Master Thesis
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Geomorphology alteration effects over Kävlinge River Basin

An analysis using a physically-based hydrological model

Erik Frias Olguín

Source: Aerial photo, straightened section over Kävlingeån, Vattenatlas,/Lnatmäteriet

Division of Water Resources Engineering
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Abstract

This thesis focuses on the case study over the Kävlinge catchment located in the south of Sweden, and mainly in the Kävlinge river. This river, which is the mainstream of the catchment, has been subject to modifications due to agricultural activities. Such modifications, like straightening or increasing the depth and channeling sections of the river, will affect the river's hydrodynamics. These interventions are often made to reduce the impacts of fluvial floods in the presence of extreme rainfall events. Such floods can be expected to occur more frequently in the future because of climate change. However, these modifications may also affect soil erosion and can have other adverse effects on the river ecosystem. This work will use a physics-based hydrological model to simulate the hydrodynamics conditions of the river and the basin, along with the effects of river straightening. These are compared with the modeling of the original river course. This study is a starting point for further analysis and research aimed at improving the ecological conditions of the Kävlinge river basin.

After running the simulations, the models show a decrease in the water level of 0.02 m and a discharge peak reduction of 2 m^3/s and a delay in the presence of the Max. water level. Furthermore, the results of a second model simulation using cross-sections generated using the elevation values, show the same tendency and showing a clearer effect of meander over the fluvial floods in sections downstream.

Sammanfattning

Denna avhandling fokuserar på fallstudien av Kävlinge-avrinningen i södra Sverige och främst i Kävlinge-floden. Denna flod, som är den viktigaste strömmen i avrinningsområdet, har ändrats på grund av jordbruksverksamhet. Sådana ändringar, såsom att räta ut eller öka djupet och kanalisera delar av floden, kommer att påverka flodens hydrodynamik. Dessa ingrepp görs ofta för att minska effekterna av fluviala översvämningar i närvaro av extrema regnhändelser. Sådana översvämningar kan förväntas inträffa oftare i framtiden på grund av klimatförändringar. Dessa ändringar kan emellertid också påverka markerosion och kan ha andra negativa effekter på flodens ekosystem. Detta arbete kommer att använda en fysikbaserad hydrologisk modell för att simulera hydrodynamikförhållandena i floden och bassängen, tillsammans med effekterna av flodrätning. Dessa jämförs med en modell av den ursprungliga flodbanan. Denna studie är en utgångspunkt för ytterligare analys och forskning som syftar till att förbättra de ekologiska förhållandena i Kävlinge flodbassäng.

Efter att simuleringarna har körts, visar modellerna en minskning i vattennivån på 0,02 m och en urladdningstoppsänkning med 2 m3 / s och en fördröjning i närvaron av Max. vattennivå. Vidare visar resultaten från en andra modellsimulering med tvärsnitt genererade med höjdvärdena, samma tendens och visar en tydligare effekt av slingrande flödesflöden i sektioner nedströms.

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1. Introduction

This thesis is based on the EcoDiver project (Enhancing Hydrodiversity for improving catchment-based climate resilience), which is a project carried out by Lund University among other institutions in Sweden. The aim of the EcoDiver project is to study and analyze the impact and influence of freshwater wetlands, and the interaction between their diversity in different catchments in Sweden. The Kävlinge catchment is the one in which Lund University is focusing its studies (Persson, 2019).

The Kävlinge River has been subject to modifications and alterations in its geomorphology over the past century (Mills, 1991). The most notorious being the straightening of sections of the river to increase the drainage of cultivated lands. By straightening a river, its length will decrease and the gradient will increase, and with this the drainage capacity. This can lead to a reduction of wetlands. It can also lead to an increase in the speed and volume of water passing through the straightened section that can lead to more rapid and more severe floods downstream (Gore & Petts, 1989). If we add to this, the increase of extreme meteorological events in the last decade, the reduction in the ecosystem biodiversity with wetland loss, the increasing number of communities and people that live alongside the river, the negative effects of straightening may be considerable.

Floods and droughts are two effects that people relate more directly to climate change, as each year these events cause damages and severe economic hardships on populations. In the last decade, as is the case in many other countries, Sweden has suffered extreme or atypical weather conditions. As recently as 2014, the southern part of Sweden (particularly cities Malmö and Burlöv) experienced one of its most drastic rainfall events. The region suffered floods affecting whole cities, causing over 300 million SEK of damages, according to Swedish Insurance (Hernebring, et al., 2015).

Besides the increasing awareness of climate change and its accompanying severe meteorological phenomena, there has also been an increase in the occurrence of what was considered low probability events such as 100-year floods[1]. It is common today to directly tie climate change as being the main cause of increases in the number of floods and droughts. However, other factors play an important role in the development of these events. Scholars have argued that only looking at climate change can be misleading as it leaves out of the discussion factors such as deforestation, intensifying agricultural practices, and urbanization, which also increase the probability of floods via the change in land-use (Blöschl et al, 2017).

It is known that climate change has been caused and worsened by the action of human activities; analyses and studies have shown an increasing and linear trend in global warming measurements, with a range that oscillates between 0.56 to 0.96 C, from 1906 to 2005. Particularly striking is the fact that it has seen its most notable increase in the last 50 years, mainly due to the anthropogenic greenhouse gases concentration during the 20th century (Bates, et al., 2008). Most of this rise in greenhouse gases can be attributed to the combustion of fossil fuels and the exploitation of ecosystems for agricultural

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[1] This expression refers to the fact that there is a 1% probability that an event of catastrophic magnitudes occur.

and livestock activities, in detriment to forest areas which are vital for the gases exchange. (European Commission, n.d.).

In the last years, the potential effects of climate change around the world have become more and more frequent and extreme, with previously atypical events now being recurrent and more drastic each passing year (Senevirante, S. I. Et al, 2012). The melting of the polar ice caps and the rise in sea levels are two of the more known parameters taken to analyze the effects of climate change. Far from being the only consequence of climate change, meteorological events have also been taking place all around the world more recurrently, such as heavy precipitations and severe droughts (European Commission, n.d.). This kind of phenomenon may be more easily perceived by the general population, as their effects directly impact cities.

1.1 Purpose and Problem Description

This thesis aims to create a physically-based hydrological model of the Kävlinge river that would allow us to compare between the hydrodynamics of the actual (current) river shape and the shape of the river before the alterations, this will allow the analysis of the flooding area along the river in both cases, being able to work as a base for further studies such as EcoDivers project, to analyze wetlands attenuation effects over the climate change. This analysis is intended to help define in further studies the effects of the wetlands as a “nature-based” solution option for adaptation and mitigation of climate change effects. From the last decades, the municipalities within the basin have committed to restore some of the wetlands lost as a consequence of the river straightening and the intense agricultural activities by the *Kavlingeå-Projektet*. However, *Kävlingeå-Projektet's* main goal was the monitoring and improvement of the quality of the water bodies in the catchment, by creating manmade wetlands in designated areas (Ekologgruppen i Landskrona AB, n.d.).

The overall goal of this thesis is to focus on modeling the effects of the alterations made to the river shape, by straightening and meander reductions in the Kävlinge Basin and their effects over the fluvial floods over Kävlinge River. These two models are built: one with the Kävlinge River as it currently stands and another based on a historical map from 1915 that shows the path of the river with its meanders. Then, simulations are run to analyze the effect of the river’s modification on water level and floods in nearby areas.

It is intended that the results and information provided by this thesis project help the EcoDiver project in future studies of the hydrological functions of the wetlands and the interconnection between them against the effects of climate change (Persson, 2019).

In summary, this project will try to answer the following research questions:

- Do the alterations over the river geomorphology influence river floods in the Kävlinge River?
- Are the effects consistent with the theoretical background?
- Can these alterations influence in case of future extreme weather events?

2. Background

2.1 Kävlingeån: Basin and River

The Kävlingeån Basin is located in the province of Skåne, in the south of Sweden. It covers an area of approximately 1200 km^2, which also comprises 9 of the 33 municipalities that constitute the county (Kävlingeåns Vattenråd, n.d.). The basin also shares the name with one of the rivers that are in it. The geographical location and the meteorological conditions of the region create the proper conditions for the development of agricultural activities, in contrast with other regions in the north of Sweden. This is reflected in the distribution of land use by county in Skåne, with approximately 400 thousand hectares, a value that is only surpassed by Västra Götlands county (SCB, 2019).

Figure 1. Skåne County map, Marking the extension of Kävlingeån Basin. Source: Author work, using data from SMHI and SCB.

Agriculture in the region plays a major role in the hydrological characteristics of the catchment, with at least 75% of its area considered cropland

(Kävlingeåns Vattenråd, n.d.). The catchment is comprised of three main branches and different tributaries. The central (or main) branch, Kävlinge River, runs through the larger part of the basin ending at the Öresund sea. As can be seen in figure 2 below, its name changes on different occasions along the length of the basin according to the towns or cities it passes by.

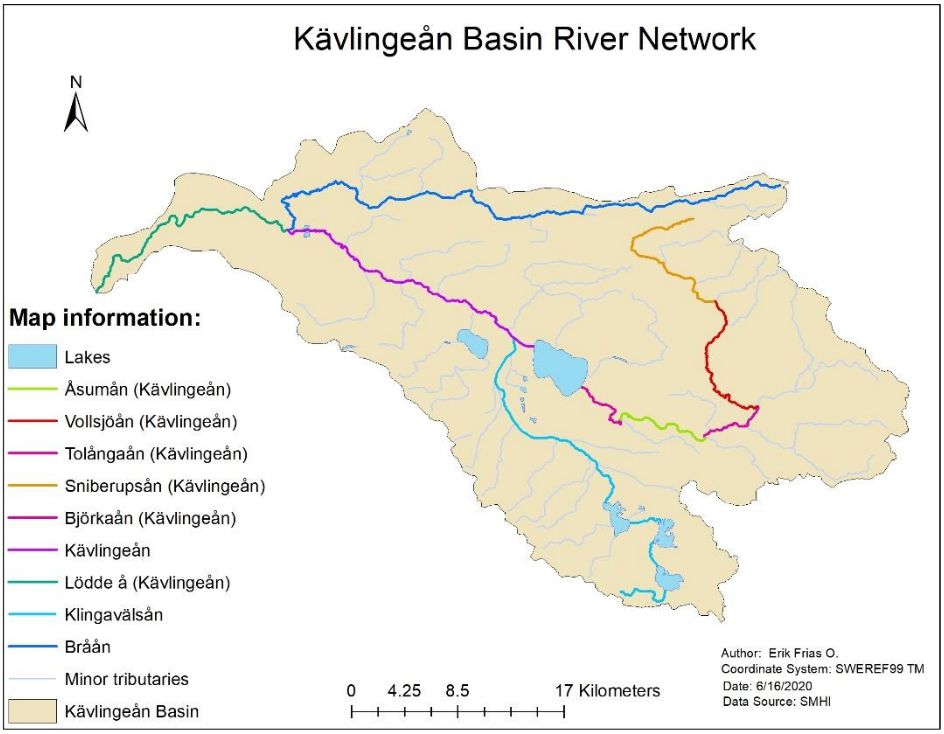

Figure 2. Kävlingeån Basin and hydrologic network, presenting the main branch and its names according to the location.   Source: Author creation with data from SMHI and SCB

The sections in which this project will focus on is the section that runs from the discharge point of the Vomb lake to the last part that leads to the Öresund sea, called Lödde River. The other two branches that are considered are the Bråån River and the Klingavälsån, that connect with the Kävlinge river.

Besides the rivers and minor branches, the catchment also contains other water bodies like lakes and wetlands. For this study, the calculations concern Lake Vomb, this is the biggest lake in the basin and one of the main sources for freshwater. Its surface is approximately 12 km^2 and it has a maximum depth of 16 m. Has an extraction of 1,500 L/s to supply to different municipalities that form part of the basin. It has been providing fresh water to Malmö, Staffanstorp, Vellinge, Burlöv, Svedala, and to some parts of Lund and Eslöv since the year 1948 (Sydvatten AB, n.d.).

Since the beginning of the establishment of communities in the area, they have mainly settled in the proximities of the watercourses in the basin, having in mind the growth of population and the urbanized area. Nowadays, the close interaction that some areas of the communities have with the watercourses can be appreciated, as can be observed in figure 3. This reality shows how further studies evaluating the impact of floods in the area are relevant.

Figure 3. Satellite Image of Kävlinge municipality.   Source: Google earth

From the beginning of the 19th century, the intensive agricultural activities in the area started showing negative effects in the basin hydrology due to human intervention. This was, in part, caused by the modification of the river's geomorphology in hopes of increased drainage efficiency (Hjorth, 1989). Specifically, straightening sections of the rivers would reduce the water table of the zones near the rivers.

Other effects engendered by alterations induced in the river and streams are the eutrophication of the river and wetlands. Eutrophication is the process of algae and plant formation in water bodies like estuaries and wetlands and is mainly a result of the increase of the nutrients in the water derived from the intensive use of fertilizers for agricultural practices. This phenomenon is usually exacerbated when river straightening accelerates the water draining from the flood plains and wetlands, increasing the nutrients in the river while the wetlands areas decrease. In other words, it is a sign that human activity has impacted the river to the point where it no longer can process and reduce pollutants by natural means.

This has led to a series of problems and negative effects that concluded with the alteration of the ecosystem and biodiversity, such as the excess of algae and decomposition that created an improper environment for the proliferation of animal species and some plants. In the end, this also influenced the communities and towns as there was a decline in fishing activities on the rivers and lakes as well as recreational activities. Thus, in 1995 the municipalities comprising the basin collaborated to solve this problem by improving the water quality. They launched a project to create and restore wetlands that would help deal with the pollutants as well as implementing cultivation-free zones (Ekologgruppen i Landskrona AB, n.d.).

