Abstract

The salinization of freshwater resources poses significant problems to agriculture, industry, and drinking water provision in coastal areas all around the world. Climatic and anthropogenic stresses create additional pressures on freshwater resources in these areas, thereby increasing competition between the different uses. In the low-lying, coastal regions of the Netherlands, the threat of salinization is already widespread due to historically saline groundwater reservoirs and being largely positioned below sea-level. Agriculture in these areas is particularly vulnerable to the threat of salinization, being exposed to brackish seepage, volatile weather conditions, and by being one of the last activities to receive fresh water in times of scarcity. To research how the agricultural sector can be made more salinization-resilient, semi-structured interviews with experts and stakeholders were conducted to identify what is currently locking-in unsustainable land- and water management practices and what could potentially support a transition to more salinization-resilience. The findings show that a lacking sense of urgency, uncertainty about the threat of salinization, uncertainty about the effectiveness, efficiency, and feasibility of different mitigative and adaptive measures, and diffuse burdens and responsibilities are locking-in the status quo. These lock-ins can be overcome by embedding the issue in existing programmes, increasing communication and collaboration between the different stakeholders, formulating long-term strategies, and increasing awareness through pilots. Furthermore, research into different measures and a societal cost-benefit analysis can elucidate possible pathways to salinization-resilience.

Keywords: salinization, climate change, salt-tolerance, mitigation, adaptation, resilience, fresh water
Table of contents

Abstract ........................................................................................................................................... 1
Table of contents ............................................................................................................................. 2
1. Introduction .................................................................................................................................. 3
   1.1 The global issue of salinization ............................................................................................. 3
   1.2 The issue of salinization in the Netherlands ......................................................................... 4
   1.3 Problem statement and research question ............................................................................ 5
2. Literature review ........................................................................................................................... 7
   2.1 Freshwater availability and management in the Netherlands ............................................... 7
   2.2 Internal salinization in the Netherlands ................................................................................ 10
   2.3 Freshwater and agriculture .................................................................................................... 14
   2.4 Salt-tolerance in the Dutch context ....................................................................................... 17
3. Methodology .................................................................................................................................. 20
   3.1 Theoretical framework .......................................................................................................... 20
   3.2 Research method .................................................................................................................... 22
   3.3 Data collection and analysis .................................................................................................. 24
4. Results .......................................................................................................................................... 26
   4.1 To what extent is salinization perceived as an issue for agriculture in the Netherlands? .... 26
   4.2 How do current dominant land- and water management practices relate to salinization? .... 29
   4.3 What are the opportunities and barriers to different mitigative and adaptive solutions in addressing the issue? ................................................................. 32
      4.3.1 The parcel and farm level .............................................................................................. 32
      4.3.2 Community, compartment and polder level .................................................................. 35
      4.3.3 Regional water system (waterboard level) .................................................................. 35
      4.3.4 Provincial and sub-national level .................................................................................. 36
      4.3.5 Main water system and national level .......................................................................... 37
   4.4 What locks-in the status quo and what creates opportunities for more salinization-resilience? 38
5. Discussion ...................................................................................................................................... 41
6. Conclusion ..................................................................................................................................... 43
7. References ..................................................................................................................................... 44
Appendix A. Overview of mitigative and adaptive measures ......................................................... 49
Appendix B. Aspects of experienced reality .................................................................................... 53
Appendix C. List of interviewees ...................................................................................................... 54
1. Introduction

1.1 The global issue of salinization

The salinization (i.e. increase in salt concentration) of fresh surface- and groundwater resources poses significant problems to farmers, industries, drinking water companies, and water managers in coastal areas all around the world (Delsman, 2015). These problems mostly relate to reduced crop yield, damaged infrastructure, adverse effects on vulnerable ecosystems, and the forced abandonment of extraction wells (Delsman, 2015). In addition, climatic and anthropogenic stresses like sea-level rise, changes in recharge and evaporation patterns, ground subsidence, population- and economic growth, increasing industrial and agricultural water demands, and contamination of surface water further intensify pressures on freshwater resources and competition between the different uses in these areas (figure 1) (Oude Essink, van Baaren & De Louw, 2010).

![Figure 1 overview of threats to coastal freshwater resources (Delsman, 2015)](image)

With regards to agriculture, salinization of freshwater resources and agricultural land is one of the biggest threats to food production worldwide (Qadir et al., 2014), as higher salinity levels result in lower crop yields (Maas & Hoffman, 1977; Singh, 2015), and as soil salinization is a global phenomenon, occurring in at least 75 countries around the world and on more than one billion hectares of total land, and 20% of global irrigated land specifically (Ghassemi, Jakeman, & Nix, 1995). Although recent statistics of the global extent of soil salinization do not exist (Shadid, Zaman, & Hang, 2018), Qadir et al. (2014) have estimated a daily expansion of this area by 2000 hectares (Qadir et al., 2014), and a subsequent crop damage of 27.3 billion US Dollars a year (Qadir et al., 2014). The issue is becoming increasingly problematic and widespread, particularly due to climate change effects like sea-level rise and more frequent and severe droughts (Singh, 2015). In the worst cases, farmers have to abandon their fields and clear new arable land, adding pressure to natural ecosystems and biodiversity (de Vos et al., 2016), thereby affecting both livelihoods and the environment. With a growing population and subsequent growing demand for agricultural products, progressing climate change, little new productive land without sacrificing valuable nature, and increasing competition for freshwater resources, salinization is a global issue that urgently requires a solution (Qadir and Oster, 2004; Singh, 2015).
1.2 The issue of salinization in the Netherlands

Salinization of soils is especially common in arid and semi-arid regions where rainfall is low and the rate of evapotranspiration is higher than the rate of percolation of rainwater through the soil (Qadir et al., 2014). Moreover, the sub-soils in these regions are often already strongly saline as they were formed by marine deposits, and because the common soil characteristics restrain salt leaching (Daliakopoulos et al., 2016). In addition, irrigation in these regions is often practised with brackish to saline groundwater and without drainage, leading to the accumulation of salts in the root zone of the soils which negatively affects certain soil properties and plant growth (Qadir et al., 2014; Daliakopoulos et al., 2016). In more temperate regions, soil salinization is mainly caused by seawater intrusion in coastal aquifers and saltwater intrusion in inland aquifers from neighbouring saline aquifers, as a result of sea-level rise and over-extraction of groundwater (Taylor et al., 2013). Annual precipitation in these regions is usually sufficient for plant transpiration demands and infiltrating water can form freshwater lenses on top of brackish or saline groundwater (Stofberg et al., 2017). However, if these lenses temporarily disappear in dry periods, this may lead to the capillary rise of saline water and in turn salinization of the root zone (Stofberg et al., 2017).

Although the Netherlands also has a temperate climate and saline aquifers due to past marine transgressions and seawater intrusion (de Louw, Essink, Stuyfzand & Van der Zee, 2010), it is rather unique because of two main reasons; firstly, about 25% of the land surface lies below mean sea level and without its dunes and dykes 65% of the country would be regularly flooded (Huisman et al., 1998), and secondly, a significant amount of the land surface (600,000 ha) consists of polders, i.e. pieces of land that have been reclaimed from a body of water (i.e. a lake, floodplain, or a marsh) through the creation of artificial and autonomous hydrological systems of dykes and drainage canals (Huisman et al., 1998). In areas that lie below mean sea level, saline groundwater may reach the surface by upward groundwater flow, a process which is commonly referred to as saline or brackish seepage (Oude Essink et al., 2010). This results in the salinization of surface waters and shallow fresh groundwater bodies, making the water unfit for drinking water supply, industrial purposes, and irrigation (de Louw et al., 2010). In addition, brackish seepage can also directly end up in the root zone and thereby cause salt stress in plants (Oude Essink et al., 2010).

A future rise in sea level is expected to increase the seepage and the salt loads in surface waters and thereby reduce the availability of both fresh surface water and groundwater (Oude Essink et al., 2010). Model simulations show that due to sea-level rise, salt loads from groundwater seepage will be doubled in several low-lying parts of the coastal zone of the Netherlands by 2100 (Oude Essink et al., 2010). Moreover, as the low elevation of polder systems requires perpetual drainage of water to avoid water logging from seepage, both direct salinization (by attracting saline water to the surface) and indirect salinization (through ground subsidence) are common (Oude Essink et al., 2010). Therefore, most of the salinization prone areas are located near the coast, in reclaimed lands and in previous intertidal zones, where seawater is (historically) present in the groundwater and relatively close to the
soil surface (Velstra, Hoogmoed & Groen, 2009; figure 2). Without the use of, often translocated, fresh water to regularly flush through the water systems and soils in these low-lying areas, the brackish groundwater would be a major limiting factor to agriculture in particular (Velstra et al., 2009). However, the combination of increasing external intrusion of seawater in groundwater aquifers and (open) waterways, decreasing river discharge, decreasing precipitation and increasing evapotranspiration in the drier seasons is limiting the freshwater availability to do this, especially in ‘end of the pipeline’ regions (Velstra et al., 2009).

**Figure 2** (left) depth of the fresh-salt interface in meters below the surface level, where 1 gram of chloride per litre is the concentration at which water is classified as saline in the Netherlands (de Lenaer, 2013); (right) provinces and main waterways of the Netherlands (Arnold et al., 2011).

### 1.3 Problem statement and research question

The threat of salinization in the low-lying coastal regions of the Netherlands is widespread and growing due to historically saline groundwater reservoirs, the relatively high (and increasing) sea level, ground subsidence and changes in recharge and evapotranspiration patterns, which are not only accelerating salinization but also diminishing the supply and availability of fresh water (Velstra et al., 2009; Oude Essink et al., 2010). Agriculture in these areas is particularly vulnerable to the threat of salinization due to its exposure to brackish seepage from the subsoils, weather events, and by being one of the last activities to receive fresh water in times of scarcity (OECD, 2014). Discovering how the Dutch agricultural sector can be made more salinization-resilient is of direct regional socio-economic importance as sensitive and intensive agriculture is especially located in salinization-prone areas (de
Louw, 2013). Moreover, it can be of global importance as well since the Netherlands will be one of the first deltas to face the impacts of climate change in combination with increased anthropogenic activities – due to the below sea-level position of, and high density of intense socioeconomic activities in, the coastal region – thereby serving as a laboratory case for many other low-lying deltas around the world (Oude Essink et al., 2010).

However, as critical freshwater shortages have always been more of an exception to the rule – as evident from the national evaluations from water managers and users after the summer of 2018 which was the driest summer ever recorded in the Netherlands – the issue of salinization is relatively new to the Netherlands (Delta Commissioner, 2018a). Therefore, business-as-usual responses are rather unlikely to solve the problems ahead; new mitigative and adaptive measures are needed for ‘climate-proofing’ the freshwater availability in the Dutch delta, as evident from the recently established Delta Decision and Delta Plan on Freshwater Supply, which aim to secure the availability of fresh water now and in the future (Delta Commissioner, 2018b). In order to contribute to the overall knowledge gap of how the freshwater availability in the Netherlands can be made more climate-proof, this research aims to fill the gap of how the issue of salinization for agriculture in the low-lying Netherlands can be addressed. Therefore, the research question is: how can the Dutch agricultural sector be made more salinization-resilient? Which will be answered through several sub-questions:

1. To what extent is salinization perceived as an issue for agriculture in the Netherlands?
2. How do current dominant land- and water management practices relate to the issue of salinization?
3. What are the opportunities and barriers to different mitigative and adaptive measures in addressing this issue of salinization?
4. What is locking-in the status quo and what creates opportunities for a transition towards more salinization-resilience?
2. Literature review

2.1. Freshwater availability and management in the Netherlands

The freshwater supply in the Netherlands is managed through an extensive system of rivers, canals, ‘boezems’ (discharge canal of a polder), and other waterways, and by the use of pumps and weirs to distribute water in virtually any direction (Huisman et al., 1998). Surface water is managed with respect to whether there is a surplus or shortage of water, the salt content, nutrient load and temperature of the water, with the aim of ensuring optimal use for safety, drinking water supply, cooling water for power plant, shipping, agriculture, nature, and recreation (Ministry of Infrastructure and Water Management (MIWM), 2009a). A large part of the freshwater supply originates from the main water...
system, i.e. the rivers, of which the Rhine is the most important one, and canals. However, the province of Zeeland and the Wadden islands have no external water supply and very limited fresh groundwater and are therefore largely dependent on precipitation (figure 3). The freshwater availability for the provinces of North-Holland, Friesland, Groningen, and Flevoland depends for a large part on the IJsselmeer – the large lake in the centre of the country which was formed after the inland sea (Zuiderzee) was enclosed by dykes (figure 3).

