Master Thesis
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A preliminary study of evidence-based tool for wetland optimization

A case study using QSWAT+

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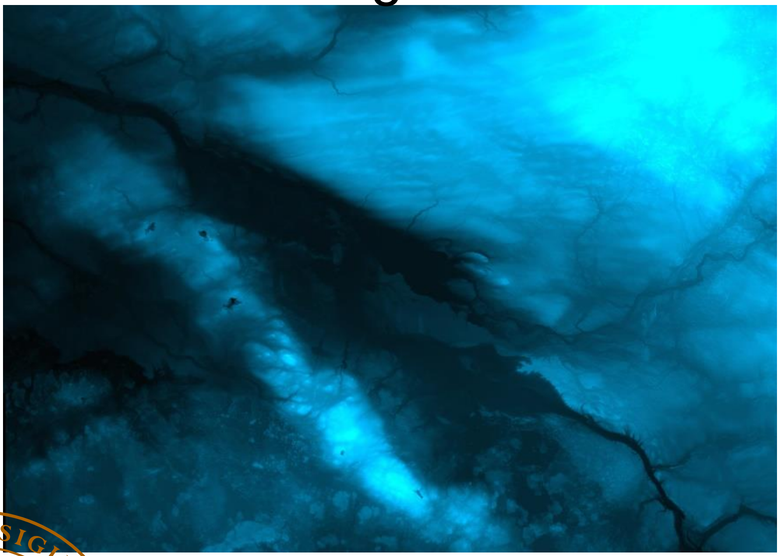

Division of Water Resources Engineering
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With this Master Thesis, we complete our studies at LTH and graduate in Civil Engineering, Master of Science in Engineering.

With tremendous gratitude we would like to thank our supervisor Linus Zhang for the support and meaningful comments during this study. Thanks to his interest in developing an evidence-based tool, he has been working with us in parallel when difficulties have arisen. Additionally, we would like to thank our faculty in the Water Department for all the knowledge they have contributed, our family members and friends that have been supportive during the time of this study.

Finally, we would like to express our gratitude to each other for an outstanding collaboration and a well completed work. Together we have been able to conduct the work with laughter, tears, and with a lot of joy.

Abstract

This Master´s thesis is a part of the Ecodiver project, conducted by the Water department at LTH. The purpose of this study is to review the open-source software QSWAT+ as a plugin in QGIS, to be able to develop an evidence-based tool for optimization of wetlands. The scope of the study area is limited to the catchment area of Kävlinge river; however, no account is taken of the validation of data, only the validation of the program. This case study starts with a brief literature review to collect the theory regarding hydrology and the current situation with climate change. To conduct this work, adequate time was spent on software learning in both QGIS and QSWAT+ using tutorials that was found on the web. The result of this study suggests that QSWAT+ has potential of being the base of the future evidence-based tool within the Ecodiver project, by providing opportunities and possibilities. However, for the current situation of the evidence-based tool, the software is not yet ready nor done developing to function as the base of the tool. Neither is all the Swedish data available to make the tool validated.

Sammanfattning

Utförande av denna Masteruppsats är en del av projektet Ecodiver och i samarbete med vattenavdelningen på Lunds Tekniska Högskola. Syftet med studien är att granska den öppna källkods mjukvaran QSWAT+ som är ett plugin-program i QGIS. Detta för att i kommande tid kunna utveckla ett evidensbaserat verktyg för optimering av våtmarker. Undersökningsområdets omfattning är begränsad till Kävlingeåns avrinningsområde; dock tas ingen hänsyn till valideringen av data, endast valideringen av programmet. Denna fallstudie börjar med en kort litteraturgenomgång för att samla in teori om hydrologi och den rådande situationen med klimatförändringar. För att genomföra detta arbete tillägnades tid åt inlärning av programvarorna QGIS och QSWAT+ med hjälp av manualer som hittades på internet. Resultatet av denna studie tyder på att QSWAT+ har potential att vara grunden för det framtida evidensbaserade verktyget inom Ecodiver projektet. Men för den aktuella situationen för det evidensbaserade verktyget är programvaran ännu inte klar eller färdigutvecklad för att fungera som ett fundament för verktyget. Varken finns all data för svensk markanvändning tillgänglig för att kunna verifiera verktyget.

Terminology

CSV- Comma-separated values, A group of text-file format and uses for saving and exporting table data.

DEM- Digital elevation model, file that contains raster information presented in pixels with an elevation value.

HRU- Hydrological response units, the smallest spatial unit of the model normally occurring in SWAT simulations as land use, soils and characteristics slopes (Kalcic & Frankenberger, 2015).

Kävlingeåns vattenråd - Water council of Kävlinge river.

Land use- Human activity of usage of the land, characterized by economic and cultural activities

Lantmäteriet - The Swedish Mapping, Cadastral and Land Registration Authority.

LSU- A landscape unit is a region draining into a channel reach, further divided into the floodplain and upslope regions if a floodplain raster is used. Landscape units are one component among others to create HRUs.

Naturvårdsverket - The Swedish Environmental Protection Agency.

NOAA - National Oceanic and Atmospheric Administration.

QGIS - The quantum version of the geographic information system application that is an open-source platform.

QSWAT+ - An interface for SWAT+, working as a plugin program in QGIS.

SGU- Swedish geological research.

SLU - Swedish agricultural university.

SMHI - Swedish meteorological and hydrological institute.

SOU -Statens offentliga utredning, Swedish government official report.

SWAT+ Editor - Used as an interface to SWAT+ where the user is available to import a project from GIS, adjust input data in SWAT+, run the model etc.

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1. Introduction

Wetlands contribute to diverse ecological services e.g., cleaning water and binding carbon dioxide which has a substantial impact on climate change (Naturvårdssverket, n.d.-a).

Due to climate change, the hydrology of Swedish catchments is changing significantly. The results of climate change and global warming will lead to higher temperatures in both Sweden and outside of Scandinavia than the global mean, moreover there will be intensive cloudbursts and higher precipitation in the autumn-, winter- and spring seasons. Warmer climates notably in southern Sweden will occur during summer times. (SOU, 2007)

This thesis is a part of Ecodiver project, which is an ongoing project with the purpose to increase the hydrological diversity of Swedish catchments to replicate a more natural state. The project is conducted by a team from LTH and KTH and is financially supported by Naturvårdsverket. One of the aims of the Ecodiver project is to develop an evidence-based and support making tool for the construction of wetlands. This by using hydrological models in QGIS with QSWAT+ as a plugin.

The result of the Ecodiver study will give a diverse system which is capable of handling climate variability and climate variation. The upcoming tool will furthermore facilitate stakeholders to make decisions regarding where to construct future wetlands and how to optimize them in regards of location, design, and management.

However, QSWAT+ is a newly developed program which makes it highly experimental, resulting in a requirement for validation.

For this study, the open-source software's QGIS, QSWAT+ with SWAT+ editor is to be operated on. The input data will be retrieved from SMHI, Lantmäteriet, SGU and SWAT global data etc. An investigation of the software could be beneficial for future work in the project Ecodiver when developing a simple evidence-based tool within the plugin program usage. More about the program software and the plugins will be further discussed in the theory and the method part.

1.1 Background and problem description

Due to climate change, consequences, and risks such as intense drought, storms, and rising sea levels have become increasingly frequent. For Sweden, climate change has been affecting, in hydrological terms, by rising sea levels and increasing extreme weather conditions leading to floods and drought (Naturskyddsföreningen, 2021a).

According to SLU (2020) there are nineteen percent of red listed Swedish animal species that inhabits Wetlands. With the increasing global warming, species lose their natural habitats at the same time as other species gain theirs, and this type of change affects the interaction between species when it comes to access to food and the vulnerability of organisms. (Bergström, 2020)

The climate has since the end of the industrial revolution, in the late 19th century changed drastically, and the global temperature has further been rising by 0.08° in every decade (Lindsey, 2021). According to the European Commission, (n.d.), climate change is normally caused by natural greenhouse gasses (GHG) when the sun radiation is trapped and absorbed inside the atmosphere. But the accelerated amount of concentration of these GHG is mostly caused by human activities such as burning fossil fuels like coal and oil (NASA, n.d.)

The global temperature has, according to the National Oceanic and Atmospheric Administration, 1901 to 2020 risen by 1.1 degrees Celsius. This extreme climate change has had major consequences on a global level (NOAA, 2019) On the contrary, a study by Brudler et al. (2016) claims that using green infrastructure instruments has lower impacts on the environment rather than using subsurface solutions.

The Swedish government has been investing in the restoration of wetlands which can be beneficial for the absorption of carbon dioxide in the atmosphere. During the later years interest in wetlands has increased due to the biodiversity and the good access to clean water. The restoration program is advantageous to reach the environmental objectives of the Government. In 2018 the Government invested in the restoration of wetland, which contributed to an increase of groundwater, balancing water flow, benefits to biodiversity and climate. (Regeringen, 2021).

According to Moomaw et al. (2018) when disturbing or warming the wetlands three major GHG will be released into the atmosphere as nitrous oxide, methane, and carbon dioxide (Hawkins et al., 2017). For a constructed wetland, it is a nature-based solution with the ability to store water, and these do not only benefit biodiversity but can purify water (Naturvårdsverket, n.d.-d). The number of wetlands in Sweden has decreased between the 19th to the 20th century. This caused by the change in land use to the creation of more agricultural land. The excavation of natural wetlands has led to more GHG emissions, less groundwater formation, poorer water quality, overfertilization etc. (Naturskyddsföreningen, 2021b). In the year 2020, approximately 6 000 hectares of wetlands were restored (Naturvårdsverket, n.d.-a).

Wetlands situated close to the coast are specifically concerned about global warming as the result of the sea level rise. It is approximately 21 percent globally of the human population who lives within thirty kilometers of the coastline and the population rate increases twice as fast as the average rate (Nicholls et al., 1999). Nicholls et al., (1999) claim that a global 1-metre level rise will eliminate 46% of the world's coastal wetlands. (Hawkins et al., 2017)

1.1.1 Ramsar convention

The Ramsar convention is a convention on wetlands with the purpose to preserve, wisely utilizing and exploiting wetlands at the local, regional, and international levels (EPA, 2001; Ramsar, 1970). According to Ramsar (1970) 64 percent of the world's wetlands since the 20th century have disappeared, and the percentage of wetland eradication is even higher in some parts of the world.

The goal of the wetland’s losses are:

- Dredging and diverting water in canals, dams and floods
- Development of infrastructure close to the coast and river valleys
- Pollution in air and water and excess nutrients
- Extensive changes in land use e.g., agricultural, grazing-cropping animals
- Dispose of fill material
- Forming ponds and dams through diking
- Introducing invasive plants to compete with the native plants
- Removal of vegetation of peat mining

(Ramsar, n.d.; EPA, 2001)

1.2 Scope of study

The evidence-based supporting tool is to be evaluated on five case catchments, according to Ecodiver. Considering that tests within the project are conducted in Skåne, the catchment area is limited to the catchment area of Kävlinge river. The purpose of this study is to perform a validation of QSWAT+ using data for the catchment area of Kävlinge river.

The input data is limited to available and applicable data. Validated data for plant and urban is retrieved from example-data provided by QSWAT+ as no other data was available. Global data for land use, soil and usersoil are used for the same reason.

The amount of average monthly weather data is limited to the years 2019 and 2020. This is attributable to the fact that these years consist of most of the required data that has been controlled and approved (G) by SMHI. Including several years of data would not make any remarkable difference as it is an average of the years taken, except for the monthly average data, observed data are likewise included in the input files making a database available in the system. The average data for dewness and wind are specifically chosen for daily data of a month when the time is 12.00 o'clock. For the sun radiation, the data is limited to the sun radiation station in Lund as that is where the only station in Skåne is located.

As the purpose of this study is to review the software plugin program QSWAT+, more emphasis was placed on implementing the program than to study the quantity and quality of the data. With this said, this study does not include a validation of the data - but a validation of the plugin software program QSWAT+.

The dataset and input data required for the usage of QSWAT+ are presented in *Table 3* in upcoming section *3.1 Data*. The data in the table are the necessary components for QSWAT+ to function and produce results.

1.3 Objectives

The aim of this study is to evaluate the software QSWAT+ as an evidence-based tool for future work in Ecodiver project. The project’s purpose is to increase the hydrological diversity of Swedish catchment and imitate a wetland natural function.

These are the project goals:

- Investigate the availability of the QSWAT+ possibilities.
    - How is the result from QSWAT+ presented?
    - Potential of using QSWAT+ for a future evidence-based tool
- Investigate the potential area of application for hydrological purposes
- *Develop an evidence-based tool to optimize the design, location, and management of future constructed wetlands.*

The goal written in the third point was the main project goal of this work. It was subsequently changed and transformed into the two goals being presented in the text. This was due to lack of time, but also because of some uncertainties that will be further mentioned in the discussion.

1.4 Study area

As mentioned in the scope of the study, this study is limited to only the catchment area of the Kävlinge river, see *Figure 1*. Therefore, a brief presentation of the Kävlinge river will be conducted.

The Kävlinge river

The catchment of Kävlinge river covers a land area of a total of 1202km^2 and is centrally located in Skåne county with extent between the municipalities: Eslöv, Hörby, Höör, Kävlinge, Lund, Sjöbo, Tomelilla and Ystad (Länsstyrelsen, n.d.).

In a study of historical wetlands, a total of two hundred wetland fields in the catchment area of Kävlinge river has been discovered on a reconnaissance map from 1812 to 1820, with a total area of more than five hectares. According to this study, at the beginning of the 19th century, up to 13% of the whole catchment area consisted of wetlands covering a total area of approximately 15 800 hectares. However, during the past two hundred years, 70-90% of the wetlands have been reconstructed into pastures, agricultural- and arable lands (Alström, 2008).

Table 1:Information about the Kävlinge river. (Om Data i Vattenwebb | SMHI, n.d.)

Land distribution	Units
Arable land	65%
Forest	17%
Urban areas	3%
Other lands	12%
Wetlands	1%
Sea surface	2%
Kävlinge river catchment	1202km^2

The percentage of different landcover area are divided in the Kävlinge river according to SMHI see *Table* 1.

According to the Kävlinge vattenråd - the Water council of Kävlinge river, the catchment of the Kävlinge river is minted by agricultural land, whereas the arable lands correspond to 65% of the catchment area. 17% is occupied by forest and the rest of the remaining lands are urban areas, sea surface, wetlands and other lands.

A program of water management was established along with their Water council by the municipalities: Eslöv, Lund, Hörby, Höör, Sjöbo, Kävlinge and Lomma with the purpose to

- keep a good ecological status and chemical balance in the Kävlinge river.
- decrease the concentrations of eutrophication and pollutants.
- increase the biodiversity in the catchment and the surrounded area.
- increase waterfront recreation areas
- handle issues of flooding issues and flow regulation.