2.2 Data Collection

For this thesis project, most of the information needed was retrieved from national data collections of agencies like the Swedish Meteorology and Hydrology Institute (SMHI) and Lantmäteriet. From the former, data files containing the hydrological information were obtained, like the measured discharged flow from the Vomb lake to the Kävlinge river or the discharge from the Klingavälsån river to the Bråån river; both of these connect and discharge in the Kävlinge river downstream from the Vomb lake. Besides the values and time series, the shapefiles for the rivers and the hydrologic network inside the basin (as well as the file of the delimitations of the basin itself) were also obtained from this institute. Lantmäteriet is the office in charge of the land survey. From its official site, it was possible to obtain the elevation map files, updated maps from the study, and the historic ones from the years 1910-1915.

Table 1. Information table from data collected. Source: Author creation with data from SMHI.

Data Collected			
Data type	**Properties**	**Source**	**Type**
Digital Elevation Model (DEM)	Definition 2m	Lantmäteriet	Raster/ASCII
River Network	Lines	SMHI	Shape file
Catchment contour	Polygon	SMHI	Shape file
Lakes	Polygon	SMHI	Sahpe file
Cross sections HEC-RAS	Text	Fiskevårdsteknik AB	ASCII
Historic Map 1915	Raster	Lantmäteriet	Raster
Old River shape	Lines	Author	Shape file
Time series	Discharge	SMHI	Excel/DSF0
	Water level	SMHI	Excel/DSF0
	Sea Level	SMHI	Excel/DSF0

Aside from this information, it was also necessary to acquire data about the river's cross-sections to present its bathymetry. The availability of this data, namely the cross-sections of some parts of the Kävlinge river, was made possible thanks to a previous thesis project done by former Lund University students, Josefin Tollgren and Julia Walldén (Tollgren, 2017). This data was provided by Erik Bergman from Fiskevårdsteknik, one of the supervisors of that thesis, from the HEC-RAS model used in this previous thesis. Therefore, it was necessary to extract the data of the geometry and convert it in a format able to be used by hydrological modeling software.

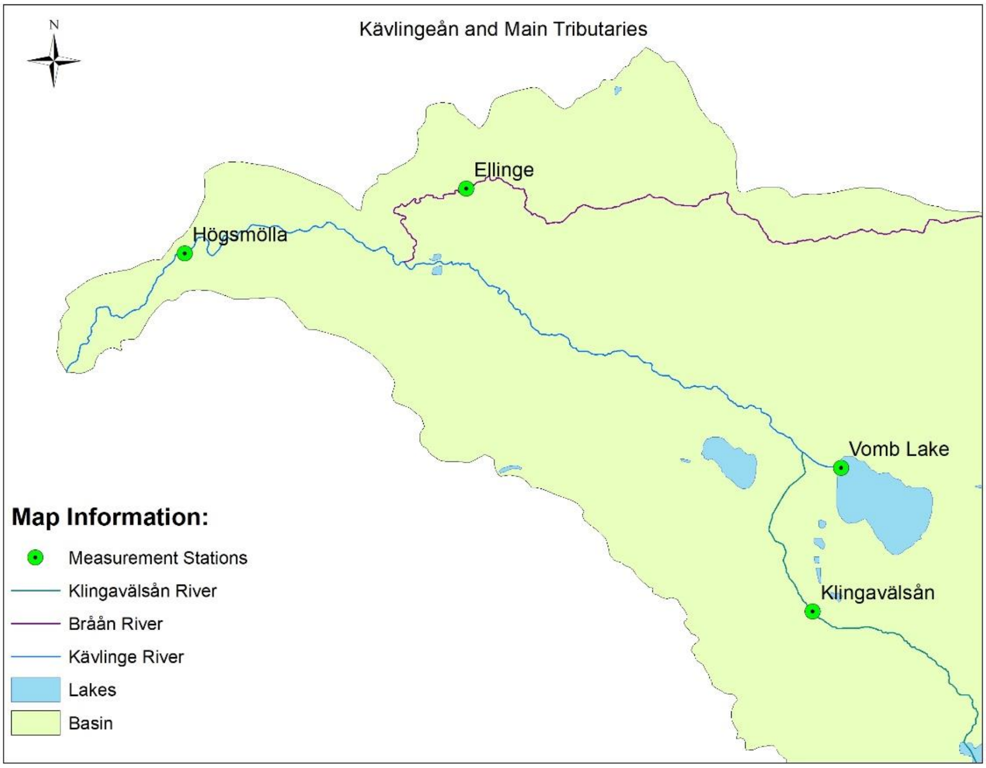

Figure 4. Map of tributaries connected to the Kävlinge river and its measurement stations. Map produced in ArcMap by author.

The model also requires input data for the flow in the network. For this, time series were retrieved from the SMHI database, containing discharge information from the Bråån, Klingavälsån and the Vomb lake, that correspond to the flow over Kävlinge river. This time series was obtained from measurement stations administrated by SMHI, at the same time it was collected discharge and water level data from the dam and measurement station

Högsmölla which is the closest to the sea[2]. Lastly, water level data from the sea level was collected in case a more detailed model was needed.

Table 2. Stations in the study area where data was retrieved. Source: Author creation with data from SMHI.

			Parameters		Coordinates		
Station Name	Code	Branch	Discharge	Water Lvl.	X	Y	Obs.
Högsmölla	*2171*	*Kävlingeån*	*Yes*	*Yes*	*379371*	*6183219*	*Observation point.*
Ellinge	2126	Bråån	Yes	No	392329	6186171	
Klingavälsån	2116	Klingavälsån	Yes	No	408080	6166940	
Vombsjön	2018	Lake Discharge	Yes	No	409170	6173471	

All the discharge and water level time series were retrieved in daily and hourly scales, except for the Vomb lake discharge data, as this is only recorded by the SMHI daily. For the data collected, it was the intent to obtain the oldest records as possible. In the case of the discharge data, for instance, the historical data that could be collected depended on the branch. For some branches, it was possible to find values from 1969 or 1975 onwards. Data was generally available until the first days of 2020, although some like the Klingavälsån station only had information until 2019. On a side note, data collected in the last years since 12/01/2018 should be taken with caution, as from this date the data wasn't corroborated by the SMHI as they stopped operating that station.

To simplify the calculations, it was decided to establish a common period length for the time series. To have a similar time data series in all the files, it was decided to work from 08/01/1975 to 05/02/2019, as all of the time series collected had contained data for this interval.

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[2] This data is used later for calibration purposes.

3. Methodology

3.1 Topographical and Geographical Data

A Geographic Information System (GIS) tool, for this project, the GIS software used was ArcMap. This tool was mainly needed to process and organize the different geographic data used, like Digital Elevation Model (DEM). These data are required for topographic or elevation information from the study area, as this will gave the model the information required to designate the direction of the flow, as it is known for the streams, but also for the superficial runoff as this will influence the direction and speed of the flow.

ArcMap allows us to create and modify shapefiles and maps from the data available obtained from Lantmäteriet and SMHI. Amongst the data obtained, there’s a hydrologic network that consists of all the streams and rivers within the lakes on the basin. To simplify the model it was decided to work at this time only with the main river (Kävlinge) and it’s most important tributaries, the river Bråån, and the River Klingavälsån. At the same time, one of the purposes of the thesis is to study the effects of the river straightening on flooding. For this, it was needed to obtain the shape of the river before the alterations by creating a shapefile from a historical map from 1915, obtained from the Lantmäteriet. This information was later used to create the models that would allow us to analyze the effects of these alterations to the river, and it impacts on extreme meteorological events.

With ArcMap, it was possible to manage and arrange the DEM file so it could be used by the MIKE software. The file obtained from Lantmäteriet was a mosaic. This means that the complete DEM model was formed by different files containing each one a section that together form the complete elevation model. With the use of ArcMap tools, it was possible to fit the different files in the mosaic to a single raster file, which later was converted to an ASCII file that would allow us to use this file in MIKE software and other models that read ASCII files.

3.2 Hydrological modeling of river and catchment

A hydrological model is a tool that simulates in a simplified way the processes related to water movement in nature, like the surface runoff, the infiltration and percolation and groundwater flow (Mujumdar & Kumar, 2012), forming what it is usually known as the water cycle, taking as the starting point the precipitation. The hydrological models use different inputs of data to run and simulates its processes, and the amount and type of information and data required will depend in great measure of the type and purpose for which the model would be built, as more complex and detailed models would require more data.

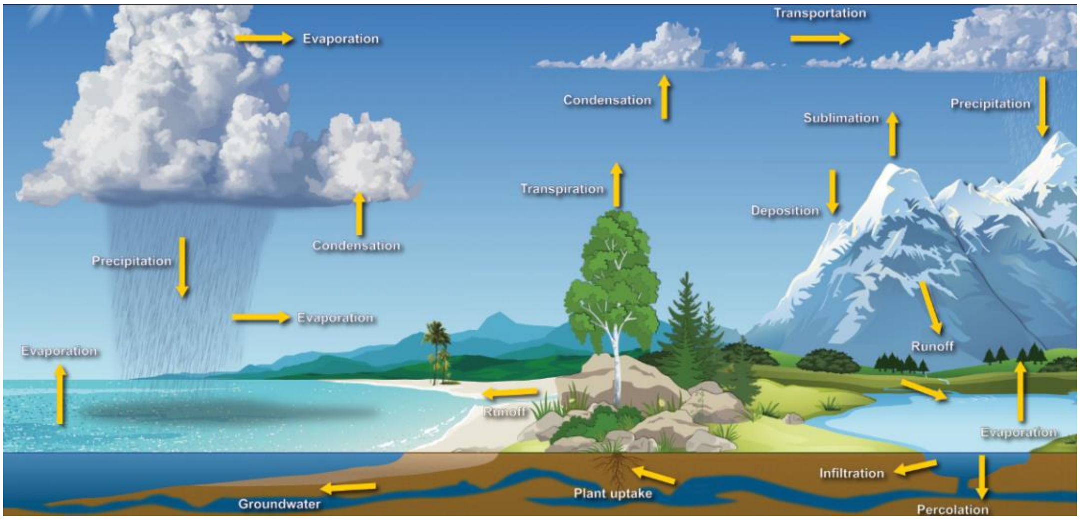


Figure 5. Water cycle diagram. Hydrologic models' main objective is to simulate the processes of the water cycle. Source: (NOAA, 2019).

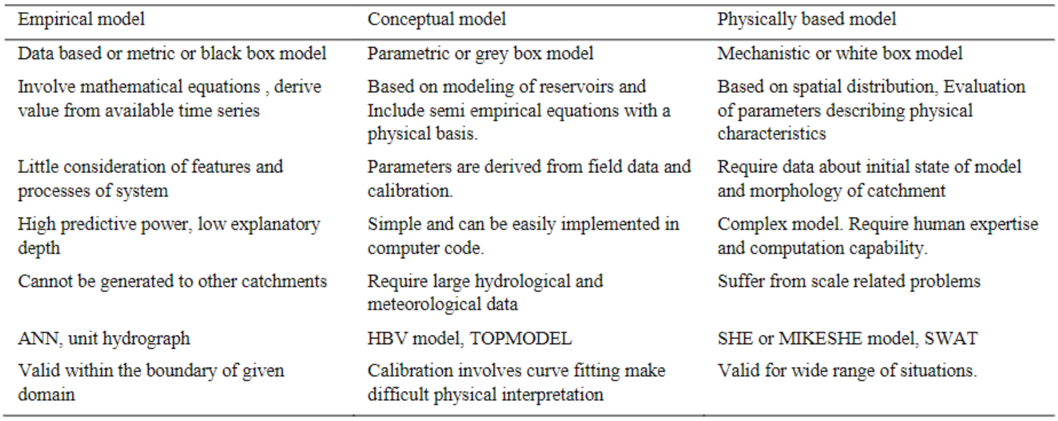
The hydrologic models can be classified in different ways according to different factors such as the inputs for the model and the parameters as well as the physical principles involved in them (Gayathri, et al., 2015). Based on this, one of the main model classifications derives from parameters such as time and space, where both are equally important to the model. Regarding the time, the model can be classified as *Discrete* or *Continuous*. A *Distributed* model is the one that takes in consideration special derivatives, while the model that does not is called a *Lumped* model, by taking in consideration space derivatives; a distributed model can make predictions distributed in space by dividing the catchment producing a spatial variable output, while the Lumped model produces one single unit output. In nature, the hydrologic processes develop in a distributed way, as they usually vary between time and space (Mujumdar & Kumar, 2012).

Another of the more common classifications in which models can be dived is depending on the physical explanation and detail in the model, having commonly three categories: *Empirical*, *Conceptual*, and *Physically-based* model. According to Gayathri, et al. (2015) this classification is one of the most important and can be described broadly as follow.

An Empirical model is the one that depends mainly on the data and information like meteorological and statistical data, not takin into account features of the hydrological process. This type of model is based on equations, mathematical calculations, and statistical methods.

The Conceptual model represents the hydrological processes shaped in reservoirs or schematically boxes. These boxes contain elements of the process and the interaction and interconnections between them. By this, we can have for example in a first reservoir the precipitation and runoff connected to the second which could be the flow in the soil by the saturated zone, finally, a third reservoir that would exemplify the groundwater.

A Physically-based model, as its name shows, is the model that resembles more closely the physical processes of the real phenomena. These models need a larger amount of data involving the parameter that describe the physical characteristics of the catchment. With this additional data and physical processes approximation, allow this type of model to have a certain advantage over the other two types in certain aspects.



Empirical model	Conceptual model	Physically based model
Data based or metric or black box model	Parametric or grey box model	Mechanistic or white box model
Involve mathematical equations , derive value from available time series	Based on modeling of reservoirs and Include semi empirical equations with a physical basis.	Based on spatial distribution, Evaluation of parameters describing physical characteristics
Little consideration of features and processes of system	Parameters are derived from field data and calibration.	Require data about initial state of model and morphology of catchment
High predictive power, low explanatory depth	Simple and can be easily implemented in computer code.	Complex model. Require human expertise and computation capability.
Cannot be generated to other catchments	Require large hydrological and meteorological data	Suffer from scale related problems
ANN, unit hydrograph	HBV model, TOPMODEL	SHE or MIKESHE model, SWAT
Valid within the boundary of given domain	Calibration involves curve fitting make difficult physical interpretation	Valid for wide range of situations.

