SalFar framework on salinization processes

A comparison of salinization processes across the North Sea Region

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1 - Introduction

The following text discusses the manifold processes that create or aggravate saline conditions in the North Sea Region. To clarify, this text focusses on the underlying ecological processes and the socio-economical or environmental drivers of salinization. The text does not address the subsequent saline conditions, equally diverse throughout the North Sea Region. For more information about the diversity in saline conditions across the North Sea Region we refer to the SalFar baseline study (WP3).

It is important to clarify that this text focuses exclusively on salinization processes in the North Sea Region. Other researchers have developed a framework for all processes that effect the coastal aquifer. For example, Oude Essink (2001) defines six categories that have an impact of the coastal aquifer, and as a result, six categories that influence the occurrence of salinization (see figure 1). While this framework is very comprehensive, it does not facilitate the discussion amongst the SalFar partners since the six-fold categorization is simply too complex. It is not suited for quick comparison between the various coastal areas of the North Sea Region.

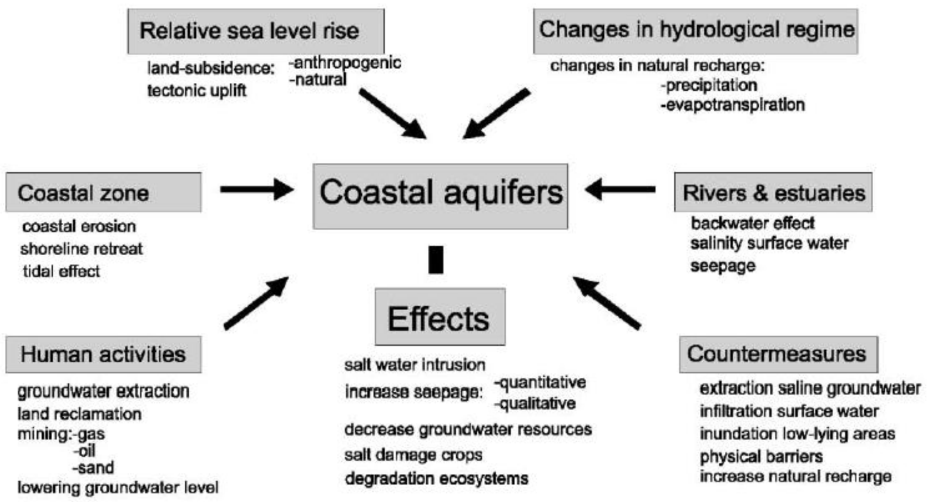

figure 1: processes that affect the coastal aquifer (Oude Essink, 2001)

Recently Daliakopoulos et al. (2016) reviewed the academic literature on salinization in Europe, and subsequently constructed an all-encompassing framework on salinization processes. They delineate two main categories of salinization processes: primary and secondary salinization (see figure 2). The first category, primary salinization, comprises all natural salinization processes, including physical or chemical weathering and transport from parent material, geological deposits or groundwater. Secundary salinization, on the other hand, results from human interventions, mainly irrigation with saline water or other ill-suited irrigation practices often coupled with poor drainage conditions. In the SalFar project we didn’t opt to make use of this framework as it is not specific to coastal regions. Moreover, the division is too extensive and in many coastal regions there is a complex interaction of natural and human-driven salinization processes.

