Risks versus Costs: A New Approach for Assessment of Diffuse Water Pollution Abatement

Master of Science Thesis

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Abstract

Complex problems require innovative methods to deal with them. Diffuse pollution, which is a primary reason for deterioration of many surface and groundwater bodies, has yet to obtain a reliable solution. This work is designated to be a part of such solution, which is to provide a valuable approach to manage inland surface water diffuse pollution problem. It is especially designed for decision makers responsible for implementation of Water Framework Directive. The key aspects of this approach are the integrating Environmental Risk Assessment and Cost-Effectiveness Assessment, which is a part of the framework used to evaluate diffuse pollution abatement measures. An extensive literature review has been made to examine integration possibilities in a wider perspective. Accomplishing this objective four separate topics were evaluated: review of watershed modeling approaches, Environmental Risk Assessment and Cost-Effectiveness Assessment in diffuse pollution problem solution, review of Lithuanian and European legislation on controlling the inland surface water diffuse pollution, inland water diffuse pollution abatement measures. Knowledge obtained from literature has been used to set a modeling part essential to demonstrate application of the integration method. SWAT model has been selected as the assessment tool to analyze diffuse pollution abatement measures for Graisupis river catchment, located in middle Lithuania. Two abatement measures (wetlands and winter crops) have been selected and evaluated. Finally, a risk reduction of not meeting environmental targets from the baseline scenario has been calculated and plotted against cost of each abatement measure. This is a simple way of providing valuable information needed for investments in abatement and uncertainties related to it, which are particularly important for decision makers working with diffuse pollution problems.

Key words: diffuse pollution, surface water, environmental risk assessment, cost effectiveness assessment, watershed modeling, SWAT, Water Framework Directive, abatement measures, Lithuania.

List of Abbreviations

BASINS – Better Assessment Science Integrating Point and Non-point Sources

BAT – Best Available Techniques

BMP – Best Management Practices

BOD_7 – Biochemical Oxygen Demand for 7 days

BSAP – Baltic Sea Action Plan

BEP – Best Environmental Practice

CAP – Common Agricultural Policy

CEA – Cost-Effectiveness Analysis

CER – Cost-Effectiveness Ratio

COD – Chemical Oxygen Demand

DEM – Digital Elevation Model

DHI – Danish Hydraulic Institute

DSS – Decision Support Systems

EIS – Environmental Information Systems

ERA – Environmental Risk Assessment

ERM – Environmental Risk Management

ESRI – Economic and Social Research Institute

EU – European Union

FAO – Food and Agriculture Organization

GRASS – Geographic Resources Analysis Support System

GIS – Geographical Information Systems

HRU – Hydrological Response Unit

HSPF – Hydrological Simulation Program – Fortran

HWSD – Harmonized World Soil Database

IMS – Integrated Modeling Systems

IPM – Integrated Pest Management

LEPA – Lithuanian Environmental Protection Agency

MC – Monte Carlo

MS – Member State

NGO – Non Governmental Organization

NPS – Non-point Sources

RBMP – River Basin Management Plans

SHE – Systeme Hydrologique European

SWAT – Soil and Water Assessment Tool

TMDL – Total Maximum Daily Loads

UA – Uncertainty Assessment

USDA – United States Department of Agriculture

US EPA – United States Environment Protection Agency

USGS – United States Geological Survey

WARMF – Watershed Analysis Risk Management Framework

WFD – Water Framework Directive

WMI – Water Management Institute

WMT – Watershed Modeling Tools

WMS – Watershed Modeling Systems

WQ – Water Quality

WWTP – Waste Water Treatment Plant

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Preface

Much attention is being focused on the global warming issue today like it seems no other environmental problems exists. However, when taking a closer look, it can be noticed that deterioration of local environment caused by years of mismanagement in many places created much more painful wounds. Ecosystems, which give nothing for high standing politicians and everything to local communities, are mostly vulnerable. Today's science and technology makes it incredibly easy to destroy them. However, restoration to previous state even with an input of enormous efforts is rarely possible. Therefore consideration of consequences should be performed in advance for every step we make, otherwise attempts to create good will be bringing more harm.

When I was a child. I loved listening my granny's stories about the past. Stories about rivers and lakes full of life, clean water, natural flows, beautiful valleys, animals and birds around were the most fascinating for me. All this was reality just 50 years ago. Since then massive melioration and agricultural intensification plans have been implemented, which have led to the destruction of all these beautiful stories. No more small streams, no more beautiful valleys, no more clean lakes and no more life. As a child I was questioning why those people could not think before destroying everything? My hope is that my children will not have to come with such questions. Hopefully this work will contribute to bring little bit more joy for new generations.

1 Introduction

An inland surface water quality is essential for the health of water ecosystems such as rivers, lakes, lagoons, seas, and even oceans. It is essential for human health and quality of life, as drinking water supplies, agriculture, recreational values of environment, fishing business are dependent on it. This has been recognized all around the world and many initiatives have been proposed on the side of the governments and international organizations to ensure quality of surface waters. Examples of them are: Clean Water Act (United States of America) and European Water Framework Directive (WFD). These legislations attempt to address many water quality deterioration problems. One of these problems, water diffuse pollution, is particularly troubling since past failures to deal with it and the scale of this problem being so enormous that it place desired improvement of water quality beyond the grasp of even the most developed and environmentally focused nations. It is especially clearly seen in the developed part of the world where solution for point source pollution is under way. The installation of “end of pipe” solutions are required through “command and control” policies, as well as financially supported by many governments. Those measures have been successful in reducing point source pollution. Diffuse pollution on the contrary is difficult to locate and nearly impossible to abate with any single measure. Therefore different innovative approaches must be tried to obtain area and problem specific solutions. Those approaches should encompass as much crucial information as possible without over flooding decision makers with unnecessary information.

One of possible approaches is an integration of Ecological Risk Assessment (ERA) with Cost-Effectiveness Assessment (CEA) in the analysis of diffuse pollution problem. These tools are especially valuable since they would provide honest information about uncertainties related to planned decisions and their costs. Addressing uncertainties or risk of failures to meet certain criteria, is what the most diffuse pollution assessment methods are missing now. An estimation of reduction made by diffuse pollution abatement measures in tons of nitrogen or phosphorus with point precision is not only too simple, but also dishonest way to analyze diffuse pollution. Firstly, it misses all information about stochastic processes happening in nature, which are the driving forces behind diffuse pollution. Secondly, it provides decision makers with one value giving no account how likely this value is and what could expected variation bounds be. Therefore integration of ERA and CEA is the key to improve decision making with regard to diffuse pollution abatement.

In Europe diffuse pollution problem gets more attention since introduction of Nitrate and Water Framework Directives. Especially Water Framework Directive sets high aims for surface and ground water quality, which are impossible to reach without solving diffuse pollution problems. It would be particularly hard for Eastern Europe countries such as Lithuania, because they have less experience in dealing with complex environmental problems. The context of Lithuania has been selected for this study to assess ERA and CEA integration possibilities. This selection was based on the need of such tools in Lithuania, as well as on authors ability to access most of necessary information sources.

A major factor influencing quality of Lithuanian surface water bodies is diffuse pollution. For instance in Nemunas river basins[1] it is responsible for 99,4 % of water bodies at risk[2] with regard to nitrates, for 57,7 % according to BOD_7, 55.1 % according to total phosphorus comparing to point source pollution (Center of Environmental Policy 2008). Overall just 6 % of water bodies are in the risk group because of point pollution alone[3], while diffuse pollution alone is responsible for 40 % of water bodies at risk in Nemunas river basin (Center of Environmental Policy, 2008). Therefore solutions or tools for solving diffuse pollution are crucial for Lithuania. Yet this is the case for many other countries as well. Principle demonstrated here could be easily used in other areas of European Union and outside .

1 This river basin occupies 72 % of Lithuanian territory.

2 Water bodies at risk are such water bodies, where analysis shows that there is a likelihood for water body will fail to meet “good” water status stated in Water Framework Directive by year 2015.

3 Point and diffuse are not the only factors influencing water bodies inclusion in risk group. Others are morphological changes, hydroelectric plants, trans-boundary pollution or any combination of previously mentioned.

2 Goal, objectives and scope/delimitations

2.1 Goal

The main goal of this study is to assess the necessity and relevance of integrating Environmental Risk Assessment and Cost Effectiveness Assessment for inland surface water diffuse pollution management related to Lithuanian context.

2.2 Objectives

In order to reach the goal of study two broad objectives were raised. The first is perform the analysis of literature related to the usefulness, feasibility of and essential tools for integration of Environmental Risk Assessment and Cost Effectiveness Assessment in the analysis inland surface water diffuse pollution abatement options. The second is to demonstrate integration example on a small river catchment in Lithuania territory by applying a selected watershed model.

2.3 Scope/Delimitations

This study was designed to provide an overview on integration possibilities of Environmental Risk Assessment and Cost Effectiveness Assessment in inland surface water diffuse pollution management than rather detailed discussion of complicated tools existing in those fields. Therefore much of specific methods to assess, for instance, environmental uncertainties or risks, were left without detailed presentation. The literature review is based on four different themes, leaving other questions, related to studied subject not discussed. Themes reviewed are watershed modeling approaches, Environmental Risk Assessment framework and Cost Effectiveness Assessment in diffuse pollution problem solution, Lithuanian and European legislation on controlling the inland surface water diffuse pollution, inland water diffuse pollution abatement measures.

The demonstration of the integration example has been built by applying watershed modeling. Graisupis river catchment located in the middle of Lithuania was chosen to be an area for carrying out the assessment. Two measures (wetlands and winter crops) were used to assess the diffuse pollution abatement. However, since modeling results have been intended to serve as demonstration example rather than real life case, the preparation of complicated watershed model has been simplified. Data inputs and calibration were designed to be sufficient to run the model, but not enough for results to be reliable, while validation procedure has been left out. One of the main reasons for such simplifications is that preparation of necessary watershed model according to standards of hydrological modeling could take (normally) not less than half a year. Other simplification was that only effects of abatement measures on nitrate concentration were examined. This simplification was based on observed data from the Graisupis river catchment area, which indicates that nitrates are the most troubling parameter. Simplifications were necessary to keep project within time boundaries given for a master's thesis. Overall this work is considered to be a preparation step before applying the integration approach on a real river basin management case.

3 Method

The flow of activities performed for this work is presented in the Figure 1. It has combined quite extensive literature review with a practical demonstration part (method application). Literature review has been made on four different topics. Those topic are watershed modeling approaches, Environmental Risk Assessment framework and Cost Effectiveness Assessment in diffuse pollution problem solution, Lithuanian and European legislation for controlling inland surface water diffuse pollution, inland water diffuse pollution abatement measures. Each of those topics had particular purpose as an input to the practical part. Evaluation of watershed modeling tools was necessary for selecting the best tool for diffuse pollution modeling. Researching into ERA and CEA integration examples was important to understand what is already done on this subject and also how it is done. Review on legislation was essential to know what requirements from decision makers are and also what kind of results would benefit the most to decision making. Review on the abatement measures was necessary to overview existing possibilities for diffuse pollution abatement and to select measures to examine in the practical part. It was critical to make research on these topics before starting the practical part, since knowledge obtained gave a clearer picture on what should be done in the practical part.

The most essential steps for the practical part were data collection, preparation of watershed model, modeling scenarios, integrating environmental risks with costs and evaluation of results. Data has been collected mainly from Lithuanian Environmental Protection Agency (LEPA) based on data requirements for selected watershed model. Costs on abatement measures have been obtained from LEPA as well. A substantial amount of time has been spent on getting familiar with the model and learning how to use it. Model preparation was a crucial step. This includes that all collected data had to be transformed into right formats. Also many parameters must have been calculated from raw data. Model calibration was necessary since initial results were far from satisfactory. Since calibration is very time consuming procedure, mainly water flow has been calibrated. Selection of scenarios has been made taking in regard information from literature review, area specifics, model capability and also available data within LEPA. Two selected measures have been evaluated in comparison to a baseline scenario. Also a long period of simulation with stochastic variation in climatic variables have been used for obtaining environmental risks. Obtained results were put on the graph against the costs of each abatement measure option and results evaluated. The practical part provided insight to usefulness and possibilities for ERA and CEA integration in inland surface water diffuse pollution management.

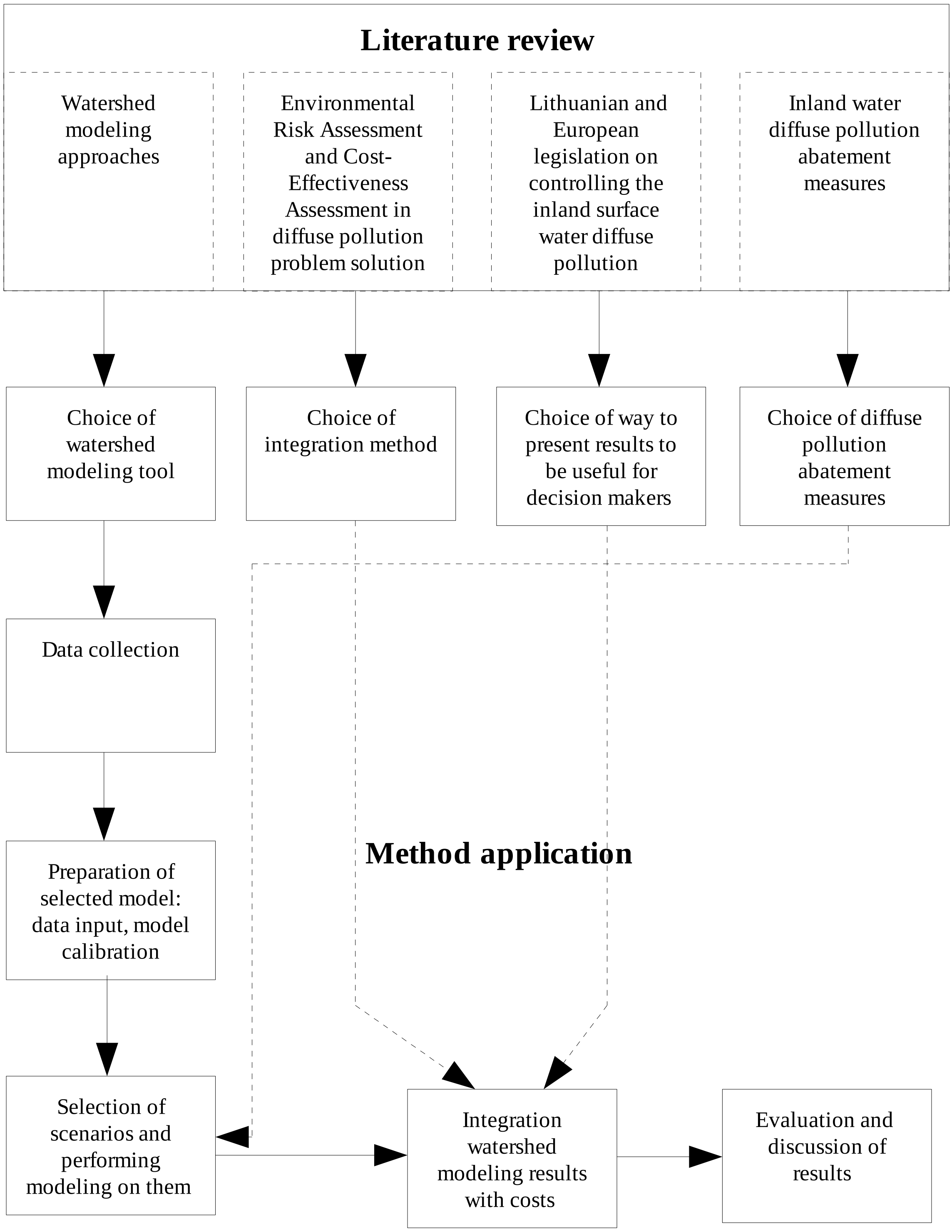

Figure 1: Work flow of master thesis.

4 Literature review

For literature review four different themes have been selected. Research in them is important for seeing implications, possibilities and methods for ERA and CEA integration for selection of inland surface water diffuse pollution abatement measures from wider perspective. Those selected themes are: watershed modeling approaches, ERA and CEA in diffuse pollution problem solution, Lithuanian and European legislation on controlling inland surface water diffuse pollution, inland water diffuse pollution abatement measures.

4.1 Review of watershed modeling approaches

Water quality in watersheds does not only indicate comfort for fish or aquatic life, but it is an indicator of environmental health (Singh & Frevert 2006). Thus it represents quality of our environment and state of natural resources, which we use. Diffuse pollution in many places is the major factor causing deterioration of water quality (Salvetti et al. 2008; Nasr et al. 2007). Yet it is the most cumbersome to deal with, since it is hard to localize. It is widely recognized that new challenges in water management are mainly linked to non-point source pollution (Even et al. 2007). Because of complexity of diffuse pollution phenomenon only two methods exists for tracking fate of chemicals and evaluation of effectiveness of abatement measures for non-point pollution (Ritter & Shirmohammadi 2001). It is field monitoring and computer modeling (Ritter & Shirmohammadi 2001). Models is the only option when required information cannot be measured (Benjamin & Belluck 2001). It is often the case, because of budget constrains, insufficient time, unavailable technologies, lack of human resources, etc (Davenport 2003).

Models generally defined as “the physical or mathematical representation of a physical system” (Davenport 2003). Yet for most people this term probably could be represented by “black box” concept (Ritter & Shirmohammadi 2001). Nevertheless models are accepted as producers of “objective” criteria, which is required for decision making (Even et al. 2007). Generally models are used to answer “what if” questions (Davenport 2003). In recent years their use in watershed management have been heavily expanding (Davenport 2003). They have been used for evaluation of loadings of agricultural chemicals to surface and groundwater, effectiveness of different pollution reduction measures, impact of climatic variables on pollution loads and water quality, for improvement of monitoring system, identification of critical areas, etc (Ritter & Shirmohammadi 2001).

Despite the fact that models are the last option (other being monitoring) it does not necessary means the worst. Recent developments in the sphere of watershed modeling tools (WMTs) shows their great potential for creation of modeling systems essential for integrated watershed management (Rousseau et al. 2005). Review of watershed modeling approaches is vital step for gaining knowledge about current developments in hydroinformatics, capabilities of watershed modeling systems and future directions. Moreover this knowledge is necessary for selection of an appropriate models, what is crucial step for success of application of watershed modeling systems (WMS)(Grizzetti 2005). According to Benjamin & Belluck (2001) “the art of the model usage lies in the selection of appropriate model to reflect the needed level of detail for use in a specific application”. Therefore great effort has been spend in this project to research current state-of-art in WMTs.

4.1.1 Framework to Decision Support Systems

Development of WMTs has been driven by the intention to provide information through a Decision Support Systems (DSS)[4] (Rousseau et al. 2005). Many watershed managers are turning toward DSS to assist in decision making with ever increasing complexity of issues. Besides providing deeper understanding on complex processes occurring in river systems, models are creating missing knowledge, necessary for decisions where there are no other means for creating it (Even et al. 2007). These are primary reasons why models are so valued in watershed management and incorporated into DSS.

According to Rousseau et al. (2005) DSS for integrated watershed management could be divided into two categories: Environmental Information Systems (EIS)[5] and Integrated Modeling Systems (IMS). While EIS mostly employ Geographical Information Systems (GIS) and Relational Database Management Systems (RDBMS), IMS beside those are heavily dependent on mathematical models. Recent DSS for integrated watershed management usually links GIS with Water Quality (WQ) models and with graphical, statistical, qualitative analysis tools (Ritter & Shirmohammadi 2001). Most of today's advanced WMTs could be categorized as IMS-based DSS. Development of tools under this category currently is going at a rapid tempo linking watershed models between themselves and with other technologies. For instance, some advanced DSS use Artificial Intelligence (AI) technique for selection of most appropriate watershed management strategies and best pollution reduction measures (Ritter & Shirmohammadi 2001). Internet technologies make DSS accessible to watershed managers everywhere. Development of integration of watershed models into DSS is of particular importance for improvement of decision making.

4.1.2 Types of watershed models

There are many different ways to categorize watershed models. That could be done by dividing them according to the method, which was used to set up model, spatial discretization, purpose of model, output, etc. Probably the most used categorizations are into empirical and theoretical, or physically-based models, but also lumped and distributed parameter models. Development of empirical models are done employing statistical relationships (obtained during regression analysis) between analyzed parameters and watershed characteristics (Breuer et al. 2008). Empirical models could only be trusted when applied on the same kind of conditions under which they have been developed. For instance, application of empirical model developed using one site data to other site could cause a significant error in predictions (Ritter & Shirmohammadi 2001). Application of empirical model on different site is impossible without performing calibration. Thus monitoring data is essential. On the other side are theoretical or physically-based models. These kind of models are developed by employing certain physical laws, which are driving forces behind the behavior of the real system (Ritter & Shirmohammadi 2001). These models have wider application area and give better understanding about processes occurring in watersheds (Singh & Frevert 2006). It is claimed, that theoretical or physically-based models could be used even without calibration and that these models could estimate water quality or discharge from ungauged basins (Ewen et al. 2000). Yet these claims are often criticized as results provided are rarely more accurate than obtained with empirical one (Ritter & Shirmohammadi 2001). Many watershed models are something in the middle, because they employ some empirical relationship as well as theoretical understanding of

4 The term of DSS refers to “an interactive computerized system that gathers and presents data from a wide range of sources” (Webopedia 2008).

5 EIS are computer systems that use a variety of tools and technologies to facilitate the interpretation of environment-related information (ESSA 2008).

processes. Some authors calls such models process-based (Singh & Frevert 2006), others semi-empirical (Ritter & Shirmohammadi 2001).

