Dimensions of Agri-Environmental Research in the Department of Environmental Engineering and Water Management

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Abstract. The impact of human activity on the biosphere has produced global environmental problems related to the natural resources and risks to ecological health such as soil and water pollution calling for new solutions that help sustain the development of agriculture and protection of water resources. The present paper begins by recalling the historical and project context from which a research work in the Department of Environmental Engineering and Water Management has arisen in the 1990s after historical and structural changes in the society of Latvia. The paper provides a discussion on research fields dealing with some of the core issues and approaches currently faced by the department, such as monitoring of agricultural run-off, environmental risk assessment, climate change impact evaluation, and water quality modelling. It can be emphasised that understanding the complex interactions between the use of land for agricultural production and water quality is essential in promoting the sustainable water management in agriculture and healthy environment.
Key words: agricultural production, environmental risk, water monitoring, modelling.

Introduction

The paper summarises the main research results of the Department of Environmental Engineering and Water Management, and provides some perspective on the attempts to cope with environmental consequences of agricultural production. Every human activity has, and always has had, an impact on the environment. This also applies to agriculture. Development of production systems has resulted in intensification, specialisation and concentration of the agricultural production. The impact of these changes has been obvious as much for the environment as for the water ecosystems (Jansons, 1999; Haraldsen et al., 1998).

Farmers use commercial fertilisers, manure and other materials, and/or crop rotations to replace nutrients withdrawn from the soil during production of agricultural crops (Busmanis, et al., 2001). Without replacing the soil with nutrients, crop yields or quality would decline in most cases (Haraldsen et al., 2001). Primary nutrients for crop growth and development include nitrogen, phosphorus, and potassium, but other macro- and micro-nutrients are also important. If improperly applied, fertilisers can leach into the groundwater or drain into the surface water (Vagstad et al., 2000a; 2000b; Busmanis et al., 2001; Deelstra et al., 2009). Nutrients in the surface water can cause eutrophication, oxygen depletion, fish kills, and reduction in recreation opportunities (Bechmann et al., 2004). High nitrate levels in drinking water also have adverse human health effects. In all countries of the Northern Europe, agriculture is estimated to be responsible for the greatest contribution of phosphorus and nitrogen to coastal waters (Vagstad et al., 2001).

Both the EU Nitrates Directive (ND) and Water Framework Directive (WFD) require that Latvia like all the Member States control the impact of agriculture on the surface and ground waters (Jansons et al., 2005). When assessing water quality, it should be considered whether all the territory of Latvia or only part of it, with the highest impact of agriculture measured in terms of high nitrate content ($\geq$50 mg L^{-1}) or eutrophication phenomena, should be designated as nitrate vulnerable zones (NVZs). In addition, the risk that in the near future freshwater bodies or marine waters may contain more than 50 mg L^{-1} nitrates (11.3 mg L^{-1} NO_3-N) and become euthropic, if actions in agriculture are not undertaken, also is a relevant aspect for designation of the NVZs. The risk assessment performed in the Department using GIS tools was based on the data of soil and groundwater media, run-off, potential erosion risk, agricultural activities, such as agricultural land and arable land use, animal density, soil drainage, and application of fertilisers (Jansons et al., 2005).

The Ministers for Environment of HELCOM member states met on November 15, 2007 in Krakow, Poland, to adopt an ambitious overarching action plan to drastically reduce pollution to the Baltic Sea and restore its good ecological status (HELCOM Baltic Sea Action Plan, 2007). The key component is a plan to reduce nutrient loads and ways how to allocate these to the countries in the region. The inland water bodies receive nitrogen and phosphorus emissions which are a net result of both diffuse and point source pollution. In the assessment of non-point agricultural pollution, it is crucial to be able to control nutrient emissions and exclude other loads, i.e., from point sources: large livestock farms and wastewater from urban areas. HELCOM recall (HELCOM Baltic Sea Action Plan, 2007) that countries should apply harmonised principles and monitoring methods for quantifying non-point losses throughout the sea catchment area in order to obtain comparable and reliable estimates on the waterborne inputs from both point sources and non-point sources entering into the Baltic Sea. In addition, climate change calls for a more effective environmental policy to protect the water resources of the Baltic Sea.

