Effects of precipitation and spatial factors on tile-drainage and surface water salinity in a coastal deltaic island (Goeree-Overflakkee, The Netherlands).

Master Thesis - 30 ECTS

In partial fulfillment of the requirements for the degree MSc Sustainable Development – Global Change & Ecosystems

July 2014

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Acknowledgments

Doing this research in combination with an internship at waterboard Hollandse Delta proved to be the right choice. As intern, I felt supported by my supervisor at WSHD (Fred Kuipers) but also by the whole of the department of 'Data & Advies'. I always found a helping hand when I needed one and worked in a pleasant working environment. Special thanks to all the people who helped me with my field measurements.

- Gerard van der Pluijm
- Harold de Ruiter
- Maarten van der Meer
- Suzanne Allerts
- Judith van Tol
- Jaco Goudriaan

Other staff members that helped me during my research are:

- Hanneke Maandag
- Rob Bovenlander
- Alex de Klerk
- Jannekee van Herrveld-Brand
- Jurgen Hell-Frijters (for the portable EC-measurement device)
- Jan Vos
- Christa Kemperman (especially for the passenger seat)

From the UU, I want to thank Stefan Dekker en Karin Rebel for being excellent academic supervisors and for proof reading my proposal as well and my concept thesis.

Best regards,

Rob Tuinenburg

Abstract

Due to its low lying properties, surface water in Goeree-Overflakkee (GO) is under the influence of saline seepage. Seepage enters the surface water directly and indirectly via tile drainage systems. Drain tiles salinities were sampled in four sites during spring in order to find spatial features which can be used to predict effluent salinity in response to precipitation events. From literature, important identified factors were seepage intensity, drainage depth, drainage area per tile and precipitation-evaporation surplus. A shortage in precipitation caused insignificant results in temporal variability in the measurements, making it impossible to quantify changes in salinity. However, drain tiles and measurement sites were significantly different suggesting an effect of spatial features to drainage salinity. Seepage intensity was identified as the only significant factor for causing differences between sites (large scale variability). A validation attempt to test the model to surface water concentrations in GO did not result in a good prediction, leaving room for future research. For variation between drain tiles, small scale variability, two mechanisms can be identified 1) boils are suspected to cause small scale spatial differences in seepage intensities, 2) cracks in the soils are thought to cause preferential flow in the rain water lens, resulting in drain tile specific mixture ratios of seepage, RW-lens water and precipitation. These ratios can cause drain tiles to respond differently to incoming precipitation and contribute to drain tile specific salinities. A spatial analysis into the salinities of surface water monitoring points did not result in identifying important factors. Future research should focus in area specific monitoring of the salinity response per area. This can give detailed information about the specific precipitation responses and can help with managing water quality according the WFD. For future research, a longer period is necessary to investigate precipitation responses in detail.

1. Introduction

Improving surface water quality in deltaic islands in the South Western delta of the Netherlands is a complex issue. Due to the implementation of the European Union (EU) Water Framework Directive (WFD) (Kallis & Butler 2001) improvement is legally required and measures should be developed by the appropriate water authority. Improving the water quality is achieved by setting requirements and a timeframe in which measures are to be established. The requirements of the water body are formulated by identifying the category to which the water body belongs. Scores are then allocated in chemical and ecological categories which define how much the water body deviates from the natural state. This natural state is formulated as when no anthropogenic influences are present. Monitoring is done in selected areas which resemble the quality of the local water basin, so called WFD water bodies. Due to stress caused by population and economic growth, intensified agricultural development, climate change and sea-level rise surface water quality improvement is difficult (Oude Essink 2001). Measures in the past have focused to stop further water quality deterioration and although the progress in the last 10 years is significant, returning to a natural state of a majority of the water systems seems unrealistic (Hering et al. 2010).

Salinity is an important feature in identifying water quality. According to the identified natural state the WFD sets requirements of the salinity for each WFD water body. Water bodies are qualified as saline, brackish or fresh resulting in appropriate ecological and biochemical standards. Islands in the South Western delta of The Netherlands do not have continuous natural supply of fresh water and are mostly rain-fed. These rain-fed areas may suffer from problems related to the occurrence of saline groundwater (salinization) (Oude Essink 2001; Post & Abarca 2010). Saline water is often present at a shallow depth due to its history of flooding, marine transgression and sea spray (Custodio & Bruggeman 1987; Post & Abarca 2009; Eeman et al. 2012). Due to the low-lying character of river deltas, mostly at or around main sea level (MSL), this saline water is forced upwards (Oude Essink 2011). This process is known as seepage and affects surface water as well as groundwater salinity. The impact of saline seepage is an important issue as the MSL is increasing with enhanced global change and as many low-lying areas suffer from land subsidence. Combined with expected altered rainfall distribution during summer due to climate change (Van den Hurk et al. 2006; IPCC et al. 2007) saline seepage will have an increasing effect on deltaic areas worldwide. Coping with these effects will require a deeper understanding of how seepage is related to surface water and precipitation.

There are two pathways by which seepage can enter surface water. Seepage can directly enter the water body via sub surface flow or indirectly by discharge of saline groundwater by tile-drainage of agricultural fields (Eertwegh et al. 2006; de Louw et al. 2011). Tile drainage is designed to discharge the groundwater to keep the water table at a specific height for optimal agricultural production. Due to its lower density, infiltrating precipitation forms a thin fresh water lens upon the saline groundwater. This lens is known as a rainwater lens (RW-lens) (de Louw et al. 2011; de Louw, Eeman, et al. 2013). Often these thin fresh water lenses and the brackish mixing zone between saline and fresh groundwater (Figure 1.1) are the only source of fresh water available for plants, keeping the topsoil available for fresh water agriculture (Katerji et al. 2003; Rozema & Flowers 2008; Eeman et al. 2012). As the water table fluctuates with incoming precipitation, the fragment of the RW-lens which is drained by the drainage systems varies. De Louw et al. (2013) showed a negative trend in salinity due to precipitation, arguing that due to incoming rain water the saline ground water discharge is diluted.

Dropping salinity due to precipitation is however not confirmed in all cases. Explorative research on Goeree-Overflakkee (GO) shows that responses in salinity contributions to the surface water seem to be depend on the drainage area and therefore can be spatially different (WSHD, 2012). Varying discharge salinities of tile-drainage systems are suspected to contribute to this variability but the impact is still unknown. RW-lens dynamics are expected to play an important role in the salinity of drainage system discharge (de Louw et al. 2013). Therefore, factors altering RW-lens properties (e.g. thickness and salinity) will possibly alter drainage salinity. This study examines into the relationship of precipitation and the spatial characteristics relative to the drainage and surface water salinity. Accordingly, the research question can be formulated as:

"How are precipitation and spatial factors related to the salinity of tile drainage and surface water?"

This relates to the two following sub-questions:

1. *"How is precipitation controlling the salinity of drain tiles relative to seepage intensity, drainage depth and water level management?"*
2. *"Is the discharge of chloride from the drainage system traceable in surface water salinity?"*

To answer the first sub-question, field research will be carried out in different areas in a time-scale of two months in GO. Precipitation is expected to decrease drainage salinity as it will dilute the incoming seepage. As seepage intensity varies spatially, areas with a high seepage intensity are expected to have a higher drain tile salinity. A deeper drainage depth is expected to result in a lower water table. This might increase in possible effect of the unsaturated zone above the water table and lower the RW-lens. How this affects drainage salinity in response to precipitation is yet unknown. Surface water level management has shown positive relations with water lens formation in low lying areas in the Netherlands (Eertwegh et al. 2006). A higher water level of the surface water is suspected to create more pressure from the fresh water body, creating a less saline environment.

