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YSSP Report
Young Scientists Summer Program

Modelling water resources management for climate change adaptation in Austrian agriculture. The case of Seewinkel.

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This report represents the work completed by the author during the IIASA Young Scientists Summer Program (YSSP) with approval from the YSSP supervisor.

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30-09-2021

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Contents

Abstract

Climate change is expected to increase the frequency and duration of droughts. During the last decades, Europe has experienced a series of heatwaves and droughts (2003, 2010, 2013, 2015, 2018 and 2019). Countries, which were originally considered water rich, are now experiencing precipitation deficits, which affect agricultural productivity. Adaptation of agriculture to climate change is therefore critical to ensure food security. Water management is a crucial aspect to adapt agriculture to climate change. The semi-arid region of Seewinkel in Austria was taken as a case study. Seewinkel requires especial attention due to its extensive agriculture and its unique biosphere of saline lakes (IUCN classified area). Local stakeholders have suggested adaptation measures requiring analysis with impact models to reduce uncertainty. Using system dynamics, an impact model for Seewinkel was developed to serve as a tool for water policy analysis. The model considers the interactions between the local aquifer, water extractions by agriculture and the saline lakes. The model was calibrated using local historical observational data and it will be forced using projected climate data (EURO-CORDEX) for three representative concentration pathways (RCP)s. Because this is a work in progress, model validation and testing of adaptation measures under climate change scenarios are still in development.

Acknowledgments

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Introduction

Countries in Central Europe were historically considered water-rich. However, Central Europe has experienced prolonged droughts and heatwaves since the beginning of the 21st century (Ionita, 2020). These drought events have caused massive losses in the agricultural sector. Current losses in Europe are estimated at €9 billion per year (Naumann et al., 2019). In the case of Austria, agricultural losses caused by drought averaged €123 Million per year (2019), a figure higher than the combined agricultural losses from hail, frost, storms and floods (Leitner et al., 2020).

At a global scale, there is high confidence that climate change will increase the frequency of concurrent droughts and heatwaves (IPCC, 2021). This situation is particularly alarming for agriculture as 82% of all damaged caused by drought is absorbed by agriculture (FAO, 2021). In Europe this figure lays between 39–60% (Cammalleri et al., 2020). Moreover, in Europe, the effect of increasing drought events on agriculture has already become noticeable. For example, it is estimated that cereal losses increase 3 %/year because of drought (Brás et al., 2021) and that climate change will reduce wheat production by 6% for each degree Celsius of temperature increase (Asseng et al., 2015).

Agriculture has also a close relationship to freshwater resources as it accounts for 70% of water withdrawals globally (FAO, 2018; IPCC, 2019). While not all regions are affected equally, agricultural groundwater extraction has caused groundwater depletion in drylands and that it has influenced the water cycle at local and regional scales (Dalin et al., 2017; Gleeson et al., 2012; IPCC, 2021; Scanlon et al., 2012). In semi-arid regions water scarcity is now one of the main problems to be solved (Araujo et al., 2019). Additionally, since the 1960s, irrigation water volume has doubled (IPCC, 2019) and under climate change, the importance of groundwater for irrigation is expected to further increase.

Climate change adaptation is especially important for agriculture in order to ensure food security (EEA, 2019). Adaptation has also additional benefits as it strengthens the preservation of water resources (Turral et al., 2011) and it promotes soil conservation (EEA, 2019). Water management for climate change adaptation involves the evaluation of adaptation measures using top-down impact modelling approaches (Ludwig et al., 2014). But developing efficient adaptation strategies requires integration of water management, hydrology and agronomy (Turral et al., 2011). Because water management decisions are usually affected by large uncertainties, climate adaptation studies should include several climate change scenarios but also use several impact models to produce robust results (Huang et al., 2018).

Under this framework, this study performed an analysis of Seewinkel region with the purpose of supporting climate change adaptation of local agriculture. For this analysis, we have developed an original system dynamics model calibrated using local observational data. The current study takes into account the interactions between agriculture, water resources and the local ecosystem under three climate change scenarios (RCP 2.6, 4.5 and 8.6). The model runs using historical and future climate projections provided by the World Climate Research program EURO-CORDEX initiative. With the model, we will test the impact of three adaptation measures suggested by stakeholders and compare their effectiveness. The goal of this study is to reduce uncertainty and support evidence-based decision making in the Seewinkel region.