According to the spatial representation, watershed models could be divided into two categories: lumped and distributed parameter models. Lumped parameter models are usually associated with empirical models. Lumped parameter means that watershed is described by one set of parameters, which represents average conditions in the basin. These type of models require calibration for each modeled basin (Ritter & Shirmohammadi 2001). Lumped parameter models are more common. In distributed parameters watershed models are divided into subunits (grid cell or other types), where for simulation purposes conditions are assumed the same inside each subunit (Singh & Frevert 2006). Therefore parameter sets are only homogeneous for subunit, however values varies between subunits (Ritter & Shirmohammadi 2001). Lumped parameter models require less data as well as less computational resources for simulation, however it could miss important dynamic fluctuations and spatial differences of environmental characteristics thus providing erroneous information from simulation. On the other hand distributed parameter models, by correcting drawbacks of lumped parameter models, run into problems of computer space storage and computational resource need as well as requirement for site specific detailed information to run simulations (Ritter & Shirmohammadi 2001). Therefore many models encompass some characteristic of both types of watershed models. These are called semi-distributed models. In those models watersheds are divided into subunits according to some unified characteristic, which are obtained by overlaying some characteristics existing in a watershed. For instance hydrological response units (HRU) used within Soil and Water Assessment Tool (SWAT) model “corresponds to a particular combination of soil and land use within sub-basin” (Grizzetti et al. 2005).

Other type of spatial discretization could be according the number of dimension calculations are performed. Great majority of today's watershed models are one dimensional models and rivers are represented as lines. However, some watershed models might integrate river channel models and in this way perform simulations in two or tree dimensions (Shoemaker et al. 2005). Generally discretization of watershed is of particular importance for capabilities of modeling systems and requirements of input data. Some authors (Breuer et al. 2008) name spatial discretization as the single most important factor influencing model complexity.

Another classification is based on temporal scale of computations. According to it, models could be event-based or continuous. Event-based requires small time steps for simulation (in order of seconds) and are used for simulation of storm events and changes in water quality during them (Singh & Frevert 2006). These kind of models require more site specific and meteorological data. For continuous models daily time step is the smallest temporal unit (Ritter & Shirmohammadi 2001). Most WMTs are the later type.

Other quite important watershed model classification is related to predictions that models could give. These predictions could be deterministic or probabilistic (Ritter & Shirmohammadi 2001). Therefore models are categorized into deterministic and probabilistic categories. Deterministic predictions gives only one value for set of certain conditions for each modeled variable, whereas probabilistic gives a certain possible range for variable values with probabilities of those values. While probabilistic model could better encompass uncertainties related with incomplete understanding of natural phenomena and variations in nature, both types of models have their strengths and weaknesses. Deterministic watershed models are dominant in hydroinformatics. Their results are easier to interpret, less data is needed to run model as well as less computational capability. Moreover discrepancies, which are left after model calibration and validation/verification, gives good indication where there is lack of understanding for natural phenomena (Even et al. 2007). Probabilistic or stochastic models are far more honest about existing uncertainties comparing to deterministic models, however because of harder interpretation and inconsistency of the developed models (Even et al. 2007) at this moment they are rarely used. Nevertheless in some cases deterministic models are utilized in probabilistic manner by incorporating Monte Carlo simulations into them (Ritter & Shirmohammadi 2001).

Purpose of a model could influence model characteristics. Therefore models are divided into categories according the purpose they are designed for. For instance some authors watershed models divide into research and management models (Ritter & Shirmohammadi 2001), others into screening, planning, design and operational categories (Davenport 2003). Research models usually are designed to develop the state-of-the-art technologies used in watershed modeling, while management models are more simple and needed to provide guidance in decision making. Research models are usually more complicated, deterministic and including many detail processes. However, recent efforts in the watershed model development are turning to make research models more usable for management purposes (Ritter & Shirmohammadi 2001). Screening models are essential for providing initial estimates. They are usually quite simple. Planning is used for assessment of watershed management strategies. Design for simulation of individual event and operational for assisting in management during actual events (such as rain).

In general models could be divided according to their complexity. Some authors (Benjamin & Belluck 2001) uses two categories for this division: screening and complex models. Others (Davenport 2003) use three: overview, mid-range, detailed. All these classifications are based on idea, that on the one side there are simple, rough models, which are demanding less data and easier to master, however because of this simplification consideration of many important natural processes is lost and models are not able realistically analyze many management strategies. On the other side are detailed models, which can analyze most management strategies in details, yet time and resources to manage those models, data requirements make them quite often impossible to use. Discussed watershed model division into categories is presented in the Table 1.

Table 1: Division of watershed models into categories according different criteria.

	Theoretical basis	Spatial complexity	Dimension	Temporal capability	Output	Purpose	Complexity
Watershed model	Empirical	Lumped	1- dimension	Continuous	Deterministic	Management	Overview
	Semi-empirical	Semi-distributed	2-dimensions				Mid-range
	Physically based	Distributed	3-dimensions	Event-based	Stochastic (or Probabilistic)	Research	Detailed

Besides distinction could be made between environment WQ models that focus on physical-chemical processes in watershed, and economical WQ model, which focus on abatement measures costs. (Davenport 2003). This chapter is focused on environmental watershed WQ models, with particular emphasis on mesoscale[6] models. Nevertheless it is important to present economical WQ models, since obtaining meaningful results for management requires integration of environmental models with economical (and other types as well). Different kinds of integration in more details will be discussed in the following section.

Finally, it is important to note that no single best model exists for all circumstances (Breauer et al. 2008). Every situation and every problem requires different type of characteristics from WMTs. Therefore it is important to understand problem composition and what type of solution is required in order to select model correctly. This knowledge is the first important step towards successful application of WMTs in watershed management.

6 “Mesoscale catchments sizes span up to fours magnitudes, ranging from 10^1 up to 10^4 km^2.”(Breuer 2008)

4.1.3 Integration with other models and GIS

Single WQ model usually have quite limited sphere of application. Therefore to overcome this disadvantage WQ models are often integrated with other models. Other models could be hydrological, other WQ, ecological or economical. Moreover, good watershed model is hardly imaginable without some kind of integration with GIS as well. In general coupling different types of models, as well as coupling those models with other systems opens new horizons and provides opportunities to use interdisciplinary approach and solve problems in a holistic atmosphere. No wonder why this technique is becoming more and more popular. It is called integrated modeling. Gaiser et al. (2008) state “integrated modeling is a novel approach to couple knowledge and models from different disciplines and research fields”.

Coupling could be also categorized is certain categories. For instance, it could be soft and rigid. By soft it is meant that only data would be exchanged and by rigid that modeling system would be integrated (Gaiser et al. 2008). In reality many watershed models employ some kind of coupling. For instance SWAT and MIKE SHE watershed models analyze water quality issues by coupling internal, which were developed for particular model, and external, which were developed separately, WQ models (Horn et al. 2004). Yet there are other examples, where many models from different disciplines have been integrated into modeling system to provide answers to all types of management questions. For instance, in Germany MOSDEW model developed, that integrates a cascade of nine different type of sub-models starting from hydraulic, WQ, to ecological and economical (Gaiser et al. 2008). However, even though coupling of different types of models provides great benefits, application of it could still be restricted by models run time (Breuer et al. 2008).

GIS coupling with WMTs are another powerful enhancements, which many nowadays leading (especially distributive parameters) WMTs are equipped with. Reason for this is that for input models require extensive datasets, which are very hard to prepare without appropriate data management tools (Ritter & Shirmohammadi 2001). Moreover, results are easier to interpret and analyze if GIS is used for it. Davenport (2003) names quicker access to information, improved decision-making capabilities, increased public awareness and acceptance among benefits, which could be obtained by coupling WMTs and GIS. Four levels of GIS – watershed model linkages have been suggested by the Ritter & Shirmohammadi (2001): no direct linkage, non-graphical file-transfer interfaces, Graphical User Interfaces (GUI), and integration of the model inside the GIS.

Two most popular GIS softwares used for coupling with WMTs are Geographic Resources Analysis Support System (GRASS) developed by the U.S. Army Crops of Engineers and ARC/INFO developed by the Economic and Social Research Institute (ESRI)(Davenport 2003). GRASS is an open source GIS software, which have been used more for raster data analysis and is more common in distributed parameters watershed models (GRASS GIS 2008). However, it's current developments encompass great variety of tools for vector analysis as well. ARC/INFO is predominant GIS software today, which is commercially supported (Davenport 2003). From other examples Map Window could be mentioned. It has been developed by the Map Window Open Source Team (US EPAa 2008) and has been adopted by the United States Environmental Protection Agency (US EPA) for Better Assessment Science Integrating Point and Non-point Sources (BASINS) software system, which integrates such watershed models as SWAT, Hydrological Simulation Program - Fortran (HSPF), Watershed Analysis Risk Management Framework (WARMF)(US EPAa 2008).

Most common problems related to coupling WMTs and GIS are related to compatibility of two systems. Since watershed models and GIS softwares are usually developed separately and are maintained by different bodies, integration with any new update of any party should be checked (which would be quite extensive work) and problems corrected again and again (Ritter & Shirmohammadi 2001). Moreover, if watershed model integrates into commercial GIS software (most common ARC/INFO) additional funds have to be allocated for obtaining and maintaining commercial GIS software licenses. There is a general tendency for commercial watershed models to be coupled with commercially distributed GIS software systems.

4.1.4 Criteria for watershed model selection for detail analysis

There is a great number of modeling tools used for water problems assessment. To review such quantity in detail would be hardly possible, besides, it is not the purpose of this project. Thus according to certain criteria WMTs were selected for more detail analysis. Selection of those modeling tools is based on following criteria: model should perform simulations in spatial and temporal dimensions, also it should be capable to model the main WQ parameters such as nitrogen, phosphorus, Biochemical Oxygen Demand (BOD) and others, which represents organic pollution, sediments, bacteria. Application of this model should be spatially universal (not tied to specific location). Moreover model must be practically used for management purposes. Finally, the most important criteria, selected model should be capable of analyzing inland water diffuse pollution and effects of abatement measures. According to above stated criteria following models have been selected:

- SWAT
- HSPF
- WARMF
- MIKE SHE
- SHETRAN

4.1.5 Discussion of selected watershed models

4.1.5.1 SWAT

SWAT model nowadays is probably the most popular watershed model in use. Scientific article review showed, that SWAT model was tested and applied not only in the United States of America (USA), but also in many places around the world. This model includes great number of functions, as well as simulation of various processes. Detail presentation of them would highly increase volume of this work. Thus only major characteristics and some important facts are presented in this review. Interested reader is referred to the official SWAT site http://www.brc.tamus.edu/swat/ - there much useful information and documentation is provided.

SWAT is physically based, semi-distributed parameter, watershed scale model (Neitsch et al. 2005). It was developed and is actively supported by the USDA Agricultural Research Service (SWAT 2008). SWAT development spans over thirty years. The latest version of it is SWAT2005. Model developed to "predict the impact of land management practices of water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time" (Neitsch et al. 2005). Development focus of this model was to support watershed scale assessments on ungauged basins (Arnold & Fohrer 2005). SWAT could give estimations for different parameters such as nitrogen, phosphorus compounds, BOD, dissolved oxygen, sediments, bacteria and agricultural pesticides (Geza & McCray 2008). In simulation of watershed processes SWAT model encompasses and considers hydrology, weather, erosion/sedimentation, soil temperature, plant growth, nutrients, pesticides, water management (Arnold & Fohrer 2005). Stream, pond and reservoirs components are considered by including different routings, sedimentation and transformation processes within water bodies, water diversions (Arnold & Fohrer 2005). Necessary input data is digital elevation model (DEM), river network, land use, agricultural practices, point sources, soil characteristics, meteorological data (precipitation, temperature), information on the pollutants of concern (Grizzetti et al. 2005; Saleh & Du 2004). SWAT model includes routines for sensitivity, uncertainty analysis and automated calibration (Arnold & Fohrer 2005). Moreover, different databases are integrated with the model (like fertilizer, weather, etc) to make SWAT application and data collection easier (Breuer et al. 2008).

The broadest spatial sub-division in SWAT could be into sub-basins. Sub-basin should have at least one hydrological response unit (HRU). HRU is a term used for SWAT model. It is defined as land parcels with unique land use, management and soil attributes (Geza & McCray 2008). Threshold values are defined for combination of soil and land use class values, which enables to designate HRUs automatically (Grizzetti 2005; Breuer 2008). Actual spatial position of HRUs within the sub-basin is not used in the model (Nasr 2007).

SWAT was coupled and interfaces were developed for both GRASS and ArcGIS (the latest integration is with ArcGIS version 9.3 (SWAT 2009)) GIS softwares (Arnold & Fohrer 2005). Coupling GIS and watershed model is important since that helps to prepare required input data for the model. GIS-watershed model system extracts model input data directly from the map layers and writes it into appropriate model input files (Arnold & Fohrer 2005). Moreover GIS-SWAT system allows to edit model input files, execute simulation, view and analyze modeling results (Arnold & Fohrer 2005). Coupling SWAT model with other WQ or different kind of models is often done to enable including or improving simulations of certain processes. Thus many different watershed simulation tools appeared with different names. Like SWAT-N, which include extended description for nitrogen cycle, SWIM, which has spatial disaggregation and nutrient modules from different model MATSALU (Breuer et al. 2008), ESWAT, which includes modified river quality accounting routines (Horn et al. 2004). Because of SWAT WMS popularity, availability (free of charge) and professionalism it is one of the main choices for integration of different WMTs.

There are few disadvantages of SWAT model. For instance Salvetti et al. (2008) states, that groundwater recharge is systematically underestimated. Barlund et al. (2007) is writing that description of nitrogen leaching from forested areas is incorrect and that efficiency of buffer strips is overestimated. Although many articles point to some type of problems connected with it, in most model comparisons and overview articles use of SWAT model is recommended and it is generally chosen over other watersheds models (Nasr et al. 2007; Saleh & Du 2004; Inamdar 2006; Geza & McCray 2008). It is also recommended for analyzing water quality issues with respect to WFD (Barlund et al. 2007; Nasr et al. 2007).

4.1.5.2 HSPF

HSPF is another quite well known watershed model. It's development history is even longer than SWAT model. It spans over forty years starting as early as 1960's with a model known as the Stanford Watershed Model (USGS 2008). This model is on the similar level as SWAT model in regard to worldwide popularity of WMTs. It was considered by some authors as the only available WMT, which have been extensively tested (Horn et al. 2004). Moreover, there is no watershed model except for HSPF, which would be able to simulate the continuous, dynamic event, or steady-state behavior of both hydrological and WQ processes in watersheds (AQUA TERRA Consultants 2008). Current version HSPF 11 was created in 1997 (US EPAb 2008).

HSPF is empirical, lumped parameter, continuous, watershed scale model (Saleh & Du 2004). It was developed with sponsorship of US EPA and was supported by the Water Resource Division USGS (United States Geological Survey) (AQUA TERRA Consultants 2008). This model perform simulations on “interception soil moisture, surface runoff, interflow, base flow, snow pack depth and water content, snow melt, evapotranspiration, ground-water recharge, dissolved oxygen, BOD, temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton,” and others, with differentiating processes on pervious and impervious surfaces, in soil profiles, within streams and well mixed impoundments (USGS 2008). HSPF model has 3 main application modules: PERLND for simulation of “runoff and water quality constituents from pervious land areas in the watershed”; IMPLND for simulation of “impervious land area runoff and water quality”; RCHRES for simulation of “the movement of runoff water and its associated water quality constituents in stream channels and mixed reservoirs” (AQUA TERRA Consultants 2008). It can perform simulation for time steps from 1 min. up to 1 day (Nasr et al. 2007). Thus model also could be regarded as event-based model, suitable to simulate storm events. In general, beside storm drainage analysis, HSPF could be used for flood control planning and operations, hydro-power studies, river basin and watershed planning, water quality planning and management, point and non-point source pollution analysis, soil erosion and sediment transport studies, evaluation of urban and agricultural best management practices, fate, transport, exposure assessment, and control of pesticides, nutrients, and toxic substances (AQUA TERRA Consultants 2008).

Spatial division of catchments in the HSPF model is based on land use (Nasr et al. 2007). Required input data for model are: meteorological data (temperature, dewpoint, wind speed, solar radiation, evapotranspiration), hydrological (reach data), soils, topological information, land use, information for pollutants (Saleh & Du 2004).

WinHSPF is the interface for accessing HSPF with BASINS (Saleh & Du 2004). Model integration with BASINS is needed to give HSPF model GIS environment benefits (spatial data preparation, etc), as well as easy access to monitoring, physiographic data (which could be downloaded directly from Internet by using BASINS program) and assessment tool functionalities what HSPF lacks (Saleh & Du 2004).

HSPF is one of the most tested, well documented and among most comprehensive watershed models. A variety of possible application areas puts this watershed model among most useful WMTs. However, many authors, which compared SWAT and HSPF models concluded that SWAT model was easier to set up, calibrate, simulate field management practices, thus more recommended to use (Saleh & Du 2004; Inamdar 2006; Nasr et al. 2007). Nevertheless suitability of particular model depends only on requirements for analysis.

4.1.5.3 WARMF

WARMF is relatively new model. It was developed by private company called Systech Engineering under support of the Electric Power Research Institute (Systech Engineering 2007). This model has different approach comparing to other WMTs. WARMF is actually more than a watershed model. It is fully functional DSS with consensus making, knowledge input modules (SYSTECH 2008). Stakeholders involvement is designed into this system by taking them through series of steps to develop and evaluate WQ management alternatives (Shoemaker et al. 2005). This model have been mostly applied in the US. Although some applications have been made in Taiwan, Korea (SYSTECH 2008). Nevertheless WARMF have been developed for application on any watershed and is also supported by extensive documentation (Chen et al. 2005). Latest version of it is 6.1.

WARMF is physically based, continuous, lumped parameter watershed model (Shoemaker et al. 2005). It's structure is based on 5 different modules (Data, Knowledge, Consensus, TMDL[7],

7 Total Maximum Daily Loads

Engineering), which are linked together under GIS-based graphical user interface (Systech Engineering 2007). Engineering module includes dynamic watershed model. Other modules are used for time series input and calibration (Data module), document storage (Knowledge module), provide guidance for stakeholder involvement (Consensus and TMDL modules)(Shoemaker et al. 2005). WARMF simulates flows, pH, temperature, nutrients, bacteria, dissolved oxygen, sediments, metals (mercury, iron, zinc, manganese, copper) periphyton in rivers, algae in stratified reservoirs (Systech Engineering 2007). Required input is meteorological data, point source loading information, atmospheric deposition loads, fertilizer application, sub-basin shape, land use and Reach Network shape files (Shoemaker et al. 2005).

WARMF is general, quite universal with multiple functionalities WMT. Beside other advantages it has linkage (or could be integrated) with BASINS as well as SWAT and HSPF models (SYSTECH 2008). Therefore data preparation and analysis of results is easier for user (at least for US territory). However, there are certain problems connected to WARMF, which were expressed by several authors. Rousseau et al. (2005) states that the main disadvantage of WARMF is lack of management module. Geza & McCray (2008) pointed to the problem of linkage absence between GIS-based soil databases and watershed model, what other models (such as SWAT and HSPF) does have and what reduces time required for data input work (Systech Engineering 2007). For setup and calibration user needs to contact Systech Engineering company. It is charged as technical support (Shoemaker et al. 2005).

4.1.5.4 MIKE SHE

MIKE SHE is developed by the Danish Hydraulic Institute (now called DHI Water and Environment group). It is commercial development of Systeme Hydrologique Europeen (SHE) model (Zheng 2008). It is quite powerful and flexible WMT, which is used worldwide in many countries.

MIKE SHE is physically based, continuous, distributed parameter model, which is capable of making tree dimensional simulations of hydrologic system (Shoemaker et al. 2005). One of the important MIKE SHE characteristics is that this model could be adjusted to needed level of complexity in regard to modeled variables and spatial detalization (it could be run as conceptual, lumped parameter model)(Horn et al. 2004; Zheng 2008). MIKE SHE does simulations on major river WQ parameters such as sediments nutrients, pesticides, dissolved oxygen, etc (Horn et al. 2004). It is used to for simulation of movement of different substances in surface water as well as in groundwater (CDM Camp Dresser & McKee 2001). Required input data for model is precipitation (rain and snow), evaporation, overland sheet flow, channel flow, unsaturated subsurface flow, saturated groundwater flow and other parameters (Shoemaker et al. 2005). It's usual application areas include “conjunctive use of water, surface and ground water management, irrigation management, changes in land use practices, farming practices including fertilizers and agrochemicals, wetland protection, contaminant transport, and determination of well capture zones”(Rousseau et al. 2005).

Among MIKE SHE advantages is integration with GIS, more specifically ArcView, which has been developed in cooperation with ESRI (CDM Camp Dresser & McKee 2001). MIKE SHE also could be easily coupled with other DHI softwares like MIKE 11, MOUSE, DAISY (Zheng 2008). The main problems are related to the cost of this program, since it is commercial, and to get full functionality many additional modules have to be purchased (Zheng 2008). Moreover comparing to other models (like SWAT, HSPF, SHETRAN) there are very few scientific articles focused on this model applications (especially in water quality issues). Horn et al. (2004) state that there was no published studies (till 2004), which would present application of MIKE SHE model for water quality issues.

4.1.5.5 SHETRAN

SHETRAN is based on SHE model. It has been developed by the Water Resource Systems Research Laboratory with intentional collaboration between different scientific groups from the United Kingdom, Denmark and France by substantial funding for development provided from the United Kingdom Nirex Limited (Nirex) for safety assessment research program for radioactive waste repositories (Ewen et al. 2000). SHETRAN is among most scientifically (or theoretically) grounded watershed scale models coupled with good analysis tools. Thus no wonder that in many applications requiring physically-based, spatially distributed model, it is considered among the main alternatives.

“SHETRAN is a physically-based, distributed, deterministic, integrated surface and subsurface modeling system, designed to simulate water flow, sediment transport, and contaminant transport at the catchment scale” (Newcastle University 2008). This model is composed by the three main components. One is for water flow, one for sediment transport and one for solute transport (Ewen 1996). It could model hydrology, nutrients and transport of sediments, chemical and radioactive substances and other parameters in three dimensional space (Shoemaker et al. 2005). Since SHETRAN is detail theoretical watershed model it requires a lot of input data such as meteorological data, information about soils, river channels, land use, vegetation, diversions and discharges, point source loadings, sediment concentrations in waters entering streams, dry deposition rates, and many other parameters (Ewen et al. 2000). Spatial division of this model is based (in horizontal dimension) on orthogonal grid, and in vertical, on columns. While channel system is represented by boundaries of the grid squares (Nasr 2007).