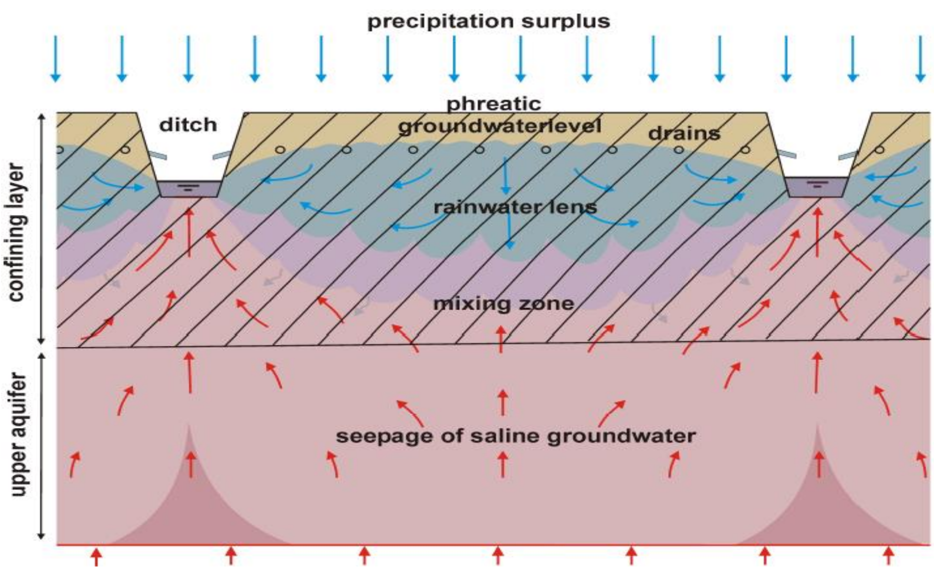

Figure 1.1 Schematic cross-section visualizing the conceptual model of a RW-lens and drain pipes in an area with upward seepage of saline groundwater (De Louw et al. 2013).

1.1. Introducing GO

Goeree-Overflakkee (Figure 1.2) is best characterized as an island of the low-laying south-west river delta of the Rhine and the Meuse. GO is a slightly different island from the rest of the delta islands as the ground is sandier and less clay layers are found. Furthermore, GO has borders with a salt water lake (Grevelingenmeer) and a fresh water body (Haringvliet). Whereas the fresh-salt intrusion in the neighbouring province of Zeeland (the rest of the delta) is well documented (Zeeland & TNO 2007; de Louw et al. 2011; de Louw, Eeman, et al. 2013), data from GO lacks far behind. This is mainly because GO falls under jurisdiction of the Province of Zuid-Holland and waterboard Hollandse Delta (WSHD) and so it has been excluded from earlier research which has been the initiative of the Province of Zeeland and waterboard Scheldestromen (TNO, 2009).

Geological development of GO started 4.500 years ago when sea level rise began to decrease from 75 cm to about 10 cm a century. Due to this slow down rise, new coastal zones had the chance to develop and eventually dunes were formed. This resulted in a silting up of the rest of the delta and gradually peat areas developed. This peat layer is called the *Hollandveen* and is found almost everywhere in the southwest delta. The thickness of this layer varies from 0.5 m to 2 m.

It is difficult to quantify year round chloride contribution due to tile-drainage in summer. The water management strategies in summer are designed to keep the surface water chloride concentration between 200 and 400 mg L^{-1} (WSHD, 2012), peaks in salinity from drainage is quickly dealt with by extra flushing of the system. This management is due to the agricultural need for irrigation and requires externally sourced fresh water from the Haringvliet. In winter, there are no agricultural requirements so there is no need to acquire external fresh water. Salinity of the surface water is therefore relatively high and more depending on natural dynamics. Furthermore, the water level in summer is around 30 cm higher than in winter. All together, the summer surface water circumstances are artificial, causing an unrealistic view of the natural situation.

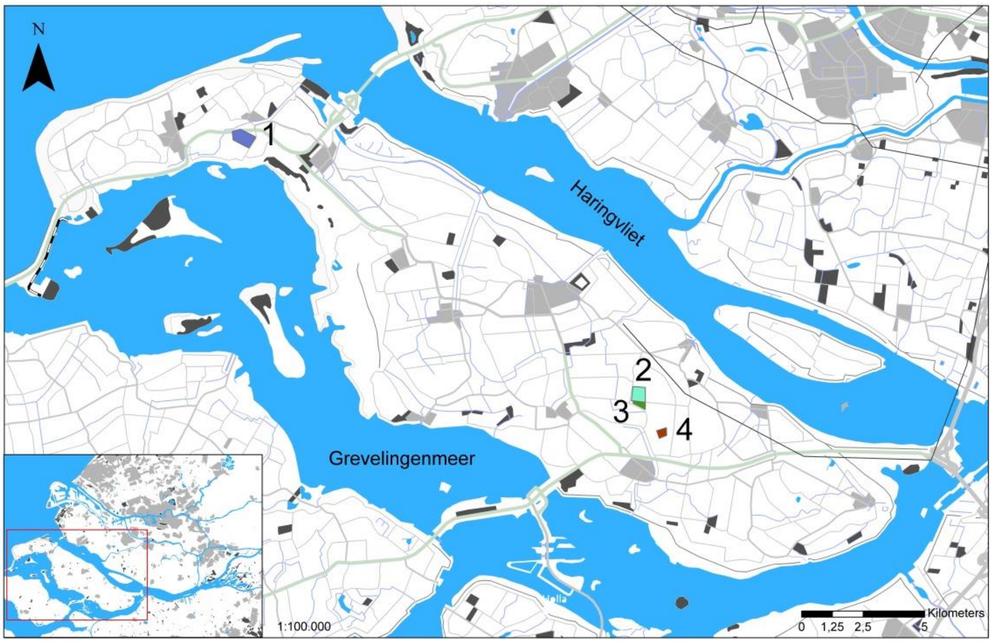

Figure 1.2
Sampling sites at GO.

2. Theory

2.1. Rainwater lens dynamics

RW-lens dynamics are essential processes contributing to the drain tile effluent salinity (Eertwegh et al. 2006; Goes et al. 2009; de Louw et al. 2011; de Louw, Eeman, et al. 2013). Often, fresh water layers on top of the saline ground water are described using the Badon Ghyben–Herzberg (BGH) principle. It describes unspoiled lens development in sand-dune areas or (coral) islands. In these BGH-lenses, freshwater recharge limits penetration depth (de Louw et al. 2011; Velstra et al. 2011; Drabbe & Badon Ghijben 1889; Herzberg 1901). Response to recharge variations in BGH-lenses is in the order of decades (Vaeret et al. 2011; Oude Essink 1996). As for low-lying coastal zones, lens dynamics are found to be differing from BGH-lens principles. Penetration depth is not only limited by the recharge quantities but also by the strength of the upward seepage (Oude Essink et al., 2011; De Louw et al., 2011). Furthermore, Goes et al. (2009) showed that the influence of short-term precipitation events on the thickness of the mixing zone is significant, making these lenses much more dynamic and vulnerable to changing precipitation and evapotranspiration patterns (de Louw, Eeman, et al. 2013). Field measurements with electric cone penetration tests by TNO (2007) in the south-western delta of The Netherlands showed that the transition zone between infiltrated rainwater and upward seeping saline groundwater is most likely to occur within 2 m below ground level (BGL). It also turned out that nearly all mapped lenses lacked truly fresh groundwater (chloride concentration <300 mg L^{-1}) (Stuyfzand 1993). To accommodate these properties, another type of description is necessary. De Louw et al. (2013) described these lenses as rainwater lenses and defines the penetration depth as the depth at when the salinity equals the salinity of the regional groundwater. This definition accommodates the relative unstable character of RW-lenses in which salinities vary in both space and in time (de Louw, Eeman, et al. 2013). De Louw et al. (2013) indicated that penetration depth of RW-lenses can fluctuate up to 1.2 m due to water table fluctuations in response to individual recharge events. Moreover, flow and mixing processes are much faster near the water table, which fluctuates at a daily basis. The position of the center of the mixing zone showed a much smaller change and fluctuated at a much longer, seasonal time scale (Goes et al. 2009).