System Dynamics Modelling

Jay Forrester, from the Massachusetts Institute of Technology, developed system dynamics during the 1950s (Elsawah et al., 2017). The method was developed as a mean to model complex systems and the interactions within them. Over the years, this approach has proven useful for the simulation of complex environmental and water system problems (Zomorodian et al., 2018). System dynamics has been extensively used as a tool for water management (Dong et al., 2019; Hassanzadeh et al., 2014; Kotir et al., 2016; Sun et al., 2017) as it allows us to consider the interactions between hydrological systems and society and the environment.

System dynamics models are advantageous for water resources management because they can be built fast and they can integrate information provided by stakeholders. Additionally, because system dynamics models are visual they are usually easier to understand. Models can be developed in sub-models, which can later be coupled or developed together. Each sub-model can integrate information about a particular area of interest such as human behavior, economy and environmental factors. System dynamics models usually compute results corresponding to periods of ten years in seconds. This is a strong advantage when compared to purely hydrological models which can take several hours to compute results. Finally, system dynamics models can be used to test policies or adaptation measures, which make them particularly advantageous for water management and policy development.

Study Area

The Seewinkel area is a semi-arid region (Mitter & Schmid, 2021a) located in the east of Austria in the state of Burgenland. The region is around 450 km2, has an average annual temperature of 10 °C and an average annual precipitation of 600 mm (Kropf et al., 2021). The region is located west of the Lake Neusiedl, the largest endorheic lake in Central Europe (Kropf et al., 2021) and also largest lake in Austria (Soja et al., 2013).

Within Seewinkel, agriculture shares the land with numerous saline lakes called "Salzlacken". These saline lakes are a local habitat for amphibians, birds and florae (Krachler et al., 2012). Preserving the saline lakes is of vital importance for the local biodiversity. The saline lakes are a fragile ecosystem that depends on groundwater (Magyar et al., 2021). Sinking groundwater levels could destroy these ecosystems, as a minimum ground water level is necessary to maintain their chemical balance (Krachler et al., 2012). However, some of the lakes were heavily modified since the beginning of the XX 20th century. Herzig (2001) mentions that currently 36 saline lakes exist in region while they were more than 100 in 1900.

A vast majority of the land in Seewinkel is used for agriculture 56% for cropland, 6% for grassland, and 10% for vineyards (Karner et al., 2019). Because of its semi-arid conditions, local agriculture requires irrigation. Farmers extract irrigation water from the single local aquifer, irrigate using sprinkler systems for the crops, and drip irrigation for the vineyards. Local crop production includes sugar beets, potatoes, corn, cereals, soya and sunflower (Mitter & Schmid, 2021b). While currently water demand is dominated by agriculture, demand by other sectors such as tourism and nature conservation are increasing (Mitter & Schmid, 2021b).

Because of its status as a semi-arid region, Seewinkel is at risk of increasing water stress caused by climate change and aggravated by human activities (Magyar et al., 2021). Currently, groundwater extraction is regulated by water cooperatives, which take legally binding decisions and constrain water use when groundwater falls under a certain level (Magyar et al., 2021; Mitter & Schmid, 2021b).

Methods

Model

The model was built to simulate soils and the single aquifer in Seewinkel and the four largest saline lakes. These lakes are the Zicksee, the Lange Lacke, the Darscholacke and the Ilmitzer Zicksee. The soil infiltration is modeled based on the curve number method (Boonstra, 1994) and it is forced with precipitation and evapotranspiration data. The Seewinkel model consists of two stocks (figure 1). The first stock represents water stored in the upper soil layers and the second stock represents the aquifer. The influence of agricultural water extraction on the aquifer dynamics is also included on the upper right side of the model.