The net effect of agricultural loading to the Baltic Sea cannot be easily predicted without using nutrient leaching models in combination with run-off models (Ziverts, Jauja, 1999) and river transport models. The predictive capacity to simulate riverine nutrient fluxes as a function of changes in human activities is facilitated by the nested modelling approach addressing nutrient fluxes from farm scale over regional scale addressing type river basins with characteristic land use patterns in the various Baltic Sea water districts up to the basin wide scale. Due to a substantial share of the anthropogenic phosphorus and nitrogen load origins from agricultural land there is a need for new innovative approaches in modelling to identify and implement the most cost-effective countermeasures on a regional and local scale.

Historical Background

After the collapse of the former political and economic system in 1990/1991, Latvia like the other Central and East European countries went through dramatic changes in agricultural sector (Jansons, 1996; Stalnacke et al., 1999; Jansons et al., 2003; Vagstad et al., 2002) as well as in all other sectors of economy. Higher education system and research programmes were transformed to meet the Western standards. In 1951 the Department of Land Reclamation of Latvia Agricultural Academy was founded. The most important research fields of the Department before the 1990s were as follows:

- subsurface drainage;
- application of wastewater and slurry for irrigation;
- irrigation scheduling;
- subsurface drainage for irrigation.

After the above mentioned changes in 1993 the Department of Land Reclamation was reorganised into the Department of Environmental Management, and in 1995 – into the Department of Environmental Engineering and Water Management. Among the most urgent topics currently put to the scientists of the Department, we may list the following:

- monitoring and assessment of non-point source pollution from agriculture;
- monitoring and assessment of area point source pollution (large animal farms) from agriculture;
- assessment of the measures to mitigate agricultural pollution to the coastal and marine environment;
- watershed modelling.

International cooperation in research projects described in Table 1 was an important factor in institutional strengthening; research capacity building and providing opportunity significantly upgrade the technical capacities for agri-environmental research being essential for the implementation of national and international commitments in environmental control undertaken by the government. As can be seen in the Table, the main cooperation partners of the Department in agri-environmental projects and research programmes were scientists from Sweden (Swedish University of Agricultural Sciences), Norway (Jordforsk/Bioforsk), and Denmark (Danish Agricultural Advisory Centre). Cooperation and transfer of knowledge and equipment enhanced the capacities of the Department to design and implement the water monitoring programmes so that they were also suitable and attractive for research and educational purposes (Vagstad et al., 2001; Deelstra et al., 2004). Moreover, it was of great importance that a monitoring programme similar to the existing ones in the Nordic countries (e.g. Norway and Sweden) was implemented and specifically aimed at assessing the impact of agriculture

Table 1

Main international scientific projects of the Department of Environment and Water Management

Project and project leader in Latvia	Project partners	Year
Baltic Sea Environmental Programme, Project: Agricultural Run-off Management Study in Estonia and Latvia (P. Bušmanis)	SLU and JTI, Sweden	1993
BAAP (Baltic Sea Agricultural Action Programme) BEAROP project, Phase I (P. Bušmanis)	SLU and JTI, Sweden	1993-1997
BAAP (Baltic Sea Agricultural Action Programme) (P. Bušmanis)	Swedish Farmers Federation	1993-1997
Drainage Basin and Load of the Gulf of Riga, sub-project: Soil and nutrient losses from small catchment (V. Jansons)	Jordforsk, Norway	1993-1997
Drainage Basin and Load of the Gulf of Riga, sub-project: Nutrient losses from agricultural areas with high livestock densities in Latvia (V. Jansons)	Jordforsk, Norway	1995-1996
Baltic Sea Experiment. BALTEX Project (A. Zīverts)	M. Plank Institute and GKSS	1997-2002
Development of a Code of Good Agricultural Practices, the Republic of Latvia (P. Bušmanis)	Denmark, DAAC	1998-1999
Environmental Monitoring in Agriculture. Nordic–Baltic Cooperative (V. Jansons)	Jordforsk, Norway	1997-2000
BAAP (Baltic Sea Agricultural Action Programme) BEAROP project. Phase II (P. Bušmanis)	SLU and JTI, Sweden	2000-2002
Baltic Sea Regional Project (Component 2, sub-task: Monitoring and Assessment) (V. Jansons)	WB & GEF (HELCOM)	2004-2007
Joint Baltic Sea Research Programme (BONUS), RECOCA (Reduction of Baltic Sea Nutrient Inputs and Cost Allocation within the Baltic Sea Catchments) project (V. Jansons)	Stockholm University, Baltic Nest Institute	2009-2011

on the surface water quality in Latvia. A detailed description of monitoring network, research methods and technologies can be found in the articles presented by Jansons (1996, 1998), Jansons et al. (1999, 2002, 2007), Deelstra et al. (1996, 2004), and Vagstad et al. (2004).

