Spatiotemporal change of stream and wetland features over 140 years in an agricultural catchment in southern Sweden

– An assessment of historical maps in GIS

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Abstract

The Swedish agricultural landscape has historically changed by draining wetlands and hydromorphological impacts by straightening and redirect watercourses. Drainage has been a part of Sweden's agricultural history, dating back to the 13th century with its peak in the 19th and 20th centuries. Draining the landscape was necessary to create more arable land to support a growing population by increased food production. However, the drainage resulted in wetland loss and a change in natural stream morphology. As new legislation arose during the late 20th century, the drainage was regulated to protect wetlands and streams with Agenda 2030 and the respective Sustainable Development Goals (SDG).

This study has assessed changes in wetlands and stream networks from the 19th century to the present time concerning drainage regulations in Tidan sub-catchment in southern Sweden. Historical maps and orthophotographs from the 19th- and 20th centuries were used with contemporary orthophotographs to assess these changes. The wetland area, land cover, stream length, and meandering degree were assessed by georeferencing and vectorizing the historical maps in ESRI ArcMap 10.8.

The results indicate that the wetland area has reduced by 54% between the late 19th century and the present. The total change in stream length indicates changes in the length of individual streams, increased sinuosity, or an increase in the number of streams from the late 19th century to the present. The land cover of the wetlands shows a shift from open wetland towards forest-covered wetlands.

However, these results should be interpreted with caution. There are uncertainties in the accuracy of the historic maps due to scale and the detail level compared to the orthophotographs used for later years. A historical map covering a large area has a lower level of detail and is less accurate due to the compromise of how much information to show. Hence wetlands area, stream length, and sinuosity index might not be represented equally between the different maps.

It could not be concluded that the resulting changes are entirely human-induced, caused by natural changes, or inaccurate due to used material limitations. However, the result shows that a decrease in wetland area and changes in stream morphology have occurred.

Keywords: Historical map, Wetland, Stream, GIS, Sinuosity index, Land cover change, Georeferencing, Vectorizing

Sammanfattning

Landskapet har historiskt sett förändrats i Sverige i form av dräningering av våtmark och påverkan på vattenmorfologi genom rätning och omledning av vattendrag. Dränering har varit en del av Sveriges jordbrukshistoria sedan 1200-talet med sin kulm på 1800- och 1900-talet. Att dränera landskapet var nödvändigt för att skapa mer åkermark för livsmedelsproduktion till den växande befolkningen. Nya lagstiftningar infördes under slutet av 1900-talet, där våtmarker och vattendrag skyddades med Agenda 2030 och de globala målen för hållbarhet.

Denna studie syftar till att bedöma förändringar av våtmarker och vattendrag från 1800-talet till nuvarande tid i förhållande till effekterna av dräneringslagar i Tidan avrinningsområde i södra sverige. För att bedöma dessa förändringar användes historiska kartor och ortofotografier från 1800- och 1900-talet, tillsammans med nutida ortofotografier. Temporala förändringar av vattendrag och våtmarker, samt markanvändning av våtmarker bedömdes genom georeferering och vektorisering av historiska kartor i programmet ESRI ArcMap 10.8.

Från slutet av 1800-talet till idag har arealen våtmark minskats med 54%. Vattendragens totala längdförädring påvisar en förändring i individuella vattendrags längd, ökad meanderingsgrad och ökat antal vattendrag från slutet av 1800-talet till idag. Våtmarkernas markanvändning visar på en förändring från öppen våtmark till våtmark med skog.

Resultaten från denna studie bör tolkas med försiktighet då det råder osäkerhet om noggrannheten hos de historiska papperskartorna. De har en osäkerhet på grund av sämre skalupplösning och minskad detaljnivå jämfört med de ortofotografier som använts för att representera senare år. Därför finns det en risk att våtmarker, vattendragens utbredning och meandringsgrad inte representeras lika mellan de olika kartorna.

Dessa felkällor medför svårigheter att dra slutsatsen att förändringarna är endast åkallad av människan, faktiska landskapsförändringar eller på grund av felkällor i det använda kartmaterialet. Resultatet visar dock att en minskning av våtmark och en förändring i vattendragens morfologi har skett.

Nyckelord: Historiska kartor, Våtmark, Vattendrag, GIS, Meandringsgrad, Markanvändning, Georeferering, Vektorisering

Popular science summary

The Swedish landscape has changed by draining wetlands to agricultural land to sustain the demand for food by a growing population. Drainage has been a part of Sweden’s history of agriculture, dating back to the 13^{th} century with its peak in the 19^{th} and 20^{th} centuries. Implications of these centenaries' long evolving drainage have caused intensified agricultural land and forest productivity. In addition, the drainage has caused reduced habitats of organisms by the loss of wetlands in the landscape. Therefore, restoration measures of wetlands and streams are needed to benefit from nutrient retention, water storage, and habitats for organisms.

This study aims to assess changes in wetlands and stream networks from the 19^{th} century to the present time concerning the effects of drainage regulations in Tidan sub-catchment area. The extent of streams, wetlands, and land coverage of wetlands was assessed in the GIS software ESRI ArcMap 10.8.

Comparing waterways and wetlands between historical maps with modern maps gives an overview of historical changes in watercourses. It is relevant to see these changes to evaluate locations to restore or construct new wetland areas. The changes have been compared using historical scanned maps from the 19^{th}- and 20^{th} centuries and contemporary aerial photographs.

The study first shows that the catchment's wetland area has decreased by 54% from the 19^{th} century to the present. Secondly, the land cover of former wetlands has shifted toward larger forest areas than wetland areas without vegetation. Thirdly, the total stream length has increased from the 19^{th} century to the present time. Lastly, the degree of meandering (curvature of a stream) has increased from the 19^{th} century to the present. The difference in map resolution needs to be considered when comparing historical maps and aerial photographs due to the level of detail that can be depicted. However, the result shows that a decrease in wetland area and changes in stream length have occurred.

Preface

The content of this study is related to the doctoral research project *Potential and boundaries for resilient water management in agricultural landscapes under climate change and extreme weather*[1]. This study will provide data for further research on water balance in Swedish agricultural catchments, including Tidan sub-catchment.

[1] https://internt.slu.se/en/cv-originals/louise-malmquist/

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Abbreviations

DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
FkV	Property map (vector format) (Fastighetskartan vektor)
GIS	Geographic Information System
GsK	Ordnance map (Generalstabskartan)
HeK	District Economic Map (Häradsekonomiska kartan)
JaK	Soil Map (Jordartskartan)
LEVA	Local Commitment to Water (Lokalt Engagemang för Vatten)
LM	Swedish mapping cadastral and land registration authority, (Lantmäteriet)
NMD	National Land Cover Database (Nationella marktäckedata)
RMS	Root mean square
SDG	Sustainable Developments Goals
SGU	Geological Survey of Sweden, (Sveriges Geologiska Undersökning)
SI	Sinuosity Index
SLU	Swedish University of Agricultural Sciences (Sveriges lantbruksuniversitet)

1. Introduction

The Swedish landscape has been drained since the late 13th century, initially by individual farmers draining their fields. In the 19th-century, drainage companies consisting of multiple farmers were formed, allowing larger areas to be drained (Myrdal & Gadd 2000; Jacks 2019). As a result, lakes and wetlands were drained, and streams were straightened, broadened, and deepened to clear land for agricultural production and increase forestry productivity (Jacks 2019; Reiter & Bölenius 2020). Draining wetlands resulted from the increased demand for food due to a growing population. Hence the drainage made it possible to create more arable land for crop production (Reiter & Bölenius 2020).

Water conditions in crop production are crucial for plant growth, where both inundation and drought can cause damage to the crop (Grusson et al. 2021; Lazin et al. 2021). Studies on future climate scenarios indicate increased precipitation intensity in Sweden with increased runoff during the spring. However, the runoff is expected to decrease during the summer due to allocation from runoff to increased uptake, transpiration, and evaporation induced by higher average temperatures (Johansson et al. 2018). Higher temperatures are affecting crop productions by enabling a longer growing season (Mattson et al. 2018). Yet, climate change deteriorates the conditions for crop growth by increased drought, which shortens the growing season (Trnka et al. 2011). Hence, a well-functioning drainage system and water availability for irrigation are needed. A drainage system ensures that the soil is bearing throughout the growing season for tillage, sowing, and harvesting (Mattson et al. 2018). However, an increase in irrigation need may be limited by insufficient ground- or surface water availability as well as current legislation for water outtake (*1998 års Miljöbalk*) (Riksdagsförvaltningen 2020). An option to secure the higher water supply-demand is to construct or restore wetlands (Mattson et al. 2018). Wetlands incorporated in the landscape increase the buffering effect of retaining water during increased precipitation and serve as a water reservoir for the dry periods (SMHI 1995; Johansson et al. 2018). Additionally, restoring or constructing new wetlands aims to increase nutrient retention in the landscape and increase biodiversity (Götbrink & Hindborg 2015). The landscape change affects habitats, and the destruction or degradation of these wetlands poses risks to biodiversity (Auffret et al. 2017).

Suitable areas in the landscape must be identified to restore former wetlands or construct new wetlands successfully. In intensively used agricultural landscapes, few places are available for new construction or restore wetlands due to space constraints (Götbrink & Hindborg 2015). Comparing historical maps and contemporary maps can estimate temporal changes of land cover and previous wetland locations (Auffret et al. 2017). Therefore, it is of interest to see where these wetlands have been situated historically to consider restoring those wetlands that have been drained or otherwise anthropogenically altered. However, where historical wetlands have been located might not be the best place for restoration due to nutrient retention, land cover, and changes in hydrology (Craft, 2015).

The benefits of wetlands are indirectly protected and included in the Sustainable Development Goals (SDGs) provided by the United Nations (UN). The SDGs associated with wetlands are End poverty (SDG 1); Zero hunger (SDG 2); Gender equality (SDG 5); Clean water and sanitation (SDG 6); Decent work and economic growth (SDG 8); Industry, innovation, and infrastructure (SDG 9); Sustainable cities and communities (SDG 11); Climate action (SDG 13); Life below water (SDG 14); and Life on land (SDG 15)[2] (Jaramillo et al. 2019): In addition to the SDGs, Sweden has its own direct environmental goals towards freshwater - "Flourishing Lakes and Streams" and "Thriving Wetlands." The aim is to preserve wetlands' ecological and water management function in the landscape and preserve these valuable wetlands for future generations (Öberg 2021).

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[2] SDG 1 - End poverty in all its forms where wetlands offer a reliable source of water for agricultural use, cattle, and human consumption.

SDG 2 - End hunger, achieve food security and improved nutrition and promote sustainable agriculture where food production relies on wetlands contribution of water.

SDG 5 - Achieve gender equality by empower and include all women in projects regarding wetland conservation, management, and restoration.

SDG 6 - Ensure availability and sustainable management of water and sanitation for all where wetlands ensure water quality and availability for consumption.

SDG 8 - Promote sustained, inclusive, sustainable economic growth, full and productive employment, and decent work for all where wetlands provide water for production systems such as agriculture.

SDG 9 - Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation by protecting wetlands instead of, due to the higher cost, restoration or constructing new ones.

SDG 11 - Make cities and human settlements inclusive, safe, resilient, and sustainable were coastal wetlands protect against heigh waves, storms, and acs as a water buffer zone.

SDG 13 - Take urgent action to combat climate change and its impacts, where wetland soil is used as carbon storage.

SDG 14 - Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

SDG 15 - Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss where wetlands are a source of biodiversity (Ramsar 2018).

1.1. Aims and limitations

This study provides an estimation of the temporal-spatial areal changes of wetlands and watercourse from the 19th to 21st century, together with the changes in land cover of these wetlands.

This study aims to assess changes in wetlands area and stream networks from the 19th century to the present time in Tidan sub-catchment, a Swedish agricultural catchment located in southern Sweden, Västergötland. Additionally, this work discusses the potential implications of changed water bodies and stream networks on agricultural land cover, focusing on former wetlands. Scanned historical maps, historical orthophotography, and contemporary orthophotographs are used to assess the temporal change.

The study has limitations in historical data availability, map accuracy, individual software usage, and temporal inaccuracy. For the analysis of changes in stream networks, tile drainage is excluded in this study.

This study compares spatiotemporal changes of wetlands and streams based on the following research questions:

I. Does the total wetland area change between the 19th to 21st centuries?

II. How does the land cover of the wetlands change between the 19th to 21st centuries?

III. Does the total length of the stream change between the 19th to 21st centuries?

IV. Does the meandering of streams change between the 19th to 21st centuries?

These research questions will provide static variables that indicated the state of the flow and storage of the water in the landscape. To understand the actual water function, a dynamic model needs to be developed.

2. Background

2.1. Drainage history in Sweden

Drainage of the Swedish landscape has been implemented since the 13th century (Myrdal 1999), with increased drainage intensity by the 19th century (Myrdal & Gadd 2000). In 1870, the drainage technique of open ditches was substituted for tile drainage systems (Myrdal & Morell 2001:4). The new drainage legislation in 1879 (*1879 års Dikningslag*) stated that an individuals' interest in implementing drainage on an area shared by multiple landowners required visual inspection by drainage corporations to approve the suggested drainage plan (Naturvårdsverket 2009). As a consequence, drainage corporations, including multiple landowners, were formed. The increase in implemented drainage systems made it possible to drain the big plains in Sweden. Implementation of tile drainage reduced maintenance of the drainage systems and increased connectivity between land consolidation parcels (Wesström et al. 2017).

During the 1960s, the use of machinery in agriculture increased, making tile drainage an important implementation to create fields suitable for machinery (Wesström et al. 2017). Furthermore, new legislation regarding water was implemented in 1983 (*1983 års vattenlag*), where an application to the county administrative board for soil drainage was required to construct new drainage systems (Riksdagsförvaltningen 1997). An act implemented in 1986 invoked an absolute requirement of permits for soil drainage throughout Sweden. In 1992, United Nations (UN) developed Agenda 21, an environmental action program designed for sustainable development, including protecting wetlands and freshwater (United Nations 1992; Åkesson et al. 1998). Additional legislation in 1998 (*1998 års Miljöbalk*) controlled the water outtake amount from the landscape (Riksdagsförvaltningen 2020). Furthermore, the protection of freshwater was implemented in the global environmental and human health goals by the Millennium Development Goals in 2000 and the current SDGs in 2015 (Sustainable Development Goals Fund 2014; Ramsar 2018).