SHETRAN main strengths are it's direct coupling of surface and sub-surface systems and level of details with which transport of substances and flows could be represented (Ewen et al. 2000). Moreover those modeling results could be visualized using animated graphical computer display system called “SHEGRAPH - Graphical Display System” (SHETRAN 2008). It is also claimed that SHETRAN could be used without calibration, because of it physical nature (Nasr 2007). This model also has good documentation and application examples around the world. The main problems are connected with requirements for input since detail data for many parameters are necessary. This model also is designed mostly for research purposes. Thus usage outside scientific community could be hardly possible. Also it is not clear, if any integration with GIS exists.

4.1.6 Future challenges

Although many of WMTs are quite advanced, future challenges waiting for this field are enormous. How these challenges would be met also depends on advances in other technologies like GIS, Artificial Intelligence, computational devises, Internet, etc. Moreover, development in scientific understanding of processes is ever more essential.

Today most WMTs lack incorporation of stochastic modeling capabilities into models. Risk assessment framework integration into WQ modeling would enhance modeling results usefulness for river basin management. Moreover, there is a great need for models with less (if possible, none) calibration, since calibration time is taking much time (Breuer et al. 2008). 3-D representation of modeling systems, analysis and animation tools would be another step to bring watershed modeling to more advanced level. Furthermore, most of WMTs lack consideration of biological and hydro-morphological parameters and processes associated with watershed systems (Horn et al. 2004).

Since growth of this field and application of models is not systematic, furthermore not controlled by central institution, comparison problems arise. There are many initiatives around the globe, which focuses on assessment of model suitability for particular purpose or integration and unification of modeling approaches to promote interchangeability and easier data comparison and calculation results. As the example Benchmark Models for the Water Framework Directive project could be mentioned, which is set to examine suitability of WMTs for implementation of WFD (Barlund et al. 2007). Another interesting example is EUROHARP project, a comparison of nine modeling tools for assessment diffuse source losses by applying them in many areas across Europe (Arnold & Fohrer 2005). These projects are small parts of larger project called HarmonIT, which attempted to simplify model linking in order to be able to assess multiple catchment processes and outcomes of different policies (HarmonIT 2005).

4.1.7 Conclusion

Watershed models especially for WQ is quite recent inventions, not older than 40 years. Advances in computational technologies, hydrology and other sciences gave momentum to development of the watershed modeling field. Nowadays scientific research and watershed management is hardly imaginable without those tools. Yet successful application of them is dependent on many factors. Most important among them is selection of proper watershed model, which data needs could be met, while important processes are considered and required output could be obtained. There is no single best model. Thus this review is quite important step for effectiveness of application of WMTs for the analysis of the selected problem.

From reviewed literature it could be concluded that currently the most appropriate watershed model for assessment of inland surface diffuse pollution abatement measures is SWAT[8]. This model has many successful application examples all around the world and active developing community as well as good documentation, excellent integration with commercial and open source GIS softwares. Model data requirements could be met with data available from governmental institutions. Model interface is well prepared, besides model setup is not complicated. There are many other advantages of SWAT model, yet probably the biggest advantage is that this model, all documentation, application examples are available free of change.

4.2 Environmental Risk Assessment and Cost-Effectiveness Assessment in Diffuse Pollution Problem Solution

Diffuse pollution is driven by stochastic nature processes, which makes diffuse pollution stochastic as well. Moreover diffuse pollution is shaped by multiple factors such as climatic variables, land cultivation form, soil character, vegetation, area morphological characteristics, etc. It causes difficulties when assessing and controlling non-point sources (NPS). These characteristics of diffuse pollution have been recognized by many authors (Xue et al. 2008; Bystrom et al. 2000; McSweeny & Shortle 1990; Wang et al. 2004; Lacroix et al. 2005; Ancev et al. 2008; Brouwer & Blois 2008; Huang & Xia 2001; Donohue et al. 2005; Barnes et al. 2008). They are creating huge problems for modeling as well. For instance application of distributed watershed models for NPS requires not only extensive monitoring data covering assessed territories, but also understanding of many complicated relationships occurring in nature between different factors (Xue et al. 2008). Yet currently both these prerequisites are far from complete for nearly all territories. Therefore diffuse pollution modeling with watershed WQ models involve significant uncertainties. Furthermore budget, time and competence restrains, which every watershed modeler faces, forces to produce guidance for decision making with even higher uncertainties.

8 Dependent of problem different models could be more suitable. Nevertheless SWAT model globally is the most used for inland surface water diffuse pollution modeling.

Usually the most common treatment of uncertainties related to diffuse pollution is ignoring them. Models are used to represent “the best guess” or “most likely” values. Yet by ignoring uncertainties decision making loses extremely valuable information. How certain is “the best guess”, what is probability of it? Indeed deterministic methods of diffuse pollution analysis are far from sincere since so much information is left out (McSweeny & Shortle 1990). It has been recognized already several decades ago by leading environmental protection agencies. They stated that for NPS assessment to be sincere it should be assessed in probabilistic terms (Beavis & Walker 1981). Many tools have been offered for it. Among the most useful of them is Environmental Risk Assessment (ERA), which encompass Uncertainty Analysis (UA) in itself. Risk concept is defined “as the function of probability and magnitude of adverse impacts” (Posthuma et al. 2008). ERA is increasingly viewed as useful tool for decision making support related to environmental problems and it's application ranges increases. Yet in many watershed management bodies this tool is rarely used, because of lack of methodologies, competence, resources, will to change, etc. Even rarer it has been integrated with other important tools used to management such as Cost-Effectiveness Analysis (CEA). CEA is becoming part of many environmental policies. It is essential for selection of the best measures for pollution abatement. This chapter is focusing on above mentioned tools and their integration examples. It is a particularly important step towards understanding the scope, amount of required efforts and possible benefits, which integration of ERA and CEA could provide for solving diffuse pollution problems.

4.2.1 Environmental Risk Assessment

Risk assessment first arose within field of economics. Later it was adopted within field of engineering, health sector, and during past 30 years it come to the field of environment as environmental and ecological risk assessment (Burgman 2005). Risk concept in literature mostly defined as probability of a certain adverse event following magnitude of harm caused by this event (Linden et al. 2008). Although there are other definitions as well. For instance Rosen et al. (1998) present risk as “a probabilistic costs of exceeding existing water quality standards”. ERA is used to assess likelihood (usually in probabilistic terms) of certain outcomes with regard to environmental effects. ERA is also a tool designed to account different kinds of environmental uncertainties (other types of uncertainties could be assessed as well) and bring this information to decision making (Burgman 2005). For this ERA uses many methods such as expert elicitation techniques, Monte Carlo (MC) simulations, etc.

ERA brings important information to the decision making and the actual risk reduction is done through process called Environmental Risk Management (ERM). It is organized by risk managers, which, organize involvement of stakeholders, experts, decision makers, general public, etc for this process. ERA is a part of the ERM process.

4.2.1.1 ***Environmental Risk Assessment/Management Framework***

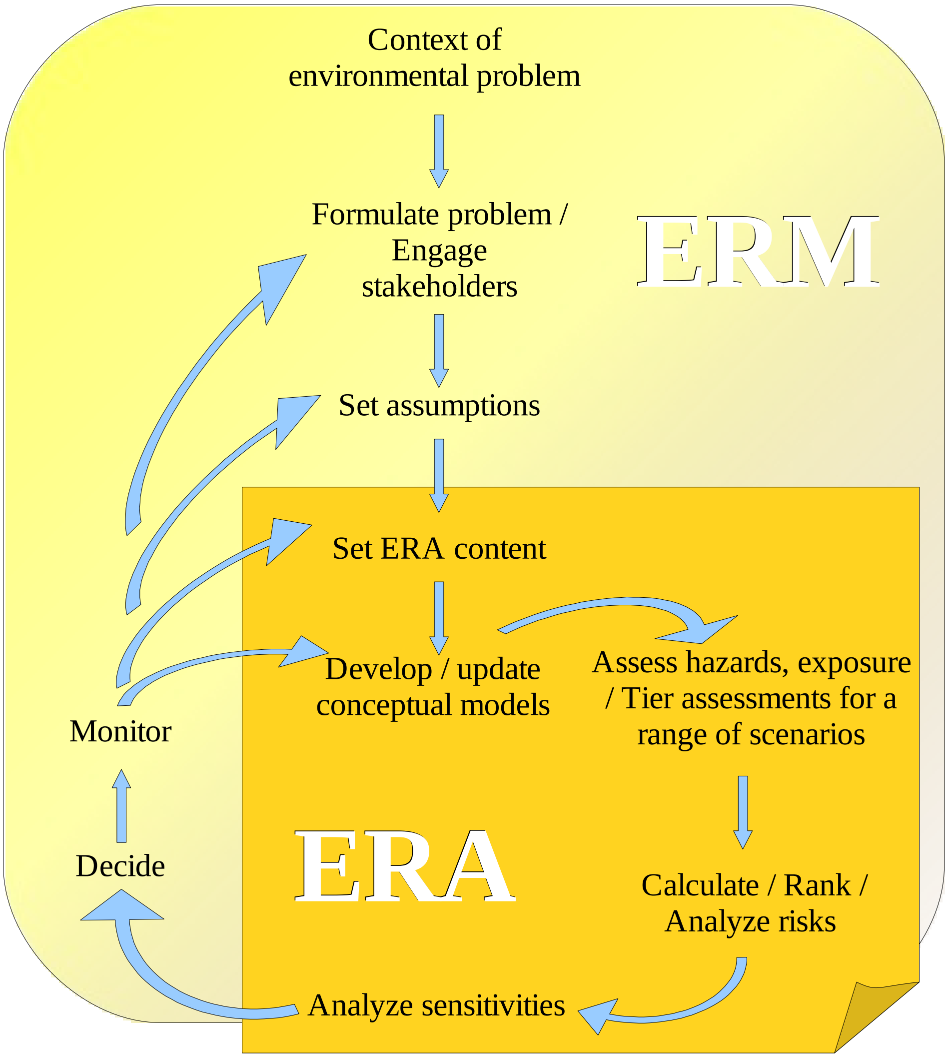

Figure 2: ERM/ERA cycle (adapted from Burgman (2005)).

ERM/ERA cycle[9] presented above (Figure 2) shows the main steps related to ERM and ERA. Generally all processes are initiated by risk manager who sets context, formulates problem and engages stakeholders. Risk manager together with group of experts should set the main assumptions. On the start of ERA process it is important to set content for it through clearing up management goals, assessment and measurement endpoints, hazards, stressors, environmental effects, receptors, exposure, which are particular terminology used in ERA. Management goals are broad statements that embody general objectives such as good water quality. Assessment endpoints are management objectives, such as water quality high enough to support valuable fish communities. Measurement endpoints are the things that actually are possible to measure, such as abundance of fish species (transformed to different fish indexes), the main hydro-chemical parameters or abundance of food. Hazard concept defines some kind of human activity or it's consequence, which could cause adverse effect (farming in diffuse pollution case). Stressors are actual elements, which could cause adverse effect (for instance nutrients and pesticides).

9 This cycle and information describing it is based on Burgman's (2005) risk management cycle.

Environmental effect is a change in the environment. For instance starting of the eutrophycation process. Receptors are organisms or groups of them (as communities, ecosystems, etc), which are actually affected or could be affected by some stressors. Exposure is existent or expected interaction between receptors and stressors in the environment.

After setting content by defining main ERA concepts and development of conceptual models, collecting available information, risk assessors goes to the hazard assessment through tier based processes. Tier based processes involves different levels of details for different levels of hazard assessment. First steps of hazard assessment are used for screening purposes. They lets find out important aspects, which must get more attention. Later steps involves more details and careful, complicated analysis. Risk calculation and risk ranking together with sensitivity analysis and communication of the management are final steps of ERA. Risk manager based on the information received from ERA facilitates decision making process, implementation of measures, organization of monitoring. Information obtained from monitoring is vital for continuing cycle of risk management as it will later be used for input to start iteration within processes of problem formulation, setting assumptions and ERA content, development of conceptual models.

4.2.1.2 Importance of ERA in diffuse pollution problem solution

In a way ERA/ERM framework includes the main principles of adaptive watershed management approach (Maxted et al. 2009). This approach is considered as a vital improvement over existing diffuse pollution management approaches. New approaches are especially welcomed after failings of NPS pollution control policies all around the world despite huge investments in abatement measures (Maxted et al. 2009; Wang et al. 2004; Broekx et al. 2008). Moreover, the latest developments in ERA are shifted from compound towards site specific ERA , which are in line with WFD requirements, and provides ground for assessing impact of multiple stressors and thus makes ERA more useful for decision making (Posthuma et al. 2008). WFD imposes requirement on watershed managers that whatever the cause of ecological water impairment, watershed managers should design measures to abate them (Posthuma et al. 2008). However for this purpose it is important to know the cumulative impacts of the stressors. Moreover, since even a small amount of pollutants coming from diffuse pollution could have an effect on ecosystems, the ERA process is seen as valuable tool to increase NPS pollution abatement effectiveness. Furthermore, calculations of optimal risk (Rosen et al. 1998) and spatial optimization (targeted approach)(Maxted et al. 2009) are seen as important developments for tools assisting in diffuse pollution abatement. Most important ERA brings UA into decision making. Research shows that stochastic uncertainty accounting policy perform better than deterministic (Barasel 2007). As well as giving decision maker more realistic picture about uncertainties he faces and risks he takes (Linden et al. 2008). Moreover ERA through risk reduction concept could be associated with economic criteria, such as willingness to pay analysis to produce more meaningful directions for decision making (Johnson et al. 2008).

4.2.2 Uncertainties

According to Brouwer & Blois (2008) uncertainty is defined as “limited (incomplete or imperfect) knowledge and information about current or future environment, social, economic, technological, political and institutional conditions, states and outcomes and the implications or consequences of these current or future conditions, states and outcomes”. Burgman (2005) adds that uncertainty is arising from the lack of perfection in human communication (linguistics uncertainty).

Understanding uncertainties and inclusion of them is necessary. According to Barasel (2007) “water pollution assessment and efficient pollution abatement require explicit consideration of various uncertainty aspects”. Thus leading environmental protection institutions such as US EPA are directing their efforts towards methodologies for inclusion of uncertainties into decision making (Brouwer & Blois 2008).

4.2.2.1 Types of uncertainties

To understand the scope of UA it is important to overview what uncertainty term includes. Uncertainty definition was presented above. This section focuses on classification of uncertainties. One of the examples is presented in Figure 3.

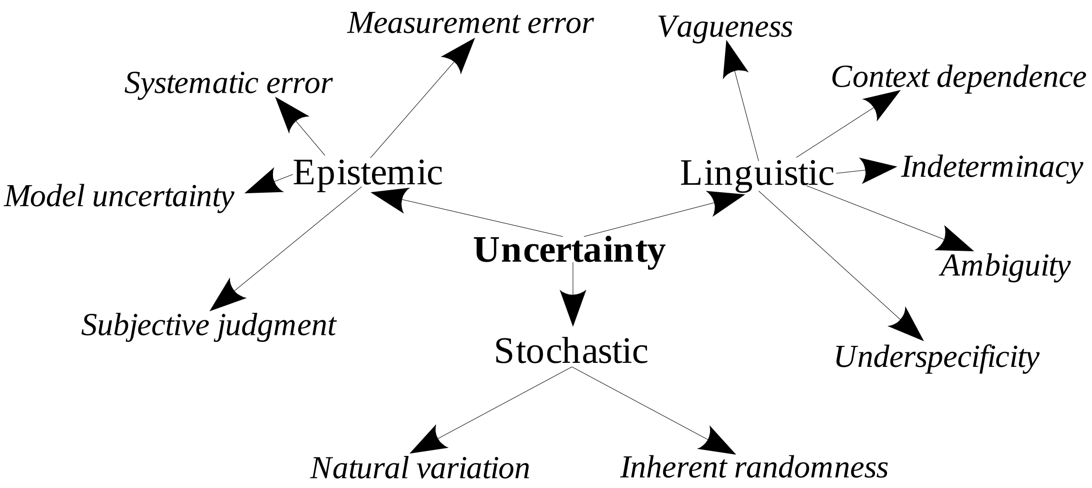

Figure 3: Uncertainty classification.

According Brouwer & Blois (2008), uncertainties could be divided into epistemic and stochastic . Additional category to this could be linguistics uncertainty, mentioned by Burgman (2005). Epistemic uncertainty includes uncertainties arising from incomplete knowledge and information, whereas stochastic includes “inherent variability in natural event and phenomena” (Brouwer & Blois 2008). Linguistics uncertainty arises because of misunderstandings coming from language communication.

Burgman (2005) made overall inventorization of uncertainties. According to him epistemic uncertainty could be further divided into measurement error, systematic error, model uncertainty and subjective judgment. Measurement error arises because of imperfections in measurement equipment and observer or measures. Systematic error is a bias in measurements caused by incorrect systems. Since models are just simplification of reality they can not perfectly represent them. Therefore model application would introduce uncertainty as well. Subjective judgment and its created uncertainty is leading assessment in every step. Stochastic uncertainty is divided into natural variations and inherent randomness. All natural processes have some kind of cyclic variation, which is caused by seasonal changes or other nature changes. It is causing natural variation in measured parameters. There is also inherent randomness, which could not be explained by natural variation or epistemic uncertainties. Linguistics uncertainty according to Burgman (2005) could be divided into vagueness, context dependence, ambiguity, indeterminacy in theoretical terms, underspecificity. Vagueness is caused by language property to permit borderline cases. Context dependence uncertainties are created if context of the statements was not properly specified. Ambiguity is caused by the fact that one word could have more than one meaning. Indeterminacy arises because it is impossible to know future use of term. Underspecificity is caused by lack of specification information on the statement. Overall uncertainty by Zheng & Keller (2007) is called global uncertainty.

There are other classifications as well. For instance Walker et al. (2003) presented by Brouwer & Blois (2008) emphasizes the need to distinguish between social and natural uncertainties. Natural uncertainty in this case represents uncertainties arising from imperfection in understanding natural phenomenon, while social arises from lack of knowledge about future incomes and technologies, what would determine value of resources. Brown (2004) cited by Brouwer & Blois (2008) makes distinction between "statistical uncertainty (all outcomes and probabilities known), scenarion uncertainty (some outcomes known, no probabilities known), qualitative uncertainty (some outcomes and some probabilities known) and recognized ignorance (no outcomes are known). Zheng & Keller (2007) while presenting uncertainties related to management-oriented watershed modeling brought up parameter, model structure, input, observations (coming from model result interpretation) and future input uncertainties. Brouwer & Blois (2008) simply divides uncertainty into environmental, economic and political. In general, many authors have different classification ways. Nevertheless different classifications do not change nature of uncertainties and importance to deal with them.

4.2.2.2 Treatment of uncertainties

In this work focus would be made on stochastic uncertainties, therefore epistemic and linguistic uncertainties will not be discussed further as well as treatment of them. Interested reader is referred to Mark Burgman's book "Risks and Decisions for Conservation and Environmental management" (2005).

According to Brouwer & Blois (2008) there is no detail guidelines how to conduct UA. In general assigning probabilities and distribution of probabilities to the outcomes has been the most common way to treat uncertainties (Brouwer & Blois 2008). Probability density functions are increasingly used in risk and uncertainty assessments (Ancev et al. 2008). In WQ modeling most often uncertainties are assessed through scenario and sensitivity analysis, which become standard procedures in modeling (Brouwer & Blois 2008). Despite availability of many uncertainty treatment methods, like Taylor expansion-based method, Rosenbluenth's method, stochastic response surface methods, Karhunen-Loeve moment equation approach, MC based methods have been recognized as the most suitable for complex watershed models (Zheng & Keller 2007). The essence of these methods consists of "finding the definite integral of a function by choosing a large number of independent variable samples at random from within an interval, averaging the resulting defendant variable values, and then dividing by span of the interval over, which the random samples were chosen" (Brouwer & Blois 2008). Zheng & Keller (2007) present methods within MC framework to deal with uncertainty such as calibration-based methods: Bayesian recursive estimation, multiobjective complex evolution, multiobjective calibration iterative procedure, generalized likelihood uncertainty estimation.

One way how integration of stochastic uncertainties into the water modeling for natural variation is done, is the use of trend and value dispersal (US EPA, 2004). For instance a trend is calculated for average year from long term measurements. Inherent randomness is included by putting distribution (normal or other), which means that value from the trend and standard deviation (dispersal around the average value) is calculated from the data. After trend and distribution of value dispersal have been obtained, MC simulations could be included in the model and probabilities calculated.

Generally, above mentioned methods are rarely used in the watershed modeling for management purposes, except for scenario and sensitivity analysis. More advanced UA for its complexity are mostly done for scientific purposes and have seldom been used for decision making. This occurs, because water quality simulations involves many uncertain parameters in complicated processes modeling, making it hard to do proper UA with pressing deadlines. Nevertheless integration of UA is essential for quality of decisions, since it is vital to know certainty of assessment or modeling on which decision is going to be based. Integration of UA has been identified as a key issue for implementation of WFD (Brouwer & Blois 2008). Moreover cost of pollution abatement measures depends not only on the targets, which should be reached, but also on reliability, by which those targets should be achieved (McSweeny & Shortle 1990). If target is vital and greater reliability should be achieved, costs would increase (Wang et al. 2004).

4.2.3 Cost-Effectiveness Analysis

Consideration of economical constrains is vital for reaching environmental targets (Brouwer & Blois 2008). For this purpose in watershed management often used tool is Cost-Effectiveness Analysis (CEA). CEA is used to select between two or more alternatives by assessing their costs and expected outcomes. It is used when full cost benefit analysis can not be performed or is inappropriate (Kenkel 1997).

4.2.3.1 Ranking and main steps of CEA

Using Cost-Effectiveness Ratio (CER) (Equation 1)(ACP 2000) alternatives could be ranked thus giving decision makers vital information to base their decisions. There are other ranking criteria as well. For instance Maxted et al. (2009) argues that ranking in watershed management should be made on water-quality restoration potential. Nevertheless it is based on similar logic as CER.

$$CER = \frac{\text{Cost}_{\text{new strategy}} - \text{Cost}_{\text{current practice}}}{\text{Effect}_{\text{new strategy}} - \text{Effect}_{\text{current practice}}}$$

Equation 1: Cost-Effectiveness Ratio.

