





### Project: Sustainable Hydro Assessments and Groundwater Recharge Projects Project acronym: SHARP

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### **APPENDIX: Long version of good practices to be adapted report**

# GPA 10 Groundwater modelling development and verification

#### **Involved Project Partners:**

Institute of Meteorology and Water Management (IMGW) Regional Agency for Rural Development of Friuli Venezia Giulia (ERSA) International Resources and Recycling Institute (IRRI) Saxon State Office for the Environment, Agriculture and Geology (LfULG)

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## 1. Concise description of the adapted good practice

Numerical simulation techniques for groundwater flow and mass transport have begun to develop relatively recent (early 70s). Model solutions of hydrological and hydrogeological issues are one of the fastest developing disciplines. With the widespread availability of computer hardware, numerical models have dominated the way of solving simple and complex environmental problems.

Numerical modeling in water management in all EU countries, allows for understanding and schematization of processes occurring in ground and water environment. It allows exploring the effects of human impact on the environment, which used to be quite impossible or too expensive to implement. And possibility of developing forecasts of anthropogenic impact on the environment through modeling is the biggest benefit of the use of computerization in hydrogeology. An additional advantage of numerical modeling is the speed and accuracy of the calculations. With the development of information technology the capabilities of using simulation methods has increased.

Modeling requires an understanding of the processes and phenomena occurring in the system, and the proper approach by merging the knowledge of hydrodynamics and the possibility of computing software. Regardless





of the type of tools to schematization water circulation conditions used by specialists in different EU countries, numerical models are developed mainly in order to: characterize the groundwater circulation conditions, evaluate the amount of water resources, assessment of anthropogenic impact on groundwater (e.g. mining), prediction of drainage, designation of protective zones for water intakes, and contaminant migration.

The use of modeling tools is the final stage of simulation studies. In the first place, it is important to develop a conceptual model, the choice of computational procedure depending on the complexity of the task, and the detailed diagnosis of the actual geological and hydrogeological conditions of the analysed area.

Use of the most advanced model programs by teams that do not understand the processes occurring in the water system, the importance of accurate diagnosis of the area and the rules for simplification in the construction of the prototype model, can not avoid errors that may affect the quantitative and qualitative protection of water resources.

Models of the water circulation conditions in order to the properly describe system, requires assembly of a database that will help restore water flow pattern. The primary source of information for the construction and verification of models is measurement data from national monitoring networks. These materials are supplemented on the basis of maps, data and archives, as well as additional measurements carried out in the modeling studies. In Poland exists national network of hydrological (gauges), meteorological, and shallow groundwater stations, where the Institute of Meteorology and Water Management (IMGW-PIB) is responsible for periodic measurements and maintenance. Geological and hydrogeological data from a nationwide network are collected by the Polish Geological Institute (PIG-PIB), and data of quality groundwater monitoring in Poland are collected by the Chief Inspectorate for Environmental Protection (CIEP).

In Poland, the first simulations were performed on the basis of physical models, that allowed recognizing the relationship between parameters of filtration by restoring the system characteristics in laboratory conditions, while maintaining the scale. With the development of science, more advanced analogous models started to be used, they are classified as mathematical models based on the mathematical description of physical processes described analogously to the process of filtration, such as use of the mathematical description of the flow of electric current in a conductive medium as a description analogous to the flow of groundwater.

In Poland, MODFLOW program is used in 80% of cases of using methods of the numerical modeling of the hydrogeological processes. Less commonly used are programs such as FEFLOW, Groundwater Vistas, MT3D, GMS, and FLOWPATH. Locally original numerical solutions are applied, however usually limited to individual projects.

In IMGW performed numerous works related to the modeling of the water cycle, water resource management and quality of water resources. Some of these elaboration concerned the groundwater modeling, eg. Modelling of flow and pollution transport at closed and reclaimed municipal landfill, where a network of measurementobservational points were established. The works were performed by using 3D authors models software. The results of modeling enables to perform an analysis of: hydrological flow, migration of contamination and environmental risks associated with the source of pollution.

