The possible impact of the restoration of River Skjern

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Contens.

Chapter One

1. Introduction

River restoration is widely used by Danish authorities due to the generally poor conditions of Danish streams. For many years the purpose of Danish stream management, has been to increase the streams ability to transport water away as fast as possible to make agricultural land free from being flooded and soaked. Therefore most Danish streams were straightened and the wetlands, meadows and field drained. Stream vegetation was also cut to make the water flow free and fast. The attitude was strictly about increasing agricultural yield from the 19th century and unto the late 20th century.

The River Skjern was channelled in the late 1960th to increase agricultural land and yield. The project included channelisation the lower part of River Skjern, drainage systems and pumping stations. Draining dried up 4000 hectares of wetland and meadows.

The channelisation was a success in respect of creating more farmland and controlling of flooding. As a consequence, the fisheries in the fjord subsequently disappeared because of increased ochre and nutrients loads from the newly created agricultural areas.

The attitude towards the management of streams changed. The streams where now not only supposed to transport water, but also to contain a wide variety of species. The stream changed from a water channel to a habitat. Because of this the channelised streams are being restored, as the case with the River Skjern.

The idea of restoring channelised streams and rivers, as well as the surrounding wetlands and meadows, is to re-meander the channelised streams and thereby recreating the natural dynamics of the watersheds.

Measurements for the success of the restorations are reductions in discharge of ochre and nutrients like nitrogen and phosphorus compounds, retained in the recreated wetlands and meadows. The reduction subsequently leads to a higher nature quality in the restored areas and the surroundings.
The aim of this report is to investigate the possible implications of the restoration of the River Skjern on its watershed, with main focus on the processes in the river course itself and the surrounding wetlands.

1.1 Problem formulation:

It has been observed that flora and fauna in the River Skjern watershed is degrading. Increased load of nutrients and ochre into Ringkøbing Fjord has been reported. The nutrients include nitrogen and phosphorus. Eutrophication in the Fjord has been common observation. Animals and plants, which depend on the bountiful natural production in watershed, were decreased in number and diversity and among them are popular Skjern salmon and a lot of high valued migratory birds, which are on EU list.

It has been acknowledged that the channelisation of the River Skjern that drained most of the wetlands and reduced the size of wetland area is the hinge of these problems. The restoration of the River Skjern is to increase the wetlands area and improve self purification of the river systems.

Problems associated with channelisation of River Skjern can be summarised as follows:

- Ochre formation due to lowering of the groundwater table.
- Eutorphication in the Ringkøbing Fjord due to extensive farming activities on the upper part.

- Decreased in the popular River Skjern salmon.
- Decreased in population of high valued migratory birds.
- Decrease in suitable habitats for the otter.

The first three are the subject of our project report.

1.2 The organisation of report

Chapter one introduces the project report, gives background information on problems in the watershed and outlines questions to be answered in the report. It also gives information on the methodology of the report.

Chapter two gives overview of the River Skjern Watershed. Land uses activities, Hydrology, climate and geological aspects of the Watershed are discussed.

Chapter three deals with socio-economy-political issues pertaining to both channelisation and restoration projects.

Chapter four outlines the entire concept that impinges on our project report.

Chapter five entails facts and application of concepts on River Skjern.

Chapter six opens discussion on the restoration project

Chapter seven draws curtains on the report by answering all the project questions.

Project questions

1. Why was channelisation important in the 1960's

2. Why is restoration important to day
3. What role does meandering play in restoration
4. What role does wetlands and meadows play in restoration
5. What is nature quality in relation to Skjern watershed
6. Will the restoration of the River decrease the nutrient and ochre load in the Fjord.

1.3. Methodology

In writing the report information were gathered from the internet homepages of DMU, SNS, MEM, DMI, SB.au, Ringamt, google search engine and from relevant text books. Visit to the site in February. Interview with Heine Glüsing. Concepts that impinges on our project.

Chapter Two

2. Overview of Skjern Watershed

2.1 The Skjern Stream

The River Skjern is located in the western part of Jutland and is the main river of the River Skjern systems. The River Skjern is the largest River in Denmark, in terms of discharge corresponding to 39 cubic metres per second, with watershed area covering 6% of the country (Prologue, 2001). It is a fourth-order stream, according to figure 1 shown below. It drains a total area of 2490 square kilometres. The major tributaries contributing to the River Skjern are Brand Stream, Holtum Stream, Rind Stream, Karstoft Stream, Vorgord Stream and Omme Stream (Svendsen & Hansen 1997). The River Skjern takes it source from ground water at Tinnet Krat about 6 kilometres from Nørre Snede and after flowing through a distance of about 78 kilometres westwards it pours itself into Ringkøbing Fjord.

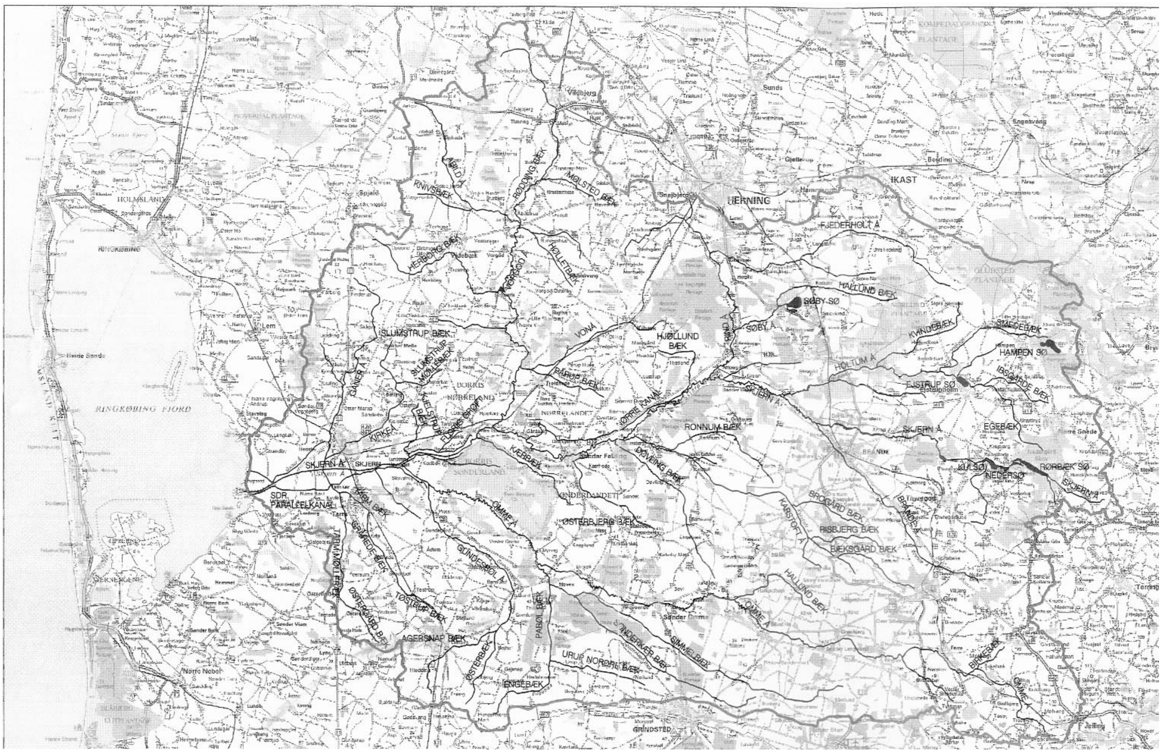


Figure.1: Shows River Skjern systems

2.2. Ringkøbing Fjord

The Fjord having an area of about 300 square kilometres is shallow and brackish. The sites surrounded by a host of small-uninhabited islands, being popular among them are Tipperne and Værnengene. The Fjord is connected to the North Sea by sluices. The source of inflow is the River Skjern, which enters through the south-eastern corner of the Fjord. Once forming the largest delta in Denmark. Though the lower part of River Skjern was modified in the 1960's some of the wetland vegetation still remain around the river mouth. The Tipperne peninsula, which extends into the southern part of the Fjord, is covered by low-lying meadows used in part for hay cutting and extensive grazing. Ringkøbing Fjord is in the List of Wetland of Importance, which is to be maintained under the Convention on Wetlands (Ramsar, Iran 1971). The Fjord area is a special EU protection area for birds. The site is internationally important for wintering and staging water birds, including Bewick *Cygnus columbianus bewickii* (384), Pink footed goose *Anser brachyrhynchus* (7,700), Grey lag-goose *Anser anser* (2,500), Barnacle goose *Branta leucopsis* (1,200), Widgeon *Anas penelope* (20,000), Teal *Anas crecca* (13,000), Pintail *Anas acuta* (1,500), Shoveler *Anas clypeata* (700) and Avocet *Recurvirostra avosetta* (1,100). It is also an internationally important breeding area for Avocets (425 pairs) (DMU, 1997).

2.3. Land use activities

75 % of the total watershed area is cultivated, 13% forested, 7% is undisturbed countryside and the remainder is urbanised (Svendsen & Hansen, 1997).

The predominant economic activity in the Skjern watershed is agriculture. The agricultural activities include cattle rearing, crop farming and fish farming.

Crop and fish farming are the main contributing activities to the deterioration of water quality in the watershed

The cultivation activities in the reclamation area during the last three decades, led to high concentration of phosphorus and nitrogen in the River Skjern and Ringkøbing Fjord. In the Fjord this has led eutrophication (Kronvang et al., 1999).

The principal human activities at the Fjord site include commercial fishing, reed harvesting, and sheep grazing, hunting and extensive farming.

Chapter Three

3. Socio-economic-political aspects

3.1. Politics of the restoration of River Skjern

The purpose of the restoration according to the law is to re-establish the River Skjern from Borris to the outlet in Ringkøbing fjord. The re-establishment shall create possibility for meandering and natural water-level variations to be re-created and thereby contribute to improve living conditions of animal and plant life. To insure a high stream quality in the watershed of river Skjern and high water quality in the Ringkøbing fjord, as well as improve recreationally possibilities in the area (Law on restoration of river Skjern, No. 493).

The project includes the restoration of 2192 hectares of river valley. The idea with restoring such a large area is to create a large correlated area of unique value (SNS, homepage).

The big channelisation in 1962-68 regulated and de-watered an area of 4000 ha, which included the lower parts of River Skjern. The regulation was a success and fulfilled its goal of reducing the water suffering area in the river valley and increased the possibility of intensive farming

The results of the de-watering of the area was big subsides in peat areas of the River Skjern, somewhere over one meter. The restoration also led to ochre pollution and increased nutrient loads to the river and fjord. The ochre pollution is thought to be main responsible of the drastic decline in fisheries following the restoration (Ringkøbing amt 2000a,b).

The Danish parliament decided in 1987 that a project should be developed for River Skjern, which would include how to recreate the self- purification of the river and how to re-establish nature and recreational values. After public hearings and discussions of several frame works the environmental minister, at

that time, decided to go through with the project to recreate the river as it was before the big channelisation.
On basic of the size of the project the ministry of environment and energy decided in autumn 1997, that the foundation of the project should be laid down in a foundation law, after all the project environmental implications was investigated, in a VVM statement, (assessment of impact on environment). The law of River Skjern, law number 493, was accepted at the 1 of July 1998. According to the law the River should be laid back in the old course as it was before the channelisation at the turn of the century. The project was sent into licitation and the work started the 7 of June 1999.
The Delta of River Skjern and all of Ringkøbing fjord has been designated as international bird protection area for wading birds (RAMSAR-/EU-bird protection area). The area has also been classified as EU habitat area, which has been established to protect valuable nature types and animal- and plant-species. The special valuable species in the area are the Skjern Salmon *Salmo salar*, the Otter *Lutra vulgaris* and the rare plant *Elisma natans* (SNS Homepage).

Table 1: The budgets of the restoration:

Acquisition/substitutions	92 Mio. Kr.
Projecting	14 Mio. Kr
Fieldwork	112 Mio. Kr.
Information	15 Mio. Kr.
Surveillance of Ringkøbing fjord	8 Mio. Kr.
General surveillance of environment	9 Mio. Kr.
Other expenses	4 Mio. Kr.
Total	254 Mio. Kr.

The two main expenses are acquisitions/substitutions and for the fieldwork, see table 1. A lot of agricultural land had to be bought from the farmers around the lower part of River Skjern, this took about 12 years to complete, from the time

where the parliament in 1987 decided to go through with the project until the first digging started in June 1999.
The expected increase in reduction of output of nutrients and ochre are 330 tons of Nitrogen/Year equivalent of 5% of total reduction, 14,4 tons of phosphorus/Year equivalent of 9% of total reduction and 635 tons of ochre/Year equivalent of 25% of total reduction (SNS homepage).

The EU effect on Danish agriculture politic

European Union regulation on environmentally sustainable agriculture production and ecosystem rehabilitation projects, now envisage implementation of changes in land use and cultivation practice in river valleys within larger connected areas/watershed.

3.1.2. The Action plan on the aquatic environment (APAE)

The main objective of the APAE is to reduce nitrogen and phosphorus discharge to the aquatic environment by 50% of Nitrogen and 80% of Phosphorus. In metric tons it is a reduction from 290,000 tons to 145,000 tons of nitrogen and 15,000 tons to 3000 tons of phosphorus. During the last 30 years the input of Nitrogen to Danish agricultural land has doubled, through the use of chemical and manure fertilisers. The cost of the Danish APAE is about 12,000 million DKr. Distributed on 4500 million DKr to agricultural reductions, 1500 million DKr to industrial reductions and 6000 million DKr to municipality reductions (sewage plants etc.). (AMBIO)

3.2. View on nature and the ethics behind.

To find out what nature quality is we will first discuss a bit about ethics, meaning the different view of nature, that lie behind the eyes that define nature quality. Nature quality has by no means been the same up through time and we find it appropriate in the case of River Skjern to look at the specific period around the channelisation, in the 1960th and around the restoration project from the 1980th to present time. The approach to ethics will not be the same approach as to the natural science part of this report, but will be more subjective. We have based the views of nature on definition written by Hans Fink Ph.D. in philosophy (Fink Hans, 1993).