The water that is being supplied by the main water system to the surrounding areas is used to maintain the level of the groundwater and surface waters, to flush through the waterways to maintain the water quality and for direct use (Arnold et al., 2011). Another important function of the main waterways is to counteract external (i.e. via surface water) salinization from the sea – mostly the salt wedge coming from the Nieuwe Waterweg, which is in open connection with the sea (Arnold et al., 2011). In times of very low river discharge, this salt wedge can be a threat to the inlet points of Gouda and Bernisse, which are important for the freshwater supply for regions in the western part of the Netherlands (ter Maat, Haasnoot, Hunink, & van der Vat, 2014). Around 80 (dry period) to 90% (normal period) of the freshwater that enters the system via the rivers is discharged into the sea (ter Maat et al., 2014).

Rijkswaterstaat (the executive body of the MIWM) is responsible for the main water system, i.e. large water bodies like the IJsselmeer, rivers, and large waterworks like dykes and storm surges, while the waterboards are responsible for the regional water systems, which consist of smaller water bodies such as canals and polder canals, and the water supply in their management areas (MIWM, 2009b). The provinces are responsible for groundwater management as well as translating national policy into regional measures (MIWM, 2009b). According to the current freshwater strategy, it is a governmental task to ensure that all users receive as much water as possible, for as long as possible, which is why there are elaborate distribution networks and numerous ‘water agreements’ between the Ministry and waterboards about issues that are transcending their management areas like the supply and discharge of water (during times of drought), the water quality, and what measures to take during extreme conditions (MIWM, 2009b).

In the event of (imminent) water shortages, e.g. the period of extreme drought in 2018, the national ‘water distribution priority sequence’ applies as set out by the Water Act, and the National Coordination Committee for Water Distribution – which includes the relevant ministries and water managers – gathers to discuss the situation, forecasts, and possible decisions (MIWM, 2009b). The priority sequence determines to whom the available water is distributed during this period; the list (Table 1) consists of four categories of functions where category 1 takes precedence over all others while category 4 has the lowest priority and thus the highest exposure to shortages (MIWM, 2009b). Within categories 1 and 2, the sequence of priorities cannot be adjusted whereas the priority of functions that fall within categories 3 and 4 can be determined by the regional water managers, with the minimisation of economic and societal damage as the basic principle to inform these decisions (MIWM, 2009b).
Despite of the seemingly robust arrangements and coordination between water users and water managers, the 2006 climate scenarios of the Royal Netherlands Meteorological Institute (KNMI) did trigger the inclusion of freshwater availability in the Delta Programme – a national programme with plans to ensure that flood risk management, freshwater supply, and spatial planning are climate-proof and water-resilient by 2050 – as it was projected that the freshwater demand will likely increase while water supply will likely decrease because of climate change (ter Maat et al., 2014). Although the Delta Programme is continually updating its scenarios on the basis of most recent climatic and socio-economic projections from domestic (i.e. KNMI) as well as international institutes (i.e. IPCC), uncertainties regarding whether the international community will be able to cap greenhouse gas emissions, how quickly the Antarctic ice sheet will melt, and how this will translate into temperature- and sea-level rise, implies that the exact changes in freshwater availability and salinization – and therefore the preferred strategies – are uncertain (Delta Commissioner, 2018b). Nevertheless, under the most likely climate scenarios, there will be bottlenecks in freshwater availability that will have to be addressed as conceptualized in figure 4 (ter Maat et al., 2014).

**Figure 4** implications of climate change for freshwater availability in the Netherlands (adopted from Ter Maat et al., 2014)
2.2 Internal salinization in the Netherlands

Brackish to saline groundwater is common to many areas of the Dutch coastal lowlands due to sea inundation and subsequent infiltration during the Holocene marine transgressions (figure 5). Salinization through upward saline groundwater flow in the Netherlands began at the start of human intervention with the landscape in around 300 B.C. – in essence by maintaining a lower surface water level than the hydraulic head in the underlying aquifer (van de Ven, 1993). At first, surface water levels declined only gradually as peaty and clayey sediments consolidated due to small-scale drainage activities for agricultural purposes (van de Ven, 1993). Around 800 AD, however, this process increased rapidly due to the large-scale mining of peat bogs for heating, causing inland lakes to arise in the landscape (van de Ven, 1993). Nevertheless, the most outspoken decline of surface water levels in Dutch history was caused by the reclamation of these inland lakes and tidal areas through which the typical Dutch polders were realized (van de Ven, 1993). Since the elevation of these polders is generally well below mean sea level, salinization also occurs through lateral migration of seawater – seawater has already intruded about 2 to 6 km from the coastline – a process which is accelerated by sea-level rise (Oude-Essink et al., 2010). The upward flow of brackish/saline groundwater from the upper aquifer towards the surface – most often to the ditches but also the (sub-)soils – in deep polders and previous intertidal areas is what is referred to as brackish or saline seepage (figure 6, de Louw et al., 2010). There are three types of seepage with differing salinity concentrations and seepage fluxes: (1) preferential saline seepage through sandy paleochannel belts in the confining layer, (2) diffuse seepage of saline...
groundwater through the semipermeable layer, and (3) intense seepage via localised boils in waterways or in the soil (de Louw et al., 2010; figure 7). In many deep polders (South-Holland and North-Holland), boils are the main form of saline seepage, thereby largely determining the salinity of the surface water system (de Louw, 2013; figure 6). In sub-recent transgression areas (Zeeland, Friesland, Groningen), the other two routes of salinization are more common, meaning that there is more salinization of the shallow groundwater (de Louw, 2013 figure 6).

**Figure 6** Schematic representations of two important saline seepage systems in the Dutch delta: (above) preferential saline seepage in deep polders via boils causing saltwater upconing of deeper and more saline groundwater, (below) saline seepage in sub-recent transgression areas resulting in thin rainwater lenses (De Louw, 2013)
The precipitation surplus in the Netherland creates fresh rainwater lenses on the brackish to saline groundwater which prevents saline groundwater to enter the root zone via capillary rise and is therefore of great importance to agriculture in these areas (Stofberg et al., 2016; de Louw et al., 2010; figure 8). The thickness, form and dynamics of these lenses differ from area to area; different factors play a role in this such as the geo-hydrological composition, drainage, water level management, the seepage and infiltration flux and groundwater replenishment (de Louw et al., 2010). There is an important distinction between rainwater lenses in saline seepage areas and freshwater lenses in infiltration areas (De Louw et al., 2010); freshwater lenses found in infiltration areas are 5 to 100m thick while the rainwater lenses in seepage areas are often no thicker than 3m because the upward flow pressure prevents the infiltration of rainwater, i.e. seepage (both saline and fresh) cancels out infiltration (figure 9) de Louw et al., 2010; Eeman et al., 2011). The ability of such lenses in preventing the capillary rise of saline water, and thereby salinization of the root zone, depends on the persistence of such lenses during the dry season (Stofberg et al., 2016). Freshwater lenses in seepage areas are very vulnerable to the effects of climate change since a relatively small increase in saline seepage and a small decrease in precipitation surplus in the summer can already significantly decrease the freshwater stock on plot level (de Louw, 2013).

Figure 7 Diagram showing upcoming mechanism for the three seepage types with different fluxes and chloride concentrations: diffuse seepage, paleochannel seepage and boil seepage. (De Louw et al., 2010).
Figure 8 Conceptual visualisation of a shallow rainwater lens on top of saline groundwater (de Louw et al., 2011)

Figure 9 Depth of the brackish-saline groundwater interface (left) and the seepage (blue) and infiltration (red) flux (right) (de Louw, 2013)
2.3 Freshwater and agriculture

Agriculture depends on the availability of fresh to (slightly) brackish water. However, in areas affected by saline seepage, increased salinity can render the surface water unfit for irrigation while increased rootzone salinity can affect crop growth directly, thereby causing either drought damage or salt damage, especially during dry periods when there is no/little alternative water supply in some high-risk areas. In figure 10 it can be seen that especially arable farming, and to some extent flower, vegetable, fruit, and tree cultivation are located in the regions where there is a risk of internal salinization and limited external freshwater supply.

To ensure that surface water is not too saline for irrigation, there are norms that the water managers and users try to steer on, e.g. by flushing through the system or by postponing irrigation until the water freshens again (Stuyt et al., 2016). Governmental guidelines for water norms are 150 milligrams of chloride per litre for drinking water, 50 to 200 mg/L for substrate cultivation and greenhouse horticulture, 500 mg/L for ground-bound horticulture, and 1000 mg/L for regular agriculture (Oude Essink & de Louw, 2014). Nevertheless, the classification of fresh, brackish and saline groundwater differs depending on the intended use, for example, freshwater has a different meaning for a bulb grower (sensitive crop) than for a beet farmer (more tolerant crop) (Oude Essink & de Louw, 2014). The classification used in the western part of the Netherlands is based on the overall vulnerability of crops to damage, i.e. 200 is fresh, 600 is brackish and 1000 Cl mg/l is saline, which is the approach used in water management (Oude Essink & de Louw, 2014). In the Zeeland Delta, the groundwater is...
naturally brackish to saline, hence, the introduction in Zeeland of the term agronomic fresh, which defines 1000 mg Cl/l as the boundary between fresh and brackish groundwater – a standard widely used in other countries as well (Oude Essink & de Louw, 2014). Nevertheless, chloride norms are ‘effort obligations’ rather than hard requirements for water managers, on top of that, it is not the only water quality characteristic for which they flush the system, for instance, keeping phosphate and nitrogen levels low is also important (Stuyt et al., 2016).

Until now, the traditional measure of flushing to ensure that the surface water has the desired water quality has been rather effective (Voorde and Velstra, 2009). However, the availability of high-quality freshwater for flushing is decreasing while the demand for it is increasing due to several developments, mainly (1) increasing salt concentrations due to saline seepage, necessitating more flushing, 2) decreasing quantities of readily available good quality water due to decreasing river discharge and seawater intrusion in rivers 3) increasing demand for more and higher quality water (e.g. due to the cultivation of high-quality, capital-intensive crops), 4) increasing salt concentration at the root zone when too little water is available to compensate evapotranspiration (Voorde and Velstra, 2009). Therefore, both changes to current land- and water management practices as well as alternative adaptive and mitigative measures can be considered (Voorde and Velstra, 2009).

Such measures can be broadly categorized into securing the freshwater availability, more salt-tolerant agriculture, and spatial reclassification, and into different scales from parcel to the national level. At the parcel and farm level, freshwater can be stored in (above or below ground) reservoirs, or the rainwater lenses in the parcel(s) can be increased by adjusting the drainage system (de Louw & Bogaart, 2014). Retaining water in the ditch by maintaining a higher water level can also retain and increase the freshwater lens in the parcel, as it keeps water from being drained (de Louw & Bogaart, 2014). Furthermore, soils can function as a buffer, as moisture can be retained in the soil by improving the soil structure through e.g. increasing the organic substance and by switching to zero-tillage soil preparation (Snellen & van Hattum, 2012). In addition, water could be used more efficiently through drip- or sub-irrigation, and by regulating irrigation on the basis of the soil moisture (i.e. data-driven irrigation) (Snellen & van Hattum, 2012). A rather simple measure is the placement of weirs in ditches that separate fresh from saline/brackish water and discharge the latter, thereby making use of the natural fresh-saline layering in the ditch (de Louw & Bogaart, 2014). Another option at the parcel- and or farm level would be to adapt to the salinization through salt-tolerance agriculture which will be discussed in the next section. At the community level, freshwater can be stored in-, and extracted from, a communal reservoir, e.g. by use of natural reservoirs like creek ridges, dunes, and aquifers (de Louw & Bogaart, 2014).