In addition, it has to be noted that scientists of the Department have been involved in the implementation of relatively large number of national research projects. About 32 projects were financed by the Ministry of Agriculture, the Ministry of Environment, the Environmental Agency, Latvia Council of Science, and Latvia University of Agriculture during 1993-2008. The most active project leaders/managers were Prof. P. Bušmanis, Prof. V. Jansons, Prof. A. Zīverts and Prof. R. Sudārs.

Monitoring of Agricultural Run-off

The environmental assessment of representative small watersheds and farms was started at selected locations in Latvia. Catchments and demonstration activities were selected to respond to regional differences and farming intensity. In 1994, the measurement of leaching and run-off losses of nitrogen and phosphorus was started in several agricultural catchments. The main objective was to quantify losses of nutrients to the surface waters and the groundwater from agricultural sources. Lack of reliable monitoring data for the estimation of agricultural pollution sources was a common problem in the post-Soviet countries, including Latvia. Designs of the monitoring system have been coordinated with the Nordic institutions (Deelstra et al., 1996) to ensure the comparability of the data sets and quality assurance measures. For these reasons, it was also important that the applied measurement methods/equipment and procedures were sufficiently advanced to comply with international scientific standards and knowledge/technology transfer from the Nordic countries including training in operation/maintenance of monitoring stations, equipped with data loggers and automatic flow proportional sampling. In order to assess agricultural pollution in Latvia, diffuse source monitoring programmes (Jansons, 1996, 1998) were implemented in 3 monitoring stations (Bērze, Mellupīte and Vienziemīte small agricultural catchments) with ordinary agricultural practice and in 3 drainage fields within these catchments (Fig. 1). In addition, a specific monitoring programme was established in 3 monitoring points (Vecauce, Ogre, and Bauska catchments) representing large pig farms as point pollution sources with high rates of animal manure (slurry) application (Sudars et al., 2005). A description of monitoring sites is presented by Jansons et al., 2002, 2007.

Non-point Source Agricultural Pollution

Figures 2 and 3 provide information on temporal and spatial trends of nutrient run-off from monitoring sites. The variations in nutrient run-off are considerable. The lowest non-point source losses were measured at the Vienziemīte monitoring site where the share of arable land within the catchment was 4-5% during 1994-2008. The highest diffuse source nutrient losses occurred in the Bērze site, and exceeded by far the

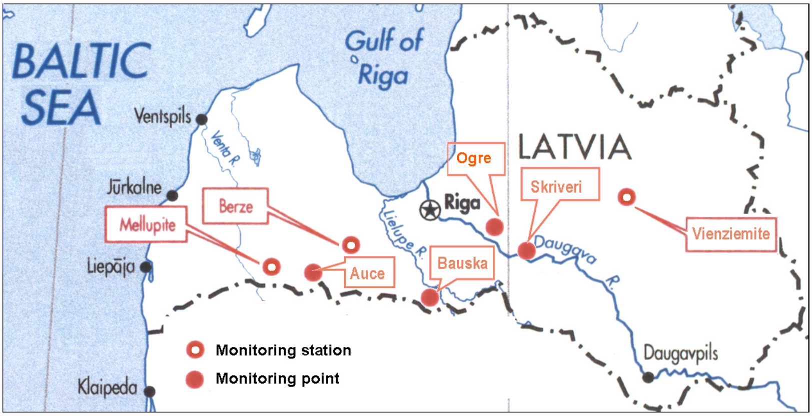

Fig. 1. Agricultural run-off monitoring stations and monitoring points in Latvia.

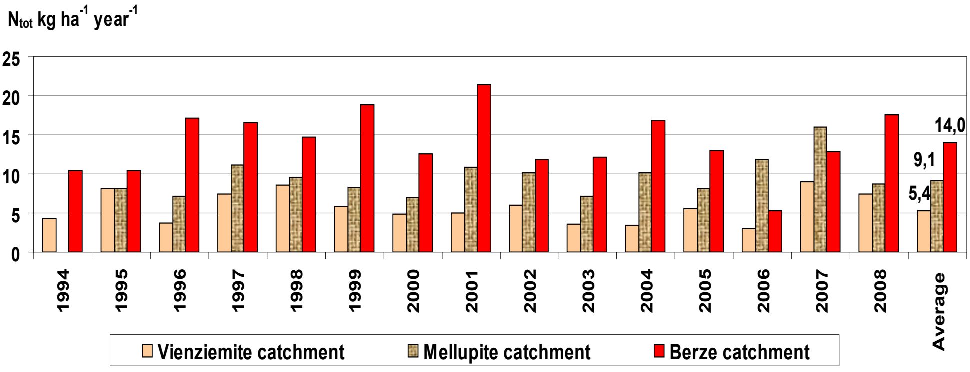

Fig.2. Nitrogen run-off from small catchments.

