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N-SINK – Reduction of waste water nitrogen load: demonstrations and modelling

D7.1. Conceptual model of linking economic and ecological approaches

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Background

Lakes, streams and the Baltic Sea provide Finns numerous ecosystem services, ranging from livelihood to recreation. However, human activities and the nutrient emissions they produce are putting these services at risk. In order to maintain a healthy state of inland waters and the Baltic Sea, and guarantee future provision of these ecosystem services, the external loads of nitrogen and phosphorus need to be reduced to a sustainable level. In fact, it has been shown that by reducing nutrient emissions human being does not only safeguard functioning aquatic ecosystems, but also increases its own welfare through increased and secured provision of cultural and provisioning ecosystem services (Hyytiäinen et al., 2013).

The recent changes in the water protection policies of Finland are mainly based on two directives, namely Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD), and the conventions and declarations agreed on within Helsinki Commission, most importantly the Baltic Sea Action Plan (BSAP). In Finland, water protection policy concentrates nowadays on agriculture, as it comprises the largest source of nutrients into water bodies. The Finnish Agri-Environmental Programme (FAEP) that states water protection as one of its main objectives was implemented in 1995 when Finland joined the European Union. The programme is also the main tool within WFD to control nutrient load from agricultural areas. Through FAEP more than 90% of the farmers are subsidized for environmentally sound cultivation practices.

In actions against eutrophication, society’s resources could be wasted on inefficient policies without careful planning. Therefore development of the cost-efficient abatement strategy is essential. Cost-effectiveness can be defined in two ways: (i) reaching some given target with minimum cost, or (ii) using some fixed budget to maximize its environmental impact.

Several research articles have studied the cost and cost-effectiveness of nutrient abatement in Finland (e.g. Helin et al. 2006, Hyytiäinen et al. 2008, Laukkanen and Huhtala 2008, Ahlvik et al. 2014) with main focus on agriculture, but some studies also covering other polluting sectors. The model that is sketched here, and constructed within the N-SINK project, will extend the previous analyses by being spatially more explicit. This spatial dimension is particularly important, because the effectiveness of an abatement measure hinges on its location. Measures implemented far from the coastline only have a small effect on the state of the Baltic Sea but might have a large effect on some lake or river. On the contrary, measures implemented on coast will have a strong effect on the sea, but no effect on inland waters.
Cost-effectiveness principle

One of the most important aims of N-SINK Action B.3 is to assess the economic viability of the sediment filtering approach technology presented in Action B.1. This is done in terms of cost-effectiveness analysis: given the water protection targets, is the new sediment technology part of the set of abatement measures that leads to the targets with least possible cost? In other words, are there other measures in agriculture or waste water treatment with lower marginal cost (€/kg) that should be implemented instead of sediment filtering approach. It should be noted that even if the sediment filtering technology reduces nutrient emissions, its high cost can make it economically inefficient.

We illustrate the cost-effectiveness principle in Figure 1, with sediment filtering technique and three other fictional techniques each associated with a constant marginal abatement cost. Height of each bar represents the marginal cost of nitrogen abatement and widths of bars are the capacity of each abatement measure. According to the cost-effectiveness principle the measure with the lowest abatement cost (measure 1) is implemented first, and then sequentially moving to measures with higher abatement cost until the target is met. Whether or not sediment filtering technique is adopted depends on stringency of water protection targets. Again, using the example shown in Figure 1, if the target is to reduce 300 kg of nitrogen, sediment filtering technique is not part of the cost-effective set of abatement measures. If the target is 600 kg of nitrogen, then sediment filtering technique is part of the cost-effective set of abatement measures. Note, that the total cost of reaching the goal is the total area left of that target.

Figure 1. An example for the cost-effectiveness principle with four fictional abatement measures.
Conceptual cost-and-effect model

In order to perform the analysis illustrated in the previous chapter, we need a model to estimate the marginal costs (€/kg) shown in Figure 1. Cost-and-effect models are tools to evaluate the total cost of nutrient abatement policies and to solve the economically efficient ways of reaching the given targets. In order to solve for the cost-effective set of abatement measures we construct a model to evaluate costs and effects of different nutrient abatement measures, in cooperation with other Actions of N-SINK and specifically using INCA-N and VEMALA –models. They are dynamic, catchment scale models for nutrient leaching and transformation processes at catchment and watershed scale. Construction of the model consists of following parts:

(i) Depict the movement of water and nutrients in the water system at a catchment level

(ii) Identify the present sources of nutrients and divide the nutrient emissions to different sectors

(iii) Choose a set of nutrient abatement measures and describe their marginal costs, effectiveness and capacities at the source

(iv) Combine the model depicting movements of nutrients in (i) to the model describing costs and effects of implementing nutrient abatement measures in (iii) within a single framework

(v) Use non-linear optimization techniques to solve for the cost-effective set of abatement measures to reach some given target
The model is spatially explicit and abatement measures can be implemented in different parts of the catchments, so that their cost and effectiveness might vary depending on the location. The first model version will be static, so that it will neglect the short-term lags in the effect of some of the abatement measures and it is therefore suitable for medium- and long-term analyses. Furthermore, to enable comparability between the measures, the first model version will be deterministic in a way that it neglects the temporal variation in nutrient loads and effectiveness of abatement measures. We calibrate the model for two case study watersheds, first for Vanajavesi (see Figure 2.) and later for Porvoonjoki.
The outline of the model is shown in Figure 3. We consider two types of nitrogen abatement measures, agricultural and wastewater treatment-related. First, we consider agricultural water protection measures that are based on current FAEP (Mattila et al. 2007). We use INCA-N-model to estimate the effectiveness and costs for a set of agricultural measures, namely reducing the use of inorganic fertilizers and choosing between conventional and reduced tillage. Spring crops, fall crops and grass are considered separately. Second, we analyze the effect of constructed wetlands on nutrient loads. Third, we estimate the cost of investments in wastewater treatment plants to reduce nitrogen loads. Then, we use VEMALA model to estimate the retention of nutrients to solve the effect of abatement measures on nitrogen loads to inland waters and the Baltic Sea. Last, we use non-linear optimization techniques and Matlab Optimization Toolbox to solve for the cost-effective combination of measures to reach exogenously the given targets for inland waters and the sea.
References


