



SWAT 2013
Toulouse France



July 17-19, 2013

Paul Sabatier University, Toulouse, France

Conference Proceedings

Texas Water Resources Institute Technical Report – TR-471

Development of Modeling System Based On the SWAT Model as a Tool for Water Management Institution

Svajunas Plunge

Chief desk specialist at the Environmental Protection Agency of Lithuania, A. Juozapaviciaus st.
9, Vilnius LT-09311, Lithuania, email: s.plunge@aaa.am.lt

Abstract

The Soil and Water Assessment Tool (SWAT) model has been used extensively in many countries and for many different applications connected to water environment. The great majority of these applications were done on the temporary basis of scientific projects. However, for the exception of the United States, there is lack of examples on the acceptance of this model by regulatory bodies, which would invest in its application as a long term strategy to answer management questions. The Environmental Protection Agency of Lithuania (EPAL) has committed itself for such a task in order to increase its capacity in solving questions related to non-point source (NPS) water pollution problems. NPS pollution is responsible for the largest part of degradation in water ecosystems occurring in the country. Activities commenced by the EPAL included: testing the SWAT model for pilot basin, building country scale detail modeling system, the continuous collection of relevant data and the adaptation of data collection to fill the SWAT model requirements. Additionally, model applications are currently designed for many tasks such as the assessment of water quality, the assessment of pollution sources responsible for the degradation of water bodies, assessment on the effectiveness of NPS pollution abatement measures, the optimization of spatial distribution of such measures, the assessment of impacts of structural agricultural changes on water environment, etc. The aim of this article is to communicate information on the progress of the SWAT model application in Lithuania and about major encountered challenges.

Keywords: Lithuania, SWAT model, modeling system, water management.

Introduction

Application of The Soil and Water Assessment Tool (SWAT) model is widespread across the globe. There are numerous examples of model use for the different hydrological, water quality, soil, agricultural and other questions (Gassman et al., 2007). Abundant scientific articles show the great potential of the SWAT model. Currently, SWAT Literature Database for Peer-Reviewed Journal Articles holds around 1300 scientific articles (available on https://www.card.iastate.edu/swat_articles/). However, important benefits can be also delivered by SWAT outside scientific community. Water managers need such tools in many countries, which would help in decision making process. The deliverance of the SWAT model from scientific to management societies has the possibility to unlock great benefits. Such examples are available in the United States, where the model has been increasingly used for the support of Total Maximum Daily Load calculations (Borah et al., 2006). The SWAT model is also used for the evaluation of conservation practices and programs performed with multi-agency efforts and coordinated by USDA within the Conservation Effects Assessment Project (CEAP, 2013). It is hard to find reported examples of the SWAT model application in the recurring tasks of management institutions outside the United States.

There are numerous sources (Nasr et al., 2007, Barlund et al., 2007, Geza & McCray 2008, Dilks et al., 2003, EUROHARP, 2003) in the scientific literature, which examined the SWAT model's suitability for solving questions related with implementation of the European Water Framework Directive (WFD) and concluded that model can be used for such a task. However, it is hard to find examples described in the scientific literature that the SWAT model has actually been employed for such task. The model was used in many scientific projects connected with WFD implementation. RECOCA (RECOCA, 2013) and EUROHARP (EUROPARP, 2013) are examples of them. Yet, it is difficult to find examples for the application of the SWAT model for recurring tasks by water management institutions in the European Union (EU). This article is aimed to address this gap by describing the work done and results achieved in the Environmental Protection Agency of Lithuania (EPAL), where the SWAT model has been selected to aid with water management tasks. This article should be useful for water managers considering similar steps.