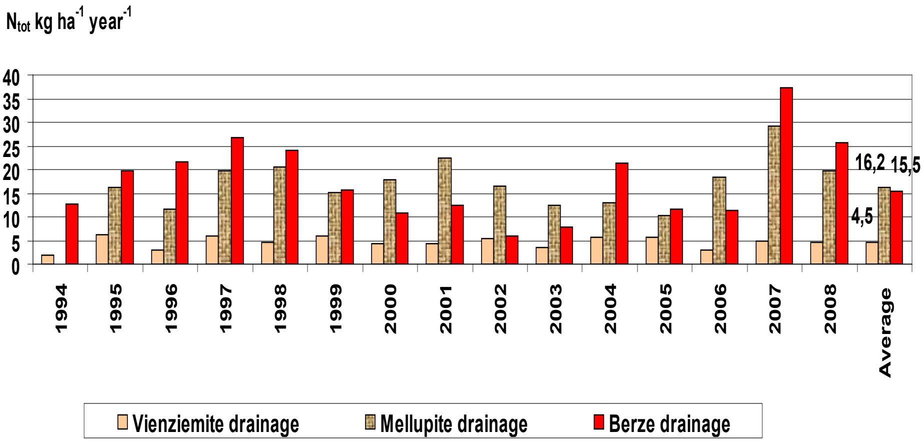

Fig.3. Nitrogen run-off from drainage fields.

losses in Vienziemīte (Jansons et al., 2002). In Mellupīte, where agricultural land use might be considered as moderately intensive for Latvia conditions nitrogen losses were about 9 kg N ha^{-1} annually. The lowest losses measured in the catchments' scale were 1.8 kg N ha^{-1} and 0.03 kg P ha^{-1} annually, while the largest annual losses were 21.4 N and 0.52 kg P ha^{-1} respectively. Generally, it seems that nitrogen loads are higher from the field drainage systems compared with small catchments' scale. At the same time, phosphorus run-off was higher in small catchments.

The diffuse source nutrient losses in the Bērze and Mellupīte small catchments appear to be low as compared with the recorded losses on similar conditions in the Nordic countries (e.g. Norway and Sweden). Nitrogen losses ranged between 15 and 70 kg ha^{-1} annually during 1994-1997 in 8 small catchments in Norway and Sweden (Vagstad et al., 2001). The average annual measured nitrogen run-off was 30 kg N ha^{-1}. These losses were approximately three times higher than the average losses (9.7 kg N ha^{-1} annually) from Bērze, Mellupīte and Vienziemīte small catchments, thus indicating differences in leaching regimes and agricultural practices between areas in Latvia and the Nordic countries. The difference in fertiliser applications may be one important factor. In Latvia catchments, the annual average nitrogen application per ha of agricultural land was: 4-5 kg ha^{-1} in the Vienziemīte catchment, 13 kg ha^{-1} – in the Mellupīte catchment, and 30 kg ha^{-1} – in the Bērze catchment during 1994-1999. Although the average applications are low, some fields within the Bērze catchment received 160 kg N ha^{-1} annually. Another reason for the observed differences in N losses may be different hydrological regimes (Deelstra et al., 2004, 2005, 2007, 2008, 2009), leading to longer water residence time, and therefore higher nutrient retention in Latvia catchments.

The correlation test between the share of arable land and nitrate contents in the run-off was tried at the small catchment and drainage field scale (Fig. 4) (Jansons et al., 2002). The result showed that this relation could be established despite the indirect causality between the nitrates losses and the use of land.

Point Source Agricultural Pollution

The impact studies by Haraldsen et al. (1998), Jansons (1998), Sudārs et al. (2005), and Bērziņa et al. (2009) give examples of a long-term investigation into the consequences of point source pollution on the water quality. The measurement results presented by Jansons et al. (2002) in the catchments with current or past high animal densities (including pig farms with the annual production capacities of 10-30 thousand pigs) showed very high losses with the average of 46-48 kg N and 2.7-3.4 kg P ha^{-1} annually. The data on phosphorus loads in Bauska and Ogre catchments reflect an extreme deviation from natural water quality status, and point sources are assumed to have major impact via direct run-off of applied slurry. Moreover, in one particular slurry dumping field of 50 ha in Bauska catchment, losses exceeding 10 kg P and 250 kg N ha^{-1} annually were recorded. In one of these catchments (Ogre) farming activities ceased in 1991/1992. The results indicate (Fig. 5) that such farm land still may function as "area point-source" with risk of significant losses of nutrients to the aquatic environment (Jansons et al., 2002).

