In: *Prediction and Reduction of Diffuse Pollution, Solid Emission and Extreme Flows from Rural Areas – case study of small agricultural catchment* (ed. by K. Banasik, L. Øygarden & L. Hejduk), 233–243. Wydawnictwo SGGW, Warszawa – PL, 2011.

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Lessons learnt: summary of experiences and further recommendations

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The project „Prediction and the reduction of diffuse pollution, solid emission and extreme flows from rural areas" has been conducted by Polish and Norwegian research teams in the period of 2008–2011. The use of hydrological and water quality data, gathered in earlier studies and data collected within this investigation, have been presented in this volume. Small agricultural catchments of the Zagożdżonka River and Zwoleńka River, both located in central Poland (ca 100–130 km south of Warsaw), were main study object. However, comparison of hydrological characteristics with two Norwegian catchments has also been carried out. The unique and modern equipment parched for monitoring of the rainfall-runoff processes and water quality during the project (financed by the EEA financial mechanism), and described earlier, will also be used in further investigation by the team of Warsaw University of Life Sciences (WULS) – SGGW. The realisation of the project allowed the partners of the project to intensify cooperation, as well as to develop contacts with end users, i.e. agricultural, forest and ecological agencies' representatives from Mazovia Region of Poland. To exchange knowledge, discuss the progress and results of the investigations, the research team met twice in Warsaw: in October 2008 and October 2010, and one time in Aas in September 2009, visiting also field monitoring stations. For transferring the investigation findings to practice, the research teams met twice with the Polish end users during workshops organised at Jedlnia and Czarna near Radom in October 2008 and in October 2010. Over 20 scientific papers on results of the investigation were published in journals of national and international impact in the period of 2008–2011. Many students of Environment Protection and Environmental Engineering of WULS-SGGW were involved in the project by collecting data for their master theses. One Ph.D. student of WULS-SGGW spent one month at Bioforsk and Norwegian University of Life Sciences in Aas to investigate the monitoring systems of rainfall-runoff and water quality in small catchments.

In this volume, the chapters 1–5 deal with annual and long term variability in runoff, flow extremes, possible changes of flood runoff due to potential increases of heavy rainfall depths, and comparison of hydrology in some selected Polish and Norwegian catchments. The chapters 6–9 deal with comparison of monitoring methods for quantifying runoff and nutrient losses in Polish and Norwegian catchments, relation between land management and water quality, and various aspects of ecological values of the river valleys. In the chapters 10–14 the BMP in Poland and Norway to keep good quality of surface water in rural area are presented as well as influence of tillage system on intensity of soil erosion, and impact of small constructed wetlands and small reservoirs on water quality. Each chapter summary as well as some recommendations are presented below.

Summary of chapter 1: Variability in runoff from a small agricultural catchment – based on long term monitoring data. River runoff is an important indicator of environmental changes, which usually include climate and/or land use changes, and is also basis for catchment water management plans. This study delivered very valuable results from monitoring and analysis of 48-year precipitation and runoff data from a small (82.4 km^2) agricultural catchment, located in central Poland. Mean monthly distributions of precipitation and runoff for the long term period has shown that July is the wettest month in respect of precipitation and dryer one in respect of runoff, averaging 12.9% and 5.2% of their annual values, respectively. The investigation on hydrological processes in the catchment, characterized by mean annual precipitation of 611 mm and average annual runoff of 106 mm, indicate a decreased trend in long term annual runoff at the probability level of 95%. Three-year hydrological investigation and monitoring – entirely financed by the PL-Nor project, in two catchments, i.e. Zagożdżonka and Zwoleńka River, allowed to establish flow duration curves (FDC) for both catchments and to indicate factors influencing differences in the FDCs.

Recommendations: The detected decreased trend in long term annual runoff should be checked also in other neighbouring rivers, monitored by state hydrological service (Institute of Meteorology and Water Management – IMGW) to confirm the regional character of the changes. The proposed extended study should also include causes of the investigated changes.