2.2. Definition of wetlands

Wetland is a broad term with regional differences in hydrological regimes, climate, soil-forming processes, vegetation type, and geomorphology. Hence a wide range of terms included in wetland definition has evolved (Tiner, 2016). However, a wetland is a generally used term for describing “environments subject to permanent or periodic inundation or prolonged soil saturation sufficient for the establishment of hydrophytes” (Tiner 2016, p. 1). A few types of landforms that naturally form wetlands are depressions surrounded by upland and landforms relatively flat located adjacent to water bodies (Tiner 2016).

Within this scope of this study, seven classifications are used to define wetlands (Table 1) and will be used hereafter to classify land cover. For the maps used within this study, Generalstabskartan (GsK), Jordartskartan (JaK), and Property map (vector format) (FkV), the definition of wetland vary. For example, both GsK and FkV are using definitions depicting wetlands as of the abundance of water. In contrast, wetlands on JaK are defined by soil types formed in excess water conditions. Following land cover classification, “open wetland” indicates any wetland types listed in Table 1 that do not have a tree canopy covering the ground or specific land usage.

Table 1. Types of wetland and soils used for wetland classification and their respective definition with the source of origin (United States Department of Agriculture 2009).

Wetland definition	**Definition**	**Source**	**Reference**
Fen	Groundwater as the source of water	Ordnance map (Generalstabskartan) (GsK)	(Lantmäteriet 2021a)
Peat	Soil type: organic matter deposited under inundation conditions due to incomplete decomposition	Soil map (Jordartskartan) (JaK)	(Sveriges Geologiska Undersökning 2014)
Peat bog	Soil type. Bog: Precipitation as the source of water	Soil map (Jordartskartan) (JaK)	(Sveriges Geologiska Undersökning 2014)
Muck	Soil type: Organic matter not recognizable, containing more mineral matter than peat	Soil map (Jordartskartan) (JaK)	(Sveriges Geologiska Undersökning 2014)
Marshland	Frequently or permanently inundated with hydrophytes	Property map (vector format) (Fastighetskartan vektor) (FkV)	(Geografiska Sverigedata Lantmäteriet 2019)
Marshland – almost impassable	Frequently or permanently inundated with hydrophytes	Property map (vector format) (Fastighetskartan vektor) (FkV)	(Geografiska Sverigedata Lantmäteriet 2019)

2.3. Restoration of wetlands

Measures are needed to counteract droughts and floods caused by predicted changes in precipitation patterns. Restoring and constructing new wetlands are examples of counteracting measures. The benefits of wetlands in the landscape include the buffering capacity, increasing groundwater formation, increasing nutrient retention and biodiversity. (Vattenmyndigheterna Västerhavet 2020). The buffering capacity affects the runoff at high floods and collects water that can later be used for irrigation during droughts (Hefting et al. 2013; Mattson et al. 2018).

For efficient nutrient retention, the residence time of the water should be as long as possible, and the water flow should be as even as possible throughout the wetlands (Götbrink & Hindborg 2015). However, when it comes to nutrient retention of wetlands, studies are showing less desired effects. In the study by Arheimer (2017), the efficiency of nutrient retention varied between wetlands. They explained possible reasons for the variation as large-scale nutrient concentration patterns and water discharge or the specific wetland location in the catchment (Arheimer & Pers 2017). Hence the location of the wetlands in the landscape needs careful consideration (Götbrink & Hindborg 2015). Land (2016) concluded that nutrient retention has been seen in treated wastewater from urban and agricultural runoff and may effectively prevent eutrophication. However, they found that restored wetlands in former farmland were significantly less effective at nutrient removal (Land et al. 2016). The study done by Thorslund (2017) shows evidence that the combined effects of multiple wetlands in the landscape differ from the effects of individual functions of a wetland. The study suggests that even though one individual wetland has good nutrient retention capacity, the overall nutrient leakage in a large-scale perspective did little change in retaining nutrients (Thorslund et al. 2017).

Support, advice, and collaboration between the authorities and landowners are required to increase the participation of wetland implementation (Graversgaard et al. 2021). Due to land cover changes on former wetlands, some identifiers for a successful restoration or construction need to be considered. On-site factors, including current land cover, availability to hold water as per wetland definition, soil properties, and vegetation cover, are considered. In addition, off-site factors such as surrounding land cover and topography are considered (Craft 2015).

In the study done by Franzén 2016, a selection of farmers in Sweden answered a questionnaire regarding the willingness to create wetlands on their land. The most common reason for farmers not wanting to create wetlands is the cost of it. However, the willingness increases if the compensation and annual subsidies increase (Franzén et al. 2016). For farmers who consider creating wetlands, the main reason is nutrient retention and biodiversity (Lantbrukarnas Riksförbund 2020). When restoring or constructing new wetlands, the land-use efficiency should be considered. A restored or newly constructed wetland placement is better suitable for areas with low yield or soil otherwise difficult to manage (Greppa näringen 2021). In Västra Götaland, approximately 257 ha of wetland has been constructed in 2019 (Öberg 2021).

Studies have been done on the history of drainage in Sweden and the environmental implications of wetlands and stream changes. For example, Krug (1993) studied the river Kävlingeån in southern Sweden, assessing the nutrient leakage from agriculture. He suggests that the largest nutrient loss is in the river's riparian zone, and hence the solution to reduce the nutrient leakage lies in proper management of the riparian zone (Krug 1993). In the study done by Duma (2011), the impacts on biodiversity of restored wetlands were made in Tullstorp in southern

Sweden. The wetlands area was score depending on birds', invertebrates, and vegetation cover status. She claims that the measurements of these features and the maintenance of newly constructed wetlands need to be improved to get higher scores (Duma 2011).

2.4. Georeferencing

One way to transform scanned historical maps into a coordinate system is by aligning control points in the scanned maps to control points in contemporary digital maps with known coordinates, so-called georeferencing (Husak 2009). A software program (HistMapR), tested by Auffret (2017) with semi-automated functions, has proven beneficial to determine land cover change for observing biodiversity change. Another approach to determine the position of features, such as wetlands, was done by Fuchs (2013). They used statistics of land change and their location to generate the positional area of the feature (Fuchs et al. 2013). Due to the complexity and data requirements for these approaches, together with the limitation of obtained data over watercourses, wetland area, and wetland land cover, georeferencing was used in this study.

Manual digitizing, as described above, is time-consuming but adds additional data that only georeferencing does not. For the scanned historic map to be compatible with digital analysis tools, the spatial relationship between features is vectorized from the scanned map and transformed to a compatible format, e.g., by transforming vectors or raster. The data can then be used for further analyses. Adding attributes to digitized historical maps by creating vector polygon features enables the comparison of features between historical or contemporary maps. In addition, the vector polygon features enable the ability to identify changes in patterns; for example, in this thesis, changes in the total area of wetlands (Husak 2009).

Historical maps have been used in analyses for different purposes. For example, Lui (2017) used historical maps to derive land cover history and changes in landscape dynamics, such as hydromorphology caused by land cover change. Rhoads (2016) used historical maps to compare the spatial extent of the channel network change between historical maps and contemporary maps. Additionally, he analyzed the change in channel planform of streams and tributaries and used historical topographic maps and historical aerial photographs to determine the location of streams obscured by tree canopy (Rhoads et al. 2016). In the study done by Kjällman (2017), the wetland area change, type of wetland, and spatial distribution of wetlands in Helsingborg municipality in southern Sweden were assessed. She used computer software to compare historical maps with contemporary maps of wetlands. The analyses showed a reduction of wetland area, which implied fewer habitats for biota, leading to lower biodiversity (Kjällman 2017).

2.5. Sinuosity index

Sinuosity index (SI) is a measurement of the degree of meandering of a stream. The total SI is calculated by the ratio of the stream's length between two points and the shortest straight distance between the two points. A SI of 1.0 indicates a straight stream. Higher values indicate a higher degree of meandering. If the stream changes overall direction, the stream's length is divided into segments of the general direction (Figure 1) (Horacio 2015).

The SI can be calculated in several different ways. For example, the inflection sinuosity method uses the length of the streambed as the nominator and a broken line by inflection points of meanders as the denominator. The Leopold and Wolman method uses the talweg[3] as the nominator and the valley's length as the denominator (Horacio 2015). In this study, the total SI is used for determining the degree of meandering due to time limits and low-resolution maps.

[3] Talweg is the deepest point in a stream depicted as a line along the stream

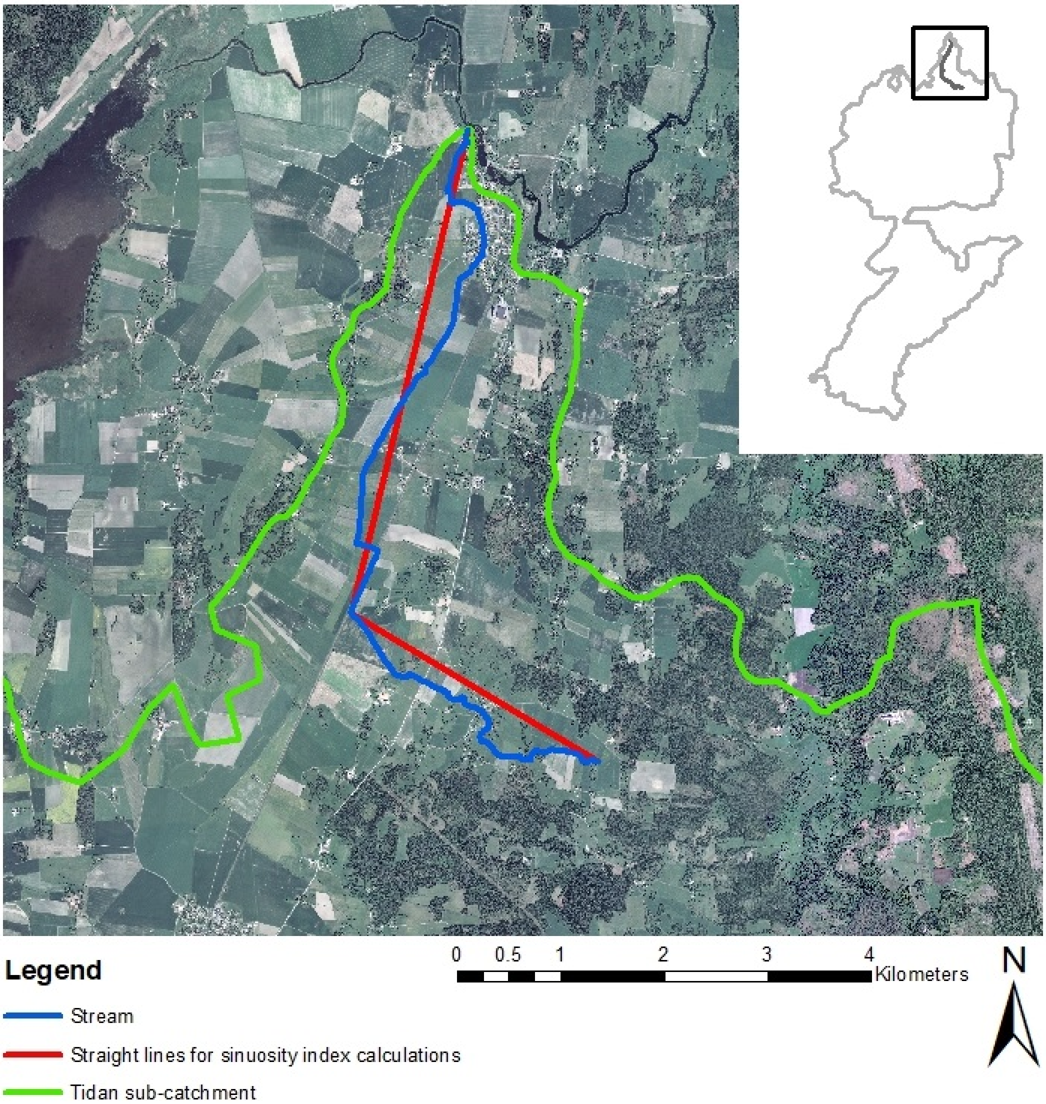

Figure 1. Depiction of a stream located in the northeast (blue) of Tidan sub-catchment with the change in the direction of the segmentation line (red) used for calculating the sinuosity index. (Base map: GSD Orthophoto, 0.5m colored © Lantmäteriet 2019).

3. Method

Several map sources have been used to calculate the change in the wetland area, land cover, stream length, and stream sinuosity index. The calculation has been done for Tidan sub-catchment located in southern Sweden, Västergötland. The map material consists of historical maps, historical orthophotographs, and contemporary orthophotographs. The data has been derived from the individual maps by georeferencing the historical maps in the software ESRI ArcMap 10.8. The georeferenced map material has been used to derive vector shape-files of wetlands and streams representing their extent for the respective map.

3.1. Study area

This study is limited to Tidan sub-catchment (481 km^2) in Västra Götaland County in southern Sweden (Figure 2). Tidan sub-catchment is one of 20 catchments included in the Local Commitment to Water (Lokalt Engagemang för Vatten, (LEVA) project. The project aims to create a new long-term mitigation methodology against eutrophication (Havs- och vattenmyndigheten 2019). Tidan sub-catchment is located below the highest coastline on the plains of southern Sweden with an overall flat landscape characterized by the glaciation (115 000-10 000 years before present) (Sveriges Geologiska Undersökning 2020) with depositions of moraine, glacial sand, silt, clay, and fluvioglacial sediments (Sveriges Geologiska Undersökning 2014). The area is dominated by agriculture (36%) and forest (40%). The stream Ösan (39 km) flows through the whole catchment area with south to north direction. The stream has its outflow into the adjacent lake Östen located in the north, which is the only larger waterbody connected to the catchment (5 km^2) (Geografiska Sverigedata Lantmäteriet 2019).