Other work related to groundwater modeling were associated with the assessment of the impact of coal mining (actually a German mine Jänschwalde) on the quantitative status of groundwater on the Polish side of the border. Model calculations were performed using the commercial software Visual MODFLOW. Modeling





results was the balance of the groundwater in the vicinity of the mine, the extent of the impact of the mining on modelled aquifers. Was also known range and area of the depression cone on Polish territory.

In Saxony, in addition to commercial software, original programs are widely used (e.g. HYDRUS model to simulate both the aeration and saturation zone; models for subsurface water balance: SiWaPro DSS, PCSiWaPro and groundwater models: PCGEOFIM, SLOWCOMP). Models can be divided into those that represent the unsaturated zone and those that represent the saturated zone (groundwater). Zone of unsaturated conditions describes the aerated zone of soil (water / air). This zone affects the amount of water resources, because runoff formation processes occur here (split into separate elements of the runoff). In the zone of groundwater there is a body of water that completely fills the air spaces of soil and moves freely under the influence of pressure and gravity; unlike to the unsaturated zone to the surface of groundwater and supplies the water. But before it comes to groundwater recharge, there previously occur processes of infiltration of precipitation and surface water, water retention in the form of soil moisture, creating drainage in the unsaturated zone (subcutaneous flow) and for removal of moisture in the soil by evaporation.

The following figure (Fig.1) shows the unsaturated and saturated soil zones and types of models that represent the area.



Fig. 1: Scheme of unsaturated and saturated soil zones and types of models.

Many modeling codes are implemented in the UK, and vary depending on the topic of investigation, and the experience and financial resources of the individual/organization conducting the work. Finite difference models such as MODFLOW are used widely amongst groundwater practitioners, but increasingly newer finite element codes such as FEFLOW are becoming available. Though finite element codes such as FEFLOW have more varied application and flexible design, issues such as the cost of purchasing additional licenses to use the code, and user unfamiliarity with the modeling program means that finite difference MODFLOW is still probably the most commonly used code in the UK. In addition to the dominant approaches to calculating groundwater flow, there are also modeling codes that have been developed with contaminant transport in mind such as MT3D, PHREEQC, and the contaminated land and landfill focused codes, Consim and Landsim respectively.





BGS has developed its own finite difference suite of groundwater modeling codes called ZOOM for their hydrogeological needs and includes a recharge model, a flow model and a steady state particle tracking model. BGS has employed these codes in recent years to investigate an entire basin to test the current conceptual understanding of the system with an emphasis on reducing uncertainties regarding surface water - groundwater interactions. In another example, the impacts of an abstraction well field on the groundwater and nearby surface water bodies were evaluated and relevant recommendations made. Other work has looked at flood alleviation options and the potential impact standing water could have upon groundwater levels underneath a coastal settlement.

An example of the activities effected in Italy at national level for the groundwater dynamics investigations, can be seen in the specific studies of the Istituto di Ricerca sulle Acque (IRSA, Water Research Institute), a branch of the CNR (National Research Council, Italy), carrying out research and development activities in the domain of "Groundwater, rock and surface ecosystems interactions".

Investigations on quantity and quality of groundwater relies on detailed knowledge of fluid dynamic processes, occurring in the vadose zone and in the deepest zones of subsoil. Groundwater recharge, flow path and pollutants transport are studied through investigations on the soil and rock hydraulic properties of saturated/unsaturated media. IRSA utilizes new lab methodologies and on field investigations to estimate hydrogeological parameters. New probes and devices are studied in laboratory. Groundwater flow and interactions between surface waters and groundwaters studies are conducted with both direct tracer experiments and indirect methods. Estimation of water evaporation from bare soil or soil covered with vegetation is also carried out with on field trials.