(Kävlinge-projektet, n.d.)

The Water Council of Kävlinge (Kävlingeån Vattenråd) river has for the past 30 years in the Kävlinge river constructed dams and wetlands on land areas corresponding to approximately seven hundred hectares, which every year clean up the watercourses from a total of 150 tons of nitrogen and five tons of phosphorus. The purpose of constructing wetlands is to reduce the municipality's vulnerability to drought and flooding (Kävlingeåns vattenråd, n.d.; Lunds kommun, 2022).

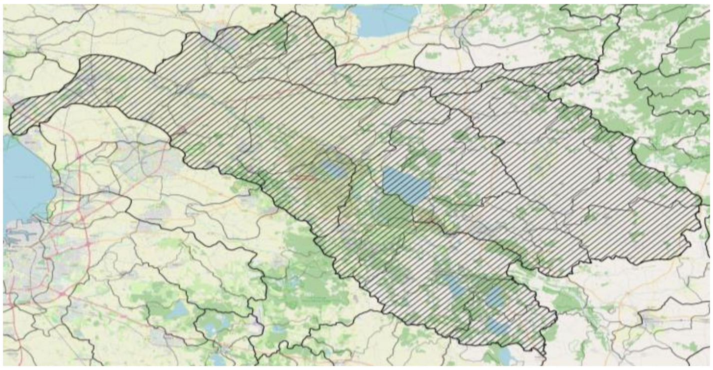


Figure 1:The catchment area of the Kävlinge river displayed on the map, within the hatched area.

2.Literature review

2.1 Water cycle

The hydrologic cycle can be explained in five processes. These can be observed in *Figure 2* and are condensation, precipitation, infiltration, runoff, and evapotranspiration (a combination of evaporation and transpiration). The water movement itself takes three phases between Earth and the atmosphere, such as solid, liquid and gas (NASA, 2010; NOAA, 2019a).

The hydrological cycle of the water evaporates from the Earth's biggest water storage in gas-phase as the result of the heat of the sun and turns into water vapor and clouds where it could move overland, to finally fall over lands as precipitation. This recurring process can go on for from minutes to millions of years, till the water makes its way back to its origin as runoff or groundwater transport. When the precipitation reaches the surface, water will infiltrate through the permeable surface, and it may also during a longer time percolate deeper to the water table and reach the groundwater level. (Hamill, 2011)

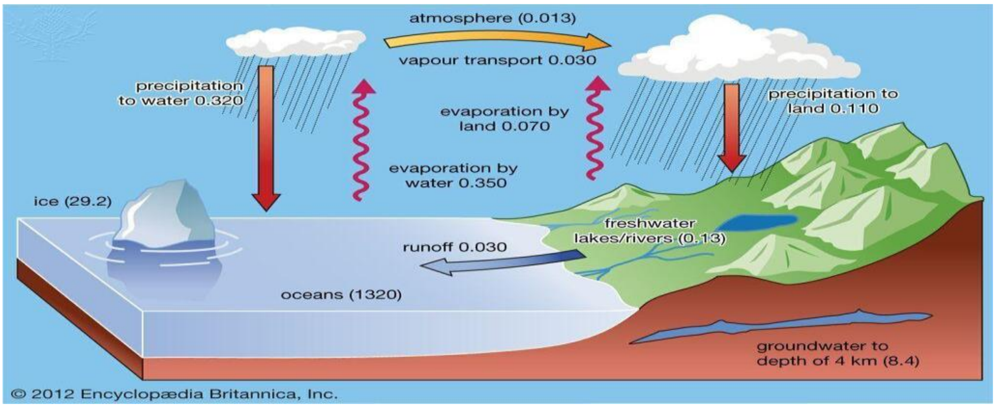


Figure 2:Present-day surface hydrologic cycle. Photograph. Britannica ImageQuest, Encyclopedia Britannica, 25 May 2016.quest.eb.com/search/309_1155991/1/309_1155991/cite. Accessed 1 Jun 2022.

2.1.1 Wetland´s hydrological functions

Wetlands hydrological functions have different approaches depending on the wetland's construction, size, and vegetation. Factors being able to influence the responsiveness of the flow are topography, geology, catchment size, soil and climate (Wang et al., 2018). With soils being able to absorb water, wetlands can function as sponge making the water being able to slowly be released into channels and streams, which reduces flooding. Wetlands also have the property of groundwater recharge and to increase low flows which facilitates for treatment plants during heavy rains. Moreover, during dry seasons downstream wetlands can have a stabilizing effect and reduce the risk of flooding. (Bullock & Acreman, n.d.; Kjellsson.A, 2018; Naturvårdsverket, n.d.-d)

2.2 Climate change

Sanderson et al. (2016) once stated that to retain the global temperature from rising by two degrees it is essential to have active removal and sequestering of carbon from the atmosphere. The Primary impact of climate change with carbon dioxide in the atmosphere is human activity, currently, the major sources are emissions arising from fuel usage, ruminant livestock, landfills and waste and rise production. Most of the carbon in wetlands is sequestered and located in the soil instead of the plants and considering climate change, wetlands provide resilience and adaptation additional to ecosystem services. Hence protecting wetlands from danger will yield reduced GHG from all sources and can be beneficial for limiting the future temperature increase.

The consequences in Europe can be explained by the European Commission, which indicates that the southern and central parts of Europe will be expecting more natural disasters. The Mediterranean area gets affected by drought and when becoming dryer, the risk of wildfire will increase. Northern Europe will become wetter and winter floods will be occurring more often. This will be affecting many Europeans since most of them live in urban areas that will be more exposed to heatwaves, flooding, and rising sea levels (European Commission, n.d.).

2.2.1 Sweden's environmental goals

The 16 environmental goals of Sweden have their origins in the Global Goals and 2030 Agenda for sustainable development, but the environmental target system has, according to Naturvårdsverket existed since 1999. In Swedish environmental policy, Sweden's environmental goals belong to the generation goal - which is the overall goal indicating that today's generation should be able to hand over a society where the major current environmental problems are solved. (FN-förbundet UNA SWEDEN, n.d.; Livsmedelsverket, 2022; Naturvårdsverket, n.d.-b). The 16 environmental goals are described in *Table 2*.

Table 2: The Swedish environmental quality objectives. (Naturvårdsverket, n.d.-d)

	Environmental quality objectives	**Development**
1	Reduced climate impact	↘
2	Clean air	↗
3	Natural acidification only	↗
4	A non-toxic environment	→
5	A protective ozone layer	→
6	A safe radiation environment	→
7	Zero eutrophication	→
8	Flourishing lakes and streams	→
9	Good quality groundwater	→
10	A balanced marine environment, flourishing coastal areas and archipelagos	→
11	Thriving wetlands	↘
12	Sustainable forests	↘
13	A varied agricultural landscape	↘
14	A magnificent mountain landscape	↘
15	A good build environment	→
16	A rich diversity of plant and animal life	↘
→ Neutral	↘ Negative	↗ Positive

The main goal is to be able to achieve all 16 environmental goals by 2030, but as the situation today, not all goals will be fulfilled. At present, it has been reported that only two goals are achieved: (2) *Clean air* and (3) *Natural acidification only*. Six goals are reported to be having a negative development and are hard to achieve, these are (1) *Reduced climate impact*, (11) *Thriving wetlands*, (12) *Sustainable forests*, (13) *A varied agricultural landscape*, (14) *A magnificent mountain landscape*, (16) *A rich diversity of plant and animal life*. (Naturvårdssverket, n.d.; Naturvårdsverket, 2021).

2.3 Wetlands

Wetlands are defined as areas of land that are either covered with water or saturated with water all year or for various amounts of months during a year. Wetlands do occur as diverse types all over the world, either as tidal wetlands or non-tidal wetlands, and they can vary from regional and local types as their topography, hydrology, water chemistry and vegetation are different (EPA, 2001). Wetlands can also be found in fens, marshes, bogs, and coniferous swamp forests, normally formed by groundwater, precipitation, surface runoff or floodplains along lakes and rivers. (Götbrink, 2015).

Because people in Sweden throughout history have dug ditches and cleared Swedish wetlands, around 25% of the original number of wetlands has disappeared. The fact that wetlands have disappeared is caused by exploitation or other development of the land, such as drying for developing agricultural lands or to increase production in the forest (Naturskyddsföreningen, 2021b). Another reason is due to the exchange of buffering surfaces for manmade ditches leading the water during heavy precipitation to one outlet where the runoff is collected. However, the consequence of this solution is flooding when the capacity of downstream water flows no longer can manage the incoming amount of water (Götbrink, 2015).

It is in recent decades that people have realized that wetlands have a particularly important function for the climate and society. The benefits are improved erosion control and water quality (TN department of Agriculture, n.d.), good for biodiversity (Naturvårdsverket, n.d.-d) and the providing of flood protection in the event of a cloudburst etc. The cutting of the wetland has led to large emissions of GHG, and other consequences are more eutrophication, poorer water quality and reduced groundwater formation. (Naturskyddsföreningen, 2021b)

According to Ramsar Convention Secretariat (2013), wetlands can have their water table recharged by excess water, but wetlands can also be maintained by groundwater access. The Ramsar Convention Secretariat states that:

” Wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent, or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.” (Ramsar Convention Secretariat,2013)

As stated by (Naturvårdsverket, n.d.-c) there are different definitions of wetlands and according to the convention’s definitions; at least 50 % of the vegetation area ought to be hydrophile to be able to be called wetlands. In Sweden, drained bottom areas of lakes, seas and watercourses are exceptions as they count as wetlands even though they lack vegetation, however, the international wetlands commission, Ramsar Convention does not consider open seas and lakes as wetlands since seas and lakes have better classifications of freshwater organisms and marine systems. (Zedler & Kercher, 2005) once said that a global comparison of wetlands requires common definitions, wetlands are defined on hydrological conditions but in which degree of wetness is the major variable.

In a report by (Engman, 2020) the majority of the fifty-one studied wetlands in Sweden have shown that the most usual sediment materials that can be found in wetlands are clay-silt, peat, and moraine. The topographic situation is also described, where most of the wetlands were documented to be closer to the sub-catchment area’s lowest height than the maximum height, corresponding to the wetland’s altitude in relation to the catchment area’s altitude. When it comes to the location of the wetlands, over 55% are reported to be within the range of 0-2 km outside an urban area. (Engman, 2020)

Globally wetlands are estimated to have lost half of the area ranging from 5.3 to 12.8 million square kilometers. Ramsar convention has prevented and helped 144 nations to protect the most important remaining wetlands, whereas the occupied surface area is approximately nine percent of the Earth’s land area (Zedler & Kercher, 2005). According to (IISD, 2018), the Global Wetland Outlook shows that wetlands succeed in economical values of services in comparison to terrestrial ecosystems with inland wetlands Worlds species lives and breeds in wetlands and it covers approximately 40 percent of all the world animals. Hence, showing the importance of wetlands statues when more than 25 percent of all wetlands plants and animals are facing risk of extinction. (IISD, 018)

2.3.2 Constructed Wetlands

When constructing wetlands, there are no explicit guidelines on how to optimize regarding location and size. However, the best possible outcomes focus on the catchment area ratio of wetlands and the land use distribution (Djodjic et al., 2020)

Djodjic et al. (2020) also wrote that increasing the wetland to catchment area ratio will result in an increase in phosphorus retention efficiency. As the result of too high or low hydraulic and nutrient load, the full phosphorus potential reduction cannot be achieved in constructed wetlands.
Both constructed wetlands and natural wetlands are regulated by various hydrological processes
that can be divided into four groups: subsurface flow, hydrological process, precipitation, and evapotranspiration (Jiang & Chui, 2022). Differently constructed wetlands depend on the type of hydrological variations e.g., high evapotranspiration could influence the important processes for constructed wetlands in countries with higher temperatures (Masi & Martinuzzi, 2007) on contrary, Wang et al. (2017) claim that some of the hydrological removal efficiencies processes are significantly reduced in cold climates in comparison to tropical climates.

The exchange of energy of mass in constructed wetlands with water bodies influences physical biological and chemical processes and controls the construction and evolvement of wetlands. Parameters that affect the hydrological process could be described by inflow source and pattern, frequency and flow rate, flooded area and period, and water balance with the influence of effects of climate, topography, and stratigraphic conditions. Hydrological processes can be summarized by the water balance in various stages and can also be determined by the location, for instance, the surface hydrological (land surface), precipitation and evapotranspiration (atmosphere), infiltration, percolation, and subsurface flow. (Jiang & Chui, 2022)

2.4 Model setup and simulation

2.4.1 Python

Python is one of many languages that is being used today when talking about programming, in most cases, the language is also designated as the most popular one (Eastwood, 2020) due to the great availability that is provided with Python. The programming language was developed by the programmer Guido van Rossum in the late 20th century, and it is today an open-source programming language used by approximately 8.2 million developers worldwide (Liam Tung, 2019). Python is used in application development and machine learning and is an easy to learn language due to the large number of standards and toolkits, its simple syntax and the possibility to integrate Python with other programming languages such as C++. (Eastwood, 2020; Kopf, 2019)

2.4.2 QGIS

QGIS is a leading open-source geographic information desktop application that allows users to create geospatial information with the possibility to be visualized, analyzed, and published. The software was developed by the QGIS development team in 2002 and is at present times still under active development where new versions are released periodically (OSGEO, n.d.) QGIS is an open-source and volunteer-driven software, several of opportunities and possibilities have been provided to stakeholders such as experts and users worldwide (Flenniken et al., 2016).

The software program QGIS stands for Quantum Geographic information system and allows the user to analyze and edit geospatial information. Geospatial information alludes to data about the geographic area of an element. The software is a free and open-source cross-platform that allows the user to export, compose graphical maps, and support viewing and editing. The focus of the software is more on map-making and cartography, and it runs on Windows, Mac OS X and Linux. (Olamide, 2020)

The interface of QGIS is strongly developed, where it supports Python as the script language. Furthermore, a collection of plugins is ready to be used within the QGIS application and these can be downloaded from the QGIS Plugin Manager.

2.4.3 QSWAT+

An open-source model program for Soil and water assessment tool (SWAT) and was created to estimate the impact of land management approaches on water, sediment, and agricultural yields over long time periods in vast complex watersheds with a variety of soils, land use, and management conditions. The model is physics-based instead of using regression equations were comparing the input and output variables. The program requires defined weather, land use, vegetation, soil properties, and topography. SWAT produces a continuous-time model and is not designed to simulate detailed single event flooding routing. (Fohrer et al., 2001; Neitsch et al., 2011).