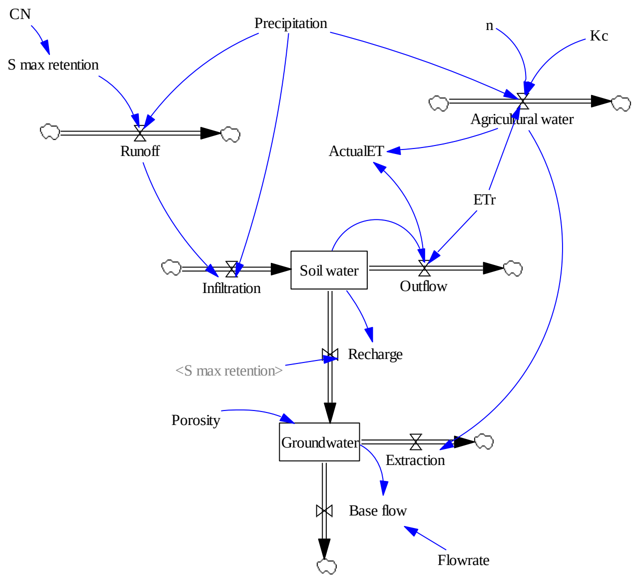

Figure 1. Hydrological model with a stock for soil moisture, a stock for groundwater and inclusion of agricultural water extraction.

First, a curve number CN = 72 was selected because Seewinkel is mostly flat, has soils with high infiltration rates and crops are planted in rows. Afterwards, equation 1 was used to calculate the maximum soil water retention capacity (S) in millimeters.

(1) $$S = \frac{25400}{CN} - 254$$

Afterwards runoff (Q) is calculated using equation 2. According to the curve number method runoff only begins if precipitation is greater than 20% of S. This accounts for surface depressions, water intercepted by vegetation, evaporation and infiltration. With the runoff and precipitation (Pp) values infiltration is calculated with equation 3.

(2) $$Q = \frac{(P - 0.2S)^2}{(P+0.8S)}\ if\ P > 0.2S$$

(3) $$Infiltration = Pp - Q$$

Infiltration then fills the soil and is stored in that stock. Water leaves this stock either by evapotranspiration or as aquifer recharge. First, potential evapotranspiration is satisfied by the water stored in this soil reservoir, thus actual evapotranspiration can be smaller than the potential one. Then, aquifer recharge only happens when the water stored in the soil is equal or greater to S. In the aquifer stock, water only leaves by two means either by base flow following a linear reservoir behavior (one recession coefficient) or by extractions.

Irrigation Demand

Because of the unavailability of data referring to the irrigation water use, the demand is calculated using an irrigation demand equation (equation 4) based on Brouwer & Heibloem, 1986; Shen et al., 2013 and Wang et al., 2016. This equation uses a crop factor (Kc) which is unique for every crop and changes over time as well as precipitation and evapotranspiration data.

(4) This equation is confidential, as it has not been published yet.

The saline lakes

The behavior of the saline lakes (Fig. 2) is based on the description done by Krachler et al., 2012. In their report, they have done extensive research and gathered most of the available information describing the dynamics of the saline lakes. Since the beginning of the 20th century, each lake has been managed and modified in different ways. The Zicksee, for example, receives an annual artificial recharge of around 300,000 m3. Some other lakes were completely dried out by a system of trenches.

