NiCA mapping of agricultural areas – a cost estimate

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Jens Christian Refsgaard, GEUS
Esben Auken, AU
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The NiCA project is led by GEUS (contact: Jens Christian Refsgaard, mail: jcr@geus.dk) and comprise the following partners:

Geological Survey of Denmark and Greenland (GEUS)
Department of Geography and Geology, University of Copenhagen
Institute of Food and Resources Economics, University of Copenhagen
Department of Earth Sciences, Aarhus University
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
1. **Purpose of the present note**

The present note provides an attempt to estimate the costs that would be associated with using the NiCA concept for mapping of larger areas in Denmark. The cost figures are intended for use in analysis of water management strategies in NiCA’s workpackage 4. Further details on the NiCA project can be found at [www.nitrat.dk](http://www.nitrat.dk), where e.g. the Description of Work can be downloaded, and in Refsgaard et al. (2014).

2. **The NiCA concept**

NiCA has developed and tested a concept for mapping nitrate reduction from agricultural fields (Refsgaard et al., 2014). The key elements are illustrated in Figure 1. The concept includes the following steps:

- **Airborne geophysical mapping** with high spatial resolution focussing on the uppermost 30 m of the subsurface. NiCA has used data from the SkyTEM101 tool developed within NiCA (Schamper et al., 2014).
- **Stochastic geological modelling** based on integration of geophysical data, geological data and geological knowledge and with a focus on geological uncertainty using stochastic geological methods like TProGS (Carle et al., 1998) to generate several plausible geological realisations (He et al., 2014; Koch et al., 2014).
- **Stochastic hydrological modelling.** Coupled surface water/groundwater models are established for each of the geological realisations/models (Step 2) and autocalibrated inversely against available groundwater head and river discharge data (He et al., submitted).
- **Estimation of depth to redox interface in the saturated zone.** The depth to the redox interface is estimated at the scale of the hydrological model grid assuming that its spatial pattern is dependent on the groundwater recharge and the redox capacity of the sediments. This involves a calibration using measured data of nitrate flux in rivers and estimated nitrate leaching from the root zone within the catchment (Hansen et al., 2014a). This calibration is carried out for each of the geological/hydrological models.
- **Nitrate reduction maps.** All the hydrological models are used with particle tracking to simulate flow paths and nitrate reduction rates. Particles are released from the bottom of the root zone at a rate corresponding to 1 kg nitrate leaching/particle from each model grid (100 m x 100 m). The nitrate particles follow the flow pathlines on their route towards the stream system. The nitrate reduction is then assessed by counting how large a fraction of particles originating from a model grid that are passing down through the redox interface (Hansen et al., 2014a).
- **Uncertainty analyses.** The uncertainty of the nitrate reduction maps is assessed by calculating the spread among the stochastic geological/hydrological models and different assumptions on parameters in the redox interface estimation (in our case a total ensemble of 30 models). Furthermore, the relationship between prediction uncertainty and spatial scale of prediction are estimated, i.e. how much does the uncertainty reduce when results are aggregated to larger spatial scales (Hansen et al., 2014b).
Thus, the NiCA concept has focused on geological mapping using new geophysical data and calculation of nitrate reduction at fine spatial scales and the uncertainties associated to these issues. NiCA studies have, however, also identified additional knowledge gaps for which field and modelling studies, beyond what was conducted in NiCA, will be required:

- **Drain pipes.** We need field studies to identify the location of the existing drain pipes in the landscape and we need more knowledge to be able to more correctly describe the dynamics of the flows in the drain pipes. This is required to more correctly assess how much of the water from a field takes the direct route from the root zone into the drains without nitrate reduction, and how much flows vertically down-
wards and maybe passes below the redox interface on its route downhill towards the streams. We also need to know how much of the water that passes the drain pipes uphill, ends up flowing into drain pipes downhill from their point of origin before flowing into the streams.

- **Riparian lowlands.** The flow processes and the nitrate reduction processes in the riparian lowlands are very complex and not sufficiently understood. Here we need both field data and improved knowledge and tools.

- **Depth to redox interface at local scale.** Although NiCA has initiated studies on depth to redox interfaces and developed a concept that appears valid at catchment scale, it is very inaccurate at small scales. In order to reduce the uncertainty of nitrate reduction at small spatial scales we need more field data and knowledge on the redox capacity.

When we in the following use the term "NiCA mapping" we mean both the type of field data collection and modelling studies that was performed in NiCA and the additional field and modelling activities that needs to be performed to address the above three aspects. Hence, the “NiCA mapping” includes the following key elements:

1. **Geophysical mapping** focussing on collecting and processing of datasets with information specifically targeting a spatially fine resolution at the upper 15-30 m of the subsurface. This could for instance be performed using the new SkyTEM 101 system, or better future systems.

2. **Addition data collection.** The following new data will be required: i) new boreholes to support the geophysical mapping and the analysis of depth to redox interface; ii) identification of drain pipes; iii) mapping of riparian lowland; and iv) flows and concentrations in drains, groundwater and streams.

3. **Geological and hydrological modelling.** This includes combining geophysical and geological data and integrating this information and other additional field data into hydrological models. In order to enable uncertainty assessments this needs to be carried out in a stochastic framework.

4. **Nitrate modelling and assessment of nitrate reduction.** This involves estimation of depth to redox interface and calculation of nitrate transport and reduction in the subsurface, including the drains and the riparian lowland. The spatial resolution of the modelling should be maximum 100 m, but is likely to be smaller for some riparian lowlands. The key output of these analyses will be nitrate reduction maps and nitrate fluxes in drains and streams, including quantified uncertainty estimates of these.