To enhance the program SWAT, Dile et al. developed QSWAT+. QSWAT+ is an open-source model plugin program for QGIS and added values such as merging small subbasins, and dynamic and statistical visualization of outputs. The program is written in the programming language Python. The plugin program uses the function Terrain Analysis Using Digital Elevation Models (TauDEM), to perform geoprocessing. The SWAT team developed a newer version of the program and called it SWAT+ and QSWAT+. (Dile et al., 2016)

The QSWAT+ software is focusing on the water balance, the hydrological cycle in the model is simulated to what happening in the watershed. There are two major division that is separated in the program, the land phase which controls the amount of sediment, nutrients, water, and pesticide loads in the main channel in each subbasin. The second phase is the routing or water phase of the hydrological cycle, which is defined migration of water, sediment etc. through the channel in the network of the watershed to the outlet. (Neitsch et al., 2011)

2.4.4 SWAT+ Editor

SWAT+ is a small watershed to river basin-scale model that predicts the environmental impact of land use, land management techniques, and climate change by simulating the quality and quantity of surface and groundwater. The program is commonly used in watersheds to assess soil erosion control, non-point source pollution reduction, and regional management, and was created by The USDA Agricultural Research Service and Texas A&M AgriLife Research. (SWAT+, n.d.)

SWAT+ editor allows the user of the program to modify input more effectively, by importing the watershed created in the plugin QSWAT+ and running it through the SWAT+ editor. The software uses SQLite database to hold model input data, which could be edited by the user of the program and make connections among the different sources. (SWAT+, n.d.)

3. Methods

The following section describes the method and approach to the milestones of this project to finally achieve the goal of the objectives. The method that was conducted during the study consists of six chronological phases: *literature review, software learning, collection of data, compilation of data, simulation of data, Compilation of the study, analysis of the study, software validation,* which can be seen in *Figure 3*.

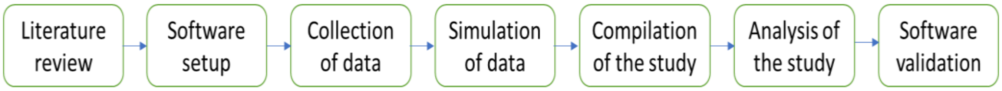


Figure 3:Methodology line-up of this study.

Literature review

The more concise literature review was conducted with the focus on developing a better understanding of wetland behavior. Many features that will be encountered in the program can be based on this literature review, but the background of the catchment area is also based on the mentioned theory collected from scholarly publications such as Lund University Publications, Google Scholar, and Web of Science.

The focus of the literature review was on scientific papers from Lund University, to begin with, but the search area was expanded to the publications from universities and organizations outside of Lund University and Sweden. This, given that universities from other countries have done more research about this study area. Moreover, a large part of the literature review regarding the current situation in the catchment area and the present state of the Swedish climate is retrieved from official websites owned by government agencies in Sweden.

The keywords for searching publications have mostly been Wetland, constructed wetland, climate change, hydrological functions, water cycle and QSWAT+.

Software setup

The program in use is QGIS long term release (LTR) 3.22.5 Biatowiesa together with the QSWAT+ version 2.2.3 and the SWAT+ editor 2.1.1.

Given that QSWAT+ and SWAT+ editor are programs under constant development, this study is highly experimental using the trial-and-error method to observe the progress of the process and to solve the errors or find alternative ways to avoid them.

The learning of QSWAT+ was carried out by following the tutorial QGIS Interface for SWAT+: QSWAT+, version 2.2 (Dile et al., 2022), using provided example data and standard available values within QSWAT+. The tutorials on the SWAT+ homepage with a video introduction called, Introduction to SWAT+ part 1-7 - Installing SWAT+ software with a total of seven parts were also used as additional help. Furthermore, the SWAT+ homepage recommended the Google forum discussion group QSWAT+ model to further discuss problems and the QSWAT+ developing team has been helpful when there were no answers to the questions and problems that occurred during this study.

Collection of data

Data for the catchment area is downloaded from Government agencies and the SWAT+ database. For the weather data from the four stations, they can be downloaded for different time periods depending on the lifetime of station, within or outside of the catchment area and are downloaded from SMHI. Before inserting the data into the SWAT+ editor they were compiled into CSV files using Excel, and text files. The flow data were downloaded from SMHI for the same period as the simulated data.

Simulation of data

This study is based on simulations of data and the validation of the simulated data. This is since the tool that the Ecodiver project aims to create is supposed to be evidence-based, where the user can easily see how the situation of a picked catchment area is today and then be able to do a simulation and further see the possibilities of adding wetlands in the local area in the future.

The simulation is mainly carried out by QSWAT+ in four steps, where preparatory work in QGIS must be completed. Moreover, the QSWAT+ review is further described in section 3.3. QSWAT+ Review.

Compilation and analysis of the study

This master thesis ends at the last step of QSWAT+ use, where an observed flow can be plotted against a simulated flow after inserting lakes and having them compared and analyzed. Analyzing the yielded result from three flow gauges in the Kävlinge river (Högsmölla, Ellinge and Vomb) with the simulated values and seeing what the correlation between values provides changes that can be made in the SWAT+ editor to make the simulated values fit the observed more. In this study standard values in the SWAT+ editor is mostly used, as the limitation of the study is to review the software and study the outcoming result.

Software validation

For the future tool for optimization of wetland location, design and management, validation is required for the tool to be evidence based. During the study, most of the data have been controlled to make sure they are properly and correctly installed. If it is possible this is verified by making a comparison with the model appearing on QGIS with official map images from government agencies such as SGU.

The validation for the output data after running a simulation for observed and simulated data can be determined by the Pearson correlation coefficient denoting the relationship between two variables that are being measured within the same interval, and the Nash-Sutcliffe Efficiency Coefficient that is normally used to evaluate the rainfall-runoff model performance.

3.1 Data

This section describes in more detail what kind of data is required to be able to carry out the simulation. The mandatory data required for the study to function are presented in *Table 3*. More data could be added such as optional data, but also data that is being dependent on what is being sought in the result, for instance nutrient balance, water cycle, environmental impact, pollution control etc.

Table 3:Compulsory data necessary for QSWAT+ to function.

	Resolution	Files
Lantmäteri		
Höjddata, grid 50+ nh	2000x2000	tif.
Översiktskartan latest, General map	-	shp.
SWAT Global dataset		
ea_soil.zip (ea_soil_1)	938 x 706	tif.
ea_landuse.zip (ea_landuse_1)	16967 x 12617	tif.
SMHI	**Unit**	
Temperature in Celsius degrees	min, max	csv.
Relative humidity in percentage	hourly	csv.
Precipitation in millimetre	monthly, daily	csv.
Solar radiation	watt/m^2 hourly	csv.
Dewpoint temperature in Celsius degree	hourly	csv.
Windspeed meter per second	monthly	csv.
Högamölla, flow data	m^3/s	xlsx.
Vombsjön, flow data	m^3/s	xlsx.
Ellinge, flow data	m^3/s	xlsx.

The different data types: raster, shapes, and numeric data were cropped, merged and specifically collected from validated provided data for the catchment area of Kävlinge river from Lantmäteriet, Naturvårdsverket etc. The weather station data and flow were downloaded from SMHI, and station data downloaded were Hörby, Vomb, Lund, Malmö, Högsmölla Vombsjön and Ellinge. The projection used in this study is determined to EPSG;3006 which are geographical reference system used in Sweden.

The data used for this study are weather data, flow data, land cover data and field models. The weather data are collected from SMHI, and both the landcover data and field models are downloaded from Lantmäteriet, using the website zeus.slu.se. The specific area for the Kävlinge river was selected on the map before downloading the data according to the *Figure 4*, and for the Kävlinge river the catchment area was divided into three distinct parts as the data retrieved from the website only offer data for a limited area and could not comprehend large shapefiles. This can be seen on *Figure 4*. The parts were then merged into a connected shapefile using QGIS.

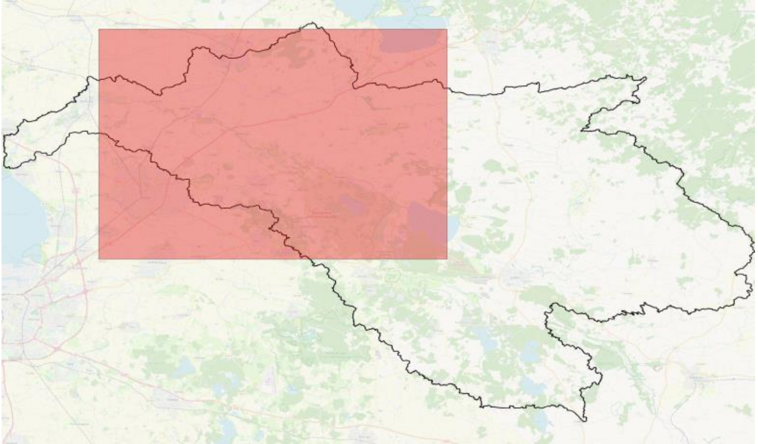


Figure 4:Marked in red is the selected area of retrieved data from SLU (zeus.slu.se). The selection could not be done for the whole catchment area; therefore, it is had to be done in multiple times.

For creating the basis of the Kävlinge river's catchment area, relevant data regarding lakes, ponds and watercourses were sought. The data presented in *Table 4* below is retrieved from Lantmäteriet and inserted into QSWAT+, representing watercourses, water surface, woodland etc.

Table 4:Data in QGIS from Swedish University of Agricultural Sciences, SLU (Lantmäteriet, 2021)

Descriptive layer name	Layer name	Description
Watercourses	HL_riks	Line layer for watercourses
Lake	MS_riks	Water surface; surface for lakes, ponds, or watercourse
Land data	MY_riks	Water surface, woodland

More data have been studied throughout the work and inserted into the model such as soil type data and land use. However, these files could not be used due to lack of information and lack of instructions on formatting the data into the CSV files. This resulted in using global data found in the SWAT+ database, see

Table 5 for abbreviation of land use and soil type. In addition, some data were missing, resulting in the functions for these data being omitted. More about this is described in Appendix B, *Omitted data*.

Table 5:Land use and soil table with explanations for the abbreviations

Land use	
URMD	Residential medium density
CRDY	Dryland, cropland, and pasture
CRGR	Cropland/grassland and mosaic
FODB	Deciduous broadleaf forest
FOEN	Evergreen needleleaf forest
FOMI	Mixed forest
WATR	Water
WETW	Wetland_wet
Soil	
Be127-2ab-6437	Loam

The data shown in *Table 5* are the land cover and soil data from SWAT+ global database with the abbreviation and descriptions.

3.2 QSWAT+ Review

To begin with, the latest QGIS LTR (long time release) version 3.2.2.5 was downloaded from the official website of QGIS and the compatible QSWAT+ version 2.2.3, QSWATPlus3_9install2.2.3.exe (released 2022-03-30) downloaded separately from Chris George's folder for QSWATplus3 at Bitbucket. QSWAT+ was then installed into QGIS as a plugin program, furthermore, an installation of SWAT+ Editor 2.1.1 was supplied by a developer of the software as the latest version of the software was not yet published on the website. Moreover, updates have been rolling out continuously by QSWAT+ developing team as error occurs periodically, but this has also caused a great number of errors due to new updates making the functions in QSWAT+ not working.

For trying QSWAT+, the 2.2 version of SWAT tutorial **QGIS Interface for SWAT+: QSWAT+** (Dile et al, 2021) was used using provided example data within the SWAT+ database. Learning the basic of the program was essential for using it, however, additional testing of the programs function was fundamental as some operations was not proceeded in the tutorial.

For choosing the elevation data two alternatives were offered by Lantmäteriet: one with 2x2 grids and another one with 50x50 grids. The 50x50 grid data, *GSD-Höjddata, grid 50+ nh* was selected. The elevation data were then merged into one file using the *merge* tool that can be found from *Raster - Miscellaneous*.

The overview map, *översiktskartan latest* was retrieved from Lantmäteriet as a shapefile (vector format), providing many layers, for instance, data for national, county, and municipal boundaries, as well as coastlines, urban areas, lakes, major watercourses etc. Furthermore, data used in step two for land use, soil, plant and urban was reclaimed from SWAT's own global dataset.

3.2.1 Input data in software

Weather data

For the catchment area, four weather stations are active. These can be seen in *Figure 5*: Hörby, Lund, Malmö A and Vomb.

The weather data for each station that needs to be collected and formatted into CSV files are:

- Monthly average or mean daily maximum air temperature
- Monthly average or mean daily minimum air temperature
- Standard deviation for daily maximum air temperature in month
- Standard deviation for daily minimum air temperature in month
- Average or mean total monthly precipitation
- Standard deviation of monthly deviation
- Precipitation skewness - using Pearson´s 2nd equation
- The probability of a wet day after a wet day
- The probability of a wet day after a dry day
- Average number of days of precipitation in a month
- Maximum 0.5-hour rainfall in the entire period of record for month
- Average daily solar radiation for the month
- Average daily dew point temperature for each month
- Average wind speed for the month

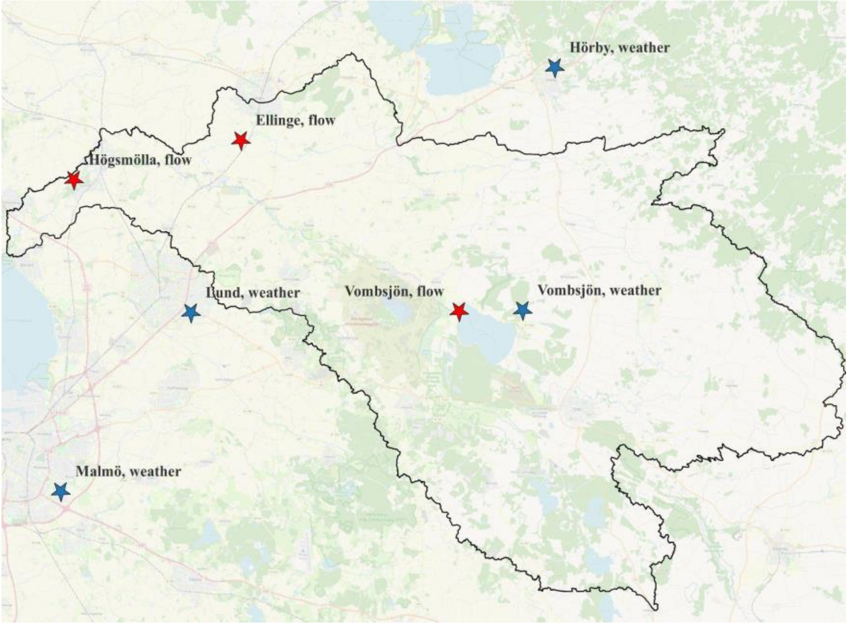


Figure 5:Presented in blue are the weather stations Hörby, Lund, Malmö and Vombsjön, and presented in red are the flow stations Högsmölla, Ellinge and Vombsjön

The weather data for the mentioned parameters presented above are manually converted into CSV files where the files represent data from different stations. The data parameters from SMHI stations that was downloaded can be found in *Table 6* together with the available data parameters that were not used. The used data parameters are specifically *air temperature, dew point, the amount of precipitation, relative humidity, wind direction and windspeed and global solar radiation*, where the data for these parameters are presented in different time steps.