Tidan sub-catchment has strategic importance for improving water quality due to the location being prone to eutrophication and turbidity (Havs- och vattenmyndigheten 2020). The area is of particular interest due to being a part of the LEVA project and the location of the stream Tidan. The stream Tidan is included as a part of the Swedish national environmental quality objective "Flourishing Lakes and Streams". It starts south of Tidan sub-catchment and flows northwards adjacent to the catchment area to unite with the lake Östen in the north.

The stream Tidan and its tributary flow Ösan are mixed within the lake Östen, which has its outflow on the east side of the lake where the stream Tidan continues towards Vänern through Mariestad in the northeast (Länsstyrelsen Västra Götalands 2009).

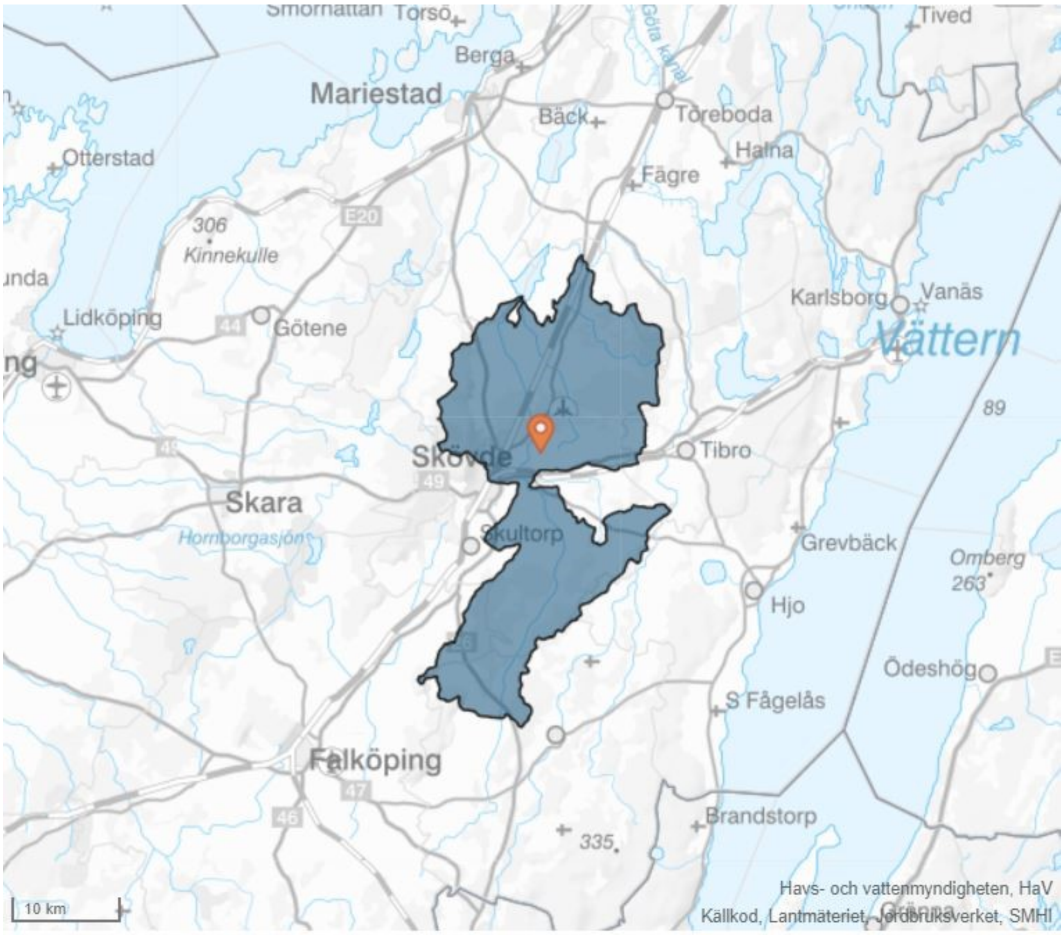

Figure 2. Tidan sub-catchment location (Base map: Havs- och vattenmyndigheten 2021 [Map] https://www.havochvatten.se/planering-forvaltning-och-samverkan/program-projekt-och-andra-uppdrag/leva---lokalt-engagemang-for-vatten/levas-atgardsomraden.html# [2021-05-25])

3.2. Data

Data for analyzing the change in the wetland area, land cover, stream length, and stream meandering was obtained from digitalized historical maps and aerial photographs of wetlands and streams in Tidan sub-catchment. The maps are produced by the Swedish mapping, cadastral and land registration authority (Lantmäteriet (LM)) and Geological Survey of Sweden (Sveriges Geologiska undersökning (SGU)). The maps used for analysis are Generalstabskartan (GsK, 1880), Häradsekonomiska kartan (HeK, 1880), Jordartskartan (JaK, 1920), black and white orthophotograph (1960), colored orthophotograph (2007), IRF orthophotograph (2018), and the Property map (vector format) (FkV, 2018). The maps' names, the year of surveying, scale or pixel size, data provider, root mean square (RMS) error, the positional accuracy, and the years that each map is referred to is presented in Table 2. The choice of maps is due to the accessibility of the material.

The orthophotographs provided information regarding stream networks and, to some extent, land cover data. The GsK (1880) and the JaK (1920) map provided valuable information on the extent of the stream network and HeK (1880) for land cover before- and during the historical intensification of drainage and farming. The software ESRI ArcMap 10.8 was used for assessing the maps and by running a few simple calculations in the attribute table by the tool Calculate Geometry. Calculations of wetland area, land cover percentage, stream length, and sinuosity index were done in Excel 2019.

Table 2. The table shows the maps used to vectorize historical wetlands and stream networks, abbreviations, scale or pixel size, map provider, positional accuracy, and reference years. RMS error stands for root mean square error representing map transformation accuracy.

Map name	**Survey year**	**Type**	**Scale or Pixel size (m)**	**Provider**	**Referred to in text to years**	**RMS error (m)**	**Positional accuracy (m)**
Generalstabs kartan, (GsK)	1842-1881	Scanned paper map	1:100000	Swedish mapping cadastral and land registration authority (LM)	1880	82	
Häradsekono miska kartan, (HeK)	1877-1882	Scanned paper map	1:20000	LM	1880	25	
Jordartskarta n, (JaK)	1898-1921	Scanned paper map	1:50000	Geological Survey of Sweden (SGU)	1920	32	
Orthophoto, black and white	1955-1965	Aerial photography	0.5×0.5	LM	1960		2
Orthophoto, color	2006-2007	Aerial photography	0.5×0.5	LM	2007		1
Orthophoto, IRF (Infrared)	2018	Aerial photography	0.25×0.25	LM	2018		0.3
Property map (vector format) (FkV)	2019	Shape-file		LM	2018		10

3.3. Georeferencing

The georeferencing (Figure 3) of GsK (1880), HeK (1880), and JaK (1920) was done in ESRI ArcMap 10.8 software with the toolbar “Georeferencing” and projected to the Swedish coordinate system SWEREF99TM. As a base map, the Property map (vector format) (FkV) dated 2019 from Geographic data of Sweden (Geografiska Sverigedata, GSD) and LM, was used. The FkV will be referred to as the year 2018 for better leniency. Churches, intersections, and railways were used as reference points to rectify the GsK (1880), HeK (1880), and JaK (1920) (Figure 4). The chosen number of reference points varied between 4 to 9 points depending on the number of well-defined features to use as control points available in each historical map. The RMS error varied between 82m on GsK (1880) and 32m on JaK (1920). The RMS error describes the accuracy of the transformation of different control points. The rectification was done with a first-order polynomial affine transformation to digitalize GsK (1880), HeK (1880), and JaK (1920). The orthophotographs were already projected in SWEREF99TM; therefore, no rectification for these maps was needed. The positional accuracy of the aerial photography varied between 0.3-2m (Table 2).

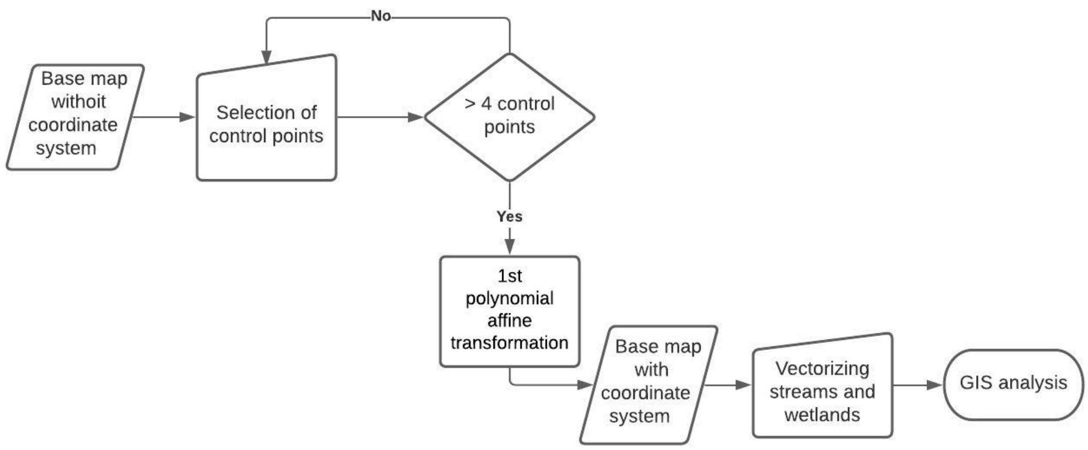

Figure 3. Flowchart over the process of georeferencing and vectorization of historical maps.

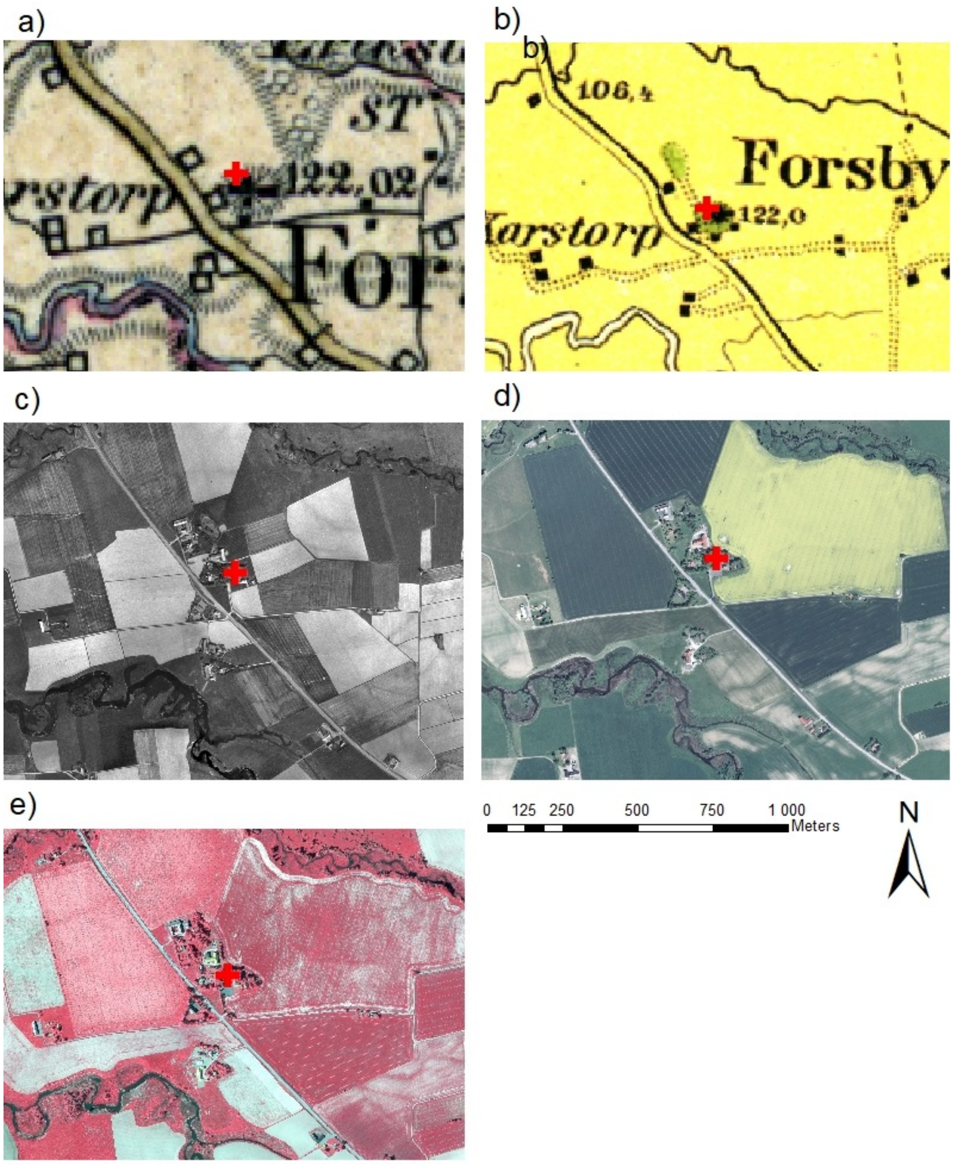

Figure 4. Five depictions of a church in Forsby within Tidan sub-catchment from the different maps, a) Generalstabskartan (GeK), b) Jordartskartan (JaK), c) black and withe orthophotograph 1960, d) colored orthophotograph 2007 and e) IRF orthophotograph 2018. Base maps: Generalstabskartan, scale 1:100000 (© Lantmäteriet 2021 https://historiskakartor.lantmateriet.se/arken/s/advancedsearch.html 4 Feb 2021), Jordartskartan scale interval 1:25000-1:1000000 (© Sveriges Geologiska Undersökning 2014 https://apps.sgu.se/geolagret/ 27 Jan 2021), GSD Historic orthophoto, 0.5m black and white (© Lantmäteriet 2019a) and GSD Orthophoto, 0.25m colored (© Lantmäteriet 2019b),

3.4. Vectorizing streams and wetlands

The GsK (1880), HeK (1880), and JaK (1920) maps were imported to ESRI ArcMap 10.8 as base maps for vectorizing streams and wetlands. They were used to determine the areal change of wetlands, land cover change of wetlands, change in total stream length, and change in the meandering of six streams spread throughout the sub-catchment of Tidan (Figure 5). The streams were chosen by their location, where streams spread across the catchment better represent the area. The five streams are referred to as their location in the catchment, i.e., northeast, north, northwest, southeast, southwest, and the stream Ösan.