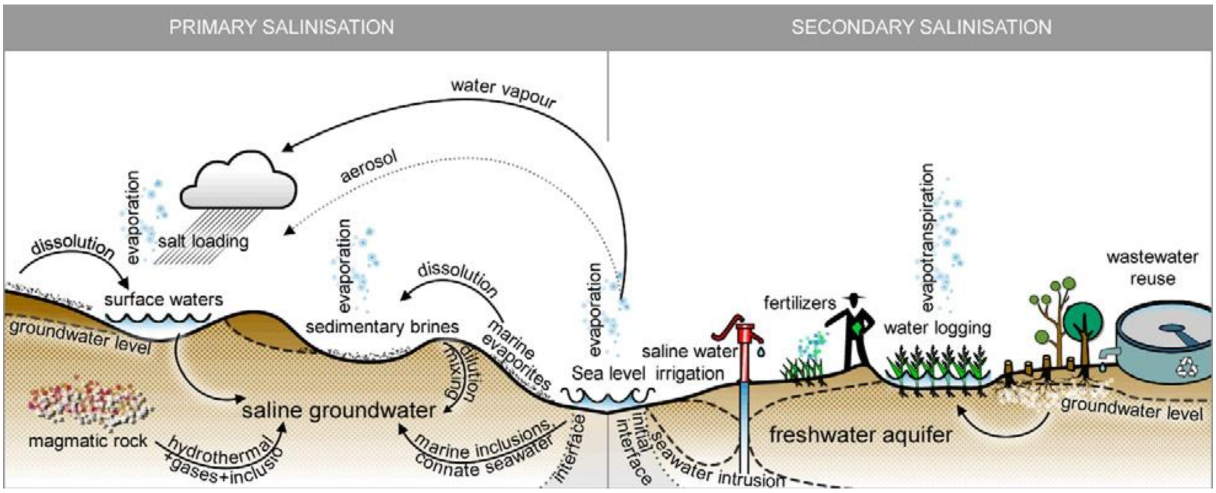

figure 2: framework on salinization by Daliakopoulos et al. (2016)

Finally, Manca et al. (2015) define eight different types of salinization in their study of the Litorale Romano Natural Reserve. Similar to Daliakopoulos et al. (2016), Manca et al. (2015) divided eight types into a set of primary (natural) salinization processes and a set of secondary (anthropogenic) salinization processes. Equally, this eight-fold categorization of salinization processes is too fine-coarse in order to facilitate quick cross-region comparison in the SalFar project.

This report constructs an easily readable framework on salinization process in the North Sea Region. It aims to facilitate quick cross-region comparison.

2 – The complexity of salinization in the North Sea Region

The issue of salinization is extremely complex as a result of the manifold area-specific (or 'territorial') characteristics. The risk of salinization (both the factor of probability as well as the factor of impact) in the North Sea Region diverges as key factors vary throughout the region. These factors can be classified into five categories.

Firstly, there are the **local geological and geographical conditions**:

- *Soil composition*
  The coastal regions of the North Sea Region are predominantly sand and clay soils. The soil composition varies throughout the North Sea Region as well as throughout the local coastal regions. More information on local soil composition can be found in the SalFar baseline study.
- *Topography*
  The elevation of the coastal area with respect to the nearby sea greatly defines the amount of saline seepage. Furthermore, local saline conditions can vary greatly as a result of micro-relief.

Secondly, there are the **hydrological conditions**:

- *Salt content of the coastal waters*
  The salt content of coastal waters varies. It is measured in parts per thousand (or ppt). Brackish waters range from 00.5 to 30 ppt, while saline water ranges from 30 to 50 ppt Throughout the North Sea Region the salt content of the coastal water ranges from approximately 35 ppt (Belgium and Holland) to 12 ppt (Øresund). To clarify, the salt content of soils is measured in a different way: the electrical conductivity in dS/M. More information can be found in annex 1 or in the SalFar baseline study.
- *Conditions of local freshwater lens*
  In many coastal regions of the North Sea Region the phreatic aquifer comprises of two layers: a freshwater lens on top, and a salt water lens underneath. The 'thickness' of the freshwater lens defines to what extent salinization occurs.
- *Influx of 'foreign water' into the local watershed*
  Foreign water supplies (the presence of major canals and rivers) can be used to irrigate farming fields, thus alleviating the threat of salinization. The Dutch mainland, for example, disposes of important foreign water supplies since the region is intersected by the great rivers Meuse and Rhine. The Danish, German and Dutch isles, on the other hand, have much less freshwater at their disposal as they are islands.

Thirdly, there are the **meteorological conditions**:

- *Annual and seasonal precipitation*
  The local precipitation defines the 'local water' supplies. The more precipitation is available, the less likely seepage-induced salinization is to occur. It must be highlighted that the local precipitation can vary greatly from one season to another. Especially in spring and summer agricultural crops are in high demand of water. If there is no precipitation during a prolonged

period, there farmers are obligated to irrigate their crops. Furthermore, we must stress that meteorological conditions vary from one year to another.