Table 6:Data parameters to choose among when downloading data from SMHI's database. The data parameters to the left are the used data and the data to the right are available data for download, but that remains unused in this study.

Used data	***Unused data***
Air temperature	**Longwave solar radiation**
Hourly	Hourly
Daily	**Air pressure**
Monthly	Hourly
Minimum and maximum value (12h)	**Current weather**
Minimum and maximum value (daily)	Hourly
Dew point	**Prevailing weather**
Hourly	Hourly
Precipitation amount	**Time of sunshine**
15 min	Hourly
Daily	**Highest wind speed in a short period**
Hourly	Max (h)
Monthly	**Total amount of clouds**
Relative humidity	Hourly
Hourly	**Significant cloud**
Wind direction and wind speed	Hourly
	Snow depth and ground condition
	Daily
	Wind speed, max and medium
	Hourly
	Precipitation type
	12h
	Daily
	Precipitation intensity
	15 min
	Maximum and mean (15 min)

From the Hörby, Lund, Malmö and Vombsjön, weather station, data were, as mentioned in the scope of this study, downloaded for two years of monthly average, limited to 2019 and 2020. For the observed weather data, all historical data from SMHI for each station is used and inserted as text files into the SWAT+ editor. The coordinates of the stations are presented in *Table 7* together with the elevations as well as *Table 8* with the flow gauges.

The data for the monthly average were processed as well as the data for skewness, dewness and wind parameters because of undeveloped data provided by SMHI. For the calculations of the processed data excel was used.

Table 7:Information about the four weather stations Hörby, Lund, Malmö and Vombsjön taken from SMHI

Identification number	Station	Latitude	Longitude	Elevation (m)
1	Hörby	55.8624	13.6673	112.812
2	Lund	55.6932	13.2251	26.451
3	Malmö	55.5715	13.0708	19.757
4	Vombsjön	55.7000	13.6333	32

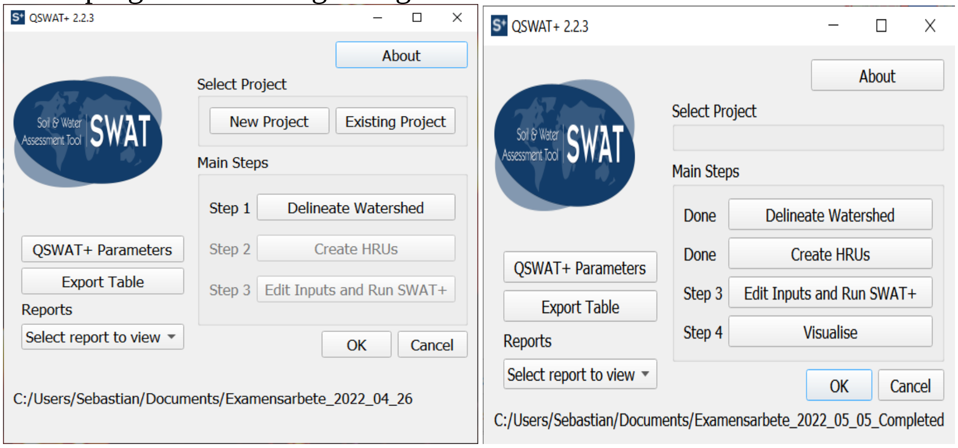
Table 8:Information about the three flow gauges Högsmölla, Ellinge and Vombsjön taken from SMHI

Identification number	Station	Latitude	Longtitude
1	Högsmölla	55.7796	13.0767
2	Ellinge	55.8090	13.2816
3	Vombsjön	55.6984	13.5551

The four stations did not consist of all the required data for all the parameters that needed to be inserted into the CSV files for weather data. Therefore, for those stations lacking data, the data was taken from the nearest station within the catchment area. This resulted in data being used at least twice, when for instance the station in Vombsjön lacked hourly precipitation data and had to be taken from Malmö instead.

3.3.2 QSWAT+ interface

After downloading QSWAT+ as a plugin, the QSWAT+ icon will be seen on the toolbar. By clicking on it, a QSWAT+ interface will occur with the version of the program according to Figure *6*.



C:/Users/Sebastian/Documents/Examensarbete_2022_04_26

C:/Users/Sebastian/Documents/Examensarbete_2022_05_05_Completed

Figure 6:QSWAT+ 2.2.3 interface. Workspace to the left showing the beginning phase of QSWAT+, the workspace to the right showing when the last step (4) of QSWAT+ appears

Clicking on New *Project* a browser will be displayed to choose in what location in the computer to save the files. Creating a new folder is recommended, and in the next step when the folder is chosen a project name will be picked. Also, category layers for *Animations*, *Results*, *Watersheds*, *Landuse*, *Soil* and *Slope* will be automatically created in QGIS.

Several experiments have been implemented in the program when it comes to lakes, where simulations have been proceeded both with and without lakes to see if the program contemplated the hydrological factor from lakes as a storages of water to regulate the flow

For running QSWAT+ three steps need to be followed. These steps are *Delineate Watershed (step 1)*, *Create HRUs (step 2)* and *Edit Inputs and Run SWAT+ (step 3)*. When step 3 is completed QSWAT+ will open for *Visualize (step 4)*.

Step 1 - Delineate Watershed

The first step is to delineate the watershed, and this is to be done by inserting the DEM file *GSD-Höjddata, grid 50+ nh* from Lantmäteriet (.tif). The boxes for *Burn in existing stream network* and *use an inlets outlets shapefile* are checked and the *Snap threshold (metres)* is set to 300 as the standard. *Channel* and *Stream threshold* are left untouched, as well as the cell numbers and grid size. The program reads the DEM file and give the minimum threshold size. By clicking on *Create Streams* the file will be running within QSWAT+ and will then result in a map of the Kävlinge river catchment area with watersheds and streams created in QSWAT+ and displayed in QGIS. See *Figure 7*.

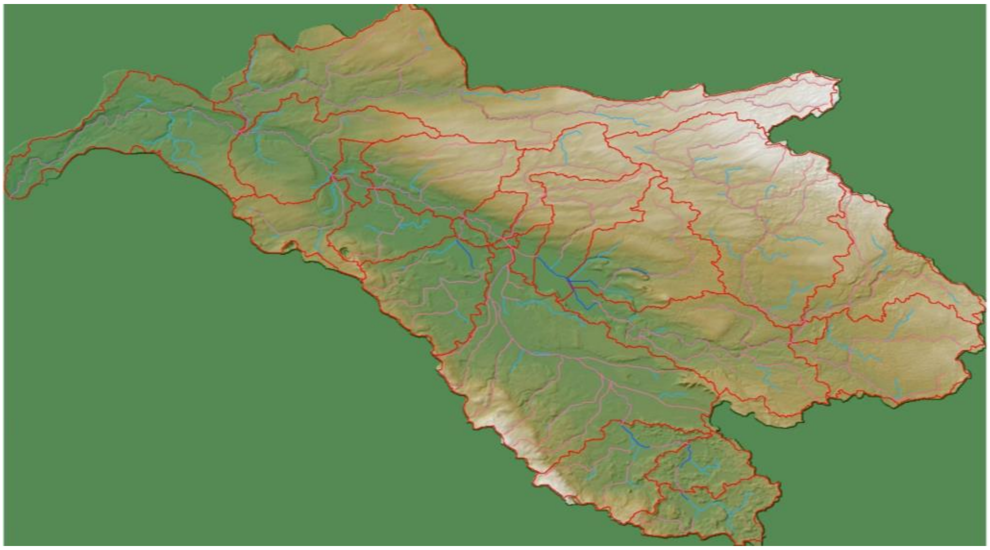


Figure 7:Streams created, and watersheds delineated according to the inserted DEM fil. Blue and purple lines are channels and streams, both burn-in and created from the program. The red line delimits the subbasins that were discovered by QSWAT+, and the surface

From this stage inlets and outlets were added to the map by clicking on *Draw inlets/outlets*. The outlet was placed at the mouth of the catchment area and at the gauge stations Högsmölla, Ellinge and Vomb. The exact position of the stations was not accurately place as the stream network at those gauges was not on the stream network, instead the closest coordinate of the station was selected. The cause of placing the outlet points at the gauge stations was for comparing simulated flow with the observed flow in the later stage four. To find the exact positions an extra plugin was downloaded in QGIS. After the stage of adding inlets and outlet reviewing the points and then *Create watershed* will be clicked on for creating the subbasin for the watershed, see *Figure 10*.

By clicking on *Create* under *Create landscape* section there will be a window for Landscape analysis popping up with three different options: *Buffer streams, DEM inversion* and *Branch length*. The *Branch length method* was used for this study since it contributed to the most realistic model esthetically after the simulation, and the outcome of this method can be observed in *Figure 8*. The other models with different creating-landscape methods can be found in the Appendix A in *Figure A2, A3*.

For simplicity, subbasins were merged with the function *Merge subbasins,* by following the water pathway of the streams. In the Kävlinge catchment area the water direction is from east to west where the water flows out to Öresund. The merging was done to reduce the number of subbasins in the catchment area. Furthermore, the function *Add Lake* was then used to import lakes (Översiktskartan_latest General map) into QGIS that was later displayed on the model, seen on *Figure 9*.

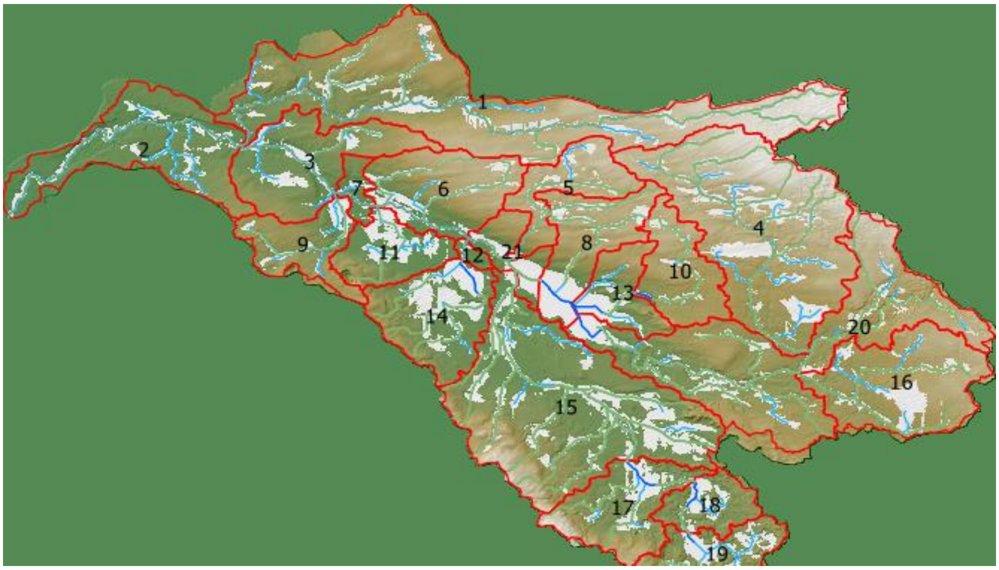


Figure 8:The floodplain showing in white using the branch length method. Also, the subbasins of the watershed that was detected by QGIS is displayed.

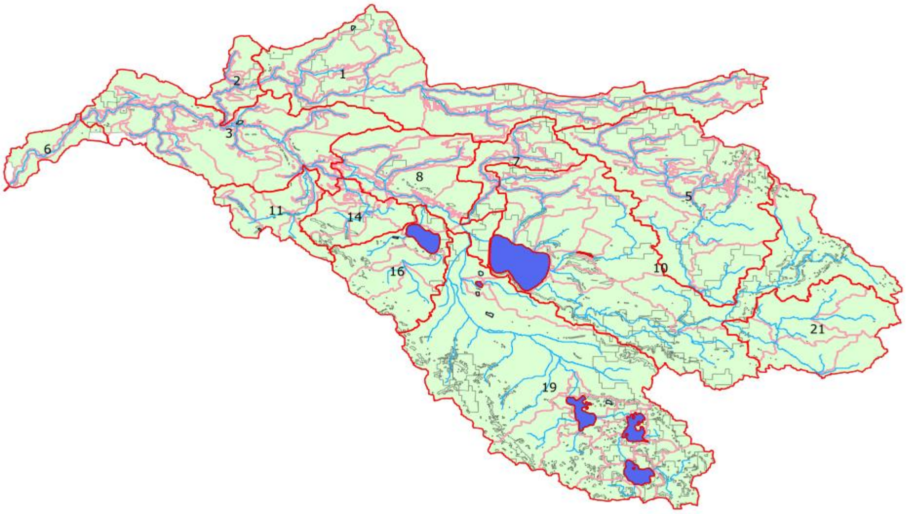
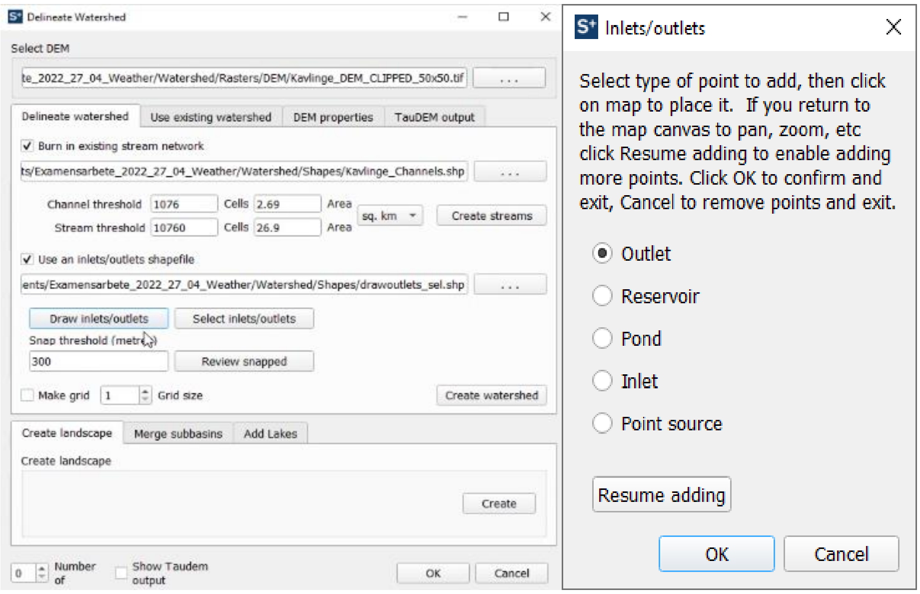


Figure 9:The watershed after inserting lakes

Step 2 - Create HRUs

QSWAT+ involves creating Hydrological Response Units, HRUs, and the window for creating HRUs can be found in *Figure 10*. This was achieved by inserting files for *landuse map*, *soil map* and *landuse and soil database*. Both the land use map and the soil map have undergone rasterization to make the maps have the same grid size (50x50) as all the other raster files. The files for land use and soildata base are standard files directly provided by QSWAT+, and considering an update of the software, a change in SQLite needs to be made.