Summary of chapter 2: Analysis of low flow characteristics and drought frequency in agricultural catchments. Lack of precipitation and high evapotranspiration are the main reasons of low flow in rivers and hydrological drought. Analysis of drought occurrence in Zagożdżonka River on the basis of daily-recorded hydrograph from the period 1963–2010 enabled to assess the phenomenon in the small river of Mazovian Lowland, forming part of Polish Lowland, the agriculture of which is especially plagued by the occurrence of frequent and severe droughts. The analysis has confirmed that hydrological droughts occur here frequently, often forming cycles which last many years. They apply to the summer half-year, mostly the months of July and August and last not much more than a month. The obtained values of drought characteristics are compatible with results of studies conducted for rivers situated in the same region of Mazovian Lowland.

Recommendations: It is recommendable to predict changes of hydrological droughts and associated with them the stream flows in this and other small catchments. This is specially important in Poland, as only around 0,5% of arable lands use irrigation. A possible increase in water deficit in agriculture, as a result of climate change, would strengthen the need for irrigation development.

Summary of chapter 3: Prediction of T-year flood in gauged and partially gauged small catchments. Flood flows, recurrence intervals or probabilities of exceedance, i.e. the design flows, are basic hydrological information required in designing dams, culverts, bridges and other hydraulic structures as well in assessing flood risk managements. The last one is especially important because of the current implementation of the EU "Flood Directive". The purpose of the Directive is primarily to document flood risks and improve the flood prognosis. The flood predictions are equally important for large and small rivers and need to be determined for gauged and ungauged locations. In case of larger rivers, which have long term monitoring data, the procedures of flood frequency estimation are commonly accepted. In case of small rivers, usually ungauged the procedures have usually high degree of uncertainty. In this study, estimation of T-year floods for two small catchments, of which one has long term, i.e. 48-year flow data and the other one only short term, i.e. 2.5-year monitoring record, is presented. Lower specific flood discharges and lower values of flood quantiles have been found out for the larger, i.e. for Zwoleńka River, what could have been expected. However in this case, there might have been also other more influential reasons of the difference in the flood characteristics as: meandering channel in a wide valley of organic soils, lower river channel slope and elongated shape (lower shape factor) of the Zwoleńka catchment.

Recommendations: The estimated flood quantiles with the use of recorded hydrological data, of two investigated rivers differ from the regional ones, which had been estimated on the base of data from larger catchments and are commonly presented in hydrological handbooks. There is a need for revitalisation of the method for small catchments.

Summary of chapter 4: Catchment responses to heavy rainfall in a changing environment. Environmental variability as land use and climate changes requires the development of tools to predict the hydrological consequences, which would form a base for adaptation strategies. Adaptation strategies to climate changes have constituted important programs of government agencies of many developed and developing countries. A procedure, called SEGMO (SEdiment Graph MOdel) was developed at the Department of Water Engineering of Warsaw University of Life Sciences – SGGW for predicting catchment response, as flood hydrograph and sedimentgraph, to heavy rainfall. The model consists of two parts; a hydrologic sub-model and sedimentology sub-model. With the use of the first one, the catchment responses to heavy rainfall events were estimated in this study. The results of application of the model indicated good agreement of the peak of runoff hydrograph simulated as catchment response to P_p, for p = 1% and 0.5%, with the statistically estimated Q_{max_p}, as the relative differences were within 13%. With such tool, the catchment response could be estimated for any predicted input data in a changing environment. The results of rainfall-runoff simulation indicated that the increase of rainfall depth $P_{1\%,\,24\,h}$ of 20% would cause the increase of runoff depth (i.e. also volume) of 42% and increase of peak discharge of 39%. Results of further analysis are presented in the chapter.

Recommendations: In the further investigation on the model development special attention should be put on: (i) applicability of the Curve Number method in the ungauged catchment in Poland and variability of the method parameter with time of the year and wetting condition of the catchment, (ii) selecting or adapting an empirical formulas for estimation of IUH characteristics, to make the model possible for application in ungauged catchments.