- *Local climate change*
  The meteorological changes and climate impacts that result from global warming vary from one region to another. In Europe, for example, the climate models predict an overall increase of precipitation in Scandinavia. In North-West Europe, however, winter precipitation is likely to increase while summer precipitation decrease. Climate change exacerbate salinization in a threefold way: via changing precipitation, via increased storminess, and via sea-level rise (Taylor et al., 2012; Wong *et al.*, 2014, p.379).

Fourthly, there are the **factors related to water management**:

- *Management of the freshwater layer*
  This factor includes all interventions that influence the ‘thickness’ of the phreatic freshwater lens, including policy choices about the drainage of the surface waters (When? How? To what extent?). Other important interventions are the deep drainage of salt rich groundwater and the supply of foreign water to the surface waters.
- *Presence of a harbor*
  Harbors have a particularly high water demand as they require freshwater every time a ship passes through a sea lock. In order to prevent saltwater intrusion when the sea lock is opened, great amount of freshwater are actively drained. In the competition for freshwater harbors are most likely to get all water needed since they have more economic value than agriculture.
- *Presence of other water consumers*
  Besides portal activities various other land uses have a high demand for fresh water. Tourism, for example, claims much of the local freshwater resources during the summer season. On the other hand, it is also a potential source of freshwater if the urban sewage is sufficiently cleaned in water treatment plant.
- *Coastal zone management*
  Policy interventions within the domain of coastal zone management have a great impact on the balance of seawater and freshwater in the coastal region. For example, the dredging of tidal inlets of the Scheldt river (Belgium) and the Weser river (Germany) in order to create deeper and wider harbor inlets increase local salinity. The creation of new tidal marshes, e.g. the Zwin nature reserver in Belgium, can equally increase the seepage of seawater.

Fifthly, there are the **factors related to agricultural use and management**:

- *Agricultural activities*
  The freshwater consumption of agricultural enterprises varies greatly since the water demand and drought tolerance of agricultural crops vary. Vegetable and fruit production requires more (irrigation) water than arable farming. Animal production requires a lot of (drinking) water as the animals need to drink constantly.
- *Agricultural water management*
  A farm’s consumption of freshwater also greatly depends on how it manages its’ water; the type of irrigation, the presence of a water collection basin or level-controlled drainage, etcetera.

3 – Four categories of salinization processes

The objective of this document is to unify and to streamline all future communication, first and foremost amongst the SalFar partners. From now on, all SalFar partners are encouraged to make use of the fourfold categorization of salinization processes in the context of arable farming at the coast (figure 3). To clarify, this document only categorizes the processes that create saline soil conditions. It does not categorize the resulting saline soil conditions. The following paragraphs elucidate the four categories. In addition, this document coins four fixed, accompanying terms: (1) irrigation salinization, (2) aerosol salinization, (3) flood salinization, and (4) seepage salinization. A rigorous application of this terminology will offer consistency and clarity throughout the SalFar project.

Note: The SalFar project focuses on salinization in the North Sea Region, a cluster of coastal areas that are characterized by either a temperate oceanic either a temperate continental climate (Köppen climate classification). As a result, the SalFar categorization does not include salinization that is caused by freshwater irrigation in arid regions: the Midwest of the United States, the Mediterranean, the Middle East, India and Northern China (Nachtergaele, et al., 2010).

The following subsections clarify the four salinization processes in a fixed chart in order to facilitate consistency and comparability. In the next section of this document you can find a juxtaposition of the charts in order to facilitate a quick and easy comparison of the four salinization processes.

figure 3: four types of salinization processes in the North Sea Region

3.1 – Irrigation salinization (IS)