Different perspectives of nature have influenced the management of the River Skjern. Two major events in the history of the river reflect two very different perspectives dominating at the given time. The first major event was the channelisation of the river, which happened in the late 1960´s. The other is the restoration of the river, taking place during (1999-2001). Too fully understand why these undertakings were and are accepted, we must look into how nature view is formed, and what guides it. Furthermore we must ask, what is nature? To clarify these, five perspectives of nature suggested by Hans Fink will be used and discussed.
First of all the word “nature” can mean: birth, arise, come into existence, origin, beginning etc. In wider extent the abilities a person or a thing, has from the birth or the beginning. Everything so to say has its own nature, every animal has its nature and even the elements have theirs nature. What we call nature has to do with what is fundamental, essential, original and what actually is (Hans Fink 1993).

The five perspectives of nature are:

The wild.

The agricultural and green.

The earthly and ordinary.

The law of nature.

Everything.

The first perspective looks at nature as the wild, as opposite to what has been influenced by human activity. In this perspective nature is, what it was before human intervened and changed the original natural conditions. Whenever humans have influenced nature, nature is seen as a cultural product. This view dominated in the 1960th during the channelisation.

The second perspective, perceive nature as whatever is outside the city limit, it could be agricultural land, villages, forests and plantations. From an urban point of view, the border between agricultural fields and the wilderness is not clear-cut. From this point of view, it makes sense to protect sites as heaths and other cultural landscapes, as being part of nature protection. Could be said to dominate nature perspective today.

The third perspective is crossing the borders of the former perspectives, here the differentiation is between what is earthly and what is celestial. This perspective originates from the religions which have a God of creation, a single god created everything and the creator is the only one with the freedom to create, and everything else has to follow the divine creation. In this perspective though humans have a special duality, they have their mortal body as well as their soul, which is in a sense above nature. Hans Fink writes:" Humans are half swine half angel, half free and half slave". This perspective has had, an immense varieties of shapes through time, at times people has turned to the divinity of their soul and trying to control their instincts. At other times people should bring the celestial order to earth etc. This perspective crosses the previous and influences nature view both in the 1960th and today as well.

The fourth perspective is the perspective of science. Everything operates after the mathematical laws of nature. Everything is measurable and testable. In this perspective the other perspectives still counts in the sense of the world and everything's essence and the original conditions, but in terms of biology/chemistry/mathematics and not the wild/agricultural or the earthly/ordinary. This is the view of the "scientist", like the biologist defining nature quality.

The fifth perspective has gone all the way and states that everything is nature, in this sense it does not make sense to differentiate between what is inside nature and what is outside nature. What the other perspectives counted as being besides nature, can be perceived as having its own nature and is a natural part of it. This view is more or less supported by Hans Fink.

In the first perspectives nature is a contradiction concept. Something is natural and something is not. There are limits to nature.

- In the first perspective nature starts when agriculture and exploitation stops.
- In the second perspective nature starts outside the citylimit.
- In the third perspective nature go all the way to the gates of heaven and all the way to the gates of the underworld, where the usual, the normal, and the ordinary decency stop.
- In the fourth perspective nature stops at the edge of awareness and where freedom stops. In all cases it is the human or some of human which is outside nature.

- In the fifth perspective nature is a totality concept. Nature is perceived as being without borders and what is human is also naturally as everything else (Hans Fink 1993).

These perspectives is a foundation for the chapter about nature quality, it is important to look at what nature quality is and what our goals are in relation to the project of the river Skjern. To discuss the possible impacts of the restoration and if it is a success we have to know what we define as nature quality.
To answer the questions raised, why was it accepted to make the channelisation in the late 1960th? At this time the perspective of nature was predominantly like the first perspective, (defines nature only as untouched by humans), from the farmers point of view. The consequences depend on whether you prefer nature or culture. If nature is preferable mankind should live as hunter/gatherers as we did in the stone age or that if culture is preferred, like a farmer in the area of River Skjern, he would make as much nature into culture as possible the more the better. When we mentioned that it was from the farmer's points of view, it of course means that in the 1960th was good sense to make the natural stream, which frequently flooded the fields, into a controllable channel thus, gaining more agricultural land. This answers the question of why it made good sense to channelised the river, the destruction of the natural processes was required to control flooding and gain more valuable agricultural land.
In a historical context River Skjern has been exposed to changes ever since 1840 (DMU nr. 114, 1999). Changes with shovel and wheelbarrow, dikes and small scale straightening has taken place. The Big channelisation could in this context be seen as the culmination of years of battling the environments.
The Perspectives changed however and nature got value in itself. This was due to several reasons, first of all it is no longer difficult to feed the population, the agriculture produces a lot more than needed, so it is no longer necessary to battle

nature for food. Thereby lowering the value of agricultural land. The need for recreational areas increased, with the population in the cities. Recreational areas are often nature areas. Farmers have become scarce, not many people work in agriculture anymore and the urban population has increased drastically. Urban people's perspective of nature is different to farmers their perspective resembles the second perspective listed above. From that point of view the nature starts outside the city including agricultural lands. Nature got value in itself. Hence it made good sense to restore the river Skjern to its old natural conditions, increasing recreational areas and improving nature quality at the expense of low valued agricultural area.

3.3. Criteria for measuring Nature Quality

The restoration of river Skjern rest very much upon an intention of increasing the Nature Quality in the area, in the stream as well as in the proximity of the river, which includes creating meadows and wetlands. The meadows and wetlands should generate themselves as a part of the natural functions of the meandering river and removal of drainage systems and pumping stations, which previously kept the farmed area from being flooded.

The criteria of which nature qualities are judged are wildness, originality, continuity and authenticity. (Nature quality DMU)

Wildness is defined as free display of natural dynamics and processes, whiteout human interference, following the first perspective of nature view, see: “view on nature”.

Originality is defined as unchanged and to be native of. Due to the dynamics of nature and the fact that certain nature types is created by human activities, and some times appreciated, originality is split in primary and secondary nature types, where primary means a nature type, which would occur whiteout human influence, not setting mankind outside what is perceived as nature.

Continuity is defined in a time and spatial dimension. Contradicting the originality criteria, continuity is reasonable short time periods, a nature type can have a reasonable long continuity whiteout being original.

Authenticity means genuine, the genuine is what it seems. Authenticity is a condition for the credibility of the landscape.

These four criteria's in relation to nature view and ethics will be discussed in the discussion and the importance of these criteria for the restoration of the river Skjern.

These criteria are a part of the selection of indicator species, indicator species are used to measure the nature quality and depending on which kind of nature type are wanted, certain indicator species typically for that nature type is then chosen. In terrestrial habitats nature quality is usually tested by vegetation analysis, whereas stream and river quality are tested on the fauna of small animals. The reason for not using animals as a measure of nature quality in terrestrial habitats is their mobility, which makes it difficult to catch and measure them. Trees and plants stay in one place making it easier to register them in a certain area. In Denmark the Danish environmental research, has made a system with indicator species, species if present at the right locality, indicates a high nature quality.

The nature quality of streams is measured, as mentioned, on the fauna based on mostly invertebrate species, and the system used is called the Danish stream fauna index (DVFI). The idea with an index, which is based on the small fauna is that the species composition reflects the stream health and not just on the day of sampling but also of the past month.

The species can be classified into three groups: clean water species, intermediary species and tolerant species. The index, based on samples from the stream, gives the stream a character between 1 to 7, where 7 is clean and 1 is very polluted. The index is used in management of the streams by the counties. All Streams has a to get a grade between 5 and 7, which grade a stream has to obtain is decided in the region plan of the area. When a stream does not have the desired quality, the county has to take some action in terms of some sort of restoration, sewage treatment etc.

In the case of river Skjern the species composition of invertebrates could indicate if the restoration really increases the water quality both in terms of organic and nitrogen compounds as well as ochre. If there still is a high load of ochre in the stream the clean water species will be the most effected and the composition of species will changes. Another indicator of the effect of the restoration on nutrient and ochre loads is Ringkøbing fjord, which river Skjern leads in to. A consequence of the channelisation was that the fish in the fjord disappeared, the fished species anyway, as they have been the only ones that have been monitored. This is reflected by the decrease in the fisheries. (nyhedsbrev jan 2000 årg.1 nr.1) One of the possible effects of the restoration could be increased fish population in the fjord. Key species in this context is the Salmon and the Trout. In the following the emphasis will be on Salomon and Trout. The reasons for emphasising the trout and salmon are the strong interest groups, anglers and the authorities for instance, working for establishing higher populations. Also the salmonid fish is used as a national and international measure of good and healthy waters. Many streams have the declaration that they have to be trout water, which means they have to have a high quality, suitable for trout.

Chapter Four

4. Concepts

In order to fully understand the impact of restoration of the River Skjern on it immediate environment, certain concepts that impinges on river and it riparian areas must first be understood. This chapter builds the concepts of and discusses in general terms stream hydrology, river channelisation, wetlands and its biochemical processes and river restoration.

4.1. Stream hydrology concepts

At the scale level of the watershed, stream hydrology consists of hydrological processes like infiltration, groundwater, flow, seepage, runoff and discharge. At the level of stream and habitat, stream hydrology comprises hydraulic processes, like current velocity and turbulence. The later is of interest to this study.

4.1.1. Meandering of watercourse

Velocity of flowing watering is the key factor for determining the amount of erosion, and the deposition, determine the meandering of streams. The velocity of water is determined by three characteristics of the stream channel (Oklahoma State University biosystems engineering, 2001):

- Grade or slope (higher slope increases velocity)
- Roughness, example rocks, trees, type of bottom (increasing roughness slows the velocity)
- Depth of the water (deeper water moves faster because there is more driving force)

The higher the velocity, the more erosive force to erode the bank and increase in sediment load.

Velocity of water in a stream or river is highest on the outside of a bend for several reasons: Due to conservation of mass, all the water that enters the bend must come out. Consequently water that travels along the out side of the curve travels a longer path and water that travels on the inside of the curve goes slower because its path is shorter.

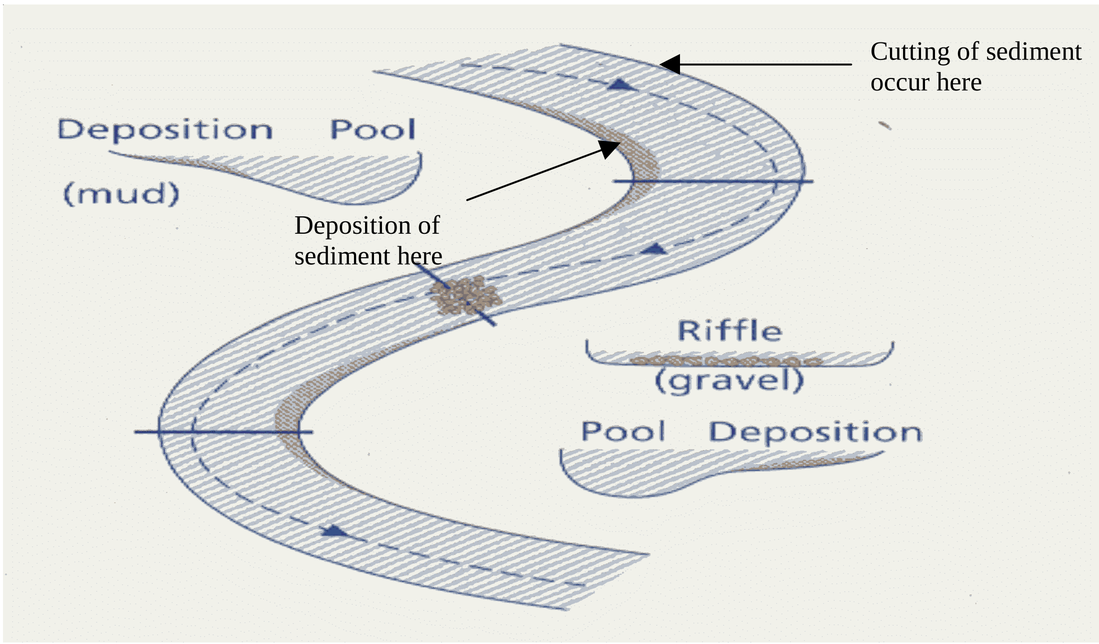


Figure 2: Physical processes cause by velocity of flowing water

Erosion occurs on the outside of the bend, due to higher velocity, and deposition occurs on the inside of the bend because the water is not going fast enough to carry the load of sediment eroded, as shown in figure 2.
Sediment deposited on the inside of the bend forms "point bars". Any system with erodible banks is expected to have some cut banks and some point bars.

The process of cutting banks and depositing point bars causes the stream to meander because the two process occur on the opposite sides of the channel. The more energy entering into a reach of channel, the more meandering is likely because the meandering is a mechanism to absorb energy. As the stream meanders, it reduces its slope, thereby reducing its velocity and consequently its energy. The erosion process also create riffles in the bed of the watercourse. Channelisation, thus taking the meanders out, of a stream will increase its slope and cause problems downstream. Sand migrating is considerably less in a meandering watercourse than in channelised watercourse because eroded material is deposited again immediately down stream of a meander bend.

Sinuosity

The degree of meandering can be explained by looking at these three types of channels shown on **figure 3** below.