Agricultural Pollution Risk Assessment

Geographic Information System, which is designed to organise, store, and access large quantities of spatially referenced data, is an excellent tool for the assessment of

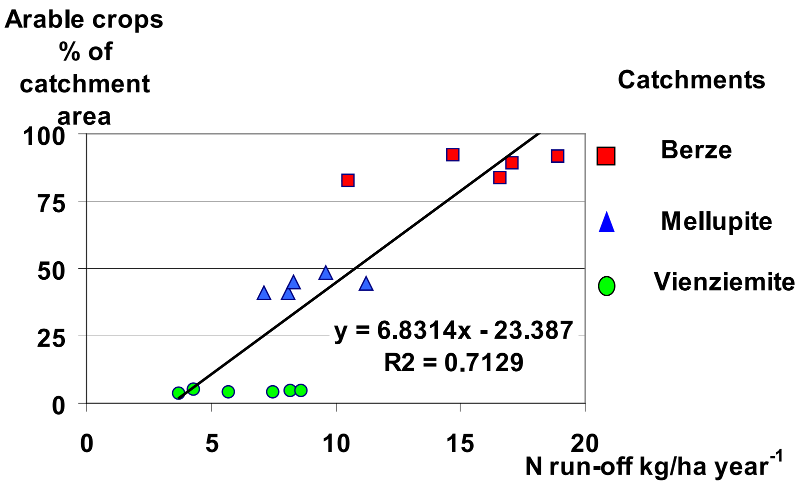

Fig. 4. Nitrogen run-off in relation to area of the arable crops in small catchments (1994-1999).

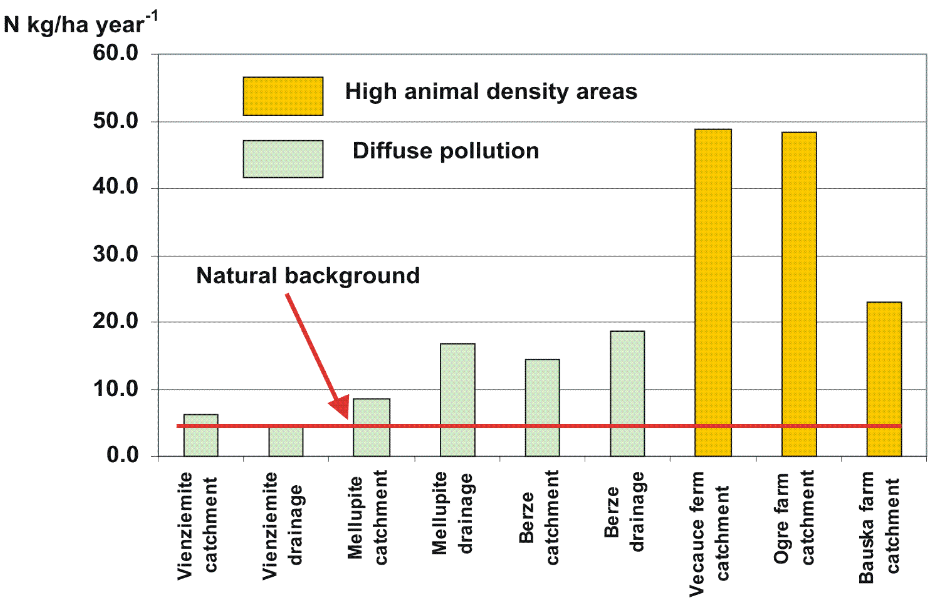

Fig. 5. Mean values of nitrogen losses from agricultural non-point sources and point sources (high animal density areas, 1994-1999).