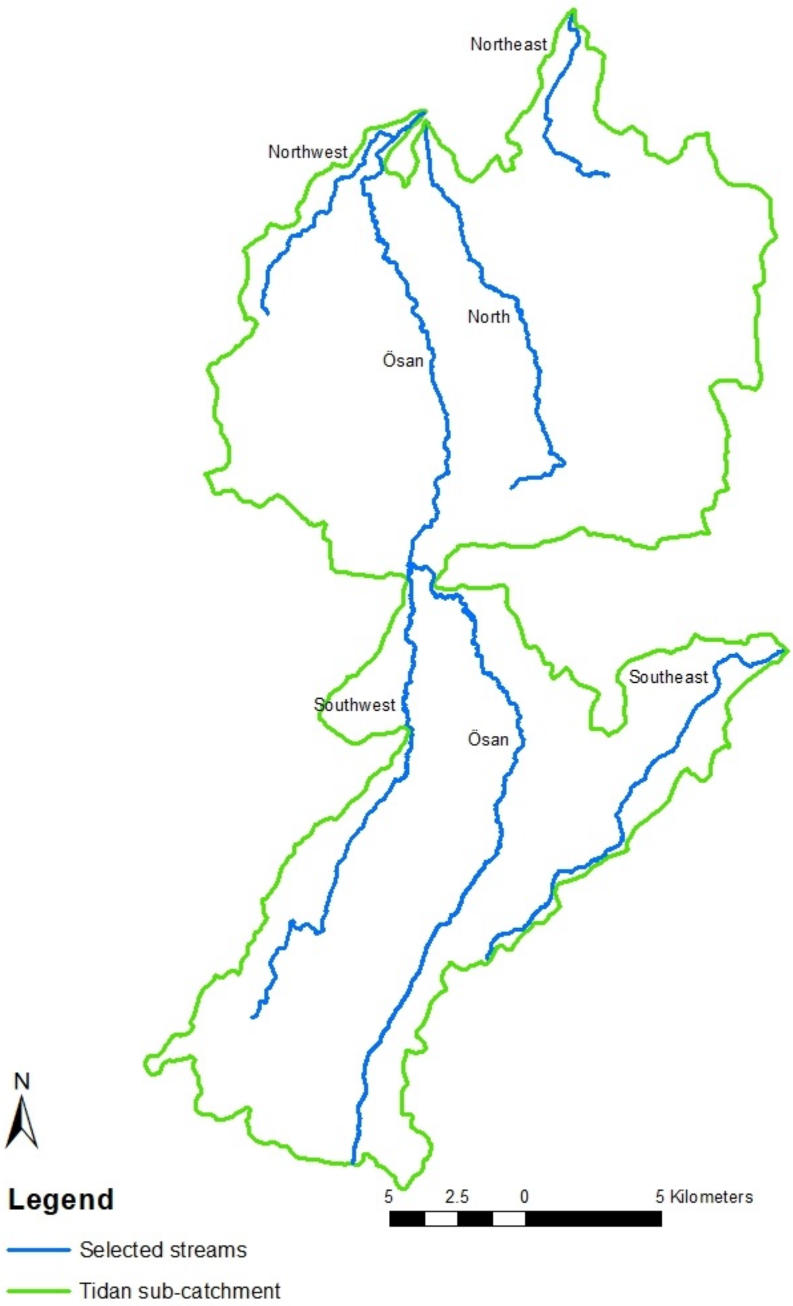

Figure 5. Selected streams for calculating sinuosity index in Tidan sub-catchment.

3.4.1. Georeferenced digitized historical maps

All streams recognized as a watercourse on the GsK (1880) and JaK (1920) map were manually added as vectors of the type polyline in an Edit toolbox session in ArcMap 10.8. The wetlands on the GsK (1880) map were similarly added but as polygons. For the wetlands on the JaK (1920) map, a shape-file with the wetlands as vector polygons already existed provided by the county administrative board, Västra Götaland county. The wetlands representing GsK (1880) were based on wetland type fen; meanwhile, JaK (1920) was based on the soil type; peat, peat bog, and muck (Lindholm & Peilot 2008; Lantmäteriet 2021a).

3.4.2. Orthophotographs

Orthophotographs were used to determine the prevalence of stream networks for the periods representing 1960 and 2007. A vector layer from the Property map (vector) (FkV, 2018) was used to distinguish wetlands on the aerial photographs for the areal cover of wetlands. A vector layer of stream network from the FkV (2018) was overlaid onto the historic orthophotographs to interpret stream position, mainly where tree canopy obscured the streams. Thus, for better visibility, IRF orthophotos from 2018 and the FkV (2018) vector layer were used to interpret the location of the streams. Stream segments were added, erased, or moved based on the interpretation of channels in the historic orthophotos. Since no historical topographic map had been obtained, which could be helpful to determine watercourses, the comparison by a contemporary orthophotograph was the available option.

3.5. Sinuosity index

The SI was calculated to determine the change in meandering degree. Due to the limited time in the project and the lower resolution of the digitized historical maps, the more straightforward method, the total SI, was used in this study. The total SI is calculated by the ratio of the stream's length between two points and the shortest straight distance between the two points (Figure 1).

$$SI = \frac{River's\ length}{Straight\ distance}$$

The index was calculated for six streams in Tidan sub-catchment located in the northeast, north, northwest, southeast, southwest, and through the middle of Tidan sub-catchment by the stream Ösan (Figure 5). The stream Ösan was divided into 13 segments, while the five shorter streams were divided into 2-3 segments. The varying number of segments depends on the number of direction changes through an individual stream.

3.6. Stream length

The manually added vectors representing streams in GsK (1880) and JaK (1920) were compared with the manually altered vector layer from FkV representing streams for 1960, 2007, and 2018. The vectors were divided into four sections representing the northeast, northwest, southeast, and southwest of Tidan sub-catchment to calculate total length within each section. The catchment division was done to rule out sections with little or no change and detect differences between the different years within the sub-catchment. In addition, the division provides information on areas exposed to a higher degree of drainage.

3.7. Determination of wetland area

The wetlands area shape-file from FkV (2018) was used for all orthophotographs due to tree and vegetation cover, reducing the visibility of detecting wetland boundaries on the orthophotos. Hence, an areal comparison of wetlands could only be made between the polygon shape-files generated using GsK (1880), JaK (1920), and FkV (2018). The classification of wetlands from the FkV (2018) was grouped from “marshland” and “marshland almost impassable” to one classification “Wetlands” (Geografiska Sverigedata Lantmäteriet 2019). The subdivisions classified in FkV (2018) are not of interest in this study. Therefore to simplify the calculation of total area, a reclassification of wetlands was done.

3.8. Land cover change of wetlands

For classifying land cover of wetlands for GsK (1880), the manually vectorized polygons generated through GsK (1880) were used with the manually georeferenced map, HeK (1880). To enable interpretation of land usage, the wetland polygon shape-file derived from GsK (1880), where all area is classified as wetland, was overlaid onto HeK (1880) as the latter has better visualization of land cover. Land cover data representing the years of the JaK (1920) map had not been obtained. Therefore an analysis of land cover during 1920 could not be implemented.

A land cover data raster from 2018 was acquired from the Swedish Environmental Protection Agency, National Land Cover Database (NMD), to distinguish between deciduous forest and pine forest on the orthophotos representing years 1960, 2007, and 2018. The raster data comes with a resolution of 10m per pixel and positional accuracy of 10m. The NMD has a higher degree of detail than the material and data used in this study. Thus, the NMD file with a total of 25 classifications of various types of deciduous trees, pine trees, and land usage was reclassified to five classifications (agricultural land, open wetland, deciduous forest, coniferous forest, and other) (Appendix D).

4. Results

4.1. Sinuosity index

The stream Ösan and the five smaller streams (northeast, north, northwest, southeast, and southwest) show a low total degree of meandering in 1880 (SI = 1.17 ± 0.11), with an increasing meandering to 1920 (SI = 1.22 ± 0.12) and 1960 (SI = 1.28 ± 0.16). Less variation occurred between the following years, 2007 (SI = 1.27 ± 0.15) and 2018 (SI = 1.27 ± 0.16) (Figure 6). The standard deviation shows that the stream morphology in 1960 (± 0.16) and 2018 (± 0.16) is more heterogeneous than in the other years. The heterogeneity indicates that there is a higher spread of meandering streams and straight streams.

The location of Ösan in 1880 has an east-west transition range between 0.005m to 233m with a mean transition of 46m compared to the location of the stream in 2018. In 1920, the east-west transition of Ösan range from 0.004m to 191m, with a mean transition of 31m compared to the location of the stream in 2018 (Figure 7). The transition is calculated for the total length of the stream Ösan within the Tidan sub-catchment. The range indicates locations of the stream with small transition and large transition. The transition can be seen throughout the sub-catchment by the streams located in northeast, north, northwest, southeast, and southwest (Appendix I).

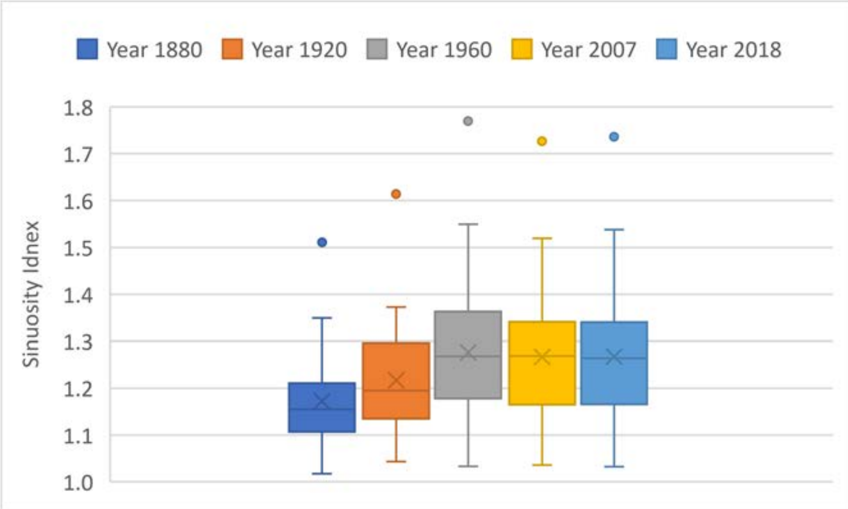

Figure 6. Variation of sinuosity index and average sinuosity index of six streams located in Tidan sub-catchment in the northeast, north, northwest, southeast, and southwest part of Tidan sub-catchment and stream Ösan. The sinuosity index is represented as the average year for the period of cartographic data.

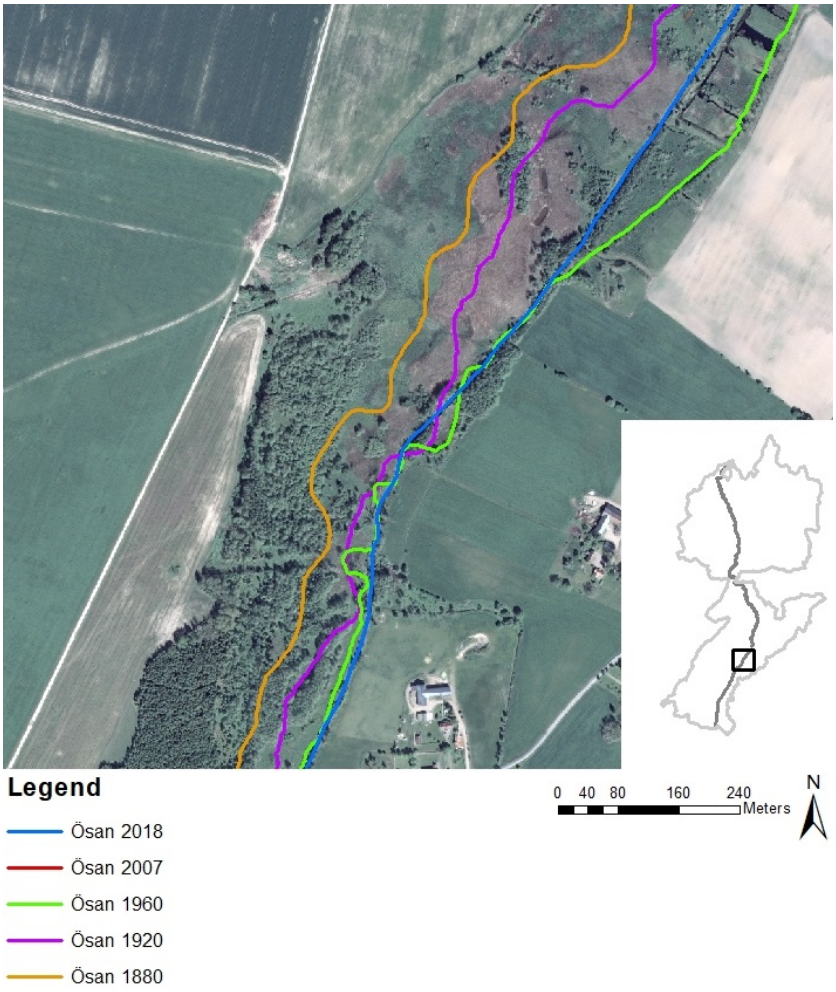

Figure 7. Spatiotemporal depiction of a part of stream Ösan's east-west transition and meandering pattern. Base map: GSD Orthophoto, 0.25m colored (© Lantmäteriet 2019b)

4.2. Length changes of stream network

By 1880, the total length of the stream network in Tidan sub-catchment is 314 km. By 1960, the total length is measured to 777 km, and by 2018, the total stream network length is 716 km. The total length of the stream network in Tidan sub-catchment identified from the FkV (2018) (716 km) is 128% longer than the total length of streams identified in GsK (2018) (314 km). Comparing total stream length in GsK (1880) (314 km) with the orthophotographs from 1960 (777 km), the total length is 147% longer (Figure 8 and Figure 9).