Figure 6. Models Classification. Source: (Gayathri, et al., 2015).

As stated at the beginning of this project, the software used was MIKE SHE which incorporates in its framework the MIKE HYDRO River module for modeling river networks. MIKE SHE, can be used to generate physically-based models, as seen in figure 7. This modeling system was developed by DHI. It provides a flexible framework, including the major processes of the hydrologic cycle, being represented in a distributed space and with different degree of complexity, depending on the type and objective of the study, as well as to the availability of data and information, (Graham & Butts, 2006). MIKE HYDRO River is contained within MIKE SHE and allows the creation of physical and conceptual models able to simulate the flow in a channel or rivers. A characteristic of MIKE HYDRO River is the capability to couple with MIKE SHE hydrological modeling system to model the entire catchment in later studies, (Graham & Butts, 2006). For this project, the models were made using the MIKE HYDRO software, which is presented in the next section.

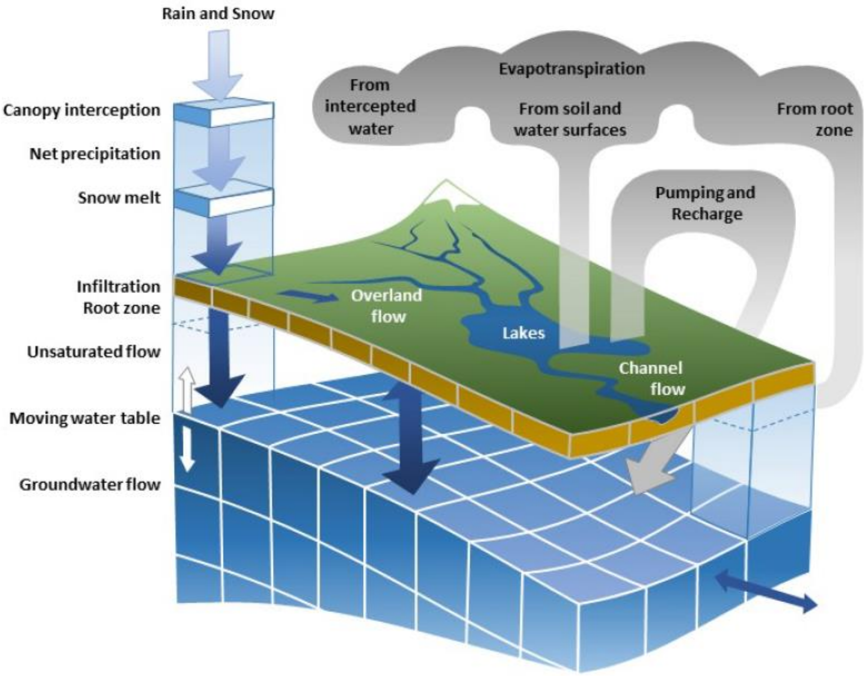


Figure 7. Simulation of Hydrologic Process by MIKE SHE source: (DHI, 2017).

3.3 MIKE HYDRO

MIKE HYDRO is a river and catchment modeling package, which allows us to create and analyze a river model, including the capability to analyze the river hydraulics, water quality, flooding, and even the dynamics and runoff characteristics of an entire catchment. MIKE HYDRO consists of a rainfall-runoff modeling component, MIKE HYDRO Basin, and a river modeling component MIKE HYDRO River, MIKE HYDRO River, previously known as MIKE 11, represents rivers and channels in one dimension, (DHI, n.d.). As described above, MIKE HYDRO River models can be integrated easily into MIKE SHE.

To create a model with MIKE HYDRO, being a physically-based model, needs physical information, such as the DEM of the area, river path and branches, cross-section profiles, and bed resistance and boundary conditions, with data such as water level time series, and discharge. All this data was gathered and introduced to create the model of the river basin section for this study. Once the model was built is possible to run simulations to study the properties of the river.

Much of this data is collected and introduced from different sources, but also the software allows us to generate some data such as cross-sections and branch paths from the DEM input, still it is also possible to these data from different programs.

3.4 Actual and Old Riverbed shape differences

While meanders and the riverbed shape may change with the time naturally (Kline, n.d.), its common that nowadays most of the alterations that are present in the rivers are mainly caused by human interaction or human-made. This is the case of some sections of the Kävlinge river as mentioned before, wherein the pursuit of improving the agricultural capabilities of the land along the river, the river was straightened and its depth increased in certain sections.

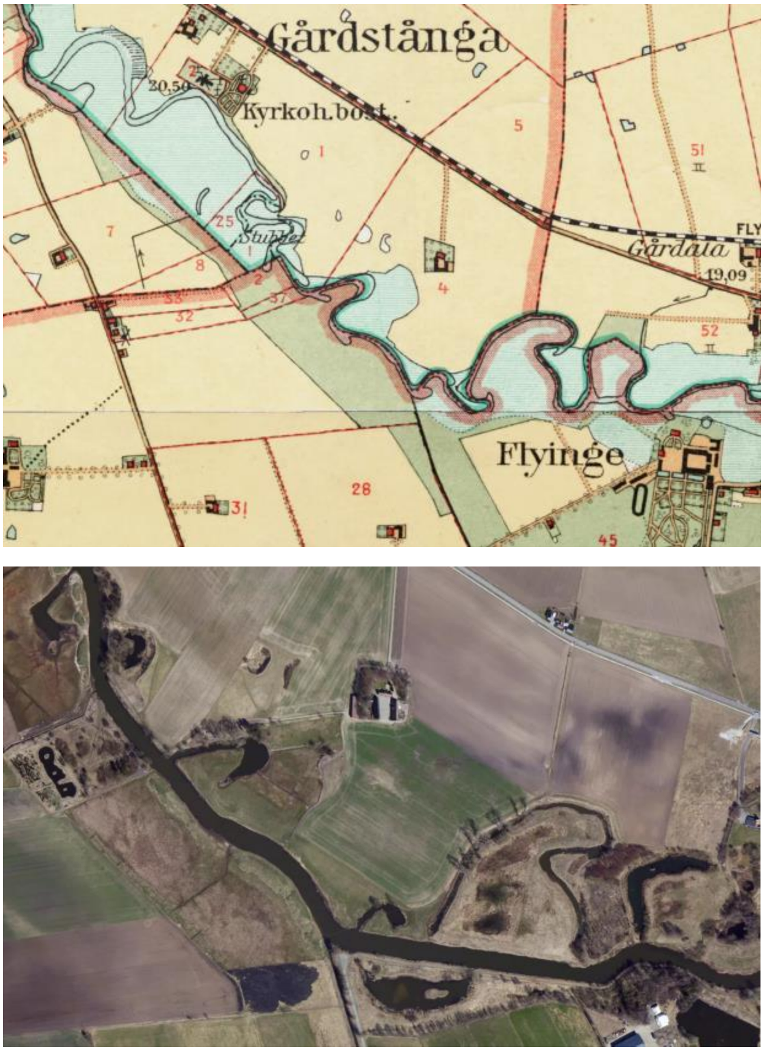


Figure 8. Straightened section of Kävlinge River near Flyinge, comparison of actual river and old river shape. Source: Lantmäteriet and Vattenatlas.

For this, it was necessary to build two models to make a comparison of the effects of these alterations, where the only variable would be the shape of the river and therefore the length of the river would also change, having an increase due to the integration of the lost meanders.

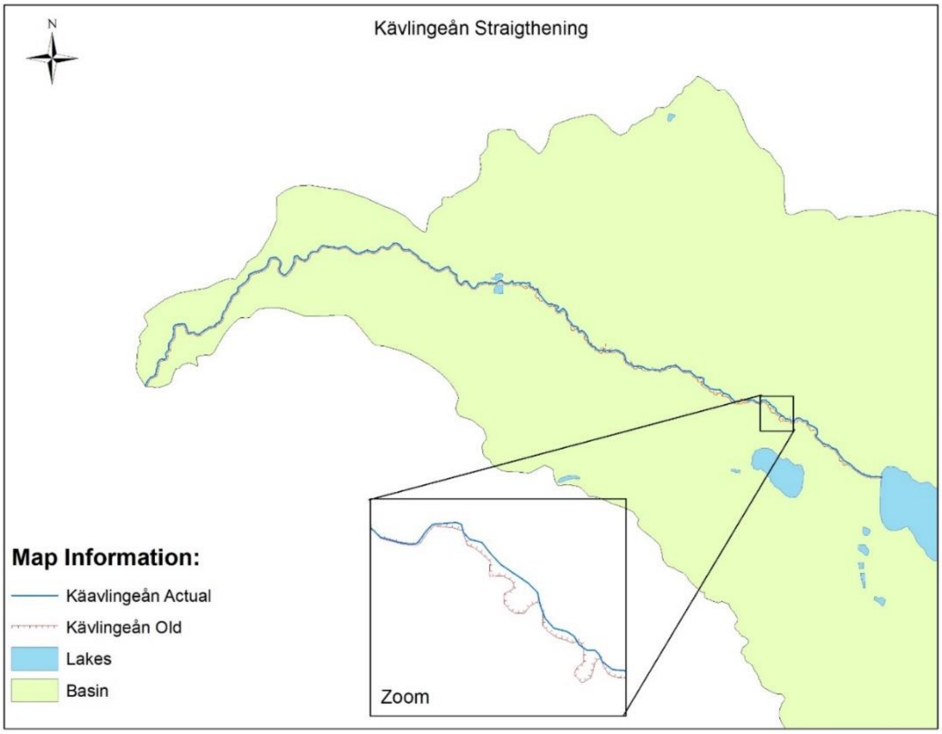


Figure 9. Map illustrating the difference of the riverbed shape after the straightening of some sections.

From fig. 9 it can be appreciated the difference in the path between the old river, generated based on a historical map from 1915, and the actual river shape. This same can be appreciated more in detail in fig.8. The presence of the meander increases the total length of the river as shown in Table 3, taking into consideration only the study area from Vomb lake discharge to the sea.

Table 3. Length difference between the old and actual river shape due to meanders. Source: Table elaborated by the author with SMHI data

		Length (m)
Actual River		48854.46
Old River		56102.48
	Difference	7248.02
	Increase (%)	15%

3.5 River Branches and Cross-Sections

By introducing cross-sections obtained from field studies provide a more accurate description of the terrain in comparison to the DEM generated cross-section. For this project the DEM was acquired from Lantmäteriet, obtaining a terrain model in grid form with a resolution of 2 m. This data was collected from aerial laser scanning. This data then is delivered regarding the SWREF99 TM projection system and a height system of RH 2000, which are the standard for Swedish data.

While using the cross-section generating tool from MIKE HYDRO using the DEM, it was noticed that the elevation model couldn't reflect in a precise way the river bed, as across the width of the river this showed a constant flat height, corresponding to the river level at the time of measurement.

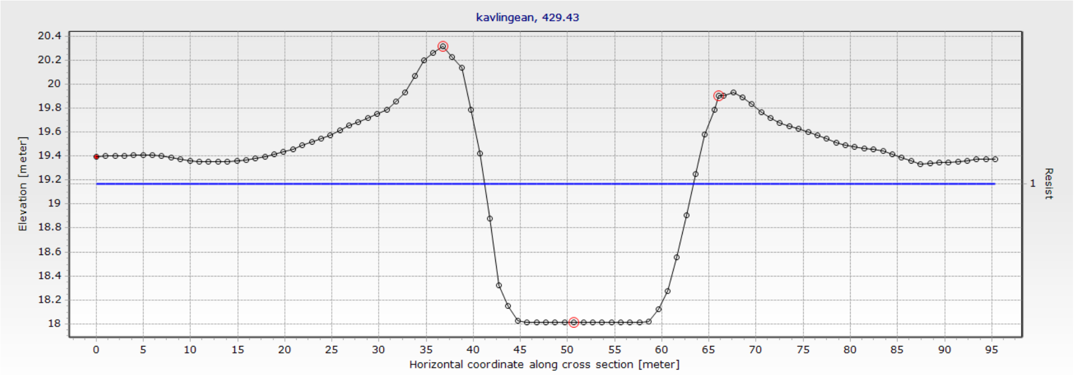


Figure 10. Cross-section generation by DEM in MKE HYDRO. (blue line belong to the resistance, not the water table) Source: author creation with data from Lantmäeteriet.

For a more accurate model, we looked for other data available about the Kävlinge River. This was possible thanks to Erik Bergman from

Fiskevårdsteknik AB, that provided an HEC-RAS model used for a study made in the river by the students in that time Josefin Tollgren and Julia Walldén, which contain cross-sections where some were retrieved in the field by using sonar to position vertical points via GPS and interpolate this data to shape in a more precise way the bottom of the river (Tollgren, 2017). This data was able to be translated for the MIKE HYDRO model by taking the elevation values, the coordinates and the distance in the x-axis, from this a new profile for cross-sections it could notice the difference in the depth of the river bed between the profile generated by the DEM tool, and the ones obtained from the HEC-RAS model.