environmental risk of agriculture. Due to the lack of monitoring data the first designation of vulnerable zones in Latvia was performed using GIS Multi-Criteria decision-making analysis (Kirsteina, Dzalbe, 2000). There are two main groups of factors: natural impact and the impact of human activities. The nitrate pollution risk assessment was based on the data of soil and groundwater media, run-off, potential erosion risk, agricultural activities, such as agricultural land and arable land use, animal density, soil drainage, and application of fertilisers (Jansons et al., 2005). These factors have been used for the GIS Multi-Criteria decision-making analysis. Statistical data traditionally available on administrative level were merged with georeferenced land cover data, and maps are presented pointing out the impact of different factors. Factor weights have been computed according to the results of the expert evaluation. The resulting impact data layer yields a map for potential agricultural risk areas in Latvia. The result of this scientific approach was used for designation of vulnerable zones in respect of the EU and national legislation (the Nitrate Directive). Finally, part of the territory located in the central part of the country, in the Lielupe river basin or Dobele, Jelgava, Bauska, and Riga administrative districts having the most intensive agricultural production and highest pollution risk, was designated as nitrate vulnerable zone (NVZ). The designation of NVZs should be revised every four years; unless not the whole territory of the country is designated as NVZ. The procedure demonstrated in this study seems to provide an effective method for assessing environmental impact from the regional perspective. It may also be used to provide a first assessment on the regional level before zooming in to focus on specific conditions such as nitrates and eutrophication, for detailed analyses.

The proper farming profile, methods, and several restrictions for the territory of NVZs should be used according to the crop, weather and soil conditions (Jansons, 1999). Therefore, the first version of the Code of Good Agricultural Practice (Busmanis et al., 1999) was prepared by the scientists of LLU under a joint Danish–Latvian Project coordinated by P. Bušmanis.

Pollution risk is an unavoidable element of our everyday activities, and it is also unavoidable in agricultural sector (Dzalbe et al., 2005; Jansons et al., 2007; Berzina et al., 2008). There is always a degree of uncertainty about the type, e.g., soil loss, nitrogen and phosphorus concentrations (Berzina et al., 2007), and the extent of adverse impacts which could arise. The probability analysis that is a common method in hydrologic studies could be used to describe the water quality, e.g., the likelihood of an event where an event is defined as occurrence of a specified value of the random variable (Jansons et al., 2009). The assessment of long time data series (1994-2007), obtained from the non-point source agricultural run-off monitoring programme, has shown that nitrate nitrogen concentrations depend on the scale of monitoring system (drainage plot, drainage field, small catchment) and intensity of agricultural production system. The available long-term data series and use of the probability curves allow the assessment of the variations of nitrate concentration on the scale of the plot, drainage field, and small catchments. Jansons et al. (2009) presented the estimation of risk exceeding the threshold limits (11.3 mg L^{-1} NO_3-N) of the nitrates concentrations. High risk to reach nitrates concentrations over the limits has been found (about 30% of samples) in field drainage of the Bērze monitoring site (Fig. 6). With regard to the small catchments' scale nitrates concentrations over limits could be expected (15% of samples) in the Bērze catchment with high intensity of agriculture.

The highest risk to reach nitrates concentrations over the limits was reported by Sudārs et al. (2005) in Bauska pig farm point source monitoring point. About 77% of water samples in the drainage channel from 50 ha slurry utilisation field have nitrates concentrations over limits during the period of 1995-2003.

To some degree the presented study and interpretation of nitrate data may be used for designation of water quality standards and designation of nitrate vulnerable zones.

Water Quality Standards for the Agricultural Run-off

For the EU Member States, the overall aim of the Water Framework Directive (WFD) is to achieve "good ecological status" and "good surface water chemical status" in all water bodies by 2015. Lagzdiņš et al. (2007a, 2007b, 2008) summarised the data of water quality that was collected monthly over twelve years (1994-2006) in Latvia agricultural monitoring sites. All available total nitrogen (N_{tot}) and total phosphorous (P_{tot}) concentration data were analysed using normal distribution curves. Percentile selections of data plotted as frequency distribution were used to establish boundaries of