CEA basis is marginal costs evaluation. Marginal costs are the costs of the additional inputs needed to produce additional unit of effect (EconModel 2009). Brouwer & Blois (2008) gives the example of increase in total cost of abatement for decreasing additional kilogram of pollution loads. According to McSweeny & Shortle (1990) "the cost effectiveness of pollution control are usually based on the general rule that efficiency is improved by relocation abatement from sources with high marginal costs to sources with low marginal costs". Brouwer & Blois (2008) gave the main steps for CEA in watershed management:

1. Identify the environmental objective(s) involved (target situation);
2. Determine the extent to which the environmental objectives are met;
3. Identify sources of pollution, pressures and impacts now and in the future over the appropriate time and geographical scale (baseline condition);
4. Identify measures to bridge the gap between the reference (baseline) and target situation (environmental objective(s));
5. Assess the effectiveness of these measures in reaching the environmental objective(s);
6. Assess the direct (and if relevant indirect) costs of these measures;
7. Rank measures in terms of increasing unit costs;
8. Determine the least costly way to reach the environmental objective(s) based on ranking of measures.

Brouwer & Blois (2008) states that CEA for watershed management is a multidisciplinary exercise, which requires efforts and integration of knowledge from various disciplines, such as economics (costs of abatement measures), environmental science (effects of abatement measures), engineers (technical knowledge about installation and use of abatement measures). Authors have also presented bottom-up and top-down approaches of CEA. Bottom-up approach directed towards technical information of measures and their effects on individual enterprises while top-down tries to evaluate wider economic impacts, not specifying detailed measures.

There are, however, some problems connected with ranking of abatement measures in watershed management. According to Broekx et al. (2008) cost curves (marginal abatement costs for emission reduction) of abating different pollutants and in different locations will differ. Moreover required reliability (or probability) by which pollution constrain should be reached also influences costs of abatement (Bystrom et al. 2000). Probability of detecting a statistically significant water quality improvement would require additional costs as well (Maxted et al. 2009). Therefore use of CEA ranking in nationwide watershed management plans might be problematic. Finally, it shouldn't be forgotten, that there are also other benefits and costs, which CEA does not include (Johnson et al. 2008). Those factors could be decisive while making decision.

4.2.3.2 Relation to Water Framework Directive

There have been consistent effort to integrate CEA into decision making. For instance WFD requirement is that by the year 2009 EU Member States must publish programmes of cost-effective abatement measures (Broekx et al. 2008). WFD even provided exception from implementation of WFD environmental requirement of reaching "good" water body status founded on cost-effectiveness basis: "if costs of mitigation are disproportionate, water quality mitigation can be derogated, at least temporarily" (Johnson et al. 2008). Johnson et al. (2008) suggested, that disproportion should be evaluated by applying classical economic theory, which says that resources should be relocated to those means and areas where marginal costs of pollution abatement would be less or equal to marginal benefits provided by those measures. In general CEA have been considered very important in water policy (Brouwer & Blois 2008). However, consistent methodologies and modeling practices for CEA focusing on surface water quality problems are yet to be developed in most of EU Member States (Broekx et al. 2008).

4.2.4 Integration examples

It was quite hard to find examples of ERA and/or UA integration with CEA for solution of diffuse pollution problems for surface water. During quite extensive literature searches only one recent article could be given as example on this issue. This article - "Integrated modeling of risk and uncertainty underlying the cost and effectiveness of water quality measures" was written by Roy Brouwer and Chris De Blois (2008). In it authors tried to integrate risk and uncertainty analysis with CEA for ranking diffuse pollution abatement measures for increasing water quality in bathing sites. Uncertainties have been assessed not only for environmental criteria, but also for economical costs . UA has been performed based on expert judgment and statistical analysis on the data collected from bathing sites. MC simulations were performed with commercial risk analysis and simulation add-in for Excel called @Risk. This article has provided quite interesting results as well as overall view on issues connected to ERA, UA and CEA .

Other works could be connected to this subject just remotely. For instance, since 1987 USA have provided funds for farmers for implementation of conservation practices to improve stream water.

Thus at this time a number of articles have been published to assess cost-effectiveness of diffuse pollution abatement measures in probabilistic way. One of the examples could be articles written by Beavis & Walker (1981) and McSweeny & Shortle (1990). Through derivation of mathematical equations scientist tried to provide answers, how to achieve environmental standards under uncertainty. However, these studies were only focused on farm level. There have been other works on uncertainty inclusion into planning of nonpoint pollution control measures, like once written by Lacroix et al. (2005), Collins & Anthony (2007), Maxted et al. (2009), etc. Yet combining ERA, UA, CEA together in solving NPS control problems is rarely analyzed in literature.

One more approach, which is worth mentioning has been presented by the Montaldo et al. (2007). In their article authors presented the rapid assessment method (called low impact development rapid assessment (LIDRA)) to evaluate cost-effectiveness of stormwater pollution reduction measures. This method integrates complicated stormwater modeling with economic analysis in management orientated way. Output of this method is simple to understand and interpret. Even though this article does not explicitly talk about ERA or UA and NPS, however the main ideas could be quite useful for methodology, which would provide solution for diffuse pollution related problems with ERA, UA and CEA integration.

4.2.5 Conclusion

Diffuse pollution is one of the most important factors for water quality deterioration, if not the most important. Especially it is crucial for developed countries. They are on the way to provide satisfactory solution for point source reduction. Yet water quality improvement requires substantial achievements in NPS reduction, which based on past experiences is extremely hard to obtain. Thus new approaches are vital to avoid past failings and give new hope for tackling this problem.

Integration of ERA, UA and CEA for solving diffuse pollution problems could be such an approach. Literature review showed that previously mentioned tools are important to improve decision making. Moreover their integration could give even more benefits, since important aspects for successful decisions would be considered in assessment rather than ignored. Some examples of this integration could be found in recent published works. For instance CEA is very often used when diffuse pollution measures are analyzed, since it is very important for decision making bodies. However examples of ERA and UA integration with surface water diffuse pollution modeling are quite hard to find. Even less plentiful are examples for ERA, UA and CEA integration in diffuse pollution analysis. Obvious reasons for this could be increase in time and financial resources for projects. It would also put requirements on hydrologists[10] for professional expertise in ERA or UA as well as CEA. Moreover, data and calculation time requirements for stochastic models could be higher. Furthermore, results for analysis might be harder to communicate to take holders if they are provided in probabilistic terms. Nevertheless many recent studies underline importance of those tools. Having in mind current European legislation requirements, it is hard to image how could diffuse pollution abatement aims be reached without accounting for as much information as possible. For this reason, integration of ERA, UA and CEA is vital.

10 Hydrologists are mainly dealing with watershed modeling. Therefore they would get responsibility for smooth integration of ERA, UA and CEA.

4.3 Review of Lithuanian and European legislation on controlling the inland surface water diffuse pollution

According to Gunningham & Sinclair (2005) point source pollution problems are first generation problems, which quite successfully are handled with traditional "command and control" type policies. Whereas diffuse pollution problems are second generation, which poses great challenges for policy makers as they are very complicated by their nature. Although it was a long time neglected, the importance of diffuse pollution problems is getting increasingly more attention and recognition by the general public and politicians. However, when reviewing current legislation, it is amusing how little regulations are focused on this issue in the EU and especially in Lithuania. Indeed, except implementation of major EU directives and Helsinki Convention, Lithuania have none (as far as I know) any other kind of legislation particularly focusing on inland surface water diffuse pollution. In other words, all requirements, which currently are in the national legislation dealing with diffuse pollution problems, come from international legislation. Therefore in this chapter Lithuanian legislation will not be further analyzed, as it sets the same requirements as the major EU directives and Helsinki Convention.

Yet EU does not have plenty of major legislation for tackling diffuse surface water pollution problems. There are two major directives: one is dealing with pollution by nitrates coming from agriculture and other dealing with all types of diffuse pollution sources (Kronvang et al. 2008). First is The Nitrates Directive (91/676/EEC) and the second is The Water Framework Directive (2000/60/EC). Since Lithuania is within the Baltic Sea drainage area, Convention on protection the marine environment of the Baltic Sea area, 1992 (or Helsinki Convention) should be included into that list as well. There are other documents, dealing with diffuse pollution. However, they do not directly address diffuse pollution, but affects it more generally by reducing impacts mostly from industries. To this group such legislation as The Environmental Impact Assessment Directive (85/278/EEC), The Urban Waste-water Treatment Directive (91/271/EEC), The Integrated Pollution Prevention Control Directive (96/61/EC), The Bathing Water Directive (76/160/EEC) and others could be assigned.

Analysis of the mentioned legislation is important on the way to bringing forth assessment tool for selection of diffuse pollution abatement measures. Not should it only set direction, but also give perspective on the level of effort designated by the policy makers to deal with diffuse pollution as well as the main requirements for these efforts. This chapter is devoted for analysis of legislation designated for control of inland surface water diffuse pollution control.

4.3.1 The Water Framework Directive (2000/60/EC)

The Water Framework Directive (WFD)[11] is the single most important inland and coast water policy act in the EU. The main ideas of this act are quite straightforward. It is to assess state of water bodies, set targets, find water bodies at risk of not reaching WFD targets, devise programs, implement them and by the end of year 2015 reach "good water status". However the way it would be done is left to decide entirely for Member States (MSs). According to Kastens & Newig (2007) WFD just sets the target, but not the path and its main method, adaptive management through iterative planning, should be used on the local level. Every MS suppose to adjust implementation of EU water policy to it's local conditions.

WFD targets are not as straightforward as it could seem from above explanation. This directive is designed for protection of inland surface waters, transitional waters (semi salt waters near river

11 Directive 2000/60/EC of the European Parliament and Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities.

mouths), coastal waters (areas include 1 nautical mile from the coast) and groundwaters. For the surface waters the goal is to reach “good ecological status“ and “good chemical status”. For heavily modified water bodies beside “good chemical status”, “good ecological potential” should be reached. While for groundwater the goal is to reach ”good chemical status” and “good quantitative status”. In reality what is “good status” is left to decide to MSs, based on broad criteria set out in Annex V of this directive. According to WFD, criteria for evaluation of ecological status should include the main hydromorphological, physico-chemical and biological quality parameters. Whereas chemical status should encompass Environmental Quality Standards for priority substances (Annex X/2455/2001/EC) and harmful substances (Annex VIII). Biological quality elements are identified as the most crucial (for surface waters) for final designation of water body's state and it should include parameters representing state of phytoplankton, macroalgae, angiosperms, bentic invertebrate fauna, fish fauna. On the whole there is much to talk about the WFD, however the main interests from this project perspective is what the directive does say about diffuse pollution and its abatement. Also, what does it say about CEA and uncertainties or environmental risks.

WFD is not addressing diffuse pollution problems as much as one could expect (because of it's importance). It mostly addressing them through causes of failure to meet “good water status” prism. Yet in Article 10 named “the combined approach for point and diffuse sources” directive states that diffuse pollution should be abated using most appropriate Best Environmental Practices (BEPs). What measures could be called BEPs is not explained in the WFD. Instead reader is referred to a list of directives. According to directive every MS should devise programme of measures (which should be published by 2009) for each river basin district, where two sets of measures should be designed: basic and supplementary (if needed). Basically, this includes all measures aimed at implementation of EU legislation connected to water protection (list provided in Annex VI part A) other than WFD. While supplementary (list provided in Annex VI part B) should be applied when basic measures are not enough to reach “good water status”. Among the basic measures there is requirement for measures against diffuse pollution: “for diffuse sources liable to cause pollution, measures to prevent or control the inputs. Controls may take the form of requirement for prior regulation, such as a prohibition on the entry of pollutants into water, prior authorization or registration based on general binding rules where such a requirement is not otherwise provided for under Community legislation.” Supplementary measures listed in Appendix VI are very general and do not emphasize measures particularly targeting diffuse pollution reduction.

WFD stresses the importance of reliable information on the development in water status of surface and groundwater bodies. Also, it emphasizes importance to know the main causes or pressures behind them. Only if reliable information is available, MSs should apply measures to bring water status on the right track. In Annex II part about Identification of Pressures directive say that MS should collect all important information about “significant diffuse pollution source pollution, in particularly by substances listed in Annex VIII, from urban, industrial, agricultural and other installations and activities”. Annex VIII includes different organic compounds, nutrients, heavy metals, biocides , etc. WFD also emphasizes selection of monitoring sites to collect reliable information about diffuse pollution pressures: “for bodies at risk from significant diffuse source pressures, sufficient monitoring points within a selection of the bodies in order to assess the magnitude and impact of the diffuse source pressures. The selection of bodies shall be made such that they are representative of the relative risks of the occurrence of the diffuse source pressures”. There is no more mentioning of diffuse pollution in WFD.

CEA is not mentioned much in WFD. Only in Annex III there is a requirement “cost-effective combination of measures” with “potential costs of such measures” must be included into the economical analysis required in river basin management plans. In regard to uncertainties and environmental risks, the directive does not provide sufficient attention to them. It could only be seen in the requirements to provide reliable information, to provide confidence and precision level of monitoring and reach “sufficient level of confidence about values of reference conditions”. It also says that “the relative risks of the failure to achieve good surface water status” should be important criteria for selection of water bodies to monitoring programmes.

Although WFD in general way recognizes importance of diffuse pollution, realization of it's broadly stated goals is huge struggle for local authorities responsible for WFD implementation (Gunningham & Darren 2005). Though requirement to remedy causes of failure meeting “good status” of water body is quite understandable, there are many reasons to expect MSs to fail implementing WFD due to diffuse pollution (and not only because of it)(Kastens & Newig 2007). For instance, required improvement of groundwater status by the year 2015 in many MSs is hardly possible due to spread of agricultural activities and nature of groundwater recharge system. Besides, detailed goal formulation is left to MSs, so there is a risk that environment objectives stated in WFD would be derogated using loopholes left in the directive (Kasten & Newig 2007). Also huge problems exists in the new MSs where staff and financial resources are very limited. Moreover scientific capacity is highly critical to prepare and implement sound river basin management plan. However most of new MSs are in huge demand for it. Essential for success reaching directive goals according to European Commission is wide public involvement, which include water users (Van Ast et al. 2005). Non Governmental Organizations (NGOs) have particularly important task for representation of public interests. Yet in the new MSs NGOs are often too weak and collaboration with authorities is not established tradition. Finally, even every of previously mentioned problems could be solved, there is also a risk that polluters (such as farmers, etc) could fail to meet new regulations or targets (Kastens & Newigs 2007). Thus smooth implementation of WFD on the EU scale could hardly be expected.

4.3.2 The Nitrates Directive (91/676/EEC)

The Nitrates Directive[12] is particularly designed for abating diffuse pollution coming from agricultural sources (EU 1991a). However it is targeted at pollution of water only by nitrates. Other pollutants (such as pesticides, phosphorus) are not mentioned. The aim of directive is reduction and prevention of water pollution by nitrates, which should be done by designating vulnerable zones (areas, which drain to water bodies effected by nitrates pollution), establishment of action programmes for them, as well as codes of good practice for farmers (those should be implemented on voluntary basis). There are two phases of action plan implementation. The first was already finished in 2007, second will be finished by the end of 2009 (EPA LT 2008). In the end of phase two, selected (for action plan) measures should be implemented in designated vulnerable zones. Mandatory measures for action plan are listed in the Annex III of this directive. It consists of such measures as certain limitations for fertilizer application, manure storage requirements, requirements for animal density on a field, manure application limitations. Similar measures are listed in Annex II for code(s) of good agricultural practice. It adds fertilizer plans for farms, maintenance of minimum vegetation, land use management and few others. According to directive cost-effectiveness should be among the main criteria when selecting preventative or pollution abatement measures.

12 Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal of the European Union.

4.3.3 Convention On The Protection Of The Marine Environment of The Baltic Sea Area, 1992 (Helsinki Convention)

Environmental aim of this convention is “to prevent and eliminate pollution in order to promote the ecological restoration of the Baltic Sea Area and the preservation of its ecological balance”. Contracting Parties by ratification of this convention have designated their internal waters for the purposes of this convention. Thus it also addresses inland diffuse pollution from areas draining to the Baltic Sea. The aim of this convention should be reached by various measures mentioned in convention, but probably the most is expected from the use of Best Available Techniques (BATs) and Best Available Practices (BEPs), which are listed in the Annex II. For instance in regard to diffuse pollution, the convention states that “pollution from diffuse sources, including agriculture, shall be eliminated by promoting and implementing Best Environmental Practices”. BEPs by the convention are defined as “the application of the most appropriate combination of measures”. Among those measures offered in Annex II , are information, education campaigns, development of Codes of Good Environmental Practices for all activities, mandatory labels, resource, energy saving, recycling, recovery, re-use, avoidance of hazardous substances when designing processes, products, etc. Quite recently amended (on 15 November 2008) Annex III Part II on Prevention of Pollution from Agriculture has introduced many measures for diffuse pollution reduction. These are: balancing animal density, emphasis on location and farm animal house design, appropriate manure storage construction, collection and treatment of agricultural waste-water and silage effluents, wise application of organic and chemical fertilizers, winter crop cover, water protection and nutrient reduction measures (such as buffer zones, riparian zones, sedimentation ponds, groundwater protection zones, wetlands), dealing with ammonia emissions. Besides, according to convention when issuing permits for farming activities (above certain farm size) conditions should be based on BATs. All those measures should be integrated into national legislation of every Contracting Party. In general Helsinki Convention provides more detailed recommendations for diffuse pollution reduction than WFD or The Nitrates Directive. Even more details are provided in the Baltic Sea Action Plan (BSAP), which aims for restoring good ecological status of the Baltic Sea by the year 2021 (HELCOM 2007). This plan sets clear objectives to be reached and measures implemented by every Contracting Party to Helsinki Convention in order to achieve the main aim of restoring ecological status of Baltic Sea. Listed measures (same as in Helsinki Convention) should be used in designing national programmes (to be ready by year 2010) and implementation of them should start not later than 2016. The selection of measures according to BSAP must be based on cost-effectiveness principle.

4.3.4 Other legislations

There are other regulations on the European level, which deal in one aspect or another with diffuse pollution abatement, though not always directly. Examples are: The Groundwater Directive (2006/118/EC), The Bathing Water Directive (76/160/EEC), The Drinking Water Directive (80/778/EC), The Environmental Impact Assessment Directive (85/337/EEC), The Urban Waste-water Treatment Directive (91/271/EEC), The Integrated Pollution Prevention Directive (96/61/EC). They rarely mention diffuse pollution as such, yet often proposing measures important for reduction of diffuse pollution. The Groundwater Directive is tightly connected to WFD. It aims at explaining criteria for assessing groundwater chemical status and identification of upward trends. It also aims at prevention of groundwater body status from deterioration (EU 2006) by complementing WFD. In this directive BEPs and BATs are advocated as well. Issue of diffuse pollution explicitly addressed in one place where it says “inputs of pollutants from diffuse sources of pollution having an impacts on the groundwater chemical status shall be taken into account whenever technically possible”. Other directives have even less emphasize on diffuse pollution. The Bathing Directive requires officially declared bathing sites and quality of water not worse, which stated in the directive (EU 1975). MSs should take measures to reach this quality. The Urban Waste-Water Treatment Directive requires by the end of 2009 to build central waste water treatment plants (WWTPs) in all settlements with more than 2000 inhabitants (EU 1991b). Connecting of not connected inhabitants to WWTPs should reduce diffuse pollution. The Environmental Impact Assessment Directive and The Integrated Pollution Prevention Directive deals with diffuse pollution indirectly through directing efforts of industrial sector to minimize environmental damage (EPA LT 2008). Finally, it is important to mention The Common Agriculture Policy (CAP) and the Sixth Environment Action Programme. CAP is the system of subsidies and programmes run by EU. Under this system funding is designated for environmental protection measures within agriculture (EC 2007). Yet every MSs have responsibility to decide upon priorities of those measures. The Sixth Environmental Action Programme is the document stating EU priorities and objectives within field of environment and measures to reach them. It is mostly connected with directing EU environmental policy making (SCADPlus 2009). There are also some other less important documents, which deals with diffuse pollution, however they would not be discussed in this work.

4.3.5 Conclusion

On a whole EU (including Lithuania) does not have single elaborated and systematic approach to tackle inland surface water diffuse pollution. WFD, the mother of all water protection policies in the EU, mention diffuse pollution being of particular importance, however does not give clear way, how it should be tackled. The Nitrates Directive is very short document, which declares it's aims and gives few hints how they should be reached, yet more guidance is not provided in this legislation. The most elaborated (in regard to diffuse pollution tackling) is Helsinki Convention, which provides clearer guidance what measures should be used and should be included into national legislation. Other legislation are just remotely related to diffuse pollution problems. Even though some implemented measures could reduce diffuse pollution, they do not have systematic approach to the problem, seldom mentioning it. Nevertheless it seems that Europe starts to understand importance of diffuse pollution problems and more efforts and funding is being allocated to solution of this issue. Examples are amending of Annex III Part II to Helcom Convention as well as many projects particularly addressing diffuse pollution in many areas across the Europe.

Finally, it should be also recognized that cost-effectiveness in selection of measures is highly advocated within all legislation connected to diffuse pollution abatement. However there is little found about addressing uncertainties and environmental risks in evaluating diffuse pollution problems and planning measures to combat them. Some requirements are in WFD. Yet probably more could be expected after review of this directive (at the latest in year 2019).

4.4 Inland water diffuse pollution abatement measures

Diffuse pollution is a complex problem, which has no universal solution. It depends on different factors, which in nature are varying. Diffuse pollution abatement is the most successful when it is adopted to particular situation, particular place and time. There are many different measures recorded, showing successful results in the past, when dealing with diffuse pollution problems. Yet most of those abatement measures are still under active research. Therefore their application requires quite a lot scientific knowledge as well. Moreover one measure is usually not enough. Measures need to be applied in composition with other measures. It requires good expertise on diffuse pollution abatement as well as knowledge of the area, if those measures would provide benefits for their costs. Selection of right composition is very important. However selection step might put efforts the wrong way when the whole range of measures are not considered. Therefore this review is an initial attempt to map available diffuse pollution abatement measures. It is necessary to increase chances in later steps.

4.4.1 General framework for diffuse pollution measures

Diffuse pollution has wide variety of abatement measures, which could be categorized in to many categories. Figure 4 presents one attempt to map diffuse pollution abatement measures. This is not intended to be complete picture of everything available at this moment, rather just to ease reader understanding about the range of diffuse pollution abatement options. Following sections will provide closer presentation on different measures under different categories and groups.