Early water modeling activities in the EPAL

The implementation of many requirements set by the EU water directives and the Helsinki Convention created the need for the application of water models. Initially the EPAL was considering using freely available models such as the Hydrological Simulation Program - FORTTRAN (HSPF) and SWAT. However, at this stage (in the year 2003) the Danish Hydraulic Institute (DHI) offered on its part to perform study to determine the best options for the EPAL to use for water modeling tasks (DHI, 2003). This study was finished in 2004 and proposed the MIKE BASIN model. This is empirical, lumped parameters, continuous time scale, river basin model, which was primarily developed to solve water allocation problems, but has added capacity to assess nutrient loads from different sources (MIKE BASIN, 2013). MIKE BASIN was used in the first round of River Basin Management Plans (RBMPs) preparation for the whole territory of Lithuania, which ended in year the 2010. However, the main limitations of the MIKE BASIN model during the preparation projects of RBMPs greatly restricted questions on

non-point source (NPS) pollution coming from agriculture, which was responsible for the largest part of deterioration in water ecosystems. As this was the first step in the application of watershed models, such limitations were probably unavoidable. Data and expertise required for the application of more robust and physically based models, capable of answering NPS related questions, was not available during early stage. Yet, acknowledging current and future requirements coming from environmental regulations, the EPAL initiated work for preparation of complex watershed model, which would have physically based and distributed parameters characteristics and allow complex assessment of NPS and its abatement measures.

SWAT selection and testing for a pilot basin

The search of suitable solution started with the identification of criteria for the tool, which would be able to provide necessary answers to NPS water pollution questions. The main criteria for watershed model in the initial search were such as:

- Capability to assess inland water NPS pollution and its abatement measures;
- Suitable for fulfilling the WFD requirements;
- Applicability with available data;
- Good integration with GIS;
- Low cost;
- Good documentation;
- Many application examples and long development period;
- Good support.

Performed literature review was in part described in the master's thesis of Plunge (2009). The other part was described in the internal EPAL documents (EPAL, 2009b). Based on this review the SWAT model has been selected. This model was also compared against other models (MIKE BASIN, FYRIS), which were proposed to the EPAL by external consultants. Comparison criteria and methodology were based on Saloranta et al. (2003) article. This resulted in the selection of the SWAT model as the best tool for fulfilling the EPAL needs (EPAL, 2009a). However, before the final decision the SWAT model had to be tested on a pilot area in order to assess its performance and possible problems connected with its application.

As a pilot area the small catchment (14.2 km²) of the Graisupis river was selected. This catchment is located in the middle of Lithuania, which is dominated by agricultural lands (they occupy more than 71% of catchment). It was selected, because long term monitoring program for assessing agricultural pollution was located in this area. Therefore, much of long-term important data describing water quality and agricultural activities were available for this area.

Detail model application results on the Graisupis river catchment are presented in master's thesis of Plunge (2011). Model testing in the pilot area was successful. It provided reasonable match with monitoring data. It is necessary to mention, that the stability of model, support from its community and developers, additional tools to ease SWAT application (such as ArcSWAT, SWAT-CUP and SWAT Check) and good model documentation contributed substantially in the successful SWAT model application. The prepared SWAT model on the pilot area was also used for testing different methodologies and the modeling of Best management practices (BMPs). Integration of Risk assessment framework and the assessment of NPS pollution abatement by applying the SWAT model has been presented in Plunge (2009). In

another work of Plunge (2011) is presented SWAT application for the identification of critical source areas, nitrate sensitive areas and the optimization of BMPs selection and placement in the catchment. The Graisupis river catchment also was used for the evaluation of wetlands as the BMP for NPS pollution reduction and selection for optimal sites for this measure (EPAL, 2012). These applications of the SWAT model provided good results and revealed the great potential of model to be used in the Lithuanian conditions. Results obtained from model testing allowed making the final decision for the application of the SWAT model for the whole territory of Lithuania.

SWAT model preparation for application on the country

The project for the preparation of the SWAT model for Lithuania has commenced in the spring of 2011 and ended in winter of 2012. Latvian company “Center of Processes’ Analysis & Research” (PAIC) specializing in the field of hydrology, has been enlisted for this task.