The streams in the southeast of the catchment show the largest length change between 1880 (47 km) and 1960 (153 km) by 224% and by194% between 1880 and 2018 (139 km) (Appendix E). The stream Ösan differs by +5 to +10% between 1880 and 2018. Notably, little change can be seen in total stream length between 1880 and 1920, ranging from -4% to +19%, and between 1960 and 2018, ranging from -1% to -10% throughout Tidan sub-divisions.

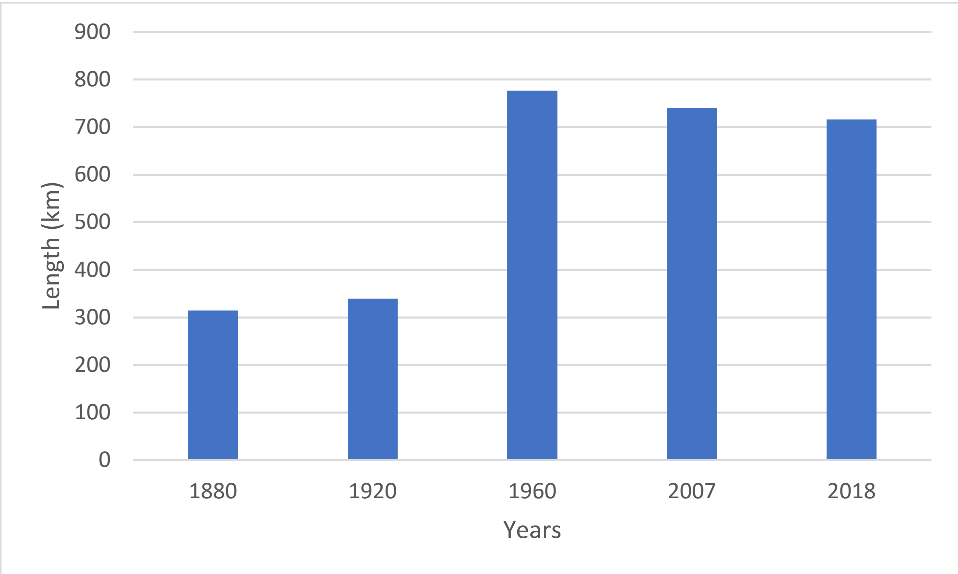

Figure 8. The total length of streams in Tidan sub-catchment for respective years of cartographic data.

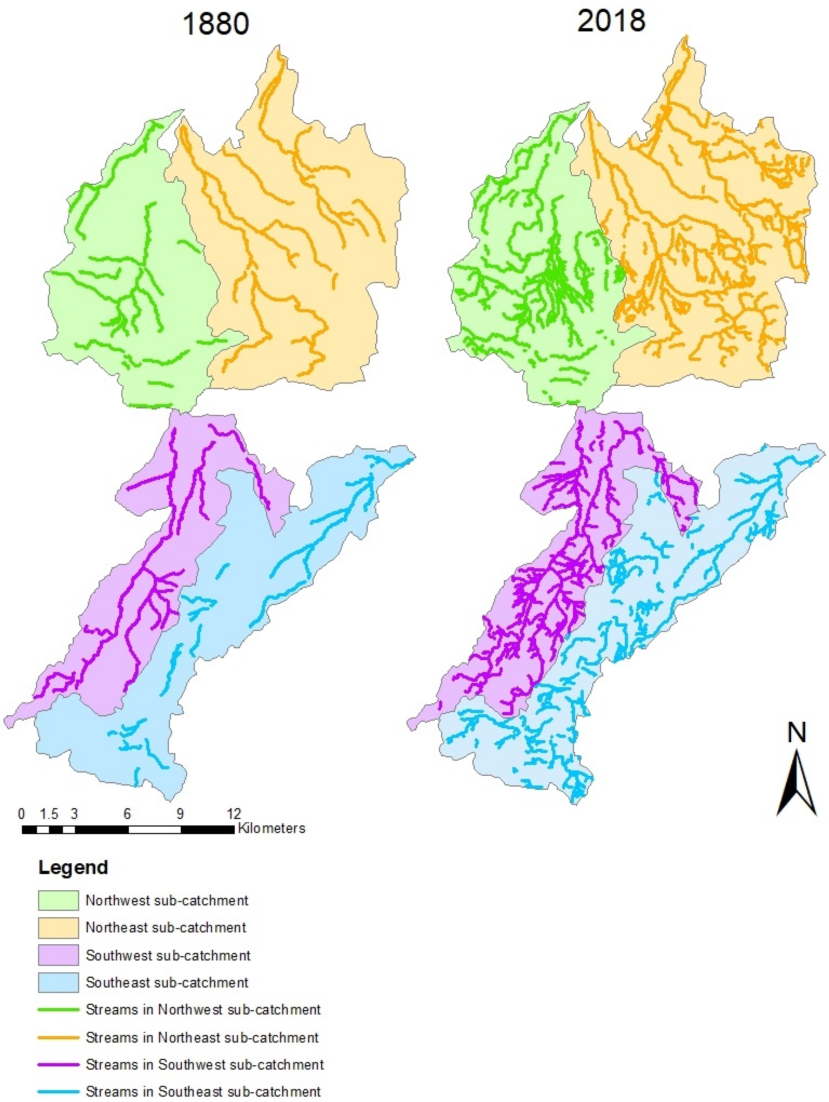

Figure 9. Comparison between four sub-catchments, northeast, northwest, southeast, and southwest, by Generalstabskartan 1880 and Fastighetskartan (vektor) 2018, and their respective depiction of the stream network.

4.3. Changes in the land cover of wetlands and total area of wetlands

Comparing the total wetland area in GsK (1880) (44.3 km^2) with the total wetland area derived from FkV (2018) (20.5 km^2) indicates an areal decrease of 23.8 km^2 of Tidan sub-catchment. Approximately 54% of the wetland area within Tidan sub-catchment was transformed between 1880 (44.3 km^2) and 1960 (20.5 km^2). Sections in the north part of the catchment area and the southern part of the lake Östen have shown the most reduction in wetland area (Figure 10 and Figure 11). The wetland area decreased by 23% between 1880 (44.3 km^2) and 1920 (34.1 km^2). From 1920

(34.1 km^2) to 1960 (20.5 km^2), the total wetland area decreased by 40%. For 1960, 2007, and 2018, the total wetland area is the same (20.5 km^2). The same area is due to the same polygon shape-file from FkV (2018) was used to determine the presence of wetlands (Table 3).

The five vegetation types, agricultural land, open wetland, deciduous forest, coniferous forest, and other (Table 3), represent the land cover on areas classified as wetlands. The results show a decrease of open wetland by 4% between 1880 (18.1 km^2) and 1960 (17.3 km^2), a 47% decrease to 2007 (9.1 km^2), and an additional decrease of 6% to 2018 (8.6 km^2). Agricultural land on wetlands decreased by 100% between 1880 (13.3 km^2) and 1960 (0.03 km^2). An increase of 233% occurred by 2007 (0.1 km^2), yet again decreased by 100% (0.0013 km^2) in 2018. Wetland covered by forest (both deciduous and coniferous) decreased by 71% between 1880 (7.7 km^2) and 1960 (2.2 km^2), increased by 409% to 2007 (11.2 km^2) and reached its maximum area in 2018 (11.8 km^2) (Figure 12). There is no indication of wetlands being constructed in new locations within Tidan sub-catchment.

Table 3. The total area of wetland classification of land cover and the total area of wetland per respective years

Area (km^2)	**1880**	**1920**	**1960**	**2007**	**2018**
Total wetland	44.3	34.1	20.5	20.5	20.5
Agricultural land	13.3		0.03	0.1	0.0013
Open wetland	18.1		17.3	9.1	8.6
Deciduous forest	0.5		1.3	1.9	2.8
Coniferous forest	7.2		1.9	9.3	9.0
Unidentified	5.2		0.001	0.08	1.6

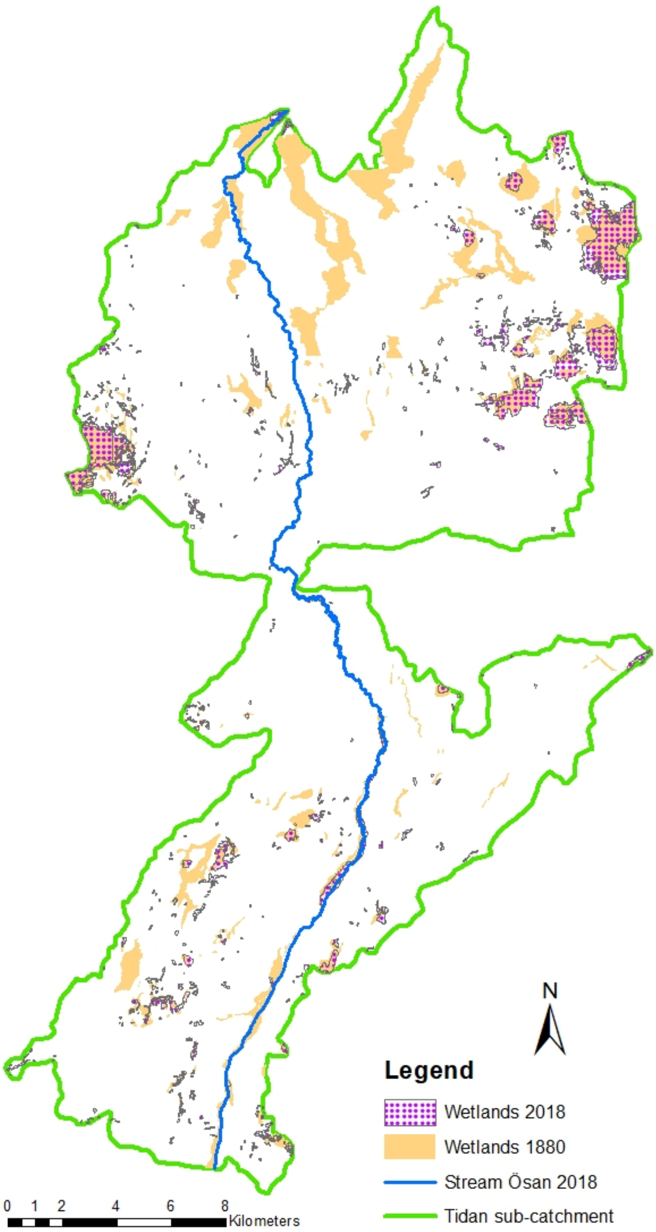

Figure 10. Areal change (54%) of wetlands between the years 1880 (44.3 km^2) and 2018 (20.5 km^2) in Tidan sub-catchment.

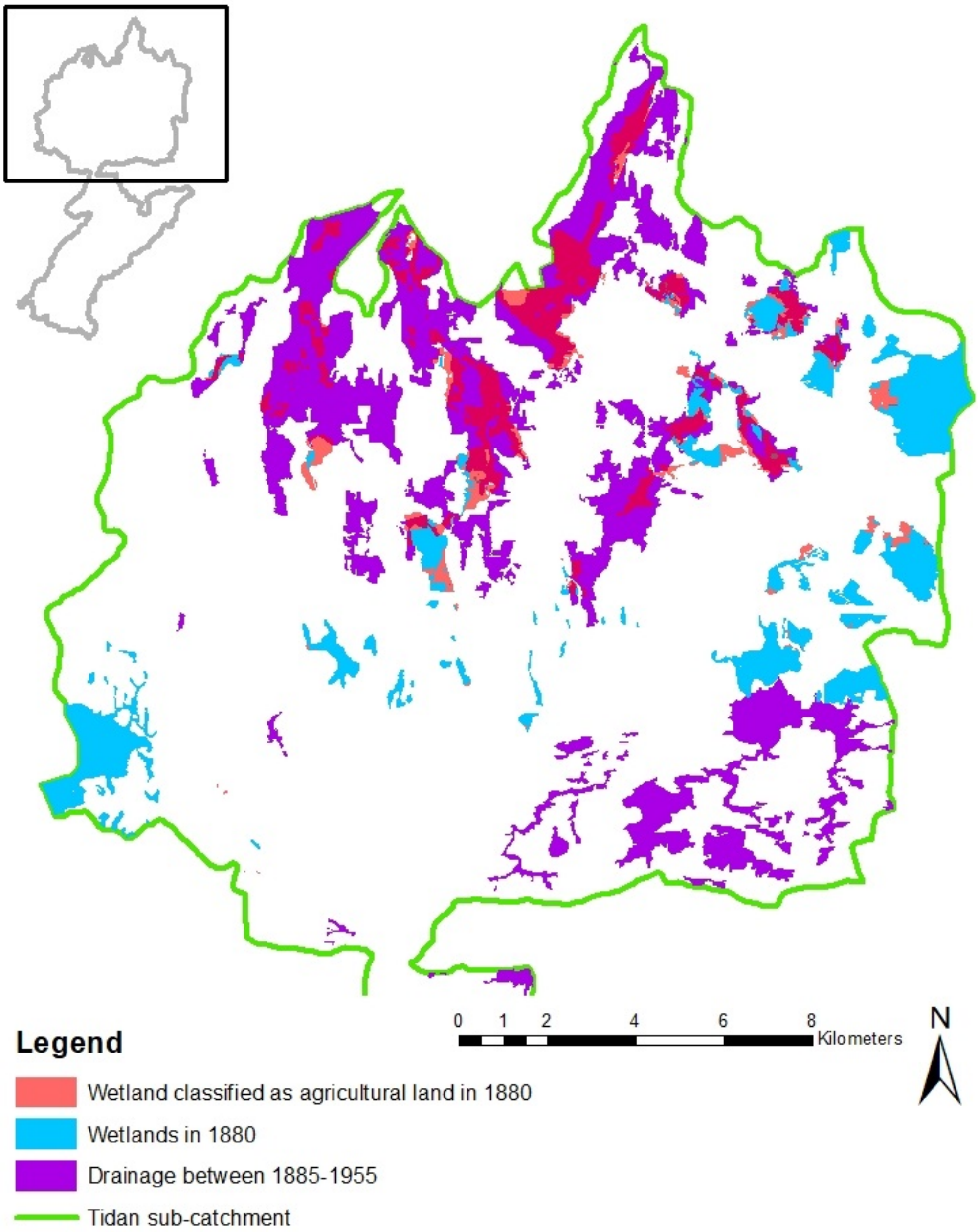

Figure 11. Wetland areas of 1880 and drained areas between the years 1885 to 1955 in the northern part of Tidan sub-catchment.