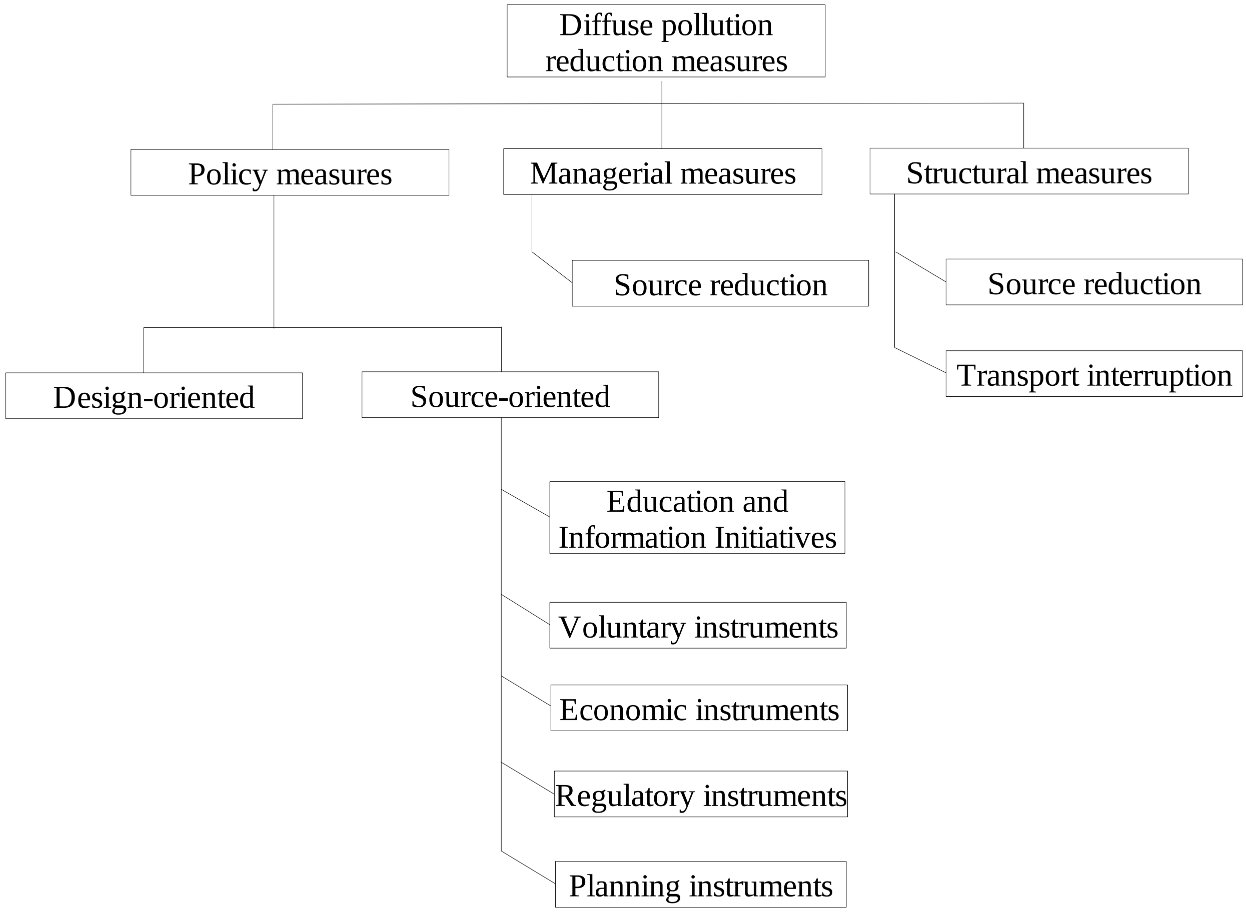

Figure 4: Diffuse pollution abatement measures.

4.4.2 Policy measures

Design-oriented policy measures are not often mentioned among diffuse pollution problems solutions. However recent developments in environmental science emphasizes that the most efficient way to solve problem is to avoid it by looking into solutions already in design stage. Indeed focus in diffuse pollution management was placed mainly on nutrients. Thus other problems as pollution with hazardous substances, such as different heavy metals, pesticides, fragrances, residues of medicines, etc, are left behind even though they could be crucial to water ecosystems. Moreover, it is now clear that for some pollutants the biggest amounts of pollution comes from factory doors rather than from factory pipes. Therefore design-oriented policies are crucial for water quality management.

A very good article on this topic is written by Van Ast et al. (2005) “Product Policy as an Instrument for Water Quality Management”. This article presents such tools as Environmental Product Declarations, Life cycle Analysis, Eco-design, Product Panels, Eco-labels, Product Stewardship. Most of those tools are voluntary at the moment. However attention to them is increasing, since industries, especially in developed countries, are pressured more by environmental and other groups to accept more responsibility for their actions and do something about it. Design-oriented policies are seen as important components to overall strategy to reduce diffuse pollution problems.

Another group of policy measures are source-oriented. Those measures are designated to control sources of diffuse pollution. Gunningham & Sinclair (2005) article presented quite an elaborated list on policy options for agricultural diffuse pollution abatement. According to them, education and information initiatives policy group includes information campaigns (government or industry associations), off-site training in environmental management, on-site training in environmental management, information from suppliers, soils, manure and water monitoring. Voluntary instruments include industry codes of practice, environmental management standards, voluntary agreements. Economic instrument group includes input taxes on levies and nitrogen and phosphorus fertilizers, or pesticides, tradable nutrient quotas or emission trading, subsidies for external audits and/or the adoptions of the best practices, financial compensation for setting aside land (such as the creation of buffer strips), Liability Rules, which guide compensation decisions when polluters are sued for damages. Regulatory instruments encompass compulsory adoption of environmental management plans, placing a cap on polluting emissions, control of rates of fertilizer application, ban on environmentally risky farm practices, compulsory disposal methods of farm waste (particularly manure), cross compliance provisions. Planning instruments include rezoning to exclude agriculture, land retirement contracts or covenants, land management contracts or covenants.

Economic instruments group according to many authors (Collins & Anthony 2007, Barnes et al. 2008, Kastens & Newig 2007) might be more effective option to tackle diffuse pollution problem, while voluntary measures are seen as quite ineffective comparing to other measures (Gunningham & Sinclair 2005). One of the most important criteria used in comparison of different measures is CEA. If taxation is chosen option, it is argued that should be as close as possible to Polluter Pays Principle (Barnes et al. 2008). However taxation is not usually seen as the best option as it generally tend to have of low political acceptability (Gunningham & Sinclair 2005). Different types of trading schemes could be more efficient (Wang et al. 2004). Nevertheless experience of countries for long time dealing with diffuse pollution problems shows that only some political measures targeted at diffuse pollution are far from enough to make a noticeable change. Therefore current plans for diffuse pollution reduction is turning to more holistic approach. For instance Danish 3 Action Plan for the Aquatic Environment is based on integrated approach, which promotes aquatic environment protection through combination of development alterations, nature protection and restoration of rivers and wetlands to their natural state (Kronvang et al. 2008). Similar trends are seen in other countries as well. WFD is an example of legislation, which encourages usage of this integrated approach.

4.4.3 Managerial measures

Managerial are such types of measures, which is applied in a field, yet it does not require any special structures to be build to catch pollutants. This might be the most attractive group of measures for diffuse pollution managers, since it often does not require substantial investments. It is also probably the most popular among politicians as well. Managerial and structural measures together are also called Best Management Practices (BMPs) in the US and Best Environmental Practices (BEPs) in Europe. They are included into many legislation such as WFD, Helsinki Convention, Clean Water Act, etc.

One of the best presentations of diffuse pollution abatement measures on a field level is given in Ritter & Shirmohammadi book “Agricultural Nonpoint Source Pollution: Watershed Management and Hydrology” (2001). This book introduces such managerial tools as conservation tillage, contour farming, strip cropping, cover crops, crop rotation, nutrient management, Integrated Pest Management, precision farming. Nutrient management probably is among the most used measures from that list, since over-fertilization is a very important source of environmental degradation in intensive agricultural areas. Nutrient management is defined as optimization of the nutrient application with objective to maximize yield while minimizing leakage of nutrients to water bodies (Ritter & Shirmohammadi 2001). Nutrient management plans quite often are obligatory for farms in the countries, which puts efforts to abate diffuse pollution from agriculture. For instance in Denmark fertilization plans are mandatory from 1987 (Kronvang et al. 2008). Among nutrient management techniques could be listed split application of fertilizers and precision farming (Ritter & Shirmohammadi 2001). Split application of fertilizers provides better uptake of nutrients by plants. Precision farming provides cost saving opportunities by directing fertilization just where it is needed. However, optimization of fertilization (in time and space) doesn't have a potential alone to solve diffuse pollution problem (Gustafson et al. 2000). Researchers showed that other measures have to be used to address diffuse pollution problem properly.

Many works showed that catch crops or cover crops is quite cheap and a very effective measure (Lacroix et al. 2005). It is defined as crops grown between harvest and planting periods (Ritter & Shirmohammadi 2001). According to Gustafson et al. (2000) those crops could reduce up to 75 % of nitrogen losses in single year and up to 50 % over successive years. Combination of cover plants with crop rotation is a low-cost practice with large environmental and economical benefits (Ritter & Shirmohammadi 2001). Crop rotation has been used already for quite a long time. Not only could it provide savings on fertilizers, but also on pesticides, since specialized pests are not survive, because of habitat change. Conservation tillage is another measure, which would require substantial investments into equipment for farmers and some change in farming practices. Conservation tillage is defined as “any tillage and planting system that maintains at least around 1100 kilograms per hectare of flat, small-grain residue equivalent on surface during critical wind erosion periods” (Ritter & Shirmohammadi 2001). Researches suggested that up to 90 % of erosion could be eliminated by this measure (Baker & Laflen 1982). Contour farming is used against sheet and rill erosion. It is defined as the sloping of farmland in such a way that land cultivation in a field is done in contours (USDA a 2007). Similar to this is strip cropping, which is divided into contour and field strip cropping. The difference between the two is that contour stripping involves just growing crops along the contours of the field, while field strip cropping arranges strips of crops perpendicular to the “general slope” (Ritter & Shirmohammadi 2001). Integrated Pest Management (IPM) is providing win-win situation for farmer and environment. Farmers save money from pesticides, which would not provide any benefits and also could reduce his yields while environment is exposed to less pollution. IPM is defined as “the use of management practices for pest control that could result in efficient production of food and fiber using the minimum amount of synthetic pesticides“ (Ritter & Shirmohammadi 2001). The last managerial measure to mention, which also partly could be assigned to structural source reduction measures, is rotational grazing. This type of measure allows land to recover by rotating livestock between different areas (USDA b 2007). It also increases profits. Researchers showed that increase in profits is 72 % comparing to continuous grazing practices (Ritter & Shirmohammadi 2001).

4.4.4 Structural measures

Structural measures require some structures to be built in a field to abate diffuse pollution. Those structures could be targeted at the non-point sources or at transport routes of pollutants. Therefore structural measures are divided into two groups source reduction measures and transport interception measures.

4.4.4.1 Source reduction measures

Stream fencing is one of simpler source reduction structural measures. It is defined as the "construction of a barrier, usually a wire of electrified fence, along the stream corridors that exclude livestock from direct access to streams" (Ritter & Shirmohammadi 2001). According to Brouwer & Blois (2008) the net to keep cattle away from water bodies is among most cost-effective measures for reduction of bathing water contamination, even its the installation and maintenance cost could still be substantial. Providing of-stream water sources for cattle could be another way to reduce diffuse pollution. Manure storage facilities is often requirement for livestock farms in developed countries. Since it's installation cost is very high, governments often provide part of finance needed to build those structures. Manure is stored in those structures until the right time to use it for fertilization. Wrong manure application timing could result in low absorption of nutrients by plants and high leakage rates to water bodies. However the "right time" is only a small period during a year. Therefore manure facilities are required by governmental agencies and they should have six or more months storage capacity for the manure or slurry produced in the farm. There are other solutions connected to manure. In article of Kasten & Newig (2007) is mentioned biogass production with nitrogen removal, which according to the authors is seen as key solution to nitrate problem in intensive agriculture areas of Germany. It could also be beneficial for employment.

Sediment detention structures are listed among structural source reduction measures. Most of these structures are simply small dams or impoundments, which traps or slows stormwater during the storm event and slowly releases after it (Jarret 1995). There are different types of them as check dams, sediment basins, impoundments terraces. The main problems are construction and maintenance costs, inability to effect transport of fine particles (which transport most of nutrients and pesticides attached to them), inability to stop eroding particles in a field and land requirements (Ritter & Shirmohammadi 2001). The last source measures to be presented are terraces, vegetated waterways, diversions. Terraces are defined as ridges and channels combined in certain system across the slope (USDA 2008). According to Ritter & Shirmohammadi (2001) effectiveness of terraces in reduction of soils, nutrient loss and runoff volume are 94-95 %, 56-92 %, 73-88 % respectively. However, high initial capital costs might be one of the problems repelling for use of this measure. Vegetated waterways are channels around the fields with established vegetation to stable conveyance runoff and increase sedimentation (Ritter & Shirmohammadi 2001). Diversions are re-directions of flow around or from potential diffuse sources. Most of diversions are vegetated waterways.

4.4.4.2 Transport interception measures

Wetlands and buffer strips are the most important structural transport interception measures, which are often considered when selection between different diffuse pollution reduction measures is done. Wetlands are used for treatment of effluents from municipal, industrial and agricultural sources. According to Bystrom et al. (2000) wetlands could be called pointifiers since they have the ability to collect and treat surface water diffuse pollution in one place. Wetlands is a cost-effective diffuse pollution abatement measure able to treat a wide range of pollutants even under heavy loads of them (Ritter & Shirmohammadi 2001). Installation costs of wetlands are high. However, comparing to other options they are among the most cost-effective ways to reach diffuse pollution abatement targets. For instance Lacroix et al. (2005) states that reaching diffuse pollution reduction goal with 50 % reduction of fertilizers are a more costly strategy than wetland restoration. Wetlands removal efficiencies given in (Ritter & Shirmohammadi 2001) are 50-90% for BOD_5, up to 86 % for COD, 95 % for Total Kjeldahl Nitrogen, 99 % for Total Phosphorus. However it is not that simple. Wetland functioning depends a lot on season and climatic conditions. During the year, wetlands have retention periods and then release periods (Gustafson et al. 2000). Also they have certain life time where at some point the absorbing capacity is at its largest. After that wetland could start releasing pollutants. There are many other advantages and disadvantages of wetlands. Ritter & Shirmohammadi (2001) list green space, wildlife habitats and recreational/educational areas to advantages of wetlands. To disadvantages: pest breeding ground, no precise design and operation guidelines, area requirements.

Buffer zones by Ritter & Shirmohammadi (2001) are defined as “planted or indigenous bands of vegetation that are situated between pollutant source areas and received waters to remove pollutants from surface and subsurface runoff”. Buffer zones are currently established requirement for farmers at least in the EU. Buffer zones are quite efficient in reducing pollutants which travel with overland flow. According to some authors buffer strips alone would be enough to reduce sediment load reaching the outlet of watershed by half (Tim & Jolly 1994). Buffers strips also are efficient for removing pathogens, nutrients and pesticides. Moreover, they provide other benefits as well, like esthetic and ecological improvements, habitats for wildlife. However, buffer strips need certain maintenance and also have defined life time (around 10 years) after which they could become a source instead of a sink (Ritter & Shirmohammadi 2001).

4.4.5 Conclusion

This short review couldn't present all inland water diffuse pollution abatement measures available at the moment. Yet hopefully it gave a good hint about variety of those measures and complexity in selecting them. There are few other important aspects to consider while selecting measures, which were hardly mentioned above. First is that interaction and opinion of stakeholders could not be downgraded. It is necessary to involve stakeholder groups for diffuse pollution problem solution, not only to gain insight in local knowledge, but also for gaining more acceptability and support for planned actions. Without this acceptability and support, even the most scientifically sound diffuse pollution reduction plans are at huge risk of failing (Ast et al. 2005). Another important detail to take into account is that the total abatement costs in many cases are smaller, if downstream measures are applied (Baresel 2007). However, if the aim is to increase water quality in all catchment areas and not only to reduce pollutant loads from it, this knowledge would hardly be applied.

5 Method application

5.1 Model selection

For the purpose of this project SWAT model has been selected, since according to available literature, it is one of the most appropriate models for inland waters diffuse pollution assessment. Moreover this model has been extensively tested around the world, well documented and available for no charge. Short description of SWAT model was presented in literature part. For more detailed information reader is referred to the model documentation: user’s guide (Winchell et al. 2008), theoretical documentation (Neitsch et al. 2005) and input/output file documentation (Neitsch et al. 2004). ArcSWAT 2.1.5 version was used, as it was the latest version for Windows XP operation system at the time of working with the project. All GIS operations have been performed using ArcGIS 9.2 and calculations done using Microsoft Office Excel 2000.

5.2 Area description

The area selected for the study was the small Graisupis river catchment area in Kedainiai district, Lithuania (Figure 5). Total area of this catchment is around 14.2 square kilometers. This catchment area was chosen, because it is the only area in Lithuania, where detail monitoring of agricultural activities and water quality has been performed for nearly ten years (since 1999). The Water Management Institute of Lithuania University of Agriculture (WMI) is responsible for this monitoring. It is also required to report monitoring results to the Lithuanian Environmental Protection Agency (LEPA). Moreover this catchment represents typical agricultural areas, which occupy large part of the country. Those agricultural areas are responsible for the biggest part of diffuse pollution problems in Lithuania (Center of Environmental Policy 2008).

Agricultural lands and pastures dominate Graisupis river catchment area. According to WMI (2009) they take up 71% of area. Forests occupy 28 % of the territory. 1 % of the area is occupied by farm buildings and the rest 0.2 % by the water bodies. This catchment is located in the Lithuanian Middle Plane, 57-70 meters above the sea level. Dominated soils are Cambisol and Gleysol. Small settlement of Azuolaiciai with 26 homesteads are located in catchment. Plant growing is the predominant agricultural activity. Yet there is one bigger animal farm with around 200 cattle. Most crops cultivated in the area are wheat, barley, maize, sugar beet, winter crops.

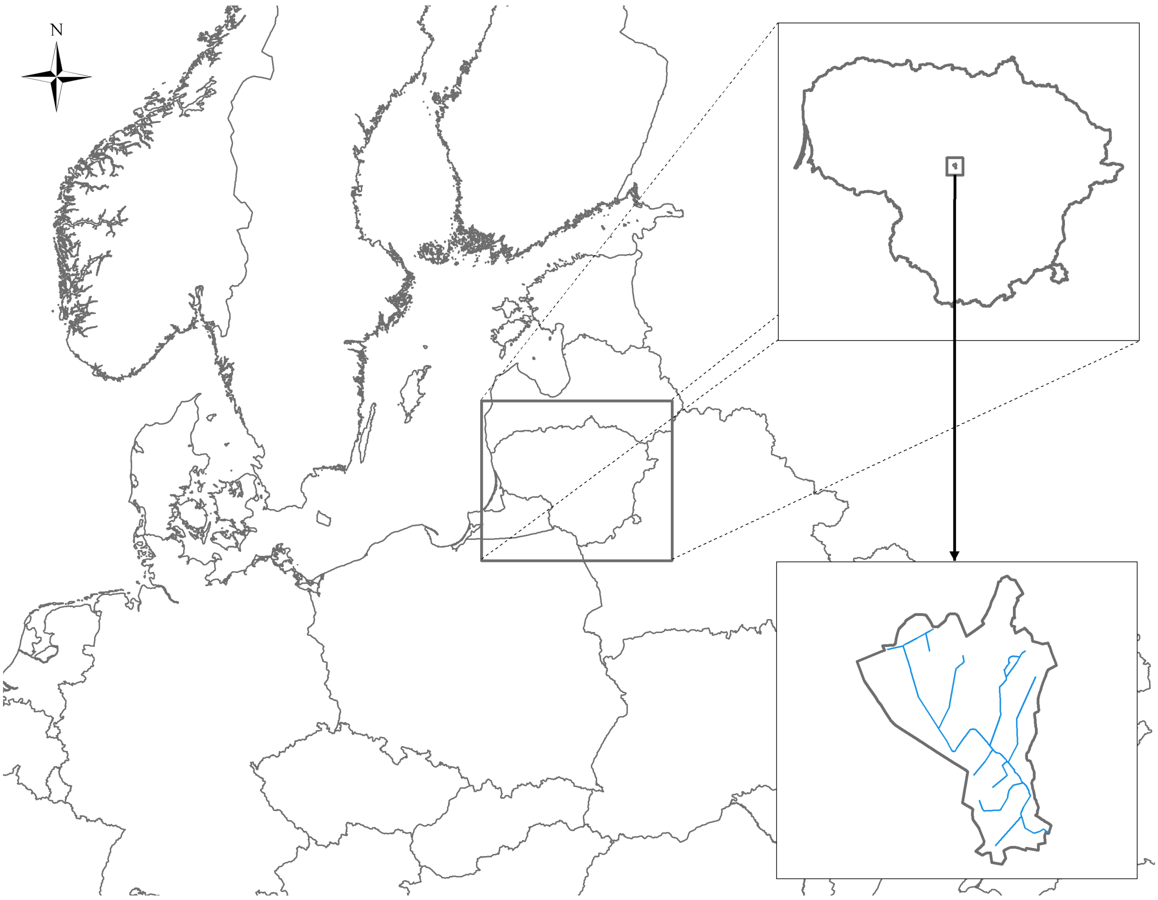

Figure 5: Location of catchment.

5.3 Data

Most data to run the SWAT model and for the economical part have been obtained from LEPA. LEPA itself organizes and supports air, water, waste and other monitoring activities. Therefore much data are available within the organization. Other data (which LEPA lacks) was obtained through cooperation with other governmental, scientific institutions or brought from commercial bodies.