The relationship of RW-lens formation dynamics in tile drained agricultural fields was also topic of research by De Louw et al. (2013). It was argued that preferential flow through cracks is playing an important role in the response of the drain tile discharge to individual rain events. A negative correlation was found between the water table height (which is raised due to incoming precipitation) and the drain tile effluent salinity. Furthermore it was shown that groundwater of variable salinity, originating from different parts of the RW-lens, as well as infiltrated rainwater, contributed to the drain tile discharge in proportions that vary on a timescale from hours to several days. This caused the dynamic behaviour of drain water salinity.

Evapotranspiration during summer (Van den Hurk et al. 2006; de Louw, Eeman, et al. 2013) and the removal of recharge through drain tiles can ultimately cause the disappearance of RW-lenses (Eertwegh et al. 2006). Climate change may result in an increasing gap between higher winter recharge due to more precipitation and more summer shrinkage (de Louw, Eeman, et al. 2013). Since the increase of winter precipitation is efficiently discharged by tile-drainage systems, RW-lenses will thus be more vulnerable. Recharge possibilities during summer are still poorly understood.

2.2. Identifying spatial factors in tile-drainage salinity.

Tile-drainage in the Netherlands has been introduced to be able to use the soils for agricultural production. It is often present in agricultural land, in combination with a free drainage situation or water table controlled drainage by collection ditches. During a rain event the water table rises above the drainage depth at which groundwater enters the drain tile and is transported to the surface water. The subsurface drain spacing is generally 10 m at a depth of about 0.8 to 1.0 m, but different situations can be found (Eertwegh et al. 2006). The salinity of the water discharged by the drain tile is suspected to not only to be defined by RW-lens dynamics but also by spatial factors. Seepage intensity, drainage depth, water level management and the total surface drained by the tile are possibly factors which may influence drain effluent salinity and are spatially variable (TNO 2007). Due to this variability in spatial factors, there may be a large diversion in drain tile salinities and responses to precipitation. **Seepage intensity** varies spatially in chloride concentration and pressure. High seepage intensities can cause pressure under the tile, which leaves a smaller space for the RW-lens to develop. De Louw et al. (2011) found that seepage intensities can vary spatially due to the existence of boils. Boils are small vents in the top confining layer through which groundwater preferentially discharges at high velocities (de Louw, Vandenbohede, et al. 2013) (Figure 2.1). This causes spatial differences in upcoming seepage which can affect each drain tile individually. **Drainage depth** is often designed specifically to maintain the water level at the depth of the drain tiles. It is therefore logical that in winter, the water table is usually defined by the drainage depth. It is unknown if the drainage depth is correlated with the drain tile salinity. Research by Eertwegh et al. (2006) shows that **water level management** has a significant effect on the drainage salinity. A higher water level is suspected to create more pressure of fresh water, decreasing seepage intensity. However, this relation is complicated by the seasonal surface water quality management in GO. Summer flushing causes the salinity to drop to about 300 mg $L^{-}1$. Analysis of the spatial characteristics in relation with salinity concentration can thus only be done in winter months. As this research is conducted in spring, the effect of water management during this research period is not testable. To test the effect of water level management, a data analysis of the winter chloride concentration of all the standard monitoring points in GO is conducted. In field studies, the high **hydraulic conductivity** of peat soils caused seepage to reach higher up in the soil, moving the mixing layer and the RW-lens upwards. To eliminate this effect, measurement sites were chosen on the same subsoil characteristics. **Land use** has an effect on the quantity of evapotranspiration (Köksal 2008), which is a significant outgoing flux, especially in summer. Since the research was conducted during spring, land use was not taken into account. Finally, each drain tile has a **specific drainage area** that may affect drain effluent salinity.

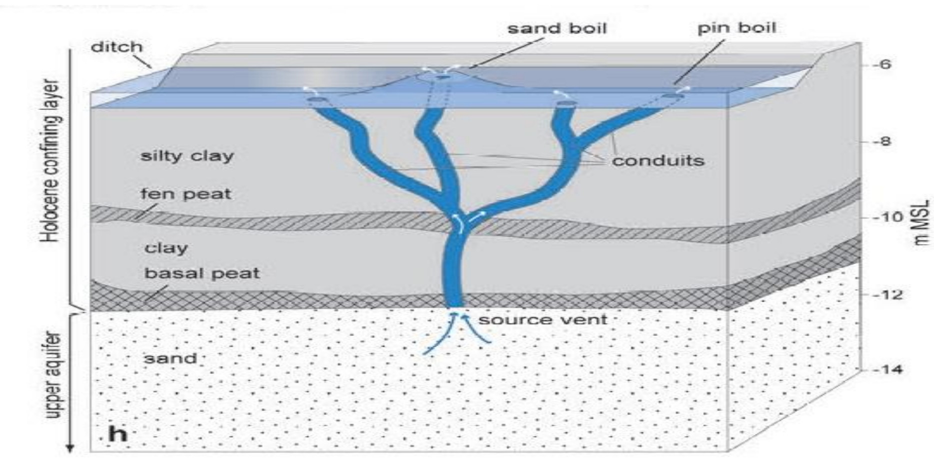

Figure 2.1
Schematic diagram of boils with several conduits (de Louw et al. 2010).

2.3. Site specific precipitation responses

Spatial factors may not only change normal drain tile salinity, but also affect the response to precipitation events. Field data collected by waterboard Hollandse Delta (WSHD, 2012) show that precipitation events cause different responses in chloride concentrations, varying per water level management area. Specifically for GO, two drainage areas show remarkable differences. Drainage area Wittebrug responds to precipitation with a higher salinity, while drainage area Smits responds the same precipitation with a lower salinity level. This shows that the response to precipitation is site specific. The reason behind this reaction might relate to the flushing of saline water storage in the capillary pores (de Louw et al. 2013). Another reason could be the difference in seepage intensity, which may be transported with the incoming precipitation flux (WSHD 2012).