SalFar **terminology** (applied consistently throughout SalFar)	irrigation salinization or IS (*zoute irrigatie* in Dutch)
Alternatives (not applied in SalFar)	the use of brackish or salt water (Bruning and Rozema, 2013), the use of saline water (Rozema and Flowers, 2008), the use of salt contaminated resources (Ladeiro, 2012), saline water irrigation (Daliakopoulos *et al.*, 2016)
Definition	Irrigation salinization (or IS) is the salinization that results from irrigation of non-saline agricultural soils with salt or brackish water. This man-made salinization can be deliberate and reasoned or just the opposite. Examples of irrigation salinization are: - IS in order to **test** the salt tolerance of crops and cultivars - IS in order to irrigate the agricultural fields with **natural salt-rich water resources** (e.g. seawater, brackish surface water and saline groundwater) because there is no or not enough freshwater resources at hand - IS in order to irrigate the agricultural fields with **man-made salt-rich water resources** because there is no or not enough freshwater resources at hand. Possible resources are cleaned sewage water (Mujeriego *et al.*, 2008), aquaculture waste water (Qadir *et al.*, 2015) and the brine that results from water desalinization (Jones *et al.*, 2019).
Important parameters	An important parameter is the **salt content of the irrigation water,** or salinity in short. The irrigation water can be pure seawater. In the North Sea Region the salinity of seawater ranges from from approximately 3.5% (Belgium and Holland) to 1,2% (Øresund). Another option for agricultural irrigation is the use of brackish water, namely water with a salt content between 0.05 to 3.0%. Brackish water can be found in nature (e.g. creeks or saline drainage channels) or can be man-made (e.g. mixing seawater and freshwater). Finally, other sources of salt-rich water are: salt-contaminated phreatic sheets, drainage water from other plantations irrigation , drainage water from humanized areas (e.g. sewage) or even water derived from aquaculture waste (Ladeiro, 2012). Irrigation with brackish or saline water is only a viable option in **sandy soils** (de Vos *et al.*, 2016). Sandy soils compare to a sieve since the salt, accumulated in the soils throughout the IS, is quickly washed out via precipitation (natural process) or irrigation with freshwater (man-made process). In clay soils, on the other hand, IS

	auses the loss of soil structure, leading to water logging and poor root development. The **timing and duration** of SI is another important parameter. In some cases of SI, the irrigation is continuously throughout the season, from germination over growth to harvesting stage. In other case, the irrigation with seawater or brackish water is applied only in times of freshwater shortages.
What is saline farming?	In the context of IS, saline farming can be defined as *all farming activities that actively irrigate cropland or grassland with brackish or salt-rich water*. Hence, such saline farming and irrigation salinization are directly related: IS occurs as a result of saline farming.
Why saline farming?	In the context of IS the main rationale for saline farming is the **reduction of freshwater consumption**. In some regions there is limited freshwater available (e.g. islands) or there is an extremely high water demand for agriculture (e.g. the cultivation of water intensive crops). Saline farming is strategy to address the inherently limited water resources. As such, the saline farming strategy 'competes' with other water saving strategies such as drought-resistant farming and precision irrigation.

3.2 – Aerosol salinization (AS)

SalFar **terminology** (applied consistently throughout SalFar)	Aerosol salinization (AS) (*zoutnevel* in Dutch)
Alternatives (not applied in SalFar)	Sea salt aerosol deposition (Manca, Capelli and Tuccimei, 2015), Deposition of marine aerosols (Gustafsson and Franzen, 1996), Sea aerosol spray (Bouzourra, Bouhlila and Elango, 2015), Marine evaporites (Daliakopoulos *et al.*, 2016)
Definition	Aerosol salinization (or AS) is the salinization that results from the accumulation of salt in the soil as droplets of seawater are deposited on the land. The droplets of seawater in the wind are the result of the wind creating waves, of which some break. Those breaking waves spread spray bubbles that evaporate in the wind. On average the amount of AS is low: 50 up to 150 salt particles per cm^3 at high wind speed (O'Dowd and de Leeuw, 2007). This results in rather low salinization stress on the soil. For example, AS near Ostia (Italy) doesn't EC values of 3,5 µS/cm (Manca, Capelli and Tuccimei, 2015).
Important parameters	A key parameter for AS is **wind direction** and **wind speed**. Needless to say, there needs to be a wind in the direction 'from the sea towards the coast' region in order for AS to occur. Secondly, the wind needs to exceed 4 meter per second in order for the wind to take up droplet of seawater (O'Dowd and de Leeuw, 2007). Moreover, the wind speed determines the total amount of salt particles that is transported by the wind. A second parameter for AS is the **distance from the coastline**. The amount of AS decreases exponentially with the distance to the sea. To be precise, most airborne salt particles are deposited at the first 500 to 1000 meters (Gustafsson and Franzen, 1996). What is more, Gustafsson and Franzen (1996) have showed that the gradient from coast to inland becomes steeper as the wind speed increases. The impact of AS is also steered by the **precipitation in the coastal area**. Salt only accumulates in the soil when there is no rain. During the rainy season all is rapidly washed out (Manca, Capelli and Tuccimei, 2015). Finally, the spatial distribution of AS is influenced is related to the **topography** and **vegetation pattern** of the coastal area (Gustafsson and Franzen, 1996). Heights, e.g. dunes, create lee effects and cause for increased deposition on windward slopes. Vegetation increases the roughness of the landscape and, as a consequence, increases the