Summary of chapter 5: Comparison of hydrology in selected catchments in Poland and Norway with focus on dominating flow paths and time resolution. Agriculture contributes a significant portion of the nutrient losses to the environment, being to a large degree responsible for the eutrophication of inland waters and coastal zones. Agricultural practices, climatic conditions, topography and geological conditions are important factors in determining these losses. However, also hydrological flow processes and pathways play an important role in the nutrient and soil loss processes. This chapter presents the results of a comparison of the hydrology in three catchments, two of the them located in Norway and one located in Poland. Compared to the Norwegian catchments, the specific discharge value in the Zagożdżonka catchment is small. A probable reason for this can be the lower yearly precipitation and higher mean annual temperature (evaporation) leading to less runoff as compared to the Norwegian catchments. The Zagożdżonka catchment is also characterized by higher value of *base flow index* and lower value of *flashiness index* than Norwegian catchments.

Recommendations: Further investigation focused on relation between base flow index and other specific river flow characteristics with catchment characteristics is suggested.

Summary of chapter 6: A comparison of monitoring methods to quantify runoff and nutrient losses in Poland and Norway. The monitoring of water quantity and quality is a basic source of data for determination of environment quality status as well as modelling purposes. The methods of environmental monitoring differ however; depending on countries and the aim of the monitoring. The comparison of two monitoring approaches in Poland and Norway shows differences in ways and scales but also some similarities. As the discharge in rivers is measured by use of similar devices, there is a significant difference between sampling method for nutrient concentration and load estimation. The volume proportional system is used in Norway and the point or grab sampling in Poland. Both methods have their advantages and disadvantages and are used for different purposes.

Recommendations: The exchange of the experiences is one of the "drag force" for the new conceptions. The environmental monitoring equipment, especially electronic devices, is evolving so fast that it is not possible to assess the usefulness even in the country scale. The collaboration between countries in this field is then the most crucial activity and should be continued.

Summary of chapter 7: Estimation of influence of land management on river water quality based on model calculations. The impact of nutrient application within the catchment on water quality is a difficult and complicated issue. The sophisticated model application is one of the possible approaches to answer the question about future development on the certain area with harmless impact on environment and especially on water quality. The SWAT model application for Zagożdżonka river catchment prove the very high complexity of land management-nutrient transport issues on one hand, and usefulness of such approach on the other hand. The quality of the input data play an important role on received result but never less the results obtained from SWAT simulation, indicate the significant role of amount of fertilizers applied into the soil on nutrient loads in Zagożdżonka River.

Recommendations: The results from the SWAT model simulation indicate good but not very satisfactory predictions by the model. It could be due to lack of precise input data especially to the pollution part of the model. The main challenge of the future work is to undertake new field investigations to implement more precise input data especially in a scope of nutrient application into fields.

Summary of chapter 8: Extreme flows and possible threats to small populations of the European pond turtle. European pond turtle Emys orbicularis is an endangered species in many parts of the area of occurrence. Protecting the aquatic and marsh-water environment is considered a key factor in protecting this species. For most of the studies the only case of lowering the water level or complete loss/destruction of certain bodies of water on the occurrence of this species is analyzed. In the course of this project, the importance of the aquatic environment on various aspects of the ecology of the species was examined. The potential impact of extreme water levels on the turtle was the scope of the chapter in this monograph. Such conditions, i.e. extreme water levels can cause damage to the small proportion of deposits eggs, which will have minimal impact on the population of this species in the river valley Zwoleńka. But, due to the small size of this and other populations as well as due to certain life history parameters, such as late sexual maturation, the key to the survival of many pond turtle may be being transferred by the floods, of even single individuals.

Recommendations: In future studies it would be important to determine the effect of extreme water levels on amphibians – animals closely related to the aquatic environment. Amphibian populations can have a significant impact not only on very low levels of water and the destruction of aquatic habitats, but also floods and rapid fluctuations in water level.