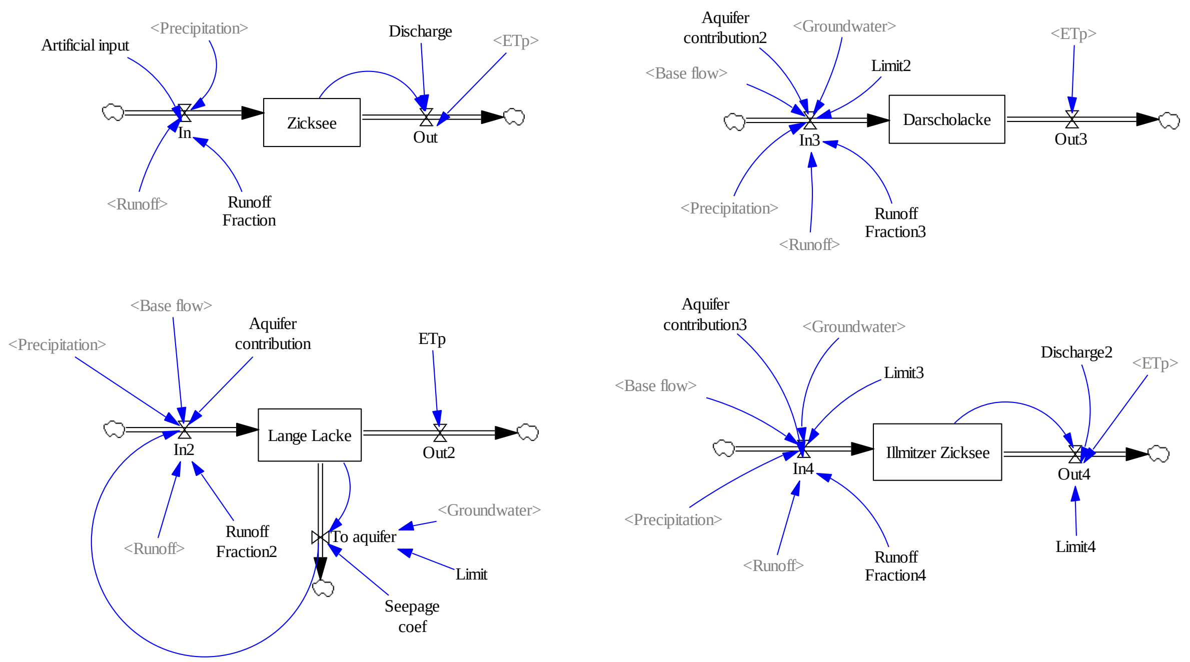

Figure 2. The four largest saline lakes in Seewinkel. The dynamics of each lake are unique as they have been modified and managed in different ways.

The saline lakes receive water from precipitation, runoff and from the aquifer. Their common characteristic is that water mainly leaves the lakes through evaporation, which explains their saline nature. In some special cases, water leaves the lakes through discharge or infiltration. In the Lange Lacke, for example, water flows in both directions. Once the aquifer level drops the water flows from the lake into the aquifer.

Data

The Austrian water portal (eHYD.gov.at) provided almost all the data required to calibrate the models. Climate data from weather stations are provided by the Central Institute of Meteorology (ZAMG). Groundwater boreholes data and lake control station are available in the portal. The evapotranspiration data was calculated using the community water model (CWatM) developed at IIASA (Burek et al., 2020). The reference period for the calibration of the model was from 1981 to 2011.

Three weather stations provided precipitation data. Precipitation was averaged for the whole region, as the model is not spatially distributed. Each of the four lakes has a measuring station controlling the fluctuations in the lake depth and temperature. Finally, for the aquifer data from seventy measuring stations was normalized and averaged to get a single set of data.

Calibration

Calibration was done using the historical data and the optimization tool in the software Vensim developed by Ventana Systems. Vensim is a software designed to build and run system dynamics models. The software optimizes user-defined parameters to calibrate results of the model and match historical data. Vensim repeats the simulation several times changing the user-defined parameters. Once the results of the model match or approximate to the observational data, the software suggests values for each of the defined parameters.

Results

The Seewinkel Aquifer

The model had a correlation R2 = 0.65 compared to the normalized and averaged observational data from the 70 measuring boreholes for the reference period 1981 - 2011. Figure 3 shows the output of the model compared to the observational data.

