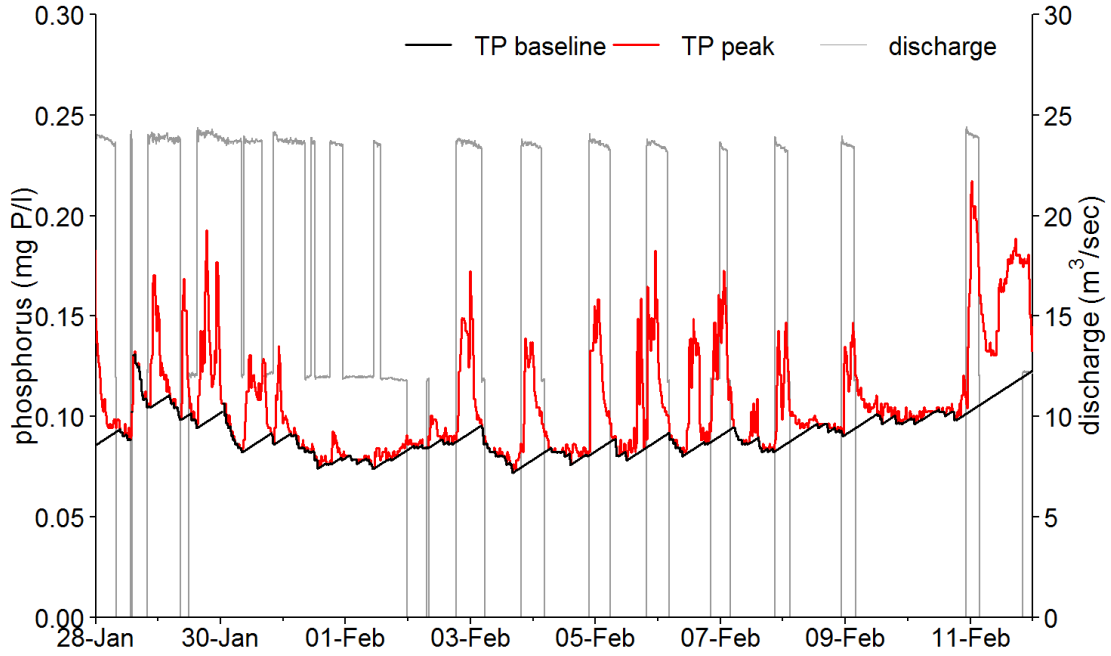


Figure S5. Separation of the high-frequency TP concentration data into baseline concentrations and peak concentrations

Table S1: Estimated parameters and associated standard deviations.

Parameter	Value	Standard deviation
A^*	0.006956	0.000954
n	1.425	0.03073
a	0.003274	7.70e-05
α	4.311	0.1349

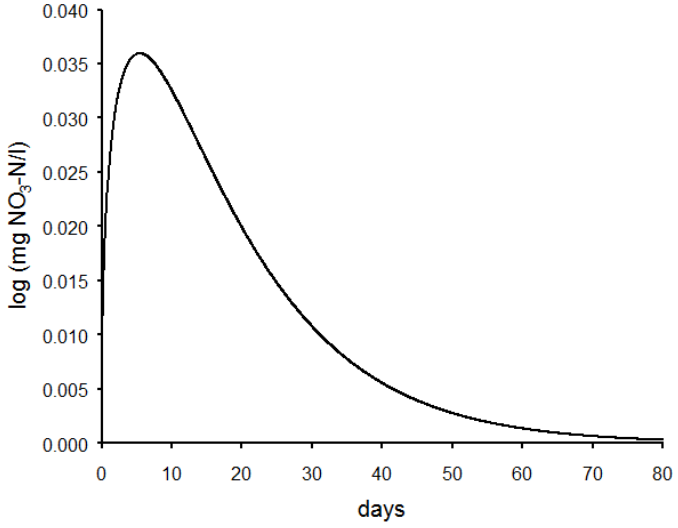


Figure S6. Impulse response function for log-nitrate concentration resulting from an impulse of 1 mm rainfall.