At the polder (or island) level, one solution is to increase the water levels in the surface water system, which could be effective when applied in ditches with many large boils (> 0.5 m) or with significant diffuse saline seepage (Oude Essink & de Louw, 2014). Adjusting the intake, discharge, storage and drainage systems of a polder is another promising measure for tackling saline seepage (Oude
This requires identification of the saline seepage areas and building a bypass around it to isolate it and prevent it from being used in summer (Oude Essink & de Louw, 2014). This system can be optimised through dynamic operational management of freshwater intake, drainage, temporary storage of saline seepage water, real-time monitoring of salt concentrations at strategic locations in the polder, and weather forecasts (Oude Essink & de Louw, 2014).

At the entire waterboard level, spatially differentiated water pricing (i.e. real coast pricing) could be implemented to better reflect the actual cost, value or scarcity, and to stimulate efficiency on the demand side (Snellen, Schipper and van Hattum, 2012). Moreover, ‘smarter’ flushing of the water system, i.e. making sure the water goes where it needs to be at the time it needs to be, could directly tackle surface water salinization and save much needed water as well since currently about five times more water is used for flushing than for irrigation while chloride standards are still not achieved for all locations within a sub-area (Delsman, 2015). Furthermore, saline groundwater seepage can be counteracted by (temporarily) increasing the water level, and/or by managing brackish water streams, as both supply and discharge currently go through the same system (Oude Essink & de Louw, 2014). At the (sub-)national level, measures in the main water system can be taken, especially with regards to using less water to directly stop the salt wedge from going land inwards, either by using bubble screens, placing water locks in the open, or by using or installing other (regional) waterways that divert more water from the main rivers to lakes (e.g. IJsselmeer) or directly into the waterboard water system (Friocourt, Kuijper, and Leung; 2014). An overview of these mitigative and adaptive strategies to reduce salinization-related freshwater scarcity and loss of productivity in the agricultural sector can be found in table 2 (appendix A), together with practical examples. These strategies vary in terms of (long-term) effectiveness and efficiency which will be discussed later on.
2.4 Salt-tolerance in the Dutch context

Generally, higher salinity levels result in lower crop yields; only one percent of the world’s plant species are salt-tolerant (Rozema and Flowers, 2008). These so-called halophytes can complete their lifecycles with 200 mM of Natrium-Chloride (NaCl) in their root medium (Colmer and Flowers, 2008). Glycophytes on the contrary, i.e. 99% of all other plant species, are generally highly susceptible to soil salinity (Chinnusamy et al., 2005). Elevated salinity levels in soil pore water negatively affect plant growth in three ways:

1. Osmotic effect: the lower osmotic potential of the saline soil pore water makes water uptake more difficult for a plant (Ghassemi et al., 1995). This effect is similar to the effect of drought.
2. Toxic effect: NaCl molecules that enter the plant via the water can quickly reach toxic levels and cause physiological damage like leaf burn (Ghassemi et al., 1995).
3. Competition effect: the high concentrations of Na* ions in the soil pore water increases competition with the uptake of potassium (K*) ions, resulting in difficulties for absorbing sufficient amounts of potassium which are essential to plant growth (Wicke et al., 2011).

Nevertheless, the magnitude of these effects on plants differs significantly per cultivar, which is why plants differ in their sensitivity to salinity (Chinnusamy et al., 2005). Besides large variations between plant species, there also exist large differences between the varieties or cultivars within species (Maas and Hoffman, 1977). The salinity tolerance of a species or cultivar is commonly expressed according the Maas and Hoffman (1977) model, which is based on two parameters for salinity tolerance, the threshold and the slope. The threshold value indicates at which salinity level the crop yield starts to decline, the slope is the percentage with which the yield decreases with every unit increase in salinity. In figure 11, the derived division for classifying crops on the basis of their tolerance to salinity is visualised.\(^1\)

---

\(^1\)“The value of the EC [mS/cm] is determined by 3 anions: Cl (chloride), HCO3 (bicarbonate) and SO4 (sulphate). For EC values below roughly 2 mS/cm, the relation between EC and chloride is not linear due to the possible presence of bicarbonate and sulphate. Above values of roughly 2 mS/cm chloride is dominant and the following relation can be used: Cl (mg/l) = 360 * EC (mS/cm) – 450 for water of 25 °C. This formula is based on groundwater analysis in the Netherlands and is described in De Louw 2013. A useful rule of thumb for EC>2 mS/cm is: Cl (g/l) = EC (mS/cm) / 3.” (van Baaren, 2015).
Although the domestication of halophytes could be considered, exploring the level of salt tolerance in more conventional crops that are already cultivated and marketed on a large scale is arguably more effective. The need for selecting conventional crops on the basis of their tolerance is further supported by the fact that 1) salt-tolerance is a complex plant trait determined by numerous genetic and non-genetic factors, 2) the improvement of salt tolerance via conventional breeding has been slow, and 3) more innovative biomanipulation techniques have yet to mature (Ashraf & Foolad, 2012). More recently, field experiments with crop salt tolerance (de Vos, 2011; de Vos et al., 2016; Stuyt et al., 2016) have shown that for several commercial crop species like potato, carrot, onion, and cabbage, varieties exist that are more tolerant than previously thought, and that cultivation of these crops on moderately saline soils with brackish water is possible without significant reductions in yield. However, crop salt tolerance does depend on many variable factors like plant characteristics, soil conditions, water quality, environmental and climatic conditions, and agricultural practices (Maas and Hoffman, 1977; Tanji and Kielen, 2002). Therefore, caution should be taken in comparing the results of different experiments and making general conclusions about specific crop salt tolerance. For instance, the experiments on the Salt Farm Texel have been conducted under specific conditions, namely sandy soils, high intensity of irrigation, drip irrigation, optimal drainage, and leaching fraction close to 90%; locations with different conditions will likely result in different Electric Conductivity (ECe) values in the root zone and will thus lead to different crop yield responses to irrigation salinity (de Vos et al., 2016). The meta-review of salt-tolerance studies in the Netherlands by Stuyt et al. (2016), which also reviewed the findings of Texel Salt Farm, concluded that on the basis of the currently available data on crop salt tolerance it cannot be determined whether irrigation water can have a higher (incidental) salt concentration than currently practised. The latter requires more research on the quantitative relations between salt-tolerance thresholds and environmental and crop characteristics (Stuyt et al., 2016). Currently available data are limited because of three reasons; firstly, the preconditions and circumstances under which the studies were conducted were hardly ever specified; secondly, the reported salt-tolerance thresholds of a crop or crop group have very large margins; thirdly, there are relatively few experiments per crop, resulting in a large statistical uncertainty of the reported salt-tolerance (Stuyt et al., 2016). Moreover, the exact salt tolerance of a crop also varies with the different stages of its growth, although this relationship is yet unclear (van Bakel et al., 2018). Nonetheless, model studies and practical experiences suggest that chloride concentrations in irrigation water can be acceptable when having to decide between (possible) salt damage and (certain) drought damage (Stuyt et al., 2016).

Besides the generally negative effect on crop growth, increased natrium and chloride concentrations can also negatively affect the structure soils with higher lutum (e.g. clay) and loam concentrations (Locher & de Bakker, 1990; Stuyt et al., 2016; de Vos et al., 2016). When soils have been in contact with saline water, they start to swell and shrink, meaning that they will be impermeable in a wet state and extremely hard when dry (Hissink, 1954). However, the exact effect of different salt concentrations on these types of soils and to what extent it can be manageable are relatively under-
researched. Considering that most of the salinization-prone areas consist of (sandy-)clay soils and intensive soil-based agriculture (Figure 12), more research on the salt tolerance of crops commonly cultivated in the Netherlands and the effect of more vulnerable soil types like clay is desired, as it could potentially increase salinization-resilience by enabling cultivation on salinized soils with brackish water.

**Figure 12** Intensive, sensitive and soil-based agriculture and horticulture (left) is especially located on sandy-clay and clay soils (middle) in salinization-prone areas (right) (Alterra, 2006).
3. Methodology

3.1 Theoretical framework

The scaling of agricultural innovations should be approached as an interdisciplinary or transdisciplinary endeavour, taking into account the complex interactions between biophysical, social, economic and institutional factors (Wigboldus et al., 2016). On the contrary, practical methods of scaling are rather experimental and based on the assumption that, if products, processes or practices go to scale, positive impacts will scale with it; hence the prevalent approach of ‘find out what works in one place and do more of the same, in another place’ (Wigboldus et al., 2016). However, as complex realities beyond the concepts of innovation transfer, dissemination, diffusion and adoption, are not sufficiently taken into account by such methods (Wigboldus et al., 2016), scaling initiatives often do not produce the desired effect, and may even produce undesirable, unanticipated side effects or negative spill-overs (Wigboldus et al., 2016). Moreover, this often results in decision-makers not having a sufficiently broad picture of what they need to engage with and prepare for in scaling initiatives, thereby limiting strategies, policies and guidance of scaling initiatives in becoming both effective and responsible (Wigboldus et al., 2016). To address the lack of a coherent approach to innovation scaling, Wigboldus et al., (2016) developed the PRactice-Oriented Multi-level perspective on Innovation and Scaling (PROMIS) framework, which connects the heuristic framework of the multi-level perspective on socio-technical transition (MLP) to a ‘modal aspects’ framework. This integrative analytical framework enables the heuristic exploration of relevant, multi-faceted dimensions and dynamics involved in innovation and scaling processes (Wigboldus et al., 2016).

MLP was designed to better illustrate and interpret how radical innovations connect to socio-technical transition processes (Geels, 2002). It provides insight into the dynamics that influence why some innovations go to scale and others do not (Wigboldus et al., 2016). The multi-level perspective incorporates three main levels: niche, regime, and landscape (Geels, 2002). The regime level relates to the system of interacting practices and structures that have come to a certain relative stability and status quo (Geels, 2002). This stability may, however, be disturbed as a result of new policies or changing environmental conditions for example (Geels, 2002). This can create opportunities for novelties (i.e. innovations) to become incorporated in, and change, a regime, particularly those that address or even create such disturbance (Geels 2002). Novelties (innovations) can benefit from sheltered conditions that favour their emergence (and scaling) – called the niche (level) (Geels 2002). The landscape within which this happens may be understood as the wider context and is considered to be the least dynamic level relating to e.g. worldviews, paradigms, culture and politics, which tend to change slowly (Geels, 2002).

MLP describes incumbent systems at the regime level that involve dominant configurations relating to e.g. markets, technology, science, and infrastructure, and that have established ‘institutional logics’, i.e. “socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality”(Thornton & Ocasio, 1999, p. 804). Usually, regimes
are not deliberately shaped, but rather the result of interdependencies that have developed between actors and processes and which have created path dependencies leading to a state of being locked into a status quo (e.g. a dominant way of agricultural production) (Holtz et al. 2008; Fünschilling & Truffer 2014). These lock-ins often involve power relations, whereby some groups may have vested interest in maintaining such a status quo while it conflicts with the interests and aspirations of other groups (Avelino & Wittmayer 2015). The economic concept of path dependence explains the set of decisions faced for any given circumstance is limited by decisions made in the past even though the past circumstances may no longer exist (Liebowitz and Margolis 1995).

The main criticism towards MLP is that biophysical and socio-ecological elements as well as notions of geographical scale are less highlighted in the regime concept, given the focus on socio-technical transitions, whereas they are highly important in the context of agriculture (Hansen & Coenen 2015). To overcome some of MLP’s limitations, Wigboldus et al. (2016) suggest to refine it with the theory of modal aspects to better define the different landscape and regime elements, people’s perception of them, and how analysis and decisions with regards to sustainability and responsible scaling can be informed. This theory provides a suite of aspects of experienced reality, which has been used as a framework for evaluating sustainable development several times (Wigboldus et al., 2016). An underlying assumption of the theory of aspects is that sustainability is supported by simultaneously paying due attention to the various aspects, as complex problems such as those generally related to scaling usually involve many aspects, while scientific disciplines usually focus on just one or two specific aspects (Wigboldus et al., 2016). It offers a basis for systematically characterising and subsequent comparing of practices technologies, processes, and systems along the lines of the aspects (Wigboldus et al., 2016). Because the PROMIS framework allows for such a broad-based application, it enables the analysis of innovation and scaling processes across different level, scales, domains and contexts in a consistent manner (Wigboldus et al., 2016). Combining the theory of aspects with the MLP, which is focused on levels and scale, thus helps developing an integrative perspective on what may interact and change in relevant practices and systems exactly as novel technologies and practices go to scale (Wigboldus et al., 2016).