	surface area that is available for the deposition of salt particles. As a result, vegetation is believed to steepen the inland gradient (Gustafsson and Franzen, 1996). In other words, if there is vegetation near the coastline, there will be less land affected by AS. Besides the plant stress that is caused by the salinization of the groundwater via AS, AS causes additional stress known as **salt spray** (Appleton *et al.*, 2009). When droplets of salt-laden water evaporate, the salt's sodium and chlorine ions can penetrate stems, buds and leaves, causing direct damage to the plant. Such salt spray can cause stem and foliage disfigurement, reduced growth, and often plant death. One symptom of salt spray is leaf burn or scorch.
What is saline farming?	In the context of AS, saline farming can be defined as *all farming activities that employ crops that are tolerant to the accumulation of salt in the soil during a dry period AND to the stress caused by salt spray.*
Why saline farming?	In the context of AS the main rationale for saline farming is **to make use of all farmland.** This includes agricultural plots that are situated next to the sea or at the leeside of heights such as dunes. Opposing strategies, on the other hand, concentrate on the creation of windbreaks or wind shields for the most vulnerable crops: e.g. rows of trees or hedges (Appleton *et al.*, 2009).

3.3 – Flood salinization (FS)

SalFar **terminology** (applied consistently throughout SalFar)	flood salinization or FS (*zoute overstroming* in Dutch)
Alternatives (not applied in SalFar)	Seawater overwash (Appleton *et al.*, 2009), Storm surge flooding (Wong *et al.*, 2014),
Definition	Flood salinization (or FS) is the salinization that occurs as soils are flooded by brackish or salt-rich water. These floods occur periodically or exceptionally. Examples of flood salinization are: - Natural and reoccurring FS in the **unprotected areas**, e.g. the areas outside the dykes - Semi-controlled FS in the **double dyke** system - FS in **recently flooded areas** (the aftermath of a dramatic weather event) - FS in **areas at risk of future flooding** (flood risk is aggravated by climate change)
Important parameters	**Flood risk** is the most important parameter in the context of FS. The flood risk results from geophysical conditions, including the elevation of the coastal area and the local storm frequency. To clarify, in the North Sea Region some of the coastal areas (e.g. the south-west of Sweden) are less exposed to storm surges than other areas (e.g. Belgium). On the other hand, the flood risk depends to a great extent on the societal choice: to what extent do we protect the coastal area? The Netherlands, for example, employ much higher standards for coastal safety than the United Kingdom. Flood risk defines the frequency of flood salinization, and thus it is a key parameter that defines the extent of flood salinization. Especially when FS occurs yearly or even more often, the need for a strategy on salinization is high. The impact of the flood salinization greatly depends on the **local soil conditions**. The damage of FS is particularly high in the case of clay soils. Here the addition of salt causes the loss of soil structure, a process known as 'soil sealing'. Another parameter is the **amount of freshwater** that is **available to flush the salinity of flooded areas**, either through natural precipitation or active flushing via man-made irrigation. To clarify, flushing also takes place in areas subjected to SS, see section 3.5.

What is saline farming?	In the context of FS, saline farming can be defined as *all farming activities that employ salt tolerant crops in areas that have been, are or will be flooded by seawater.* Building on the conceptual framework of climate adaptation by Burton et.al. (1998), we distinguish **two types of saline farming** in response to FS: (a) 'preventative' or 'anticipatory' saline farming, and (b) 'corrective' or 'reactive' saline farming. In the first type of saline farming the change of cultivars and crops has occurred before the saline flood. The latter type of saline farming the change of cultivars and crops takes place in the aftermath of a flood.
Why saline farming?	In the context of FS the main rationale for saline farming is **the use of land where traditional farming is or will become unviable** as a result of flood risks. The FS perspective on saline farming is best framed within the IPCC framework on adaptation responses to sea-level rise (see Dronkers et al. 1990). The concept of saline farming classifies as an 'accommodate' strategy: the local land use are prepared for possible calamities (De Waegemaeker, 2017). Opposing adaptation responses to sea-level rise are dyke reinforcement (classifies as 'protect') or land abandonment (classifies as 'retreat').