Delineate Watershed

Select DEM: te_2022_27_04_Weather/Watershed/Rasters/DEM/Kavlinge_DEM_CLIPPED_50x50.tif

☑ Burn in existing stream network: ts/Examensarbete_2022_27_04_Weather/Watershed/Shapes/Kavlinge_Channels.shp

Channel threshold 1076 Cells 2.69 Area sq. km

Stream threshold 10760 Cells 26.9 Area sq. km

☑ Use an inlets/outlets shapefile: ents/Examensarbete_2022_27_04_Weather/Watershed/Shapes/drawoutlets_sel.shp

Snap threshold (metres) 300

☐ Make grid 1 Grid size

0 Number of

☐ Show Taudem output

Inlets/outlets

Select type of point to add, then click on map to place it. If you return to the map canvas to pan, zoom, etc click Resume adding to enable adding more points. Click OK to confirm and exit, Cancel to remove points and exit.

● Outlet

○ Reservoir

○ Pond

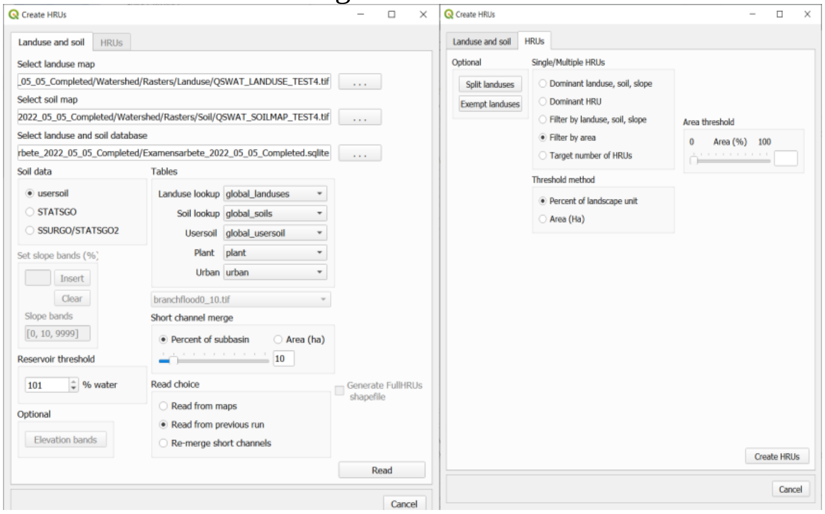
○ Inlet

○ Point source

Figure 10:Interface for when creating delineating watersheds and for adding inlets and outlets.

When opening SQLite, in the plants_plnt table the column "aeration" is changed to "wnd_live" - this was necessary due to an update that occurred during the usage where wnd_live was replaced by aeration, making that column unrecognized by the program and error would occur.

Under tables, the land use lookup, soil lookup and usersoil are set to standard global data, and the plant and urban data are from the example dataset. *Usersoil* under Soil data is checked, as the result of *STATSGO* and *SSURGO/STATSGO2* are meant to be for the United States of America. The Reservoir threshold is set as standard, to 101%, the percentage of subbasin to 10% - this is because when the percentage of subbasins is below a certain percentage it will give an increasingly higher amount of HRU, but on the contrary, it will display less reaches in QGIS. The percentage is set to 10% as a standard value for the slope band. For the floodplain map, the branchflood file that was created in step one was selected as it provides information about up-, and downhills and more realistic information about how the runoff is connected to the terrains and elevations. *Generate FullHRUs shapefile* was checked as it provides the full HRU in the whole catchment area. Furthermore, the option for the *Elevation band* is not selected as is only applicable to the Northern climate with longer winter seasons.


Create HRUs

Landuse and soil

Select landuse map: _05_05_Completed/Watershed/Rasters/Landuse/QSWAT_LANDUSE_TEST4.tif

Select soil map: 2022_05_05_Completed/Watershed/Rasters/Soil/QSWAT_SOILMAP_TEST4.tif

Select landuse and soil database: rbete_2022_05_05_Completed/Examensarbete_2022_05_05_Completed.sqlite

Soil data: ● usersoil ○ STATSGO ○ SSURGO/STATSGO2

Tables:
Landuse lookup: global_landuses
Soil lookup: global_soils
Usersoil: global_usersoil
Plant: plant
Urban: urban

Set slope bands (%)
Slope bands: [0, 10, 9999]

branchflood0_10.tif

Short channel merge: ● Percent of subbasin ○ Area (ha)
10

Reservoir threshold: 101 % water

Read choice: ○ Read from maps ● Read from previous run ○ Re-merge short channels

☐ Generate FullHRUs shapefile

Optional: Elevation bands

Create HRUs

HRUs

Optional: Split landuses, Exempt landuses

Single/Multiple HRUs: ○ Dominant landuse, soil, slope ○ Dominant HRU ○ Filter by landuse, soil, slope ● Filter by area ○ Target number of HRUs

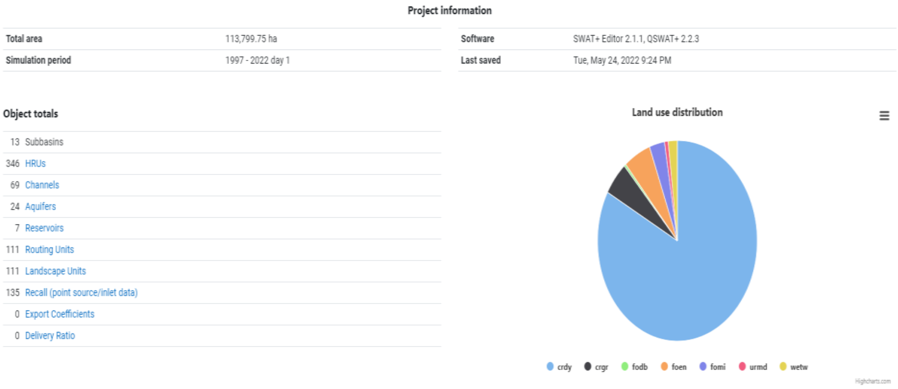
Threshold method: ● Percent of landscape unit ○ Area (Ha)

Area threshold: 0 Area (%) 100

Figure 11:Interfaces for when creating HRUs.

When the following steps are completed, the *Read* button is to be selected, the data will be analyzed by the program and the numbers of subbasins, channels and full HRUs will appear on the bottom right according to *Figure 11* below. Reading the data will also open for the tab HRUs that can be found next to Land use and Soil on the top left. Under Single/ Multiple HRUs *Filter by area* is selected and set to zero resulting in the HRU values being maintained, this was done instead of choosing the standard function as it removes the smaller HRUs. The other function is not to be considered since the highest amount of HRUs wish to be maintained. In the SWAT+ editor, land use and the total object will be displayed, see *Figure 12*.

Additionally, in the QSWAT+ interface, reports can be shown after HRUs has been read, displaying the elevation data, land use and soil data and HRU data.



Project information

Total area	113,799.75 ha	**Software**	SWAT+ Editor 2.1.1, QSWAT+ 2.2.3
Simulation period	1997 - 2022 day 1	**Last saved**	Tue, May 24, 2022 9:24 PM

Object totals

13	Subbasins
346	HRUs
69	Channels
24	Aquifers
7	Reservoirs
111	Routing Units
111	Landscape Units
135	Recall (point source/inlet data)
0	Export Coefficients
0	Delivery Ratio

Figure 12:Overview of SWAT+ editor displaying Land use distribution and total objects in the software.

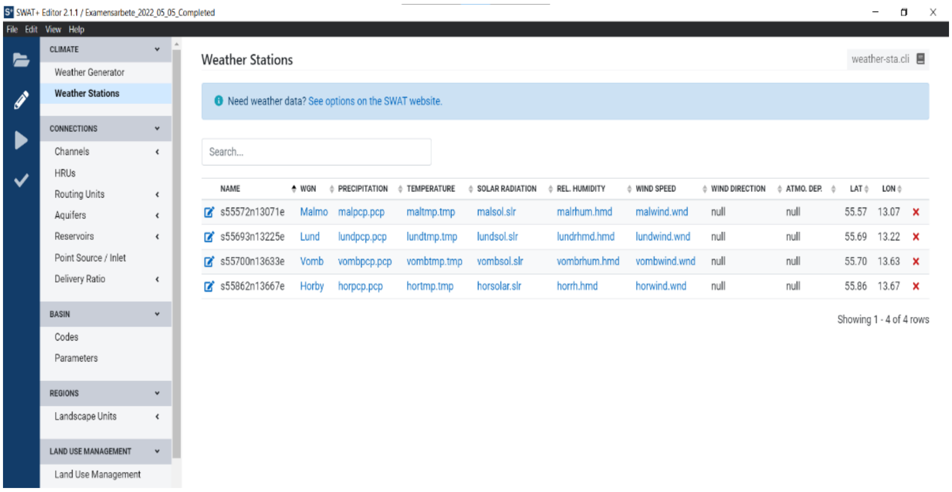
Step 3 - Edit Inputs and Run SWAT+

The workspace in SWAT+ Editor is where the input files can be edited and where the sensitivity, auto-calibration and uncertainty can be analyzed. A vertical bar that is found on the left of the workspace consists of the options: *Project setup and information*, *Edit SWAT+ inputs*, *Run SWAT+* and *SWAT+ Check*. *The project setup* describes the available information about the catchment area, where the data is summarized and visualized.

In *Edit SWAT+*, after retrieving watersheds, data can be both inserted and edited under the main sections:

- Climate
- Connections
- Basin
- Regions
- Land use management
- Decision tables
- Change
- Initialization data
- Hydrology
- Soils
- Databases
- Structural

Under *climate*, data for both the *Weather Generator* and *Weather Stations* need to be inserted as CSV files for both the monthly average data but also the historical weather station data for the four stations that is included in this study. How the data is collected is further described in section 3.3.1. After importing the data, the stations will be displayed according to *Figure 13*, showing inserted data of the weather parameters and the coordinates of the stations.



Need weather data? See options on the SWAT website.

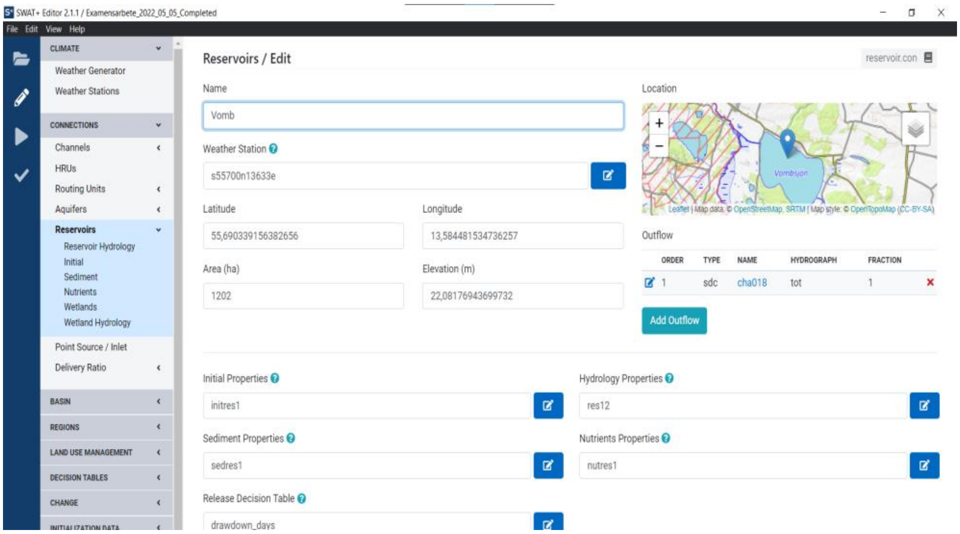
NAME	WGN	PRECIPITATION	TEMPERATURE	SOLAR RADIATION	REL. HUMIDITY	WIND SPEED	WIND DIRECTION	ATMO. DEP.	LAT	LON
s55572n13071e	Malmo	malpcp.pcp	maltmp.tmp	malsol.slr	malrhum.hmd	malwind.wnd	null	null	55.57	13.07
s55693n13225e	Lund	lundpcp.pcp	lundtmp.tmp	lundsol.slr	lundrhmd.hmd	lundwind.wnd	null	null	55.69	13.22
s55700n13633e	Vomb	vombpcp.pcp	vombtmp.tmp	vombsol.slr	vombrhum.hmd	vombwind.wnd	null	null	55.70	13.63
s55862n13667e	Horby	horpcp.pcp	hortmp.tmp	horsolar.slr	horrh.hmd	horwind.wnd	null	null	55.86	13.67

Showing 1 - 4 of 4 rows

Figure 13:The workspace of SWAT+ Editor when looking at weather stations under climate.

The simulated objects can be found under connections where the channels, HRUs, Reservoirs etc. are identified under their own categories. The objects can be edited manually according to *Figure 14*. When changing the coordinates, the arrow on the map will immediately be moved.

What has displayed on the workspace are the coordinates of the station as well as the area and the elevation of the reservoir. If the data are incorrect from the simulation, there are possibilities to edit in the panels and be overwritten by the correct data. The location is further displayed on the map in the upper right corner, ensuring the user that the reservoir is located within the catchment area.