3. Methodology

3.1. Site selection & data collection

Field sampling was done in four locations in GO (Figure 1.1). The sites were selected using geographic information software (ArcGIS), with maps available from the database of the waterboard Hollandse Delta. The data maps contained various sorts of data:

- A basis layer of municipal areas, agricultural fields, waterways and roads.
- The location of drain tiles (inaccurate and outdated).
- A map of seepage intensity (modelled).
- The winter water levels and water level areas in GO.
- The standard chloride monitoring points
- The sub soil types
- Elevation (MSL)
- Satellite images of GO

In the first selection selected all agricultural fields with the same subsoil type and various classes of seepage intensities. Classes were allocated according to the standard deviations. The exact location of the sites was appointed by a combination of factors. First, factors as seepage intensity and water level management policies needed to be clearly identifiable. Factors as drainage depth and drainage area were not included but calculated afterwards because of incomplete, inaccurate or absent data. Second, the maximum allowable distance between the sites was limited due to practical requirements (all sites were to be tested in one day). Site 1 was located in an area with relatively high seepage intensity and was therefore isolated from the other sites that were located more land inwards. Sites 2, 3, and 4 were clustered together in an area with as much variability in spatial characteristics as possible. Site 2 was selected due to other agricultural use (tulip field), site 3 was chosen since it had a different water level management policy and site 4 was selected as it resembled a normal situation for GO with average conditions.

$$[Cl]\ mg\ L^{-1} = 303.03EC\ (mS\ m^{-1}) - 0.5755$$ *Equation 1*

The drainage tiles at the selected sites were selected by practical availability. Then, the exact spot of the drain tile was saved with a GPS-device. Field measurements were taken during March and April 2014 with special attention to rainfall events. Water from the drain tiles and surface water was collected with a plastic cup and measured for electronic conductivity (EC) with a field measurement device. Chloride concentrations were calculated using results from earlier research (WSHD, data not published) which presented a linear relationship from EC to chloride concentrations in GO (Equation 1, Figure 3.1).

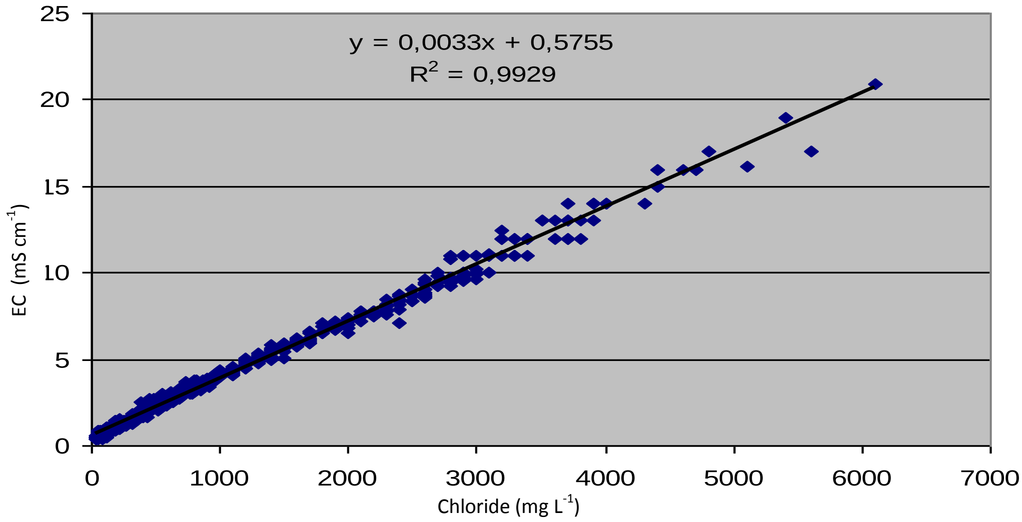

Figure 3.1
Cloride vs. electronic conductivity in GO in 2008 and 2009 (Source: Waterboard Hollandse Delta; Data not published).

3.2. Analysis

Temporal and spatial variability

Indicating temporal and spatial variability is important to validate differences which can be caused by incoming precipitation and spatial factors. To demonstrate these differences, multiple statistical analyses of variance tests (ANOVA) were conducted to test for:

- Temporal variability
  For each site, the chloride concentrations of the drain tiles were accumulated per measurement date. Indicating difference between these measurement dates, indicates thus temporal variability. As precipitation is the only variable in time, change across measurement dates is an indicator for precipitation influence on drain tiles salinities.
- Small scale spatial variability
  Per site, the chloride concentrations were accumulated per drain tile. Variability between drain tiles in the same site indicates a small scale spatial difference.
- Large scale spatial variability
  Chloride concentrations were stored per site. A significant difference between sites indicates spatial differences at a larger scale.

The null hypothesis was established by assuming no difference in chloride concentrations in time, within and between sites. Next, the data was loaded to a statistical testing software (IBM SPSS 22). To determine which test is appropriate for the data at hand, a Shapiro-Wilk test was used to test if a normal distribution was present. With a normal distribution in chloride concentration, a one-way ANOVA was considered the most appropriate. As it did not require an equal number of measurements in each data sequence (across the tiles, dates or sites) a lack of running drains or a varying number of drain per sites or dates was not giving statistical problems. If there are two or less measurements per sequence, the data is taken out of the analysis. With data which lacked a normal distribution a non-parametric test (Kruskal-Wallis) was used for testing whether samples originate from the same distribution. As the Kruskal–Wallis test does not assume a normal distribution of residuals it can be used to assess significant differences (Field 2009).

Multiple regression analysis

Field data was combined with the daily precipitation and evapotranspiration surplus monitored by the Royal Dutch Weather Institute (KNMI). Drainage depth was calculated by distracting elevation by the drainage height at MSL. Drain specific surface area was estimated by hand in GIS. Mean seepage intensity per drain was also calculated using GIS datasets. All GIS data were available at the waterboard Hollandse Delta.

The outcomes of the regression model will help to identify factors that have significant impact on the salinity of the drain discharge. The resulting correlation formula was used to model the salinity contribution from drainage systems to the surface water salinity. To validate the results of this model, the produced equation will be used to extrapolate the identified relation to the whole of GO using ArcGIS. This data will be compared to the monitored averaged water salinity of the surface water.

Standard chloride surface water monitoring points

Data from standard surface water monitoring points are measured monthly for regulatory purposes. The effects of saline discharge of the drain tiles to the surface water are possibly observable at a larger scale and traceable to the precipitation and spatial characteristics as seepage intensity and water level management. To correct for specific events that may have affected chloride concentration temporally (e.g. exceptional wet or dry seasons), the values are averaged over a period of ten years. Since the summer flush with fresh water has a major flattening effect on surface water salinity, summer measurements are excluded from this analysis. The chloride concentrations will be plotted spatially to visualize any occurring patterns or relationships. To examine the possible influence of the precipitation the coefficient of variation (CV) is used (Equation 2). A high CV could be a sign of sensitivity to precipitation events or could be correlated to water level management policies. The CV is calculated over a period of 10 years, as some spatial relationships are expected, the CV will also be plotted spatially. To relate standard chloride measurement point concentrations to seepage intensities and water level management, these values where clipped to the point values in GIS. The resulting data will be plotted in a scatter plot to determine possible correlations.

$$Coefficient\ of\ Variation = \frac{Standard\ Deviation}{Mean} \qquad \text{Equation 2}$$

4. Results

4.1. General observations of drain tile data

For all four measurement sites, the calculated chloride concentrations of the tile-drain effluent and precipitation over time is presented in Figure 4.1. Site 1 has the highest average salinity with 804 mg L^{-1} and site 2 has the lowest average with 311 mg L^{-1}. This is corresponding to the seepage intensity, with site 1 having the highest seepage intensity, and site 2 having the lowest (Table 4.1). During this research, GO received 54 mm of precipitation in total. The precipitation was roughly divided into two precipitation events, the first on March 21,22 and 23 with a total of 23 mm and the second on April 8 with a total of 13 mm. The second precipitation event did not result in more drains to carry discharge (Table 4.2). To compensate for this lack of data, more drain tiles were included in the research sampling database. This let the total number of drain tiles increase during the research period. Nevertheless, this measure did not result in finding drain tiles which were continuously carrying discharge. Consequently, this prohibited the monitoring of one single drain over the whole duration of this research. Water level rise during the research period as a result of the flushing policy resulted into submerged drain tiles, which then could not be sampled.