The EPAL collected all necessary and available data before the beginning of project. Time series were collected up to the year 2011. Collected data included:

- GIS soil data showing spatial distribution of soils (at scales 1:10000 and 1:300000);
- GIS data on land use (CORINE data and crop declaration data);
- DEM data (10 meter raster resolution);
- River network and river basin GIS data (of different scales);
- Yearly point source data since year 2000 (loads of pollutants and coordinates of point sources);
- Daily meteorological data since year 1990 (18 stations);
- Daily flow data since year 1991 (from 64 stations);
- Monthly water quality data since year 1996 (from 139 stations);
- Fertilizer application data (collected by the Lithuanian Department of Statistics);
- Other data (various reports, statistical data, GIS and monitoring data).

The preparation of the SWAT model was done in several stages. Detail explanation of it is out of scope for this article. Yet, this information could be found in the final report of project (PAIC, 2012a). This article presents only broad overview of the main steps (see Fig. 1). Firstly data were processed into necessary form and formats. It took substantial time. Secondly, the ArcSWAT software was used for each setup to get MDB files. Later on these raw setups have been changed by applying prepared Python scripts in order to update default information with necessary parameters. After this the SWAT2009 rev. 477 (with some modifications done by PAIC) was used to run setups for obtaining initial results. The PAIC-SWAT program has been prepared for integration of all setups, monitoring data, editing and visualization tools into one system. This program was used for the model calibration and validation procedures. It is also important tool for working with prepared modeling system.

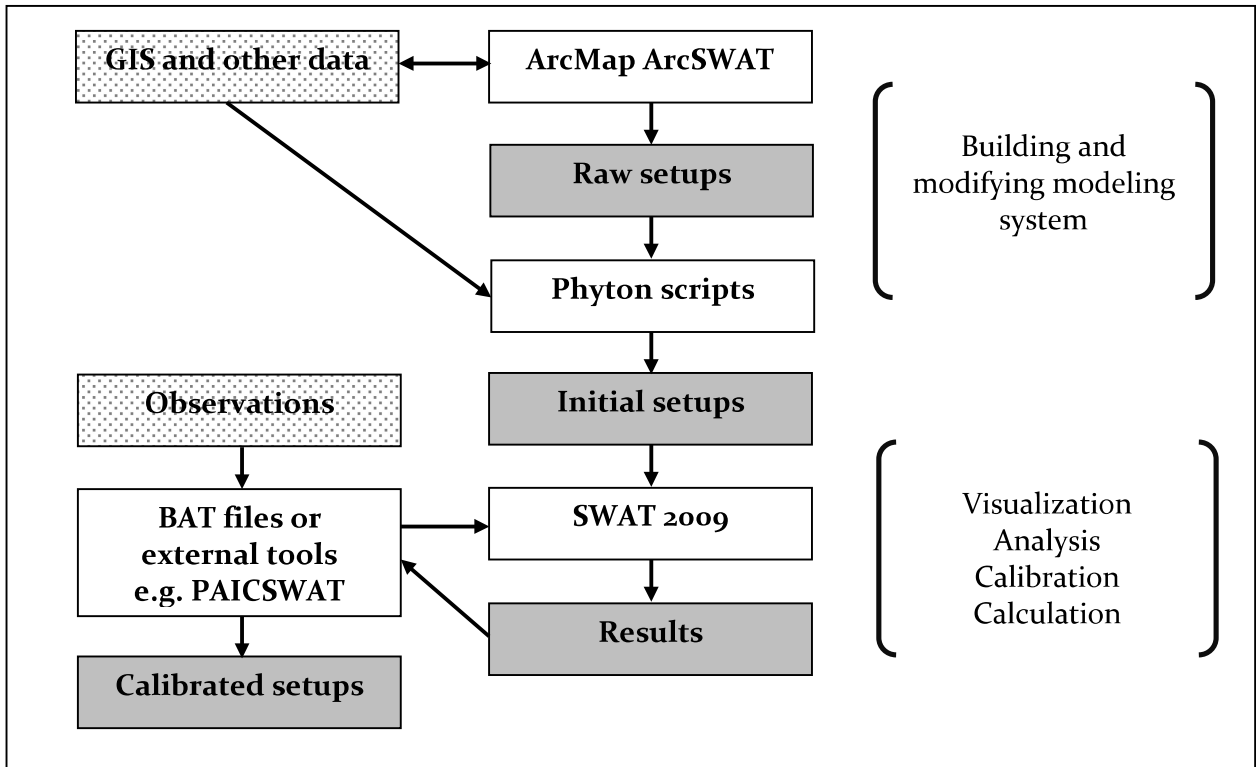


Fig. 1. Steps used in the preparation of the SWAT model setups.

