Mitigating Climate Change Impacts on Terschelling by 2100

innovative strategies and sustainable solutions

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Abstract

The island of Terschelling faces multiple challenges regarding its freshwater supply, which are exacerbated by the imminent threats of climate change. Surrounded by seawater, the island's freshwater resources are limited and increasingly vulnerable to salinization and depletion. As summers become drier and winters wetter, the island must adapt to ensure a sustainable and resilient water system. The dependence on mainland water supplies, which are themselves uncertain due to aging infrastructure, highlights the need for Terschelling to achieve greater self-sufficiency.

The projected impacts of climate change, including sea-level rise, increased frequency of extreme weather events, and shifts in precipitation patterns, present significant risks to the water management of Terschelling, agriculture, and overall ecosystem. Rising sea levels will increase the likelihood of groundwater salinization, impacting local agriculture, particularly dairy farming, and the natural reserves. The shift in climate will also necessitate changes in water retention and discharge policies to manage the threats of drought and flooding.

The stakeholders involved in this research, including the local authority, water management agencies, drinking water suppliers, dairy farms, and those involved in saline cultivation, recreation, and nature conservation, all have a great interest in the island's water future. Each stakeholder faces unique challenges and will need to collaborate on integrated solutions to mitigate the impacts of climate change. This collective effort will be crucial to balancing the various needs of drinking water, agriculture, and natural habitats.
The four climate scenarios outlined by the Royal Netherlands Meteorological Institute (KNMI) for 2050 and 2100 provide a framework for understanding the potential future climate conditions. These scenarios range from high emissions, leading to severe global warming, to low emissions aligned with the Paris Agreement targets. Within these emission scenarios, variations of wetter and drier conditions offer further insight into the possible extremes Terschelling might face. The island's adaptation strategies must be flexible enough to accommodate these uncertainties, ensuring robustness against a range of possible future climates.

To address these challenges, a multifaceted approach is necessary. This includes exploring innovative water management practices, enhancing the resilience of local agriculture through salinity-tolerant crops, and improving infrastructure to better manage water retention and discharge. Stakeholder cooperation will be key to implementing these strategies effectively, minimizing disruption and ensuring that the island's water resources are managed sustainably.

In conclusion, Terschelling stands at a critical juncture where proactive measures and collaborative efforts are essential to securing its freshwater future. By focusing on opportunities for innovation and resilience, the island can navigate the challenges posed by climate change, ensuring the well-being of its residents, the viability of its agricultural practices, and the preservation of its natural ecosystems. The research underscores the importance of strategic planning and stakeholder engagement in building a resilient water system that can withstand the uncertainties of a changing climate.
Water usage across sectors like agriculture, tourism, and recreation must be optimized to combat salinization and rising sea levels. Efficient farming practices, saline crop cultivation, and sustainable urban planning are key. Stakeholders need to collaborate on integrated solutions that

balance water management with environmental goals, particularly as freshwater availability on Terschelling decreases.

Conflicts, such as the government's preference for higher water levels versus the municipality's need for lower levels for housing, require careful compromise. Managing water demand, especially during peak tourist seasons, can be aided by capping tourist numbers and designating water retention areas.

Expanding the island to prevent saltwater intrusion is viable if the island's water balance is fully understood. Collaboration, adaptability, and innovative solutions like saline farming and local water extraction will ensure a resilient freshwater supply for Terschelling's future.

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Dissertation preface

Before you lies the research paper "Mitigating Climate Change Impacts on Terschelling by 2100: Innovative Strategies and Sustainable Solutions". It has been written for the Young Professionals Coastal Community (YPCC) Program 2024 of Littoral 24 in Constanta, Romania. We were engaged in researching and writing this research paper from March to August 2024.

While writing this paper, we realized how complex this topic is. We had to step outside our comfort zone to understand the topic and to accept that some information wasn't available (yet). Many things are still very uncertain because you are dealing with predictions.

We would like to thank our supervisors, Ineke Baan, Leo Bentvelzen, André Dijkstra, and Mindert de Vries, for their exceptional guidance and support throughout the process. Their mentorship has greatly enriched our understanding of the subject, including writing a research paper in English and climate scenarios in general. Additionally, we would like to thank Johan Medenblik for his willingness to share his knowledge and explain certain topics. Our appreciation also goes to the team at Deltares for providing us with maps and addressing our inquiries.

Nika van Asselt, Amber Maxime Hendriks, Anne Smulders & Anke Visser
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1 Introduction

Since seawater encircles the entire island of Terschelling, its freshwater supply is a concern. This raises several questions, such as: “Will there always be adequate fresh water for everyone on the island, and if so, how can the water system and land usage be designed to withstand drought?” (Deltares, 2024-b). According to Deltares (2024), the island wants to remain as independent from the mainland as possible. Two-thirds of the water supply comes from the mainland, but aging water pipes are putting the future supply at risk. For this reason, research into the island's defences against climate change impacts is crucial.

The island will experience the following climate challenges (Deltares, 2024-b):

- Summers are becoming drier and warmer, making freshwater shortages increasingly common. It's also imperative that flood prevention, particularly as winters continue to become wetter will be prioritized. This can involve the water level rising above the surface and potentially overflowing waters within natural reserves.
- By 2100, the Netherlands' sea level is predicted to rise by 30 centimetres to 1.2 meters. Since the sea encircles Terschelling, this will significantly impact the groundwater system.
- Seepage can bring brackish, salty water up to the surface from its subsurface location. In the future, more cases similar to this one are anticipated.
- With drier summers and wetter winters, policies must balance water retention and discharge. To do this, the water system must be modified.
- There is pressure on the supplies of drinking water available today. Terschelling might need to completely supply its own drinking water in the future. To do this, new water supplies must be available.

These challenges have a huge impact on the islanders. The island has its own freshwater lens beneath the dunes, however, fresh water is lighter than salt water and therefore floats as a bubble on top . The density difference causes the freshwater bubble to rise to the top. (Ocean Circulation Patterns, 2024) When sea levels rise, saltwater rises too, bringing with it all unavoidable effects on locals, farmers, and tourists. A possible outcome could be the inability of dairy farms to continue operating since the island's soil has become too salinized for grass to grow. The cost of importing fodder for the cows will become prohibitive. Due to the reduction of the freshwater bubble, this will lead to the island being dependent on the mainland for drinking water. These challenges have a huge impact on the islanders. The island has its own freshwater lens beneath the dunes, however, fresh water is lighter than salt water and therefore rises as a bubble to the surface (Omrop Fryslân, 2024). Additionally, that causes the freshwater bubble to rise to the top (Omrop Fryslân, 2024). When sea levels rise, saltwater rises too, bringing with it all unavoidable effects on locals, farmers, and tourists. A possible outcome could be the inability of dairy farms to continue operating since the island's soil has become too salinized for grass to grow. The cost of importing fodder for the cows will become prohibitive. Due to the reduction of the freshwater bubble, this will lead to the island being dependent on the mainland for drinking water. Desiccation and (extremely) wet periods will, as discussed earlier, play a role. This has consequences for locals, farmers, nature and of course tourists.
The following people/topics are involved in this study as stakeholders, these stakeholders were interviewed about their areas of concern:

- Local authority
- Water management
- Drinking water

- Dairy farm
- Saline cultivation
- Recreation
- Meadow birds
- Nature in the dunes

Salinization and a lack of fresh water will be caused in the future by rising sea levels and hotter and drier summers. According to researchers, the limited freshwater supply on the island itself and the restricted water supply from outside make an island like Terschelling especially vulnerable to this, especially since Terschelling is encircled by the North Sea and the Wadden Sea. (Omrop Fryslân, 2024) The island is completely dependent on rain water (Omrop Fryslân, 2024). Although numerous approaches for Terschelling and other islands in the world, like raising the water level and growing different types of grass, not all stakeholders will consider these to be suitable (Omrop Fryslân, 2024). Table 1 outlines the various climate change risks for the Netherlands, including the island, throughout this century. These risks are more severe for Terschelling, as its smaller size provides less of a buffer against environmental impacts. It is therefore important to examine which approaches are most suitable for the different stakeholders on the island and to come up with a plan for the entire island. The key to this research will be to focus on the opportunities rather than the obstacles, and the cooperation of all stakeholders involved is crucial. The goal is for every stakeholder to experience the least amount of inconvenience possible, that's the primary objective of the strategy plan for the entire island.

Table 1: Climate change risks for the Netherlands this century. Courtesy of the Netherlands Environmental Assessment Agency. Based on (Bessembinder, et al., 2023)

Sectors	Risks
Coastal effects	The rising sea levels have implications for flood protection and water management policies. The latter includes, for example: an increasing need for sand supplementation, and an increasing water demand to prevent salt intrusion. Sea-level rise will increase the likelihood of flood and hence the risks for people, the environment, and the economy.
Flooding	Increased precipitation in the winter will lead to higher ditch levels and so a greater risk of the ditches overflowing. As heavy rain will occur more frequently, the risk of flooding will increase.
Water supply	The increase in drought events will lead to more regular water shortages. When water availability is limited, people will have to decide how to distribute the scarce water available between the various functions it needs to meet: drinking water, nature management, agriculture, and mainland import.
Water quality	As surface water temperatures rise, the ecology of the water will also change. Surface water will become less suitable as a source of drinking water. Blue-green algae will occur more frequently in ponds and lakes, making these waters unsuitable for swimming.

Health	As temperatures rise, winter mortality will decrease, but heat and smog will cause more problems and higher mortality in the summer. More exposure to UV radiation will mean an increased risk of skin cancer. The longer pollen season will also mean more 'allergy days'. More cases of infectious diseases transmitted by vectors such as ticks and mosquitoes are also expected.
Mobility	An increase in extreme precipitation events will lead to more traffic disruptions in the summer. While less frequent frosts will mean a lower risk of slippery roads and frost damage, there will be an increased risk of surface rutting during heat waves.
Energy	Less energy will be needed for heating, but more will likely be used for cooling.
Agriculture	An increase may reduce agricultural yields in extreme weather. Droughts, in particular, are a major risk for crop yields. Salinization will affect sensitive crops in the lower-lying parts.
Nature	The risks are greatest for ecosystems that depend on precipitation, such as heathlands, grasslands, and bogs. Heat-loving plant and animal species will increase, and cold-loving species will decline. This may lead to mismatches in the food chain. Global warming also increases the risk of wildfires.
Recreation	Higher temperatures will mean more 'recreation days', but the number of days cold enough for skating will decrease. Major recreational events are more likely to be disrupted by extreme weather.

1.2 Problem definition

The island of Terschelling faces significant challenges regarding its freshwater supply and future increased pressures from climate change, including rising sea levels and alterations in precipitation patterns. The island's freshwater supply is vulnerable to salinization and depletion, posing a threat to the livelihoods of the island. As a result, Terschelling must confront pressing questions regarding the sustainability and resilience of its water system to ensure the well-being of its residents and ecosystem. The coming and current changes threaten and the viability of the agricultural, nature and tourism sectors.

1.3 Scope definition

This study will address the following eight stakeholders: local authority, water management, drinking water, dairy farm, saline cultivation, recreation, meadow birds and nature in the dunes. Terschelling in 2100 is the focus of the study, with Terschelling in 2050 serving as a stepping stone. Because the climate scenarios and the Deltares model are both set in the year 2100.

1.4 Reading guide

This document is structured to guide the reader through the research on **Terschelling's water management and climate change adaptation strategies**. Below is an outline of each section:

1. **Chapter 1, Introduction**: This chapter introduces the freshwater challenges faced by Terschelling due to its geographic location and the impacts of climate change. It discusses the island's dependence on mainland water, rising sea levels, and future risks to the local ecosystem, economy, and livelihoods. Key climate risks, such as water shortages and

salinization, are presented, highlighting the urgency of developing resilient water management strategies for the island's future.

2. **Chapter 2, Theoretical Framework**: This chapter provides the foundational concepts and theories that underpin the research. It begins by exploring the broader impacts of climate change on a global scale, before narrowing down to the specific implications for the island of Terschelling. Key topics include climate change projections, rising sea levels, and the risks of salinization. The chapter also examines Terschelling's geographical vulnerabilities, emphasizing how these factors interact with the island's freshwater system and local ecology.
3. **Chapter 3: Research and Sub-Questions**:
   This chapter outlines the main research question, which focuses on developing holistic, transdisciplinary measures for ensuring a resilient freshwater supply on Terschelling by 2100. The chapter also presents several sub-questions, addressing topics such as the dynamics of the island's freshwater bubble, stakeholder-specific challenges and solutions, and strategies for incorporating stakeholder perspectives into effective water management. These research questions guide the investigation, ensuring that both environmental and social factors are considered in the proposed solutions.
4. **Chapter 4, Method**:
   This chapter details the research methodology used to address the study's main and sub-questions. A non-experimental literature review was conducted, relying on available data sources that combined both qualitative and quantitative characteristics. Data collection involved reviewing stakeholder perspectives, analyzing hydrological maps provided by Deltares, and conducting an internet search to ensure comprehensive coverage of the topic. The chapter also explains the steps taken to ensure the validity and reliability of the sources used, with a focus on reviewing the credibility and biases of each source.
5. **Chapter 5, Result**:
   This chapter presents the findings of the research, focusing on two key aspects: the temporal dynamics of Terschelling's freshwater bubble and stakeholder-specific solutions for managing freshwater resources. The section on the freshwater bubble explores its rate of decline due to salinization and how this aligns with projected sea-level rise. The second part identifies challenges and tailored solutions for each stakeholder group, including local authorities, farmers, water management entities, and the tourism industry, with a focus on enhancing resilience against freshwater shortages and salinization.
6. **Chapter 6: Conclusion and Discussion**
   This chapter synthesizes the key findings from the research and addresses the main research question: *"Which transdisciplinary/holistic measures can be developed in order to establish a resilient freshwater supply on Terschelling in 2100?"* It provides a detailed response to the sub-questions regarding the decline of the freshwater bubble and presents stakeholder-specific solutions. It discusses the importance of integrating stakeholder perspectives into water management, emphasizing collaboration and innovative strategies such as saline crop cultivation and efficient water use. The conclusion highlights the need for proactive, adaptive measures to ensure water resilience in the face of rising sea levels. The discussion section reflects on the challenges of long-term planning, given the uncertainties of future climate conditions.

2 theoretical framework

This chapter delves into the multifaced impacts of climate change on the Netherlands, highlighting both national and local scales. With a detailed examination of the following critical climate variables: temperature, precipitation, summer showers, hail and thunderstorms, drought and evaporation, solar radiation and cloud cover, wind, storms and wind gusts, visibility and fog, and sea-level rise. Each of these factors plays a crucial role in shaping the country's environmental and socio-economic structure.

Shifting focus to Terschelling, providing a detailed case study of how these climate variables are shaping this unique environment. Terschelling represents a microcosm of the broader challenges faced by coastal communities worldwide.

This exploration highlights the interrelation of climate change impacts across different scales and settings. Examining both the Netherlands and the specific context of Terschelling allows a comprehensive understanding of how climate change is reshaping the Netherlands. From broad systemic changes to localized, community-specific challenges.

2.1 Climate change

The Netherlands is facing significant challenges due to climate change scenarios outlined by the Royal Netherlands Meteorological Institute (KNMI). These scenarios necessitate proactive and strategic water management strategies to address issues such as rising sea levels, changing precipitation patterns, and extreme weather events. The KNMI has described four different climate scenarios for the Netherlands for the years 2050 and 2100. Table 2 shows the summary of the KNMI'23 climate scenarios for the Netherlands.

The KNMI'23 climate scenarios for the Netherlands in summary
Accelerated sea-level rise
Increase in average and extreme temperatures
More sunshine
More droughts
Wetter winters
More extreme summer showers
Potentially stronger wind gusts and downbursts during heavy showers
Little change in wind speed and direction

Table 2: How the climate will change this century in all scenarios compared to the reference period (1991-2020). The extent of change varies per scenario. (Bessembinder, et al., 2023)

Which scenario may occur in 2050 and 2100 depends on CO_2 emissions, as Figure 1 illustrates. The quantity of greenhouse gases released in the future and the sensitivity of the climate system will determine how much our climate changes (Bessembinder, et al., 2023). Consequently, there have been chosen two scenarios:

- First, there is the high emission scenario (shown by a capital "H"), in which emissions rise sharply until 2080 and then start to level out. This will cause a 4.9°C global warming around the year 2100 (based on the best estimate for climate sensitivity). (Bessembinder, et al., 2023)
- In the low emission scenario (denoted by a capital 'L'), emissions are reduced rapidly, and greenhouse gases are removed from the atmosphere in line with the Paris Agreement, aiming to limit global warming to well below 2°C. By around 2100, this will result in global warming of 1.7°C. (Bessembinder, et al., 2023)

In all scenarios, the Netherlands will experience drier summers and wetter winters as temperatures rise. The magnitude of these changes varies depending on the climate models used. (Bessembinder, et al., 2023) Two different options for each emissions scenario have been selected to demonstrate these varying degrees:

- A "wet" scenario (represented by a lowercase "n," from the Dutch word "nat"), where the summers are somewhat dryer and the winters are much wetter (Bessembinder, et al., 2023);
- A "dry" scenario (represented by a lowercase "d") when summers are much drier and winters are somewhat wetter (Bessembinder, et al., 2023).

Figure 1: Four scenarios for climate change in the Netherlands. The number of small blocks represents the extent of climate change around 2100 compared to 1991-2020. (Bessembinder, et al., 2023)

The Netherlands is situated between regions that are expected to experience either drier or wetter conditions in the future. It is uncertain whether the Netherlands, including the island of Terschelling, will follow scenario “d” or “n”. As a result, the decision was made to consider both possibilities. The extremes in the climate of the Netherlands around 2100 compared to 1991-2020 are shown in Figure 2.
Combining the two emission scenarios (High (worst case) and Low (best case) with the two 'wet' (n) and 'dry' (d) variants results in the climate scenarios Hn, Hd, Ln, and Ld. Climate change in the Netherlands is likely to occur within the boundaries of these climate scenarios, making them suitable for assessing the effects of climate change on most applications. (Bessembinder, et al., 2023)

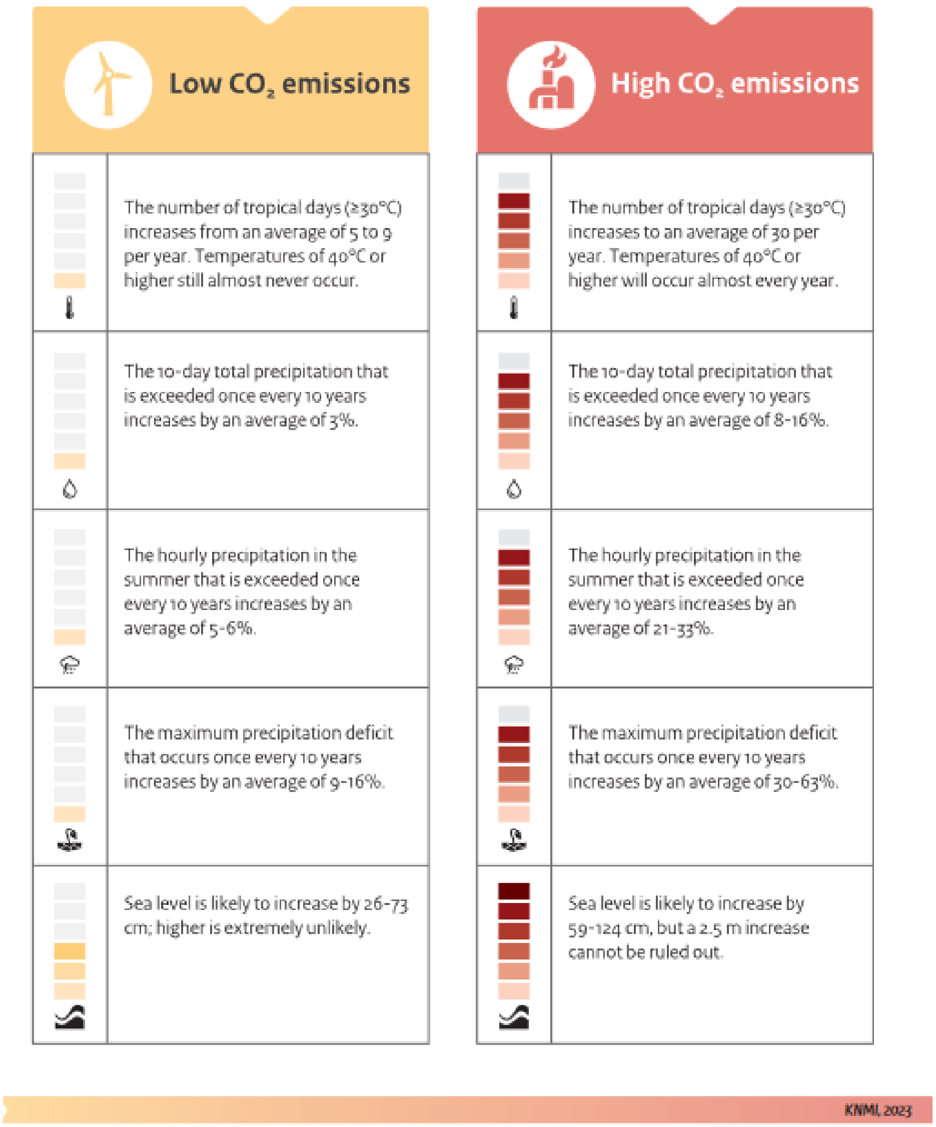

Figure 2: More extremes in the climate of the Netherlands around 2100 compared to 1991-2020. (Bessembinder, et al., 2023)

The consequences for each topic for the Netherlands in 2100 will be briefly covered below.

2.1.1 Temperature

Ever since records began in 1906, the yearly mean temperature in the Netherlands has increased by more than two degrees (refer to Figure 3). This increase is nearly twice as large as the global mean temperature increase from the pre-industrial era of 1850–1900, which was 1.2°C (as of 2022). (Bessembinder, et al., 2023) The temperature rise is partially attributed to the more frequent westerly winds during winter. Additionally, there is further warming in spring and summer due to increased solar radiation resulting from reduced air pollution and cloud cover (Bessembinder, et al., 2023). In the past 30 years, the Netherlands has experienced half of the temperature increase observed since the beginning of the 21st century (Bessembinder, et al., 2023).

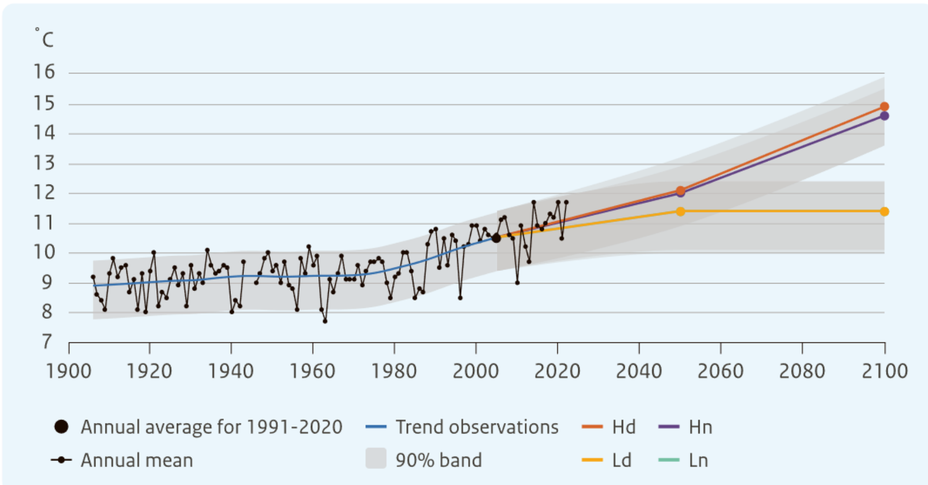

Figure 3: Annual mean temperature (national average): observations (black) and the four KNMI'23 climate scenarios (2050 and 2100, in three colors; Ln and Ld coincide). (Bessembinder, et al., 2023)

The KNMI'23 climate scenarios predict that the effects of global warming will have the greatest impact during the summer season, leading to increased temperatures. On the other hand, the impact is expected to be less pronounced during the winter and spring seasons.

The increased warming during the summer will be partly due to drier soils. Additionally, there will be more frequent easterly winds (see Figure 4) bringing warm and dry air. These effects will be more pronounced in drier scenarios, resulting in stronger summer warming compared to wet scenarios. (Bessembinder, et al., 2023) In general, the average annual warming in the Netherlands in 2050 and 2100 will be slightly higher than the global average (Bessembinder, et al., 2023).

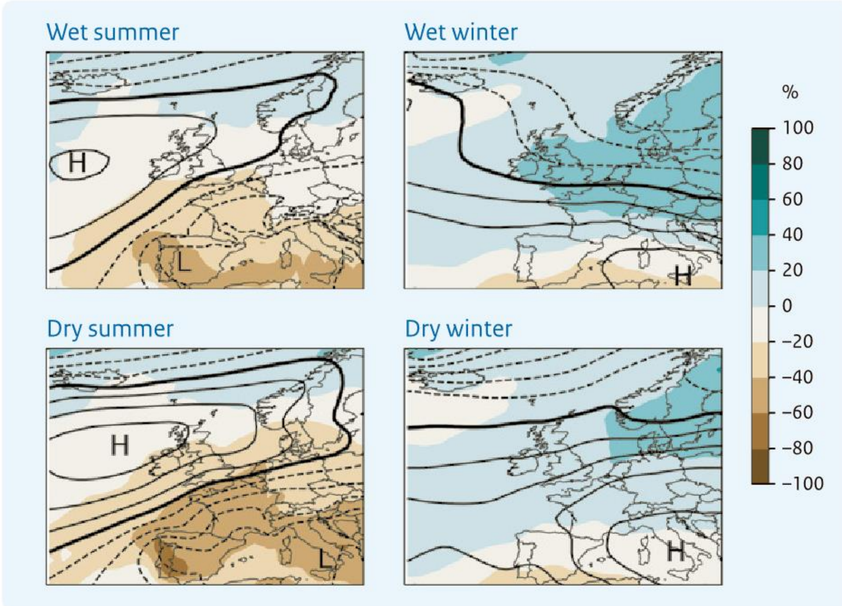

Figure 4: Air pressure and precipitation patterns over Europe for dry and wet global climate models with high emissions around the year 2100. Precipitation changes are shown as percentages. (Bessembinder, et al., 2023)

The warming in the high- and low-emission scenarios varies significantly. This implies that emission-reduction strategies for the global climate can result in less warming. (Bessembinder, et al., 2023)

The hottest summer days and the coldest winter days are most affected by the temperature rise in the Netherlands. The air often moves in from northern Europe, where winter temperatures will increase the most, on the coldest winter days. (Bessembinder, et al., 2023) The wind usually comes in from the south, where summer temperatures will increase the highest, on the warmest summer days. This will lead to a notable drop in the number of days during the winter with maximum temperatures below zero (ice days). There will be more tropical evenings, defined as those with a low of at least 20°C. (Bessembinder, et al., 2023)

2.1.2 Precipitation

When warm and cold air masses converge, large-scale precipitation happens. The warmer, lighter air rises above the colder, denser air during this process, cools, and precipitates. Small-scale precipitation, such as a summer shower, also follows similar pattern, but the sun heats the air close to the ground, which acts as a separate trigger for the rising air. (Bessembinder, et al., 2023) As long as there is enough water for evaporation, the air's ability to contain water vapor rises by roughly 7% with every degree of warmth. Summertime soil tends to be somewhat drier than wintertime soil, so this requirement isn't usually met. (Bessembinder, et al., 2023) More precipitation usually follows an increase in atmospheric moisture. However, precipitation levels may change if the direction of the dominant wind changes, affecting the availability of dry or moist air. (Bessembinder, et al., 2023)
All climate scenarios show an increase in winter precipitation.

Developments to date
Every season has gotten increasingly wet, with winter becoming particularly so. More precipitation occurred each year, especially in the 1980s and 1990s.

However, precipitation varies greatly naturally every time. (Bessembinder, et al., 2023)

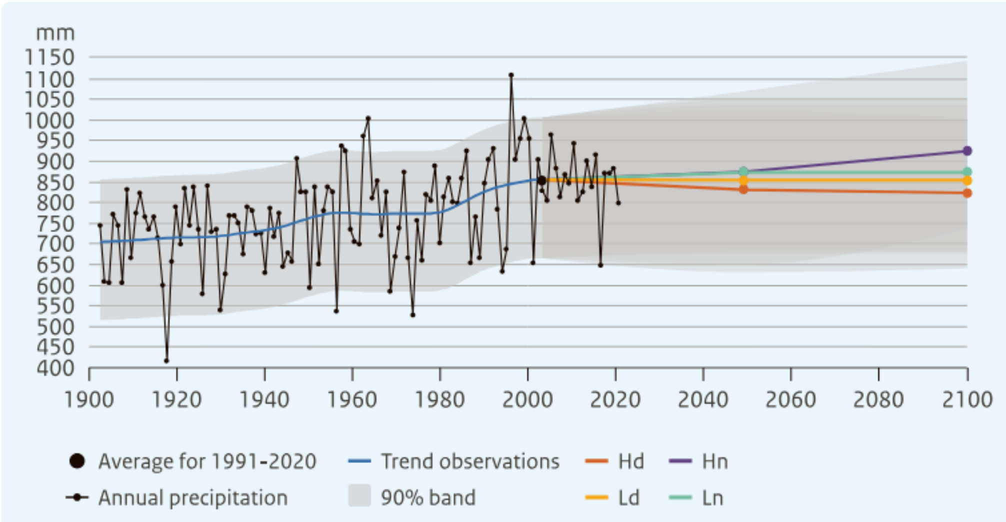

Figure 5: Annual precipitation changes (1900-2100) (Bessembinder, et al., 2023)

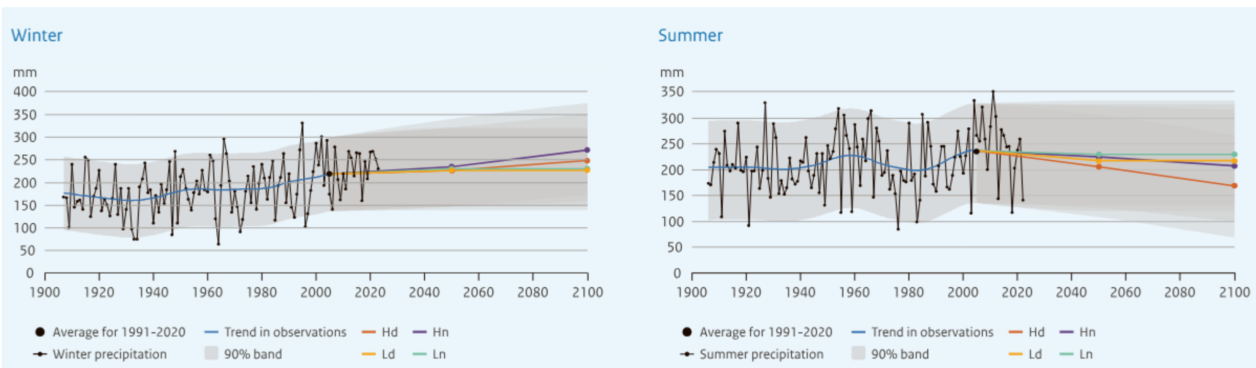

Figure 6: Forecasted precipitation in winter and summer (Bessembinder, et al., 2023)

Future developments

In all four climate scenarios winter precipitation will continue to rise. (figure 5) In both L scenarios, precipitation around 2100 will be the same as that around 2050. The increase in precipitation is between +4% and +24% between all 4 scenarios. (Bessembinder, et al., 2023) In future winters the wind direction will blow from the west more often on average. Notably a significant increase in wind from the west in scenario Hn, carrying more humid air form the north Atlantic Ocean. (Bessembinder, et al., 2023) Summer precipitation has increased in the last decades. However, in all four scenarios summer precipitation will decrease, especially in the Hd scenario (-29%). (Bessembinder, et al., 2023) Summer precipitation decreases since more dry air is brought in from the east, this is caused by changes in sea water temperatures around Ireland and the increasing temperatures in west Europe. (Bessembinder, et al., 2023)

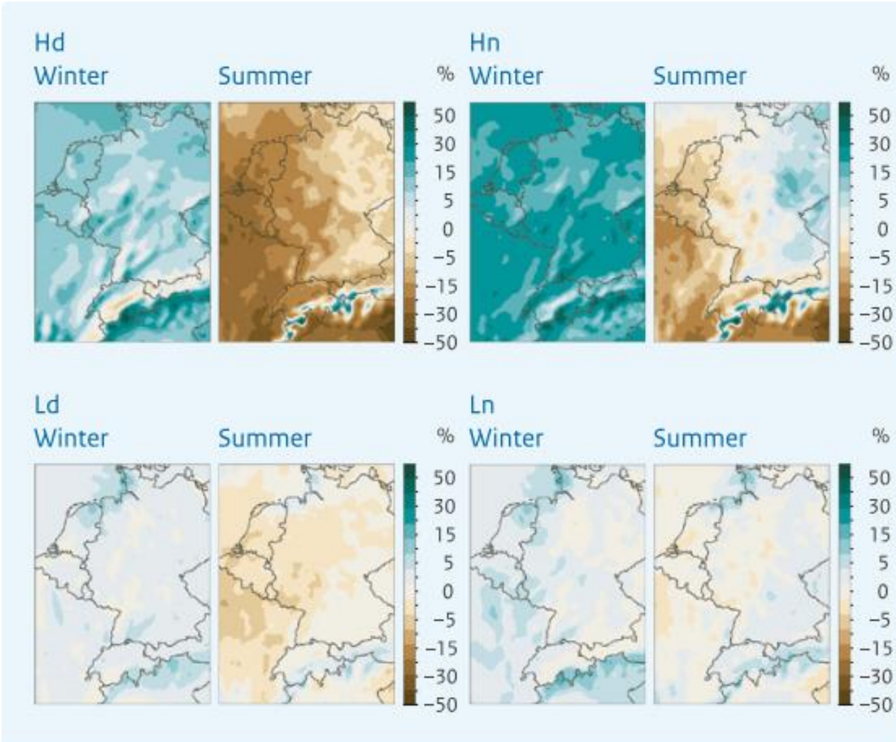

Figure 7: Changes in precipitation (Bessembinder, et al., 2023)

Precipitation is expected to increase during spring and autumn, but not as significantly as in winter. The most substantial increase is projected in the Hn scenario. (Bessembinder, et al., 2023) Consequently, winter, spring, and autumn will become wetter seasons, while summers will become drier, particularly in the H scenarios. The projected change in annual precipitation ranges from a decrease of 3% in the Hd scenario to an increase of 8% in the Hn scenario by 2100. (Bessembinder, et al., 2023) In the H scenarios, winter precipitation will rise across most of Western Europe, while summer precipitation will decline (see Figure 14). The increase in winter precipitation will be relatively uniform across the region, whereas the reduction in summer precipitation will vary more significantly, with the greatest decreases occurring in the south and west. (Bessembinder, et al., 2023)

2.1.3 Summer showers, hail, and thunderstorms

Whether the Netherlands experiences more showers as a result of a warmer climate will depend on a variety of things. Shower frequency will vary depending on these parameters. (Bessembinder, et al., 2023) Figure 8 shows the formation and development of summer showers.

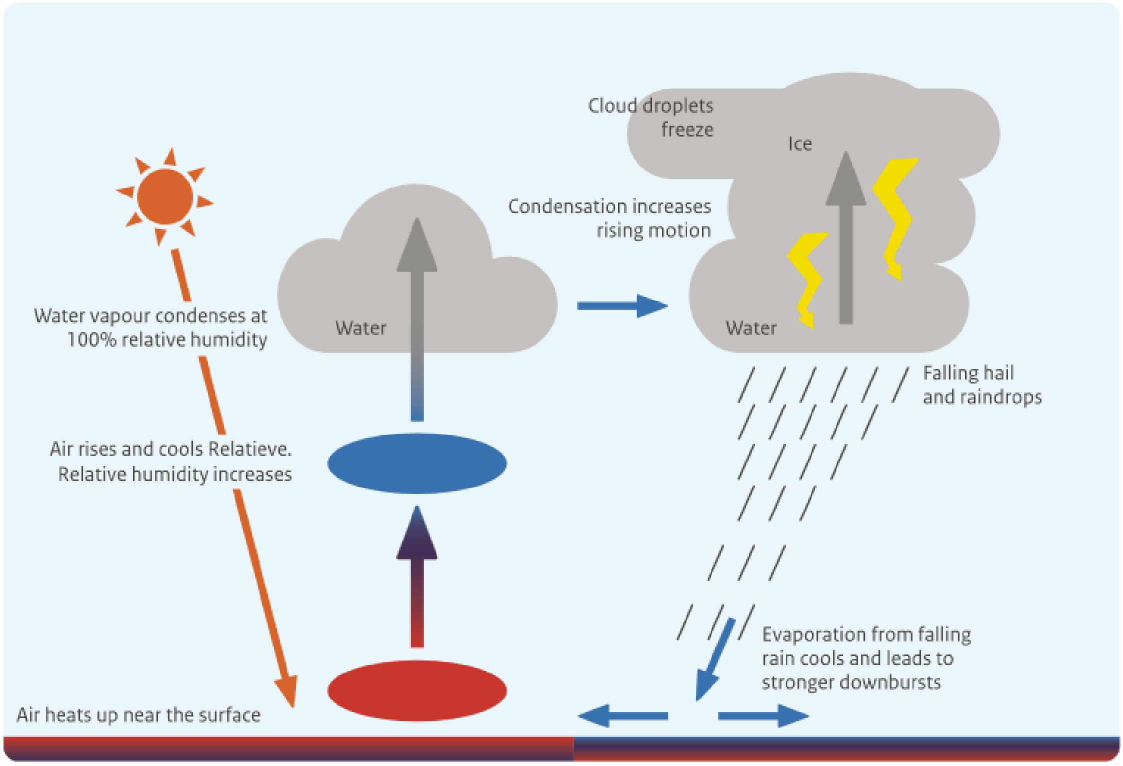

Figure 8: Formation and development off summer showers (Bessembinder, et al., 2023)

More water vapor is present in the atmosphere in warmer regions. Showers therefore cause additional precipitation (Bessembinder, et al., 2023). More condensation heat is created when there is more water vapor in the atmosphere, which causes the air to rise and rain more quickly. Climate simulations, on the other hand, show that the air at Earth's surface is warming more slowly than that of the upper atmosphere. (Bessembinder, et al., 2023) The rising air will slow down as the environment becomes more stable. Future intense rains will happen more frequently due to the increased influence of rising condensation heat. (Bessembinder, et al., 2023)

Only at higher altitudes may cloud droplets develop if the air's relative humidity is low. Showers are therefore less likely to occur during low relative humidity periods, which will happen more frequently in the summer owing to climate change. (Bessembinder, et al., 2023)
A sizable amount of precipitation will evaporate before reaching the earth's surface when the relative humidity is low. The air gets cooler due to evaporation, grows heavier, and falls. Downbursts are more likely as a result of this. (Bessembinder, et al., 2023) As the cold air descends, it disperses upon reaching the earth's surface, elevating the pre-existing air. New rains follow from this. (Bessembinder, et al., 2023)

Because of the extreme precipitation models' high resolution and considerable processing overhead, the findings are only available for the Netherlands and a small surrounding region (Bessembinder, et al., 2023). Furthermore, only a small number of possibilities have been computed thus far. Therefore, the findings of these high-resolution models were combined with the results of lower-resolution models to compute the possibilities for increases in severe precipitation, see Figure 9. (Bessembinder, et al., 2023) This was carried out for two scenarios that reflected the average rainfall and drought in the Netherlands. Based on the distribution provided by the high-resolution climate models, each scenario has a range. (Bessembinder, et al., 2023)

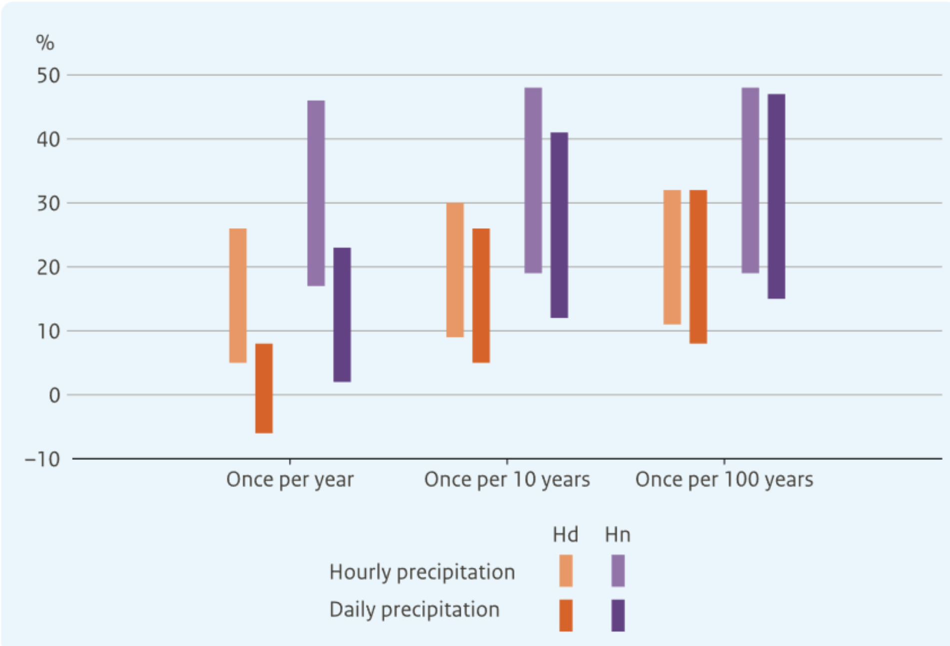

Figure 9: Range of percentage changes of extreme daily and hourly precipitation in summer (according to the high KNMI'23 climate scenarios for around 2100). (Bessembinder, et al., 2023)

It can be assumed that there will be a decrease in mild summer showers and an increase in heavy showers in the future. As a result, showers will change from being lighter to heavier (i.e., producing more precipitation per shower) and more intense (more rain in a certain amount of time). (Bessembinder, et al., 2023)

Very little data is currently available to create scenarios for future wind gusts, hail, and thunderstorms. More doubt exists regarding the future evolution of these meteorological conditions' strength as a result of recent studies. (Bessembinder, et al., 2023) The largest hailstones are expected to become bigger because increasing air motion is caused by a rise in atmospheric water vapor. The wind gusts and downbursts that happen during showers may also get stronger as more rainwater evaporates. (Bessembinder, et al., 2023) It is unclear if the Netherlands will see an increase in lightning frequency (Bessembinder, et al., 2023).

2.1.4 Drought and evaporation

A drought is characterized by either abnormally low precipitation, abnormally high water evaporation, or both. A water absence might result from this, which would have negative effects on the environment, agriculture, residential areas, water quality, safety (weaker flood defences owing to drier embankments), and water quality. (Bessembinder, et al., 2023) These impacts are especially caused by extended or multi-year droughts, as in 2018, 2019, 2020, and 2022, see Figure 10, left (Bessembinder, et al., 2023).

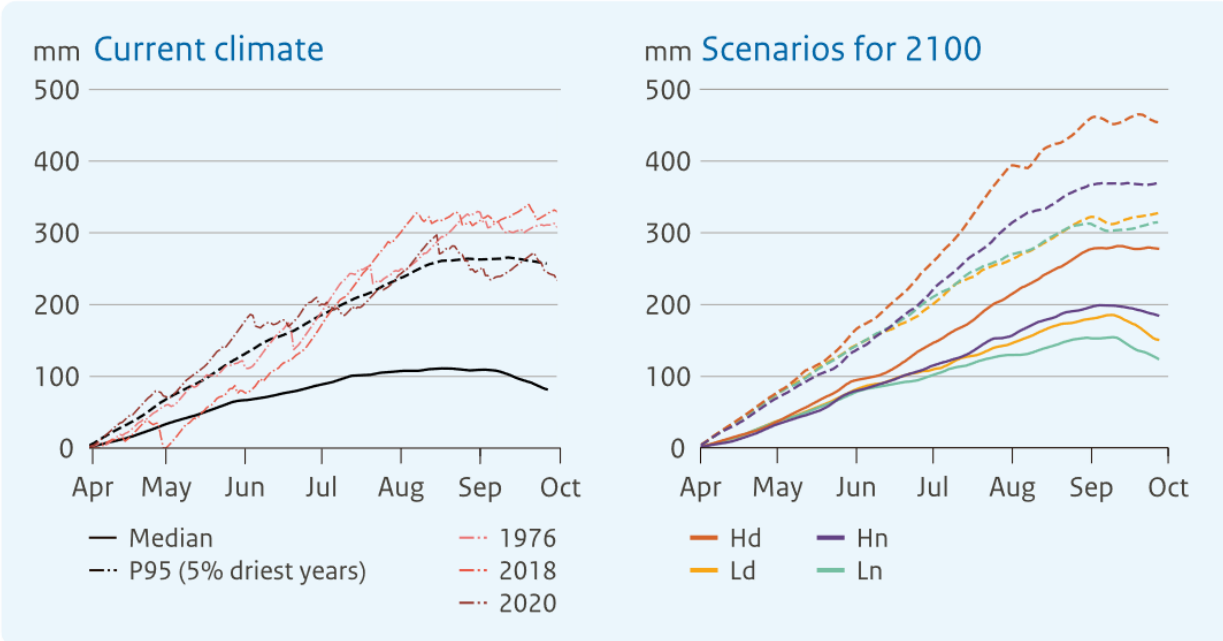

Figure 10: Precipitation deficit in De Bilt in the current climate (1991-2020, left) and around 2100 for the four KNMI'23 climate scenarios (right). Dotted lines give the 5% driest years. (Bessembinder, et al., 2023)

Precipitation is more than evaporation in the fall and winter. This is not the case in the summer, which results in a precipitation shortage. Since precipitation and evaporation vary greatly from season to season, it is challenging to spot consistent patterns. (Bessembinder, et al., 2023)

Drought and extreme drought are more likely to occur in the Netherlands, especially under the "High emission scenario, dry" (Hd) scenario (Figure 10, right). A future ordinary summer will be roughly as dry as an exceptionally dry summer is now, under the driest scenario. (Bessembinder, et al., 2023)

The Netherlands is situated in a region where summertime precipitation declines, and evaporation rises with rising temperatures. Variations in air circulation have an impact on precipitation and evaporation. (Bessembinder, et al., 2023) Westerly winds bring moist air, which increases precipitation. Dry air is often brought by easterly winds, which increases evaporation, particularly in the summer. It is anticipated that the Netherlands' rainfall deficit would worsen significantly. (Bessembinder, et al., 2023)

2.1.5 Solar radiation and cloud cover

Clouds stop solar radiation from reaching the earth's surface, the thicker the cloud the more solar radiation is reflected. Above the coastal area a reduced amount of clouds is present caused by the cooler sea water in spring and summer. (Bessembinder, et al., 2023)
Solar radiation is also influenced by aerosols, aerosols are suspended particles in the atmosphere. Aerosols are air pollution, these pollutions influence cloud formations.
Aerosols are in decline since the 1980s, this is a result of the increase of air quality. (Bessembinder, et al., 2023) During this period, the total amount of cloud cover has decreased and the clouds have become more slender. This has increased the amount of solar radiation by about 4 W/m2. (Bessembinder, et al., 2023) Thus resulting in warming the Netherlands more (figure 11).

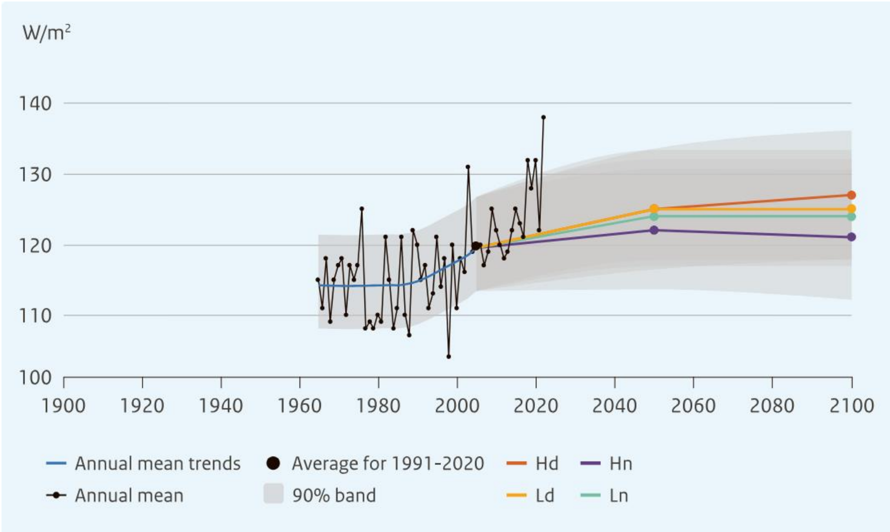

Figure 11: Annual mean solar radiation Netherlands 1965 – 2100 (Bessembinder, et al., 2023)

The air is anticipated to improve marginally in the future, particularly under the low emission scenario, where aerosol levels are projected to continue their gradual decline. Consequently, average solar radiation is expected to experience a slight increase compared to the period from 1991 to 2020. (Bessembinder, et al., 2023)

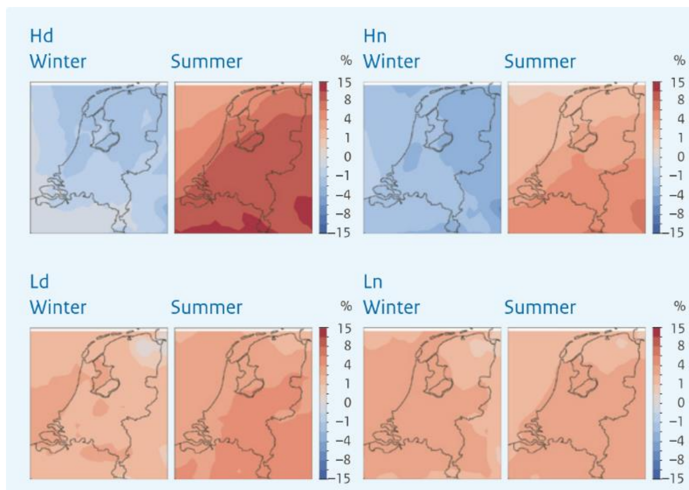

Figure 12: Solar radiation in winter and summer around 2100 (Bessembinder, et al., 2023)

In the high emission scenarios, there is a noticeable distinction between dry and wet conditions: solar radiation exhibits the most significant increase in the dry scenario (Hd), especially in the southern regions of the country (Figure 12), especially during summer. (Bessembinder, et al., 2023) This rise is attributed to an increase in clear-sky days, influenced by more occurring dry easterly winds. In contrast, in the winters the solar radiation is projected to decrease due to more prevalent westerly winds and an uptick in cloud cover. For the low emission scenarios, differences between summer and winter are less pronounced. (Bessembinder, et al., 2023)

2.1.6 Wind, storms, and wind gusts

Since around 1990, there has been a small decrease in the wind speeds recorded over land in the Netherlands (Figure 13). The North Sea does not exhibit this pattern. (Bessembinder, et al., 2023) The reduction over land is most likely the result of increasing surface roughness brought on by urbanization (Bessembinder, et al., 2023).

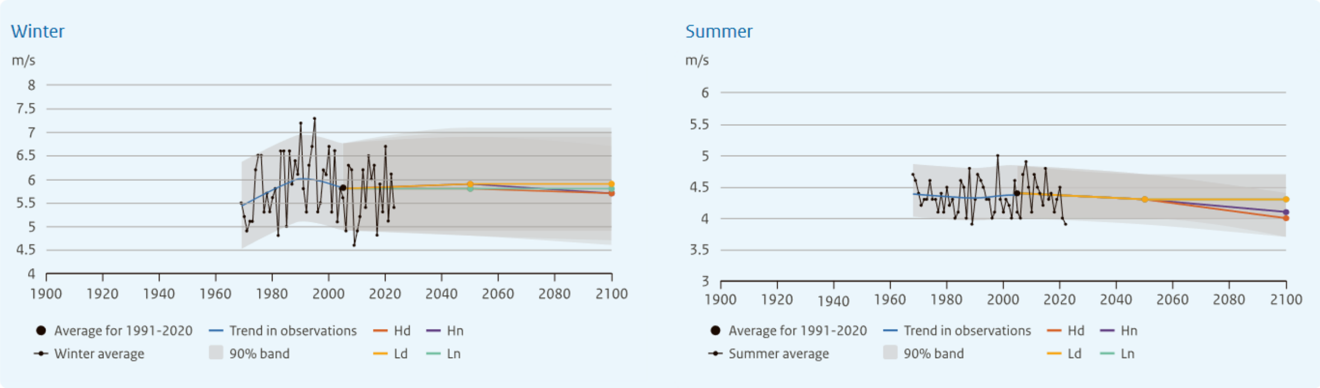

Figure 13: Mean wind speeds in winter (left) and summer (right) at the Schiphol weather station: observations (black) and the four KNMI'23 climate scenarios (2050 and 2100). (Bessembinder, et al., 2023)

The primary concern of strong winds is that they may result in storm surges. The strength of strong winds and its direction also have a significant impact. The Netherlands is most at danger from gale-force north-westerly winds. (Bessembinder, et al., 2023) Figure 14 shows a modest drop in the projected number of days with average north-westerly winds of at least 14 m/s (wind force 7 or above). The actual wind speed is predicted to fluctuate very little or not at all. (Bessembinder, et al., 2023) Thus, although future storms it will not raise the water level over the current average sea level, the average sea level will rise (Bessembinder, et al., 2023).

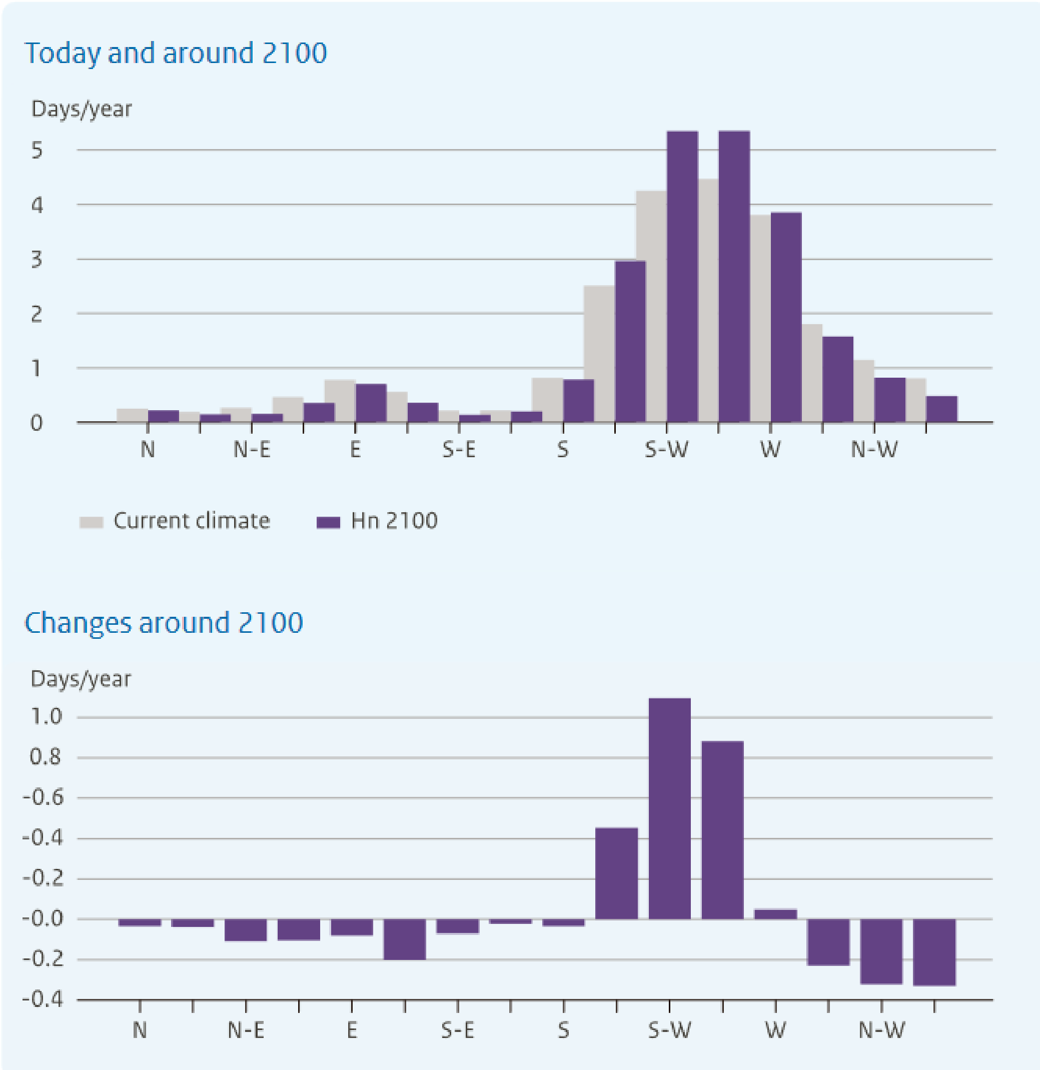

Figure 14: Days per year with wind speed at K13 (North Sea, 53.2°N, 3.2°E) exceeding 14 m/s, for various wind directions in 1991-2020, and in the Hn scenario around 2100 (top), and the differences between the two (bottom). (Bessembinder, et al., 2023)

2.1.7 Visibility and fog

The Netherlands distinguishes between several kinds of fog. The most prevalent kind is radiation fog, in which the air becomes very wet due to a fast cooling of the lower air layers brought on by infrared radiation. (Bessembinder, et al., 2023) The horizontal movement of the air can occasionally produce fog, especially along the coast when warm, humid air from the North Sea crosses the cooler surface of the land. Lastly, during the summer months, ground fog frequently forms over damp fields and relatively chilly water surfaces. Inland fog is more common than coastal fog. (Bessembinder, et al., 2023)

According to models, the amount of meteorological conditions, regardless of season, in which fog occurs will be mostly unaffected by global warming. Further improvements in air quality may result in a little drop in fog, see Figure 15. (Bessembinder, et al., 2023)

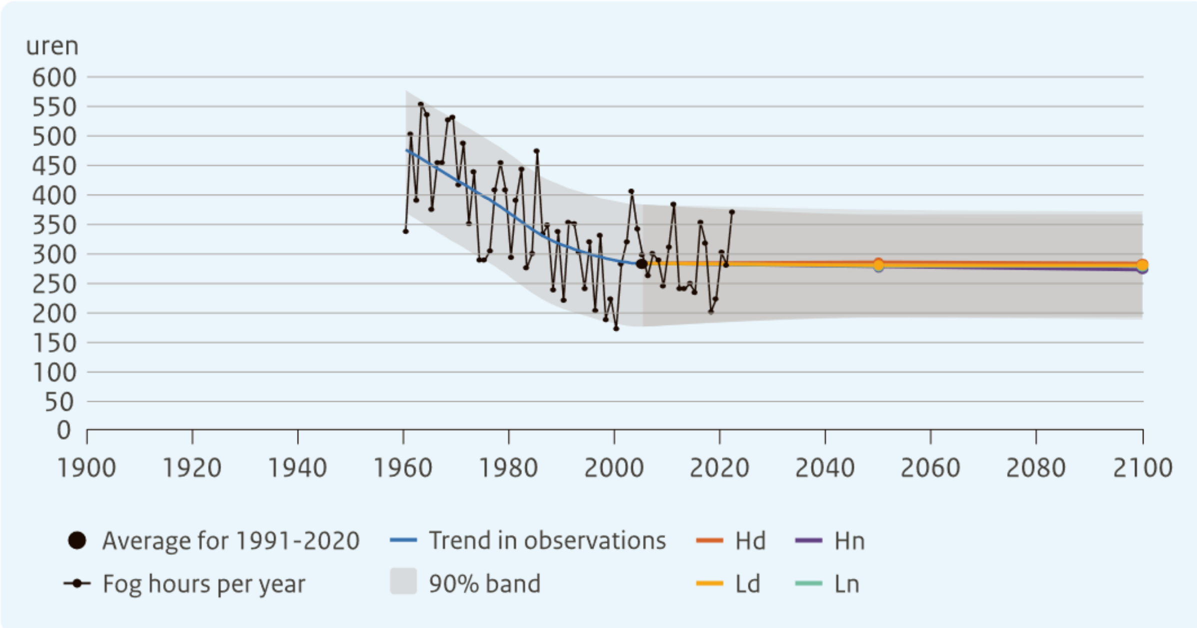

Figure 15: Hours with fog (visibility less than 1 km) per year in De Bilt: observations (black) and the four KNMI'23 climate scenarios (2050 and 2100). (Bessembinder, et al., 2023)

2.1.8 Sea-level rise

Since the start of the Common Era, the global sea level has barely fluctuated; nevertheless, throughout the 19th century, it began to rise. Sea level has increased by around 20 cm (1.7 mm/year) since 1900. (Bessembinder, et al., 2023) During the previous 50 years, sea level rise has increased, reaching a pace of around 2.3 mm/year from 1971 to 2018 and 3.7 mm/year from 2006 to 2018. The rising sea level is still becoming faster. (Bessembinder, et al., 2023)

The sea level has increased 25 cm since 1890 compared to the Dutch reference level (NAP), which results in a ~ 1.9 mm/year sea-level rise over 130 years (Figure 16). About 25% of the relative sea-level increase may be attributed to land subsidence, which is integrated into this figure. (Bessembinder, et al., 2023) Natural variations in wind direction and speed can affect changes in regional sea level by dictating surge levels off the shore. There is a noticeable acceleration from 1993 to 2021 (2.9 mm/year) compared to 1890 to 1993 (1.8 mm/year) when wind fluctuations are taken into account. (Bessembinder, et al., 2023)

A further sea level rise of 16-34 cm is anticipated for the Dutch coast by 2050 under the low emission scenario and 19-38 cm under the high emission scenario. In the low emission scenario, an increase of 26-73 and in the high emission, 59-124 cm, is anticipated by 2100 (see Figure ...). If poorly known processes, mostly related to the increasing instability of the Antarctic ice sheet and ignored in typical forecasts, do contribute significantly, the maximum limit of sea-level rise around 2100 might approach 2.5 m.

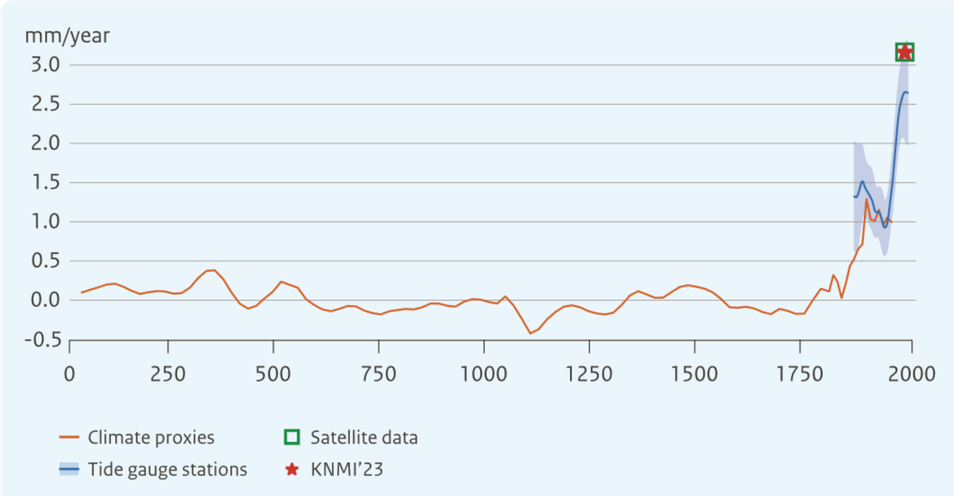

Figure 16: Rate of sea-level rise off the European coastline over the past 2000 years according to different methods. Climate proxies are estimates based on coral growth and archaeological information, for example. (Bessembinder, et al., 2023)

Sea level would rise not only this century but for many hundreds of years to come, even if greenhouse gas emissions were to stop today. The reason for this is that the ice sheets are out of balance with the warming temperature of the present and the future. They will continue to shrink even in the event of a steady temperature. Thus, the degree to which land ice and climate continue to drift apart over the next years will determine the rate and pace of sea level rise. Here, the overall quantity of greenhouse gases released is crucial.
Because of this, sea level along the Dutch coast is expected to have risen by more than a meter by 2150, even under the low emission scenario. The sea level rise in the high emission scenario will surpass one meter significantly sooner.

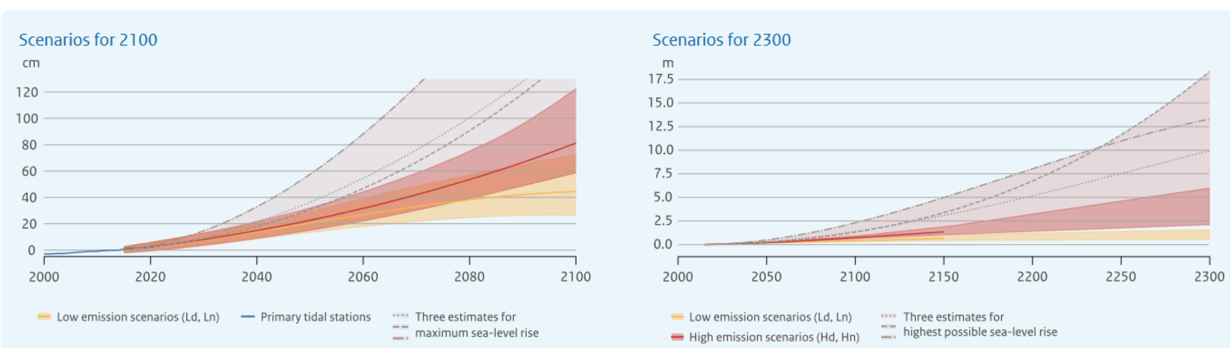

Figure 17: Sea level scenarios for the Dutch coast around 2100 and 2300 relative to current levels (median and 90% band), including three estimates of the highest possible sea-level rise (dashed line in light pink band). (Bessembinder, et al., 2023)

The rate at which the Antarctic ice sheet loses mass will largely dictate the rate of sea level rise in the Dutch region, while the Greenland ice sheet's melting has little effect on sea level rise along the Dutch coast. By 2300, the high emission scenario predicts that sea levels would have increased by two to six meters. This value might increase to more than 17 meters if the possible impacts of lesser-known Antarctic processes are also considered (Figure 17).

Table 3 has been used to accurately illustrate the changes in each scenario's components.

Table 3: KNMI'23 scenario table with country averages. (Bessembinder, et al., 2023)

Variable	Indicator	The climate in 1991-2020 = reference period	**2050** (2036 – 2065)				**2100** (2086 – 2115)			
			Ld	**Ln**	**Hd**	**Hn**	**Ld**	**Ln**	**Hd**	**Hn**
Global temperature rise compared to 1991 - 2020			+0.8°C	+0.8°C	+1.5°C	+1.5°C	+0.8°C	+0.8°C	+4.0°C	+4.0°C
Global temperature rise compared to 1850 - 1900			+1.7°C	+1.7°C	+2.4°C	+2.4°C	+1.7°C	+1.7°C	+4.9°C	+4.9°C
Sea level along the Dutch coastline	Average level	0 cm	+24 (16 – 34) cm	+24 (16 – 34) cm	+27 (19 – 38) cm	+27 (19 – 38) cm	+44 (26 – 73) cm	+44 (26 – 73) cm	+82 (59 – 124) cm	+82 (59 – 124) cm
	Rate of change	3 mm/year	+3 (1 – 6) mm/year	+3 (1 – 6) mm/year	+5 (4 – 8) mm/year	+5 (4 – 8) mm/year	-1 (-4 – 4) mm/year	-1 (-4 – 4) mm/year	11 (6 – 23) mm/year	11 (6 – 23) mm/year
Temperature	Average	10.5°C	+0.9°C	+0.9°C	+1.6°C	+1.5°C	+0.9°C	+0.9°C	+4.4°C	+4.1°C
Precipitation	Amount	851 mm	0%	+3%	-2%	+3%	0%	+3%	-3%	+8%
Solar radiation	Average	120 W/m^2	+5.8 W/m^2	+4.8 W/m^2	+5.4 W/m^2	+2.5 W/m^2	+5.8 W/m^2	+4.8 W/m^2	+7.1 W/m^2	+1.3 W/m^2
Humidity	Amount	82%	-1%	-1%	-1%	0%	-1%	-1%	-1%	+1%
Evaporation	Potential evaporation (Makkink)	603 mm	+7%	+6%	+9%	+6%	+7%	+6%	+17%	+11%
Wind	Average wind speed	4.8 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	0.0 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s

2.2 Terschelling

Terschelling, one of the Frisian Islands, is located north of the Netherlands. This island serves as a critical case study in understanding the localized impacts of climate change. As a small island, Terschelling exemplifies the vulnerabilities and challenges that coastal areas face globally, particularly in the context of rising sea levels, challenges weather patterns, and shifting ecological balances.

2.2.1 Temperature and precipitation changes on Terschelling

Similar to the broader Netherlands, Terschelling has experienced a notable rise in annual temperatures, reflecting the trends observed across the country. The island's climate, however, is uniquely influenced by its coastal environment, which moderates temperature extremes but also exposes it to the rapid changes occurring in the North Sea. The increase in average temperatures, particularly during the summer months, has resulted in drier conditions on the island, affecting both the natural landscape and agricultural practices that rely on consistent moisture levels.

Winter precipitation on Terschelling has increased, consistent with national trends, leading to concerns about water management and potential flooding during storm surges. However, summer precipitation has shown signs of decline, particularly under scenarios predicting more frequent easterly winds that bring dry air from continental Europe. This shift poses significant challenges for the island's ecosystems, which are adapted to a delicate balance of wet and dry conditions.

2.2.2 Sea-level rise and coastal erosion

One of the most pressing concerns for Terschelling is the rise in sea levels, a direct consequences of global warming. As a low-lying island, Terschelling is particularly vulnerable to even minor increases in sea level. The accelerated pace of sea-level rise, which has become more pronounced in recent decades, threatens the island's coastal dunes and the extensive wetlands that are crucial for local biodiversity.

The island's natural defences, such as sand dunes, are under increased stress from more frequent and intense storm surges. These surges, in combination with rising sea levels, lead to greater erosion, reducing the effectiveness of these natural barriers. The potential loss of land and changes to the coastal landscape could have profound impacts on both the environment and the local economy, particularly tourism, which relies heavily on the island's natural beauty.

2.2.3 Ecosystem shifts and biodiversity

The ecosystems of Terschelling are highly sensitive to changes in temperature, precipitation and sea levels. The island's wetlands, forests and dunes host a high variety of species, many of which are at risk due to the shifting climate. For instance, the increasing temperature and changing precipitation patterns may alter the habitats of bird species the rely on specific conditions for breeding. Moreover, saltwater intrusion from rising sea levels could degrade freshwater habitats, threatening species that depend on these ecosystems.

The warming climate also impacts the flora of the island. Drier summers and warmer winters could lead to shifts in the types of vegetation that thrive on the island, potentially disrupting the balance of native plant species. These changes could cascade through the food web, affecting everything from insects to large mammals that inhabit Terschelling.

2.2.4 Social-economic impacts and adaptation strategies

The social-economic fabric of Terschelling is tightly interwoven with its natural environment. The tourism industry, which is a significant part of the local economy, depends on the island's natural assets, potentially reducing the island's appeal to visitors. Additionally, changes in agricultural conditions, driven by altered precipitation patterns and increased temperatures, could affect local farming practices, which are an important part of the cultural heritage of Terschelling.

In response to these challenges, Terschelling has begun to explore adaptation strategies that align with the broader efforts across the Netherlands. These include enhancing coastal defences, promoting sustainable tourism practices, and engaging in community-based conservation efforts to protect and restore vulnerable ecosystems. Moreover, the island is looking at ways to diversify its economy to reduce reliance on tourism, making it more resilient to the unpredictable impacts of climate change. (Alphen, Koenis, & Kok, 2023)

3 Research and sub-questions

The research's main question is as follows: "*Which transdisciplinairy/holistic measures can be developed in order to establish a resilient fresh water supply on Terschelling in 2100?*".

The following research questions were developed in order to address this research question:

Temporal dynamics of the freshwater bubble:

- What is the rate of decline of Terschelling's freshwater bubble due to salinization, and how does this trajectory align with projected sea level rise?

Stakeholder-specific solutions and enhancements:

- What are the unique challenges and vulnerabilities faced by each stakeholder group (e.g., municipality, dairy farming industry, water management authorities, nature conservation organizations, tourism sector) regarding freshwater supply?
- What stakeholder-specific strategies, innovations, or adaptations can be implemented to mitigate the impacts of declining freshwater availability and enhance resilience to salinization?

Integrating stakeholder perspectives into water management:

- How can stakeholder engagement and collaboration be optimized to add inclusive decision-making processes and ensure the effective implementation of water management strategies?
- How can the insights derived from the Deltares model be effectively utilized to inform decision-making processes regarding water management strategies for Terschelling Island?

4 Method

To answer the research and sub-questions in this paper a non-experimental literature review method was used. During the research phase provided- and searched information and data was utilized. This indirect data had a combination of qualitative and quantitative characteristics. This method of data collection was chosen because all the data that was necessary for the research was already been available. This is why there was no need to do any experiments.

Data collection

To give an adequate conclusion there has been an inventory done of the stakeholders whom are of importance in this research. The interest of the stakeholders have been taken into account by researching their strengths and the weaknesses they face. Because of the development of an instable fresh water supply caused by climate change. Furthermore, there has been a use of maps that have been provided by Deltares to determine the hydrology of Terschelling. These maps are displayed in appendixes B & C and have been used to determine how the freshwater bubble will be impacted in the year 2100. Lastly, searched information from the internet such as: local news articles, scientific reach paper's about Terschelling and the stakeholders have been used to provide a broader understanding of matter and to give additional backing of arguments.

Searched terms

To write chapter 5.1 and answer the research question terms such as: Terschelling freshwater bubble salinization, sea level rise freshwater bubble decline, impact of sea level rise on groundwater systems, groundwater elevation and salinity distribution, Badon Ghijben-Herzberg theory, and saline intrusion groundwater islands were used.

For the research questions in chapter 5.2 terms such as: local authority responsibilities in the Netherlands, municipal government roles in climate adaptation, N2000 and UNESCO heritage guidelines Netherlands, land reclamation Wadden Sea history, sustainable agriculture and climate change adaptation, climate resilient infrastructure design, watertight basement construction techniques, sustainable building methods for drought and rainfall, impact of water scarcity on dairy farming, water management challenges freshwater scarcity, nature conservation strategies for freshwater protection, and the impact of freshwater scarcity on tourism were used.

Lastly, terms such as: best practices for stakeholder engagement in water management, stakeholder involvement in environmental decision-making, role of local communities in water management, and public participation in water resource decisions were used to answer the research questions in chapter 5.3.

Validity and reliability

To ensure that the sources that were used to write this paper are of quality a review of the sources have been conducted. It has been of importance to determine the interests and the purpose of the source.

5 Results

In this chapter the sub-questions will be answered per section. Section 5.1 will address sub-question 1. Section 5.2 will look at sub-questions 2 and 3, while Section 5.3 will discuss sub-questions 4 and 5.

5.1 Temporal Dynamics of the Freshwater Bubble

The first sub-question was as follows: "What is the rate of decline of Terschelling's freshwater bubble due to salinization, and how does this trajectory align with projected sea level rise?".

Literature research has indicated that the size of the freshwater bubble mainly depends on the height of the groundwater level compared to the seawater level. This is based on the Badon Ghijben-Herzberg theory. (Medenblik, 2024) Because the sea level will rise to a maximum of 124 cm by 2100 (in the worst case) compared to now (see Appendix A), the distance between the groundwater level and the seawater level will decrease if no changes are applied.
The Badon Ghijben-Herzberg theory treats fresh and saline groundwater as two separate liquids with a vertical pressure distribution that is hydrostatic. The densities of fresh and salt groundwater, along with the thickness of the freshwater lens, are related to the height of the groundwater table and various other factors. (Pauw, 2015) For the Island Terschelling, the H value (the thickness of the lens relative to a reference level) (Pauw, 2015), as shown in Figure 18, ranges between 20 and 25 meters per meter above sea level (Medenblik, 2024). In this figure, the H represents the height of the freshwater bubble and the letter M represents the height of the combination of fresh and salt water.

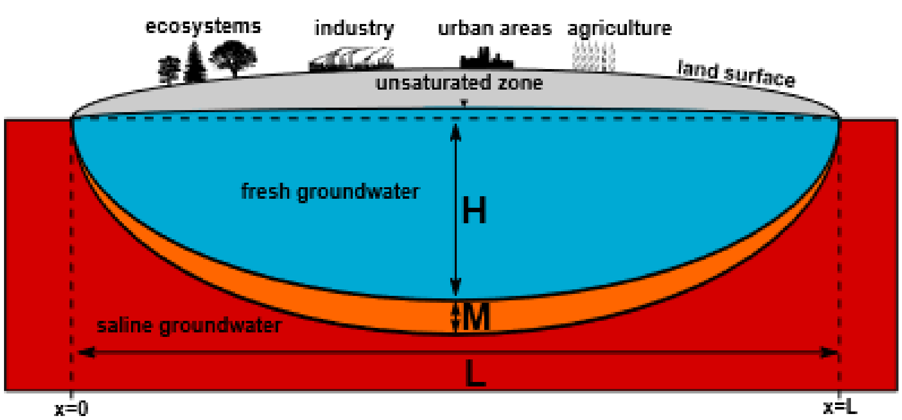

Figure 18: Concept of a freshwater lens in vertical cross-section. The lens terminates on the left (x=0) and right (x=L) at a draining feature (a stream, a canal, or marine water). The dashed line indicates as reference level, such as mean sea level. (Pauw, 2015)

The freshwater bubble shrinks as the elevation differential between the ocean and groundwater levels drops. This causes the lens's thickness to decrease by around 25 to 31 meters at 124 cm (Bessembinder, et al., 2023). It is also anticipated that in 2100, the groundwater level may fluctuate. This will have an impact on the various seasons, particularly in the polder, the bottom portion of the island. This has been mapped out on several cross sections. These cross sections are shown in Appendix C. A part of the cross sections are based on a reference scenario, the other cross sections belong to the comparison of scenarios Hn or Hd to the reference scenario. These cross sections show that the freshwater bubble becomes smaller when the Hd or Hn scenario is involved.

5.2 Stakeholder-Specific Solutions and Enhancements

5.2.1 Local authority

Examining the many responsibilities of a local authority can help to have a clear understanding of how climate change may impact the local authority of Terschelling. A local authority has multiple responsibilities, for example including (Rijksoverheid, n.d.):

- Maintaining a record of the residents of the municipality in the Personal Records Database (BRP).
- Being in charge of managing school housing and allocating funds for pupils in need of additional support.
- Creating zoning plants. This indicates the sections designated for homes, parks, and commercial buildings.
- Monitoring housing construction and making agreements with housing associations about this.
- Constructing bike trails, sidewalks, and roadways and ensuring that they are maintained.
- Implementing the Environmental Management Act. The collection of household waste separately is an example.
- Ensuring that industrial sites are easily accessible.

The local authority will be affected by climate change for the island in every way (sea level rise, temperature increase, more intense rainfall, desiccation, higher intensity of solar rays and higher humidity) because of its numerous jobs and obligations. In addition, the local authority itself also has various wishes for the future. The above-mentioned climate changes have also been considered. The local authority wants to make sure that it is still possible to live and develop (new homes) on the island. They want to encourage individuals to have strong social and/or financial ties with the island. The municipality would like the island to be self-sufficient in terms of energy and water supply. (Gemeente Terschelling, 2023) The water supply could be made possible through land reclamation in the Wadden Sea, as was done in the past. Land reclamation can provide more safety, it expands the freshwater bubble, it will prevent salty seepage and it offers extra (experience) value in terms of nature and landscape. (Gemeente Terschelling, 2023) This measure would therefore help against sea level rise. This will only be very difficult in connection with the regulations regarding N2000 and the UNESCO heritage policy and guidelines.
For the municipality, maintaining the polders is crucial because it feels that they ought to be prouder of their agricultural heritage. Meadow birds are therefore also quite significant. The island's distinctive features include its agricultural landscape and its meadow bird population. (Gemeente Terschelling, 2023)

When building and designing a neighbourhood, it is important to take dehydration and rising temperatures into account. This could include planting trees on streets for shade or creating shade with buildings, but also collecting and draining rainwater in a natural way. When constructing or adapting the infrastructure, the local authority can choose to separate the wastewater. By separating it, the water can be cleaned more easily and may even serve as drinking water. The new construction will also have to be built in the least vulnerable places, so that they experience as little inconvenience as possible. In order to minimize disruption from climate change, it can also be investigated whether alternative building methods should be used. For drought, the predictions of the Hd scenario will have to be used, while for rain, the predictions of the Hn scenario will have to be used, see Table 3 in Chapter 2. The current buildings are already experiencing flooding. The cellars could be made watertight using German techniques, both from the inside as from the outside (Köster Waterproofing Systems, n.d.; Ready Made Basements, 2016). Germany established itself as a leader in technology, manufacturing and engineering (E., 2023). When the cellars are watertight, less drainage is required. This allows the environment to be a little wetter and it is possible to raise the groundwater level a little, so that the freshwater bubble can be expanded.

5.2.2 Water management

In all four KNMI'23 scenarios, as depicted in Figure 1 in chapter 2, the data indicates a consistent trend of increasing temperatures. Additionally, chapter 2 has spoken about a decrease in summer rainfall, which could exacerbate issues related to desiccation. Consequently, there is a pressing need for water management strategies to adapt to these anticipated changes. Moreover, while winters are expected to become wetter, it is crucial to recognize the escalating significance of addressing challenges associated with drought and salinization. (Bessembinder, et al., 2023)

It is crucial to preserve the freshwater bubble beneath the island. To maintain or even increase the freshwater bubble, the Badon Ghijben-Herzberg theory needs to be considered. This theory was discussed in section 5.1.
To tackle this issue, it will be vital to explore the option of elevating a section of the island to increase the groundwater level, thereby improving overall water management. It is also essential to prioritize the conservation and potential enhancement of the current dunes, as they serve a fundamental purpose in safeguarding the island, particularly in the face of inclement weather conditions such as storms. The KNMI'23 model predicts that there will be roughly the same number of storms, but more rain will fall in a given period of time. Dunes may be impacted by this. By raising the dunes, the groundwater level here can also be increased in this area. (Bessembinder, et al., 2023)

The rising sea levels will have an impact, especially on the polders. Although salinization is already occurring, it will accelerate due to seepage of additional salt water from behind the dike into the polders. It will not be able to raise the polder to its full level, thus maintaining and growing the freshwater bubble beneath the dunes is crucial. (Medenblik, 2024)

Another crucial factor is water retention. Waterpracht, a European POP3 financed project, is under progress on the island. The autumn of 2022, the island-wide initiative has implemented measures aimed at increasing water retention and simultaneously enhancing the quality of the water. Enhancing weirs and deepening ditches are two of the measures. (Staatsbosbeheer, n.d.) Groundwater will need to be utilized less often both today and in the future by retaining surface water for longer. It is essential that ditches no longer empty into the sea. A large part of the rain flows directly via the ditches or the beach to the sea or it evaporates. Another part penetrates into the sandy bottom and feeds the freshwater bubble. (Nationaal Park Schiermonnikoog, n.d.)

5.2.3 Drinking water

As of today, one third of the drinking water on Terschelling comes from a location that is located north of West-Terschelling. There are well fields in the forest where groundwater is being pumped for drinking water. The water extraction area is shown in figure ...

Figure 19: map of Terschelling which shows the water extraction area, the inner dune and the polder (Van Alphen et al., 2023)

Two thirds of the drinking water originate from the mainland which is supplied trough a pipeline (the Wadden Sea pipeline). About half of the water that comes from the mainland is being used by tourists. Figure 19 shows an overview of the clean water delivery each year on Terschelling. The total drinking water use shows a stable trend and does not increase. Looking more closely at the water usage each year it shows peaks in the summer (namely during the Oerol-festival), the vacations and the weekends, shown in figure 20. Those peaks are currently completely intercepted by the Wadden Sea pipeline. (Van Alphen et al., 2023) It is striking that the fluctuations in monthly consumption within the year are great as a result of tourism. Summer consumption is on average 2.5 - 3.0 times higher than the winter consumption. On the mainland this ratio is much smaller, namely about 1.5 (Kok et al., 2024).

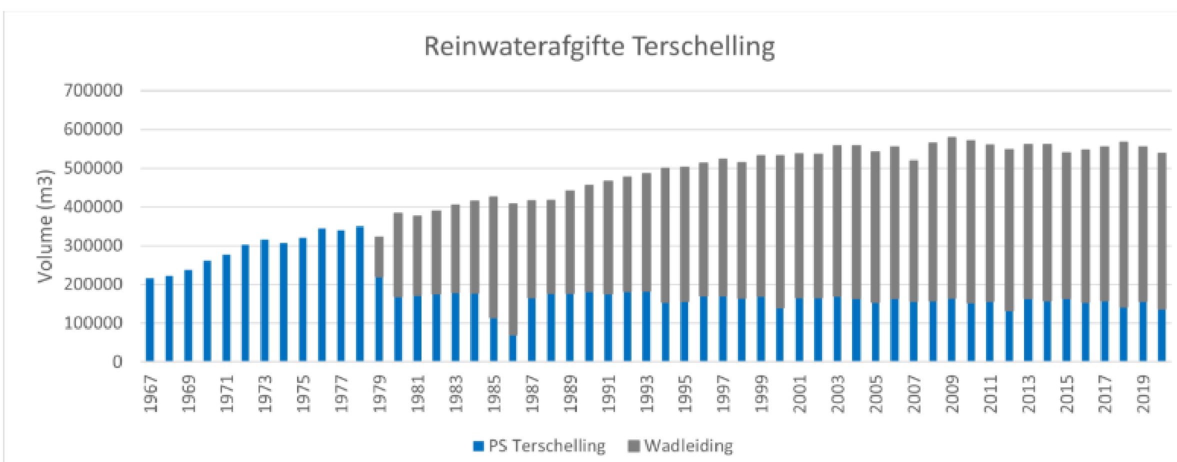

Figure 20: drinking water delivery Terschelling 1956-2019 (Van Alphen et al., 2023)

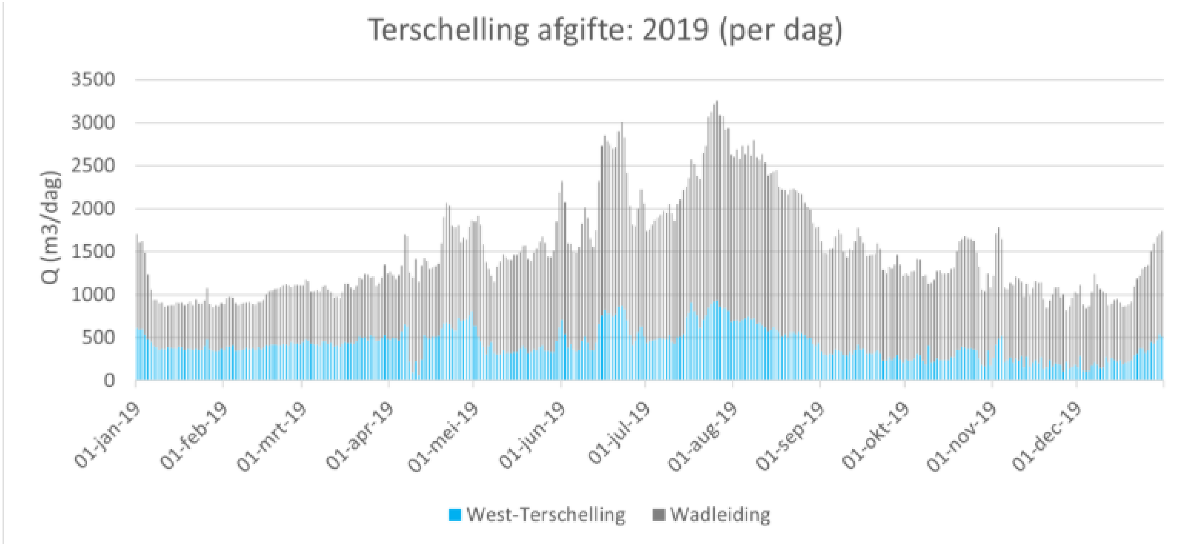

Figure 21: daily drinking water delivery Terschelling 2019 (Van Alphen et al., 2023)

The figures show that a large amount of drinking water originated from the mainland which means that the Wadden Sea pipeline plays a large role in maintaining the drinking water supply on Terschelling. Terschelling is vulnerable as a consequence of the Wadden Sea pipeline since they are dependent on the drinking water that comes from the Wadden Sea pipeline. The challenge that occurs is securing drinking water on Terschelling in the future. In particular, because the Wadden Sea pipeline will eventually need to be replaced. How long the Wadden Sea pipeline will last is still unclear, but estimates are around 10 – 20 years. (Van Alphen et al., 2023)

When the Wadden Sea pipeline is at the end of its lifetime it is not expected that the pipeline is going to be replaced in the near future. This means plans on making Terschelling self-sufficient in terms of water extraction (Van Der Zee et al., 2016). Possibilities to expand the drinking water supply through more local water extraction are being investigated. When the local water extractions increase, it would impact the groundwater levels and cause other negative effects (Van Alphen et al., 2023). In the past, before the Wadden Sea pipeline ran to the island, there were already problems with vulnerable nature drying out and the salinization of the water (Van Der Zee et al., 2016). The search for a new water extraction area on the island should weigh the different interests of local stakeholders and minimize the possible negative effects (Van Alphen et al., 2023).

This additional water extraction should preferably concern groundwater. This is more sustainable since fewer raw materials have to be removed from the water than when extracting salty or brackish water. There is a necessity for a protected area around the extraction area. Within this protected area, the groundwater must meet a certain quality. This affects the area functions in said area. (Van Alphen et al., 2023)

In addition to the supply side (drinking water availability), the water supply can also be analysed from the demand side (drinking water demand). Terschelling relies' on its available drinking water. How large the drinking water supply should be in the future depends on the future demand. This involves the question of what kind of island Terschelling wants to be in the future. (Van Alphen et al., 2023)

5.2.4 Dairy farm

As sea levels continue to rise, the island of Terschelling faces a significant environmental challenge: the encroachment of saline water into traditionally freshwater zones. This phenomenon forces the sweet water bubble, which sustains much of the island's agriculture, upwards, resulting in increased salinity in the surrounding soils. The impact of this rising salinity is profound, particularly for dairy farmers who rely on the productivity of traditional crops and grasses to sustain their livestock. These crops and grasses, typically sensitive to salt, experience reduced growth and nutritional value in such brackish conditions, leading to a decrease in overall agricultural productivity.

To adapt and survive in these changing surroundings, dairy farmers on Terschelling can explore several strategies that leverage the resilience of salt-tolerant plant species. One of the primary adaptations involves the integration of salt-tolerant shrubs and grasses into their farming systems. These plants not only survive in higher salinity levels but can also improve the microclimate and soil conditions for other species. For instance, salt-tolerant shrubs can lower the water table, facilitating the growth of shallow-rooted, high-nutrition plants (E. Barrett-Lennard, 1996). This synergy between different plant types can enhance overall dry matter production, essential for maintaining livestock health and productivity. (Opportunities and limitations for animal production from saline land, 2001)

The adoption of mixed-species planting is another promising strategy. By combining various salt-tolerant species, farmers can create a more robust and productive pasture. Mixtures of species can improve the microclimate and growing conditions, which in turn enhances the nutritive value of the pasture when grazed by ruminants (animal production from saline land). This method not only ensures a steady supply of feed but also maximizes the use of available land, even under saline conditions. (Opportunities and limitations for animal production from saline land, 2001)

Additionally, the development and utilization of new salt-tolerant legumes and grasses present specific opportunities for adaptation. Establishing comprehensive nutritional screening methods can help identify plants with the best potential for growth and nutritional value in saline soils. This involves developing a comprehensive panel of nutritional and anti-nutritional laboratory tests to determine critical levels of these factors for ruminants (Opportunities and limitations for animal production from saline land, 2001). By selecting and breeding the most promising plants, farmers can optimize production on saline land.

Research suggests using compounds like betaine and proline as markers for salt tolerance. Targeting these compounds in breeding programs can enhance the salt tolerance of traditionally sensitive pasture plants (Opportunities and limitations for animal production from saline land, 2001)
Moreover, understanding the interactions between different soil components such as Na, K, Ca, Mg, Cl, Sulphate, Bicarbonate, and Carbonate on animal health and production is crucial. These interactions can affect the overall quality and productivity of the feed, and consequently, the health and output of the dairy cows. (Opportunities and limitations for animal production from saline land, 2001)

In conclusion, while rising sea levels and increased soil salinity pose a substantial challenge to traditional agriculture on Terschelling, dairy farmers have viable pathways to adapt. By integrating salt-tolerant plants, utilizing mixed-species planting, and adopting advanced breeding and nutritional strategies, they can maintain their agricultural productivity. The success of these adaptations will not only support the dairy industry but also contribute to the island's overall environmental sustainability.

5.2.5 Saline cultivation

As sea levels rise, saltwater intrudes into freshwater aquifers, especially on the southern side of the island (Figure 22). This process results in the saltwater flowing under dykes and increasing the salinity of the groundwater, leading to more saline and brackish conditions.

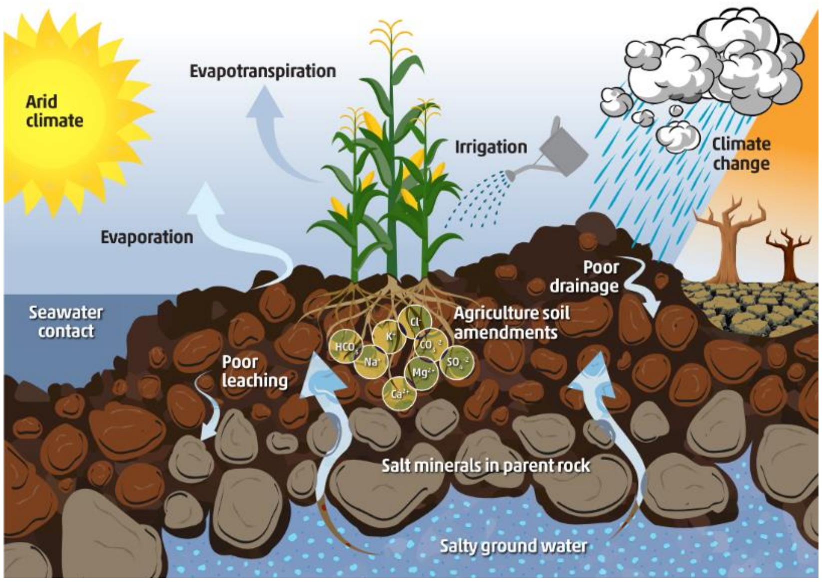

Figure 22: Factors influencing salt accumulation in the soil (Agriculture, n.d.)

The intrusion of saltwater into freshwater resources is problematic for traditional agricultural practices, which rely heavily on fresh water for irrigation. Increased salinity can significantly reduce crop yields or even render traditional crops unusable. As the salt percentage in the water rises,

plants accustomed to fresh water struggle to survive, let alone thrive. The increased salinity can be seen in Figure 23 and Figure 24. Which show the difference in salt mg/L in the water, in what it is right now and what it will become in 2100.

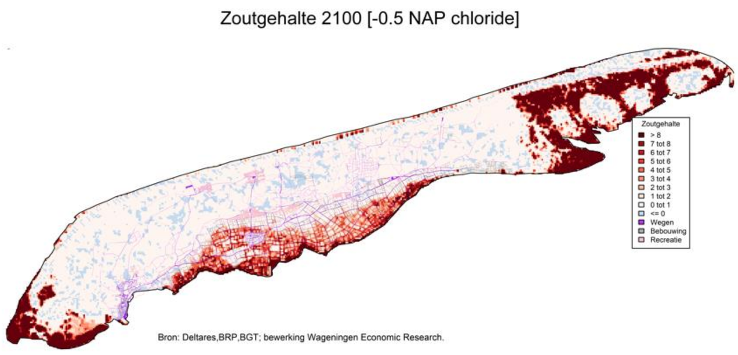

Figure 23: Salinity mg/L 2100, Terschelling (Deltares, 2024-c)

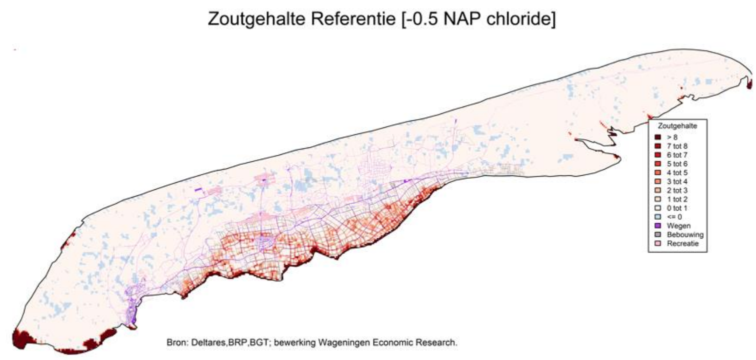

Figure 24: Salinity mg/L reference, Terschelling (Deltares, 2024-c)

Insufficient Freshwater, Salt Contamination, and Soil Degradation

Salinity is one of the most widespread soil degradation processes on Earth, affecting an estimated 30.7 million hectares in Europe, Europe accounts for only 3.3% of global soil salinization. (I.N. Daliakopoulos, 2016) It is regarded as a major cause of desertification and a serious form of soil degradation . The availability of freshwater is a major limiting factor in sustainable agriculture, particularly in developing regions with burgeoning population pressures . (Saline agriculture, 2024)

Saline cultivation on global scale

With the continuous increase in the world population, the requirements for food, freshwater, and fuel are growing every day. This situation creates an urgent necessity to develop, create, and practice new types of agriculture that are environmentally sustainable and suitable for various soil types. Among the stresses in plant agriculture worldwide, the increase in soil salinity is considered a major problem. This is particularly emerging in developing countries that present the highest population growth rates and often high rates of soil degradation. Therefore, salt-tolerant plants provide a sensible alternative for many developing countries. These plants have the capacity to grow using land and water unsuitable for conventional crops, producing food, fuel, fodder, fiber, resin, essential oils, and pharmaceutical products. (Salt farm Texel, 2020)

Population Growth and Agriculture Challenges
United Nations predicted a population increase to 8.01 billion by 2025. This represents a doubling of the human population in approximately 50 years, posing significant challenges for agricultural strategies to feed everyone. Consequently, there is enormous demographic and economic pressure to increase crop production by about 50% in a sustainable manner over the next 40 years to fulfil world food necessities. (UnitedNations, 2009)

Saline Cultivation: An Adaptive Approach
In response to this growing issue, a practice known as saline cultivation is being explored and implemented. Saline cultivation involves the use of crops and crop varieties that have a higher

tolerance to saline conditions. This agricultural technique is particularly relevant for areas like Terschelling, where increasing salinity threatens conventional farming practices.

Developing Salt-Tolerant Crops

To further enhance saline cultivation, efforts are being made to develop and evolve certain plants to be more resistant to saline conditions. This involves both the selection of naturally salt-tolerant species, known as halophytes, and the genetic modification of conventional crops to improve their salt tolerance. Advances in biotechnology and plant breeding are crucial in this process, enabling the cultivation of crops that can thrive in high-salinity environments, thereby expanding the range of viable agricultural land and contributing to food security in affected regions. (Salt farm Texel, 2020)

Benefits of Saline Cultivation

- Resilience to Salinity: Saline-tolerant crops are specifically bred or selected for their ability to grow in salt-affected soils, ensuring agricultural productivity despite increased soil salinity.
- Sustainable Agriculture: By adopting saline cultivation, farmers can continue to produce food in areas affected by saltwater intrusion, contributing to food security, independence and sustainability.
- Economic Viability: Saline agriculture can provide new economic opportunities for farmers by introducing alternative crops that may have higher market value due to their unique properties or scarcity.

For Terschelling, the adoption of saline cultivation could be a vital strategy in adapting to changing environmental conditions. By identifying and planting saline-tolerant crops, the island can maintain agricultural productivity and resilience. Additionally, ongoing research and development in this field can further enhance the effectiveness of saline agriculture, making it a viable solution for many other coastal regions facing similar challenges.

5.2.6 Recreation

The recreation industry in 2100 will be mostly impacted by the existing groundwater level and more intense rains. Both lead to floods since the KNMI'23 scenarios anticipate that there will be greater rain within a certain period of time. Flooding will happen when the soil layer is too wet from the rain and the level of the groundwater. Recreationists may decide not to return because of the threat of flooding or the recent flooding. The entrepreneurs in the recreation sector want customers to return, therefore finding a solution to the water issue is crucial. There are several ways to solve this, one of which is to investigate if accommodation may be constructed differently. Lowering the groundwater level by consulting with the water authority is an additional choice. To keep recreationalists around, the recreation industry would like to keep an eye on and have a say in choices about water levels.

If a decision is made to build accommodation differently, the industry can make the buildings more sustainable, for example placing as solar panels on the roof and/or collecting rainwater to flush the toilet. The industry is already working on becoming more sustainable and not being dependent on the mainland. Unfortunately, in 2100 the freshwater bubble under the island will decrease in size due to, among other things, the rise of sea water. When the number of tourists increases, higher temperatures and the increasingly drier periods that will occur in 2100 (see table 3 in chapter 2), the freshwater bubble will probably be too small. For this reason, it is important that there is a water pipe from the mainland to the island, so that there is no shortage of drinking water.

5.2.7 Meadow birds

Figure 25: Threats that migratory birds encounter on the East Atlantic Flyway (East Atlantic Flyway, n.d.)

Terschelling is known for its diverse birdlife. The island's varied habitats, including dunes, beaches, salt marshes, and woodlands, provide an ideal environment for a wide range of bird species. Terschelling is a crucial stopover for migratory birds traveling along the East Atlantic Flyway. The East Atlantic Flyway (EAF) extends from the Arctic to the southern part of the African Atlantic coastline. Every year millions of waterbirds migrate from their breeding grounds in the Siberian tundra to their non-breeding (wintering) sites in the Western and Southern Africa. The Wadden Sea is at the heart of the EAF and is used as a breeding, wintering and stopover site. (*East Atlantic Flyway*, n.d.) In the summer Terschelling is home to different breeding populations and in the winter the island is home to various wintering birds. With its rich avian biodiversity, Terschelling is a vital for bird conservation.