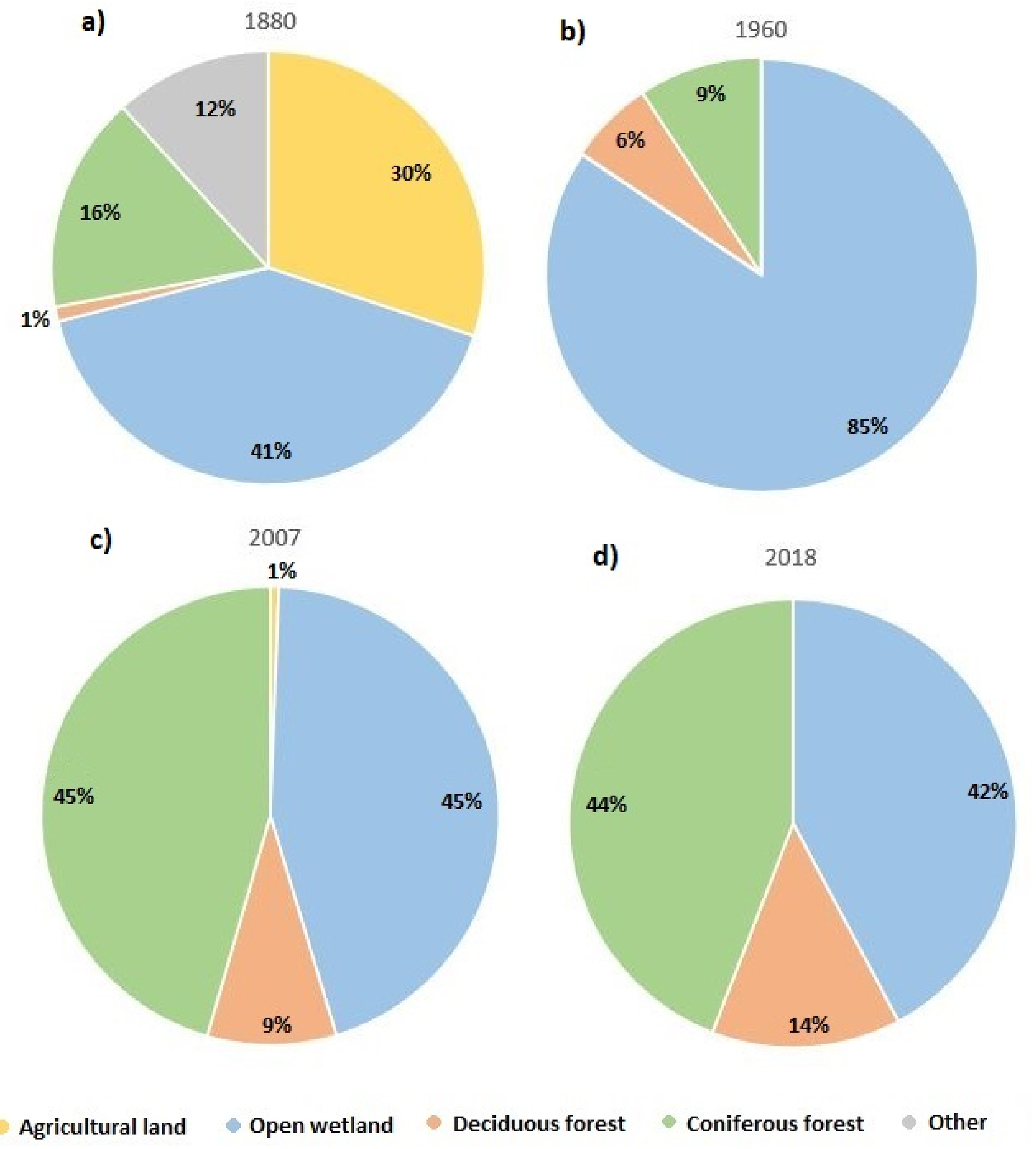

Figure 12. Share of land cover on wetlands for respective years 1880, 1960, 2007, and 2018 of cartographic data. Base maps and map data used for identification of land cover on wetlands; a) Generalstabskartan and Häradsekonomiska kartan, b) Black and white orthophotography and National Land Cover Database, c) Colored orthophotography and National Land Cover Database and d) Property map (vector format) and National Land Cover Database.

5. Discussion

5.1. Georeferencing and RMS error

Comparing historical maps and attributes with contemporary orthophotographs can be problematic. A problem of measuring the spatial attribute in historical maps is the positional inaccuracy and uncertainty of these maps (Tucci & Giordano 2011). The manually georeferenced maps GsK (1880), HeK (1880), and JaK (1920) are influenced by human-induced errors such as differences in decision making of control points and accuracy of control points between the different maps. The type of control point used for georeferencing should be stable features such as railroads, intersections, monuments, and buildings rather than natural features more likely to change through time, such as coastlines, lakes, and streams (Piovan 2019). For referencing GsK (1880) and HeK (1880), stable reference points such as churches were used, and for JaK (1920), both churches, railroads, and intersections were used. Hence, the maps have a reasonable basis for rectification and transformation. The control points are generating an RMS error which is a good assessment of the transformation accuracy. However, a low RMS error does not correspond to an accurate registration because the transformation might contain one or more poorly placed control point (ESRI n.d).

The mapping methods before aerial photographs are often representing scale, angle, distance, and direction imprecisely. Hence, historical maps are difficult to align accurately to a modern coordinate system. The location of stable reference points such as churches and railroads generates residual errors and positional inaccuracy. The georeferenced map results represent an approximate location of the features depicted on the historical map (Husak 2009).

5.2. Sinuosity index change in the stream network

The sinuosity index indicates a temporal variation with the least meandering in 1880 (SI = 1.17 ± 0.11), the highest meandering degree in 1960 (SI = 1.28 ± 0.16). In 2007 (SI = 1.27 ± 0.15) and 2018 (SI = 1.27 ± 0.16) the meandering degree slightly decreases. The general increase in SI between 1880 and 2018 could be caused by the lower detail level of historical maps. What is considered a meandering in the orthophotographs might not have been depicted in the historical maps for compromised detail requirements.

The generalization of meander bends in GsK (1880) could explain the increased sinuosity index seen between 1880 and 1960. The black and white orthophotograph (1960) has an accuracy of 0.5m. Thus a meandering bend of 0.5m or greater will be visible on the orthophotograph but not on the historical maps GsK (1880) and JaK (1920), where a meander bend of 10m is the minimum curvature to be depicted (Appendix H).

The standard deviation of the sinuosity index follows the trend of being greater from 1880 to 1960. The higher value of standard deviation in 1960 orthophotographs could be caused by the difficulty of determining where the streams are located due to vegetation cover. Hence, where it was possible to detect the streams by comparing FkV (2018), the streamlines were altered, while where a canopy covered the streams, the general stream by the FkV (2018) was accepted. The alteration of the streams from FkV (2018) could be the reason for the slight increase in SI seen between 2018 (SI = 1.27 ± 0.16) and 1960 (SI = 1.28 ± 0.16).

An example of improving the accuracy of stream placement by historical topographic maps is done by Rhoads et al. (2016). The historical topographic maps were incorporated with blue lines representing watercourses to help interpret stream channel position on the historical aerial photograph, mainly where the stream is covered by vegetation. However, as Rhoads et al. (2016) describes, the historical topographic maps have limitations by indicating streams where historical aerial imagery shows terrestrial land. Another example is Hasselquist et al. (2018), who used a Digital Elevation Model (DEM) to determine the extent of ditches in a catchment area in northern Sweden. The DEM detected ditches doubled the size of the stream network (Hasselquist et al. 2018).

The maps GsK (1880) and JaK (1920) have different purposes, and to accurately depict watercourses might not have been the primary goal (Sveriges Geologiska Undersökning 2014; Lantmäteriet 2021a). Hence the usage of historical topographic maps would have been helpful for both the historical maps (1880 and 1920) and for detecting streams covered by tree canopy in the orthophotographs (1960 and 2007)

Figure 7 indicates a noticeable transition of the stream Ösan from GsK (1880) and JaK (1920) compared to the stream in FkV (2018). The RMS error for the GsK (1880) map is 82m and 32m for JaK (1920), which possibly explains the difference in stream transition. The mean stream transition difference between GsK (1880) and FkV (2018) is 46m, and between JaK (1920) and FkV (2018), it is 31m. The mean transition lies within the RMS error for GsK (1880) (82m) and JaK(1920) (32m) and suggests the transition is due to imprecision of the data. However, the

RMS error value is exceeded by the maximum stream transition value of 233m and 191m for GsK (1880) and JaK (1920), respectively (Appendix I). The maximum stream transition value indicates either landscape impact, anthropogenically alteration, or differences in the resolution of the data.

5.3. Change of stream network length

The results show a change in stream length over the studied period towards streams being longer in the present time than historically. However, the stream length is subjected to errors by input data indicating inaccurate temporal differences. The increased stream length between GsK (1880) and FkV (2018) could be caused by differences in map resolution and level of detail (Appendix G). The positional accuracy of historical maps is generally less than contemporary maps (Tucci & Giordano, 2011). Therefore, the different detail level needs to be considered when comparing the extent and lateral changes of the stream. Smaller streams are likely simplified and not depicted in the historical maps, which gives an uncertainly when comparing the total length of the streams between the years (Appendix F).

The scale of GsK (1880) and the JaK (1920) varies between 1:100 000 and 1:50 000, respectively. The lowest level of detail that could be detectable from GsK (1880) and JaK (1920) is 10m. For the orthophotographs representing the years 1960 and 2018, the lowest level of detail is 0.5m and 0.25m, respectively. The fewer and shorter streams depicted on GsK (1880) and JaK (1920) could be caused by the map's scale, purpose, or the surveyor.

Due to ditches and stream networks being grouped in this study, the representation of total stream length might be misrepresentative since ditches from GsK (1880), and JaK (1920) might not be depicted on the historical maps due to water fluctuation during the year (Hasselquist et al. 2018). The longer stream length in 1960, 2007, and 2018 compared to GsK (1880) and JaK (1920) could be due to streams on the orthophotographs (1960 and 2007), and FkV (2018) are missing on the historical maps. In connection to this, the small difference in stream length between 1880 (314 km) and 1920 (339 km) might be due to the scale difference, where there is a higher level of details in JaK (1920) (scale 1:50000 compared to 1:100 000 in GsK (1880)). The decrease in stream length between 1960 (777 km), 2007 (740 km), and 2018 (716 km) indicate little change in the length of the stream network. However, the small change that can be seen might indicate that the streams either have been straightened or parts have been changed from open ditches to tile drainage. Tile drainage affects the flow pattern and water quantity (Gramlich et al. 2018). Streams abundant with water might not be considered a stream due to the change in water quantity.

A helpful method to explore the spatial variation of the stream network is to use the Strahler stream order. The study by Li (2021) used the Strahler stream order to identify headwater streams for researching greenhouse gas emissions from these streams. Though the study is on greenhouse gas emission, the usage of identifying headwater and tributaries helps determine the stream network extent in the Tidan sub-catchment

5.4. Land cover of wetlands and wetland area change

The results show a change in wetlands' land cover, comparing 1880 data with data from 1960, 2007, and 2018. In 1960, open wetland and forest (coniferous and deciduous) corresponded to 85% and 15%, respectively; meanwhile, in 2018, open wetland and forest represent 42% and 58%, respectively (Figure 12). The change of open wetland and forest cover stands out when comparing 1880 to 1960 because of the large percentage change. However, some variables need to be considered before comparing these land cover changes. One crucial factor is the maps used for classifying land cover on the wetlands.

The wetland area representing 1880 is generated from four map sheets of GsK (1880). The four sheets covering the catchment area are produced between the years 1842-1881 (Appendix A). The land cover classification of these wetland areas is determined by using 14 map sheets of HeK (1880) covering the catchment area between the years 1877-1882 (Appendix B). Most of the wetland area classified as agricultural land in 1880 is located in the GsK (1880) map sheets from 1845. Meanwhile, the classification of agricultural land is done by using HeK (1880) map sheets between 1877-1882. One explanation for the 100% decrease in land classified as agricultural land between 1880 and 1960 could be due to differences in the production year of GsK and HeK. According to Myrdal (2000), Sweden underwent increased drainage in the 19th century, starting in 1820. Hence the decrease in agricultural land on wetland base on HeK (1880) is because the wetlands were already drained before the production of the map, causing the results to be misrepresenting land cover classification. The result of 30% of the total wetlands area being used as agricultural land in 1880 is questionable from the beginning due to the difficulties of growing crops on wetlands.

The HeK (1880) map used to classify land cover for 1880 has distinct boundaries between open land and forest. In addition, it has different symbology for the deciduous and coniferous forest. The distinct boundaries are making the different land covers easy to distinguish. On the contrary, the boundaries between open land and forest in the orthophotographs (1960, 2007, and 2018) are fuzzy. Deciduous forests and coniferous forests are indistinguishable from the orthophotographs, making the land cover classification difficult. With imagery taken during the autumn or winter, land cover classification accuracy might have improved due to the canopy color change or the disappearance of the leaf during winter. Hence, area differences between open land and forest between 1880, 1960, 2007, and 2018 could result from subjective decisions by the map interpreter and by the land surveyor. These differences could affect the results by either overrepresent or underrepresent the areal share of land cover classifications in the individual maps.

The decrease in open land and increase of coniferous forest between 1960 to 2007 and 2018 could be caused by an increase in forestry during the early 20th century (Li et al. 2013). Drainage in the forest affects soil water conditions, thus improving soil conditions potentially enables improved conditions for tree growth. Increased tree growth could explain the decrease in open wetland and increased coniferous forest between 1960, 2007, and 2018 (Sikström & Hökkä 2016).