Summary of chapter 9: Small river valleys management and nature protection on the basis of amphibians. Zagożdżonka and Zwoleńka river catchments create suitable habitat conditions for the majority of lowland amphibian's species occurring in Poland. There are suitable habitats for two species listed in Annex II of Habitats Directive that require protection within Natura 2000 ecological network: great crested newt *Triturus cristatus* and fire bellied toad *Bombina bombina.* Management of the catchment should consider preservation of all habitats used by amphibians. The condition of water bodies cannot be changed, and the water flow in the rivers should allow existence of seasonal, small water bodies. Amphibians terrestrial habitat is also very crucial – extensive agriculture and forest seem to create the best conditions for these animals. Conservation of these habitats is possible only by responsible, sustainable management of catchment concerning all amphibians habitat needs.

Recommendations: The studies on amphibians' habitat preferences in Zagożdżonka and Zwoleńka catchments should be continued in order to find further relationship between amphibians' occurrence and human activities, such as water management, agriculture intensification or house and roads investments.

Summary of chapter 10: Erosion studies in plot field experiments with different tillage systems in Norway. Erosion studies in plot experiments in Norway started about 1979. In the period from 1990 to 2007, these studies were focused on comparing how different soil tillage (methods and timing) influenced losses of soil, phosphorus and nitrogen through surface and drainage runoff. The results have been the fundamental basis for authorities when designing the subsidy system for reduced tillage to reduce erosion. The results have also been used for calibrating hydrology and erosion models adapted to Norwegian soil and winter conditions and for developing erosion risk maps.

Recommendations: Erosion measurements in plot studies document the relative soil losses depending on tillage methods like autumn ploughing, autumn harrowing, direct drilling, spring harrowing, spring ploughing. These experiments, from different soil types, give recommendations of tillage and effect on soil losses (sheet and rill erosion) than can be used when planning measures to improve water quality. Autumn harrowing can reduce soil losses by 50% while spring ploughing can reduce losses by 85%. In the landscape scale also other erosion processes like erosion in waterways and gullies must be accounted for.

Summary of chapter 11: BMP in Poland to keep good quality of surface waters in rural areas. Best management practices (BMP) are one of the most important factors influencing the quality of surface water in agricultural areas. Among others, the quality of manure storage, the way and time of fertilizers application, proper land management are the most important practices in Poland. Those activates are regulated by a several legislation acts, where the three of them are: the Water Act, the Fertilization Act and the Plant Protection Act. Those acts are the source of law for appropriate detailed dispositions. Some of the activity is summarized in Polish Code of Good Agricultural Practices which is available free for all interested parties.

Recommendations: The best management practices become one of the most important issues in Poland in the future. The role of BMP will grow with the decease of importance of point source pollution in the rural area. So, it is a need and space for implementation of BMP in Poland as well as for investigation of a particular activates impact on water quality.

Summary of chapter 12: BMP in Norway to keep good quality of surface waters in rural areas. Implementation of the EU "Water Frame Directive" has led to increased focus on how agricultural production systems and management practice influence water quality. In each county in Norway there is a Regional Environmental Program supporting environmental measures in agriculture. Most of the economic support is given to reduce erosion and thereby phosphorus. Support is given for reduced tillage like light autumn harrowing, direct drilling or leaving the fields in stubble during winter period. Support is given for buffer zones, grassed waterways and sedimentation ponds. Recommendations for use of fertilizer related to nutrient status of soils and expected yields have also been adjusted. For some exposed watersheds used for drinking water there are specific regulations of farming practices to improve water quality.

Recommendations: Since agricultural management practices influence both nutrient losses to water and losses to air there is need both for research and extension services to focus more on the agricultural management systems and recommended measures. Control with surface runoff, drainage systems and hydro technical equipment will be more important if climate change results in increased precipitation in the vulnerable seasons autumn and during snowmelt. For reduction of greenhouse gases measures to reduce nitrogen losses are important and this can include other measures than needed for losses of phosphorous to water.