The salinization of Terschelling and saline cultivation can have significant impacts on meadow birds, affecting their habitat, food resources and nesting sites. By altering traditional grassland habitats that many meadow birds depend on, saline cultivation and salinization can lead to various ecological changes.

One of the primary impacts of saline cultivation is the alteration of existing meadow habitats. The traditional grasslands, which provide nesting and foraging grounds for meadow birds, are replaced by salt-tolerant vegetation. This shift can lead to habitat loss for specific species that rely on grassland conditions (Mugatha, Ogutu, Piepho, & M., 2024). The changes in vegetation structure can also make these areas less suitable for nesting, as many meadow birds require dense grass cover for their nests. Leading to fewer suitable nesting locations. Studies have shown that changes in vegetation can lead to reduced nesting success and lower reproductive rates, traditional grasslands are critical for nesting and foraging (Mugatha, Ogutu, Piepho, & M., 2024). In addition, the salinization of the island can impact the availability and quality of freshwater habitats that many meadow birds rely on, making it unsuitable habitat for meadow birds (Erwin, 2002).

The salinization and saline cultivation can affect the availability and diversity of food resources for meadow birds. The introduction of salt-tolerant plants alters the plant community, which can impact insect populations and seed availability. Birds that feed on specific insects or seeds may find their food sources diminished, leading to potential declines in bird populations that cannot adapt to the new conditions (Otte, n.d.). On the other hand, salinization and saline cultivation could attract different bird species that are better adapted to the new conditions. This could potentially lead to an increase in competition for resources such as food and nesting sites. This increased competition can further stain the existing meadow bird populations, impacting their survival and reproductive success (Otte, n.d.).

Despite the challenges, the salinization and saline cultivation can also create new habitats that may benefit certain bird species. If managed carefully, it can lead to different habitats types, providing new opportunities for some birds to thrive (Otte, n.d.). The effects of saline cultivation and salinization on meadow birds are complex and multifaced. While saline cultivation provides a viable agricultural strategy in saline environments, it also poses significant challenges for the conservation of meadow birds.

There are various projects on Terschelling to enhance bird habitats and promoting biodiversity on the island. The “PolderPracht” project is a project which run from 2014 to 2019 and is a project which primary focused on creating and restoring habitats that support a wide variety of bird species. This involves managing and maintaining landscapes in ways that provide optimal conditions for breeding, feeding, and sheltering birds. The project involves restoring traditional landscapes, such as wet meadows, salt marshes, and dune areas, which are crucial for many bird species (Vogelbescherming Nederland, n.d.).

Another project is Wij & Wadvogels (We & Wading birds) which is a project dedicated to the conservation and protection of shorebirds in the Wadden Sea region, which also includes Terschelling. The project aims to address the various challenges that shorebirds face, such as habitat loss, disturbance and climate change. Wij & Wadvogels is not limited to Terschelling but encompasses the broader Wadden Sea region, which includes multiple islands and coastal areas (Waddenfonds, n.d.).

The “Wij & Wadvogels” and “PolderPracht” projects share several commonalities, primarily focused around environmental conservation and the sustainable management of natural resources. Wij & Wadvogels focuses on the conservation of shorebirds and their habitats in the Wadden Sea area, and PolderPracht aimed to create and restore habitats that support a wide variety of bird species on Terschelling.

Both projects place a strong emphasis on engaging with local communities, including residents, farmers, and visitors while raising awareness and understanding about conservation. Educational programs, guided tours, and workshops are being organized to engage the public and to foster a sense of stewardship (Waddenfonds, n.d.; Vogelbescherming, n.d.).

5.2.8 Nature in the dunes

Terschelling's dunes are classified as a Natura 2000 area and are one of the most lime-poor dune areas of the Wadden Sea (Natura 2000, n.d.). Ditches cross the Terschelling dunes in several places. They were built around the beginning of the last century to prepare the dunes for agriculture, which needed drainage. (Staatsbosbeheer, n.d.) These days, these ditches ensure the rapid drainage of a lot of ground and rainwater, making the dunes a lot drier than they should be naturally (Staatsbosbeheer, n.d.). This guarantees that the dunes, as well as the plants and animals that inhabit them, are more vulnerable to drier periods. As discussed under the heading water management, the number of storms will not increase, but the amount of rain in a certain time will. This is why the vegetation of the dunes is of great importance. The roots keep the sand in place as much as possible. With the Waterpracht project, Staatsbosbeheer has lowered the depth of several of these ditches (Staatsbosbeheer, n.d.). As a result, the dunes' water levels rise, and they become more resistant to drier periods. Species of plants and animals that are unique to moist dune valleys may also reappear. (Staatsbosbeheer, n.d.)
Thus, the major effects on nature in the dunes will be increased rainfall, rising sea levels, and desiccation. The dunes will still exist in 2100 as how they are right now, if their original condition is maintained together with a variety of plants.

Management in the dunes will also be important in the future, as the dunes are overgrown with shrubs in many places. This is partly due to the blowing in of fertilizers and desiccation. In many places, plowing, mowing or grazers are used. (Nationaal Park Schiermonikoog, n.d.) This maintenance ensures that the nature of the dunes remains biodiverse and that rare animals and plants that belong in the dunes are preserved (Nationaal Park Schiermonikoog, n.d.).

5.3 Integrating stakeholder perspectives into water management

Integrating stakeholder perspectives into water management is crucial for developing effective and sustainable strategies for Terschelling. Ensuring that all parties are informed and involved in the decision-making process can lead to more comprehensive and accepted solutions. Here are key approaches to achieve this integration:

Communication
Regular Dialogue: Establish regular communication channels between all stakeholders, including local authorities, water management organizations, residents, farmers, and businesses. This ensures that everyone is informed about the latest findings from the Deltares model and the government's idea's and evolving views. Thus, creating the opportunity and time to interfere or brainstorm ideas that might have been overlooked or need to be adjusted.

Awareness: Conduct public awareness campaigns to educate stakeholders about the potential dangers posed by climate change and the importance of sustainable water management. Highlight the potential solutions and developments that can mitigate these risks.

Stakeholder Solutions
Collaborative Development: Involve stakeholders in the development of water management strategies. Since different stakeholders have varying priorities and concerns, it is essential to incorporate their input to create balanced and acceptable solutions. Using stakeholders as co producers of the potential implementations, ensuring fitting solutions for stakeholders.

Scenario Testing: Allow stakeholders to propose potential solutions and test these within the Deltares model. This collaborative approach ensures that proposed strategies are not only theoretically sound but also practical and tailored to local needs.

Implementation and Monitoring
Pilot Projects: Implement pilot projects based on model insights and stakeholder input. These projects can serve as real-life adjustments that test the feasibility and effectiveness of proposed water management strategies.

Tracking: Include systems to monitor the effectiveness of implemented solutions. Use data from these monitoring efforts to refine and adjust strategies as needed.

Feedback: Create feedback loops where the results of implemented strategies are communicated back to the stakeholders. This transparency builds trust and ensures that all parties are aware of the progress and any necessary adjustments.

By effectively integrating stakeholder perspectives into water management, Terschelling can develop adaptive strategies that address the diverse needs and concerns of its community.

6 Conclusion and discussion

In order to conclude a conclusion, the various sub-questions must be answered. The various sub-questions will be answered below.

Temporal dynamics of the freshwater bubble

The sub-question is as follows: "*What is the rate of decline of Terschelling's freshwater bubble due to salinization, and how does this trajectory align with projected sea level rise?*".

The rate of decline of Terschelling's freshwater bubble due to salinization is closely tied to projected sea level rise, as explained by the Badon Ghijben-Herzberg theory. This theory shows that the size of the freshwater bubble depends on the height of the groundwater level relative to the seawater level.
By 2100, the worst-case scenario predicts a sea level rise of up to 124 cm. This rise will decrease the distance between the groundwater and seawater levels, leading to a reduction in the thickness of the freshwater lens by approximately 25 to 31 meters. Consequently, the freshwater bubble will shrink as the elevation differential drops.
This trajectory highlights the critical need for proactive water management strategies to mitigate the adverse effects of rising sea levels on Terschelling's freshwater supply.

Stakeholder-specific solutions and enhancements

The sub-questions for this sub-subject are as follows: "*What are the unique challenges and vulnerabilities faced by each stakeholder group (e.g., municipality, dairy farming industry, water management authorities, nature conservation organizations, tourism sector) regarding freshwater supply?*" and "*What stakeholder-specific strategies, innovations, or adaptations can be implemented to mitigate the impacts of declining freshwater availability and enhance resilience to salinization?*".

Local authority

- The local authority itself also has various wishes for the future
- Improving cellars for extreme/heavy rainfall
- Expanded freshwater bubble so the island can be independent
- The municipality would like the island to be self-sufficient in terms of energy and water supply. The water supply could be made possible through land reclamation in the Wadden Sea, as was done in the past. Land reclamation can provide more safety, it expands the freshwater bubble, it will prevent salty seepage and it offers extra (experience) value in terms of nature and landscape. This measure would therefore help against sea level rise.
- For the municipality, maintaining the polders is crucial because it feels that they ought to be prouder of their agricultural heritage.
- When building and designing a neighbourhood, it is important to take dehydration and rising temperatures into account. This could include planting trees on streets for shade or creating shade with buildings, but also collecting and draining rainwater in a natural way. When constructing or adapting the infrastructure, the local authority can choose to separate the wastewater.

Water management

- By raising the dunes, the groundwater level here can also be increased in this area.

- Initiatives to increasing water retention and simultaneously enhancing the quality of the water

Drinking water

- Current sources of drinking water:
    - One thirds comes from drinking water well's located north of West-Terschelling
    - Two thirds comes from the mainland, supplied by the Wadden Sea pipeline
- Water usage patterns:
    - About half of the mainland-supplied water is used by tourists
    - Water consumption peaks in summer, vacations, weekends and during Oerol
    - Summer water consumption is 2.5-3 times higher than in winter, compared to 1.5 on the mainland
- Pipeline dependency:
    - The Wadden Sea pipeline is crucial for maintaining the drinking water supply on the island
    - The pipeline probably needs to replace in 10 to 20 years
    - Plans are made to make Terschelling self-sufficient in water extraction due to the uncertain future of the pipeline
- Local water extraction challenges:
    - Increasing local water extraction may affect groundwater levels and have negative environmental impacts, such as drying out vulnerable nature and water salinization
    - A search for new water extractions areas must be consider local stakeholder interests and minimize negative effects
    - Sustainable groundwater extractions are preferred, requiring fewer raw materials and necessitating a protected area to maintain groundwater quality
- Future water demand:
    - The future drinking water supply depends on the island's future water demand and its vision for development
    - Balancing supply and demand involves strategic planning to ensure sustainability and resilience of the water supply system
- Dairy farm
    - Efficient Water Use: Implement water-efficient farming practices and technologies, such as drip irrigation and soil moisture sensors, to reduce water usage.
    - Alternative Feed Sources: Explore the use of alternative, less water-intensive feed sources to mitigate the impact of potential fodder shortages.
    - The use of more saline tolerant crops and grasses, the crops are able to be cultivated on more saline grounds that are unsuitable for regular crop production.
- Saline Cultivation
    - Salt-Tolerant Crops: Investigate the potential for saline cultivation, focusing on crops that can thrive in saltier conditions, to adapt to the increasing salinity of the soil and water.
    - Developing salt tolerant crops. This involves both the selection of naturally salt-tolerant species, known as halophytes, and the genetic modification of conventional crops to improve their salt tolerance

Recreation

- Recreationists may decide not to return because of the threat of flooding or the recent flooding. The entrepreneurs in the recreation sector want customers to return, therefore

finding a solution to the water issue is crucial. → water level lower or that they can have impact on the decisions about the water level.
- make the buildings more sustainable, for example placing as solar panels on the roof and/or collecting rainwater to flush the toilet.
- water pipe from the mainland to the island, so that there is no shortage of drinking water

Meadow birds
- Terschelling and Birdlife:
  - Key stopover on the East Atlantic Flyway.
  - Diverse habitats (dunes, beaches, salt marshes, woodlands) support a wide range of bird species.
  - Crucial for migratory birds traveling between the Arctic and Africa.
- Impact of Salinization and Saline Cultivation:
  - Habitat Changes:
    - Traditional grasslands replaced by salt-tolerant vegetation.
    - Loss of nesting and foraging grounds for meadow birds.
  - Food Resources:
    - Altered plant communities affect insect and seed availability.
    - Potential decline in bird populations due to reduced food sources.
  - New Habitats:
    - Possibility of attracting different bird species.
    - Potential increase in competition for resources.
- Conservation Projects:
  - "Vogel Pracht" (2014-2019):
    - Restoration of habitats like wet meadows and dune areas.
    - Aimed at supporting a variety of bird species.
  - "Wij & Wadvogels":
    - Focus on protecting shorebirds in the Wadden Sea region.
    - Addresses challenges like habitat loss and climate change.

Nature in the dunes
  - the dunes' water levels rise, and they become more resistant to drier periods. Species of plants and animals that are unique to moist dune valleys may also reappear.

Integrating stakeholder perspectives into water management

- How can stakeholder engagement and collaboration be optimized to add inclusive decision-making processes and ensure the effective implementation of water management strategies?

Optimizing stakeholder engagement and collaboration involves establishing regular communication channels between all stakeholders, including local authorities, water management organizations, residents, farmers, and businesses. Conducting public awareness campaigns to educate stakeholders about the potential dangers and solutions is essential. Involving stakeholders in the development of water management strategies and allowing them to propose and test potential solutions within the Deltares model ensures that strategies are balanced, practical, and tailored to local needs. Finally, implementing pilot projects and creating feedback loops where results are communicated back to stakeholders helps build trust and transparency.

- How can the insights derived from the Deltares model be effectively utilized to inform decision-making processes regarding water management strategies for Terschelling Island?

Insights from the Deltares model can be effectively utilized by communicating the findings to all stakeholders, ensuring everyone is aware of potential dangers and solutions. Involving stakeholders in the development and testing of strategies within the Deltares model ensures that proposed solutions are practical and tailored to local needs. Implementing pilot projects based on model insights and stakeholder input can test the feasibility and effectiveness of strategies. Monitoring the effectiveness of implemented solutions and communicating these results back to stakeholders creates a transparent and adaptive decision-making process.

6.1 Conclusion main question

The research's main question is as follows: "*Which transdisciplinairy/holistic measures can be developed in order to establish a resilient fresh water supply on Terschelling in 2100?*".

Ensuring the integration of diverse perspectives is essential for creating effective and accepted water management strategies. By involving local authorities, water management bodies, farmers, tourism operators, and conservationists, Terschelling can establish a robust participatory framework for decision-making.

Water usage among key sectors, such as agriculture, tourism, and recreation, should be optimized. For instance, efficient farming practices, saline crop cultivation, and sustainable urban planning will be critical in mitigating the effects of salinization and rising sea levels.
Specific solutions are available;
Local authority

- Improving cellars for extreme/heavy rainfall
- Expanded freshwater bubble so the island can be independent
- Land reclamation can provide more safety, it expands the freshwater bubble, it will prevent salty seepage and it offers extra (experience) value in terms of nature and landscape.

Water management

- By raising the dunes, the groundwater level here can also be increased in this area.

Drinking water

- Current sources of drinking water:
    - One thirds comes from drinking water well's located north of West-Terschelling
    - Two thirds comes from the mainland, supplied by the Wadden Sea pipeline which is due to be replaced in 10-20 years. It is crucial for maintaining the drinking water supply on the island
    - About half of the mainland-supplied water is used by tourists
    - Water consumption peaks in summer, vacations, weekends and during Oerol
    - Summer water consumption is 2.5-3 times higher than in winter, compared to 1.5 on the mainland
    - Plans are made to make Terschelling self-sufficient in water extraction due to the uncertain future of the pipeline
    - A search for new water extractions areas must be consider local stakeholder interests and minimize negative effects

  - Balancing supply and demand involves strategic planning to ensure sustainability and resilience of the water supply system

Dairy farm

- Efficient Water Use: Implement water-efficient farming practices and technologies, to reduce water usage.
- Alternative Feed Sources: Explore the use of alternative, less water-intensive feed.
- The use of more saline tolerant crops and grasses, the crops are able to be cultivated on more saline grounds that are unsuitable for regular crop production.

Saline Cultivation

- Salt-Tolerant Crops: Investigate the potential for saline cultivation, focusing on crops that can thrive in saltier conditions, to adapt to the increasing salinity of the soil and water.
- Developing salt tolerant crops. Selecting the most salt tolerant halophytes and the genetic modification of conventional crops to improve their salt tolerance

Recreation

- Recreationists may decide not to return because of the threat of flooding or the recent flooding. The entrepreneurs in the recreation sector want customers to return, therefore finding a solution to the water issue is crucial. → water level lower or that they can have impact on the decisions about the water level.
- water pipe from the mainland to the island, so that there is no shortage of drinking water

Meadow birds

- Key stopover on the East Atlantic Flyway.
- Diverse habitats (dunes, beaches, salt marshes, woodlands) support a wide range of bird species.
- Crucial for migratory birds traveling between the Arctic and Africa.
- Impact of Salinization and Saline Cultivation:
  - Traditional grasslands replaced by salt-tolerant vegetation.
  - Loss of nesting and foraging grounds for meadow birds.
  - Altered plant communities affect insect and seed availability.
  - Potential decline in bird populations due to reduced food sources.
  - Possibility of attracting different bird species.
  - Potential increase in competition for resources.

Nature in the dunes

- The dunes' water levels rise, and they become more resistant to drier periods. Species of plants and animals that are unique to moist dune valleys may also reappear.

Given the decreasing availability of freshwater on Terschelling, it is essential that all stakeholders work together to develop integrated solutions that balance water management needs with the island's environmental and social goals. The local authority's plans for self-sufficiency in energy and water, including land reclamation, must align with water management strategies like raising dunes and increasing retention. Not all solutions are able to be executed smoothly alongside one another, for instance the government wants the water level higher, however the municipality wants it lower for homes. Careful consideration is needed to satisfy all party's if possible.

Furthermore, the island's growing drinking water demand, especially during peak tourist seasons, requires careful management. Setting a cap on the number of tourists can help control water consumption, while certain areas can be designated for water collection and retention.

Finally, expanding the island to prevent saltwater intrusion is feasible, provided a thorough understanding of the island's water balance is achieved beforehand. Collaboration and adaptability are key to ensuring a resilient freshwater supply on Terschelling for the future.

By integrating stakeholder perspectives, enhancing local autonomy, and implementing sustainable water management strategies tailored to each sector, Terschelling can secure a resilient freshwater supply amidst rising sea levels and climate change. Regular collaboration, innovative solutions such as saline farming, and local water extraction initiatives will help safeguard the island's future.

6.2 Discussion

The solutions are an attempt to enable people's enjoyment of the island for years to come. Making sure that the island is still fully habitable for all stakeholders in 2100. However, with the constant rising sea levels, after 2100 the question still remains, how to deal with the rising sea levels.
The report attempts to give a broad picture of possibility's that are possible in 2100. There is a maximum and a minimum which is accounted for, however changes between now and then can still occur changing the amount of depletion of the saltwater bubble.

The saline cultivation and dairy farm suggestions are possible however, the amount of mg/l salt in the soil is not calculated and thus there is a possibility the production of crops and fodder is not possible on the more saline possibility in 2100. Therefore, these suggestions might not work in practice.


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Bibliography

(2020, April). Retrieved from Salt farm Texel: https://www.saltfarmtexel.com/

Agriculture, U. N. (n.d.). *Global map of salt-affected soils GSASmap v1.0*. Retrieved from United Nations: https://openknowledge.fao.org/server/api/core/bitstreams/31be1fac-a057-4b6b-80ea-a4554910368c/content

Alphen, M. v., Koenis, M., & Kok, A. (2023). *Sociaal-economische verkenning van*. Wageningen: Wageningen Economic Research.

Bessembinder, J., Bintanja, R., Dorland, R. v., Homan, C., Overbeek, B., Selten, F., & Siegmund, P. (2023, October 9). *KNMI'23 climate scenarios.* Retrieved June 21, 2024, from Koninklijke Nederlandse Meteorologisch Instituut: https://cdn.knmi.nl/system/ckeditor/attachment_files/data/000/000/358/original/KNMI23_climate_scenarios_user_report.pdf

Deltares. (2024-a). *Cross sections reference, hd and hn.*

Deltares. (2024-b, February 28). *Freshwater supplies on Terschelling - February 2024*. Retrieved April 1, 2024, from Deltares: https://specials.deltares.nl/february_2024/freshwater_supplies_on_terschelling

Deltares. (2024-c). *Groundwater map Terschelling.* Deltares.

E. Barrett-Lennard, R. G. (1996). *Saltbush for water-table reduction and land rehabilitation.*

E., A. (2023, March 21). *Germany: A Culture of Precision and Efficiency*. Retrieved September 24, 2024, from LinkedIn: https://www.linkedin.com/pulse/germany-culture-precision-efficiency-abderrahmane-el-masaoul/

East Atlantic Flyway. (n.d.). Retrieved from Wadden Sea World Heritage : https://flyway.waddensea-worldheritage.org/east-atlantic-flyway

Erwin, R. M. (2002). *Integrated Management of Waterbirds: Beyond the Conventional.* Waterbird society .

Gemeente Terschelling. (2023, October 26). Functies Polder Algemeen. (ARC, Interviewer)

I.N. Daliakopoulos, I. T. (2016). *The threat of soil salinity: A European scale review.*

Kok, A., Vollenbroek, R., Bronts, M., Geurkink, B., & Moraca, M. (2024). *Waterbeschikbaarheid Noord-Nederland; Analyse voor de periode 2010 - 2022.* Leeuwarden: Waddenacademie.

Köster Waterproofing Systems. (n.d.). *W - Waterproofing systems - Basement, tank, and area waterproofing*. Retrieved June 29, 2024, from Köster Waterproofing Systems: https://www.koester.eu/de_en/pgroup-133-1/waterproofing+systems+-+basement%2C+tank%2C+and+area+waterproofing.html

Medenblik, J. (2024, June 11). Water management Terschelling. (M. Hendriks, Interviewer)

Mugatha, S. M., Ogutu, J. O., Piepho, H.-P., & M., M. J. (2024). *Bird species richness and diversity responses to land use change in the Lake Victoria Basin, Kenya*. Scientific reports .

Nationaal Park Schiermonikoog. (n.d.). *Duinbeheer*. Retrieved June 27, 2024, from Nationaal Park Schiermonikoog: https://www.np-schiermonnikoog.nl/over-het-park/beheer/duinbeheer/

Nationaal Park Schiermonnikoog. (n.d.). *Waterbeheer*. Retrieved June 27, 2024, from Nationaal Park Schiermonnikoog: https://www.np-schiermonnikoog.nl/over-het-park/beheer/waterbeheer/

Natura 2000. (n.d.). *Duinen Terschelling*. Retrieved June 28, 2024, from Natura 2000: https://www.natura2000.nl/gebieden/friesland/duinen-terschelling

Ocean Circulation Patterns. (2024). Retrieved from My NASA Data: https://mynasadata.larc.nasa.gov/basic-page/ocean-circulation-patterns

Omrop Fryslân. (2024, January 15). *Terschellingers en wetenschappers bundelen krachten in strijd tegen klimaatverandering*. Retrieved April 1, 2024, from NOS: https://nos.nl/artikel/2505022-terschellingers-en-wetenschappers-bundelen-krachten-in-strijd-tegen-klimaatverandering

Opportunities and limitations for animal production from saline land. (2001, Januari). Retrieved from Researchgate: https://www.researchgate.net/publication/269391514_Opportunities_and_limitations_for_animal_production_from_saline_land

Otte, P. J. (n.d.). *Bird migration in a warming world: A review of challenges and.* Retrieved from Student theses : https://fse.studenttheses.ub.rug.nl/28339/1/Essay_migration_P.Otte.pdf

Pauw, P. S. (2015, June 8). *Field and Model Investigations of Freshwater Lenses in Coastal Aquifers*. Retrieved June 22, 2024, from Hydrology: https://www.hydrology.nl/images/docs/dutch/2015.06.08_Pauw.pdf

Ready Made Basements. (2016). *German engineered basement systems*. Retrieved June 29, 2024, from Ready Made Basements: http://www.readymadebasements.co.uk/brochure.pdf

Rijksoverheid. (n.d.). *Taken van een gemeente*. Retrieved June 28, 2024, from Rijksoverheid: https://www.rijksoverheid.nl/onderwerpen/gemeenten/taken-gemeente

Saline agriculture. (2024). Retrieved from Salt doctors: https://www.thesaltdoctors.com/

Staatsbosbeheer. (n.d.). *Waterpracht Terschelling*. Retrieved June 27, 2024, from Staatsbosbeheer: https://www.staatsbosbeheer.nl/wat-we-doen/werk-in-uitvoering/terschelling-waterpracht

UnitedNations. (2009). *How to Feed the World in 2050.* Rome.

van Alphen, M., Koenis, M., & Kok, A. (2024). *Sociaal-economische verkenning van*. Wageningen: Wageningen Economic Research Wageningen Economic Research. Retrieved from https://edepot.wur.nl/645859

van der Zee, F., de Knegt, B., Meeuwsen, H., Sanders, M., Veraart, J., Grashof-Bokdam, C., & Wegman, R. (2016). *Waterwinning en natuur* . Wageningen : Wageningen University .

VVV Terschelling. (n.d.). Retrieved from https://www.rtl.nl/lifestyle/artikel/5450461/terschelling-wadden-wadlopen-strand-zeehonden-schapen-unesco-flang-de-pan

Waddenfonds. (n.d.). *Wij & Wadvogels*. Retrieved from Waddenfonds: https://waddenfonds.nl/projecten/project-2/

Wagenaar, R. (n.d.). *Drenkelingenhuisje Terschelling.* Terschelling.

Appendixes

Appendix A: KNMI’23 scenario table with country averages

Season	Variable	Indicator	The climate in 1991-2020 = reference period	**2050** (2036 – 2065)				**2100** (2086 – 2115)			
				Ld	**Ln**	**Hd**	**Hn**	**Ld**	**Ln**	**Hd**	**Hn**
	Global temperature rise compared to 1991 - 2020			+0.8°C	+0.8°C	+1.5°C	+1.5°C	+0.8°C	+0.8°C	+4.0°C	+4.0°C
	Global temperature rise compared to 1850 - 1900			+1.7°C	+1.7°C	+2.4°C	+2.4°C	+1.7°C	+1.7°C	+4.9°C	+4.9°C
Year	Sea level along the Dutch coastline	Average level	0 cm	+24 (16 – 34) cm	+24 (16 – 34) cm	+27 (19 – 38) cm	+27 (19 – 38) cm	+44 (26 – 73) cm	+44 (26 – 73) cm	+82 (59 – 124) cm	+82 (59 – 124) cm
		Rate of change	3 mm/year	+3 (1 – 6) mm/year	+3 (1 – 6) mm/year	+5 (4 – 8) mm/year	+5 (4 – 8) mm/year	-1 (-4 – 4) mm/year	-1 (-4 – 4) mm/year	11 (6 – 23) mm/year	11 (6 – 23) mm/year
	Temperature	Average	10.5°C	+0.9°C	+0.9°C	+1.6°C	+1.5°C	+0.9°C	+0.9°C	+4.4°C	+4.1°C
	Precipitation	Amount	851 mm	0%	+3%	-2%	+3%	0%	+3%	-3%	+8%
	Solar radiation	Average	120 W/m^2	+5.8 W/m^2	+4.8 W/m^2	+5.4 W/m^2	+2.5 W/m^2	+5.8 W/m^2	+4.8 W/m^2	+7.1 W/m^2	+1.3 W/m^2
	Humidity	Amount	82%	-1%	-1%	-1%	0%	-1%	-1%	-1%	+1%
	Evaporation	Potential evaporation (Makkink)	603 mm	+7%	+6%	+9%	+6%	+7%	+6%	+17%	+11%
	Wind	Average wind speed	4.8 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	0.0 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s
Winter	Temperature	Average	3.9°C	+0.7°C	+0.7°C	+1.2°C	+1.3°C	+0.7°C	+0.7°C	+3.7°C	+3.9°C
		Average daily maximum	6.3°C	+0.7°C	+0.7°C	+1.1°C	+1.2°C	+0.7°C	+0.7°C	+3.5°C	+3.6°C
		Average daily minimum	1.4°C	+0.7°C	+0.7°C	+1.2°C	+1.4°C	+0.7°C	+0.7°C	+4.0°C	+4.2°C
	Precipitation	Amount	218 mm	+4%	+5%	+4%	+7%	+4%	+5%	+14%	+24%
		Number of wet days (0.1 mm)	57 days	0.0 days	0.0 days	0.0 days	+0.6 days	0.0 days	0.0 days	0.0 days	+1.1 days
		Days with >= 10 mm	5.4 days	+0.04 days	+0.5 days	+0.5 days	+0.8 days	+0.4 days	+0.5 days	+1.6 days	+2.5 days
		10-day total precipitation exceeded once every 10 years	109 mm^3	-2%	+2%	0%	+2%	-2%	+2%	+8%	+15%
	Solar radiation	Average	120 W/m^2	+1.2 W/m^2	+1.5 W/m^2	+0.8 W/m^2	+0.4 W/m^2	+1.2 W/m^2	+1.5 W/m^2	-0.7 W/m^2	-1.5 W/m^2
	Humidity	Amount	87%	0%	0%	+1%	+1%	0%	0%	+1%	+2%
	Wind	Average wind speed	5.6 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	+0.1 m/s	-0.1 m/s	-0.1 m/s	+0.1 m/s	+0.2 m/s
		Days with wind direction between north and west	13 days	+0.1 days	-0.8 days	0.0 days	+0.1 days	+0.1 days	-0.8 days	-1.7 days	-1.0 days

Table…: KNMI’23 scenario table with country averages (Bessembinder, et al., 2023)

Season	Variable	Indicator	The climate in 1991-2020 = reference period	**2050** (2036 – 2065)				**2100** (2086 – 2115)			
				Ld	**Ln**	**Hd**	**Hn**	**Ld**	**Ln**	**Hd**	**Hn**
Spring	Temperature	Average	9.6°C	+0.8°C	+0.7°C	+1.3°C	+1.1°C	+0.8°C	+0.7°C	+3.6°C	+3.3°C
		Average daily maximum	13.7°C	+0.9°C	+0.8°C	+1.2°C	+1.0°C	+0.9°C	+0.8°C	+3.3°C	+2.9°C
		Average daily minimum	5.5°C	+0.7°C	+0.7°C	+1.4°C	+1.3°C	+0.7°C	+0.7°C	+3.9°C	+3.7°C
	Precipitation	Amount	153 mm	+1%	+3%	0%	+4%	+1%	+3%	+4%	+10%
	Solar radiation	Average	161 W/m²	+6.6 W/m²	+5.2 W/m²	+3.2 W/m²	+0.8 W/m²	+6.6 W/m²	+5.2 W/m²	-0.2 W/m²	-4.8 W/m²
	Humidity	Average relatively humidity	78%	-1%	-1%	0%	0%	-1%	-1%	+1%	+2%
	Evaporation	Potential evaporation (Makkink)	190 mm	+6%	+5%	+6%	+4%	+6%	+5%	+10%	+6%
	Drought	Maximum precipitation deficit April and May	76 mm	+11%	+6%	+15%	+5%	+11%	+6%	+21%	+8%
	Wind	Average wind speed	4.7 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	0.0 m/s	-0.1 m/s	-0.1 m/s	+0.1 m/s	0.0 m/s
Summer	Temperature	Average	3.9°C	+0.7°C	+0.7°C	+1.2°C	+1.3°C	+0.7°C	+0.7°C	+3.7°C	+3.9°C
		Average daily maximum	6.3°C	+0.7°C	+0.7°C	+1.1°C	+1.2°C	+0.7°C	+0.7°C	+3.5°C	+3.6°C
		Average daily minimum	1.4°C	+0.7°C	+0.7°C	+1.2°C	+1.4°C	+0.7°C	+0.7°C	+4.0°C	+4.2°C
	Precipitation	Amount	218 mm	+4%	+5%	+4%	+7%	+4%	+5%	+14%	+24%
		Number of wet days (0.1 mm)	57 days	0.0 days	0.0 days	0.0 days	+0.6 days	0.0 days	0.0 days	0.0 days	+1.1 days
		Days with >= 10 mm	5.4 days	+0.04 days	+0.5 days	+0.5 days	+0.8 days	+0.4 days	+0.5 days	+1.6 days	+2.5 days
		10-day total precipitation exceeded once every 10 years	109 mm³	-2%	+2%	0%	+2%	-2%	+2%	+8%	+15%
	Solar radiation	Average	120 W/m²	+1.2 W/m²	+1.5 W/m²	+0.8 W/m²	+0.4 W/m²	+1.2 W/m²	+1.5 W/m²	-0.7 W/m²	-1.5 W/m²
	Humidity	Amount	87%	0%	0%	+1%	+1%	0%	0%	+1%	+2%
	Wind	Average wind speed	5.6 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	+0.1 m/s	-0.1 m/s	-0.1 m/s	+0.1 m/s	+0.2 m/s
		Days with wind direction between north and west	13 days	+0.1 days	-0.8 days	0.0 days	+0.1 days	+0.1 days	-0.8 days	-1.7 days	-1.0 days

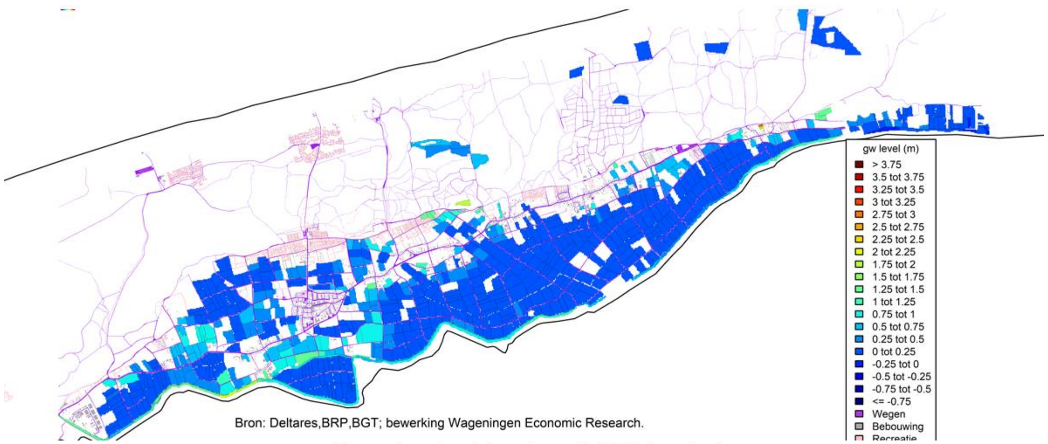
Season	Variable	Indicator	The climate in 1991-2020 = reference period	**2050** (2036 – 2065)				**2100** (2086 – 2115)			
				Ld	Ln	Hd	Hn	Ld	Ln	Hd	Hn
Fall	Temperature	Average	3.9°C	+0.7°C	+0.7°C	+1.2°C	+1.3°C	+0.7°C	+0.7°C	+3.7°C	+3.9°C
		Average daily maximum	6.3°C	+0.7°C	+0.7°C	+1.1°C	+1.2°C	+0.7°C	+0.7°C	+3.5°C	+3.6°C
		Average daily minimum	1.4°C	+0.7°C	+0.7°C	+1.2°C	+1.4°C	+0.7°C	+0.7°C	+4.0°C	+4.2°C
	Precipitation	Amount	218 mm	+4%	+5%	+4%	+7%	+4%	+5%	+14%	+24%
		Number of wet days (0.1 mm)	57 days	0.0 days	0.0 days	0.0 days	+0.6 days	0.0 days	0.0 days	0.0 days	+1.1 days
		Days with >= 10 mm	5.4 days	+0.04 days	+0.5 days	+0.5 days	+0.8 days	+0.4 days	+0.5 days	+1.6 days	+2.5 days
		10-day total precipitation exceeded once every 10 years	109 mm^3	-2%	+2%	0%	+2%	-2%	+2%	+8%	+15%
	Solar radiation	Average	120 W/m^2	+1.2 W/m^2	+1.5 W/m^2	+0.8 W/m^2	+0.4 W/m^2	+1.2 W/m^2	+1.5 W/m^2	-0.7 W/m^2	-1.5 W/m^2
	Humidity	Amount	87%	0%	0%	+1%	+1%	0%	0%	+1%	+2%
	Wind	Average wind speed	5.6 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	+0.1 m/s	-0.1 m/s	-0.1 m/s	+0.1 m/s	+0.2 m/s
		Days with wind direction between north and west	13 days	+0.1 days	-0.8 days	0.0 days	+0.1 days	+0.1 days	-0.8 days	-1.7 days	-1.0 days

Season	Variable	Indicator	Climate in 1991-2020 = reference period	**2050** (2036-2065)				**2100** (2086-2115)			
				Ld	Ln	Hd	Hn	Ld	Ln	Hd	Hn
Spring	Temperature	average	9.6°C	+0.8°C	+0.7°C	+1.3°C	+1.1°C	+0.8°C	+0.7°C	+3.6°C	+3.3°C
		average daily maximum	13.7°C	+0.9°C	+0.8°C	+1.2°C	+1.0°C	+0.9°C	+0.8°C	+3.3°C	+2.9°C
		average daily minimum	5.5°C	+0.7°C	+0.7°C	+1.4°C	+1.3°C	+0.7°C	+0.7°C	+3.9°C	+3.7°C
	Precipitation	amount	153 mm	+1%	+3%	0%	+4%	+1%	+3%	+4%	+10%
	Solar radiation	average	161 W/m²	+6.6 W/m²	+5.2 W/m²	+3.2 W/m²	+0.8 W/m²	+6.6 W/m²	+5.2 W/m²	-0.2 W/m²	-4.8 W/m²
	Humidity	average relative humidity [2]	78%	-1%	-1%	0%	0%	-1%	-1%	+1%	+2%
	Evaporation	potential evaporation (Makkink)	190 mm	+6%	+5%	+6%	+4%	+6%	+5%	+10%	+6%
	Drought	maximum precipitation deficit April and May	76 mm	+11%	+6%	+15%	+5%	+11%	+6%	+21%	+8%
	Wind	average wind speed	4.7 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	0.0 m/s	-0.1 m/s	-0.1 m/s	+0.1 m/s	0.0 m/s
Summer	Temperature	average	17.3°C	+1.2°C	+1.1°C	+2.1°C	+1.7°C	+1.2°C	+1.1°C	+5.1°C	+4.7°C
		average daily maximum	21.7°C	+1.4°C	+1.2°C	+2.2°C	+1.7°C	+1.4°C	+1.2°C	+5.4°C	+4.7°C
		average daily minimum	12.9°C	+1.0°C	+1.0°C	+1.9°C	+1.8°C	+1.0°C	+1.0°C	+5.0°C	+4.9°C
	Precipitation	amount	235 mm	-8%	-2%	-13%	-5%	-8%	-2%	-29%	-12%
		1-day total precipitation exceeded once every 10 years [4]	63 mm [3]	+4 (1-6)%	+5 (2-7)%	+6 (2-9)%	+9 (5-14)%	+4 (1-6)%	+5 (2-7)%	+15 (5-26)%	+26 (12-41)%
		hourly precipitation exceeded once per year [4]	16 mm [3]	+4 (2-6)%	+6 (3-8)%	+6 (2-9)%	+11 (6-16)%	+4 (2-6)%	+6 (3-8)%	+15 (5-26)%	+31 (17-46)%
	Solar radiation	average	206 W/m²	+12 W/m²	+9.1 W/m²	+14 W/m²	+7.4 W/m²	+12 W/m²	+9.1 W/m²	+24 W/m²	+11 W/m²
	Humidity	average relative humidity [2]	77%	-2%	-1%	-2%	-1%	-2%	-1%	-4%	-1%
	Evaporation	potential evaporation (Makkink)	286 mm	+8%	+6%	+11%	+7%	+8%	+6%	+22%	+14%
	Drought	maximum precipitation deficit for April-September	160 mm	+22%	+13%	+35%	+15%	+22%	+13%	+79%	+37%
		maximum precipitation deficit for April-September exceeded once every 10 years	265 mm	+16%	+9%	+30%	+16%	+16%	+9%	+63%	+30%
	Wind	average wind speed	4.2 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	-0.2 m/s	-0.2 m/s
Autumn	Temperature	average	11.2°C	+1.0°C	+0.9°C	+1.8°C	+1.6°C	+1.0°C	+0.9°C	+5.0°C	+4.8°C
		average daily maximum	14.5°C	+1.1°C	+1.1°C	+1.9°C	+1.6°C	+1.1°C	+1.1°C	+5.1°C	+4.6°C
		average daily minimum	7.8°C	+0.9°C	+0.9°C	+1.8°C	+1.7°C	+0.9°C	+0.9°C	+5.1°C	+5.1°C
	Precipitation	amount	245 mm	+4%	+5%	+1%	+4%	+4%	+5%	+1%	+13%
	Solar radiation	average	77 W/m²	+3.7 W/m²	+3.5 W/m²	+3.7 W/m²	+1.4 W/m²	+3.7 W/m²	+3.5 W/m²	+5.4 W/m²	+1.0 W/m²
	Humidity	average relative humidity [2]	85%	-1%	0%	-1%	0%	-1%	0%	-1%	0%
	Wind	average wind speed	4.7 m/s	-0.1 m/s	-0.1 m/s	-0.1 m/s	0.0 m/s	-0.1 m/s	-0.1 m/s	-0.2 m/s	-0.1 m/s

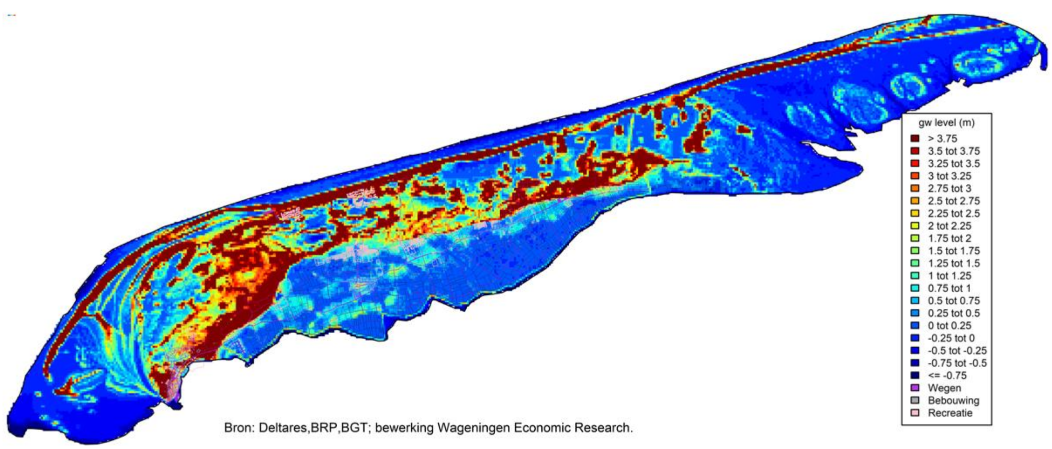
Appendix B: Maps groundwater level

(Deltares, 2024-c)

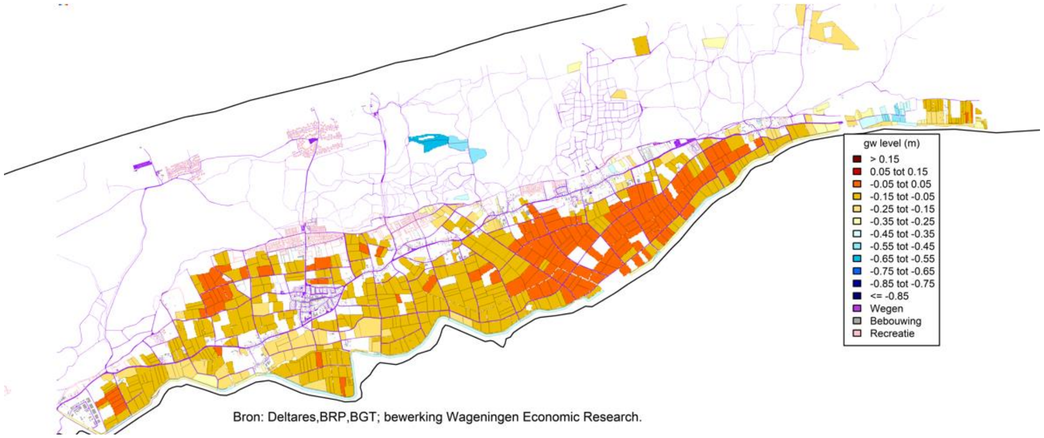
Grondwater Voorjaar 2100 Grasland (meter)



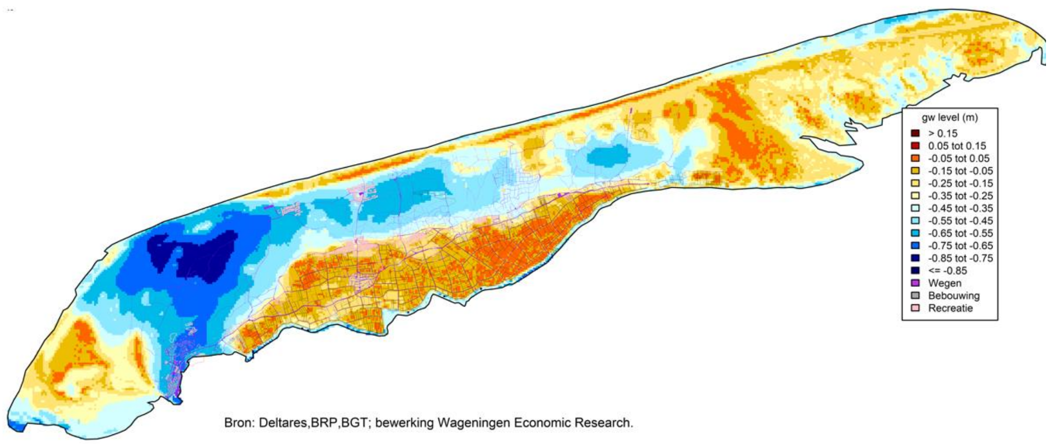
Grondwater Voorjaar 2100 (meter)



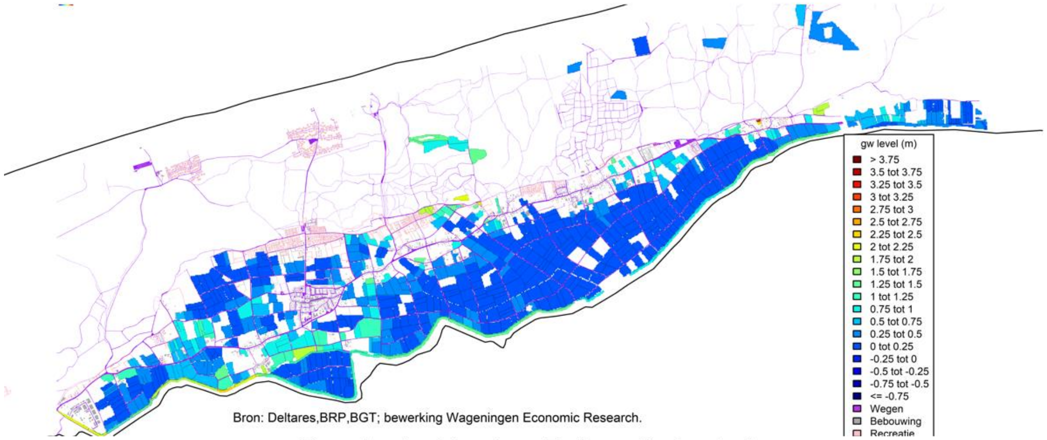
Grondwater Voorjaar diff 2100-Ref Gras (meter)



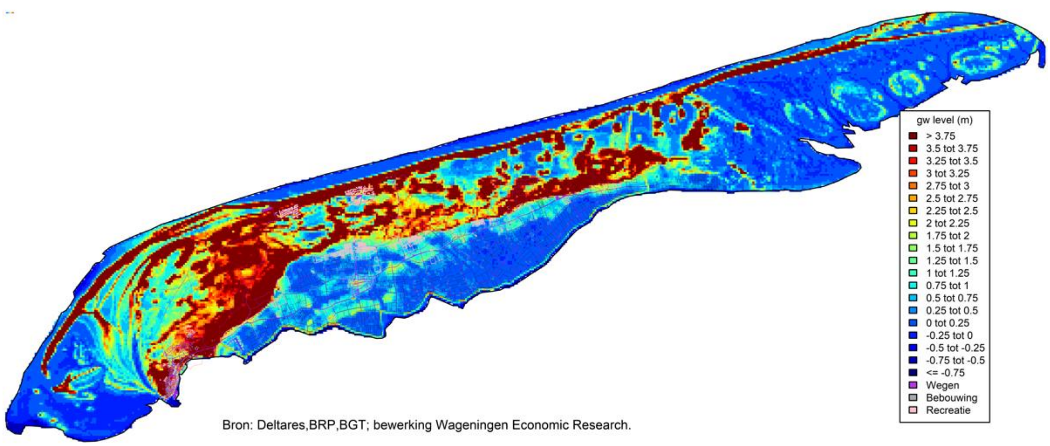
Grondwater Voorjaar diff 2100-Ref (meter)



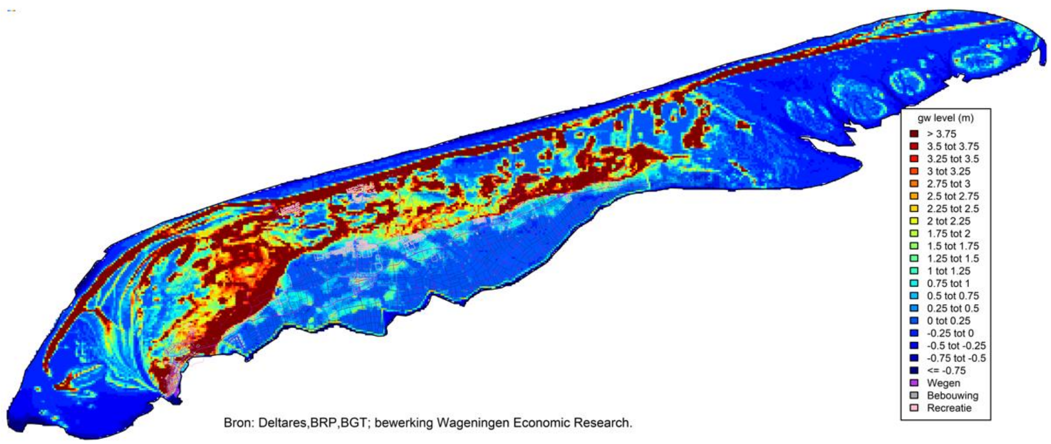
Grondwater Voorjaar Referentie Grasland (meter)



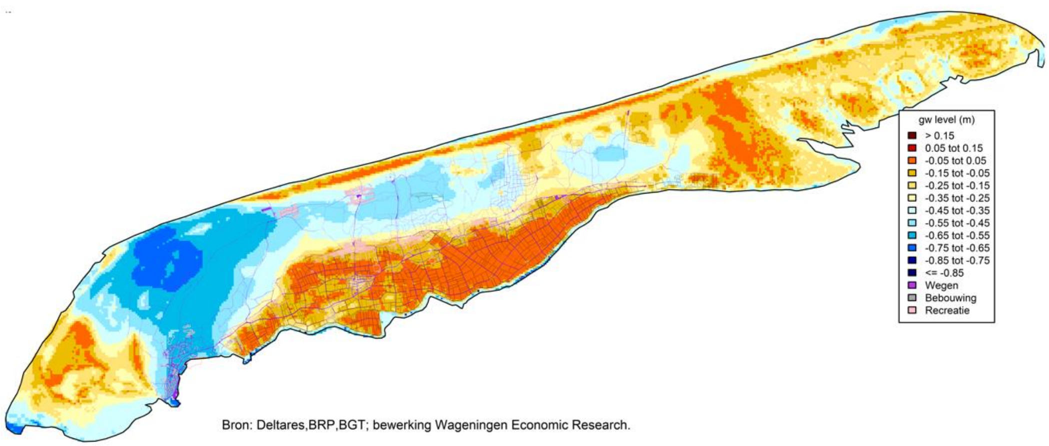
Grondwater Voorjaar Referentie (meter)



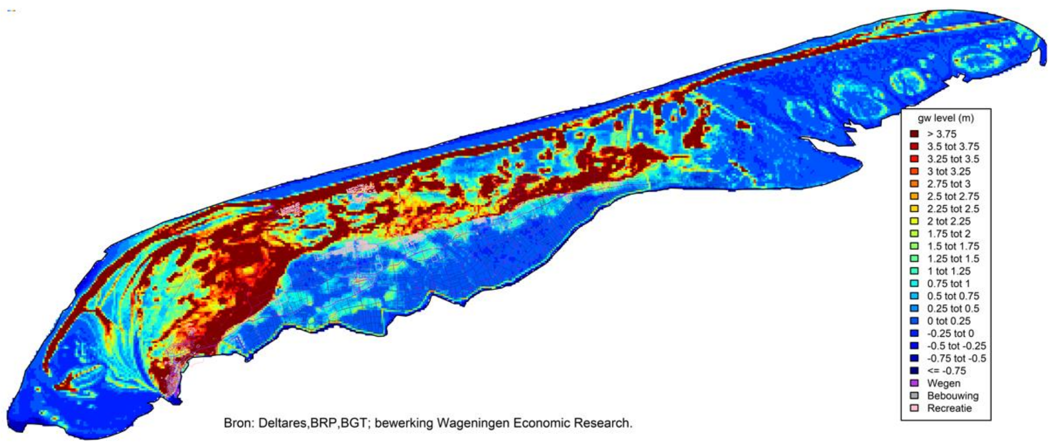
Grondwater Winter 2100 (meter)



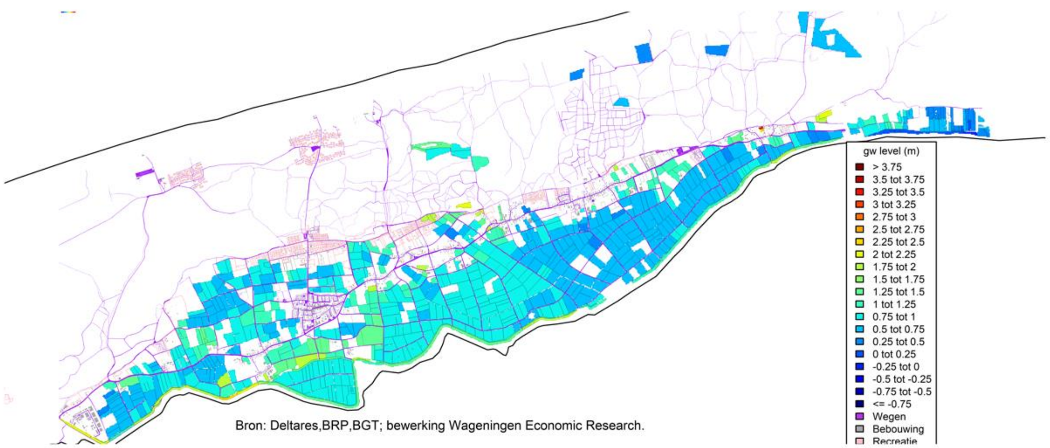
Grondwater Winter diff 2100-Ref (meter)



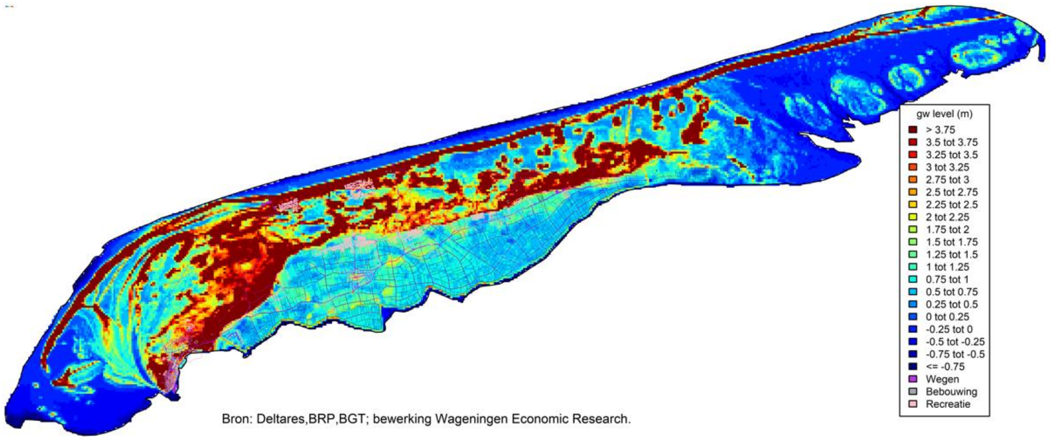
Grondwater Winter Referentie (meter)



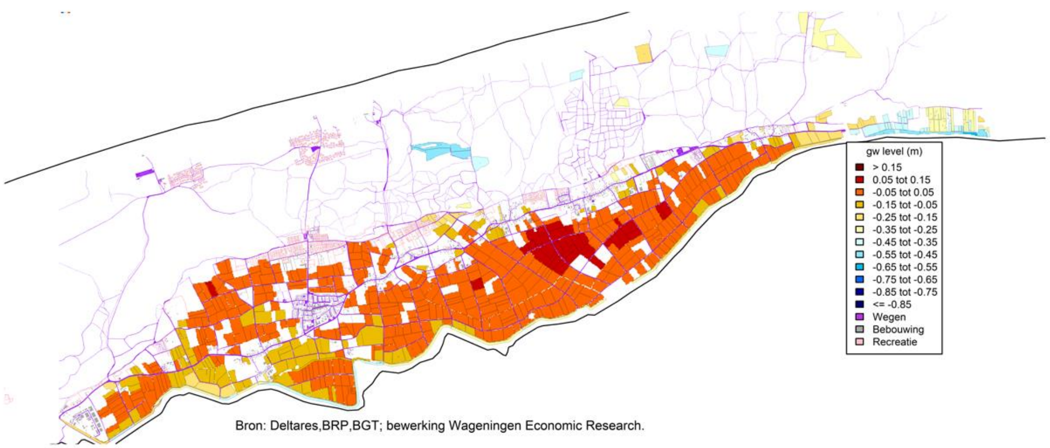
Grondwater Zomer 2100 Grasland (meter)



Grondwater Zomer 2100 (meter)

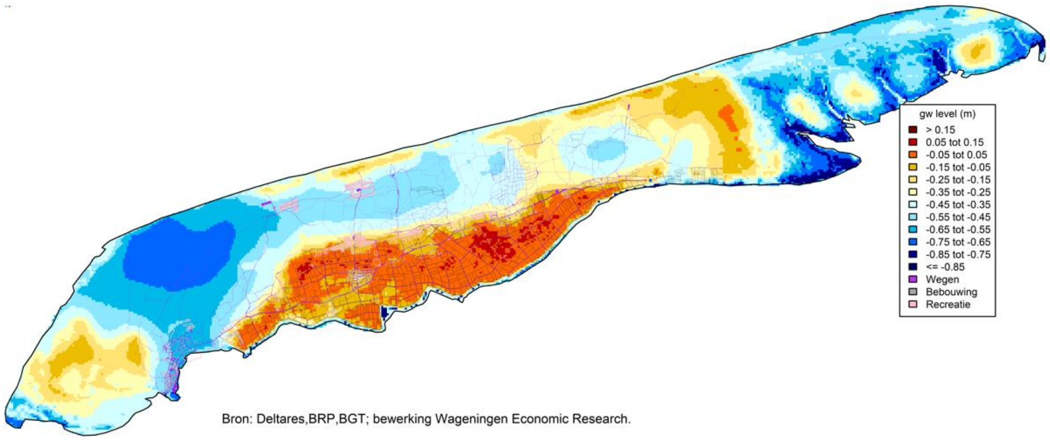


Grondwater Zomer diff 2100-Ref Gras (meter)

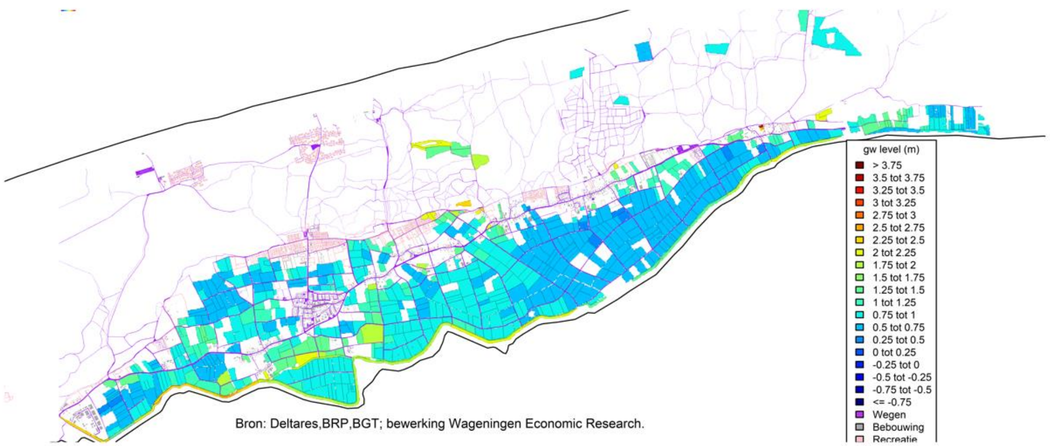


X

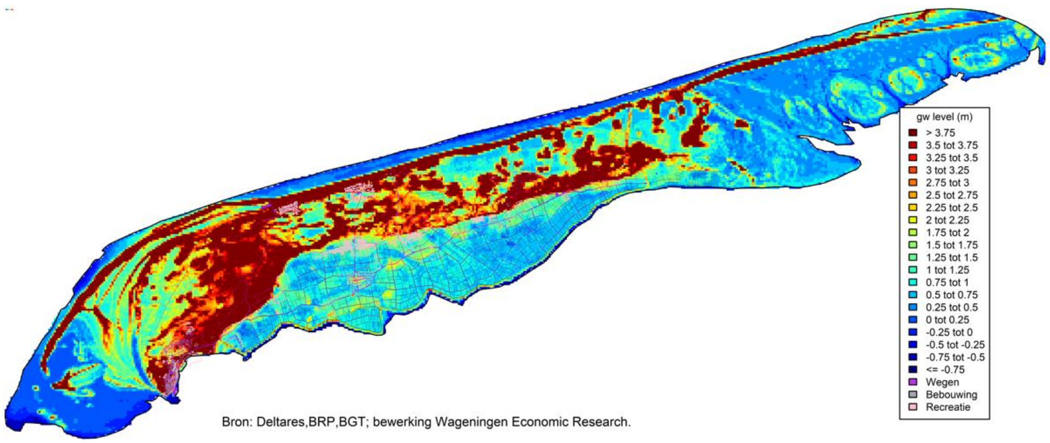
Grondwater Zomer diff 2100-Ref (meter)



Grondwater Zomer Referentie Grasland (meter)



Grondwater Zomer Referentie (meter)



Bron: Deltares,BRP,BGT; bewerking Wageningen Economic Research.

Appendix C: Cross-sections of the island Terschelling

Cross-sections Reference

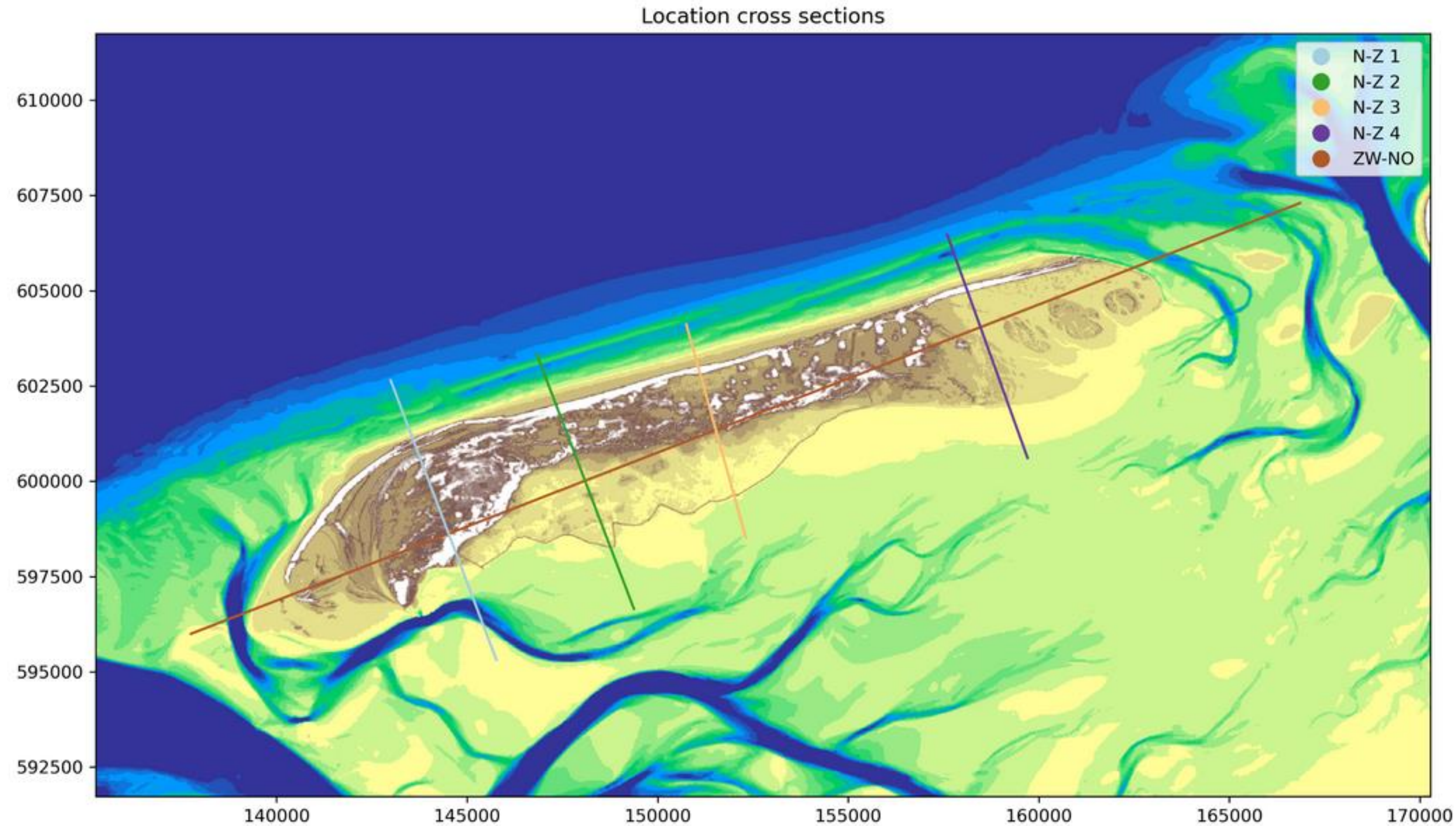


Figure C1: Location cross sections reference (Deltares, 2024-a)

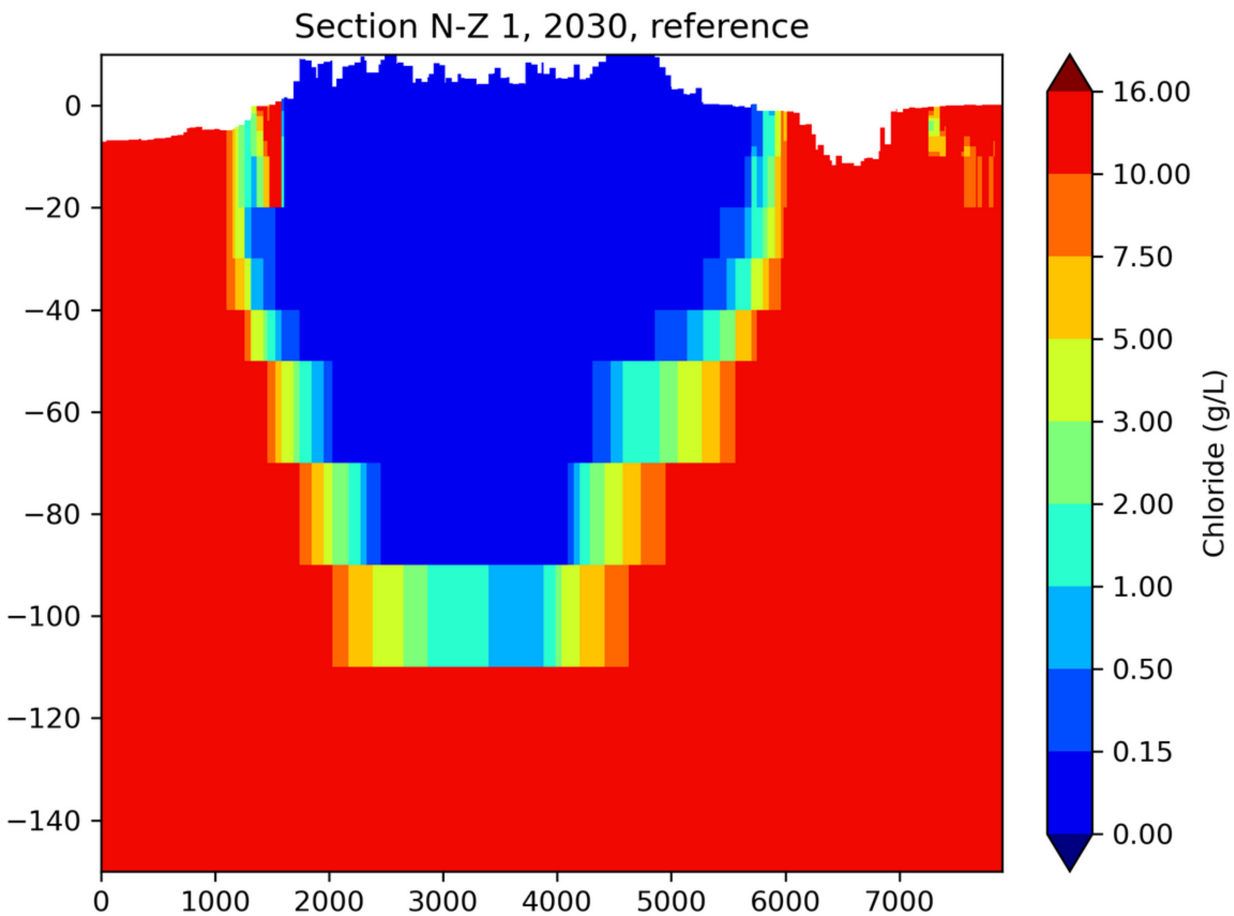


Figure C2: Location cross section N-Z 1 2030 reference (Deltares, 2024-a)

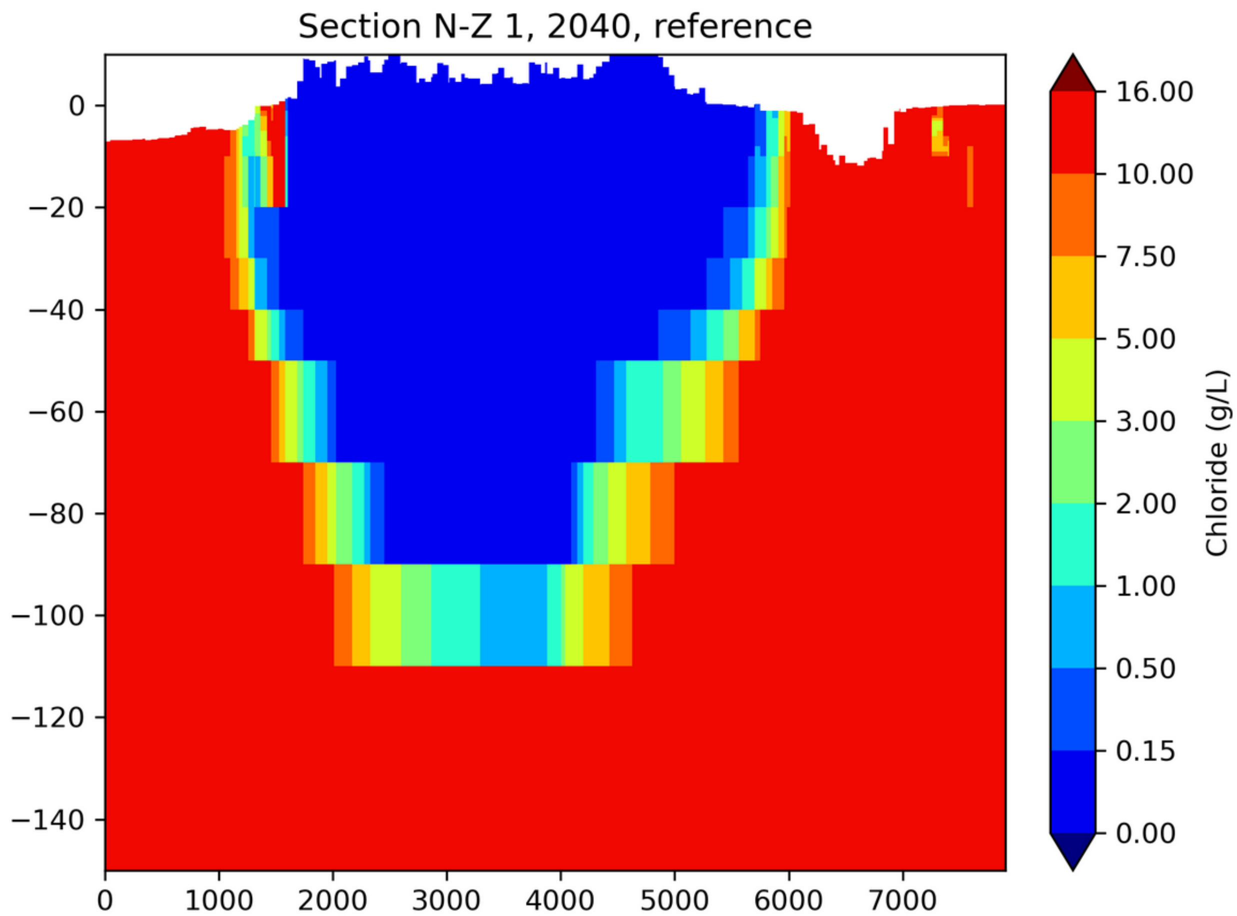


Figure C3: Location cross section N-Z 1 2040 reference (Deltares, 2024-a)

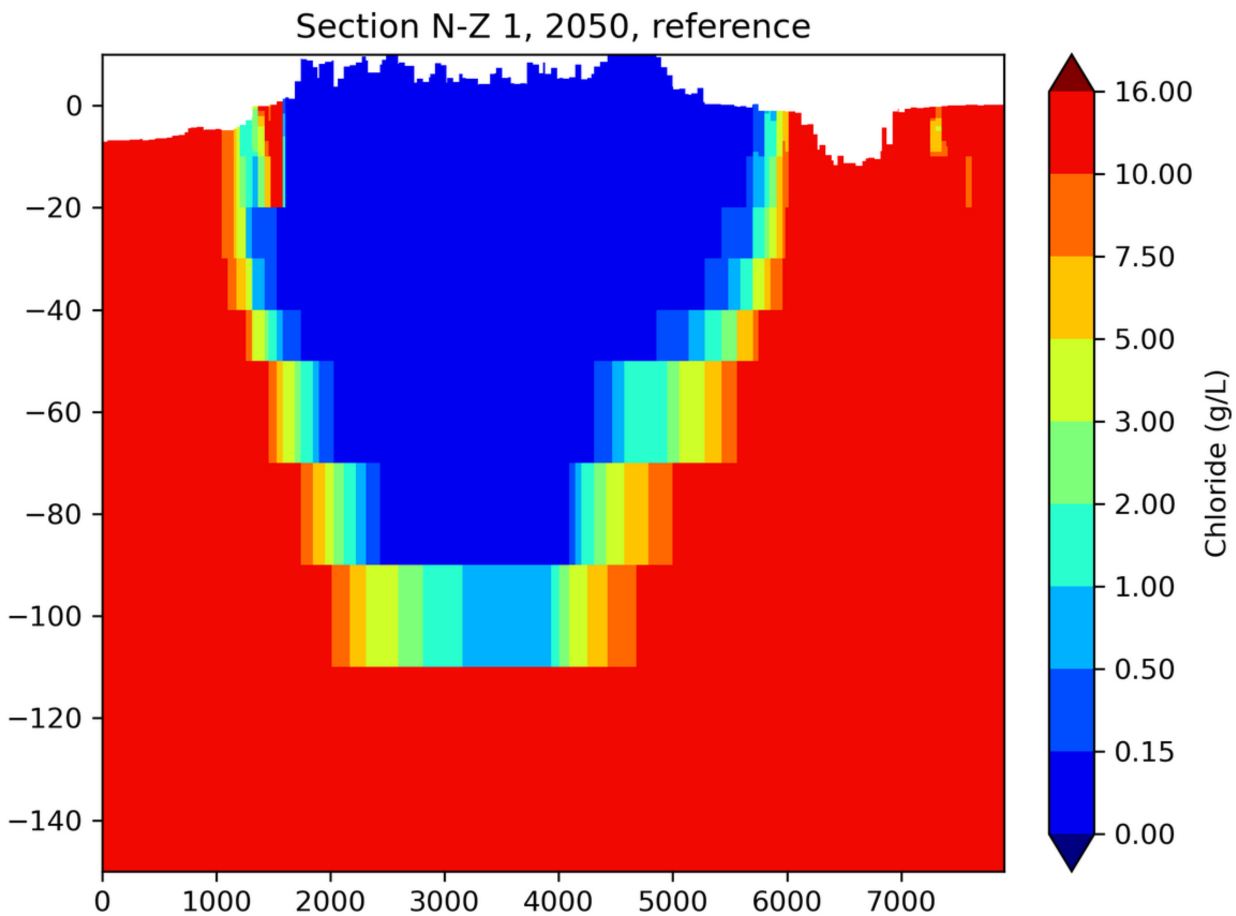


Figure C4: Location cross section N-Z 1 2050 reference (Deltares, 2024-a)

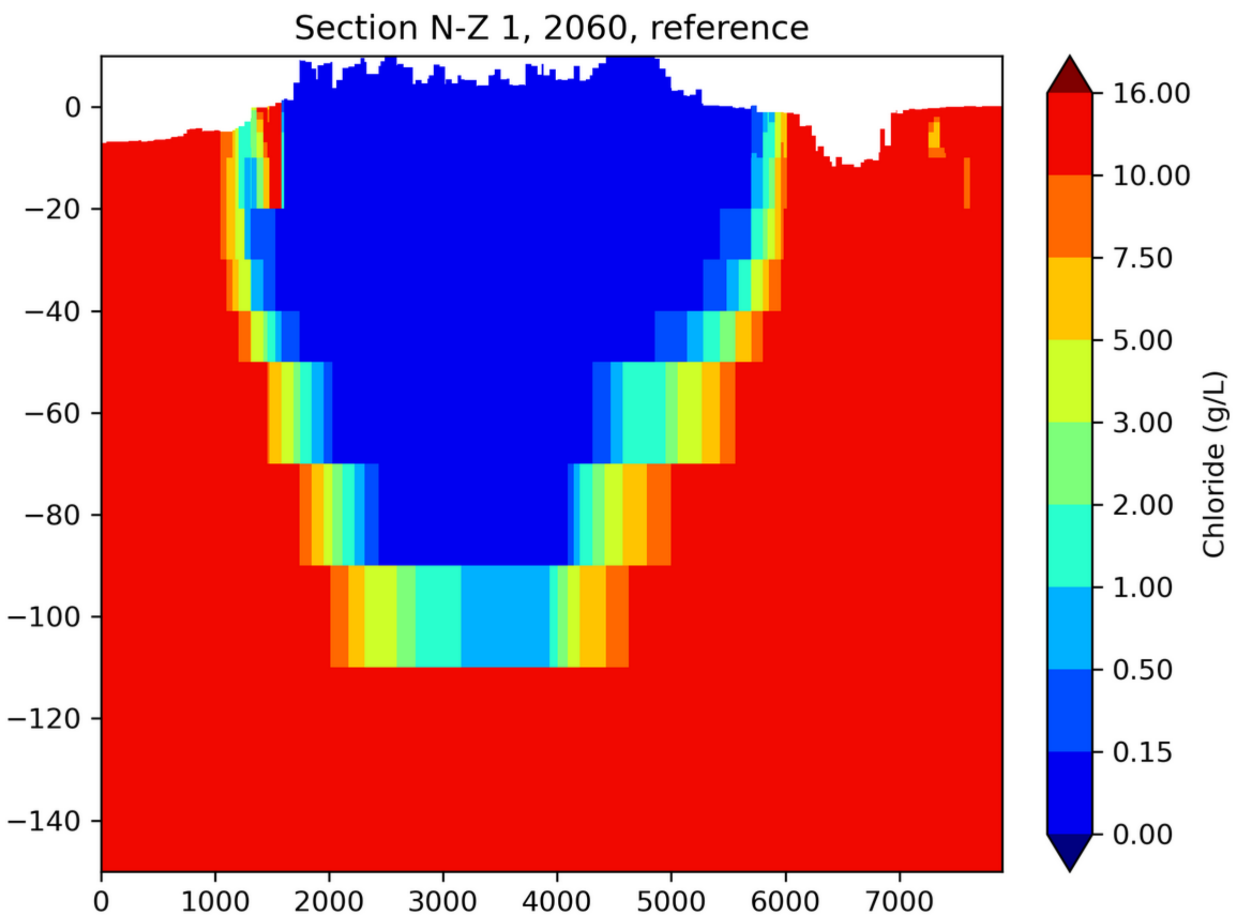


Figure C5: Location cross section N-Z 1 2060 reference (Deltares, 2024-a)

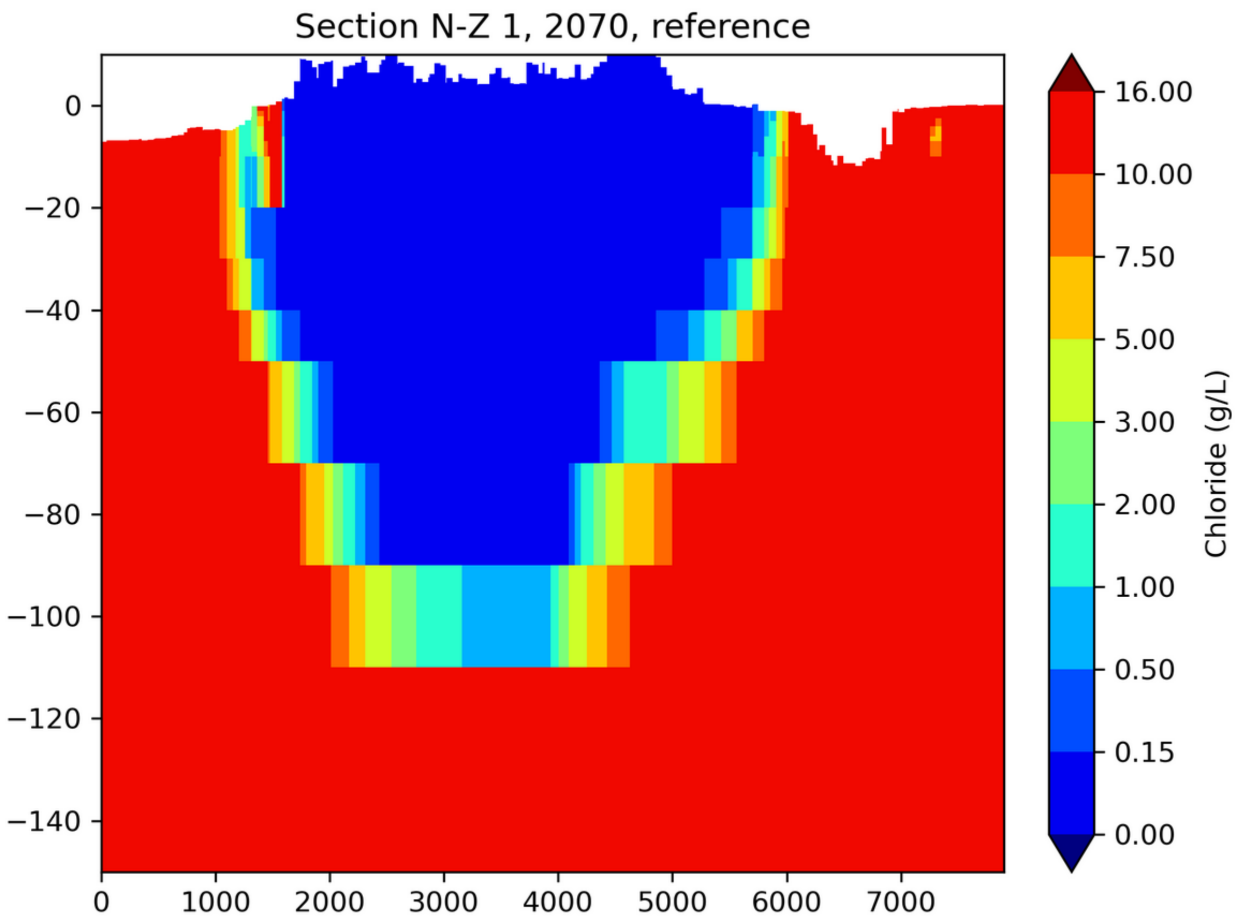


Figure C6: Location cross section N-Z 1 2070 reference (Deltares, 2024-a)

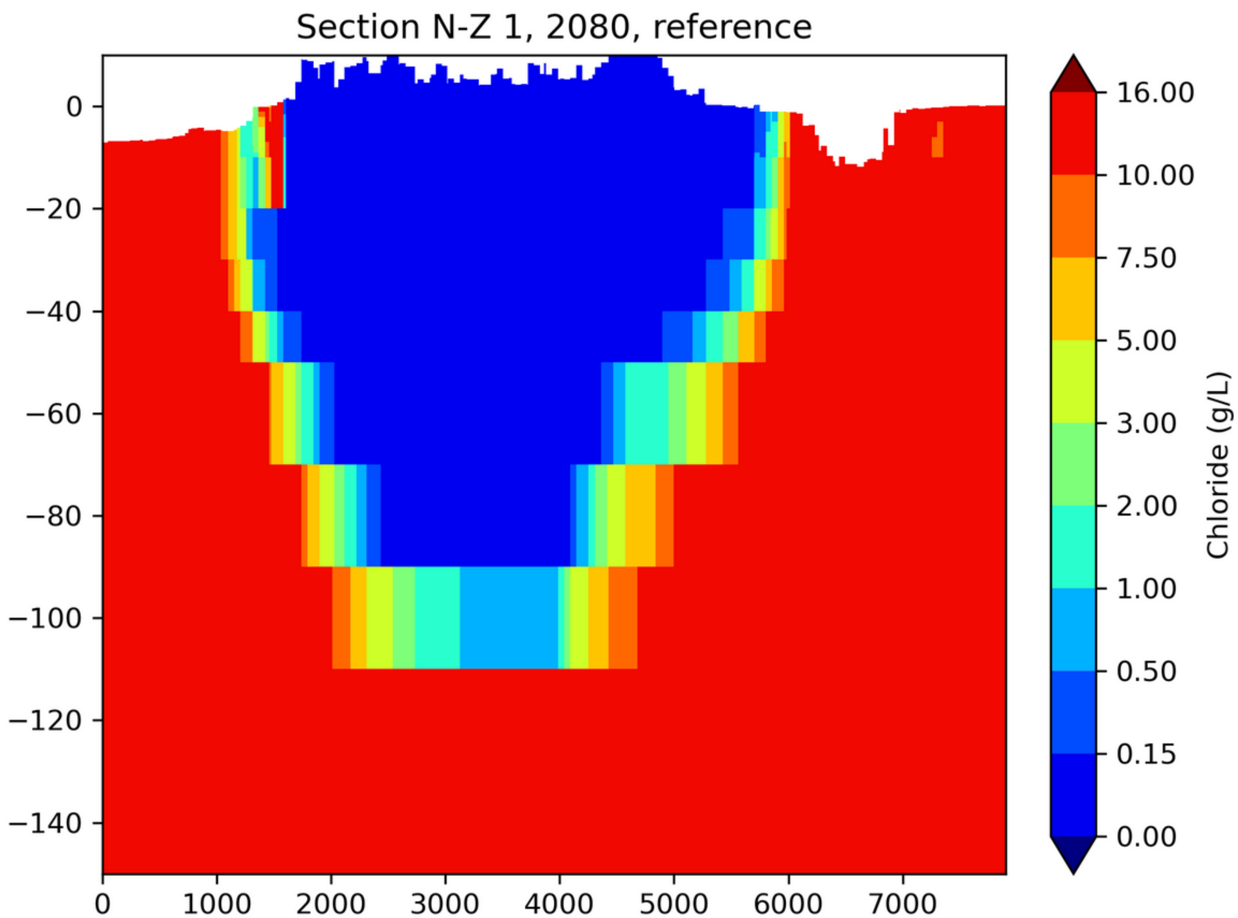


Figure C7: Location cross section N-Z 1 2080 reference (Deltares, 2024-a)

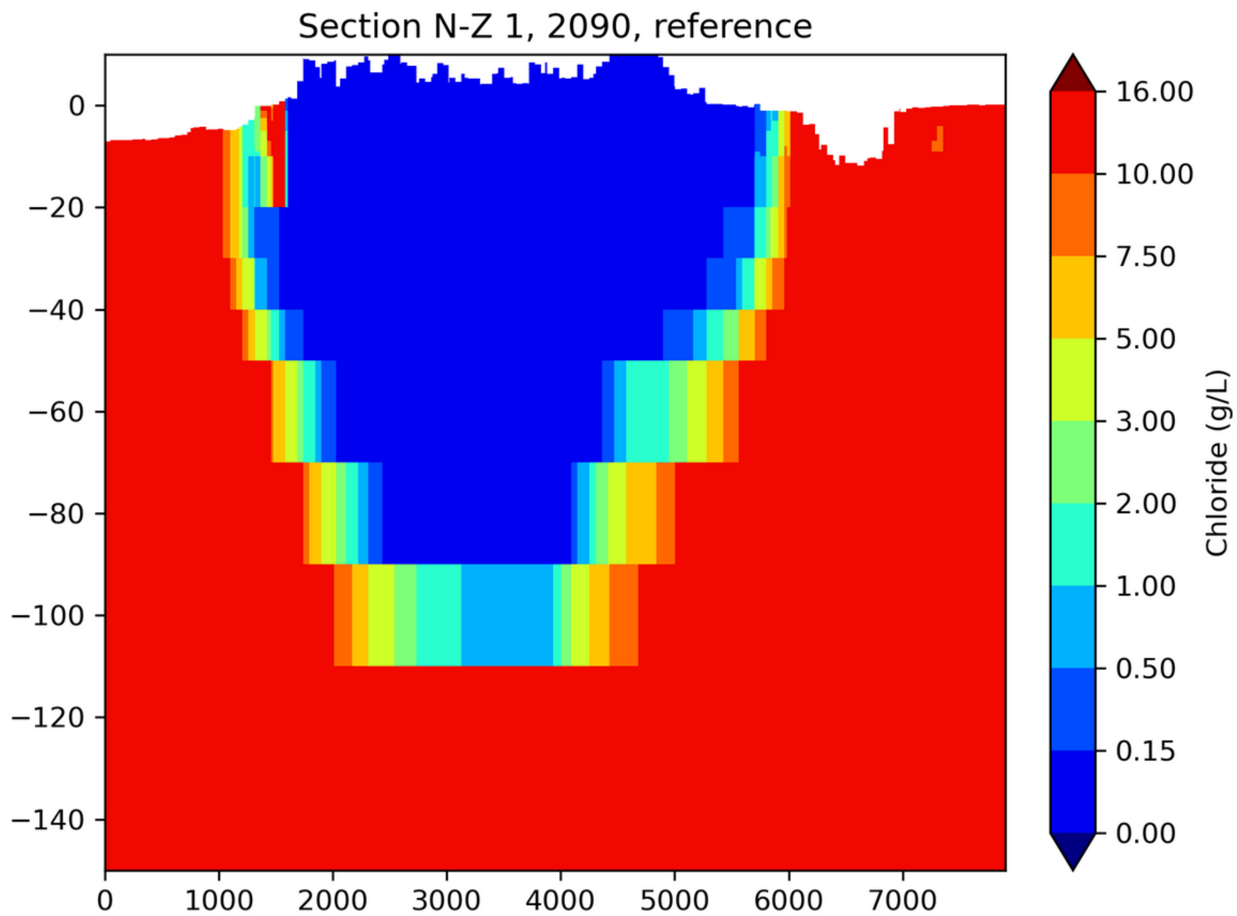


Figure C8: Location cross section N-Z 1 2090 reference (Deltares, 2024-a)

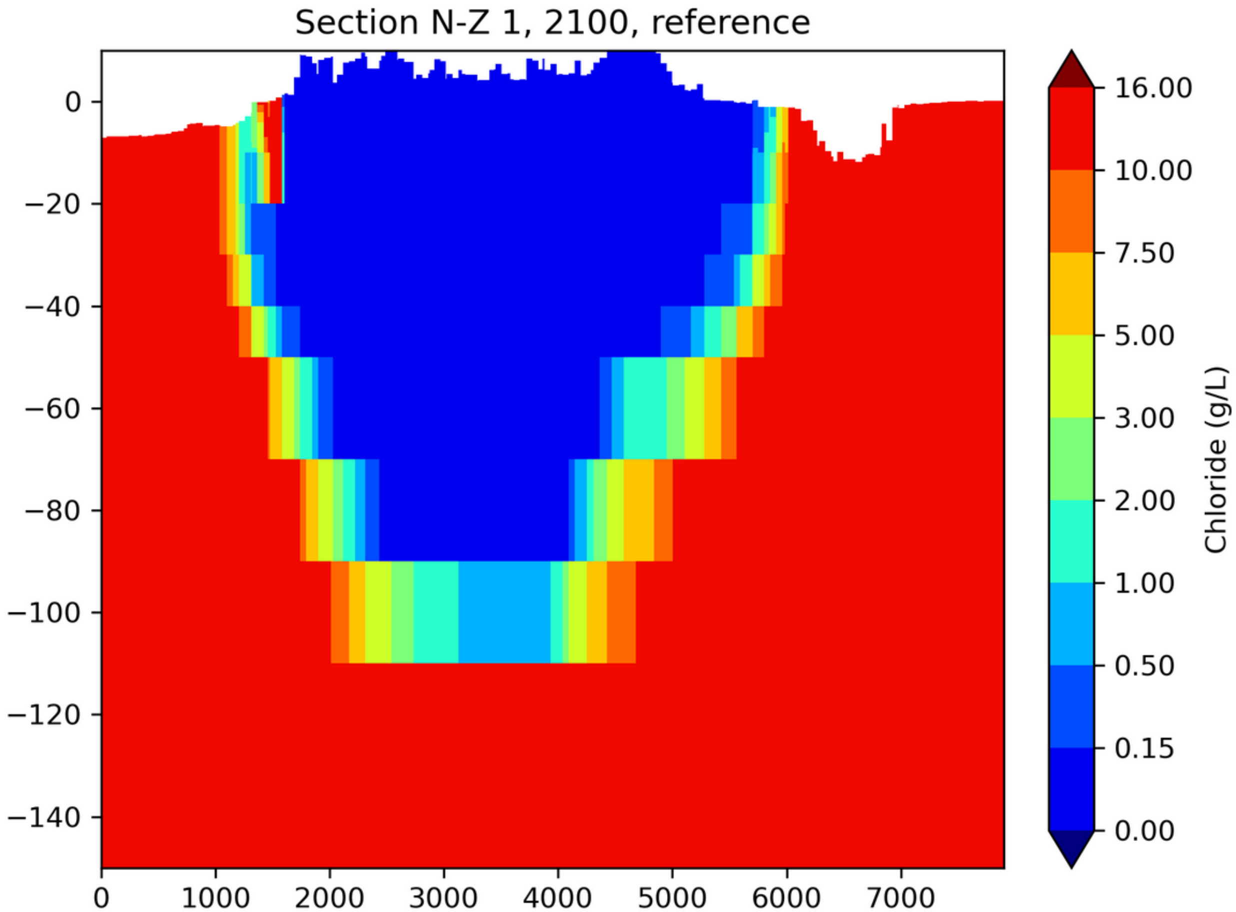


Figure C9: Location cross section N-Z 1 2100 reference (Deltares, 2024-a)

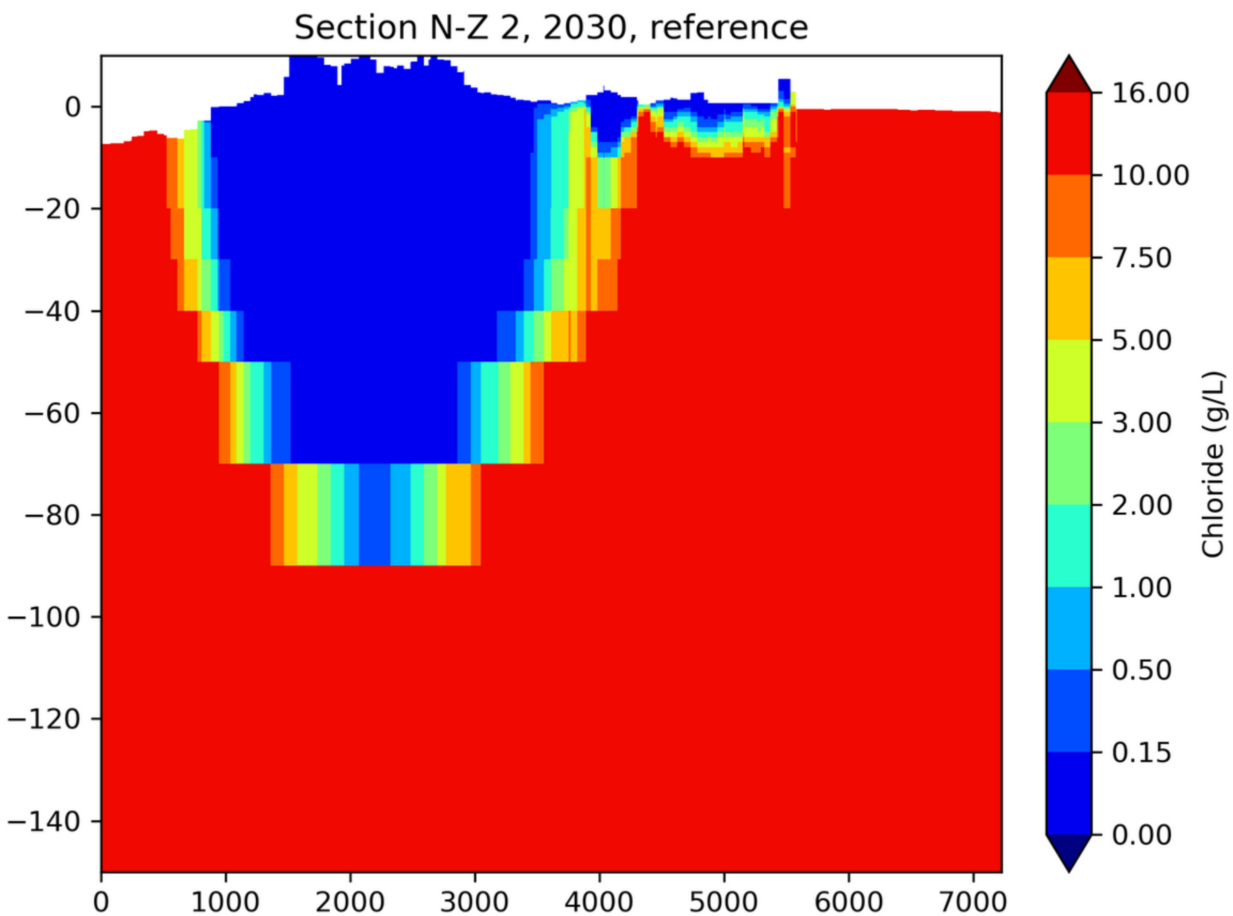


Figure C10: Location cross section N-Z 2 2030 reference (Deltares, 2024-a)

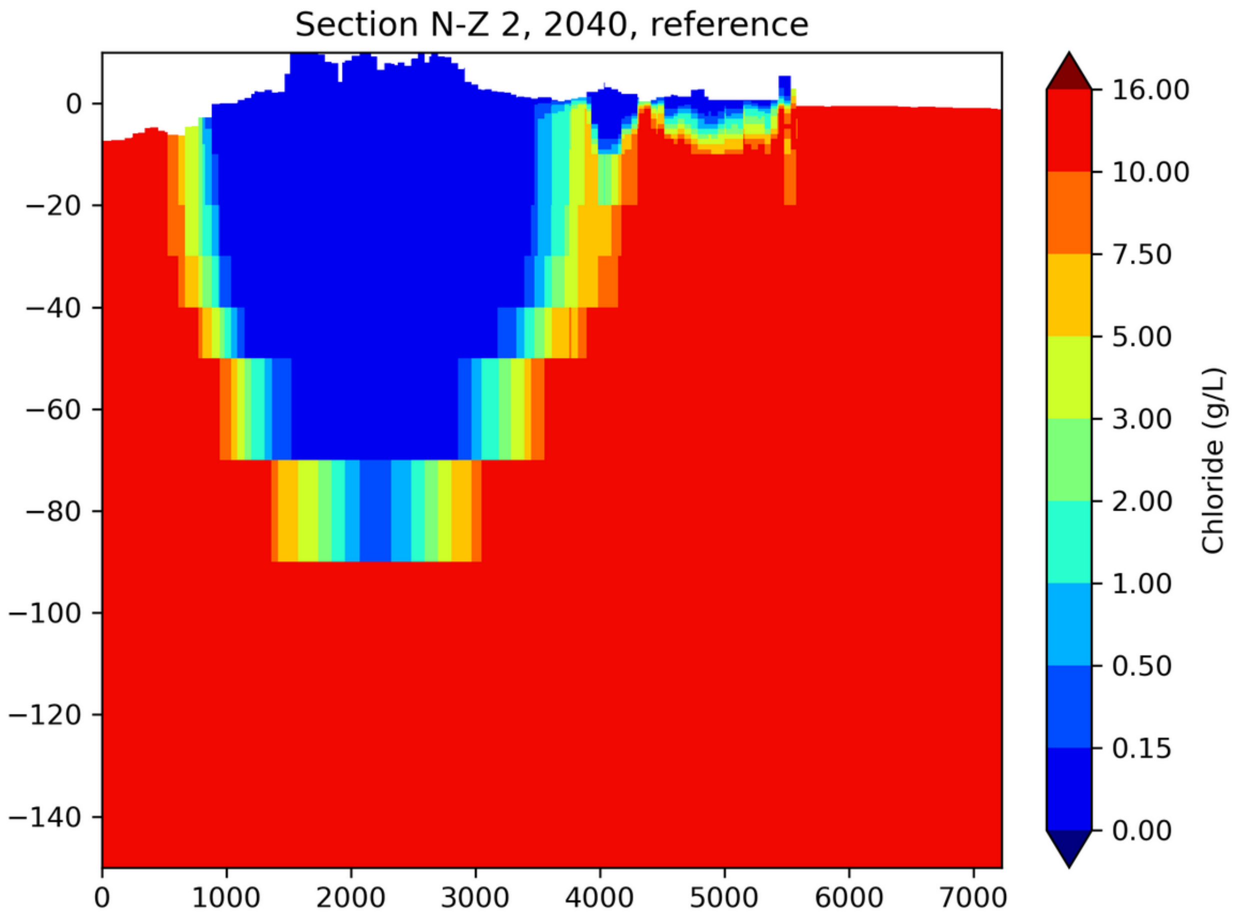


Figure C11: Location cross section N-Z 2 2040 reference (Deltares, 2024-a)