The Digital Elevation Model (DEM) was not available at the LEPA, however it had the Point Elevation Model (.xyz text files) obtained from National Land Service Under the Ministry of Agriculture of the Republic of Lithuania with resolution of 5 meters. This has been transformed using an algorithm written in Matlab to text files importable into ArcGIS and then converted in to GRID file (Figure 7 a). Elevation data was recorded in year 2005. This is the latest and most precise data with regard to elevation for the territory of Lithuania. Land use (Figure 7 d), catchment borders, river channel, flow, water monitoring data has been obtained from report of WMI “Land use, chemical composition of water and precipitation analysis in typical Middle and West Lithuania agro-ecosystems” of year 2009. These reports are issued annually for LEPA to supply monitoring results from monitoring of typical agricultural catchments. The latest report presents data from 2 small river catchments: Graisupis and Lyzena. Yet only Graisupis have longer monitoring period (around 10 years Graisupis and 1 year Lyzena). The latest report describes monitoring results for year 2008. Hourly meteorological data for temperatures, precipitation, relative humidity, wind, solar radiation, temperature dew point for the year 2008 have been obtained from LEPA. Lithuanian Hydrometeorological Service under the Ministry of Environment supplied this data. Daily precipitation and temperature have been available within LEPA River Basin Management Department for the years between 1993 to 2008. This data was used as an input and for calculation of parameters to Weather Data Definition and Weather Generator. All meteorological except for solar radiation was collected in Dotnuva meteorological station (Figure 6). Solar radiation data was collected in Kaunas meteorological station.

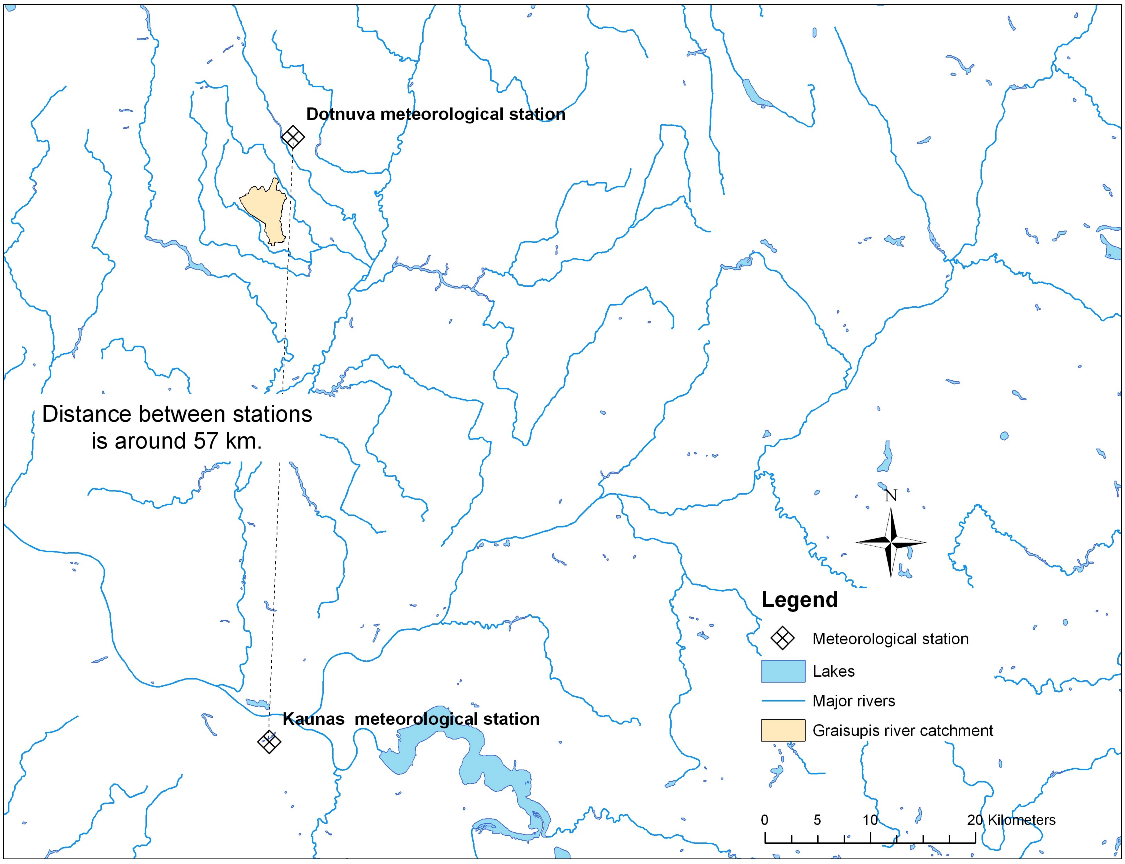

Figure 6: Location of meteorological stations.

The soil database have been obtained from LEPA. Its scale was 1:300000 and the soils classified into national and FAO soil classification systems (Figure 7 c). Even though this soil database is too coarse for small river catchment modeling and better data were available, it has been selected for input. Official procedures to obtain more detail soil data (at scale 1:10000) would have prolonged project without benefiting its aims. Therefore the latest data haven't been used in the analysis. Most of soil parameters for the model have been obtained from Harmonized World Soil Database (HWSD) (Fischer et al. 2008). Other parameters have been estimated, left default or obtained through calibration.

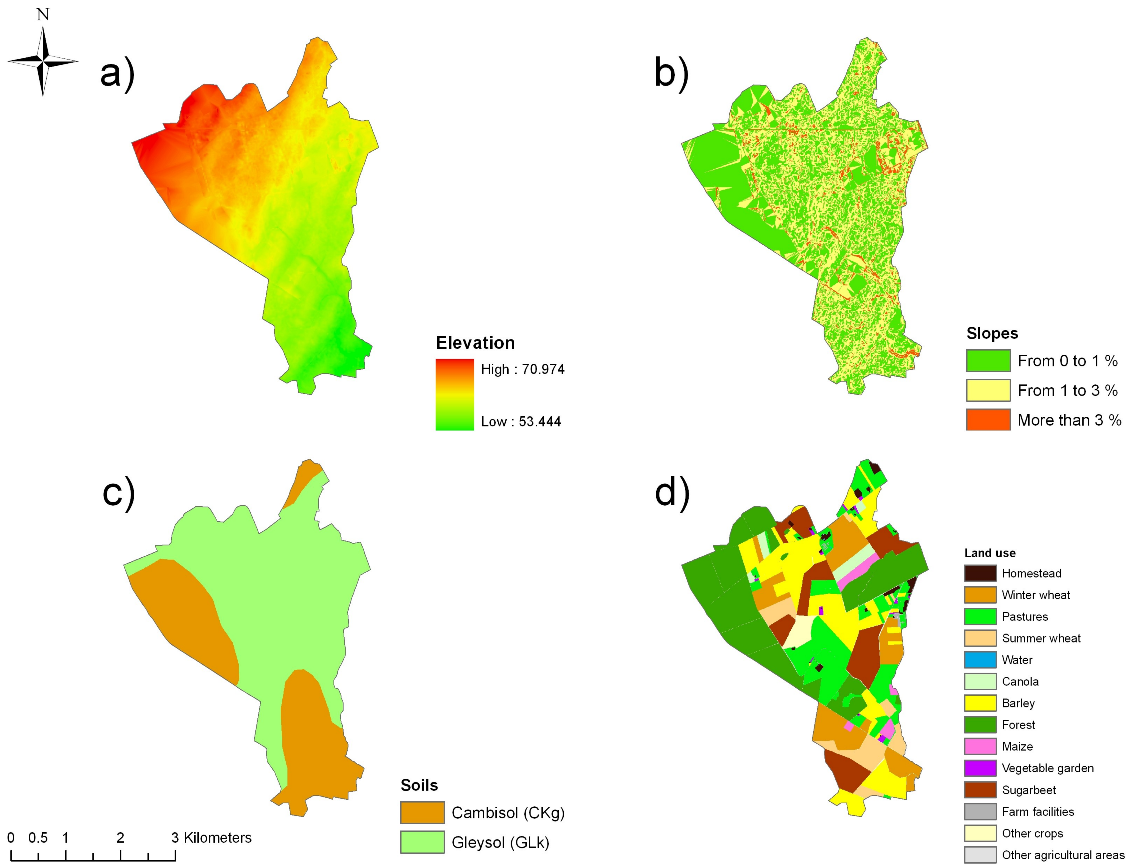

Figure 7: Elevation (a), slope (b), soil (c) and land use (d) data for Graisupis river catchment.

Economical values on costs of growing winter crops were obtained from report "Preparation of recommendations for reduction of erosion from agricultural territories and effective implementation of good agricultural practice measures in pursuance of reduction pollution to water bodies" prepared by the Agrochemical Research Center of Lithuanian Institute of Agriculture for LEPA (Mazvila et al. 2009). Economical values of wetlands have been obtained from another report prepared for LEPA. This report is based on study organized by Nature Heritage Fund called "Feasibility assessment of wetland creation/restoration to reduce pollution load of organic material and nutrients to water bodies and preparation of recommendations for wetland creation/restoration" (Gulbinas et al. 2009).

5.4 Model preparation

Data have been gathered from different sources, changed to the right format to be able to use it in model setup. The SWAT model has quite straightforward model setup routine. Even an inexperienced user, if familiar with GIS software and SWAT documentation, would be able to prepare model. First step is Watershed Delineator where user defines watersheds, streams, sub-basins and calculates their parameters. In this project predefined streams and watersheds have been used, which were obtained from report of WMI (2009). Two reaches and two watersheds have been used as an input to the model. Though one reach and one watershed were phony (extremely small) since the SWAT model doesn't allow modeling just one sub-basin in watershed. Therefore all Graisupis river catchment area was modeled as one sub-basin. Predefined streams and watersheds have been chosen, because Graisupis river catchment undergone scientific studies, which specified exact catchment area taking into account drainage schemes. DEM-based stream definition and delineation of watershed was providing different results. Thus, as data from WMI report have been obtained from field measurements, it has been selected for Watershed Delineation.

5.4.1 Model input parameters

Land use through monitoring activities is mapped yearly. Land use of 2008 has been used as input for the model. Most appropriate parameter compositions have been assigned to the land use categories from model crop and urban databases through look up table. Assigned categories are presented below in Table 2.

Table 2: Assigned land use from SWAT database comparing to original land use.

Original land use	Assigned land use from crop or urban databases	Code of assigned land use
Homestead	Residential-Low Density	URLD
Winter wheat	Winter Wheat	WWHT
Pastures	Pastures	PAST
Summer wheat	Corn	CORN
Water	Water	WATR
Canola	Spring Canola-Polish	CANP
Barley	Barley	BARL
Forest	Forest-Deciduous	FRSD
Maize	Sweet corn	SCRN
Vegetable garden	Garden or Canning Peas	PEAS
Sugarbeet	Sugarbeet	SGBT
Farm facilities	Industrial	UIDU
Other crops	Agricultural Land-Close-grown	AGRC
Other agricultural areas	Agricultural Land-Generic	AGRL

Clipped soil layer had just 2 soil categories according to FAO classification. Most parameters for those categories have been obtained from HWSD. They have been used as follows (Table 3 & Table 4).

Table 3: General soil parameters.

Soil Component Parameters	Definition	Soil 1	Soil 2	Data source
SNAM	Soil name	CMg	GLk	
LAYERS	Number of layers	2	2	HWSD
HYDGRP	Soil hydrologic group (A,B, C, or D)	B	B	HWSD
SOL_ZMX (mm)	Maximum rooting depth of soils profile (mm)	800	800	HWSD
ANION_EXCL (fraction)	Fraction of porosity (void space) from which anions are excluded	0.5	0.5	Default
SOL_CRK) (m3/m3)	Potential or maximum crack volume of the soil profile expressed as fraction of the total soil profile	0.5	0.5	Default

Table 4. Layer specific soil parameters.

Soil Layer Parameters	Definition	Soil 1		Soil 2		Data source
		Layer 1	Layer 2	Layer 1	Layer 2	
SOL_Z (mm)	Depth from soil surface to bottom of layer (mm)	300	1000	300	1000	HWSD
SOL_BD (g/cm3)	Moist bulk density (Mg/m^3 or g/cm^3)	1.42	1.36	1.42	1.42	HWSD
SOL_AWC (mm/mm)	Available water capacity of the soil layer (mm H_2O/mm soil)	0.15	0.15	0.15	0.15	HWSD
SOL_CBN (% wt.)	Organic carbon content (% soil weight)	1	0.47	4	0.44	HWSD
SOL_K (mm/hr)	Saturated hydraulic conductivity (mm/hr)	83	46	57	76	Calculated
CLAY (% wt.)	Clay content (% soil weight)	19	27	19	19	HWSD
SILT (% wt.)	Silt content (% soil weight)	36	34	40	37	HWSD
SAND (% wt.)	Sand content (% soil weight)	45	39	41	44	HWSD
ROCK (% wt.)	Rock fragment content (% total weight)	4	18	4	5	HWSD
SOL_ALB (fraction)	Moist soil albedo	0.01	0.08	0.01	0.08	HWSD
USLE_K	USLE equation soil erodibility (K) factor	0.16	0.167	0.134	0.175	Calculated
SOL_EC (dS/m)	Electrical conductivity (dS/m)	0.1	0.1	0.1	0.1	HWSD

The only parameters calculated were USLE_K and SOL_K. USLE_K parameter has been calculated from sand, silt, clay, organic content parameters using Williams equation given in SWAT Input/Output File Documentation (Neitsch et al. 2004). SOL_K values have been estimated using sand content and SOL_K relationship calculated from records in SWAT soil database. Equation for this relationship is SOL_K=0.1635*SAND%^2-7.5108*SAND%+90.227. Determination coefficient for this equation is 0.69.

Multiple slope discretization have been used for model setup with 3 categories: from 0 % to 1 %, from 1 % to 3 % and from 3 % and more. During HRU Definition multiple HRUs have been the selected option as it accounted for the variability in the catchment. To reduce the level of details in regard to account for the most important processes threshold as percentage of different land use, soil and slope classes has been set to 10 percent for HRU Definition.

Data of 2008 Dotnuva meteorological station have been used as an input for Weather Data Definition. Kaunas meteorological station data was used just for solar radiation input since in Dotnuva meteorological station this parameter was not measured. All inputs for Weather Station Definition have been supplied, therefore leaving none of the parameters for Weather Generator simulation. Yet Weather Generator parameters have been calculated and supplied as well for forecasting simulations. Weather Generators input parameters are presented in the Table 5.

Table 5. Weather station parameters (parameter code explanation is located below the table). Parameters calculated from data supplied by Lithuanian Hydrometeorological Service.

Month	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	PCPMM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	RAINHHMX	SOLARAV	DEWPT	WNDAV
1	**3.96**	**-14.9**	**2.86**	**5.63**	**38.26**	**2.06**	**1.48**	**0.32**	**0.65**	**14.88**	**10.7**	**41.22**	**-3.19**	**3.63**
2	**3.15**	**-12.8**	**2.81**	**5.57**	**32.22**	**1.78**	**1.31**	**0.4**	**0.63**	**14.81**	**5.4**	**76.57**	**-1.05**	**3.1**
3	**6.53**	**-5.93**	**2.6**	**4.5**	**29.96**	**1.93**	**1.29**	**0.31**	**0.52**	**12.25**	**9.7**	**172.9**	**-1.63**	**2.63**
4	**15.53**	**0.52**	**2**	**1.81**	**28.86**	**2.12**	**1.27**	**0.22**	**0.55**	**9.75**	**11.2**	**274.7**	**2.06**	**2.28**
5	**19.7**	**6.47**	**1.94**	**1.91**	**46.17**	**3.22**	**1.37**	**0.25**	**0.54**	**11.13**	**18.7**	**367.1**	**4.01**	**2.19**
6	**21.38**	**11.41**	**2.34**	**1.19**	**54.61**	**3.48**	**1.5**	**0.38**	**0.52**	**13.44**	**14.9**	**457.1**	**8.59**	**2.22**
7	**23.68**	**14.36**	**2.49**	**2**	**69.48**	**4.41**	**1.31**	**0.37**	**0.48**	**12.88**	**18.35**	**422.7**	**11.9**	**1.9**
8	**22.12**	**12.93**	**2.01**	**1.8**	**67.14**	**4.5**	**1.23**	**0.33**	**0.6**	**13.88**	**18.3**	**292.7**	**12.65**	**2.23**
9	**17.94**	**6.89**	**2.31**	**2.51**	**41.89**	**3.1**	**1.31**	**0.29**	**0.53**	**11.31**	**18.3**	**215.4**	**8.08**	**2.19**
10	**13.52**	**0.59**	**1.22**	**2.06**	**53.61**	**3.3**	**1.41**	**0.32**	**0.61**	**13.69**	**17.2**	**111.6**	**6.11**	**2.42**
11	**8.43**	**-5.97**	**2.21**	**4.31**	**37.11**	**2.46**	**1.34**	**0.37**	**0.54**	**13**	**11.3**	**59.2**	**1.25**	**2.95**
12	**4.64**	**-10.9**	**2.79**	**6.95**	**40.97**	**2.32**	**1.46**	**0.37**	**0.59**	**14.75**	**8.2**	**29.5**	**-1.46**	**2.38**

TMPMX – Average or mean daily maximum air temperature for month (℃)
TMPMN - Average or mean daily minimum air temperature for month (℃)
TMPSTDMX – Standard deviation for daily maximum air temperature in month (℃)
TMPSTDMN – Standard deviation for daily minimum air temperature in month (℃)
PCPMM – Average or mean total monthly precipitation (mm H_2O)
PCPSTD – Standard deviation for daily precipitation in month (mm H_2O/day)
PCPSKW – Skew coefficient for daily precipitation in month
PR_W1 – Probability of a wet day following a dry day in the month
PR_W2 – Probability of wet day following a wet day in the month
PCPD – Average number of days of precipitation in month
RAINHHMX – Maximum 0.5 hour rainfall in entire period of record for month (mm H_2O)
SOLARAV – Average daily solar radiation for month (MJ/m^2day)
DEWPT – Average daily dew point temperature in month (℃)
WNDAV – Average daily wind speed in month (m/s)

Additional parameters of tile drains were used from model recommended parameters to include tile drainage in the model, because it exists in the Graisupis river catchment. Those parameters were set DDRAIN_BSN1 (depth to subsurface drain (mm)) to 1000, TDRAIN_BSN2 (time to drain soil to field capacity (hrs)) to 48 and GDRAIN_BSN3 (drain tile lag time (hrs)) to 48.

5.4.2 Calibration

The prepared model was run for one year (period of 2008/01/01 to 2008/12/31). Initial results were far from satisfying. Nash-Sutcliffe[13] coefficients for daily and monthly flow were –8920.322 and –102083.401 respectively, while determination coefficients 0.000004 and 0.05. Therefore calibration has performed to obtain better results.

13 Nash-Sutcliffe coefficient is used in hydrology to evaluate model predicting power. Values of it ranging from 1 to -∞. 1 is indicating perfect fit, 0 that model predictions are as good as calculated mean from observed data. If value is less than 0 then the mean from observed data is better predictor than model being evaluated (Nash & Sutcliffe 1970).

Firstly, important parameters for flow were identified during sensitivity analysis, which is built in the latest SWAT version. Those important parameters were used for automatic calibration (also build into SWAT model) to get model results closer to measured in the field. After calibration Nash-Sutcliffe coefficient for daily flow reached 0.373 and determination coefficient 0.382 (Figure 8), while calibration results for month flow were 0.422 for Nash-Sutcliffe coefficient and 0.477 for determination coefficient. As model was intended for use only on yearly average simulation these results were considered sufficient. Parameters changed in calibration process are presented in Table 6.

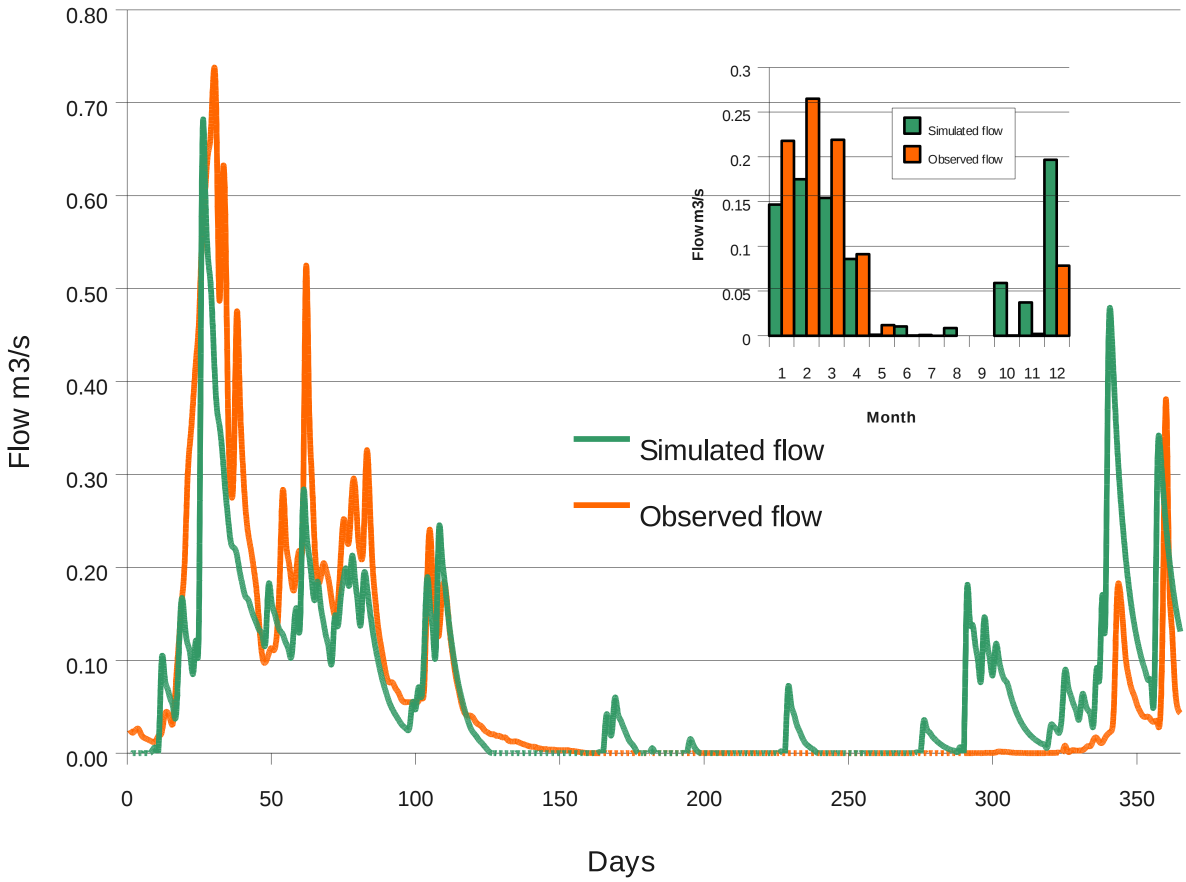

Figure 8: Simulation of flow at the outflow from catchment after calibration.