Model has been prepared to be run between years 1997 to 2010. The first 3 years was used for the model warm-up. The territory of Lithuania has been divided into 129 setups (with more than 1000 SWAT model sub-basins), which in turn have been connected by 4 level hierarchical system (see Fig. 2). The first level of setups represented upstream watersheds and was designed to run first. Results from the first level were utilized by using inlets in second level watersheds. Third and fourth levels represented two largest rivers and were run in subsequent stages. Whole country model was prepared to run by using batch files to run setups in right sequence.

Model calibration requirements were set low for the project as results from it were intended to be the first step in the preparation of the SWAT model for whole country. The main reasons for this were project financial constraints and the poor quality of important data such as soil parameters and fertilization data.

As a first-step, an extensive calibration was done on the Susve river basin (1173 km²), which was selected as the pilot basin. This basin was selected because the availability of data and the influence of multiple pressures (industrial and agricultural pollution, dams, etc). In the second step, the territory of Lithuania has been divided into 19 major regions. Each of those regions had a selected representative flow and water quality monitoring station on a main river. Initial parameters obtained from the calibration of the Susve river basin were applied for those regions. In the third step, parameters were further adjusted to fit monitoring data of selected station within each region. Finally, all setups in each of these regions were modified according to the one set of parameters obtained during calibration. This regionalization approach allowed

taking into account special hydrological characteristics of different regions while reducing substantially calibration task. The calibration on every flow and water quality station was out of the scope for this project.