As technologies, practices, processes and systems function can be distinguished from one another on the basis of the aspects and its core value in all – whether part of a niche, regime or landscape – the prevalent conditions regarding all aspects will affect the performance of an agricultural practice (Wigboldus et al., 2016). Therefore, the extent to which all the core values of a technology or practice that determine its very reason of existence are simultaneously realised determines its classification of being good or not (Wigboldus et al., 2016). Therefore, the framework can help alert researchers and decision-makers to the trade-offs that are generally involved in agricultural innovation (Wigboldus et al., 2016).
3.2 Research method

The PROMIS framework was applied to gain integrative perspectives on the scaling of salinization-resilient innovations for reducing the negative impacts of salinization. It aided in unravelling the different dimensions of the current agricultural and water management system that keep it from becoming more sustainable and that affect the scaling of more sustainable technologies, practices, and policies (Wigboldus et al., 2016). Moreover, it helped to identify how a variety of dynamics in scaling interact, thereby locking current practice into its unsustainable mode or stimulating change (Wigboldus et al., 2016; figure 13).

![Diagram](image)

**Figure 13** An integrative perspective on multilevel dynamics that have implications for opportunities to make a transition to a more salinization-resilient agricultural sector. The dominant system of land- and water management practices is composed of different dimensions that need to be tackled and would involve scaling of alternative technologies, practices, and policies relating to these dimensions to support salinization-resilience (adapted from Wigboldus et al., 2017).

The MLP methodological element of the framework was particularly useful for making sense of dynamics in innovation and scaling, while the modal aspects (table 3, appendix B) element helped to unpack the multifaceted nature of innovation and scaling, and identify the aspects of salinization-resilient measures that are different, non-aligned, or in conflict with the aspects of the regime, clarifying
which aspects will need to be considered in scaling (Wigboldus et al., 2016). It also helped to identify the type of regime lock-ins (e.g. particular regulations limiting choice options) that may affect scaling (Wigboldus et al., 2016). The need for adaptation and change often relates to stress (e.g. ground subsidence), which is gradual, and to shock (e.g. droughts), which is sudden and relates to short-life-span events; these relate to what is called the landscape in the MLP and as they can induce innovations, they may also be seen as windows of opportunity (Elzen, et al. 2012; Geels, 2011). Decision-makers can identify appropriate scaling strategies by using the framework for understanding how an envisaged scaling initiative connects to such stress and shock factors (Wigboldus et al., 2016).

In addition, the suite of aspects was used to develop a systematic understanding of the different roles of stakeholders in scaling processes, related to both niches and regimes (Wigboldus et al., 2016). Firstly, the aspects were used to distinguish between types of stakeholders in terms of what aspect characterises their core practices, and hence their interests, to prevent an undue focus on particular objectives of scaling (Wigboldus et al., 2016). Secondly, the aspects were used to characterise the core motivations of stakeholders in terms of what drives stakeholders’ decision making, e.g. being market-driven or service-driven (Wigboldus et al., 2016). Thirdly, the aspects were used to identify the variety of ways in which practices, systems, and their effects are evaluated by stakeholders, including how comprehensive their views of effects are, as this may affect their ability to negotiate convergence in multistakeholder processes (Wigboldus et al., 2016). In conclusion, the framework was used to organise the actor perspectives in light of scaling salinization-resilient measures, such as what different stakeholders think are the most important/relevant aspects to be considered in the initiative, and to evaluate how the initiative may affect stakeholders, e.g. power issues regarding who drives or benefits from the scaling initiative (Wigboldus et al., 2016).

This particular application of the PROMIS framework serves to elucidate relevant issues with scaling salinization-resilient measures that have not been considered before (Wigboldus et al., 2016). This initial wide-ranging assessment can then be used for a more focused analysis of selected aspects that are deemed most pertinent by this research (Wigboldus et al., 2016). This study will also provide input into strategy development for responsible scaling of salinization-resilient measures, regarding both the range of interactive factors and dynamics that would need to be taken into account as well as the experts and stakeholders’ perspectives on how this could be done (Wigboldus et al., 2016). Finally, it aims to broaden perspectives on what is involved in scaling the practice of salinization-resilient measures from merely exploring ‘technical’ options, to the inclusion of the role of institutional and paradigmatic constraints and opportunities, and to highlight the possibly required changes in land and water management in a wide landscape perspective to prevent shifting problems (Wigboldus et al., 2016).
3.3 Data collection and analysis

As single actors will rarely have a complete view of, let alone a mandate and/or control over, the multi-faceted dimensions and dynamics involved in agricultural scaling processes (Wigboldus et al., 2016), a wide range of experts and stakeholders were interviewed. The interviews were semi-structured to ensure that a large range of dimensions and dynamics relevant to the scaling of salinization-resilient measures were able to emerge. This was especially important, considering that little peer-reviewed literature on the issue of salinization and (innovative) salinization-resilient measures existed to inform which specific aspects should be reviewed by the interviewees.

For the selection of stakeholders, Reed et al.’s (2009, p.1933) definition of a stakeholder as someone who is “affected by the decisions and actions [that are taken], and who has the power to influence the outcome” was applied. Under this broad definition, agricultural businesses, the waterboards and provinces, and any other individual or organization that has the power to influence the issue of salinization could be included. To ensure a wide range of explored perspectives and interests, interviewees (50 in total) were selected from each salinization-prone province, with a balance between interviewees from both the niche level and the regime level, as well as between private and public stakeholders.

For the expert interviews, twelve Dutch experts in the field of salinization and/or salinization-resilient measures were selected. These scholars were mostly identified from the literature review and were selected on the basis of their evident expertise, i.e. either having published multiple papers on the topic and/or being referred to as an expert by the research institute they are connected to. Several experts were selected on the basis of referrals, as these were practical experts (e.g. advisors) instead of scholars. Experts were incorporated in the research for their relatively objective and/or nonpartisan evaluation of the issue of salinization and possible solutions, as compared to stakeholders.

For the stakeholder interviews, the officials from six provinces and eight waterboards in salinization-prone areas, were interviewed. The reason for including all relevant provinces and waterboards is to ensure that relevant regional differences like the dominant type of soils (e.g. clay or sand), agriculture (e.g. arable farming or horticulture), and water supply (e.g. presence of a river body or not) are accounted for, and to see how they deal with the interconnectedness of their water systems. The experiences and perspectives of agricultural stakeholders (i.e. farmers) were represented by the farmer network organizations (eleven representatives in total), as these are most aware of the current situation and issues in the sector and can thus provide a good overview of the perspectives of most farmers. Furthermore, nine farmers that are experimenting with salinization-resilient measures were interviewed, as these represent the niche level and can thus identify the relevant factors and dynamics that allow or prevent the scaling of these measures. Furthermore, three plant breeders were interviewed to discover whether and how they incorporate salt-tolerance since this can tell something about the demand for- and feasibility of- breeding on the basis of salt-tolerance. Finally, two national governmental bodies were interviewed as well since these are also involved in the issue of salinization,
mainly through coordination, legislation, and funding. Most stakeholders were identified through google searches and snowballing, i.e. selecting through the referrals of those that are interviewed already (Reed et al., 2009). The list of the interviewees can be found in table 4 in appendix C.

The face-to-face interviews were recorded and transcribed afterwards, whereas the interviews over the phone were transcribed on the spot, meaning that there is inherently a difference of preciseness and perhaps accuracy between the two. The analysis of the transcriptions was done by identifying the overarching, categories, concepts, and patterns. The aspects of experienced reality from table 3 (appendix B) were used to guide the process to ensure coherence and completeness. The subsequent emerging themes were then analysed by use of the PROMIS framework, and categorized into the niche, regime, and landscape level, including the interactions between them, and the lock-ins of the current non-salinization resilient practices, as well as the opportunities for more salinization-resilience, were identified. Due to the large quantity of interviewees, the results are supported by use of a scale of how many times a certain theme emerged from the interview data, i.e. few (<3), some (4 to 9), many (10 to 19), majority (20 to 34), practically all (>35).² For regional specific information, statements are always based on the majority of stakeholder specific perspective.

² Note that the classes are skewed to the left, which is to account for incompleteness of answers on all the semi-structured questions, as not all stakeholders (e.g. innovative farmers) were able to answer every question.
4. Results

4.1 To what extent is salinization perceived as an issue for agriculture in the Netherlands?

Although all interviewees recognize that the availability of fresh water is of great importance to agriculture and that salinization is largely harmful to agriculture, the exact extent to which it is or will be harmful is difficult to determine because of several reasons (*majority*). Firstly, salt-stress and drought stress look very similar and predominantly appear at the same time since saline water can reach the surface in dry periods (*majority*). Secondly, (the risk of) diffuse brackish seepage is largely invisible to farmers as the conditions within the parcel cannot easily be observed (*many*). Thirdly, the threat of salinization and salt-damage depends on many different cultivation specific factors (*majority*), like the cultivated crop (i.e. length of roots, growth stage at time of exposure, salt-tolerance), soil type, soil quality, thickness of the freshwater lens, the type of drainage, and can therefore differ per parcel and even within a parcel. Fourthly, salinization is not a linear process, it comes in peaks and fluctuates per season and year (*majority*). Fifthly, the effect of different salt concentrations on commonly cultivated crops and soils other than sand are largely unknown (*practically all*). Sixthly, salinization risk maps cannot be directly extrapolated to the parcel level, nor estimate actual damage (*many*).

The complex nature of salinization could also explain why although there are many regions with a risk of salinization and although last year was recognized to be exceptionally dry, there are not that many signs nor reporting of widespread salinization-related issues or damage yet (*majority*). Another explanation could be that the issue has not been identified as such yet by farmers as it is not common practice to measure the salt concentrations of parcels and irrigation water (*many*). Moreover, it is rather difficult to establish maximum possible yield and to link sub-optimal yield to just one factor like salinization (*many*). Few, argue that the low reporting of salinization problems is the result of the issue being a taboo, e.g. as salinized lands drop significantly in financial value once discovered. Either way, there is a consensus that there is very much an awareness issue, i.e. that the threat and issue of salinization are not being recognized and/or acknowledged.

In terms of the threat and issue of salinization, there are regional differences as well. In Zeeland, in contrast to the neighbouring islands of South-Holland, there is hardly any external water supply. Furthermore, as the ditches are brackish due to saline seepage, farmers have to rely on precipitation and the yearly precipitation surplus, which falls in times when it is less needed or even unwanted due to the potential threat of flooding. Some farmers do extract freshwater from groundwater sources and freshwater lenses, especially ever since the saline-fresh borders measures of the underground showed where fresh water was available, but the sustainability of these extractions is difficult to check and control and therefore there is a risk of exhausting/salinizing these sources. Moreover, as these sources are not available for the majority of the province and as the freshwater lenses are already very thin, Zeeland is much more vulnerable to drought and salinization than most other regions in the Netherlands and has already experienced salinization, and especially drought damage, to a larger extent. Because of Zeeland’s vulnerability, it is a frontrunner in pilots of innovations that increase salinization-resilience.
Nevertheless, there are still only a few farmer pioneers in this regard – a sense of urgency still seems to be lacking amongst farmers.