Table 4.1 Seepage salinity loads and mean chloride concentration in drains.

	Seepage intensity (mg Cl day^{-1})	Mean Chloride in drains (mg L^{-1})	Difference in Mean chloride surface water March – April (mg L^{-1})	Mean Reclamation depth (m)
Site 1	5265	804	1356	1,15
Site 2	248	311	219	1,09
Site 3	292	559	101	1,21
Site 4	549	423	-25	1,20

Table 4.2 Number of drain tiles sampled at the various sampling dates.

Date	13-3-2014	20-3-2014	24-3-2014	26-3-2014	31-3-2014	4-4-2014	8-4-2014	10-4-2014	15-4-2014	23-4-2014
Drain tiles sampled	6	26	36	31	18	13	13	25	21	7
Drain tiles not sampled	-	-	-	-	13	18	20	16	27	41
Total	6	26	36	31	31	31	33	41	48	48

Difference between sites

To identify differences in sites, an ANOVA was conducted between the drain tile salinities across all four sites. As no normal distribution is present (Shapiro-Wilk - Sig. 0,00) a non-parametric Kruskal-Wallis test was used. This resulted in a significant different chloride concentration between the sites, rejecting the null hypothesis. This means that the drain effluent salinity varies spatially in GO. Identifying spatial factors is thus useful and may help to explain these differences.

Surface water salinities

As this research was carried out in spring, it ran simultaneously with the preparations for the summer fresh water flushing policy. The effect of this procedure on surface water salinities is clearly visible in the fresh water salinity measurements. Especially in site 1, the mean chloride concentration dropped with 1356 mg L^{-1} (Table 4.1). In the other sites, the effect of the flushing policy was less apparent (Table 4.1).

4.2. Site 1

The highest measured concentration was 1300 mg L^{-1} and the lowest 410 mg L^{-1}. Site 1 is the only location where saline seepage effluent (>1000 mg L^{-1})(Stuyfzand 1993) was measured (Figure 4.1 A). As normality was only present in the distribution across drain tiles (Table 4.3) a Kruskal-Wallis test was used to assess temporal variability and a one-way ANOVA was used to assess variability in drain tiles. The Kruskal-Wallis test was significant but did not indicate altered distributions. The one-way ANOVA across drain tiles resulted in a significantly different distributions (Table 4.3). This results in no variability in time but a significant difference between the individual drain tiles. In other words, the drain tiles have different ranges in which they vary from other drain tiles at the same site. However, without temporal differences it is impossible to establish a relationship to precipitation (the only variable in time). Discontinuity in the data for a single drain originates from the lack of available running drains or practical reasons (a more detailed explanations for practical reasons is found in the discussion). It is therefore not possible to examine one drain over the whole duration of this research. A qualitative analysis is more useful for identifying responses of chloride concentrations in the drain tiles. During the first rain event, a rise of salinity in the drain effluent is clearly visible at drains nr 45 and nr 44. Most of the drains were not measured in the first two rounds so their response to the first rain event remains unclear. In the second event, the responses are smaller and vary from a small increase to a small decrease in salinity.

Table 4.3 Variability in time and drain tiles at site 1.

	Normality (Sig.)	Variance Test (Sig.)	Decision	Result
Variability in time	No (only 2 dates > ,05)	Kruskal-Wallis (0,122)	Retain the null hypotheses.	No variability in time.
Variability in drains	Yes (All drains > ,05)	One-way ANOVA (0,000)	Reject the null hypotheses.	Variability between drain tiles.

4.3. Site 2

The highest measured concentration was 451 mg L^{-1} and the lowest was 285 mg L^{-1}. Both date or the drain tile chloride concentration were not distributed normally so for both variance tests, a Kruskal-Wallis test was necessary (Table 4.4). Both tests did not show a statically altered distribution, which resulted in retaining both null hypotheses. Through assessing the graph qualitatively (Figure 4.1 B), individual drain chloride concentrations are easily identifiable. The lack of statistical conformation is probably due to a lack of running drains which led to a relatively small amount of data. This can possibly be explained by a difference in land use (tulip production) or a difference in the top soil type (especially designed for tulips), elevation or drainage depth. Regarding the response to precipitation, no clear relationship can be deducted.

Table 4.4 Variability in time and drain tiles at site 2.

	Normality (Sig.)	Variance Test (Sig.)	Decision	Result
Variability in time	No (All dates <,05)	Kruskal-Wallis (0.161)	Retain the null hypotheses.	No variability in time.
Variability in drains	No. (Only 2 drains > ,05)	Kruskal-Wallis (0.086)	Retain the null hypotheses.	No variability between drain tiles.

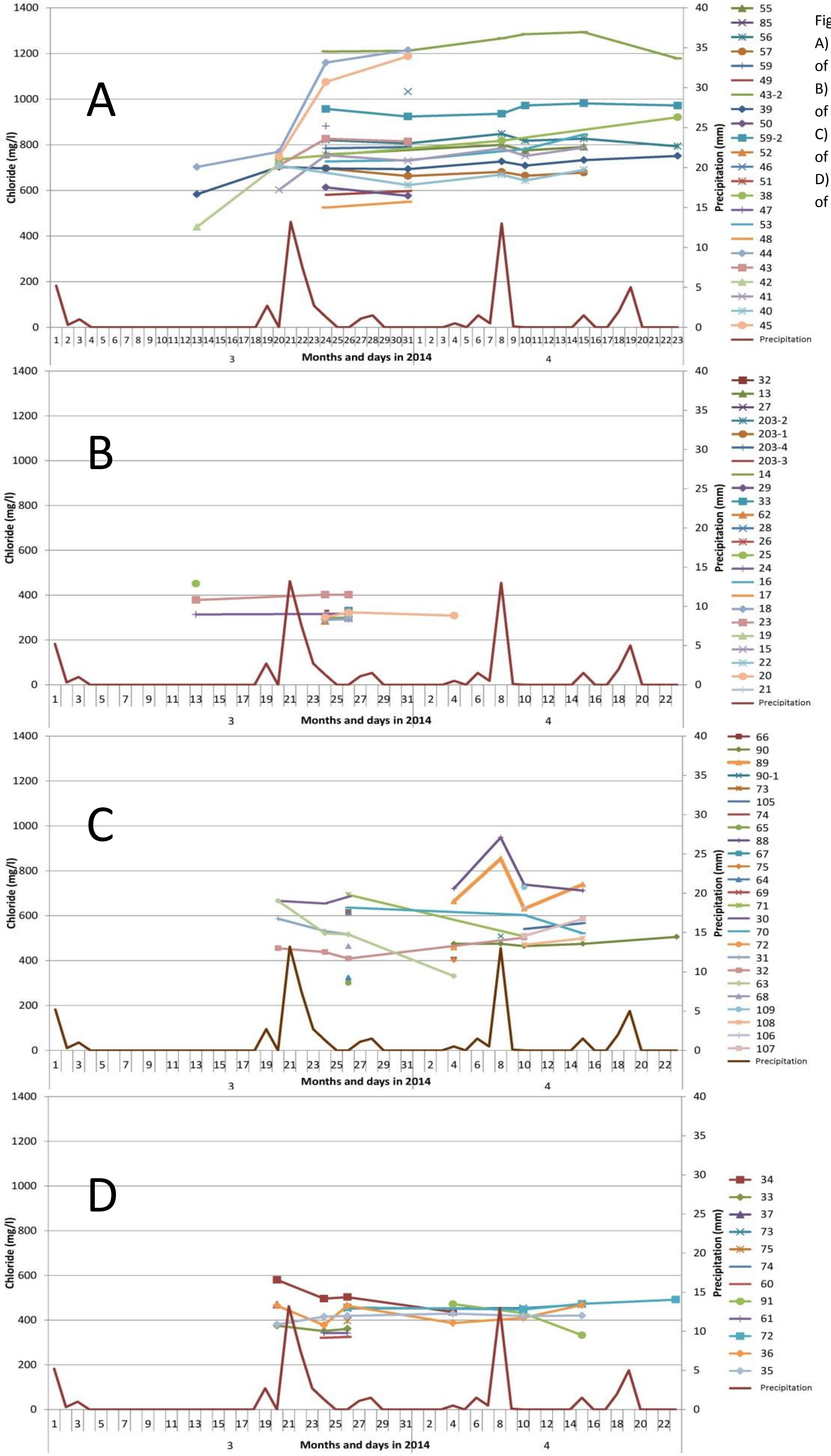

Figure 4.1:
A) Chloride concentration of drains on site 1
B) Chloride concentration of drains on site 2
C) Chloride concentration of drains on site 3
D) Chloride concentration of drains on site 4