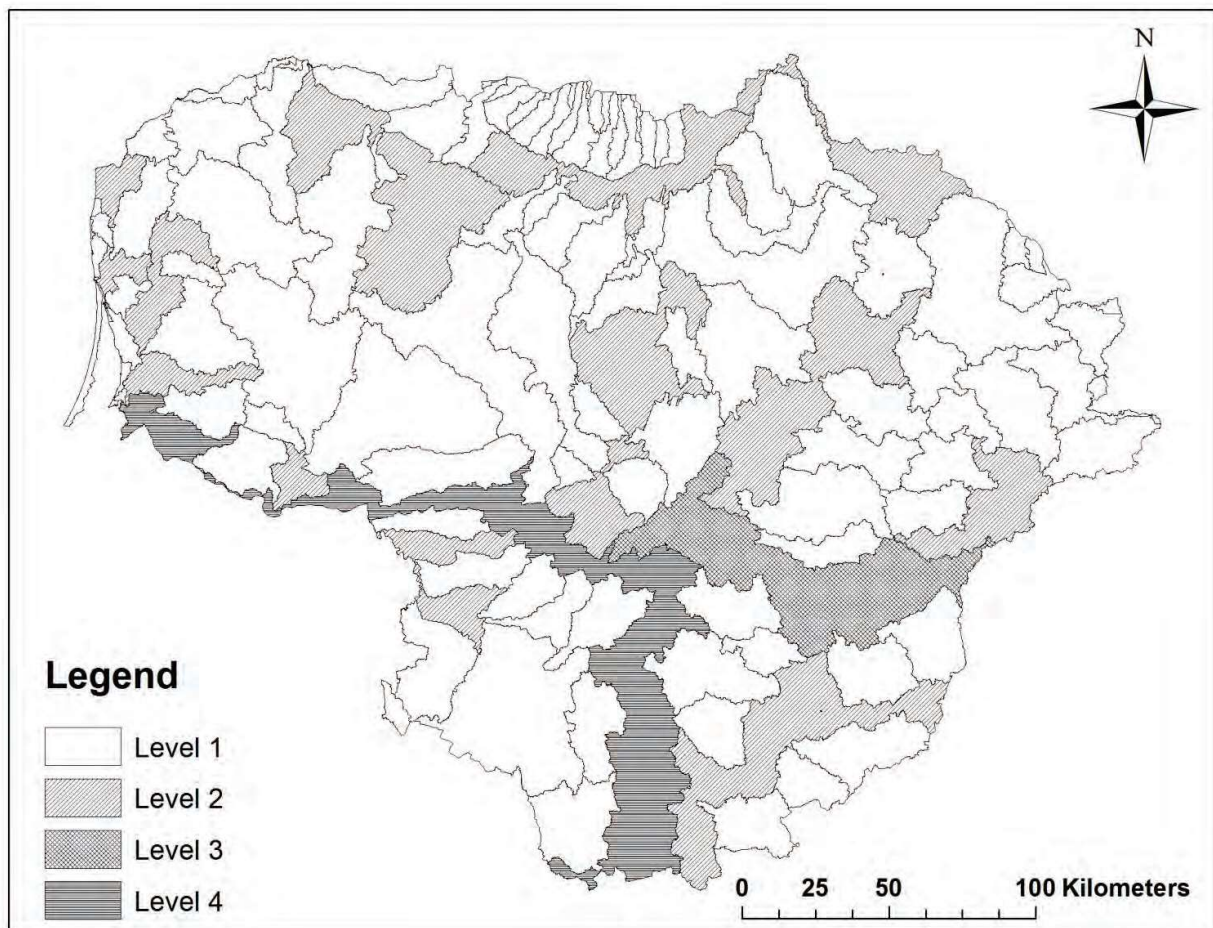


Fig. 2. Division of Lithuania's territory into watershed levels.

The results from such model calibration were satisfactory for the larger part of monitoring stations. However, for many stations results were not satisfactory, because the bigger part of data was not used for calibration and the final calibration of parameters was biased due to relation with the conditions of the Susve river basin. The data from 42 water flow stations have been used in the assessment. As the average of statistical parameters was skewed, because of the influence from extreme values, medians were calculated instead. The median of Nash-Sutcliffe values was 0.5 for daily flow modeling and 0.6 for monthly flow. The median of percent bias values for water flow modeling was around 9%. The median of Nash-Sutcliffe values for daily nitrate load values was 0.27 and a median for monthly values was 0.17 for all water quality stations (120 stations used in the assessment). For water quality stations with at least 5 full years of monitoring data (89 stations) the median of Nash-Sutcliffe values for nitrate daily values was 0.37 and for monthly - 0.26. The median of percent bias values for modeled nitrate values was

41%. Median of percent bias for modeled phosphate values was 39%. According to model evaluation guidelines given in Moriasi et al. (2007) article, model overall performance, if evaluated based on the results of medians, could be graded as satisfactory.

The main result of the SWAT model preparation project was not a fine tuned model (as this was not possible due to data limitations), but instead tools and model setups, which would enable to work further with the model. These tools include all necessary scripts and software required to manipulate input data, setup preparation, the extraction of modeling results and the integration of modeling results with monitoring data for assessment purposes. These results are vital for next steps of work on the SWAT model application. There are no possibilities to present those results in detail for this article. However, such information could be obtained from the "User manual of water quality modeling system for Lithuania" (PAIC, 2012b).

Next steps in the development of modeling system

One of the main activities, which has been initiated even before finishing the SWAT model preparation project, was continuous work on data gathering in order to collect missing data and adjust some data collection programs. The most monitoring programs are long term and designed for the implementation of certain laws or EU directives. Therefore, no quick and far-reaching changes could be made. However, discussions have been initiated by the EPAL with relevant institutions on the collection of missing data. For instance, intensive discussions are undergoing with the Ministry of Agriculture on possibilities to collect data on fertilization and agricultural practices. Moreover, some of missing data are being or have been collected within the boundaries of EPAL monitoring activities or ongoing projects. As example could be mentioned necessary parameters for the Graisupis river catchment, soil parameters for soil profiles, detail DEM, information about river channels, etc. During next steps increased collaboration between the EPAL and other relevant institutions is planned to ensure growing data availability for the SWAT model.