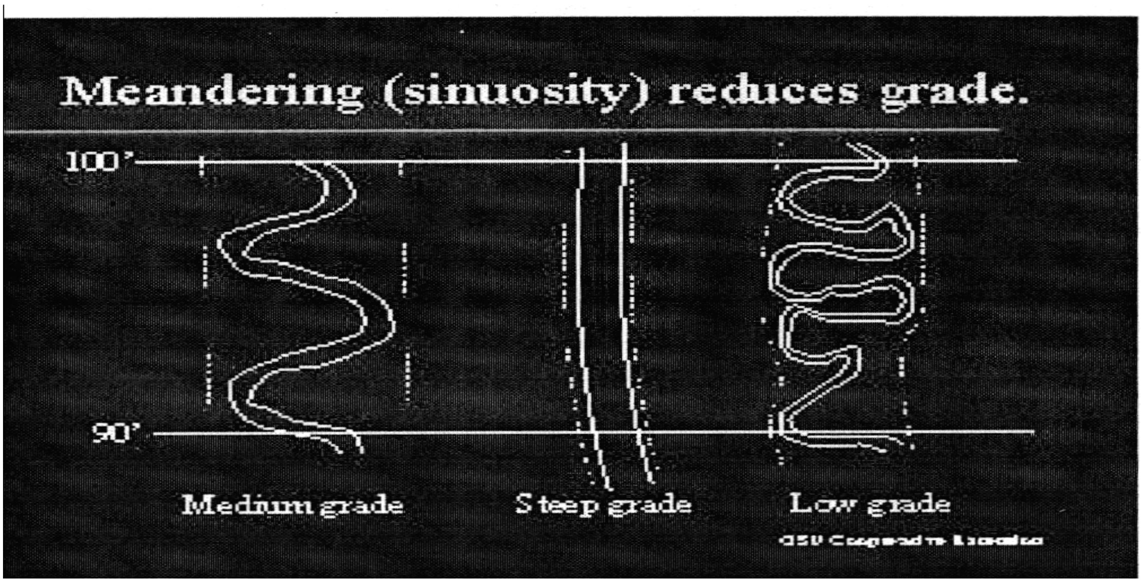


Figure 3: Shows degree of meandering

If three streams start from an elevation of 100 m and drop to an elevation of 90 m, which of these three channels will have the steepest slope? It obvious that the straightest channel will have the steepest slope. If the stream is allowed to meander, it will reduce its slope by meandering. If the energy entering the reach is very high, there will be some bank erosion/cutting and some deposition that starts the meandering process.

Meandering will continue until the slope is reduced so far that deposition blocks the streams. At that point the channel's course may change, increase slope by cutting/eroding to the next meander.

In a naturally meandering watercourse, the distance between meanders is generally approximately 10 to 14 times the width of the watercourse when full to the edge (Hansen et al., 1996, section 1).

The great physical variation in current velocity, depth, bed substratum and bank form which characterises naturally meander watercourses provides a wide variety of habitats for plants and animals because of increase in macrophyte and macro invertebrate species diversity and number.

Re-meandering the River Skjern will create variable current velocity in the river and therefore improve physical and biological processes in the stream.

4.1.2. River Channelisation

This means removing meanders from watercourse, that's straightening up watercourse, making the cross sectional area of the channel uniform and consequently, less variable current velocity are observed.

Channelised streamflow (Q) into and out of a wetland can simply be described as the product of the cross-sectional area of the stream (A) and the average velocity (V).

$$Q=AV$$

This equation suggests a linear with low turbulence flow. In most cases, the more a river meanders, the higher the reareation rate, consequently high oxygen concentration is expected in the river.

Modifying the course of a river improve certain features, such as flood control, drainage of surrounding land, navigation and sometimes erosion prevention. River channelisation comprises a number of physical measures, each of which is related to hydrological parameters; hence straightening changes the slope, dredging changes the depth and width, and dredging and weed cutting change the roughness. Other more radical methods of river channelisation include culverting, lining, and piping.

In many countries where there is intensive agricultural production, many of the rivers have been regulated. According to Brookes (1987) and Iversen (1993) reports, 85 to 98 per cent of the total river network in Denmark has been channelised.

Physical and Biological impact

Channelisation has great impact on river because it disrupts the existing physical equilibrium of the watercourse; to compensate for the alteration in one or more of the hydraulic parameters, and establish a new, stable equilibrium, other parameters will change. Because straightening of a river increases its slope, the energy in the moving water has to be dispersed over a smaller surface; as a result the water is able to move larger particles and sediment discharge increases through bank erosion. If the channelised river is not repeatedly manipulated or maintained or stabilised, this will eventually lead to widening of the river channel and to subsequent reduction in water velocity. River channelisation generally changes a heterogeneous system into a homogeneous one such that flow becomes uniform, pools are lost and the substrate becomes uniform throughout the channel.

Straightening of river can also have great impact on riparian vegetation, see section under ecosystem of River Skjern. Trees are often logged to allow channel maintenance, such as machine dredging, and scrubs are cut to ensure sufficient drainage. This increases solar radiation at the stream surface, thereby increasing the water temperature, reducing the concentration of dissolved oxygen, and increasing in-stream primary production. In nutrient-rich watercourses this results in enhanced growth of benthic algae and macroalgae.

Another important effect of the channelisation of rivers, lakes and drainage of wetlands may be increased nutrient and organic matter loading of rivers and the marine environment. The reason is that while the annual nitrogen removal capacity of wetlands and natural rivers can be as much as several hundred kg/ha, that of channelised rivers and drained wetlands may be negligible. Naturally meandering riparian zones alongside rivers may therefore play an important role in balancing intensive agricultural and ecologically interests.

The velocity of river water is one of the major factors regulating the structure of riverine plant and animal communities (Brookes, 1988; Westlake, 1973). The uniform and often unstable sediment found in channelised watercourse is suitable for a few plant and animal species. Besides, as the uniform water flow precludes areas with little or no flow, resting sites for fish and invertebrates are virtually absent. The general effect of channelisation is therefore a reduction in habitat number and diversity. The latter may be further reduced by the above-mentioned decrease in oxygen concentration. Hence, the biodiversity of organisms such as fish and invertebrates is usually lower in channelised watercourse.

However, not only animals and plants living within the watercourse are affected by channelisation. Animal species, which depend on the bank and adjacent wetlands for foraging and/or breeding, decline in number, with the consequence that species diversity on the riverbanks and adjacent wetlands correspondingly, decreased. Furthermore, a number of plant species that are confined to the more or less water-saturated soil adjacent to the river are also affected.

The last channelisation (thus in the late 1960's) of the River Skjern converted 4,000 hectares of wetland, meadow, marshlands in the lower part of the River Skjern system into arable land, mostly for grain production. This drained the adjacent wetland and resulted in huge reduction of the wetland area to 2 percent of its original area, see figure 4.

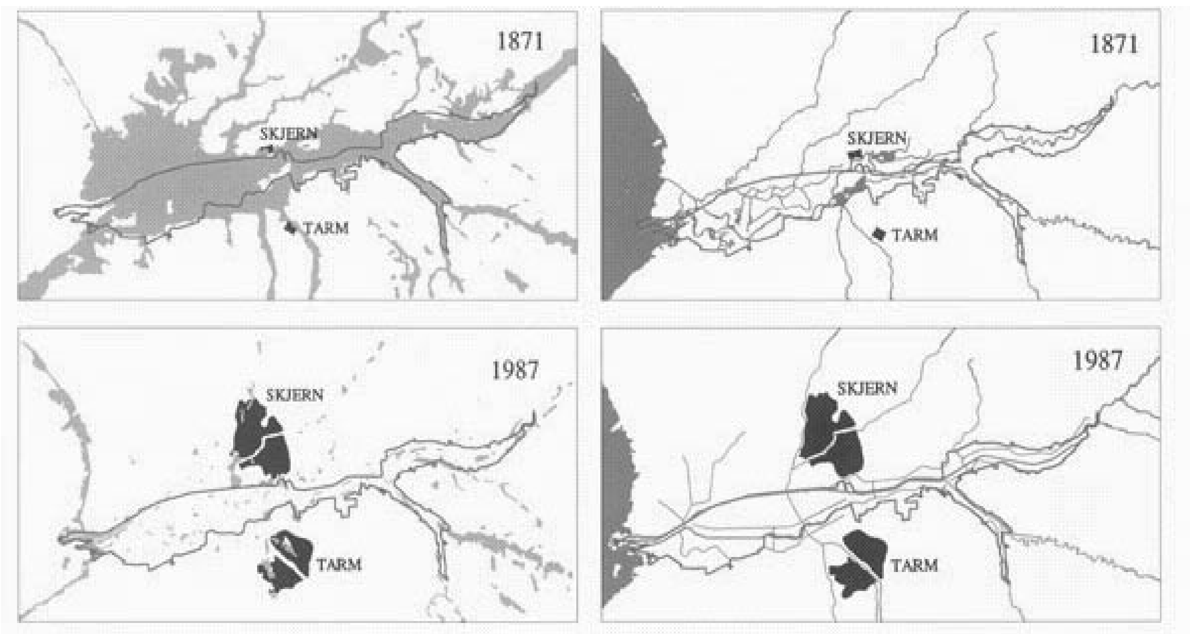


Figure 4: Meadows and marshland in the lower part of River Skjern system in 1871 and 1987. (Source: taken from SNS, 1999)

4.2. Wetlands and their functioning

4.2.1. Wetlands

The term "wetlands" applies to those areas where water is near, at, or above the level of the ground. This water comes from tidal flows, flooding rivers, or connections with groundwater.

Wetlands are found on every continent except Antarctica and in climates ranging from the tropics to the tundra. They occupy about 6 percent of the land surface of the world, or approximately 2.2 billion acres.

Wetland Definition

Many scientific definitions of wetlands do exist, they include early U.S, Canadian Wetland, U.S National Academic of Sciences and the international (Ramsar Convention) definitions.

Probably, the most profound definition of wetlands is the one from the Ramsar Convention, which states “wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters” (Ramsar Bureau 1990). Hence, the water may be present as groundwater close to the surface or as flooding water down to a depth of 2 metres (some authors 6 metres).

Navid (1989) interprets this definition as including a wide variety of habitat types including rivers, coastal areas, and even coral reef. According to Scott and

Jones (1995), the rationale for such a broad definition of wetlands “stemmed from a desire to embrace all the wetland habitats of migratory water birds.

For the purpose of this report the international definition, Ramsar Convention definition is adopted
The are many types of wetlands depending on the classification. In the River Skjern watershed marshland and meadows are dominant.

4.2.2. Functions of wetland

Wetlands serve as aquatic buffer zone, with processes removing or retaining plant nutrients, resulting in decreased transport to the coastal waters. Wetlands can be termed as *“the liver of the landscape, improving the quality of the runoff water”***.** They favour assimilation of nutrients into living material, sedimentation of particulate material, including dead plant material which is buried in the sediments (important for phosphorus removal), and dissimilative processes as denitrification. Breakdown of the sedimented material, or example changed redox conditions, may result in reversed transport of nutrients, at least temporarily, back to the water.

Wetlands provide essential habitat and feeding grounds for breeding of many freshwater species.
Some animals spent their entire lives in wetlands, for example migratory waterfowl, while others use wetlands primarily reproduction and raising young. Other species visit marshes to take advantage of the abundance of food and water provided by these systems.
Also provides recreational opportunities such as fishing, hunting, boating and birdwatching.

The key way to understand the importance of restoration is understanding biochemical processes taking place in the wetlands.

Chemical Transformation in Wetland

When soils, whether mineral or organic, are inundated with water, anaerobic conditions usually result. As the result of inundation water fills the pores spaces, rate at which free atmospheric oxygen is drastically reduced. Diffusion of oxygen in an aqueous solution is about 10000 times slower than oxygen diffusion through a porous medium such as drained/unsaturated soil (Greenwood, 1961, Gambrell and Patrick, 1978). The low diffusion rate of oxygen leads to anaerobic and anoxic conditions, with the time required for oxygen depletion on the order of several hours to a few days after inundation begins.

The rate at which the oxygen is depleted depends on the ambient temperature, the availability of organic substrates for microbial respiration, and sometimes the chemical oxygen demand from reductant such as ferrous iron.

In wetlands, there is usually a thin layer of oxidised soil, sometimes only a few millimetres thick, as shown on figure 5.

This thin oxidised layer is often very important for the chemical transformations and nutrient cycling that occurs in wetlands. Oxidised ions such as Fe^{3+}, Mn^{4+}, NO^{3-}, and SO_4^{2-} are found in this microlayer. Reduced forms as ferrous and manganous salts, ammonia, and sulphides dominate the lower anaerobic soils. These conditions labelled above provide suitable environment for various chemical and biological transformations in wetlands, which is dominated by oxidation and reduction reactions.

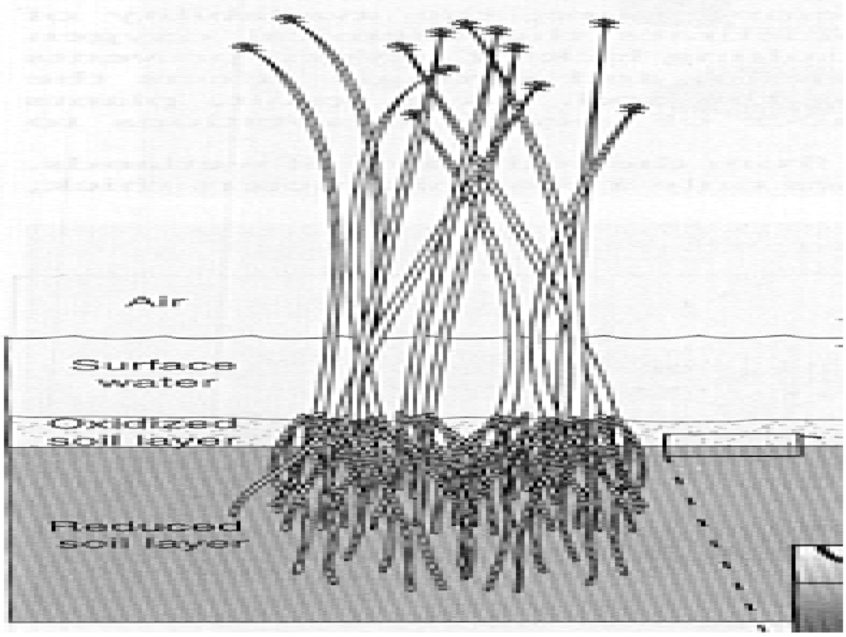


Figure 5: Characteristics of wetland soil showing oxidised and reduced zone

Well documented biochemical transformations taking place in the wetland include; nitrogen, iron and manganese, sulphur and carbon transformations.