In South-Holland, salinization of freshwater and soils especially occurs through saline boils in the ditches of deep polders, and saline seepage through the soils and ditches in the South-West and on the islands. Although the salt flux and load is increasing due to sea-level rise, there is much external water supply for flushing because of the main rivers that run through this region, meaning that the water quality is normally very fresh. However, due to the decreasing river discharge in dry periods, the sea wedge, and thus, the salt load in these rivers increases. This can result in a complete water shortage for the area, since the chloride norms for the inlet points are very low (150 mg/L), as required for industry and drinking water. Since the latter would especially affect the tree nurseries in Boskoop, which is an important economic hub to the region, the so-called climate-proof water supply – an alternative water supply route that originates further upstream – is perceived to be of great importance to this region, and is expected to become the main water supply in dry summers, instead of just an emergency measure. However, arable farmers are expected to suffer the most from water shortages, as they are in the last category of the water distribution priority sequence.

In North-Holland, the damage of salinization is thought to be limited yet as there has been enough freshwater supply. Neverthelesss, it is expected that in the future the issue will become more prominent and that there will be a turnover point at which the growing demand exceeds the decreasing supply of water, and the water system cannot be managed anymore. Especially the flower bulb region in the North of the province is vulnerable to salinization, as the brackish seepage is especially problematic in this region, and as flower bulbs are rather sensitive. Nevertheless, as the freshwater supply has been secured until now, the urgency amongst farmers to invest in their self-sufficiency is low. On Texel the issue of salinization through saline seepage is already widespread, due to its position near the sea, the absence of external freshwater supply, and the fact that irrigation is not allowed, therefore farmers there are frontrunners in dealing with salinization.

In Flevoland, the urgency of the issue amongst the water managers is lower than amongst the farmers. Where farmers notice the issues with brackish seepage in their ditches, the water managers are mostly unaware of this as this mostly happens in certain end of the pipeline regions, and are mostly focused on the salinization of groundwater wells due to over-extraction. Nonetheless, the increasing water demand due to the emergence of high-capital crops like flower bulbs in salinization-prone areas is bringing extra challenges to the water managers.

In Groningen and Friesland, the issue seems to be less prominent yet than in Zeeland or Texel, which could partly be because there is still flushing with external freshwater supply from the IJsselmeer, although there was an irrigation ban last summer due to too little external supply. Nevertheless, most stakeholders are very worried about the future since there is a high risk of salinization in the northern regions of the provinces where seed-potatoes are cultivated, which are perceived to be 1) rather sensitive to salt and drought, 2) very important for the regional economy. Therefore, there is a growing urgency
amongst farmers and policy-makers for research on the risk and effect of salinization and what they can do about it. This urgency is currently higher in Friesland than in Groningen, as they have mapped out the groundwater situation already.

To summarize, although the issue has become more prominent in recent years and is starting to become more and more of a concern amongst farmers and (to a lesser extent) policy-makers due to climate change and especially the exceptionally dry summer of 2018 (majority), there is still a lack of urgency because 1) the issue is only little or just recently starting to be experienced, recognized and/or signalled by farmers (majority), 2) the damage has not been significant enough yet (majority), and 3) it is relatively low on the priority list of current pressing issues in the agricultural sector, like droughts, floodings, nutrients, biodiversity, etc. both from the perspective of policy-makers as for farmers (majority). For example, flooding has a higher urgency amongst farmers as this causes instant damage and occurs more often, and will occur even more frequently because of climate change (majority). Droughts, due to more frequent water shortages during times of low or no precipitation, also have a higher urgency amongst farmers, although still not as prominent as flooding, since the reduction in yields is less significant and/or less immediate, and therefore often difficult to determine (majority). The lack of urgency is also highlighted by the potato breeders who mention that the growing interest for more salt-tolerant cultivars is mostly coming from abroad, i.e. regions where salinization is more prominent already like Morocco and Egypt, and that very few requests are coming from Dutch potato cultivators.

It is thus generally recognized that it will take more summers like the one in 2018, more dry periods, to make salinization into a prominent theme (majority). Nevertheless, the majority of the interviewees, expect the latter to happen sooner or later as salinization will become more and more of a problem, mostly due to autonomous salinization, sea-level rise, decreased river runoff, and decreased precipitation and increased evapotranspiration during the summer months – although the exact extent of the issue is unsure as this is largely determined by how climate change will develop exactly. However, many also view the issue of salinization and drought as mostly a distribution issue, both seasonally as well as spatially, rather than an absolute freshwater shortage issue. On the one hand, there is too much water in the winter and too little in the summer, and since these peaks are getting even more extreme, there is a challenge in how to balance the supply and demand of water under increasingly volatile weather conditions (many). On the other hand, there is also the critique that on a yearly basis, there is and there will be enough water entering the main water system to supply all current externally water fed areas, and possibly even new areas, but that this water is now being used inefficiently on stopping the salt wedge from entering the open waterways, instead of diverting freshwater from the rivers directly to water demanders or preventing the sea from entering the waterways in the first place (many). Moreover, farmers tend to be especially fearful of the intentional salinization of polders and water bodies for the sake of nature and how this can decrease the availability of fresh water and increase brackish seepage (many). Farmers thus worry about the salinity levels in the regional and main water systems, and the decreasing certainty of external freshwater supply, as many farmers rely on freshwater in the ditches for
irrigation (for back-up) in drier periods (*majority*). This fear of freshwater shortages and frustration with seeing large quantities of freshwater being directly discharged in the North Sea, is aggravated by the fact that arable farming is in the last category in the water distribution priority sequence during times of water shortages, increasing the chances that arable farming gets no or insufficient fresh water (*many*).

Although for many interviewees it was difficult to give a straightforward and definite answer to the question to which extent salinization already is and will be an issue for agriculture – due to the many uncertainties as identified above – there is a shared notion that salinization is a threat to agriculture at large, and an increasing threat (*practically all*). Therefore, salinization is an issue that deserves to be addressed, not only because it is harmful to the livelihoods of farmers directly, but also because it can have negative repercussions to the regional economies of which especially seed-potatoes and floriculture, but also agriculture in general, are important pillars (*many*). Moreover, business-as-usual, i.e. the current dominant land- and water management practices, are perceived as largely unsustainable, both in the sense that they facilitate salinization and/or can become impracticable because of salinization (*majority*), as will be discussed in the next paragraph.

4.2 How do current dominant land- and water management practices relate to salinization?

In general, it is recognized that many of the current dominant agricultural land- and water management practices are contributing to salinization. As recognized by *practically all* interviewees, the regime of the past decades has been to dispose of freshwater as much as possible, since without it these regions would be flooded due to their position beneath sea-level (*many*), but also because floodings have been, and to a large extent still are, more common and impactful (*majority*). In line with this regime, the dominant drainage method amongst farmers is conventional drainage with which water is continuously drained until a certain depth (*practically all*). This method, however, does not ensure that freshwater is retained for periods in which it is necessary (*majority*), 1) as it will keep on draining the soils to a certain depth, and 2) as it drains the fresh precipitation water instead of the saline groundwater, thereby attracting saline groundwater to the (sub-)surface in drier periods, possibly salinizing the root zone. The reason that this is still the dominant method of draining is because 1) it is the customary practice, i.e. farmers do not know any better (*many*), 2) it is rather unproblematic in ‘normal’ years (*many*), 3) farmers are more focussed on removing water instead of retaining it, for example because heavy rains are more common and impactful than drought or salinization (*majority*), 4) farmers are not that aware of a freshwater lens (*some*), 5) farmers do not know or do not acknowledge that this type of drainage can cause salinization or contribute to their drought problems (*many*), and 6) other systems are more expensive (*majority*).

Another preference amongst farmers is that the water level in their parcel and their regions is kept as low as possible to lower the risk of flooding during heavy rains and for them to be able to work on their fields with their heavy machines (*practically all*). However, the water level in their parcels is determined by the water level in the ditches, and in turn determined by the compartment water level,
which is a legal agreement between the farmers and the waterboards (many). Therefore, many farmers have installed so-called under-drainage with which they can artificially lower the water level beneath that of the regional system, whereas this also increases the risk of saline seepage (some). Next to the parcels being designed to drain as much water as possible, the intensification of cultivation practices over the past decades has led to the large-scale deterioration of the structure and fertility of soils, which are therefore not capable of draining large quantities of rainfall during heavy precipitation events, nor retaining fresh water when it is drier (many). The latter also results in an increased risk of salinization, since saline groundwater can more easily reach the root zone if the soils are dry (many). In regions where farmers use deep freshwater lenses to irrigate because there is no fresh surface water available, there is a risk of exhausting and/or salinizing these wells, since sustainable extraction is difficult for farmers and local water managers to determine and control (some).

Due to the historical function of regional water systems (many) – and sometimes also the technological inabilities and lack of fresh water in the surrounding areas at the time which restricted a supply function (some) – most regional water systems have been historically designed to dispose of water instead of retaining or supplying areas with water (many). Next to the lacking ability to retain water, another consequence of this historical function and design is that most systems do not have separate discharge and supply channels, and/or that these are often not located in the right places. This results in the inefficient flushing of the system, i.e. large variation in chloride levels between ditches, and the general water quality being lower than it could be due to the mixing of fresh and saline water (many). The regional water systems that have been designed for flushing and the supply of fresh water are often the locations where more sensitive high-capital cultivations like flower bulbs have been historically located or where they start to emerge (many). The paradoxical situation of high capital and high-quality water demanding crops being located in the most salinization-prone areas is a widespread phenomenon (many), occurring in South-Holland, i.e. the tree nurseries in Boskoop and the (emerging) flower bulbs on the island of Goeree-Overflakkee, North-Holland, i.e. the flower bulbs in the polders in the north, in Flevoland, i.e. the (emerging) flower bulbs in the Noordpolder, and in the seed-potato region of Friesland and Groningen – although seed-potatoes cannot be irrigated due to brown-rot. This phenomenon is mostly explained by the fact that the soils here are very suitable to these types of cultivations (many), that the distribution infrastructure is already there (some), but in some cases – especially flower bulbs – also because of the fact that there is a secured freshwater supply for flushing (some). However, the facilitation of high-quality freshwater demanding cultivations in largely salinization-prone areas results in significant challenges for waterboards during dry periods and might become too technically challenging and costly in the future (many).

The challenge that waterboards face of having to keep the water supply fresh mostly relates to there being ‘effort obligations’ of chloride norms they have to adhere to for flushing (many), though these norms are quite arbitrary and it is difficult to determine at what point the effort a waterboard has to take is no longer ‘reasonable’ (many). Moreover, as the waterboards are in charge of the regional
water system and therefore responsible for the water quality in the ditches, farmers tend to pressure them into adhering to the norms (many). The latter is also the result of farmers being largely dependent on this collective service, as they have never invested in water retaining measures or their own water storage since the disposal, supply, and quality management of water have been arranged collectively in the Netherlands ever since the waterboards were established (many), but also because water is not seen as a scarce resource according to some. Therefore, although several waterboards state their historical function has changed and that they are not legally obligated to supply farmers with enough freshwater at all costs, the practical reality is that they do go to great lengths of making it possible (many). On top of that, most farmers believe this should actually be the case because they pay waterboard taxes and as they think freshwater availability should, or is best to be, arranged collectively (many). What is adding on to this challenge is the fact that although the function an area gets – e.g. agriculture, residential area, nature – should be based on the water situation according to the waterboards and the provinces, this is currently not yet the case in provincial spatial planning policies, implying that high-quality water demanding types of agriculture can settle in salinization-prone areas and that waterboards will have to facilitate these at the best of their ability (many). The latter is also the result of this spatial classification being rather broad, i.e. not differentiating between different types of agriculture (some).

Another dominant water management practice at a higher management level that is perceived as unsustainable – especially by agricultural stakeholders but also by several waterboards and provinces – is the fact that the majority of freshwater that is entering the country is immediately being discharged into the North sea (many). Although this is not much of an issue in ‘normal’ years, it can be an issue during dry summers when river discharge is low and much more water is needed to counterpressure the salt wedge from entering the main waterways (some). This is where the different functions of the main waterways and inlet points start to collide, i.e. the shipping sector profits from the open connection to the sea at the Nieuwe Waterweg, whereas this increases the salt load in the main rivers to the point where the salt concentrations near the inlet points of the regional water systems can become too high for drinking water and industry, resulting in water shortages for agriculture in the area behind the inlet point as well (some). When this happens, the so-called climate-proof waterway which directs water from the IJsselmeer and the east of the country directly to the west via an alternative route, which is expected to become the rule rather than the exception due to climate change (some). In addition, the IJsselmeer is seen as an important water buffer by the adjacent provinces and there will be increased competition between the different regions for using this source in the future if the supply of river water to it and/or its buffering capacity is not increased (many).