4.4. Site 3

The highest measured concentration was 948 mg L^{-1} and the lowest was 301 mg L^{-1}. The date and drain tile distributions were both normally distributed (Table 4.5). This allows the use of two one-way ANOVAs to assess the differences between the distributions. The results are comparable to site 1, there are significant differences per drain but no significance in temporal variability. Qualitative observations (Figure 4.1 C) suggest some relation to precipitation events. Per event, some drain remain constant (drain nr 90), while other drains are possibly under the influence of incoming precipitation (drain nr 89 & 88, precipitation event two). Due to missing data of the drains throughout both precipitation events, no clear distinction between events can be made. At drain nr 63 and nr 31, a declining trend is observed, it is unknown which processes are responsible for this drop.

Table 4.5 Variability in time and drain tiles at site 3.

	Normality (Sig.)	**Variance Test (Sig.)**	**Decision**	**Result**
Variability in time	No (only 2 dates > ,05)	One way ANOVA (0,052)	Retain the null hypotheses.	No variability in time.
Variability in drains	Yes. (All drains > ,05)	One way ANOVA (0,000)	Reject the null hypotheses.	Variability between drain tiles.

4.5. Site 4

The highest measured chloride concentration was 451 mg L^{-1} and the lowest was 285 mg L^{-1}. Normality was shown in both time and drain tile (Table 4.6) and two one-way ANOVAs were used to assess differences. Although data continuity of this site was relatively high, the results were similar to sites 1 and 3. Variability between the drain tiles is significant while no temporal variability could be confirmed. Towards the end of the research period, the running of drain tiles was irregular. A qualitative view shows little temporal difference. The effect of the precipitation events may be present in some cases (drain nr 36, 34 & 90), in other cases drain salinity remains constant (drain nr 72).

Table 4.6 Variability in time and drain tiles at site 4.

	Normality (Sig.)	**Variance Test (Sig.)**	**Decision**	**Result**
Variability in time	Yes (All dates above >,05)	One way ANOVA (0.190)	Retain the null hypotheses.	No variability in time.
Variability in drains	Yes (All dates above >,05)	One way ANOVA (0,000)	Reject the null hypotheses.	Variability between drain tiles.

4.6. Multiple regression analysis

As the ANOVA showed significant difference between the sites, a multi criteria analysis can provide an insight into the strength of the identified factors to the drain tile effluent salinity. Input factors were: 1) Seepage load intensity (mg CL L^{-1} mm^{-1} day^{-1}) 2) Drainage depth (m) 3) Drainage area per drain (m^2) and 4) Precipitation and evaporation surplus (mm).

With a stepwise input method, a significant correlation of drainage salinity was only found with seepage intensity (R^2 = 0,564). Other factors could not be identified as significantly influential and are therefore not used in the describing model. The resulting model of the relationship between the drainage salinity and the seepage intensity is given (equation 3). An attempt to validate this model by extrapolating this relationship to the whole of GO using ArcGIS did not result in any similarities between the surface water and the resulting estimated drain tile salinities. Possible reasons for this inconsistency might be due to the inapplicability of surface water as an indicator for testing this relationship. This can be due to the flushing policy or other water management policies. Another reason for the failure of validating the model could be the inaccuracy of the model due to yet unidentified (spatial) factors.

However difficult to quantify, seepage intensity seems a realistic contributor to drain effluent salinity (Figure 4.1). The resulting trend line connects a dense cloud of points to a more diffuse assembly of drain salinities near 5000 to 6000 mg CL L^{-1} mm^{-1} day^{-1}. The correlation between the two data clouds is questionable as only two points around 1700 mg CL L^{-1} mm^{-1} day^{-1} seem to relate to the identified relationship. Combined, the multiple regression analysis and Figure 4.1 illustrate the correlation of the seepage on salinity loads. The results can be used as a qualitative validation to express the effect of seepage intensity on salinity in the drainage effluent.

$$CL_{DRAIN}\ (mg\ L^{-1}) = 419{,}98 + 0{,}074\ SI\ (mg\ CL\ L^{-1}\ mm^{-1}\ day^{-1}) \qquad \text{Equation 3}$$

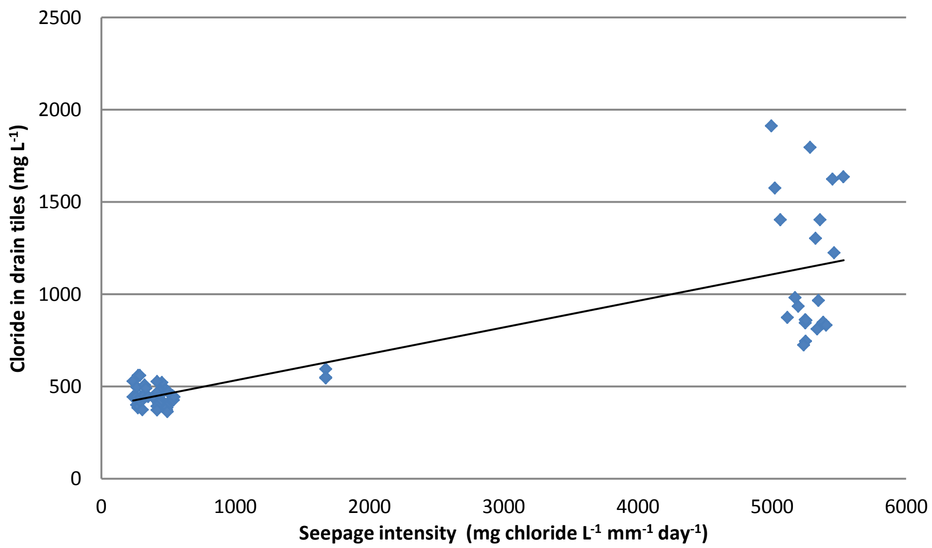

Figure 4.1
Mean chloride concentration of measurement locations versus seepage intensity.

4.7. Standard monitoring data

Spatial distribution of winter chloride concentration & variance

Plotting mean chloride concentrations in the winter of standard measurement points results in an inconsistent pattern (Figure 4.2). Generally, the lower south side of GO has smaller concentrations then the upper north side. Also it is very clear that chloride concentration near inlets is lower than near outlets. The highest chloride concentrations are found near outlet 'De Drie Polders'(lower black arrow in figure 4.2) and near at the upper north corner near a natural area 'Koudenhoek' (upper black arrows in Figure 4.2). Also this is close to site 1, which was selected because of the high seepage intensity. Seepage intensity however, is not per definition leading, as various measurement points in the same area did not have a high chloride concentration. The coefficient of variance also displays an irregular pattern, which cannot be seen in any sort of relationship to any spatial factor or other variables.

