AQUARIUS project
Assessing water quality improvement options concerning nutrient and pharmaceutical contaminants in rural watersheds

Czech-Norwegian Research Programme (CZ09), project n. 7F14341 (2014 - 2017)
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Coordination: Czech University of Life Sciences Prague
Partners:
T.G. Masaryk Water Research Institute
Research Institute for Soil and Water Conservation
Norwegian Institute for Agricultural VODNÍ ZDROJE, Ltd. Research Institute for Soil and Water Conservation
Research Institute for Soil and Water Conservation
Norwegian Institute for Agricultural and Environmental Research (NIBIO)

The project AQUARIUS is focused on evaluation of significant point and non-point sources of water pollution and its origins including evaluating the current/typical and alternative waste water treatment methods, aiming at minimizing surface and groundwater pollution. Attention is turned to reveal the true concentration/load dynamics of main nutrients and pharmaceuticals and personal care products (PPCPs), for which the factors/parameters of the related processes are assessed. The project assesses cost effective land and agricultural management actions or measures and waste water treatment technologies, including the use of constructed wetlands, to enhance landscape’s retaining water potential and to reduce input of pollutants into waters. Both for water quantity and quality, methods of continuous monitoring are employed in submerged hydrological and hydrogeological units of various scales. Results from monitoring serve as a base for modelling approach within a catchment area. Short term events as well as long term water balance are modelled to distinguish and quantify runoff components and pollution being transported by them. Models simulate diverse scenarios of land use, agricultural management, wastewater technologies and involvement of various biotechnical measures to increase water retention time in a catchment and to enhance surface and groundwater quality. The project outcomes are necessary for completing conceptual and expert documents and guidelines for soil and water conservative management and proper wastewater treatment in a catchment scale, as well as for planning of land use within areas used as water supply sources.

WP1: Testing the efficiency in removal of nutrients and pharmaceuticals from waste water
Objective: Testing the effectiveness of diverse alternative wastewater treatment approaches/methods and formulating their applicability for small villages/dwellings. Aspects of: water quality and quantity, costs, management.

WP2: Monitoring of waste water types, surface- and groundwater pollution in the catchment sites
Objective: Reveal the true concentration/load dynamics and source of origin of the main nutrients and PPCPs. Assess the effectiveness of current treatment technologies for waste waters containing pharmaceuticals and the processes of natural attenuation of pharmaceuticals in the rock environment.

WP3: Modelling of hydrological and environmental data
Objective: Integration of findings from WP1 and WP2 to model water and nutrient balance of selected area (watershed, sub-catchment/wetland system itself or more units together).

WP4: Cost and social analyses
Objective: Assessment of all measures / changes in waste water treatments and catchment management from the view of cost / effectiveness to formulate options for (re)constructing the WWTP, wetlands and/or alterations on land use within a catchment (grassing of arable land, etc.).
WP5: Coordination, dissemination and management

WP6: Economical and social problems of drugs in water

This WP6 was added in the year 2016 to support the socio-economic results of the project.

Main objective of additional research activities is to increase the quality of ongoing sociological survey among Czech and Norwegian populations. This survey examines the reaction of people to information that the water for the drinking purposes contains potentially harmful substances. These issues are addressed by means of statistical evaluation of questionnaires distributed in network of Norwegian and Czech communities around the existing pilot sites. The questionnaire, which takes into account social, economic and genders factors, age and education issues, has already been designed and approved by the Czech and Norwegian partners. The weakness of the existing solutions is the limited informative value of this survey, which is based on a relatively small number of the answers, which, in addition, will come from only a few locations.

The aim of additional research activities is to eliminate this problem and to expand an inquiry to a much wider range of respondents. New study should gain a statistically more significant amount of data, which will include a more diverse set of processed data (including e.g. the urban population, the municipality of protected areas and vice versa very environmentally affected regions). This will significantly improve the planned output.

WP4: Testing the efficiency in removal of nutrients and pharmaceuticals from wastewater

The aim of WP4 is to evaluate treatment efficiency of constructed wetlands in the watersheds of drinking water reservoirs Švihov in the Czech Republic and Lake Gjersjøen in Norway. In the Czech Republic, four constructed wetlands that have been in operation between 12 and 25 years were selected (Pict. 1). All constructed wetlands treat municipal sewage from small villages. In Norway, two constructed wetlands were selected (Pict. 2). The first system is designed to treat a mixture of municipal sewage and road runoff, the second system has been designed to treat agricultural runoff and drainage. Treatment efficiency is evaluated on the basis of chemical parameters such as organics, suspended solids, nitrogen and phosphorus. In addition, 47 pharmaceuticals including several metabolites were evaluated as well. The monitored pharmaceuticals belongs to NSAID drugs (non-steroidal anti-inflammatory drugs, antibiotics, antibacterial agents, pain relievers, anticoagulants, antidepressants, beta-blockers, diuretics, antiepileptics and fibrates). Both in Norway and the Czech Republic, the effect of discharged water on receiving streams is evaluated as well. In Norway tracking of the pollution sources (microbial source tracking – MST), in particular human (mostly from wastewater) and non-human (mostly from agriculture) has been performed. For this reason, microbial analyses of faecal water pollution (E. coli) and molecular tests applying a suite of sensitive host-specific quantitative real-time PCR were employed to determine the source and origin of the contaminants.
The results indicate that constructed wetlands in the Czech Republic exhibit very high removal of organics and suspended solids while removal of ammonia and phosphorus is lower. However, this is expected as all constructed wetlands with horizontal subsurface flow are predominantly anoxic and therefore do not support nitrification. Due to low flow, the effect on water quality in receiving streams is negligible. Similar results were found in Norway despite different wastewater characteristics (much lower inflow concentrations).