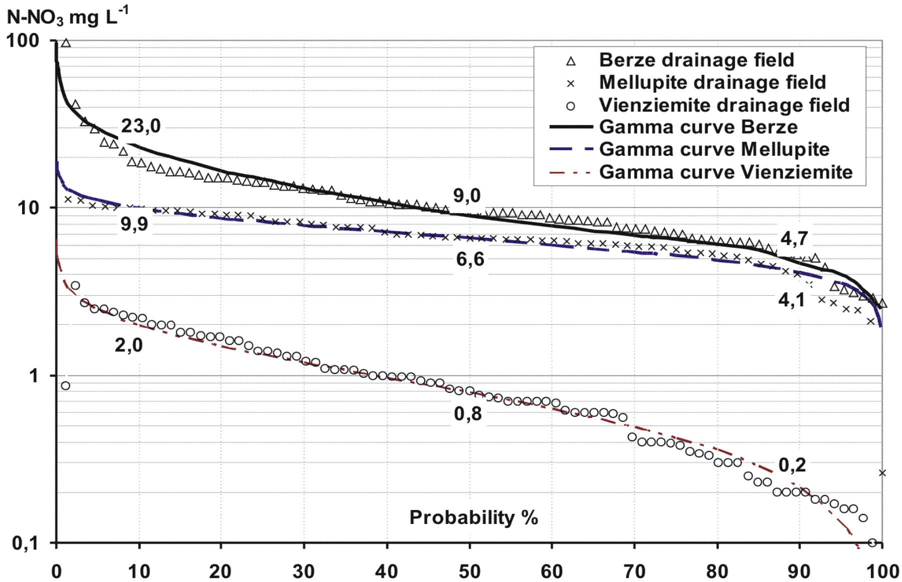

Fig. 6. Probability curves for NO_3-N winter concentration in the drainage field run-off.

Table 2

Recommendations for water quality (N_{tot} and P_{tot}) standards in agricultural areas

Quality	N_{tot} (mg L^{-1})		P_{tot} (mg L^{-1})	
	field drainage run-off	channel and main drain run-off	field drainage run-off	channel and main drain run-off
High	<4.5	<1.5	<0.015	<0.025
Good	4.5-5.5	1.5-2.5	0.015-0.020	0.025-0.050
Moderate	5.5-10.0	2.5-7.5	0.020-0.075	0.050-0.150
Poor	10.0-12.0	7.5-10.5	0.075-0.135	0.150-0.250
Bad	>12.0	>10.5	>0.135	>0.250

water quality standards. The research showed that in small agricultural streams good chemical status represents concentrations of <2.5 mg N_{tot} L^{-1} and <0.05 mg P_{tot} L^{-1}, but in the drainage system water – <5.5 mg N_{tot} L^{-1} and <0.02 mg P_{tot} L^{-1}. The paper (Lagzdins et al., 2008) also deals with the surface water quality assessment and recommendations for the classification system based on nutrients concentrations (Table 2).

From monitoring to the discharge and water quality modelling

Due to the costs and practical aspects, it is not possible to measure the complete load of nutrients from agriculture. The spatial and temporal variability in loads can be very large due to natural conditions and differences in agricultural practices. Thus, the practical approach is to monitor in pilot areas supposed to represent typical conditions with regard to climate, soils, crops, and management practices. However, from the viewpoint of the marine environment and the regional drainage basin level management it is a prerequisite to know the total loads from agricultural activities. Specific tools (models) are therefore used to up-scale the monitoring results from pilot areas (drainage fields, small catchments) to the river basin (regional) level, and for this reason modelling and monitoring are integrated parts in the future management schemes of non-point sources in agriculture.

Hydrological models are an important part of water quality modelling. In many cases, these models are integrated into water quality models. In the 1990s, the development of hydrological models was started by A. Zīverts in LLU. The Professor has participated in one of the world's largest projects within hydrometeorology – BALTEX since 1995. Several versions of conceptual mathematical model METQ for modelling of hydrological processes (METQ96, METQ98, METQ2007BDOPT) were calibrated and tested during the period of 1996-2007. Description of the hydrological processes of METQ is similar to the HBV-type watershed simulation model developed in SMHI (Sweden). The METQ model allows simulating the daily run-off regime as well as actual evapotranspiration, water storage in different soil layers, groundwater table dynamics, and other elements of water balance (Ziverts, Jauja, 1999). The METQ was tested for the application in the river basins with various sizes, including the large scale river basins like the Daugava river (Jauja, 1999). Moreover, METQ was used for discharge modelling medium size rivers (Apsite et al., 2008) and agricultural monitoring points in small catchments and drainage fields, where the measurement structures are not constructed.