Summary of the chapter 13: Influence of small constructed wetland on surface water quality. Constructed wetlands can contribute to reduced diffuse pollution through sedimentation of particles and retention of phosphorus. In Norway, subsidies for construction of wetlands have been given from 1994 with 70% of the construction costs. During the last decade 1000 constructed wetlands are built with such support. The surface area of the constructed wetlands constitutes about 0.1% of catchment area but has still shown good retention capacity. This is due to high surface runoff giving high particle transport and that clay particles are transported as aggregates which sediment in the wetlands.

Recommendations: Guidelines for designing wetlands in Norway to optimize retention are given. They include factors like: depth, vegetation, size of vegetation area and use of filters (organic and mineral) for retention of soluble pollutants. Since constructed wetlands often have the best retention performance under storm runoff they should be located in low-order streams.

Summary of the chapter 14: Impact of small reservoir on reduction of solid transport – case study. The amount of sediment deposited within a reservoir depends on the fall velocity of the various sediment particles, flow rate and velocity distribution through the reservoir, which are determined mainly by the size, depth, shape and operation rules of the reservoir. It is commonly accepted that the small reservoirs are more susceptible to quick sedimentation, simply because of their capacity. If the sediment inflow is large relative to the reservoir storage, then the useful life of the reservoir may be very short. On the other hand, sedimentation in the reservoir area usually improves the water quality of the downstream river because of reduction of solid transport. The investigations were carried out for a small river of Zagożdżonka with a small reservoir "Staw Górny", which is located ca. 100 km south of Warsaw. The reservoir was built in 1976 by construction of a concrete main dam consisting of a rectangular weir/drop structure, which is flanked by an earth dam. The reservoir area is about 14 ha, capacity ca. 250,000 m^3 and its watershed area is 91 km^2. The volume of sediment deposit was estimated on the base of on reservoir surveys carried out in

1980, 1991, 2003 and 2009. Sediment yield from reservoir catchment was estimated using Universal Soil Loss Equation and bed load transport rate was estimated using different empirical formulas. Achieved results have shown that nearly 99% of solid transport is trapped in the reservoir.

Recommendations: Investigation on property and quality of sediment at the catchment outflow with relation to land use practices, and on quality of sediment deposited in reservoir with relation to its eutrophication is recommended.

Summary of the recommendations: The study reported in chapter 1 detected a decreased trend in runoff, recommended to be checked with monitoring of neighbouring rivers. Further analysis could also study how future climate with such reduced runoff will affect erosion and losses of nutrients from agricultural areas. This is important for the planning of measures in agriculture to fulfil the requirements set by the Water Frame Directive. Analyses of long term data (chapter 2) confirmed that hydrological droughts occur frequently often in cycles which last many years. Increased drought frequency can increase the need of irrigation. Local possibilities for irrigation, effect on crop yield and economical costs should be investigated for advice on best adaptation. In contrast chapter 3 focus on the hydrological cycle, too much precipitation and possibilities of predicting flooding. Understanding of flooding regimes in catchments is important and necessary for adaptation and minimising risk of damage. The study showed high variability between flood prediction in two catchments compared to regional values and underlines the need of methods for predicting flooding in smaller catchments, like agricultural catchments. Heavy rainfall can cause flooding, another effect is the catchments response with sediment transport. Chapter 4 illustrates this with the tool **Se**diment**g**raph **mo**del – SEGMO – for predicting catchment response as flood hydrograph and sedimentgraph related to heavy rainfall. Such relationships can be valuable tools for other catchments without gauging and there is an increased need for developing such tools. These studies and the funding in the project has allowed new instrumentation and measurements, monitoring that has given a lot of new valuable results. These results are compared with measurements in smaller monitored catchments in Norway. Comparisons showed higher rainfall and runoff from the Norwegian catchments resulting in almost no drought problems but higher runoff result in erosion and nutrient losses from agricultural fields. A National Agricultural Environmental Monitoring Programme is therefore established to monitor how agricultural management practices influence on such losses. Both Polish and Norwegian results illustrates the importance of hydrology as the driving force for losses and the need for monitoring and development of predicting tools for adaptation to drought, flooding and reduce diffuse pollution. Monitoring depending on instrumentation, available resources for analysing samples, available data from catchment e.g. on farming practices on each field. Chapter 6 documents that the project have compared the monitoring methods used in Poland and Norway. This can be a basis for further cooperation and can be useful for designing new monitoring programmes and for the comparison and interpretation of results, For studying effects of climate change long term studies is necessary and especially valuable both for documentation of effects and for adaptations. A lot of effort is put into prediction of how climate change and management practices in agriculture will affect nutrient losses. For Polish conditions this has been tested with the SWAT model for catchment studies. Results show that there is a need for more precise input data and information from the catchment to succeed with modelling. For Norwegian catchments the SWAT model is being tested and calibrated for monitoring catchments where the farmers gives information from each field on their farms.