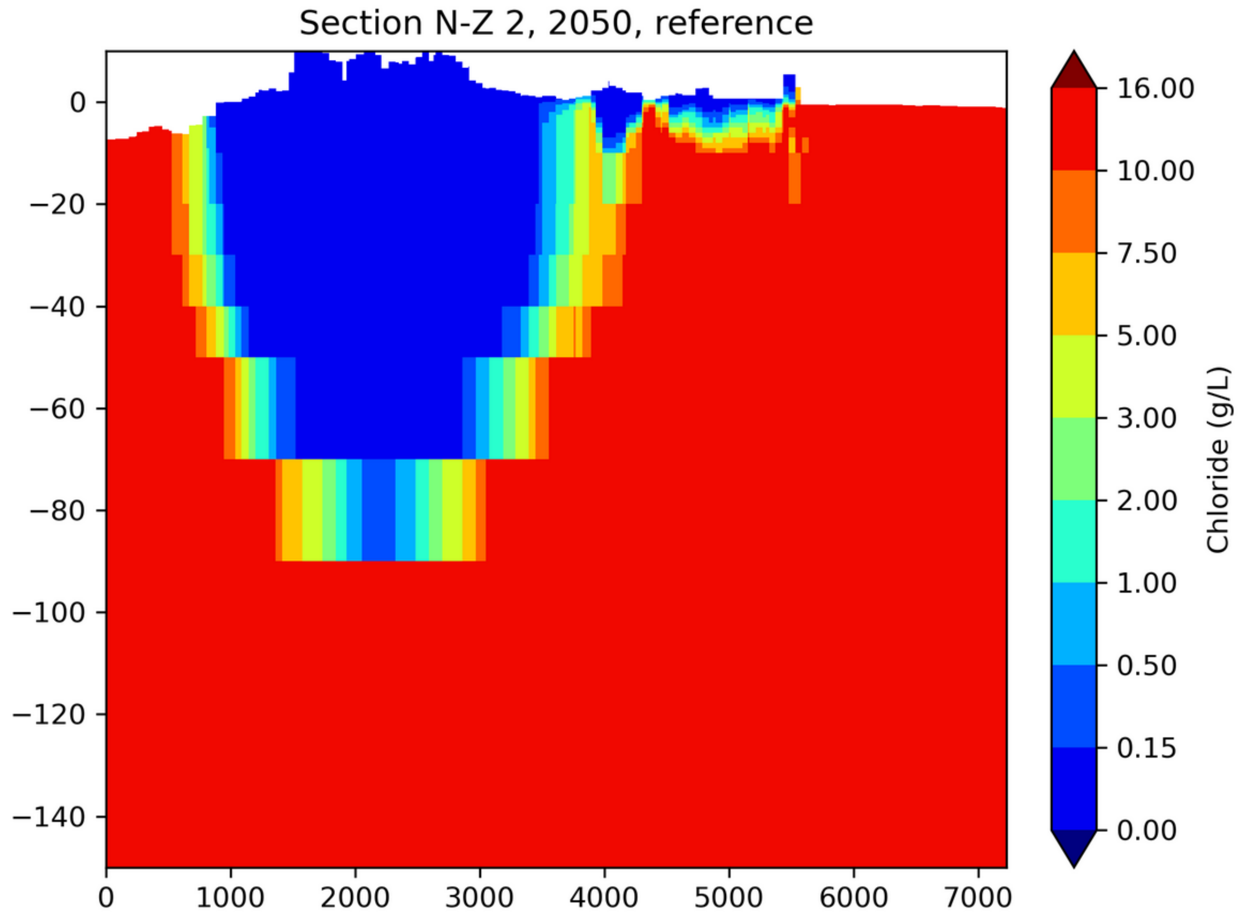


Figure C12: Location cross section N-Z 2 2050 reference (Deltares, 2024-a)

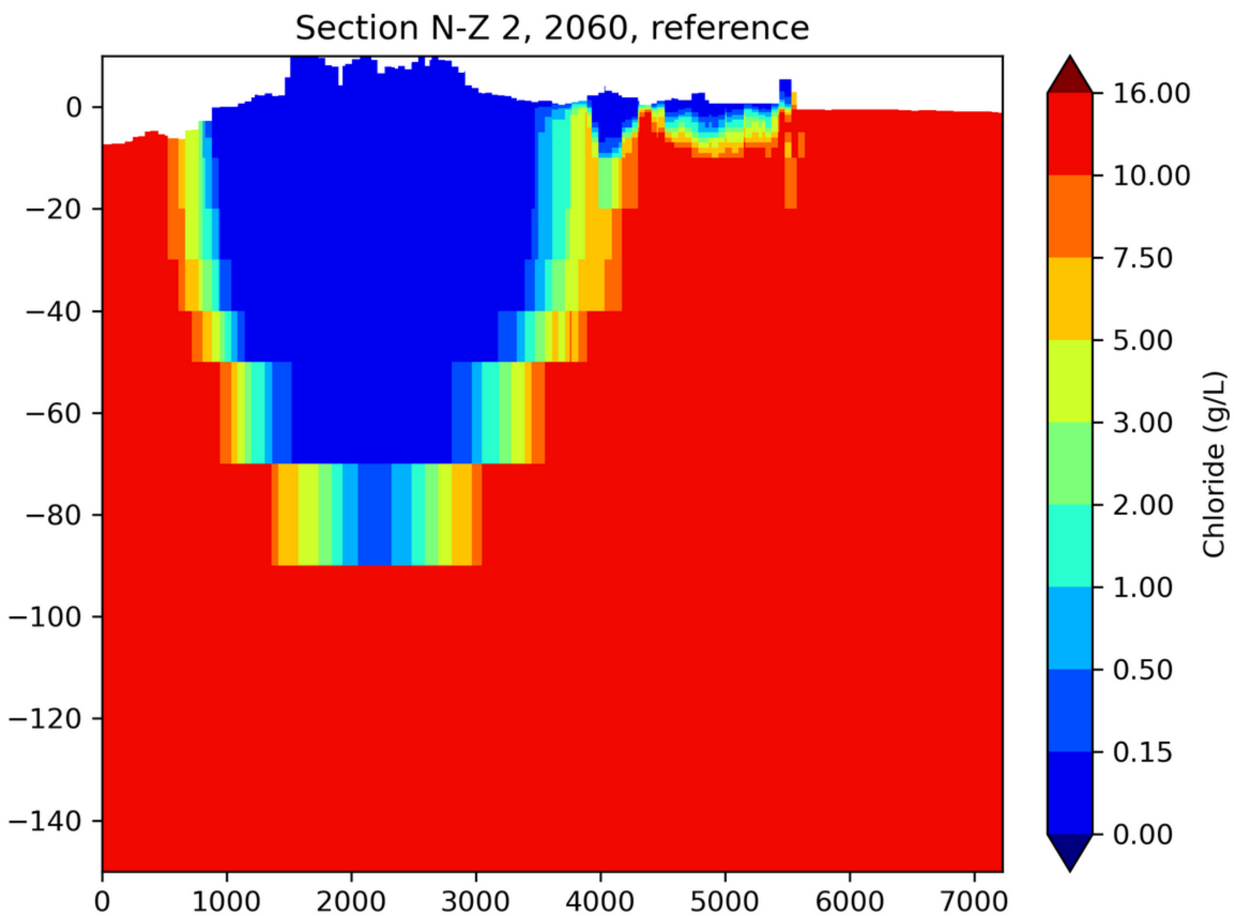


Figure C13: Location cross section N-Z 2 2060 reference (Deltares, 2024-a)

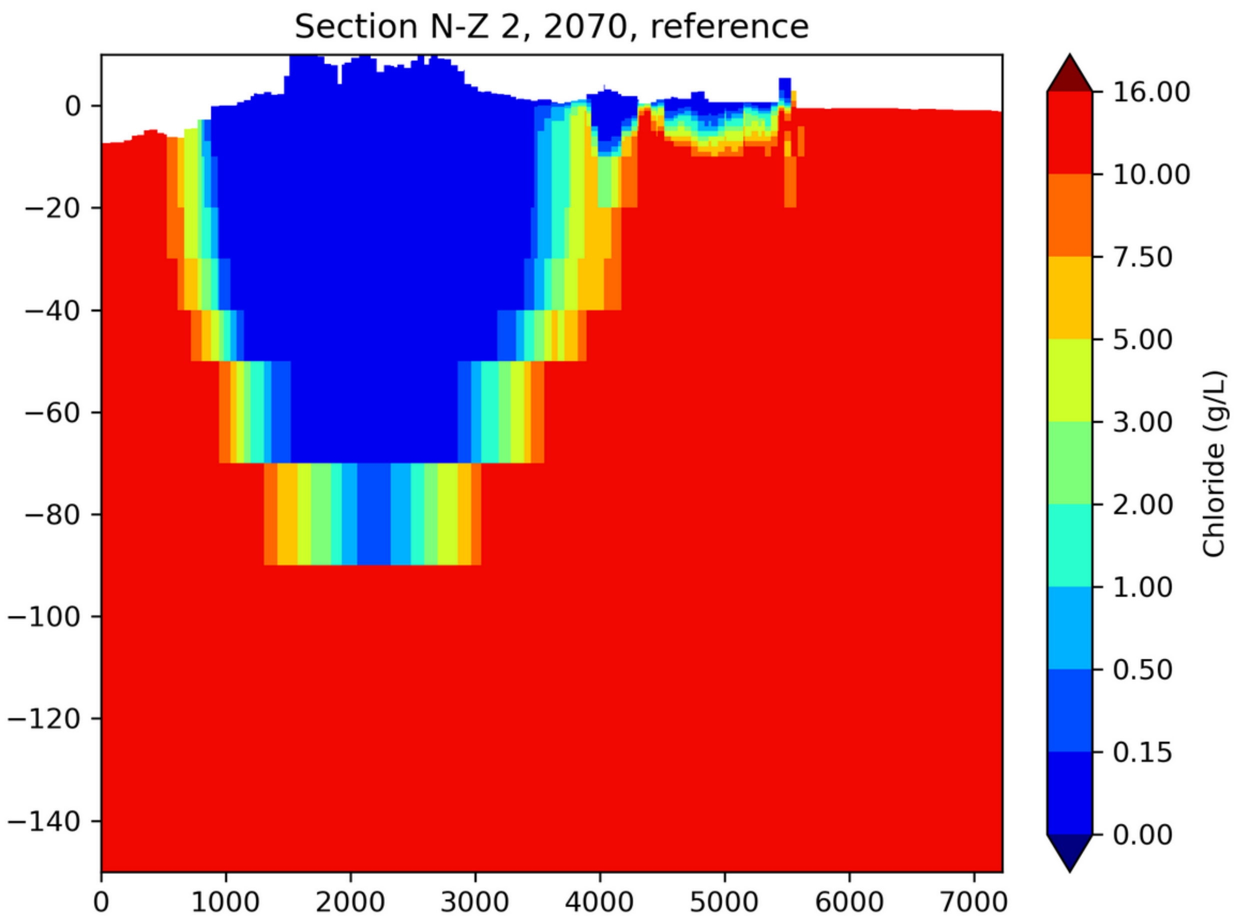


Figure C14: Location cross section N-Z 2 2070 reference (Deltares, 2024-a)

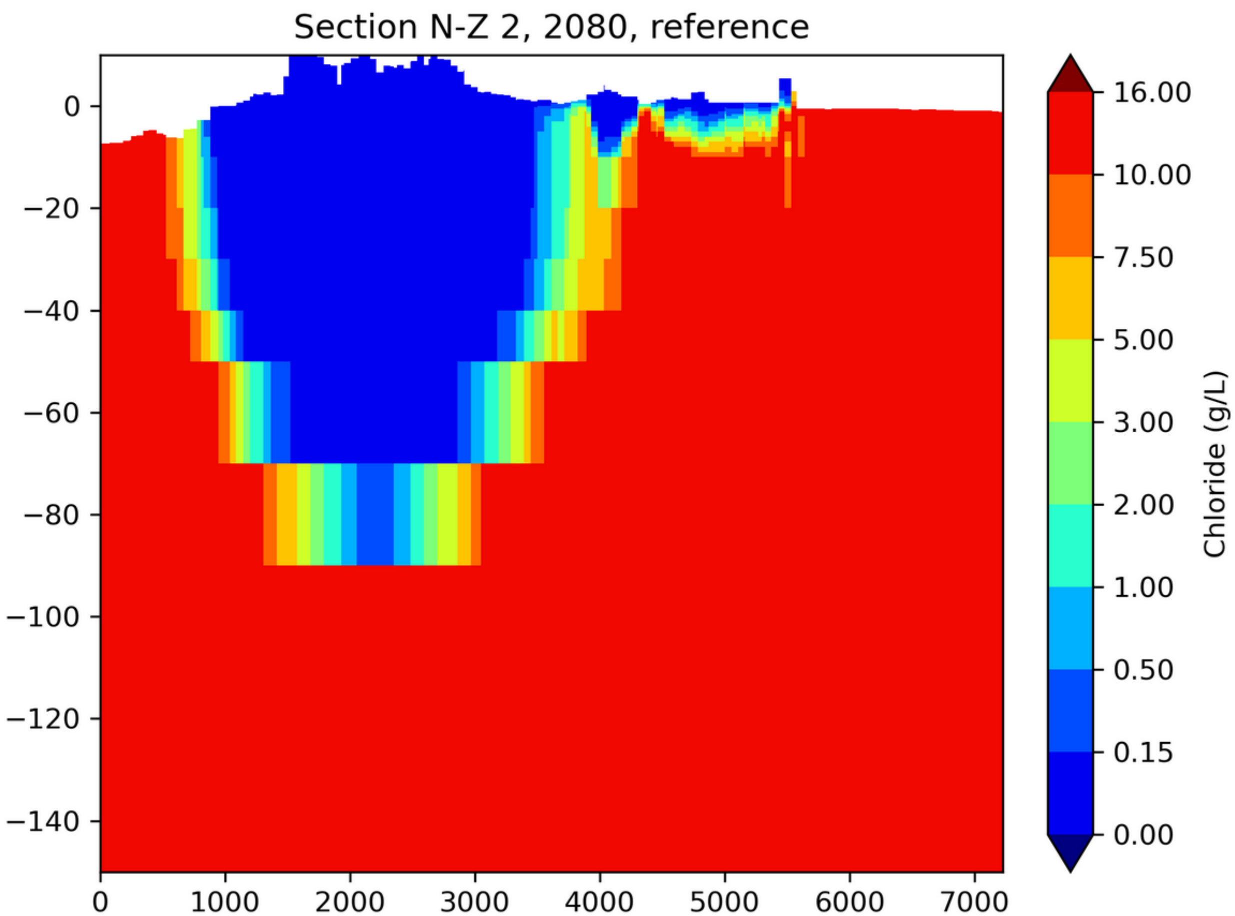


Figure C15: Location cross section N-Z 2 2080 reference (Deltares, 2024-a)

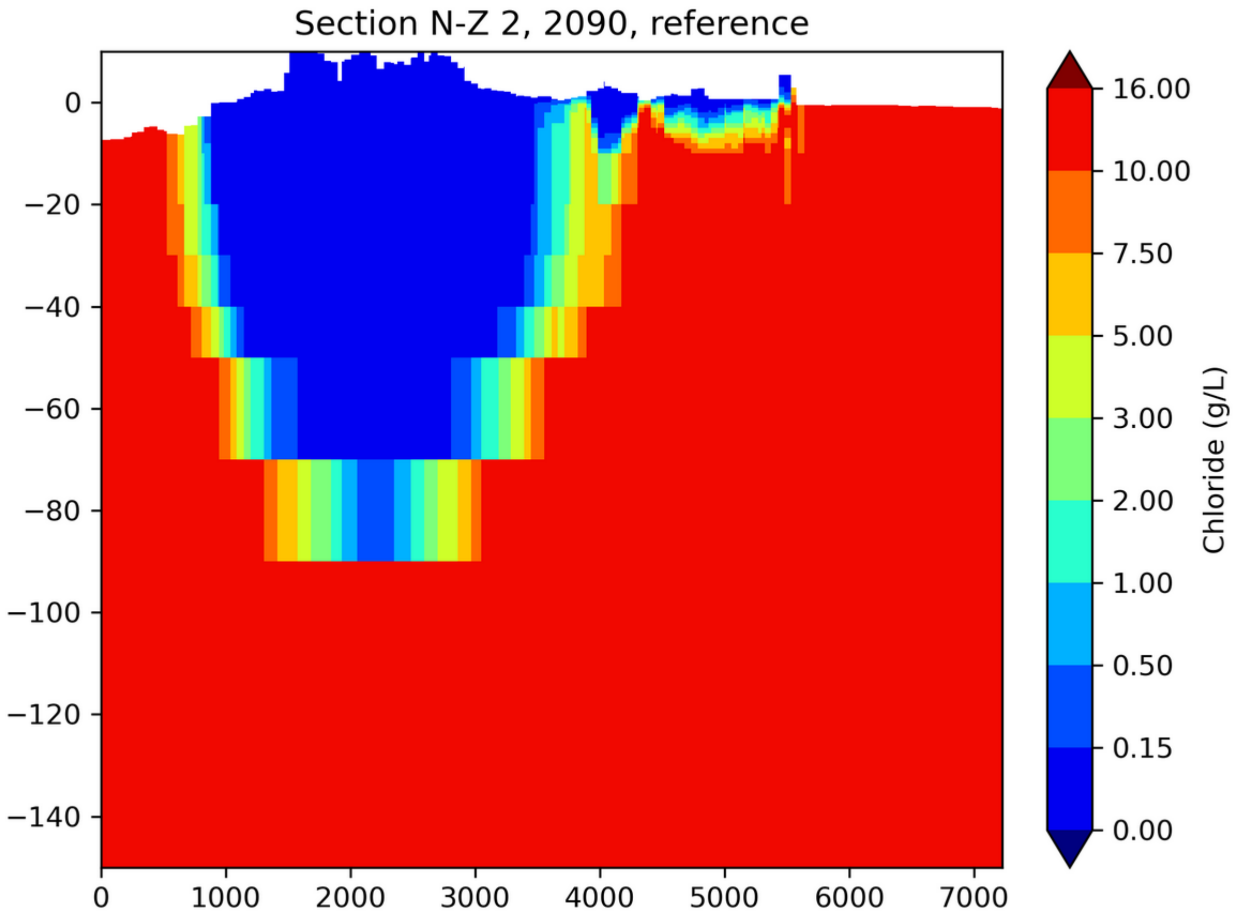


Figure C16: Location cross section N-Z 2 2090 reference (Deltares, 2024-a)

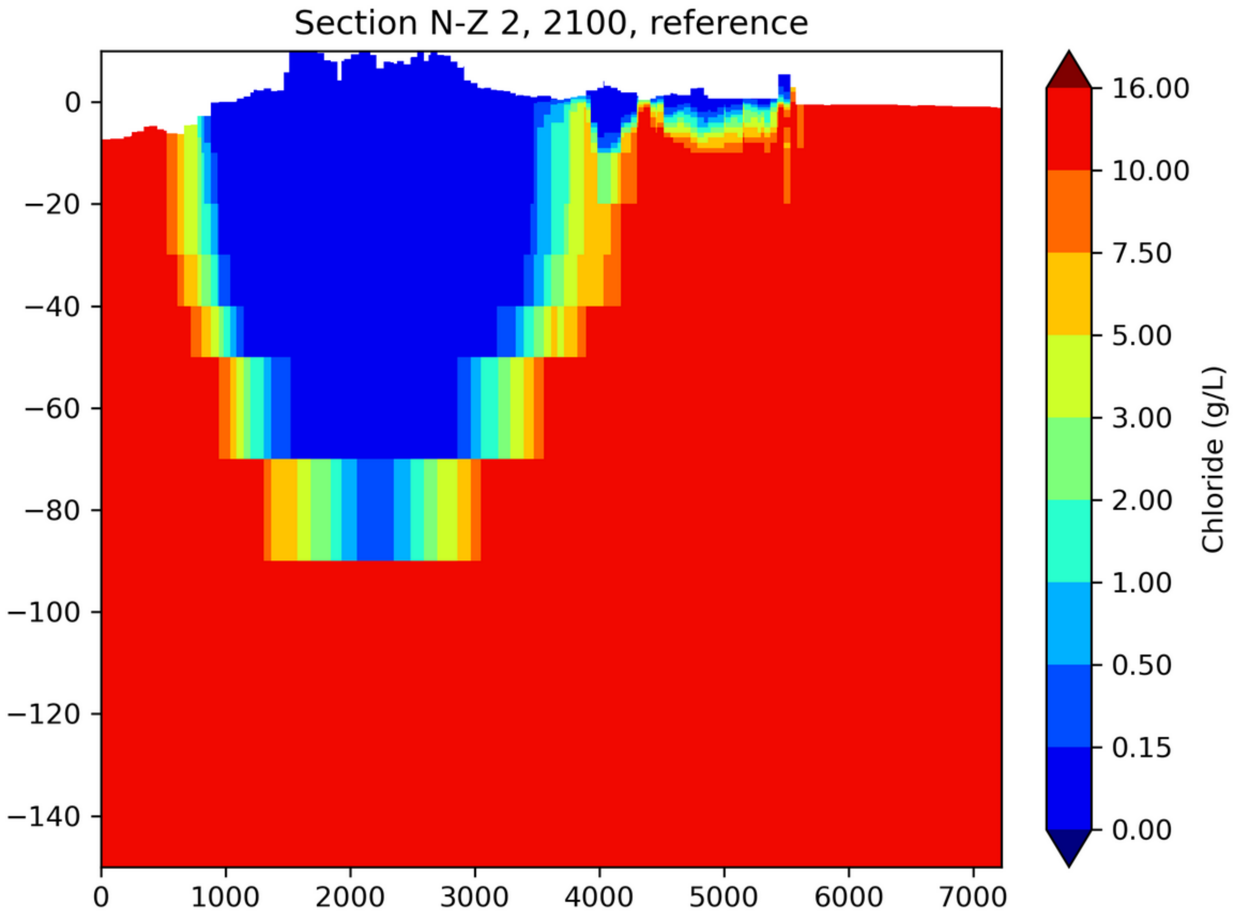


Figure C17: Location cross section N-Z 2 2100 reference (Deltares, 2024-a)

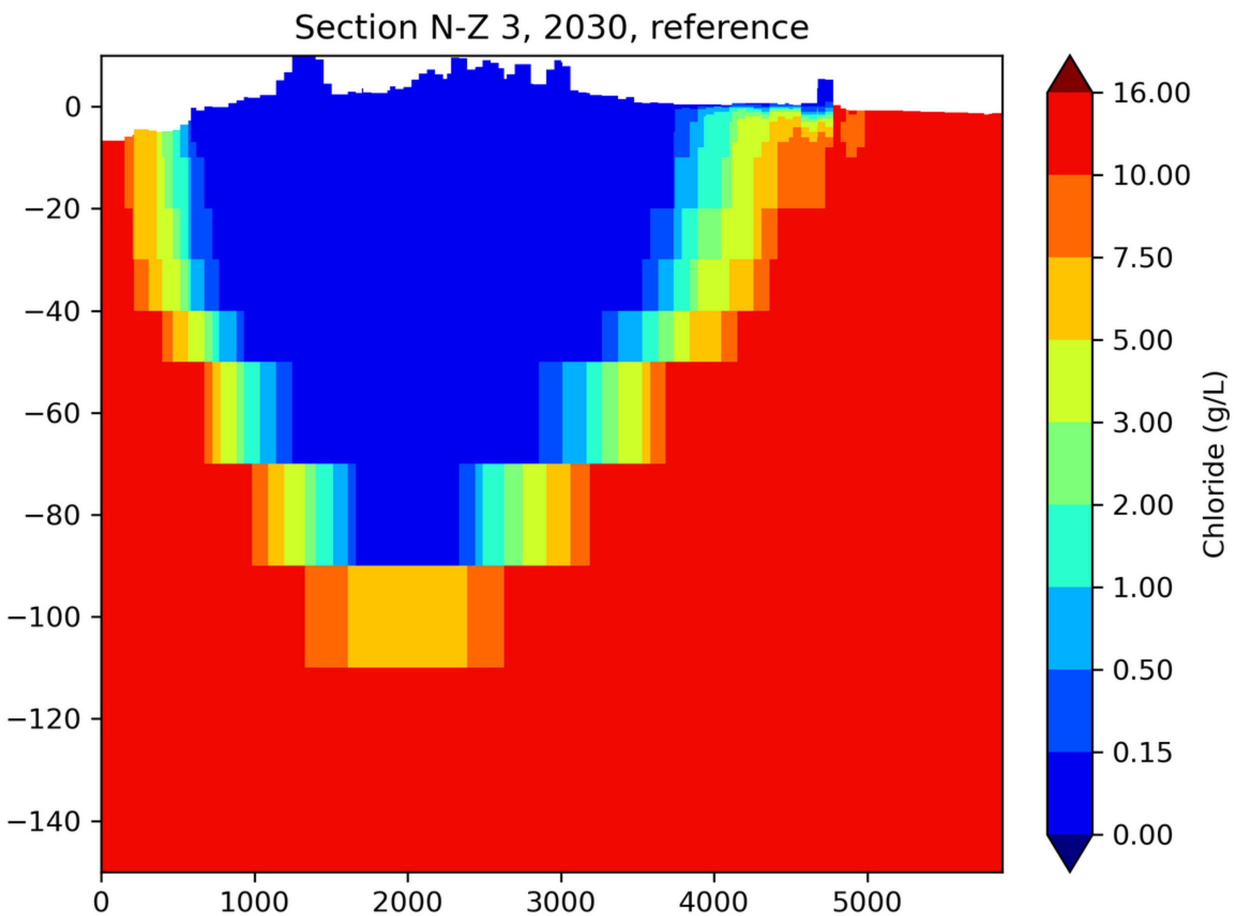


Figure C18: Location cross section N-Z 3 2030 reference (Deltares, 2024-a)

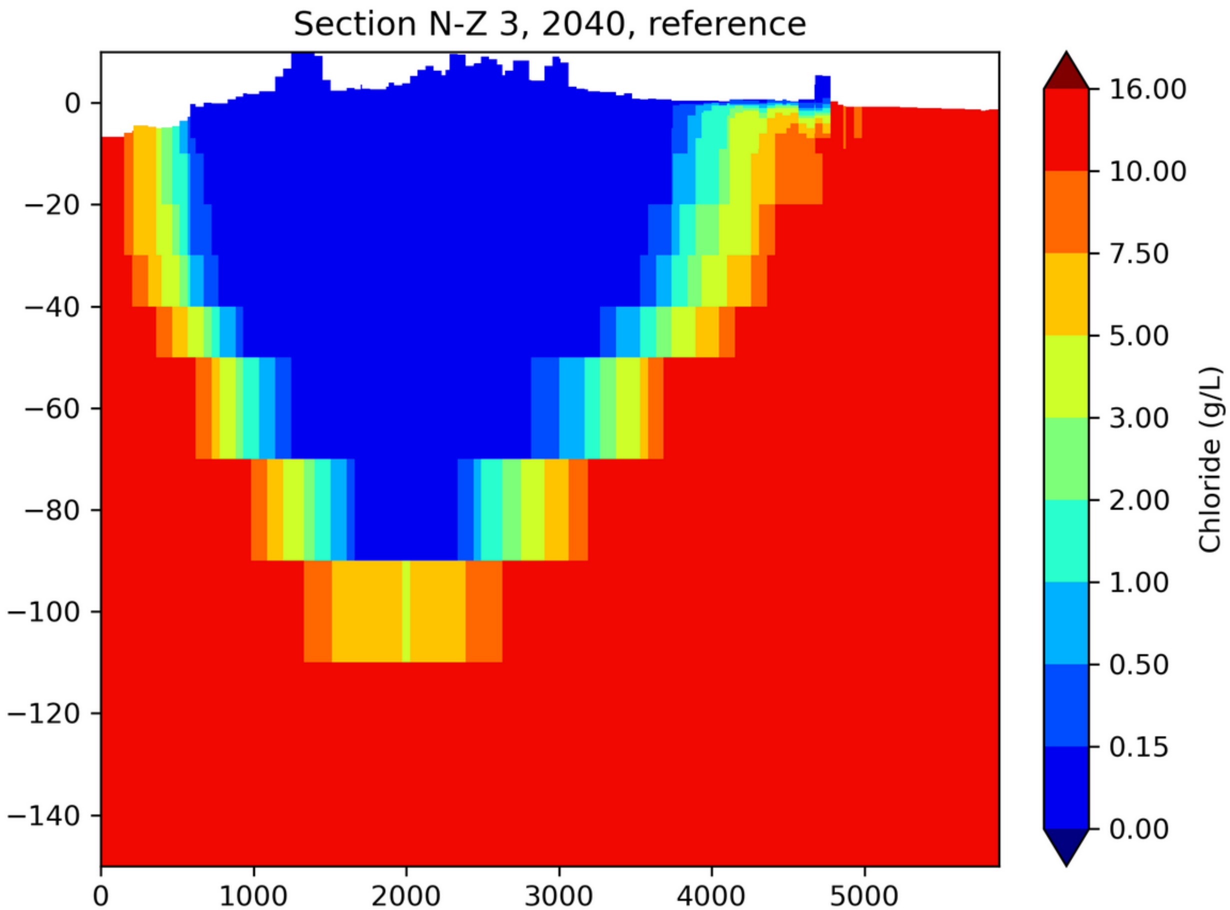


Figure C19: Location cross section N-Z 3 2040 reference (Deltares, 2024-a)

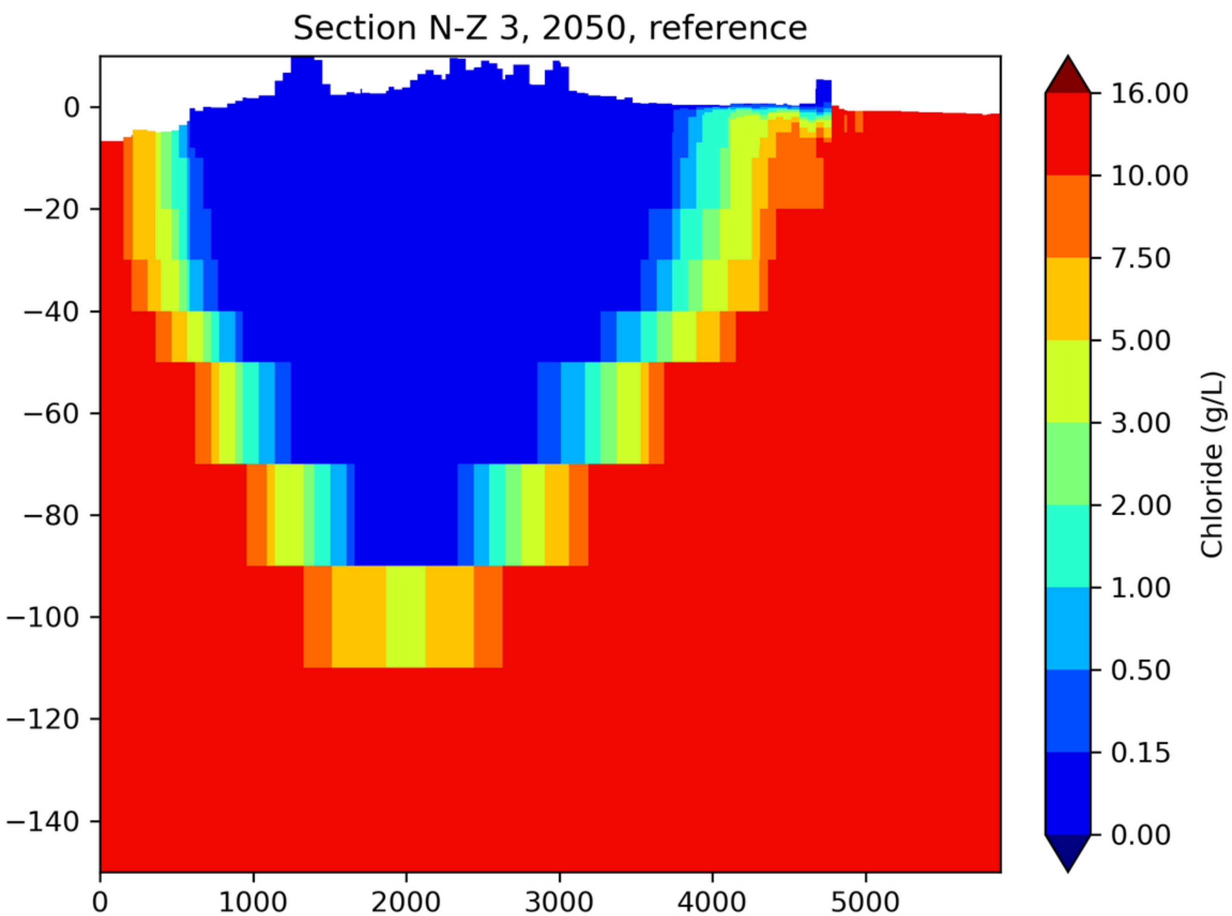


Figure C20: Location cross section N-Z 3 2050 reference (Deltares, 2024-a)

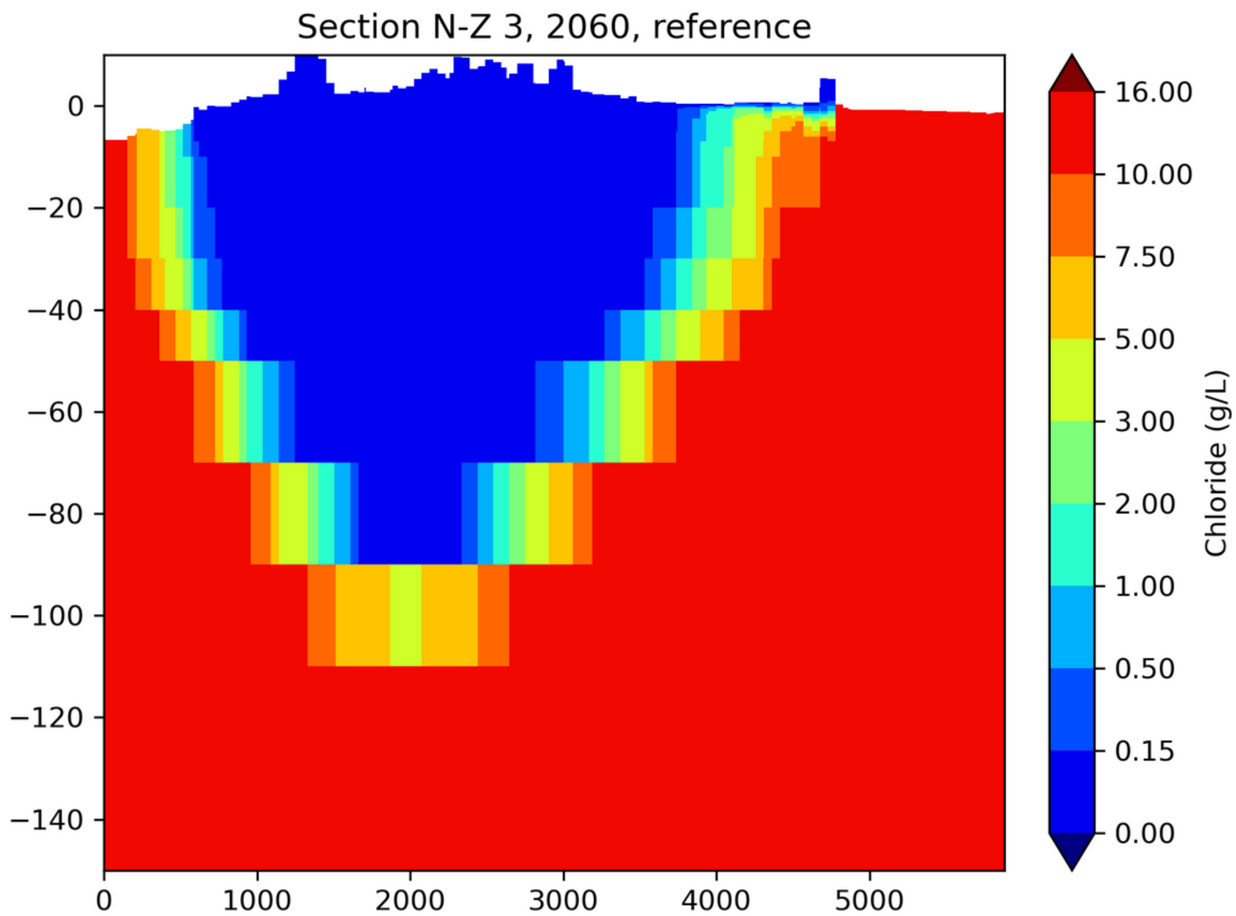


Figure C21: Location cross section N-Z 3 2060 reference (Deltares, 2024-a)

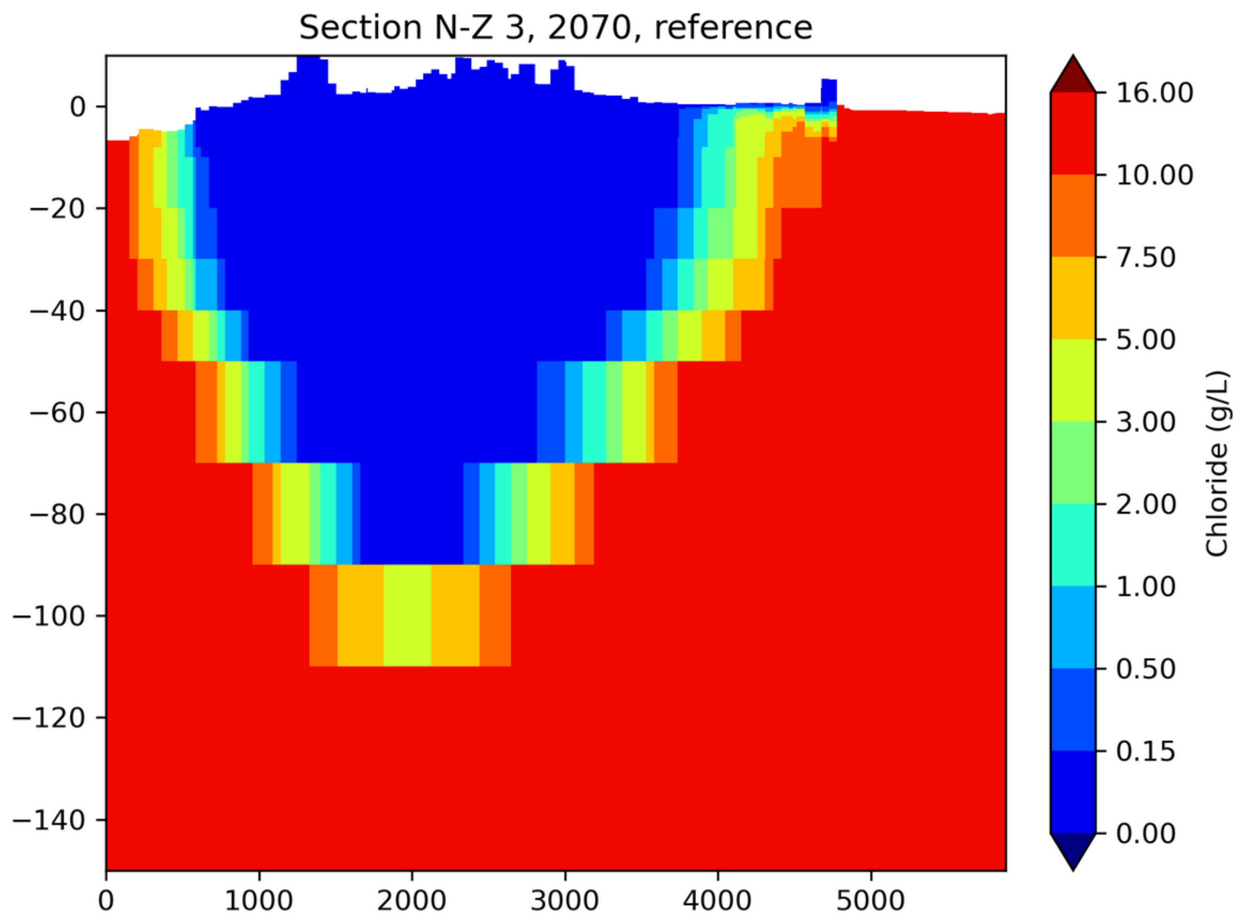


Figure C22: Location cross section N-Z 3 2070 reference (Deltares, 2024-a)

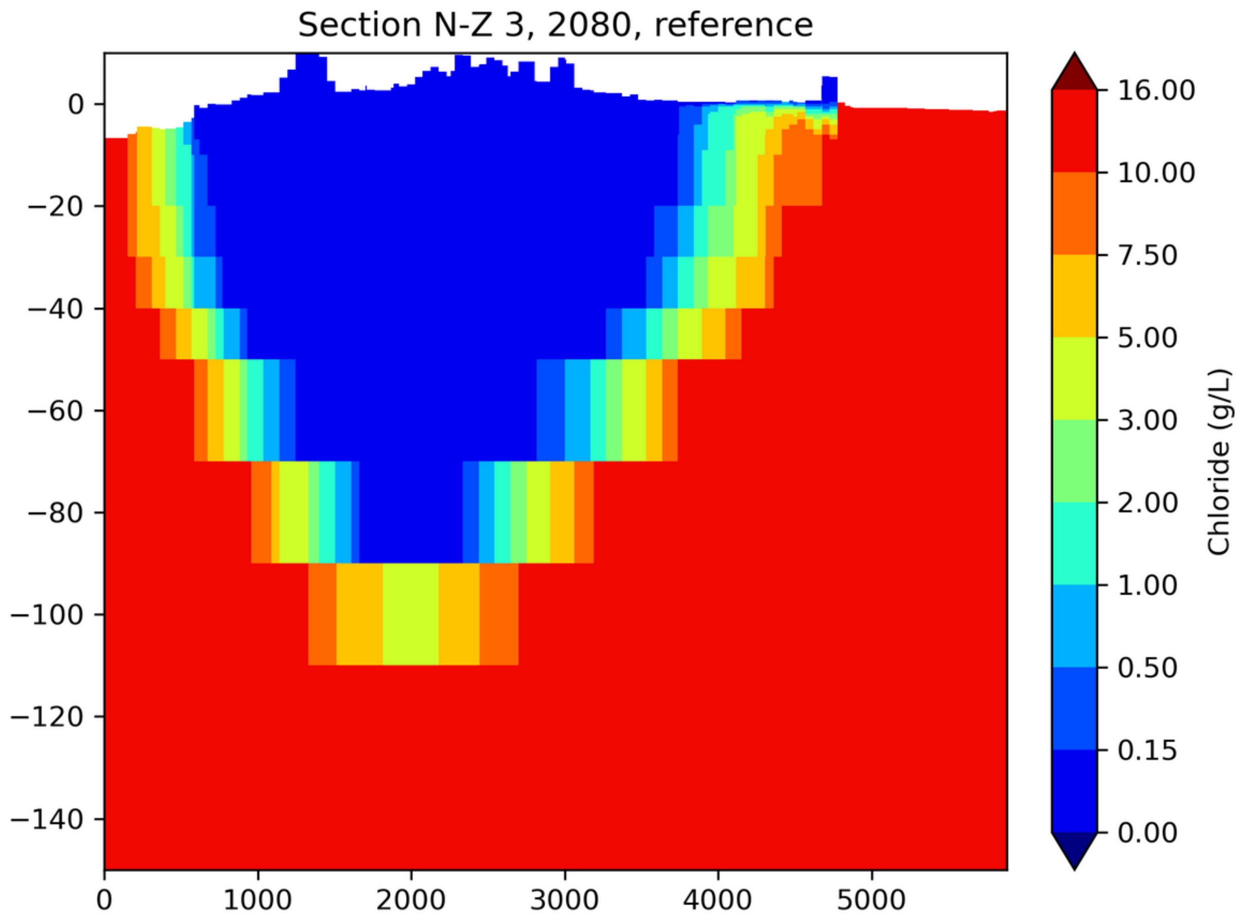


Figure C23: Location cross section N-Z 3 2080 reference (Deltares, 2024-a)

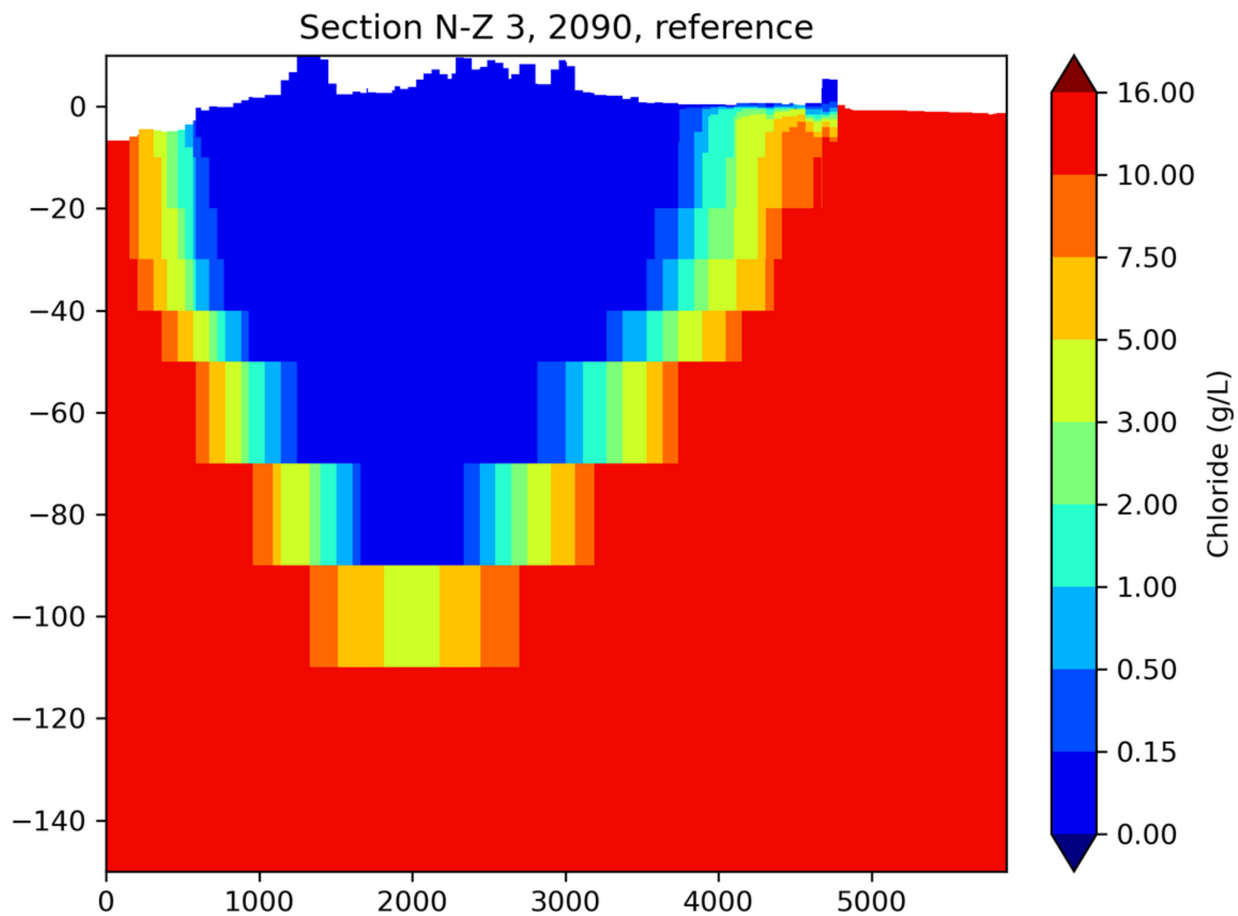


Figure C24: Location cross section N-Z 3 2090 reference (Deltares, 2024-a)

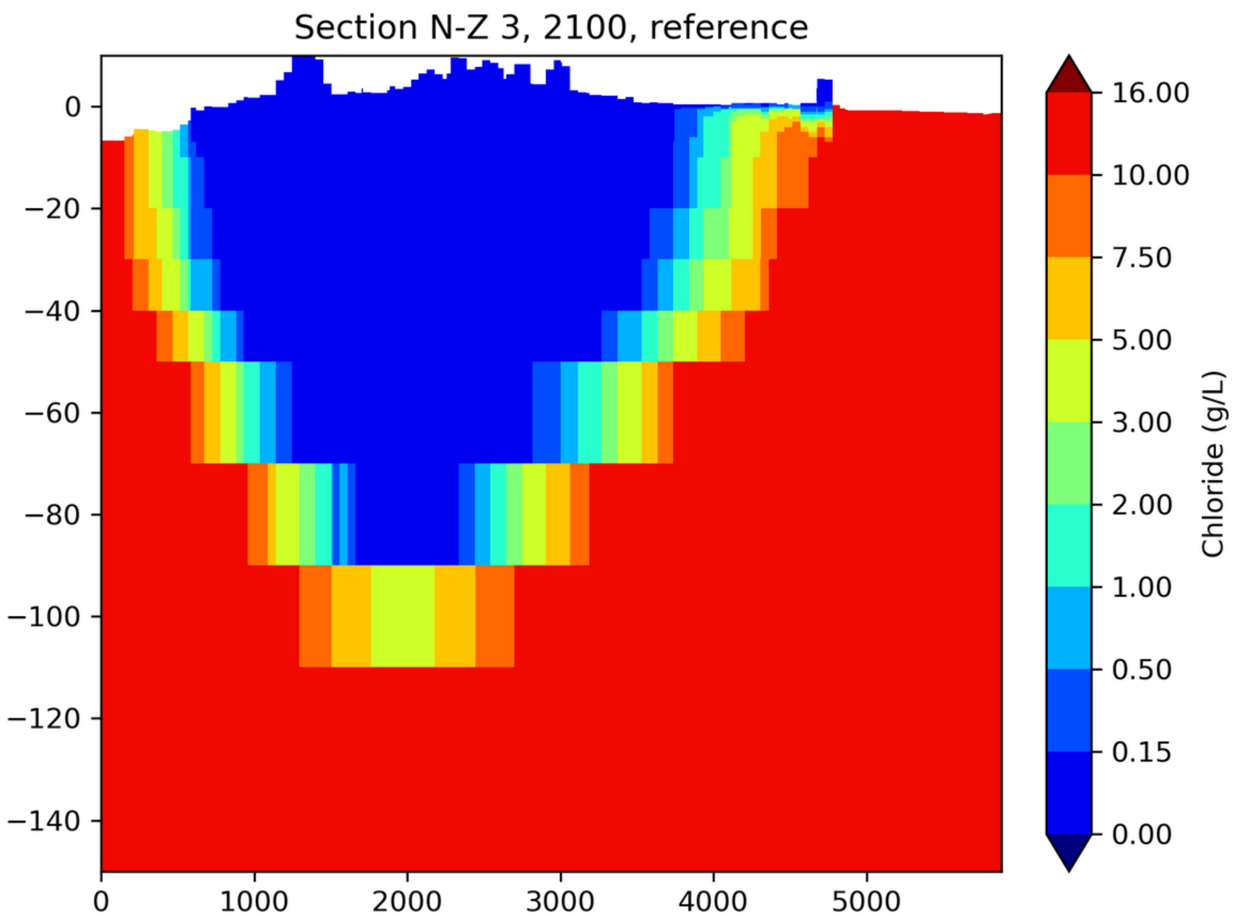


Figure C25: Location cross section N-Z 3 2100 reference (Deltares, 2024-a)

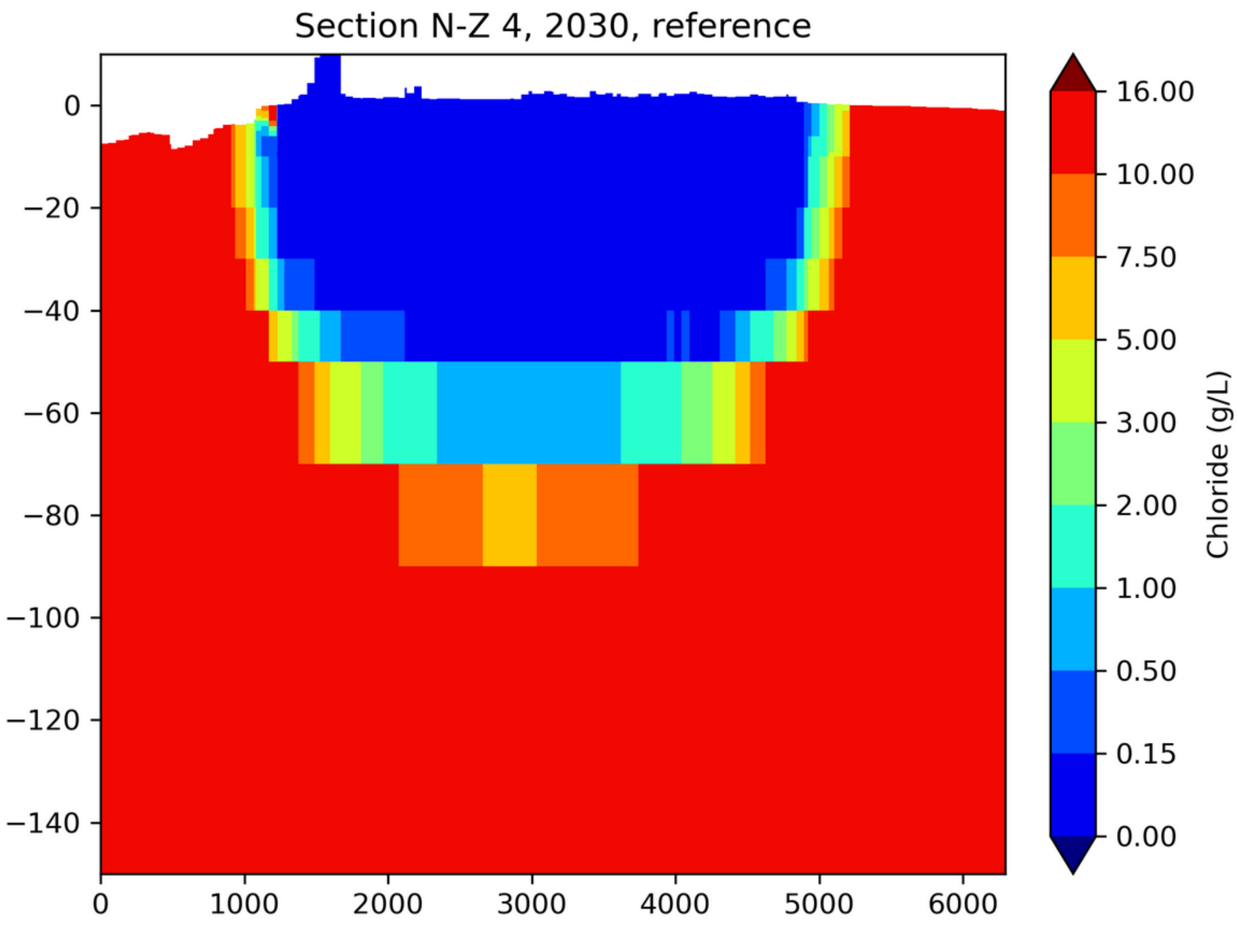


Figure C26: Location cross section N-Z 4 2030 reference (Deltares, 2024-a)

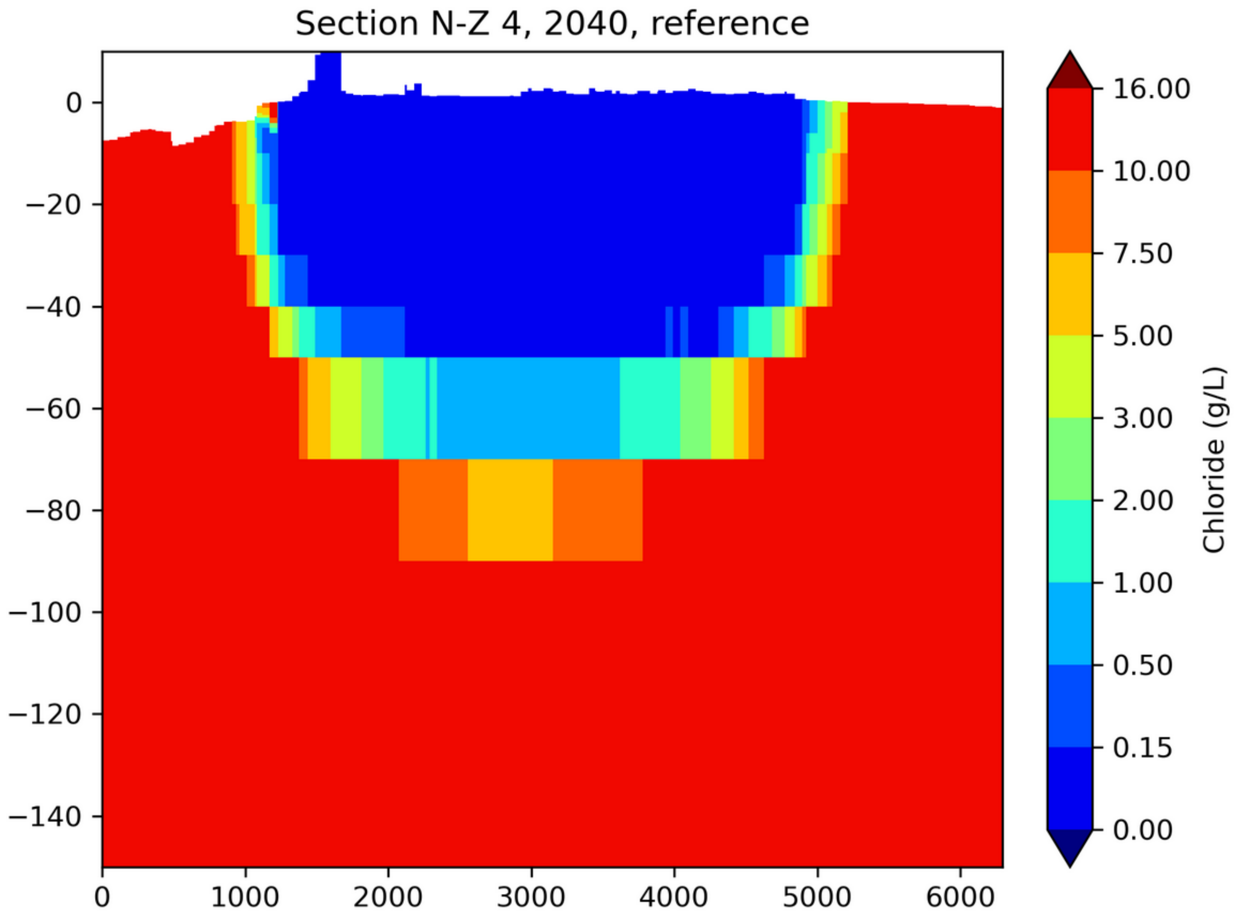


Figure C27: Location cross section N-Z 4 2040 reference (Deltares, 2024-a)

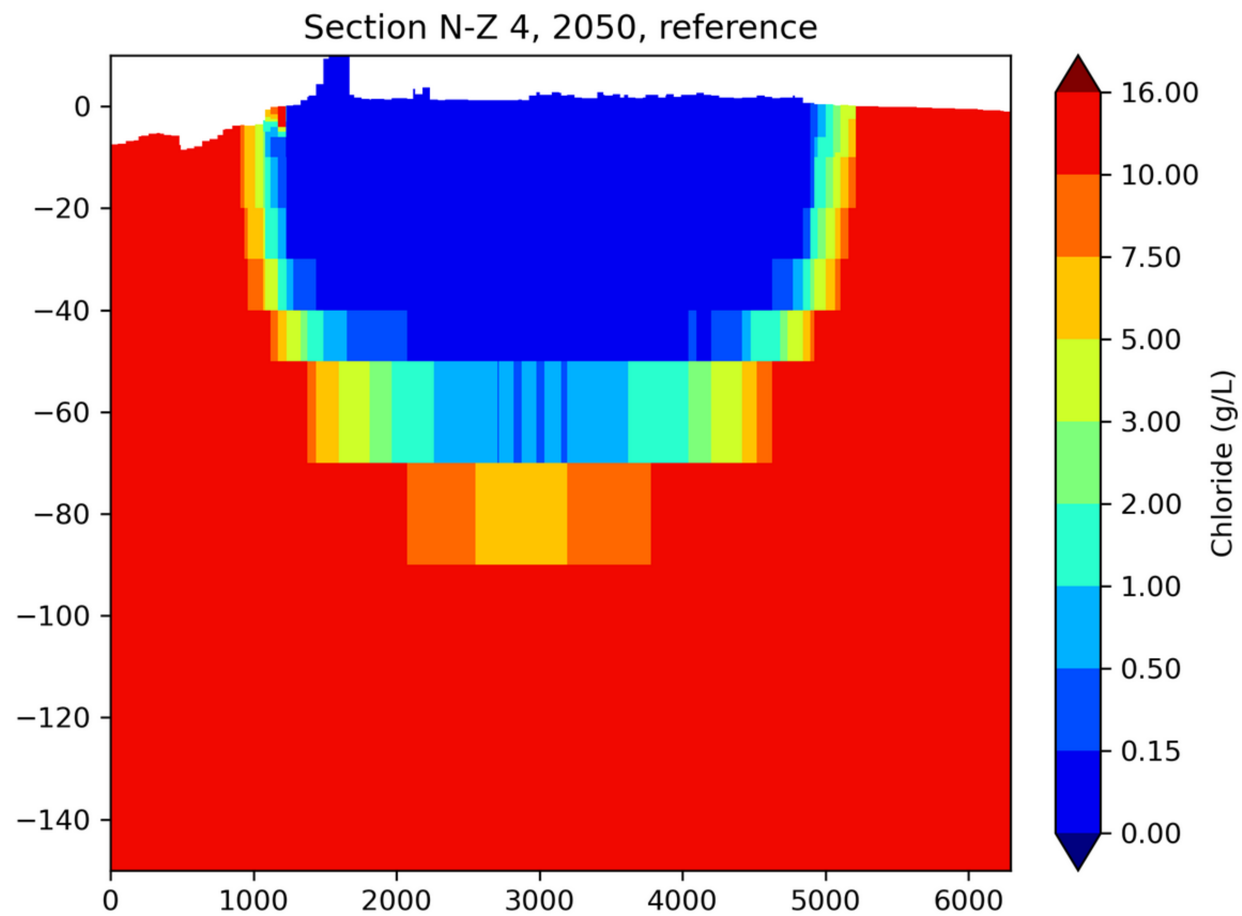


Figure C28: Location cross section N-Z 4 2050 reference (Deltares, 2024-a)

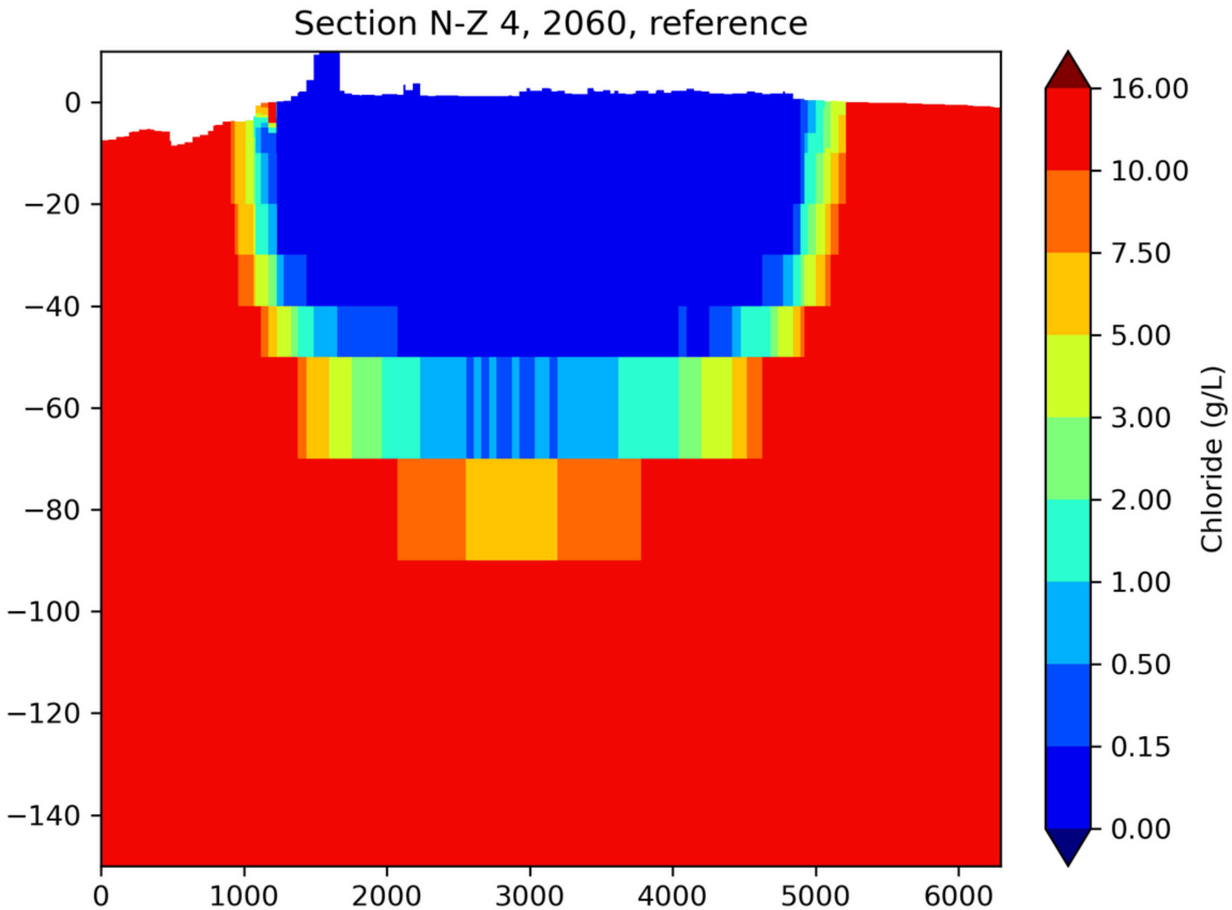


Figure C29: Location cross section N-Z 4 2060 reference (Deltares, 2024-a)

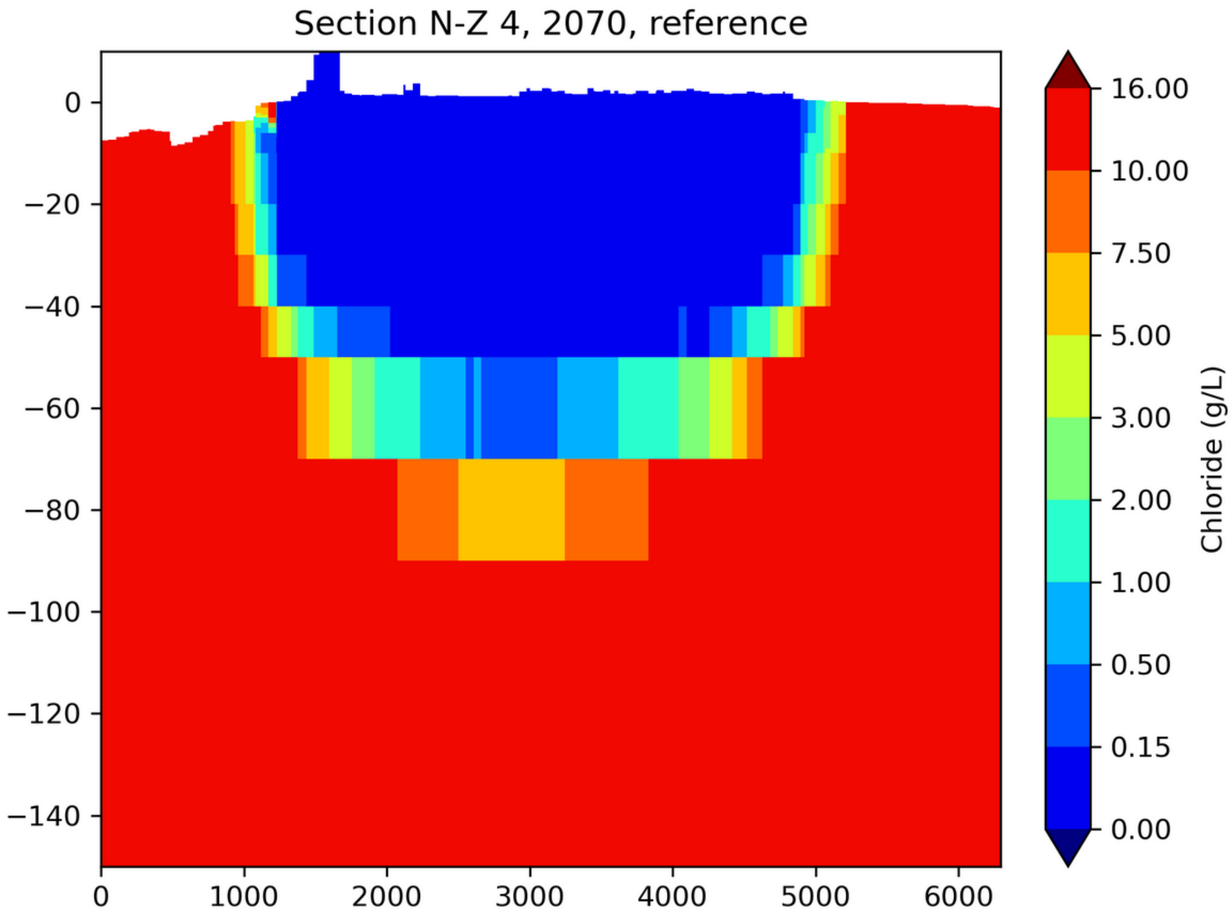


Figure C30: Location cross section N-Z 4 2070 reference (Deltares, 2024-a)

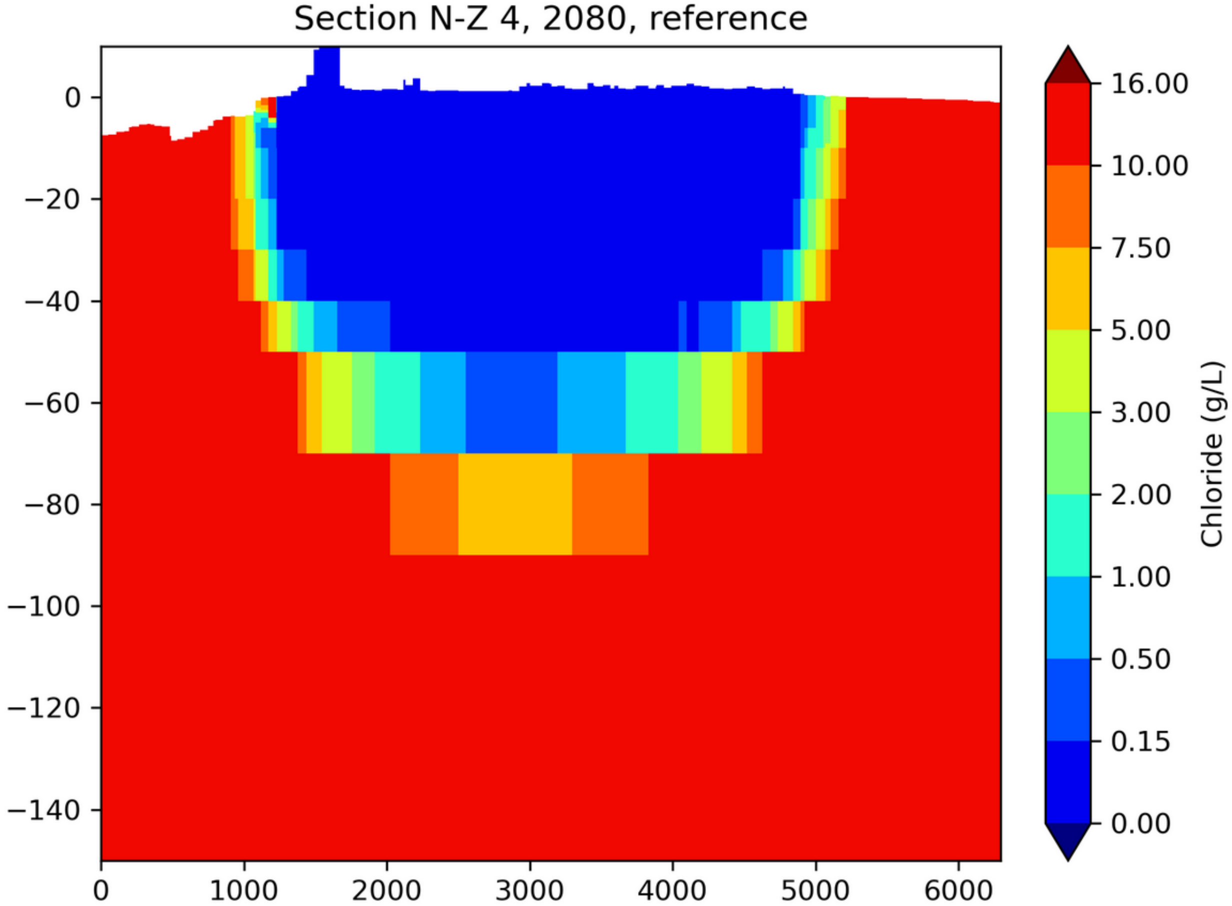


Figure C31: Location cross section N-Z 4 2080 reference (Deltares, 2024-a)

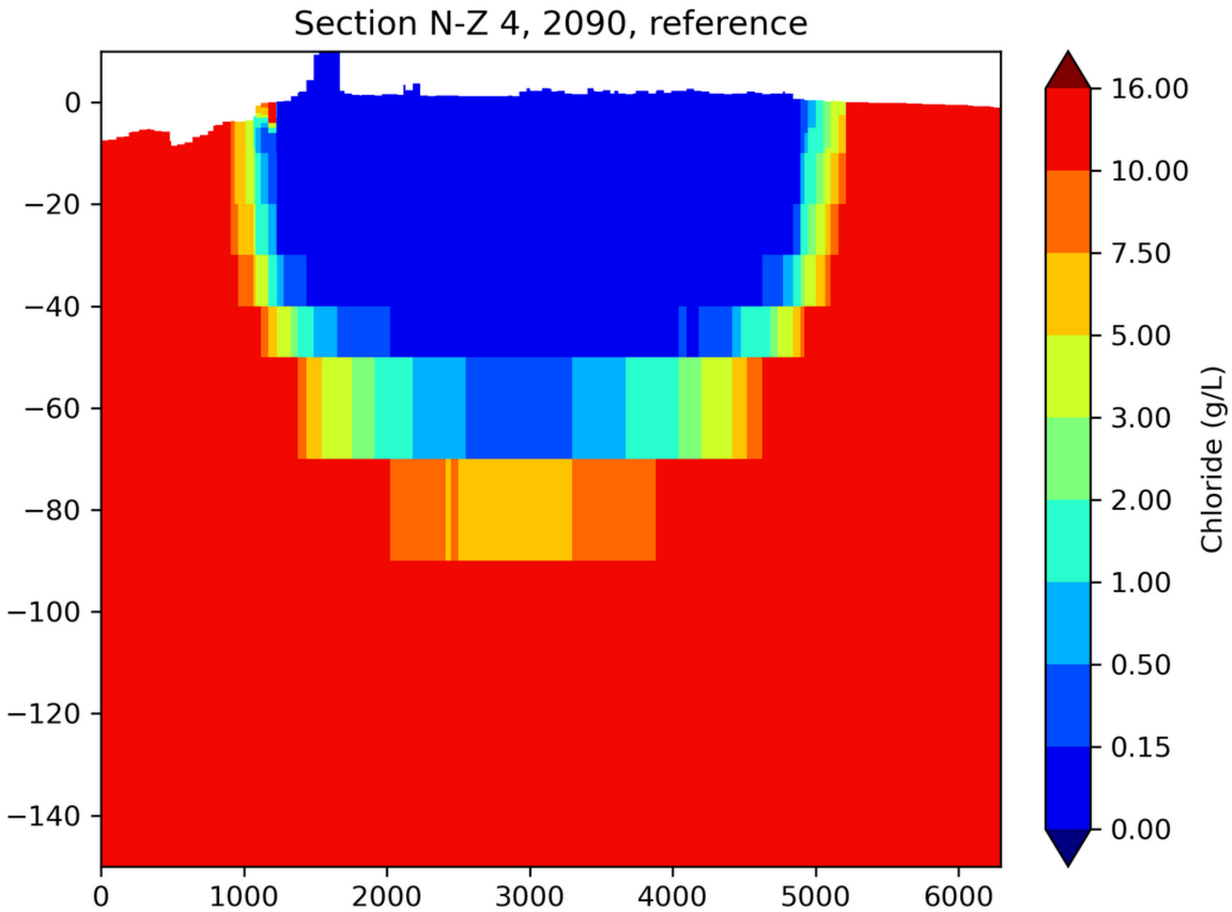


Figure C32: Location cross section N-Z 4 2090 reference (Deltares, 2024-a)

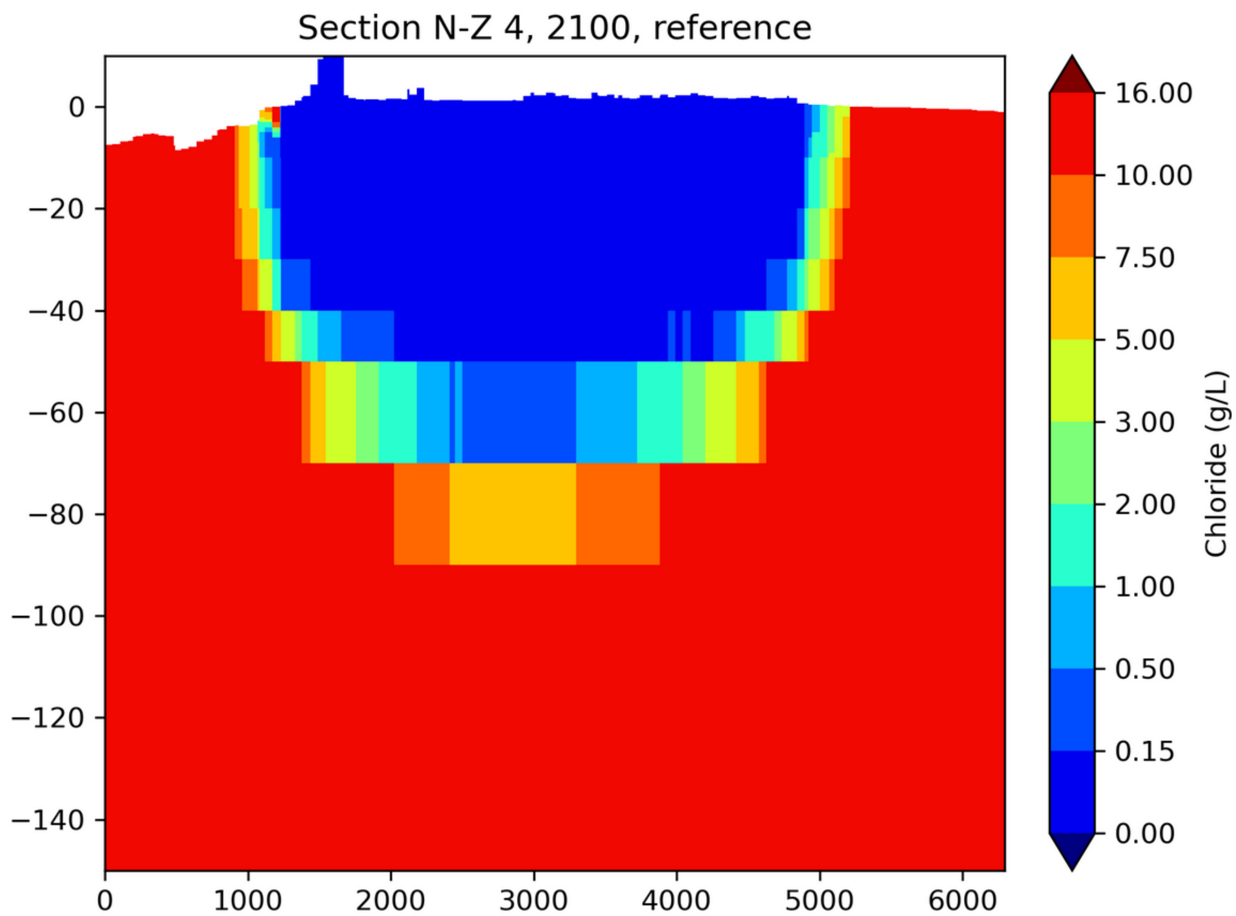


Figure C33: Location cross section N-Z 4 2100 reference (Deltares, 2024-a)

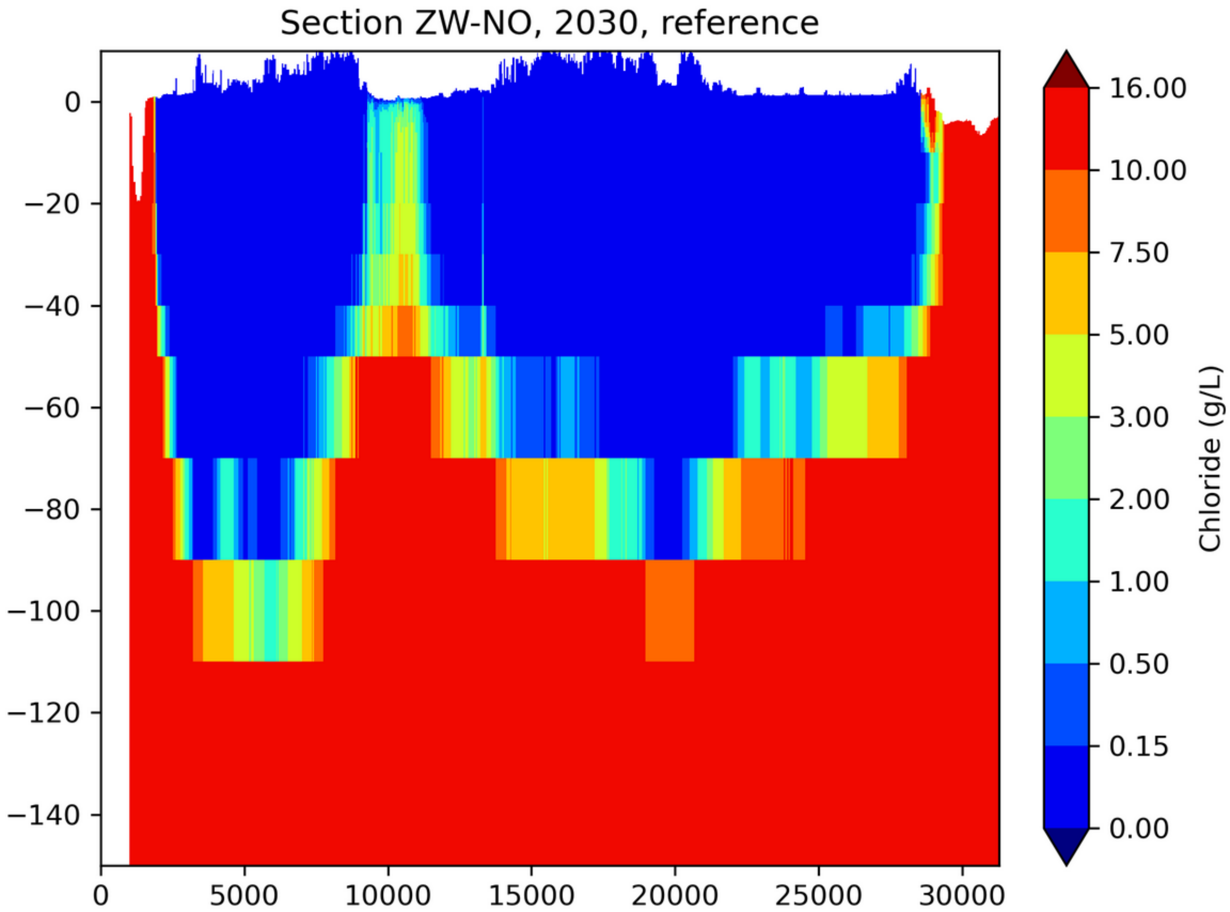


Figure C33: Location cross section ZW-NO 2030 reference (Deltares, 2024-a)

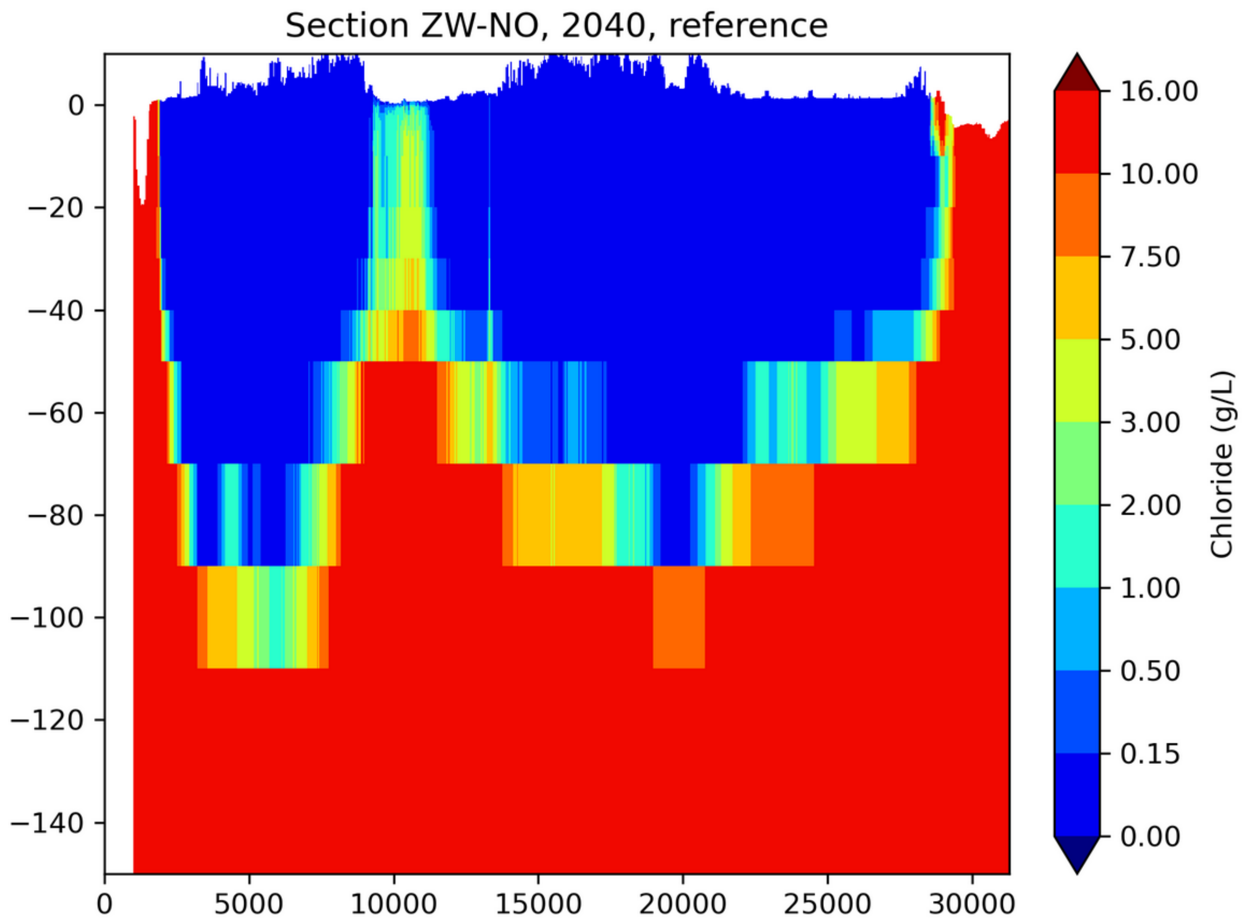


Figure C34: Location cross section ZW-NO 2040 reference (Deltares, 2024-a)

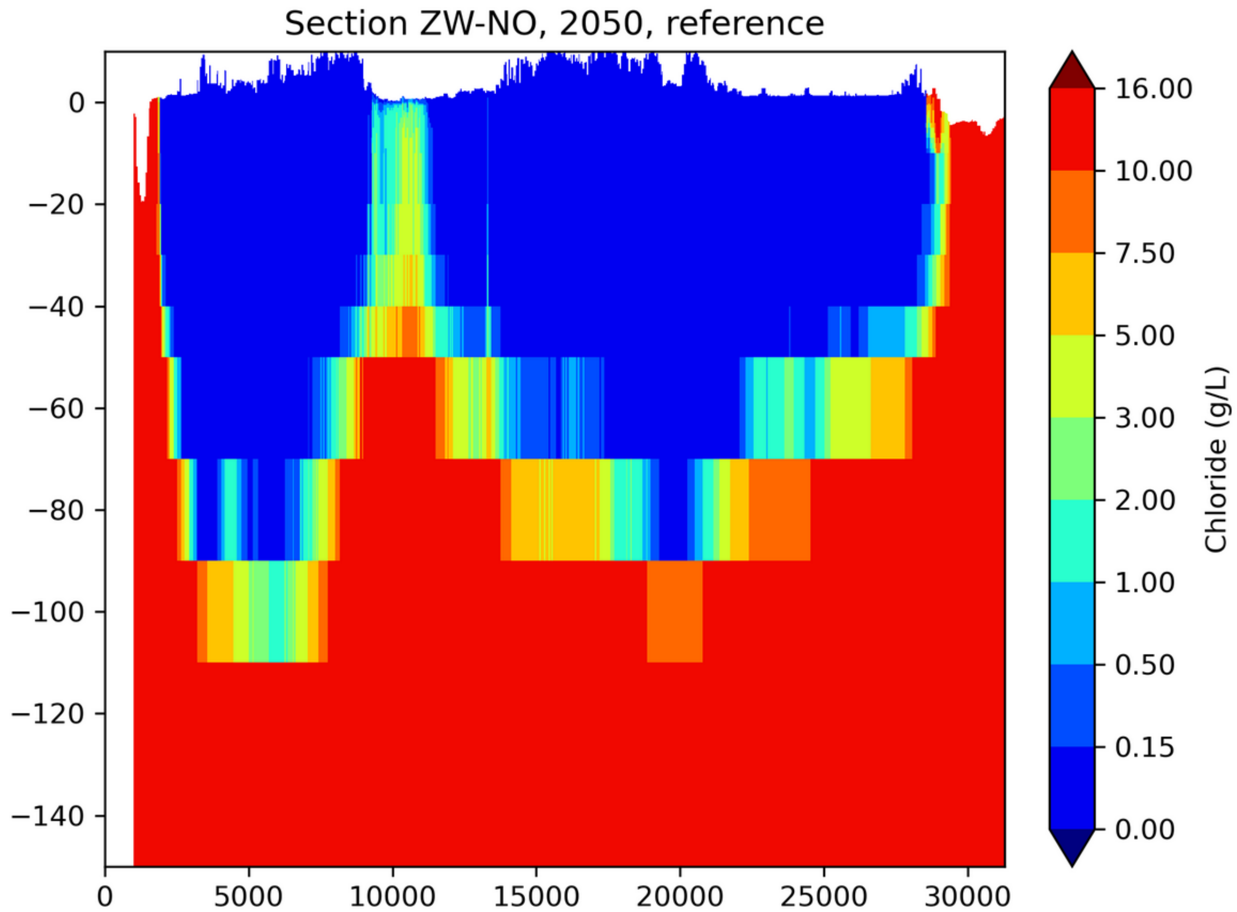


Figure C35: Location cross section ZW-NO 2050 reference (Deltares, 2024-a)

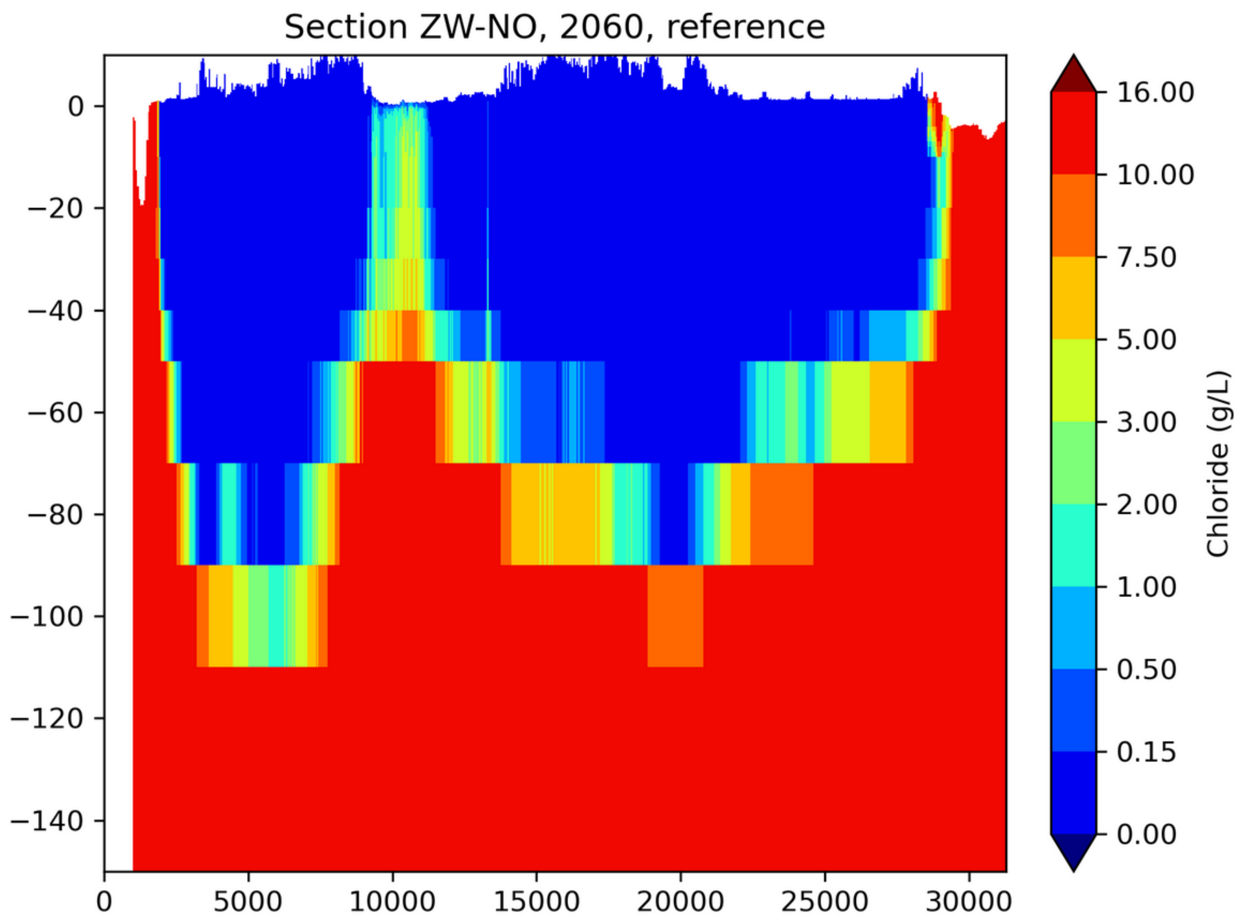


Figure C36: Location cross section ZW-NO 2060 reference (Deltares, 2024-a)

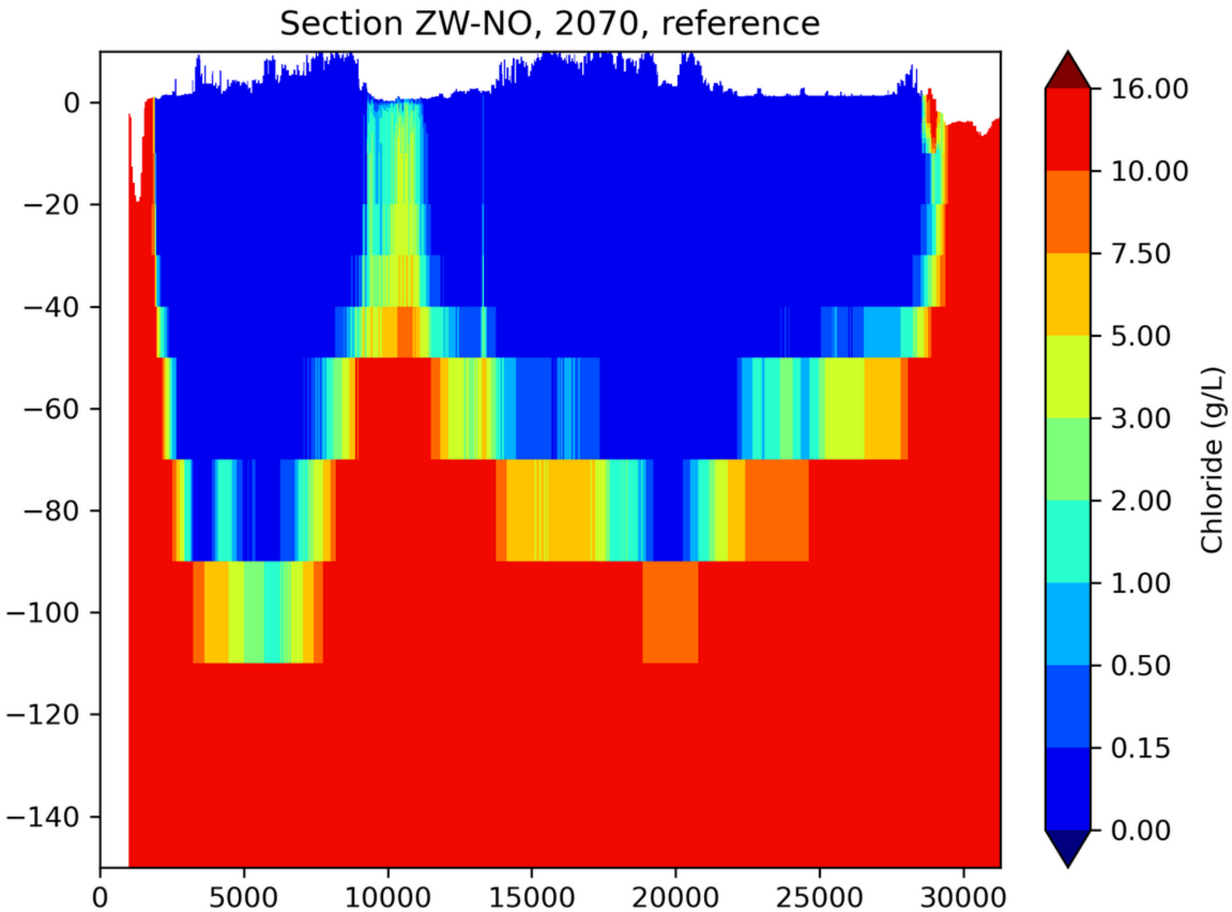


Figure C37: Location cross section ZW-NO 2070 reference (Deltares, 2024-a)

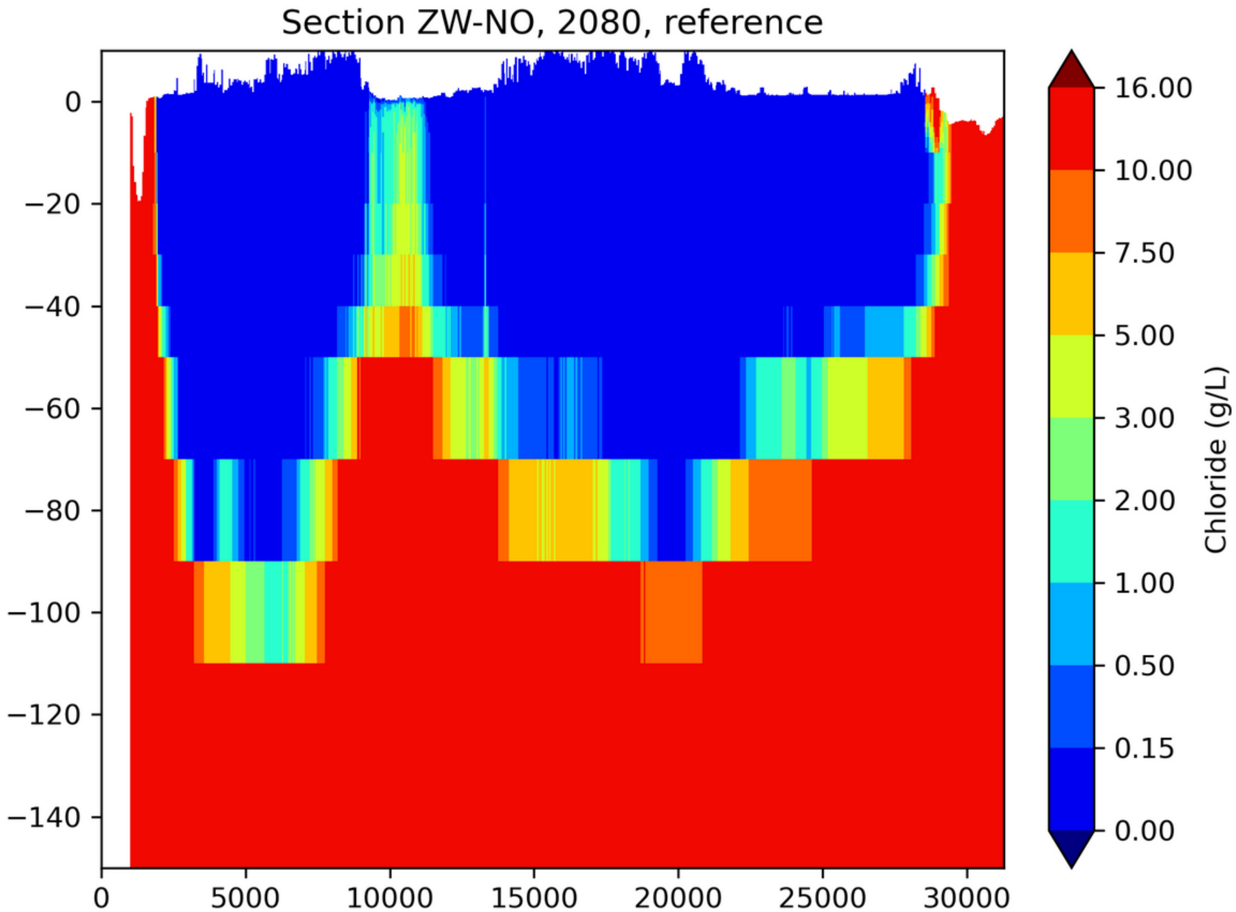


Figure C38: Location cross section ZW-NO 2080 reference (Deltares, 2024-a)