3.4 – seepage salinization (SS)

SalFar **terminology** (applied consistently throughout SalFar)	seepage salinization or SS (*zoute kwel* in Dutch)
Alternatives (not applied in SalFar)	aquifer salinization (Wong *et al.*, 2014), seawater intrusion (Werner *et al.*, 2013), saline intrusion (Taylor *et al.*, 2012), lateral + salt-wedge intrusion (Manca, Capelli and Tuccimei, 2015), groundwater salinization (Pauw, Louw and Essink, 2012), saline seepage (Oude Essink, Baaren and Louw, 2010), saltwater seepage (Lebbe, Meir and Viaene, 2017) upconing of salt water (Delsman, 2015, p.10)
Definition	Seepage salinization (or SS) is the salinization that results from the rise of salt rich groundwater, a process known as seepage. The salt rich groundwater is a continuation of the nearby seawater. As saline seepage reaches the root area, farmers are challenged by salinization. Examples of seepage salinization are: - SS as a result of **climate change**. As global warming causes sea-level rise and aggravating drought, coastal regions are increasingly confronted with SS (Taylor *et al.*, 2012). - SS as a result of **water management in the low-lying land**. For example when freshwater is drained in order to improve the workability of agricultural soils. Extensive drainage, however, facilitates SS. - SS as a result of **maritime infrastructural works** such as the creation of an inland harbor or dredging of tidal inlets. - SS as a result of **nature development**. For example, the creation of saline grasslands. Noteworthy, the IPCC highlights that human activities are the main driver for SS and that they will remain the main driver for SS in the upcoming century (Wong *et al.*, 2014, p.379).
Important parameters	A first important parameter is the depth of the phreatic seawater lens, and in particular **the local crops and the associated root area**. The latter parameter defines the plants' exposure to seepage salinization. The depth of the saline groundwater results from the conditions of the phreatic aquifer, and **the thickness of the freshwater lens** to be precise. There is much variation in that parameter throughout the North Sea Region.

	Even within one coastal region the thickness of the freshwater lens varies greatly as a result of **soil patterns**. In the low-lying coastal areas of Flanders and Holland, for example, the freshwater lens is shaped by the area's geological origins (Vandenbohede *et al.*, 2010; Pauw *et al.*, 2015). Former tidal creeks are today's sand ridges. Here, the freshwater lens is thicker as the sandy soils allows for easy water infiltration. Although climate change has an impact on the freshwater lens, the main driver for freshwater lens fluctuations are man-made (Wong *et al.*, 2014, p.379). In other words, the **local management of both the surface water and the phreatic groundwater** (e.g. drainage or storage of freshwater) defines the likelihood of seepage salinization. More information see section 'why saline farming?'. The **moment of occurrence** defines to a great extent the sensibility of the agricultural crops. The impact of salinization on a plant is, for example, far more negative at germination than at ripening stage. This moment of occurrence is also linked to the plants' root area.
What is saline farming?	In the context of SS, saline farming can be defined as *all farming activities that employ crops and cultivars that are adapted to saline groundwater in order to prevent the loss of harvest in the event that salt rich groundwater rises. This includes both the use of salt tolerant cultivars as well as the use of crops with a limited root area. The latter avoids the exposure of the plants to SS.*
Why saline farming?	In the context of SS the main rationale for saline farming is **to customize agriculture to the coastal hydrology**, and the local presence of a salt rich groundwater layer to be precise. This salt rich groundwater layer fluctuates and transforms as a result of human interventions or climate change. Opposing strategies, on the other hand, concentrate on stabilizing the coastal aquifer through water management. Firstly, there are 'wet' strategies such as the increase of the rainwater infiltration or the reduction of surface drainage of freshwater (De Louw *et al.*, 2015). These strategies requires modified agricultural management, namely the cultivation of water-loving or drought-tolerant crops. On the other hand, there are various strategies that are purely within the domain of phreatic groundwater management; e.g. the deep drainage of the saline groundwater, the deep-well infiltration of freshwater or the creation of a physical barrier between the freshwater and saline water bodies (Oude Essink, 2001). Moreover, the seepage salinization can be counteracted by surface water flushing: the supply of freshwater to the area's water network in order to lower salinity levels. This requires vast amounts of freshwater, e.g. today 15 percent of the total freshwater resources