As for the state of the art in the Region Friuli Venezia Giula, at the moment an overall mathematical conceptual model has not been developed yet for the territory. In 2011 a comprehensive and quantitative balance of the groundwater resources of Friuli Venezia Giulia has been published . This latter report describes the aquifers concerned, the water cycle and the trend observed for the water withdrawal from the groundwater wells; guidelines for planning the use of water resources are also outlined with special emphasis to the hydrogeology, the water balance and its steady state, the measures concerned with ground water recharge, the consume reduction, the quality standard conservation, the sustainability and the knowledge process. A database on groundwater resources as well as metadata and maps in Friuli Venezia Giulia are maintained and updated by the Servizio idraulica of the Region Friuli Venezia Giulia along with the data collected through the piezometric network. Both these data sources can be reached through the web and represent a valuable source of information and knowledge regarding ground water balance and dynamics.

Other modeling applications available in Italy are dealing with irrigation and related topics. IRRIWEBVENETO (Veneto Region, 2004) is a tool aimed at informing the farmer on "when" intervene as well on the most appropriate amount of water to be supplied to the crops . Another tool aimed to assist farmers and decision makers is IRRIFRAME (Italy, 2009); it has been proposed by the Italian National Association of Land Reclamation Consortia (ANBI). IRRIFRAME is aimed at improving the water use efficiency. The most convenient period for irrigation and the amount of water to be supplied is suggested by the water balance conditions for the crops . A recent model dealing with irrigation has been developed by the University of Udine (MiniCSS University of Udine, 2011). MiniCSS is a dynamic model aimed at optimizing the irrigation interventions and the nitrogen fertilization, taking into account the farm profitability (modules: crops, soil, water, soil OM, nitrogen, crops management, economy)





Transfer by providing a guideline discussing purpose of constructing numerical models, what types of models exist and where sources of information for modeling can be found.

Following this guideline provides the basis for creating a tool for useful prognoses of measures to protect groundwater resources.



Fig. 2: Proposal of scheme of development and verification of hydrodynamic models.

The benefits of implementing adaptation "Development and verification of groundwater modelling" are:

- enable the performance of rational water management based on modelling results, which provide the information necessary to determine the possibility of achieving the environmental objectives within the meaning of the Water Framework Directive, including: good groundwater quantitative status;
- enable a diagnosis of the state of the aquatic environment of the area and the development of forecasting the direction and rate of change of the hydrogeological conditions;
- determine the scale of the impact of the drainage system of lignite opencast mine and therefore the range of a depression cone and the impact of drainage on surface water;
- allows to define water resources, and therefore the groundwater balance component that is necessary for the sustainable water management.





Describing own practical experience in implementing adaptation or good practice, including the benefits and problems allows for effectively and efficiently implement developed during the project objectives and guidelines for the practice of water management.

Additional gained experience in terms of how to transfer information about achieved results and about the possibilities of their application, going beyond the traditional expertise is also the added value of the SHARP project. When preparing information about adaptations / best practices for project co-partners (PPs) one can gain practice in:

- contact with a potential customer (official),
- method of communication,
- method of presentation and promotion of the results obtained from the implementation of adaptation / good practices.

The main benefit of the developed adaptation is establishing and development four steps of procedure concerned the development and verification of the models and the preparation of the scheme transferable to the other countries/areas (Fig. 2).

### 2. Description of adaption process

The construction of numerical models and performing simulations and further verification is a complex process, which should be divided into four stages:

Step 1: Understanding the real system – at this stage data is collected, compiled and interpreted, allowing identification of the environmental conditions of the studied structure. The goal is a detailed diagnosis of the studied area structure and anthropogenic factors affecting the current state and which can affect the forecasted conditions.

Condition for proper development of the model and the reliability of simulation studies is to understand functioning of the actual system. Complete diagnosis of the centre and all factors that affect it, is important. From these elements depend whether the model will sufficiently describe the actual conditions in relation to the objective assigned to it.