Reservoirs / Edit

Name: Vomb

Weather Station: s55700n13633e

Latitude: 55,690339156382656

Longitude: 13,584481534736257

Area (ha): 1202

Elevation (m): 22,08176943699732

Outflow

ORDER	TYPE	NAME	HYDROGRAPH	FRACTION
1	sdc	cha018	tot	1

Initial Properties: initres1

Hydrology Properties: res12

Sediment Properties: sedres1

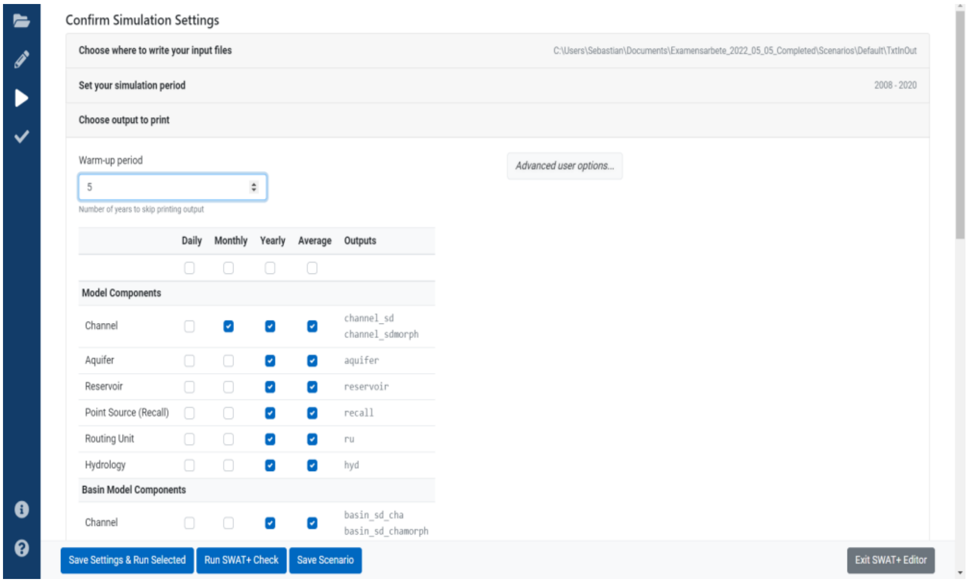
Nutrients Properties: nutres1

Release Decision Table: drawdown_days

Figure 14:The workspace of SWAT+ Editor when look at reservoirs under connections.

In the category *Basin Codes* under the basin, one can determine the method used for simulations and calculations in the software. The user can choose among different methods depending on the preferences of the study. SWAT+ editor can detail change values and parameters on the user's choice, by going into different sections of the categories many of the properties of every parameter can be changed. This study uses predetermined values and methods.

In *Run SWAT+ Editor* the number of the warm-up period the simulation can be decided, as well as the simulation period. The studying period of the simulation is set from 1997 December until 2020 January with a warm-up period of five years. The time step for the simulation can also be selected after own choice, and unwanted parameters can be unchecked in the bar, see *Figure 15*. When the editing is accomplished *Save Settings & Run Selected* buttons are checked to save all the edits. Thereafter, the program will return to QSWAT+ where step four for visualization appears, as seen in *Figure 16.*


Confirm Simulation Settings

Choose where to write your input files: C:\Users\Sebastian\Documents\Examensarbete_2022_05_05_Completed\Scenarios\Default\TxtInOut

Set your simulation period: 2008 - 2020

Choose output to print

Warm-up period: 5

Number of years to skip printing output

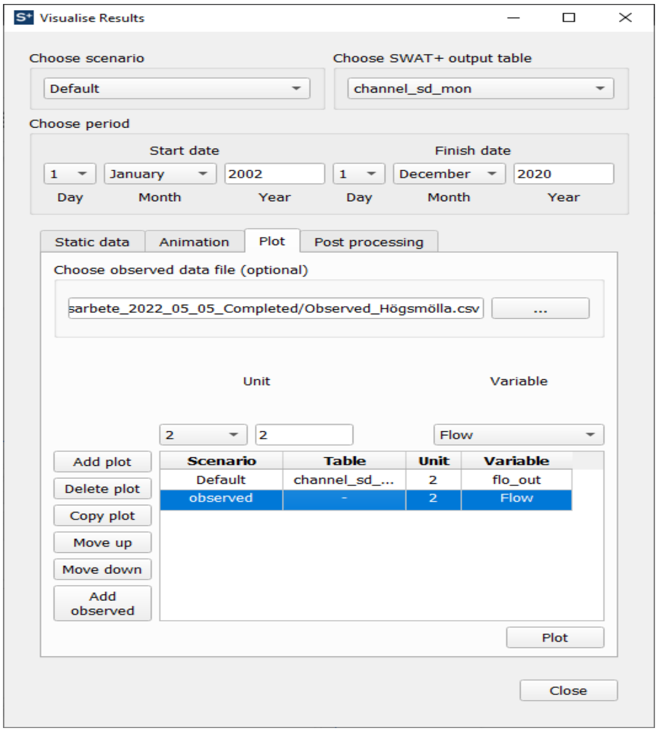
	Daily	Monthly	Yearly	Average	Outputs
	☐	☐	☐	☐	
Model Components					
Channel	☐	☑	☑	☑	channel_sd channel_sdmorph
Aquifer	☐	☐	☑	☑	aquifer
Reservoir	☐	☐	☑	☑	reservoir
Point Source (Recall)	☐	☐	☑	☑	recall
Routing Unit	☐	☐	☑	☑	ru
Hydrology	☐	☐	☑	☑	hyd
Basin Model Components					
Channel	☐	☐	☑	☑	basin_sd_cha basin_sd_chamorph

Figure 15:The workspace in the SWAT+ editor where components for different time periods can be chosen.

<u>*Step 4 - Visualize*</u>

The last step is to visualize the input data in the software program. When clicking on the *Visualize* button, another pop-up window will appear, see *Figure 16*. The output table can be selected as desired, and the options are produced from SWAT+ Editor depending on the checked output to print out as seen in *Figure 15*. The period for the simulation can be determined within the time interval under *Choose period*. Observed data inserted in the SWAT+ Editor can be added from the button on the left bottom. This enables the observed data to be plotted together with the simulated data.

Plotting is one of the four options offered by the SWAT+ Editor when visualizing the results: *Static data*, *Plot*, *Animation* and *Post-processing*. *Static data* visualize specific output from the chosen data and depending on the choice output from either: total, daily, monthly mean, annual mean, maximum and minimum, will be visualized to the model in QGIS which are displayed with colors and data of range. Animation is similar as it displays the data in the static during the time interval chosen, in the time series chosen in the SWAT+ editor output table as a picture video. Post-processing is the environmental flow which is not relevant in this case study.



Choose scenario: Default

Choose SWAT+ output table: channel_sd_mon

Choose period

Start date: Day 1, Month January, Year 2002

Finish date: Day 1, Month December, Year 2020

Choose observed data file (optional): sarbete_2022_05_05_Completed/Observed_Högsmölla.csv

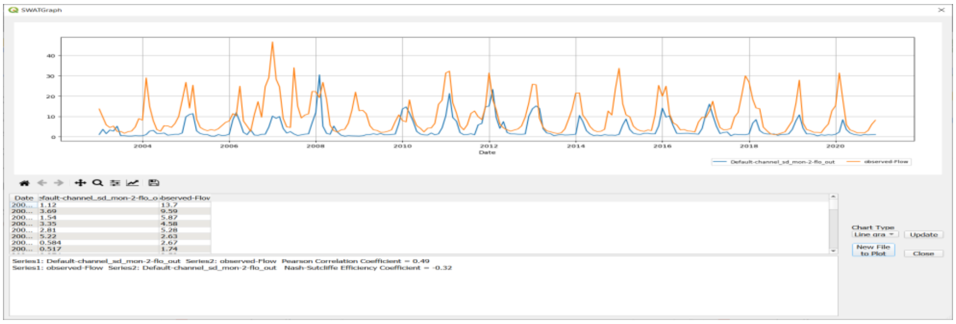
Unit: 2 2

Variable: Flow

Scenario	Table	Unit	Variable
Default	channel_sd_...	2	flo_out
observed	-	2	Flow

Figure 16:The workspace for when visualizing the result and putting in an observed and a simulated flow to plot them against each other

The workspace can appear according to *Figure 16* - representing the flow plots for Högsmölla. The plots for Ellinge and Vombsjön can be found in Appendix A, *Figure A4*, *Figure* A5. As can be seen, the observed data is plotted against the simulated data shown in blue color. The plot curves are then compared to each other using both the Pearson's Correlation Coefficient and the Nash-Sutcliffe Efficiency Coefficient for validation, revealing the relationship between the observed and the simulated data.



Date	efault-channel_sd_mon-2-flo_o	bserved-Flov
200...	1.12	13.7
200...	3.69	9.59
200...	1.54	5.87
200...	3.35	4.58
200...	2.81	5.28
200...	5.22	2.63
200...	0.584	2.67
200...	0.517	1.74

```
Series1: Default-channel_sd_mon-2-flo_out  Series2: observed-Flow  Pearson Correlation Coefficient = 0.49
Series1: observed-Flow  Series2: Default-channel_sd_mon-2-flo_out  Nash-Sutcliffe Efficiency Coefficient = -0.32
```

Figure 17:Observed and simulated data from the flow in Högsmölla station in channel 2.

4. Result

4.1 Presentation of result

The result from QSWAT+ can be presented in several diverse ways depending on the user´s purpose of the study and the desired result. The options in *visualize (step 4)* are making a plot with graphs representing the simulated and observed flows, an animation of the movement of a certain parameter, the static data displayed on a model and the environmental flow of the chosen area. Additionally, the water cycle of that area can be visible on SWAT+ editor, displaying the value of precipitation, evapotranspiration, percolation, return flow and other parameters within the hydrological cycle.

For this study, the plotting of graphs has been used most frequently where the simulated flow from station data and the observed flow from historical data are being plotted against each other. Furthermore, for this, the relationship between the plots can be determined with the help of the Pearson Correlation Coefficient and the Nash-Sutcliffe Efficiency Coefficient that is displayed beneath the plotted graph. What is noticed in *Figure 17,Figure* A4 *and Figure* A5 from Högsmölla, Ellinge and Vombsjön are that the plotting curves do not follow each other completely.

Instead of having a flow being limited to the stations, one can also find a flow with the help of coordinates of choice within the stream network. Moreover, in the reports displayed from the QSWAT+ interface, land use and soil data present information of land use, landscape, soil and slope distribution in percentages and hectares. The results presented from the land use compared to the Länsstyrelsen are different see the comparison in the Appendix *Table A1*.

4.2 Future evidence-based tool

This study is a pre-study for developing an evidence-based tool helping stakeholders to streamline the future constructed wetlands. With the help of this tool, the construction of wetlands can be optimized in consideration of location, design, and management. Being able to simulate the change in hydrology when adding wetlands to the model may determine the effects of the catchment area, such as the potential possibilities and risks.

QSWAT+ as software is still in development and serveral errors and occurrences happened during the usage of the program. Furthermore, the faulty messages come without any descriptions or any solutions on how to solve the problem. Therefore, times has been spent on solving the problems using the trial-and-error method, as well as finding answers on the QSWATS+ Google forum and sending emails to the software developers.

4.2.1 Possibilities

QSWAT+ have shown multiple possibilities during the usage of the software. Inserting lakes is one of them and could be accomplished by adding shapefiles with correct values in the attribute table and channel connections to the lakes.

Another option is to manually add reservoirs into the model, although the size of the lakes and shapes detected by the program did not fully correspond to the ones provided by SMHI or Lantmäteriet, due to pieces of the map being omitted by QSWAT+. Moreover, the lakes that can be displayed in QGIS, but visually misleading on the map as it only shows a few reaches, see *Figure 18.*

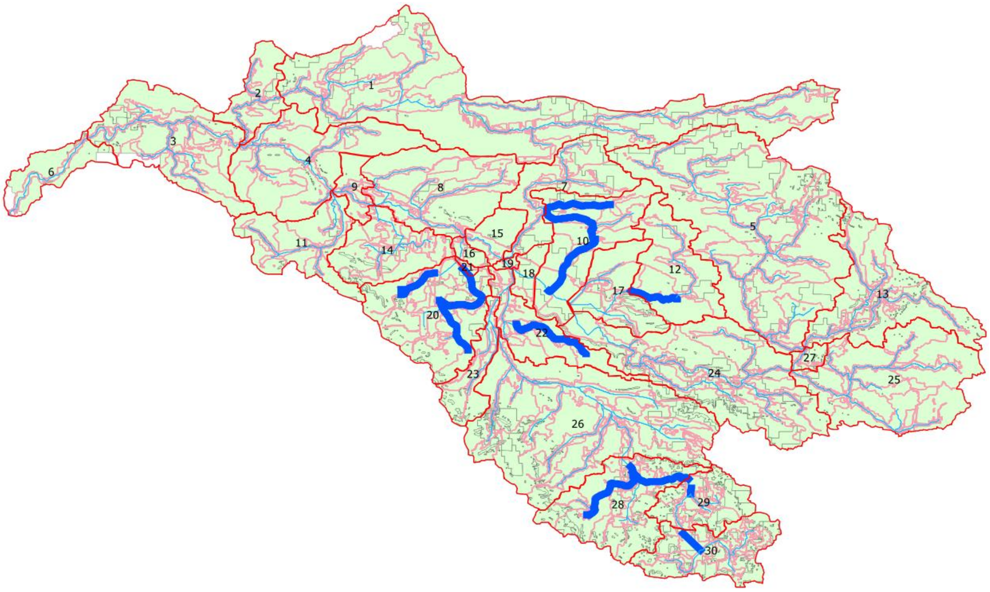


Figure 18:Alternative way of adding reservoir. Blue colored lines displaying reaches.

Despite the inaccuracy when positioning reservoirs on the map using the function *inlet/outlet*, the reservoir could be found in the SWAT+ editor. This can be explained by a higher snap threshold number making it easier for the software to find the positions of the channel and place the manually inserted reservoirs on it.
Depending on where the point of the reservoir is placed on the map in QGIS, the elevation will be different, making the elevation relatively accurate but with some uncertainties. This may depend on the DEM file that was inserted. However, the area of the reservoirs has shown a high inaccuracy in the SWAT+ editor as the area of the reservoirs is significantly smaller than the actual reservoir area.

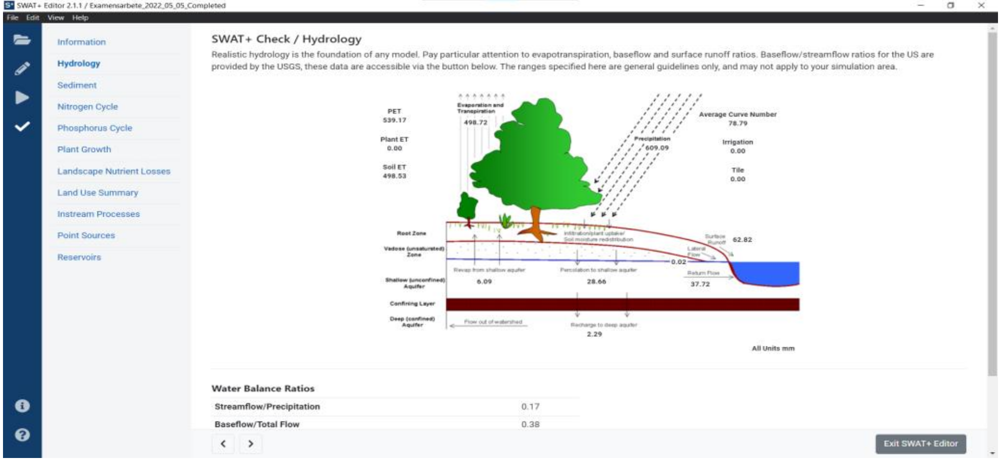
The percentage number of the reservoir threshold determines the amount of water for it to form a reservoir for a channel. The standard value 101% means that no reservoir will be formed other than the reservoir being set during step one in water delineation. Values below 101% displayed more reservoirs as expected in the model, resulting in the number of HRU numbers decreasing. On the other hand, this is a beneficial function for users lacking reservoir information.