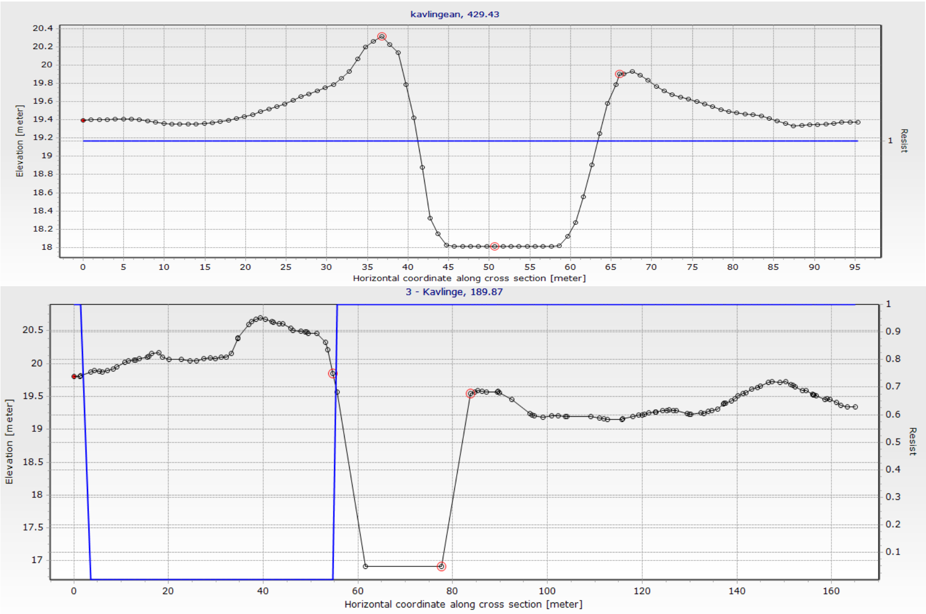


Figure 11. Comparison of cross-sections, top image cross-section generated by DEM. Bottom image cross-section obtained from the previous study. Source: author creation with data from (Tollgren, 2017).

From figure 11 it can be appreciated a difference in the depth of the channel around one meter, as from the first profile (DEM tool generated) the elevation at the water channel was of 18 meters, in the second profile, extracted from the HEC-RAS model obtained from a previous study, it marked an elevation of less than 17 m in sections downstream, immediately before the Vomb lake. These disparities continue between the profiles along all the river, therefore the decision of using the extracted profiles. As an additional analysis, the model would be created for both types of profiles of cross-sections, a model using the interpolated cross-section from the HEC-Ras model, and another using the cross-sections created by the DEM tool from MIKE HYDRO.

Besides the creation of the models using the interpolated cross-section from HEC-RAS, two more models were created to provide a comparison point for sensitivity analysis in the use of external data into the model, and by having in consideration the proper difference between this to types of input data.

The hydrological network was obtained from the database of the SMHI, this network contains all the streams and branches registered by the Institute, from this network the Kävlinge river was extracted and introduced in the model. MIKE HYDRO, provides the option of tracing the river with a tool, using the DEM layer information. However, it was decided to use the shapefile obtained from the SMHI, as this file may be more true to the actual river shape after its modifications. The river generated by the DEM tool may give an incorrect path of the river, as some meander traces work as ponds and wetlands but aren’t part anymore of the channel and that may be taken into consideration by the tool.

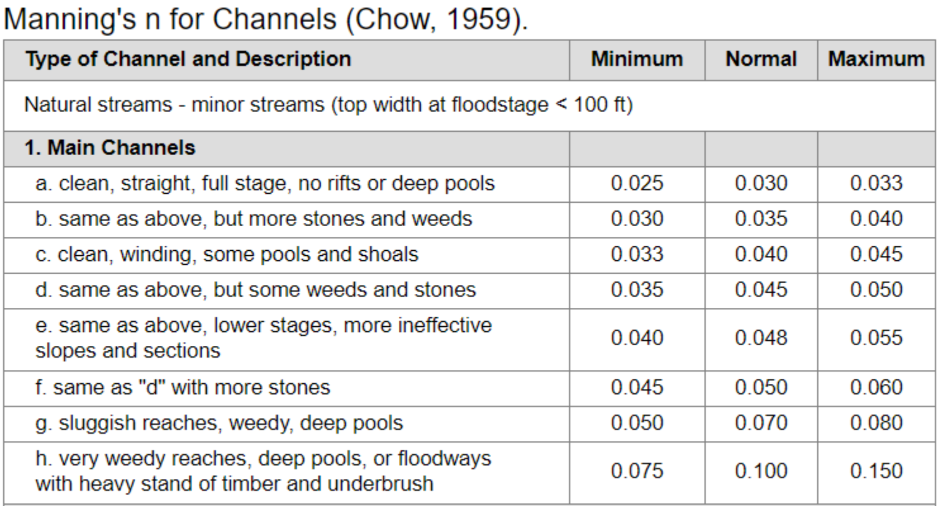
For the amount workload and time reasons, this model focused mainly on the Kävlinge river. Consequently, it was only the cross-sections from this river was retrieved, while in the model the Bråån and Klingavälsån river were introduced, they only worked as routing branches in the model not requiring the input of cross-section for them. By having these branches working as a routing type, the only data required for the model was the input of the time series containing the discharge data, obtained from the SMHI.

Besides the input data, it was also considered to have some data that would help to calibrate the model. As mentioned in the data collection section, time-series information was retrieved for the Högsmölla station, which is the closest station to the sea, therefore would be the one that could give the closed measure to the total outflow that would reach to Öresund, this data comprehend the water level measured at the station and the discharge at the same location.

3.6 Hydrodynamic Parameters

The model also requires the input of hydrodynamic parameters such as bed resistance. We can define the roughness of the river bed, by a coefficient, and MIKE HYDRO River allows us to introduce different coefficients such as the Manning coefficient (M,n), Chézy (C) and Darcy-Weisbach (k), having the possibility to work with different methods or equations according to our requirement and preferences and the data available.

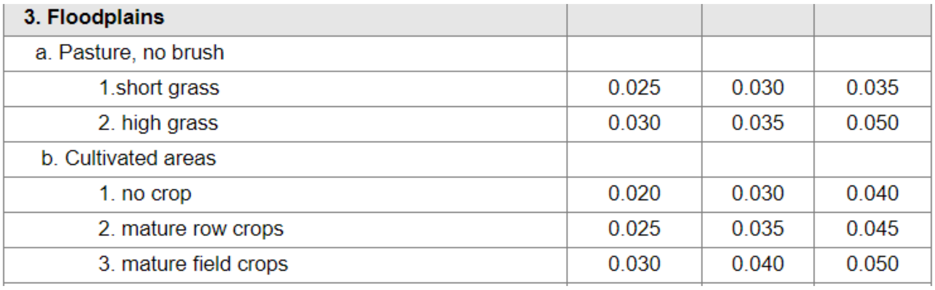
For this model, a global bed resistance parameter was introduced using the Manning coefficient of (n), the value for this coefficient was decided to be between the range of n=0.025 to n=0.045, as it was not possible to make a field study to obtain a particular value. This range for the coefficient was taken according to the Ven Te Chow tables (Fig. 12 & 13) from the book Hydraulic for Open Channels (Chow, 1959).



Manning's n for Channels (Chow, 1959).

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Figure 12. Image of tables with common Manning coefficients for bed resistance. Source: Image obtained from (FishXing, 2006).



3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050

Figure 13. Image of tables with common Manning coefficients for bed resistance. Source: Image obtained from (FishXing, 2006).

3.7 Boundary conditions

The model hydrological model requires the input of data that would represent the boundary conditions. These conditions can be as simple as an open or a closed boundary, this allows us to define if there is an upstream or downstream connection to the branch or river. In the case of having open boundaries, the type of boundary and characteristics for each one must be defined.

For this project all the boundaries are open, and by these, it is required to define the type of each one, as each one required different data from a list that includes, Water Level, Discharge, Q/h relation, Free outflow, Rainfall, Evaporation, and Runoff. From the data that it was able to retrieve, this model is using a discharge boundary for each branch connection to the river Kävlinge (Bråån, Klingavälsån and lake Vomb) and a water level type the furthest downstream, where the river ends and connects with Öresund.

For the discharge boundaries, it was established a time-varying constant represented by the time series data collected from SMHI, and for the Sea boundary, it was used a constant sea level of 0,1 to simplify the model.

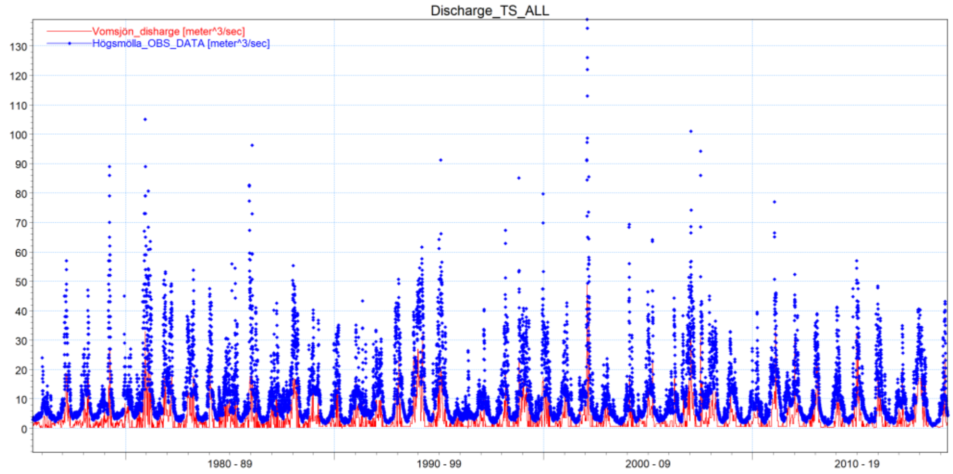


Figure 14. Graph illustrating the time discharge time series used for the boundary conditions. Source: author creation with data from SMHI.

3.8 Calibration

Once having all the required data for creating the model it was all congregated in the MIKE HYDRO mode, a simple model of the river Kävlinge, this model was run in the first attempt for a period that goes from 01/01/1993 to the 01/01/2019, beside of having data from 1975, this in an attempt to reduce the workload and time requires for the simulation. For the boundary conditions, it was only considered the discharge from the Vomb lake, from Bråån river, and Klingavälsån.

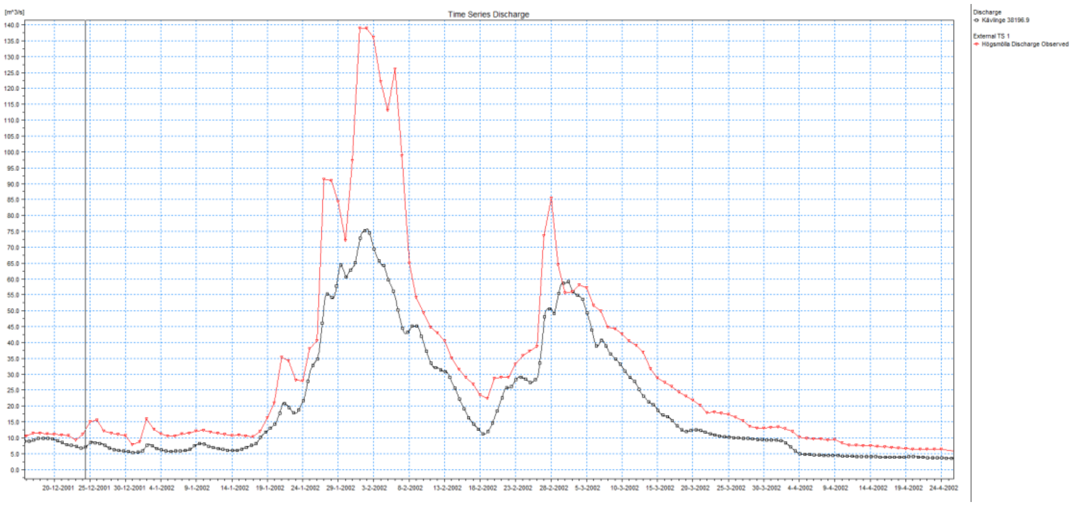


Figure 15. Discharge comparison at Högsmölla station, simulated data (black line) against the observed data (red line) after the first simulation. Source: author creation with data from SMHI.

As it could be appreciated on figure 15, the first simulation run demonstrates that there is a high correlation of the values, still, the observed discharge data at Högsmölla present considerable differences mostly at its peaks; from this, it was assumed and as it can be expected, there are inflows which this model is not taking in account, as they are small tributaries and the recompilation of discharge data from them is more complicated to achieve or inexistent unless it is done in a field study. This correlation was checked by using the R factor, this data is provided by the software. That according to it the model had a correlation coefficient of R^2 =0.96, this analysis was later recalculated in excel by analysis the observed data obtained from Högsmolla against the data obtained. This analysis can be found in appendix 8.2.

To try to cover this gap, it was considered two options, performing and regression and correlation analysis between each branch, and it influences observed discharge and increasing the inflow from the branch with the higher correlation over the observed data. The other option and in a certain way the most straight forward was creating a new time series by calculating the difference between the sum of the inflows from Vomb, Bråån, and Klingavälsan against the observed outflow at Högsmölla, and introduced this time series as a correction factor time series.

All the analyses were done to improve the fit of the model are present in appendix 8, as it was done one analysis to show which branch has a higher correlation over the river Kävlinge if in a future is decided only to introduce correction factors in one branch. However, the creation of a new time series to use it as a correction discharge was created to simplify the process and suited more while looking for a simpler model for a first approach. After this correction discharge, the model presented a higher quality index with an $R^2 = 0.99$. which can also be observed in appendix 8.2.