Change in location and size of the wetlands are to be considered when interpreting the wetland land cover change. The wetland area in Tidan sub-catchment decreased by 54% from 1880 to 1960. The overall wetland area is situated at the same locations throughout the years, with no indication of new wetlands. However, in the maps representing the year 1960, 2007 and 2018 there are small wetlands areas which are not detected on GsK (1880) and JaK (1920) (Figure 10). The wetland locations and areal difference could be caused by the lower resolution of GsK (1880) and JaK (1920). The loss of wetland has occurred in the north part of Tidan sub-catchment. That wetland decrease would be expected due to those areas being subjected to drainage (Figure 11) (Länsstyrelsen Västra Götaland 2020).

To compare the change of the total area of wetlands, the individual definition of wetlands should be the same between the comparing years. The definition of wetlands made by LM on FkV (2018) differs from wetlands' definition in GsK (1880). Where LM is defining wetland as “marshland” and “marshland almost impassable” (Geografiska Sverigedata Lantmäteriet 2019). Meanwhile, GsK (1880) is defining wetland as fen (Table 1). The total wetland area based on JaK (1920) is determined by soil types peat, peat bog, and muck (Lindholm & Peilot 2008). To classify wetlands based on soil type is problematic because the soil type does not verify the definition of the area being a current wetland, as per wetland definition. Like the above mentioned, differences in wetland classification affect the results by possibly giving an inaccurate comparison of their areal extent. The interpretation of drainage being the reason for the wetland area decrease should consider the definition differences. The decrease in wetland might not exclusively be due to drainage. Parts of the area change could be due to the classification differences of wetland in GsK (1880), JaK (1920), and FvK (2018).

By researching Swedish historical documentation and archives, the accuracy of historical wetland locations and more detailed wetland classification could be obtained. There might be information from farmers' documentation and from drainage companies on the areal extent of the drainage and a detailed description of wetland type in the Swedish archives.

6. Conclusions

The objective of this study was to quantify the spatiotemporal changes of streams and wetland areas in Tidan sub-catchment in Västergötland. This study shows a 54% decrease in wetland area and a land cover shift of wetlands from open wetland to forest-covered land between 1880 and 2018. In addition, the results indicate an increase in stream length and meandering degree between the same years. However, it could not be concluded entirely that the changes are human-induced and not an inaccuracy issue from the material used. Nevertheless, the result shows that there is a change in the study area.

The results can be used for further research in assessing the importance of the historical locations of wetlands when implementing wetlands. Further to be investigated is if former wetland areas are suitable for wetland restoration to increase water - and nutrient retention capacity and if the restored wetland is working as intended.

Even though the results are unreliable due to the inaccuracy of historical maps, the results show an overview of where these wetlands have been located historically. Together with additional data such as field confirmation or historical documentation, the results can be helpful for further research.

For implementing wetlands, the location needs to be assessed considering the economic aspect of the land use from an agricultural and forestry perspective. The environmental benefits of wetlands are to be weighed with the economic benefits of that specific location.

For similar sub-catchments studies, the methods used could be complemented with a more detailed determination of types of streams differentiating between a stream and open ditches.

The decrease of wetland area (54%) has adverse effects on the availability of surface water for irrigation (Mattson et al. 2018). With a growing population, increased demand for agricultural products, and a changing climate, the irrigation need increases (Government Offices of Sweden 2016). Not only do wetlands suffice the need for irrigation, but increasing the wetland areal is a step towards reaching the SDGs and the Swedish goal of “Thriving Wetlands”.

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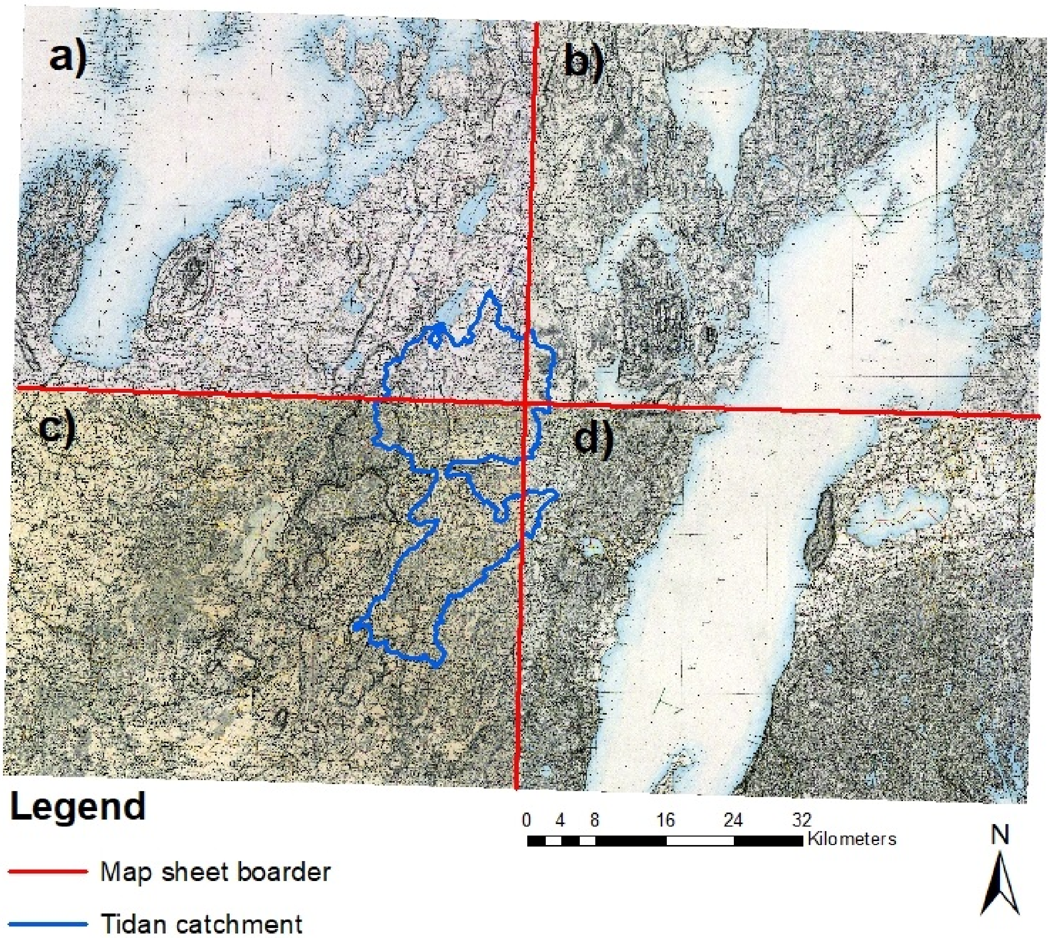
Appendix

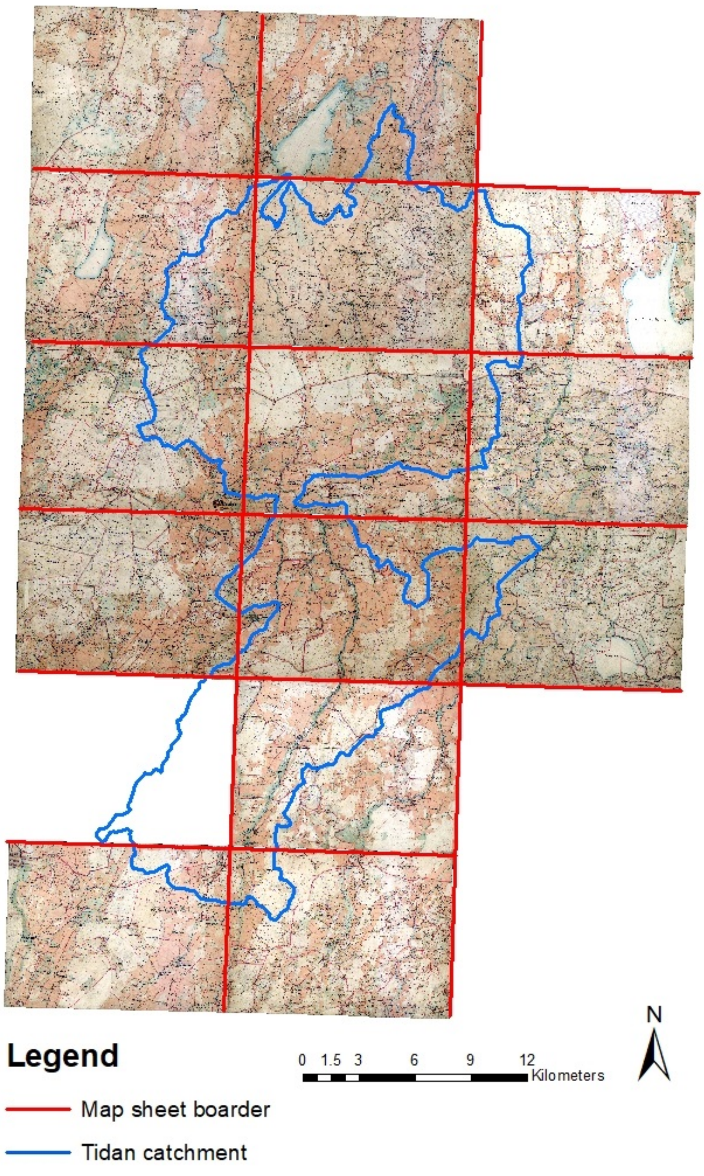
Appendix A

The base map, Generalstabskartan (©Lantmäteriet 2021 https://historiskakartor.lantmateriet.se/arken/s/advancedsearch.html 4 Feb 2021), consists of four map sheets to cover Tidan sub-catchment. The map sheets are merged and used to determine the wetland area and stream network extent. The sheets represent years a) 1845, b) 1842, c) 1881, and d) 1880.



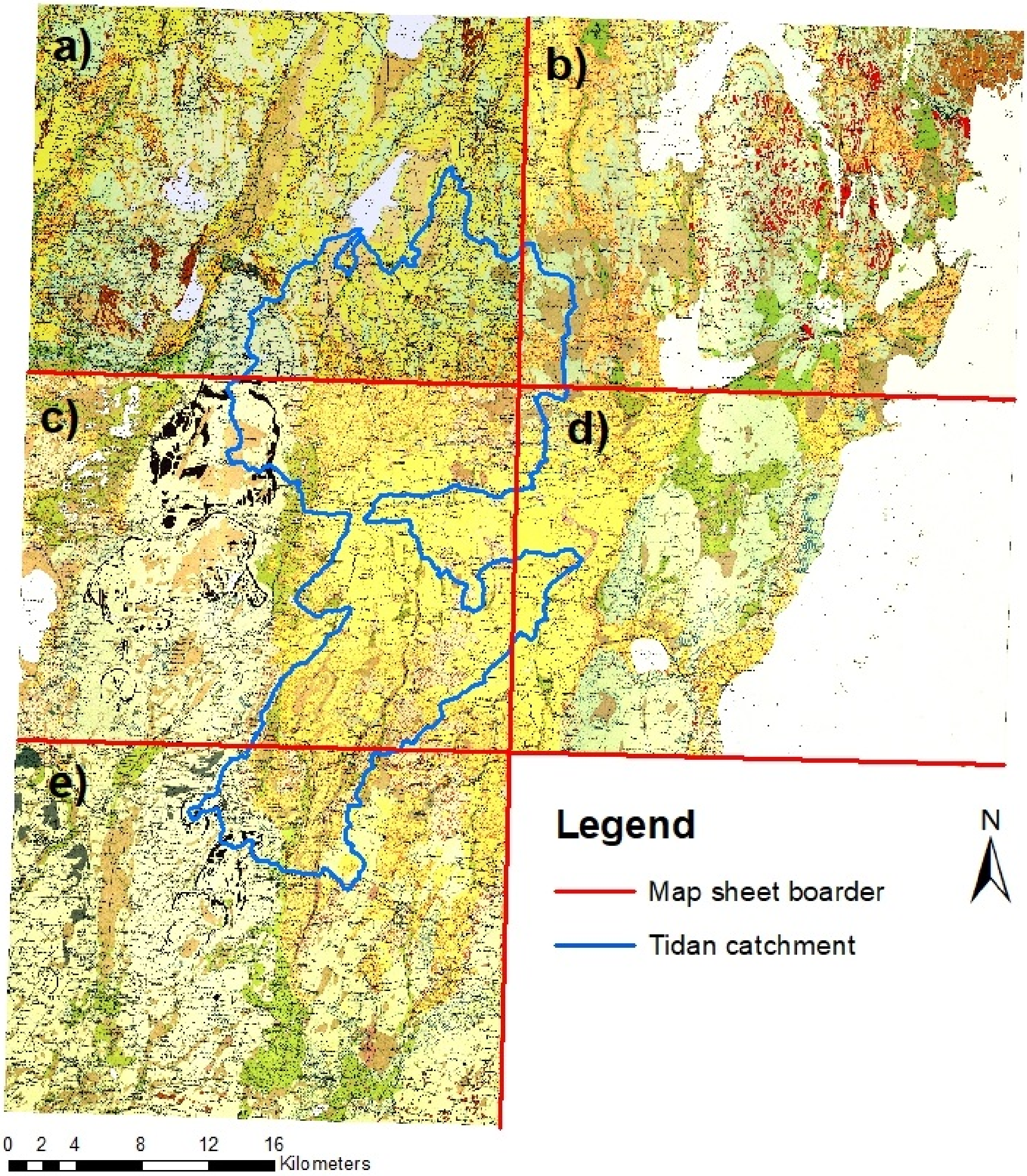
Appendix B

The base map, Häradsekonomiska kartan (© Lantmäteriet 2021b https://historiskakartor.lantmateriet.se/arken/s/advancedsearch.html 25 Feb 2021), containing 14 map sheets merged to cover Tidan sub-catchment. The maps are used for classifying land cover representing the year 1880. One sheet is missing in the southwest part of the catchment. The individual sheets are missing a specific production year, but and the survey period ranged from 1877-1882.



Appendix C

Base map of Jordarskartan (© Sveriges Geologiska Undersökning 2014 https://apps.sgu.se/geolagret/ 27 Jan 2021) was used to calculate the stream network extent in 1920 together with the wetland area based on the shape-file obtained by the county administrative board, Västra Götaland county. The sheet represents the years a) 1921, b) 1905, c) 1899, d) 1900, and e) 1899.