Nitrogen transformation

Nitrogen transformations in wetlands involve several microbiological processes, some of which make the nutrient less available for plant uptake. The bacteria involved in these processes are both heterotrophic and autotrophic which include Nitrosomonas, Nitrobacter and blue-green algae. Up to date, well-known biological processes pertaining to nitrogen transformation taking place in wetlands include nitrogen fixation, ammonification, nitrification and denitrification.

Nitrogen fixation

This is a microbial process where atmospheric nitrogen is converted to plant available nitrogen compounds. Heterotrophic bacteria living in root nodules of legumes carry out symbiotic nitrogen fixation under formation of ammonium in organic combination. Nonsymbiotic nitrogen fixation can be carried out by certain heterotrophic bacteria and by autotrophic blue-green algae as following reaction:

$$2N_2 + 3CH_2O + H^+ + 6H_2O \Rightarrow 4NH_4^+ + 3HCO_3^- \quad (1)$$

Ammonification

Ammonification refers to mineralisation of organically bound nitrogen to ammonium nitrogen under aerobic and anaerobic conditions. The typical formulas for mineralisation for a simple soluble organic nitrogen (SON) compound are shown below;

$$NH_2CONH_2 + H_2O \rightarrow 2NH_3 + CO_2 \quad (2)$$

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^- \quad (3)$$

The formed ammonium can take several pathways. It can be up take by plants through their root systems or by anaerobic micro-organisms and convert back to organic matter. Under high pH conditions (pH>8), common occurrence in marshes with excessive algae blooms, the ammonium ion can be converted to NH_3 which is then released to the atmosphere through volatilisation.

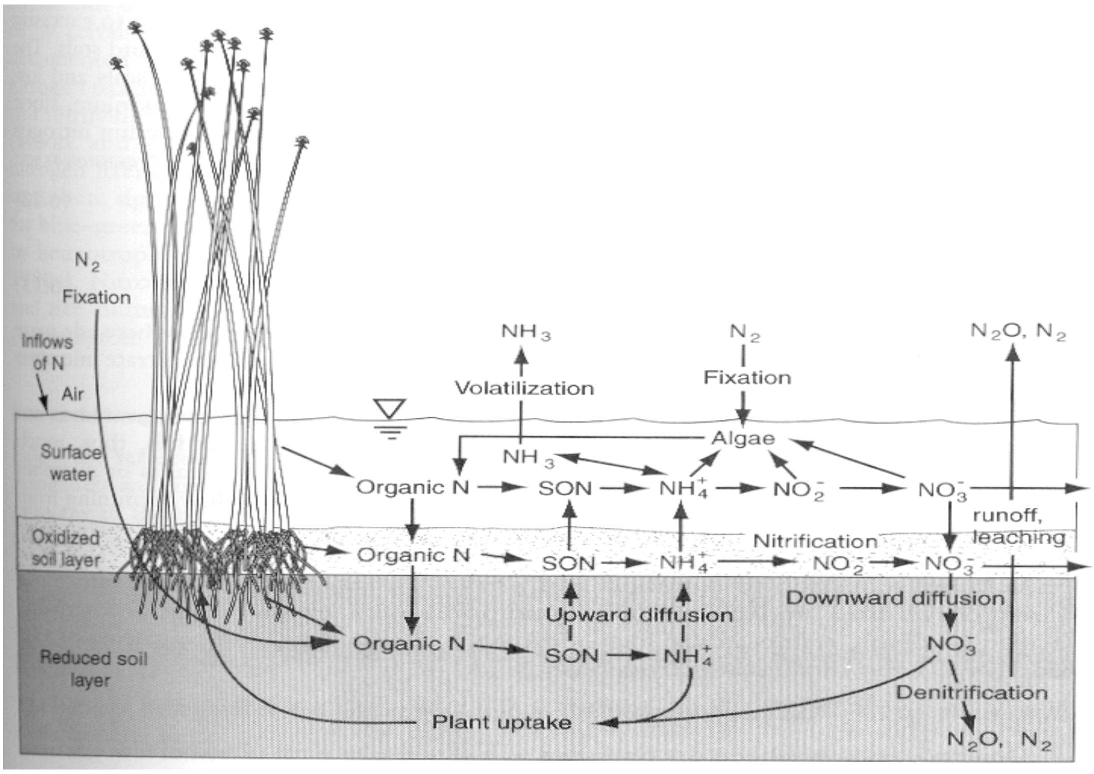


Figure 6: Transformation of nitrogen in wetland

Nitrification

The ammonium ion can also be immobilised through ion exchange onto negatively charged soil particles. The anaerobic conditions inhibit further oxidation and would build up to excessive levels if the oxidised layer were absent. The difference between ammonium concentration gradient in the oxidised and reduced layers causes an upward diffusion to the oxidised layer. In the oxidised layer, the ammonium nitrogen is oxidised to nitrate, i.e nitrification process. Nitrosomonas and nitrobacter microorganisms are responsible for nitrification process. These bacteria are most numerous in the root zone, which can be an extremely active area for nitrification. The process takes place in two steps as indicated below:

Nitrosomonas: $55NH_4^+ + 76\ O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57H_2O + 104H_2CO_3$ (4)

Nitrobacter: $400NO_2^- + NH_4+ + 4H_2CO_3 + HCO_3^- + 195\ O_2 \rightarrow C_5H_7O_2N + 3H_2O + 400\ NO_3^-$(5)

There is also possibility of nitrification occurring in oxidised rhizosphere of plants, like the reed, where adequate oxygen is available.

Denitrification and dissimulation

If the produced nitrate is not assimilated immediately by plants or lost through ground water flow, it has the potential to undergo dissimilatory nitrogenous reduction. Denitrification and dissimilation are parts of another natural process that converts nitrate to atmospheric nitrogen gas. This process only occurs in the absence of oxygen (i.e anoxic and anaerobic conditions). The denitrifying bacteria need constant organic carbon source, which is found abundant in wetlands.

The first stage is dissimilatory nitrate reduction, which reverses the nitrification process and converts nitrate (NO_3^-) back to nitrite (NO_2^-). The second stage of denitrification converts nitrite to nitric oxide, nitrous oxide and finally nitrogen gas – all of these last three products are gases that can be released into the atmosphere.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \qquad (6)$$

The overall denitrification reaction is shown below:

$$C6H12O6 + 4NO3 \rightarrow 6CO2 + 6H2O + 2N_2 \qquad (7)$$

Denitrification has been documented as a significant path loss of nitrogen from most kinds of wetlands (Mitsch & Gosselink, 2000, page 172)

Iron Transformation

Iron can be oxidised naturally by chemosynthetic[1] bacteria from ferrous to insoluble ferric form in aerobic environment (Mitsch & Gosselink, 2000, page 173):

$$4Fe^{2+} + O_2\,(aq) + 4H^{+} \rightarrow 4Fe^{3+} + 2H_2O \quad (8)$$

At a lower pH,

$$4Fe^{3+} + 2H_2O \rightarrow Fe(OH)_3\,(\text{ochre}) + 3H^{+} \quad (9)$$

The formed ferric combines with water at lower pH to form ochre. Ochre is toxic to fish even at low concentrations when release into aquatic environment. The ferrous ion can be toxic plants in high concentrations. The reduced ion, diffusing to the surface of the roots of wetland plants, can oxidised by oxygen leaking from root cells, immobilising phosphorus and coating roots with an iron oxide, and causing a barrier to nutrient uptake (Gambrell & Patrick, 1978).

In the River Skjern watershed, pyrite is naturally found in soil under anaerobic condition, especially when the soil is covered with water , see section under geology. When the soil is drained, oxygen influx from the atmosphere into the soil's pores creates condition conducive for pyrite oxidation. Pyrite oxidation lead to release of ferrous ions Fe (II), which is dissolved ions. Under continues oxidation, the dissolved ferrous iron can leads to formation of ochre [Fe $(OH)_3$ + H_2O] under strong acid formation as shown in the below reactions.

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4H^{+} + 4SO_4^{2-} \qquad (10)$$

[1] biosynthesis of organic compounds using inorganic compounds as energy source

Fe^{2+} can be oxidise to ochre as following reaction

$$Fe^{2+} + O_2 + H_2O \leftrightarrow Fe(OH)_3 \downarrow + H_2O + H^+ \quad (11)$$

The ochre deposits as particles in the soil layer, while the sulphate washes to the water stream. The big proportion of dissolved iron and ochre reached to the lowest part of the River Skjern-system, and farther more to the Ringkøbing Fjord, which impacts the environment negatively (Svendsen et al., 1997).
The increasing of the iron concentration was very high in the first ten years after draining the water shed, that is due to pyrite oxidation figure 7 (Kronvang et al).

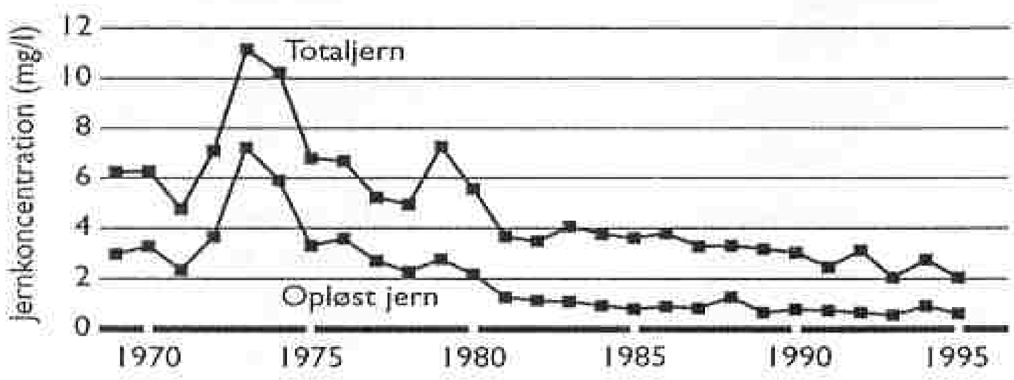


Figure 7: The iron concentration in the River Skjern, the upper curve is the total iron and the down one is the dissolved.

Also pyrite oxidation can take place in aquifers containing nitrate, by reducing the nitrate to nitrogen gas as shown in the below reaction (Ramsay 1999).

$$2FeS_2 + 6NO^-_3 + 2H_2O \Rightarrow 2FeOOH + 2H^+ + 4S^- + 3N_2 \quad (12)$$

The Effect of Pyrite oxidation processes and Ochre formation on the environment

The oxidation of Pyrite effect the environment:

- The formation of the strong acid (sulphuric acid) causes high water acidity. Many water plants and animals are very sensitive for acidity change.
- Ferrous- iron has directly toxic effect on fishes, plants and can damage the biological condition even at concentrations between 0.3-0.5 mg I^{-1} (Svendsen et al., 1997).
- The sulphate can be washed to the stream, which has damaging effect to the small animals.

Ochre effects on the environment:

- The ochre particles can make the water turbid, preventing sunlight from penetrating the water down to the bottom, which reduce the growth and photosynthesis of the water plants and algae.
- Ochre particles fill in the cavities between sand and gravel - particles in the bottom of the stream. Thereby the living places of the small animals disappear and suffocate salmonid eggs and larvae.
- Ochre particles settling in the streams can effect lives on the bottom of the streams. When in suspension can be very harmful to the fishes gill and the small animals and can cause immediate death of many of them.

The channelisation of the River Skjern lowered the ground water table. Extreme cases have been recorded where the groundwater has fallen between 1 to 2 metres (Hansen et al., 1996). Consequently, creating an aerobic environment in the soil sediment, a condition conducive for transformation of pyrite (FeS_2) into ochre. The wetland, which the restoration is to create, will create anaerobic conditions that will disfavour oxidation of pyrite.

Phosphorus Transformation

Phosphorus retention is considered one of the most important attributes of wet lands, particularly those that receive arable lands (nonpoint pollution) and wastewater (point pollution).

Phosphorus occurs as soluble and insoluble complexes in both organic and inorganic forms in wetland soils, Table 2.

Table 2: Major types of dissolved and insoluble phosphorus in natural waters

Phosphorus	Soluble form	Insoluble form
Inorganic	Orthophosphates, Polyphosphate, Ferric phosphate Calcium phosphate	Clay-phosphate complexes, Metal hydroxide phosphates Minerals, e.g. apatite
Organic	Dissolved organics, e.g sugar phosphates, inositol phosphates, phospholipids, phosphoproteins	Insoluble organic phosphorus bound in organic matter

Source: Wetlands (Mitsch & Gosselink, 2000)

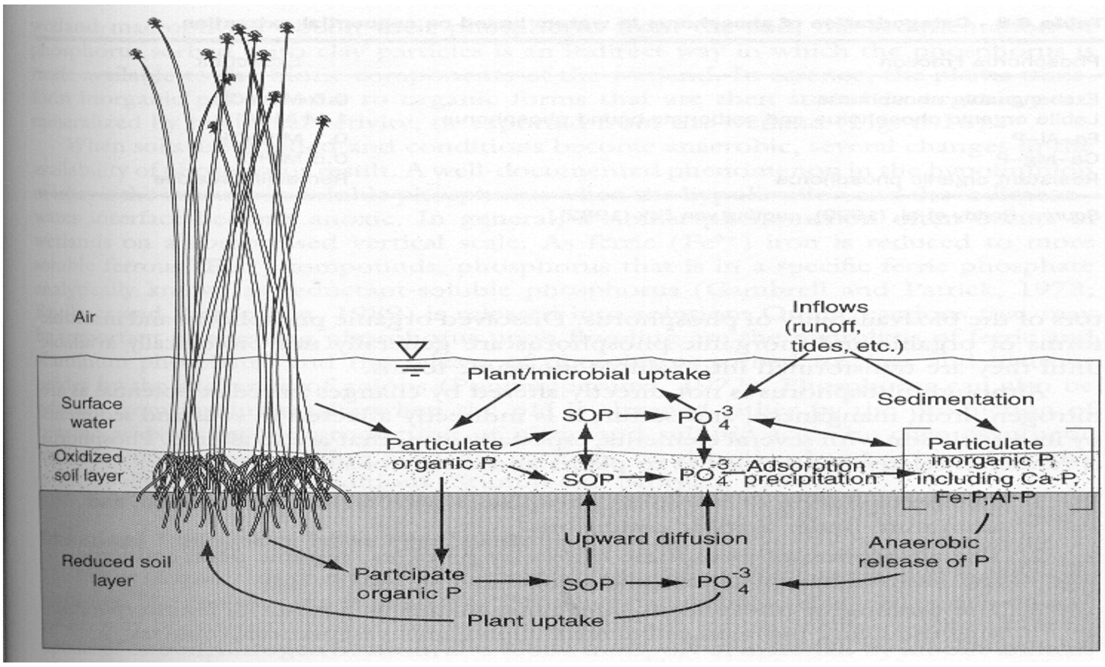


Figure 8: Phosphorus transformations in wetlands, SOP indicate organic phosphorus

Phosphorus can form complexes with calcium, iron, and aluminium if they are available in the sediments at variable pH. Phosphorus occurs in sedimentary cycle rather than in a gaseous cycle. Major proportion of the phosphorus in wetlands is tied up in organic litter and peat and in inorganic sediments, with the former dominating peatlands and the latter dominating mineral soil wetland. Geologically, lower part, central restoration area, of the River Skjern Watershed lies in peatlands. The principal inorganic form is orthophosphates. Another important phosphorus transformation in wetland is sorption of phosphorus to positively charged clay particles (Mitsch & Gosselink, 2000, p.186). Clay-phosphorus complex is important for many wetlands, including riparian wetlands and coastal salt marshes, because a considerable portion of the phosphorus brought into these systems by flooding rivers and tides is brought in sorbed to clay particle. Thus phosphorus recycling in many mineral soils wetlands tends to follow the sediment pathway of sedimentation and resuspension.

