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 2	Application of water balance models with respect to climate change

Involved Project Partners:
Saxon State Office for the Environment, Agriculture and Geology (LfULG)
Region of North Aegean (RNA)
Region of Western Macedonia (RWM)

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1. Concise description of the adapted good practice

Especially today where the predicted climate change calls for urgent adjustments to its impacts on a worldwide scale and poses new challenges on the management and prognostics of water resources, the following method is a good example for how to tackle this issue.

Particularly in times of climate change, it is important to know the distribution of water resources. For this reason the KliWES Project (Assessment of the impact of the climate changes predicted for Saxony on the water and material balances in the catchment areas of Saxon water bodies – Water Balance Section) were developed (see description GP 13 on page X of this Manual).

The technique based on a scientifically founded method or combination of several appropriate methods for the calculation of "complete" water balances (based on mean and/or day values) for any of the areas in Saxony, while offering the possibility to run and evaluate scenarios. The results can be used to classify catchment areas by their water balance's sensitivity to the climate change. In a second step, the results can be used to give region-specific management recommendations to ensure sustainable management of the surface and ground water resources. The results will enable decision-makers to identify the areas in greatest need of adjustment strategies for water resources, agriculture and forestry. The results and recommendations are intended for a broad target group, namely engineering bureaus, industrials, administrations, institutional users, researchers and scientists, politicians and accountants, as well as to national/international bodies and citizens.

Resulting of projects such as KliWES the LfULG has much experience in the modeling of the water balance.

1.1 Characteristics of the good practice

In the following the procedure for modeling of water balance and is explained step by step.

A. Specification of input data and derivation of hydrological relevant system characteristics Analysis and preparation of data bases

The data basis is the major item in water balance modelling approaches. The first step is to make a check to identify the data that is necessary or available and needs to be processed and used. The quality and the quantity of the data are crucial for the modelling result. The required data can be divided into three groups: geodata, meteorological data and hydrodata. The basic condition for all data is: For the application of a countrywide water balance calculation giving consistent and robust water balance results, it is necessary to have a largely homogenous and countrywide data record.

The quality requirements for the data record are variable, depending on the particular model.

Three geodata selection criteria (soil, lithofacies, land use,…) were defined specifically for the KliWES project:

<u>Availability</u>

The major criterion for the selection or suitability testing of all data bases is a uniform digital availability of the geodata in the studied project area. The KliWES project for the consistent calculation of the water balance cannot be implemented unless or until this criterion is fulfilled.

<u>Scale or high surface detail</u>

In digital data, a distinction is made between vector data and raster data. Vector data refer to a large scale for a spatial resolution in high detail. In contrast, the raster data resolution is defined by the size of the grid cells. The smaller the cells are, the more detailed the resolution is. A detailed spatial resolution improves the positional accuracy of each of the individual objects described in the geodata.

<u>Model parameter derivation options</u>

For a countrywide water balance modelling approach, it is important to be able to determine the necessary parameters for the models on a countrywide scale. Normally, parameters cannot be obtained directly from the maps. Depending on the information required by a given model, it is necessary to derive them from digital maps by means of parameter models. For instance, the "hydraulic conductivity" parameter can be derived from the BK50 map (soil map in a scale 1:50,000) by means of the parameter model laid down in the soil mapping instruction "Bodenkundliche Kartieranleitung" (KA4, 4th edition). The geodata are linked to specific attributes (properties), which are crucial for the selection of the modelling approach to be used.

Especially, the meteorological data are important inputs to the model. Meteorological time series must be homogenous and consistent and need to be available without any gaps over a period as long as possible. Since the data are available as stationary data only, they need to be regionalised in a first step to be prepared for the countrywide water balance calculation. Methods like Kriging, Thiessen polygons, or Inverse Distancing can be used. The data must be available in a daily resolution.

For modelling purposes, it is important to have hydrodata in addition to the meteorological data. The hydrodata includes time series of discharge and groundwater levels as well as management data that might be indicative of an impact on the natural water balance. Discharge series are required for the calibration and validation of the models. The data basis is composed of several years of daily discharges.

B. Selection of suitable modeling approaches (soil water balance, groundwater etc.)

A model is an ideal and abstract description of the reality. The relationship between cause and effect of this system is representing by a concept, which captures the basic laws of physics, the system structure and parameters. These concepts must be implemented in mathematical algorithms. The type of implementation depends on the purpose of the model application and the type of process to be modeled. Hydrological models mathematically represent the movement of the water and its contents on a part of the earth's surface or in the subsurface.In most cases, a hydrological model is used with the aim to predict expected conditions (forecast) or to analyse and understand the system behaviour (what-if scenario). In addition, a distinction must be made between whether the models are operated in real time (e.g. operative flood forecast) or in the scenario mode without any direct relation to currently ongoing hydrological processes (e.g. calculation of the expected effects of climate changes on groundwater recharge). Model results are generally just approximate results with more or less significant deviation from the actual process, which often is not or just hardly measurable or observable.