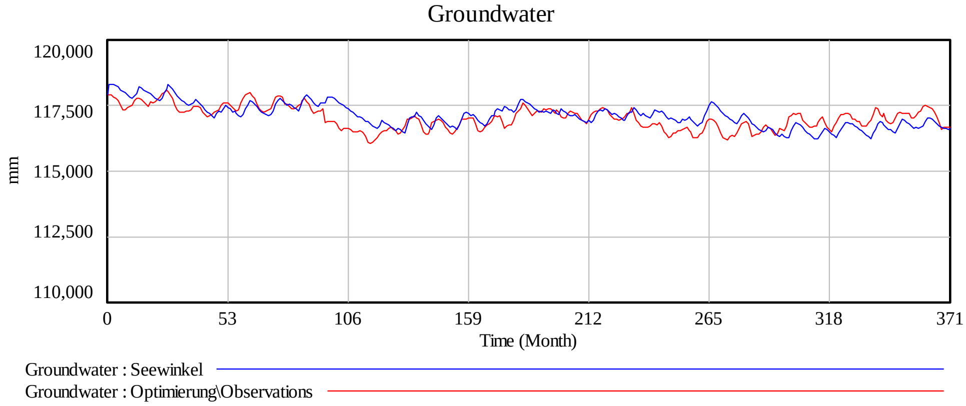

Figure 3. Output of the model (in blue) and the observational data (in red) for Seewinkel aquifer.

The saline lakes

In the case of the saline lakes, the model had better correlations with R2 = 0.77 for the Zicksee (Fig. 4), R2= 0.78 for the Lange Lacke (Fig. 5), R2 = 0.69 for the Darscholacke (Fig. 6) and R2 = 0.67 for the Ilmitzer Zicksee (Fig. 7). The model was also able to follow the yearly and seasonal variations of the water depth

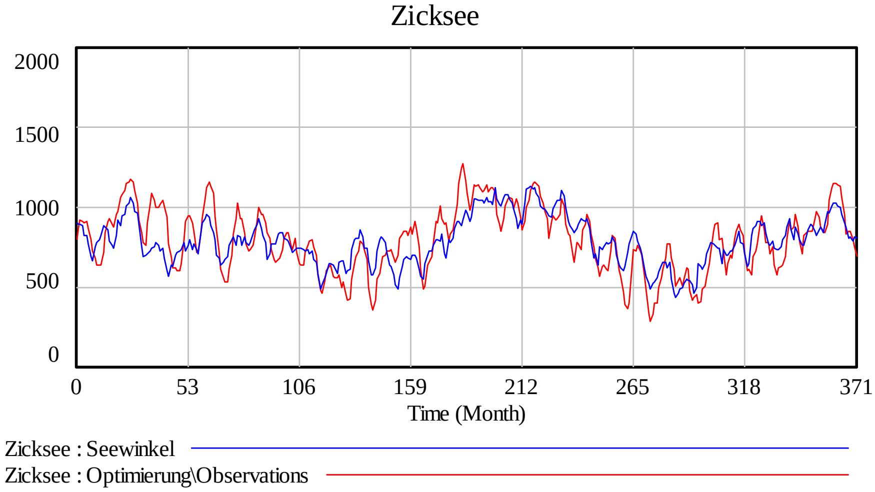

Figure 4. Comparison between model output (in blue) and historical data (in red) for the Zicksee.

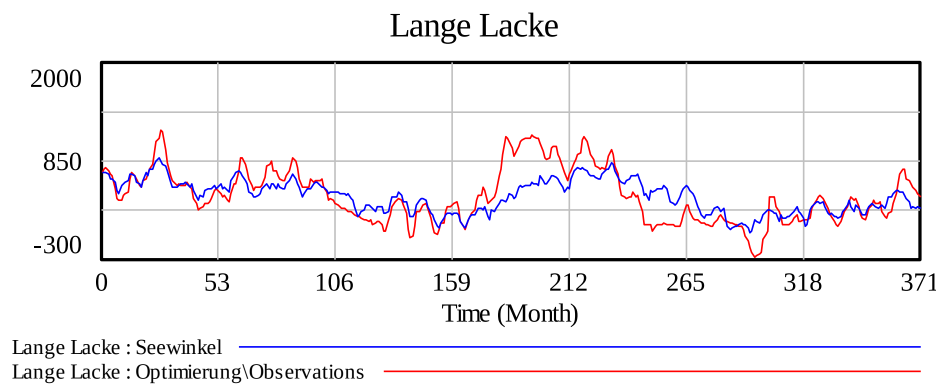

Figure 5. Comparison between model output (in blue) and historical data (in red) for the Lange Lacke.