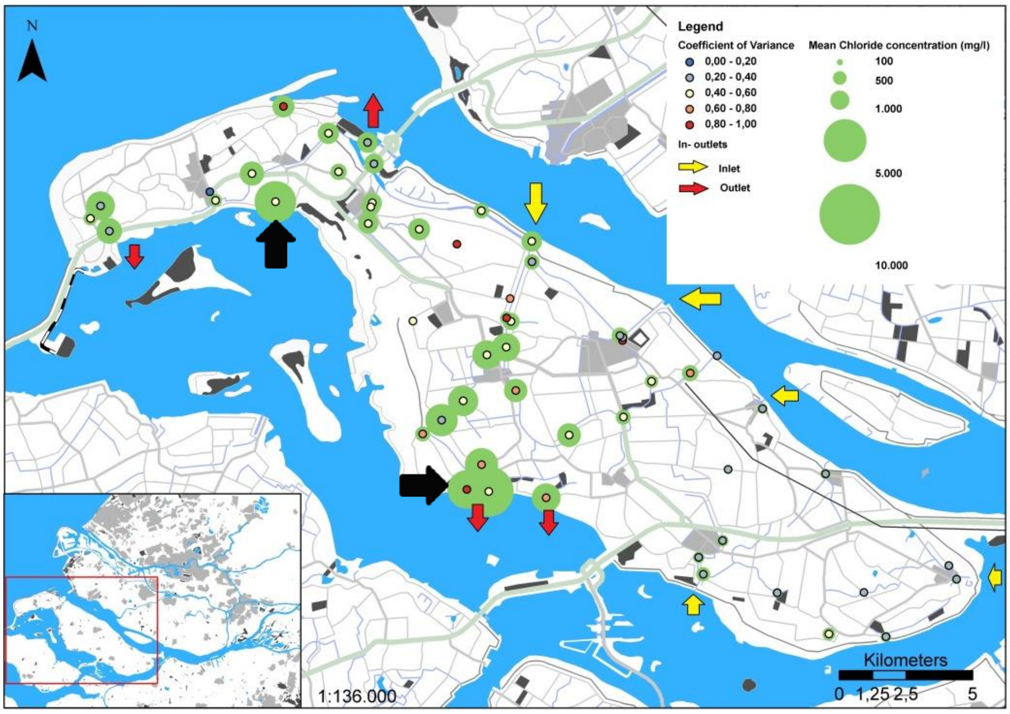

Figure 4.2 Mean winter chloride concentration, coefficient of variance and in- and outlet of surface water in GO.

Effect of water level management and seepage intensity

The winter water level management areas and the seepage chloride intensity load are plotted against the mean chloride concentrations (Figure 4.3 and Figure 4.4). The suggested negative correlation between the water level management and chloride concentrations is not supported by this data. Still, it can be observed that the rather high chloride measurements (> 4000 mg L^{-1}) are taken in areas with a relatively low winter water level (< -0,8 m). The expected positive correlation between the seepage intensity and chloride concentrations is not present either. High chloride concentrations occur when an average seepage intensity is present. High seepage intensities do not result in high chloride concentrations. Between 0 and 2000 mg $L^{-1}day^{-1}$ seepage load, a positive trend is present.

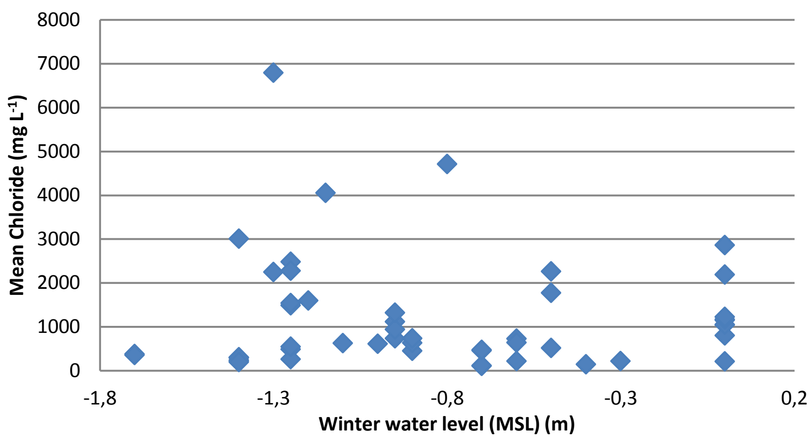

Figure 4.3
Mean Chloride concentration versus winter water level.

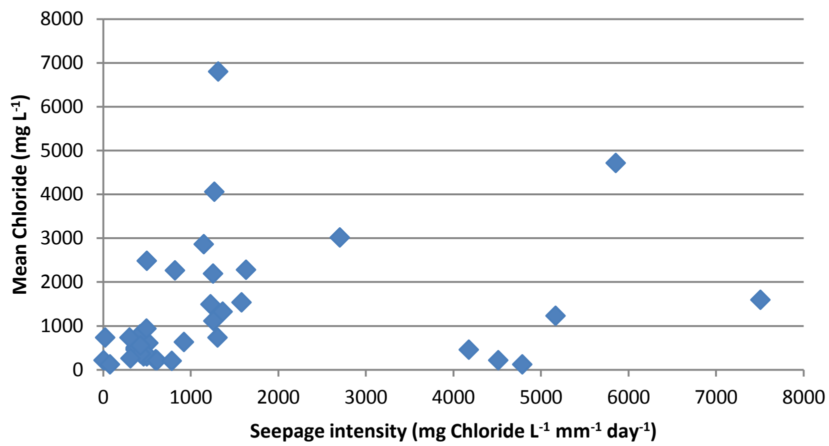

Figure 4.4
Mean Chloride concentration versus seepage load intensity.

5. Discussion

5.1. Precipitation response

The results of this research give some new insights into how the drain tile salinity can vary across a deltaic island as GO. As rainfall was the only variable in time and temporal variation in salinity was not shown during this research, the effect of precipitation on drainage salinity remains unquantifiable. A qualitative analysis indicates that the drain tile variability and response is drain specific. Precipitation events caused some drain tiles salinities to drop, some showed an increase and often a response was not detected at all. An increased salinity in the drain tiles could be due to saline water storage in the capillary pores in the unsaturated zone. Saline pore water could be flushed out to the drain tile during precipitation events, ending up in the drain tile. Varying responses might be caused by individual drain mixing ratios of seepage, RW-lens water and precipitation creating a drain tile specific response to infiltrating precipitation. Variability per drain tile was not found by De Louw et al. (2013) who showed a linear negative correlation between water table depth and salinity and these results can therefore be seen as contradictory. However, due to the relatively low precipitation fall during the research period, there is not enough evidence to support any of these suggestions. According to De Louw et al. (2013), the salinity of a drain tail never falls below 2 mS cm^{-1}. As the drain tile EC often fell below 2 mS cm^{-1} (600 mg L^{-1}) this study suggest a wider range of possible salinities. Nevertheless, the drain tile salinity was never indicated as fresh (<50 mg L^{-1})(Stuyfzand, 1993), corresponding with De Louw et al. (2013).