Farmers cope with salinization of fresh water for irrigation in various ways (majority), it depends on the crop they cultivate (i.e. sensitive flower bulb versus relatively tolerant sugar beet), the chloride/EC levels they are used to, their practical experience, their risk perception, the soils type, quality of the crop or yield (the poorer the more they are willing to take the risk), growth stage of their crop (seedlings can take less), time in the season (if it is at the beginning or the end of the growing cycle,
do they expect rain or not), and so on. Therefore, there are large discrepancies between what different arable farmers, vegetable farmers, and flower bulb growers perceive as ‘too saline’ for irrigation – even between different regions – and also between what they do and what scientific experiments have determined what is possible, both in the positive and negative direction (many). Practically all interviewees state that it is largely uncertain what the salt tolerances of commonly cultivated crops and soils are and that farmers, therefore, maintain a conservative standard, especially considering the large financial risk they would be taking (many). This also implies that there are hardly any field measurements of the effect of different salt concentrations on crop yield (some), whereas raising these norms could potentially limit drought damage by increasing the amount of usable water in times of drought (some).

As it is recognized by practically all interviewees that many current dominant water- and land management practices are unsustainable in light of increasing salinization, there is a need for innovations and/or new measures that can increase the salinization-resilience of the agricultural sector on both the short- as well as the long-term. Therefore, the next section will discuss these and the main opportunities and barriers in addressing the issue.

4.3 What are the opportunities and barriers to different mitigative and adaptive solutions in addressing the issue?

4.3.1 The parcel and farm level

Practically all interviewees recognize that, at the parcel and farm level, salinization-resilience can be increased on the short- and medium-term by increasing the freshwater lens in the parcel. The majority of the interviewees see a large role for level-controlled drainage or so-called anti-salinization drainage in preventing soil and rootzone salinization by conserving and even enlarging the freshwater lenses in the soils. Projects like Spaarwater in the northern regions of the Netherlands and the pilots in Zeeland are therefore perceived to be of great importance to research what is possible but also to demonstrate to farmers what the positive effects of these alternative types of drainages are (majority). By buffering freshwater in the sub-soil, farmers simultaneously lower the risk of drought and salinization (many). Moreover, as these alternative measures are similar to what farmers are already used to, it is more attractive to make the switch (some). The complexity with anti-salinization drainage, however, is that it has to be carefully customized since the thickness of the freshwater lens is very parcel specific and can even differ within a parcel, and as soil structure matters as well (many). An obstacle to installing level-controlled or anti-salinization drains in general is that drains are installed only once every 20 years and that it is uncertain whether this more expensive investment is profitable since farmers cannot foresee how much they will suffer from salinization or droughts in the future (some). There is also the confusion/perception amongst farmers that increasing the freshwater lens through drainage can result in a wetter environment and a higher risk of flooding, which hampers the implementation of these types of drainage as well (some). Another obstacle to these systems is that they still rely on the
availability of fresh water, as it can still run dry and/or because setting up the water in the drains with saline water is not desirable (some). An opportunity to further increase the freshwater lens by use of innovative drainage is by combining it with water infiltration in the sub-soil (some). Nevertheless, freshwater infiltration into the freshwater lens or deeper aquifer is not always possible and currently not allowed due to regulations on preventing groundwater contamination (some).

Another way farmers can increase the freshwater lens in their parcels quite easily is by more shallow dewatering, or by increasing the water level underneath the parcel by keeping the water up in their ditches with (simple) weirs (some). Nevertheless, barriers are that most farmers are more fearful of flooding or not being able to work their fields with heavy machinery (many) and because they think that setting up brackish water in the ditch might increase the brackish seepage in their parcel (some). The latter interaction is contested by what farmers do on Texel, where they set up the water early in the year already to keep the freshwater in their parcels, despite the water in the ditches being brackish or even saline (some). Another low-hanging-fruit for farmers with brackish ditches is to install weirs that separate and subsequently dispose of the brackish water and retain the fresh water – a rather simple and cost-effective measure (some). Nevertheless, this measure is not widely implemented yet, arguably since people were, or still are, unaware of the water stratification in ditches (some). Next to conserving and enlarging the freshwater lens, there are different low-investment measures which can improve the structure and fertility of the soil in order to retain more water and be more drought, salinization, and even flooding resilient; these include zero-tillage, supplying more organic matter, and the cultivation and use of green manure (some). However, it is rather unknown how farmers can do it most effectively (some).

Another yet uncommon practice which could lower the risk of salt-stress and drought-stress is the more economical use of freshwater through sub-soil drip-irrigation or similar methods (some). However, the cost-effectiveness of such a measure depends on whether, and how much, you have to irrigate as these systems are costly and time-consuming to install and only last for a (couple of) year(s) (some). Moreover, as drip irrigation is quite expensive, it is seen as more suitable to high-value cultivations (some). Nevertheless, even without investing in different types of irrigation, there is already much efficiency to gain with conventional irrigation by irrigating on the basis of data instead of experience/intuition – the latter still being the dominant basis of decision-making (some).

Next to the different mitigative measures at the parcel level, adaptation to brackish circumstances, i.e. (more) salt-tolerant agriculture is also a strategy that can be considered. However, currently available research on salt-tolerances is rather old, on different crops/cultivars than those that are common in the Netherlands, conducted under a different climate, and on different soils (i.e. mostly sand), and are therefore considered to be of no or little use in the Netherlands (many). This also means that the exact effect of salt on crop yield is largely uncertain and that current norms used by farmers are largely based on a limited knowledge base, rough estimates and/or intuition (many). Although it is recognized by the majority of the interviewees that it is desirable to have more research on this –
especially on peak salt events and salt tolerance at different growth stages as crops are often exposed to salinization at specific moments – the main question is who should and would pay for this.

Furthermore, according to the potato breeders, it is really difficult to determine salt-tolerance, as there are large differences between the results from tests in the greenhouses (controlled environment) and the tests in the field – where the variations in results tend to be large, poorly repeatable, and rather unpredictable. Moreover, breeding takes a lot of time, and although research on the genetics that determine salt-tolerance can speed up this process, this is rather complicated and time-consuming as well. Another complicating factor in adapting to more brackish conditions is that farmers have to apply crop rotation and that there are large variations between the salt tolerance bandwidths of these crops, e.g. seed-potato is sensitive, whereas sugar-beet is rather resilient (some). Nevertheless, knowing the salt tolerance of different cultivars would help in making a more informed decision on whether to irrigate with more brackish water or not and/or what crop/cultivar a farmer might be able to switch to (many).

However, even though a crop might be or might become more tolerant, this cannot compensate the fact that, in general, salts affect the structure of soils, thereby resulting in lower yields as well (many). Where salt on sand does not give soil structure issues, salt on clay does lead to soil quality issues, e.g. water cannot infiltrate due to the hardening of the soil, the soil becomes compacted, deprived of air, and difficult to cultivate, and seedlings and plants cannot come up (many). The more lutum and loam there is in a soil, the more you need to compensate with calcium and ensure that the topsoil remains ‘fresh’, i.e. that there is enough precipitation or fresh irrigation water from now and then, to infiltrate the calcium and leach the natrium (some). Even for saline agriculture, e.g. the cultivation of glasswort or saline potatoes, freshwater supply is needed to rinse through the salts (with calcium) within the soils, otherwise, the same negative soil structure effects as in conventional agriculture will occur (some). Thus, there is a maximum amount of salinity soils can take, fresh water is still required from time to time (some). Nevertheless, it is recognized that it is largely uncertain at which threshold salt concentrations become too high for effectively cultivation on clay, and also what one can do with e.g. gypsum, green manure, and/or organic matter to compensate the negative effect until that threshold (many). Therefore, it is recognized that (large-scale) field experiments on clay are desirable to establish this and provide action perspectives for farmers (many), although so far it has been very difficult to get government funding for this, arguably because of a lack of urgency and interest (some). Finally, practically all interviewees do not see halophyte or ‘saline crops’ as part of the solution, mostly due to lacking markets, the intolerance of soils, and the manual work it requires. Furthermore, at least in the short- to medium-term, some see it as less complicated to resist salinization from happening than to effectively adapt to it. Nevertheless, researching the salt tolerance of ‘cash crops’ and especially cultivars that are already marketed is seen as contributing to more salinization-resilience (many).
4.3.2 Community, compartment and polder level

At the community level, there is only one example of a union of neighbouring that collectively tries to solve a common drought and salinization issue, and that is the so-called Waterhouderij van Walcheren (‘Water farm of Walcheren’). The farmers in this union collectively own and share a water source, and make agreements of who can use what and when. They have been effective in gaining more yield by creating their own collective freshwater sources through solutions like anti-salinization drainage, creek-ridge infiltration, separating fresh and brackish water flows in the ditch, and raising the water table (few). This combined approach has been effective and ensures salinization and drought resilience for a long time (few). This cooperative model could also be applied to underground water storage, however, collectively maintaining a source can be rather challenging and time-consuming (few).

At the community, compartment, and polder level, freshwater can be retained through the use of weirs (some). Using so-called ‘fresh’ or ‘smart weirs’ like they do on Texel can also result in the freshening of the surface water of an entire compartment or even polder, as the brackish water is disposed of while the fresh water is retained (few). Furthermore, saline channels and ditches could be separated from the supply channels, and/or saline ditches could be closed off from the system to make flushing more efficient, but often waterboards are not aware of chloride differences at such detail (some). At the compartment level, the waterboard can retain water longer by (seasonally) raising and maintaining the water level, which also counter-pressures saline groundwater, thereby lowering the risk of saline seepage (some). However, raising the water level in a water level compartment is not simple as there is a legally bounding agreement between the farmers and the waterboard, therefore, if part of the community wants the water level to be raised, everyone has to agree with it, if only one disagrees then it has to be adhered to again (some). The latter can be very difficult as there are often conflicting interests, e.g. one farmer wants the water table to be low in order to cultivate the land, whereas another one needs the water for its crops (some). Moreover, if it goes wrong, especially because a higher level can increase the risk of floodings, the waterboard might be held accountable by the farmers (some).

4.3.3 Regional water system (waterboard level)

At the regional water system level, i.e. the waterboard, there is still some efficiency in flushing to be gained, e.g. by redesigning waterways, separating saline and fresh waterways, but also through more data-driven operations, as currently most of the operations are based on human decisions rather than measurements and forecasting (some). Furthermore, the chloride norms waterboards have to adhere to could become more area-specific, taking into account the variations in salt loads in different parts of the regional system and the ability to flush it through (some). In terms of raising the norms of inlet points, there is very little they can do, as often more functions depend on this norm (some).

Another (drastic) measure would be to differentiate the price farmers pay on the basis of their location in the system and/or even their extractions (some), as is currently the case in just one region, namely Tholen and St Philipsland in Zeeland. Here, the waterboard did not have a flushing obligation
as it was not needed nor possible at the time, but as the farmers suffered from the high chloride levels in the ditches and a nearby water body became fresh, making it possible to flush, they requested it collectively (some). Although the majority of the community wanted it to be paid collectively through taxes like in the rest of the Netherlands, a judge ruled that the waterboard could not levy a fee on farmers that do not physically extract from the ditch (few). Therefore, farmers in these regions now pay for what they extract and in what part of the system they are, i.e. the fee is higher if you are located in a higher quality part of the system (few). Nevertheless, the majority of the farmers would prefer the system to be paid collectively, as they argue that everyone profits from a ‘fresh environment’, as farmers do not have to extract every year (while they still benefit and there are still costs), and as a price incentive could result in only the farmers that have to irrigate carrying the burden of the system (few). This is an example of the dominant (historical) perception that arranging water supply and quality collectively is less expensive, more effective, and therefore more preferable than farmers paying a (full) users fee or becoming (completely) self-sufficient (many). This is further supported by the fact that although waterboards and provinces generally promote self-sufficiency and think it is important that farmers take their responsibility in the issue, they also state that flushing is actually not that expensive whereas many self-sufficiency measures are not near cost-effective (many), exposing a tension between the distribution of societal costs and benefits.