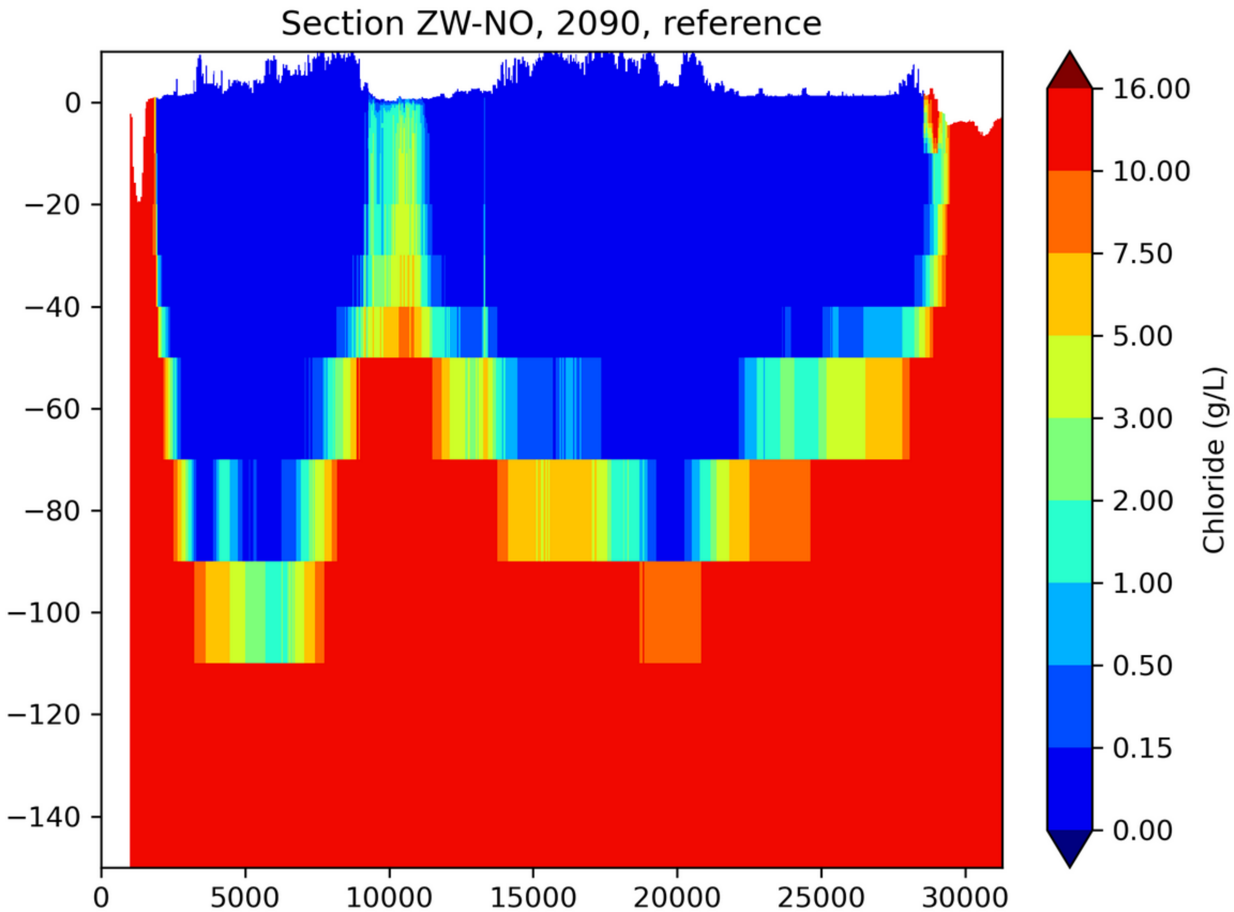


Figure C39: Location cross section ZW-NO 2090 reference (Deltares, 2024-a)

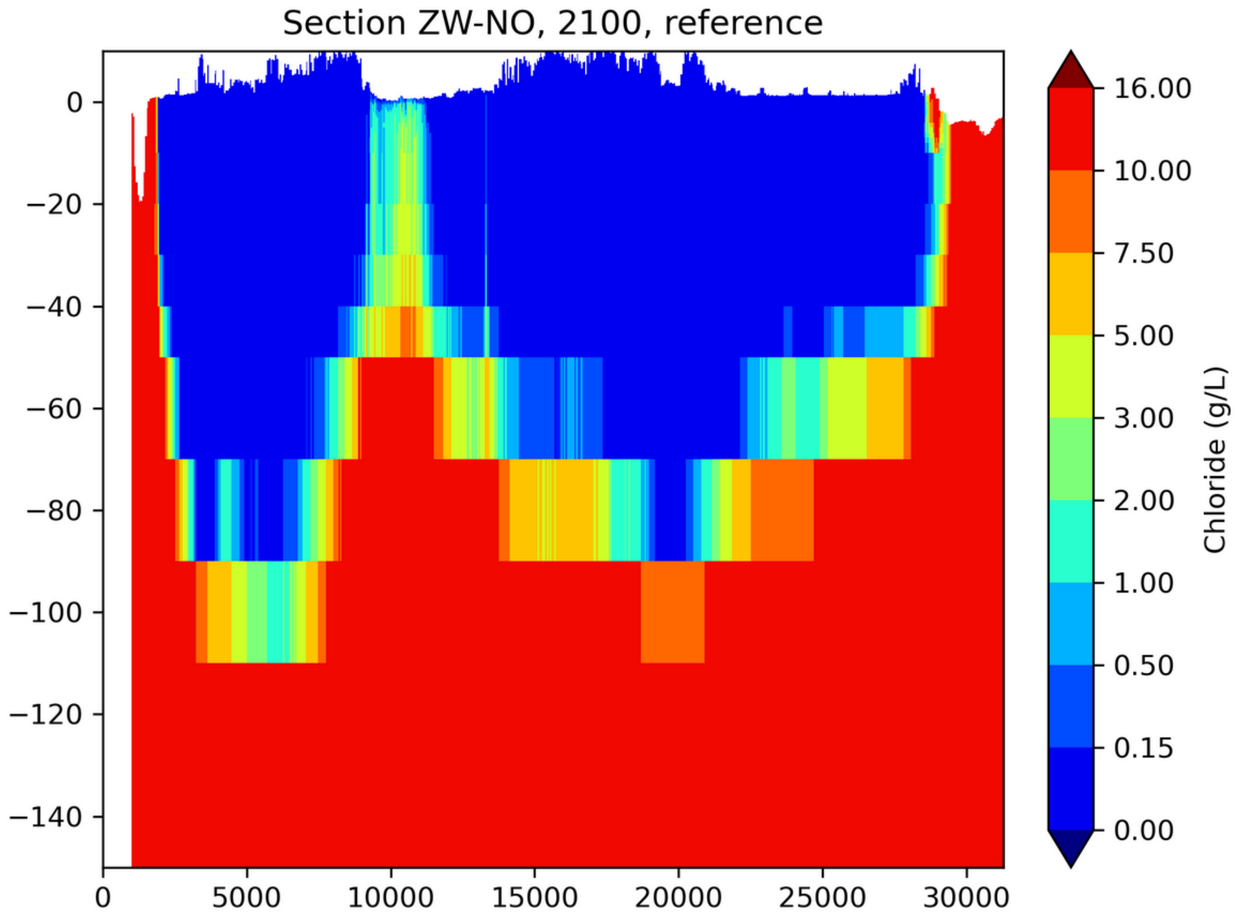


Figure C40: Location cross section ZW-NO 2100 reference (Deltares, 2024-a)

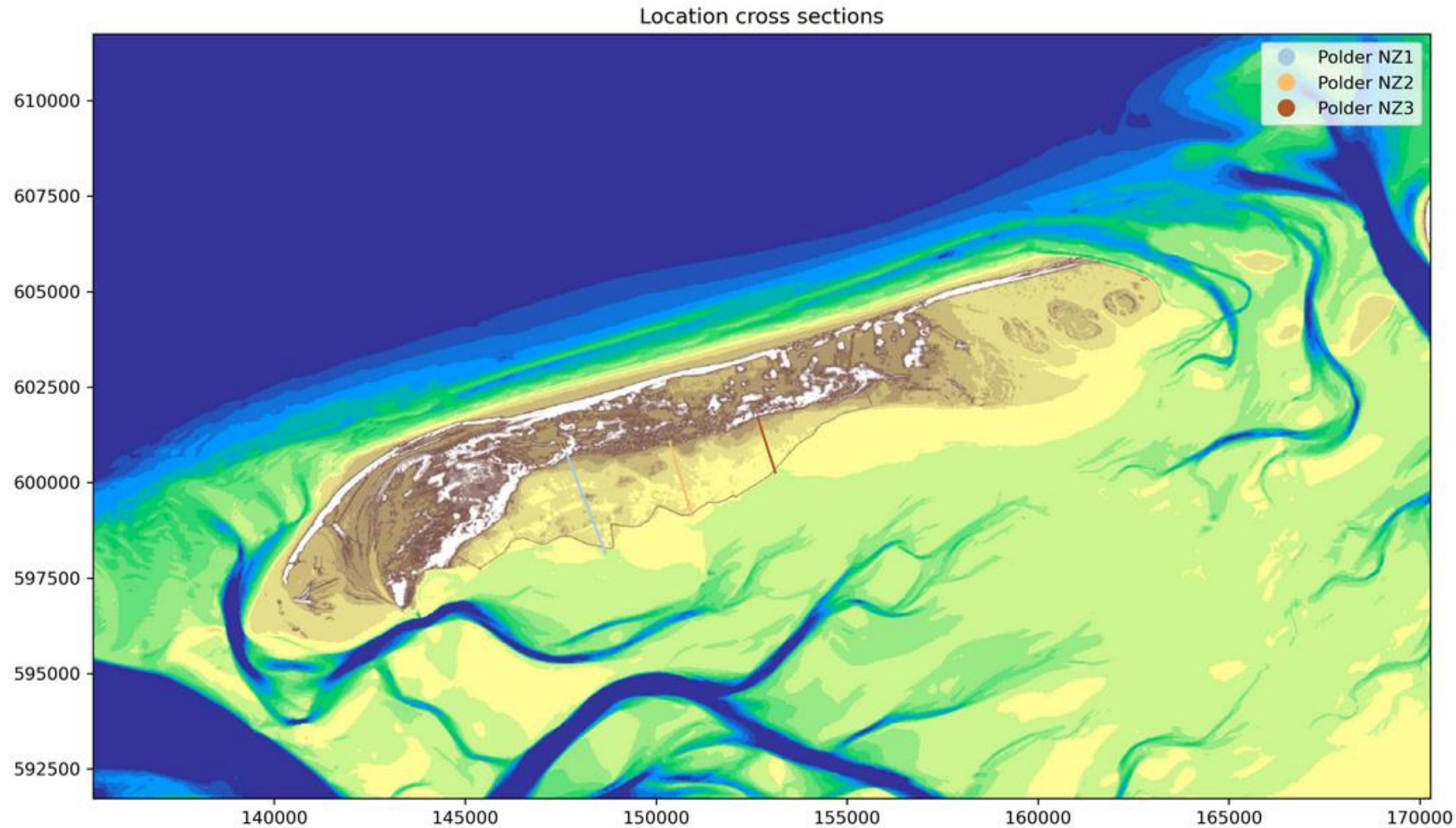


Figure C41: Location cross sections polder reference (Deltares, 2024-a)

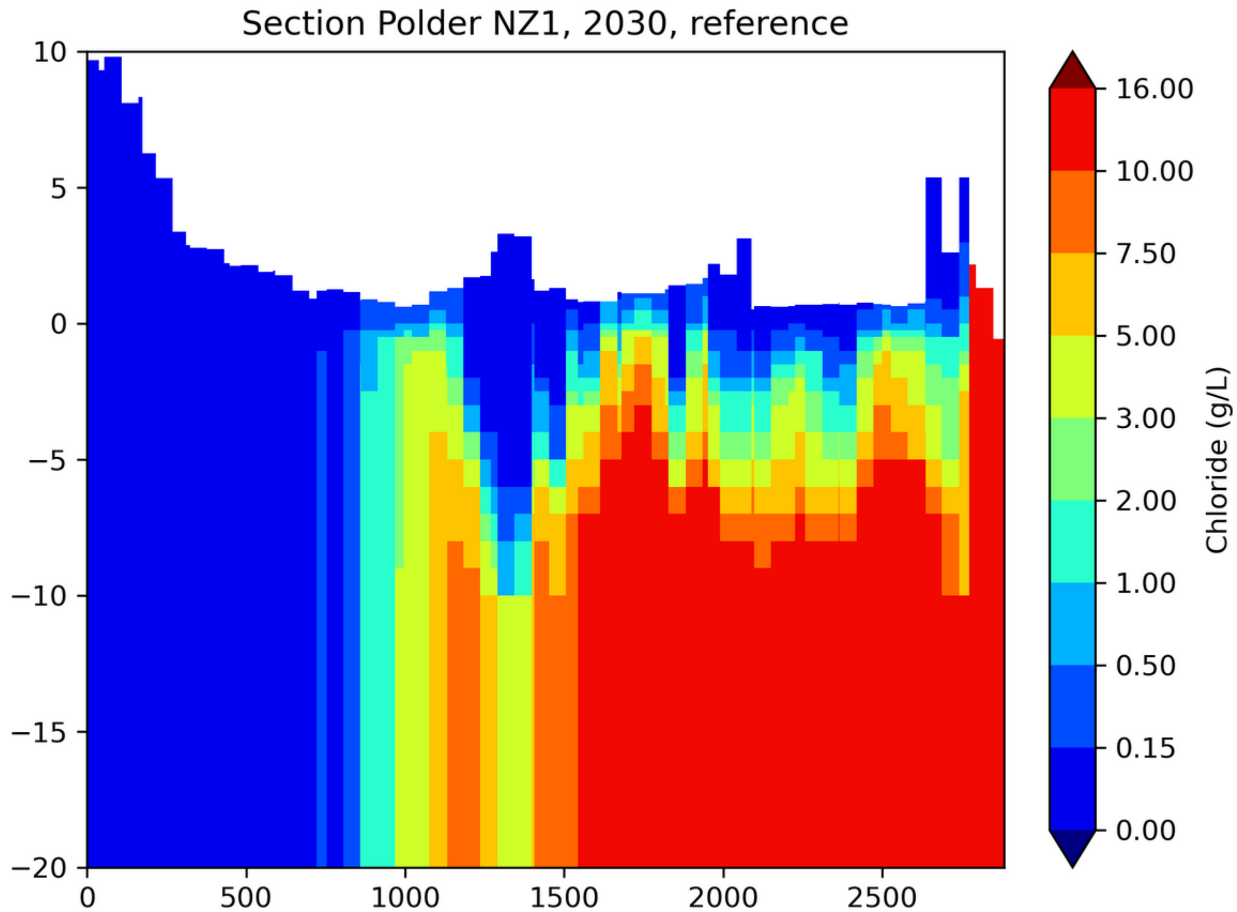


Figure C42: Location cross section Polder NZ 1 2030 reference (Deltares, 2024-a)

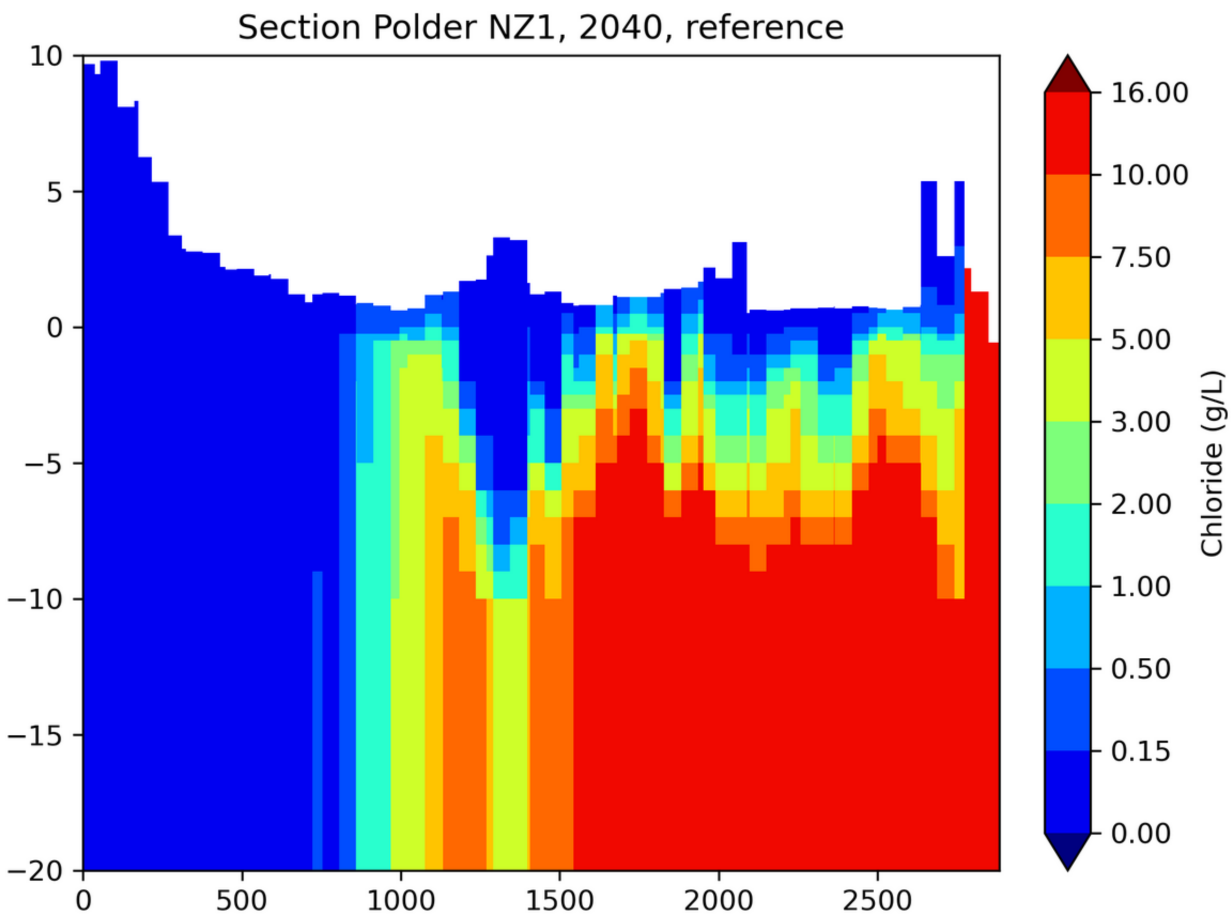


Figure C43: Location cross section Polder NZ 1 2040 reference (Deltares, 2024-a)

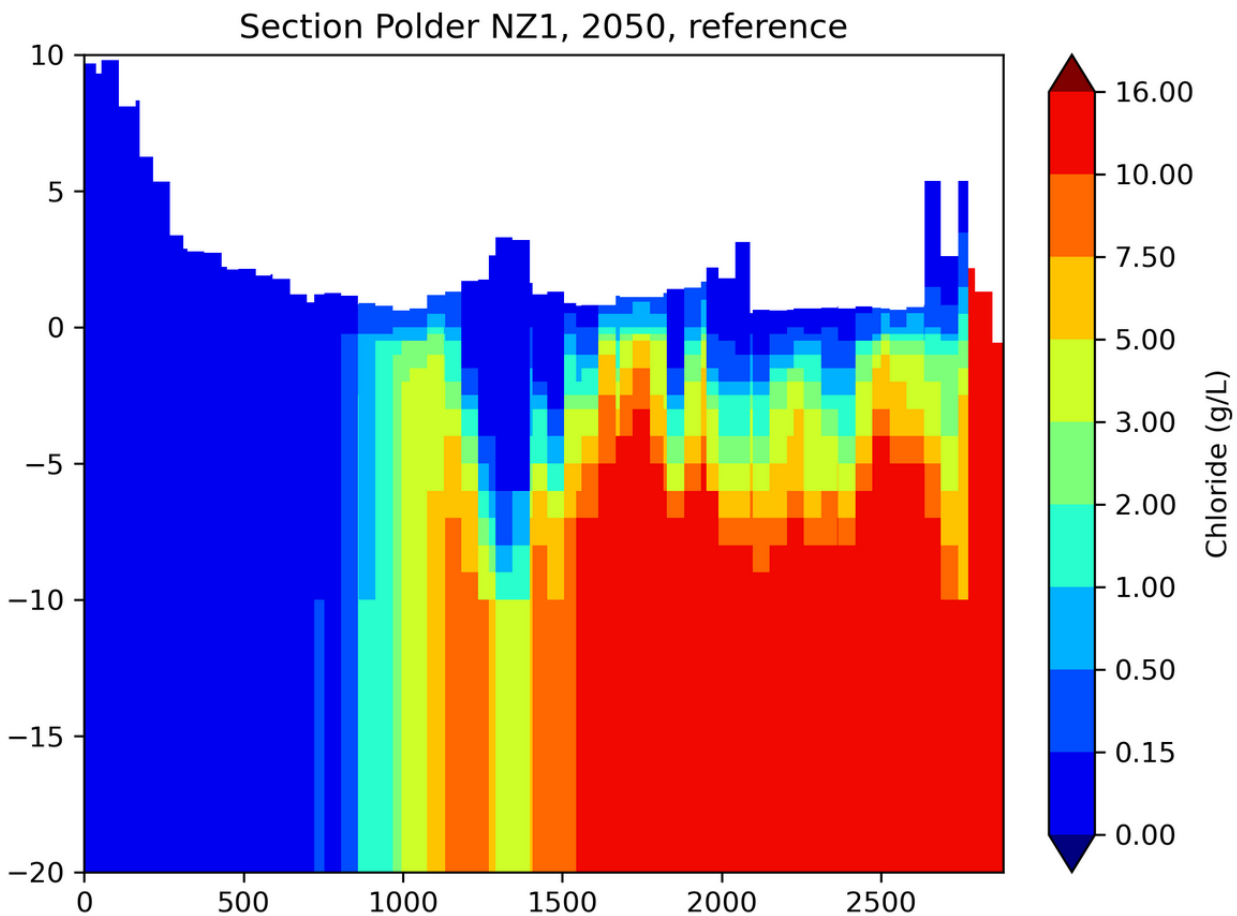


Figure C44: Location cross section Polder NZ 1 2050 reference (Deltares, 2024-a)

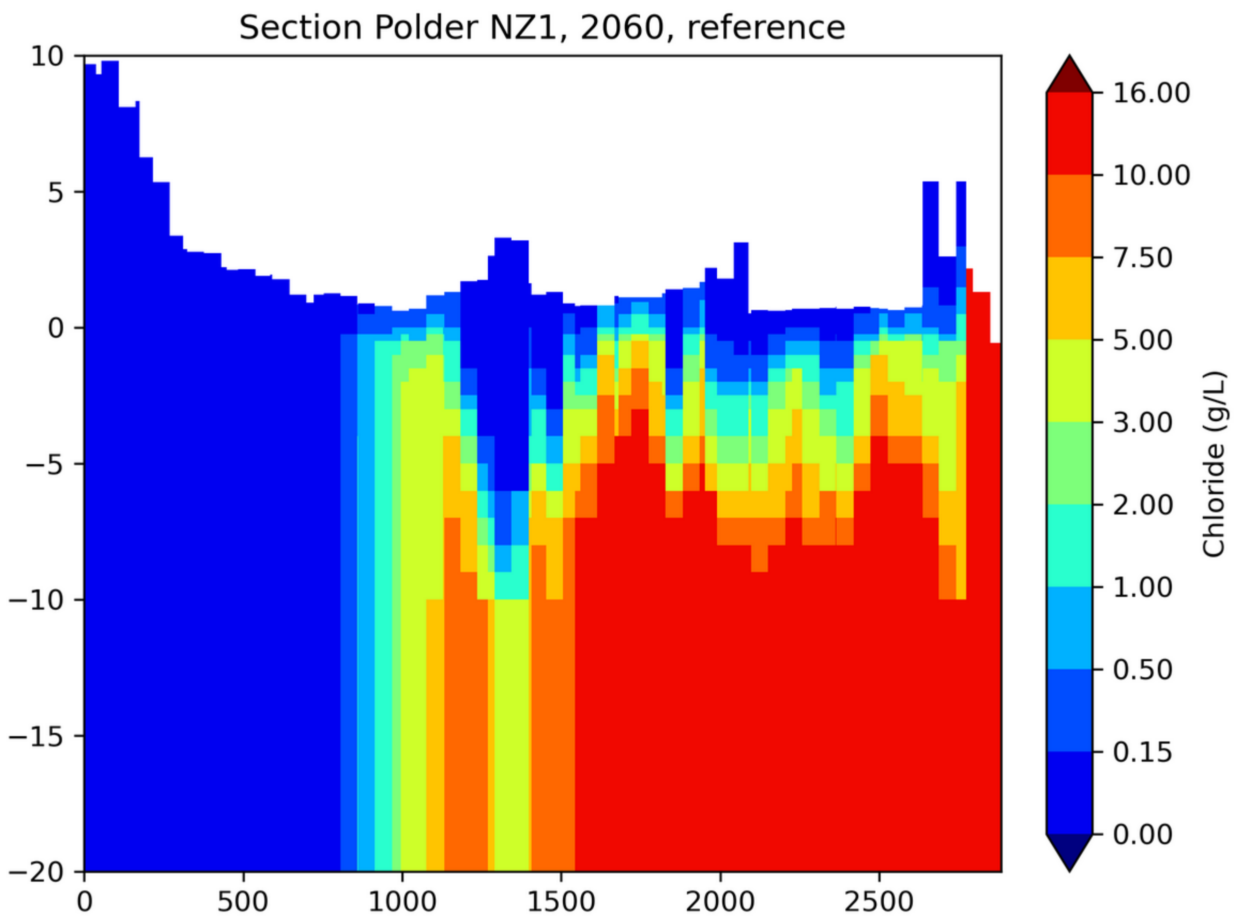


Figure C45: Location cross section Polder NZ 1 2060 reference (Deltares, 2024-a)

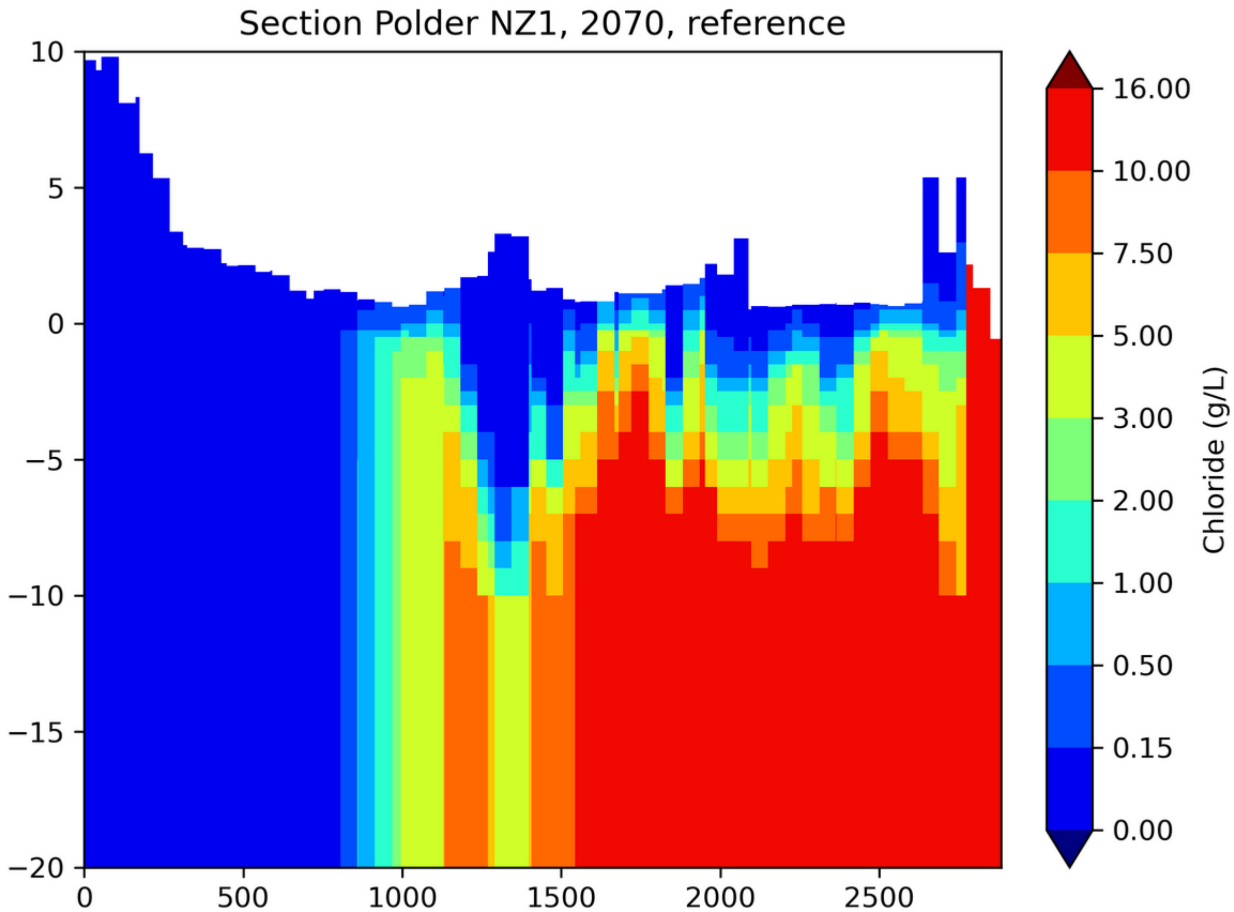


Figure C46: Location cross section Polder NZ 1 2070 reference (Deltares, 2024-a)

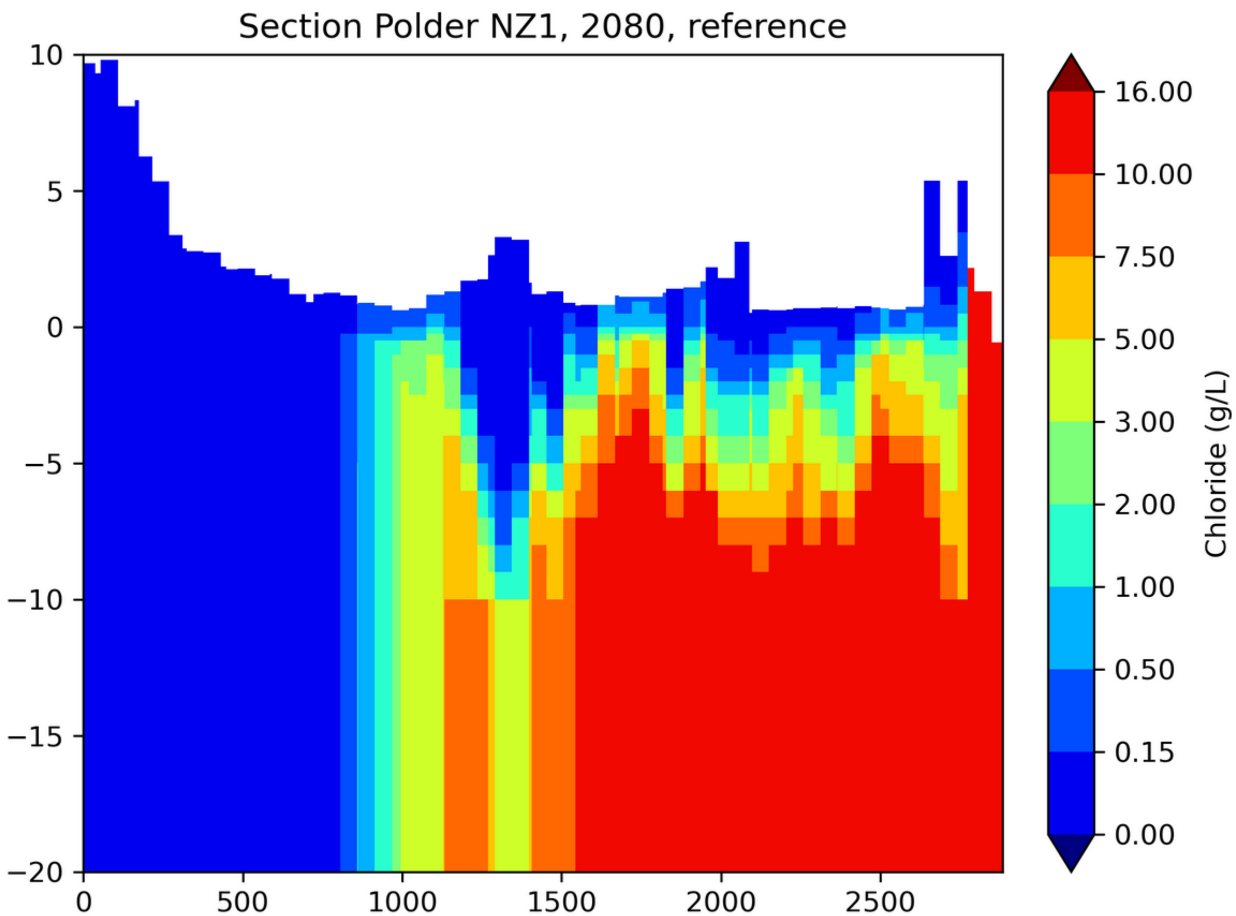


Figure C47: Location cross section Polder NZ 1 2080 reference (Deltares, 2024-a)

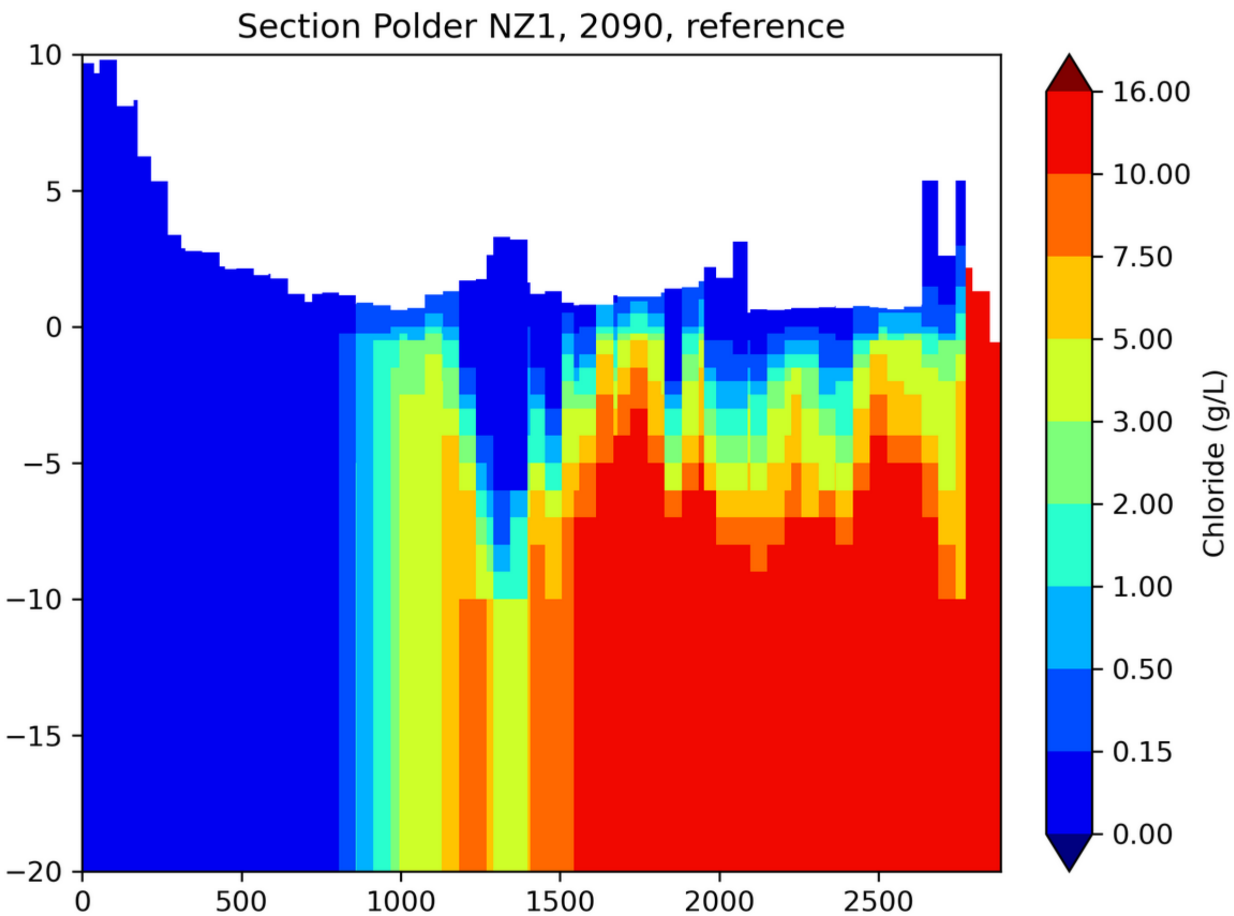


Figure C48: Location cross section Polder NZ 1 2090 reference (Deltares, 2024-a)

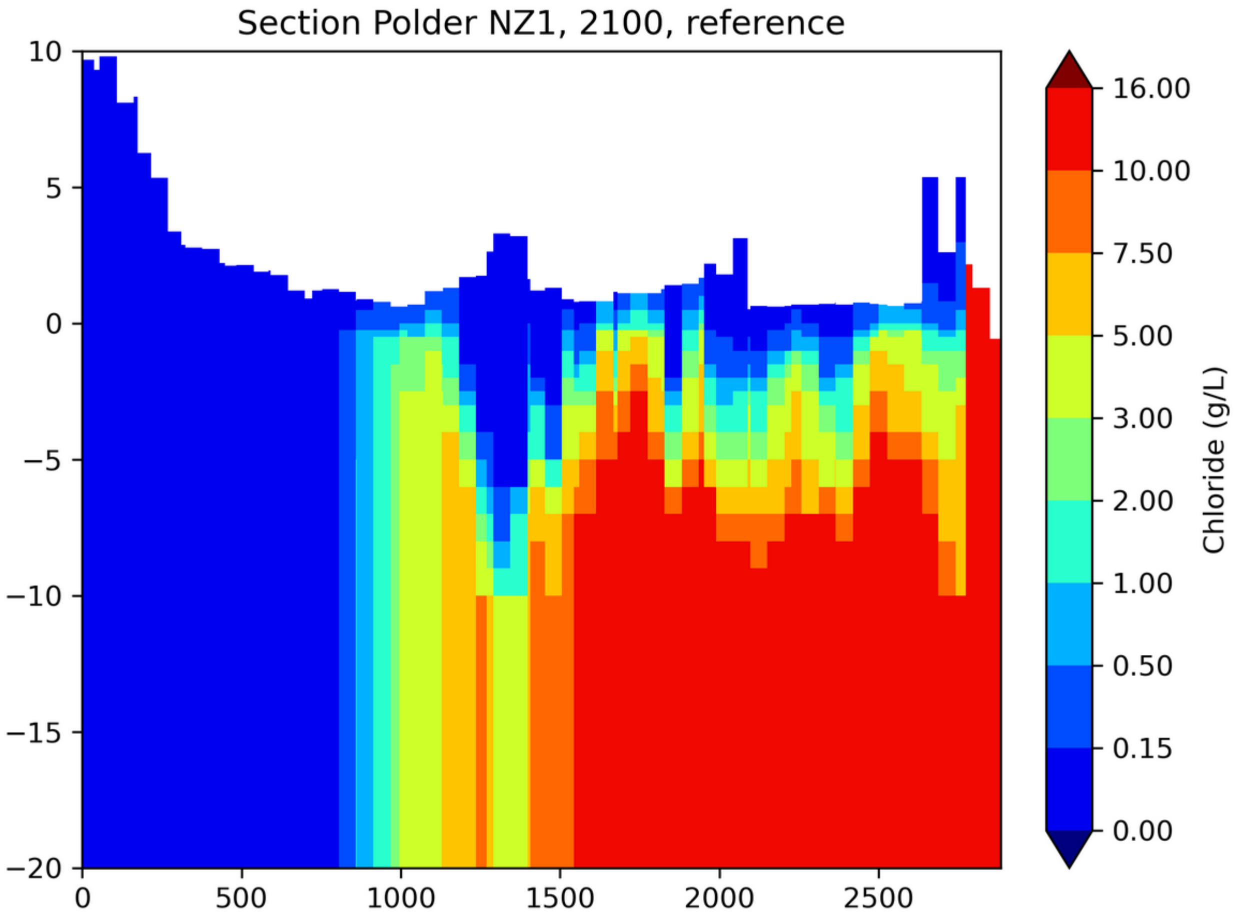


Figure C49: Location cross section Polder NZ 1 2100 reference (Deltares, 2024-a)

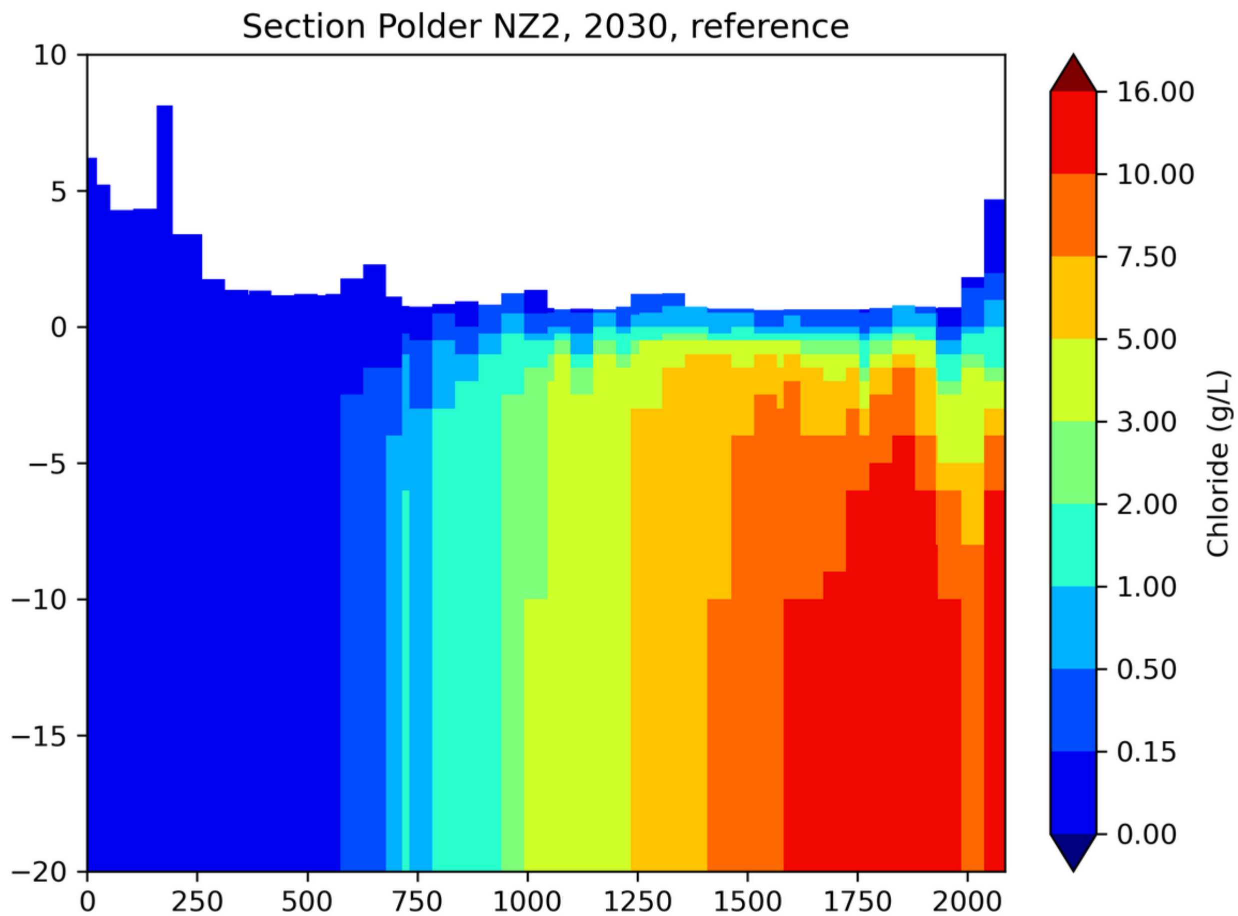


Figure C50: Location cross section Polder NZ 2 2030 reference (Deltares, 2024-a)

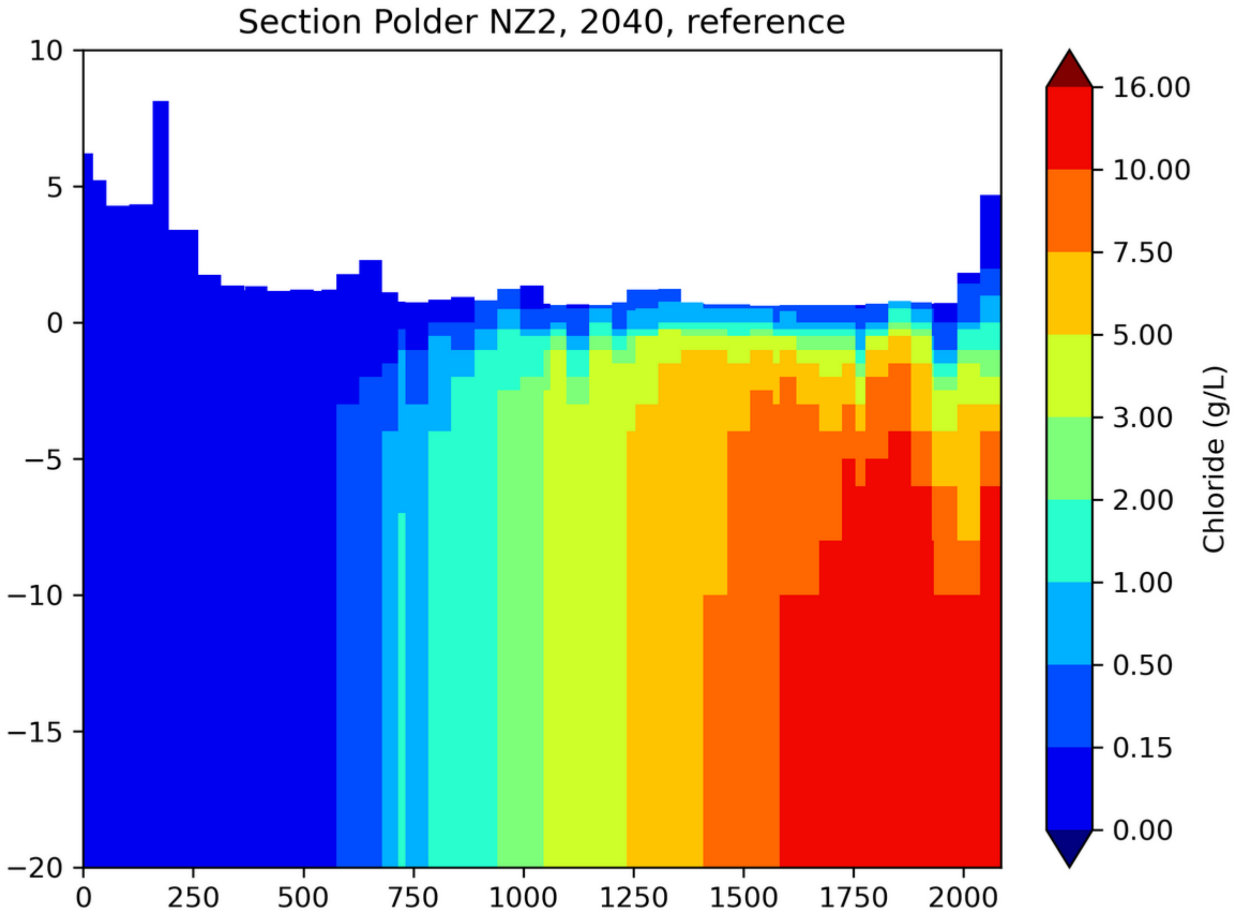


Figure C51: Location cross section Polder NZ 2 2040 reference (Deltares, 2024-a)

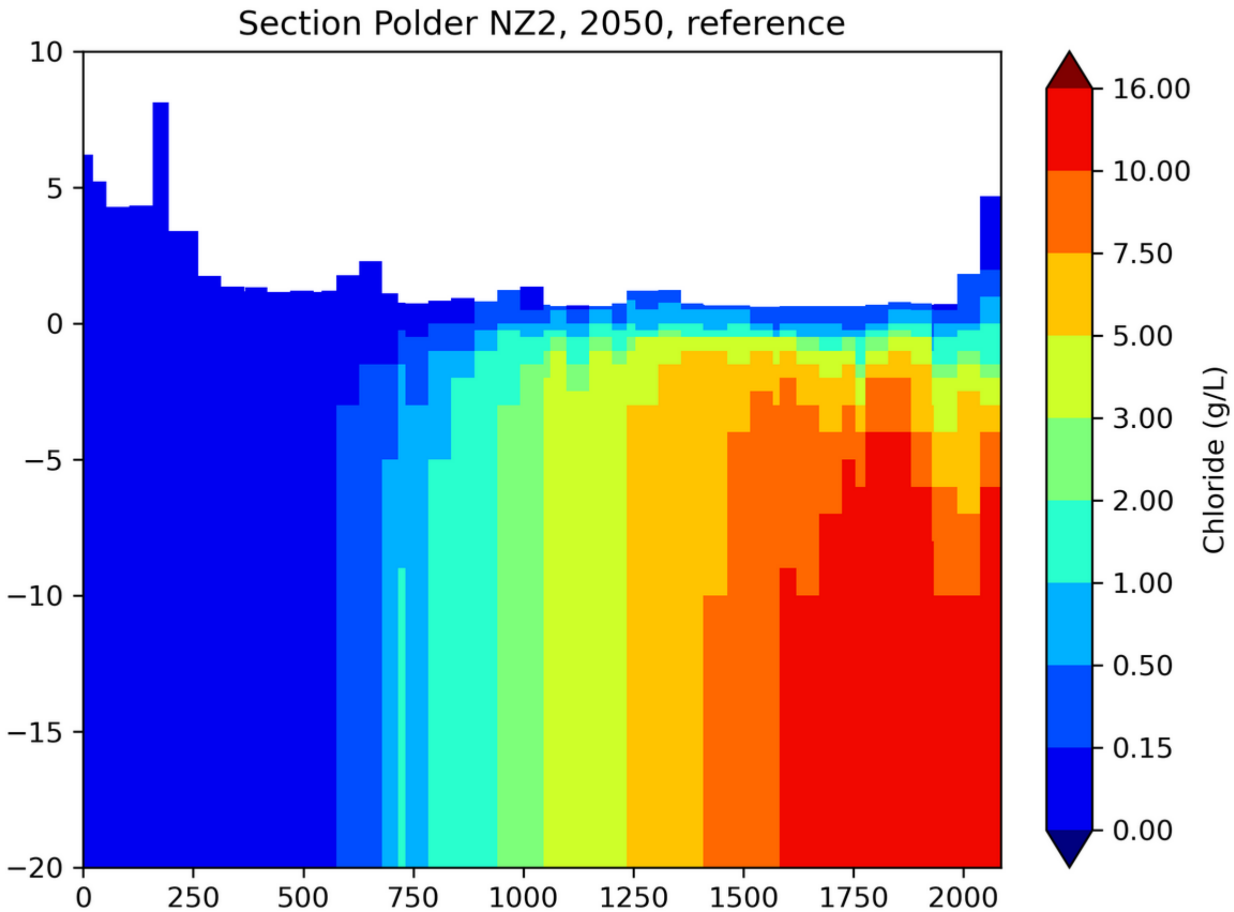


Figure C52: Location cross section Polder NZ 2 2050 reference (Deltares, 2024-a)

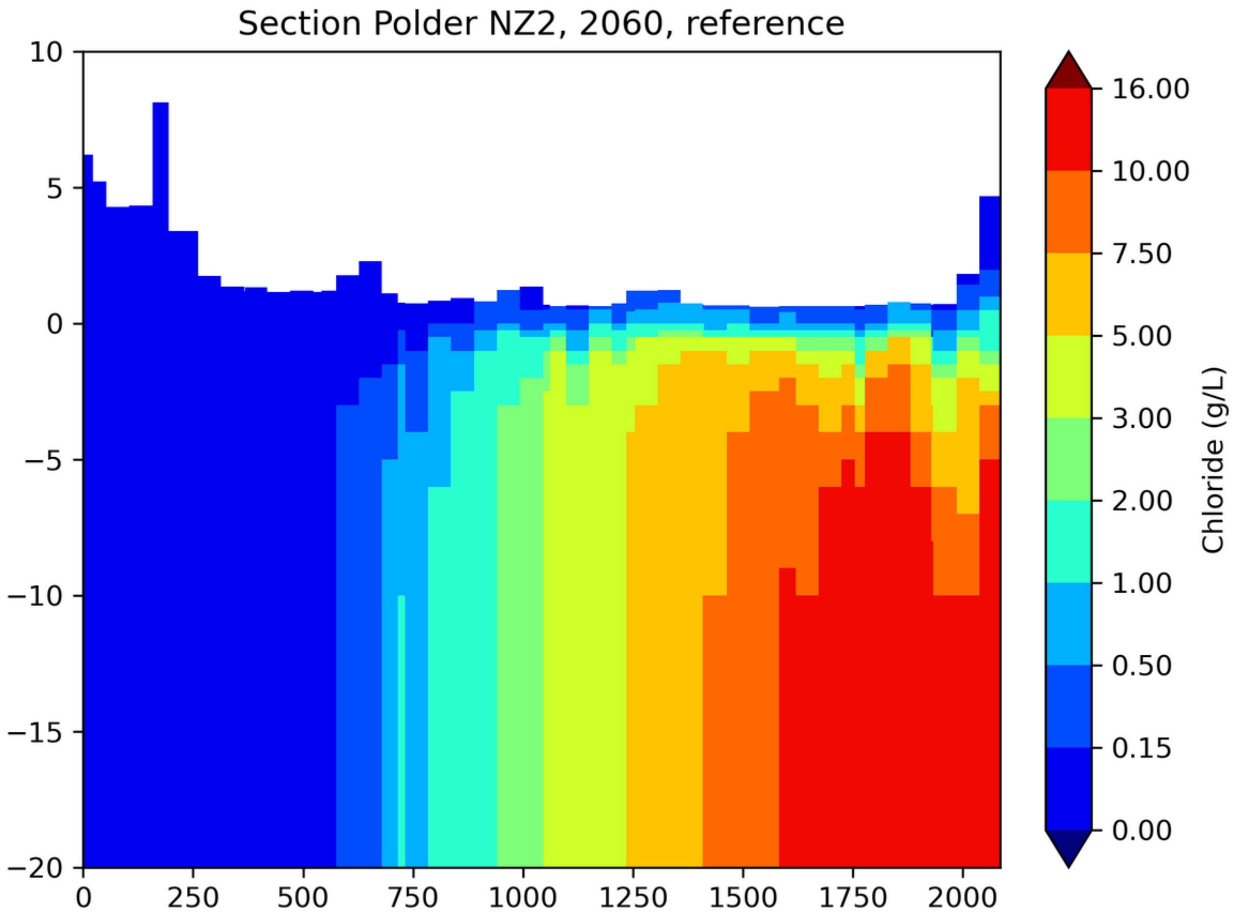


Figure C53: Location cross section Polder NZ 2 2060 reference (Deltares, 2024-a)

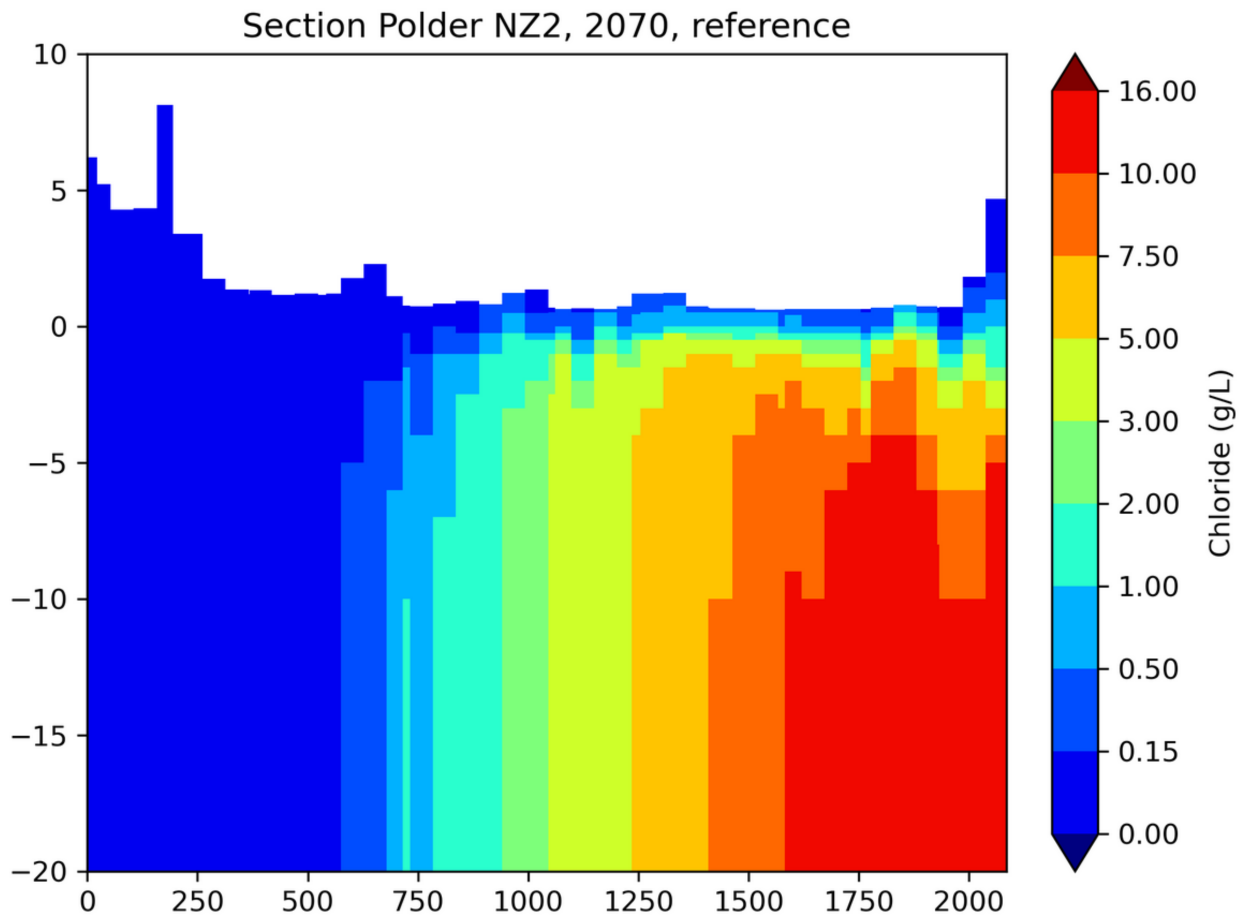


Figure C54: Location cross section Polder NZ 2 2070 reference (Deltares, 2024-a)

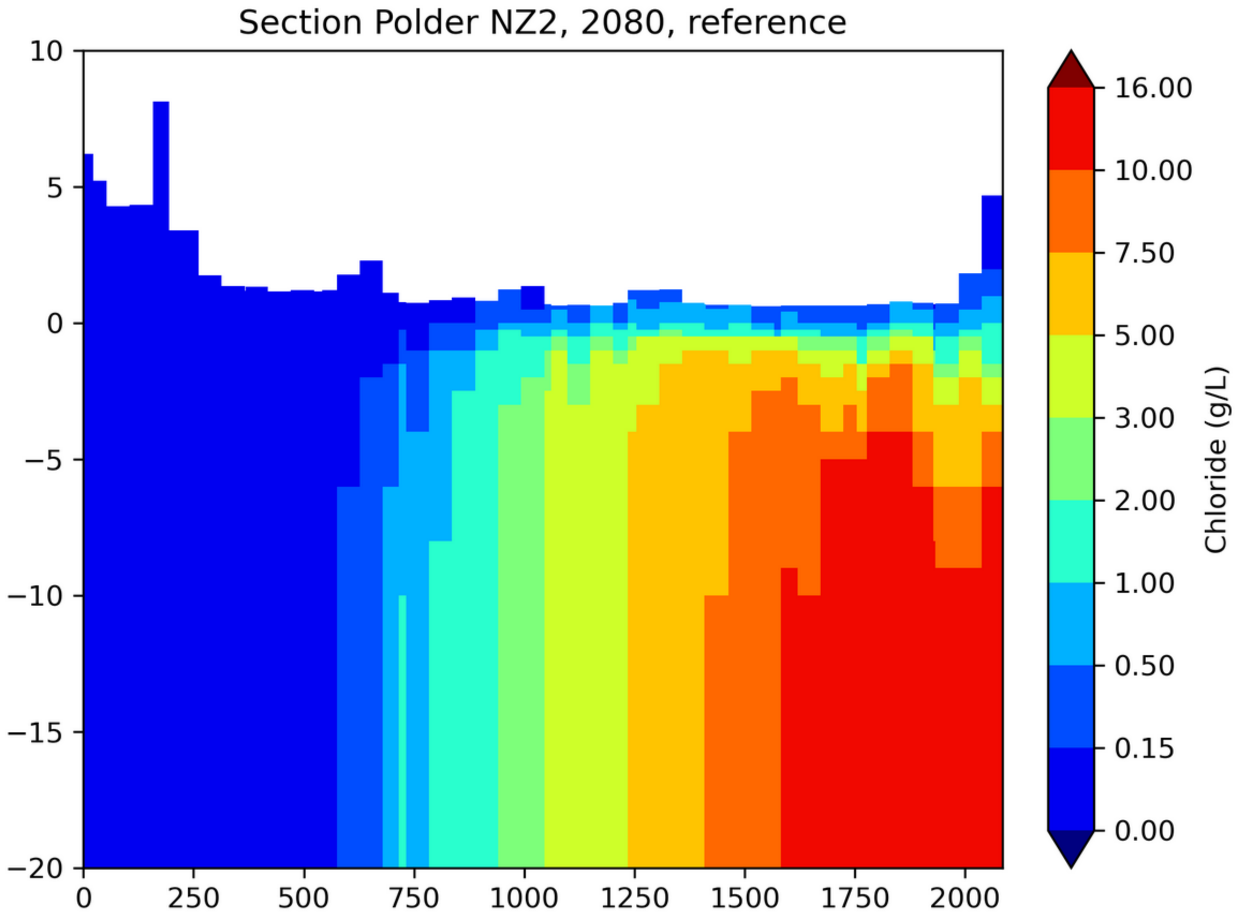


Figure C55: Location cross section Polder NZ 2 2080 reference (Deltares, 2024-a)

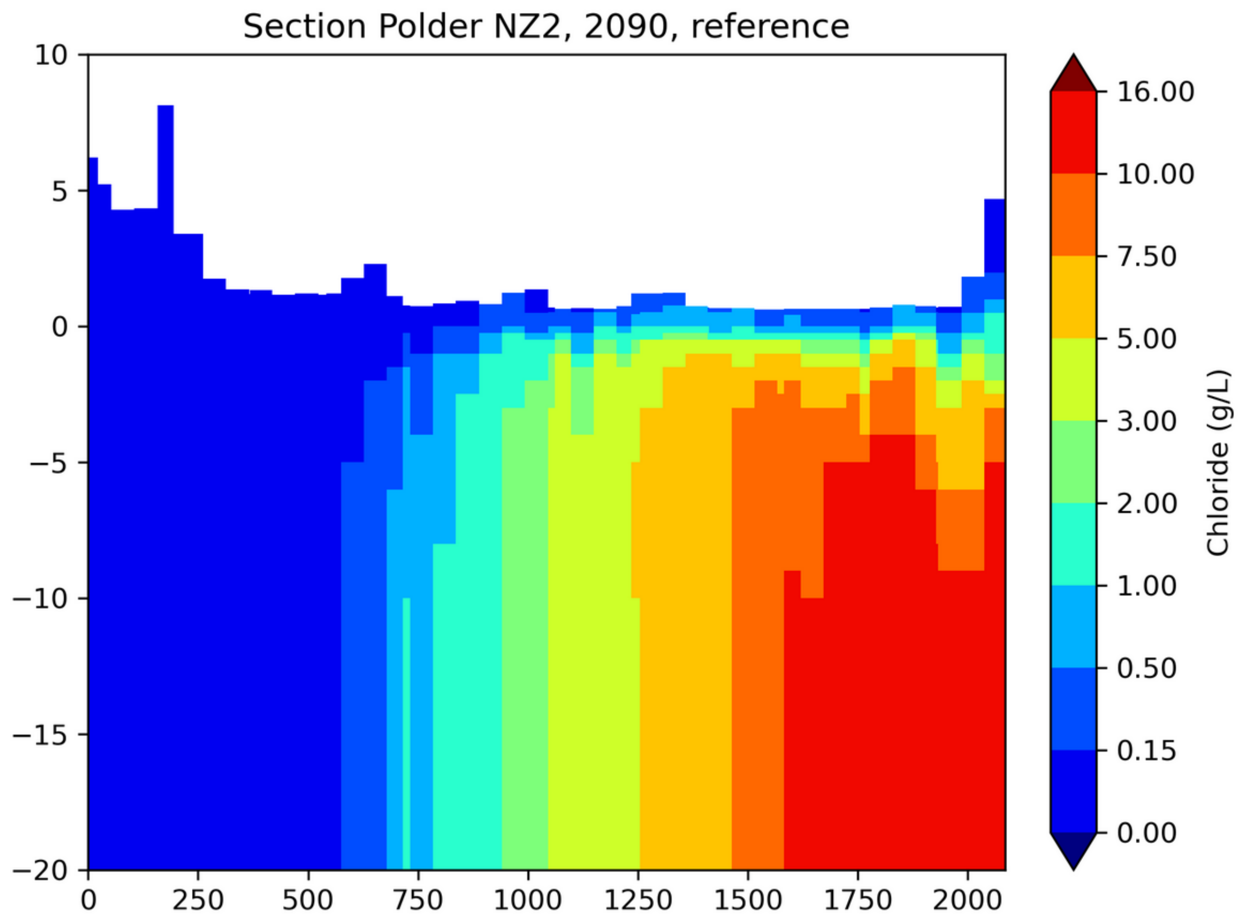


Figure C56: Location cross section Polder NZ 2 2090 reference (Deltares, 2024-a)

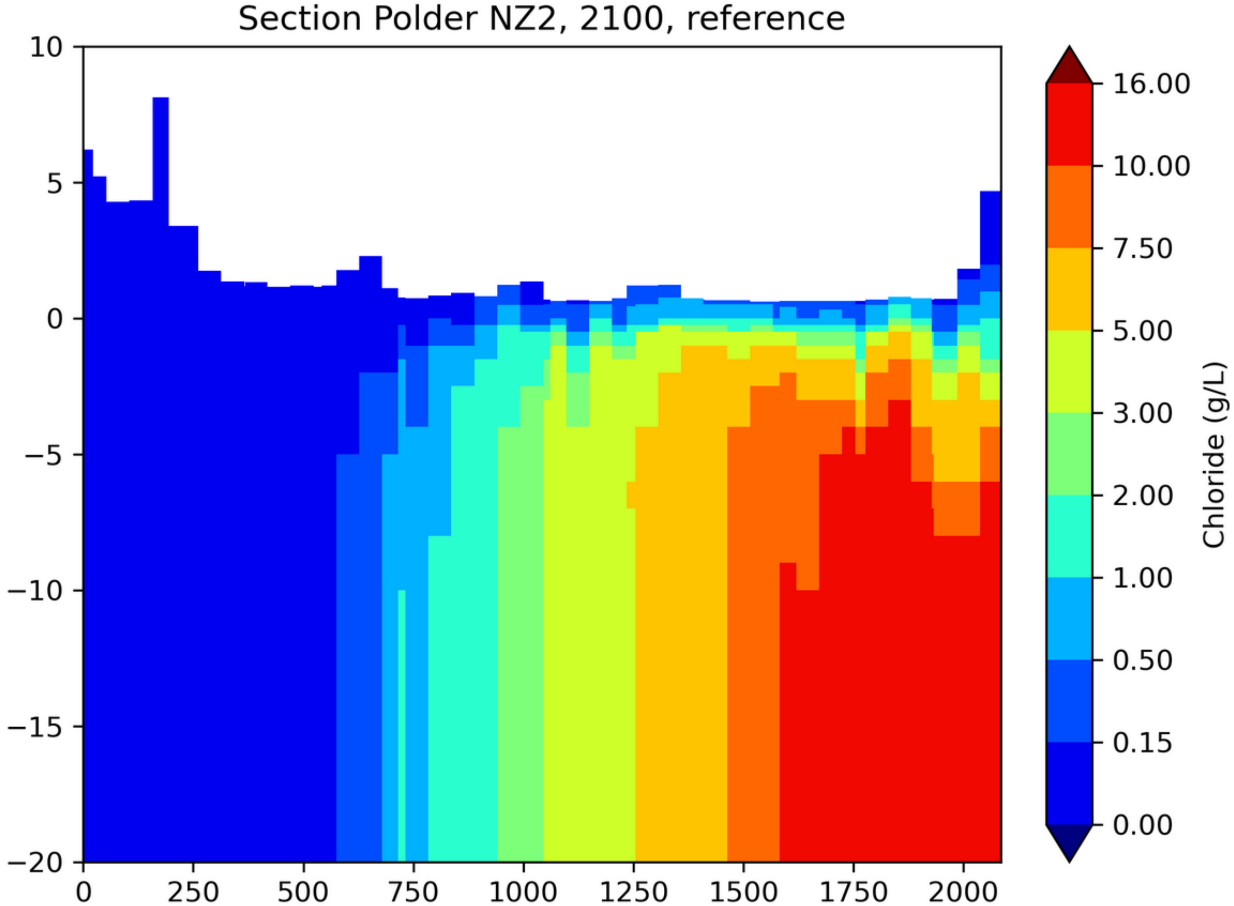


Figure C57: Location cross section Polder NZ 2 2100 reference (Deltares, 2024-a)

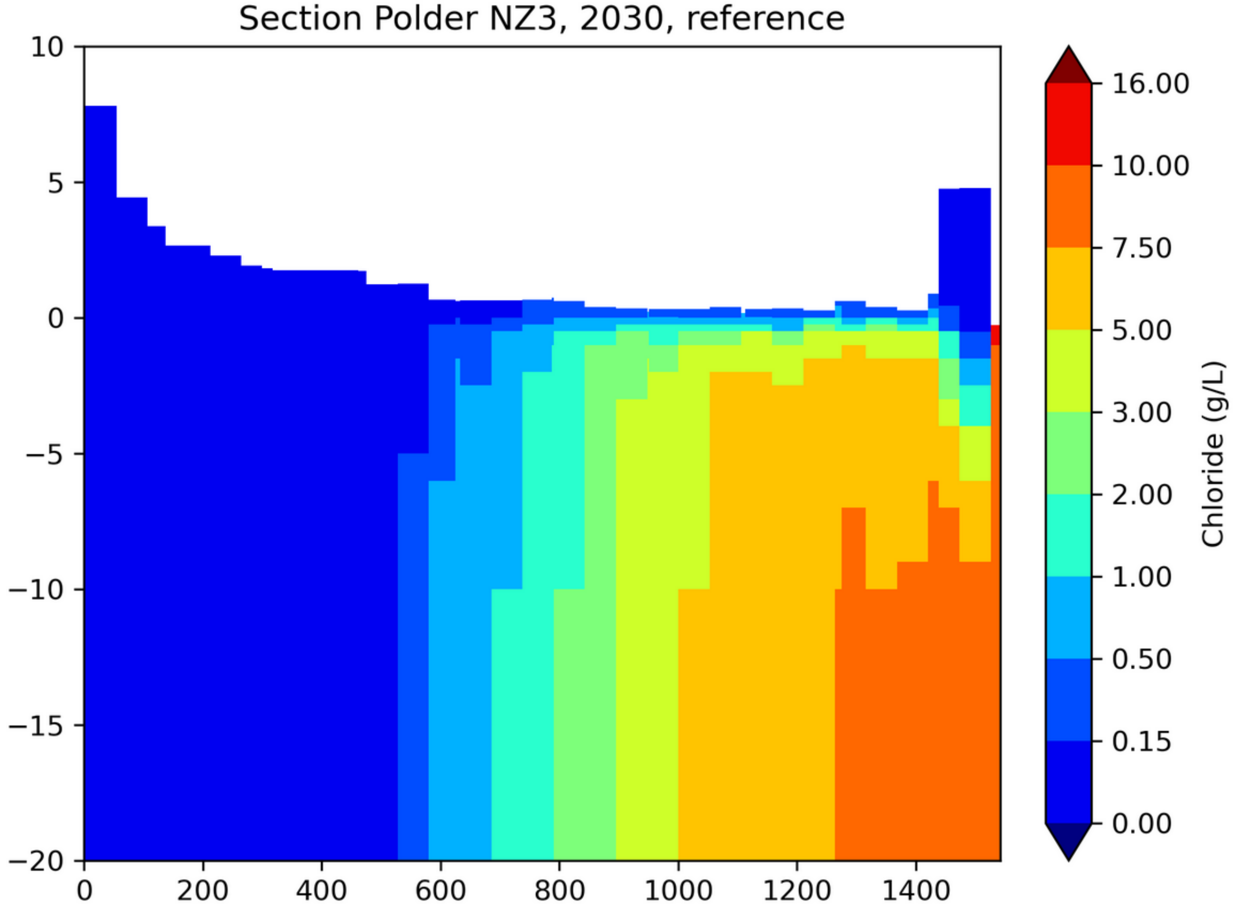


Figure C58: Location cross section Polder NZ 3 2030 reference (Deltares, 2024-a)

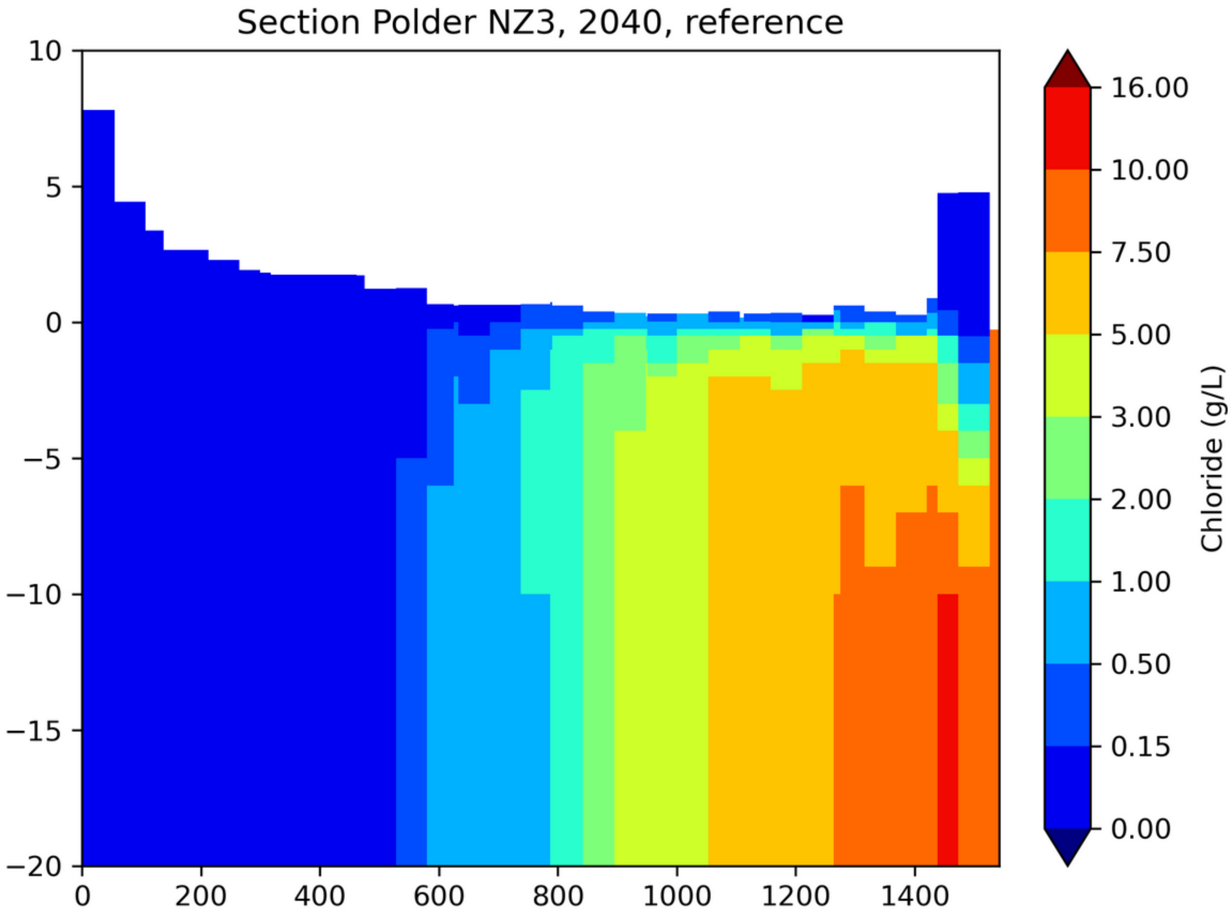


Figure C59: Location cross section Polder NZ 3 2040 reference (Deltares, 2024-a)

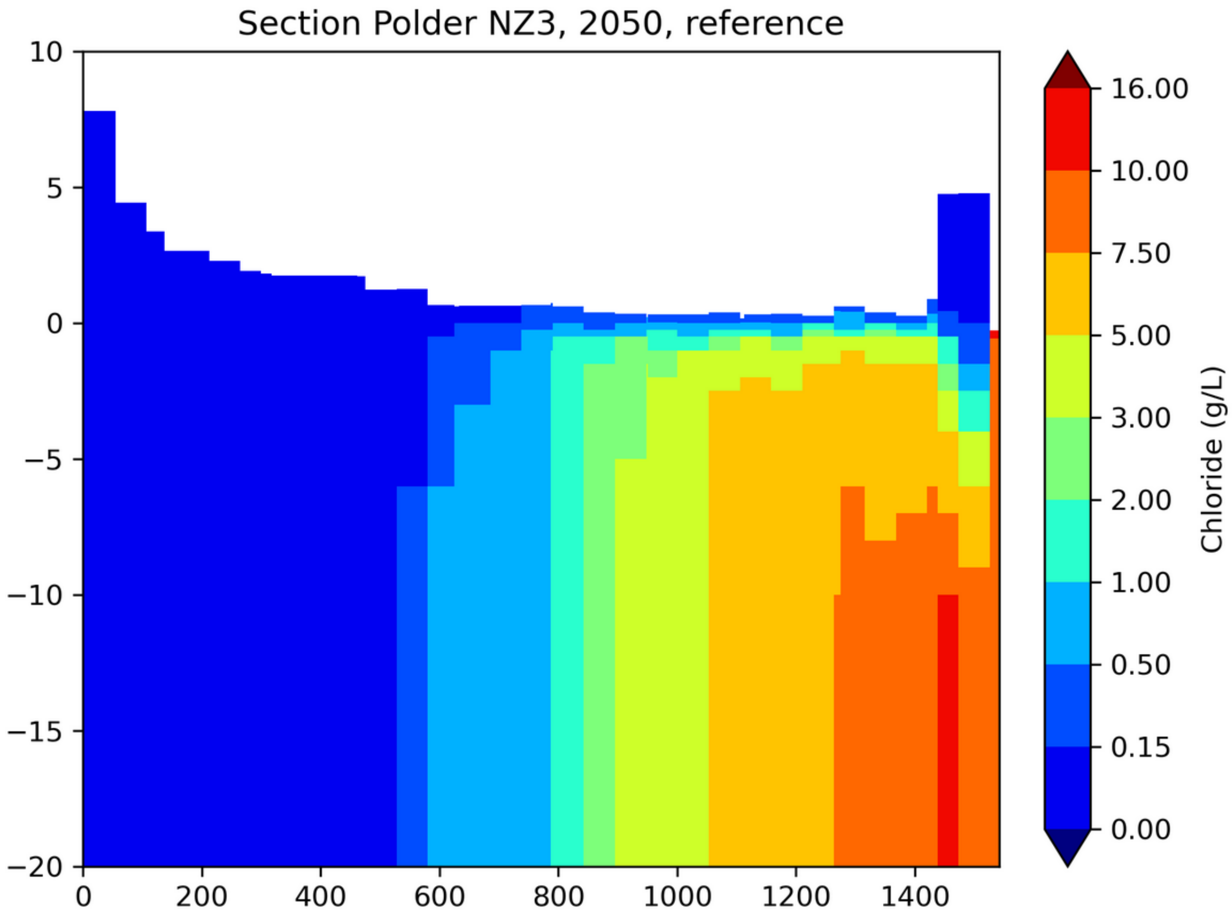


Figure C60: Location cross section Polder NZ 3 2050 reference (Deltares, 2024-a)

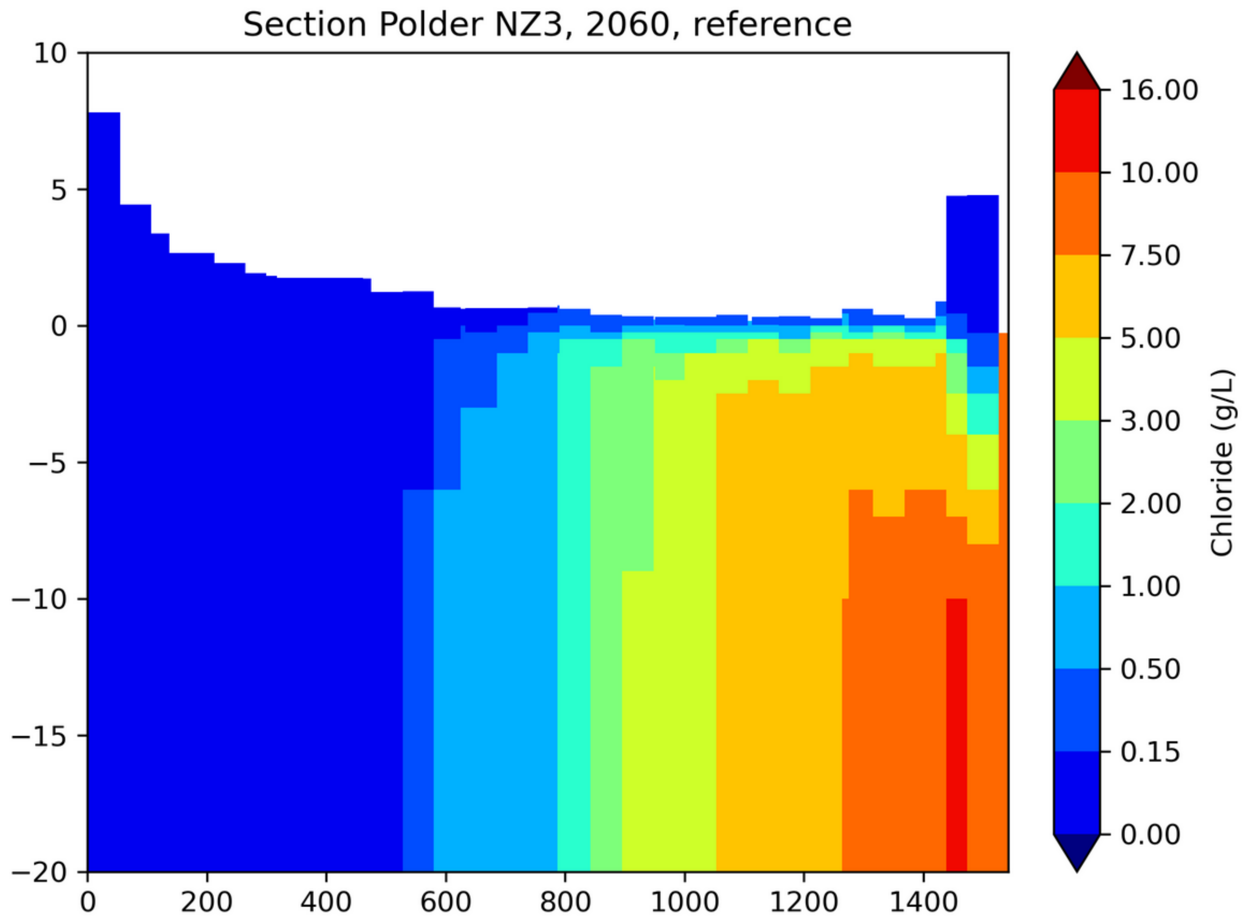


Figure C61: Location cross section Polder NZ 3 2060 reference (Deltares, 2024-a)

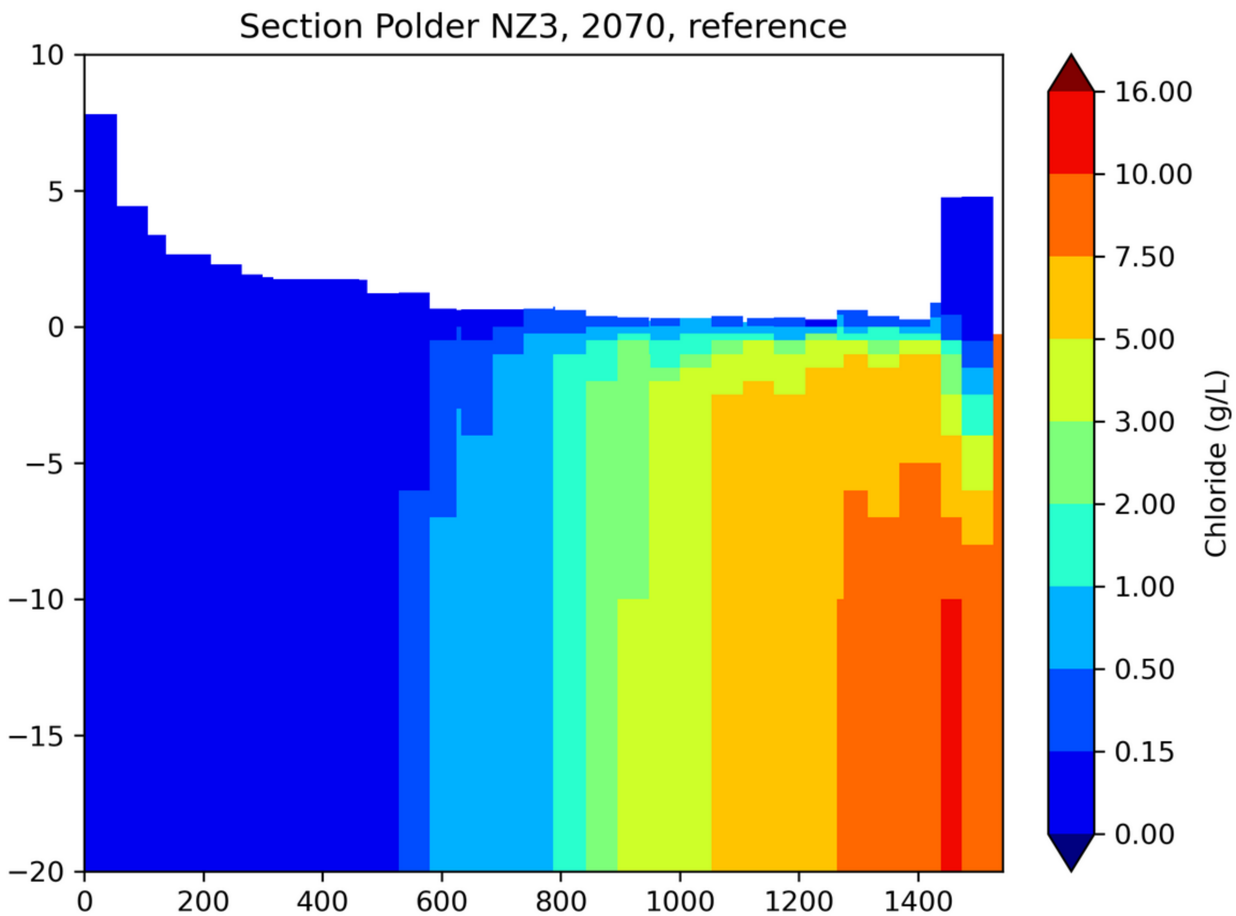


Figure C62: Location cross section Polder NZ 3 2070 reference (Deltares, 2024-a)

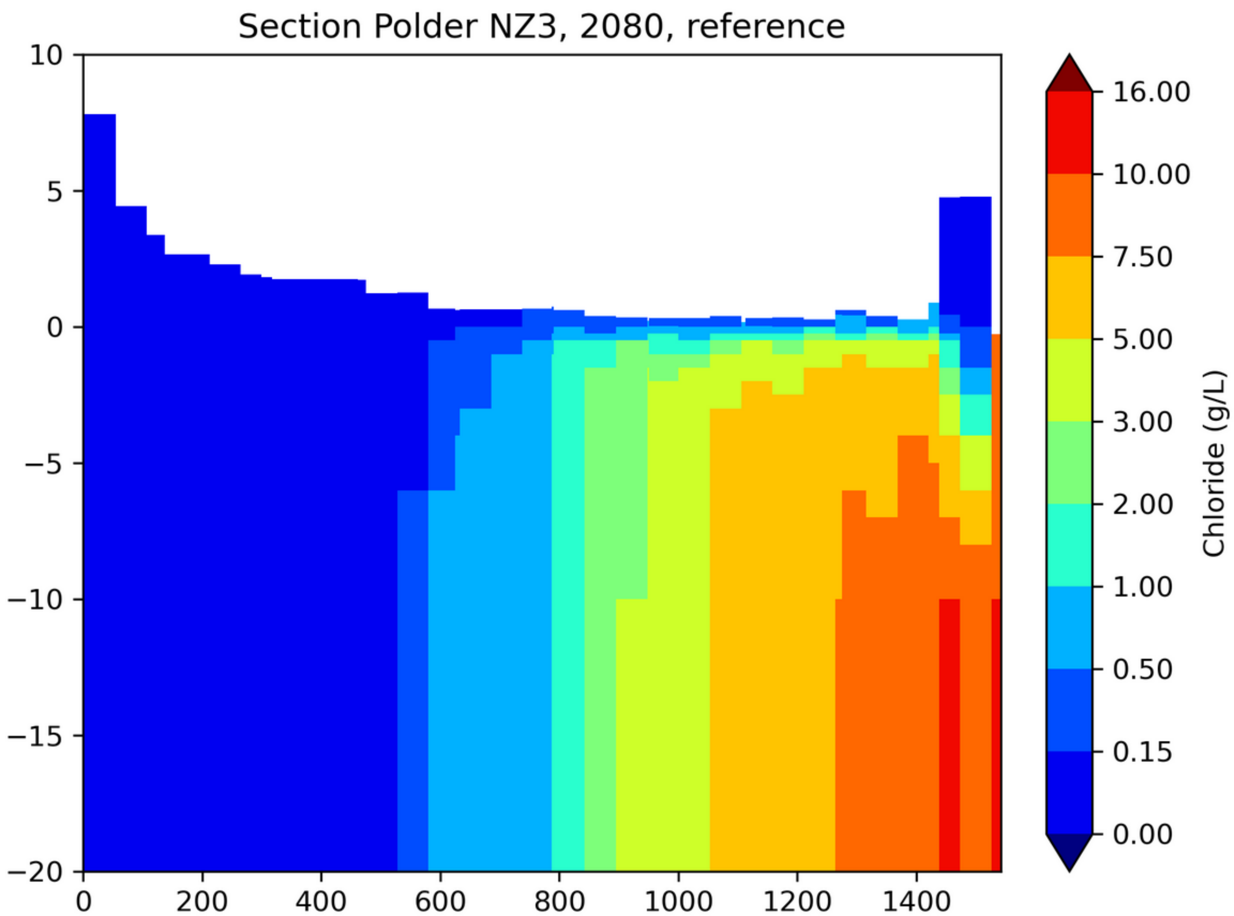


Figure C63: Location cross section Polder NZ 3 2080 reference (Deltares, 2024-a)

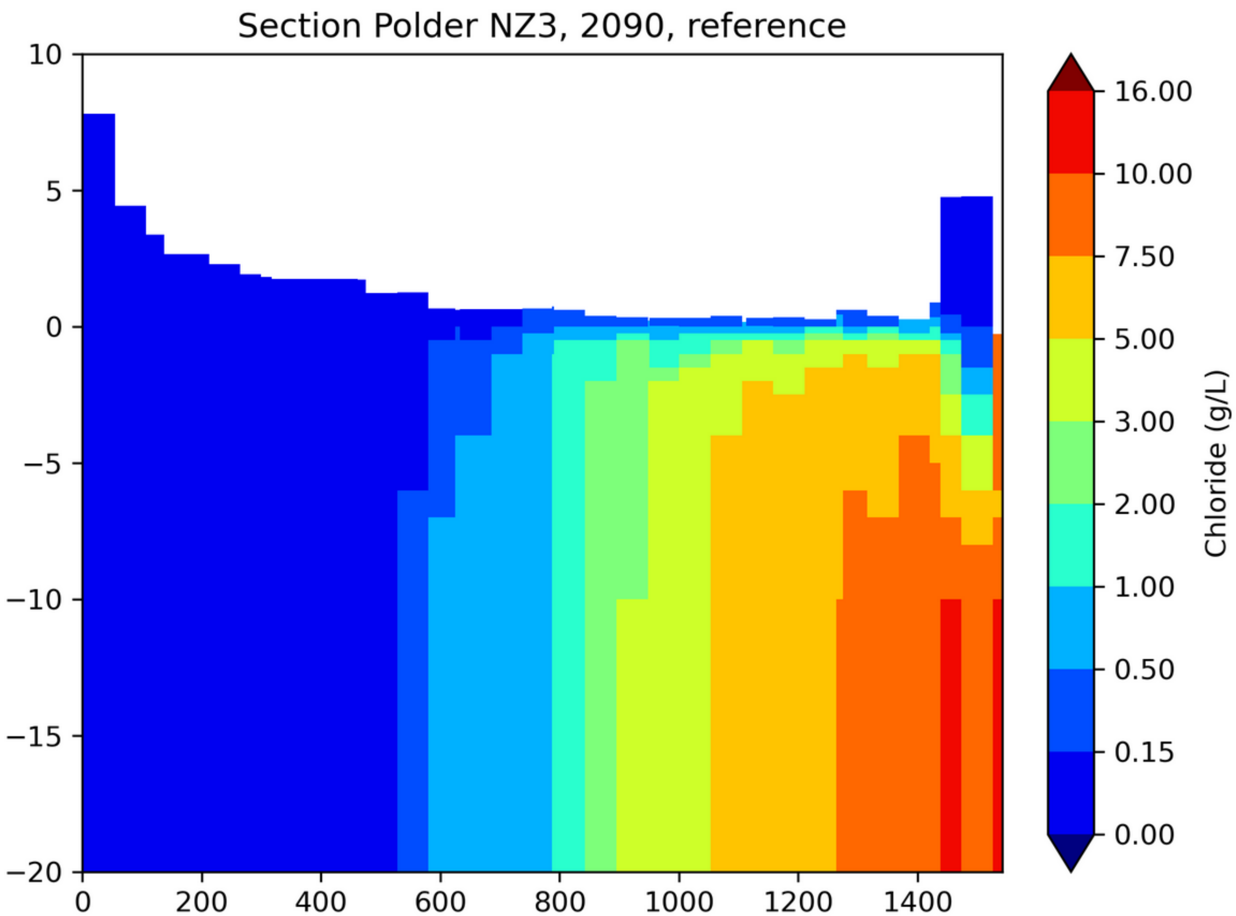


Figure C64: Location cross section Polder NZ 3 2090 reference (Deltares, 2024-a)

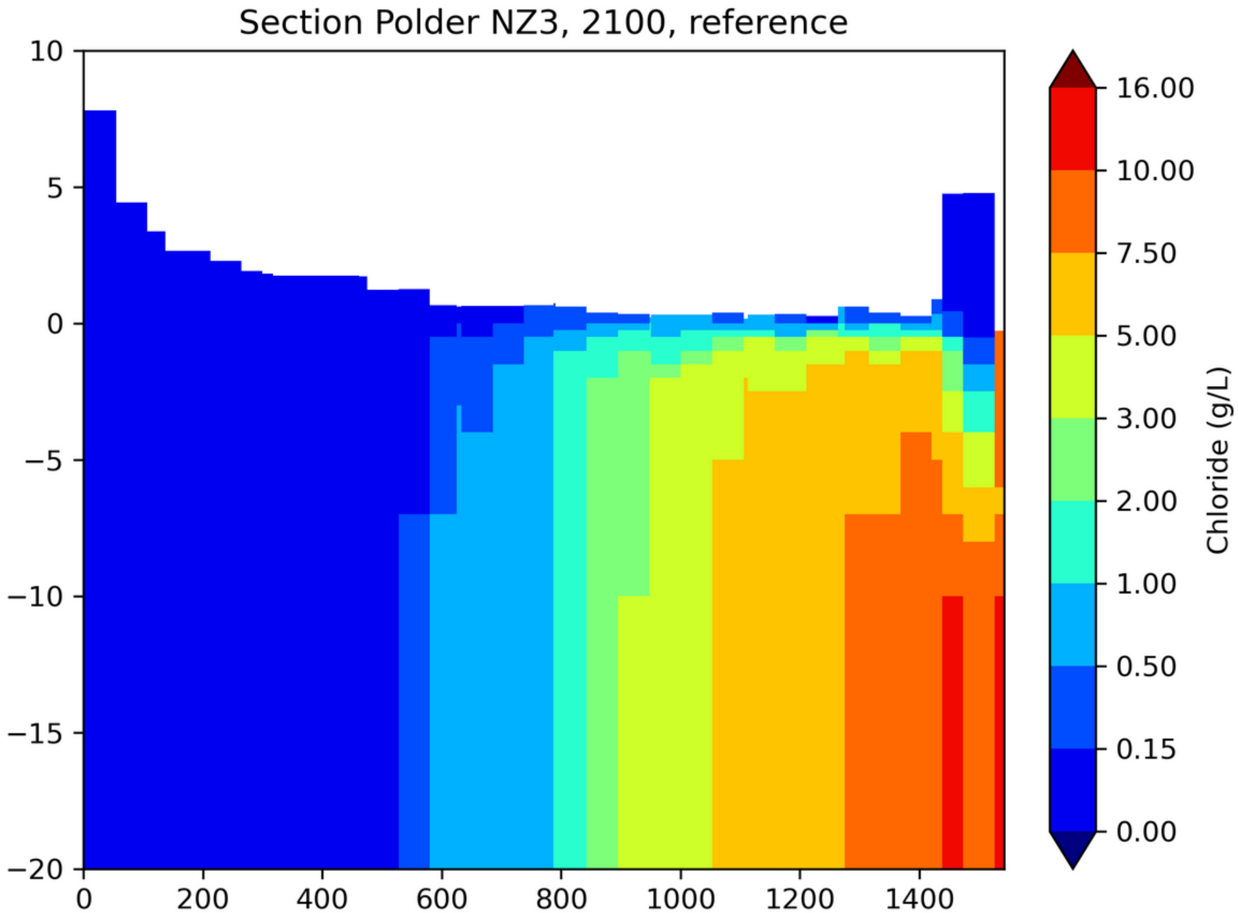


Figure C65: Location cross section Polder NZ 3 2100 reference (Deltares, 2024-a)