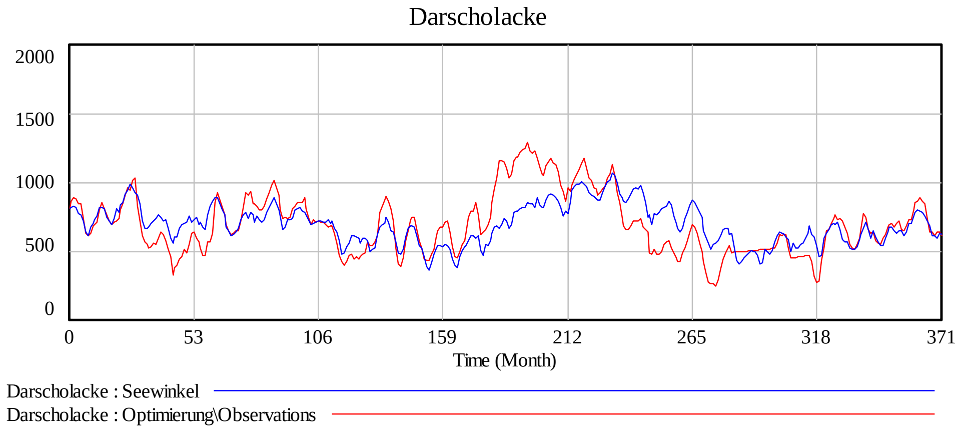

Figure 6. Comparison between model output (in blue) and historical data (in red) for the Darscholacke.

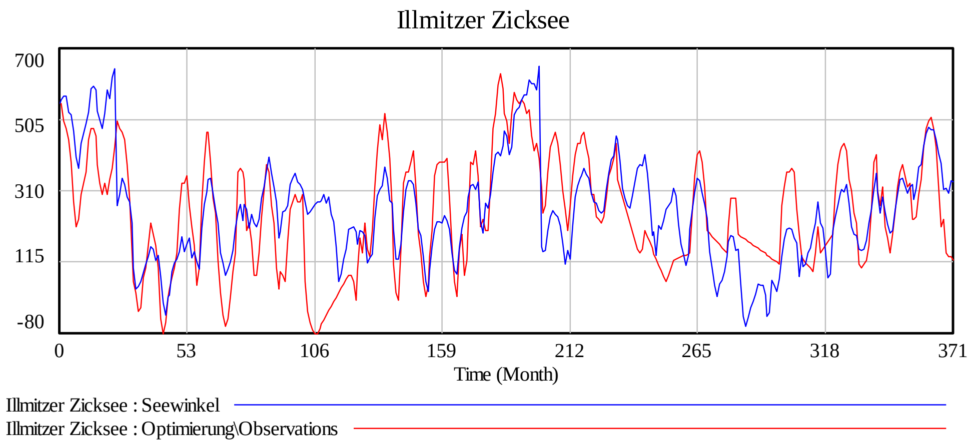

Figure 7. Comparison between model output (in blue) and historical data (in red) for the Ilmitzer Zicksee.

Discussion and Conclusion

Because of its dryland characteristics and the coexistence of agriculture and a unique biosphere of saline lakes, climate change adaptation in Seewinkel has to consider the interactions between agriculture, the aquifer, the saline lakes and climate. This system dynamics model was built to consider these sectors and it is intended to function as a tool to test adaptation measures in the Seewinkel region.

The model was designed and built based on literature-available information and on information provided by stakeholders. Afterwards the model was calibrated using historical data for the reference period 1981 -2011 and it achieved an acceptable correlation to the historical data with correlations between R2 = 0.65 and R2 = 0.78. In addition, inferred parameter values should have some physical meaning making the aquifer model relevant. The model offers acceptable results but it is not intended to substitute hydrological models. However, due to its modular design, the model can be coupled to other models representing additional socio-ecological systems.

This project and the model presented here are work in progress. Due to time limitations, there is still much to be done. As following steps a validation of the model will be done, followed by forcing the model with EURO-CORDEX data for the three RCPs mentioned above. Lastly, the model will be used to test the policies suggested by stakeholders and evaluate their climate change adaptation potential.

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