Phosphorus is not readily soluble and can be transported to aquatic environment through the under listed ways:

- Raining water as dissolved form down to the ground water and drainage water
- The phosphorus bound on the soil particles can be washed down via cracks in large soil pores to the stream water.
- The wind and water erosion can lead to extensive transportation of phosphorus to the watercourses. Strong windy rain water can cause sheet erosion and therefore resulting intensive transport of phosphorus into rivers

Dissolution and erosion are two processes that can mobilise phosphorus, erosion is physical transport, while dissolution is the transport of phosphorus either dissolved in water or attached to colloidal material (David M. Nash et al., 1999).

A high loss of dissolved and particulate phosphorus from arable fields to surface water can seriously affected the ecology in the rivers, lakes and fjords through an increased growth of benthic and pelagic algae resulting in eutrophication. In the Skjern Watershed channelisation of the River Skjern led to increased phosphorus load into the fjord and this resulted in eutrophication in the fjord, flora and fauna in the site was seriously affected. The Transportation of sediment particles in the bottom of the stream is less in summer due to low discharges, which lead to low current velocity. Transportation of the sediments becomes difficult and can be kept for a while by the water plant. In the winter, high discharges in the stream leads to high current velocity water current, the transportation of the phosphorus particles at bottom stream become easy due to strong turbulence, see figure 14.

Carbon Transformation

The major processes of carbon transformation include photosynthesis and aerobic respiration, and fermentation of organic matter and methanogenesis. Photosynthesis reaction and degradation of organic matter by aerobic respiration is given below.

$$6CO_2 + 12H_2O + LIGHT \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O \quad (13)$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 12e^- + ENERGY \quad (14)$$

Fermentation plays an important role in wetlands by breaking down high-molecular-weight carbohydrates to a low-molecular-weight compounds, usually as dissolved organic carbon, which can easily assimilated by other micro-organisms.

Methanogenesis is important for transforming dissolved CO_2 into gaseous methane in wetlands.

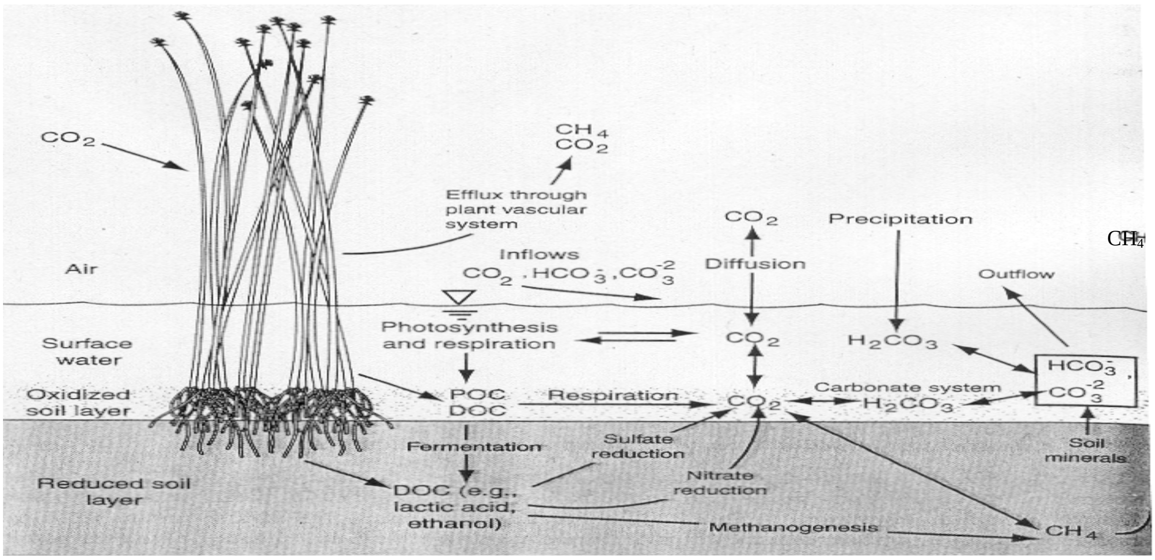


Figure 9: Carbon transformation in wetland

Due to the geological sitting of the River Skjern restoration area, there is large deposit of organic matter in the sediment found in the form of peat soil (refer, section under geology). There is also contribution from wastewater treatment plants upstream of the watershed. The organic matter is not a treat to the water quality in the area.

4.3. Restoration

River restoration has become a topic of interest in some, mainly developed, countries of which Denmark is no exception because such projects form part of a sustainable development for river basin (Rodney White & Wallingford, 1999). River restoration aims at re-establishing a river to its natural (former) state. The objectives of river restoration are normally to create a wider diversity of eco-systems and improve biodiversity, by bringing the river into closer contact with flood plain (Bettess & Fisher, 1998). The restoration processes include breaking down dikes, dams and culverts and redirecting the river to its former watercourse as also in the case of River Skjern restoration project. River restoration usually improves visual amenity of the watercourse, meandering and its natural function for flood storage and conveyance regained. Greater hydrological contact between a watercourse and its riparian areas leads to improvements in biological conditions and water quality, but also plays an important role with regard to the capacity of the system to even out water and sediment input, especially under conditions of extreme precipitation and runoff. Better hydrological contact with the possibility to flood the riparian areas during periods of high discharge can increase the retention time of the water, thereby limiting extreme discharge events. This can reduce the risk of flooding downstream, where the riparian areas are often lower-lying. Furthermore, flooding results in considerable retention and sediments in the watershed (Aub-Robinson et al, 1996).

River restoration leading to raising of the water level in the watercourse and increasing the frequency of flooding reduce the nitrogen loading problem because of the natural capacity of wet riparian areas to remove nitrate-nitrogen by denitrification (Kronvang et al 1994).
In addition, river restoration that leads to more frequent flooding of riparian areas also has other positive effects. Large amounts of phosphorus can sediment out on the riparian areas together with fine particulate matter during flooding and thereby reducing the amount reaching the watercourse.

In a nutshell river restoration lead to improved wetland hydrology, which provides suitable conditions for physical, biological and chemical processes in the main river and its adjacent riparian area/floodplain.

The restoration of the River Skjern will lead to improved environmental conditions in the its watershed. As a consequence of breaking down hydraulic structures which confine the river to the channelised channel 2% of open water (i.e lakes and pond), 19% of reed forest, 37% wet meadow, 22% dry meadow, 13% pastures and heaths and 7% river course and roads of the total drained area will be created. This will enhance self-purification of the river system.

4.4. The river continuum concept

In a river system, such as the River Skjern, the ecosystem can be described according to the river continuum concept, RCC (Allan 1995). The river continuum concept describes the river from source to mouth in terms of the change in biota as well as the changes in physical and chemical properties. The RCC is an idealised river, with a dynamic meandering river course etc., which is what a river looks like whiteout antrophogenic influence. The River Skjern is by no mean an example of this, but it is important to get an idea of how a natural river ecosystem works in general, many of the dynamics also holds for the River Skjern.

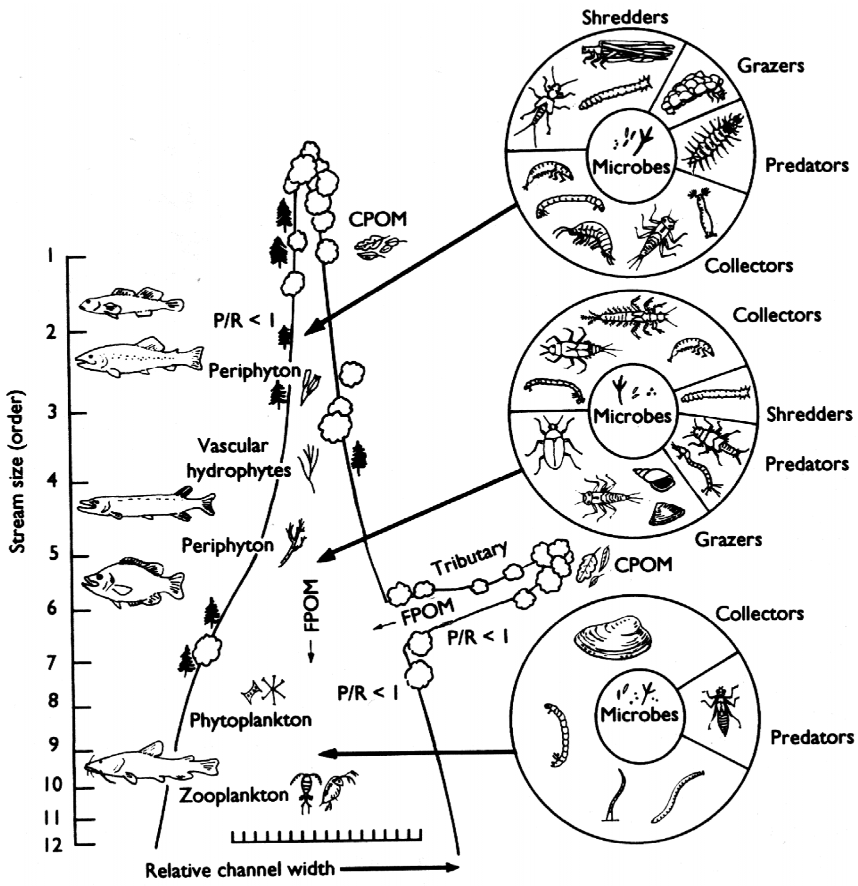


Figure 10: Generalised description of the relationship between stream size (order), energy inputs and ecosystem function expected under the river continuum concept. (From vannote et.al. 1980)

The biota mostly invertebrates and fish are highly dependent of the quality of the water and the type of surroundings.

4.4.1. Upper part of the river: see figure 10.

At the source of the river the stream is small, order of 1 to 3 and width 1 to 2 meters, the influence of the surrounding vegetation is high due to the fact that a narrow stream, flowing through a forest for instance, would be totally covered of trees causing shade and high input of organic matter. Thus the ratio between photosynthesis and respiration p/r is well below 1, meaning a much higher respiration of the organic matter than photosynthesis inhibited by the shading of the trees. Mainly the invertebrate, juvenile fish and the bacterial degradation carry out the respiration. Because of the high organic input, which at this state is rather coarse, leaves and so on, there is lot of invertebrates termed shredders. Shredders tear up large organic parts as leaves also termed coarse particulate organic matter CPOM. They transform the CPOM into fine particulate organic matter FPOM, mostly they live of the biofilm, consisting of bacteria, on the organic matter leaves etc. The FPOM is then transported by water flow downstream. Because of the shading and low photosynthesis, grazers are not very abundant at the upper part of the stream.

The upper part of the stream is also characterised by relatively high input of groundwater, in the upper part of river Skjern anyway, that also means a relatively stable temperature all year round, in the summer it would seem cold and in the winter it would seem warm. Due to relative low temperature during the summer oxygen concentrations is relatively high, which is preferred by salmonid fishes.

The fish in the upper part of the stream is mostly hatchlings and juveniles. The upper part of the stream is extremely important for a lot of fish species as hatcheries and nursing grounds, as for example the trout.