	in the Netherlands is currently used for the flushing of low-lying polders (Delsman, 2015, p.153).Finally, the reclamation of land by expanding the dune area can increase the amount of freshwater and, as a result, mitigate SS (Oude Essink, 2001). Recent research, however, has showed that such reclamation of land is not an effective countermeasure for SS (Oude Essink, Baaren and Louw, 2010).

4 – Quick comparison of salinization processes

In order to allow for an easy and quick comparison of the four salinization processes, this section juxtaposes the charts in section 3.

Terminology	Definition	What is saline farming?	Why saline farming?
irrigation salinization (IS)	Irrigation salinization (or IS) is the salinization that results from irrigation of non-saline agricultural soils with salt or brackish water. This man-made salinization can be deliberate and reasoned or just the opposite.	All farming activities that actively irrigate cropland or grassland with seawater.	SalFar in order to **reduce the freshwater consumption** and thus address the inherently limited water resources.
aerosol salinization (AS)	Aerosol salinization (or AS) is the salinization that results from the accumulation of salt in the soil as droplets of seawater are deposited on the land. The droplets of seawater in the wind are the result of the wind creating waves, of which some break. Those breaking waves spread spray bubbles that evaporate in the wind.	All farming activities that employ crops that are tolerant to the accumulation of salt in the soil during a dry period AND to the stress caused by salt spray.	In the context of AS the main rationale for saline farming is **to make use of all farmland**. This includes agricultural plots that are situated next to the sea or at the leeside of heights such as dunes.
flood salinization (FS)	Flood salinization (or FS) is the salinization that occurs as soils are flooded by seawater. These floods occur periodically or exceptionally.	All farming activities that employ salt tolerant crops in areas that have been, are or will be flooded by seawater.	SalFar in order the **use of land where traditional farming is or will become unviable** as a result of seawater flood risks.
seepage salinization (SS)	Seepage salinization (or SS) is the salinization that results from the rise of salt rich groundwater, a process known as seepage. The salt rich groundwater is a continuation of the nearby seawater. As seawater seepage reaches the root area, farmers are challenged by salinization.	All farming activities that employ crops and cultivars that are adapted to saline groundwater in order to prevent the loss of harvest in the event that salt rich groundwater rises. This includes both the use of salt tolerant cultivars as well as the use of crops with a limited root area. The latter avoids the exposure of the plants to SS.	SalFar in order to **customize agriculture to the coastal hydrology**, and the local presence of a salt rich groundwater layer to be precise.

6 – What about saline livestock farming?

Up to now this SalFar report focused exclusively on arable farming and horticulture in saline conditions. As such, the document's perspective on saline farming is limited to vegetable production. Equally, all research within the SalFar project is limited to crops used for human consumption. There are, however, many animal farmers and mixed farmers in the North Sea Region. This section explores the possible types of livestock farming in saline conditions, which we call 'saline livestock farming' in the following paragraphs.

Compared to the literature review of arable farming and horticulture in saline conditions, there is far less literature on livestock farming in saline conditions. Consequently, we suggest that there is much to learn about saline livestock farming, and about saline livestock farming in the North Sea Region in particular. Based on the available literature, we suggest to delineate three categories; (a) the grazing of salt marshes, (b) the grazing of saline grasslands and (c) the use of saline fodder (see figure 5).