Complex watershed models can be extremely powerful tools to assist in the development, and implementation of practical water quality management strategies in agriculture. Water quality simulation and modelling for that purpose so far is not developed in Latvia. Therefore, the Fyris model developed in Swedish University of Agricultural Sciences (SLU) was selected for simulation of the water quality. The cooperation between the Department and SLU continued in the Baltic Sea Regional project (2004-2007). Furthermore, a comprehensive training and upgrading of the modelling competence is considered a significant contribution to the capacity building in management of agricultural pollution. Therefore, experience and BSRP created additional research capacities of the research team of the Department that had very positive future development in the field of modelling: the National Research Project (NRP): Climate Change Impact on Water Environment in Latvia (2006-2009). The Department is responsible for work package – WP2 Climate Change Impact on the Nutrient Run-off from Drainage Basin[1]. Implementation of the research results will develop capacities for water quality modelling, where progress in Latvia has been too slow. The Fyris model was validated for water quality assessment in the Bērze river. This modelling activity has established an empirical link between water quality and load measurements on the field and small catchment level (the Bērze monitoring station), and medium sized river level (the Bērze river). The assessment of the Fyris model performance and the applicability of the models supported implementation of the required activities of WFD and could be used for the evaluation of Latvia share of nutrient load in pollution of the Baltic Sea. Use of the regional climate change data with the calibrated modelling tools in the next phase of NRP will provide scientific evaluation of climate change impact on the surface water quality. The water quality sampling programme started in 2005 provided data for the first attempts of simulation for the Bērze river and 15 sub-catchments of the river. The results of modelling for sub-catchment 12 are shown in Figure 7. The results of the Fyris model calibration showed a good coincidence (r=0.79) between the simulated and the measured nitrogen concentrations for the calibration period of 2000-2008. It is necessary to take into account that water quality samples were collected on the event basis by Latvia Agency of Hydrometeorology (2000-2004), but since 2005 on a monthly basis by the Department.

Taking into account variation of weather conditions, successful modelling approaches in future will depend on the availability of long-time data series of water quality for the river and sub-catchments. The experience from other sites suggests that longer data series and data runs than that gathered here would be required to improve the results of modelling. Therefore water sampling should be continued.

[1] See: http://kalme.daba.lv/en/wp2/

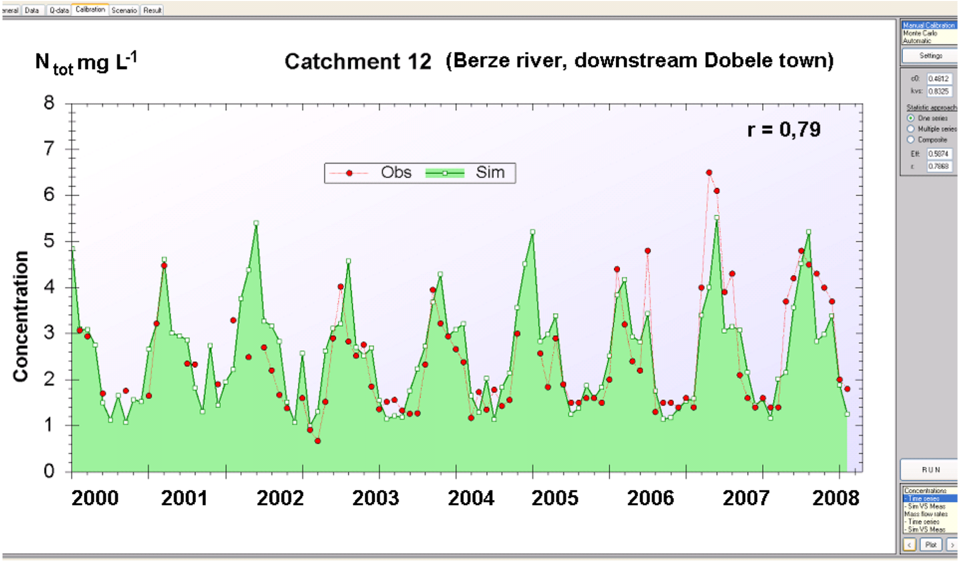

Fig. 7. Measured and simulated nitrogen concentrations in the Bērze river.

Summary and Conclusions

Agricultural and environmental problems have to be analysed on a different scale, taking into account the natural and anthropogenic impacts. The examples discussed here illustrate how the theory, research and practice of agro environmental studies, in contact with other disciplines such as ecology, hydrogeology, soil science, GIS, and mathematical modelling, address the most urgent water pollution problems currently faced by the society in the Baltic Sea basin.

Environmental conditions, such as weather, soil type and fertility, soil moisture, and the stochastic variability of these conditions, in turn, influence non-point sources nutrient losses. The issue of interactions between natural variability (soil, hydrology) and human impacts on different scales is very complex and requires further investigations.

An important finding of the research is that water quality standards for drainage water as well as for small catchments with intensive agriculture should be less stringent than for rivers, otherwise it will not be possible to fulfil the objectives set by the WFD in agricultural areas.

A further recommendation is that modelling should be a key component of the catchment management systems. This technique allows the assessment of management actions that are difficult to quantify through environmental monitoring; linking the catchment-scale evaluation of pollution sources with the effects of management changes implemented on the farm scale.

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