Table 6. Original parameter values and their values after calibration.

Parameters	Definition	Original	Replaced by value	Multiplied with factor
Alpha_Bf	Baseflow alpha factor [days]	0.048	0.18	
Canmx	Maximum canopy storage [mm]	0	418.14	
Ch_K2	Channel effective hydraulic conductivity [mm/hr]	0.014	131.43	
Ch_N2	Manning n value for main channel	0.014	0.3231	
CN2	Initial SCS CN II value	Dependent on management		1.39
Esco	Soil evaporation compensation factor	0.6	0.94	
Gw_Delay	Groundwater delays [days]	50	21	

Gw_Rewap	Groundwater “revap” coefficient	0.03	0.78	
Revapmn	Threshold water depth in the shallow aquifer for “revap” [mm]	1.0	296.73	
Smtmp	Snow melt base temperature [℃]	0.5	0.57	
Sol_Alb	Moist soil albedo	0.01	0.0091	
Sol_Awc	Available water capacity [mmH_2O/mm soil]	0.15		0.44
Sol_K	Saturated hydraulic conductivity [mm/hr]	Dependant of soils		1.25
Surlag	Surface runoff lag day [days]	4.0	8.2159	
Timp	Snow pack temperature lag factor	1	0.3758	
Phoskod*	Phosphorus soil partitioning coefficient	175	15.603	
Perco*	Phosphorus percolation coefficient	10	16.430	

** These parameters were used only for water quality calibration.*

Water quality parameters are more complicated to calibrate and obtained results were far from satisfactory. For instance Nash-Sutcliffe coefficient for monthly load of nitrates was 0.117 and determination coefficient 0.061, ammonium –0.274 and 0.2841, organic nitrogen 0.186 and 0.594, organic phosphorus –0.838 and 0.558, mineral phosphates –0.446 and 0.6889, dissolved oxygen –0.834 and 0.233 respectively.

It requires a lot of experience with model, knowledge of the area, as well as field measurements of important parameters and data required by the model. Yet the most important it requires much time. Since purpose of this project was not to accurately represent effectiveness of certain diffuse pollution reduction measures, rather than to illustrate the main principles and ideas behind usage of CEA and ERA in selection of diffuse pollution abatement measures, calibration (and overall modeling) part did not received efforts required for model to reach a good prognosis, capacities or results to be reliable in their application. However, those results are certainly enough to demonstrate principles of method application. This was the primary reason why only one-year observed water quality data inputs were used for this study and why validation procedure was not performed as well.

5.4.3 Inputs to assess abatement measures

Two measures have been selected for assessment of inland water diffuse pollution abatement. They are: wetlands and winter crops. There were few reasons for this. First, both those measures often are suggested among the most cost effective ways to reduce diffuse pollution. The second reason was, that economical evaluation was available for those measures (LEPA reports). Moreover those measures represented different types of diffuse pollution abatement measures. Wetland represent transport interception measures, while winter crops managerial measure. Lastly, both of those measures are viable options for diffuse pollution reduction in the Graisupis river catchment.

The wetland was placed in the outflow of the catchment. It was assumed that all the catchment area would drain to the wetland. Several examples of wetland in different sizes were modeled. Those sizes were 0.5, 1, 2.5, 5, 10 hectares. Depth of wetland for volume calculation was assumed to be 0.5 meters. Maximum area and volume of wetland was assumed to be twice as large as a normal area and volume. Initial water quality parameters have been calculated from monitoring data of 2008 (yearly averages were used). Since sediment concentrations haven’t been monitored, sediment values had been calculated from model (model run for 1000 years and then concentrations averaged). Other parameters haven’t been changed from default model parameters. Parameters used for the wetland modeling are presented in the Table 7.

Table 7. Parameters used for wetland modeling.

Parameter name	Description of parameter	Value	Data source
IPND1	Beginning month of mid-year nutrient settling "season"	1	Default
IPND2	Ending month of mid-year nutrient settling "season"	1	Default
IFLOD1	Beginning month of non-flood season	0	Default
IFLOD2	Ending month of non-flood season	0	Default
NDTARG	Number of days needed to reach target storage from current pond storage	0	Default
WET_FR	Fraction of subbasin drains into wetland	1	Default
WET_NSA	Surface of wetland at normal water level (ha)	10*	Calculated for scenario
WET_NVOL	Volume of water stored in wetlands when filled to normal water level (10^4 m^3 H_2O)	50*	Calculated for scenario
WET_MXSA	Surface of wetland at maximum water level (ha)	20*	Calculated for scenario
WET_MXVOL	Volume of water stored in wetlands when filled to maximum water level (10^4 m^3 H_2O)	100*	Calculated for scenario
WET_VOL	Initial volume of water in wetlands (10^4 m^3 H_2O)	10	WMI 2009
WET_SED	Initial sediment concentration in wetland water (mg/L)	8.1	Calculated from model
WET_NSED	Equilibrium sediment concentration in wetland water (mg/L)	8.1	Calculated from model
WET_K	Hydraulic conductivity through bottom of wetland (mm/hr)	0	Default
PSELTLW1	Phosphorus settling rate in wetlands for month IPND1 through IPND2 (m/year)	10	Default
PSELTLW2	Phosphorus settling rate in wetlands for months other than IPND1-IPND2 (m/year)	10	Default
NSETLW1	Nitrogen settling rate in wetlands for months IPND1 though IPND2 (m/year)	5.5	Default
NSETLW2	Nitrogen settling rate in wetlands for months other than IPND1-IPND2 (m/year)	5.5	Default
CHLAW	Chlorophyll a production coefficient for wetlands	1	Default
SECCIW	Water clarity coefficient for wetlands	1	Default
WET_NO3	Initial concentration of NO_3-N in wetland (mgN/L)	4.92	WMI 2009
WET_SOLP	Initial concentration of soluble P in wetland (mg P/L)	0.07	WMI 2009
WET_ORGN	Initial concentration of organic N in wetland (mg N/L)	1.51	WMI 2009
WET_ORGP	Initial concentration of organic P in wetland (mg P/L)	0.09	WMI 2009

** Star market values have been varied depending of wetland size. Values given in the table are for wetland size of 10 hectares.*

For winter crop evaluation spring barley crop HRUs have been changed to winter barley leaving other parameters the same except for auto-fertilization, which have been removed when spring barley crops were changed to winter barley. Area for the crop change has been evaluated for 43, 83, 187 and 309 hectares. Values of evaluated crop change areas were dependent on HRU sizes.

For each option (wetland or increase in winter crops) model has been run for 1000 years. All inputs into the model were the same, except for weather parameter values, which were generated by Weather Generator from supplied data. Thus uncertainty about weather was introduced into the model. After model runs, concentrations from total load and flow data were calculated and probabilities of values falling into certain categories of water body ecological status, were calculated. However, to simplify assessment only nitrogen concentration was selected for this, since it was the driving force behind deterioration of water quality in the Graisupis river catchment. The change of probability comparing to baseline results has been plotted on one graph together with monetary cost of this change. In the end, using those graphs effectiveness of diffuse pollution abatement measures were evaluated and two measures compared with each other.

5.5 Results

5.5.1 Results from model preparation

During model preparation some results were obtained that were not important in the final stages. Yet it is important to show them since they increase understanding about model input and area specifics. Slopes during slope definition have been divided into tree groups: 0 to 1, 1 to 3 and more than 3. However after HRU definition only two groups have been left in the model, as only those groups occupied more than 10 % of area. Group from 0 to 1 has been assigned to 56 % of territory and from 1 to 3, 44 % of territory. In regard to soils 66 % of the Graisupis river catchment area is covered with Cambrisol type of soils and 34 % with Gleysol. After HRUs Definition only 5 land use types have been left (Figure 9). 14 % of area has been assigned to winter wheat, 14 % to sugarbeet, 18 % to pastures, 22 % to spring barley, and 32 % to deciduous forests. The final distribution of HRUs obtained after defining thresholds for HRUs Definition presented in the Figure 10. The most dominant is FRSD/CMg/0-1, which occupies around 14.4 % of the area, while most of others occupies nearly half. The following most larger HRUs are FRSD/GLk/0-1 8.8 %, BARL/GLk/1-3 8.6 %, PAST/GLk/1-3 8.1 % and PAST/GLk/0-1 6.4 %.

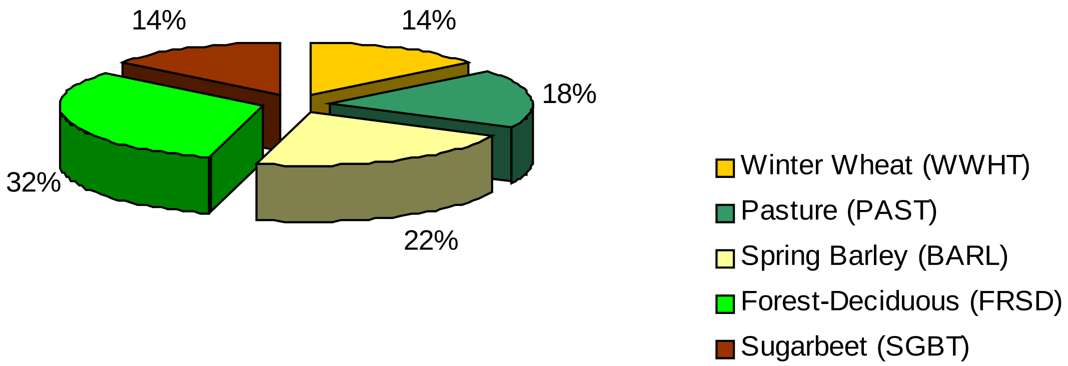

Figure 9: Land use distribution after HRU definition in the Graisupis river catchment.

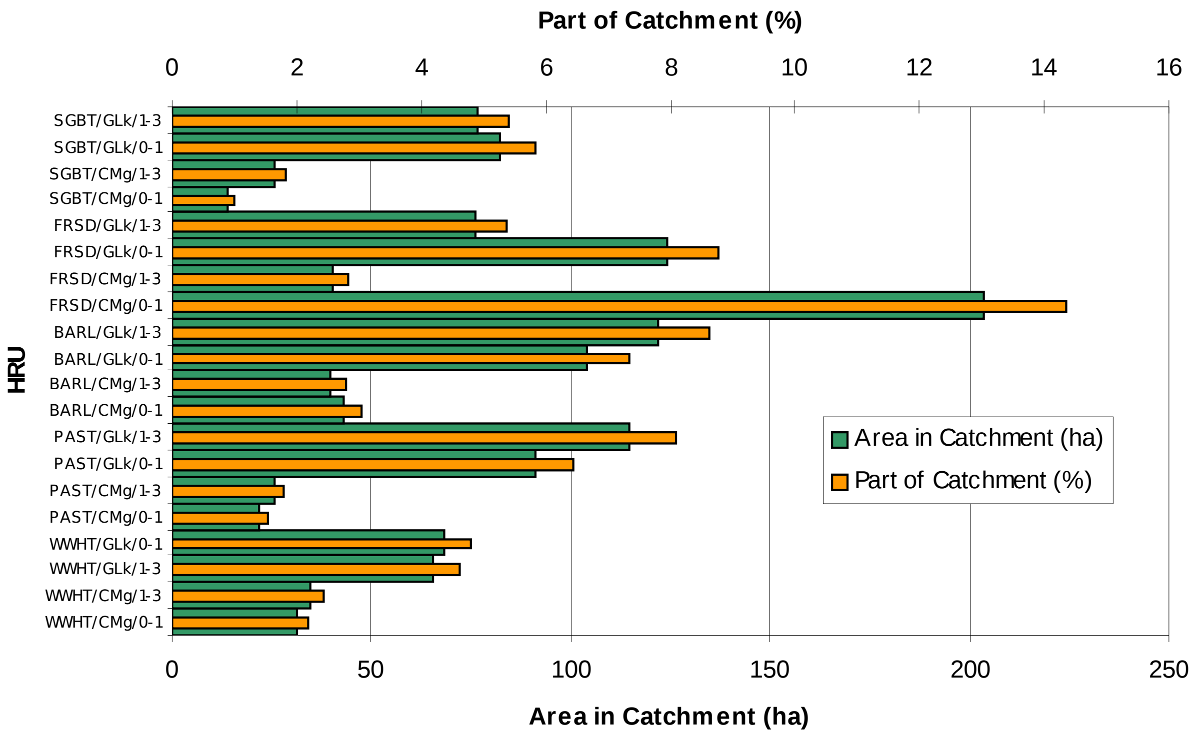

Figure 10: HRU distribution in the Graisupis river catchment according to total area covered by HRU and it's percentage part in catchment.

5.5.2 Results from modeling

Weather Generator is a simple way to induce stochasticity into SWAT model. It could be used for normal simulation or forecasting. Weather Generator is one way to account for uncertainty related to weather variation. In this study only uncertainties related to weather has been included in the model. The SWAT model has the option of choosing number of simulations for forecast period to account for uncertainties. Yet during this project due to lack of professional guidance related to model, it was not possible to run SWAT forecast simulation for more than one iteration. Therefore other way was chosen to obtain essential results for analysis. Statistical parameters were obtained from result distribution of modeling long enough period (1000 years).

SWAT model has been run for all chosen options of diffuse pollution abatement measures as well as baseline scenario[14]. The only part of the results are presented in the Figure 11 and Figure 12. Figures present just 100 year period[15], since putting more on the figure (up to 1000 simulated years) would impede ability to see the main pattern of effects for application of diffuse pollution abatement measures. In those two figures, it is possible to see that increased scale of diffuse pollution reduction measures would reduce nitrates level in the Graisupis river.

The model has slight wash of nitrates from the system with time. For results to be reliable and convincing one would need to look back into model inputs or to use forecast simulation with many iterations. However, since the aim of the modeling was to find what difference diffuse pollution

14 Baseline scenario is representing situation with current conditions in the river catchment without abatement measures.

15 First 20 years have been left out from presenting in graphs, since simulated concentrations were not having a stable variation due to problems with model setup. After 20 years model showed similar variation patterns, which were essential to compare scenarios for stochastic simulations.

measures were making on water quality, obtained results were applicable as inputs for further steps. This statement is based on the logic, that it is not very important if model doesn't produce only one pattern during whole simulation period, as long as difference between baseline and diffuse pollution measure scenario represent real patterns. If the same model would be used to all measures, the difference between baseline to diffuse pollution abatement scenario would provide reliable basis to compare diffuse pollution abatement measures. Nevertheless one should be fully aware that provided result is not meant to be reliable or sufficient to base decision on. Much more scientific researches should be done with quite large amount of time spending on model parameter search, calibration and validation. This is just a demonstration of ERA and CEA applicability in the diffuse pollution abatement measures selection.

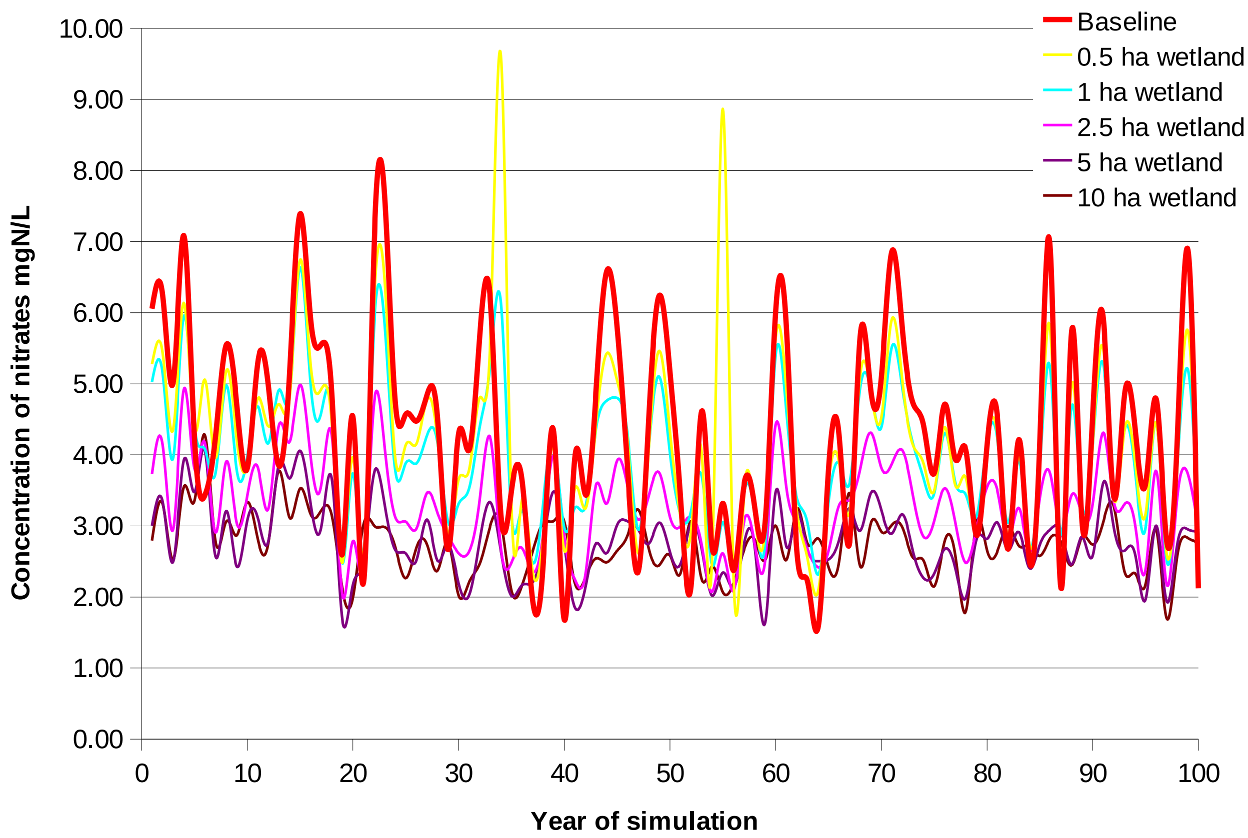

Figure 11: Simulation of wetland effects on water quality in regard to nitrate concentration.

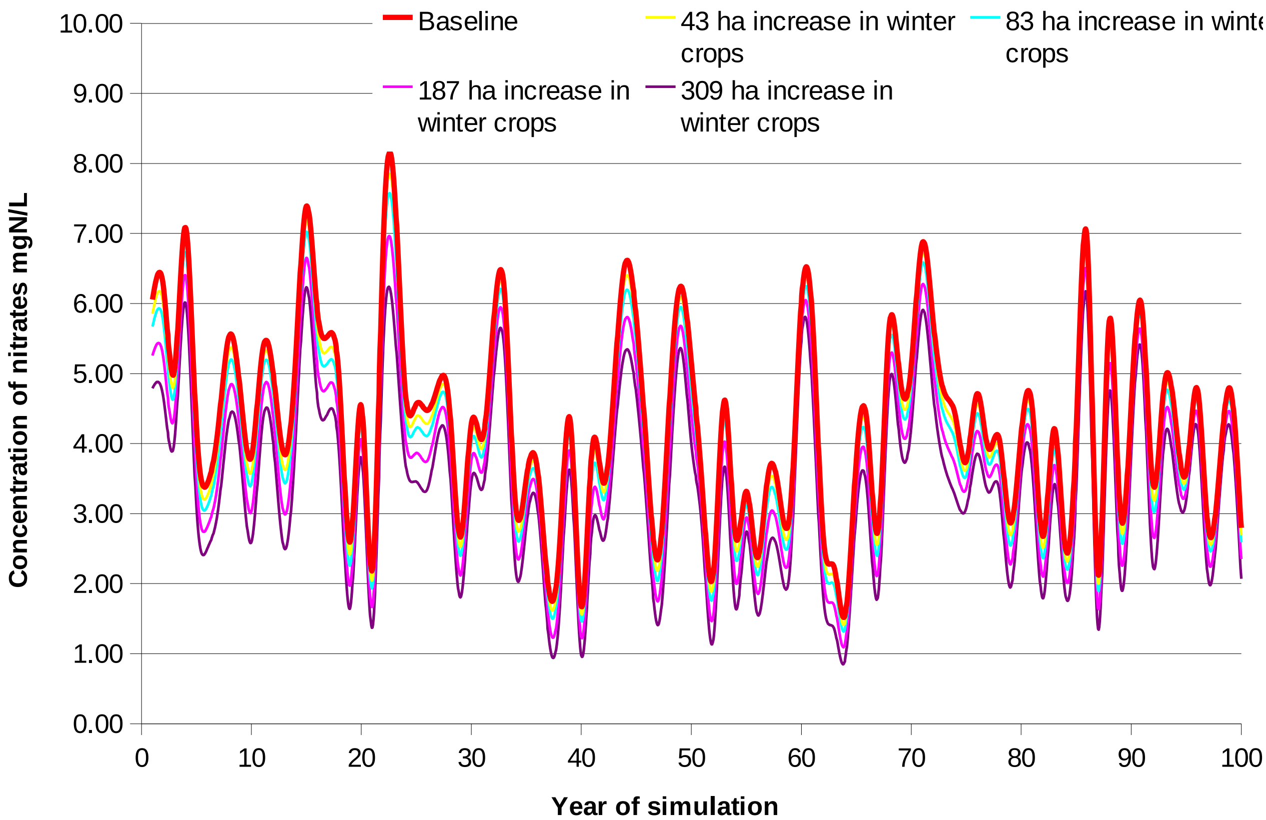

Figure 12: Simulation of winter crop effects on water quality in regard to nitrate concentration.