Furthermore, difficulties have arisen, for instance, when inserting data for land use, soil, usersoil, plant into the software. This could not be done as the knowledge of creating the required CSV files was lacking and no instructions on how to proceed were available. The example files that were downloaded from SWAT+ editor did not have any explanations on how the plant data should be formed in CSV files and did neither describe what necessary components and parameters had to be collected for the files.

Several experiments have been implemented in the program when it comes to lakes, where simulations have been proceeded both with and without lakes to see if the program contemplated the hydrological factor from lakes as storage of water to regulate the flow. The results from simulations show higher flow when running the simulation without lakes than with lakes see appendix *Figure A1*. Regardless, the resulted simulated flow without lakes that resulted in a higher flow was still more like the station flow where the peaks got a better pitch. On the contrary, when looking at the Pearson correlation coefficient the simulated flow with lakes demonstrated higher validity.

The insertion of DEM files was successfully added to the model, and subbasins and watersheds were created from the DEM and then compared to the merged shapefiles of the Kävlinge catchment area from Lantmäteriet. The subbasin and watershed gave an acceptable match despite the area loss of 4% which corresponds to 4400 hectares of the original catchment. On the contrary, in the subbasins created by the software and displayed as a model, the numbers of subbasins did show a larger amount than in the shapefile from SMHI. However, in the software, the subbasins can be somehow merged according to the division displayed on the SMHI shapefile, although inserting outlets and reservoirs makes limitations on the merging capability. As every outlet and reservoir inputted creates a boundary of subbasin and error occurs when merging due to the requirements of the software to have one subbasin for one outlet and reservoir.

The SWAT+ editor reads the project database generated by QSWAT+ and then allows the user to make changes and insert more data if needed. With this function, errors can be changed at an early stage, instead of having to go back and look for the errors after the simulation has taken place. In the QSWAT+ editor one can also go through the hydrology of the current situation with the function SWAT+ checker, showing schematically how the water cycle is adapted by the software. Besides, information about the sediment, nitrogen cycle, phosphorus cycle etc. can also be found in the QSWAT+ editor, see *Figure 19*.



SWAT+ Check / Hydrology

Realistic hydrology is the foundation of any model. Pay particular attention to evapotranspiration, baseflow and surface runoff ratios. Baseflow/streamflow ratios for the US are provided by the USGS, these data are accessible via the button below. The ranges specified here are general guidelines only, and may not apply to your simulation area.

Water Balance Ratios

Streamflow/Precipitation	0.17
Baseflow/Total Flow	0.38

Figure 19:The SWAT+ Editor showing the current state of the catchment area using the hydrological cycle.

5. Discussion

As a developing software, QSWAT+ is highly experimental with various hydrological features. This chapter will, however, be divided into three parts: *Evaluations of QSWAT+, Analysis of collecting and simulating data and Analysis of the software.*

5.1 Evaluations of QSWAT+

The use of QSWAT+ as a plugin in QGIS has been successful where the software has been able to synchronize with QGIS. It can with some uncertainty be stated that the evidence-based tool can be applied in Sweden, where the uncertainties are the result of inaccuracy and lacking data. On the contrary, if this tool were meant to be for American use, the answer would have been different. This is because of the great compatibility of American data and the program as the program is being developed in the USA. More descriptions and tutorials on how to use the program more properly would simplify the making of an evidence-based tool, as many other functions such as adding lakes, land use, soil, urban and plant table were deficient and would be beneficial for the results.

At the beginning of using the software, many different versions of QGIS and QSWAT+ had to be downloaded to find the compatible versions. As both QGIS and QSWAT+ are still under development and dropping new releases periodically, one cannot be sure of the latest versions of the two software being compatible with each other, as well as the criteria for both to work. QGIS LTR is recommended to use for better and more credible features. Another thing that was constantly causing errors was the placement of the input data files and the saved files. QGIS could not find the data if they were not collected in the same folder, making error codes appear.

However, options for inputting wetlands were found either by using grids or without grids to instead insert polygons shapefiles added into the model. This is a great function when creating an evidence-based tool in future work as alternative methods could be chosen from preferences.

Worth mentioning is that the developing team of SWAT+ is helpful when it comes to questions and problems appearing during the usage of the software. This reduces the uncertainty in using a software program that is still developing. Furthermore, because the software QSWAT+ is under constant development, great numbers of errors did occur. For this, there is a community in the Google forum where stakeholders and users are gathered to ask questions. Although the questions asked in the forum did not always get a response.

5.2 Analysis and simulation of collected data

At the beginning of the study, validated data was acquired from SMHI, Lantmäteriet, SLU, Naturvårdsverket and Jordsbruksverket. Data was specifically chosen and compiled for the catchment area using the QGIS functions. Inputting quality data (2x2) into the program resulted in prolonged processing time for the software and hardware which was caused by big file sizes. As an alternative the files were compressed into smaller sized files (50x50), resulting in bigger grids and data loss which was necessary for the plugin to work in a functional manner. Resizing to 50x50 grids was done for all the raster files that have been implemented into the model. However, using the file with 2x2 grids would with a higher probability give better results and more HRUs due to more provided information.

Multiple data have been downloaded from the SWAT+ database because of lacking available data for the certain catchment area for the CSV tables. Due to despite using unofficial data, the result still turned out to be acceptable. Furthermore, parameters in input data files such as wet_dry and dry_dry were estimated by hypothetical theories and probability from data obtained by SMHI, as other data from a credible source was unavailable. Additionally, the weather files (CSV) for plant and urban were obtained from example data from SWAT+ database due to the same reason.

The catchment area could be identified by inserting DEM files, soil data, land use, lakes and other information HRUs are consisting of. The program has worked in its entirety despite all the occurring errors. Although many of the data that have been processed were not used in the program was validated data caused by the errors that appeared in the software resulting in a worse result than expected.

The faultiness is mostly due to bad instructions and unexpected updates and errors during the usage of the software, causing several downtime during the work of the thesis. As a result of this, the primary objectives of creating the

evidence-based tool changed to investigate and review the software QSWAT+, and the main idea of optimizing wetlands was discarded.
In some parts of the program, standard values were necessarily used because no other data was provided, also, several functions were not studied as they weren´t compatible for this study. For instance, the elevation band was not used in the second step in *Create HRU* as the bands are used for subbasins at higher elevations concerning by snow and ice. By defining a minimum elevation: only subbasins whose maximum elevation exceeds this are given slope bands, and by defining how many bands to use.

The land use in this study retrieved from the database of QSWAT+ in comparison with the data from Länsstyrelsen for the whole catchment area has shown differences and can be motivated by how the program reads the DEM file, also where the used data downloaded. By using land use from Lantmäteriet and soil data from SGU would improve the resulting result since the data from trustworthy sources yield higher accuracy, resulting in better fitting peaks of simulated flow, and more accurate land use and soil data.

5.3 Analysis of the software

QSWAT+ with the SWAT+ Editor has shown good potential in participating as a basis for the evidence-based tool. Regarding the water cycle, the SWAT+ Editor can, as mentioned earlier, display the ongoing hydrological cycle of the study area of interest. With this function, the three phases between earth and atmosphere: solid, liquid and gas can be detected, and the current hydrologic state can be further studied when knowing the values for the parameters within the hydrological cycle. It can also be used to detect the concentration of phosphorus and nitrogen which can be used to reduce the likelihood of eutrophication occurring.

Wetlands have an important function for the climate and the society and can both improve the quality of water and contribute to the achievement of environmental goals. By creating an evidence-based tool wetlands can be optimized and increase the catchment´s ability to cope with future extreme weather. This will not only improve the water quality but can also be economically beneficial on potential floods.

Giving the availability of increasing the number of wetlands will not only facilitate for the already existing catchments but likewise increase the biodiversity, saving endangered animal and plant species, which is also one of Sweden´s 16 environmental goals.

5.4 Possibilities of QSWAT+

Possibilities of QSWAT+ have also been detected, increasing the potential of using this software as an evidence-based tool. The possibilities can for instance be inserting validated data, making grids, coupling channels, inputting lakes, and creating lakes and wetlands using grids and shapes.

Regarding the program, there are still multiple things to discover and further updates might provide more functions, but more importantly a better understanding of the usage with better instructions and descriptions. This would improve the tool significantly.

The program can contribute with several information and can certainly be used in different study areas. In this study, only hydrology was considered, but QSWAT+ also allows the user to do studies in other areas such as the nutrient cycle, sediment transport, landscape, and land use. If utilizing all the provided functions together, one physics-based model and validated tool might be developed.

6. Conclusion

During the time of this thesis, when studying QGIS and QSWAT+ as a plugin, one can conclude that the software has the potential for developing the evidence-based tool for the optimization of wetlands. The reason is that the plugin software QSWAT+ provides a wide range of features and big possibilities, mentioned in the result section. At present, however, one can say that the usage of QSWAT+ can be challenging when the sufficient knowledge of the program is low and there are no clear instructions provided.

On the other hand, not everything has gone as planned. Many error codes have occurred during the study period, as well as problems that could not be solved. QSWAT+ has also consisted of various uncertainty. Lacking instructions have already been mentioned but lacking descriptions for inserting input data as land use, plant and urban tables has also been problematic and will be for future work if no further explanation of the insertion requirement is stated.

In conclusion, QSWAT+ can be used to form the tool, but it is not valid enough to be able to be called an evidence-based tool. This is since not all lakes within the catchment area were successfully shown in the model. Moreover, the program cannot read the boundaries of the catchment area of the Kävlinge river completely correctly if compared with the one in SMHI. In addition, there are no good instructions on forming plant and urban tables in CSV format at the present, making it almost impossible to be able to use our own data. However, even if there were instructions on making plant- and urban tables, the availability of required data was still limited.

6.1 Future work

The original idea of this study could not be completed due to the lack of both data and more information on how to use the program when using QSWAT +. The main goal of this study was, as mentioned in the objectives, to develop an evidence-based tool to optimize the design, location and management of future constructed wetlands. Therefore, a recommendation for future research would be to follow the main original objective to develop the evidence-based tool within the Ecodiver project with the help of this study. The future work may also consist of a calibration and validation part of the data that is being used, as it has not been taken it into account due to lack of time. Calibration creates validation, which in turn yields higher accuracy of data for future use.

Other studies could consider the water balance and nutrient cycle, transportation of sediment and landscape and land use, as there are great functions for these parameters in QSWAT+.

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Appendix A

Table A1:Comparison of data from SMHI versus the computed data from the software QSWAT+

Areas	Units	Computed
Arable land	65%	82%
Forest	17%	9%
Urban areas	3%	1%
Other lands	12%	5%
Wetlands	1%	3%
Sea surface	2%	0
The Kävlinge river catchment area	1202km^2	1158km^2

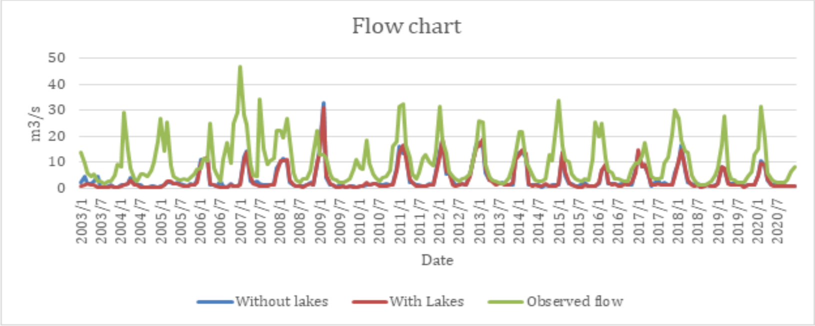


Figure A1:A flow chart where the observed flow is plotted against the simulated flow with and without lakes

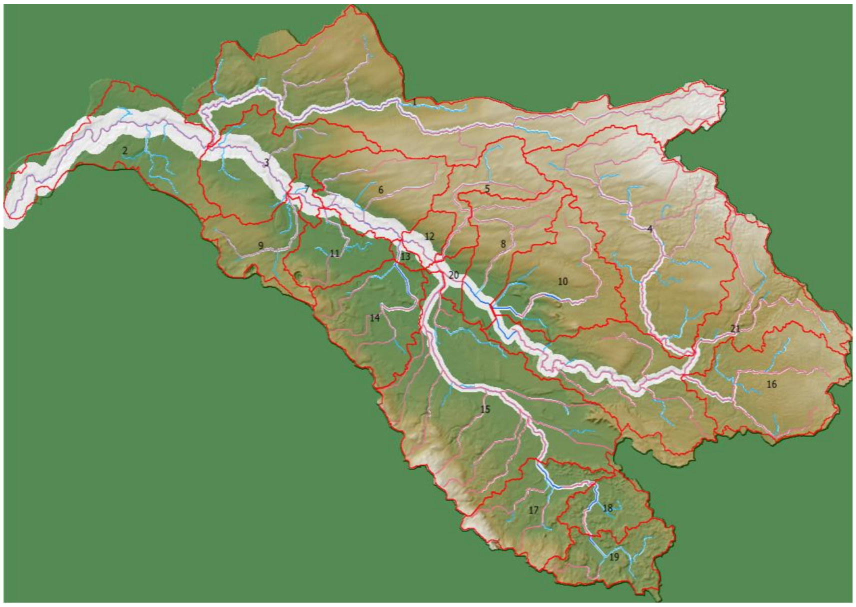


Figure A2:The floodplain displayed in QGIS using the buffer streams method.