Step 2: Schematization of aquifer system - is a stage of limiting the field of simulation in space, these are both horizontal and vertical restrictions. This step requires separation of the modelled aquifers and creation of the concept of operation of aquifer system by defining the factors influencing the water flow in the system. Stage is based on the previously developed conceptual model that describes in a simplified way the actual hydrogeological conditions. Only the correct conceptual model allows to correctly reproduce the actual condition with numerical methods.

Step 3: Tool selection and model construction - at this stage comes to the choice of tools, methods of modelling studies that will allow you to answer the question about a particular problem. Previous stages required good recognition of the actual conditions of the study area. At this stage, the key is knowledge of the capabilities of software and operating principles of environmental modelling programs to make the choice of a





proper computer program that will allow a solution of assumed hydrogeological tasks. In the next step the filtration area is divided into calculation blocks, initial and boundary conditions are defined and data matrices describing filtering parameters and other characteristics of the studied system are created. Filling the input data matrices allows the recognition of the numerical model as a prototype of model of the real system, which will become a full-fledged after performing in the next stage the calibration and verification processes.

Step 4: Application of the model - this stage begins with the restoration process, based on the constructed model, of specified hydrodynamic state, documented with fieldwork. Conducting calibration and verification of the model is to bridge the gaps in the input data, and an evaluation of the accuracy and the need to input to the model simplifications of natural system presenting.

Experience with other models. Contribution of each of the co-partners may be their previous experience in the use of numerical models for the purpose of defining water resources (renewable, disposable, prospective), directions of groundwater flow, determination of trends of water resources in a given period, etc. These results of numerical models can provide an important base / contribution to the sustainable management of water resources. The experience of co-partners of the project may also concern information on the range of applicability of the model (software), eg. for which of analysed cases, they consider that a given numerical model will be adequate and for what will not. An example would be a group of models, MIKE (MIKE SHE which is dedicated to ..., MIKE BASIN to ...., etc.). Moreover, sharing the experience of working on the software can be helpful during the calibration and verification of the model at the end of verifiability results analysis. Comments of the expert using that software help to find possible errors, for example, make it easier to determine the correct boundary conditions that the best reflect real conditions. The use of the existing potential in this area (PP) on the one hand allows for better results of the project (SHARP) on the other hand allows to avoid common errors that occur in the familiarization with the new software or the creation and implementation of new models.

<u>Experience of cooperation with decision-making bodies</u>. Contribution of each of the co-partners may be their previous experience with the transmission of the results of numerical modeling for the government entities involved in water management. For example IMGW-PIB presented the results of modeling the range of influence of the mine Jänschwalde on groundwater at a meeting of the International Polish-German Commission on Boundary Waters - W1 Group, where decisions are made about water management in the transboundary Neisse basin.

The main problems related to the implementation of adaptation in the form of the Development and verification of groundwater modelling are:

- financial aspects (cost of software and work of someone with experience in modelling groundwater). The software costs can be significantly different depending on the manufacturer, the complexity and computational tools and mechanisms. In addition, mathematical models can be used for example to the calculation of water resources, calculation and determination of the movement of contaminants in groundwater, etc.;
- time-consuming process of data collection and preliminary work. Prior to modeling, it is essential to collect a number of data (hydrogeological, geological, hydrological, DTM, etc.) and analyse them. Then it is necessary to prepare the conceptual model, selection and choice of software, calibration and validation of the numerical model;





participation of experts in the interpretation of results. People with experience in groundwater modeling are necessary for the verification and interpretation of the modeling results.

To reduce the costs of modelling works the simplifying the model structure is needed: increasing generalization of the model, reducing the number of layers of the model (if possible). Simplifying the modeling assumptions can lead to the possibility to select a less complicated, less expensive software. Using less complicated software may entail further benefits associated with easier building of model structure and less time-consuming and also can result in not having to hire external experts to solve problems related to modelling work.