4.3.4 Provincial and sub-national level

At the provincial level, both the interviewees from the waterboards as well as the provinces agree that the function assignment of an area should be based on the water situation, i.e. what would be the current ability of a waterboard to provide that region with freshwater of a certain quality, as well as its future ability based on salinization projections (many). Until now, this has not been the case, mainly because 1) provinces are in charge of spatial planning policies whereas waterboards are in charge of the surface water management (many), and 2) salinization has not been a significant bottleneck so far (some), 3) the current water situation and projections of salinization have not been (sufficiently) mapped out (few) and 4) there are many other factors that a province has to take into account when assigning spatial functions (few). In the future, functions could be changed as an adaptive measure when it becomes to (societally) costly to facilitate certain functions in specific areas and to ensure that there is still enough freshwater of sufficient quality for regions where it is not too costly (many). This should also preferably include differentiation between different types of agriculture – e.g. differentiation between livestock, flower bulbs, arable crops – based on a reasonable chloride norm (some). However, such function differentiations are perceived to be politically difficult since it could come across as prescribing businesses what they should do, although in theory, it only determines what functions are actively being facilitated (some). Nevertheless, several experts, agricultural stakeholders, and governmental advisors agree that it will be impossible to facilitate ‘fresh agriculture’ everywhere in the future (many). Although some of them, and especially the agricultural stakeholders, are critical of the
intentional salinization of water bodies or polders, without having researched what this does to the freshwater security of surrounding areas, and without formulating a long-term vision for the future of an entire area first.

4.3.5 Main water system and national level

As previously discussed, some think the current distribution of the freshwater that is entering the main water system could be changed in order to supply more areas with sufficient fresh water for flushing and to increase the buffer capacity of freshwater bodies like the Volkerak-Zoommeer (which is actually still planned to become brackish for nature), Haringvliet (of which part of the sluice is left open intentionally to allow fish migration), and IJsselmeer (which is used by six provinces). Especially the external salinization at the Nieuwe Waterweg, which is in open connection to the sea for the sake of the shipping sector, is criticized, as most of the freshwater entering the country is used on counter-pressuring the salt wedge, while still not being able to completely prevent salinization of important inlet points (some). Moreover, salt water enters the regional- and main water system during the locking for ships, meaning that different economic considerations have to be made during times of increasing salt loads and decreasing river discharge (some). Although several changes to the infrastructure of the main water system are possible, they are often still not effective in the long-term and/or not cost-effective, e.g. because the shipping sector is affected by it which economic interest tends to be larger than that of the agricultural sector (few).
4.4 What locks-in the status quo and what creates opportunities for more salinization-resilience?

The main lock-ins of the current status quo and the opportunities for a transition towards salinization-resilience which emerged from the interviews are summarized in figure 14. Currently, the majority of experts and stakeholders share the notion that a sense of urgency is lacking for addressing the issue of salinization, mostly due to 1) the lack of widespread (signalled) damage, 2) uncertainty about the extent of the issue in the (near) future, and 3) the priority of other issues. Closely related is the lacking knowledge and awareness amongst farmers of the causes of salinization and their personal risk of salinization, which is largely preventing them from changing their current practices, as they 1) are not aware of how their practices can induce salinization, 2) do not know if they should be taking measures, and 3) do not know what type of measures would be most effective. This also relates to the general uncertainty about the current and future extent of the threat of salinization as 1) hardly any projections have been made of soil salinization, 2) salinization is a dynamic rather than a linear process, closely coupled to drought anomalies, and 3) large differences in expected salinization amongst the different climate scenarios. Another lock-in of the status quo is the limited available research on salt-tolerances of commonly cultivated crops and soils specifically, which results in the widespread application of a precautionary principle, especially considering the financial risk a farmer would take. Moreover, lack of funding for (practical) research and pilots, and subsequent limited knowledge on sal
tolerances and measures is also locking in current practices. This lack of funding can be tied back to the lacking sense of urgency, interest and long-term perspective amongst policy-makers, but also the fact that it is difficult for a sector to invest collectively in a common issue when there is no or little collective research money, as this type of research is expensive, of long duration, and in the interest of many (different) stakeholders. Another lock-in is the economic stake of the agricultural sector in keeping certain practices and arrangements – like the flushing of the system based on the current chloride norms (or even lower) – in place, as they largely depend on such guarantees for their productivity and, therefore, profitability. This also leads to certain administrative considerations like ‘function follows water’ or rules and legislation on e.g. under drainage prohibition or obligatory level-controlled drainage to be politically sensitive/difficult. Although the economic stake of the agricultural sector could also be viewed as supportive in a transition to more salinization-resilience – i.e. the future viability of an agricultural business depends on it – factors like focus on short-term gains and issues, lacking awareness/knowledge, uncertainty about the future threat of salinization, other priorities, but also the current uncertain cost-effectiveness or unprofitability of alternative measures are all reasons for not changing the status quo. The latter also relates to the distribution of burdens, responsibilities, and even benefits, between farmers and waterboards – or society as the waterboard is financed through taxes – since farmers are affected by salinization, both through brackish seepage in their parcels as well as in the ditches, and profit from the availability of fresh water, whereas the waterboard carries the responsibility of providing freshwater of a certain amount and quality. Since this creates a situation in which the (economic) incentives are not with one stakeholder, the (societal) cost-effectiveness of salinization-resilient measures for both farmers, as well as waterboards, is (even more) difficult to calculate or known to be negative.

On the other hand, there are also factors that can support a transition into more salinization-resilient practices when they prevail over the lock-in factors (figure 14). First of all, in recent years and especially after the summer of 2018, farmers and policy-makers have become increasingly aware of the issue of salinization, which has led to a growing interest into the topic, as evident from emerging measuring and monitoring projects and it being part of waterboard and provincial (development) programmes. However, it is recognized that it takes more consecutive dry periods for salinization to become a more prominent issue. Nevertheless, projects in which farmers measure and monitor salinization at the parcel level and its effect amongst farmers can also aid in raising awareness. Furthermore, the Delta Programme Freshwater has opened up a window of opportunity for integrative, inter-stakeholder, and inter-regional addressing of freshwater issues, including salinization – although its share in the programme is yet small. Another factor that is recognized by both experts and stakeholders to be crucial in stimulating this transition is more collaboration between the different stakeholders, i.e. the agricultural sector (e.g. LTO, KAVB), waterboards, provinces, and even the Ministries, Rijkswaterstaat, and knowledge institutes, as they all have a stake or (potential) role in addressing the issue, and need each other to successfully and sustainably address the issue. In the same
Increased communication between waterboards and farmers has already promoted more mutual understanding of each other's position and situation and helps in formulating an area-oriented approach. The latter is perceived to be very important by many of the interviewees, as the issue and therefore the possible solution(s) differ greatly per area. This also highlights the importance of involving multiple sectors, e.g. drinking water, industry, and nature, as they are often spatially mixed and have different interests, but could also work together on solutions. Furthermore, the majority of the interviewees call for the development of a long-term strategy, most logically on behalf of the province as this is already their formal role, but in collaboration and/or consultation with the stakeholders, in order for both waterboards and farmers to know what to expect and incorporate this in their own policies/business operations, but also to ensure that no decisions are made or pilots are initiated that might turn out to be harmful (to others) or a waste of money. Nevertheless, pilots of innovative measures like Spaarwater (i.e. anti-salinization drainage and sub-soil storage) have helped with raising awareness about the issue of salinization, but also to show the positive effects of certain measures. As action-perspectives for farmers are currently limited, multi-faceted solutions, i.e. those that address multiple issues like flooding, nutrients, and drought, at once, increase the attractiveness of such measures; again, pilots can contribute to making the positive effects visible. Finally, although difficult, some sort of analysis of the (distribution of the) costs and benefits of different measures can aid in the decision-making on to what extent the issue should be dealt with collectively or individually.
5. Discussion

The results indicate that salinization is generally perceived as a threat for agriculture in the low-lying regions of the Netherlands and that the issue is desired to be addressed sooner rather than later. Simultaneously, however, a sense of urgency seems to be lacking amongst the majority of farmers and policy-makers, mainly due to the lacking awareness and recognition of the issue, the absence of widespread damage so far, and the priority of other issues. Therefore, dominant land- and water practices amongst farmers, waterboards, and provinces – for example the focus on water drainage rather than retention, flushing of the water system to meet chloride norms, and not taking the water situation into account in spatial planning – that can stimulate salinization, aggravate its negative consequences, or no longer be sustained due to salinization, still prevail. However, it should be taken into account that, usually, regimes like these have not been deliberately shaped but are rather the outcome of path dependencies and developed interdependencies between actors and processes which have led to a state of being locked into a status quo (Holtz et al., 2008; Fünfshilling & Truffer, 2014). In this case, the (historical) widespread occurrence and severity of flooding problems amongst farmers, for example, can explain why there is a focus on water disposal rather than retention, as well as why water-related issues are often (preferred to be) solved collectively, e.g. by the waterboard, and on the basis of a solidarity principle (by use of taxes). In the same line, interdependencies that have been formed and institutionalized in the past, like farmers being largely dependent on waterboards for the supply of sufficient freshwater – both in volume as in quality – and waterboards being largely dependent on provinces (e.g. through spatial planning) and the central government (e.g. through the distribution of water from the main water system) for the feasibility of meeting their ‘effort obligations’, have led to a situation in which burdens, benefits, and responsibilities are shared, and therefore no one has a strong incentive nor complete power to change the status quo. However, the gradual stress of climate change and salinization and sudden shocks like the extraordinarily dry summer of 2018 do have the ability to disturb the current regime, as is evident from the growing attention to the issue and its increasing embeddedness in programmes like the Delta Programme Freshwater.

There are multiple limitations to the findings of this study. First of all, the selected interviewees do not completely represent the targeted stakeholder groups as 1) the interviewees from the provinces and waterboards are the (senior) advisors and not the administrators/policy-makers themselves, and 2) the interviewees from the agricultural interest groups represent the interest of their constituents and not necessarily that of all farmers. Nevertheless, as the advisors do work closely with policy-makers and provide them with information and advice, they are aware of the political situation surrounding the issue and why it is on the agenda or not, and also have the ability to shape this agenda. Moreover, although it can be argued that the agricultural interest groups might be too conservative as their role is to protect the interests of their constituents, this is also exactly what makes them representative at large. Besides, including the innovative farmers should have compensated for a too conservative formulation of the issue, although the opinions and perceptions were often in accordance as the agricultural representatives
were generally well aware of the many facets of the issue. Nevertheless, this research could be complemented by a large-scale survey amongst farmers to identify the current magnitude of the issue and the bottlenecks for farmers in addressing it. Another limitation of the research is that other sectors, e.g. industry, drinking water, and nature, were beyond the scope of the research, whereas their stake in the issue does have implications for the possibilities of certain measures (and the other way around) especially considering that these functions are often spatially mixed. Furthermore, as there was no list of pertinent issues regarding the topic of salinization in the Netherlands, the analysis might be incomplete despite the large number of interviews. Nevertheless, as the aim of the study was to provide an initial wide-ranging assessment, the results can be used for a more focused analysis of selected aspects that are deemed most pertinent by this research. Moreover, the results highlight a knowledge gap in the effectiveness, efficiency, and feasibility of different measures, which should be addressed by future research. Preferably, this is complemented by a societal cost-benefit analysis to inform stakeholders about the different possible pathways to salinization-resilience.
6. Conclusion