5.5.3 Results for ERA and CEA integration in diffuse pollution abatement measure selection

Simulation of water quality from different scenarios was used to prepare results for assessment of environmental risk reduction, which is the final component on the analysis intended for the use of decision makers (in the real projects). Two sets of graphs were prepared for comparison of diffuse pollution abatement measures. One graph presents probability of water quality falling below certain ecological level due to nitrates. Only nitrates has been chosen as criteria for assessment of water body status. Nitrates is the most troubling parameter in the Graisupis river catchment. Therefore improving water quality in regard to nitrate concentration should result in improvement of "ecological status" as well. This also allowed to simplify analysis, not necessary highly reducing its credibility. Analysis of parameters, which are less troubling would substantially increase work load hardly changing final outcome[16]. Values for nitrates are taken from "Method description for assessment of surface water bodies", which was prepared under LEPA (Minister of Environment Republic of Lithuania (in preparation)). However it is not yet an official document. Nevertheless, it is very likely, that it would be adopted as it is. According to this document values for ecological status classes[17] of water bodies in regard to nitrates are: < 1.3 mg N/L for very good, 1.3 – 2.3 mg N/L for good, 2.31 – 4.5 mg N/L for moderate, 4.51 – 10.00 mg N/L for poor, > 10.00 mg N/L for very bad. Every single class according to WFD should present severity of water body degradation

16 Final out come is "ecological status" of water body.

17 According to WFD, surface water bodies should be classified into 5 classes of "ecological status" depending on their degradation state. WFD requires of reaching at least "good ecological status" for all surface water bodies by the 2016.

in regard to biological, chemical or hydromorphological criteria. Despite this simplistic approach, Figure 13 and Figure 14 is representing environmental risk[18]. It is probability versus severity. Even though in this case, opposite from most common usage of this terminology, risk is used in the context of being reduced from baseline.

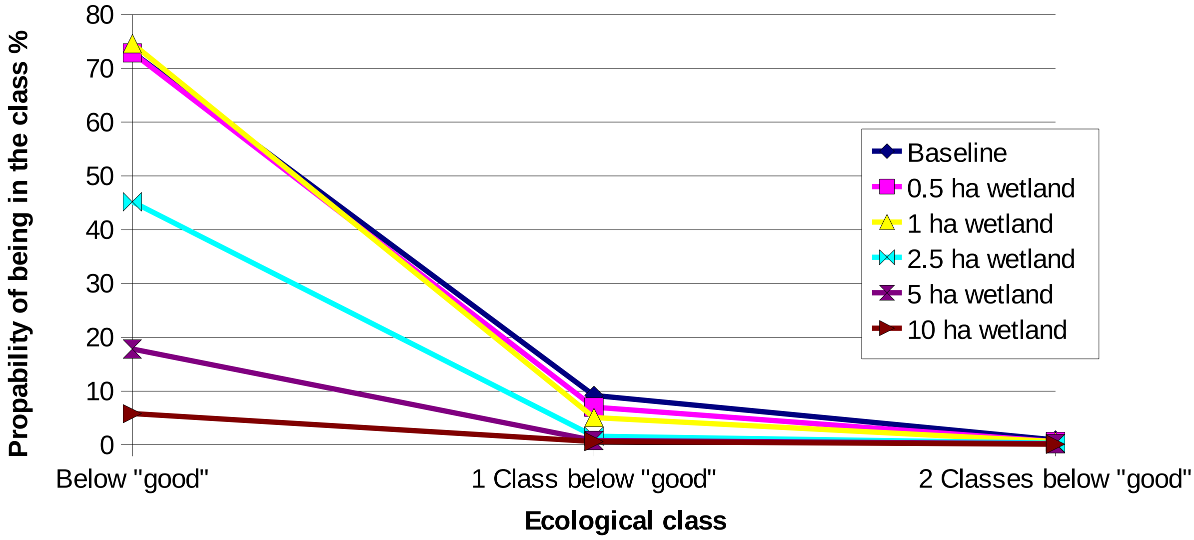

Figure 13: Probability of water quality falling below "good ecological status" of water body due to nitrates during different wetland scenarios.

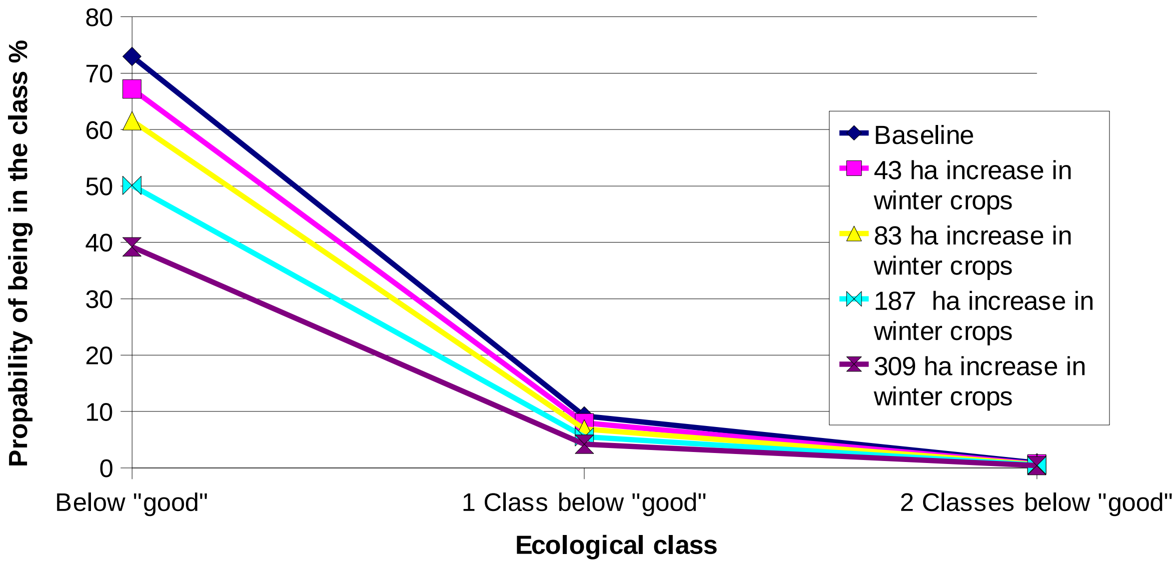

Figure 14: Probability of water quality falling below "good ecological status" of water body due to nitrates during different winter crop scenarios.

By looking at the Figure 13 it could be concluded, that building wetland at outflow from catchment with less than 2.5 ha area would not provide any significant effect. Wetlands of 1 ha or smaller would only slightly reduce probability of very effected water body (it is being in "poor" or "very bad" class). 5 ha on larger wetlands would provide significant reduction of risk of not reaching "good" water body status at the outflow from the catchment.

18 Probability is lined up on Y axis, while severity on X (in figures 13 and 14). Below "good" category includes water body being in "moderate", "poor" or "very poor" class of water body in regard to nitrates. 1 class below "good" includes "poor" or "very poor" classes. 2 classes below "good" includes just "very poor ecological status".

Figure 14 shows, that increase in winter crop area affects water quality positively. Water quality increase in those scenarios is consistent with winter crop increase. In other words, any increase in winter crop area would reflect with similar scale in water quality increase. From the figure it is well seen, that more winter crop the better water quality will be. Yet to reach any significant changes in risk reduction one should consider increase in winter crop area no less than 300 ha.

Figure 15 has been made by calculating risk reduction of not meeting WFD target with Equation 2 and then plotting results versus the costs of selected scenario. Costs have been obtained from reports of Mazvila et al. (2009) and Gulbinas et al. (2009) and are assumed to be 15024 euro per hectare for wetlands and 641 euro per hectare for winter crops. Figure 15 integrates ERA and CEA for comparison of diffuse pollution abatement measures. According to it, it is possible to conclude, that wetland is a more cost effective solution as well as having ability for complete risk minimization (for instance 92 % risk reduction of current risk could be reached with 150000 euro investment). Wetland would be less cost effective comparing to winter crops, if less that 20000 euro investment in abatement measures is considered option.

$$\textbf{Risk reduction \% = 100 *}\left(1 - \frac{\text{Scenario X probability of being below “good” ecological water body status}}{\text{Baseline scenario probability of being below “good” ecological water body status}}\right)$$

Equation 2: Risk reduction calculation.

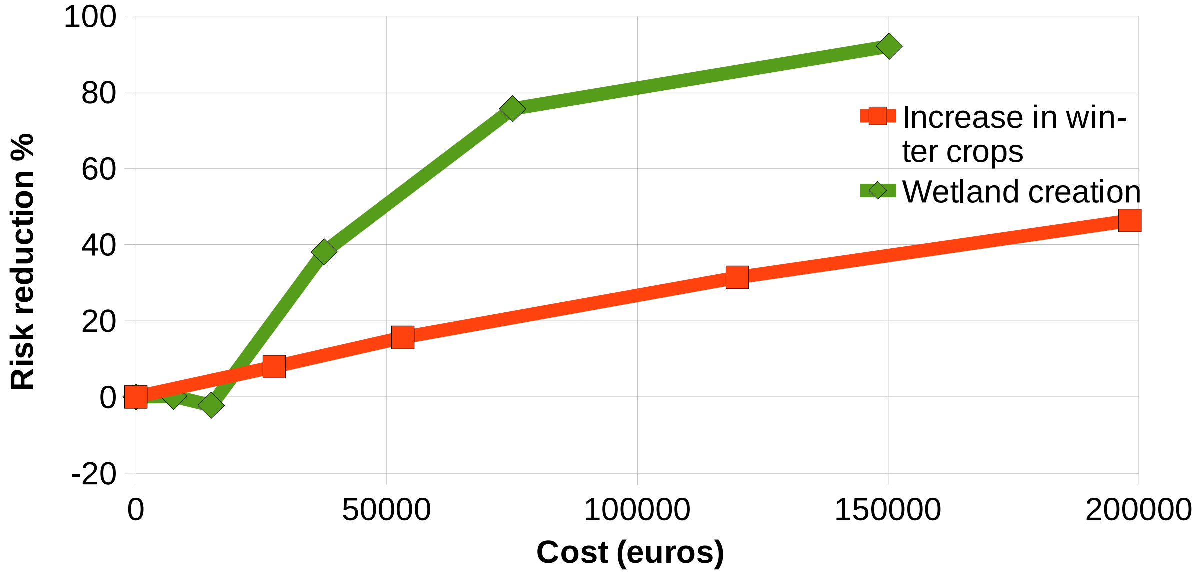

Figure 15: Risk reduction of falling below “good ecological status” of water body due to nitrates comparing to monetary investment.

6 Discussion

This study was an attempt to combine extensive literature review with demonstration example of integrating ERA and CEA in selection of diffuse pollution abatement measures. An extensive literature review was essential to better understand a complicated problem of diffuse pollution and different mechanisms for it's assessment and abatement. Analysis of watershed modeling tools, ERA and CEA integration, policies of dealing with diffuse pollution and abatement measures provided essential knowledge to guide this study. During extensive literature review and application of integration example some issues were encountered, which must be discussed in more details.

6.1 Reassessment of literature review

The literature review of watershed modeling approaches examined the ways of assessing inland surface water diffuse pollution problems. Some popular models discussed in scientific literature have been presented. However, those presented models are very few in comparison to high number of models that are available at the moment. Therefore, an extensive search for proper modeling tool should be helpful for increasing chances of success in dealing with diffuse pollution. Presented review includes just the most popular models within scientific community, as literature sources were mainly scientific articles. Professionals working outside the scientific community could have different preferences. Review also showed that stochastic watershed models are rarely used in watershed modeling. More often deterministic models are used in stochastic way to assess uncertainties. The possibility to run the model easily in stochastic way is getting quite important. There is a considerable discussion between professionals dealing with modeling of diffuse pollution if physically-based models are better than empirical. Theoretically, they should be better, since they give opportunity for better understanding of the systems, as well as having a wider application area. Yet in practice they are often faced with extensive data requirements. It is important to mention that previously widely used compound specific watershed management is being changed by area specific management, that requires assessment of multiple substances in integrated way. An Integrated Catchment Management has arisen, because of this need. Integrated catchment management requires DSS, which would integrate different models to be able to account for many outcomes of different management and policy options. This is one of the driving reasons, why possibility for coupling models easily becomes quite important. The OpenMI standard (OpenMI Association 2009) has been developed to provide mechanisms for smooth model coupling. Therefore it is also important to take into account for larger project, if selected watershed modeling tool has been prepared for integration with other models.

The review of ERA and CEA integration for solution of diffuse pollution problems showed that UA is more often used when assessing diffuse pollution problems. ERA and CEA integration examples were not plentiful. This might be caused by increased requirements for financial, time and data resources or other difficulties in working on such integration. Also it is important to note that environmental risk reduction from baseline scenario is a concept, which is rarely used in literature. Mostly the environmental risks are assessed in a way of some project or human activity could create disturbance to environment or humans. Improvements made for baseline scenario with some abatement measures for now occurring environmental degradation could be new way of using ERA. Overall ERA, UA and CEA have been just presented in literature review. Refraining from a discussion on specifics of those tools enables to keep project in manageable limits. However, it is very important to use appropriate techniques to obtain most benefit from integration of those tools.

For instance PARASOL, SUNGLASSES methods are used for UA is SWAT model (Winchell et al. 2008). There are many other methods used in ERA, UA and CEA. Deepening knowledge in this area would provide more possibilities for successful ERA and CEA integration.

In legislation review the most essential documents were presented and discussed. Yet especially in the case of EU directives it might also be important to look into supporting EU and national acts for implementation of those directives. EU directives dealing with diffuse pollution sets a broad goal to be reached and leaving the way of reaching it responsibility of each MSs. In case of Lithuania, important national acts are in the final stages of preparation (such as RBMPs). Thus analysis of those documents, even though they are not yet approved, would provide better understanding of efforts to abate diffuse pollution. Moreover, discussion of legislation alone does not provide a full picture. It is important to relate legislation for actual practices happening in a field, to assess how that legislation is actually implemented. Then it would be possible to see what the actual efforts and attention given to diffuse pollution problem. Furthermore, analysis of legislation from outside EU (as the Clean Water Act) could give broader perspective on possibilities to address diffuse pollution.

Review of diffuse pollution abatement measures gave overview of available options. However, crucial questions on effectiveness of them and application in different circumstances have not been discussed. This discussion would be critical for successful solution of diffuse pollution problems. A proper discussion should look for the most cost-effective way to reduce pollution as well as gain strong support from stakeholders for implementation of selected abatement measures. This kind of discussions is being made in RBMP prepared under LEPA. Yet stakeholder involvement and adaptation for area specific situation are not done. This could be a reason for RBMPs to be in high risk of not reaching desired goals. However, it is still too early to make a judgment. Nevertheless, when dealing with environmental problems, it should be taken into account scientific advise as well as stakeholders opinion.

Although literature review presented the main aspects of discussed subjects, it was just a brief introduction to those fields. Successful integration of ERA and CEA for diffuse pollution abatement could require more detail knowledge on analyzed subjects. This could only be possible when approaching problem in interdisciplinary way. A key to the success, when dealing with diffuse pollution, could be employing professionals from different areas to work in collaborative atmosphere. Yet despite problems mentioned above, literature review gave a deeper understanding, provided valuable source of key references as well as guiding application of ERA and CEA integration for demonstration example.

6.2 Shortcomings of modeling

The performed modeling provided a good basis for the integration of ERA and CEA for selection of diffuse pollution abatement measures. However, shortcomings of modeling part should be addressed. Firstly, due to lack of time (for official procedures to obtain data and to put it into model) observation data of just one year were used for calibration. Moreover, a validation procedure has not been performed. This would be unacceptable, if results should be used for planning abatement measures rather than doing a demonstration example. Also different parameters important to run SWAT model should be selected having deeper understanding of modeled area characteristics. Preferably they should be measured in field. Using default values, roughs estimations or automatic calibration are the least sound ways of obtaining important model parameters. Moreover there is a great need for better soil profile data. Lack of data for soil profiles could cause problems to calibrate model even if all other data and parameter requirements are met. There are no meteorological stations located in the Graisupis catchment. This could be one of the reasons for problems with model calibration. Furthermore, selection of diffuse pollution abatement measures is very simplistic as parameters chosen to represent them in model.

The economic part of the result analysis could be much improved too. Firstly, monetary calculations should be adopted to specific analyzed area. Secondly, costs of measures should represent clear change in financial costs/benefits between baseline and analyzed scenarios. For instance, change of spring barley to winter crops could be less costly, if we account for returns from winter crops as well. Moreover, wetlands would also cost reduction in areas currently used for farming, thus increasing cost of this measure.

The result analysis presented very simplistic approach to assess diffuse pollution abatement measures. Only nitrates were used in assessment of water body status in this study while generally assessing water body status many different parameters should be used. Also methodology, which is now under preparation in LEPA for combining those different parameters are quite complicated. It would be difficult to provide results from modeling to fulfill all methodology requirements. It is also important to note that the assessment was done for water quality in one point (outflow from the catchment). Where as WFD require “good” status of water bodies in every place. Having this in mind, wetland at catchment outflow probably would not be the best option, since it provides water quality increase just at outflow, leaving water quality in catchment untouched. Despite of this wetlands are important options for reduction of diffuse pollution. WFD requires reaching aims for all water bodies yet interpretation of what is considered water body could be adopted to MSs. LEPA for instance is currently planning not to classify rivers with less than 50 ha catchment as water bodies due to hydrological nature of such water systems[19]. However, increase of water quality in small river catchments would be beneficial for larger rivers as well. There are many other issues and possible shortcomings to discuss modeling and result parts, yet the main aim of demonstrating usefulness of ERA and CEA integration in diffuse pollution abatement measures selection has been presented in this project.

6.3 Future directions

Even if it might look as a burden on time and financial resources, integration of ERA with CEA could be very useful for diffuse pollution abatement. Providing the assumption that many of above mentioned problems could be solved, using this kind of tool would give meaningful information for decision makers without compromise the accounting for risks connected with assessed options. Moreover, this kind of tool could be used for other purposes than only diffuse pollution abatement measure selection. It could be used for setting level of taxes for polluters. For instance, if a certain activity is planned it might be possible to calculate risk increase from baseline due to effects of activity. Then obtained percentage of risk increase could be multiplied with cost for one percent of risk reduction with the least costly abatement measures. This is how costs of environmental degradation could be obtained and used for taxation based on Polluter Pays Principle.

In this study only stochastic uncertainties have been accounted. However, integration of ERA and CEA is not limited on this. Other types of uncertainties such as epistemic, could be included. For instance effectiveness of certain diffuse pollution abatement measures could not be well estimated, therefore parameters to represent those measures should get not exact value, but interval. Also it is essential not to forget economical uncertainties, since they could be particularly interesting for decision makers. For example, the cost of building of 10 ha wetland would vary depending on many factors and could be estimated to be within bounds of specified interval. Inclusion of this

19 Rivers with less than 50 ha catchments could be completely dry for few months during the year. Therefore reaching “good ecological status” is impossible since hydrological conditions are not suitable for continuously maintaining water life.

information would be helpful to decision makers. Whether if it should be done, depends on every project requirements.

7 Conclusions

The main goal of this study was to answer, how useful and feasible an integrated application of Environmental Risk Assessment and Cost Effectiveness Assessment for solving inland water diffuse pollution problems. It has been achieved through an extensive literature review and a demonstration of method with application of a watershed model on a selected river catchment. It is possible to conclude, that integration of Environmental Risk Assessment and Cost Effectiveness Assessment could bring a lot of benefits for inland surface water diffuse pollution abatement. The main benefit is providing relative and honest information for decision makers. However, currently Environmental Risk Assessment and Cost Effectiveness Assessment integration examples for solving diffuse pollution problems are not common in scientific literature. Uncertainty Assessment is more often performed when dealing with diffuse pollution instead of Environmental Risk Assessment. Moreover, the use of environmental risk terminology traditionally bears context of negatively affecting environment. Therefore application of Environmental Risk Assessment for analysis of environmental improvement from a baseline could be a new way to use the environmental risk concept.

An integrated application of Environmental Risk Assessment and Cost Effectiveness Assessment for water diffuse pollution abatement measure analysis would not have been possible without a watershed model. Therefore a search for an appropriate tool has been performed. From the literature review it could be concluded, that the SWAT model is one of the most suitable watershed modeling tools for assessment of inland water diffuse pollution abatement measures. This model is physically-based and has semi-distributed parameters, which provides multiple assessment possibilities. Moreover, a long history of development, large user community, many application examples around the world, good documentation, moderate data requirements, well prepared user interface, integration with GIS packages and adding to this the cost of the model, makes SWAT highly preferable for many applications dealing with inland water diffuse pollution.

Literature review also provided an insight to decision making process through analysis of legislation related to inland water diffuse pollution management. Conclusion could be drawn, that diffuse pollution problem does not get special attention in the EU water protection legislation. Yet latest amendment to Helsinki Convention puts more emphasis on diffuse pollution issues. Also it is possible to conclude that legislations, dealing with water diffuse pollution have very few (if any) requirements for performing Environmental Risk Assessment or Uncertainty Assessment. Meanwhile, a cost effectiveness principle as requirement is incorporated in all main legislation dealing with diffuse pollution.

When it comes to diffuse pollution abatement measures, it is important to emphasize that it is hardly possible to expect positive results with single measure and within period of time. Diffuse pollution abatement could only be successful if abatement measures are applied in right composition adopted to particular area.

Based on this example of method application the conclusion could be made, that integration of Environmental Risk Assessment and Cost Effectiveness Assessment for water diffuse pollution abatement measure analysis by using SWAT model is a feasible approach in Lithuania. At least in the Graisupis river catchment. This is the most suitable area in Lithuania for such analysis due to long and detail monitoring activities and due to problems related to diffuse pollution. However, more detailed data on soil profiles and water quality would be desirable for increasing chances of successful application of the SWAT model.

Few abatement options (building wetlands and increasing winter crops) have been chosen for modeling and analyzed in the method application part. Result analysis makes it possible to conclude, that wetland restoration would be a better option comparing to winter crop increase in the Graisupis river catchment, since it provides the highest risk reduction with the lowest cost. Moreover, it has showed the highest risk reduction potential as well. 90 % of the risks of not meeting environmental target ("good ecological status" of water body) could be eliminated with 150 000 euros.

Overall conclusion from this work is that integration of Environmental Risk Assessment and Cost Effectiveness Assessment with surface water diffuse pollution modeling is a valuable and possible approach to assess the suitability of diffuse pollution abatement measures in Lithuania (and other countries). As well as to provide decision makers with valuable information. This approach could also be applied for other purposes, such as setting fine and tax levels for polluters.

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