The EPAL also set aside resources for the project to update the RBMPs and the programmes of measures in accordance with the WFD requirements (EC, 2000). This project is planned to start in the middle of 2013 and to finish at the latest in the year 2015. Updating of the SWAT model for the territory of Lithuania and its application for running different scenarios is designated as the one of most important activities of this project. New, corrected and additionally collected data, which were previously not available, will be used in updating SWAT setups. Elaborated, extensive calibration and validation procedures are planned. The application of prepared model is planned for the evaluation of baseline scenario, which would take into account expected results from the implementation of the EU directives relevant to water environment. Additionally are planned the identification of critical source areas, the multi-objective spatial optimization of BMPs, the evaluation of impacts induced by structural changes in agriculture. One of the most important expected outcomes of planned project is the prepared reliable detailed model for the whole territory of Lithuania, which could be used for solving water management questions and providing necessary data for reporting. It is expected that the model will be used for the needs of the HELCOM Pollution load compilation data periodic reporting, the estimation of impacts of applied BMPs for National Rural support programme, the Nitrate directive, the estimation of nitrate leaching to surface and groundwater required for National reporting of greenhouse gas emissions, etc.

The EPAL also initiated collaboration with national scientific institutions (universities and institutes). For instance, lectures have been given in several universities by the EPAL specialists, which were invited as guest lecturers. These lectures were taught within relevant courses in order to attract students interested in the field of hydroinformatic to work on the SWAT model. Institutes are involved in the EPAL projects providing consultations. The EPAL freely shares results of those projects with institutes for their activities and projects and sees this as a long term strategy to attract specialists and increase benefits from investment in the SWAT model.

Main challenges

Certainly, the lack of important data is one of the main challenges for the EPAL. No usable national soil parameter data were available for the initial SWAT model preparation. For this purpose Harmonized World Soil Database was used (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). Used fertilization data were also very poor. Information about agricultural practices was not available as well as many specific model parameters. Moreover, there are also plenty problems related to data quality. The EPAL is working continuously for solving these problems.

Another, probably the most serious challenge, is attracting competent specialists required for the model development. Due to a small size of the country, there is no pool of prepared hydroinformaticians capable to work with SWAT. Even more troublesome is that payment ceilings for civil servants make it very hard to hire specialists with needed skills (especially in IT field). The EU funding is on some occasions available for hiring external consultants during different projects. However, to get long term benefits from model application, it is necessary to have competence and capacity for the model development and for its usage within the EPAL.

Lastly, it is important to mention, that despite many technical challenges connected with the application of such sophisticated tools as the SWAT model (such as the constant changes of the SWAT model revisions and versions, the lack of proper tools for model output assessment, problems related with updating input information, the lack of information about processes in the environment required for model calibration, etc), probably the most complicated are connected with the perceptions of relevant decision makers. Much of the time has to be spent in order to explain the different aspects in the development of such tools for decision makers, which have to be involved and to build trust for a process that require long term thinking.

Conclusion

The SWAT model has been selected by the EPAL as a tool to provide decision support in the field of water management. Employment of this tool is the important part of strategy for solving current and future problems connected with NPS water pollution abatement. The selection of model has been done after considering various characteristics of different models. The SWAT model has been tested on the pilot basin. Positive results were obtained for flow and water quality simulations as well as the examination of the usability of model's results for various NPS assessment methods. These results allowed making decision for starting project on the SWAT model preparation for the territory of Lithuania. Such project has finished in the end of 2012. It delivered all necessary setups and tools required to work with modeling system. The

EPAL is planning to develop further this modeling system by updating input data, improving its performance and using it in the updating of RBMPs. The development of modeling system with the long-term view is expected to provide Lithuanian water management institutions with sophisticated tools necessary for answering questions about NPS water pollution.

Acknowledgements

The author would like to thank his colleagues Jurgita Prunskyte and Martynas Pankauskas for the valuable comments, which helped to improve the quality of the manuscript.