Exchange of nitrate in the transition zone between groundwater and stream water in the Norsminde catchment

NiCA Technical Note
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The NiCA project is led by GEUS (contact: Jens Christian Refsgaard, mail: jcr@geus.dk) and comprise the following partners:
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- Department of Geography and Geology, University of Copenhagen
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- Knowledge Centre for Agriculture
- Laval University, Quebec, Canada
- Aarhus Geophysics
- Alectia A/S
- DHI
- SkyTEM
- Municipality of Aarhus
- Municipality of Odder

Read more about the project and see its outputs at [www.nitrat.dk](http://www.nitrat.dk)
**Content**

Background and motivation.................................................................................................................. 2
Problem to solve.................................................................................................................................... 2
Conceptual geological model .............................................................................................................. 2
Riparian Hydrogeological Types..............................................................5
Specific baseflow..............................................................................................5
Hydraulic gradients..........................................................................................7
Nitrate in stream and groundwater ................................................................................................. 8
Stable Isotope Composition .................................................................................9
References........................................................................................................10
**Background and motivation**
EU Water Framework Directive makes clear demands on the Danish water managers to improve the regulation of nitrate leaching to surface waters in Denmark (i.e. estuaries, coasts, lakes and rivers) from agricultural land. The goal is to avoid eutrophication and to achieve a better ecological balance in surface water systems for the benefit of the groundwater dependent flora and fauna. Previous studies have shown that water chemical sampling of river water and in the river bed at the same location, may be useful as a screening tool for identifying sub-regions with special nitrate problems within hydrological catchments with large geological variability. This study is part of the NICA project, and the results will be included in the overall assessment of specific nitrate vulnerable areas in the Norsminde catchment (Refsgaard et al., 2013). However, this study is far from staying alone and cannot identify specific agricultural areas with a particular vulnerability for leaching of nitrate.

**Problem to solve**
The exchange of nitrate between the local and regional groundwater aquifers and the stream system (River Odder and Rævså) is assessed in the Norsminde catchment by juxtaposition of GIS themes and the establishment of a data set of discrete measurements of stream flow and nitrate concentration in stream water and groundwater in a dry season (June to August) and a wet season (December). The new knowledge obtained will be used in the regional hydrological model established for the Norsminde area by creating a higher precision of the distributed leakage characteristic along the stream reaches in contact with different types of groundwater aquifers in the catchment.

**Conceptual geological model**
A conceptual geological model is made as 2D profiles along the main reaches of the River Odder. The model is based solely on geological borehole data from the JUPITER database (www.geus.dk). The relation between the geological substrate which the river bed is embedded in is thus established as the contact between the river bed and the underlying aquifers (GW/SW interaction) can be interpreted together. Further it becomes evident along the river reaches, where no or little exchange of groundwater / stream water may be expected. The geological data basis is considered to be satisfactory for the Southern and Middle reaches of River Odder, while it was not possible to create a satisfactory geological profile of the Northern reach. Similarly, the amount of lithological information from boreholes along Rævså was too sparse, why a true line profile cannot be established. On the other hand, it is assumed that the regional model developed by Flemming Jørgensen could be interpreted together with the measured stream flow and water chemistry in the Eastern part of the catchment.

The following groundwater aquifers have been identified, that may be in hydraulic contact with the stream (Figure 2):
- River Odder, Southern reach: Local near-surface glacial sandy aquifer up to 10 meter thick (#9-10); At greater depth exist a regional quartz sand aquifer, that likely coincides with the position of the stream with the gauging station. Groundwater monitoring GRUMO wells are screened in the quartz sand aquifer and indicate artesian groundwater conditions immediately downstream of the mill pond (#10-12) (Figure 1 & 2(a)).

- River Odder, Middle reach: Local surface related meltwater sand aquifer a few meters thick and several km horizontal extension (upstream #6); deep regional quartz sand aquifer (15m thick) downstream #7 (Figure 2(b)).

- River Odder, Northern reach. Impossible to construct geological profile due to inadequate data.

- Rævså. Impossible to construct geological profile due to inadequate data.

*Figure 1. Topographical map of the Norsminde catchment, including the 20 measuring locations.*

In summary, there are three relatively steep middle reaches of River Odder, located in the Western part of the catchment, that are eroded into a local meltwater sand aquifer, approximately at the same distance (1-2km) from the headwater of the three streams. Whether this local aquifer is in hydraulic contact across the three stream reaches is not likely and will hopefully be addressed in larger detail by the new SKYTEM data. A more regional (deeper) quartz sand aquifer cut the same three reaches about 1km further downstream. It is very likely that this regional aquifer is one hydraulic coherent groundwater body. Finally, the northern part of Rævså is embedded in Paleogene clays in accordance to the new
SKYTEM soundings and the southern part of Rævså is laying in a West-East oriented tunnel valley system filled with a regional Quaternary sandy aquifer that is different from the regional aquifer occurring in the western part of the catchment.

Figure 2. Geological profiles along (a) the Southern and (b) the Middle stream reaches of River Odder. The sampling/measuring locations are shown in the two profiles.
**Riparian Hydrogeological Types**

At each of the 20 sites where the measurement campaign of stream flow and water sampling has taken place, a geological assessment of the local geological conditions was performed using hand drilling equipment. The contact between the aquifer and rivers have been conceptualized according to the typology of groundwater-surface water interaction (GOI) developed by Dahl et al (2007). The representative riparian hydrological types for the Norsminde area are shown in Figure 3.