Depending on the type of process description, hydrological deterministic models are divided into empirically, conceptually and physically founded models.

Empirical models are so-called black-box models based on a cause-effect relationship. Only the system input and the system output are known, whereas the intrinsic structure of the system (the system operator) remains unconsidered. These models are based on the observations of events in nature and describe the relationships between input data (e.g. precipitation) and output data (e.g. runoff) by means of mathematic equations. The mathematic descriptions do not translate the laws of physics, but are e.g. simple regression equations or exponential functions. Empirical models are e.g. the unit hydrograph method for the transformation of heavy rainfalls into flood hydrographs, the HAUDE method for the calculation of potential evaporation, or the BAGROV-GLUGLA method for groundwater recharge calculations.

Physically founded models are based on the fundamental laws of physics and attempt to represent as closely as possible the hydrodynamics and thermodynamics of the underlying processes. So they allow for realistic process descriptions on the basis of defined measurable parameters. Moreover, they need data in high surface detail in the microscale range and in most cases it is impossible or very complex to obtain such data. Physically founded models are e.g. the PENMAN-MONTEITH method for the calculation of potential evaporation, the groundwater flow models according to DARCY, the RICHARDS model of water flows in unsaturated zones, and the SAINT-VENANT (shallow water) equation for unstationary flow conditions in surface waters.

Conceptual models are also based on the fundamental laws of physics, but they use simplified forms (analogy models and/or model reductions) and may retain a certain degree of empiricism. If physically founded models (where possible) are used outside the space and time scale they were derived from, they normally tend to be conceptual models.

Typical conceptual models in hydrology are e.g. retention and translation analogies.

Both conceptually and physically founded models are often referred to as process descriptive models. In contrast with empirical models, they explicitly consider the process causality in formulating the system operator. Process descriptive models can thus be applied and transferred to non-observed territories. In addition, there are parameter models used to derive the characteristics of a catchment from available information and to describe the characteristics by parameters in the models.

The following Fig. 1 gives an overview of the model approaches.

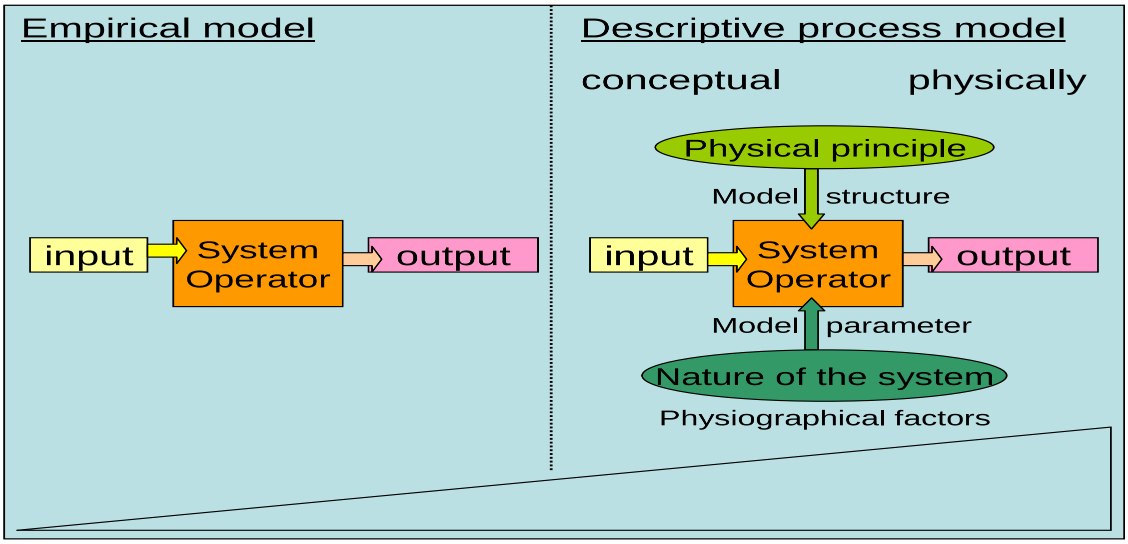

Fig. 1: Models -overview of the model approaches.