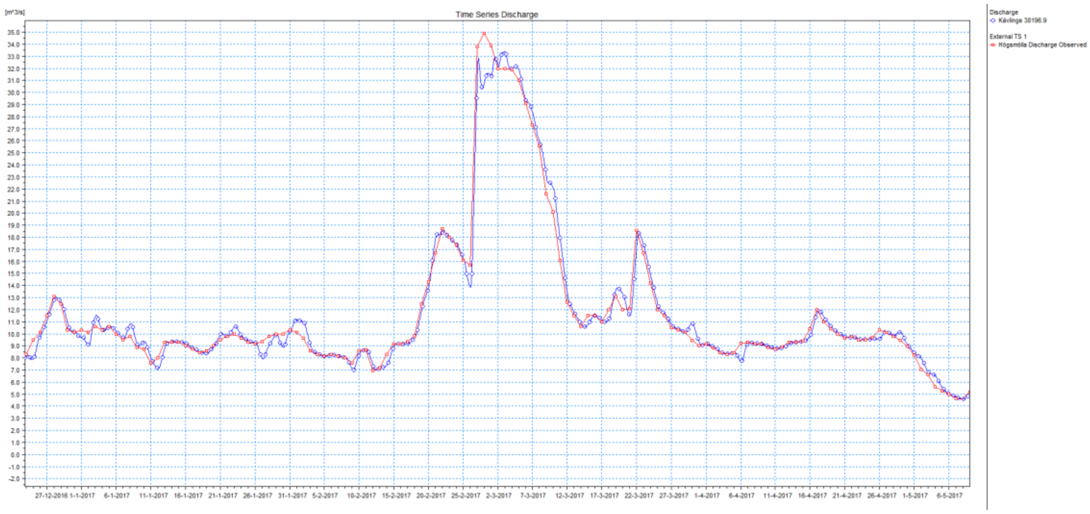


Figure 16. Comparison of the simulated discharge at the Högsmölla locations (blue line) against the observed data time series (red line). Source: author creation with data from SMHI.

To have a better fit between the two-time series it was also needed to use adjust the bed resistance coefficient between the range exposed previously in an attempt to reduce or reduce the delay of the peak depending on what it is needed, reaching the best fit with a Manning coefficient of n=0.033 (≈ M=30).

From this calibration results, it was possible to create two models to fulfill the aim of this thesis project, the analysis of effects from the alteration of the geomorphology of the Kävlinge river over the flooding in the surrounding areas.

4. Results

Table 4. Result main from first simulations

Model	**Simulation attempt #**	**Period of simulation**	**Sim. Max. WL @Högsmölla (m)**	**Obs. WL**	**Sim. Max. Disch. @Högsmölla (m3/s)**	**Obs. Disch**	**Observations**	**Parameter modified**
Actual River	1	01/06/2013 to 30/05/2014	4.75	**2.97**	50	**41.25**	Discharge with low correlation , error in the Time series file	Time series observed data corrected
Actual River	2	01/06/2013 to 31/05/2014	3.4	**2.4**	48	**61.3**	Hot start file, steady state run	
Actual River	3	05/06/1993 to 01/01/2019	4.9	**3.42**	75	**139**		
Actual River	4	01/06/1990 to 09/10/2018	4.5	**2.85**	138.5	**139**	Discharged results similar	introduced a correction discharge time series.
Actual River	5	01/06/1990 to 09/10/2018	3.82	**2.85**	79.5	**139**	Reduction of sim. Period for fater run	Bed Resistance n=0.02
Actual River	6	01/06/1990 to 09/10/2018	3.92	**2.85**	138.5	**139**		Bed Resistance n=0.03
Actual River	7	01/06/1990 to 09/10/2018	4.65	**2.85**	138.46	**139**		Bed Resistance n=0.033

As seen in Table 4, the first two simulations present higher discrepancies over the simulated result data and the observed data, these errors were in part originated from the time series data, as there were some missed values. For this, the data were inspected in detail and it was selected a period to work were all series have complete data. In simulation 3 the correlation of the data increased against the observed, but there the differences in the peaks mostly in the discharge, were relevant, having a simulated result of 75 m3/s, against the observed data of 139 m3/s. This difference can be explained mainly by the lack of data from other discharge points that contribute to the total flow over the river. As mentioned in the section 2.2 Data Collection, at this moment we are working with only two branches that are connected to the river, and the discharge information from the Vomb lake upstream, and which are also the only tributaries with data available. It was needed to introduce a correction time series to fill this lack of data.

Once those adjustments were done, the next simulations fitted better, simulations 4 to 7 changes mainly depend on the bed resistance, affected by the Manning coefficient, taking as a guide the Ven Te Chow tables from Fig. 12 in section 3.4, from where it’s taken the range from n=0.025 to 0.45, the models are run, comparing the results between them and the observed value at Högsmölla, as shown in the next figure, Fig. 17.

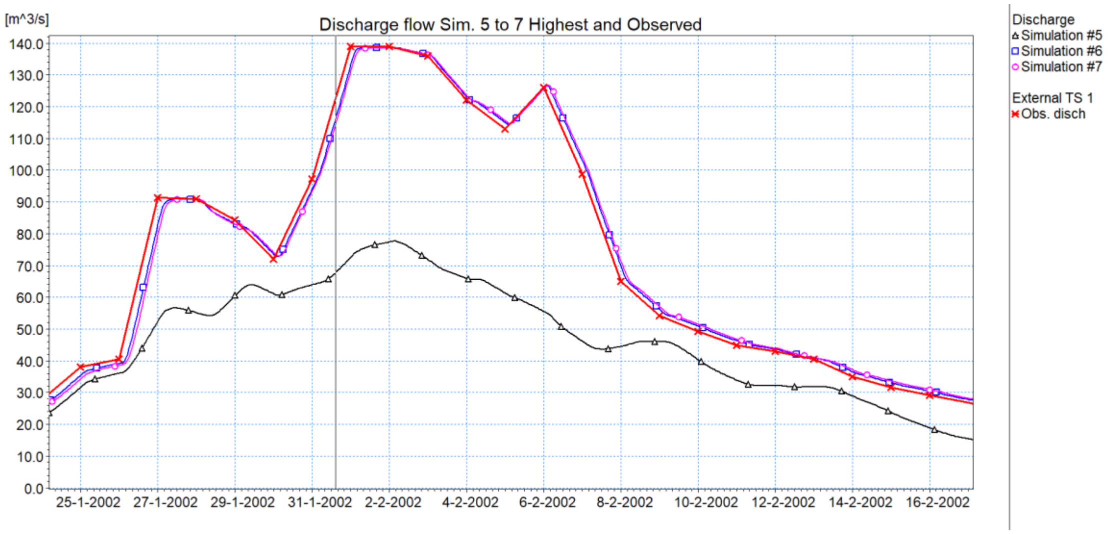


Figure 17. Simulation result time series 4 to 7, Maximum peak discharge. Source: Author creation with SMHI data.

Using the Högsmölla time series observed data on the highest peak present on the 2nd of February 2002, it can be observed the similarity and correlation between the simulated data from simulations (Fig,17) 6 and 7 (lines blue and pink) with the observed data from Högsmölla (red line).

These simulations represent the highest peak from the time series data available, using Fig. 18, it can be observed that the highest peak is in the year 2002, with a considerable difference to the next hight peak in the year 1980 of 105 m^3/s, having a difference above 30 m^3/s. A reason for taking this particular date is because by using this maximum peak it would be more perceptible the effects over the floods by the meanders, also considering in the future the effects of the climate changes which may increase the presence of extreme events like this one.

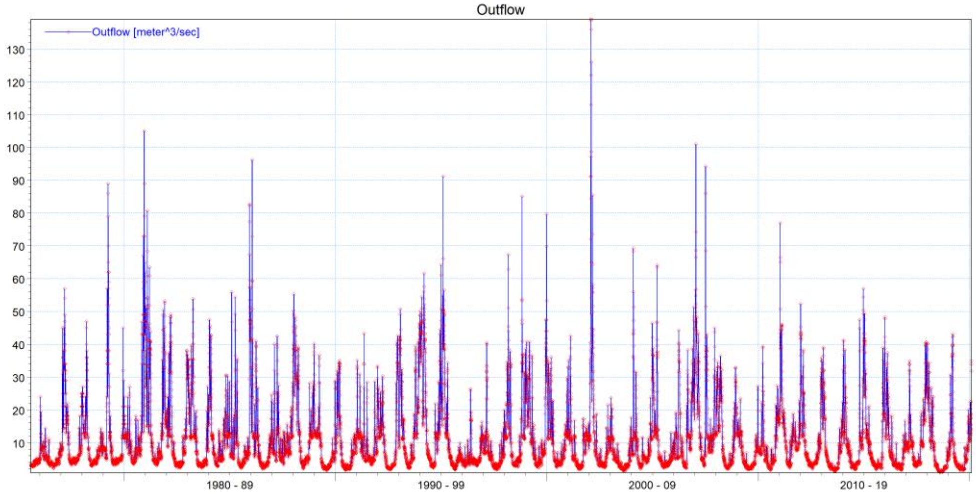


Figure 18. Observed discharged at Högsmölla, with the highest peak at the beginnings of the year 2002. Source: Authors own elaboration using data from SMHI.

While the simulation results for discharge reach a close approximation to the observed data, as been noted in table 4 and can be observed in Fig. 19, the discrepancies between each simulation results and as well with the observed water lever data from Hösmölla are higher. Considering the difference between the average of the simulation peaks against the observed data is around 1.26 m which can be considered as a considerable amount. These differences between the results and the observed data may be related mostly to a references system use, as when the data was retrieved it the SMHI warned that the data didn't have the datum specification to let us know if the station had old local hight reference system, which is probable; after taking in consideration this possible difference in the reference system, the Observed was modified by introducing a correction factor to compensate this difference.

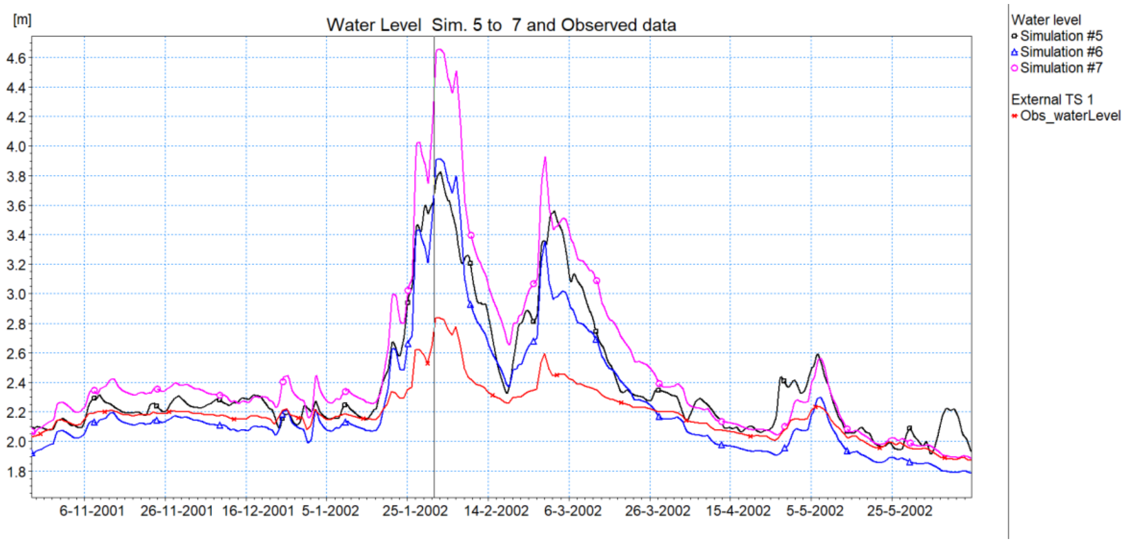
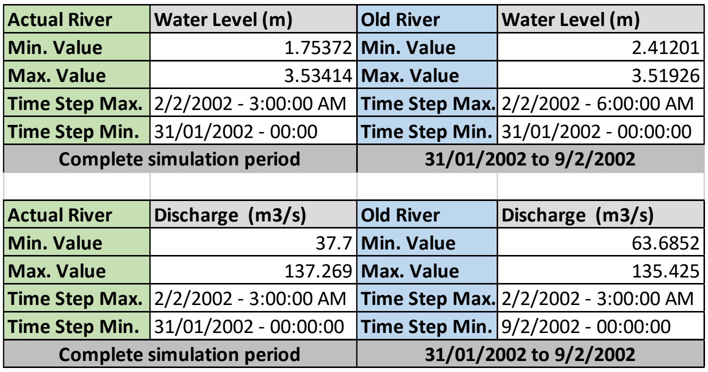


Figure 19. Water lever results from a comparison against observed time series at Högsmölla, with the highest peak in the year 2002. Source: Author creation with information from SMHI.

Once having the results of this simulation, the data was used to run new simulations between a shorter period, focused mainly in the year 2002, as this has the highest peak from as mentioned before, and besides this, the following simulations were done looking for dynamic results and the creation of the flooding maps for further analysis.

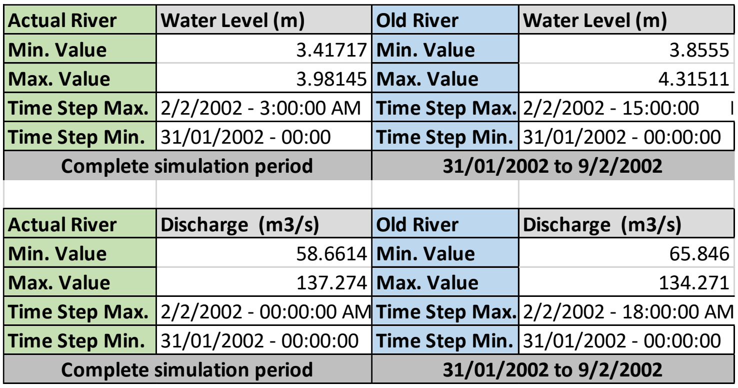
Table 5. Dynamic simulation results model using Interpolated cross-sections Source: Authors creation



Actual River	Water Level (m)	Old River	Water Level (m)
Min. Value	1.75372	Min. Value	2.41201
Max. Value	3.53414	Max. Value	3.51926
Time Step Max.	2/2/2002 - 3:00:00 AM	Time Step Max.	2/2/2002 - 6:00:00 AM
Time Step Min.	31/01/2002 - 00:00	Time Step Min.	31/01/2002 - 00:00:00
Complete simulation period		31/01/2002 to 9/2/2002	

Actual River	Discharge (m3/s)	Old River	Discharge (m3/s)
Min. Value	37.7	Min. Value	63.6852
Max. Value	137.269	Max. Value	135.425
Time Step Max.	2/2/2002 - 3:00:00 AM	Time Step Max.	2/2/2002 - 3:00:00 AM
Time Step Min.	31/01/2002 - 00:00:00	Time Step Min.	9/2/2002 - 00:00:00
Complete simulation period		31/01/2002 to 9/2/2002	

Table 6. Dynamic simulation results model using DEM generated cross-sections Source: Authors creation



Actual River	Water Level (m)	Old River	Water Level (m)
Min. Value	3.41717	Min. Value	3.8555
Max. Value	3.98145	Max. Value	4.31511
Time Step Max.	2/2/2002 - 3:00:00 AM	Time Step Max.	2/2/2002 - 15:00:00
Time Step Min.	31/01/2002 - 00:00	Time Step Min.	31/01/2002 - 00:00:00
Complete simulation period		31/01/2002 to 9/2/2002	

Actual River	Discharge (m3/s)	Old River	Discharge (m3/s)
Min. Value	58.6614	Min. Value	65.846
Max. Value	137.274	Max. Value	134.271
Time Step Max.	2/2/2002 - 00:00:00 AM	Time Step Max.	2/2/2002 - 18:00:00 AM
Time Step Min.	31/01/2002 - 00:00:00	Time Step Min.	31/01/2002 - 00:00:00
Complete simulation period		31/01/2002 to 9/2/2002	

Table 5, present further simulations done to generate maps that represent the flooded areas along the river and the depth, with this, it is possible to compare and analyze the effects of the straightening of the river between the actual river and the old river shape obtained from a historic map from 1915, the data, as well as the first simulation, was taken in the location of the Högsmölla station.