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<td>6 or 8</td>
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*Figure 3. Riparian Hydrogeological Types. Left: Conceptual models from Dahl et al (2007). Right: Different types at the twenty measuring locations.*

**Specific baseflow**

Stream flow measurements have been carried out in June (limited number of locations) and at all 20 locations in August and December 2011 using an Acoustic Digital Current Meter (OTT ADC). June was a dry summer period; August was a rather wet summer period and December a normally wet period as expected. Stream flow at location 20 (Sander Enggård, ISCO sampler) was 3 to 4 times higher in December than in August. As stream flow measurements were not obtained at all locations in June, the August flow data has been chosen to exemplify a baseflow situation in the Norsminde catchment. Values are calculated as increase (or decrease) in flow (Q in L/sec) between an upstream and downstream location divided by the distance along the stream between the locations (Figure 4).
At the disconnected or confined types (type 1 & 2), located in the headwater of the three stream reaches of both River Odder and Rævså, inflow in the range of 0-5 L/sec/km is measured. However, the first and second order streams of River Odder are still conducting stream water during this “wet” summer month. No groundwater aquifers have been delineated in these regions of the catchment, thus the stream water is most likely originating from tile drains still in function during summer time. At the lateral local or regional types (type 3 or 4), located along the more downstream parts of all stream reaches are the riparian areas and stream bed are receiving up to 10 L/sec/km. After the confluence of both the three Odder stream reaches near location 20 (Sander Enggård) and around location location 15 of Rævså are the riparian area embedded in a regional groundwater aquifer. These reaches are classified as both lateral regional and bottom regional types. The specific baseflow increase to more than 50 L/sec/km along the downstream reaches of both River Odder and Rævså, respectively.

Figure 4. Specific baseflow in streams reaches along River Odder and Rævså.
Hydraulic gradients
Vertical hydraulic heads measured in December 2011 in piezometers screened 0.5m below the stream bed are related to the stream water stage at the 20 locations (Figure 5).

Figure 5. Vertical hydraulic gradients across the stream bed, December 2011. Negative vertical hydraulic gradients (red) indicate recharge of stream water to the groundwater aquifer and positive (blue) indicate discharge of groundwater to the stream.

Head differences between the water table in the piezometer and the stream water stage are given with an accuracy of ± 1 cm. Measurements with less than 2cm difference between water table in piezometer and water stage in stream are set to zero. Negative vertical hydraulic gradients indicate recharge to the groundwater aquifer and positive indicate discharge of groundwater to the stream. The vertical hydraulic gradients are positive along most stream reaches indicating potential discharge to the stream. However, it should be noted that a significant proportion of the increase in stream flow along the stream system is believed to be caused by drain flow in the Western part of the Norsminde area where River Odder is draining the clayey till plain. The Middle reach of River Odder do show indications of stream
water loss into the underlying groundwater aquifer along the stream reach that pass right through Odder town between location #7 and #13. The recharge observations are both supported by vertical head measurements and the fall in stream flow measured between location #7 and #13. The local groundwater-stream interaction conditions are very likely influenced by urban hydrological impacts of bypass of surface water runoff through sewage pipe systems and piping of the water course (less than 100m long stretch right downtown). Further discussions are appreciated on this topic.

**Nitrate in stream and groundwater**

Nitrate has been detected in 11 out of a total of 20 groundwater samples during the August and December 2011 sampling. Five piezometers have nitrate concentrations between 3 and 16 mg NO₃/L and another 6 wells have concentrations less than 0.5 mg NO₃/L (Figure 6 (left)). The locations with high concentration in August were also contaminated with nitrate in the December sampling. However, not at all sampling locations with low nitrate concentrations was nitrate found during both sampling rounds. The locations with high nitrate concentration in groundwater samples can all be correlated to either the local or regional groundwater aquifers underneath the stream bed.

![Figure 6. Nitrate in groundwater (left) and in stream water (right). August sampling (pink column) and December 2011 sampling (orange column) are given.](image)
Nitrate concentrations in stream water are ranging from 3 to 25.2 mg NO$_3$/L in August and 10 to 32 mg NO$_3$/L in December with an average of 16 mg NO$_3$/L in August and 23 mg NO$_3$/L in December. The systematic increase from August to December is observed at all 20 locations (Figure 6 (right)), which is believed to be caused by higher nitrate leaching fluxes via tile drains during the wet season (December).

**Stable Isotope Composition**
The stable isotope ratios of hydrogen ($^2$H/$^1$H) and oxygen ($^{18}$O/$^{16}$O) were determined in stream water and groundwater samples during the three sampling campaigns in June, August and December. The aim of this sampling was to evaluate the dynamic relationship between groundwater and stream water by using deuterium and oxygen-18 as tracers in the Norsminde catchment. Data are shown in Figure 7 without any further interpretation of data. This will be done later on in the NICA project.

![Figure 7. Plot of $\delta^{18}$O versus $\delta^2$H samples collected from stream water and groundwater at the 20 locations in the Norsminde catchment (Figure 1). The Global Meteoric Water Line (GMWL) (Craig, 1961) is shown together with a Local Meteoric Water Line (LMWL) determined using isotope data from Arrenæs, Denmark (Jørgensen & Sørensen, 2000).](image-url)
References