### 3. Cost estimate

#### 3.1 Assumptions

The cost estimate for the above four elements of a “NiCA mapping” is based on the following assumptions:

- The work will be carried out with a similar balance between the private sector (consulting companies), the public sector (state agencies and municipalities) and re-
search institutions as in the ongoing groundwater mapping. The costs of both public and private sectors are included.

- The time required to do the specific tasks of a “NiCA mapping” have been estimated based on our experience in the NiCA project. We have, however, adapted the time estimate assuming that the work will be carried out in a routine consultancy mode characterising practical work rather than in an experimental research mode like NiCA.
- Some of the tasks to be carried out are new and not yet standard on the shelf products among consultants and not well known among water authorities either. Hence capacity building will be required. This will have some impacts on the personal time required.
- Some funds are allocated to research and development. This will allow development of new innovative solutions and products and enable lessons learnt to be incorporated in gradually improved procedures making the entire work more cost-efficient.

### 3.2 Cost numbers

The following two tables show estimated costs for a 500 km² catchment. Costs are estimated for two programmes:

- **“NiCA mapping”** with a comprehensive field data collection and thorough modelling analyses including uncertainty assessments. The output will be nitrate reduction maps and flows in drains and streams including uncertainty estimates. This is our best estimate for a programme that can reduce the uncertainties best possible and carried out at a high professional level without being a research study.
- **“Minimum mapping”** with the field programme reduced to 50% and less comprehensive modelling analysis. The output will be one nitrate reduction map and flows in drains and streams without uncertainty estimates. This programme will, due to the reduced field programme, have a larger output uncertainty that will not be quantified.

For smaller catchments the costs will be larger per unit area, while it is not expected that studies of catchments above 500 km² will result in significant unit cost reductions. Most of the cost estimates are assumed to have an uncertainty characterised by a standard deviation of 50% of the estimate, except for the geophysical mapping, which have well known costs. The standard deviation of the total investigation is then calculated as the square root of the sum of the variances. Consequently, the 95% uncertainty interval, shown at the bottom of the tables, is calculated as the best estimate +/- two standard deviations. As part of a catchment has non-agricultural land use (urban area, forest, etc.) the cost per ha arable land can be calculated by dividing by the arable land percentage (assumed here to be 65% which is slightly above the national average).
4. Discussion – limitations and warning

4.1 Price versus quality – how much analyses should be made?

The above cost estimates should be seen as an attempt to provide order of magnitude estimates allowing a first meaningful discussion of costs and benefits of differentiated regulations. They are not meant as final numbers that can be used to design new legislation – for such purpose more actors should be involved to provide more consolidated estimates.

Assuming that the “NiCA mapping” is carried out for large catchments, the cost per ha of agricultural land in the catchments is estimated to be within the range 450 – 850 DKK/ha as a one-time expense. If very accurate results are required in geologically complex sub-areas within the large catchment, the cost for additional field data may be larger than listed in the table above and the total costs will then be correspondingly higher.

If a lower quality of work is accepted, a reduced “Minimum mapping” programme can be adopted. This can be done at around half price by reducing the field programme and omitting the uncertainty analyses. We strongly recommend the full “NiCA mapping programme” if the objective is to obtain best possible basis for regulatory decisions including full information on where the remaining uncertainties are.
Some of the costs are difficult to estimate, because the activities, except the geophysical mapping, are not standard activities that previously have been carried out by consultants. Also, the costs for water management are difficult to estimate, but we have included it and listed it separately to achieve transparency.

### 4.2 Groundwater mapping – relation and cost comparison

The current groundwater mapping, carried out during the period 2000-2015 covering all areas with particular drinking water interests (around 40% of Denmark), will have a total cost of about 3,100 MDKK in 2013 prices (2,700 MDKK in 2006 prices). This is equivalent to about 1,800 DKK/ha area or 2,750 DKK/ha agricultural land. This price is much higher than our estimate for a “NiCA mapping”, and it may therefore be questioned if our cost estimates are too low. We, however, believe that the difference makes sense, as the groundwater mapping is broader in scope and includes more types of investigations as well as a comprehensive management component. We see the “NiCA mapping” as being more focussed and therefore requiring substantially less management support.

The groundwater mapping has a focus on pollution threats to deep aquifers suitable for drinking water abstraction, while a “NiCA mapping” will have its focus on delineating the flow paths and nitrate reduction in the upper 30 m of the subsurface in order to estimate the nitrate load to streams and fjords. Due to these fundamental differences in purpose, the groundwater mapping has not produced the type of results a “NiCA mapping” aims at. The SkyTEM data acquisition in the groundwater mapping has for instance focussed on deep aquifers, while it in a “NiCA mapping” will focus on achieving a best possible resolution of the upper 30 m of the subsurface. Furthermore, while the geophysical data in the groundwater mapping primarily were used to delineate large scale geological units, they will in a “NiCA mapping” be much more integrated into the hydrological modelling by using them explicitly for describing the small scale geological heterogeneity in the upper 30 m of the subsurface. Therefore, if a “NiCA mapping” in a particular area is required to support differentiated regulation of nitrate loads from agricultural land, it will be required irrespective of whether a groundwater mapping has previously been carried out. It will, however, be possible to reduce the 2NiCA mapping” costs, maybe in the order of 20%, for areas already covered by groundwater mapping.

The geophysical data in a “NiCA mapping” will be of much higher quality than the geophysical data in the groundwater mapping, as the technology and data processing have been significantly advanced since the original mapping took place. In addition to a much more detailed spatial resolution of the geological heterogeneities of the upper 30 m, the data will therefore inevitable also contain information on the geological layers at a much larger depth (>100m) than what is needed. This implies that if the dataset is made publicly available, it can be exploited in future work for e.g. mapping of raw materials, groundwater mapping at intermediate depth, geological modelling etc.
5. References