4.4.2. Middle part of the river: see figure 10

When you move to the middle part of the stream, order of 3 to 5 and width of 2-10 meters, more light penetrates to the stream and the amount of organic input CPOM from the banks decreases compared to the input of more FPOM from

upstream. The p/r ratio changes as photosynthesis increases and especially in Danish streams such as river Skjern the water plants, macrophytes starts to dominate the stream. With the increase in photosynthesis, grazers will be more dominant in the invertebrate fauna. Another food group called scrapers (Sand-Jensen1996) appears they live of the biofilm on plants and stones. As the available food changes from CPOM to FPOM the shredders from upstream more or less disappears. In the middle part of the stream the fauna will be divided into zones, living on and in the bottom, called the benthic fauna and the fauna living on and near the macrophytes.
With the distance from the source in general the water starts to flow more slowly and the wider and deeper a stream gets the ability to oxygenate the water decreases. This means that the species living in the stream have to be more tolerant to fluctuations in oxygen content and the number of invertebrate species from the upper part of the stream decreases. Though the number of species decreases, the number of individuals increases due to high amounts of food.
With the widening of the river to width of 2-10 meters, the populations of fish changes from small fish and juveniles to large fish like adult stream trout *Salmo trutta fario*. Trout water is characterised by being fast running and oxygen rich. Trout water is a definition in the Danish water policy described in the section of nature quality.
The high input of groundwater in river Skjern and other rivers of WestJutland causes macrophytes to overwinter with green parts, this sustains an invertebrate population throughout winter, which sustain a relatively high fish-population in the river system (Sand-Jensen1996)

4.4.3. The lower part: see figure 10

The lower part of the river, in Danish rivers, is of the order 5 to 6 and the width about 10 to 30 meters. The contribution of organic matter comes mainly from upstream and tributaries in the form of FPOM. The macrophytes are confined to zones near the banks so their contribution to the primary production is relatively small. The greater depth and more slowly moving waters allows for sedimentation and the substrate of the bottom will be of finer particles, therefore the fauna lives in the sediment and is comprised of different animals than upstream. Species in the bottom sediments includes clams and mosquito larvae. The fish is comprised of carp fish like Bream *Abramis brama* (L) and Roach *Rutilus rutilus* (L). Perch *Perca fluviatilis* (L), and the predatory pike *Esox lucius* (L), which can have a big influence on the fish species in the river due to predation.

In a natural stream, which meander and is changing between rapids and holes there is a big diversity. The salmonid fishes and a lot of invertebrates live on the rapids, Pike and Bream live in the holes. The rapids are also important spawning grounds for the Salmon *Salmo salar*. The system of rapids and holes are dependent of a meandering river and the substrate material on the bottom, which for good spawning conditions should be comprised of gravel.

Chapter Five

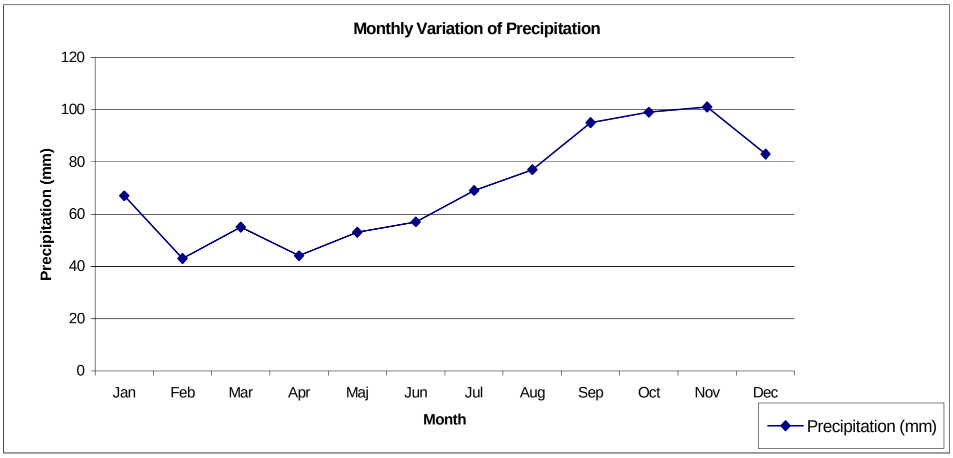
5. River Skjern watershed

5.1. Climate and Hydrology of Watershed

The inputs of materials to watershed occur through geologic, biologic, and hydrologic pathways (Mitsch & Gosselink, 2000, p. 187). The geologic input from weathering of parent rock is important for most watersheds because it effects water quality. Biologic inputs include photosynthesis uptake of carbon, nitrogen fixation, and biotic transport of materials by mobile animals such as birds. Apart for gaseous exchanges such as carbon fixation in photosynthesis and nitrogen fixation, elements/material input into watercourses and wetlands are generally dominated by hydrology inputs. Natural hydrological processes promote optimal watershed functioning, thereby preserving significant watershed values.

5.1.1. Climate

Precipitation



The figure 11 shows monthly variation of precipitation at Borris precipitation station for 31 years period in the Skjern watershed. The mean monthly precipitation over this period is 843 mm.

Highest precipitation in the watershed is recorded in November while the lowest in February. Autumn experience the highest (295 mm) precipitation with spring Experiencing the less precipitation.

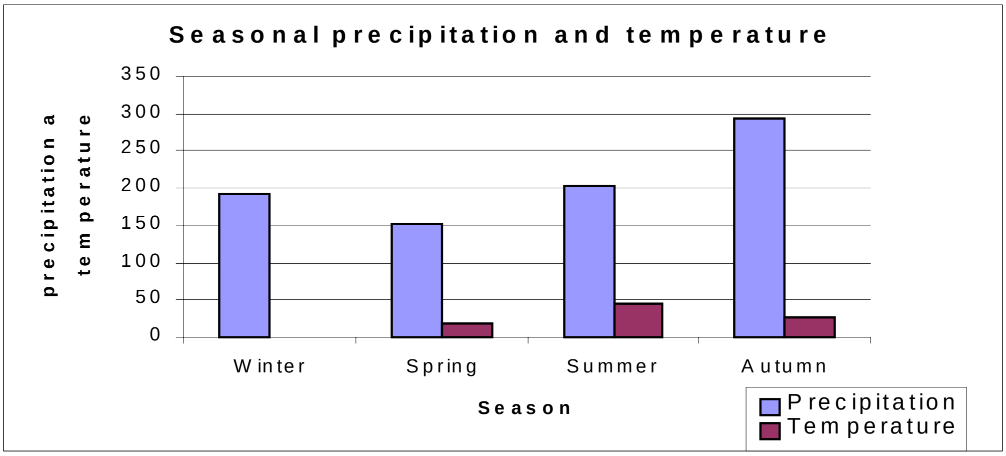


Figure 12: Show seasonal precipitation and temperature variation at Borris station

Temperature

The highest temperature is observed in July and August whereas the lowest is in January, see figure 13. Summer temperatures are comparatively high with a mean of 14.8 °C whereas, it is almost frozen in winter, temperatures around 0°C.

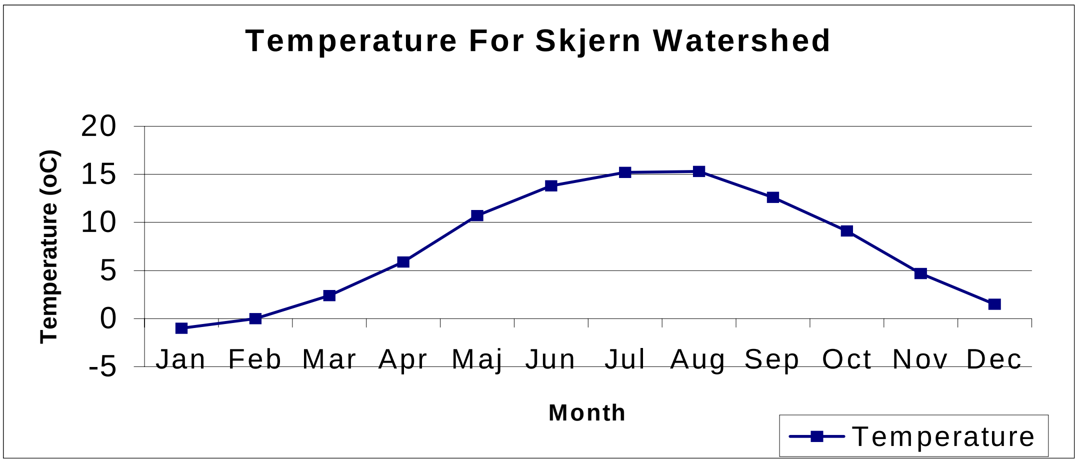


Figure 13: Monthly variation in temperature at Borris station

Though autumn and summer precipitation are higher compare with the rest of the season evaporation is high during this period. The amount of water retained in the soil sediments after precipitation is therefore higher in winter and spring than autumn and summer.

5.1.2. Hydrology

Discharge

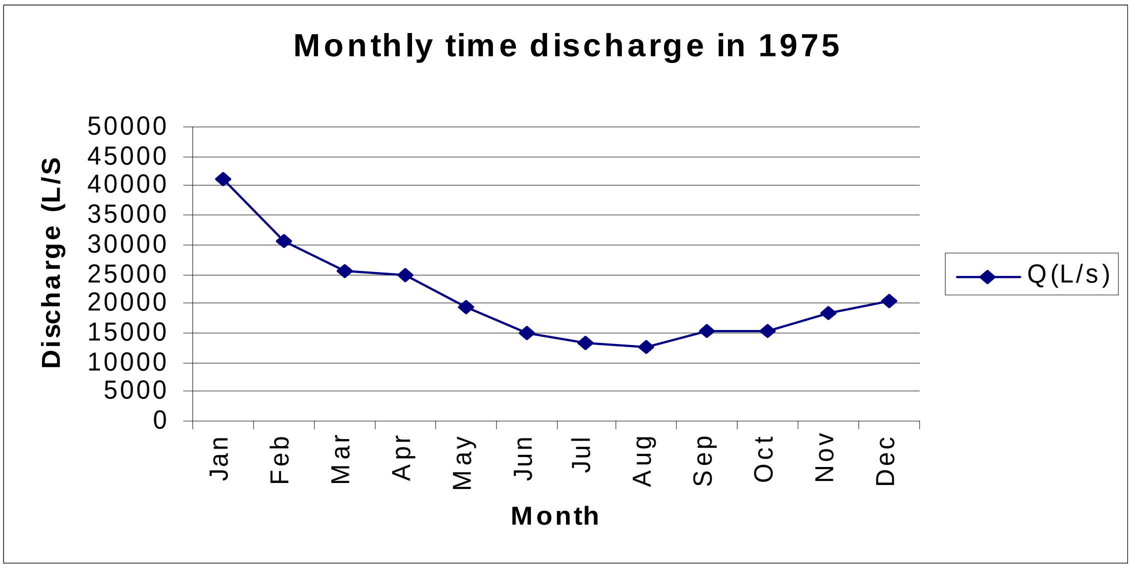


Figure 14: Monthly discharge at gjaldbækbro station in the River Skjern

From figure 14, there is high flow in the River Skjern in winter and spring than in spring and autumn. Discharge in the river is high in January, it decreases in the subsequent months as the temperature gets higher reaching minimum in August where the temperature is the highest. The discharge in the river begin to rise again as the temperature begin to fall. One of the reasons for this observation is low evapotranspiration take placing in winter and spring (period where most plant leaves are shed) and high evapotranspiration in summer. Restoring the River Skjern will lead to flooding of its banks thereby creating floodplains particularly in winter and spring.

5.2. Geology of Skjern Watershed

Studying the geological formation of the area can be helpful to study the present situation and in the same time to improve its environmental condition.

The River Skjern is a part of one big ecological system: River Skjern-system (its valley and all its tributaries), Ringkøbing Fjord and the Northsea (Svendsen1 et al., 1997). Each part of this system effect the other, therefor any changing occur in one part can influence the whole system.

River Skjern- valley was formed under the last ice age, which was finished for about 10,000 to 12,000 years ago (Svendsen 1997). The glacier covered the east part of jutland and did not reach the west part. The melt water from the glacier flowed from the east toward the sea in the west, running through the landscape. The melted water was loaded with materials as moraine depositing, which is called till. The river has been running through the valley since that time carrying nutrients, sand and other materials, to the valley and wetlands. Hence, the terrain is dominant by three landscapes:

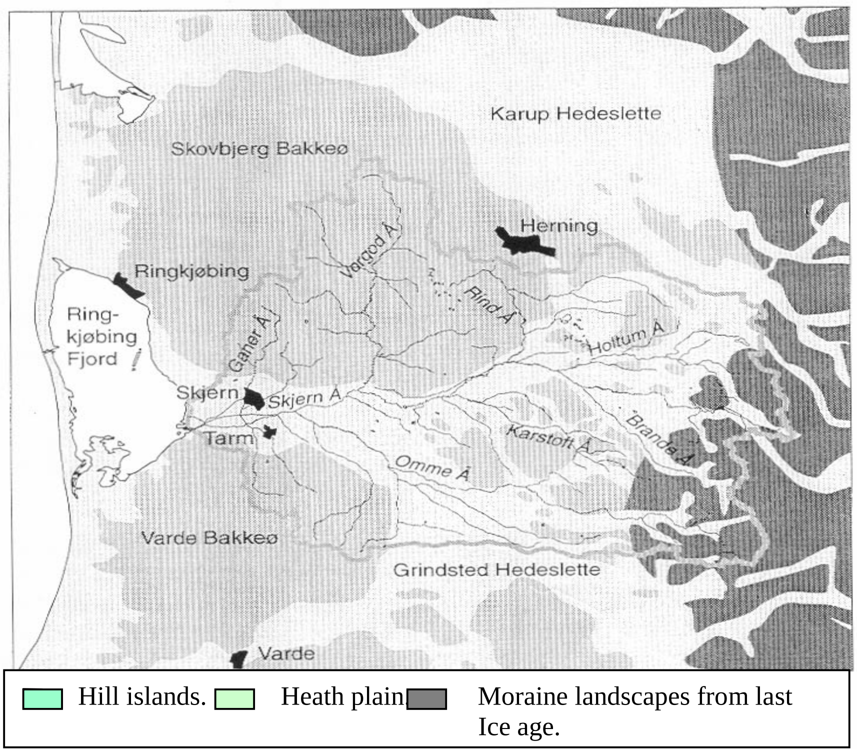


Figure 15: Hill island and heath plain in River Skjern watershed

5.2.1. Hill islands

They account for as the oldest landscape type. As we can see in figure 15, the location is around the main River Skjern and many of its tributaries running in this type. The hill islands consist mainly of the older sand moraine[2], and melted water deposit. Its old forming helped to be exposed to the wind and water erosion, rain and all nature effect, which influence the final smooth forming.

4.2.2.Heath plain

This landscape is located as spread flats around the hill islands. They were formed during the last ice age, by the melting water discharging of ice masse. The huge mass of melted water found its way toward the sea, as small and big streams, that gives the present valley system. The heath plain landscape is a combination of sand and gravel depositing and erosion of moraine hills, which were on the way of the melt water. The main part of the River Skjern-system especially River Skjern, Omme river, Kastroft river and Holtum river, run through the heath plain sediment.