Cross-sections Hd

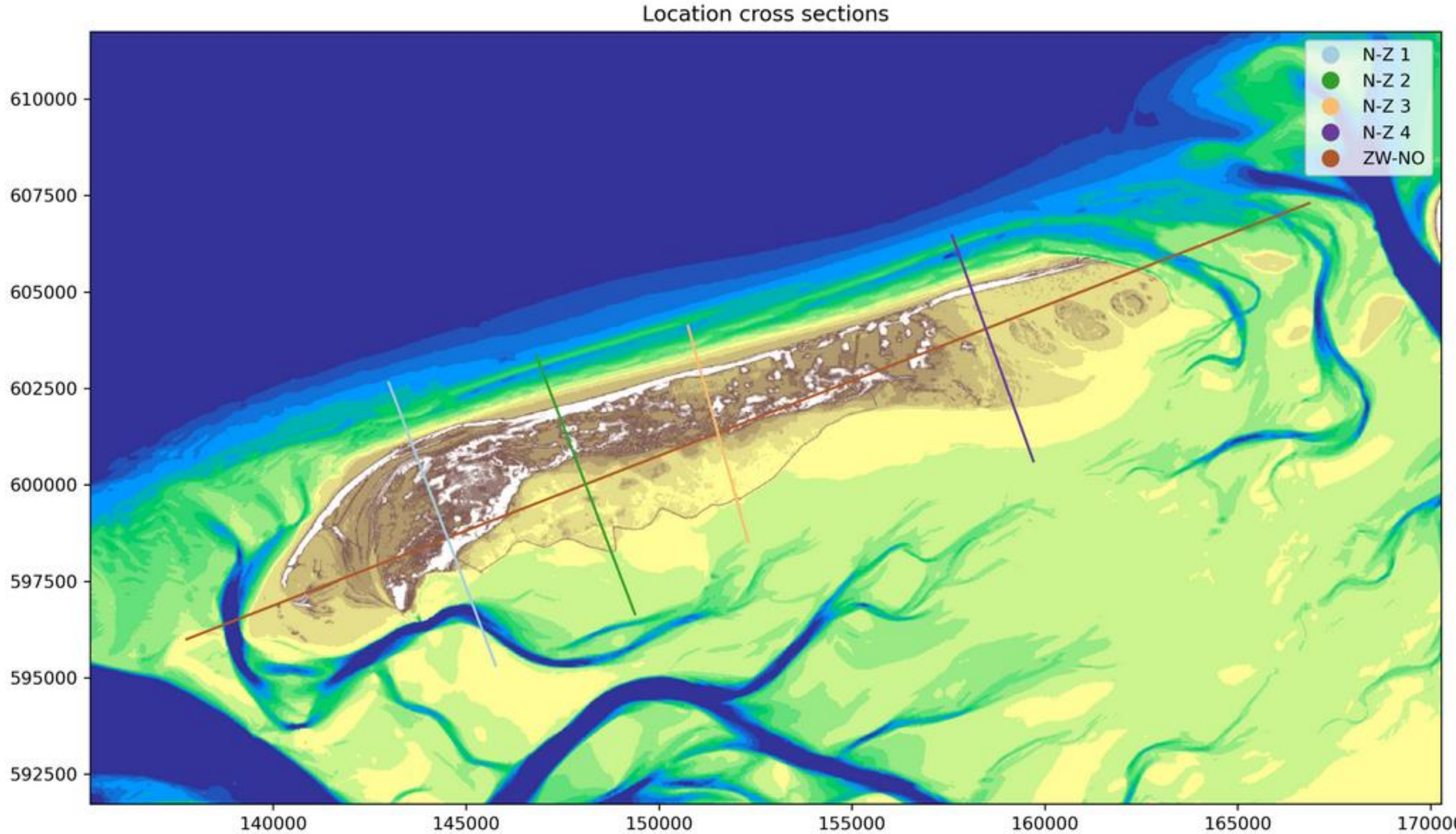


Figure C66: Location cross sections Hd difference with reference (Deltares, 2024-a)

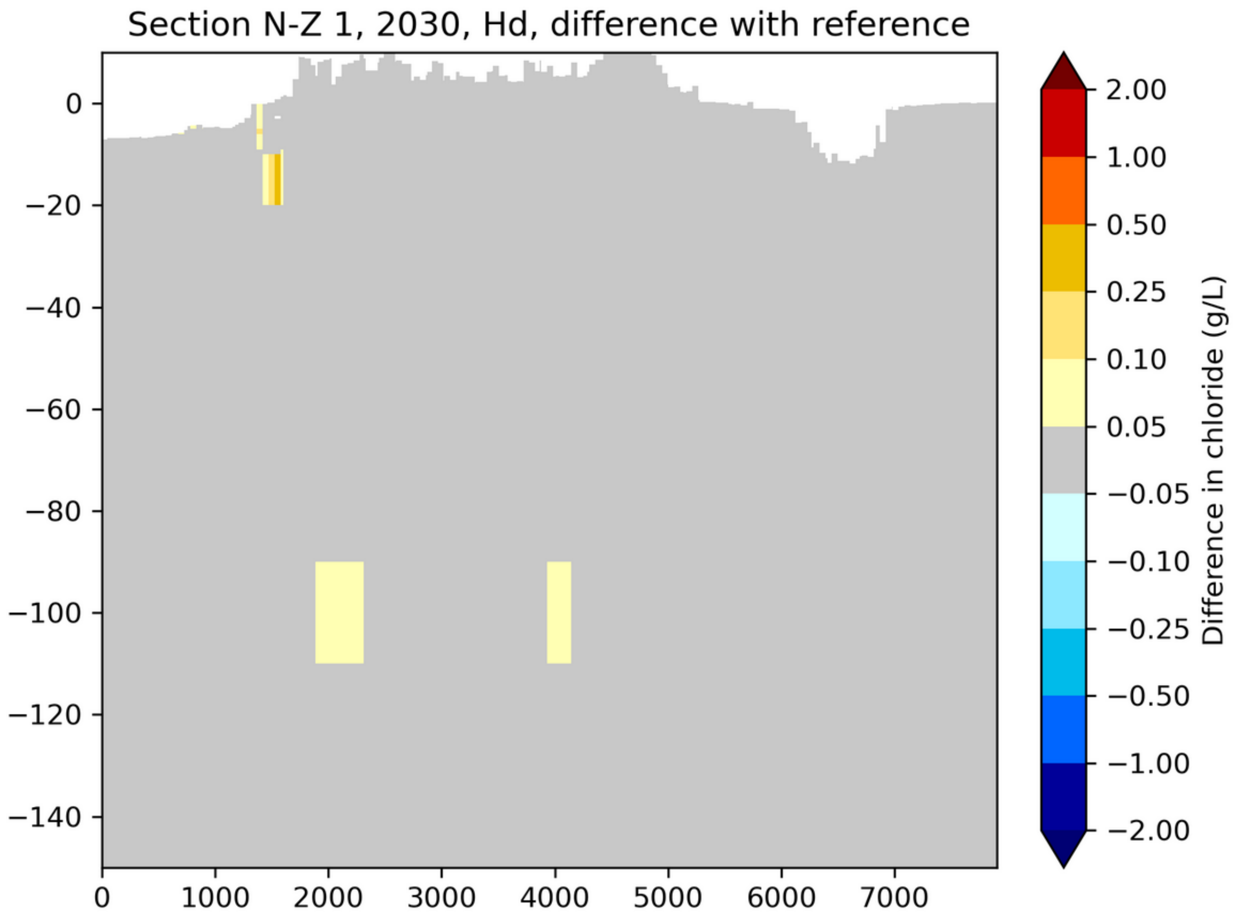


Figure C67: Location cross section N-Z 1 2030 Hd difference with reference (Deltares, 2024-a)

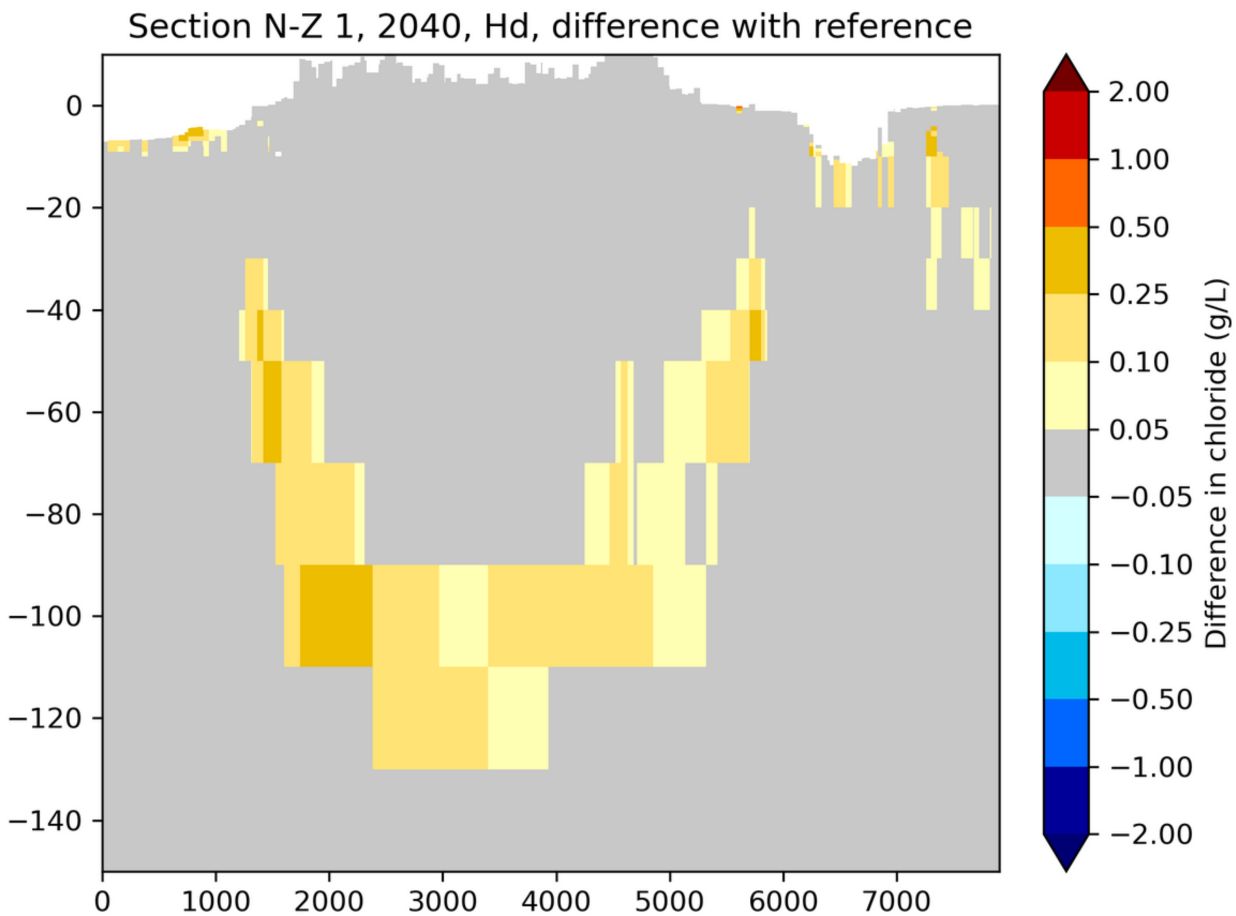


Figure C68: Location cross section N-Z 1 2040 Hd difference with reference (Deltares, 2024-a)

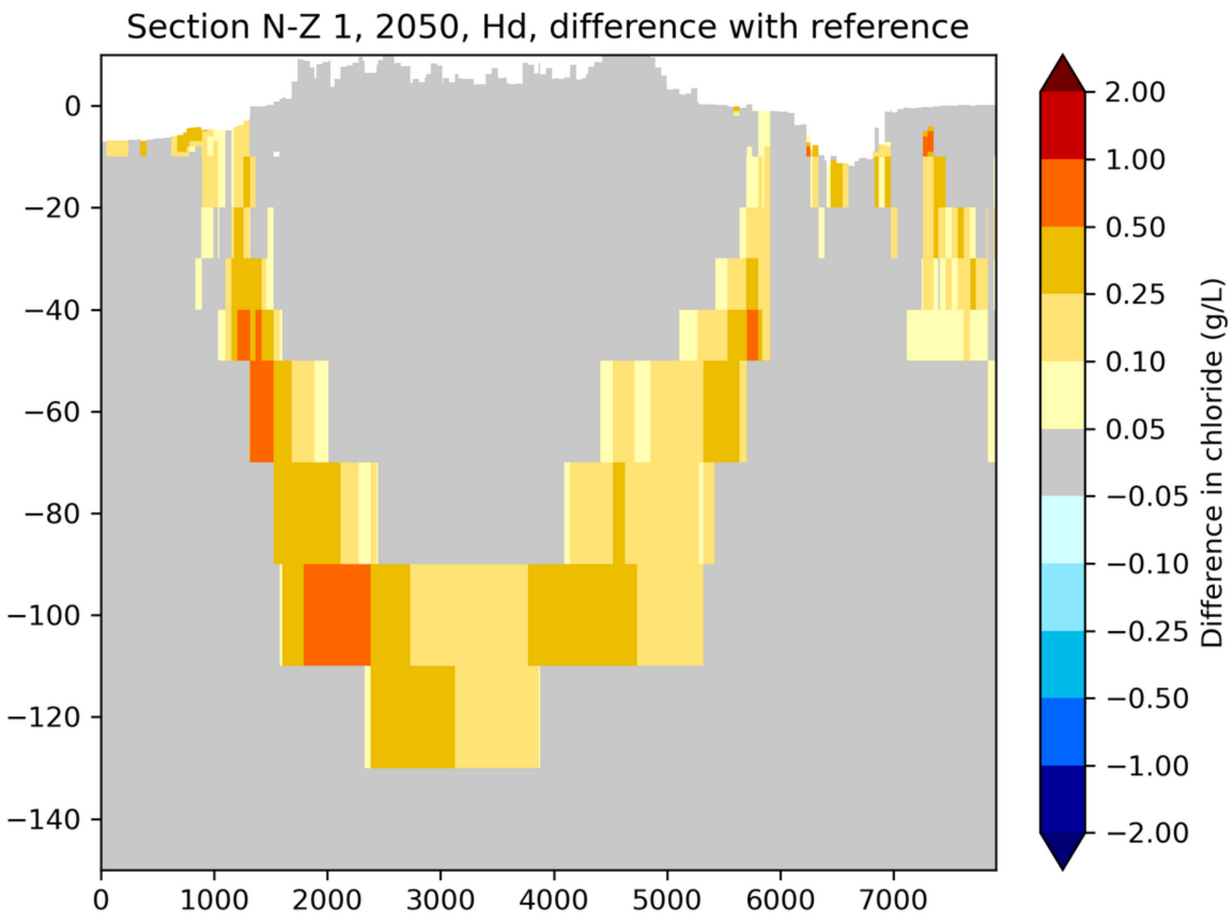


Figure C69: Location cross section N-Z 1 2050 Hd difference with reference (Deltares, 2024-a)

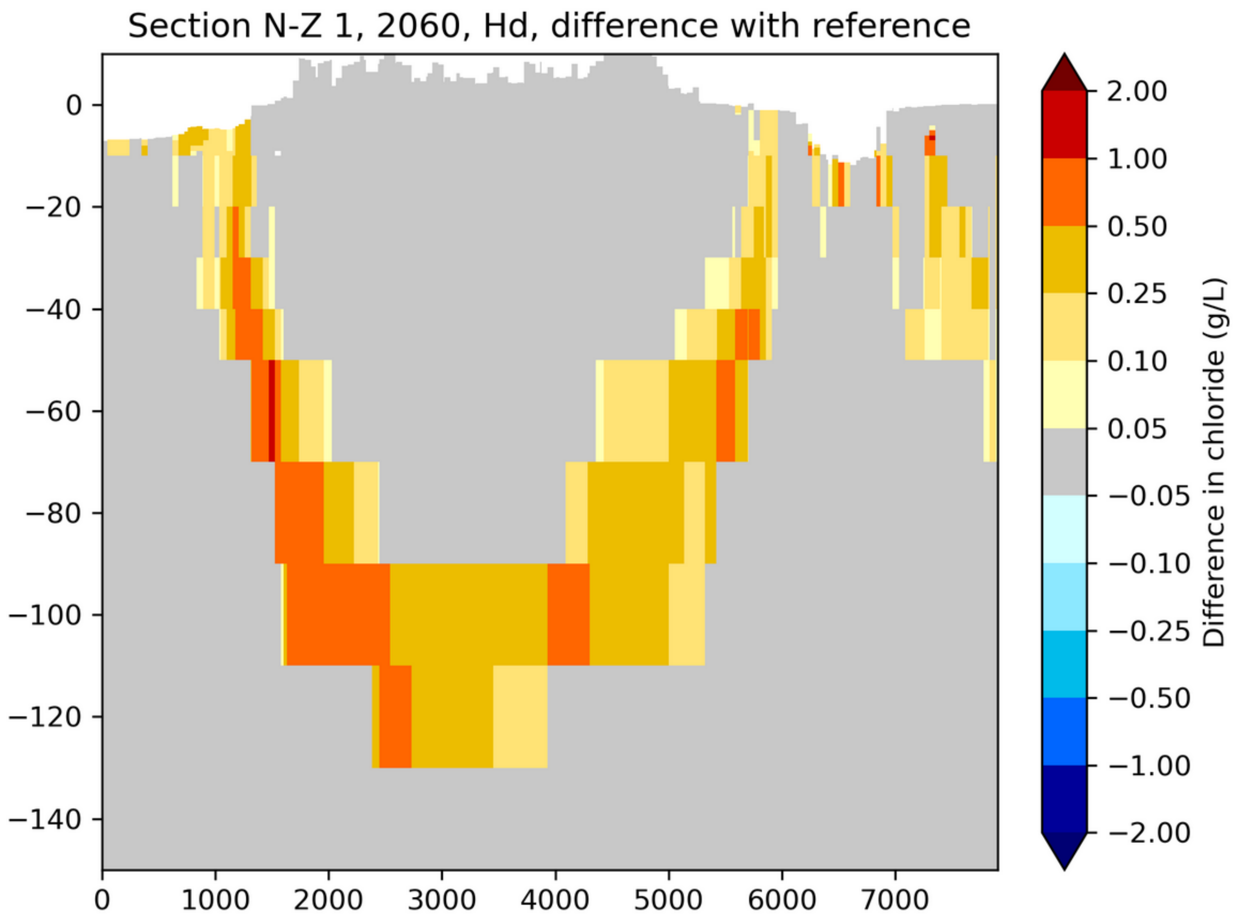


Figure C70: Location cross section N-Z 1 2060 Hd difference with reference (Deltares, 2024-a)

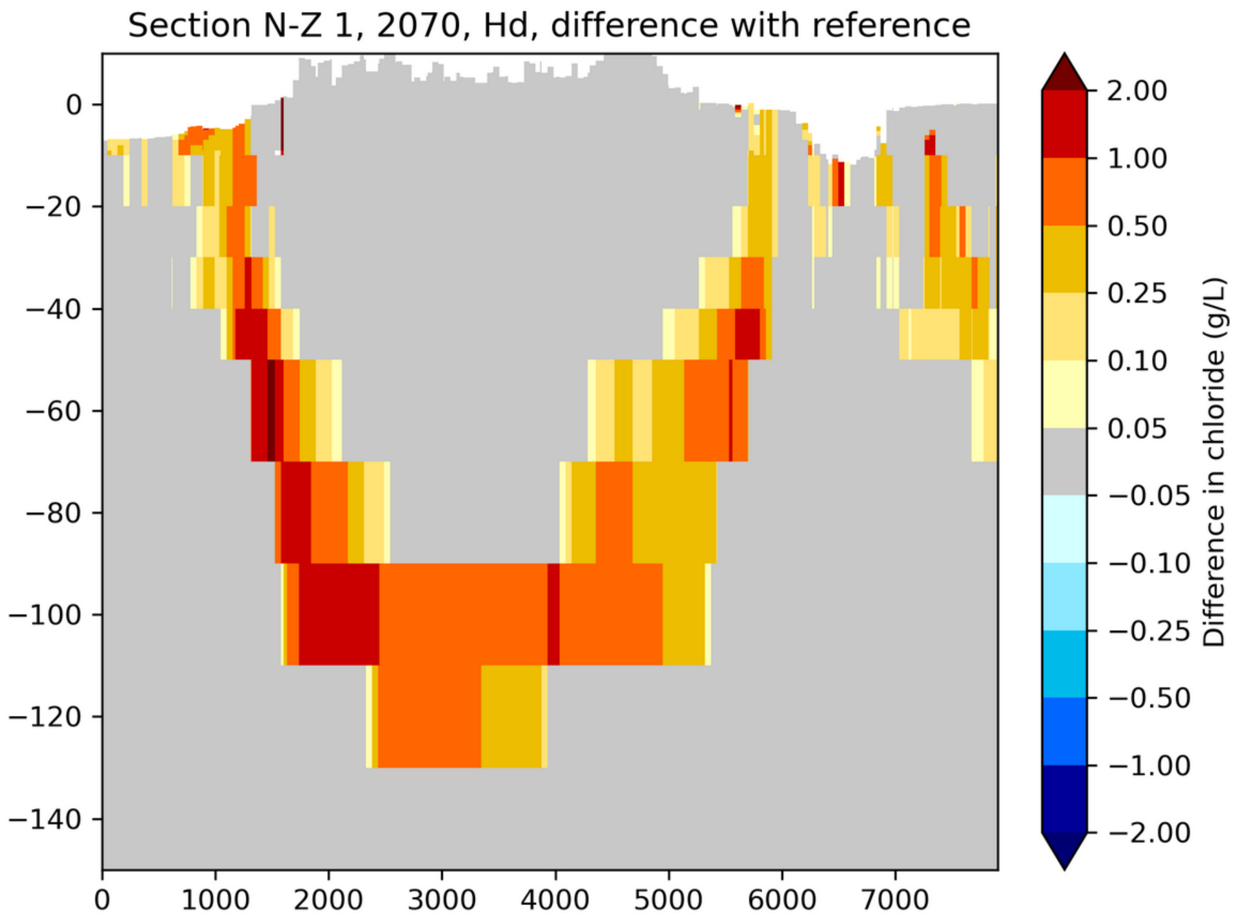


Figure C71: Location cross section N-Z 1 2070 Hd difference with reference (Deltares, 2024-a)

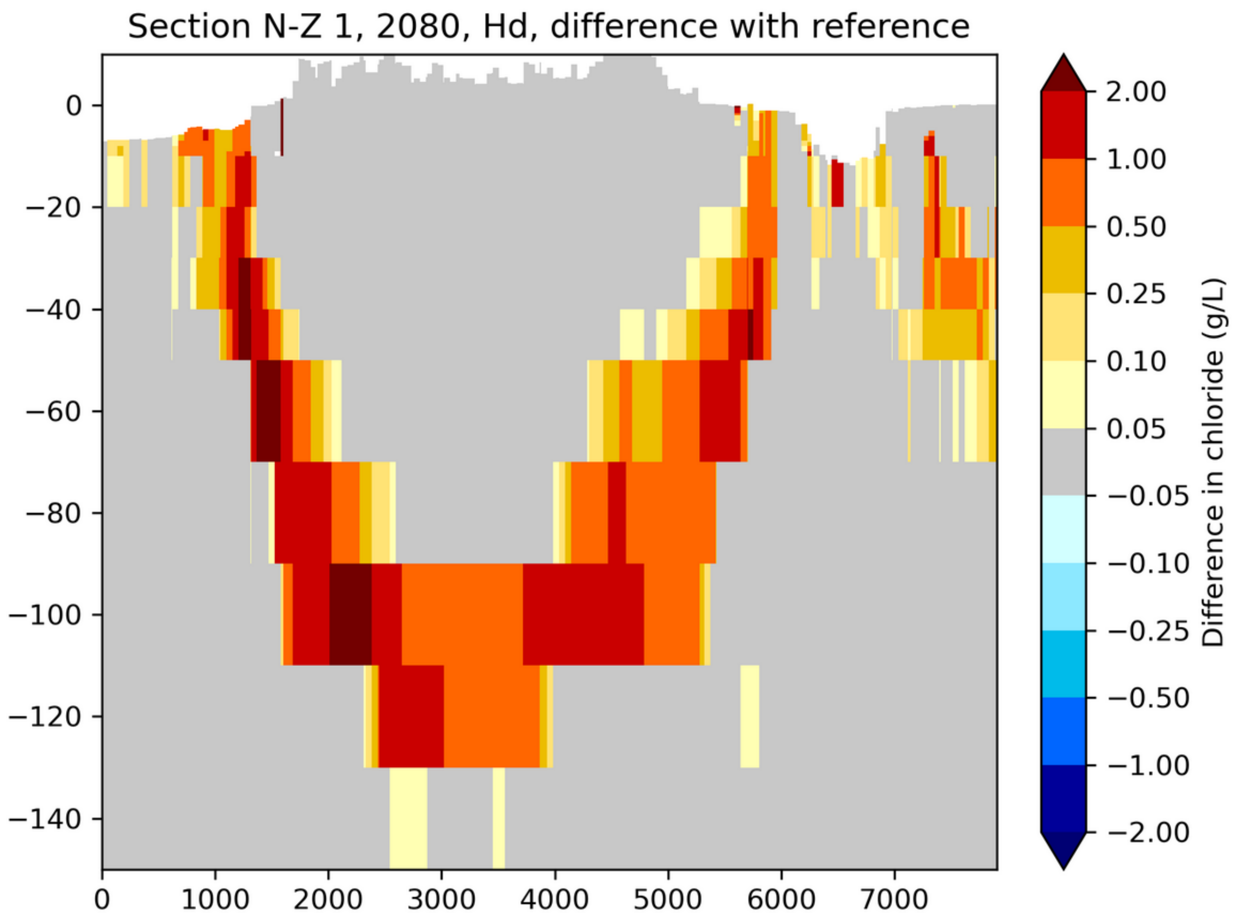


Figure C72: Location cross section N-Z 1 2080 Hd difference with reference (Deltares, 2024-a)

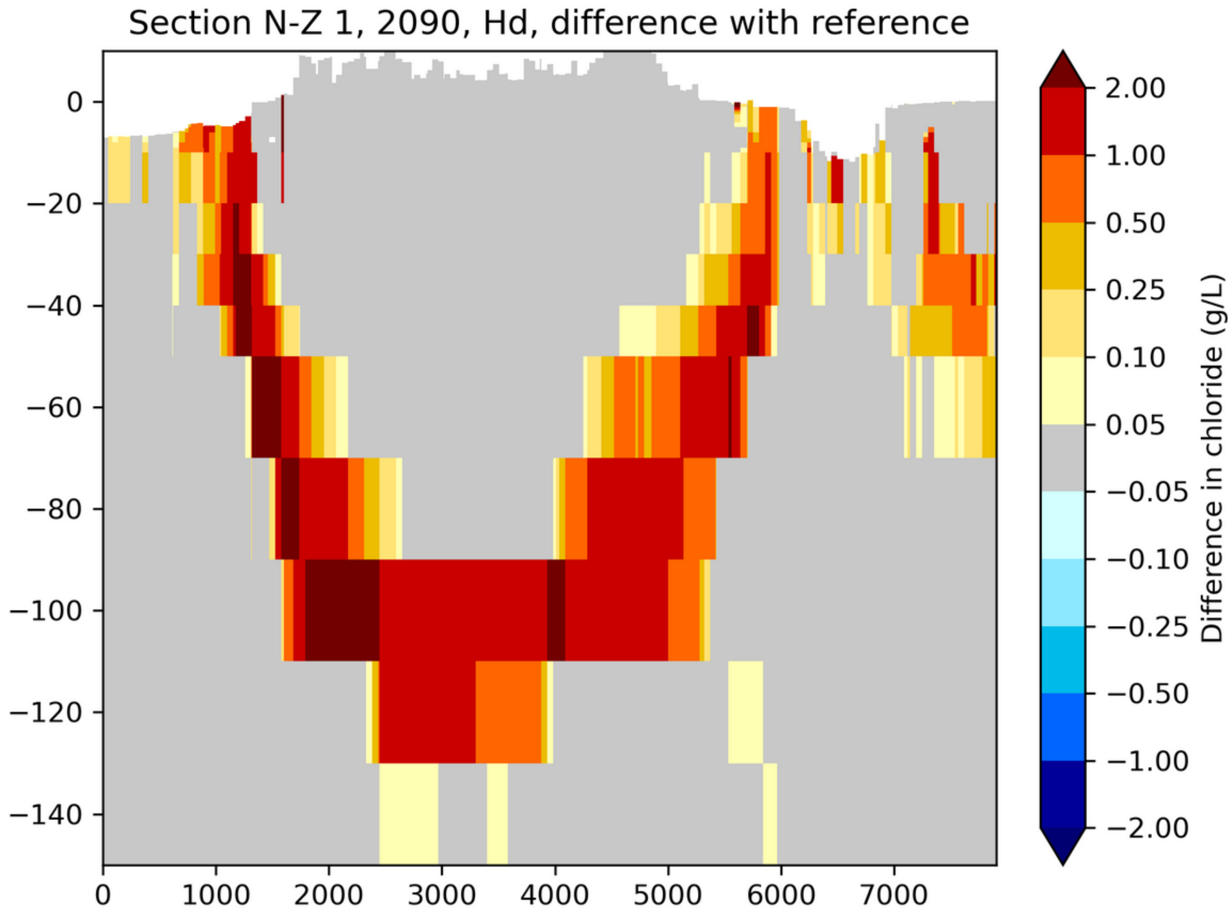


Figure C73: Location cross section N-Z 1 2090 Hd difference with reference (Deltares, 2024-a)

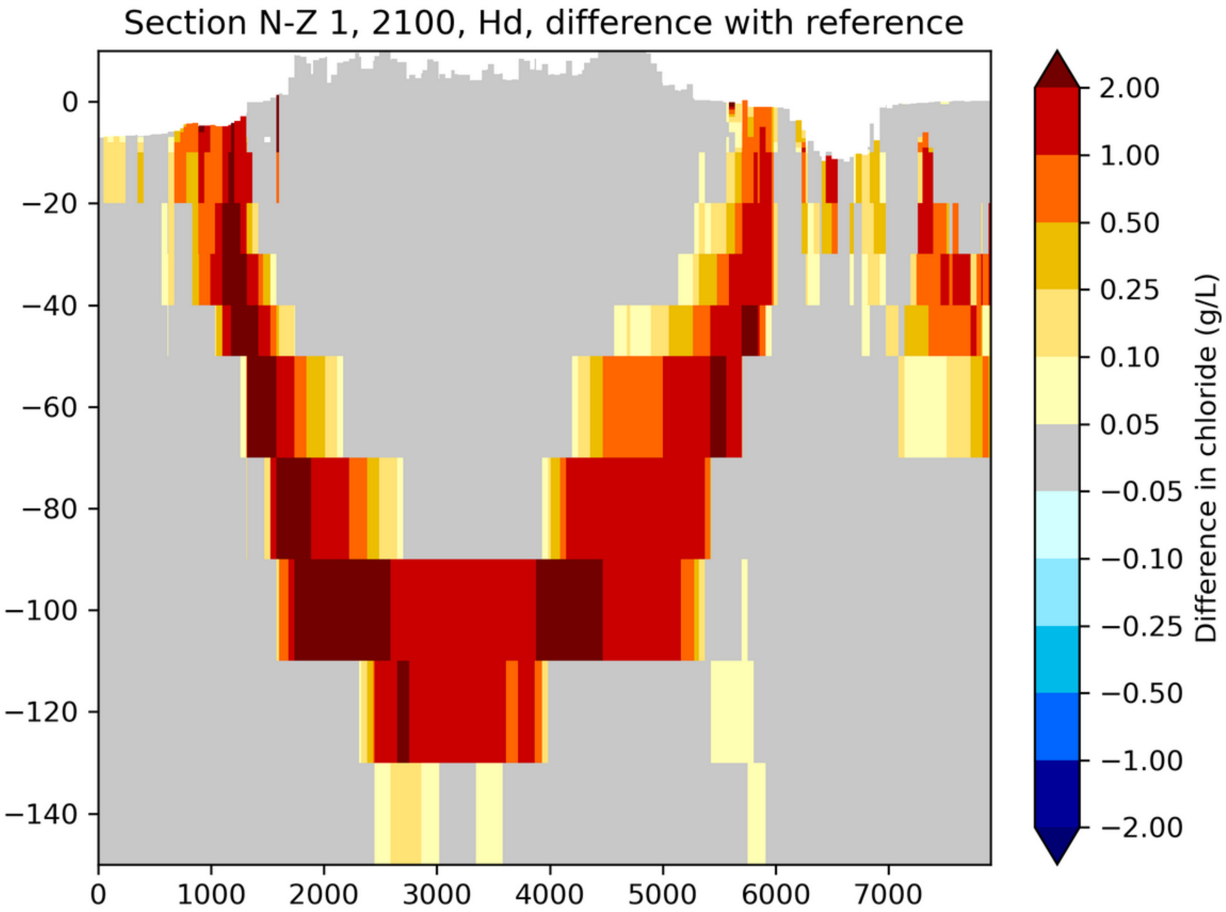


Figure C74: Location cross section N-Z 1 2100 Hd difference with reference (Deltares, 2024-a)

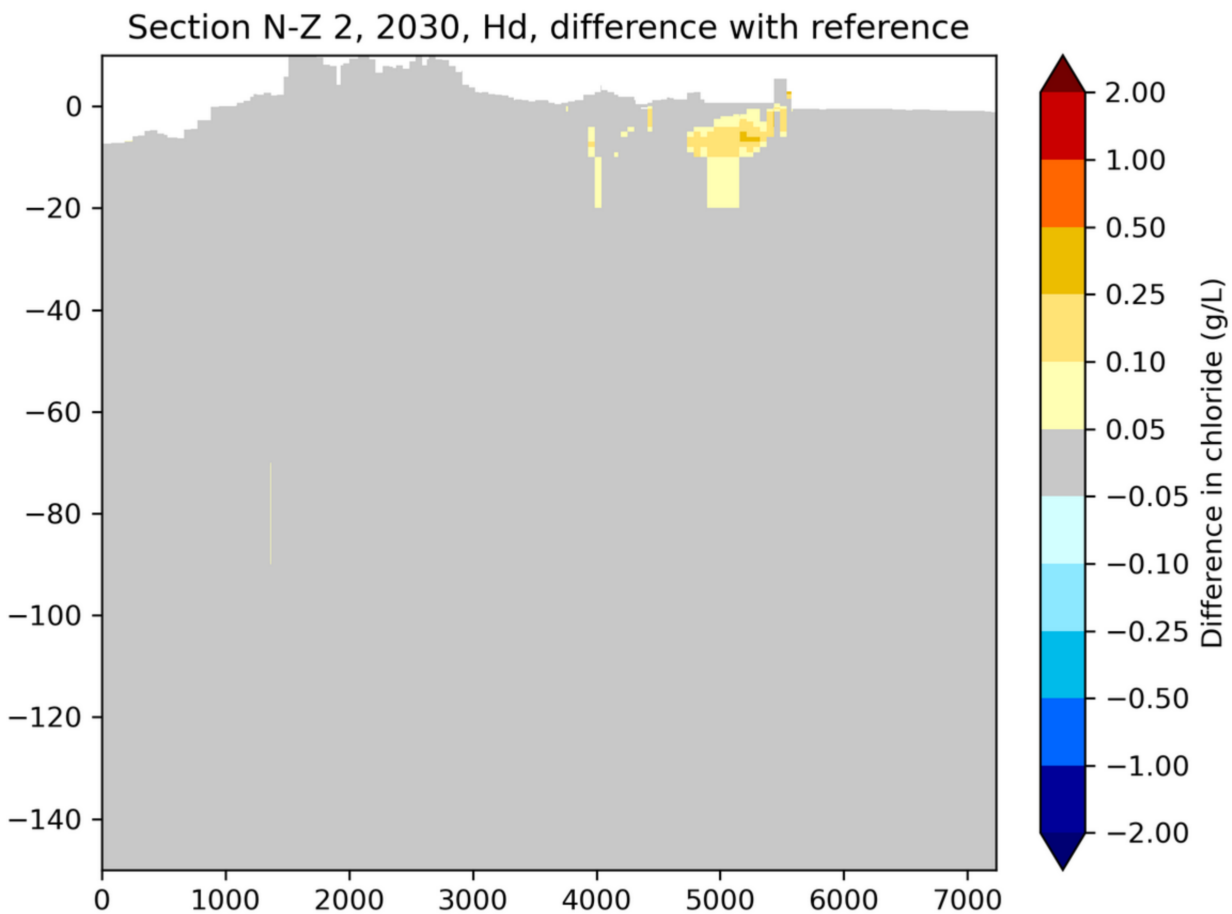


Figure C75: Location cross section N-Z 2 2030 Hd difference with reference (Deltares, 2024-a)

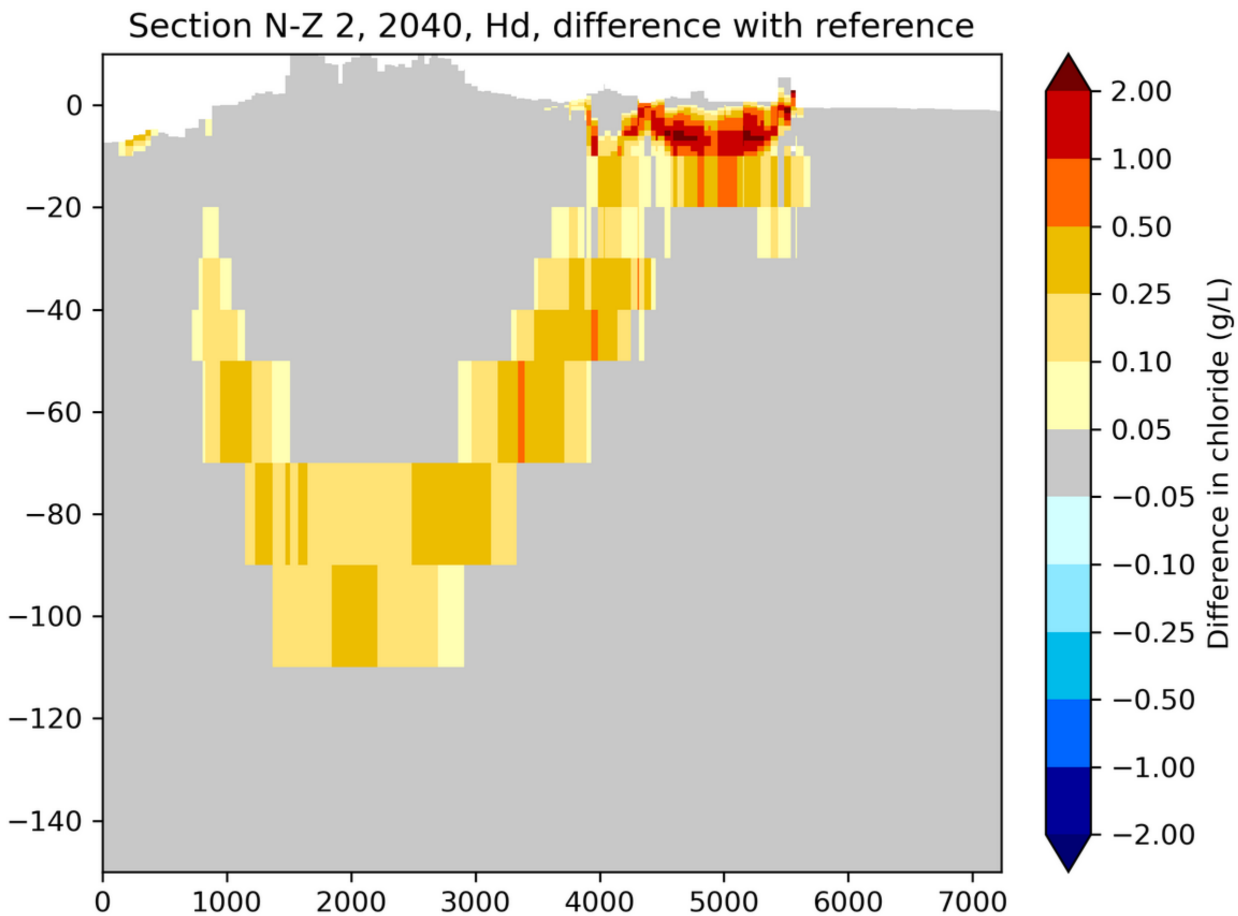


Figure C76: Location cross section N-Z 2 2040 Hd difference with reference (Deltares, 2024-a)

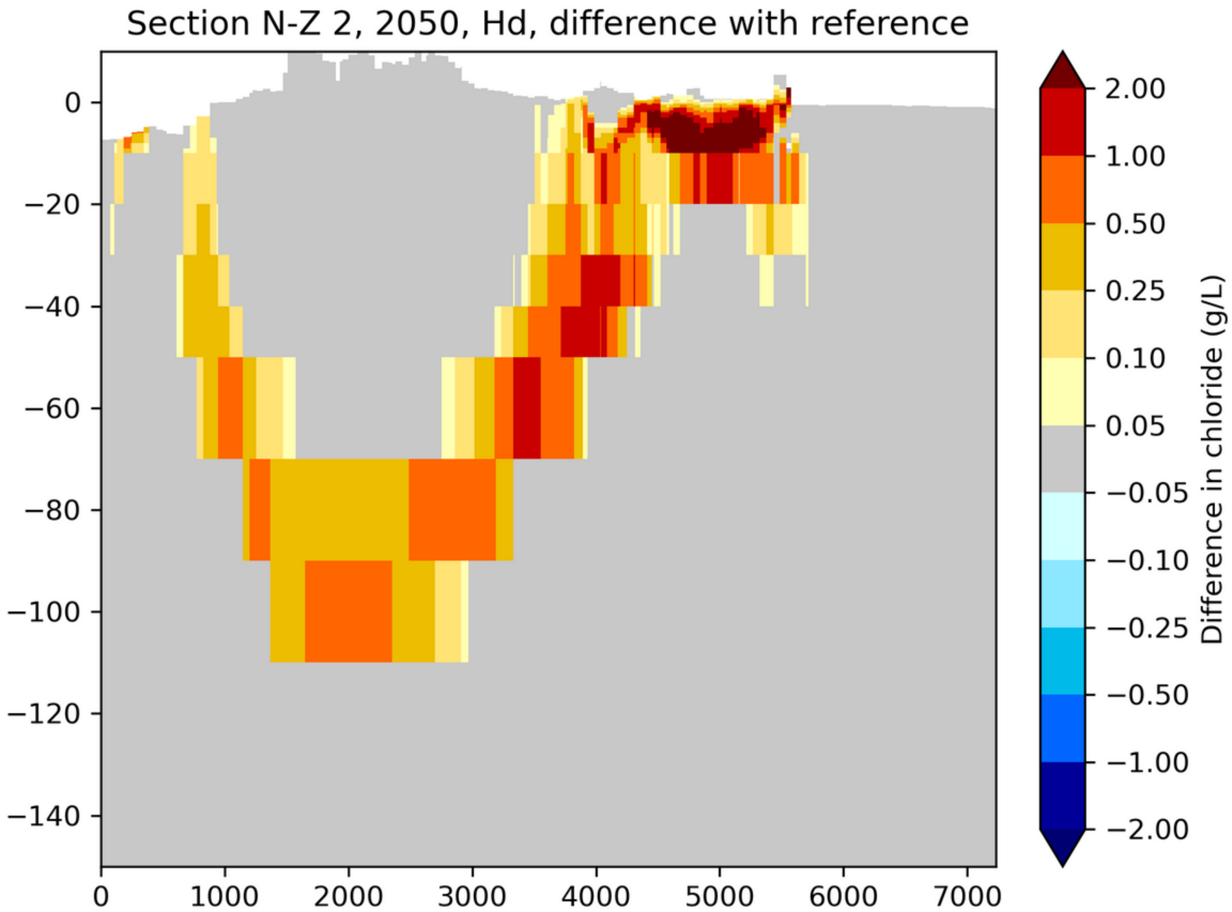


Figure C77: Location cross section N-Z 2 2050 Hd difference with reference (Deltares, 2024-a)

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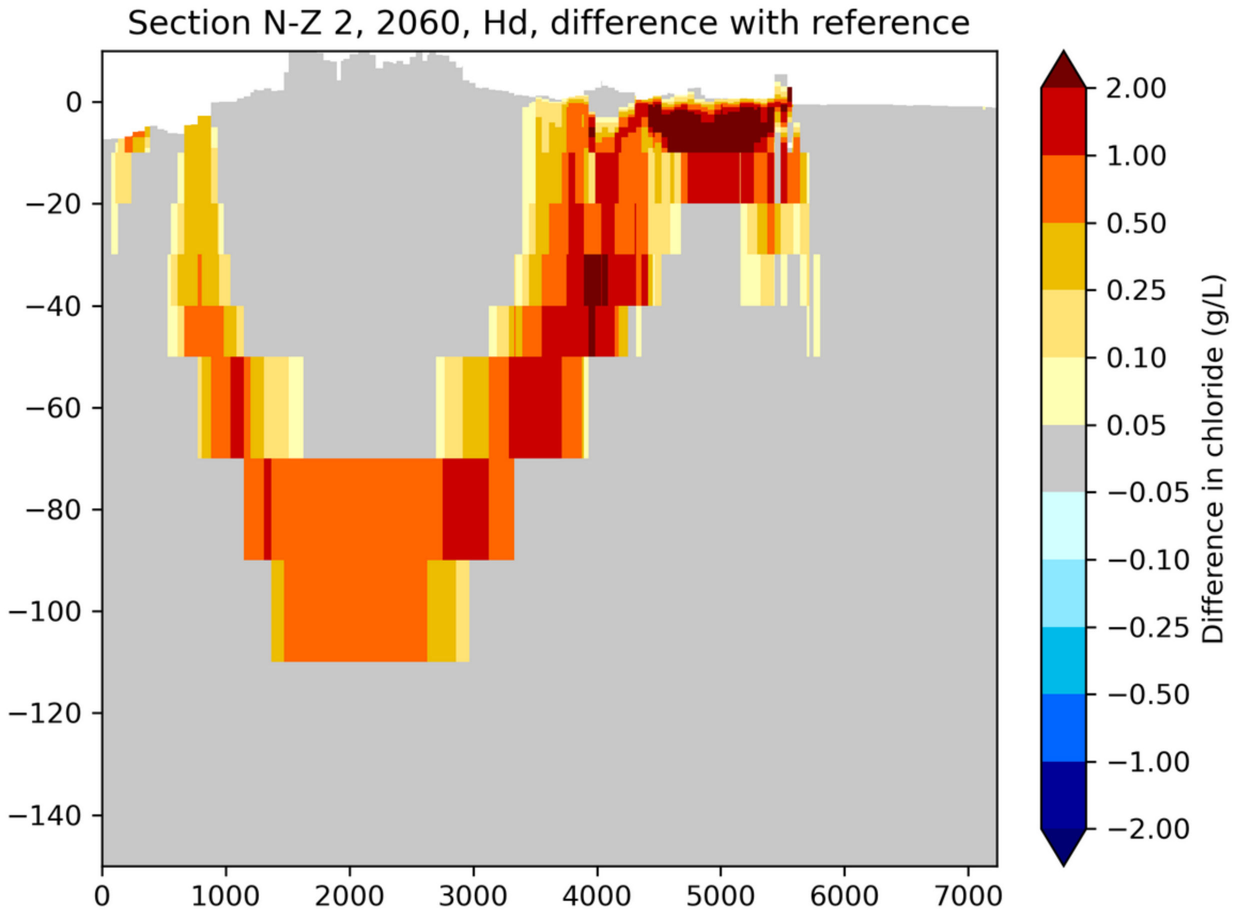

Figure C78: Location cross section N-Z 2 2060 Hd difference with reference (Deltares, 2024-a)

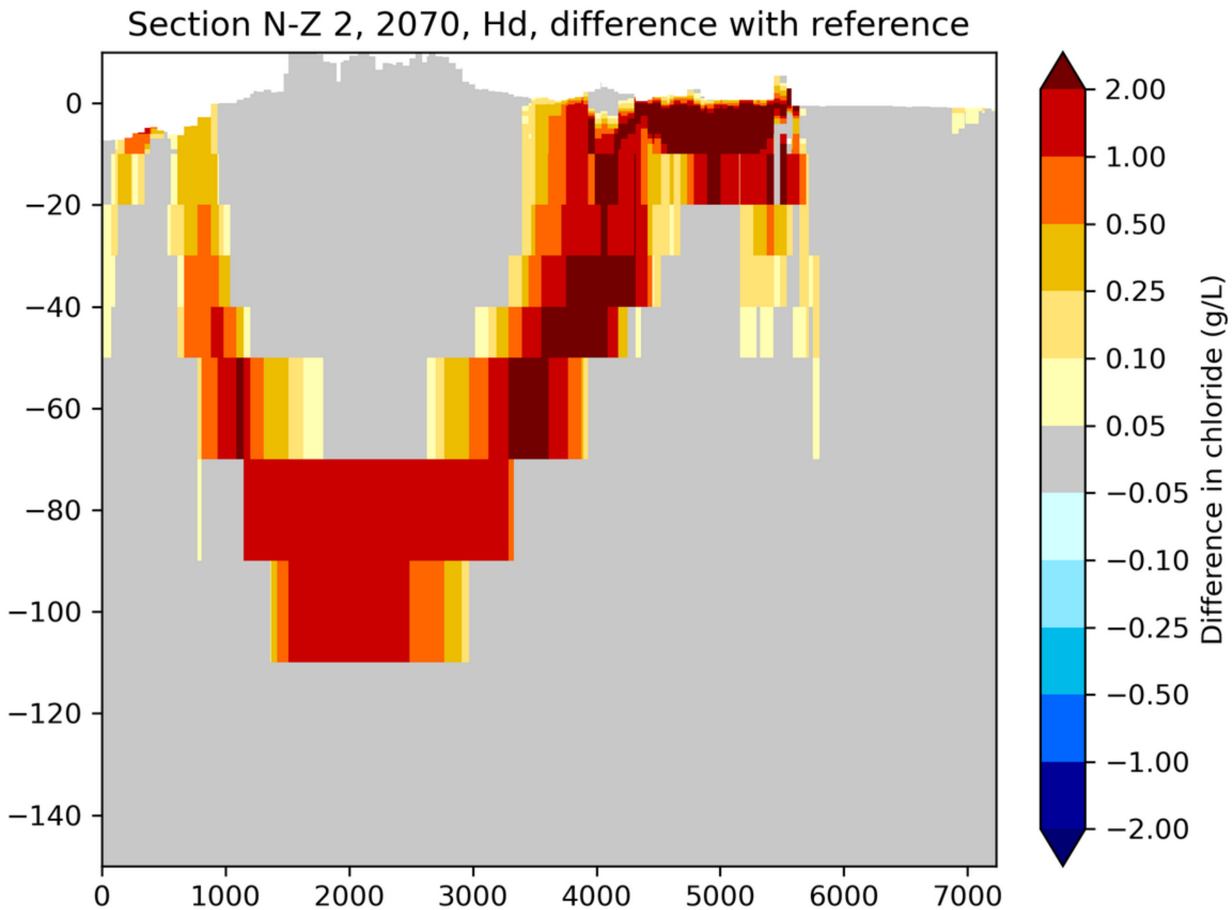

Figure C79: Location cross section N-Z 2 2070 Hd difference with reference (Deltares, 2024-a)

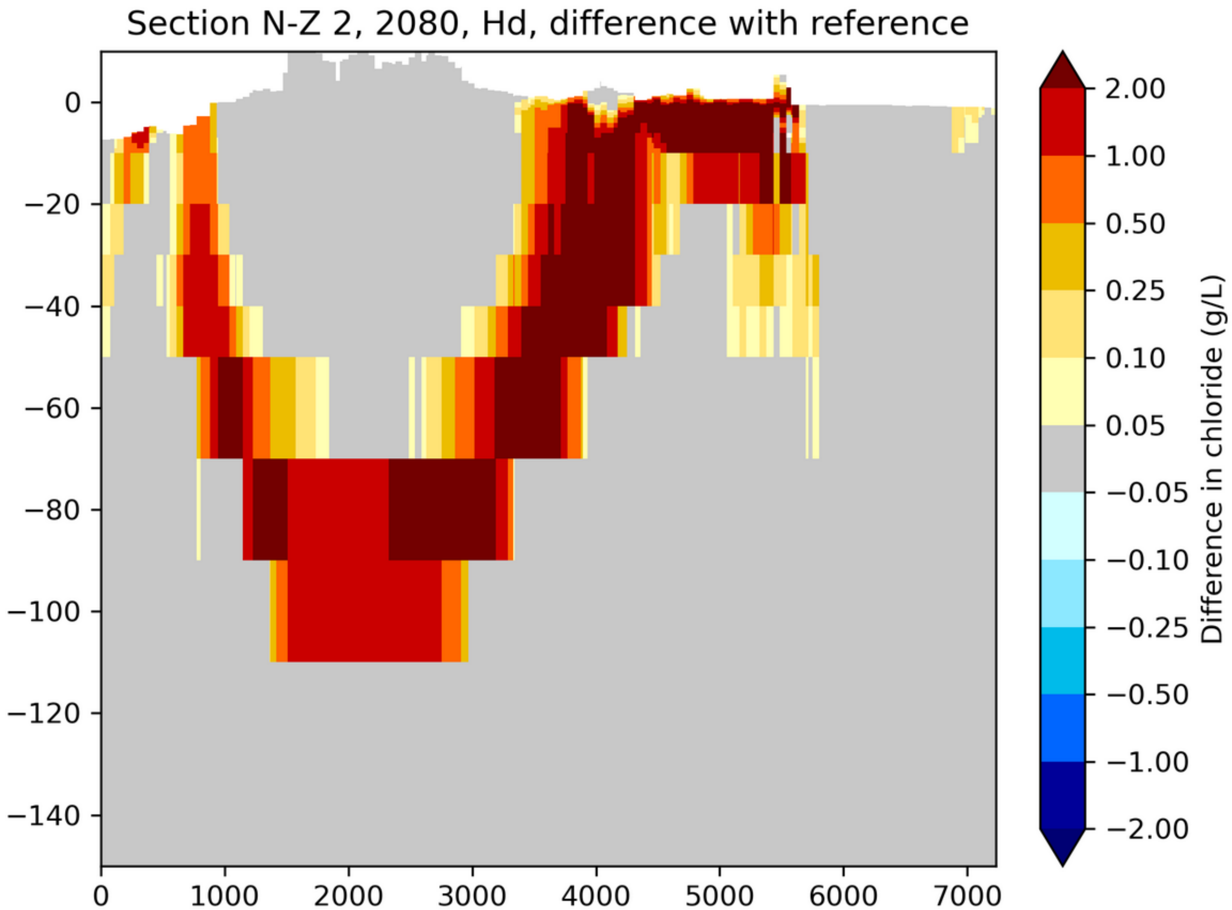

Figure C80: Location cross section N-Z 2 2080 Hd difference with reference (Deltares, 2024-a)

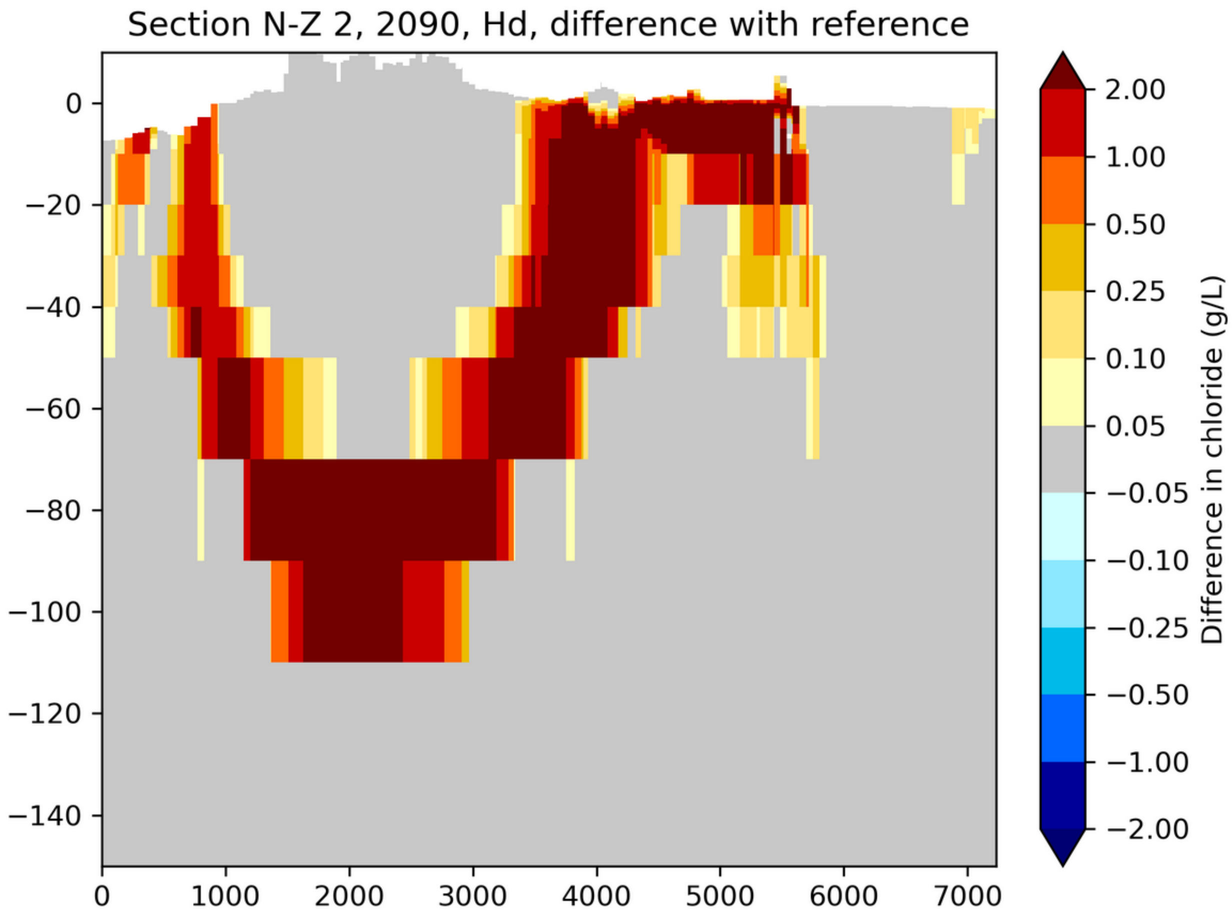

Figure C81: Location cross section N-Z 2 2090 Hd difference with reference (Deltares, 2024-a)

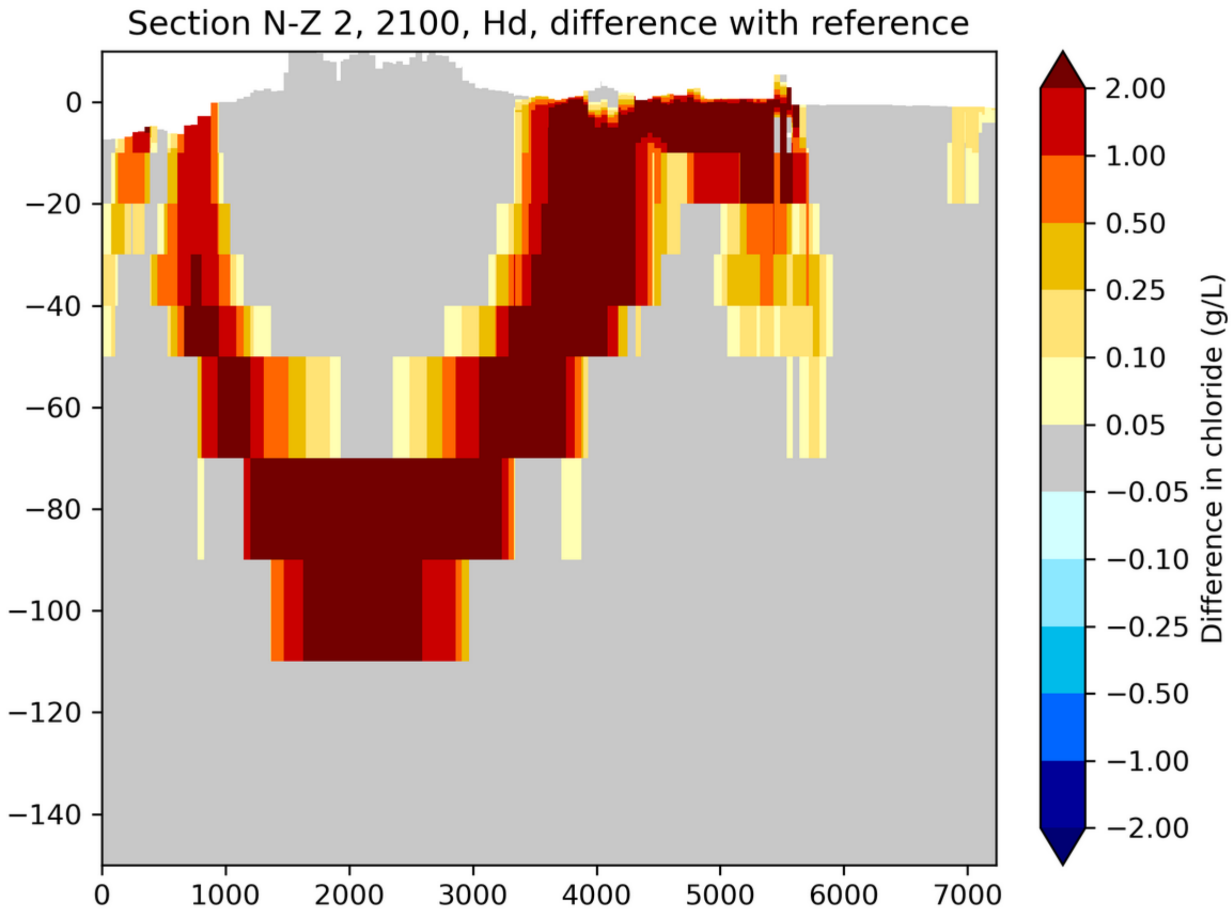

Figure C82: Location cross section N-Z 2 2100 Hd difference with reference (Deltares, 2024-a)

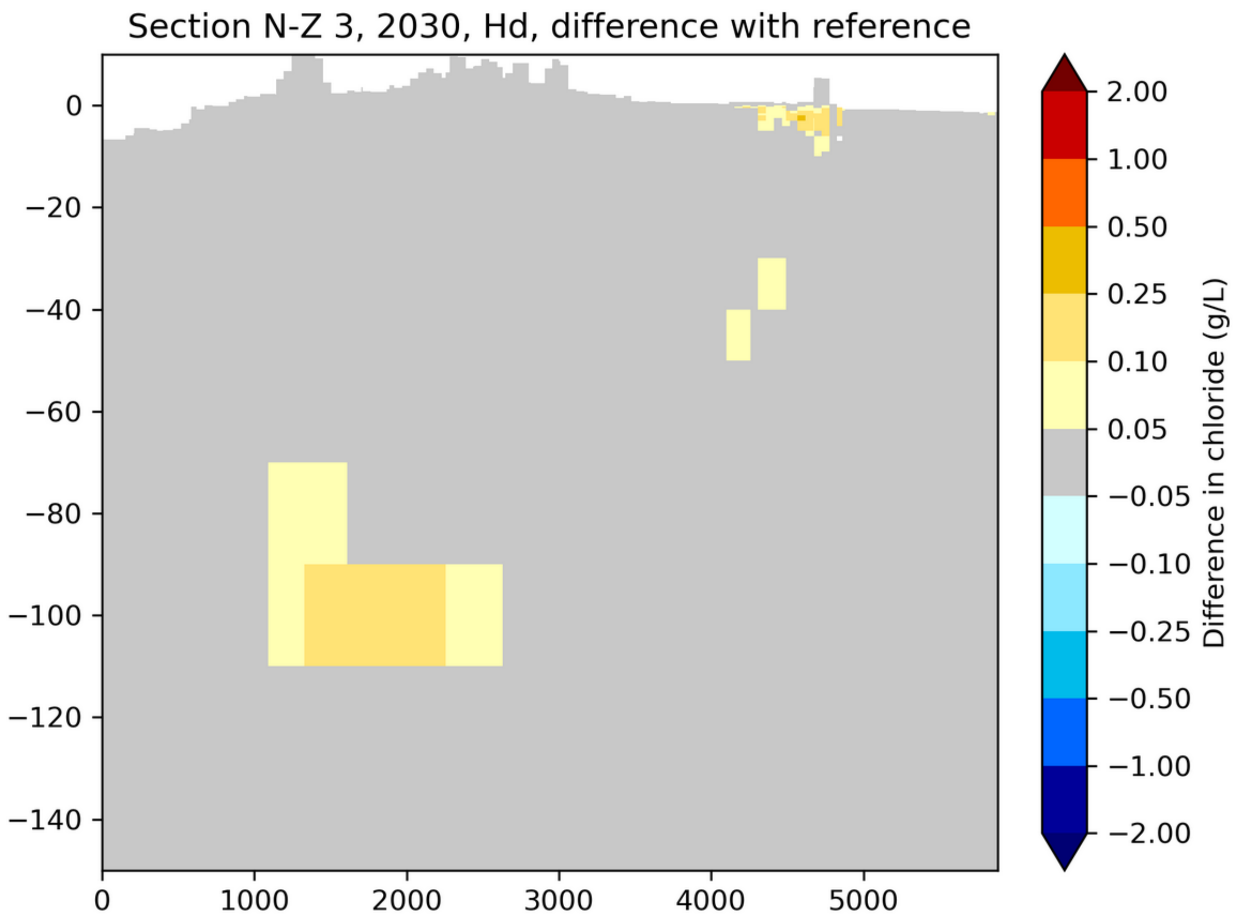

Figure C83: Location cross section N-Z 3 2030 Hd difference with reference (Deltares, 2024-a)

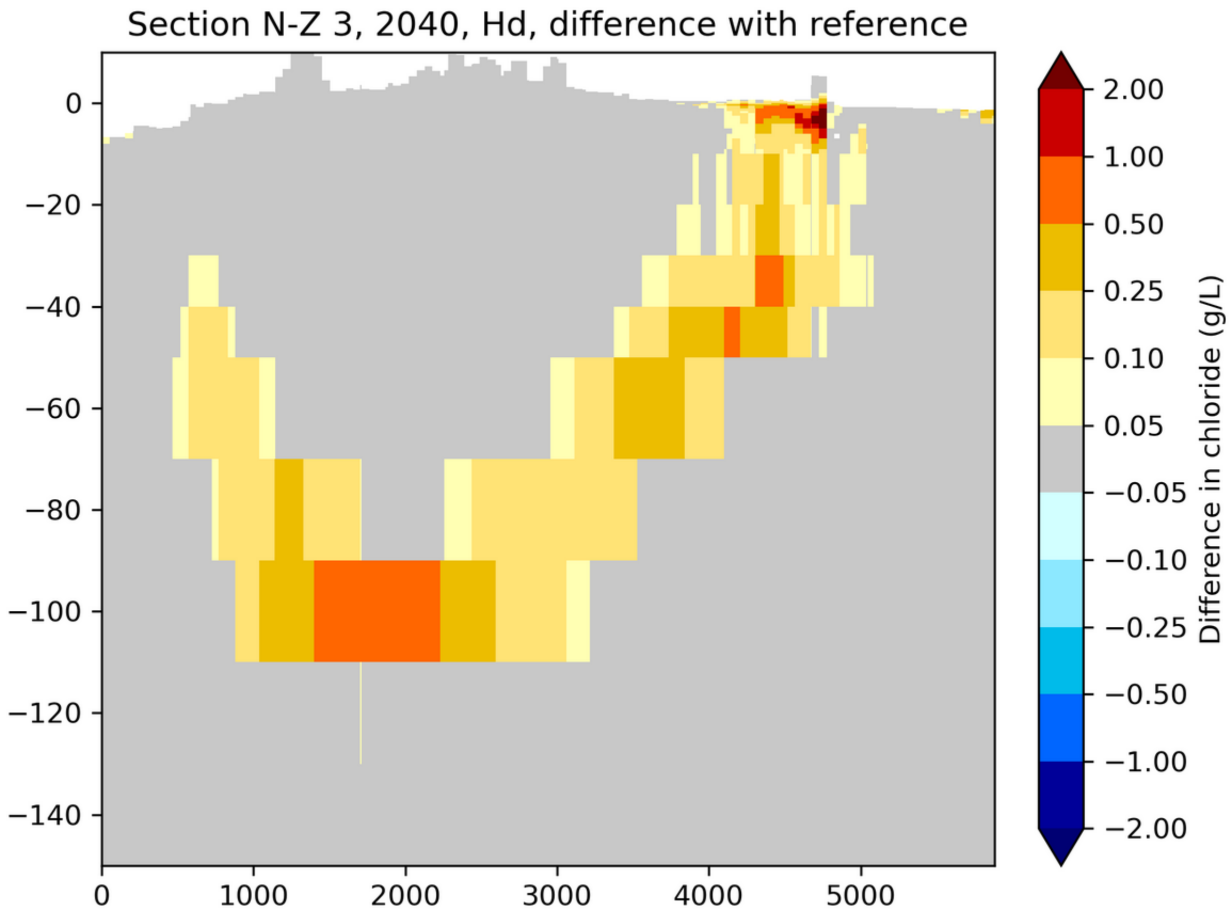

Figure C84: Location cross section N-Z 3 2040 Hd difference with reference (Deltares, 2024-a)

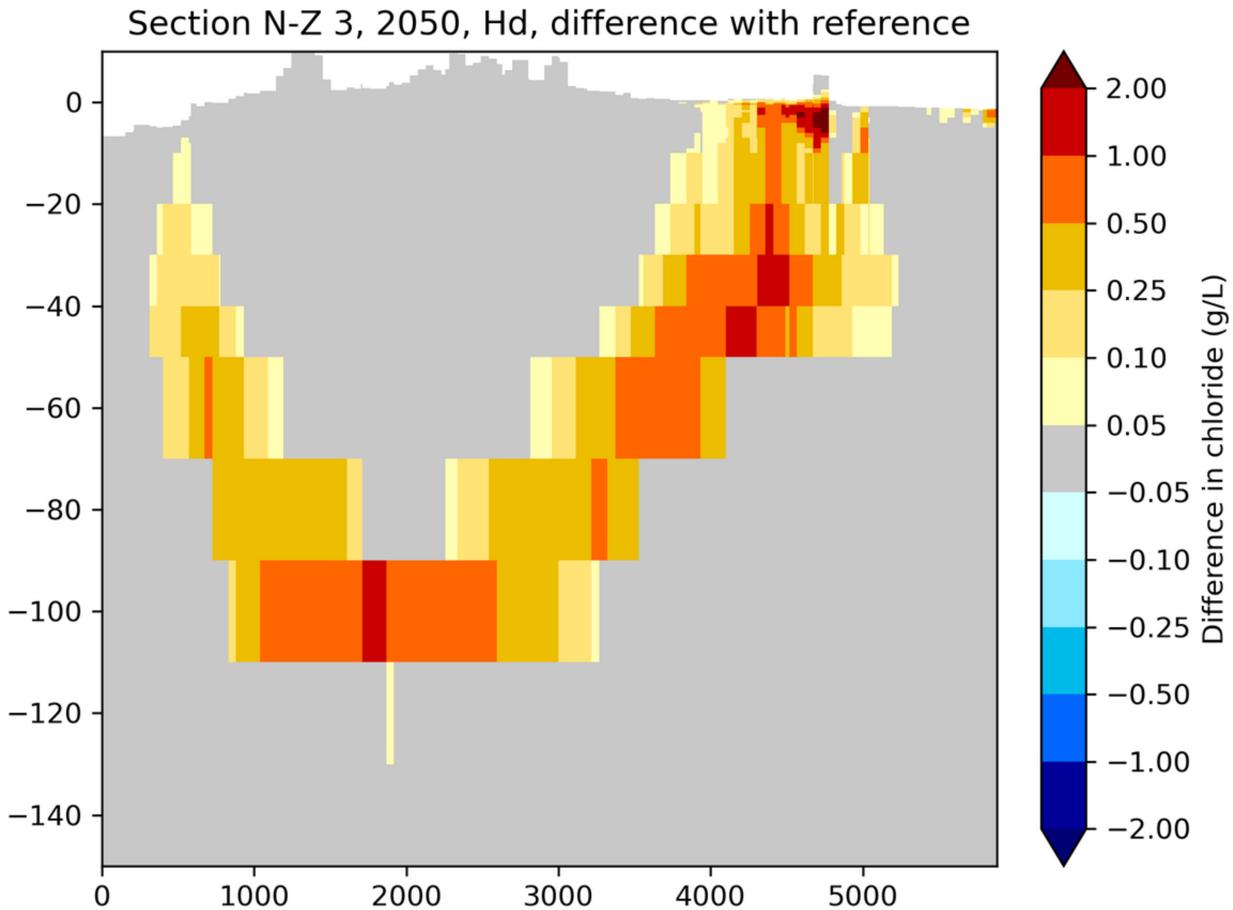

Figure C85: Location cross section N-Z 3 2050 Hd difference with reference (Deltares, 2024-a)

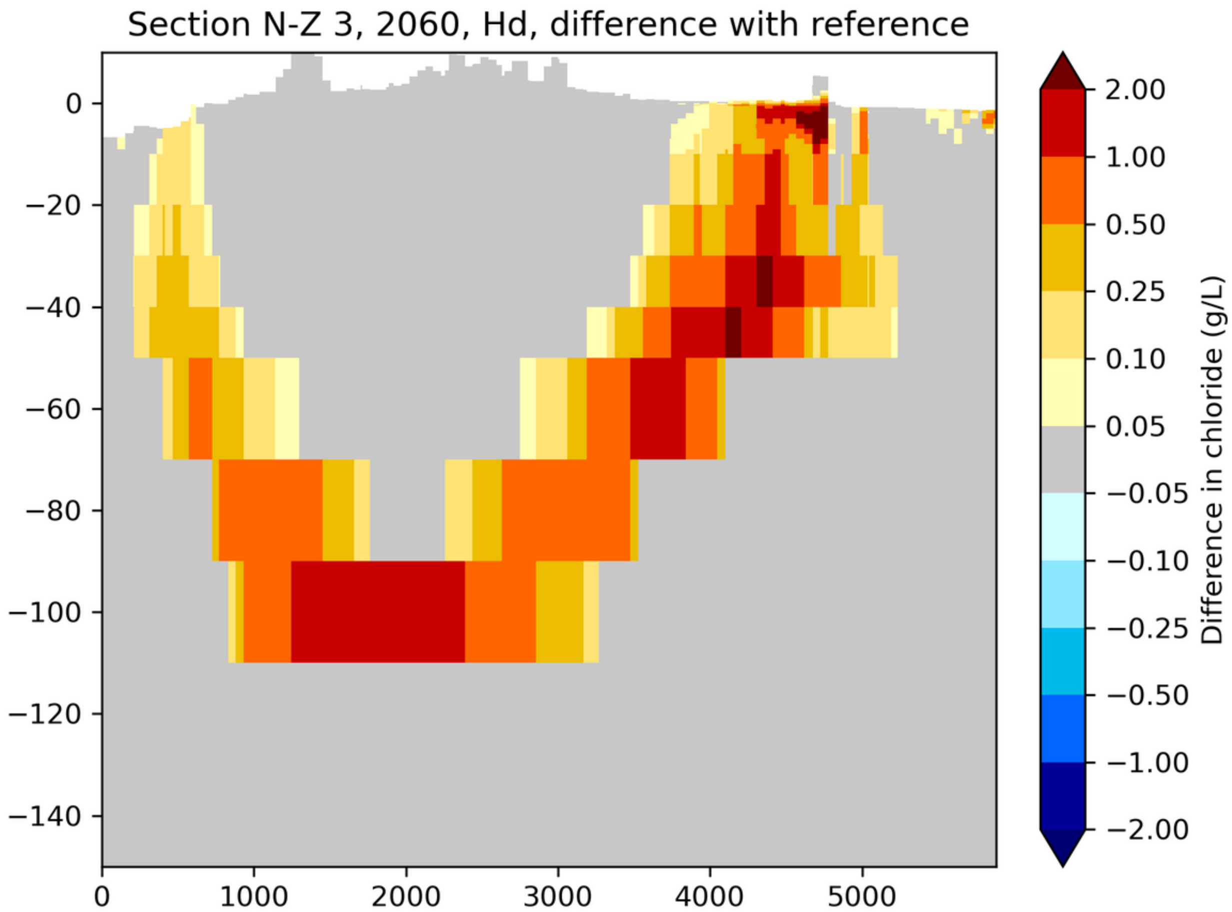

Figure C86: Location cross section N-Z 3 2060 Hd difference with reference (Deltares, 2024-a)

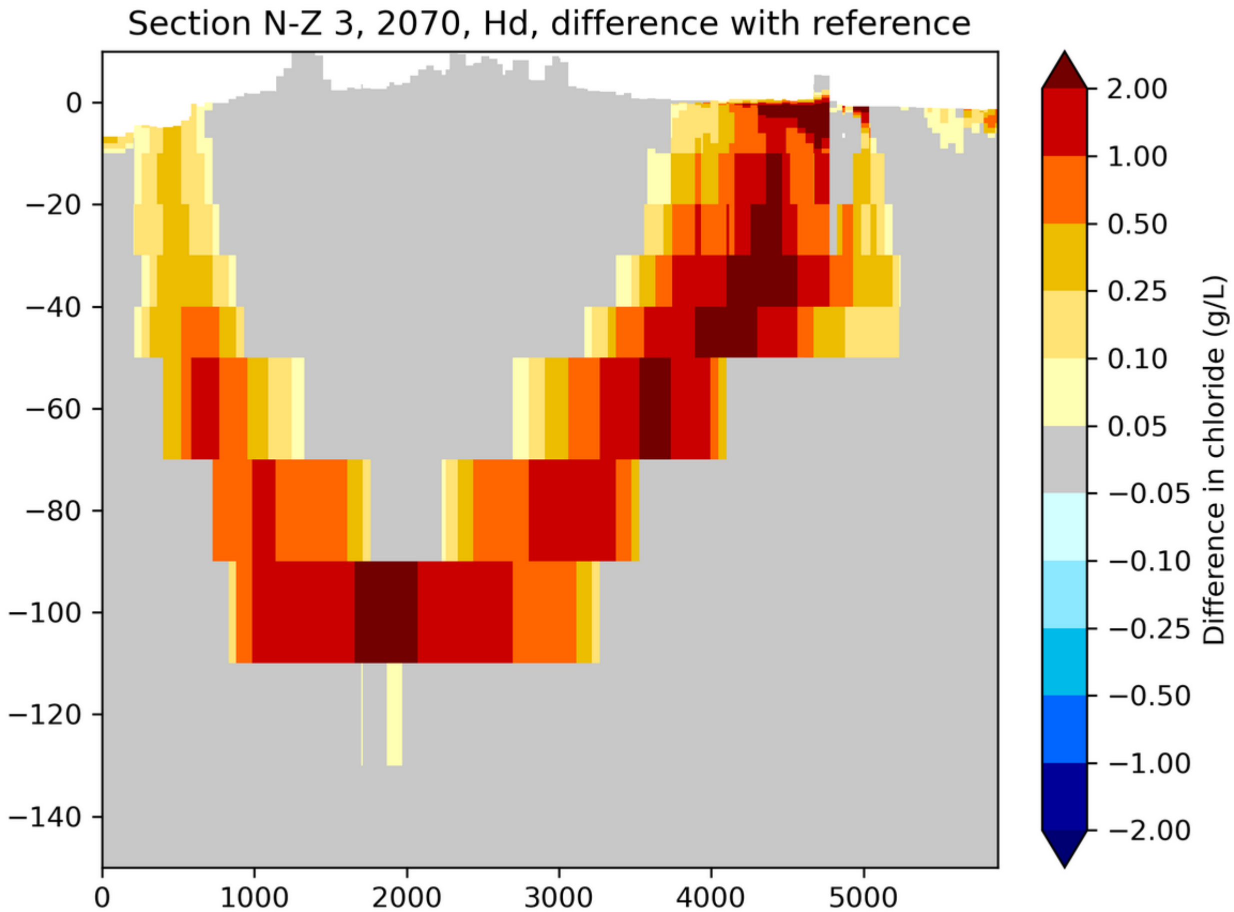

Figure C87: Location cross section N-Z 3 2070 Hd difference with reference (Deltares, 2024-a)

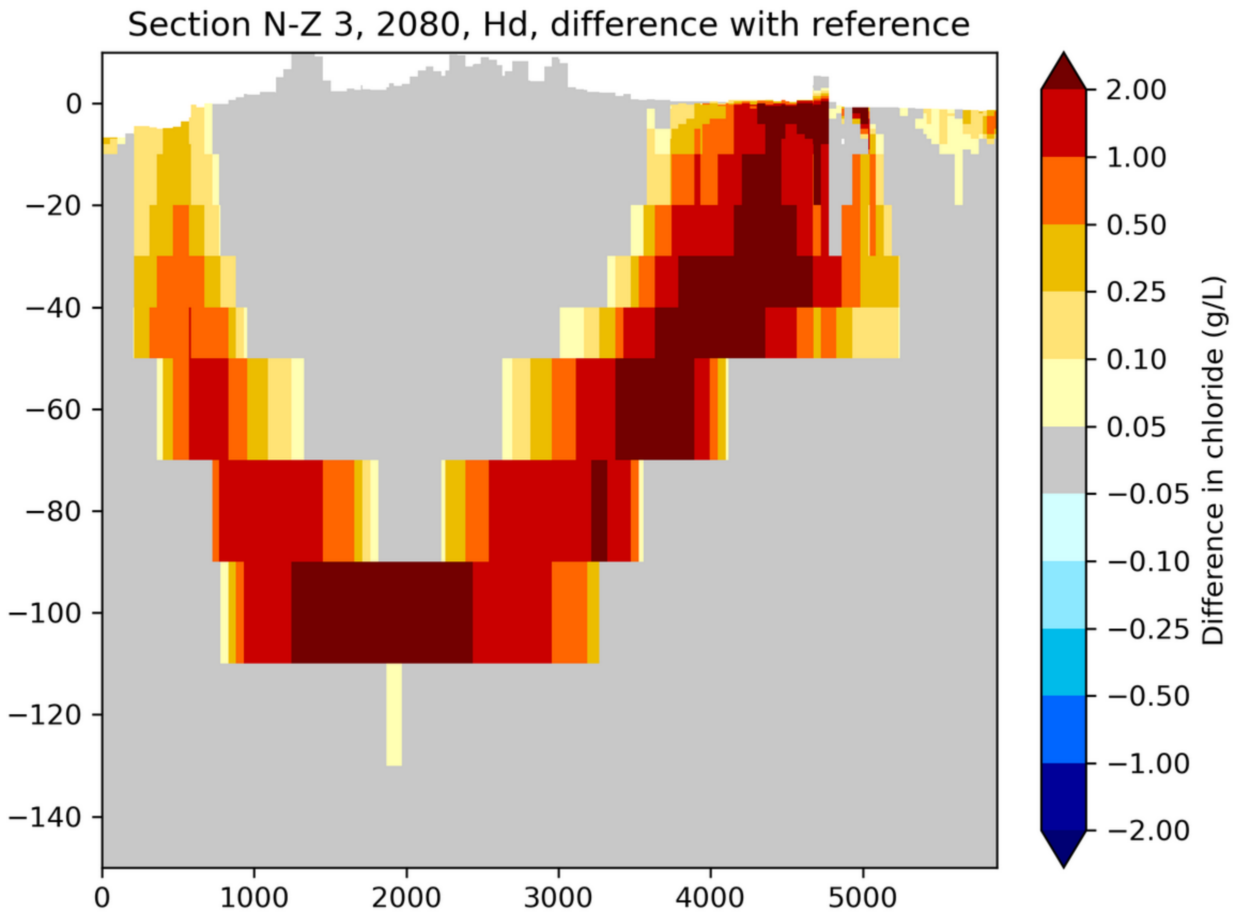

Figure C88: Location cross section N-Z 3 2080 Hd difference with reference (Deltares, 2024-a)

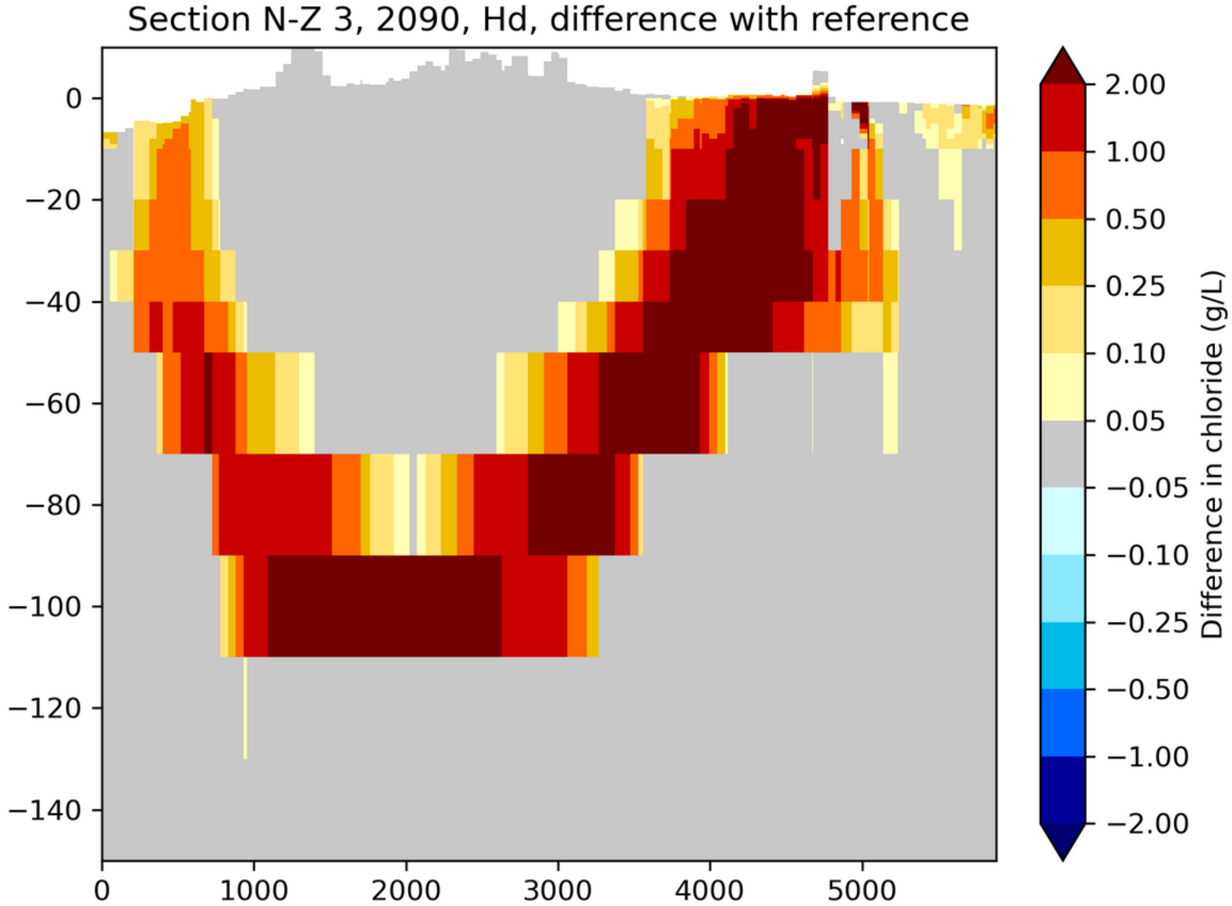

Figure C89: Location cross section N-Z 3 2090 Hd difference with reference (Deltares, 2024-a)

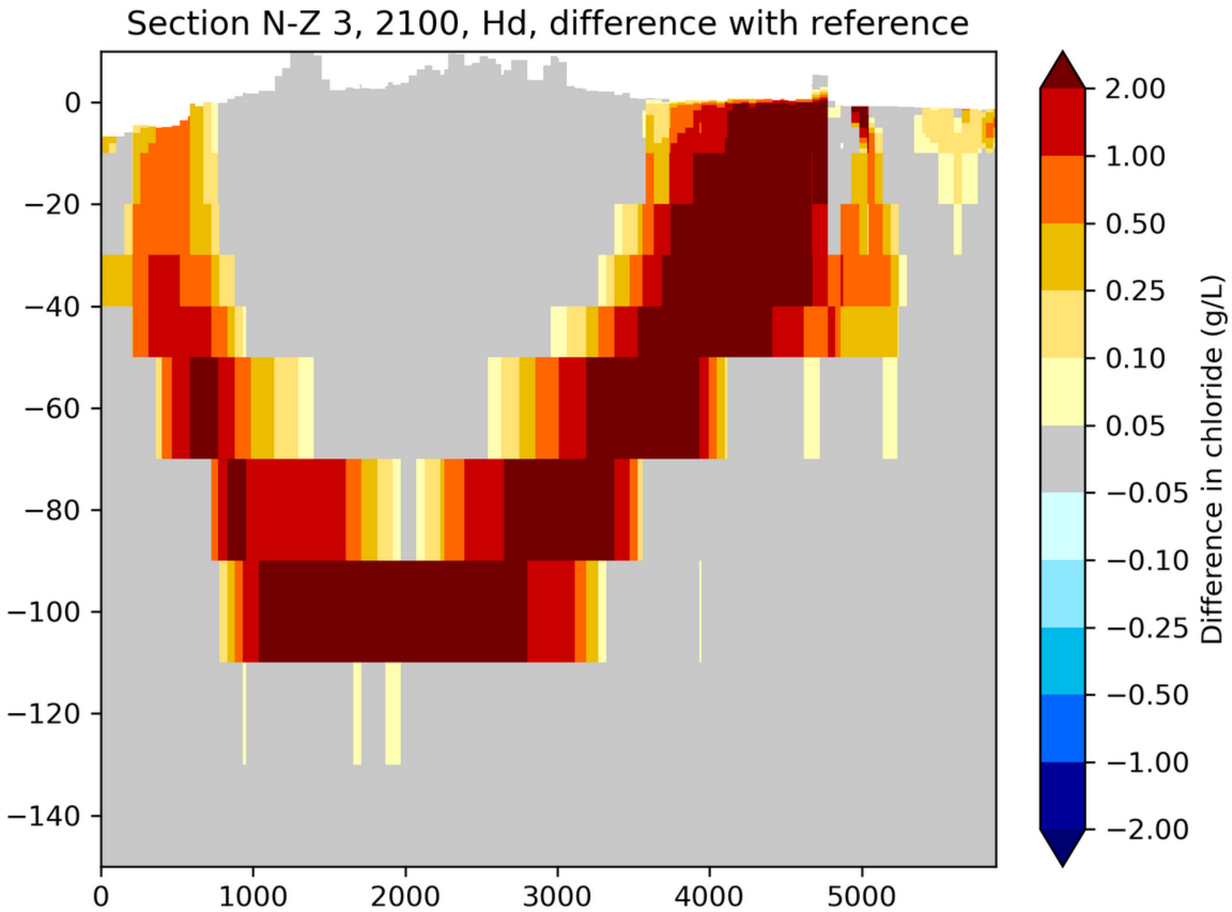

Figure C90: Location cross section N-Z 3 2100 Hd difference with reference (Deltares, 2024-a)

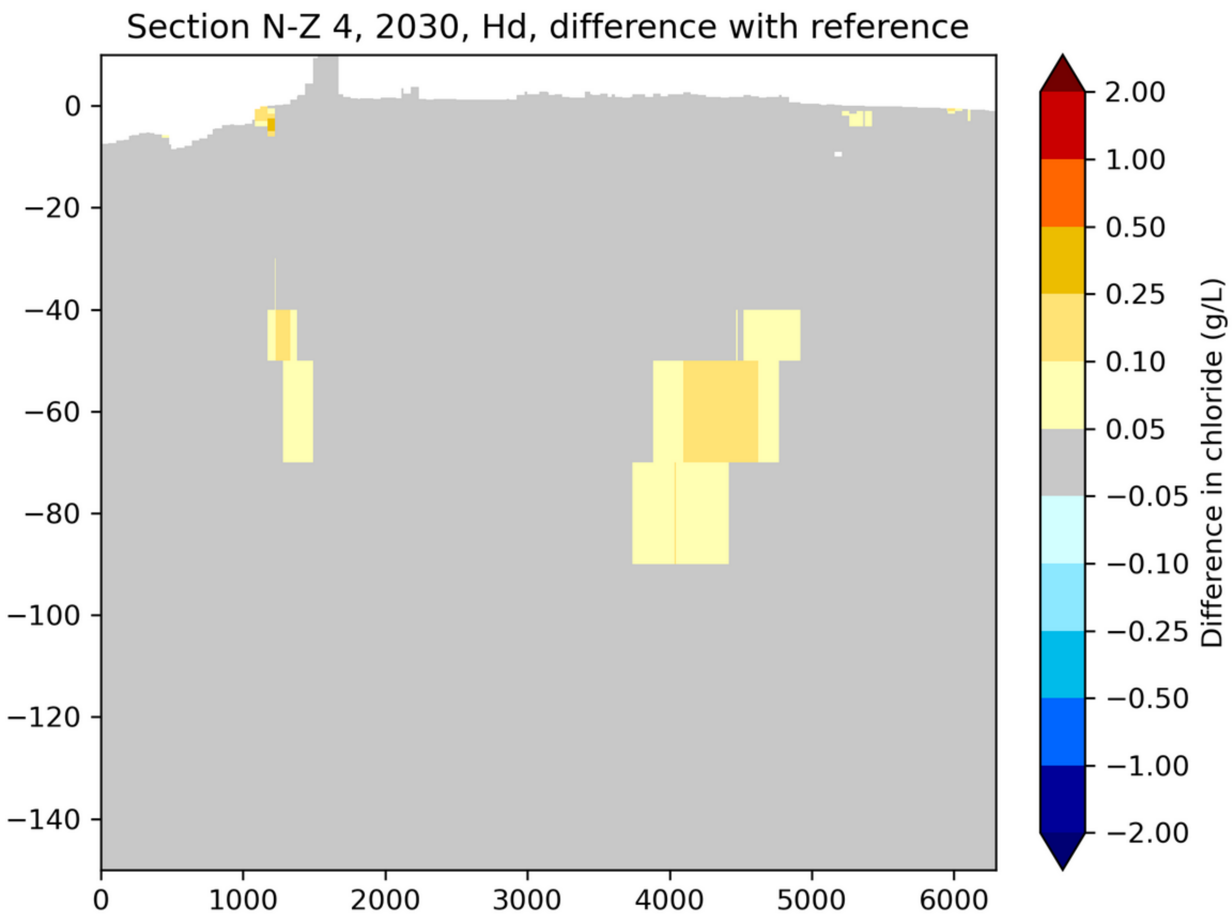

Figure C91: Location cross section N-Z 4 2030 Hd difference with reference (Deltares, 2024-a)

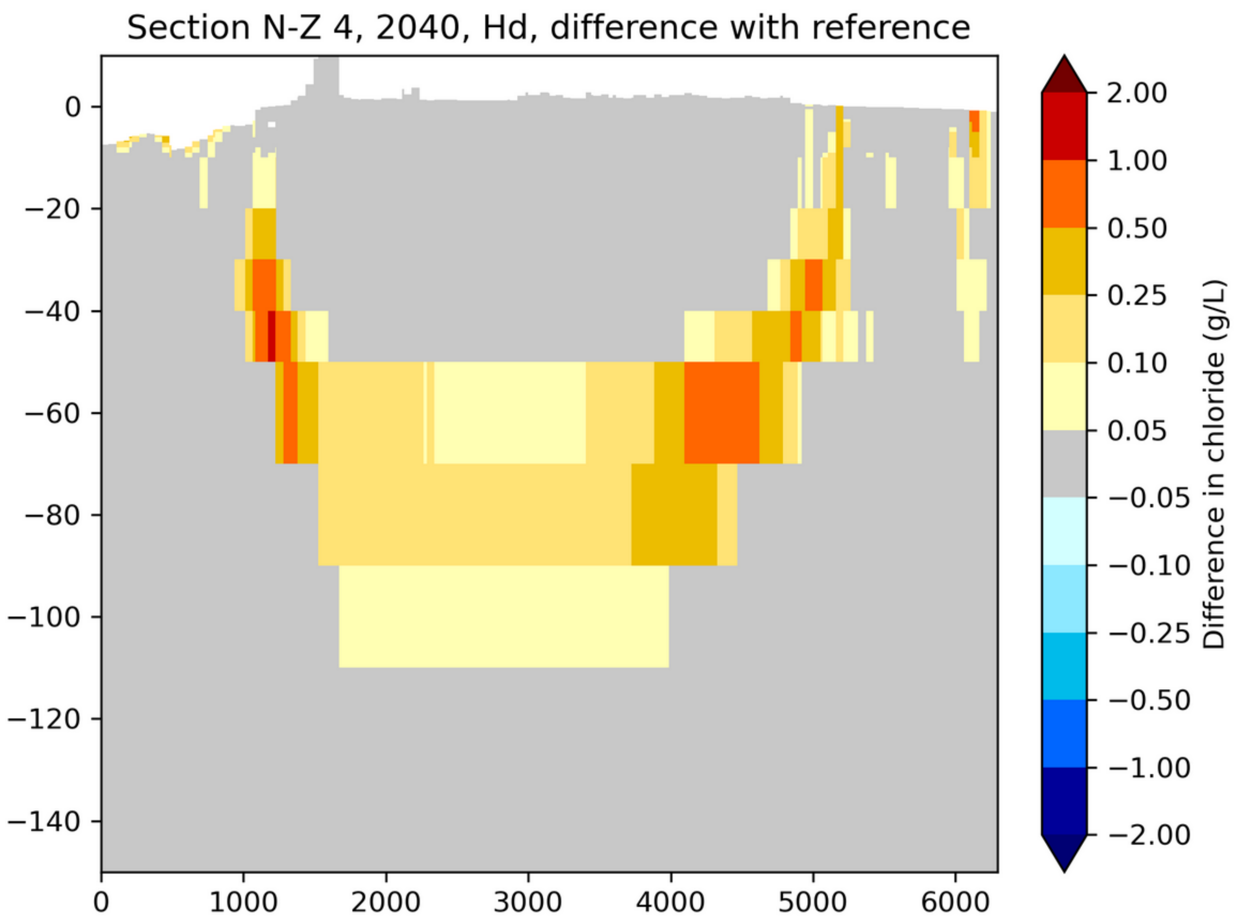

Figure C92: Location cross section N-Z 4 2040 Hd difference with reference (Deltares, 2024-a)

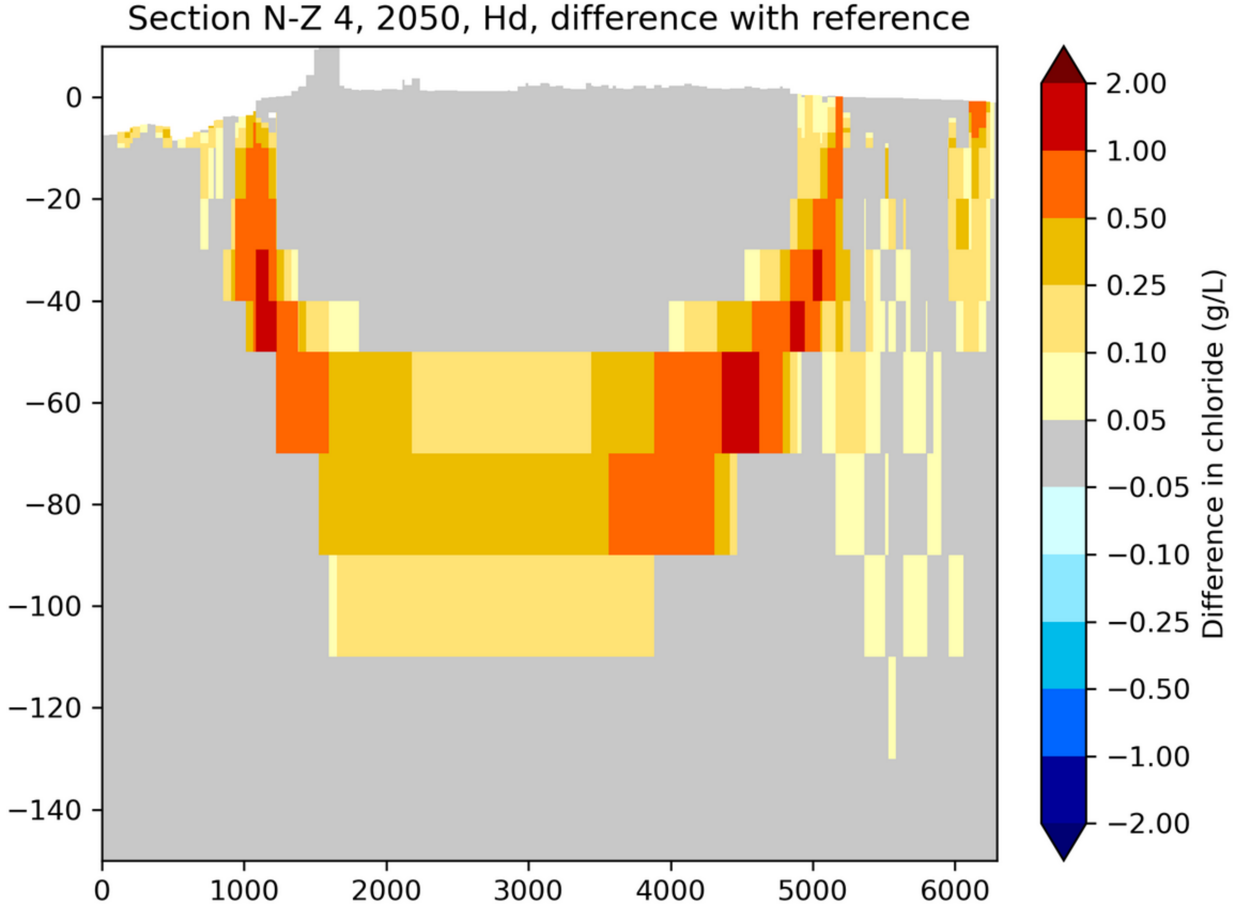

Figure C93: Location cross section N-Z 4 2050 Hd difference with reference (Deltares, 2024-a)

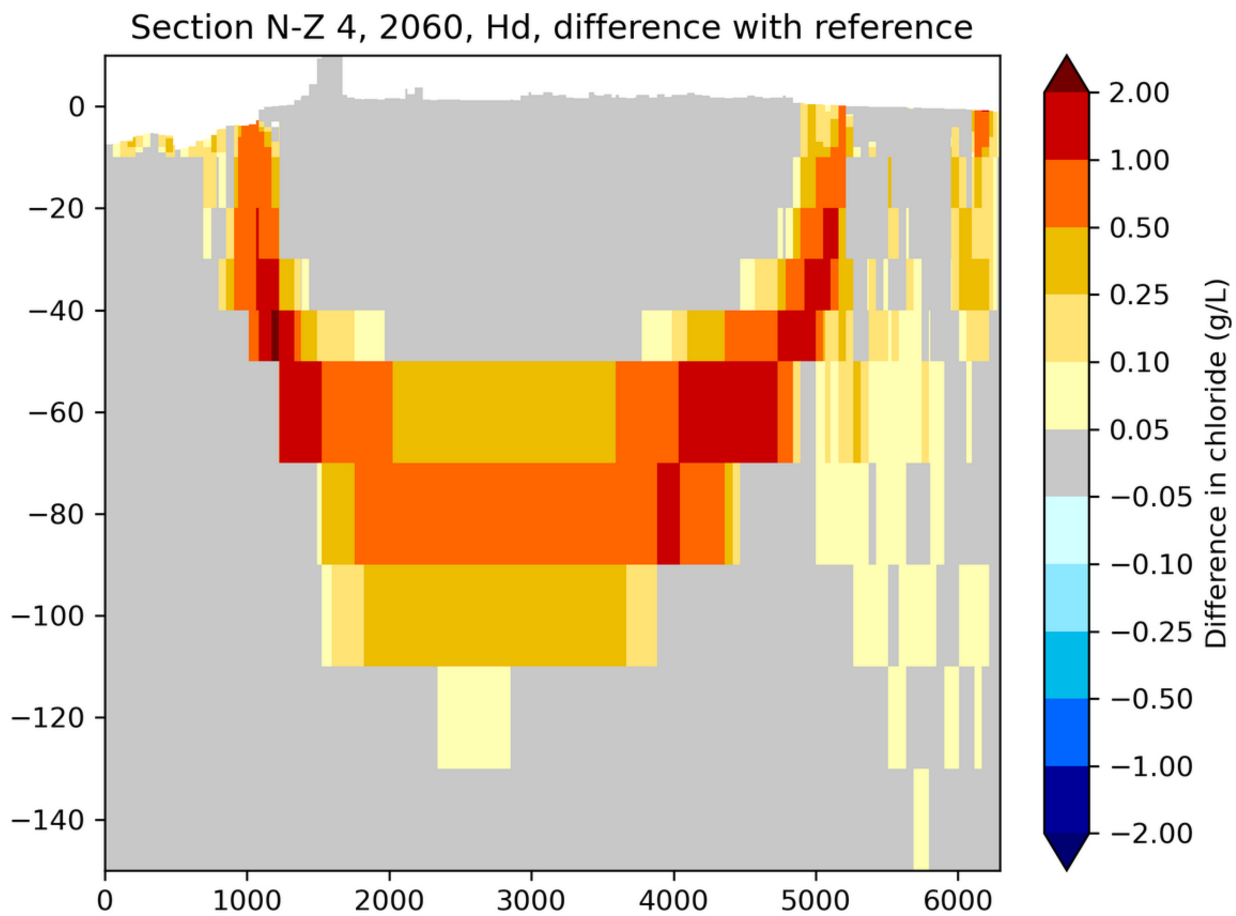

Figure C94: Location cross section N-Z 4 2060 Hd difference with reference (Deltares, 2024-a)