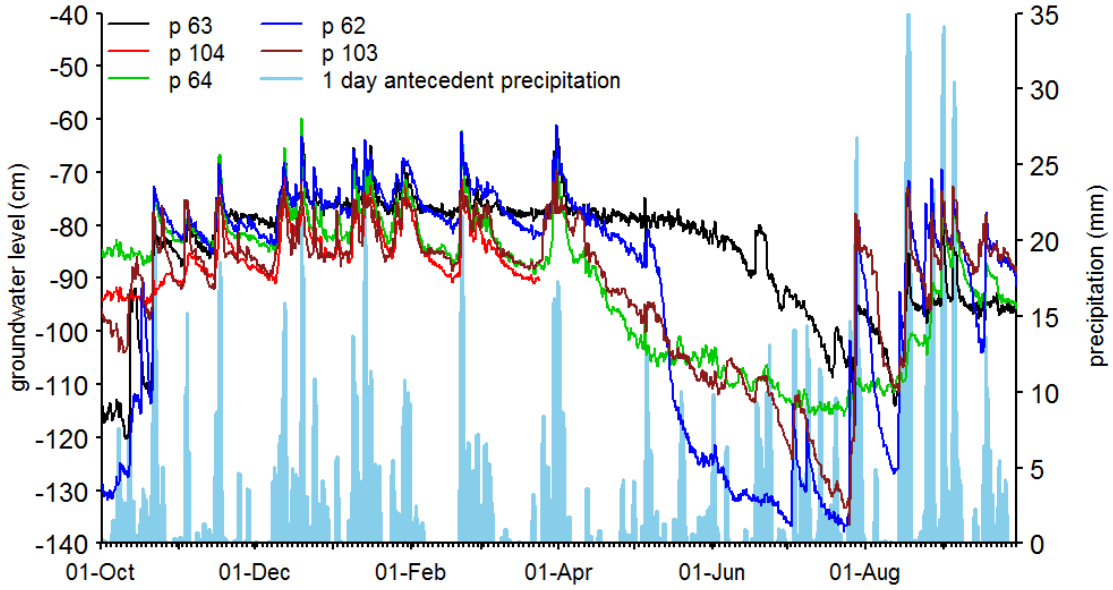
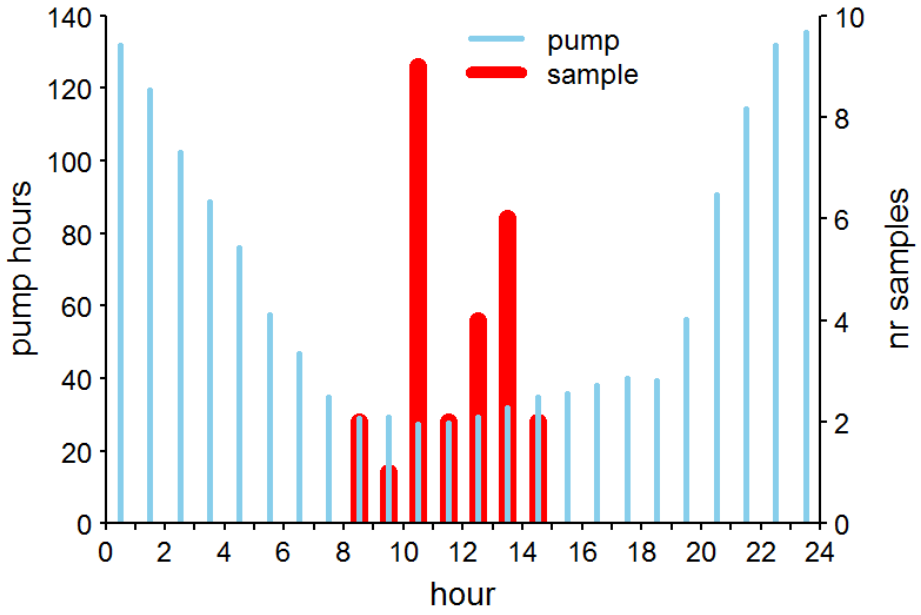


Figure S7. Groundwater levels (in cm below surface) within the Lage Afdeling drainage area. Fig. 1 for locations of the groundwater wells.



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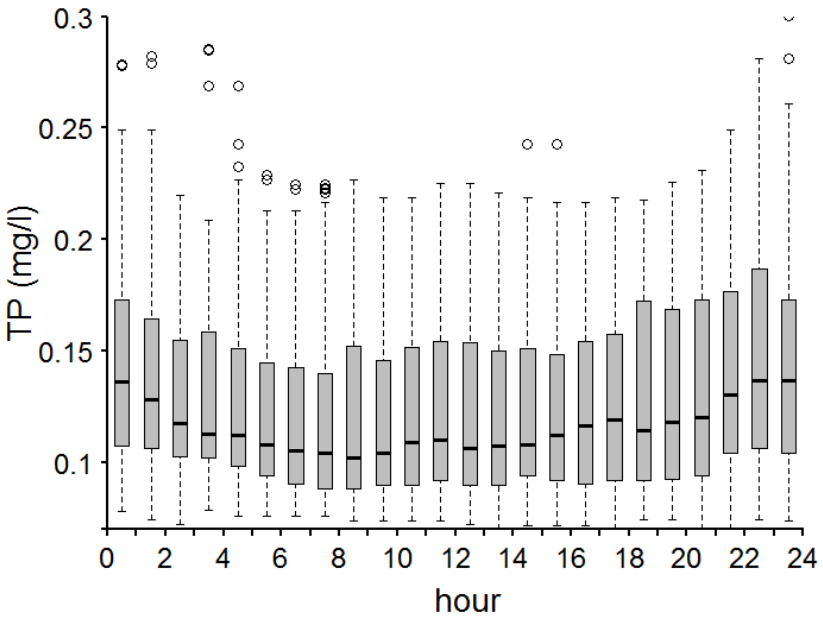

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3 Figure S8: Hourly distribution of pump hours and water quality sampling during the period Oct. 2014
4 – March – 2015 (A) and boxplots of measured TP concentrations during the months Jan. – Feb. 2015 .
5 The lower and upper side of the box represent the 0.25 and the 0.75 quantile. Whiskers extend to
6 the maximum and minimum value unless the values are larger than 1.5 times the box length. Open
7 circles are extreme values.