5.2.3. Post glacial sediment

From the end of the last ice age there are deposited a new material that is called post glacial sediment, that can be found locally and often are dominant in the low land e.g. moor, meadows and marshes.

The postglacial fresh water sediment can be found with high content of organic matter in most parts of the river valley, as peat and mud.

5.2.4. Soil type

Coarse sand soil is the prevalent soil type in the watershed.

[2] Moraine: An accumulation of till having a surface form that is unrelated to the underlying bedrock

- 70% - 80% of the watershed consist of sandy soil.
- 15% - 20% is loamy sandy soil
- 4% - 8% is organic (humus) soil (Svendsen 1997)

The heath plain are formed from the sandy soil, and the hill islands are an older, so the acidic front level is very low deep in the soil (acidic front: is the zone when calcium can be found in dissolved form). The soil calcium has been washed from the soil. Other minerals as manganese and iron were dissolved and transport ether deep to the soil or deposit as bog iron ore[3].
Podsol-soil dominate 80 – 85% of the River Skjern Watershed. This soil is found in sandy acidic soil, where the aluminium and iron oxides together with the soil organic matter is mobilised down to the deeper soil layer forming a dark hard horizon. The rest of the watershed is loamy (downwashed) erosion soil, which effected with high ground water level (Svendsen 1997).

The soils at the upper parts of the watershed are mainly sandy and loamy tills from the previous ice age and the last ice age, while those of the stream valleys and the lower parts of the watershed are postglacial, alluvial sandy and loamy deposits.
The soil in the central restoration area, located between the channelised River Skjern and the southern channel are peat soils and organic matter-rich alluvial loamy and sandy soils containing 5%-6% pyrite (Andersen et al., 1997).

[3]An impure, limonitic deposit, usually porous, and probably formed as a result of bacterial action in swamp condition, it is a law – grade ore iron which was used extensively in early iron smelting.)

The pyrite iron di - sulphate (FeS_2) in the watershed area was formed, when the sulphate -rich seawater meet the iron-containing river water after the last ice age, therefore pyrite often occur in the soils seawater effect. (Kronvang et al., De strømmende vande). So pyrite is naturally existing in the area. The water flowed freely between the fjord and Northsea until 1930 when the sluice was build.

5.3. The river Skjern and the River Continuum Concept

The river Skjern follows the dynamics listed in the river continuum concept, though the system has never been left to its own dynamics, not in recent time anyway. The biggest change was the channelisation in the 1960Th. The river is now returned to its old streambed in the lower part. Besides returning the river to its old course a lot of the surrounding farmlands have been flooded and turned into meadows and wetlands once again. The dynamics of meadows and wetlands are highly influenced by the river and vice versa. The river floods the meadows especially in spring, autumn and wintertime. The meadows in turn partly controls leaching of nutrients, organic matter and ochre to the river, see more of this under functions of wetland. The natural succession and dynamics have not taken place for decades, what this means for biodiversity and nature quality will be discussed in detail in the discussion.

The functions of wetlands are of great importance for the ecosystem of the river, because of sediment load, nutrient load and ochre leaching. The functions of the wetlands around river Skjern are explained in the part of wetlands. It should be evident how important the removal of these substances is too the whole ecosystem of the river Ochre will suffocate invertebrates, fish and plants.

Nutrients will increase algae blooms etc. The channelisation itself will decrease habitat diversity and so on.

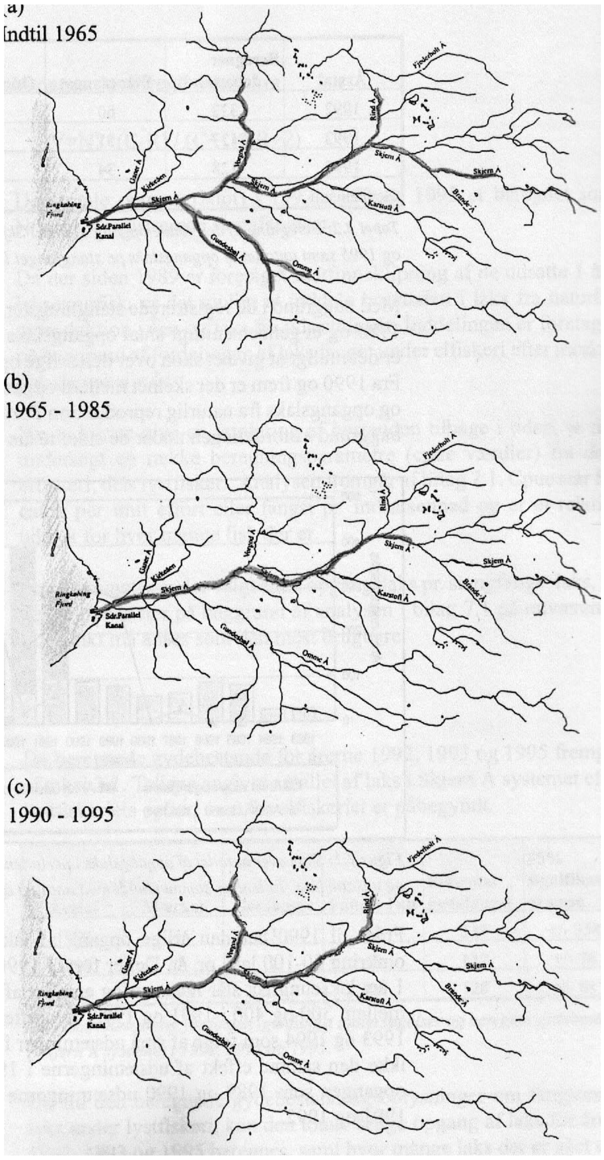
5.3.1 Salmon & Trout in the River Skjern

The salmon *Salmo salar* in the river of Skjern is of a special strain, situated in the Northsea. The strain in the river Skjern is the only one left of its special kind. One of the characteristics of the Skjern Salmon is the huge size, it grow to more than 20 kg (Wegner 1985). This special strain of Salmon has the interest of many, as the angler society, the fishers and others with interest in the welfare of wildlife. The government through various institutions and the county of Ringkøbing is doing a lot to safe and increase the population of the salmon.

Lifestyle of the Salmon

The Salmon is a fish, which lives partly in the sea and partly in freshwater. It spends the time from egg too smolt, the juvenile stage migrating to see, in the river system. The Salmon migrates to sea as smolt and spends one to three years in the sea before returning to the stream or river to spawn. In Skjern the Salmon spawns from November to January. The spawning takes place over gravel in ditches dug up by the female salmon, mainly situated in the main course of the river or in the major tributaries. The Salmon has to have a refugee in daytime, which limit the number of spawning sites to the larger part of the River Skjern. The spawning places in river Skjern has decreased after the channelisation, it is clear that the channelisation and numerous of other human activities up to the 1960th had disruptive effects on spawning grounds, as shown in the figure 16 (Wegner, 1985). After spawning the Salmon retreats to the sea, though survival is fairly low, in best cases up to 30%, but usually it is around 4-9%

The Eggs spawned in the gravel on spawning grounds, has some resistance to mechanic stress, fluctuations in oxygen level and so on, but sediment load and ochre in the river can cover up eggs and suffocate them. The eggs will hatch in River Skjern around April or may depending on temperature. The sediment load



in the spring is a critical link in the Salmon lifecycle, because of the growing eggs and hatched larvae the oxygen demand increases in the gravel and as water temperature increases, thereby lowering of oxygen concentration, it becomes critical if the area is covered by sediment or ochre.

Figure 16: The distribution of Salmon in river Skjern through time. (Bisgaard 1996)

When hatchlings appear form the spawning gravel a competition over space, food and hiding places begins, the juvenile fish are extremely competitive. Some of the young fish stay at the spawning ground, which now acts as a nursery area, some fish migrates downstream to find another suitable area, if they do not succeed they succumb. The suitability of the area is determined of the variation in the stream, macrophytes near the banks, big rocks and stones all contribute to create hiding places for the fish. In a channelised river the variation is very small and food production and shelter therefore very scarce. The yield of Salmon is only about 1 to 2 Salmon per 10 square meters of nursery area, this means that if a big population of Salmon is wanted, a big area of the river has to be of a high quality suitable for salmon offspring. This fact also makes the Salmon a good indicator of the nature quality of the area. The fisheries yield of Salmon have severely decreased after the channelisation in the late 1960th see figure 17. The quantity of Salmon caught in River Skjern has severely decreased to nearly nothing.

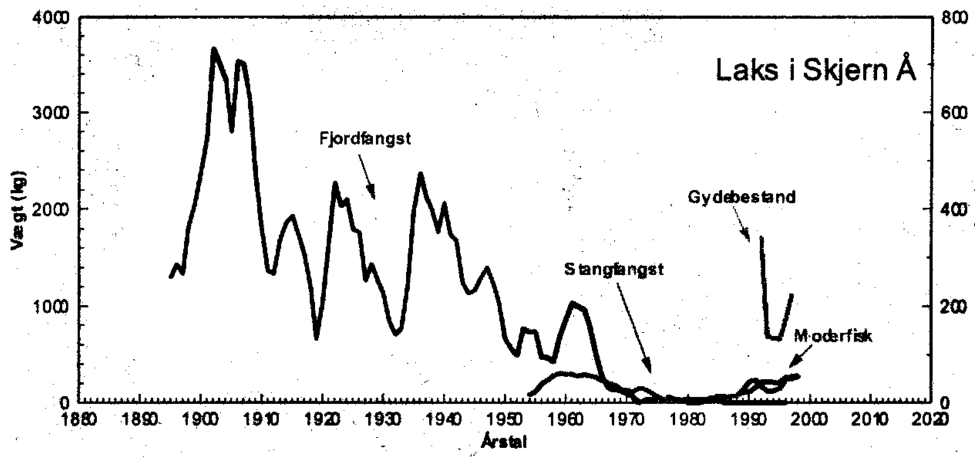


Figure 17: Catches of Salmon in kg pr year in the River Skjern. Figure from Ringkøbing amt 2000a.

The population of Salmon in river Skjern has increased over the last few years, in 1999 the number of spawning fish was estimated to be 713 individuals, though the numbers are connected with a high uncertainty. The reasons for the positive development are thought to be fishing regulations and release of hatchery reared fish as well as changed praxis of the sluice (Glüsing 1999). The effect of the restoration remains to be seen, at the moment the salmon does not seem limited by spawning grounds, but when the population increases the area of spawning grounds will probably be important. The restoration will probably be improving the area as a nursery area. When sediment load in a channelised and a meandering river, sediment load is expected to be lower in a meandering river, see chapter three on hydrology.

Trout in River Skjern

The life of Trout is somewhat similar to that of Salmon in many ways, both species has the same demands for a high water quality. The Trout differs though, it generally stays in the smaller and upper part of the stream. In the main stream usually the Salmon offspring stays in the deeper parts and the Trout offspring stays near the banks. Another major difference is that not all Trout changes morphology, the so-called smoltification, and migrates to sea. The Trout have three ways of life, the Stream Trout *Salmo trutta fario*, Lake Trout *Salmo trutta lacustris* and Sea Trout *Salmo trutta*. All three forms are the exactly same species they only differ in way of life. Stream Trout is stationary, staying in the streams all their life, the lake and sea Trout are migratory only returning to the streams to spawn. In the Skjern watershed Trout its almost exclusively sea and stream Trout because of the lack of lakes.

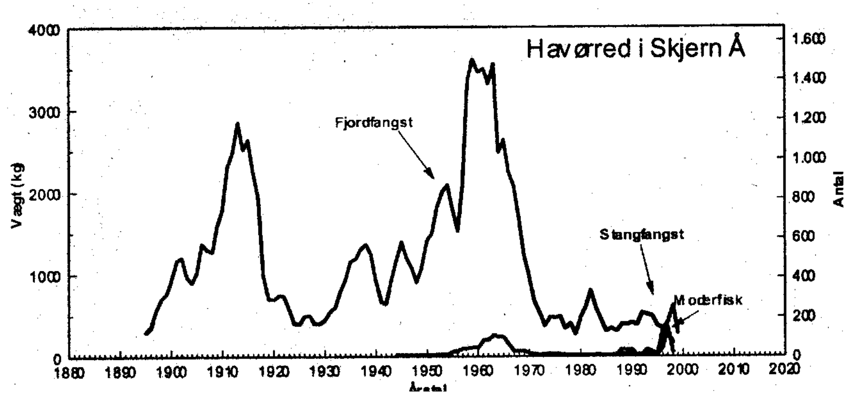


Figure 19: Catches of sea Trout in River Skjern, in kg per year.
(Source: Ringkøbing amt 2000a.)

The catches of Trout in River Skjern have, like the Salmon, decreased severely, see figure 19. Which is a good indicator for a fall in nature quality.

Chapter Six

6. Discussion

6.1 The influence of the Restoration on nature quality

Nature quality is a relatively new concept, when the channelisation was done in the 1960th nature quality was hardly a concept considered. Humans, mostly biologists, set the standards of nature quality. We define what kind of nature is the preferred one. The criteria's wildness, originality, continuity and authenticity all imply that nature is more or less still viewed as being besides human influence.

- According to the four criteria's for nature quality, the channelled river had no wildness. In a completely controlled channel, no natural dynamics can be found and human influence was dominating. The new meandering river however, got its freedom back. The naturally processes of meandering and thereby changing course over time as well as flooding the meadows now and then will definitely give a higher nature quality, based on the wildness criteria.