At the same time, we consider to make a simulation to corroborate the effects of using the Interpolated cross-sections, by running another model making use of the MIKE HYDRO tool for creating cross-section from the DEM, as in a certain way depending on the data availability and time requirements using this tool may simplify the model to obtain some preliminary results that can motivate a further study more detailed, which could require the field measurements, this will also help to analyze the sensitivity of the model towards the cross-sections type. The results of the water level and discharge peaks can be observed in table 6 and graphically on figures 22 and 23.

From Fig. 20 and 21 and Table 5, it can be appreciated a small difference in the water level and discharge, which can be related to the effect of the meanders. As presented in table 5, a difference of 2 cm to be specific, can be observed on 02/02/2002 in the water level, as well there is a delay when the water reaches this level of 3 hrs. In the same way, this tendency can be also appreciated in the discharge results presented in Fig. 21, while in the discharge case, the difference of measurements is more clear with a variation approximately of 2 m^3/s.

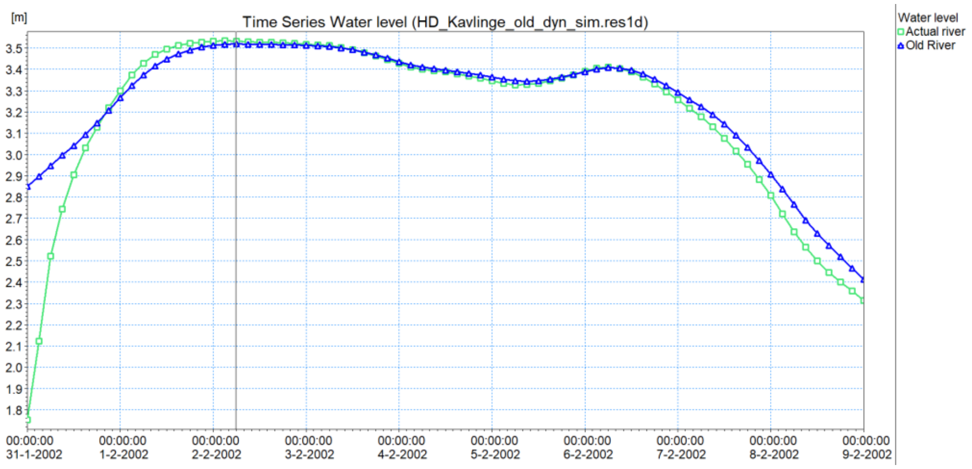


Figure 20. Water level differences between the actual river and old river simulations Interpolated cross-sections. Source: Author creation.

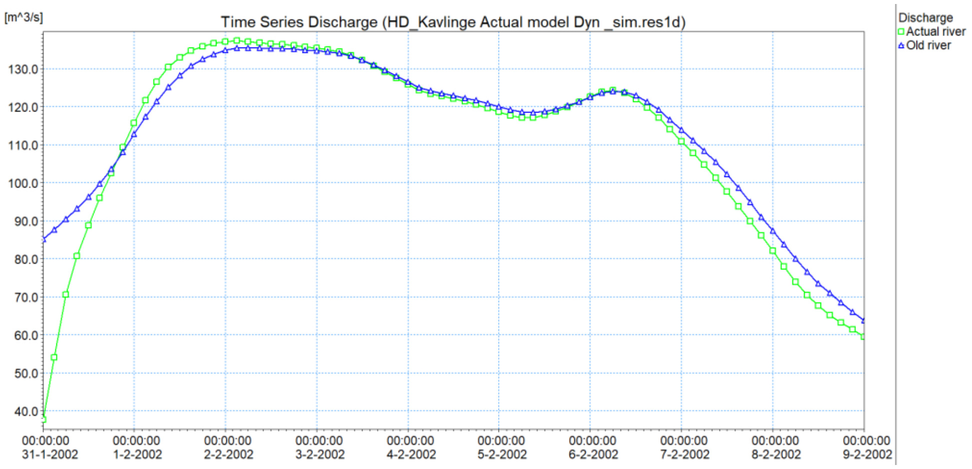


Figure 21. Discharge results from simulation carried out with Interpolated cross-sections. Source: Author's creation.

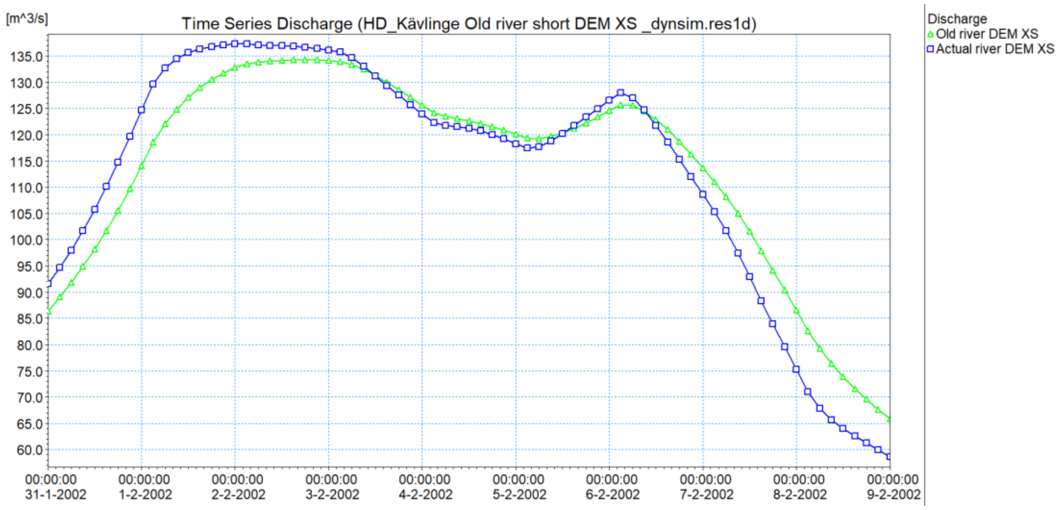


Figure 22. Discharge differences between the actual river and old river simulations DEM cross-sections. Source: Author creation.

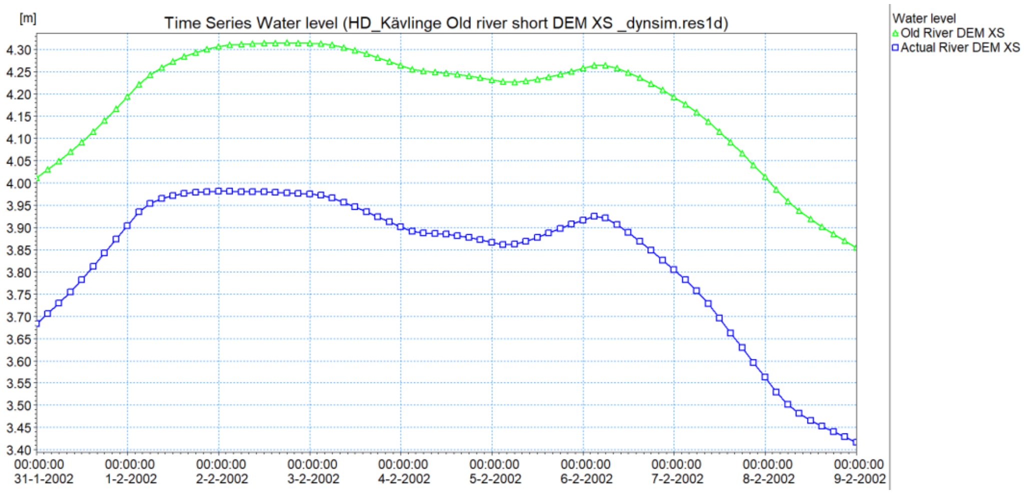


Figure 23. Water level differences between the actual river and old river simulations DEM cross-sections. Source: Author creation.

From previous figures, both models one with interpolated and another with DEM cross-sections, it is possible to notice in both results a subtle increase in the amplitude in the old river curve, which also is a reason of the decrease on the peak and in the valley presented in the figures, as mentioned in the section 3.3 the actual river suffered modifications like straightening and increase of the river depth of some section. The lost this meanders is translated in a decrease in the length of the river, therefore that in the figures 20 and 23, the water level curve from the actual river present a steeper increase and decrease, while in the old river the meander has an attenuation effect at the same time by having a long distance to travel a particle of water take more time to move from point A to B, this delay causes that locations downstream of the meanders have fewer probabilities of experiencing drastic fluvial floods in the case of an extreme precipitation event.

The effects of the meander in the floods downstream of this can be more easily related in Fig. 24 and 25, where it is presented the flood map of a section of the complete river. It is possible to appreciate the meanders lost in the actual river, fig. 26, in comparison to the old river fig. 27, located in the section comprehend between the Longitud 13°16’ E to 13°18’ E.

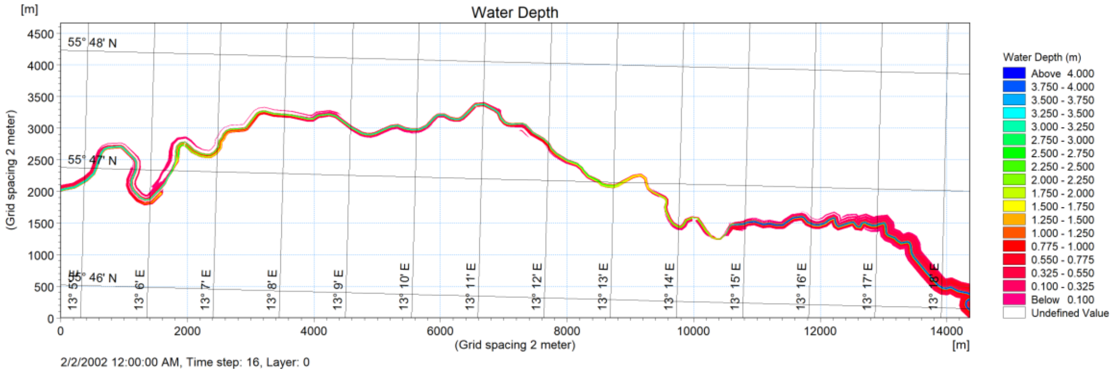


Figure 24. Flood simulation map and water depth in the actual river.   Source: Author's elaboration.

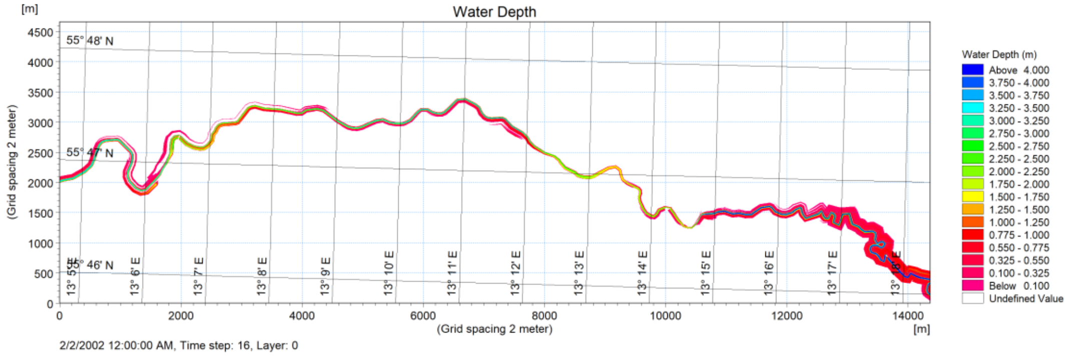


Figure 25. Flood simulation map and water depth in old river case. Source: Author's elaboration

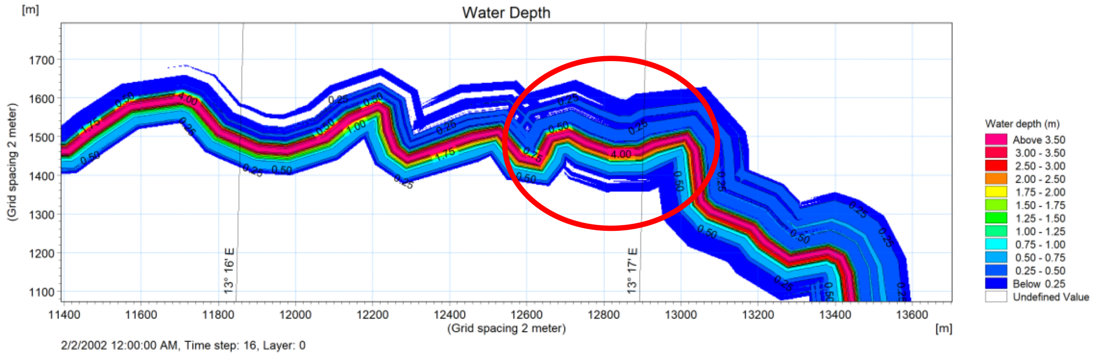


Figure 26. The straightened section in the actual river and water depth of flooded areas. source: Author's elaboration.