C. Modelling of the actual state of water and of future water balance considering the climate change to development of strategies for protecting natural water resources

The determination of the actual state is necessary to determine what resources are still available.

Climate change requires the development of adaptation strategies and measures to changing conditions and therefore new demands on the management of water resources and the associated land development. Based on the results in the future recommendations for region-specific management measures are derived in order to ensure a sustainable surface water and ground water management.

2. Description of adaption process

As described in the Good Practice KliWES, for the needs and demands of the Greeks, the first steps for modeling of the water balance in a Greek basin are presented in this paper.

To adapt the topic Water Balance Models to the Greek needs, a questionnaire was sent to the partner. This questionnaire gives some background information about the Greek expectations on this topic and conditions of their region. Within the 4th SHARP Seminar in Kozani, Greece 2012 Greek partner (PP2) expressed their interest in this topic. Therefore the further information about the KliWES Project and also the questionnaire was additional sent the PP2.

The questionnaire and the responses of PP3 are shown in the following table.

Tab. 1: Questionnaire and the answers of PP3.

Elaboration of adaptations: Application of water balance models with respect to climate change
Please give a short description of the hydrological, geological and meteorological conditions in your region.
➢ Climate: Mediterranean, characterized by a rainy winter, a cool spring and a dry summer. ➢ Geology: Complex geological formations, limestone and dolomite prevail. ➢ Hydrogeology: Karstic formation.
For which purposes or tasks you would like to use a water balance model?
➢ Better underground water management ➢ Submit proposals and master plans for sustainable underground water use
What do you expect from a water balance model?
➢ To support decisions made by Policy and Decision makers. ➢ Perform scenarios and predict possible changes in annual precipitation to be prepared to face floods and drought problems.
1. Do you have any experiences with water balance models?
➢ capable to understand and perform calculations related to water balance model
2. Which data are available from your region?
➢ data are available such as : Geological, Land use, Digital Terrain Model , climate stations (precipitation, radiation, temperature, etc.), climate scenarios, gauge data, groundwater data

As the table shows, PP3 needs a water balance model to perform scenarios and predict possible changes in annual precipitation to be prepared to face floods and drought problems, to submit proposals and master plans for sustainable underground water use and support decisions made by Policy and Decision makers. For this it is important to know the water balance in the catchment area.

The basin of Korakaris is located on the island of Chios in Greece. The following Fig. 2 shows the catchment area.

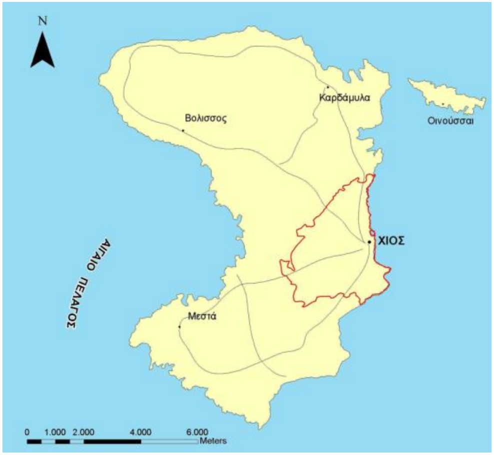

Fig. 2: catchment area Korakaris provided by Vasilis Rozakis (PP 3).

The catchment area has a size of 23 km ².

It is Mediterranean climate and it is characterized by a rainy winter, a cool spring and a dry summer. The dry period appears between the months of April and September. The peak of the dry period occurs in July. The high temperatures have as a consequence more water losses by perspiration and evaporation.

There are complex geological formations like limestone and dolomite prevails.

The geological formations that exist in Korakaris area according to the maps of the Greek Geological Institute are:

- <u>Paleozoic Sedimentary Bedrock</u>: Psammite, Slate S-C, GrW.
- <u>Limestones and Dolomites formations</u>: TRm-I, TRm-S, Kd-t .
- <u>Alluvial deposits</u>: gravels, sands, silts -Qal. Deposits appear within Kokalas and Parthenis torrents.

Tectonic has played important role in creating both relief and the formation of hydrogeo-logical conditions.

There are two main directions of the faults in the region (NE-SW & NW-SE).

The geological formations encountered in the area of Korakaris can be divided into the following categories based on their Hydrogeology behavior:

- <u>Karstic formations</u>: Limestones and dolomites regardless water permeability.
  - <u>Limestones medium to high permeability</u>
  - <u>Limestones low to medium permeability (little or no flow)</u>
  - <u>Porous formations (fed by rainwater infiltration)</u>
- <u>Sedimentary clastic rocks of the Paleozoic:</u>
  - <u>Psammite, shales and chert (the entire formation is no permeable)</u>

In Southern and Eastern parts of Korakaris area drillings are operating since ’50s. The water which is drilling is coming from Korakaris limestone aquifer. This aquifer is fed mostly from rainwater. Initially, it was consider that the presence of a relatively impermeable formation between Korakaris aquifer and the sea, would protect the water aquifer from salinization.