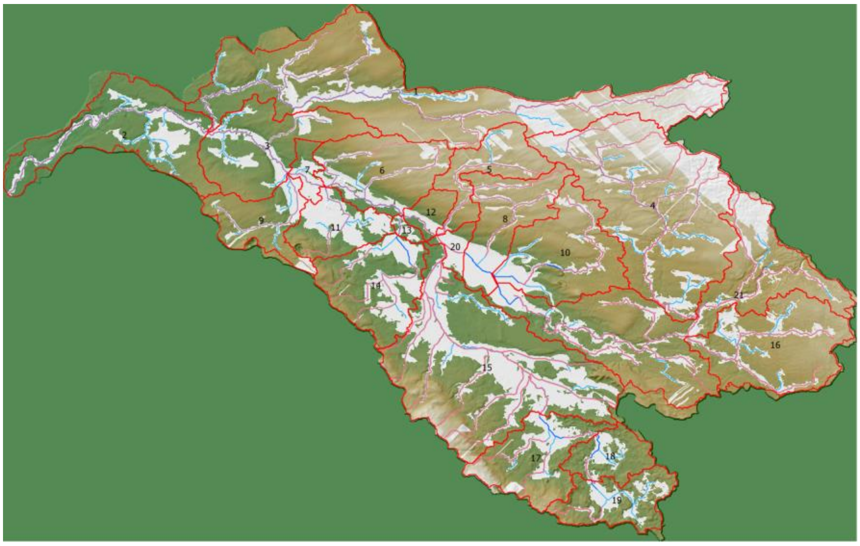
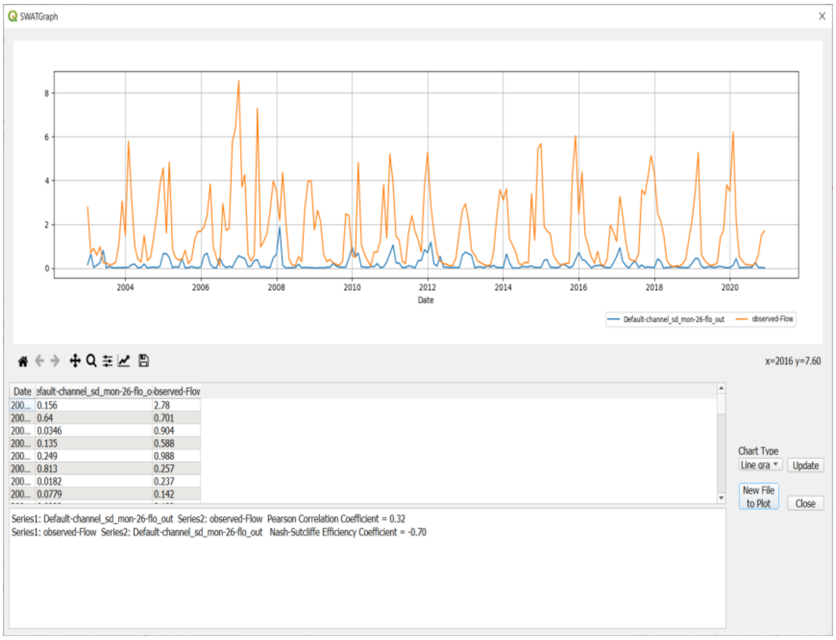


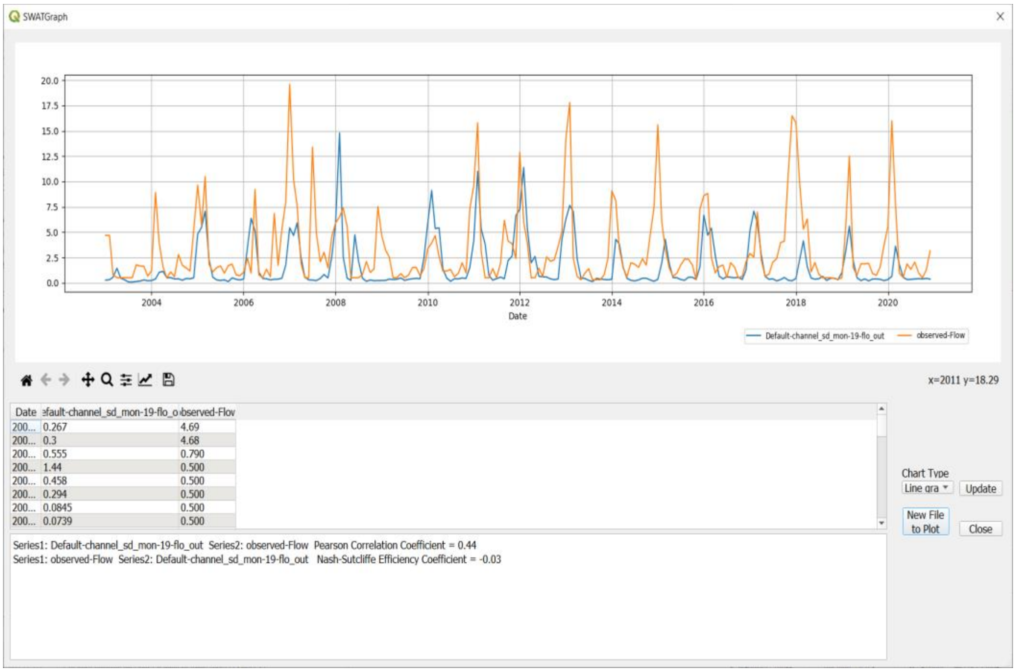
Figure A3:The floodplain displayed in QGIS using the DEM inversion method.



Date	efault-channel_sd_mon-26-flo_o	bserved-Flov
200...	0.156	2.78
200...	0.64	0.701
200...	0.0346	0.904
200...	0.135	0.588
200...	0.249	0.988
200...	0.813	0.257
200...	0.0182	0.237
200...	0.0779	0.142

Series1: Default-channel_sd_mon-26-flo_out Series2: observed-Flow Pearson Correlation Coefficient = 0.32
Series1: observed-Flow Series2: Default-channel_sd_mon-26-flo_out Nash-Sutcliffe Efficiency Coefficient = -0.70

Figure A4:Observed and simulated data from the flow in Ellinge station in channel 26



Date	efault-channel_sd_mon-19-flo_o	bserved-Flov
200...	0.267	4.69
200...	0.3	4.68
200...	0.555	0.790
200...	1.44	0.500
200...	0.458	0.500
200...	0.294	0.500
200...	0.0845	0.500
200...	0.0739	0.500

Series1: Default-channel_sd_mon-19-flo_out Series2: observed-Flow Pearson Correlation Coefficient = 0.44
Series1: observed-Flow Series2: Default-channel_sd_mon-19-flo_out Nash-Sutcliffe Efficiency Coefficient = -0.03

Figure A5:Observed and simulated data from the flow in Vombsjön station in channel 19.

With the help of the SWAT+ Editor, an observation of future flow can also be simulated, like *Figure A6* where the flow is determined to 2050.

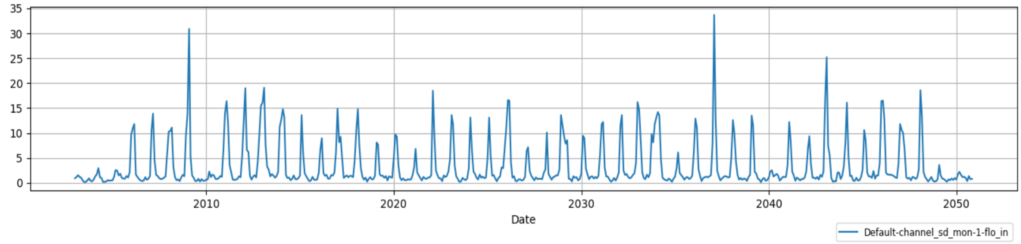


Figure A6:Future simulated scenarios 2050.

Appendix B

Omitted data

This section is for the data that was processed during the work, but which was not used.

- JORDARTER 1:1 miljon (lantmäteriet) (soil type)
- JORDARTER 1:25 000-1:100 0000 (lantmäteriet), rasterized to 50x50
    - Jordarter_25-100k_jy1
    - Jordarter_25-100k_jg2
    - jordarter_25-100k_jd3
- NMD, Nationella marktäckedata 2018; basskikt (Miljödataportalen, naturvårdsverket)
- NMD, Nationella marktäckedata 2018; tillägsskikt objekthöjd och objekttäckning (Miljöportalen, naturvårdsverket)

The quaternary deposits, or soil data, could also be downloaded from Lantmäteriet's database where there were five different alternatives with different scales to choose among. The one downloaded for this application was *Jordarter 1:25 000 - 1:100 000 latest (shp.)*. The activated files are specifically Jordarter_25-100k_jy1, Jordarter_25-100k_jg2 and Jordarter_25-100k_jd3, providing a considerable number of different sediments appearing on the map of the catchment area. The data from the three files were merged into one by using the function *concat* in the field calculator - making all the data end up under the same category in the browser. With the help of the soil map in Skåne (SGU, 2000), the sediment types could be categorized accordingly, see *Figure B2*. The shape file was then converted from a vector format into a raster. The rasterized file was then categorized into different sediment, presented in the *Figure B1*, which was sorted manually and compared with SGU (Skånes jordarter, skala 1:250 000).

Land use data was retrieved from Naturvårdsverket (2018) as a raster file and was cropped in QGIS according to the shape of the catchment area.

The categories are divided into subcategories with either another shade of the same color as the head category, or with a pattern. This can be seen on *Figure B1*.

The colors are categorized as follows:

- Green - forest
- Purple - open wetland
- Light yellow - arable land
- Beige - other open land
- Red - artificial surfaces
- Blue - water

(Naturvårdsverket, 2020).

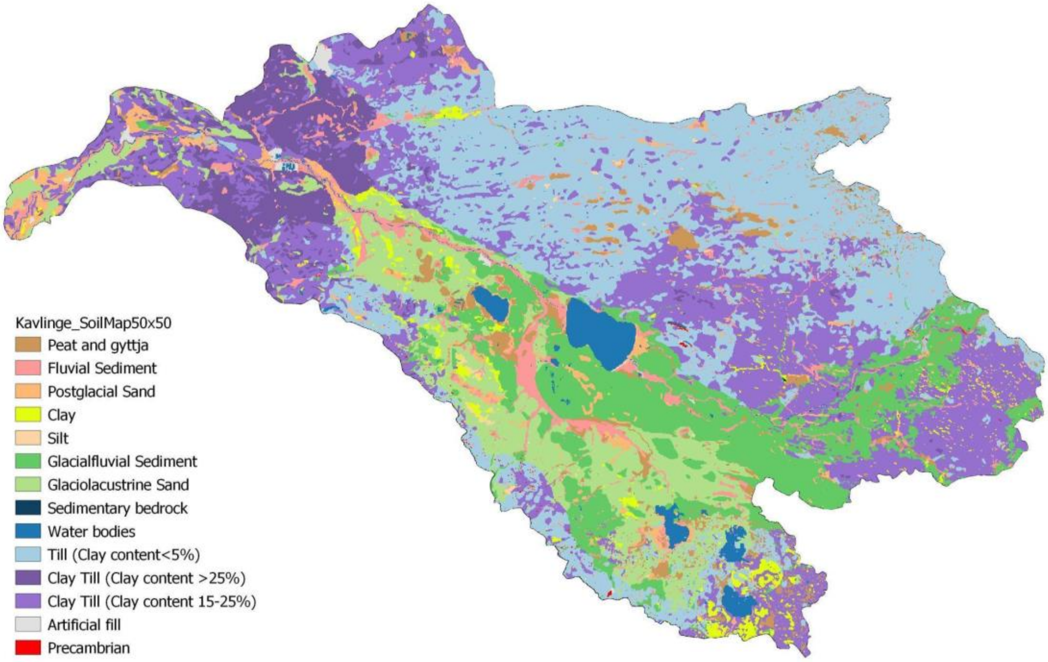


Figure B1:The soil map of the Kävlinge river catchment area.

Urban data could be found in Naturvårdsverkets database, Miljödataportalen (https://miljodataportalen.naturvardsverket.se/miljodataportalen/) where Swedish data for data environment and nature are collected. The files come in NMD format and for the base layer Nationella marktäckedata 2018; basskikt

(National ground cover data 2018; base layer) the NMD is presented in assorted colors. (Naturvårdsverket, 2020)

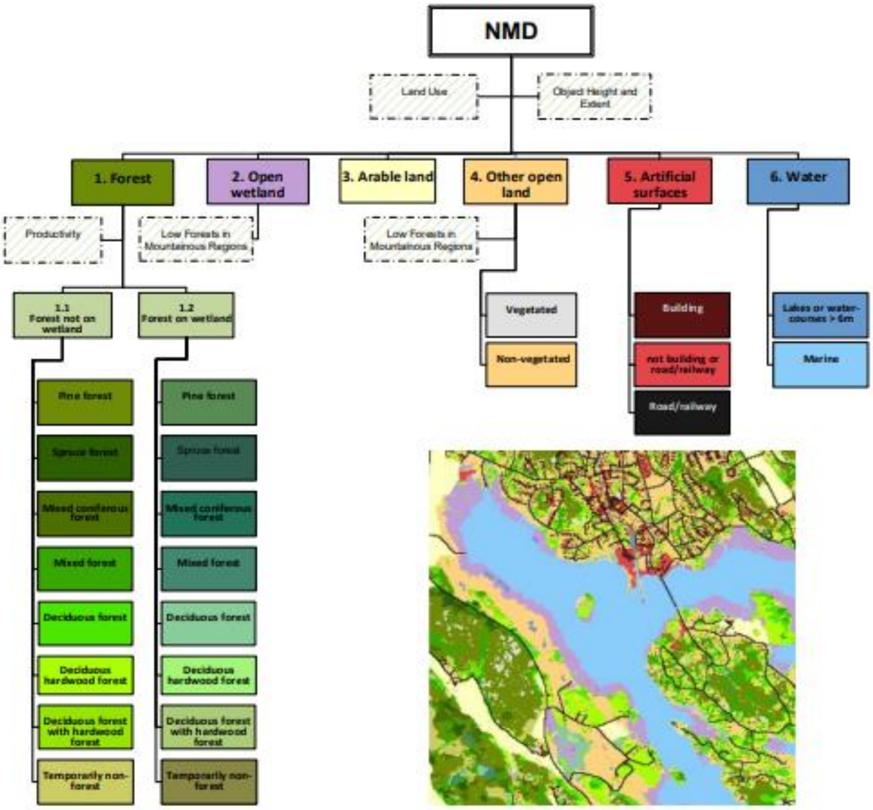


Figure B2:A schematic of the NMD colour system, by Naturvårdsverket and can be found on Miljödataportalen.

Another NMD file, Nationella marktäckedata 2018; tillägsskikt objekthöjd och objekttäckning (National ground cover data 2018; additional layer object height and object coverage), for additional information and layers was added. This data could provide with pastures from LPIS data collection and Jordbruksverket (the Swedish Board of Agriculture), power lines from Lantmäteriet's property land map, and landscaped areas from SCB. (Naturvårdsverket, 2019)