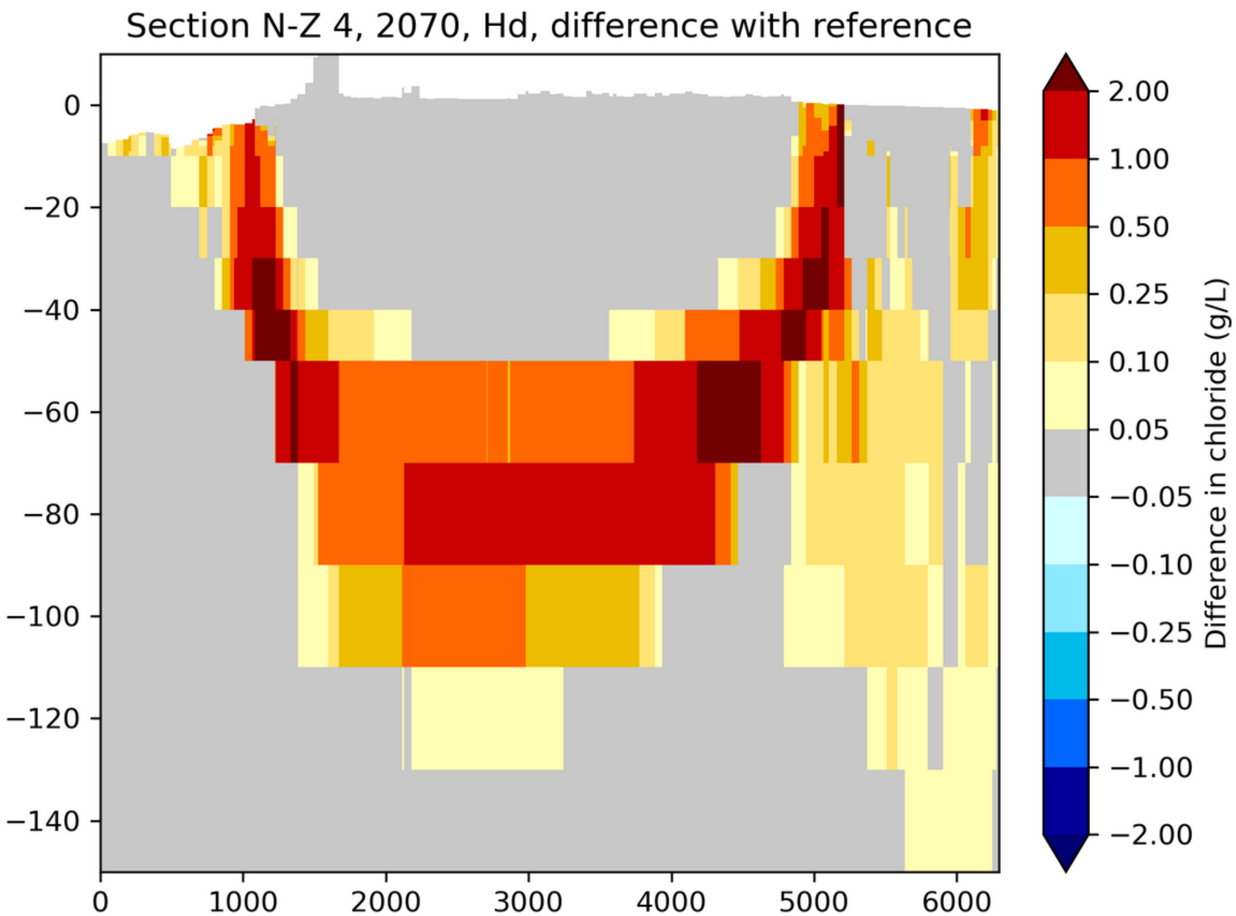

Figure C95: Location cross section N-Z 4 2070 Hd difference with reference (Deltares, 2024-a)

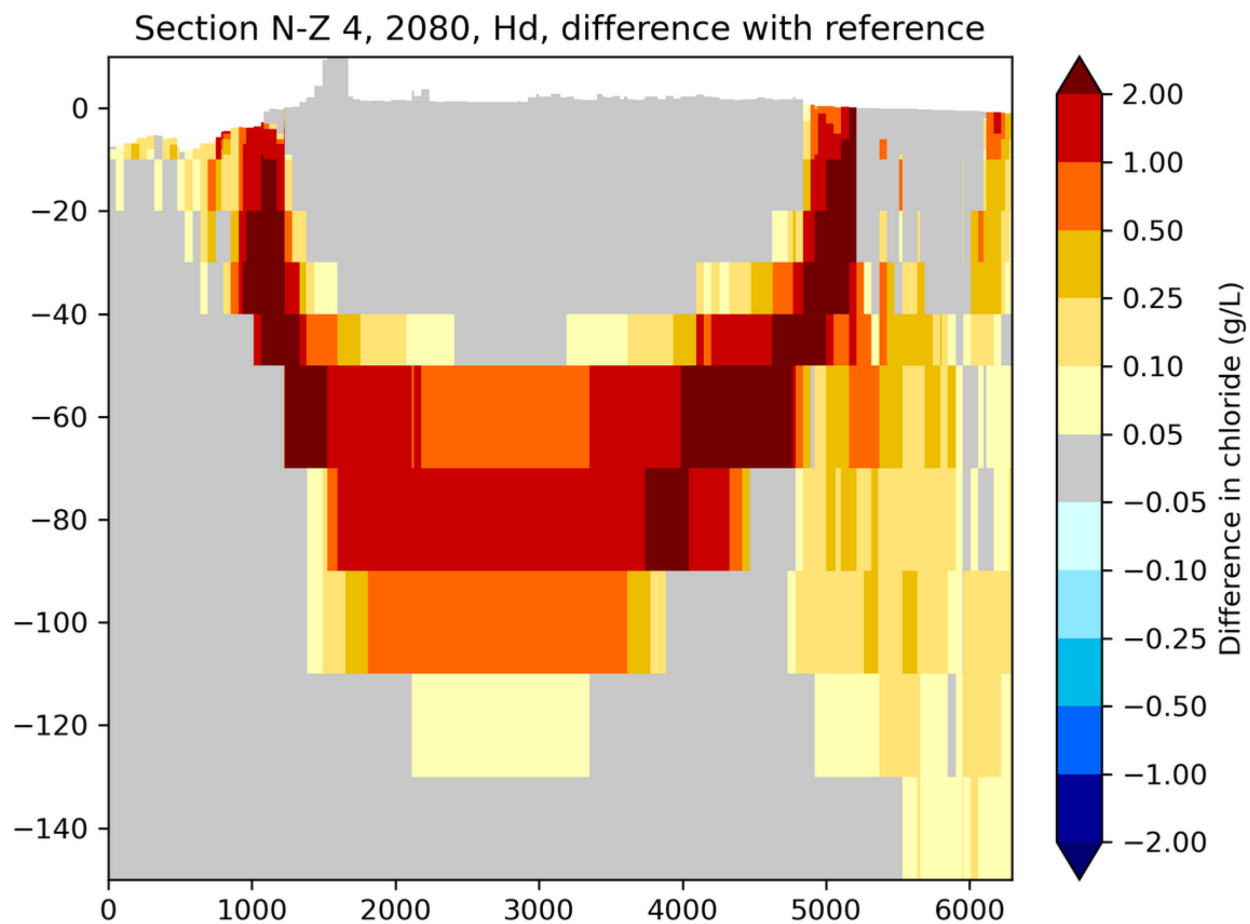

Figure C96: Location cross section N-Z 4 2080 Hd difference with reference (Deltares, 2024-a)

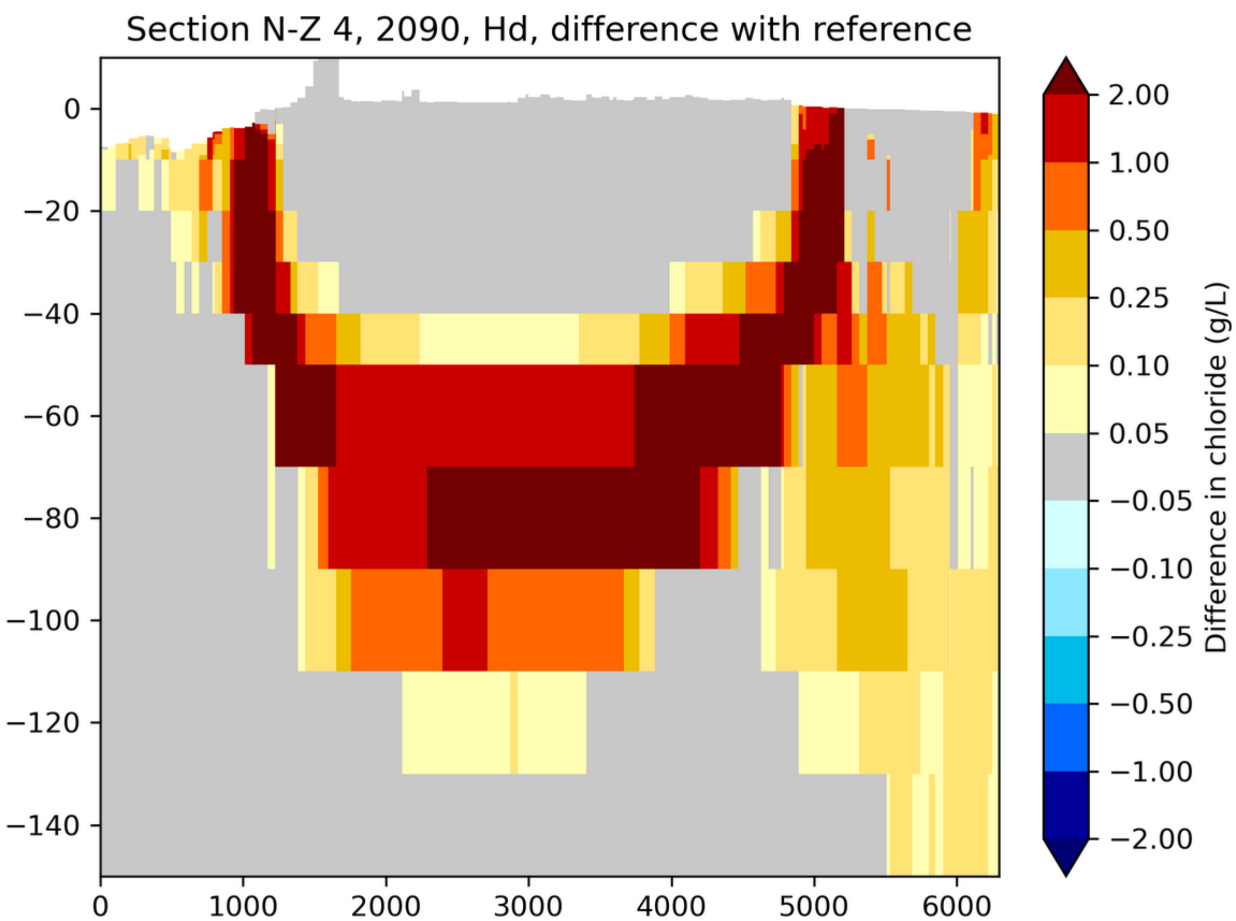

Figure C97: Location cross section N-Z 4 2090 Hd difference with reference (Deltares, 2024-a)

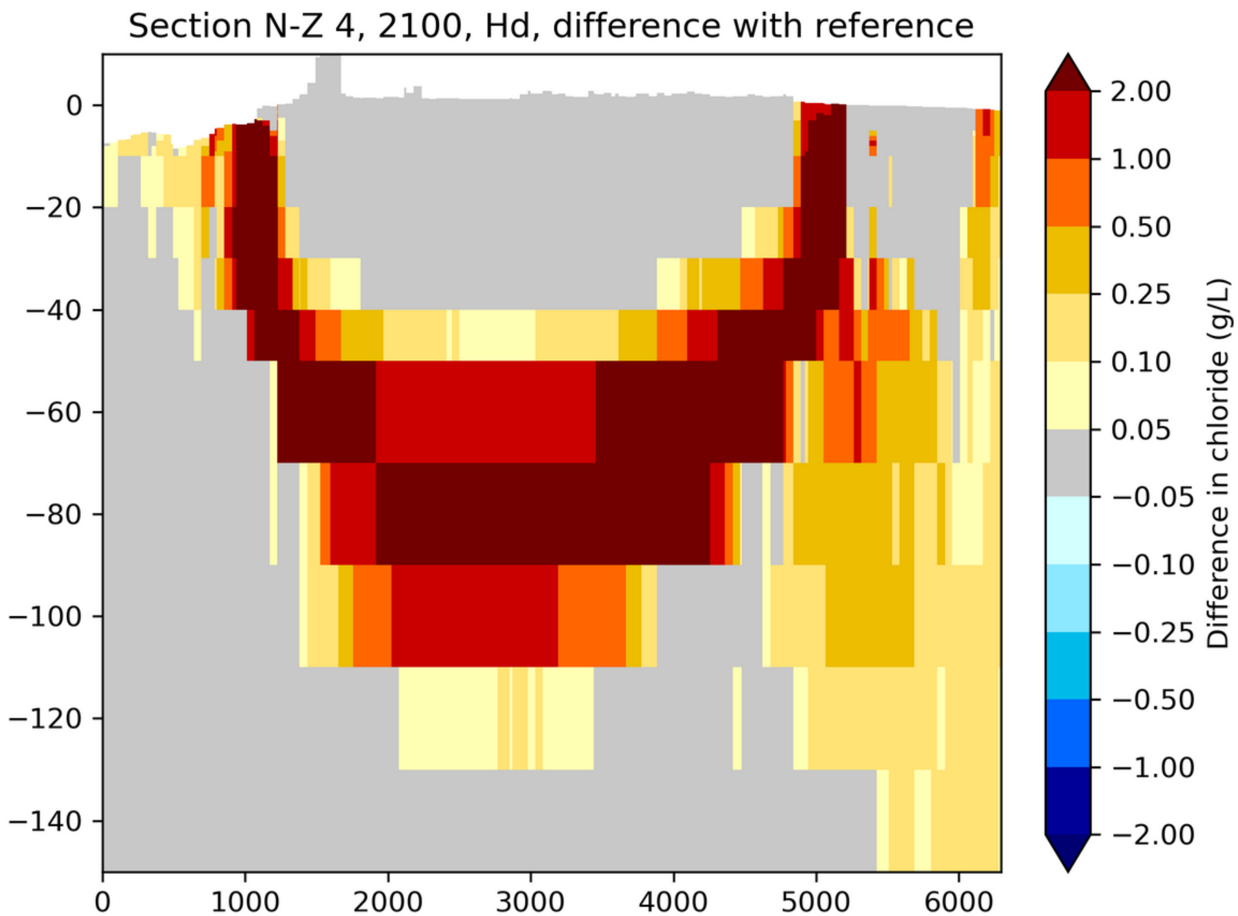

Figure C98: Location cross section N-Z 4 2100 Hd difference with reference (Deltares, 2024-a)

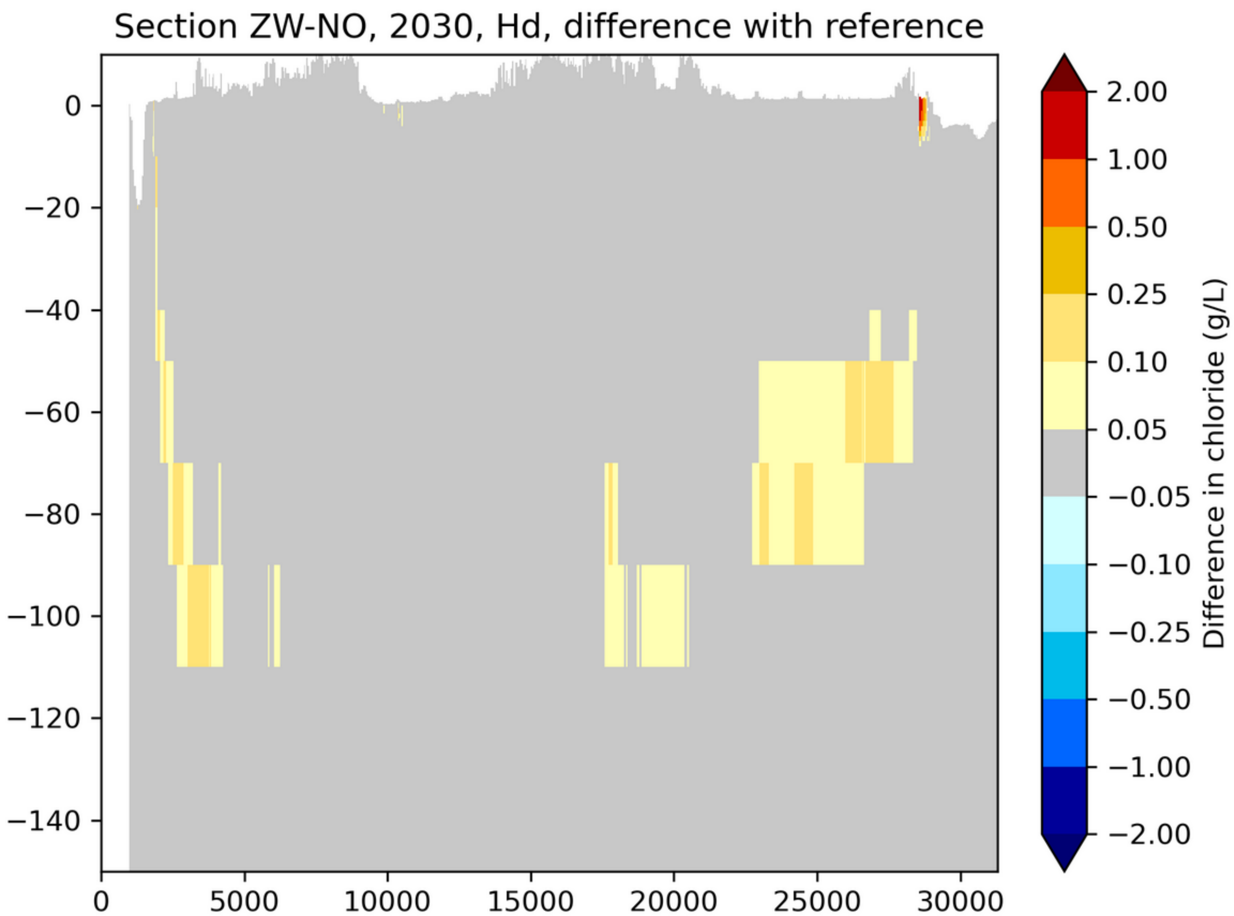

Figure C99: Location cross section ZW-NO 2030 Hd difference with reference (Deltares, 2024-a)

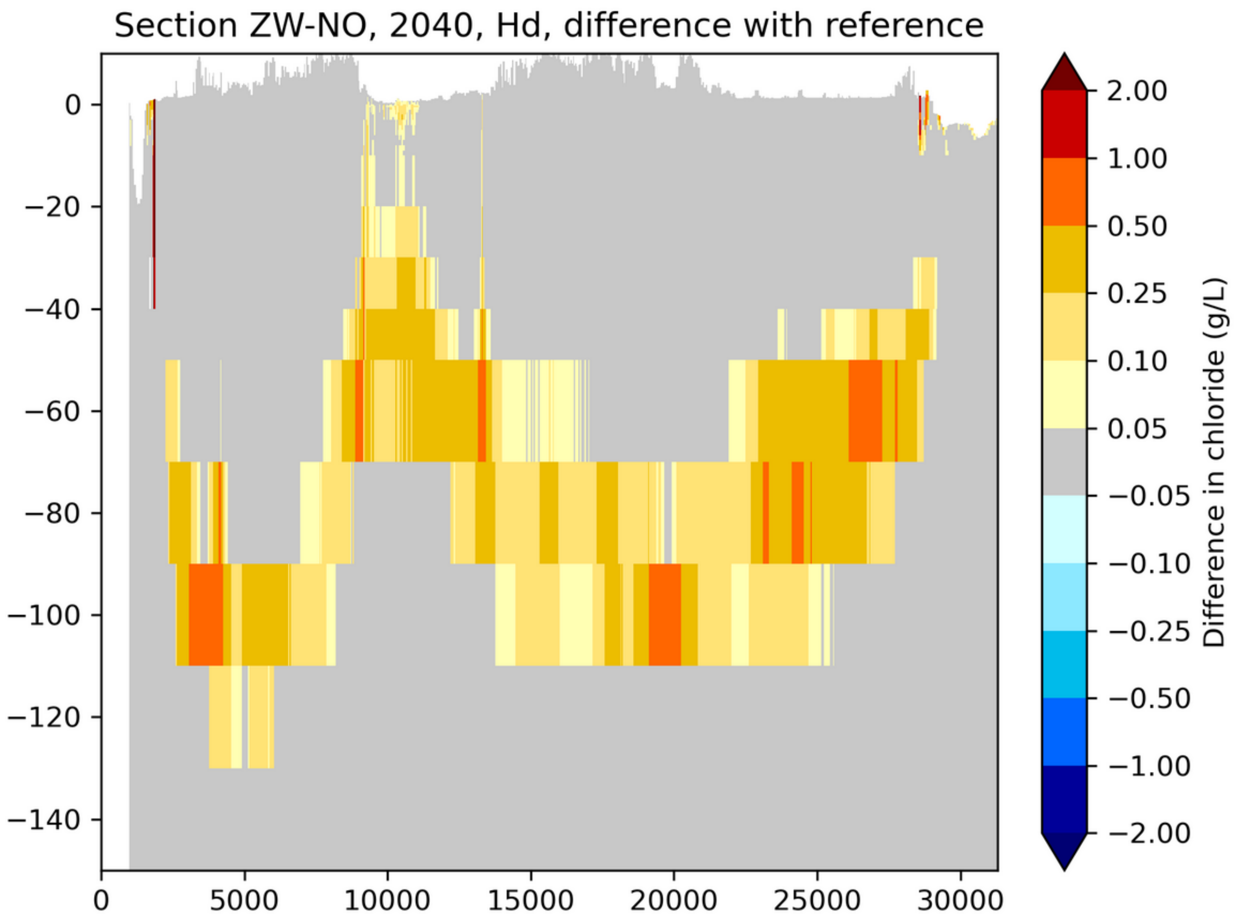

Figure C100: Location cross section ZW-NO 2040 Hd difference with reference (Deltares, 2024-a)

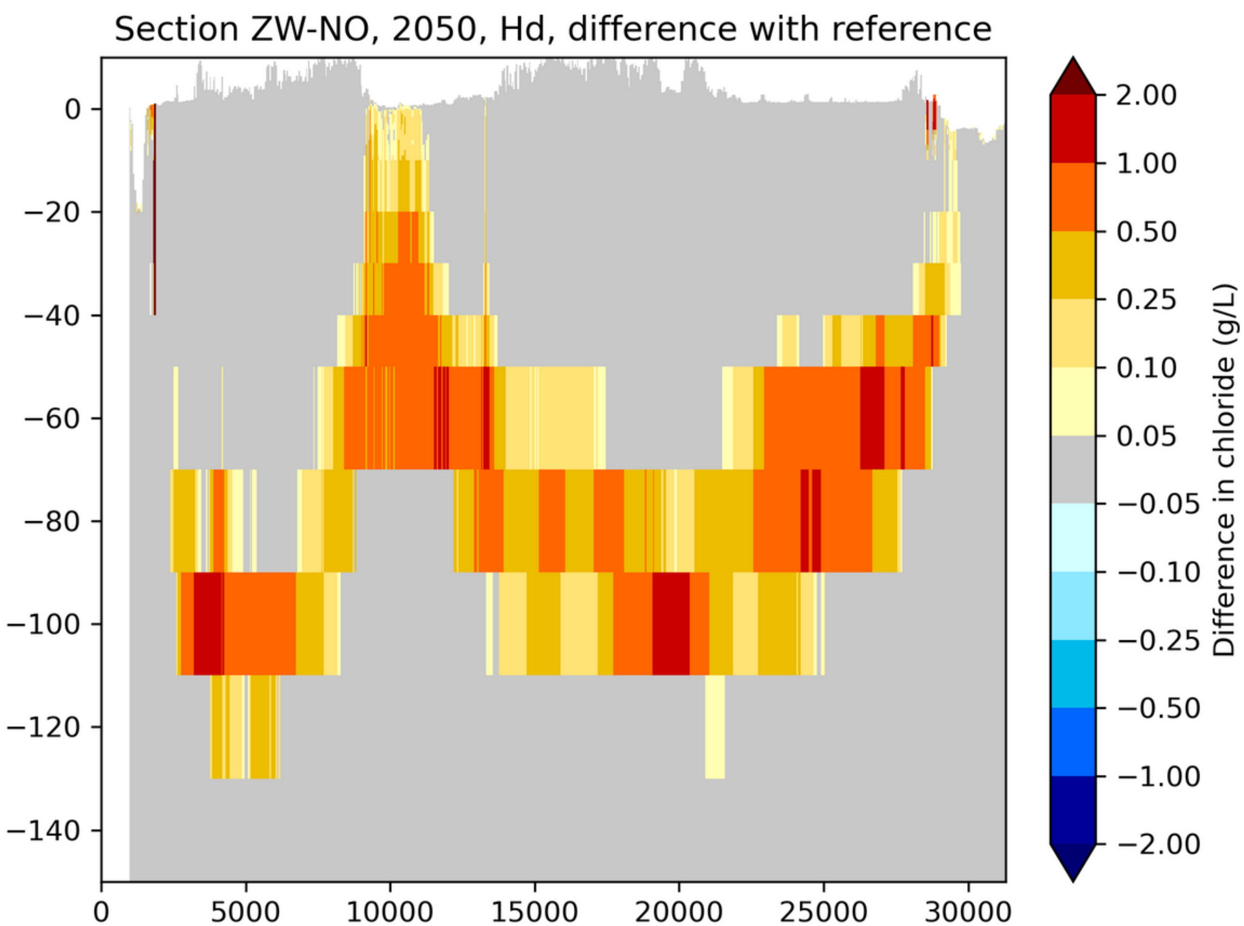

Figure C101: Location cross section ZW-NO 2050 Hd difference with reference (Deltares, 2024-a)

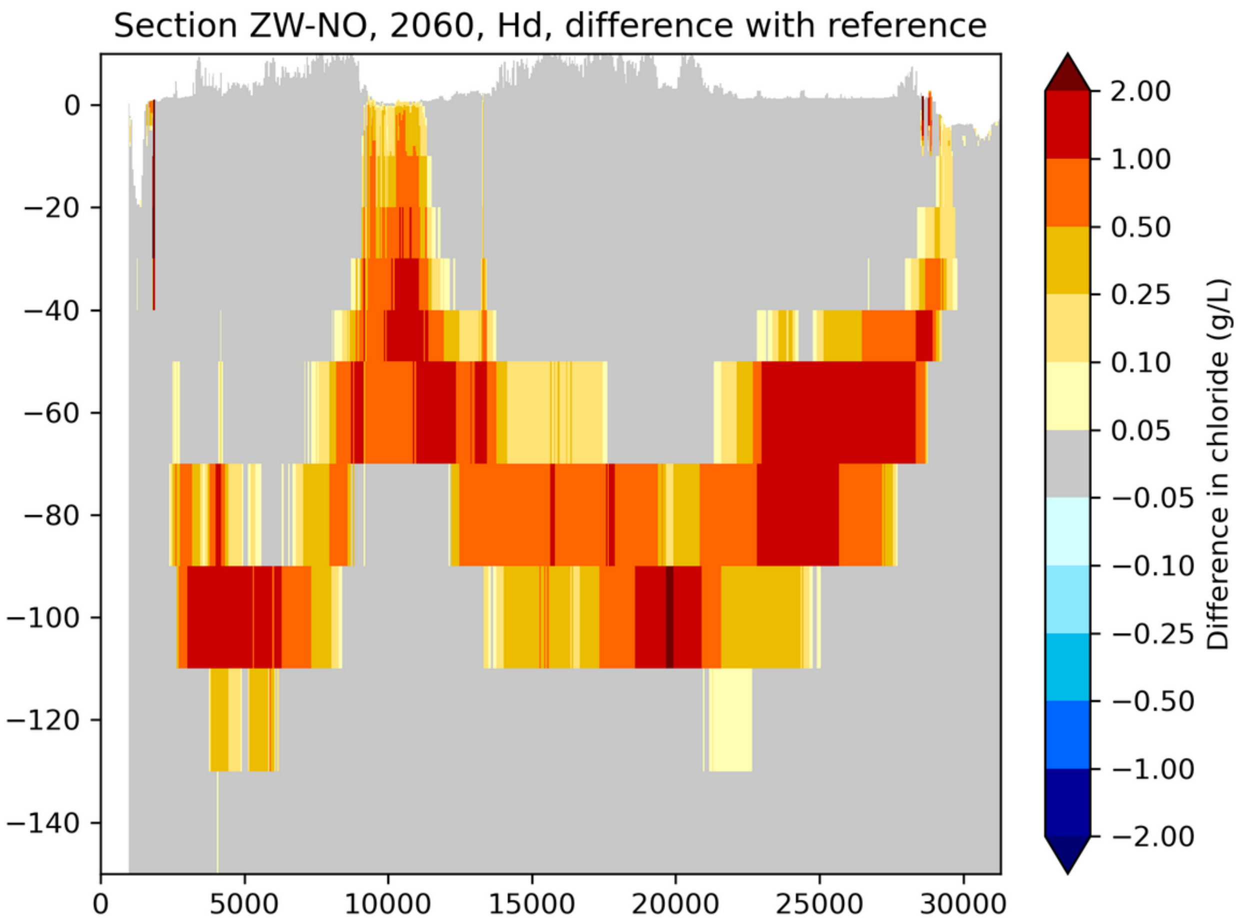

Figure C102: Location cross section ZW-NO 2060 Hd difference with reference (Deltares, 2024-a)

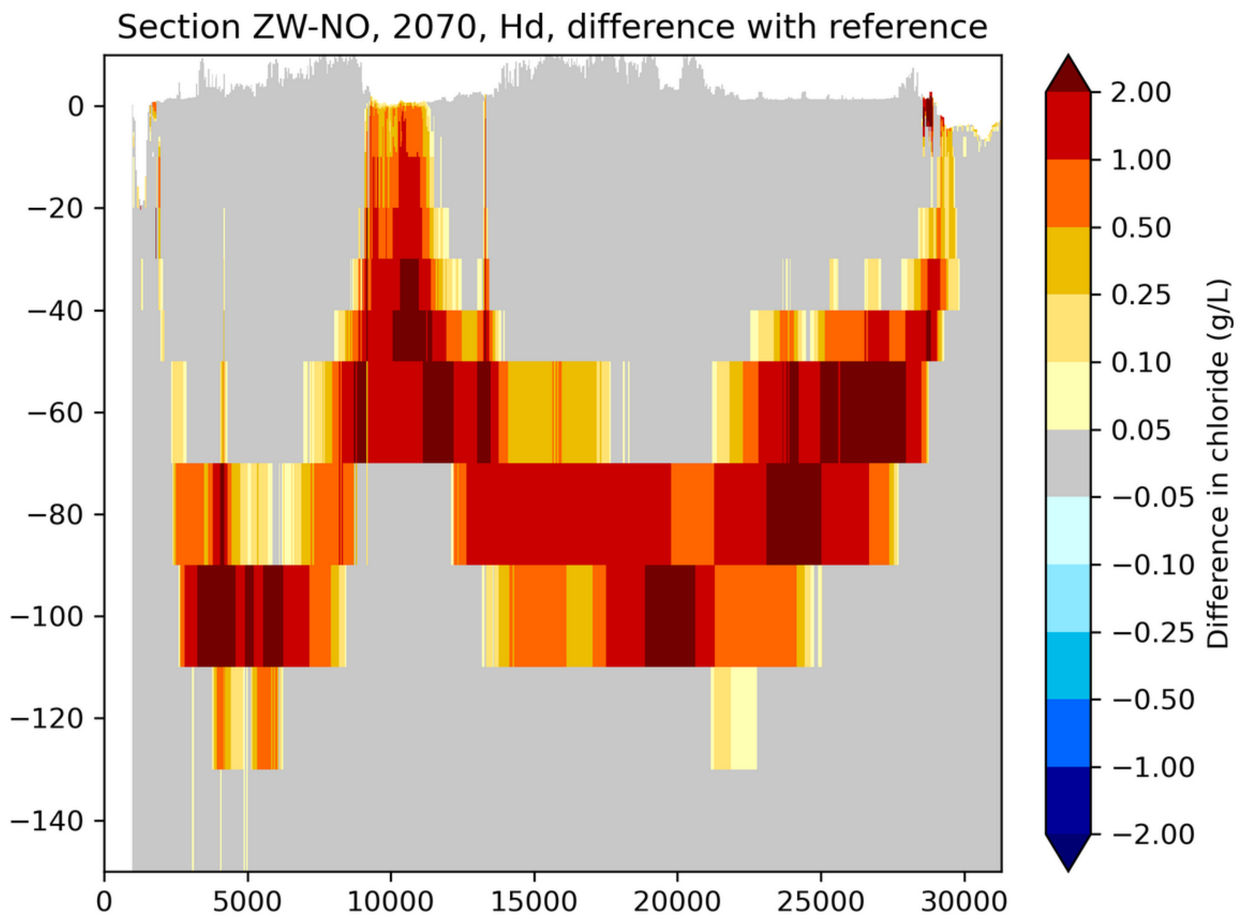

Figure C103: Location cross section ZW-NO 2070 Hd difference with reference (Deltares, 2024-a)

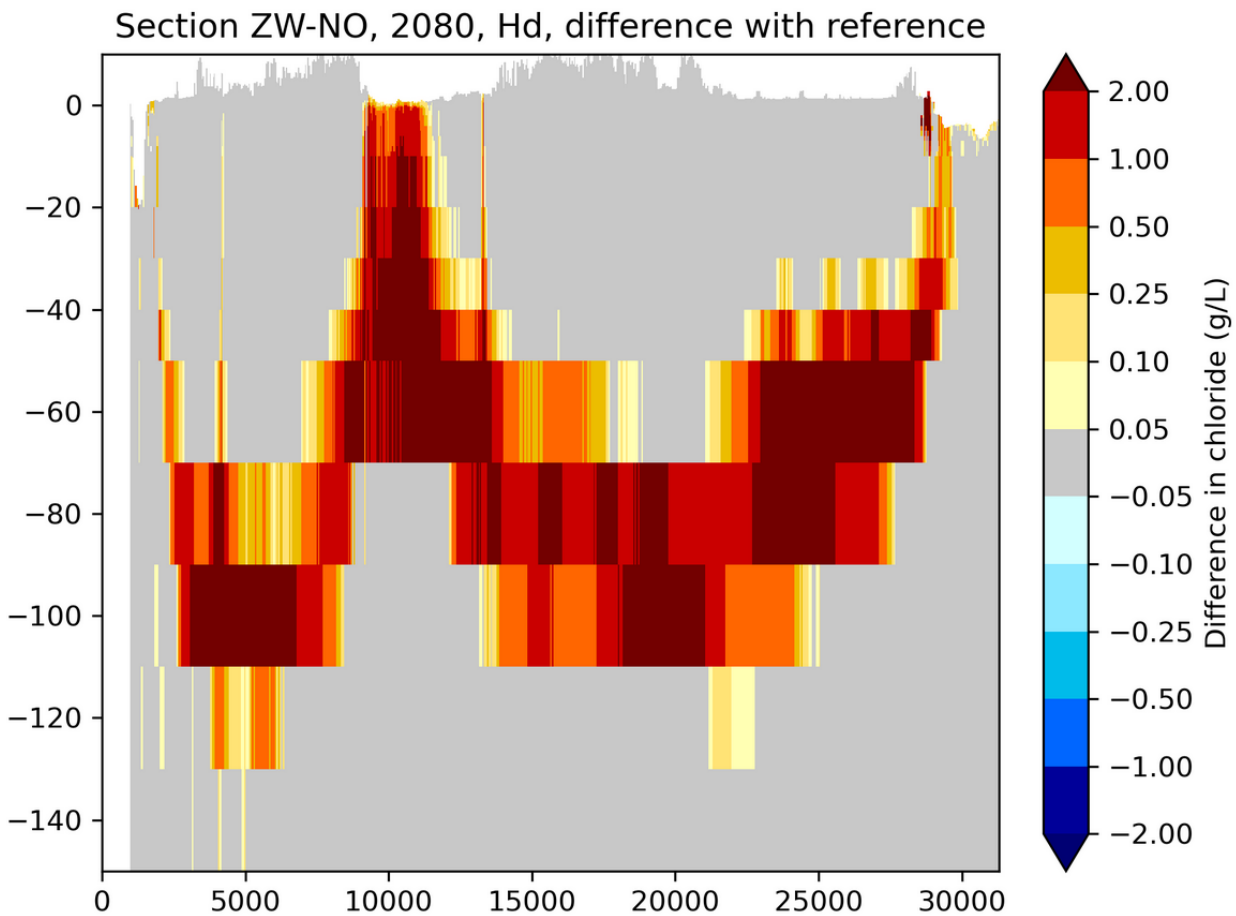

Figure C104: Location cross section ZW-NO 2080 Hd difference with reference (Deltares, 2024-a)

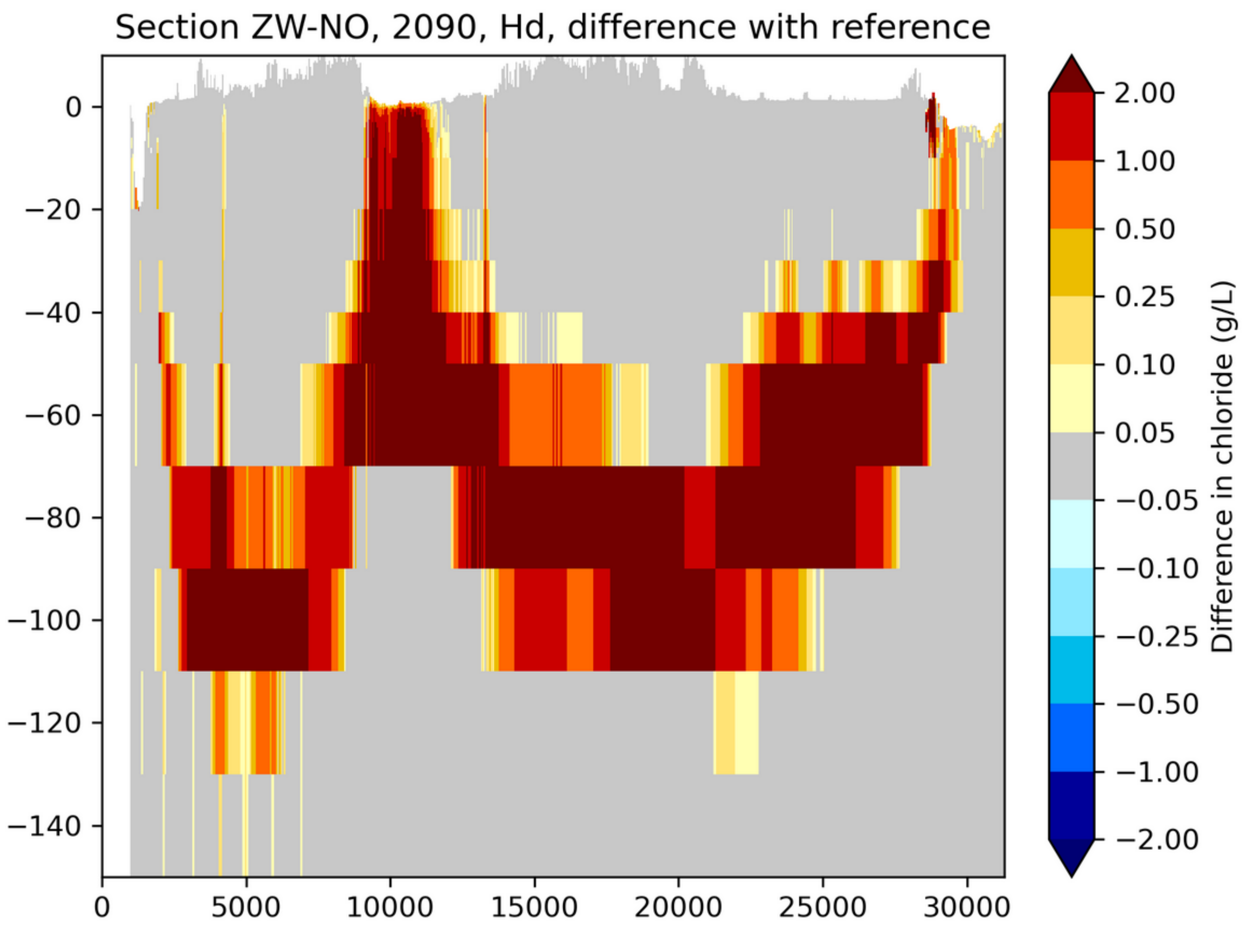

Figure C105: Location cross section ZW-NO 2090 Hd difference with reference (Deltares, 2024-a)

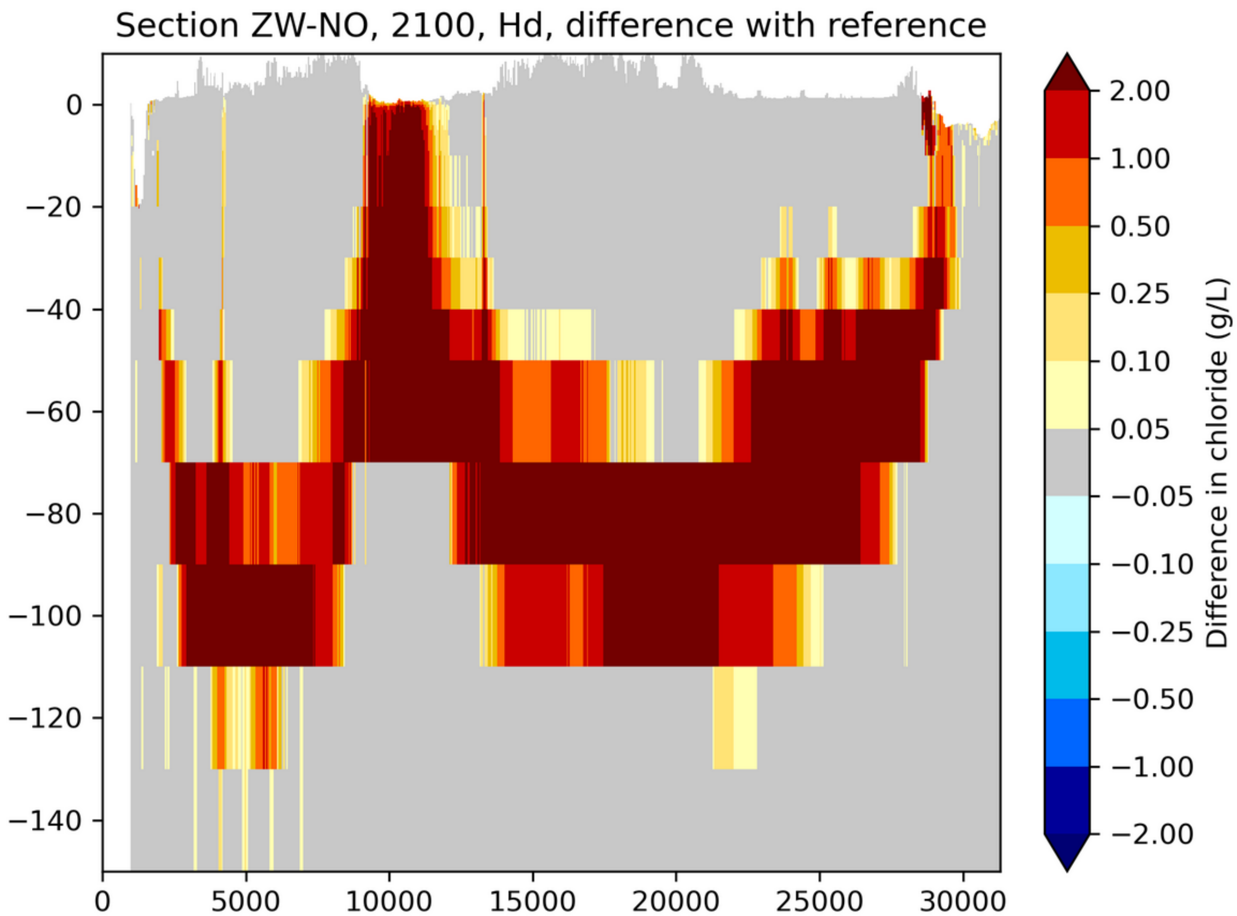

Figure C106: Location cross section ZW-NO 2100 Hd difference with reference (Deltares, 2024-a)

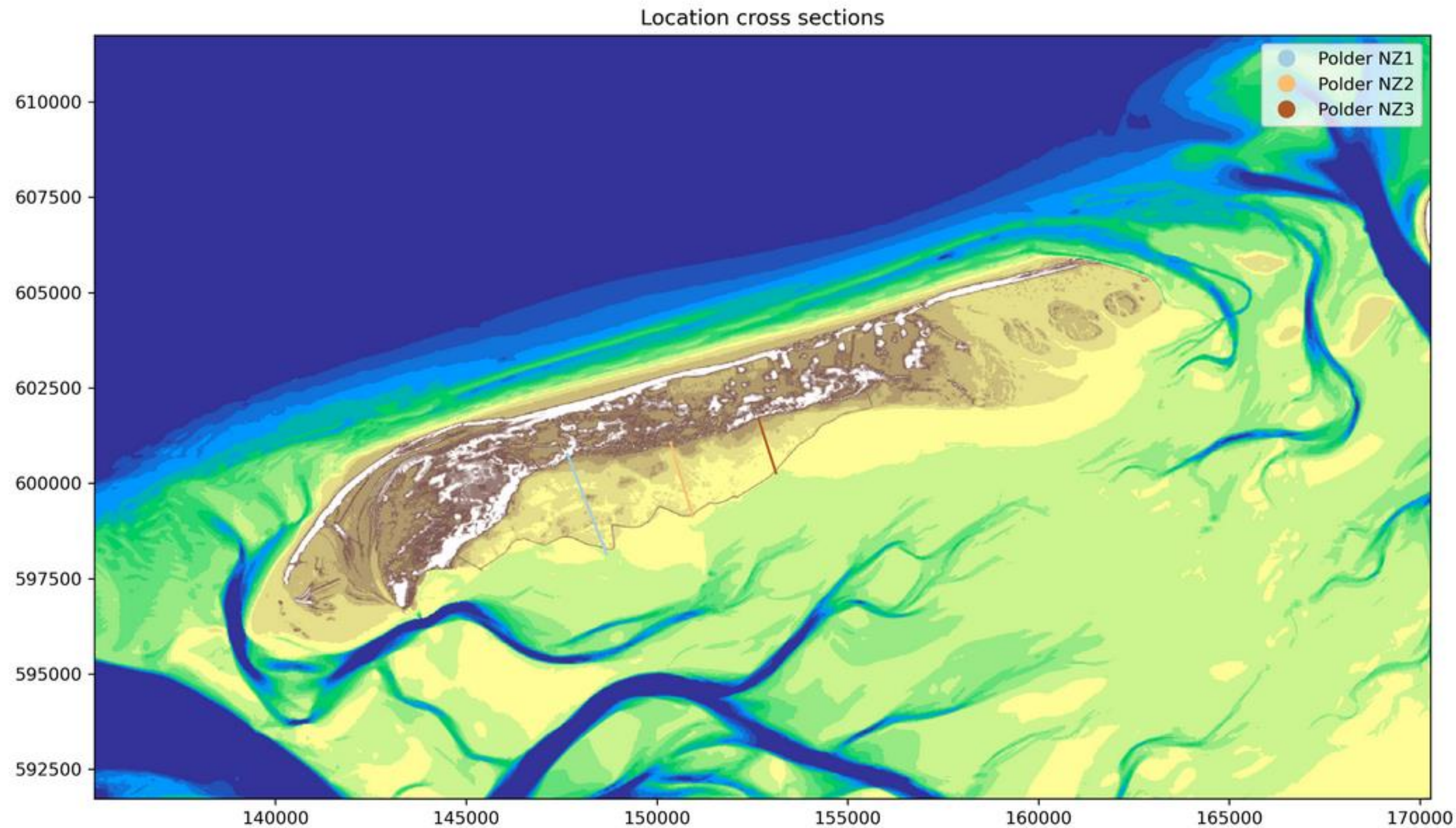

Figure C107: Location cross sections polder Hd difference with reference (Deltares, 2024-a)

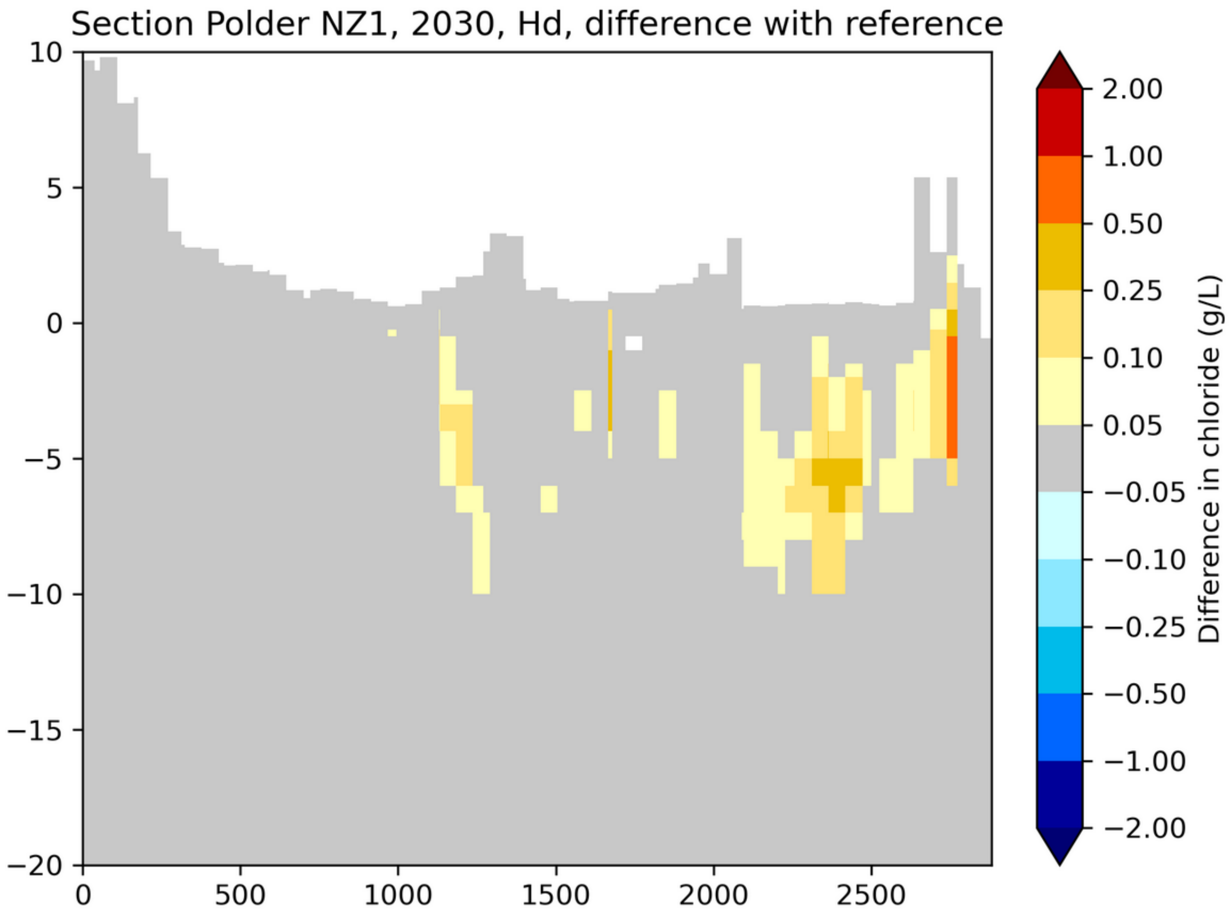

Figure C108: Location cross section Polder NZ1 2030 Hd difference with reference (Deltares, 2024-a)

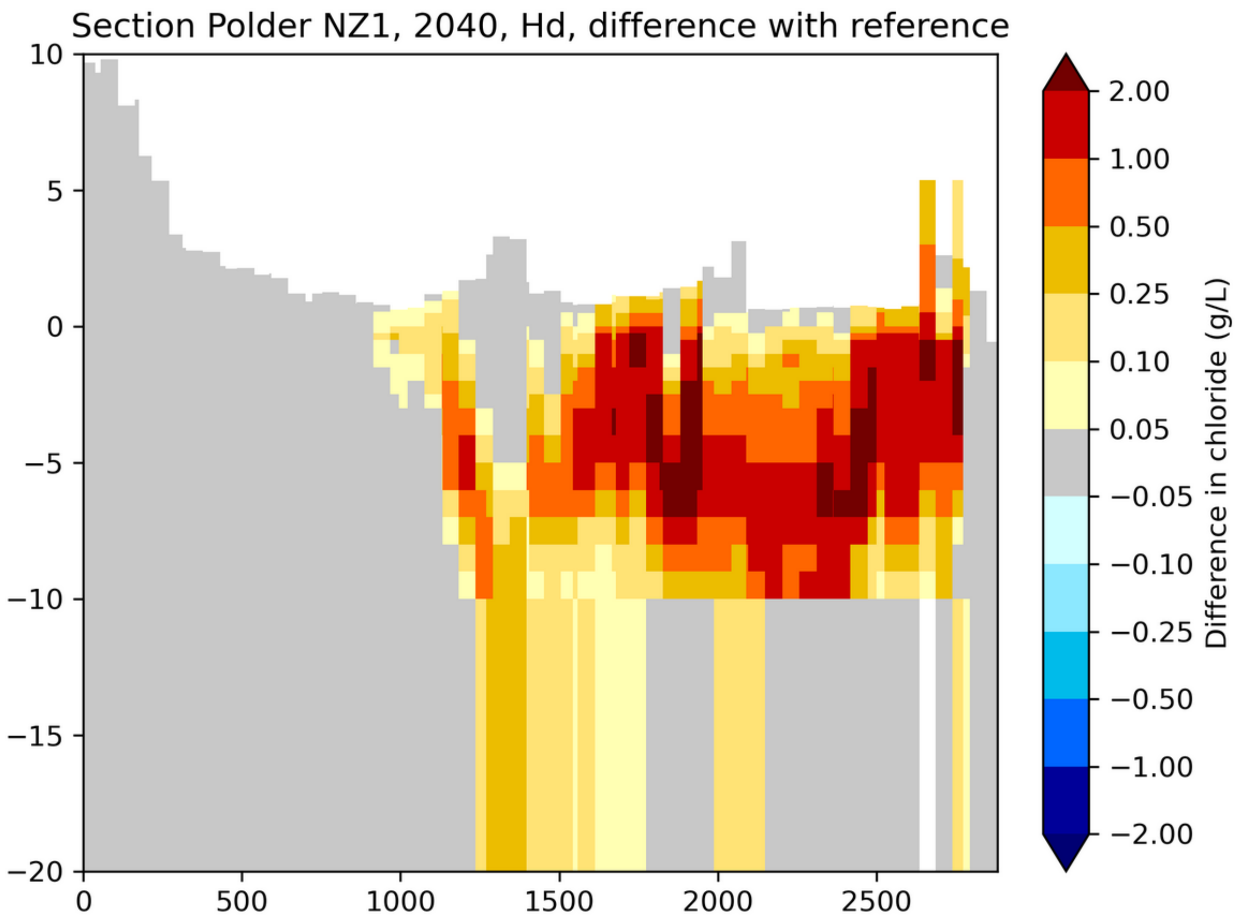

Figure C109: Location cross section Polder NZ1 2040 Hd difference with reference (Deltares, 2024-a)

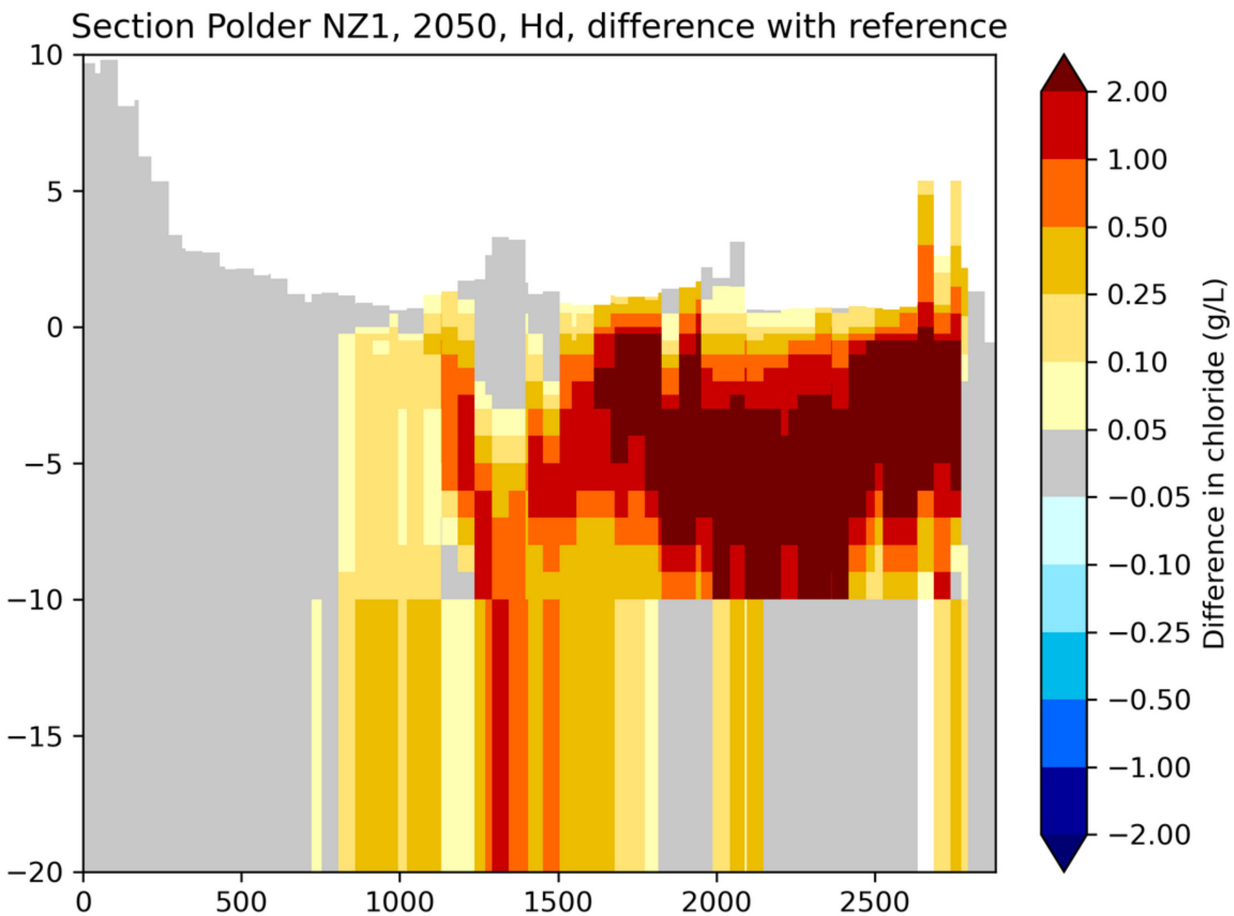

Figure C110: Location cross section Polder NZ1 2050 Hd difference with reference (Deltares, 2024-a)

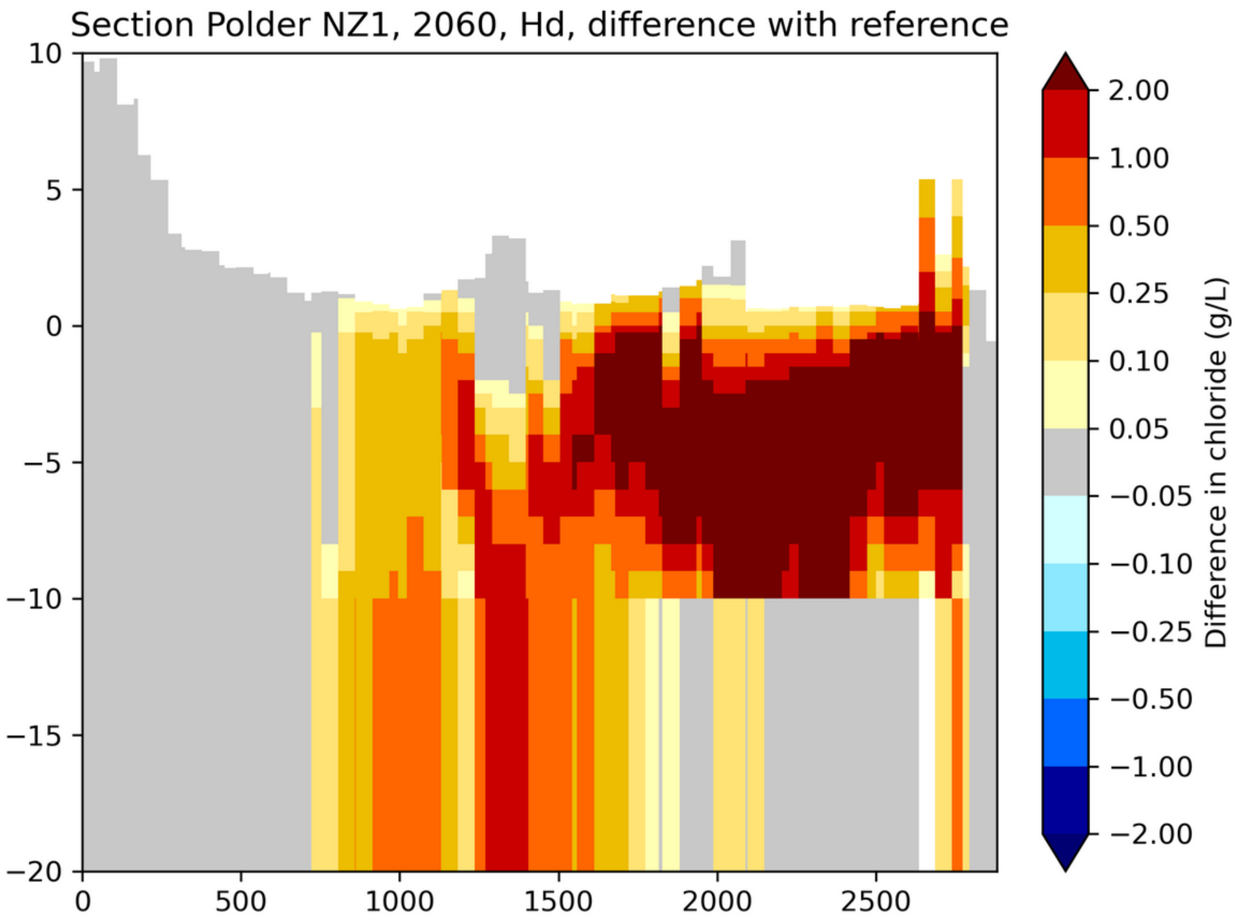

Figure C111: Location cross section Polder NZ1 2060 Hd difference with reference (Deltares, 2024-a)

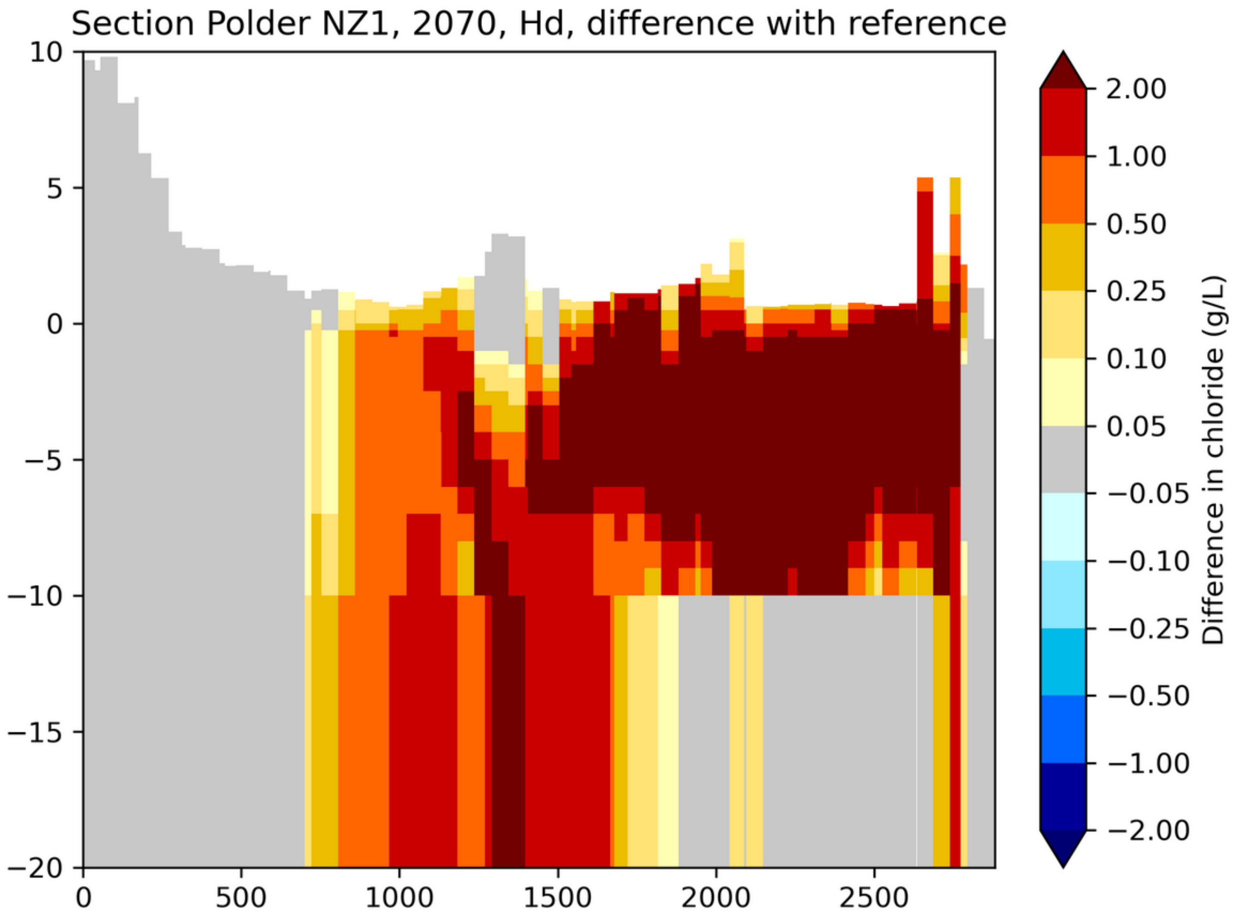

Figure C112: Location cross section Polder NZ1 2070 Hd difference with reference (Deltares, 2024-a)

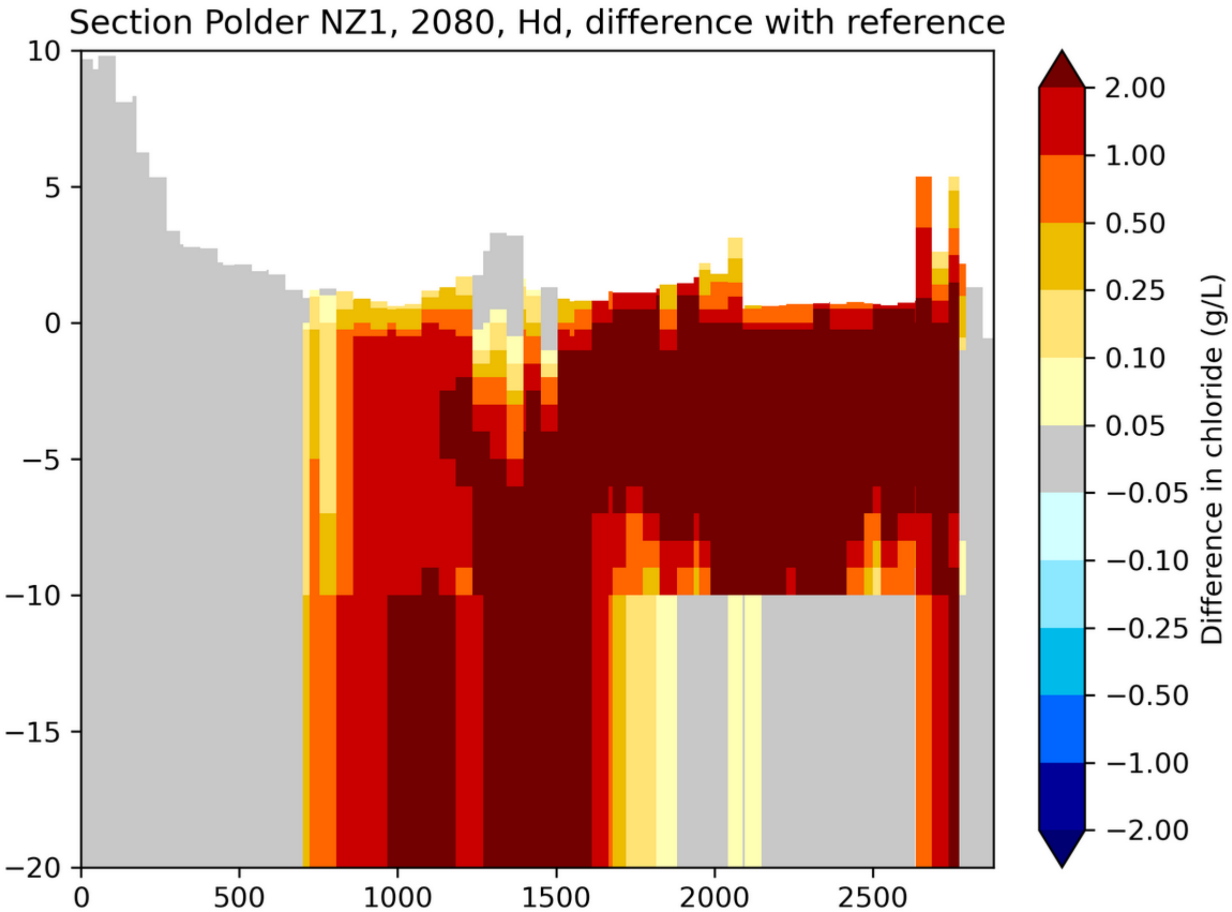

Figure C113: Location cross section Polder NZ1 2080 Hd difference with reference (Deltares, 2024-a)

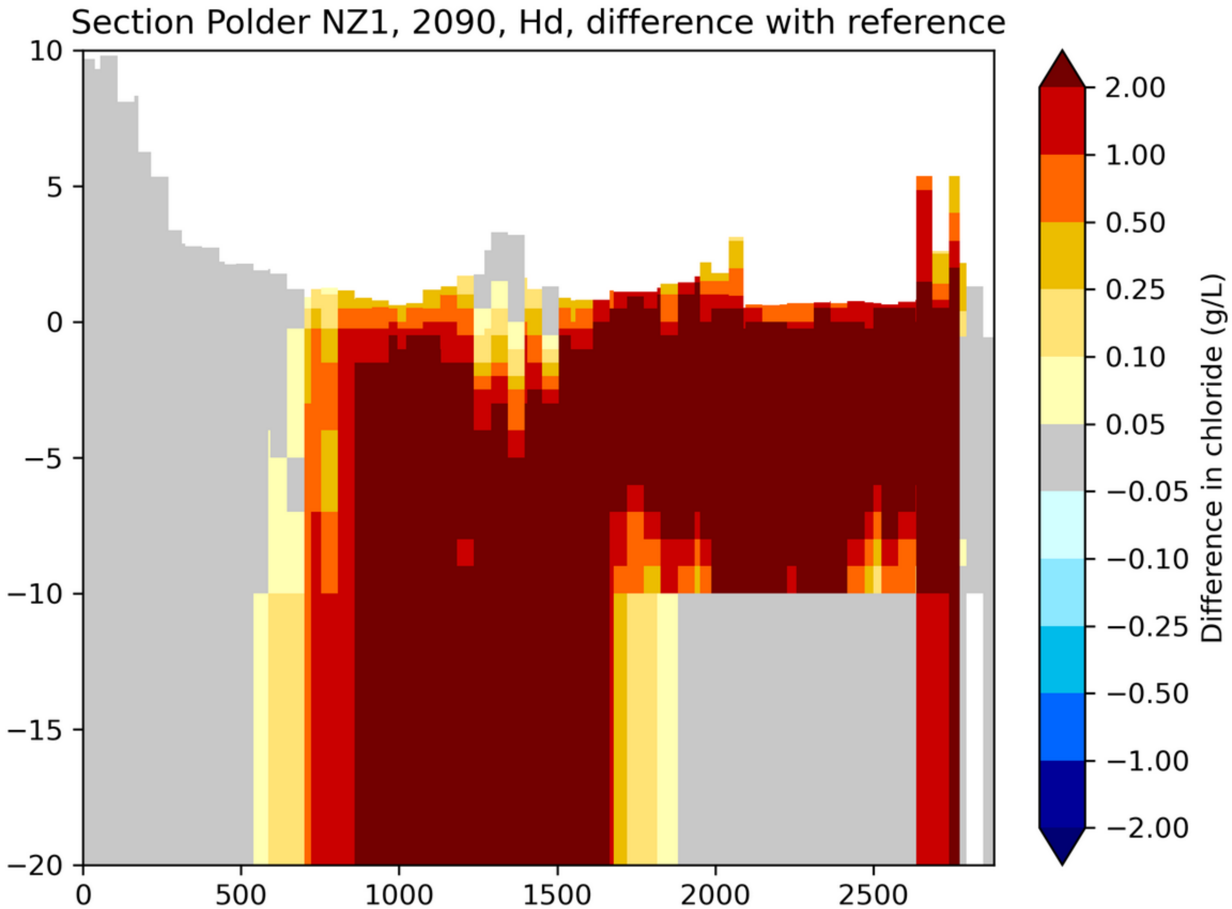

Figure C114: Location cross section Polder NZ1 2090 Hd difference with reference (Deltares, 2024-a)

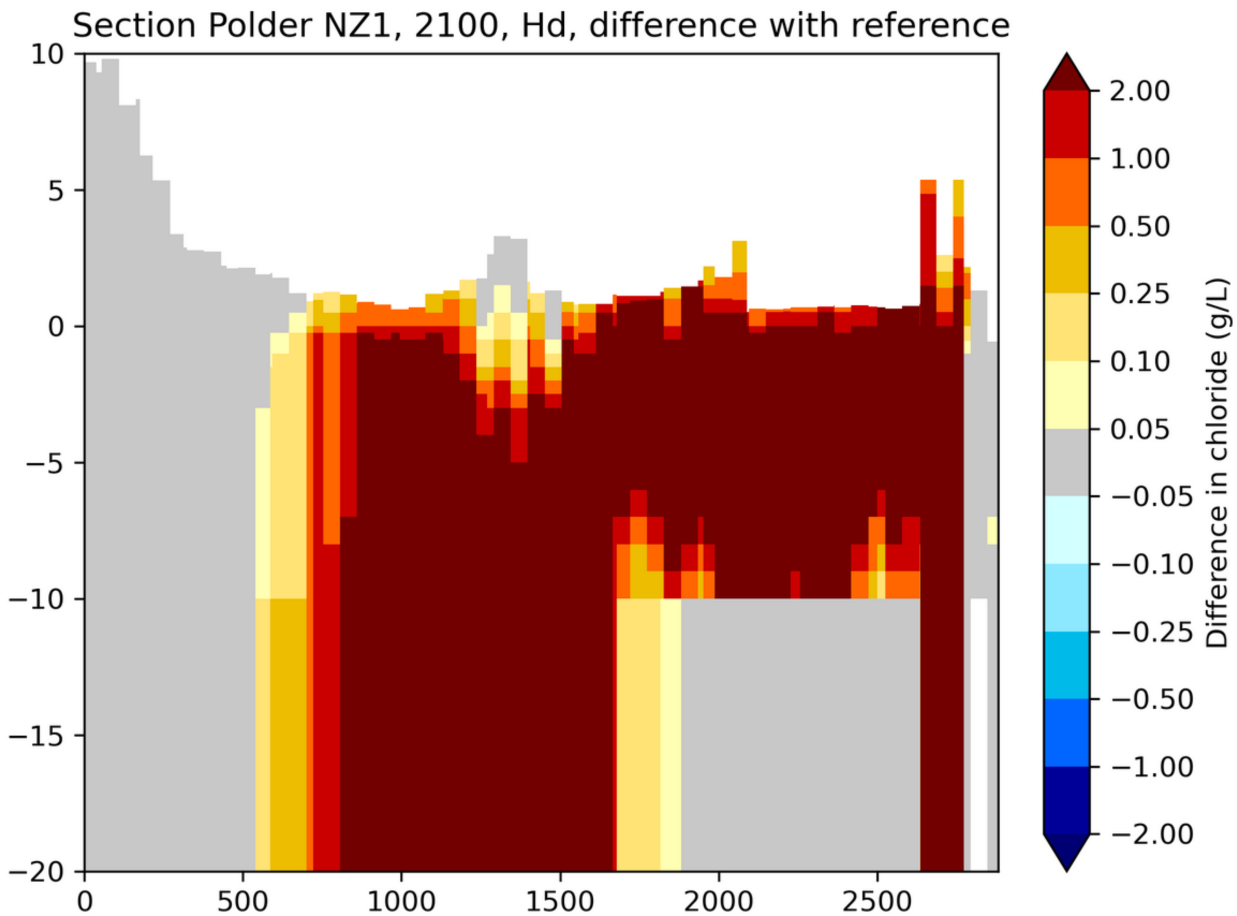

Figure C115: Location cross section Polder NZ1 2100 Hd difference with reference (Deltares, 2024-a)

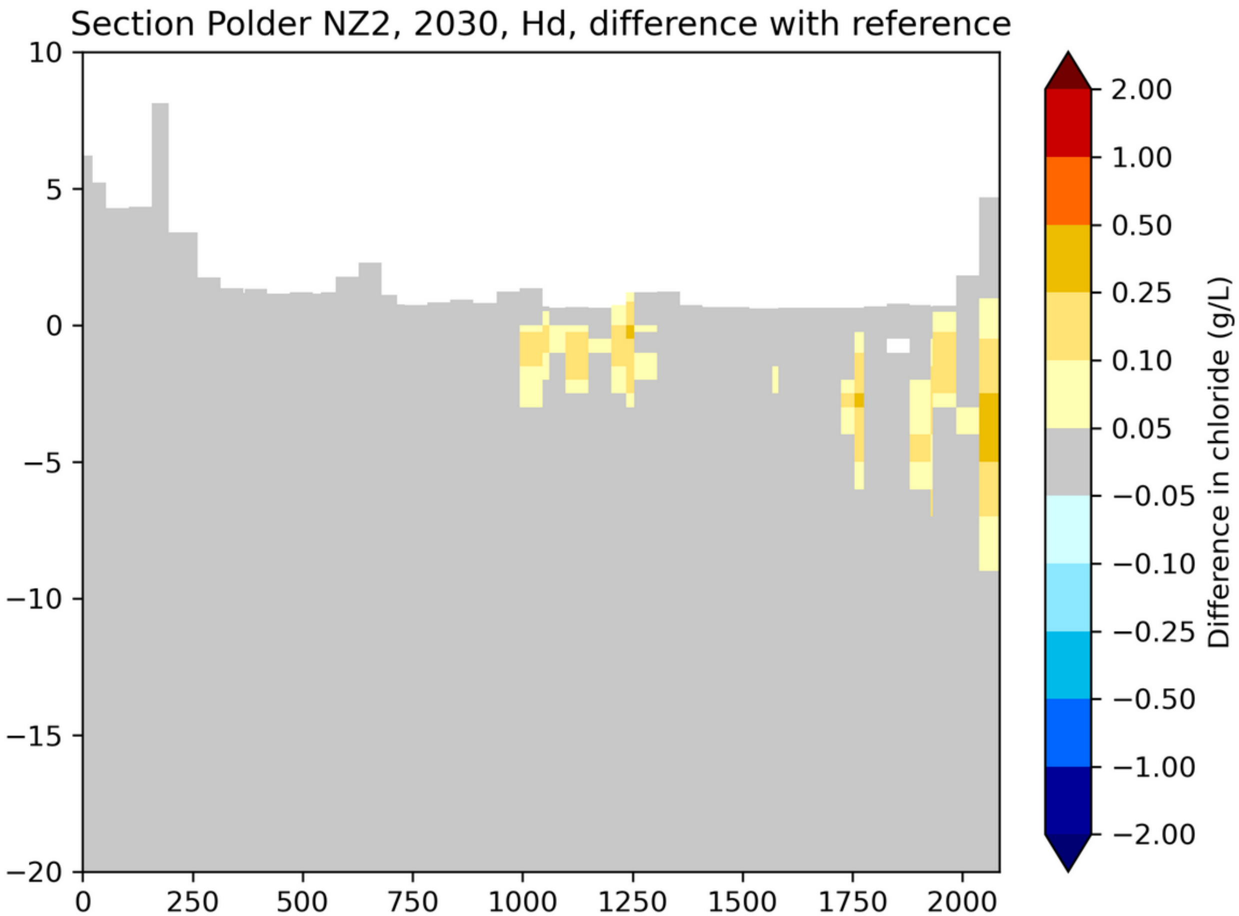

Figure C116: Location cross section Polder NZ2 2030 Hd difference with reference (Deltares, 2024-a)

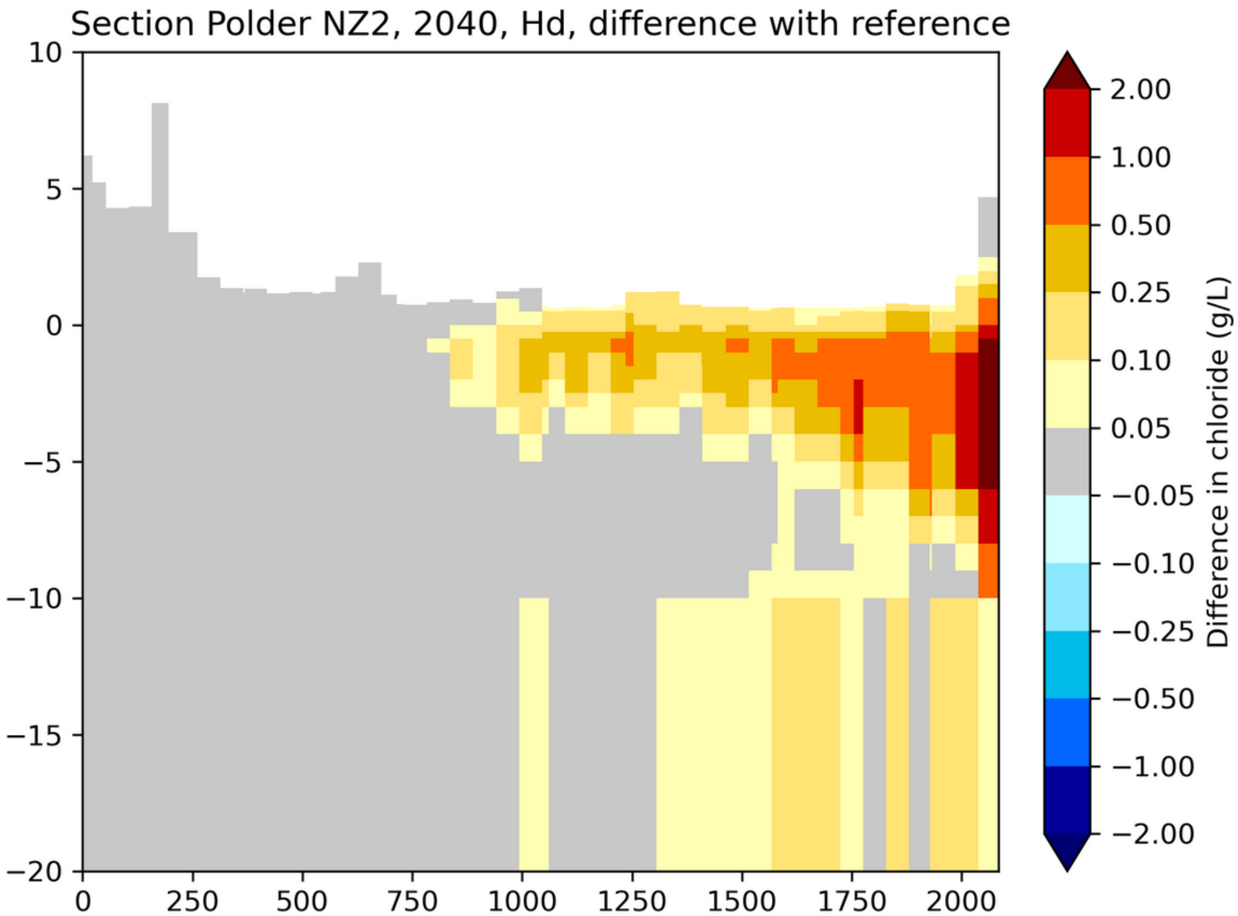

Figure C117: Location cross section Polder NZ2 2040 Hd difference with reference (Deltares, 2024-a)

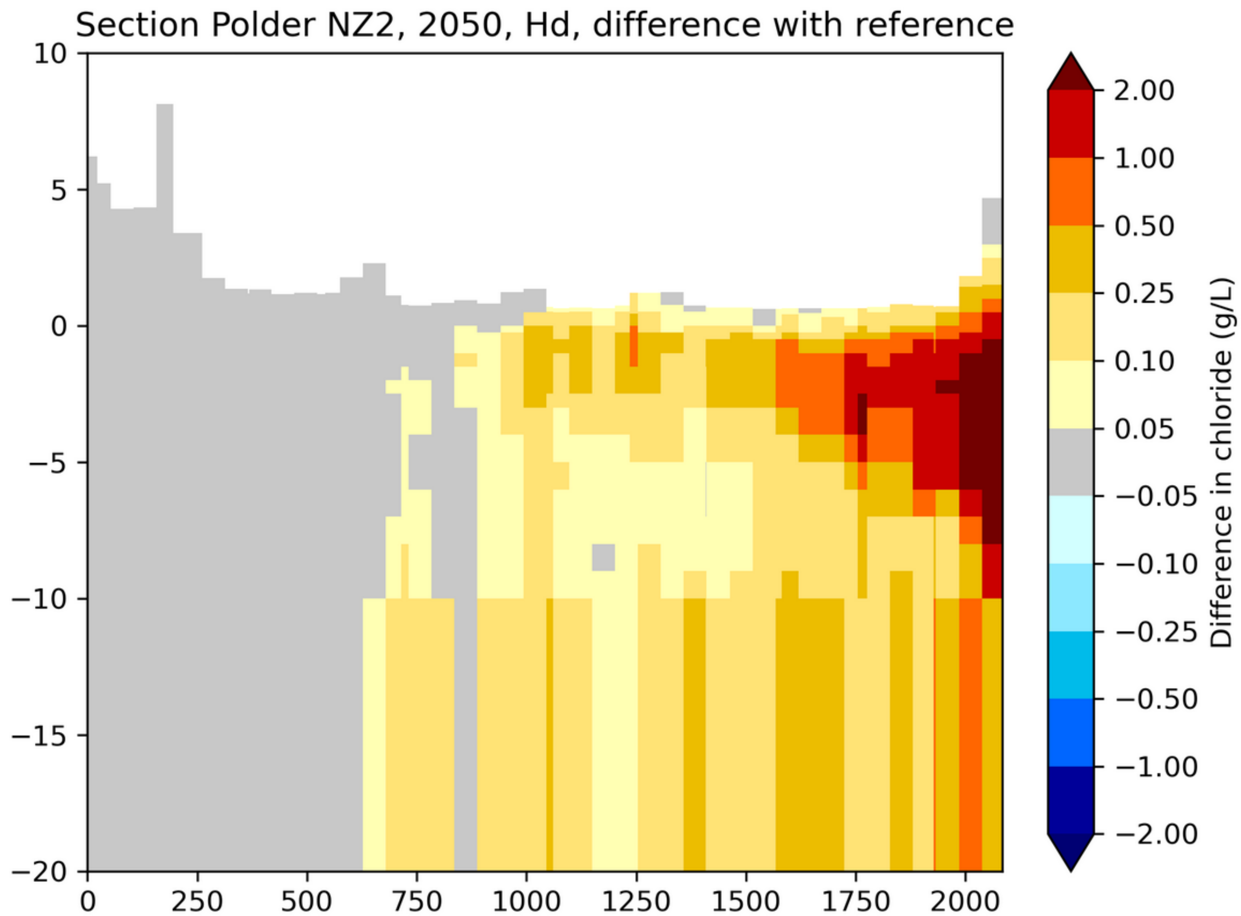

Figure C118: Location cross section Polder NZ2 2050 Hd difference with reference (Deltares, 2024-a)

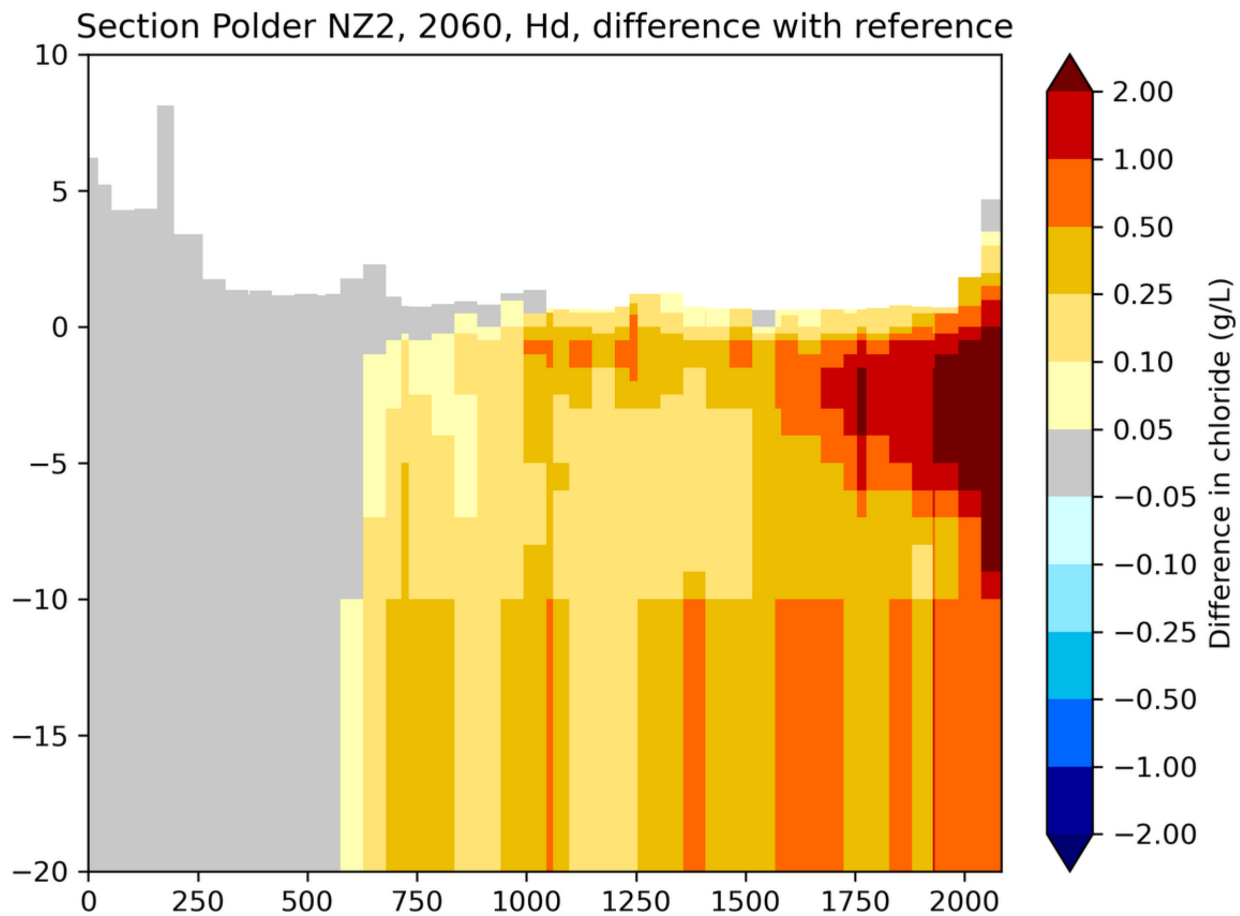

Figure C119: Location cross section Polder NZ2 2060 Hd difference with reference (Deltares, 2024-a)

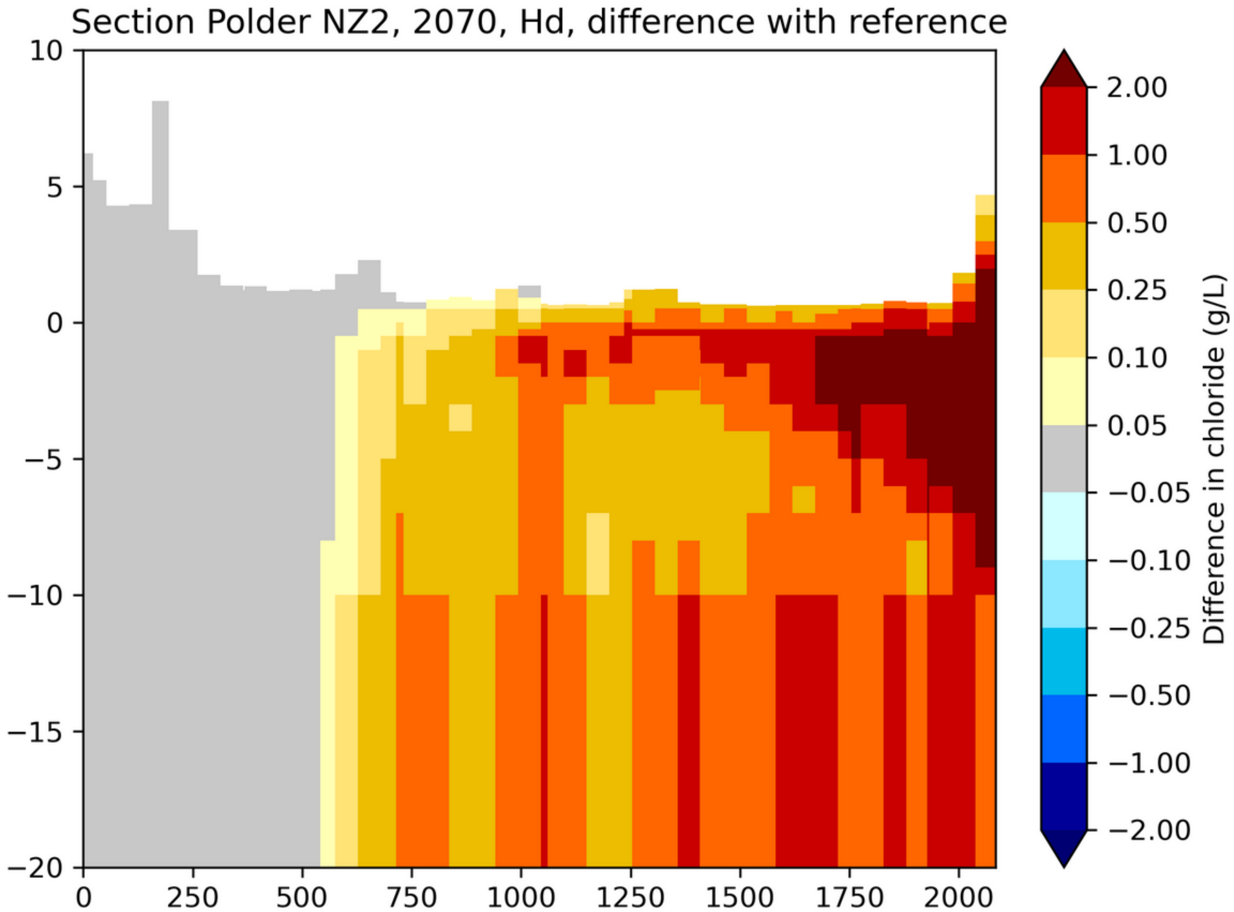

Figure C120: Location cross section Polder NZ2 2070 Hd difference with reference (Deltares, 2024-a)

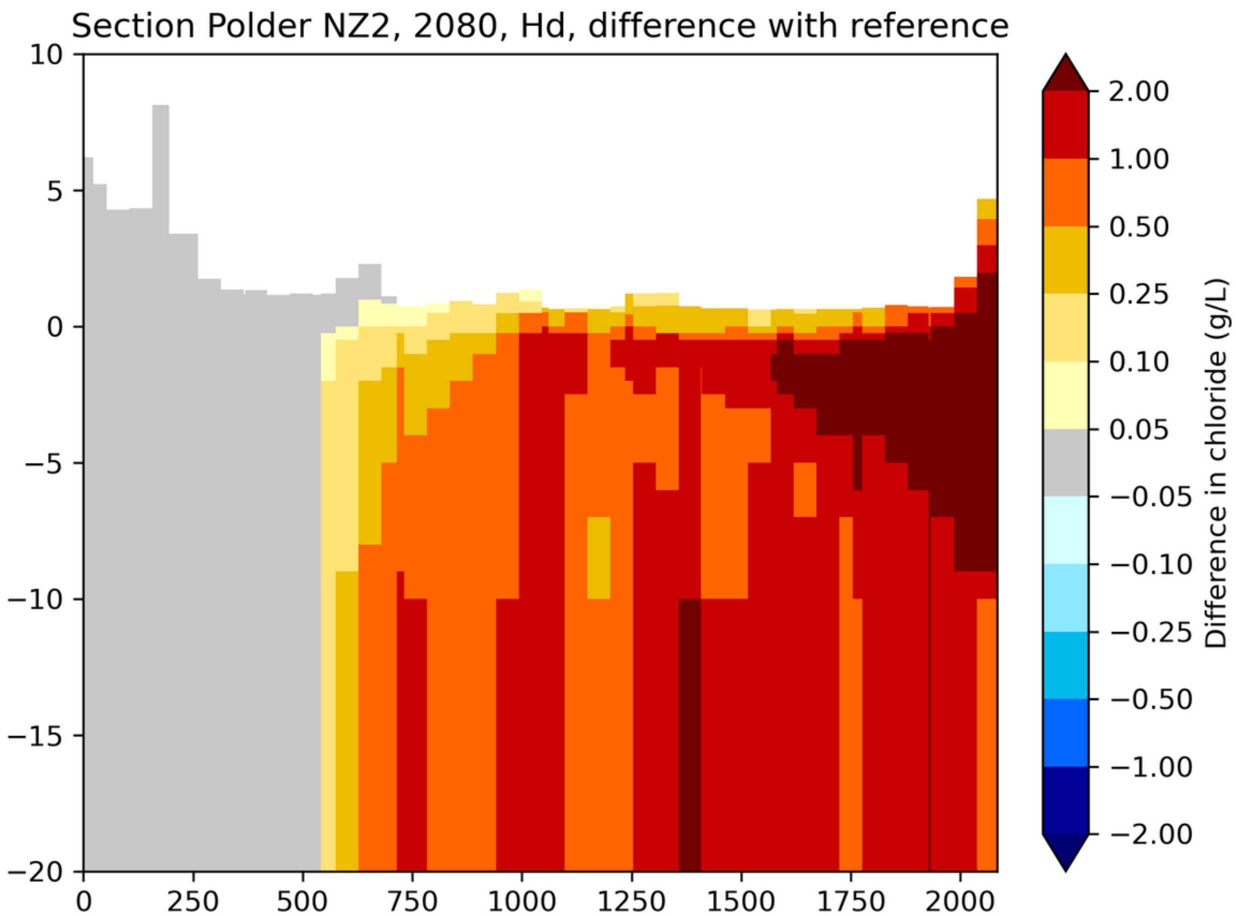

Figure C121: Location cross section Polder NZ2 2080 Hd difference with reference (Deltares, 2024-a)