The following problems in water quantity have the Greek partner on the island Chios: floods and droughts.

The water quality is also in problem. In the following the different problems on Chios Island were listed:

- Insufficient water resources,
- the poor quality of the supplied drinking water, mainly due salinisation and to over-pumping,
- imbalance in population and irrigated areas mainly in Chios area,
- the climate conditions the last years (extended arid periods) and the geological formations of the area are the main factors which contribute to the two main problems of water degradation: -> **Salinisation** + Appearance of **Mercury**

The biggest problem that Chios faces as it was mentioned also above is the salinisation. The water supply and the irrigation are made mostly from water drill works in Korakaris basin. Korakaris limestone mass extends in an area of 8-10 km² and it is open to the sea through the psammite bedrock. Every basin has a capacity of water extraction and the exploitation must not exceed this. Unfortunately, Chios authorities in early 50's, in order to cover the population increasing demand on water, were preceded in the construction of a numerous wells and drills. The irrational exploitation of water combined with the increased demands for water created serious quality problems and allowed the sea to enter the aquifer. The situation became worse after the arid period of 1989.

Proof of all the above are the results of analyzes where concentrations of chloride and sodium ions exceed drinkable limits (250mg/l), which certifies the encroachments of the sea and the mixing of seawater with the sweet water of the aquifer.

However, salinisation aquifer creates an extra problem. The charge of water aquifer with Mercury (Hg) rates higher than the permissible.

In the bedrock of Korakaris Basin exists the rock cinnabar (HgS). When cinnabar come in contact with salty water a chemical reaction occurs and quantities of mercury are released in the underground water. This makes water extremely dangerous for human health.

In our survey we used Pearson coefficient to test the dependence of mercury on chloride.

The results showed that there is a strong and positive dependence between the Mercury and Chloride.

2.1 Steps for Adaptation

The approach of KliWES can be generally taken:

A. Specification of input data and derivation of hydrological relevant system characteristics Analysis and preparation of data bases
B. Selection of suitable modeling approaches
C. Modeling of the actual state of water and of future water balance considering the climate change to development of strategies for protecting natural water resources

But in some catchment areas, it isn't easy. The problem is that in the special case of the identified catchment area of Chios Island is located directly on the coast and is in a karst area. In KliWES there is no experience with catchment areas near the coastal region. Additionally it is complicated by the fact that it is a karstic region.

For this reason, experience from further projects could be used to support the Greek partners in the determination of the water balance and necessary management strategies.

In a subproject of the IWAS (http://www.iwas-initiative.de/), which is concerned with the water supply of a coastal basin (Oman), there are also problems related to groundwater salinisation. It searches for methods, how the country will irrigated, without negative impacts on water quality and quantity. With the help of models different scenarios can be calculated. In the report of IWAS with the title "Towards an integrated arid zone water management using simulation-based optimization" is written following:

"For ensuring both optimal sustainable water resources management and long-term planning in a changing arid environment, we propose an integrated Assessment-, Prognoses-, Planning- and Management tool (APPM). The new APPM integrates the complex interactions of the strongly nonlinear meteorological, hydrological and agricultural phenomena, considering the socio-economic aspects. It aims at achieving best possible solutions for water allocation, groundwater storage and withdrawals including saline water management together with a substantial increase of the water use efficiency employing novel optimisation strategies for irrigation control and scheduling. To obtain a robust and fast operation of the water management system, it unites process modeling with artificial intelligence tools and evolutionary optimization techniques for managing both water quality and quantity."

An initial discussion with the experts found that in regions such as Chios, an intensive monitoring of the aquifer is particularly important, especially in relation to the withdrawal quantities. These are very simple and can be measured with a relatively high reliability, which ultimately contributes to a more accurate and reliable determination of the water balance and the future helps to make the right management decisions.

At the moment, only those articles can be exchanged and contacts of IWAS Project can be provided. However, in a further collaboration after SHARP a detailed procedure could to be developed with the help of the project IWAS.

List of Literature:

Good Practice KliWES.

Towards an integrated arid zone water management using simulation-based optimization, Jens Grundmann • Niels Schütze • Gerd H. Schmitz, Saif Al-Shaqsi; Received: 31 January 2011 / Accepted: 15 July 2011; Springer-Verlag 2011.