Hydrology, drought and flooding, extreme rainfall can influence on agricultural production and diffuse pollution from areas. In the landscape system hydrology also affect natural ecosystems. The projects have studied how influence on aquatic extreme low water levels can influence on the European pond turtle. Flooding will also influence on aquatic environment and for future studies it should be focused on extremes both for low flow and flooding conditions. In chapter 9 nature protection and habitat conditions for lowland amphibians for two Polish catchments are studied. Human activities such as water management, agricultural management practices, house and road investments all influence on habitats for amphibians. Such relationships are important to study for securing habitats for species that require protection within Natura 2000 network. A major part of the studies in the project have been related to how management practices on agricultural fields and retention systems can improve water quality and requirements set by the Water Frame Directive. Exchange of results and experience between Poland and Norway have been prioritised also for information to end users. In Norway much of diffuse pollution is related to erosion processes transporting phosphorus to water bodies. Reduced soil tillage like leaving field in stubble during winter period, light autumn harrowing or direct drilling can reduce erosion. Research with plot studies have documented these effects and subsidy systems for farmers reducing tillage have promoted changes. Subsidies are paid according to erosion risk of the fields given on erosion risk maps for farms. In specific watersheds with bad water quality and used for drinking water there are specific regulations the farmers have to fulfil to receive also general production support. Economic support is also given for buffer zones, grassed waterways and sedimentation ponds. Control with surface runoff, drainage and hydro-technical equipment is expected to be even more important in Norway if climate change results in increased precipitation. In Poland farming practices influencing water quality are regulated through different legislation acts and summarized in Polish Code of Good Agricultural Practices. It is not promoted by subsidy systems in the same way as in Norway. More focus is put on manure storage, fertiliser application but it is expected that diffuse pollution will need more focus regarding measures for the Water Frame Directive. Small reservoirs, sedimentation ponds can be efficient in trapping sediments and thereby improve water quality. Chapter 13 and 14 compare different systems in Poland and Norway and the case studies show that such systems are very efficient. However, the size of reservoirs and their design highly influence on filling rate, efficiency and the life time of the reservoir. The Polish case study illustrated this for a large catchments while the Norwegian recommendations (and supporting system) promote smaller sedimentations ponds near farmers fields. Such smaller ponds must be emptied when filled with sediments, but such filling also illustrate their effectiveness. Smaller sedimentation ponds are also beneficial for other purposes like biodiversity, hiding and resting places for animals and regarded as positive elements for recreation.

Solving problems and finding answers to the questions indicated in the recommendations will foster the implementation of the EU Directives and will help in forming a base for adaptation strategies in rural areas to climate changes. Since agricultural practices influence on soil and nutrient losses to water and of losses of green house gases to air, both research and extension services must focus more on total environmental effects of agricultural production systems.