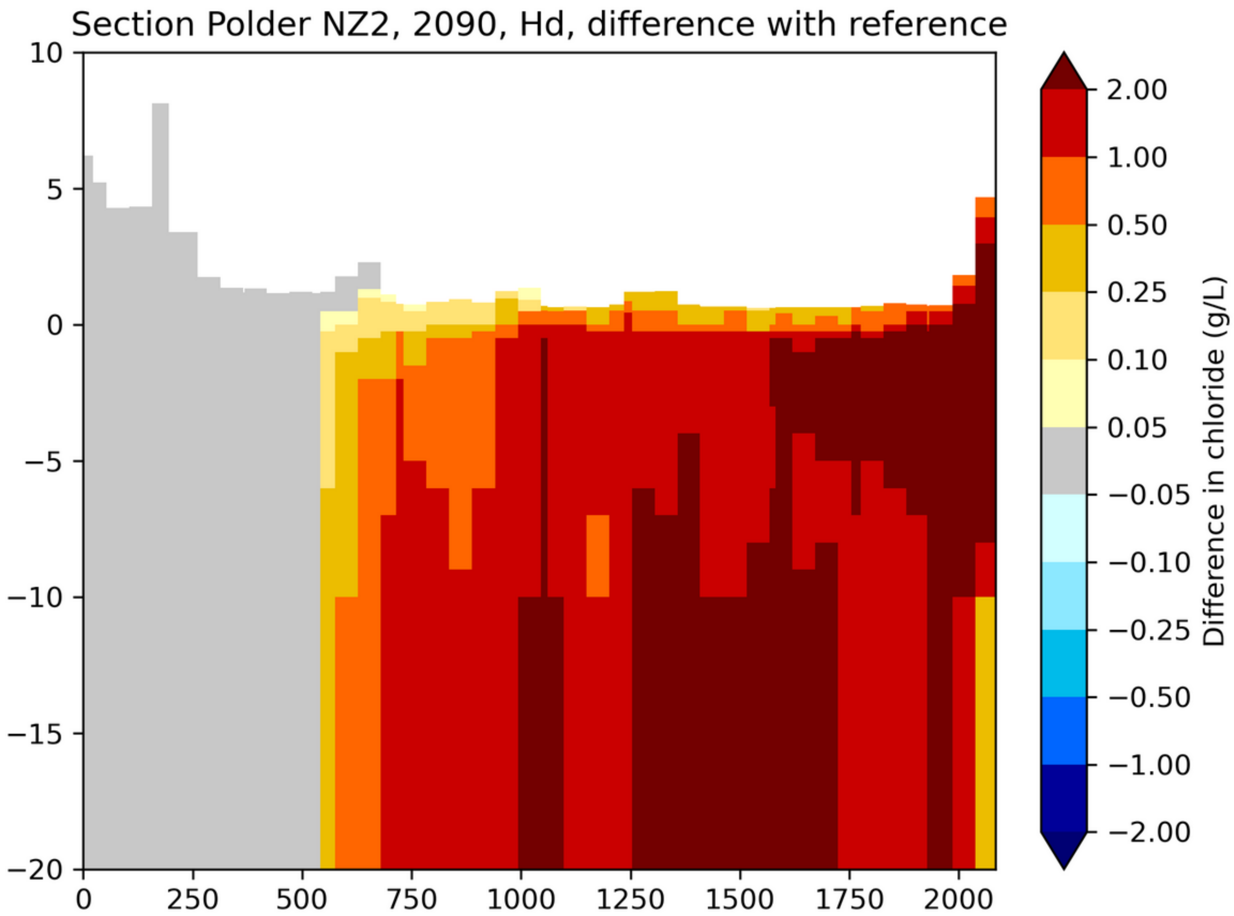

Figure C122: Location cross section Polder NZ2 2090 Hd difference with reference (Deltares, 2024-a)

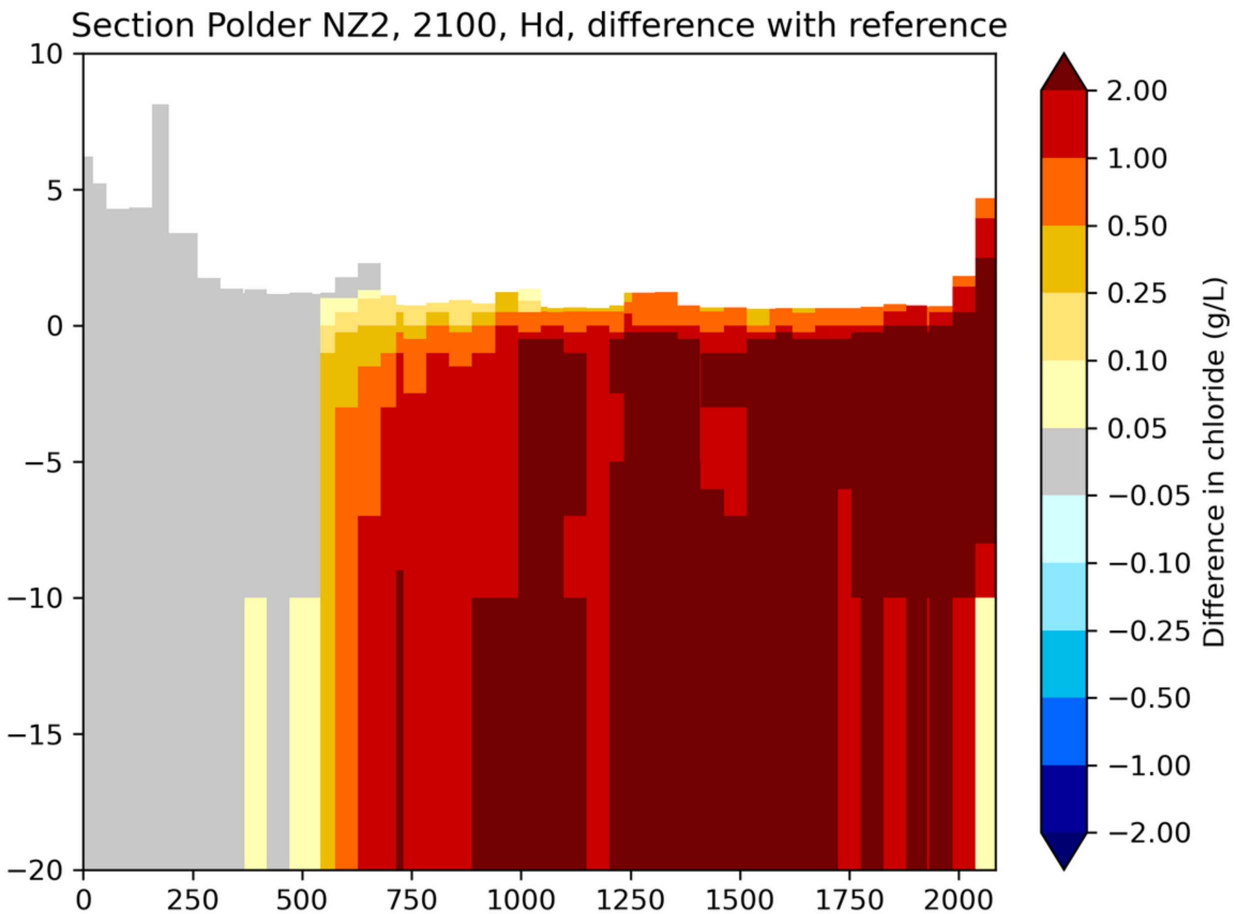

Figure C123: Location cross section Polder NZ2 2100 Hd difference with reference (Deltares, 2024-a)

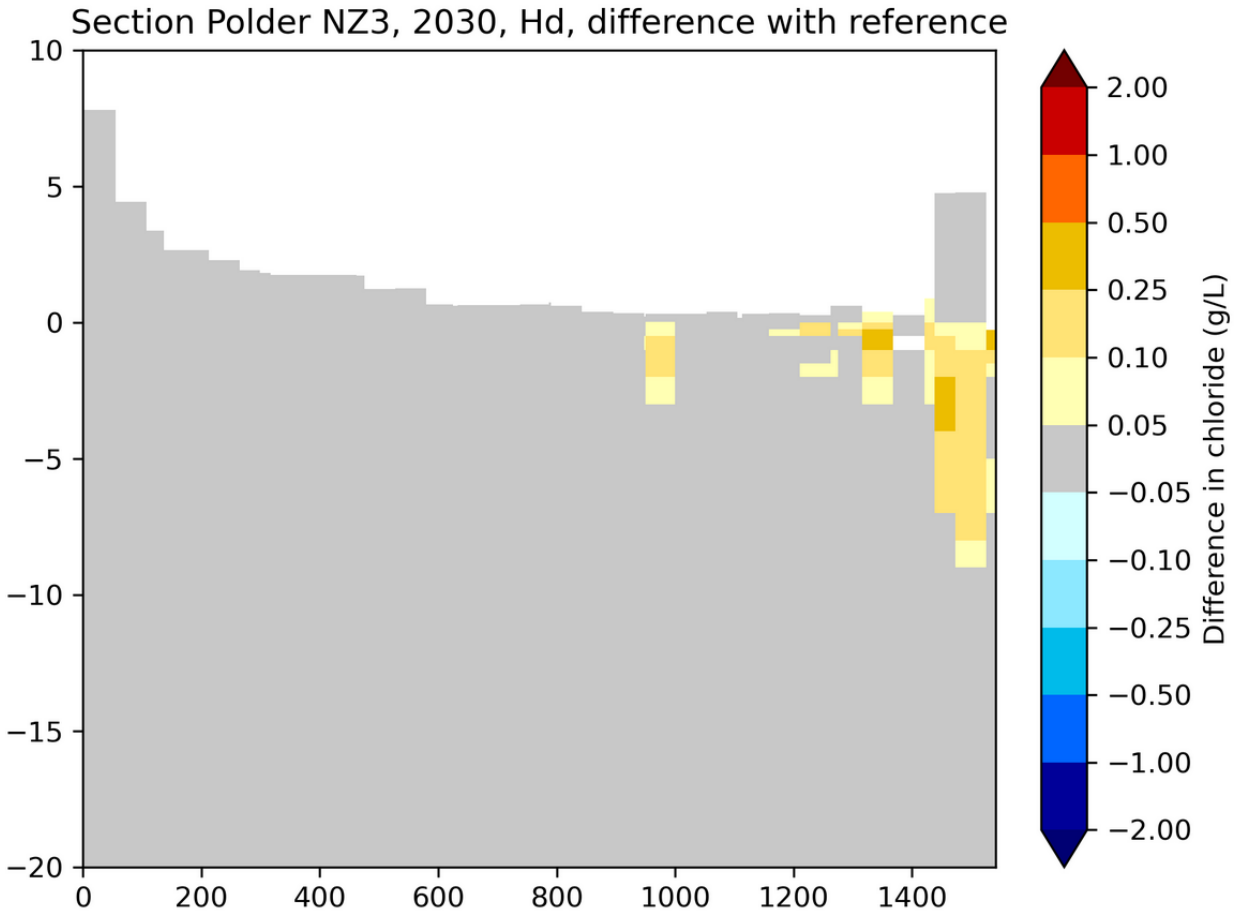

Figure C124: Location cross section Polder NZ3 2030 Hd difference with reference (Deltares, 2024-a)

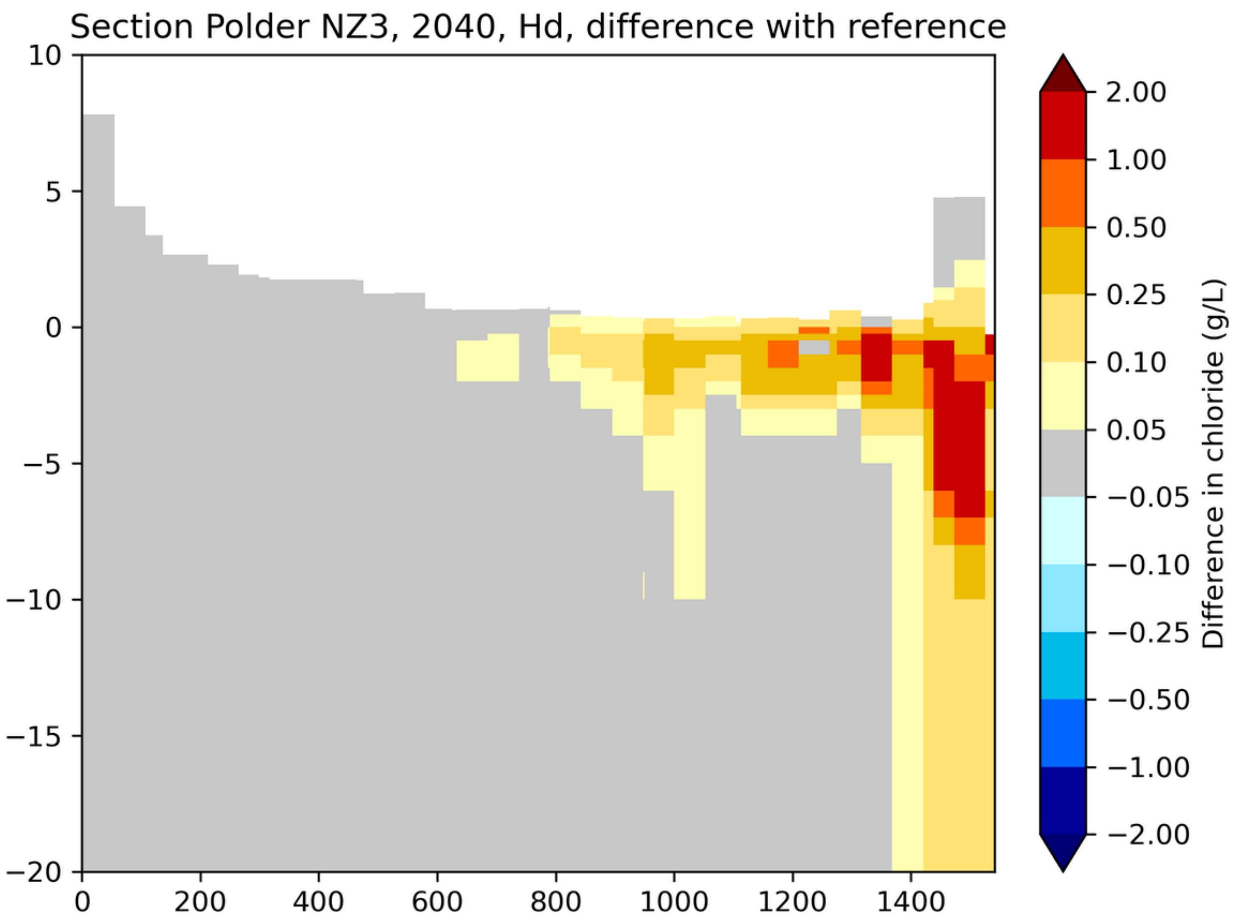

Figure C125: Location cross section Polder NZ3 2040 Hd difference with reference (Deltares, 2024-a)

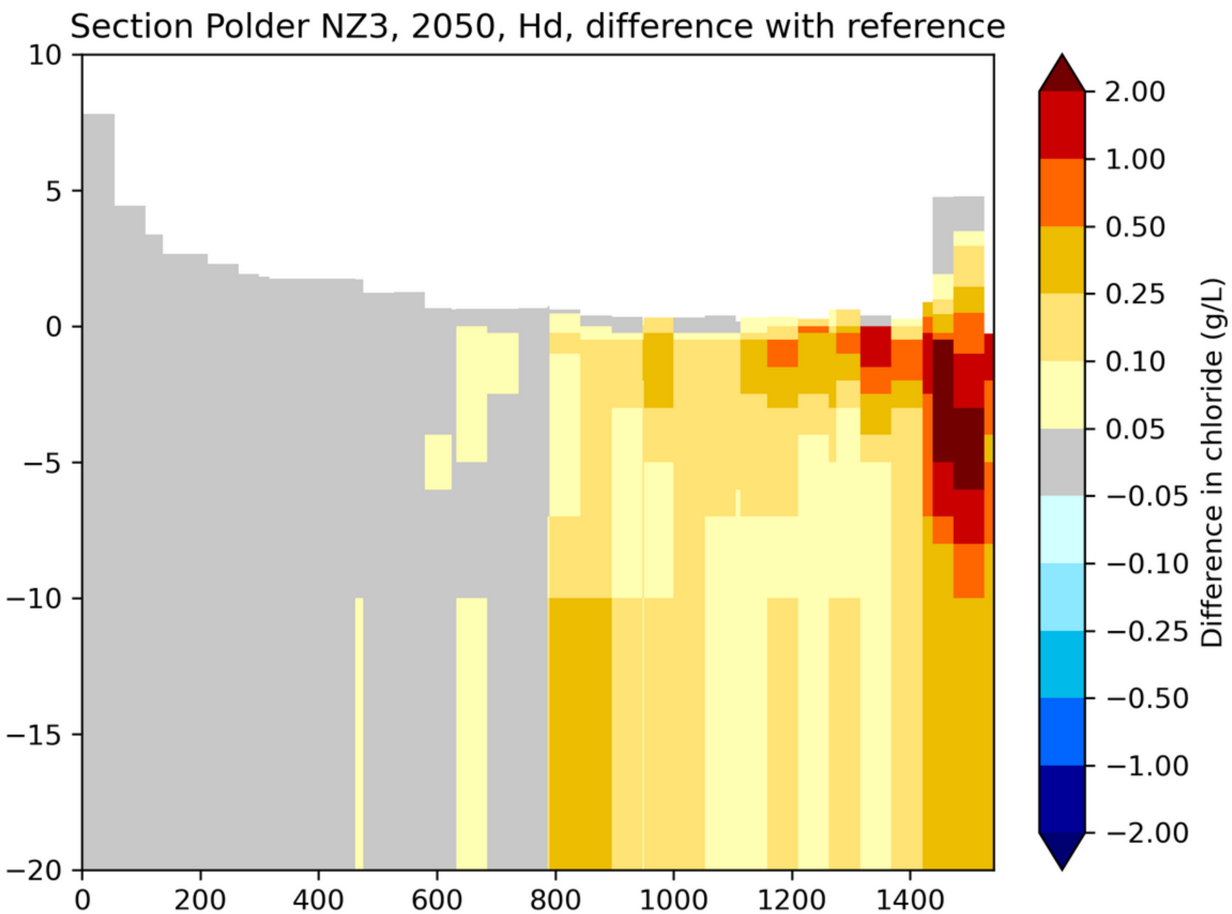

Figure C126: Location cross section Polder NZ3 2050 Hd difference with reference (Deltares, 2024-a)

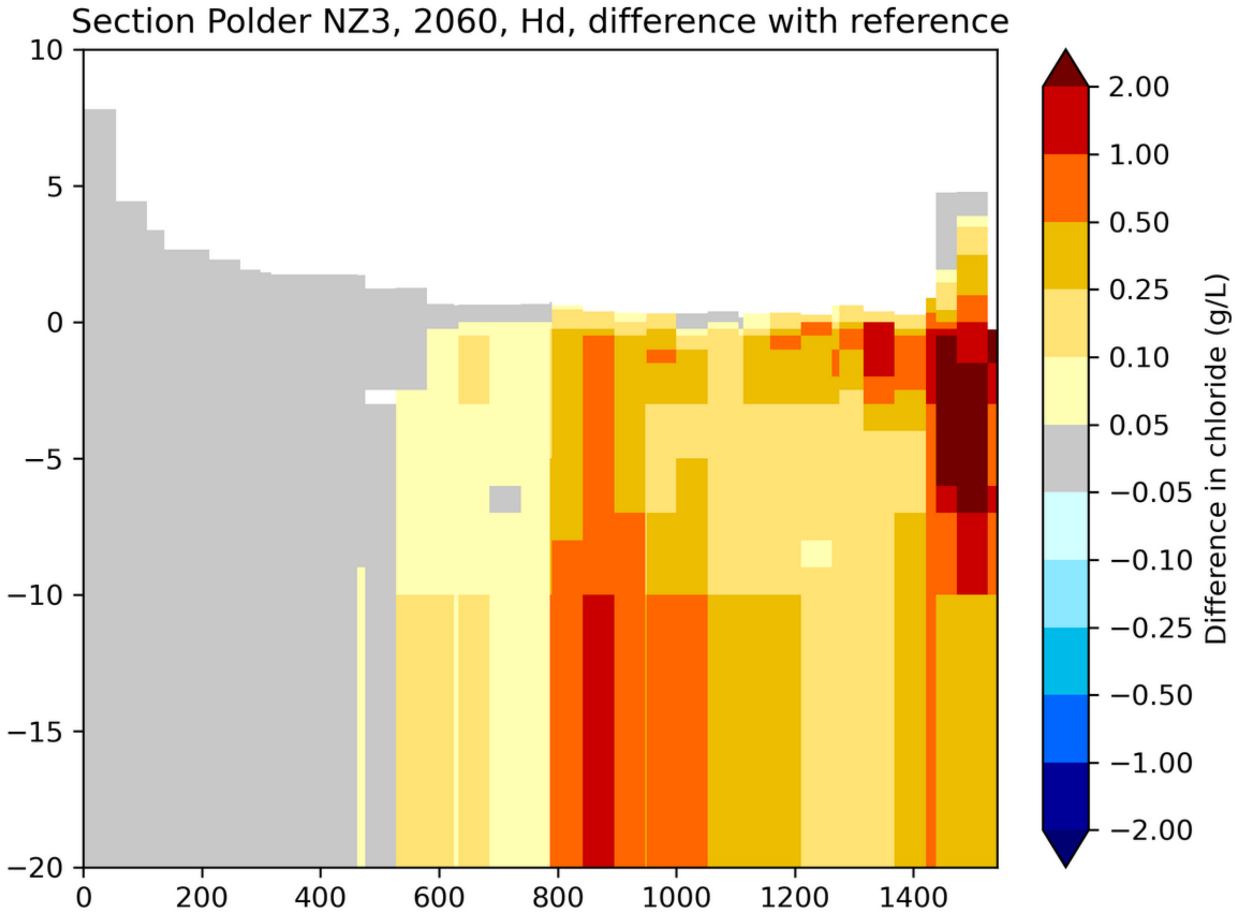

Figure C127: Location cross section Polder NZ3 2060 Hd difference with reference (Deltares, 2024-a)

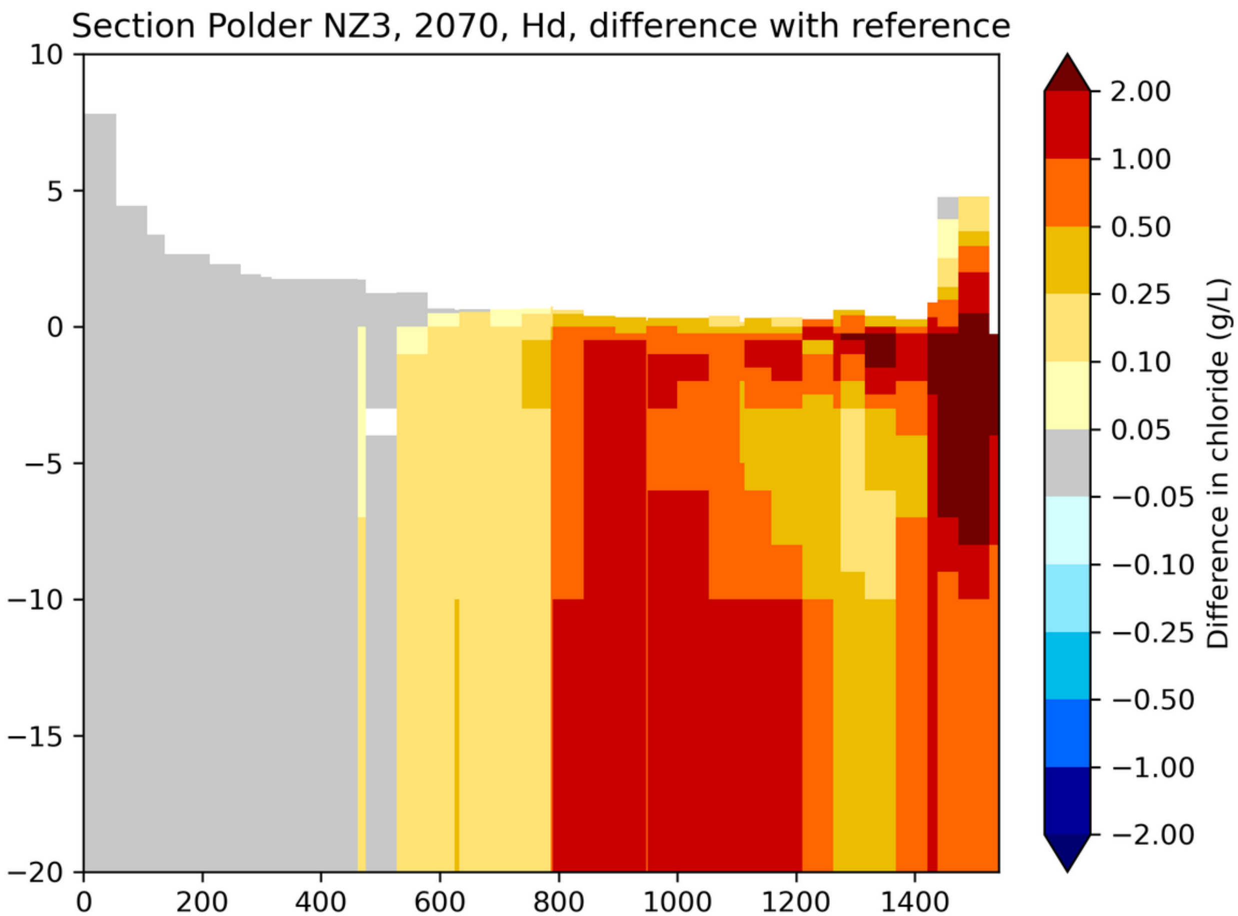

Figure C128: Location cross section Polder NZ3 2070 Hd difference with reference (Deltares, 2024-a)

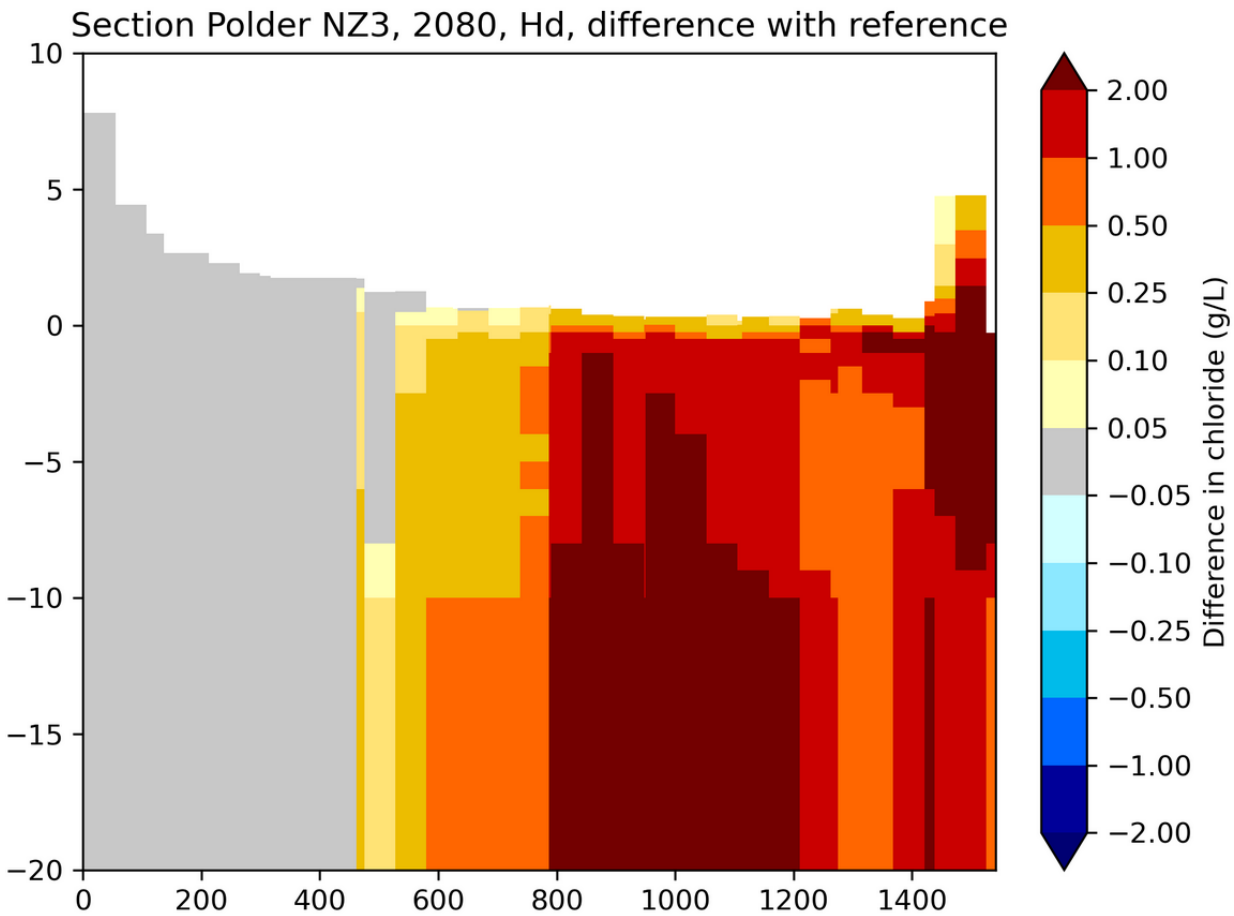

Figure C129: Location cross section Polder NZ3 2080 Hd difference with reference (Deltares, 2024-a)

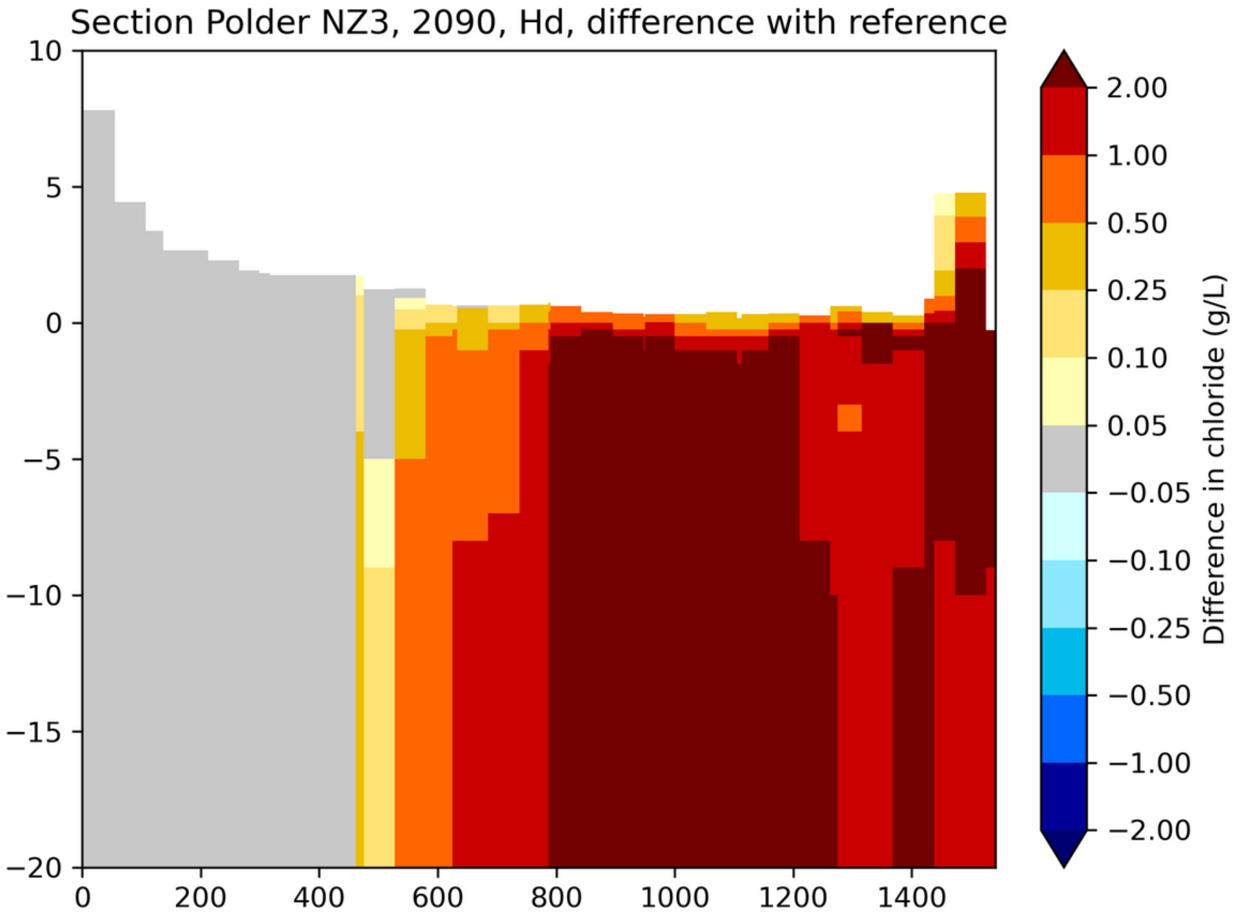

Figure C130: Location cross section Polder NZ3 2090 Hd difference with reference (Deltares, 2024-a)

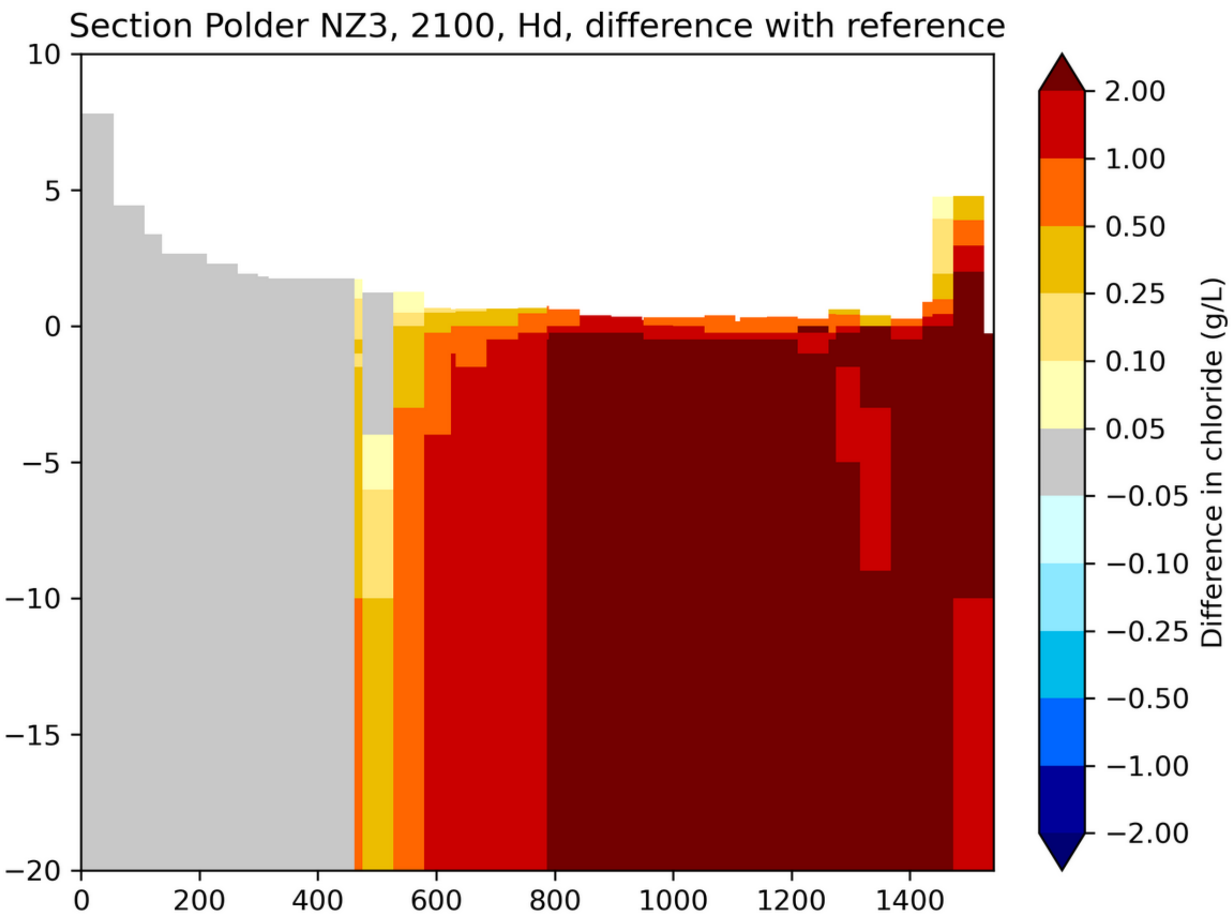

Figure C131: Location cross section Polder NZ3 2100 Hd difference with reference (Deltares, 2024-a)

Cross-sections Hn

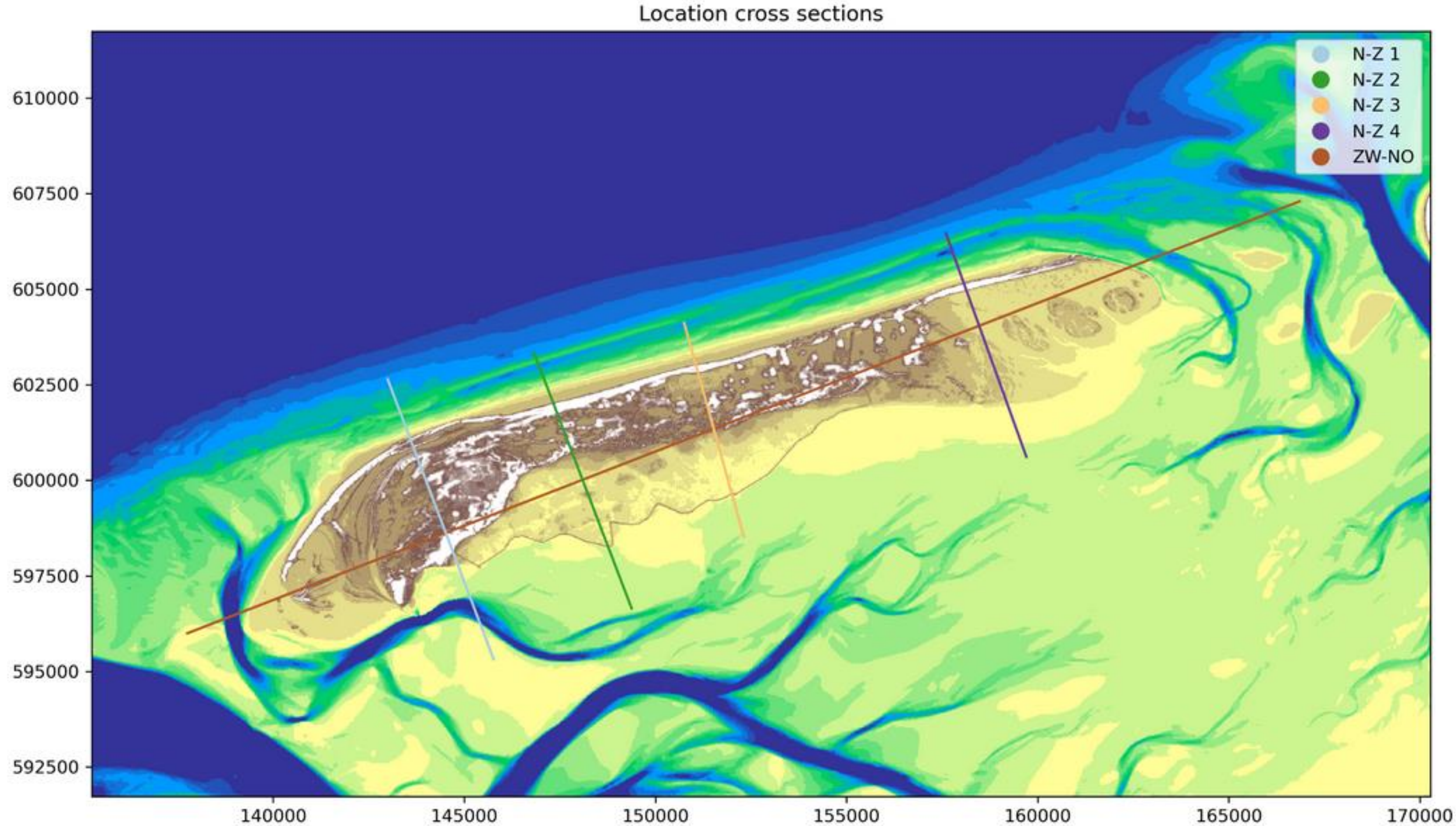

Figure C132: Location cross sections Hn difference with reference (Deltares, 2024-a)

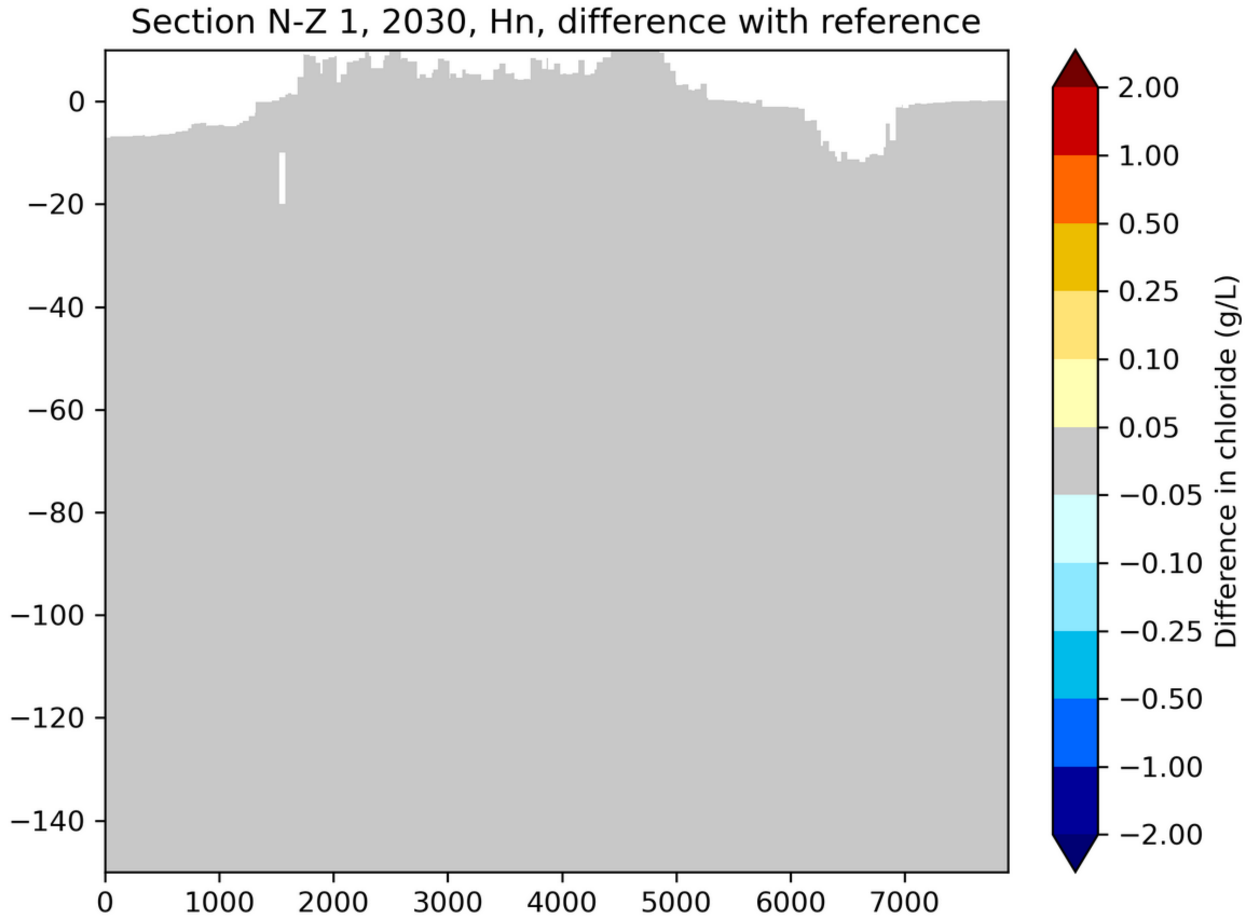

Figure C133: Location cross section N-Z 1 2030 Hn difference with reference (Deltares, 2024-a)

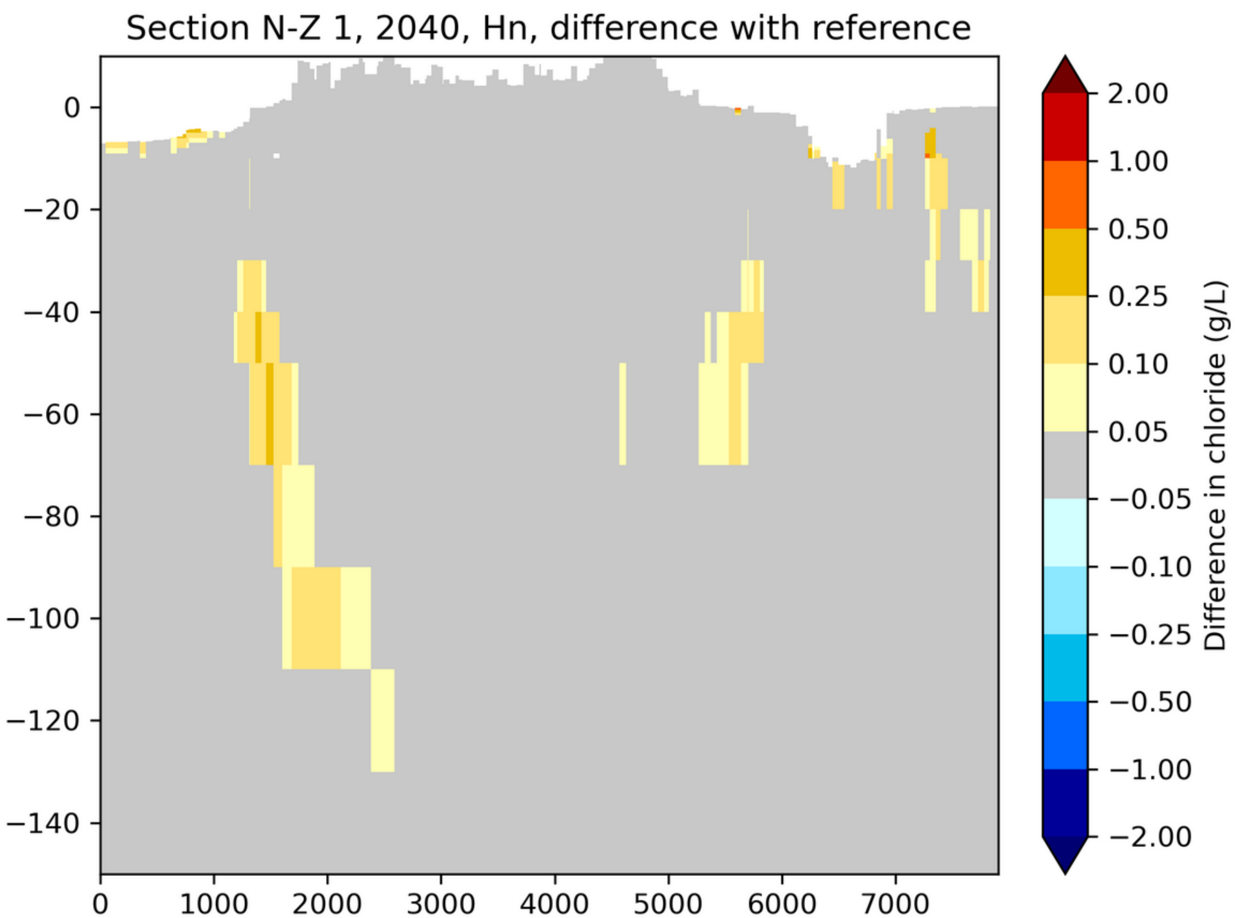

Figure C134: Location cross section N-Z 1 2040 Hn difference with reference (Deltares, 2024-a)

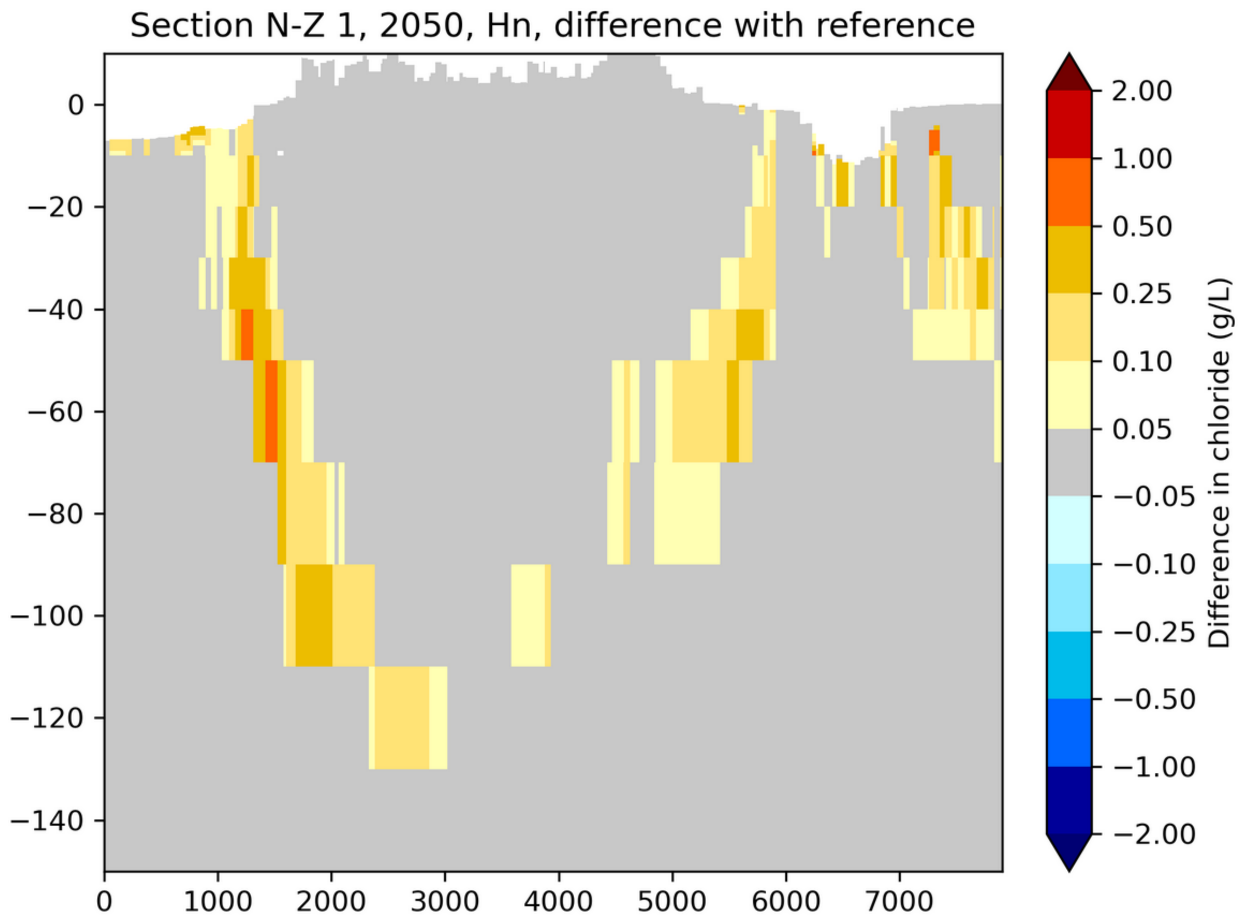

Figure C135: Location cross section N-Z 1 2050 Hn difference with reference (Deltares, 2024-a)

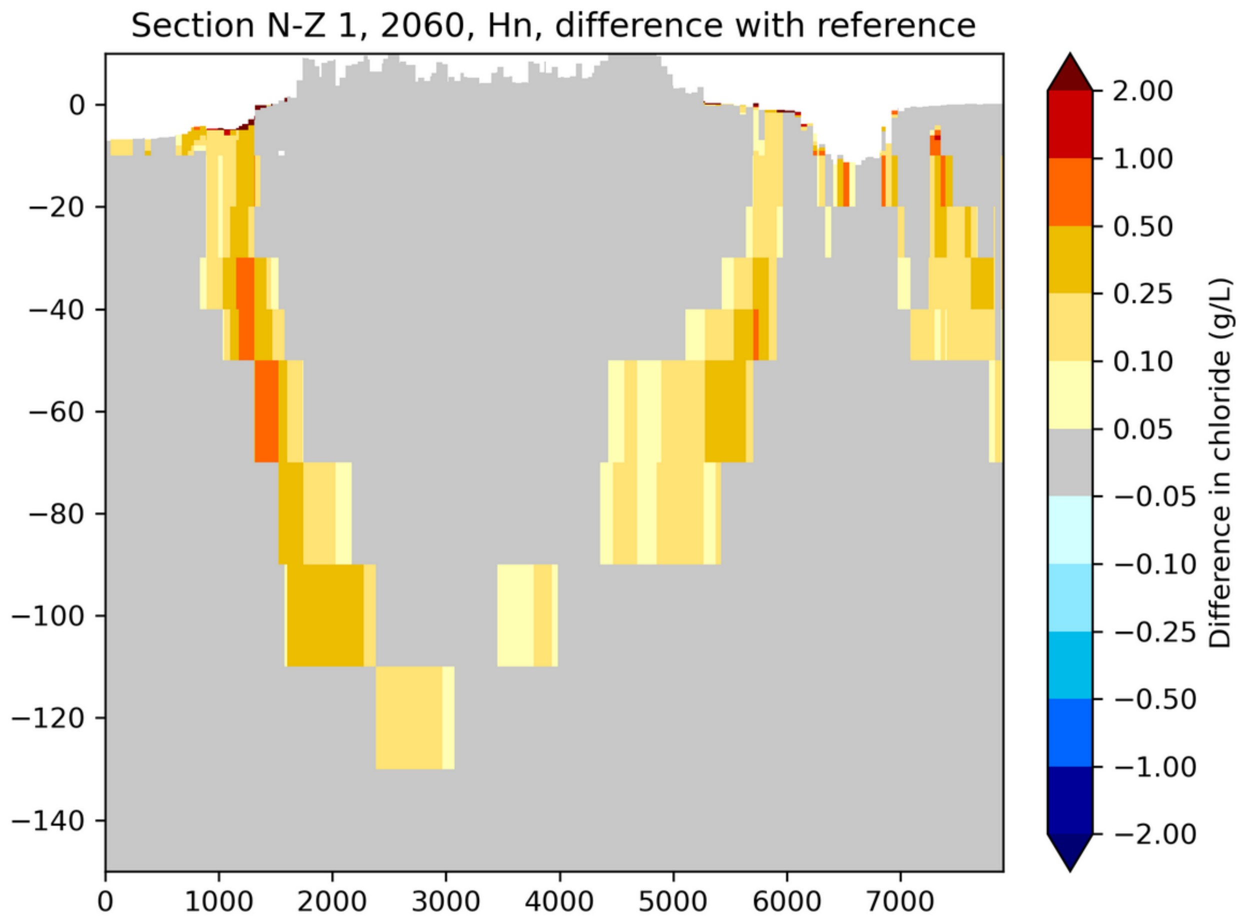

Figure C136: Location cross section N-Z 1 2060 Hn difference with reference (Deltares, 2024-a)

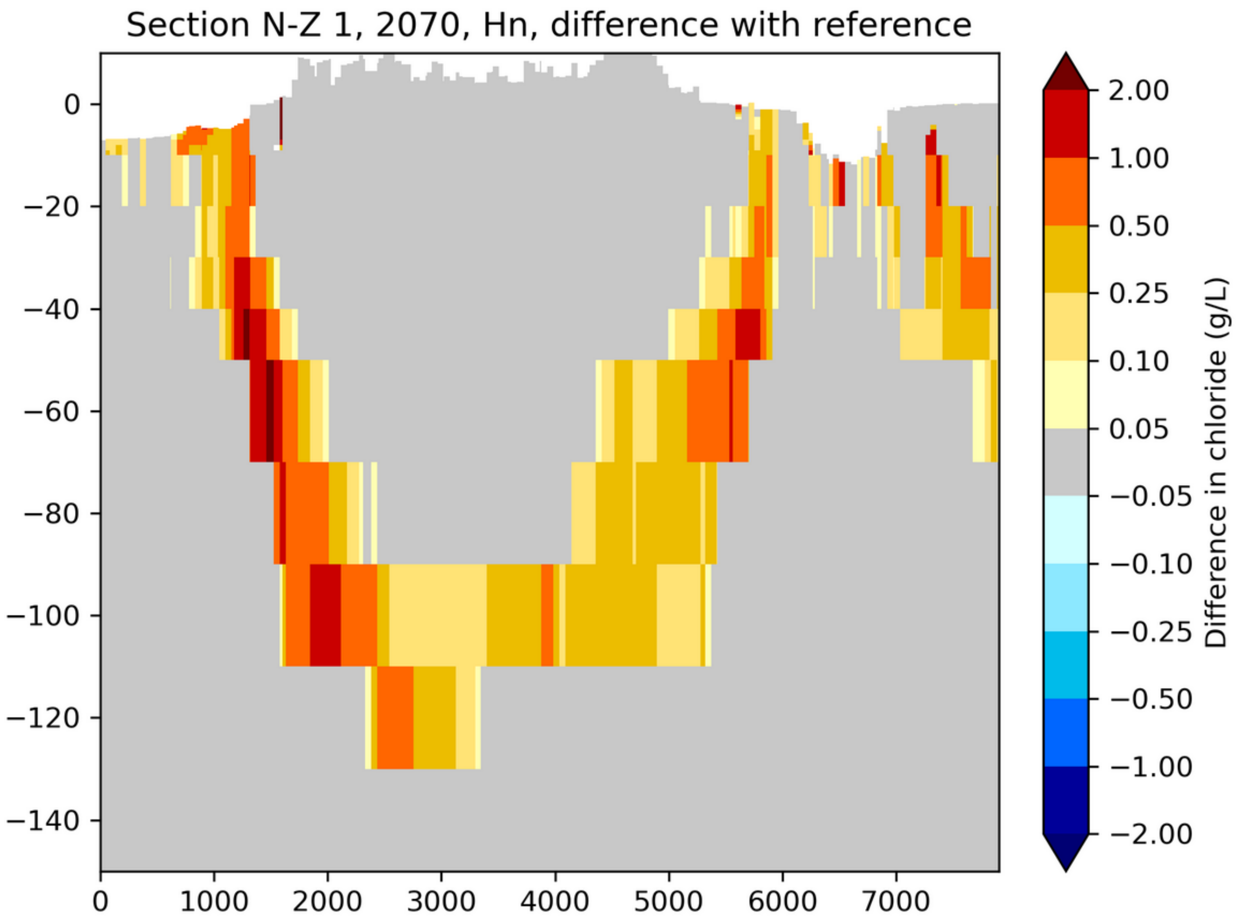

Figure C137: Location cross section N-Z 1 2070 Hn difference with reference (Deltares, 2024-a)

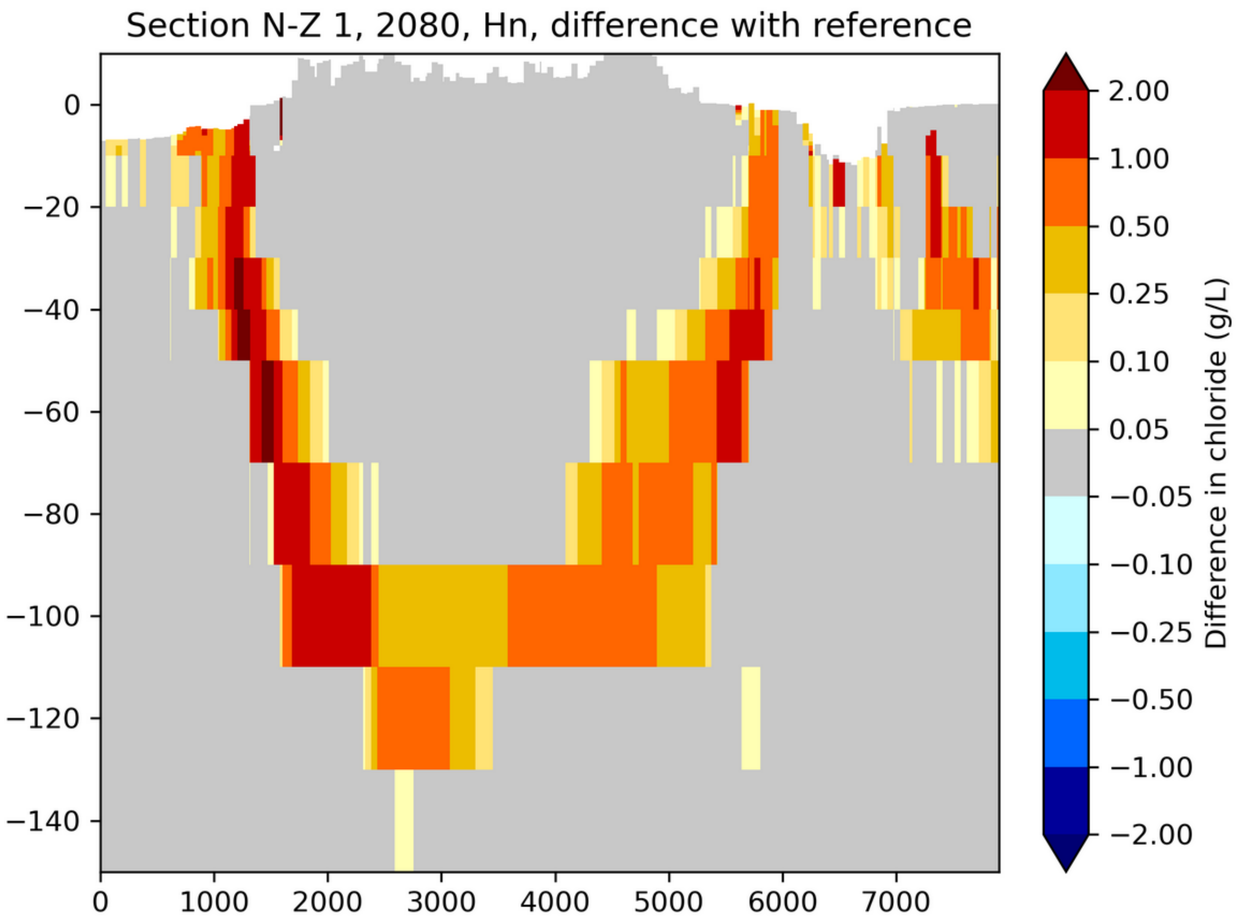

Figure C138: Location cross section N-Z 1 2080 Hn difference with reference (Deltares, 2024-a)

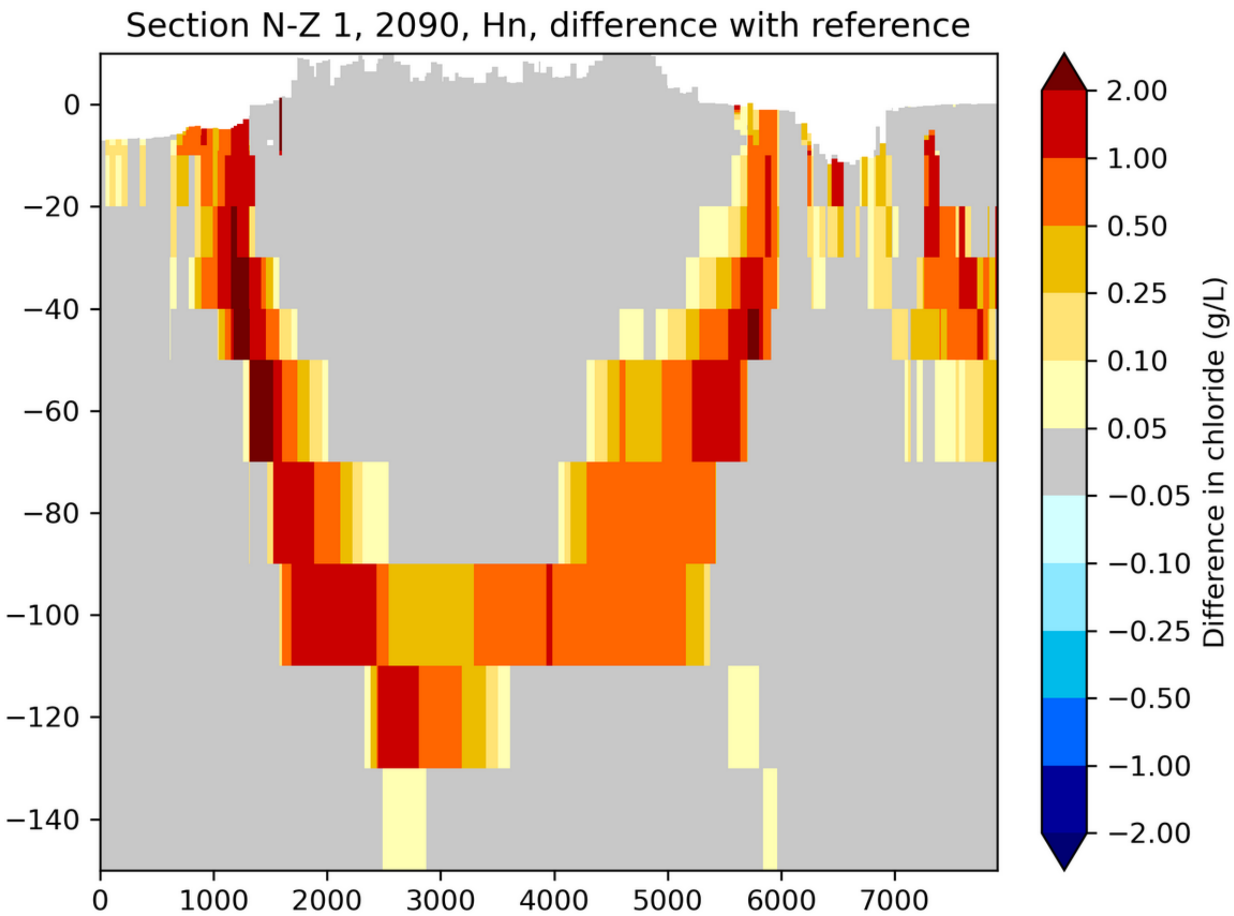

Figure C139: Location cross section N-Z 1 2090 Hn difference with reference (Deltares, 2024-a)

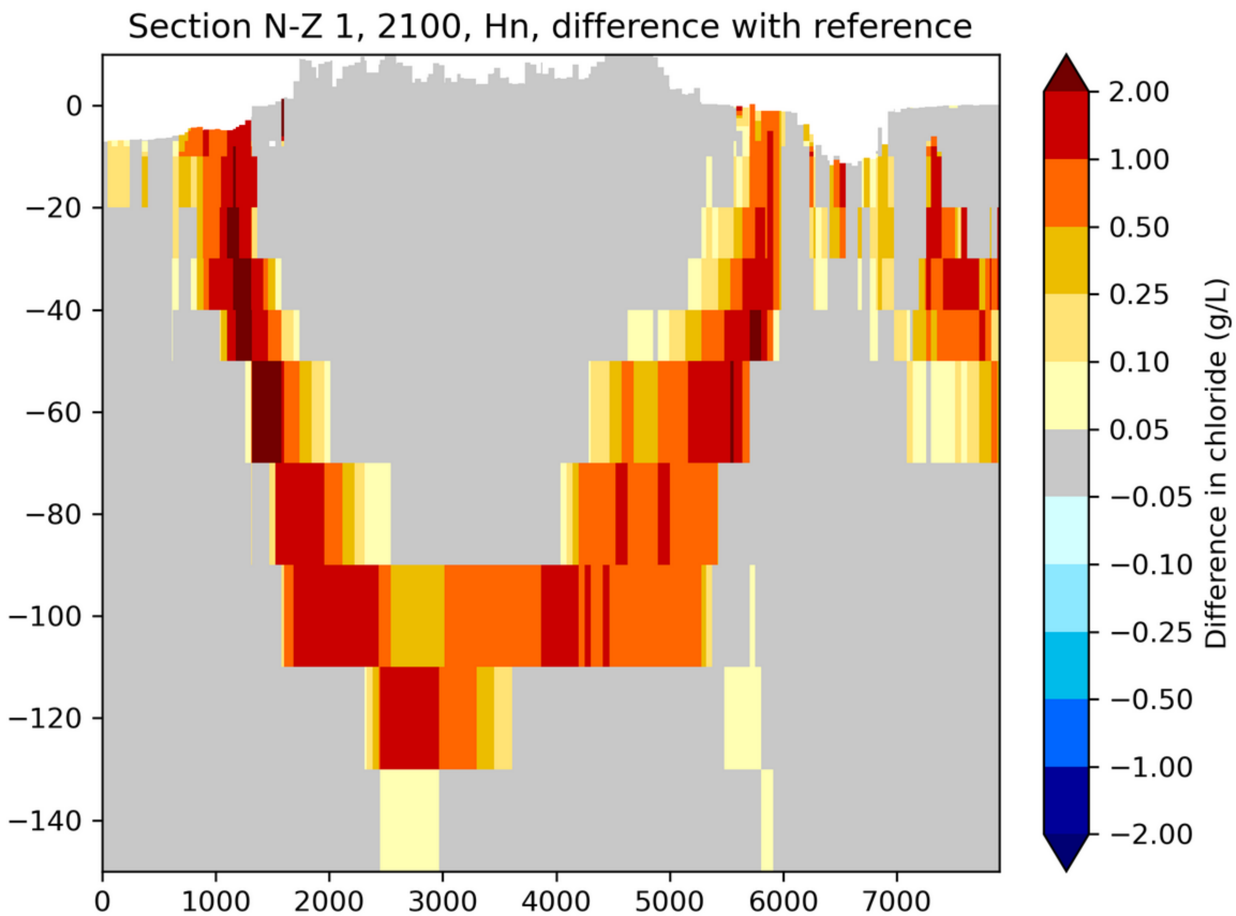

Figure C140: Location cross section N-Z 1 2100 Hn difference with reference (Deltares, 2024-a)

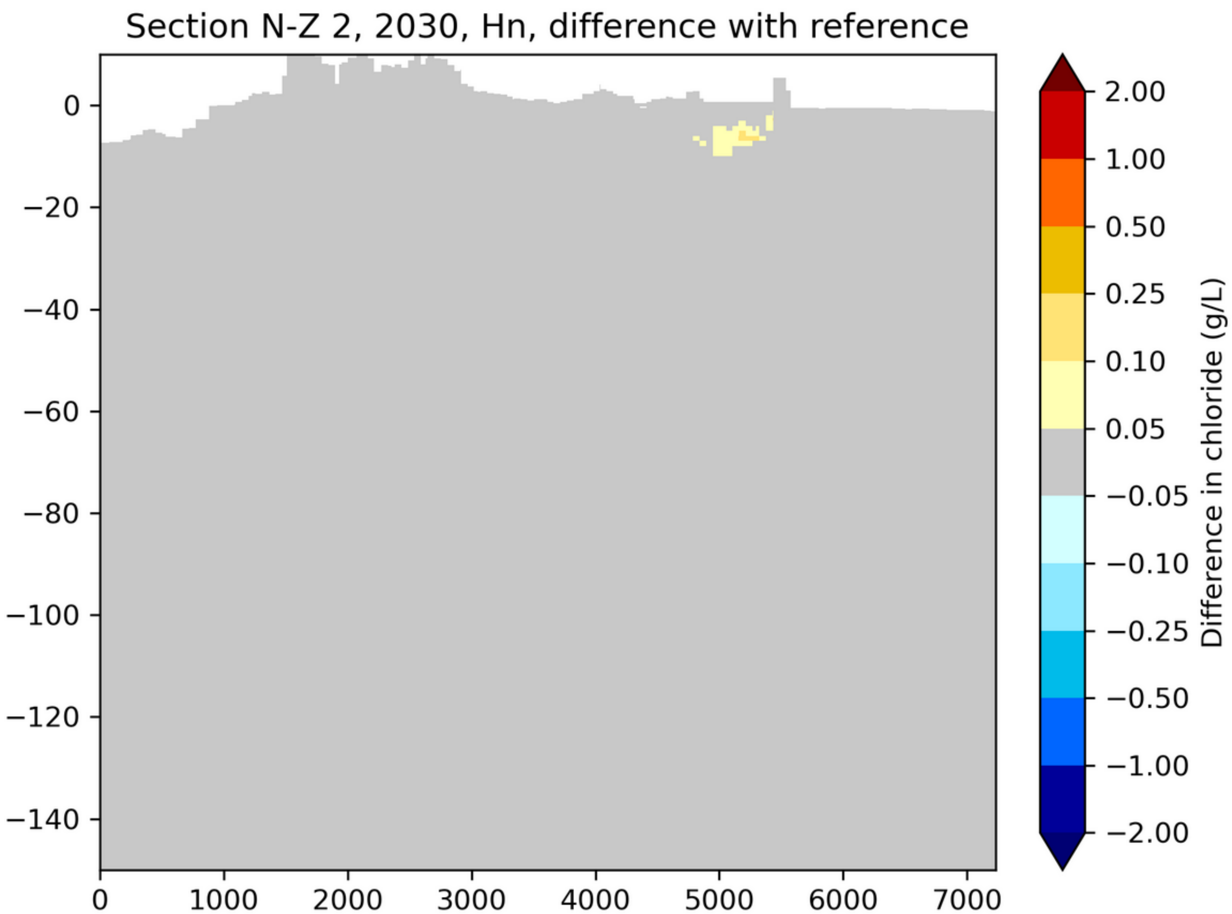

Figure C141: Location cross section N-Z 2 2030 Hn difference with reference (Deltares, 2024-a)

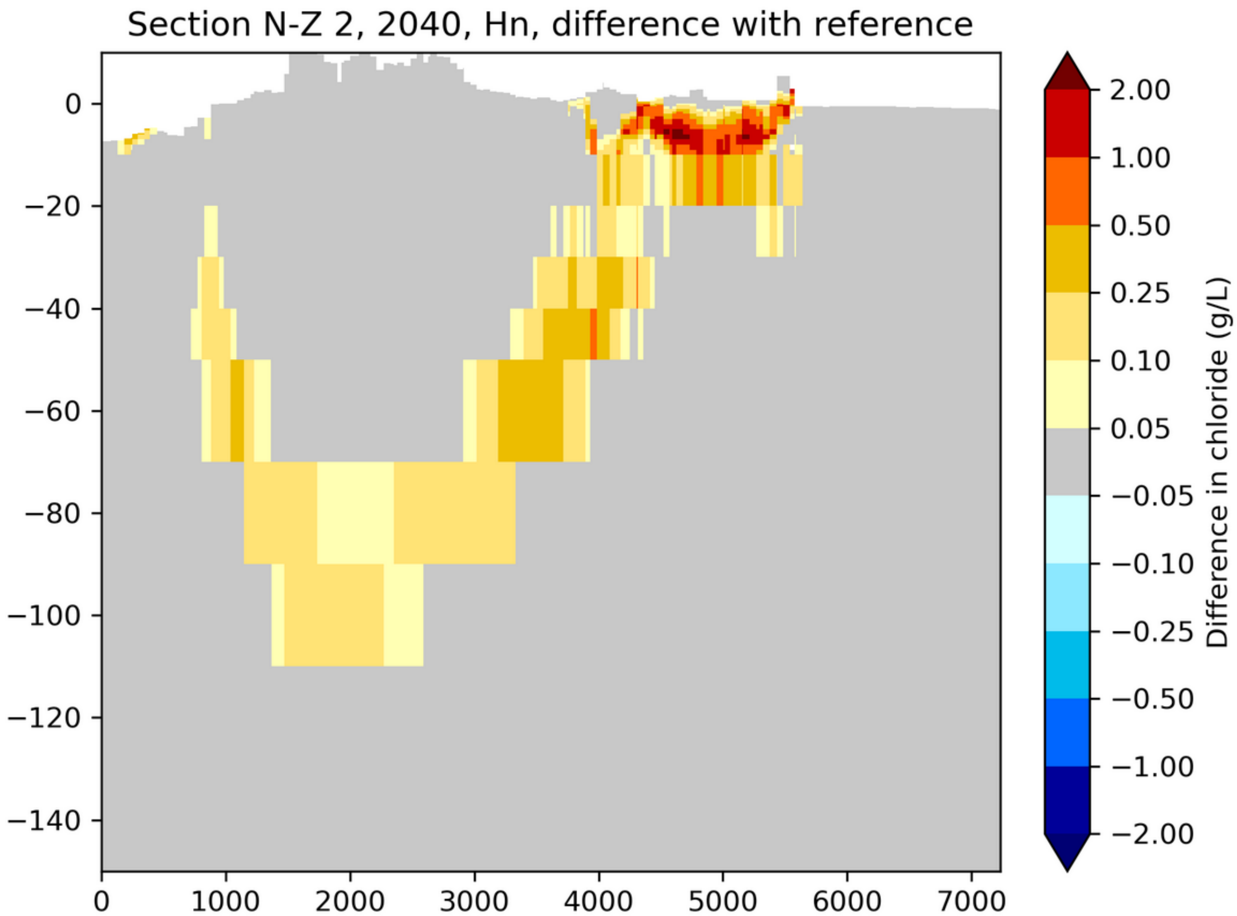

Figure C142: Location cross section N-Z 2 2040 Hn difference with reference (Deltares, 2024-a)

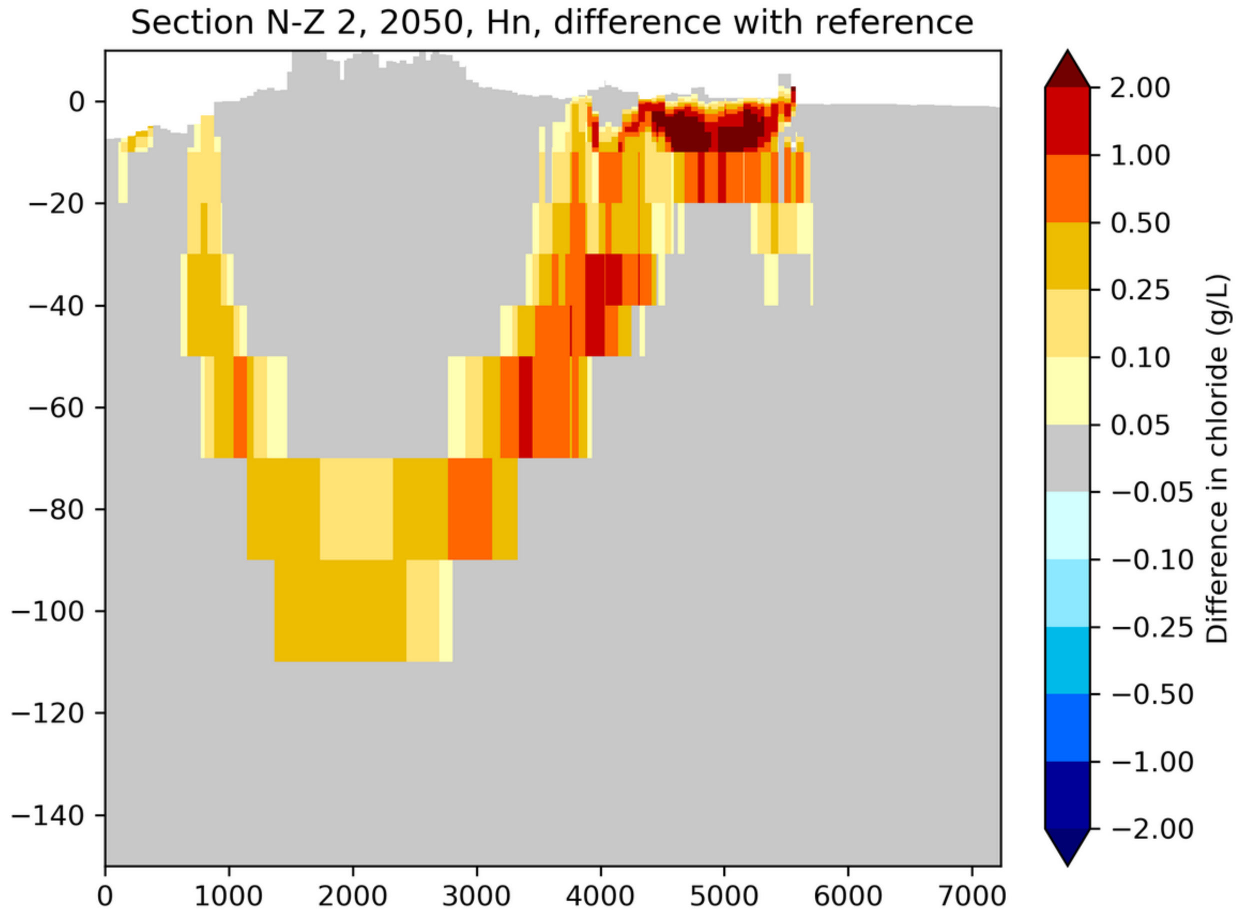

Figure C143: Location cross section N-Z 2 2050 Hn difference with reference (Deltares, 2024-a)

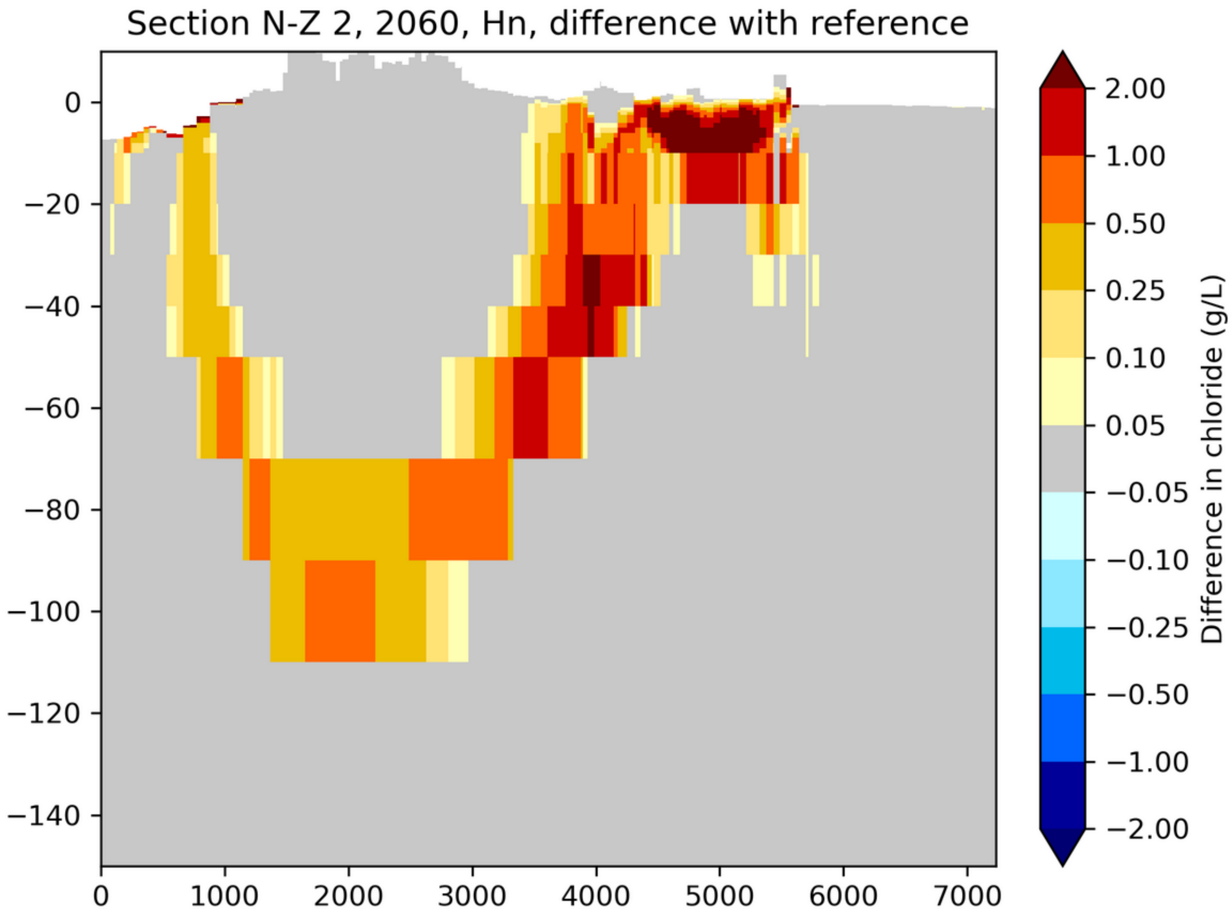

Figure C144: Location cross section N-Z 2 2060 Hn difference with reference (Deltares, 2024-a)

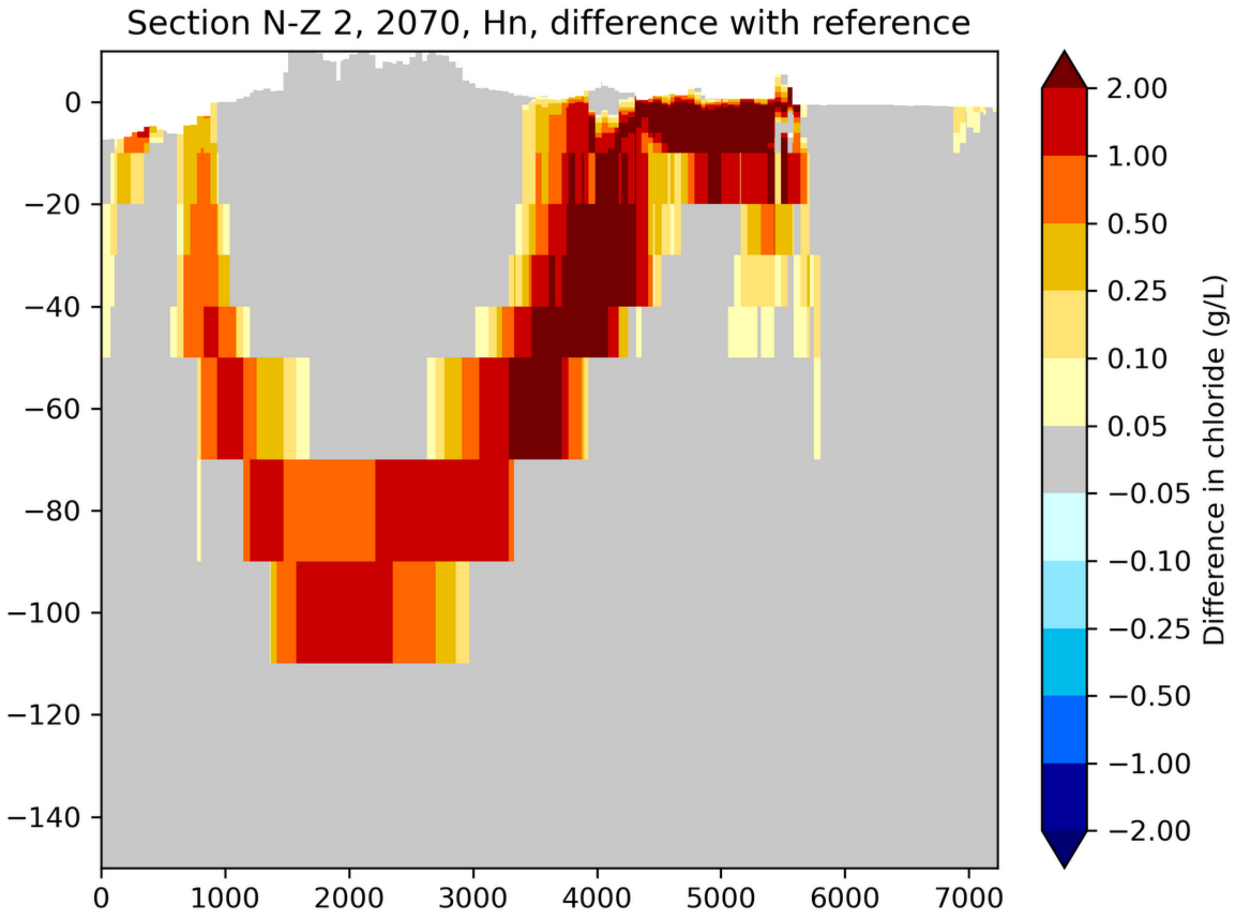

Figure C145: Location cross section N-Z 2 2070 Hn difference with reference (Deltares, 2024-a)

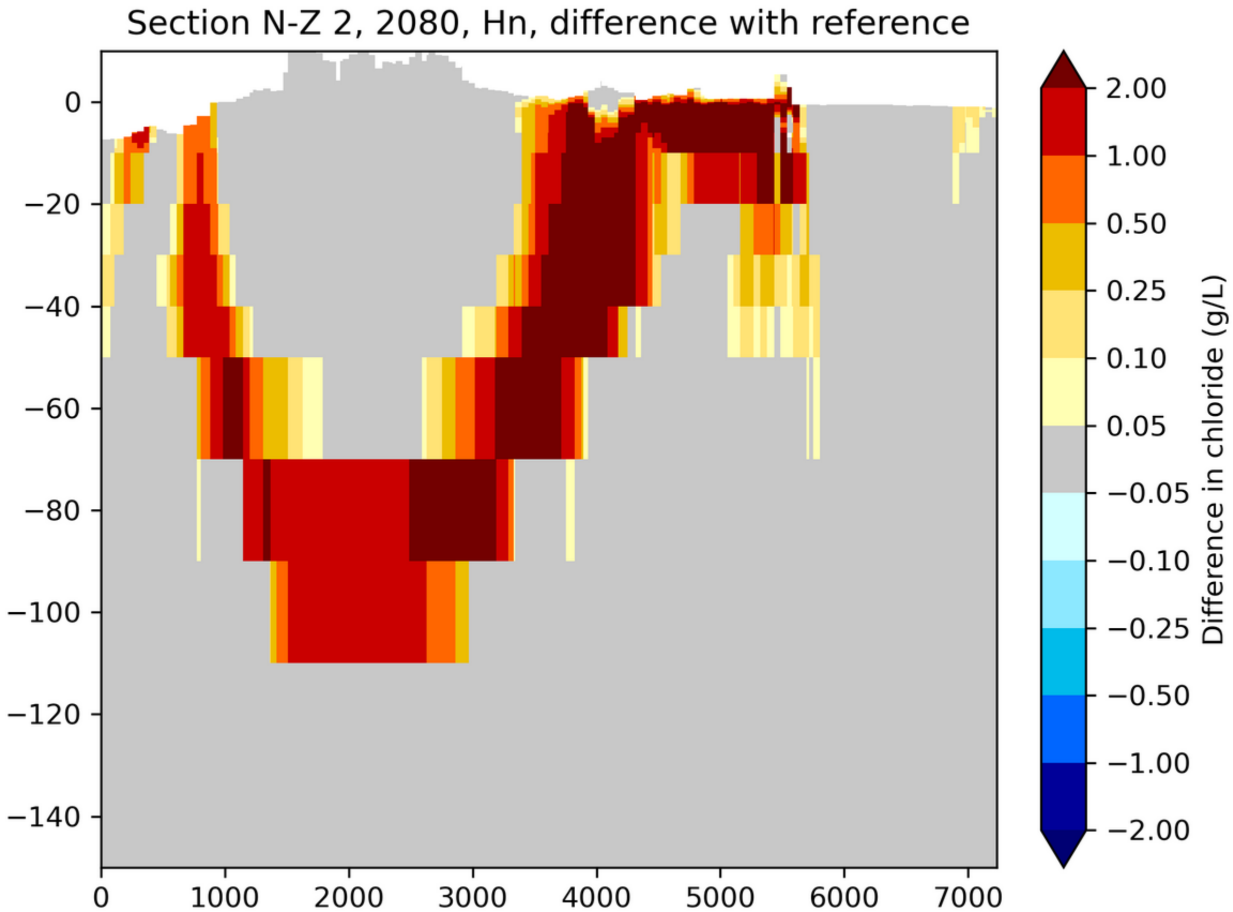

Figure C146: Location cross section N-Z 2 2080 Hn difference with reference (Deltares, 2024-a)

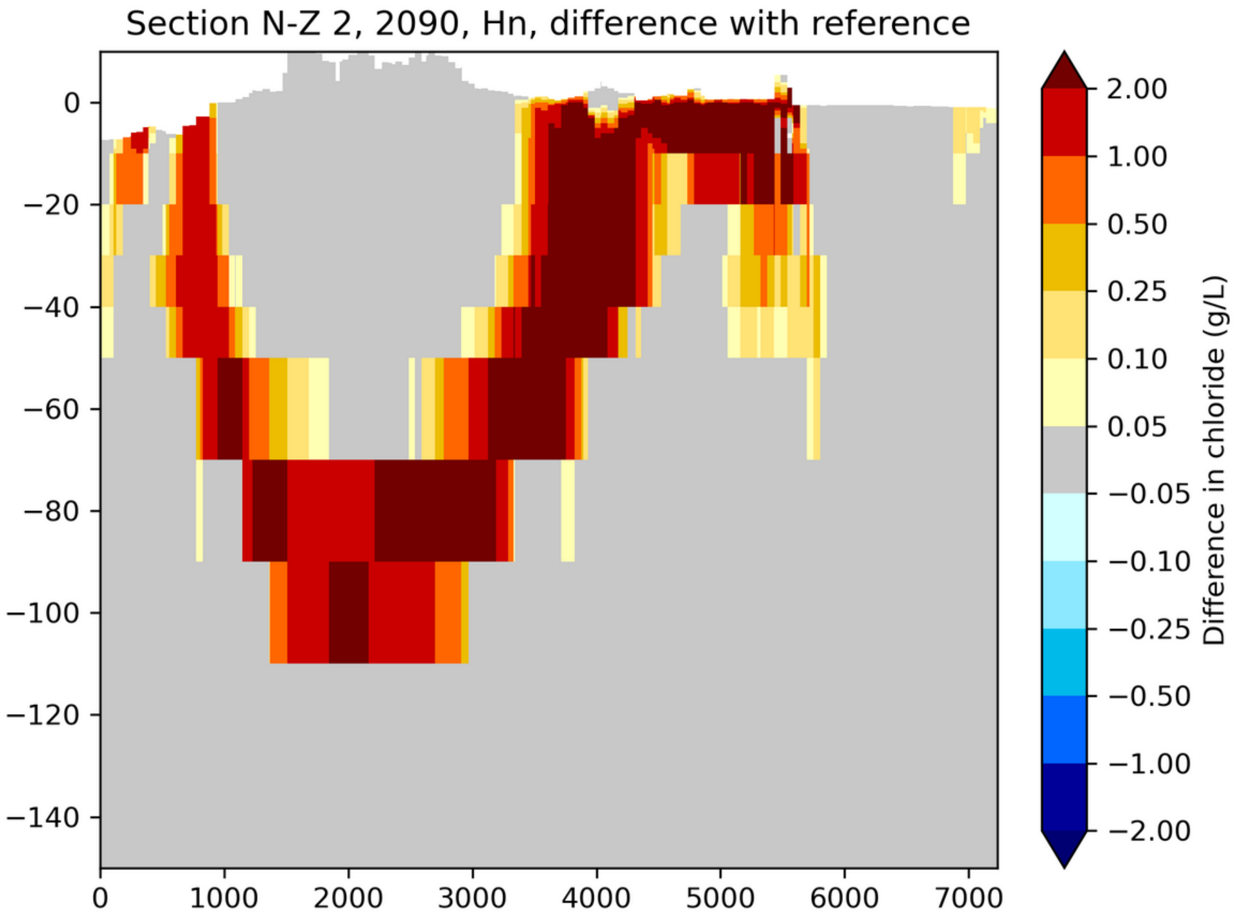

Figure C147: Location cross section N-Z 2 2090 Hn difference with reference (Deltares, 2024-a)

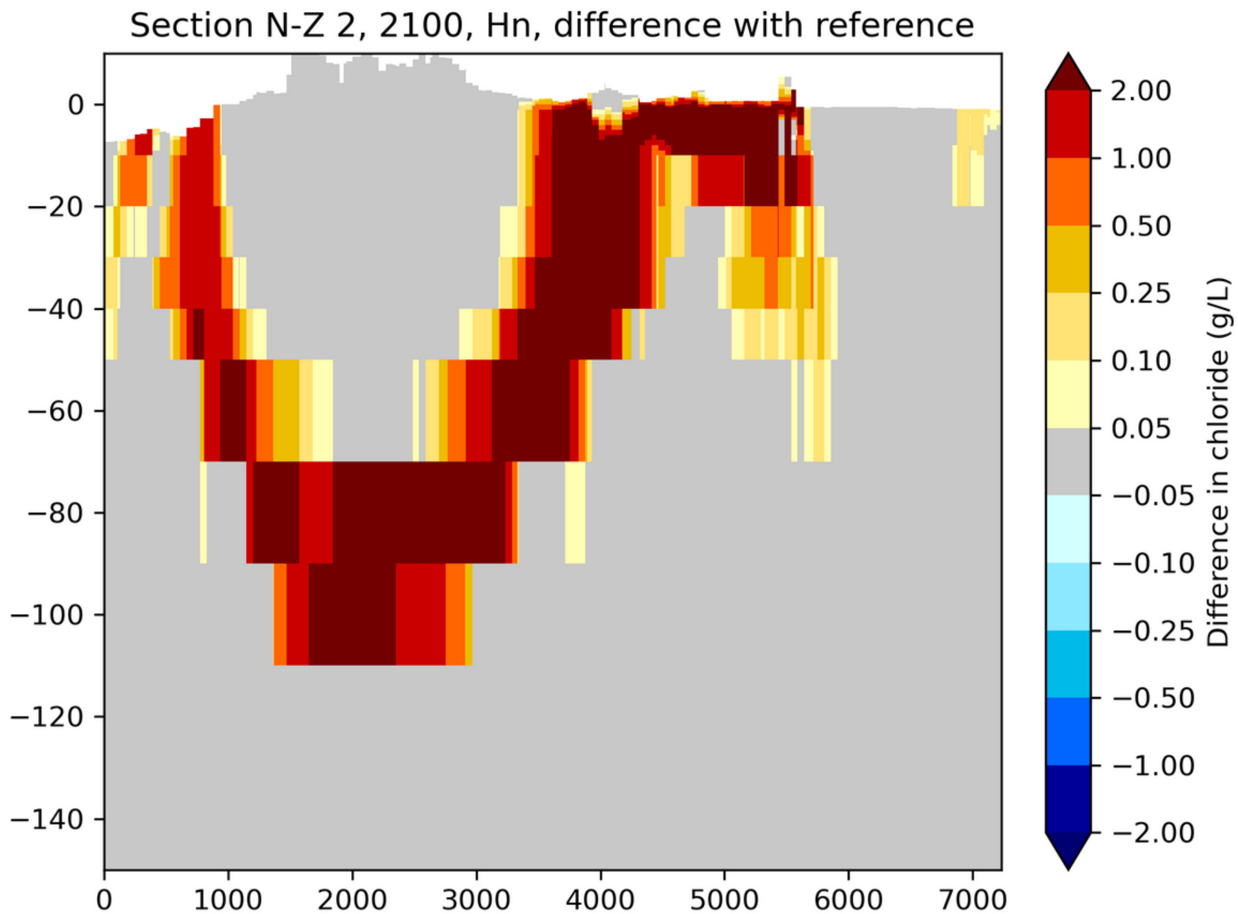

Figure C148: Location cross section N-Z 2 2100 Hn difference with reference (Deltares, 2024-a)

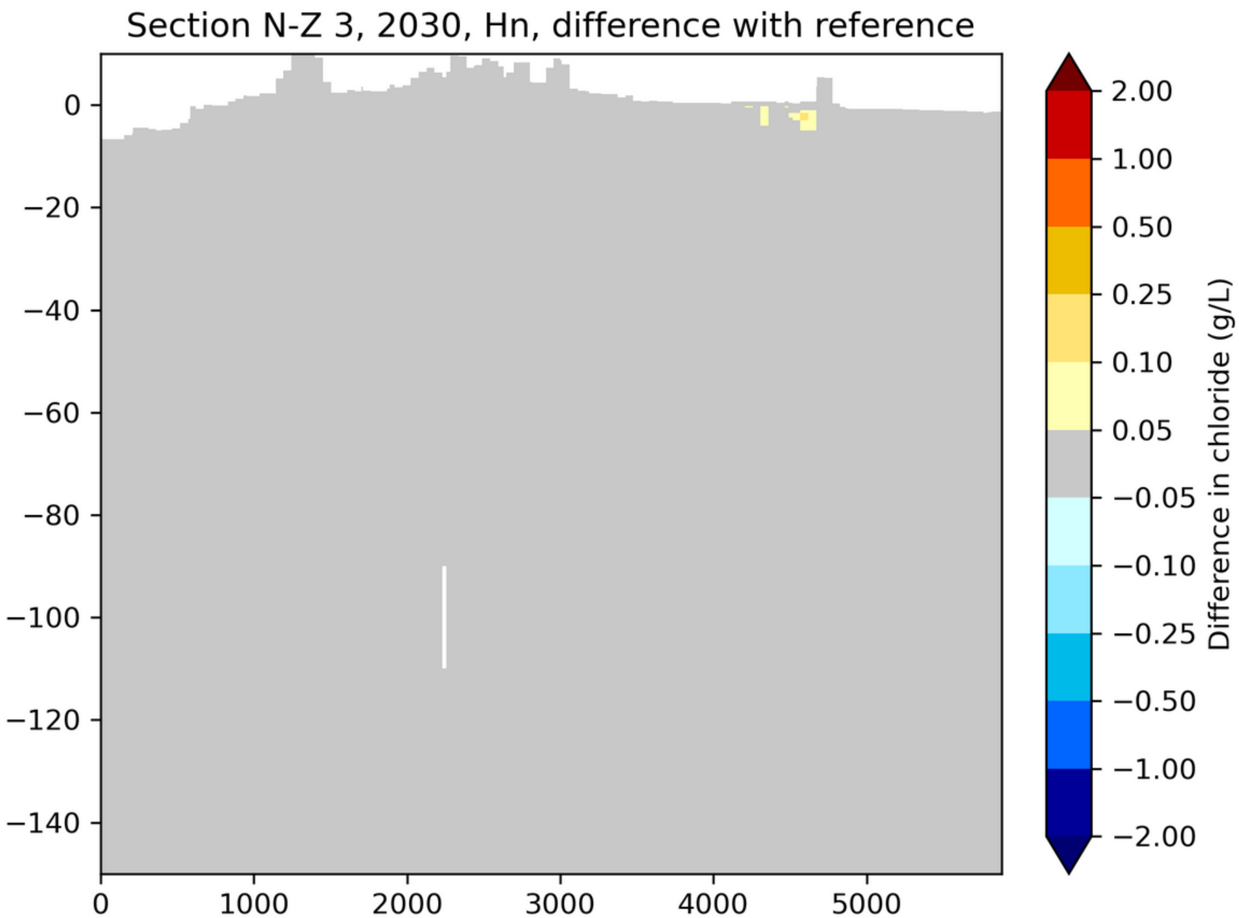

Figure C149: Location cross section N-Z 3 2030 Hn difference with reference (Deltares, 2024-a)