Appendix D

Table showing the land cover classifications acquired by the Swedish Environmental Protection Agency, Nationella marktäckedata. The color-coding represents the reclassification.

ID number	Land cover classification
1	Open wetland
2	Agricultural land (Permanent crop, grazing, and fallow)
3	Open land without vegetation
4	Open land with vegetation
5	Exploited land, buildings
6	Exploited land, no buildings or road/railway
7	Exploited land, road/railway
8	Lakes and streams
9	Ocean
10	Pine forest (outside wetlands)
11	Spruce forest (outside wetlands)
12	Coniferous forest (outside wetlands)
13	Leaf-mixed conifers forest (outside wetlands)
14	Deciduous forest, non economically important (outside wetlands)
15	Deciduous forest, economically important (outside wetlands)
16	Deciduous forest, mixed economic importance (outside wetlands)
17	Temporarily no forest (outside wetlands)
18	Pine forest (on wetlands)
19	Spruce forest (on wetlands)
20	Coniferous forest (on wetlands)
21	Leaf-mixed conifers forest (on wetlands)
22	Deciduous forest, non economically important (on wetlands)
23	Deciduous forest, economically important (on wetlands)
24	Deciduous forest, mixed economic importance (on wetlands)
25	Temporarily no forest (on wetlands)

Land cover reclassifications	Classification ID numbers
Agriculture land	2
Open wetland	1, 3, 4 17 and 25
Deciduous forest	13, 14, 15, 16, 21, 22, 23 and 24
Coniferous forest	10, 11, 12, 18, 19 and 20
Other	5, 6, 7, 8 and 9

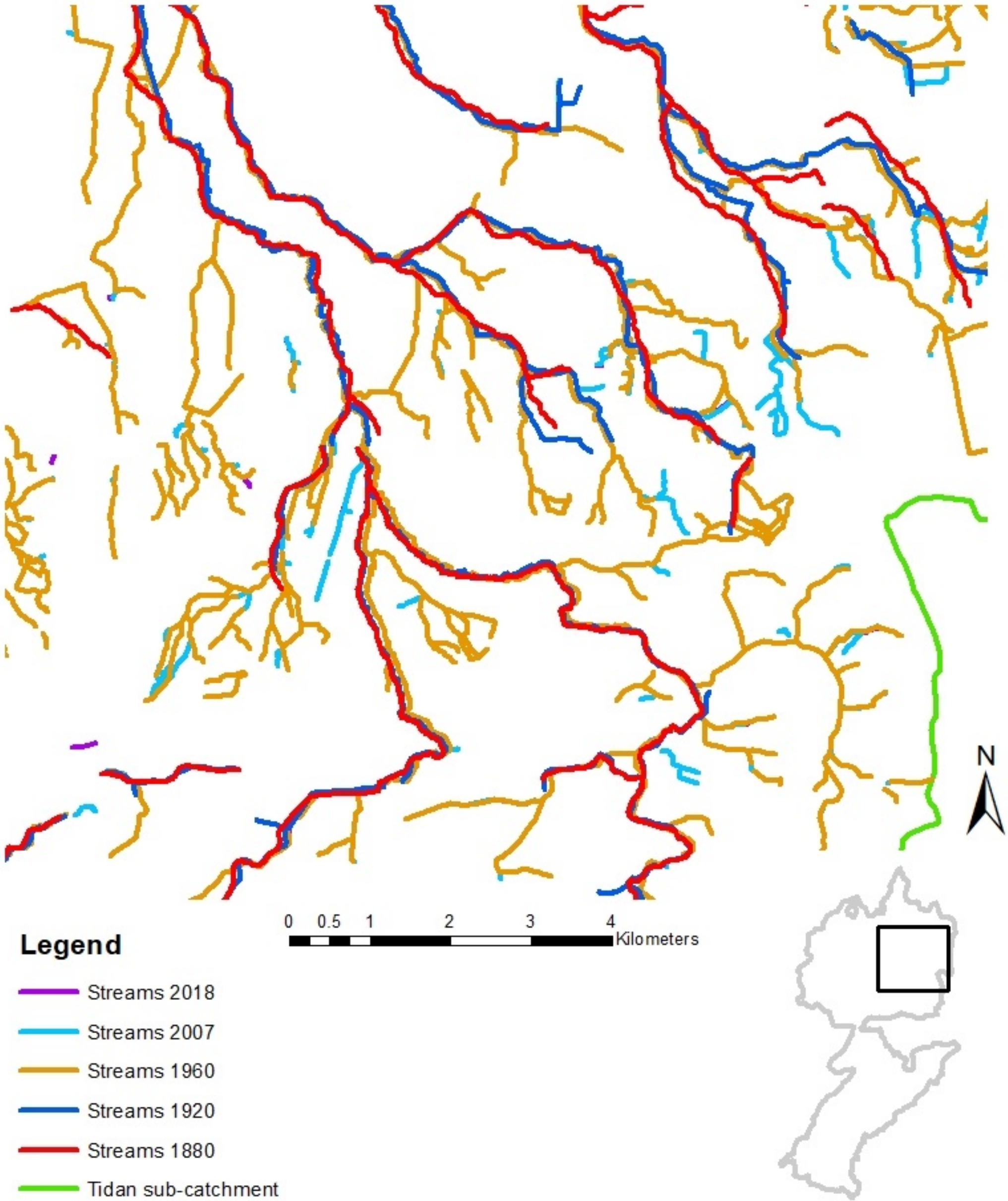
Appendix E

Table of the total stream length of the subdivisions and stream Ösan in Tidan sub-catchment and their respective percentage change compared to 1880.

	1880	1920	1960	2007	2018	1880 to 1920 change %	1880 to 1960 change %	1880 to 2018 change %
Northeast	91	108	243	238	225	19	166	146
Northwest	61	66	159	153	148	7	160	141
Southeast	47	46	153	141	139	-4	224	194
Southwest	65	69	168	155	151	5	157	131
Stream Ösan	49	51	54	54	53	5	10	8
Total length	314	339	777	740	716	8	147	128

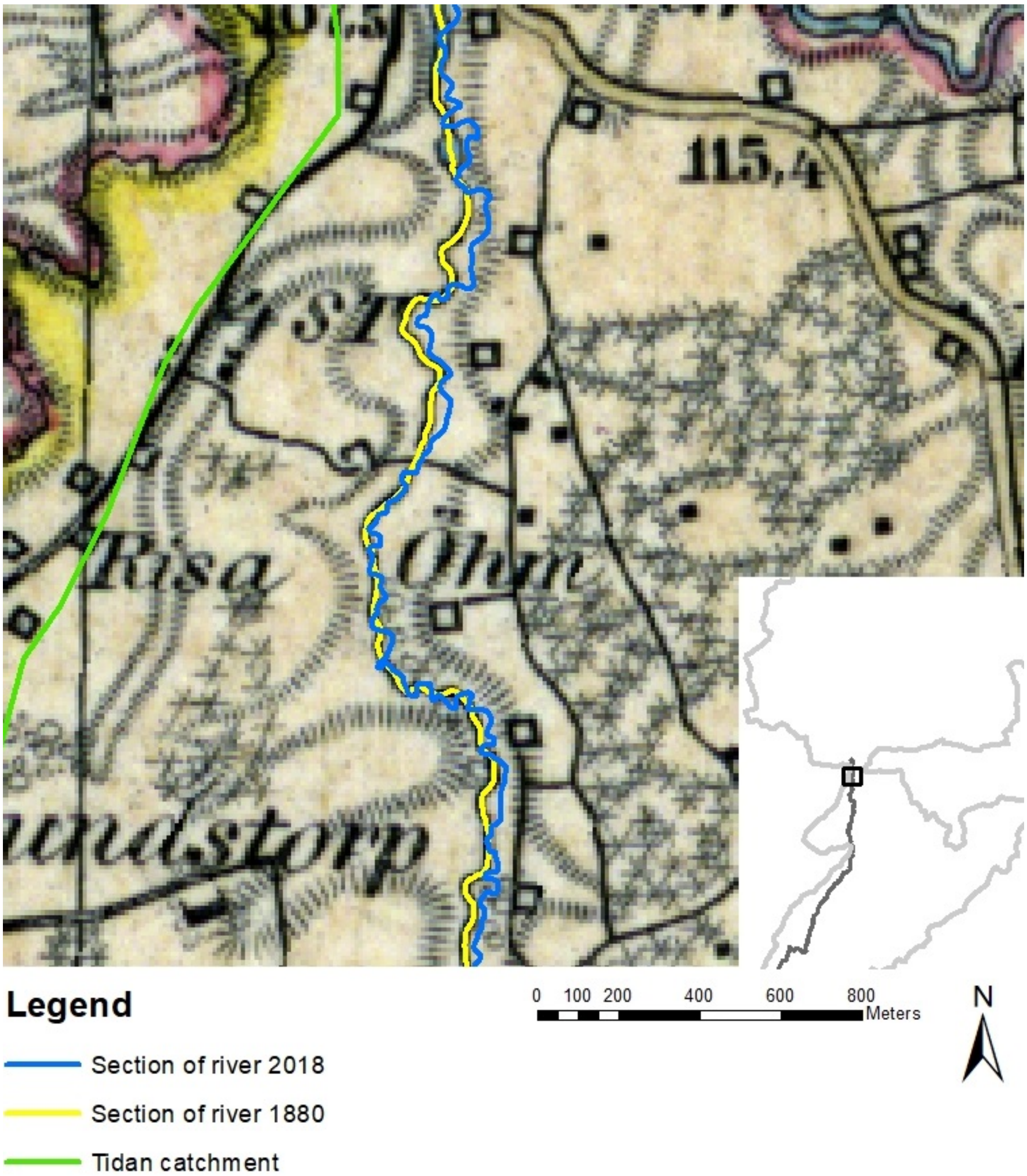
Appendix F

The figure depicts the vector shape-files representing streams in 1880, 1920, 1960, 2007, and 2018.



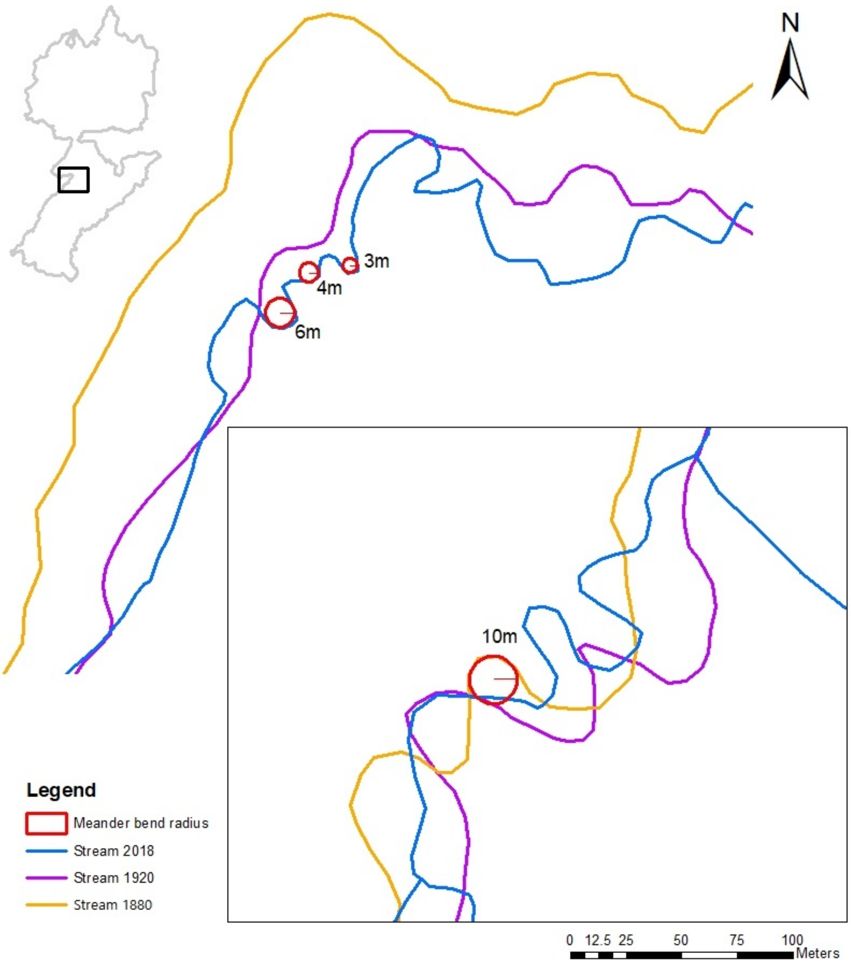
Appendix G

The figure depicts a section of a stream from GsK (1880) in yellow compared with the same section of the stream from FkV (2018) in blue. The streams show the difference in meandering accuracy. Base map: Generalstabskartan, scale 1:100000, (©Lantmäteriet 2021 https://historiskakartor.lantmateriet.se/arken/s/advancedsearch.html 4 Feb 2021)



Appendix H

Figure showing a depiction of the same stream representing GsK (1880), JaK (1920), and FkV (2018). The level of detail differences is shown by the red radius marked on the stream from 2018 (blue), where a meander bend by 6m, 4m, and 3m is not included in the stream's depiction from 1880 or 1920. The radius marked as 10m shows the minimum level of details seen from GsK (1880) (Orange).



Appendix I

The table presents the transition mean, minimum, maximum, and standard deviation of the six streams (northeast, north, northwest, southeast, southwest, and stream Ösan) in the Tidan sub-catchment. The transition is measured between 1880-2018 and 1920-2018.

1880	**Mean (m)**	**Minimum (m)**	**Maximum (m)**	**Standard Diviation (m)**
Northeast	138	0.1	437	91
North	100	0.2	257	74
Northwest	113	0.2	446	101
Southeast	43	0.06	109	25
Southwest	83	0.03	515	121
Ösan	46	0.005	233	38
1920	**Mean (m)**	**Minimum (m)**	**Maximum (m)**	**Standard Diviation (m)**
Northeast	18	0.04	69	17
North	34	0.02	171	25
Northwest	33	0.05	136	24
Southeast	30	0.03	171	28
Southwest	56	0.04	525	105
Ösan	31	0.004	191	26