5.2. Spatial factors

Large scale spatial variability between sites as observed by WSHD (2012) can be confirmed with seepage intensity as the only statically significant spatial factor. Small scale spatial differences between drain tiles are also found. This confirms research by De Louw et al. (2011) who argued that spatial differences in seepage intensity are caused by the preferential discharge of groundwater discharge through boils. This mechanism causes spatial differences in the salinity which affects each drain tile individually. Additionally, De Louw et al. (2013), indicates preferential flow in the RW-lens through cracks in the topsoil causing different parts of the RW-lens, as well as infiltrated rainwater to contribute to the drain tile effluent. Combined with the spatial diversity caused by boils this can lead to a variability in the drain discharge between tiles in the same agricultural field.

An attempt to relate the surface water salinity to the seepage intensity did not succeed. Sources for this failure may be found in an inaccuracy of the model (wrong parameters and spatial factors) or a mismatch between the surface water and the drain tile effluent salinity. Furthermore, observations that the surface water in areas with a relatively high seepage intensity react differently to precipitation events can be supported qualitatively. A possible explanation for this reaction can be found in the suspected drain tile specific mixing ratio of seepage, RW-lens water and precipitation. As more precipitation will cause a larger volume to be discharged by the tiles, the amount of seepage discharged by the drain tile will increase too. More precipitation will thus not result in a large drop of salinity of the specific tile. Future research could find the quantitative effect of these factors.

5.3. Surface water salinity

Chloride data from standard monitoring points was available on a monthly basis over a period of ten years. Measurements were mostly taken in large waterways and near water pumping stations. Eertwegh et al. (2006) found a negative relationship between salinity and water level height. However in this research, the water level management was not identified as an influential factor for the surface water salinity when plotted spatially in standard monitoring point of GO. The only spatial relation found is the higher chloride concentration near outlets. This suggest a transport of incoming saline seepage by the surface water from inlet to outlet. The exact source of this incoming seepage is however not identifiable. Furthermore, higher water levels are not proven to have a significant effect on the CV. The observed variability in the CV cannot be related to any spatial factor and gives a yet unknown indication for responses to precipitation events.

The approach to surface water monitoring points in large waterways is questionable. A large part of this water originates from other parts of GO and is therefore a result of a combination of the spatial features from these and other areas. The salinity of the monitoring points is thus not necessarily representing the effects of the spatial features on that specific location. This causes incoherence in the data, resulting in difficulties when looking for spatial relationships. Especially during summer, the flushing regime decouples the surface water quality, which is maintained at an average of 300 mg L^{-1}. A more detailed analysis to a) where the water in a specific (monitor) point originates from b) which agricultural areas are (in)directly discharging their drain tiles into the surface water and c) how the water level management policy is situated might give a better interpretation of the winter situation. Research to the effect of the water level management in GO is further complicated by the changing surface water level between summer and winter. As groundwater needs a relatively large amount of time to reach a new equilibrium, this research cannot go into detail to whether the higher surface water level in mid-April had any effect on the drainage salinity. This is especially interesting since

Vandenbohede et al. (2014) showed RW-lens growth for irrigation practices in a low-lying coastal plain of Ravenna, Italy. The same could be true for GO due to the submerged drains in the summer fresh water flushing period. This may result in a thicker and more robust RW-lens with lower effluent salinities.

5.4. Limitations

A total of 35 mm precipitation in only two precipitation events is too low for a quantitative analysis into the relation of rain fall versus drainage salinity. Another effect of the shortage of precipitation was the scarcity of running drains. During the research period, a decreasing number of drain tiles discharged enough water to sample. Even right after both precipitation events, this number did not increase. This is likely due to the relatively dry period between the two events combined the water uptake op developing crops. This resulted in fragmented data pieces which, especially since the difference between drains is significant, disturbs normality and consistency of the data. Due to practical restrictions, a limited number of sites was chosen to sample, also there was a limitation to the number of drains that were chosen to sample per site. As some drains were not running regularly, this number of possible drains was roughly the same (with less precipitation, drains discharge slowed down and were harder to measure) while the individual drains varied. Another source of inaccuracy was caused by the GPS-receiver. Due to bad reception, the accuracy of the position was sometimes larger than the difference between drains. This may have caused the data to be accounted to a mismatching drain number. To prevent this, additional comments about the location and the specifics were made and compared to previous comments of the tubes. Another difficulty during the research period was the annual switch from the lower winter water level to the higher summer water level. Not only this caused flooding of drains, which limited the number of measureable drains even more.

The data used for this paper in the spatial and monitoring data analysis was usually of good quality and resulted in trustworthy results. Still, some data was outdated or ill-suited for answering the research question. The drainage data on the main island of GO was gathered in 2004. As the main replacement term for drainage systems is five to ten years (Droy 2010), a number of newly installed drainage systems that were not present in the GIS data were found while taking measurements. As this is not a problem of the individual drain analysis (drains were numbered and registered with a GPS device), this may have caused inaccuracy when calculating drainage depth in the GIS analysis.

These facts, combined with the short duration period of the field work (2 months) mean the results of this research should not be seen as an investigation to the effect of rainfall, but rather as an analysis into the (spatial) variation of the drainage salinities combined with an exploratory study to the sources of this variability. Further research should include as many precipitation events as possible.

5.5. Recommendations

For the quality of the surface water in GO, these outcomes have a variety of consequences. First, since drain salinity is spatially differing, precipitation will possibly cause more salinization in areas with a high seepage intensity compared to areas with a lower seepage intensity. This response is however not linear and currently unpredictable. This means that due to irregular peaks in the salinity discharge from the drain tiles, maintaining a year round fresh water policy in the whole of GO seems unrealistic. Instead of a top-down approach which begins with identifying spatial factors and zeroing down to specific areas, a bottom-up approach might be more fruitful. Ideally, this could begin with identifying areas where the water quality needs improving according to the WFD, followed up by an investigation of where the water in that specific area originates from. Finally a precipitation response guided monitoring program per site or drainage area could obtain data for quantifying the salinity precipitation response. Repeating this trajectory for multiple area’s and combining these results will hopefully lead to a more detailed identification of the spatial factors. Consequently, water management becomes more area specific and should be taken into account when new WFD categorizations are assigned.

Together, this knowledge can help to make better assessments and set realistic water quality requirements for water bodies in GO. As some drainage systems in GO are designed to submerge during the summer flush of fresh water, changes to water level policies can have negative consequences. They should be planned carefully so that farmers can adapt their drainage systems to the new situations.

6. Conclusion

Precipitation response cannot be quantified as a cause for the variability in drain tile salinities. A qualitative analysis shows irregular relationships with yet unknown causes. An increase of the salinity with a precipitation event might be caused by saline water in the capillary zone which can be flushed out during rain events. Stable drain tile salinities may be due to drain specific mixing ratios and decreasing salinities can be a consequence of dilution and confirm results of earlier studies. The observed variability between individual drain tiles and measurement sites are signs of small and large scale spatial factors controlling drainage salinity. From the three variables, seepage intensity, drainage depth and surface area per tile, only seepage intensity shows to be correlated with the drainage salinity (R^2=0.564). A model which predicted drain effluent salinity could not be validated with surface water measurements in GO. This can be due to the inaccuracy of the model or the low correlation between the surface water and the tile drain salinity dynamics.

An analysis of a ten year average of measured chloride concentration points against seepage intensity and water level management did not detect any correlation. Furthermore, the plotted average of measured chloride concentration and the CV did not result in verifying any spatial relationship. Consequently, this research failed to trace precipitation influences and spatial factors to surface water salinity.

The indicated large and small scale spatial variability means area specific water management is necessary to define its natural condition with respect to the WFD. Future research should focus on area specific precipitation response monitoring. Ideally, this should result in area specific water management policies with regard to precipitation responses. Further research should have a longer term then 2 months with a wide variety of precipitation events.

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