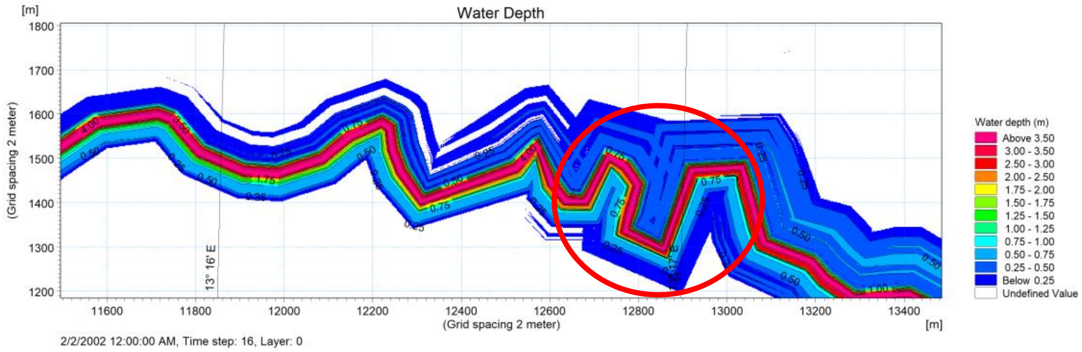


Figure 27. Meanders section in the old river and water depth in the flooded area. Source: Author's elaboration.

By focusing in the meander locations in both maps, Longitude 13°14’E 55°47’N to 13°18’E 55°46’N, it is possible to realize a more accurate comparison between the effects of the meanders in the flooded area and the water level in it; even if the differences are minimum it can be appreciated that the flooded area around the meanders (Fig. 27) is in a certain way larger than the flood are in that section of the actual river (Fig. 26)

The meanders on a river naturally formed flood plains, the increase in the length of the river in addition to the floodplain help mitigate the effects of flood in downstream areas, by this is expected that the water level and flooded area increase in areas around meanders.

To corroborate this results and at the same time to analyze the sensibility of the model towards the cross-sections implemented for the model two more simulation was conducted as presented in Table 6, these simulations were done using the same data and configuration, for an exception of the cross-section, which in this case they were generated by MIKE HYDRO using the DEM of the study area.

As seen in Table 6, there is a not notable difference between the old and actual river created, with a water level difference of 33 cm and 3 m^3/s in the discharge at the highest peak on 02/02/2002, as considered in the previous simulations.

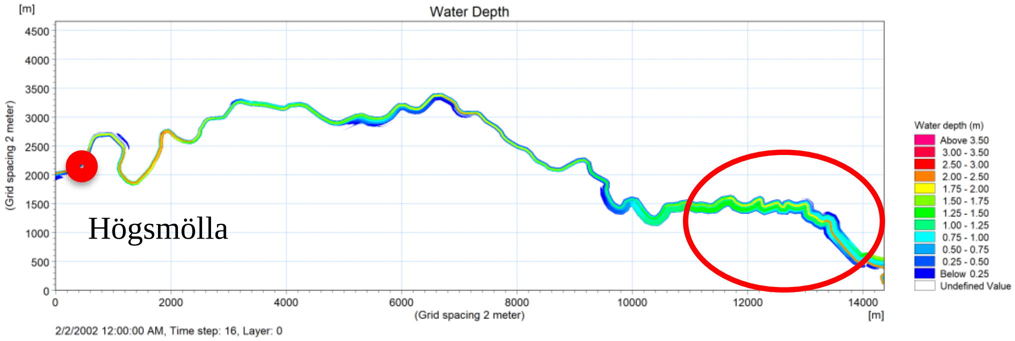


Figure 28. Map of flooding area in the actual river, peak flow 02/02/2002. Source: Author's elaboration.

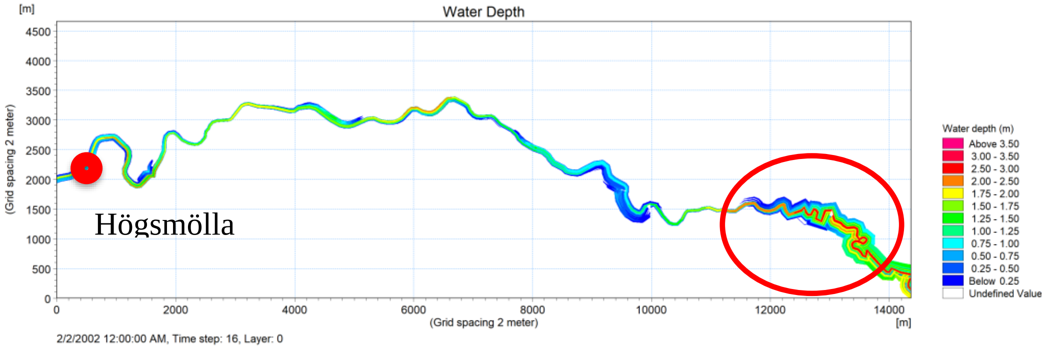


Figure 29. Map of flood areas in the old river, peak flow 02/02/2002 source: Author's elaboration.

Besides the results shown in Table 6, the comparison between Fig. 28 and 29, make more evident the difference in the water depth and the flooded area between the two models, the old river and the actual river. If we analyze the location where a section of the meander was straightened as in the previous models it is possible to appreciate a clearer image of the attenuation and flood mitigation effects the meander has on downstream river areas

In figures 30 and 31 we have an enhanced view of the flooding areas in the meanders and immediately downstream. The attenuation of the floods generated by the meander in the old river model is seen, as with the meander, the width of the flood plains in that section is around half of the current river. Either case Interpolated cross-sections and DEM generated, there is a tendency corroborating the mitigating effects of river meanders over floods, still, the difference is more evident in the DEM model simulation

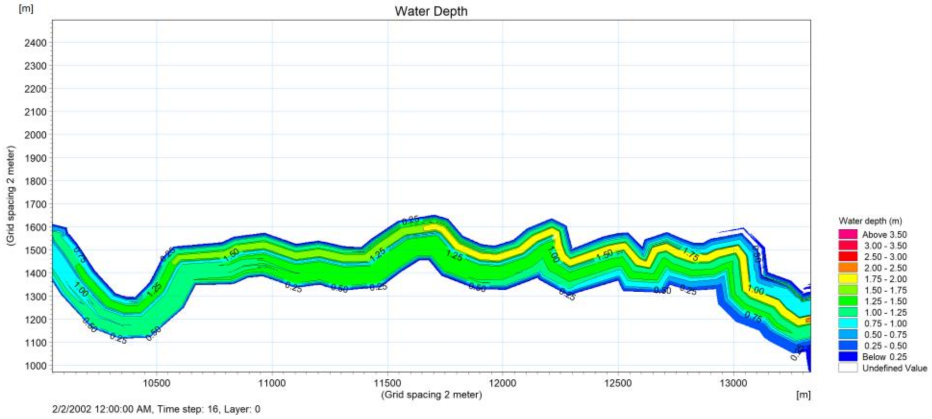


Figure 30. Flood area map (actual river), simulation model using DEM cross-sections. Source: Author's elaboration.

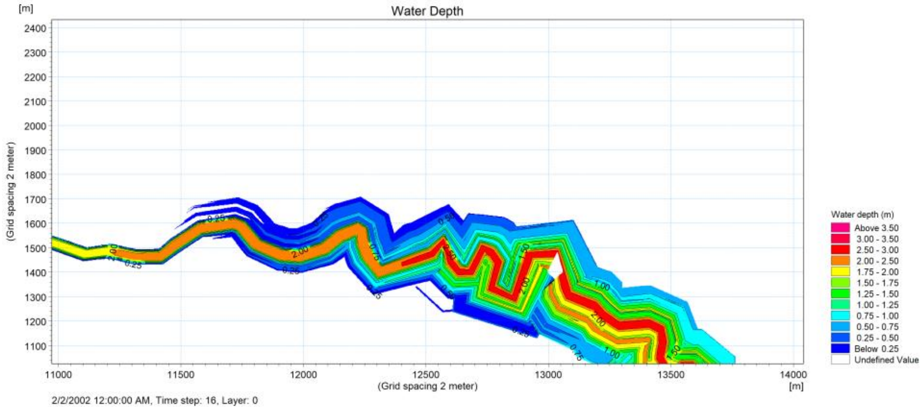


Figure 31. Flooded area map (old river), simulation model using DEM cross-sections. Source: Author’s elaboration

5. Discussion

After analyzing and reviewing the results and data in the simulations of all models, it was noticed that even while there is a difference between the models created with DEM cross-sections and Interpolated cross-sections from a previous study done, both cases point in the same direction, showing and decrease in the peak discharge as well as in the water level. The results also show the sensitivity of the models to characteristics like the cross-sections, while comparing the flood map of the old river in both models, there is a clear difference. This may be good to consider for further studies, considering obtaining their data from field studies and adapting them with the DEM tool.

For this it should be considered in a more detailed way, the introduction of external data, done by a third party, as we should take into considerations that this data may present a different configuration or features that in this project may have not been taken in considerations.

There were details such as the chainage order, or the position according to the river, as the cross-sections must be perpendicular to the river flow, which may have influenced the performance and the results of the model.

It is also relevant to mention that while simplifying the model, other factors may influence the results such as the presence of structures, such as dams and weirs that are present in the river, and that in a certain way have an influence over the hydrodynamics of the river.

5.1 Limitations

In the process of making this project, it comes in evidence different limitations that may be taken into consideration when analyzing this work, nevertheless, the results and overall data may help and be of use for further works and projects. In the beginning, the first stages of the project consist in data collection, the lack of some information that would be required for the creation of a detailed model was evident, as an example the cross-sections for the river, as there aren't official data from the official institutions, in this case, it was used data retrieved from a previous thesis project, while other was generated within the model.

In the same way data like the resistance coefficient for the riverbed were assumed from the literature review and then adjusted while doing the calibration of the model. Besides, the data collected regarding the inflow and outflow in the model may present a deviation from the real data as it was only possible to find time series from the larger branches leaving out different minor streams which lead to a difference in the water balance, In other to fill this gap it was introduced a correction factor. In this same matter from the data obtained from SMHI, it was informed that two stations ceased being part of their system since 2017 and by this, they couldn't assure the reliability of the date for the last couple of years.

6. Conclusions

The results obtained from the simulation on the two models created on MIKE HYDRO, allowed us in a certain way, to answer the research question established at the beginning of the project.

- *Do the alterations over the river geomorphology influence river floods in the Kävlinge River?*

  Yes, the results provide information that shows that in a certain amount the alterations have and effect over the fluvial floods in the river basin. In the studied area, the lost of the meanders represent a decrease over the river length of 15%, and this could also be translated to an increase over the water level and discharge, nevertheless, the increment is not that high, around 0.56% in the water lever and 1.35% for the discharge. While in the second model the discharge increment is about 2.18%
- *Are the effects consistent with the theoretical background?*

  The effects that the straightening of the river had over some parts of the river can be appreciated in the flood maps, where its possible to see an increase in the flooded area in the meanders allowing to have a decrease in the flood plains width and depth in sections downstream.
- *Can these alterations influence in case of future extreme weather events?*

  Will require more studies to be able to have a concrete answer to that question but is fairly to say that from the results obtained that by straightening the river, the hydrodynamics of the same change, having and effect over it flood plains and its capacity to attenuate fluvial floods.

By straightening the meanders there is a reduction in length around 15%, there would be an initial effect over the hydrodynamic as this would reduce the hydraulic gradient over the river. At the same time, by looking through the discharge graph (fig. 21) and the water level (fig. 20) the difference between the actual river and the old, is not as high as it was expected in the first instance, a difference of 0.02 meter can seem not significant but we also have to consider the length over the flood plains beside the river. In both simulations done with different cross-sections, the flood in the meander is increased.

The effect of the meanders allows that fluvial floods concentrate in the meander area, allowing that downstream the flood decrease considerably. For this case, this effect is better appreciated in the DEM cross-sections model, as it can be appreciated almost a constant width of the flooded area is about 150 m approximately along the section, while the same section in the old river the downstream part of the river the flood are width is around 60m.

Nevertheless, the data obtained present the effects that the loss of the meander had over the Kävlinge river and the surrounding areas against floods, and the increasing presence of extreme rainfall events as a result of the climate change effect may in a future lead to increasing threats of damages and complications to the communities and people that have direct interaction with the river.

After this analysis, it can be concluded that from the initial research question made at the beginning of this project is possible to say that the alterations made over the Kävlinge river, affected its capacity to mitigate floods, as the theory and other studies had shown according to the background. As the results in the models follow the same tendency over the models even changing variables as the cross-section, the project was able to answer this question.

Due to time limitations and other factors, it was not able to introduce a climate change factor to study the effect of this over the model, still by using a period with the highest historical values from the time series. Nevertheless, this could be done in a future study.

At the same time, these results incentive to make a study more in detail, as is the case of the Eco Diver project. This project can be used as a starting point for further works or studies, event while some complications and limitations were faced, by experiencing them, in this project it may lead to the acknowledge of them for future students and researchers that would work over this river.

The Kävlinge river relevance for the municipalities that interact with it is notable. It is not only important for leisure but also lays part in the economic development of the municipalities within the basin. However, in the search for economic growth, man-made alterations over the river have already caused environmental problems in the past. While the municipalities and different stakeholders take action to improve the water quality by creating ponds and wetlands, the increasing threat of extreme meteorological events from the climate change effects requires the increase in programs focused on taking preventive actions to mitigates the effects to these events like floods and droughts.