Pharmaceuticals were quite commonly recorded in inflow water samples in high concentrations with the highest concentrations being found for paracetamol, caffeine, furosemide and ibuprofen. Treatment efficiency for pharmaceuticals varies widely between pharmaceuticals: highest concentrations being found for paracetamol, inflow water samples in high concentrations with the highest concentrations being found for paracetamol, in Norwegian drinking water reservoir basins in Czechia and in Norway. Further goals are to assess the effectiveness of current treatment technologies for waste waters containing pharmaceuticals and the processes of natural attenuation of pharmaceuticals in the rock environment in order to increase the efficiency of wastewater treatment in the existing sewage treatment plants.

To achieve this, two small agricultural, tile-drained catchments are monitored within drinking water reservoir basin Švihov and one site for groundwater monitoring close to Prague in Czechia. Groundwater in the Skuterud catchment is monitored in Norway (Pict. 3). During the project, the continuous monitoring of discharge, nutrient (N, P) concentrations in waters, including rainfall-runoff (R-R) events by the help of automatic samplers is performed in tile-drained catchments to quantify the share of R-R events on the total nutrient flux. Moreover, measurement of stable isotopes $^{18}$O and $^2$H in precipitation, drainage waters and groundwater is realized to assess the mean water residence time (MRT) in catchments.

The acquired findings are useful for improvement of nutrient load assessment in tile-drained catchments of various scales, as already employed in Norway JOMA monitoring programme. Further, the gained knowledge can help to design various mitigation measures on agricultural land or tile drainage systems, together with an estimation of "lag time" for efficiency of these measures, applicable e.g. in Nitrate Directive, Water Framework Directive or River Basin Management Plans.

WP2. Monitoring of drainage-, surface- and groundwater pollution in the catchment sites

The main aims of WP2 are to reveal the true concentration/load dynamics and sources of pollution in small water courses, and tile drainage under different soil, land use and agricultural management manners, in drinking water reservoir basins in Czechia and in Norway. Further goals are to assess the effectiveness of construction technologies for waste waters containing pharmaceuticals and the processes of natural attenuation of pharmaceuticals in the rock environment in order to increase the efficiency of wastewater treatment in the existing sewage treatment plants. To achieve this, two small agricultural, tile-drained catchments are monitored within drinking water reservoir basin Švihov and one site for groundwater monitoring close to Prague in Czechia. Groundwater in the Skuterud catchment is monitored in Norway (Pict. 3). During the project, the continuous monitoring of discharge, nutrient (N, P) concentrations in waters, including rainfall-runoff (R-R) events by the help of automatic samplers is performed in tile-drained catchments to quantify the share of R-R events on the total nutrient flux. Moreover, measurement of stable isotopes $^{18}$O and $^2$H in precipitation, drainage waters and groundwater is realized to assess the mean water residence time (MRT) in catchments.

The results show considerable differences among the Czech monitored tile-drained catchments and seasons in the years 2013–2016. MRT for baseflow is 0.5–3 years, whereas for quick flow components (interflow, overland flow), it is in minutes or hours. For small tile-drained catchments, the mean specific load was for N 3.5–55 kg ha $^{-1}$ year$^{-1}$ and for P 0.025–0.45 kg ha $^{-1}$ year$^{-1}$. The share of R-R events on N loads was 5–30% (on average 24%) of the total year load, whereas for P (dissolved and total), the share of discharge events was 10–80% (on average 45%) on the total year load. The most precise method for solute load estimation was apparently the one including the R-R events. The methods for load assessment based on point monitoring of discharge and water quality under- or over-estimated the solute loads of N by 10–20%, of P by 30–80%. Run-off and water residence time in catchments were revealed as the main driving forces influencing N and P dynamics in surface and drainage waters.

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Special case study: Monitoring of pharmaceuticals in the vicinity of psychiatric hospital Horní Beřkovice

The environs of the psychiatric hospital at Horní Beřkovice in Central Bohemia represent a unique pilot site, where infiltration of treated wastewater into the aquifer has been taking place for decades. Ongoing complex monitoring compares the quality parameters of local wastewater and wastewater in four other catchments with no concentrated pharmaceuticals contamination sources. While the monitoring in a common sewerage system showed 10 pharmaceuticals, at Horní Beřkovice their number increased threefold. Regularly monitoring of the water quality allowed to determine the efficacy of removal of pharmaceuticals from wastewater at the local sewage treatment plant. The monitoring also registered the fate of substances that move from the treatment plant into the recharge ponds and then gradually infiltrate into ground waters.