This research aimed to identify how the Dutch agricultural sector can be made more salinization-resilient, by reviewing the extent to which salinization is already perceived as an issue, how the dominant land- and water practices relate to the issue of salinization, the opportunities and barriers of different mitigative and adaptive measures in addressing the issue, and what is generally preventing a transition towards salinization-resilience and the opportunities to stimulate such a transition. Based on the interviews with experts, agricultural representatives, waterboards, provinces, and innovative farmers, it can be concluded that salinization is perceived as a large threat to agriculture in the low-lying regions of the Netherlands that should be addressed sooner rather than later, but that the urgency to do so is lacking due to low recognition and awareness of the issue amongst policy-makers and farmers, as well as the priority of other issues. Moreover, it can be concluded that current dominant land- and water management practices like the focus on disposing water instead of retaining it, the lacking efficiency in the use and supply of freshwater, and the paradigm of ‘water follows function’ in spatial planning and chloride norms are largely stimulating salinization and/or are expected to become unsustainable in light of salinization. Furthermore, the opportunities and barriers of different mitigative and adaptive measures like anti-salinization drainage, a higher water level, soil conservation, more efficient water use and supply is that they often have other positive side-effects and/or are not too different from current practices, thereby relatively attractive to implement, but that these are not expected to be effective on the long-term and that their (cost-)effectiveness is still rather unknown. For salt-tolerant agriculture, the opportunities lie with the selection of more salt-tolerant cash crops, and although this could be a more long-term solution, the salt-tolerance of these crops and common soils is currently under-researched. For spatial differentiation of water prices and in functions, the opportunities are that this can respectively increase efficiency in use and supply, as well as secure enough fresh water for certain areas. Nevertheless, such measures are politically challenging and might take a long time to become the standard. A lock-in of the status quo is that the diffuse burdens and responsibilities between farmers and water managers are resulting in virtually no-one having a strong incentive nor power to change the status quo. Moreover, the lacking long-term perspective amongst stakeholders and the uncertainty about the effectiveness and efficiency of different measures are preventing a transition to more salinization-resilience. On the other hand, especially more communication and collaboration between the stakeholders can create opportunities for such a transition. Furthermore, it is strongly advised that more research is done on the effectiveness of different mitigative and adaptive solutions, as this is currently lacking and thereby limiting the action-perspectives for both farmers as well as water managers. Finally, it is advised to supplement such research with a societal cost-benefit analysis to identify the societal cost-effectiveness of different measures and the distributions of the costs and benefits, thereby informing decision-making on a preferred strategy.
7. References


**Appendix A. Overview of mitigative and adaptive measures (adapted from Tolk, 2012)**

<table>
<thead>
<tr>
<th>Mitigation</th>
<th>Parcel</th>
<th>Farm</th>
<th>Neighbours/Cooperative</th>
<th>Polder or island</th>
<th>Water board</th>
<th>Provincial</th>
<th>(Sub-)national</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh water storage</td>
<td>Freshwater storage in a reservoir at the parcel</td>
<td></td>
<td>Fresh water storage in the surface water system or in large reservoirs</td>
<td>Use natural areas for water storage</td>
<td></td>
<td></td>
<td>Screen of bubbles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fresh water extraction from natural storage in ancient creeks, dunes or aquifers</td>
<td>Install extra between boezem</td>
<td></td>
<td></td>
<td>Weir spui</td>
</tr>
<tr>
<td>Increase the freshwater holding capacity</td>
<td>Increase rainwater lenses through <em>(Spaarwater)</em>: - optimizing height and distance of drainpipes - convey brackish seepage with (deep) drains <em>(Drains2Buffer)</em></td>
<td></td>
<td>Increase the fresh water storage in the ground: - Controlled drainage in ancient creeks <em>(Waterhouderij van Walcheren)</em> - Extracting saline groundwater from a creek ridge and inject it with fresh water <em>(Freshmaker – GO-FRESH project)</em></td>
<td></td>
<td></td>
<td></td>
<td>Waterlock Nieuwe Waterweg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Raise the buffer capacity of- or increase the water supply to (existing buffer) lakes, e.g. IJsselmeer and Markermeer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Divert water directly from the rivers to the users, to avoid water scarcity when the</td>
</tr>
</tbody>
</table>
- controlled drainage to hold fresh water during periods of water surplus
- customized regulation of the water level in the ditch

Soil moisture retention and reduction of runoff by improvement of the soil structure (*Gouden Gronden*)

- Increasing fresh water reserves in a creek ridge by infiltrating surface water (*Creek Ridge Infiltration Trial - GO-FRESH project*)
- Fresh water injection in deep aquifers (*Aquifer Storage and Recovery/LASR*)
- Actively store fresh water in aquifers during periods of water surplus for use in dry periods

<table>
<thead>
<tr>
<th>Optimization of water use</th>
<th>Optimization of water supply</th>
<th>Flexible water level control: customized</th>
<th>Spatial differentiated water price</th>
<th>Dynamic waterdivision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency water use:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- drip/sprinkler/sub-irrigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- soil moisture regulated irrigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

inlets closer to the river mouth salinize (*Klimaatbestendige Water Aanvoer*).
<table>
<thead>
<tr>
<th>Reduce/redirect brackish seepage</th>
<th>Increase of the water level</th>
<th>Polder water reuse/recirculation</th>
<th>Separated supply and removal through the water courses</th>
<th>(real cost pricing)</th>
<th>‘Smarter’ flushing of the water system</th>
<th>Water agreement external supply (foreign)</th>
<th>Points IJsselmeer and rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptation of agricultural land use</td>
<td>Irrigation with brackish water (regular crop tolerance) with or without use of gypsum to restore the soil structure</td>
<td>Temporarily dam drainage level areas affected by extensive saline seepage in dry periods so as to keep the rest of the polder water fresh.</td>
<td>Spatial differentiated water price (real cost pricing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cultivating crops with a high tolerance of salt <em>(Texel Salt Farm, SalFar)</em></td>
<td></td>
<td>Increase the inlet criterium of the chloride concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Halophytes</td>
<td></td>
<td>Price water supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aquaculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptation of spatial planning</td>
<td>Relocate salt sensitive crops</td>
<td></td>
<td>Revision of the area classifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relocate the company</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative water sources</td>
<td>Desalinization of brackish water <em>(CapDI)</em></td>
<td></td>
<td>Different source</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B. Aspects of experienced reality that can in various ways be affected by, or affect, innovation and scaling processes (adapted and abbreviated from Wigboldus et al., 2016).

<table>
<thead>
<tr>
<th>Categories of Experienced Reality</th>
<th>Aspects of Experienced Reality</th>
<th>Example of Entities that Distinguish Themselves from Other Entities Primarily Along the Lines of That Aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural and Physical Capital</td>
<td>Quantitative, spatial, kinematic, physical</td>
<td>Numbers, location, atmosphere, climate, water, soil, natural forces, chemistry, transportation, infrastructure, buildings, equipment</td>
</tr>
<tr>
<td></td>
<td>Biotic, sensitive</td>
<td>Plants, animals, birds, fish, organic processes, ecosystem, biodiversity, forest, desert, habitat, farm, crops, livestock, animal behaviour</td>
</tr>
<tr>
<td>Human Capital</td>
<td>Biotic, sensitive</td>
<td>Awareness, health, physical and mental abilities, emotion, personality, disposition, passion, observation, population dynamics, safety</td>
</tr>
<tr>
<td>Analytical-logical</td>
<td>Knowledge, theory, logic, conceptual framework, science, research, education</td>
<td></td>
</tr>
<tr>
<td>Formative</td>
<td>Construction, creativity, skill, computer software, design, power (in relationship): technology, strategy, methodology, innovation, adaptation</td>
<td></td>
</tr>
<tr>
<td>Social and Financial Capital</td>
<td>Lingual, social</td>
<td>Symbols, signs, language, communication, information, media</td>
</tr>
<tr>
<td></td>
<td>Relationships, roles, social cohesion, competition, collaboration, organisation, societies, alliances, partnerships</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>Resource management, conservation, stewardship, exchange of goods and services, transactions, efficiency, sustainability, economy, land use, market, value chain, firm, employment</td>
<td></td>
</tr>
<tr>
<td>Cultural, Political and Moral Capital</td>
<td>Juridical</td>
<td>Rights, law, responsibility, appropriateness, policy, legal system, constitution, mandate, police, the state, democracy, ownership</td>
</tr>
<tr>
<td></td>
<td>Aesthetical, ethical, certitudinal</td>
<td>Appeal, beauty, enjoyment, leisure, sports, art</td>
</tr>
<tr>
<td></td>
<td>Attitude, care, sharing, goodwill, integrity, equity, being right, solidarity identity, belief, trust, faith, vision, commitment, aspiration, worldview, ideology, paradigm</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix C. List of interviewees

<table>
<thead>
<tr>
<th>Category</th>
<th>Organization or specialization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agro-hydrological experts</strong></td>
<td>Wageningen University</td>
</tr>
<tr>
<td></td>
<td>Acacia Water</td>
</tr>
<tr>
<td></td>
<td>Deltares</td>
</tr>
<tr>
<td></td>
<td>STOWA</td>
</tr>
<tr>
<td><strong>Agricultural experts</strong></td>
<td>Wageningen University</td>
</tr>
<tr>
<td></td>
<td>Salt Farm Texel (2x)</td>
</tr>
<tr>
<td></td>
<td>SPNA</td>
</tr>
<tr>
<td></td>
<td>Delphy (flower bulbs, Zeeland, and South-Holland)</td>
</tr>
<tr>
<td></td>
<td>Agrifirm</td>
</tr>
<tr>
<td><strong>Plant breeders</strong></td>
<td>Agrico Research</td>
</tr>
<tr>
<td></td>
<td>HZPC</td>
</tr>
<tr>
<td></td>
<td>C. Meijer B.V.</td>
</tr>
<tr>
<td><strong>Provinces</strong></td>
<td>Groningen</td>
</tr>
<tr>
<td></td>
<td>Friesland</td>
</tr>
<tr>
<td></td>
<td>North-Holland</td>
</tr>
<tr>
<td></td>
<td>South-Holland</td>
</tr>
<tr>
<td></td>
<td>Zeeland</td>
</tr>
<tr>
<td></td>
<td>Flevoland</td>
</tr>
<tr>
<td><strong>Waterboards</strong></td>
<td>Noorderzijlvest</td>
</tr>
<tr>
<td></td>
<td>Frislan</td>
</tr>
<tr>
<td></td>
<td>Hollands Noorderkwartier</td>
</tr>
<tr>
<td></td>
<td>Rijnland</td>
</tr>
<tr>
<td></td>
<td>Hollandse Delta</td>
</tr>
<tr>
<td></td>
<td>Scheldestromen</td>
</tr>
<tr>
<td></td>
<td>Zuiderzeeland</td>
</tr>
<tr>
<td><strong>Central government bodies</strong></td>
<td>Rijkswaterstaat</td>
</tr>
<tr>
<td></td>
<td>Ministry of Infrastructure and Water Management</td>
</tr>
<tr>
<td><strong>Agricultural network organizations</strong></td>
<td>LTO North (Friesland and Groningen) 2x</td>
</tr>
<tr>
<td></td>
<td>LTO North-Holland</td>
</tr>
<tr>
<td></td>
<td>LTO South-Holland</td>
</tr>
<tr>
<td></td>
<td>ZLTO Tholen</td>
</tr>
<tr>
<td></td>
<td>ZLTO Zeeland</td>
</tr>
<tr>
<td></td>
<td>LTO Flevoland</td>
</tr>
<tr>
<td></td>
<td>Greenport North-Holland Noord</td>
</tr>
<tr>
<td></td>
<td>Greenport Boskoop</td>
</tr>
<tr>
<td></td>
<td>Royal General Union for Flower bulb culture (KAVB)</td>
</tr>
<tr>
<td></td>
<td>Water Commission Northern Sand Region</td>
</tr>
<tr>
<td><strong>Innovative farmers</strong></td>
<td>Zeeland (5x): saline agriculture and freshwater measures at parcel, community, and regional level</td>
</tr>
<tr>
<td></td>
<td>North-Holland (2x): freshwater measures parcel</td>
</tr>
<tr>
<td></td>
<td>Groningen: freshwater measures parcel</td>
</tr>
<tr>
<td></td>
<td>Friesland: freshwater measures parcel</td>
</tr>
</tbody>
</table>