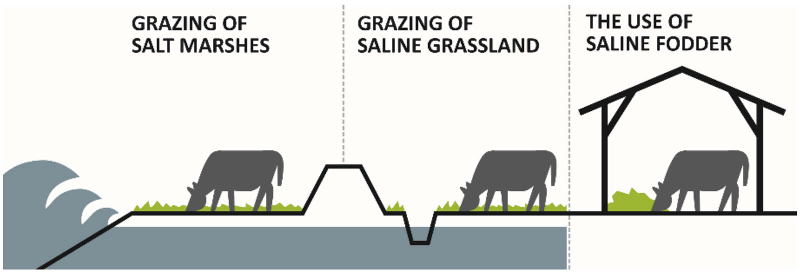

figure 5: three categories of saline livestock farming

6.1 – The grazing of salt marshes

A first type of saline livestock farming is the grazing of the salt marshes. There are multiple animal species that can graze tidal areas; ducks, geese, rabbits, hares, wild boars, horses, sheep and cattle (Antoine *et al.*, 2013). Today nearly all tidal areas in the North Sea Region are allocated to nature, or at least local land uses are subjected to many environmental restrictions. In order to improve the plant diversity nature managers allow for or apply grazing. Within the scientific community there is debate about the type of grazers that should be employed: is man-controlled grazing, i.e. the use of sheep and cattle, a viable pathway for natural salt marshes (Antoine *et al.*, 2013)?

The following example showcases the potential of the first type of saline livestock farming (figure 6) in the tidal area *Verdronken Land van Saeftinghe*. This tidal area is situated along the river Scheldt at the border of Belgium and the Netherlands and is grazed by Belgian Blue cattle (see 2017.saeftingher.com). During six months a year -*from mid-spring until mid-autumn*- a tidal area of 230 hectares is grazed by about 90 females. These cows are specially selected and all are between four and seven years of age. The tidal area floods twice a day and, as a consequence, the cows are required to occasionally swim to higher areas. In the recent Horizon2020 project Internet of Food and Farm 2020, each cow was equipped with a GPS transmitter in order to easily found when lost. In salt flats and channels the cows can get trapped in the mud. The technology, however, proved to be insufficiently adapted to the harsh conditions in the tidal area. The animal farmer brands his meat as 'pré-salé', a French term meaning 'salted in advance'.

figure 6: grazing in Verdronken Land van Saeftinghe by Belgian Blue cattle (2017.saeftingher.com)

6.2 – The grazing of saline grassland

A second type of saline livestock farming is the grazing of saline grassland (translated from the Dutch *zilt grasland*). Contrary to salt marshes, saline grassland is not subjected to the tide but seawater seepage creates saline conditions. As a result, halophytes thrive, including sea lavender, sea beet, sea aster, sea kale and glasswort. Saline grassland is a rare and valuable ecotope and most Europe's saline grasslands are protected by the EU Habitat Directives. In concrete terms, this means that farmers are prohibited from converting saline grassland into arable land. The occasional grazing of halophytes by sheep or cattle is not known to negatively affect animal production. There is, however, a risk that local surface waters contain too much salt. In these cases, farmers need to supply foreign fresh water to the grazing cattle. The Stiftung Ökowerk Emden, for example, experiments with a filtering system that turns the local surface water from brackish to freshwater.

6.3 – The use of saline fodder

Finally, a third type of saline livestock farming is the use of halophytes as fodder. Such agricultural practice is common in arid regions, including the Mediterranean, Syria and Australia (Norman, Masters and Barrett-lennard, 2013). In these arid regions the conventional animal feed is supplemented with halohphytes, mostly grasses and chenopods, in times of drought. To clarify, such use of 'saline fodder' must be balanced with other nutrients in order to ensure a healthy diet, especially since halophytes can contain toxins (Norman, Masters and Barrett-lennard, 2013). The latter does, however, not detract from the potential of saline fodder. Indeed, the use of non-halophyte fodder, that was grown in saline conditions, causes poor animal production as a result of low edible biomass production, low nutritive value, depressed appetite, or a reduction in efficiency of energy use (Masters *et al.*, 2006).

7 – References

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Annex 1: classification of soil salinity

In the SalFar project the soil salinity in the participating regions is studied by measuring the electrical conductivity via two methods: the saturated paste method and the 1:2 method. The table below classifies the soils from no to very high salinity. More information can be found in the SalFar baseline study.

Classification/method	Saturated paste method	1:2 method
	dS/m	
No salinity	0-2	
Low salinity	2-4	<1
Moderate salinity	4-8	1-2
High salinity	8-16	2-3
Very high salinity	> 16	> 3

Table: Classification of soil salinity, conditional to method of analysis