7. References

Bates, B., Kundzewicz, Z., Wu, S. & Palutikof, J., 2008. Climate Change and Water. In: *Technical Paper of the Intergovernmental Panel on Climate Change.* Geneva: IPCC Secretariat, p. 210 pp..

Chow, V. T., 1959. *Open-Channel Hydraulics.* n.d. ed. New York: McGraw Hill.

DHI, 2017. *User Marnual.* n.d.: DHI.

DHI, n.d. *MIKE Hydro River.* [Online]
Available at: https://www.mikepoweredbydhi.com/products/mike-hydro-river
[Accessed 14 May 2020].

Ekologgruppen i Landskrona AB, n.d.. *Kävlingeå-Projektet.* [Online]
Available at: http://www.kavlingeaprojektet.se/English_summary.htm
[Accessed 26 04 2020].

European Commission, n.d. *Causes of Climate Change.* [Online]
Available at: https://ec.europa.eu/clima/change/causes_en
[Accessed 23 04 2020].

European Commission, n.d. *Climate change consequences.* [Online]
Available at: https://ec.europa.eu/clima/change/consequences_en

[Accessed 23 04 2020].

FishXing, 2006. *Manning's n Values.* [Online]
Available at: http://www.fsl.orst.edu/geowater/FX3/help/FX3_Help.html
[Accessed 15 06 2020].

Gayathri, K. D., Ganasri, B. P. & Dwarakish, G. S., 2015. A Review on Hydrological Models. *INTERNATIONAL CONFERENCE ON WATER RESOURCES, COASTAL AND OCEAN ENGINEERING,* n.d.(4), pp. 1001-1007.

Gore, J. A. & Petts, G. E., 1989. *Alternatives in Regulated River Management.* n.d. ed. Boca Raton: CRC Press.

Graham, D. N. & Butts, M. B., 2006. Flexible, integrated watershed modelling with MIKE SHE. In: V. P. Singh & D. K. Frevert, eds. *Watershed Models.* Boca Raton: CRC Press, pp. 245-272.

Hernebring, C. et al., 2015. The cloudburst in Southwestern Scania 2014-08-31, with a focus on consequences and in relation to rainfall statistics in Malmö. *Journal of Water Management and Research,* Issue 2, pp. 85-99.

Hjorth, P., 1989. *Some Principles for Sustainable Management of Natural Resources.* Lund, Lewis Publishers.

Kävlingeåns Vattenråd, n.d.. *Om Kavlingean.* [Online]
Available at: http://www.kavlingean.se/OM-KAVLINGEAN.html
[Accessed 14 04 2019].

Kline, M., n.d. *Freedom to roam: How meandering rivers can decrease destructive flooding..* [Online]
Available at: https://anr.vermont.gov/node/1026
[Accessed 24 05 2020].

Mills, D., 1991. *Ecology and Management of Atlantic Salmon.* 1st ed. London: Chapman & Hall.

Mujumdar, P. & Kumar, N., 2012. *Floods in a Changing Climate: Hydrologic Modeling.* 1st ed. Cambridge: Cambridge University Press.

NOAA, 2019. *Water Cycle.* [Online]
Available at: https://www.noaa.gov/education/resource-collections/freshwater/water-cycle
[Accessed 20 05 2020].

Persson, M., 2019. *EnhanCing hydrODIVERsity for improving catchment based climate resilience (EcoDiver).* Lund: Lund University.

SCB, 2019. *Jordbruksmarkens användning 2019,* Stockholm: SCB.

Sydvatten AB, n.d.. *Vombsjön.* [Online]
Available at: https://sydvatten.se/vombsjon/
[Accessed 16 04 2020].

Tollgren, J. W. ,. J., 2017. *En flödesanalys för Kävlingeån - HEC-RAS modellering med fokus på dämmens inverkan,* Lund: Department of Building & Environmental Technology Lund University.

8. Appendix:

8.1 Correlation Analysis between the river branches and the observed data.

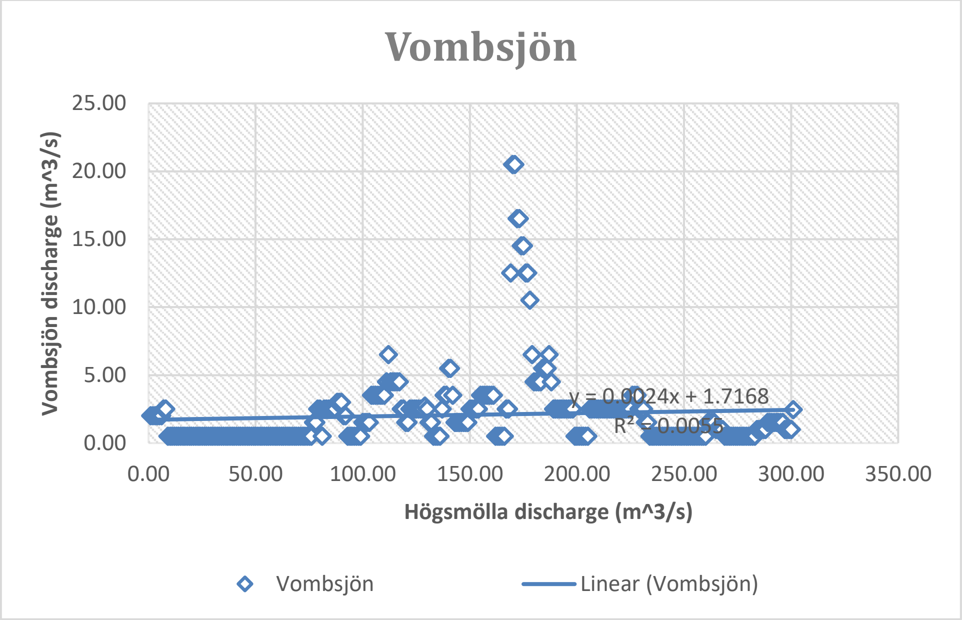
Correlation analysis made to compare the correlation of each branch discharge over the River, by comparing it against the outflow in the last observation point, Högsmölla. This analysis can be of use in further studies for correction factors over the flow.

SUMMARY OUTPUT **Vombsjön**

Regression Statistics	
Multiple R	0.7925
R Square	0.6281
Adjusted R Square	0.6268
Standard Error	3.5742
Observations	301.0000

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0E+00	6.5E+03	6.5E+03	5.0E+02	3.5E-66
Residual	3.0E+02	3.8E+03	1.3E+01		
Total	3.0E+02	1.0E+04			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.498	0.256	17.567	0.000	3.994	5.002
Vomb	1.641	0.073	22.470	0.000	1.497	1.785



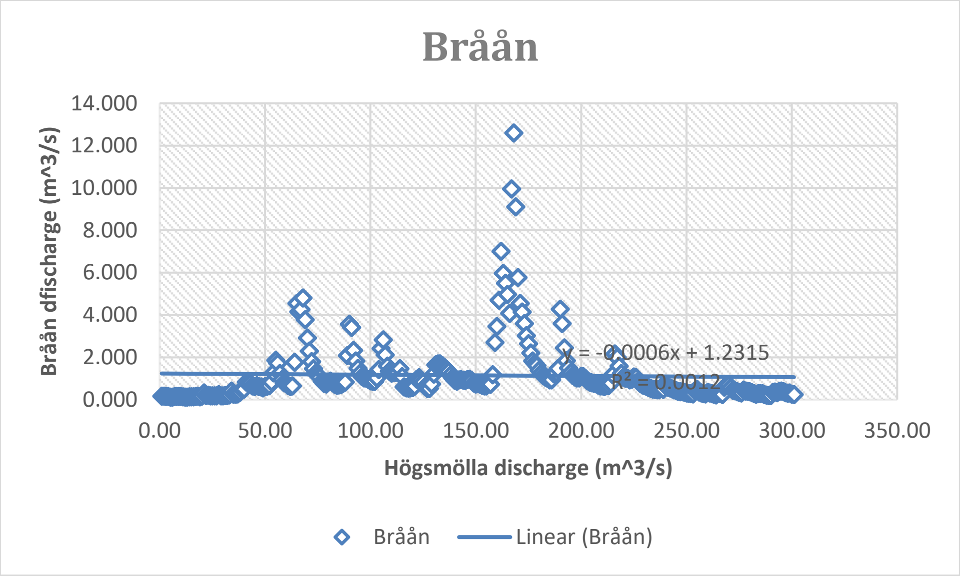
SUMMARY OUTPUT **Bråån**

Regression Statistics	
Multiple R	0.745
R Square	0.554
Adjusted R Square	0.553
Standard Error	3.913
Observations	301.000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.00E+00	5.69E+03	5.69E+03	3.72E+02	2.09E-54
Residual	2.99E+02	4.58E+03	1.53E+01		
Total	3.00E+02	1.03E+04			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	4.502	0.287	15.704	0.000	3.938	5.066
Braan	2.984	0.155	19.284	0.000	2.680	3.289

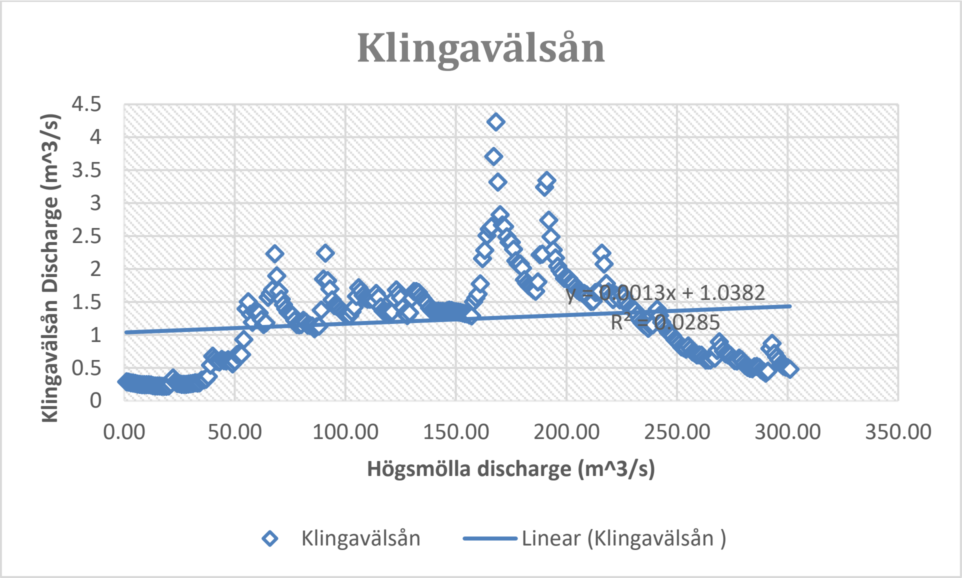


SUMMARY OUTPUT	**Klingavälsån**
Regression Statistics	
Multiple R	0.8691
R Square	0.7554
Adjusted R Square	0.7546
Standard Error	2.8986
Observations	301.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.0E+00	7.8E+03	7.8E+03	9.2E+02	2.0E-93
Residual	3.0E+02	2.5E+03	8.4E+00		
Total	3.0E+02	1.0E+04			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.365	0.348	-3.921	0.000	-2.050	-0.680
Klingavalsan	7.503	0.247	30.386	0.000	7.017	7.988


Klingavälsån
Klingavälsån Discharge (m^3/s)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
Högsmölla discharge (m^3/s)
y = 0.0013x + 1.0382
R² = 0.0285
Klingavälsån
Linear (Klingavälsån)

8.2 Quality and fit analysis of the model

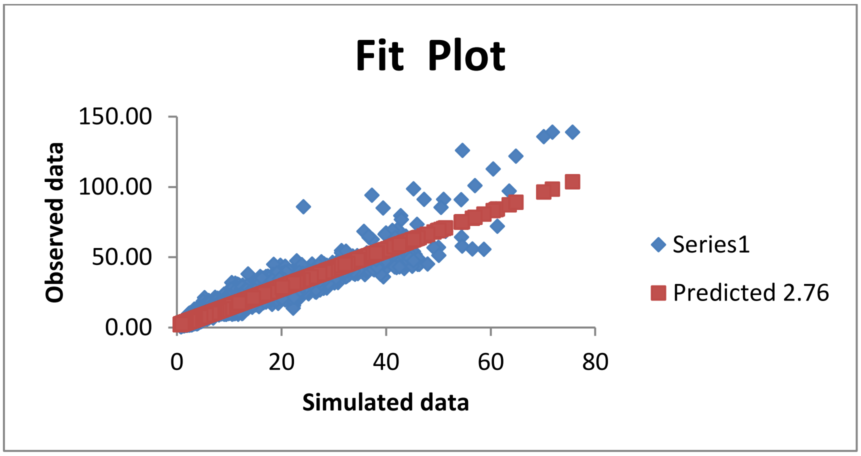
<u>First Simulation Quality Index R2</u>

The first model was run using only the data obtained from the sources, as appreciated in the text, and later with this analysis, the results show a good fit against the observed data. Still, this data is missing some information there for it was introduced correction data to increase the fit.

Regression Statistics	
Multiple R	0.960535
R Square	0.922627
Adjusted R Square	0.922619
Standard Error	3.124585
Observations	9256

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1077342	1077342	110349.1	0
Residual	9254	90347.11	9.763034		
Total	9255	1167689			



<u>Simulation after data corrections Quality Index R2</u>

After the first simulations, it was realized that the data needed some adjustments to obtain a better fit. As mentioned in the text before, to this model it was only taken into account the data from the three biggest branches, as they are the only ones it was able to get information. Still, it was decided to create some correction time series to fulfill this gap and increase the fit of the model.

Regression Statistics	
Multiple R	0.996583
R Square	0.993178
Adjusted R Square	0.993177
Standard Error	0.927801
Observations	9256

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1159723	1159723	1347239	0
Residual	9254	7965.979	0.860815		
Total	9255	1167689