- There is no originality over a channelled river, the original river was in principal lost when farmers settled around the river watershed, primary originality however, not the secondary. The secondary originality is the nature types created by human activity, the secondary originality is needed in classification of nature quality due to the fact that a lot of interesting nature types in Denmark is man made, Heaths for instance. The differentiation of the two kinds of originality made by Danish authorities, primary and secondary is actually recognition of humans as an actor in nature, indicating the perspective of nature as everything. The new meandering river has much higher originality than the channelised. Meandering is the original course of almost any river and the processes following.
- The continuity of the channelled river was short it only existed from 1968 to 1990 a relatively short period, the new meandering river could be argued to have no continuity. On the other hand, the river has meandered since it was created after the last ice age, so in respect of meandering as a concept there could be talk about continuity. The new meandering river has actually no continuity, in this respect the new meandering river will actually have a lower quality then the channelled river.
- The authenticity of the channelled river, was it what it seemed, a totally controlled watercourse? Yes in that respect the channelled river is authentic, no more no less than a channelled river draining a lot of water from agricultural fields. It is a bit more complicated with the restored river. If you see the restored river as a restored river and not as a naturally river, made from naturally meandering processes, it is authentic. If you on the other hand view the river as

a river made from its own meandering forces and not by human entrepreneurs it's definitely not authentic.

- To conclude whether nature quality improves in River Skjern as a consequence of the restoration, the answer will be yes, the wildness and a bit of the originality has returned, which definitely was not present before the restoration. The continuity decreases but the continuity in the channelled river was small anyway and had very little value. The authenticity is a bit complicated but most people are not in doubt of the new meandering river is man made.
- An interesting question of whether the restoration was the right solution however is another matter. It's a matter of effort and rewards the restoration is a huge project costing a lot of money 254 million DKr. Could it have been done cheaper by making the river re-meander by its own processes, taking considerable longer time to re-establish itself, but on its own terms?
- From political side and through public hearings different frameworks for the project where proposed and discussed. It was also the case with the channelisation project in the 60th it was generally thought to be a good project, which actually was a success at the time. The perception of the restoration project in the future remains to be seen.
- The reduction in discharge of nutrient is expected to be 330 tons of nitrogen per year and 14,4 tons of phosphorus per year. If this is true then a question could be if the price of the project in this respect could have been spent more effectively in another place, for instance to reduce fertilisers on agricultural fields instead. The current model is based on nutrient containment in the meadows and wetlands and not on reduction of fertilisers in agriculture. This has implications for nature quality in for instance wetlands and meadows, they will be enriched and give rise to eutrophic, nutrient rich, nature types. This will

decrease nature quality for meadows, because of the decrease in the oligotrophic, Nutrient poor, nature types and species, which was present before the channelisation.

- The consequence of this restoration project in the future could be a lowered nature quality at the wetlands and meadows, because they only contain nutrient demanding species, caused by the high load of nutrients.

6.2. The impact on the ecosystem

- The restoration recreated the meandering of the river and the flooding of the surrounding meadows and wetlands controlled by the river dynamics. Thereby creating more habitat diversity in the River.
- Macrophytes are likely to spread in the meandering river as the velocity of the water slows in some areas and the water depth vary, increasing the possibility of water plants settle in the right place. If water plants become more numerous and also during winter, the macro invertebrate prosper as well.
- The Salmon of the River Skjern is not presently limited by spawning grounds, so the increase in spawning grounds probably has no immediate effect. The nursery ground, where the juvenile Salmon grow up, also increases which might have an effect. Of course if macro invertebrate population’s increase, food availability might to, which could be advantageous for the Salmon.

The restoration also recreates a delta of the river Skjern, which was not present before this will definitely attract and improve both habitat and species diversity in the newly formed area.

6.3. Restoration impact

The restoration project, which aimed at re-meandering the River Skjern to its origin course, has created floodplains (visit to the restoration site, March 2001).

Such hydrologic condition as found in the area, will lead to a condition which is similar to the one shown in figure 5. Consequently biological and chemical processes in these floodplains will be enhanced. But the scale which these processes will occur, is difficult to predict because of lack data. Looking at biological and chemical processes from theoretical point, it is easy to mention that nitrification and denitrification will take place in a large scale in that Carbon/Nitrogen ratio is higher than 7[4] due to the geological sitting such as found in the area. Carbon is one of the main constituents of peat soil found in the restoration area. Usually, carbon is limiting factor for most denitrification process. In winter, it is possible that denitrification process might slow down because of the low winter temperatures (see figure 13) found in this region. It is also arguable that soil temperature differ from air temperature, in winter temperature (around 8 degrees) in the sediments is higher than that of the air. Implying nitrification-denitrification will go on as normal without temperature hindrance. The amount of Nitrate and ammonium reaching the Fjord may be high during this period. On the other hand, during summer when most of the wetlands in the area are dry up and the groundwater level is lowered continuous pyrite oxidation may occur leading to formation of ochre in the sediments which will be led/wash into the River Skjern after major rainfall. From theoretical point of view, full control of formation of ochre in the restoration area will be difficult because other possibilities of ochre formation. As illustrated above, continuous pyrite oxidation also takes place in the presence of nitrate which is found in most of the aquifers in this region.

Comparing the environmental performance of the restoration to channelisation, it is obvious that the restoration project is showing positive impact on the environment in the watershed. Last visit to the site, the authors notice a lot of

[4] optimum C/N for denitrification process to take place

wading bird (whooper swan, oyster catcher, sandpiper and mute swan) enjoying nature provision, which was not available to them after channelisation.

6.4. Pathways of nutrients and Ochre

Following the nitrogen processes the de-nitrification is the natural way to reduce nitrate in the nature. When the nitrate leaches to the natural stream can be exposed to the anaerobic condition that led to de-nitrification, and releasing nitrogen gas to the atmosphere.

Plants are capable for using ammonium (NH_4) and nitrate (NO_3) and both are used as fertiliser, and can be washed from the soil to the stream water or ground water. In the sandy soil as in the west Jutland including the River Skjern watershed, nitrate is the main reason of the most polluted groundwater. And because the high mobility of nitrate, it is leaching to the ground water and remaining in the aquifer, which contain pyrite. Here it can be used in pyrite oxidation (reaction 12). The nitrite concentration in the ground water can be used as indicator for ochre forming possibility in the future, when the ground water is discharged to the river.

The nitrate can easy be washed from the root zone to the ground water and stream water thereby supplying more nutrients to the aquatic system. Under drainage process, nitrate can easy transport directly to the stream with the water run off, through the channel (figure 20).

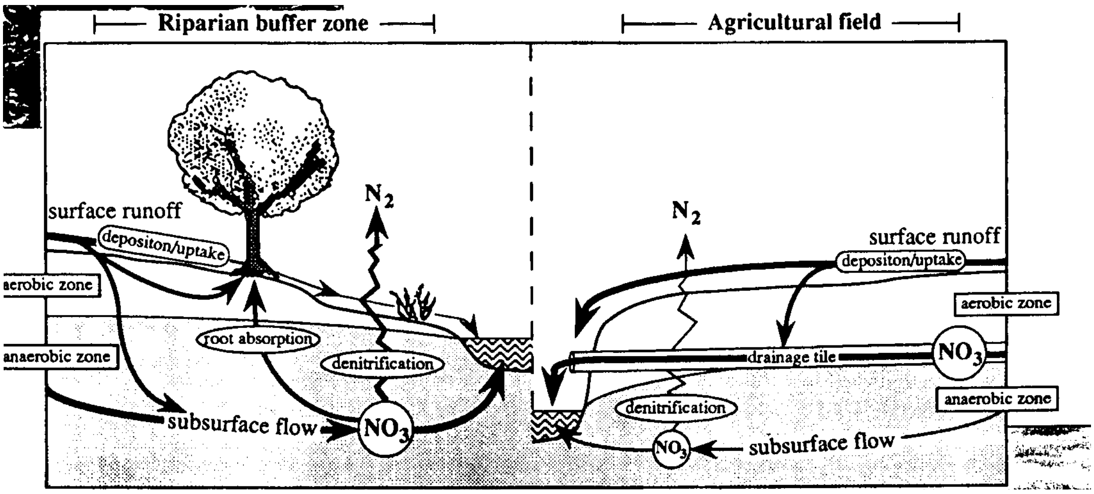


Figure (20) Schematic representation of the main nitrogen pathways through a buffer strip along a natural and a channelised stream (Lena et al., 1994)

- The high phosphorus input in the Fjord led to increasing alga growth, which reduces sunlight, reaching the bottom and inhibits growth of water plants. The high algae growth, leads to oxygen depletion, which suffocate the fishes. In 1972 the bottom plants could be found at 3,5-meter depth water, now it can be at 0,80 meter (Svendsen 1997). That is due to high phosphorus in put in the past, in it take a lot of time to reduce this effect, although the intensive work in swage treatment plan.
- The low dissolved phosphorus can be related to high concentration of dissolved iron that deposits phosphorus as iron phosphate. Although the reducing of phosphorus input to the fjord in these last ten years, but the phosphorus reducing is not obviously. The large accumulating of ochre in the bottom of the fjord related phosphorus. There is about 1,000 tons phosphorus in the upper 20 centimetres of ochre sediment.
- The annual realising and removing of phosphorus from the fjord sediment can be double the phosphorus input (in reducing phosphorus input condition). That means it takes about 5 to 10 years to empty the phosphorus pool, and the

phosphorus will become a limiting factor and reducing algal blooms (Svendsen 1997).

- The total phosphorus loading from the municipalities, industry and fish farms has been reduced 65% during the last decade corresponding to 33% over all reduction in total phosphorus loading of the river system (Andersen1997).
- The using of heavy machines in the cultivation processes can effect on the soil structure led to transporting soil and organic material to the river. This can cause phosphorus transporting to the aquatic system. The new forming wet lands change the kind of activity in the area.
- The vegetation with a high stem density will decrease water velocity, hence, reducing its sediment carrying capacity.

In anaerobic condition, reduction of iron often occurs with soil organic matter, which represented by a carbohydrate CH_2O. This reaction only proceeds under strongly reducing condition, where the soil is saturated with water and a strongly reducing environment is developed.

The restoration project lead to flooding of the stream water on the banks, which create wet land for. The flooding water can be happen from October to mars every year, this condition can contributes in forming ochre reduction condition and deposits pyrite in the sediment

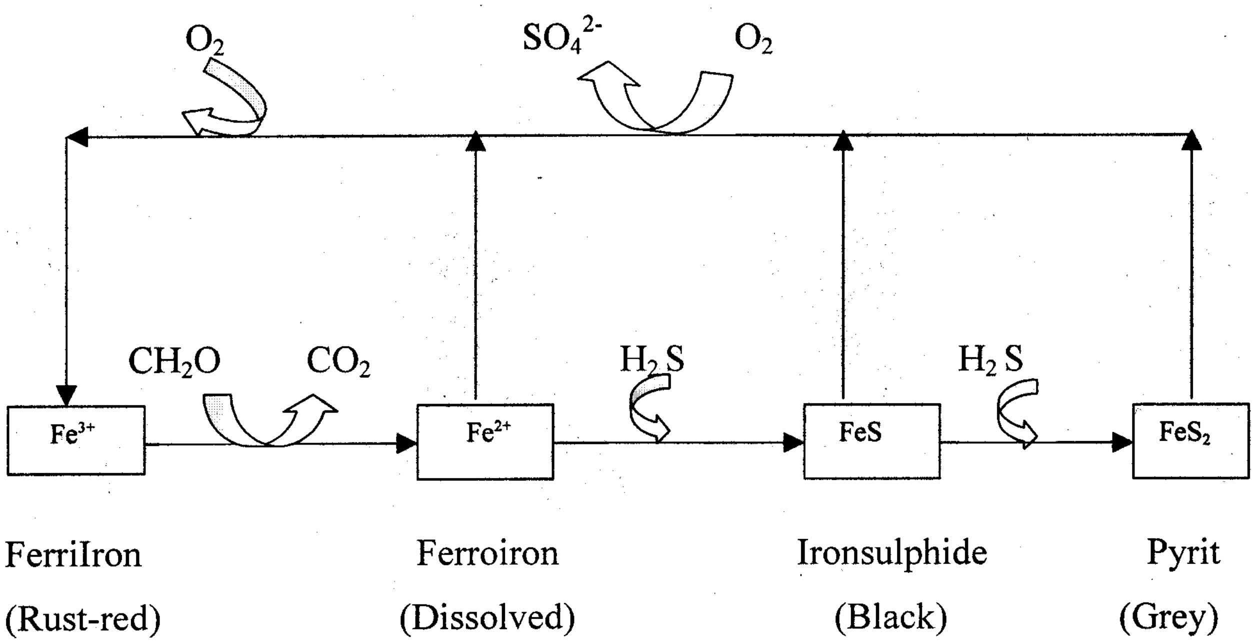


Figure 21: The schematic outline of iron oxidation and reduction in sediment.

Under anaerobic condition Fe organic substances or sulphide reduces (111). The Fe (11) released can bind with hydrogen sulphide forming first iron-sulphide, and then pyrite. In aerobic condition the pyrite is oxidising to ferriiron and sulphate. The sediment colour can be an indicator to the iron status. (Havmiljøet under forandring..1996)

Chapter Seven

7. Conclusion

- River Skjern was channelised in the late 1960th creating 4000 hectares of agricultural land, which at the time was so important that the huge project was undertaken and successfully fulfilled the expectations of controlling the flooding. Following the channelisation the draining of wetlands caused environmental damage to the main river, the fjord and the surroundings.
- Changes in social values and priorities and decrease in agricultural economic importance motivated the restoration project.
- The Restoration recreated the meandering and the natural dynamics of the area also recreating 2200 hectares of wetland. The meandering creates habitat diversity in the river and improves the self-purification of the river by removal of nutrients.
- The recreated wetlands and meadows retain nitrogen and phosphorus thereby reducing nutrient loads to the river, fjord and sea. The eutrophication in the fjord will improve as a result.
- The Nature quality of the Skjern watershed in respects to stream, river and delta quality, qualities of Ringkøbing fjord and qualities of the meadows and wetlands are measured on the habitat and species diversity. Habitat diversity is definitely increasing. Species diversity is also increasing in stream/river and the fjord/delta area. The species diversity in the meadows however will probably be low due to the eutrophication conditions.
- The restoration of the River Skjern which will re-establish most of its wetland will have positive effect on nutrient and ochre loads into the Ringkøbing Fjord.

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