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Pict. 3 Sampling spot of stream water at the Skuterud catchment in Norway.

Pict. 4 Box plots of carbamazepine concentrations in Horní Beřkovice pilot site.
The results showed a significant decrease of all moni-
tored micropollutants, which remained bound in sedi-
ments and in the unsaturated zone. Their passage into ground-
water was very limited, and after a few hun-
dreds of meters in the saturated zone they virtually
disappear. The only locally problematic substance is Carba-
mazepene, for which the existing treatment tech-
nologies are inefficient. The substance passes through
the unsaturated zone and systematically appears in
samples of groundwater at a distance of about 1 km
from the site of infiltration.

WP3. Modelling of hydrological and
environmental data

Assessment of potential reduction
in nitrogen loads by biotechnical measures

The Jankovský stream is a tributary to Želivka river
which contributes to the Svihov drinking water reser-
voir. The catchment has an area of 130 km² with eleva-
tion ranging between 445 – 765 m a.s.l. The catchment
is a typical agriculturally exploited catchment (nearly
50% of area consists of arable land, about 30% is for-
ested), see Pict. 5. It contains 37 settlements (with or
without waste water treatment plants) and there is
considerable number of fish ponds (4% of catchment
area). Since the water quality is of a special concern
due to the direct connection to the Svihov drinking wa-
ter reservoir, we assessed the potential reduction of
nitrogen loads in the catchment outlet by changing the
land use (for reduction of diffusive sources) and con-
struction of wetlands under each settlement. The
assessed effectiveness in reduction of nitrogen loads of a con-
structed wetland (45%) was estimated from long-term
measurements. We used a Soil and Water Integrated
Model (SWIM) for assessment of the effect of these
measures. It was concluded that the limit land use
scenario S0 which transforms all arable land to grass land and a more realistic
S1 scenario transforming only arable land situated on
coarse-textured, shallow and leaching-prone soils to
grasslands leading to a 22% reduction in the propor-
tion of arable land (Pict. 6). In addition we consider
construction of wetland under each settlement. The
effectiveness in reduction of nitrogen loads of a con-
structed wetland (45%) was estimated from long term
measurements. We used a Soil and Water Integrated
Model (SWIM) for assessment of the effect of these
measures. It was concluded that the limit land use
scenario S0 leads to reduction of nitrogen loads in the
catchment outlet by ca 30% while the effects of con-
structed wetlands on total catchment nitrogen load is
relatively smaller (ca 6%). However, the local effects
of constructed wetlands are considerable. Additional
reduction could be gained when constructed wetlands
for treatment of diffusive sources were employed.

WP4. and WP6. Economical and
social problems of drugs in water

The issue of pharmaceuticals existence in surface wa-
ter, groundwater and drinking water subsequently
brings significant social impact, which is reflected in
two spheres. Disclosure of information about the ex-
istence of potentially dangerous substances in drink-
ing water can adversely affect the behavior of certain
population groups. The question is, what will be the
willfulness of people to accept higher financial costs
associated with the application of new technologies,
wastewater treatment and water resources manage-
ment.

AQUARIUS project have been aware of this problem
and should therefore be dealt with in a separate WP
“Ethical and social problems of drugs in water” It seeks
to answer the following questions: Is it appropriate
to disclose information about these new kinds of pollu-
tion in the water when until now we have only little
information about the level of the real danger? Are the
stakeholders interested to know information about the
water quality? How much they would like to pay for
really clean water? Equally important is the socio-eco-
monic issue: What will be the reaction of consumers on
increased prices of drinking water?

These issues are addressed by means of statistical
evaluation of questionnaires distributed in network of
90 Norwegian and 450 Czech communities. The ques-
tionnaire, which takes into account social, economic
factors, age and education issues has already been
approved by the Czech and Norwegian partners. The
weakness of existing solutions is limited informa-
tive value of this survey, which is based on a relatively
small number of answers, which, in addition, will come
from only a few locations.

The aim of additional research activities is to elimi-
nate this problem and to expand an inquiry in Czech
Republic and Norway. Study gain a statistically signifi-
cant amount of data, which include a diverse set of
processed data (including e.g. the urban population,
the municipality of protected areas and vice versa very
environmentally affected regions).

The economic part of the project represents the esti-
nated cost to implementation of filters on activated
carbon in waste water treatment plants throughout
the Czech Republic. This amount is CZK 1 billion annually.

Pict. 5 Current land use in Jankovský stream catchment.

Pict. 6 Scenario considering transformation of arable
land to grass lands in Jankovský stream catchment. The
transformed land use is given in red.