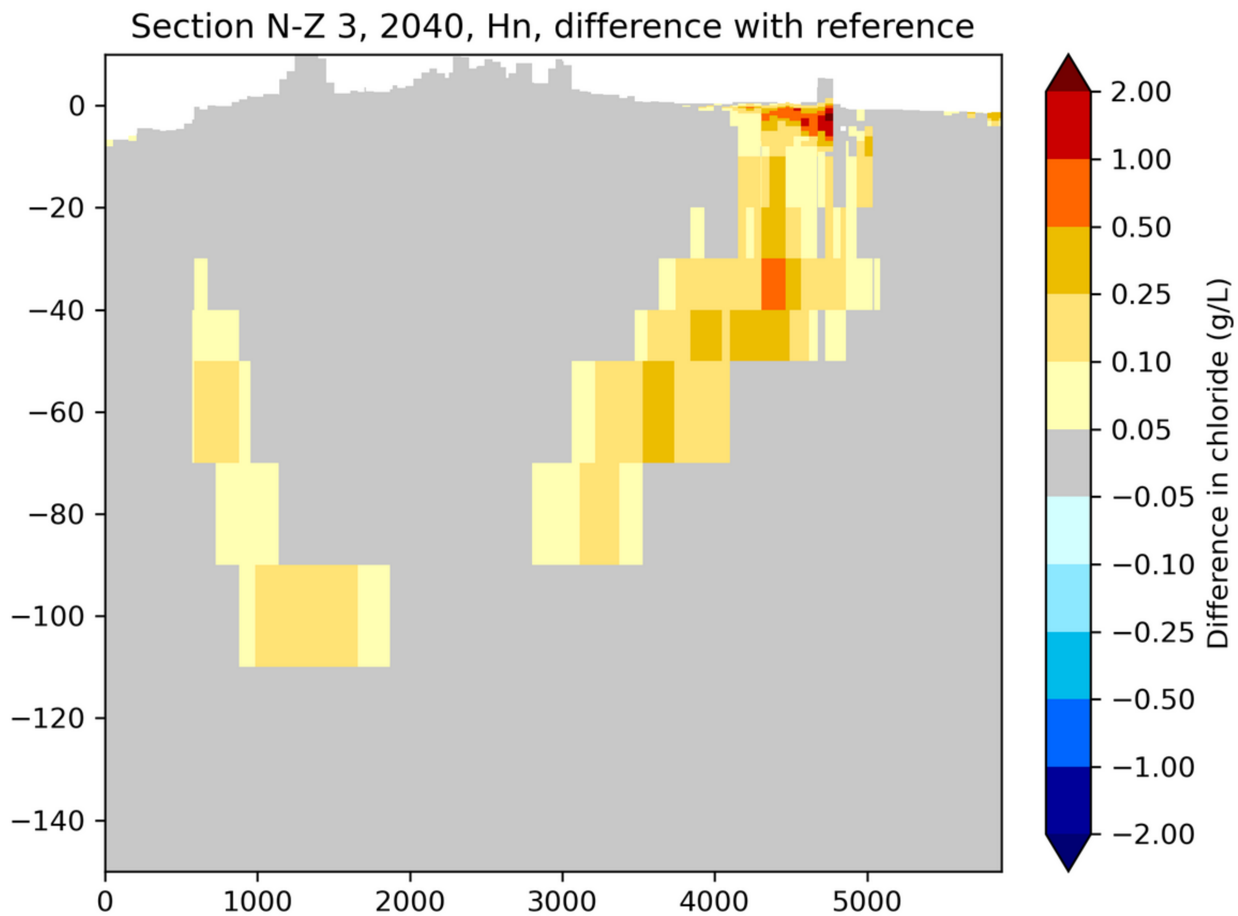

Figure C150: Location cross section N-Z 3 2040 Hn difference with reference (Deltares, 2024-a)

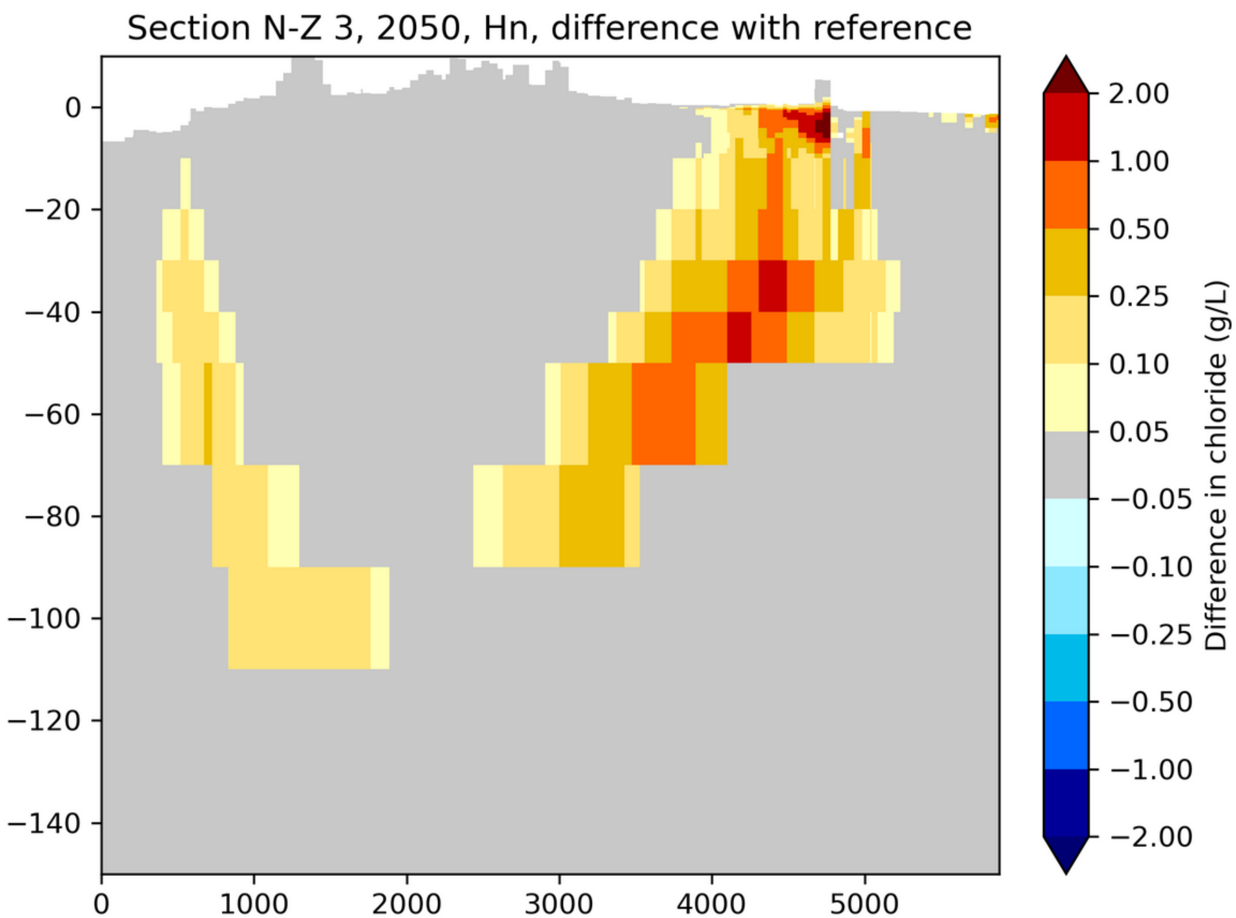

Figure C151: Location cross section N-Z 3 2050 Hn difference with reference (Deltares, 2024-a)

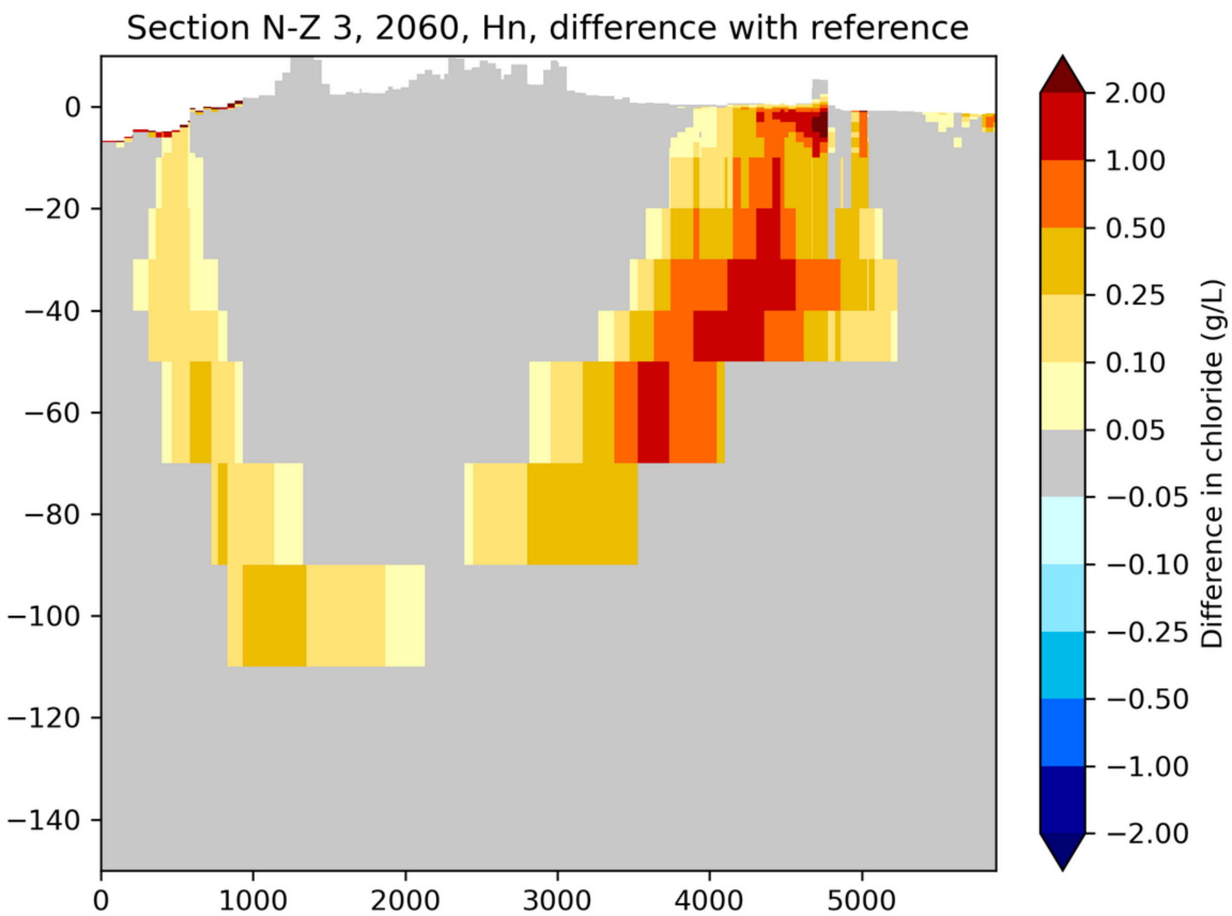

Figure C152: Location cross section N-Z 3 2060 Hn difference with reference (Deltares, 2024-a)

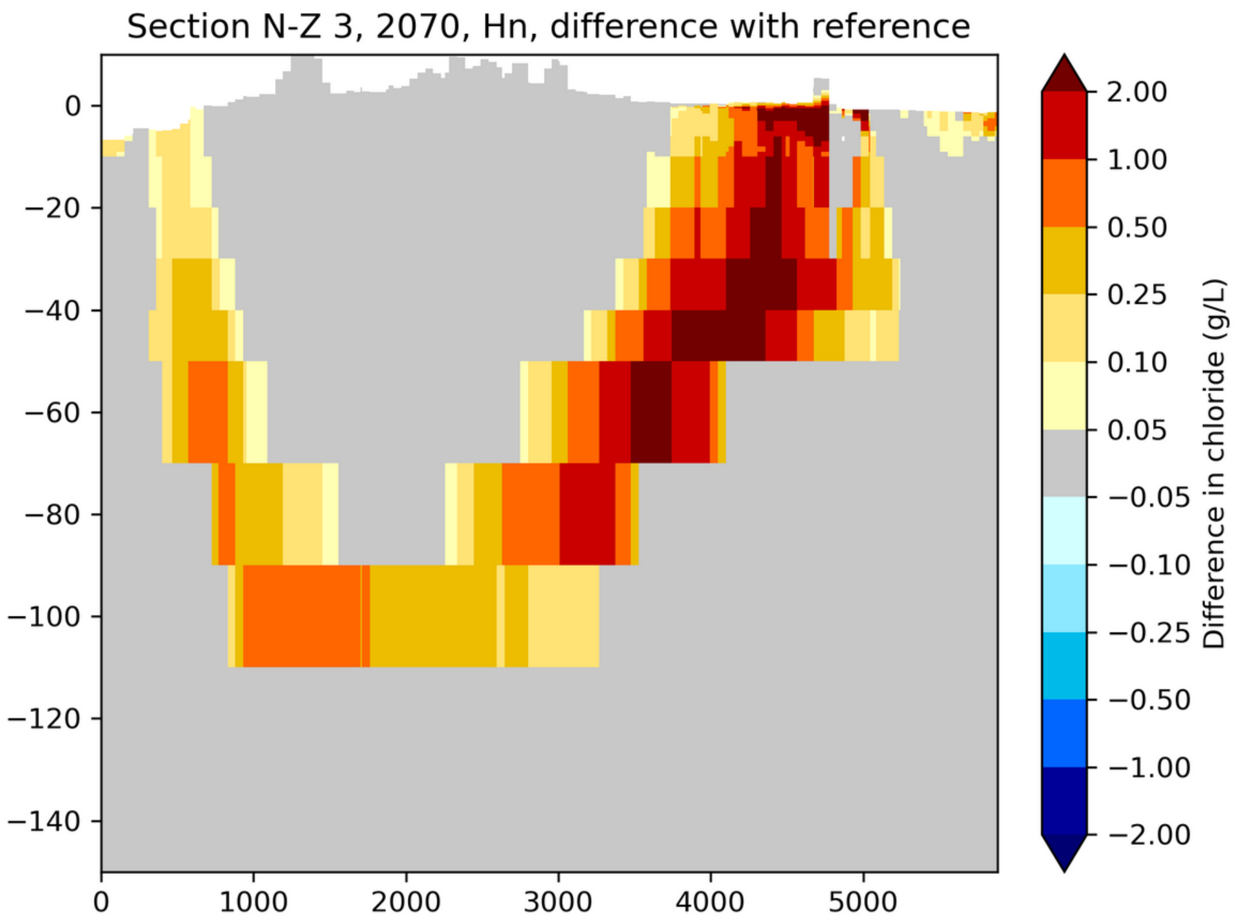

Figure C153: Location cross section N-Z 3 2070 Hn difference with reference (Deltares, 2024-a)

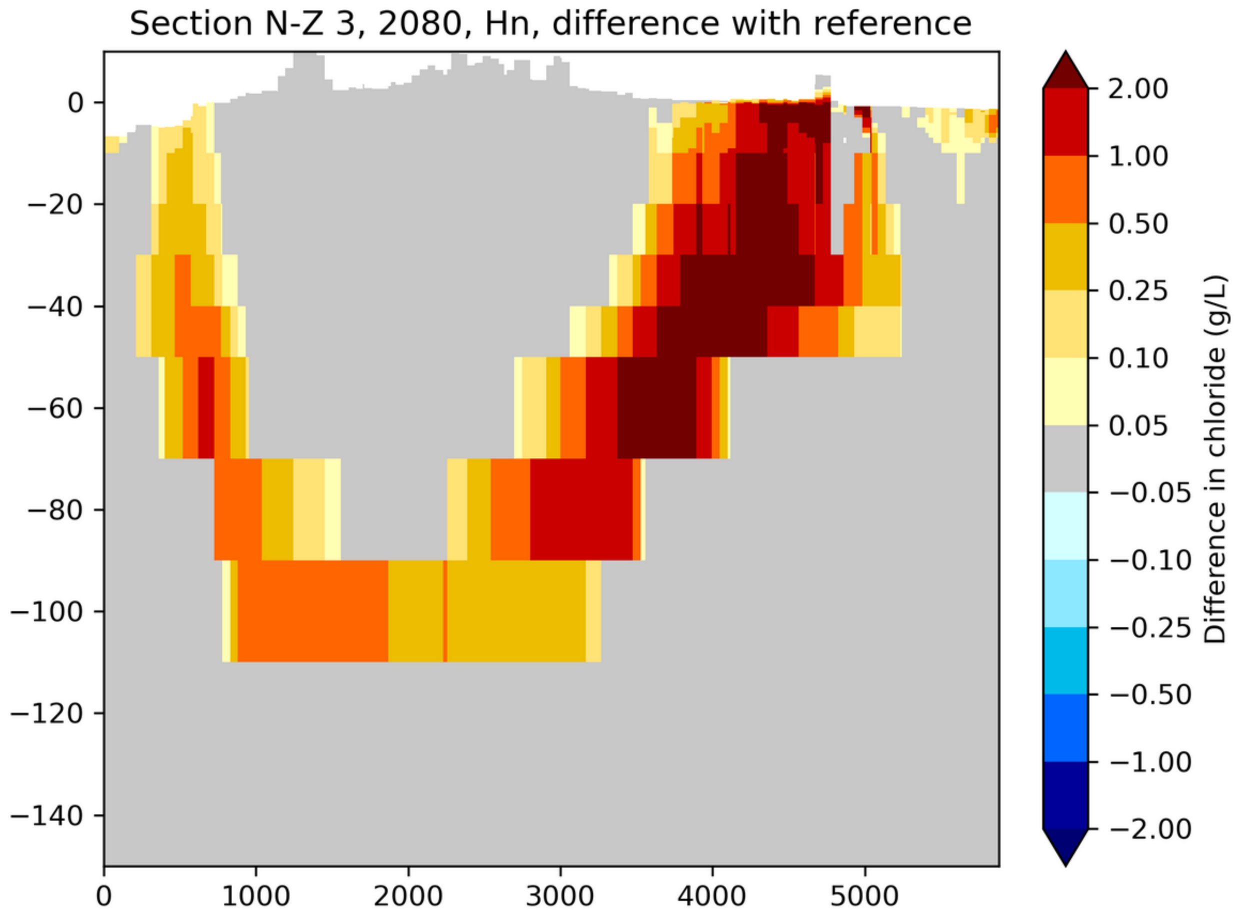

Figure C154: Location cross section N-Z 3 2080 Hn difference with reference (Deltares, 2024-a)

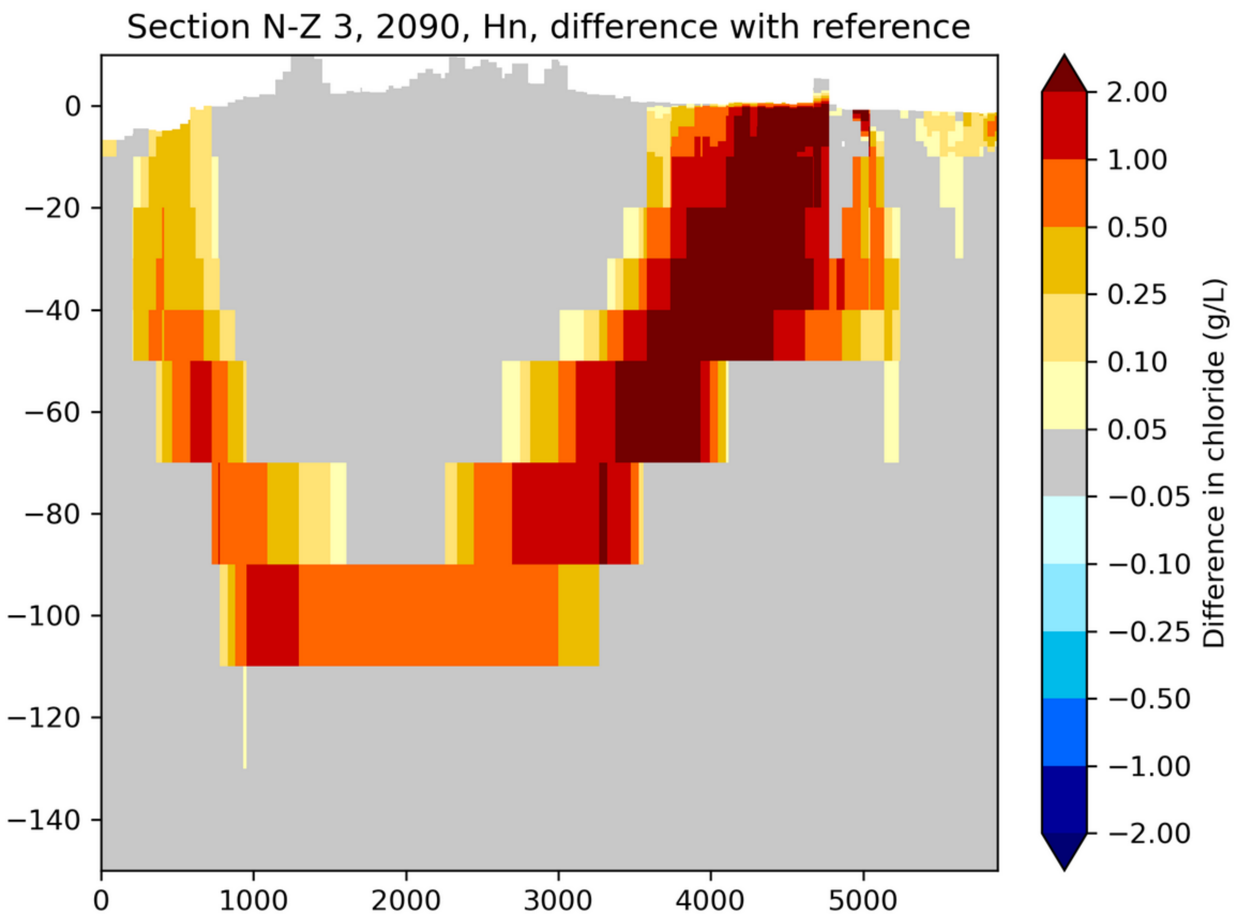

Figure C155: Location cross section N-Z 3 2090 Hn difference with reference (Deltares, 2024-a)

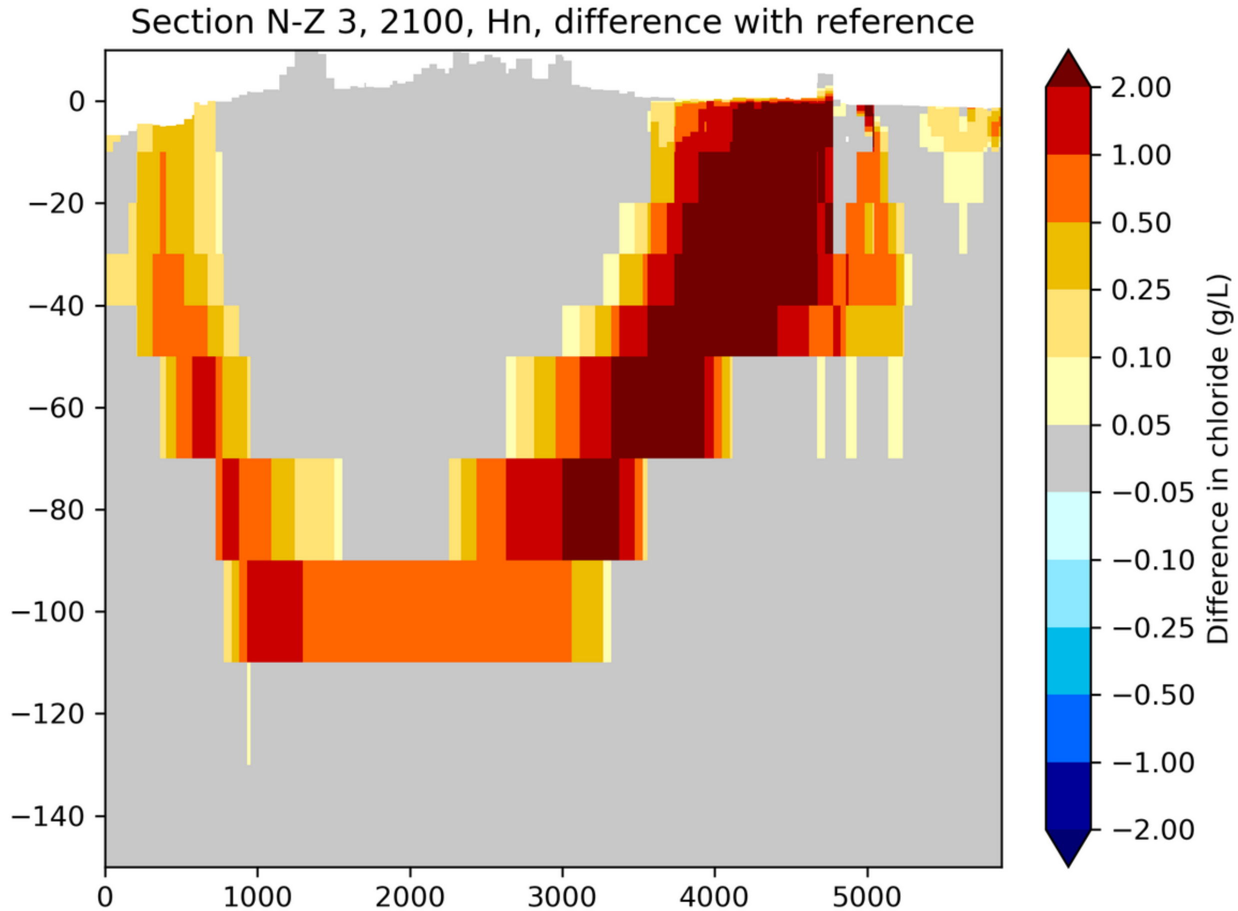

Figure C156: Location cross section N-Z 3 2100 Hn difference with reference (Deltares, 2024-a)

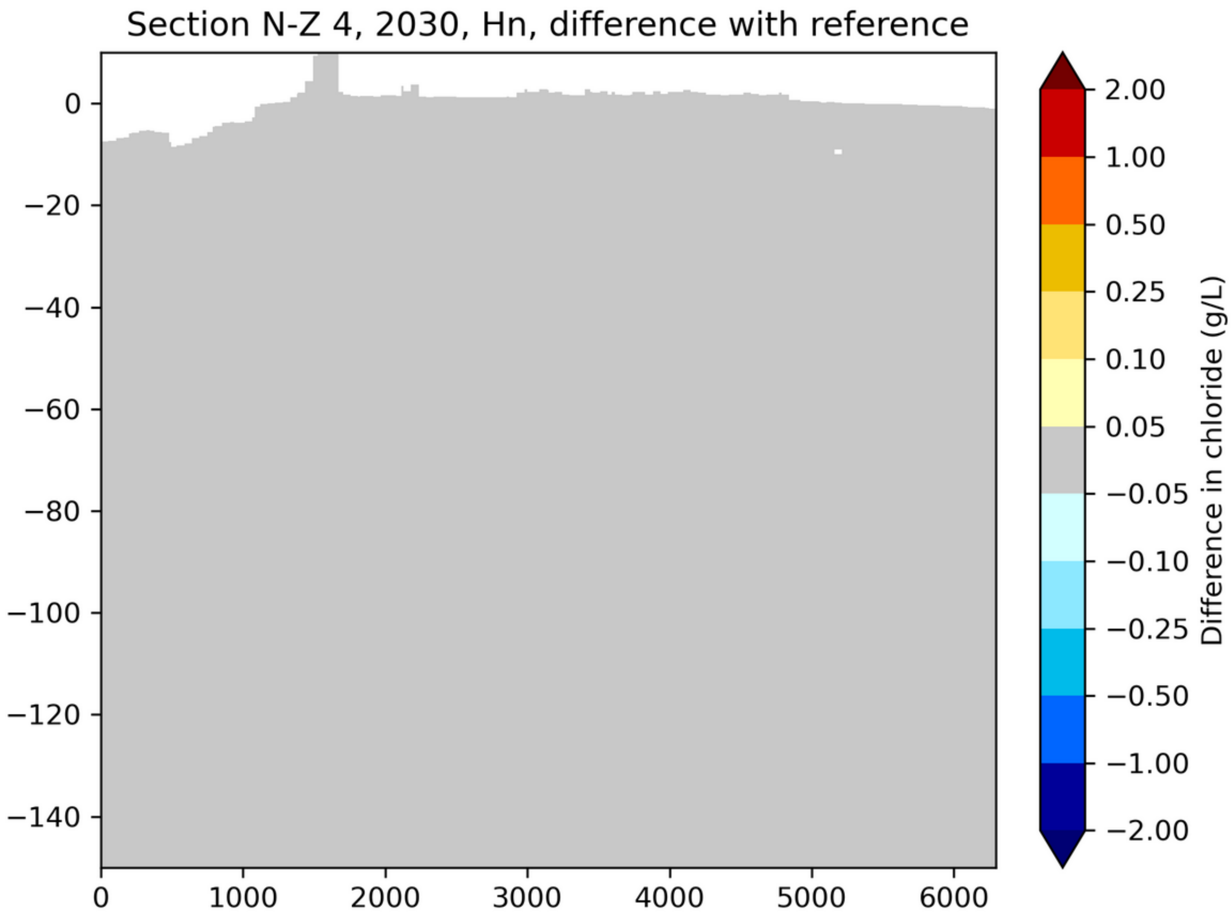

Figure C157: Location cross section N-Z 4 2030 Hn difference with reference (Deltares, 2024-a)

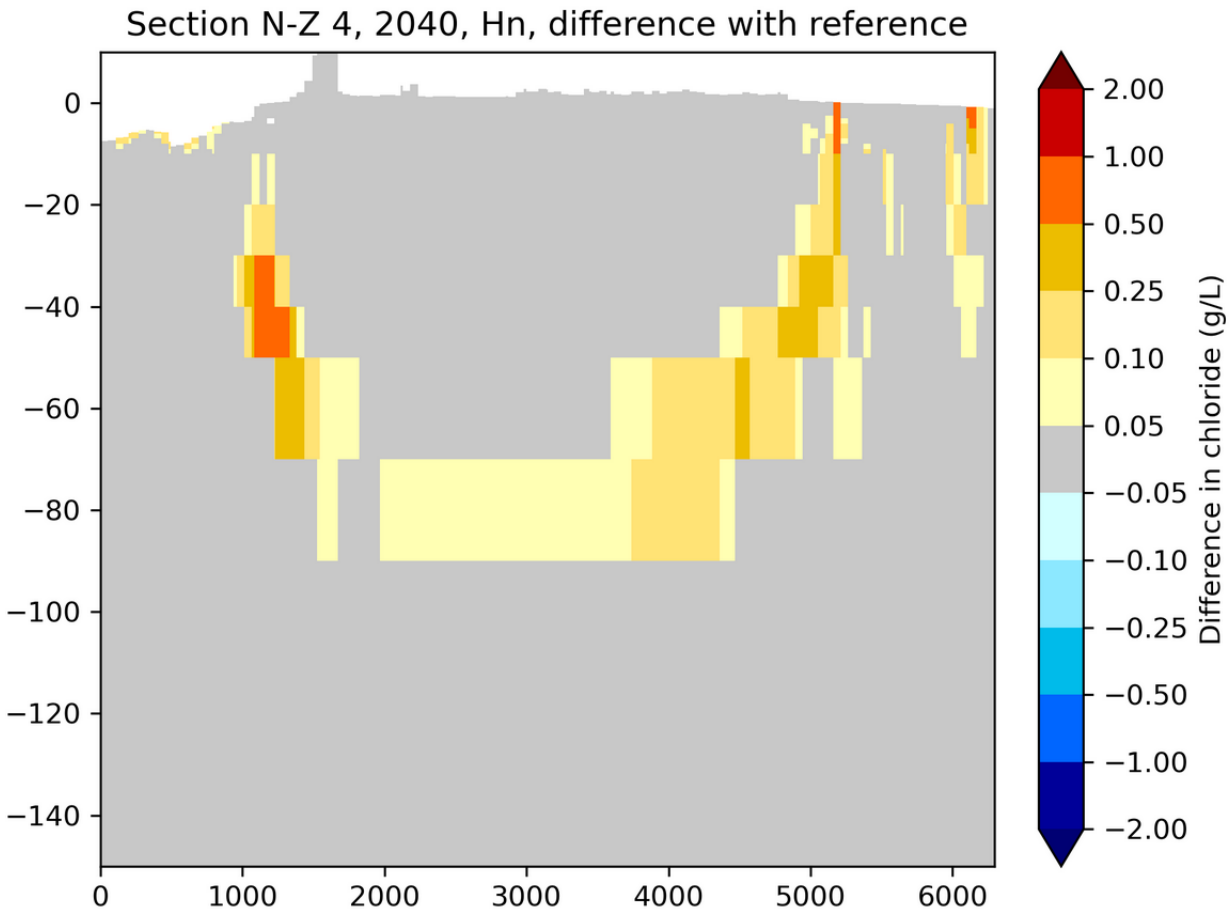

Figure C158: Location cross section N-Z 4 2040 Hn difference with reference (Deltares, 2024-a)

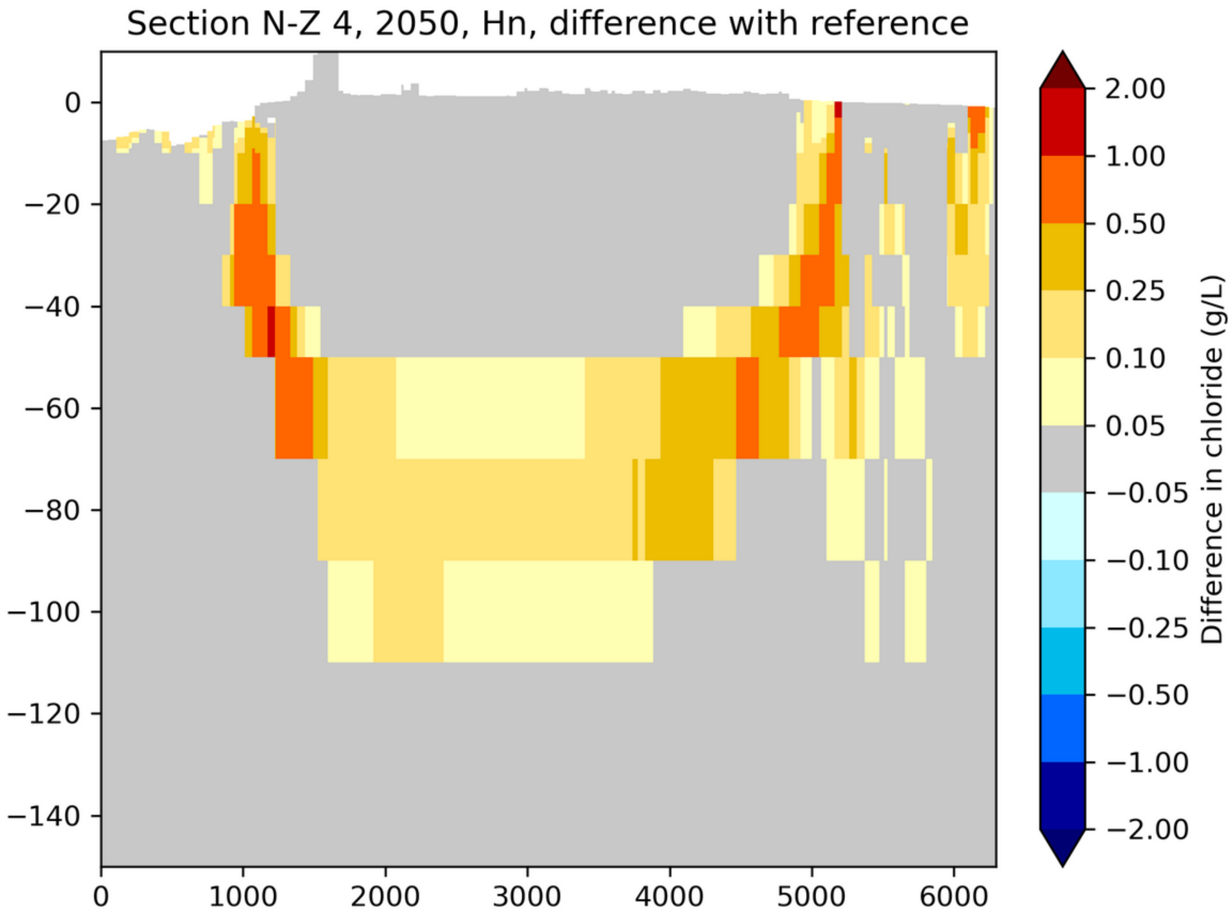

Figure C159: Location cross section N-Z 4 2050 Hn difference with reference (Deltares, 2024-a)

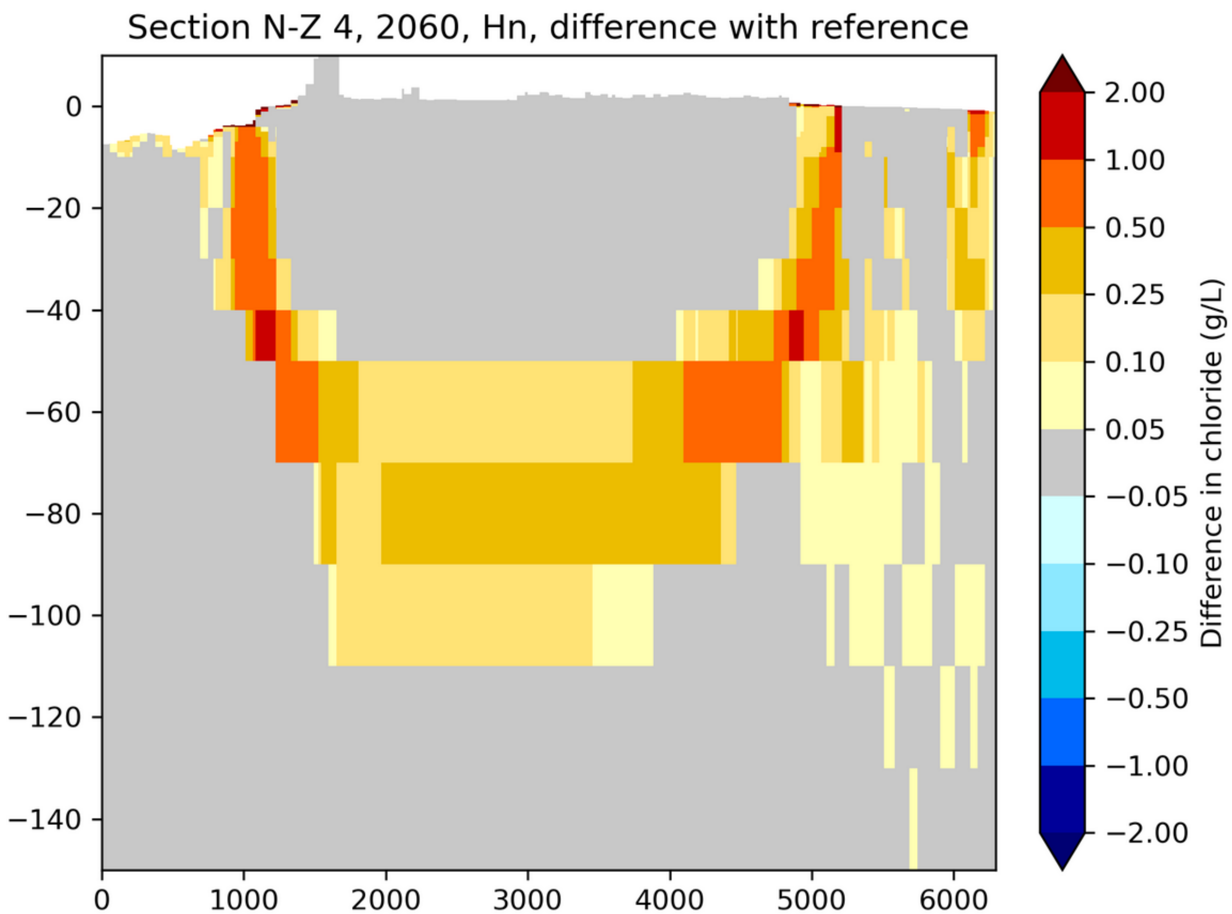

Figure C160: Location cross section N-Z 4 2060 Hn difference with reference (Deltares, 2024-a)

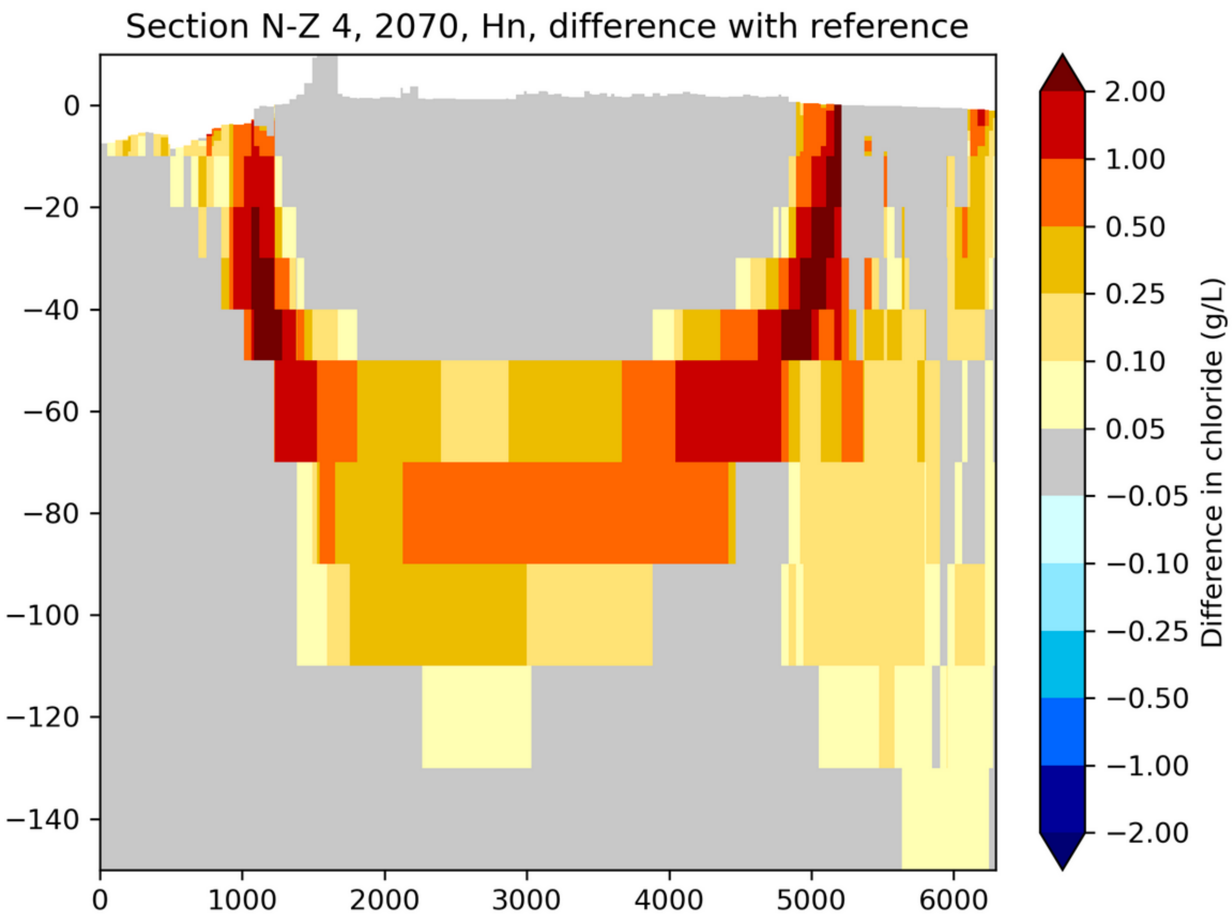

Figure C161: Location cross section N-Z 4 2070 Hn difference with reference (Deltares, 2024-a)

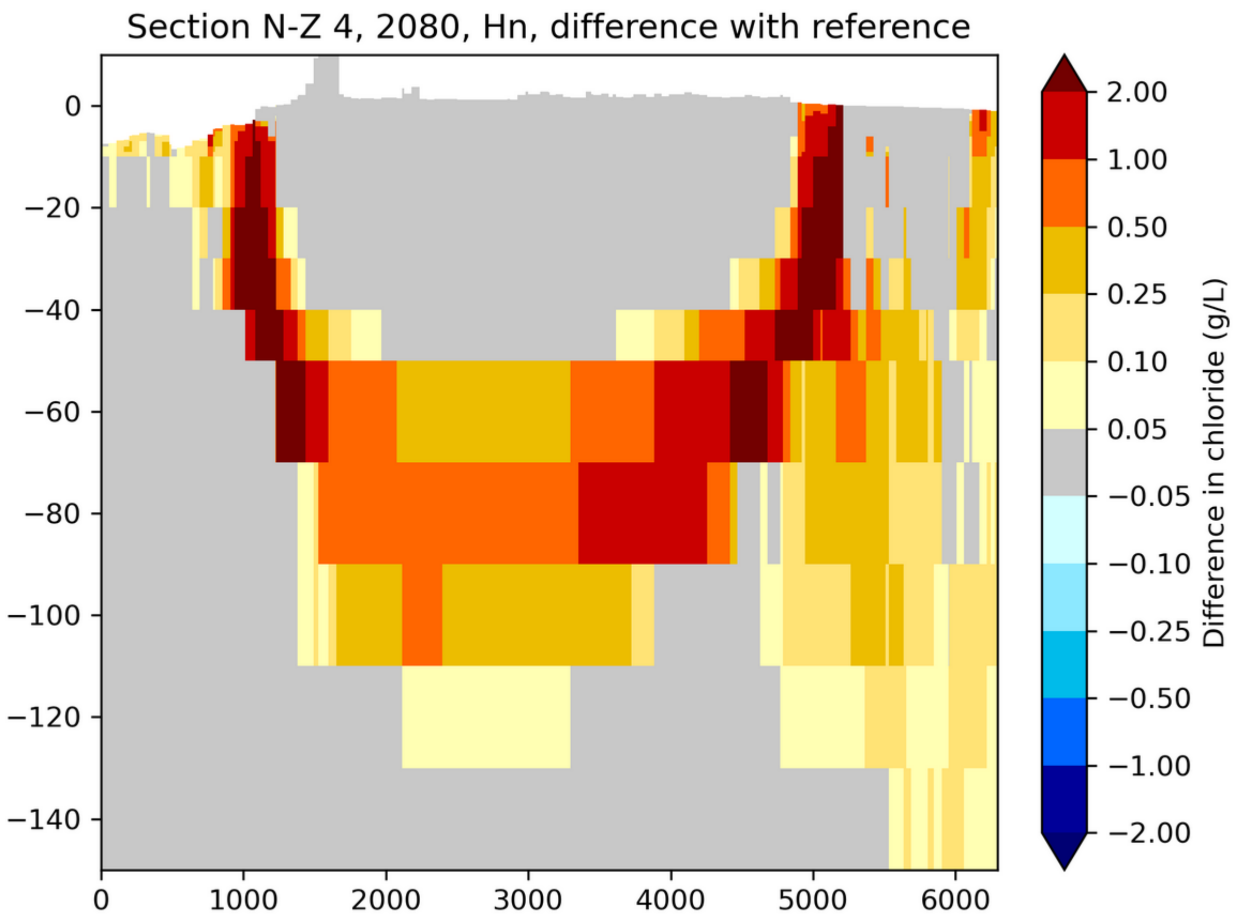

Figure C162: Location cross section N-Z 4 2080 Hn difference with reference (Deltares, 2024-a)

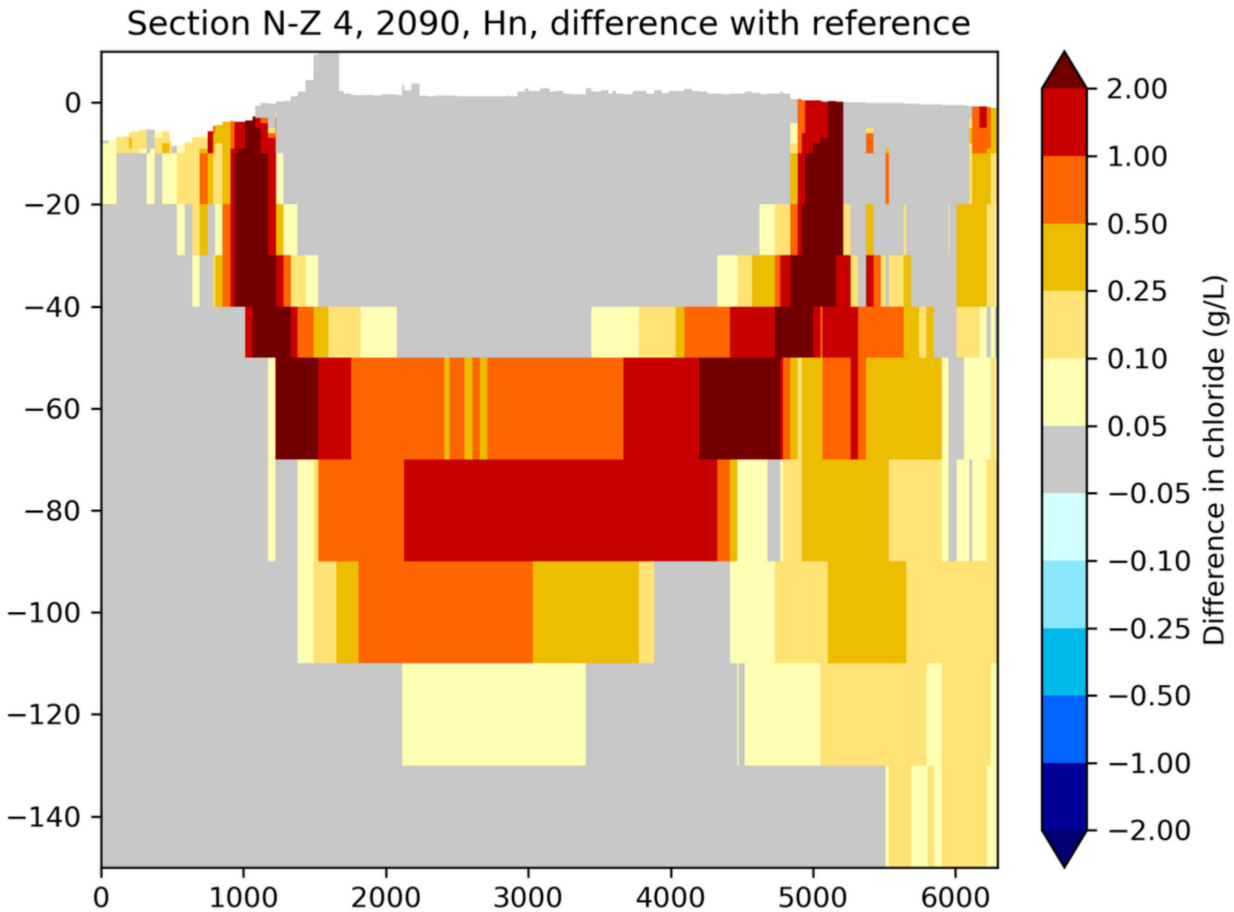

Figure C163: Location cross section N-Z 4 2090 Hn difference with reference (Deltares, 2024-a)

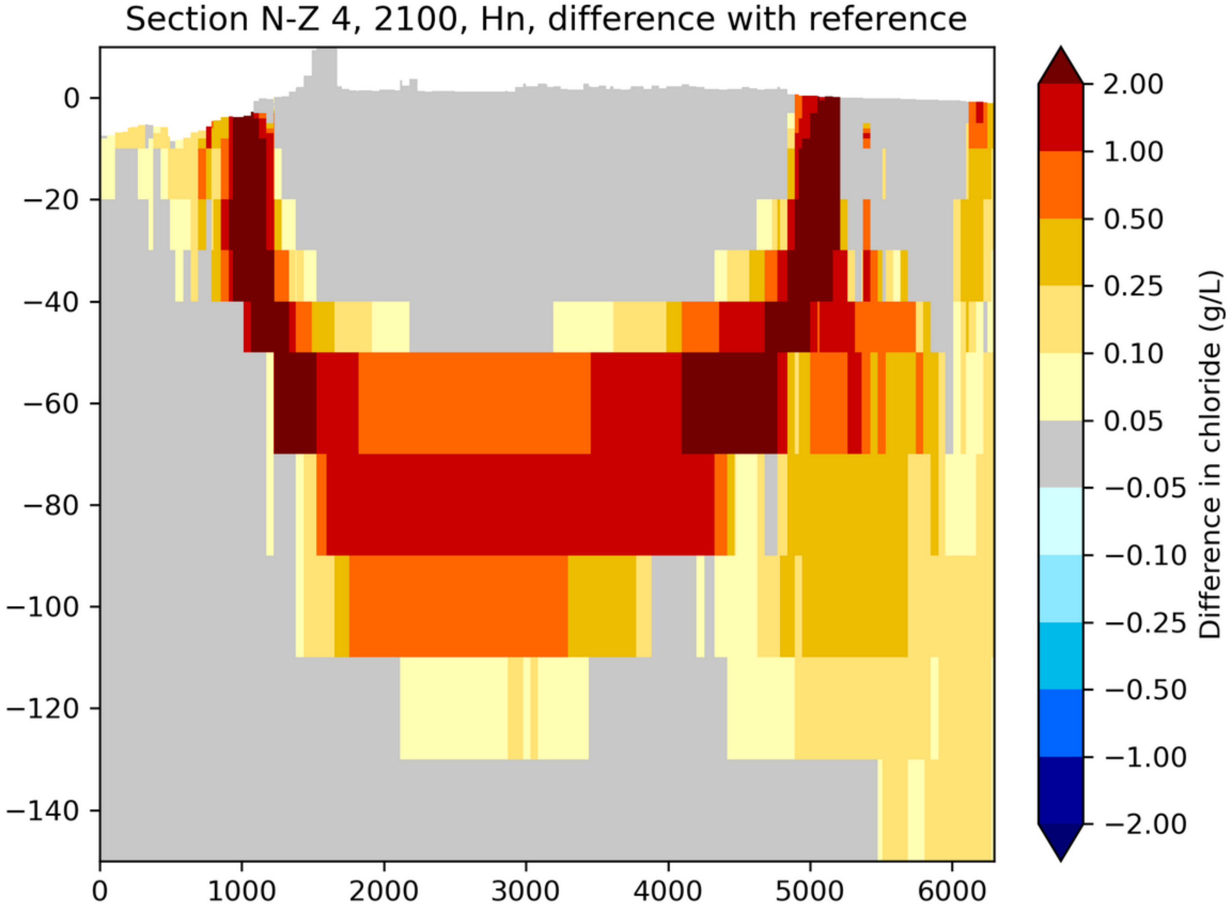

Figure C164: Location cross section N-Z 4 2100 Hn difference with reference (Deltares, 2024-a)

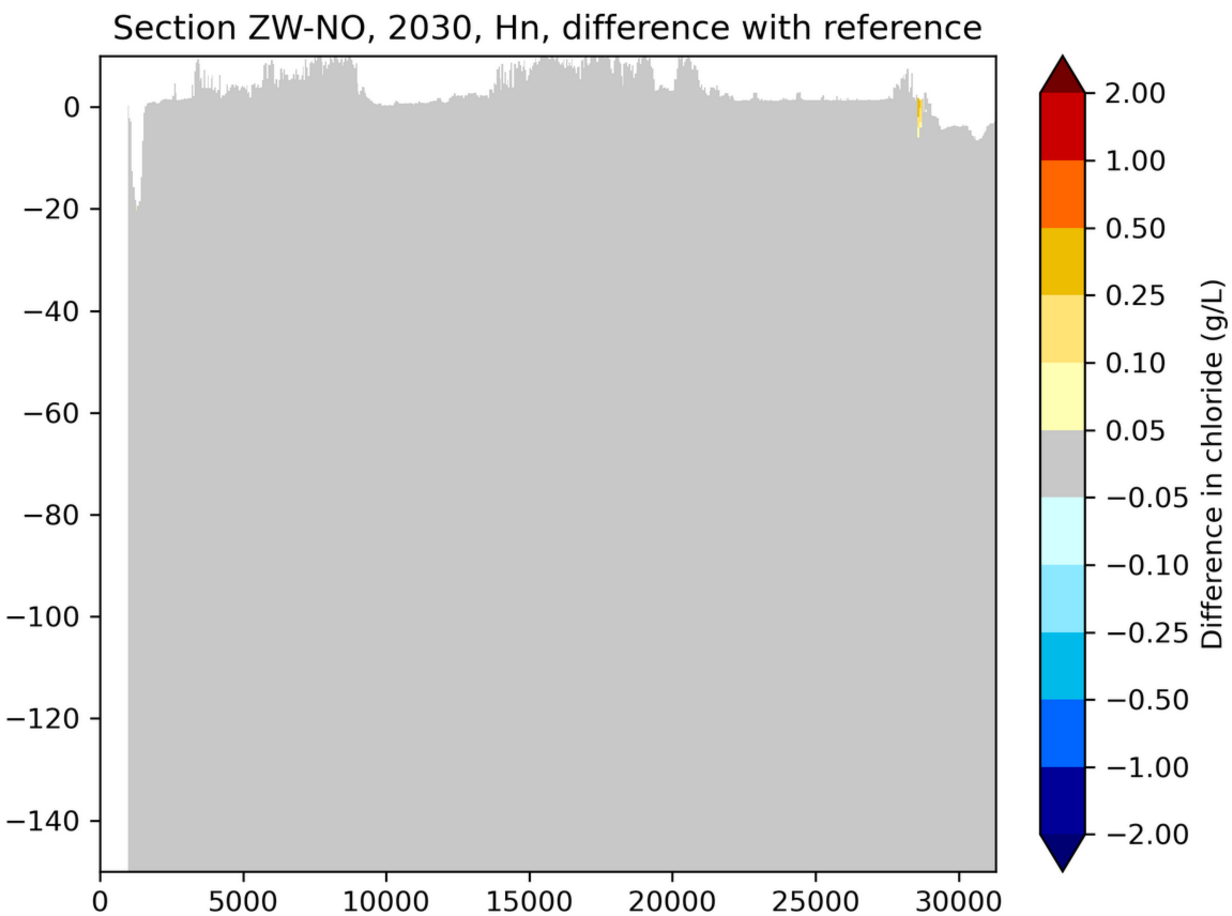

Figure C165: Location cross section ZW-NO 2030 Hn difference with reference (Deltares, 2024-a)

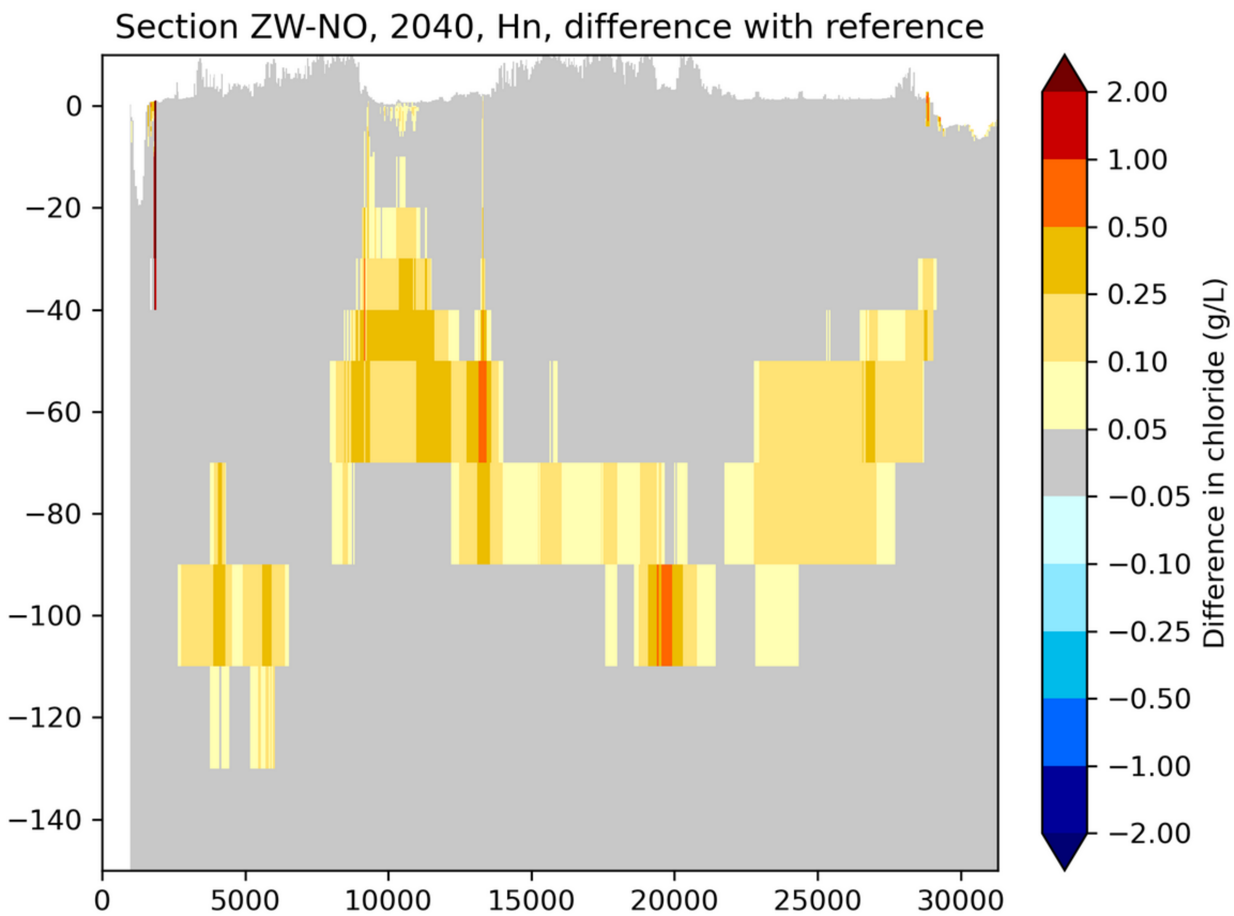

Figure C166: Location cross section ZW-NO 2040 Hn difference with reference (Deltares, 2024-a)

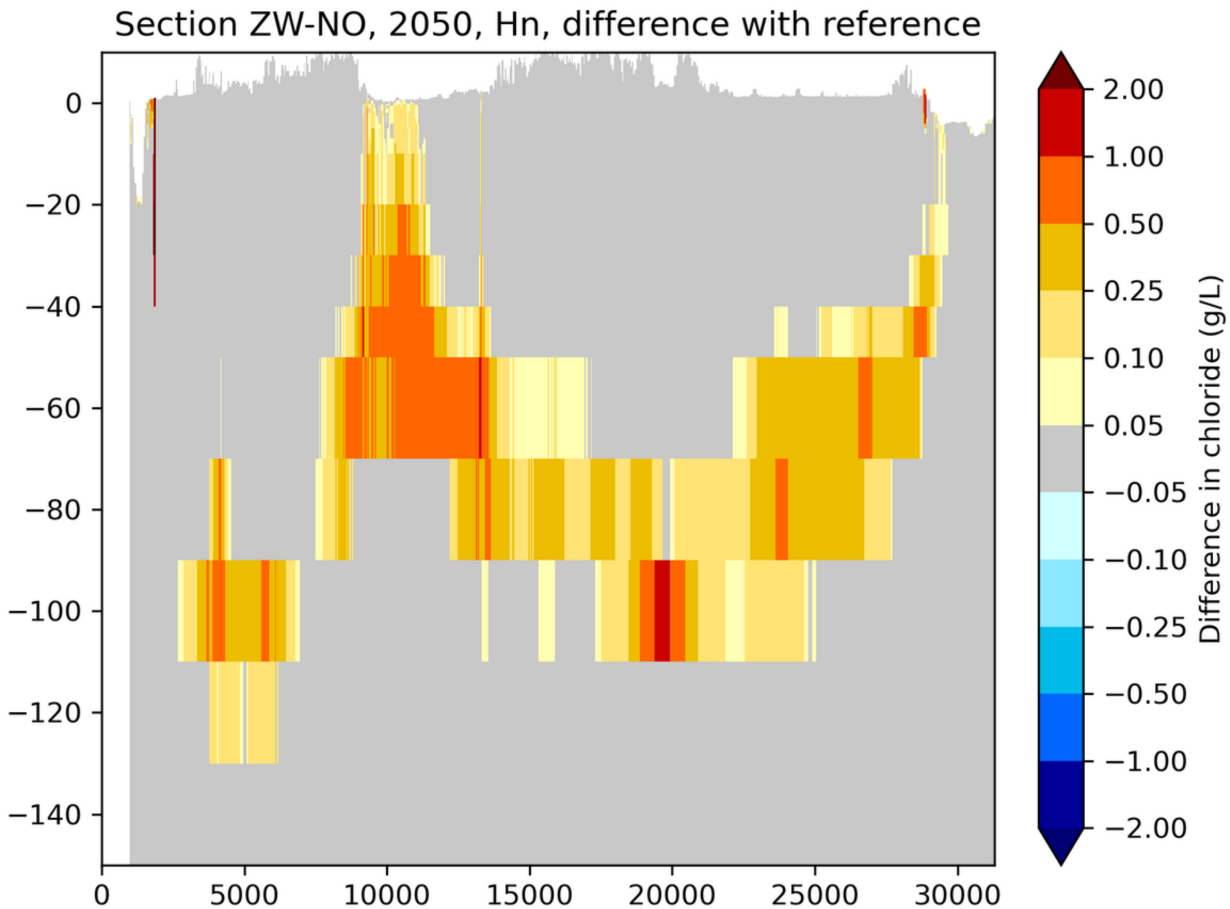

Figure C167: Location cross section ZW-NO 2050 Hn difference with reference (Deltares, 2024-a)

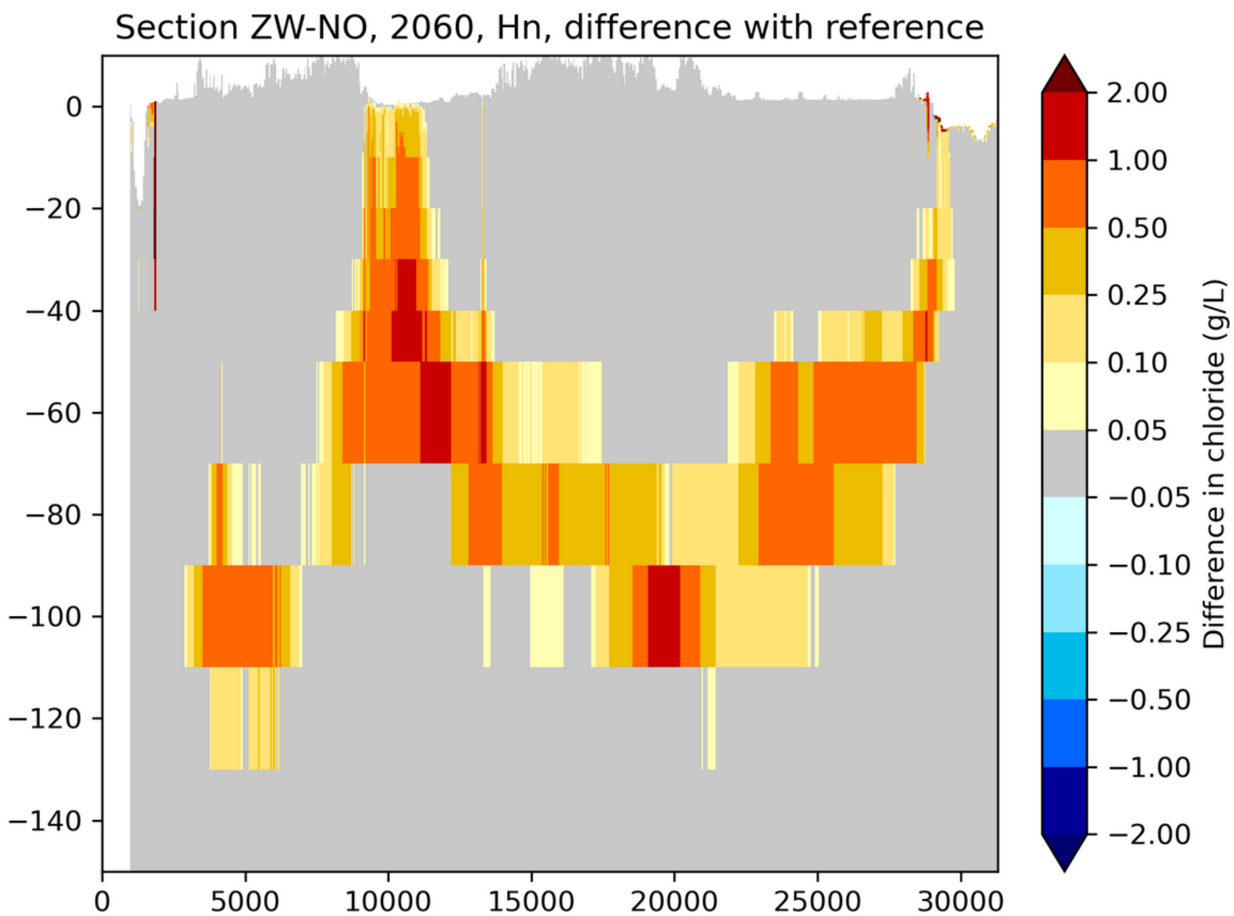

Figure C168: Location cross section ZW-NO 2060 Hn difference with reference (Deltares, 2024-a)

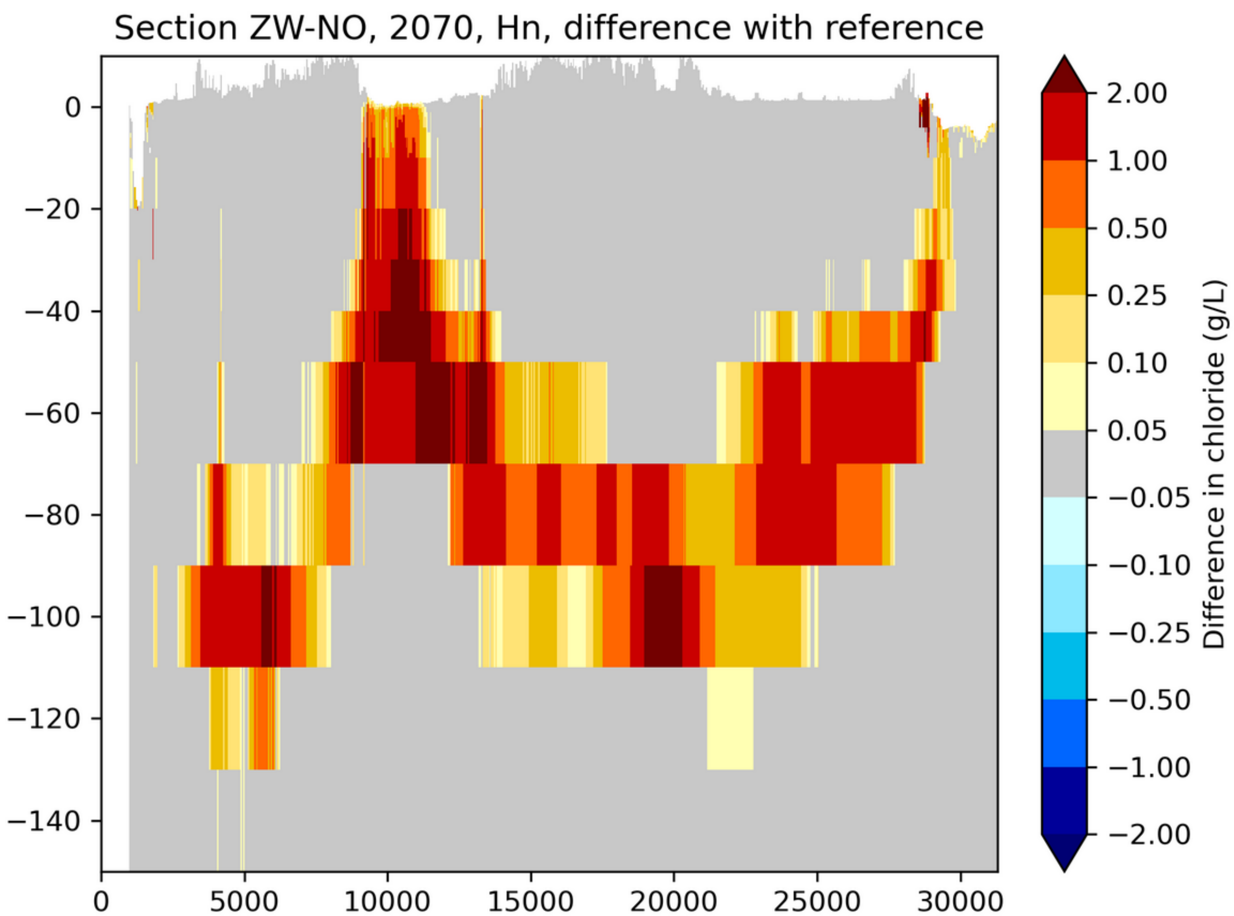

Figure C169: Location cross section ZW-NO 2070 Hn difference with reference (Deltares, 2024-a)

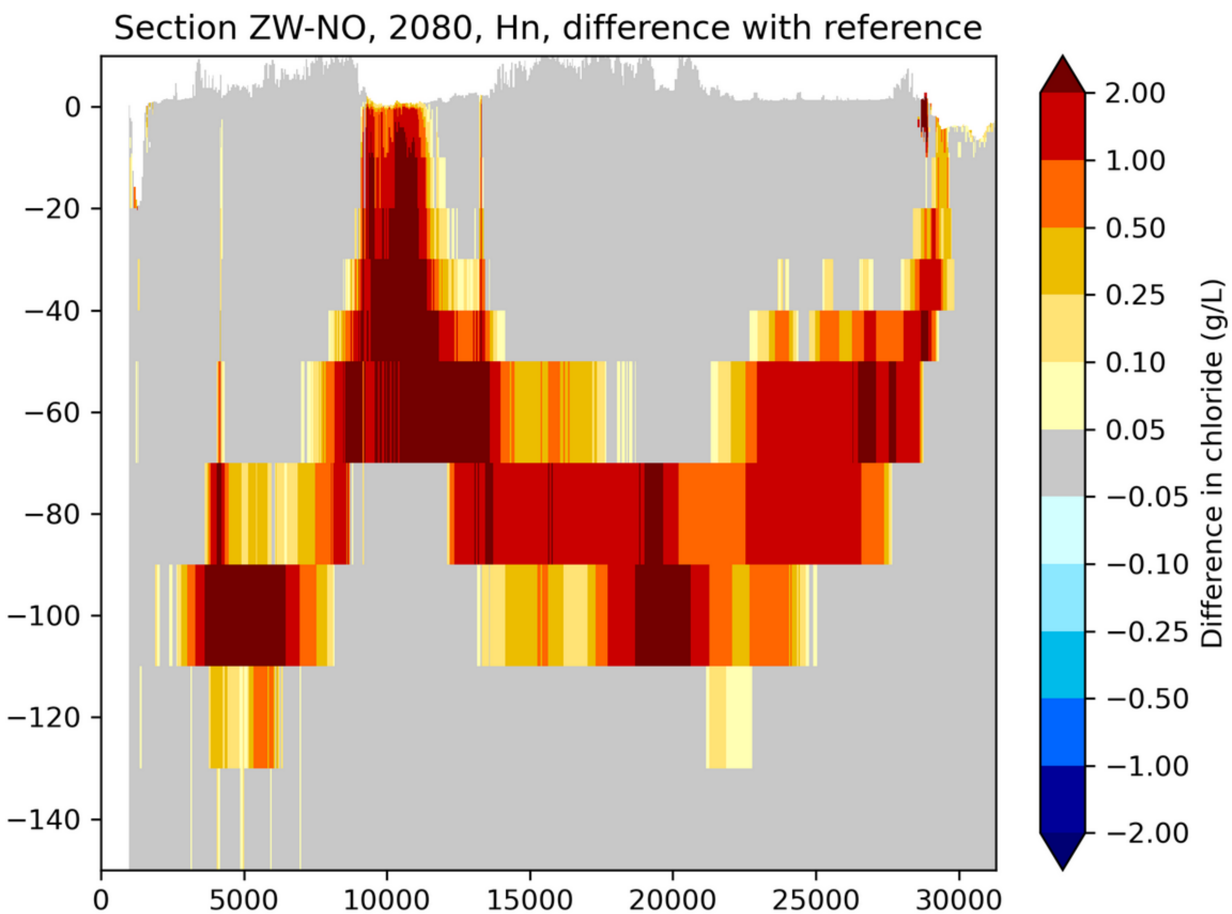

Figure C170: Location cross section ZW-NO 2080 Hn difference with reference (Deltares, 2024-a)

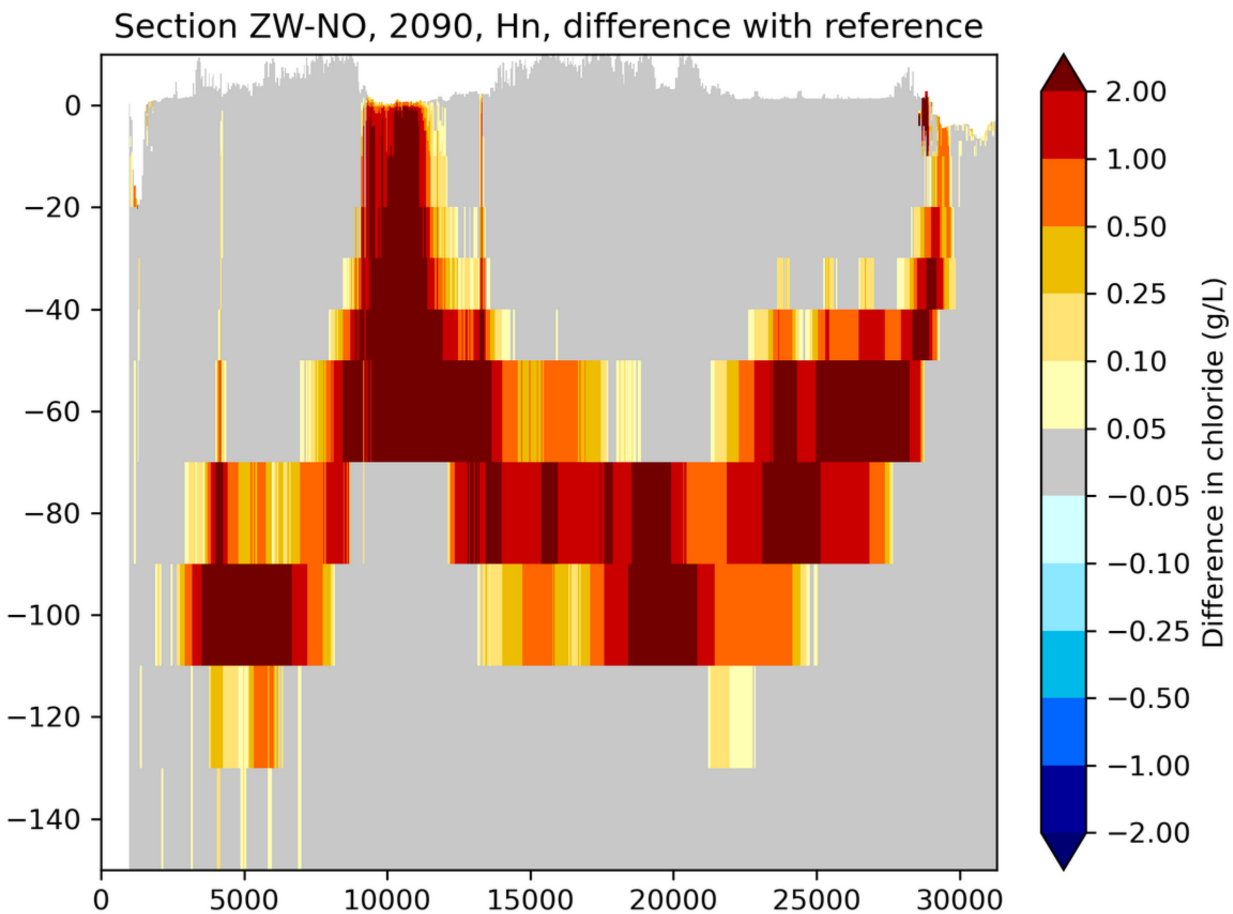

Figure C171: Location cross section ZW-NO 2090 Hn difference with reference (Deltares, 2024-a)

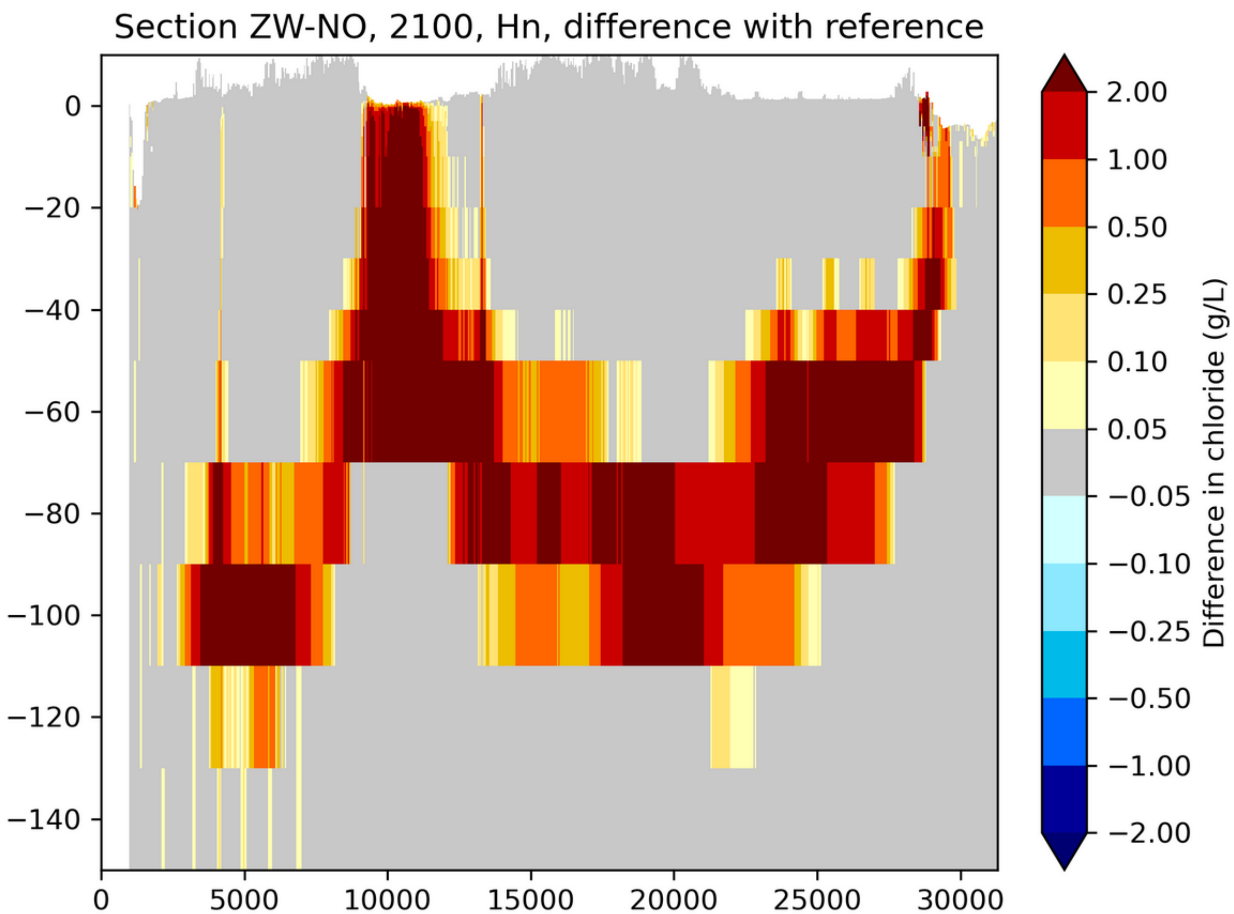

Figure C172: Location cross section ZW-NO 2100 Hn difference with reference (Deltares, 2024-a)

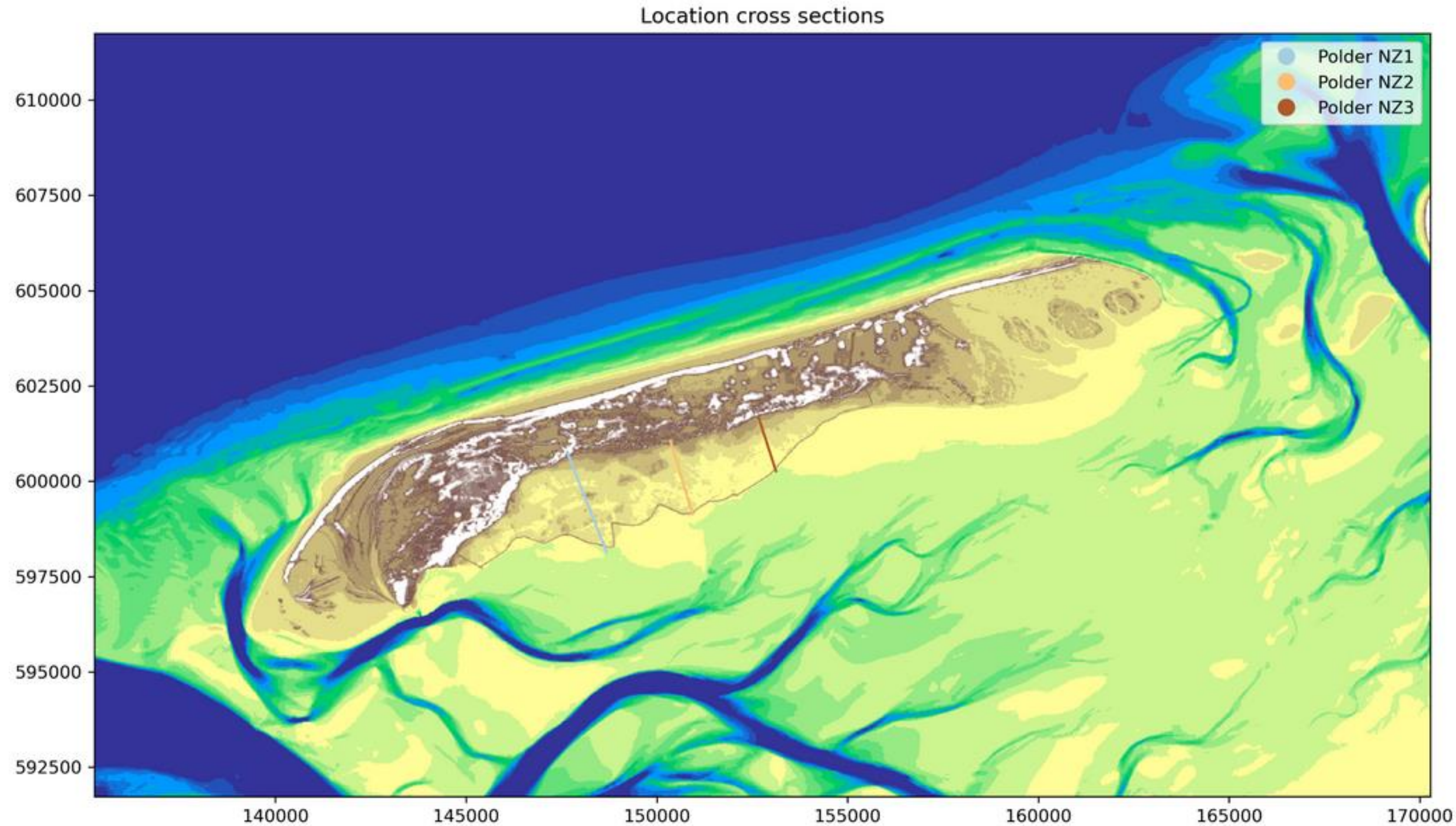

Figure C173: Location cross polder sections Hn difference with reference (Deltares, 2024-a)

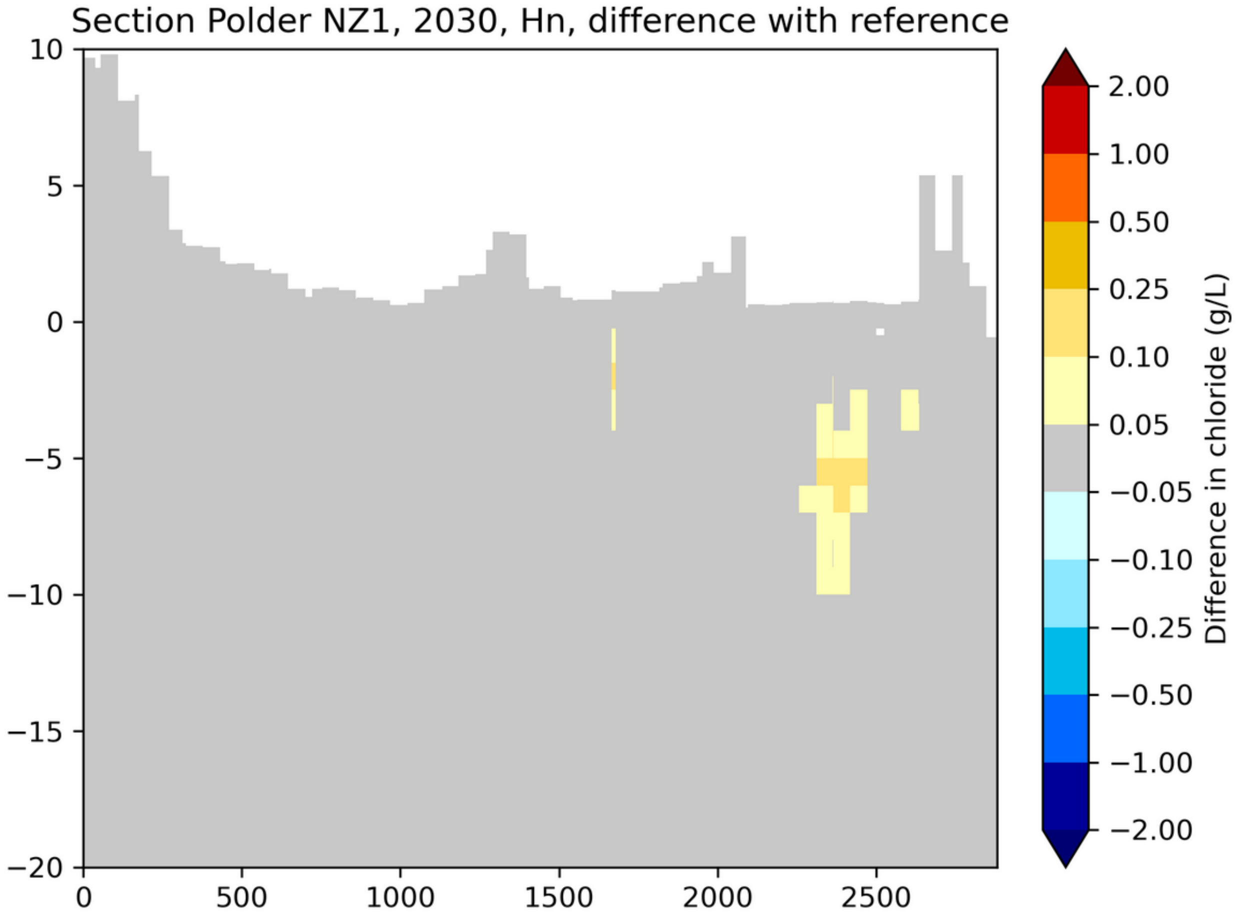

Figure C174: Location cross section polder NZ1 2030 Hn difference with reference (Deltares, 2024-a)

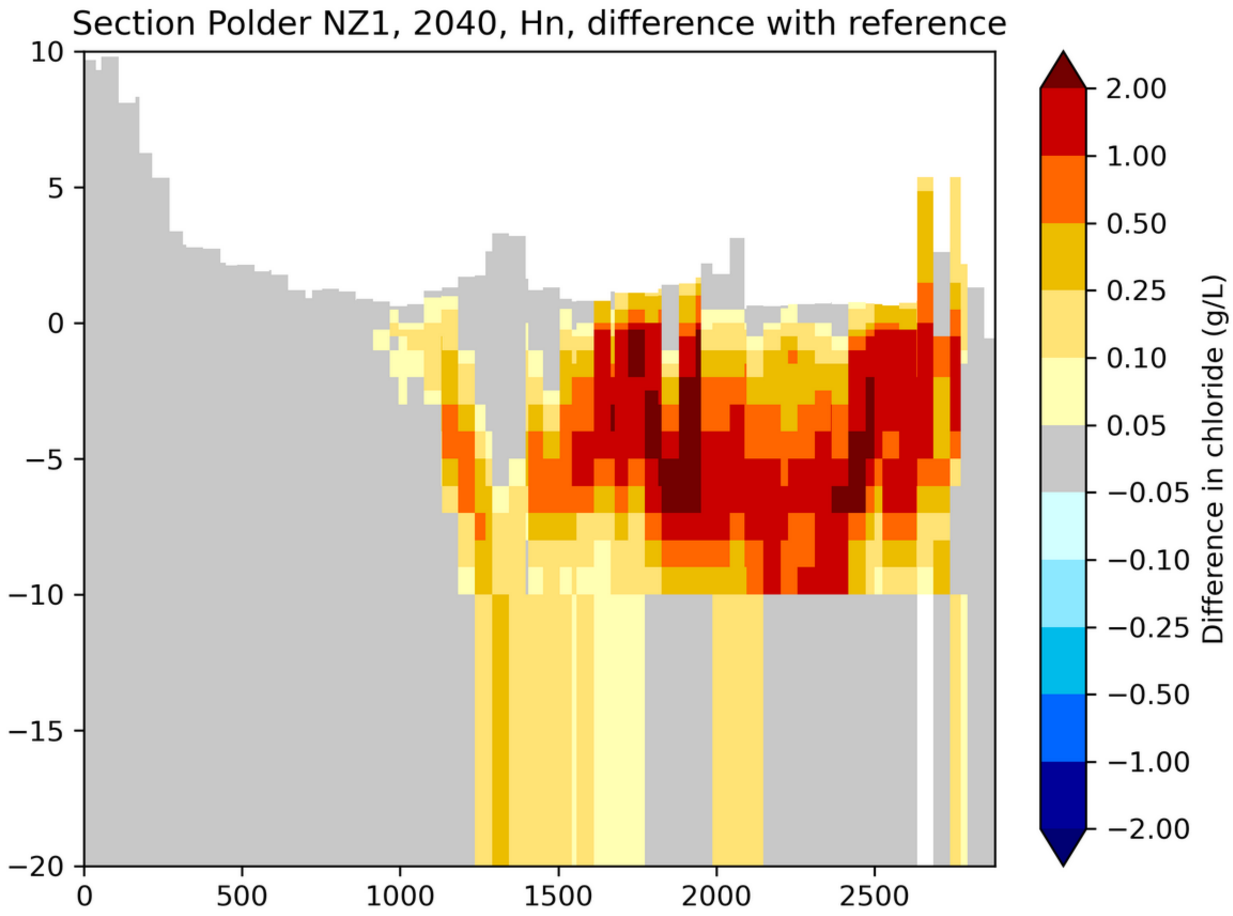

Figure C175: Location cross section polder NZ1 2040 Hn difference with reference (Deltares, 2024-a)

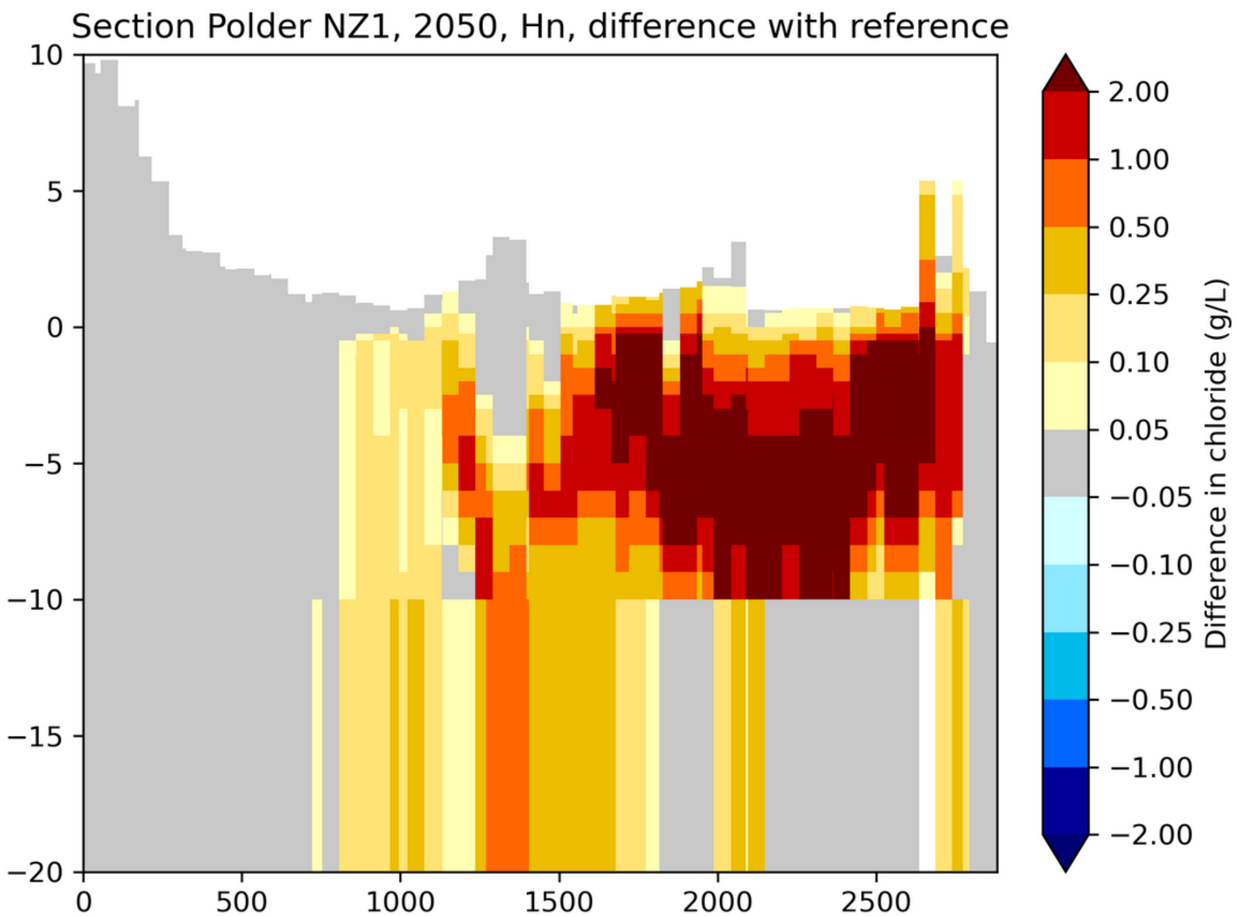

Figure C176: Location cross section polder NZ1 2050 Hn difference with reference (Deltares, 2024-a)

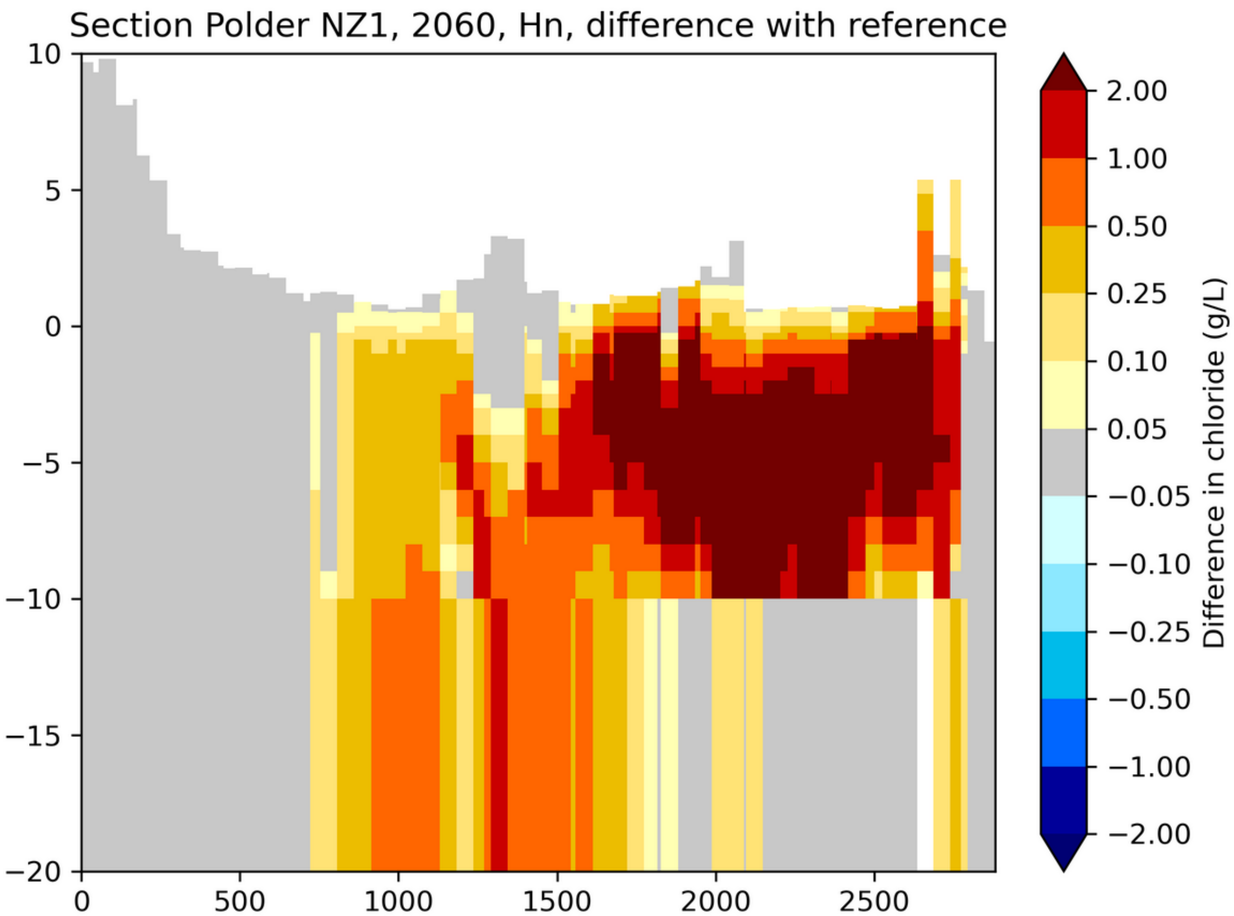

Figure C177: Location cross section polder NZ1 2060 Hn difference with reference (Deltares, 2024-a)

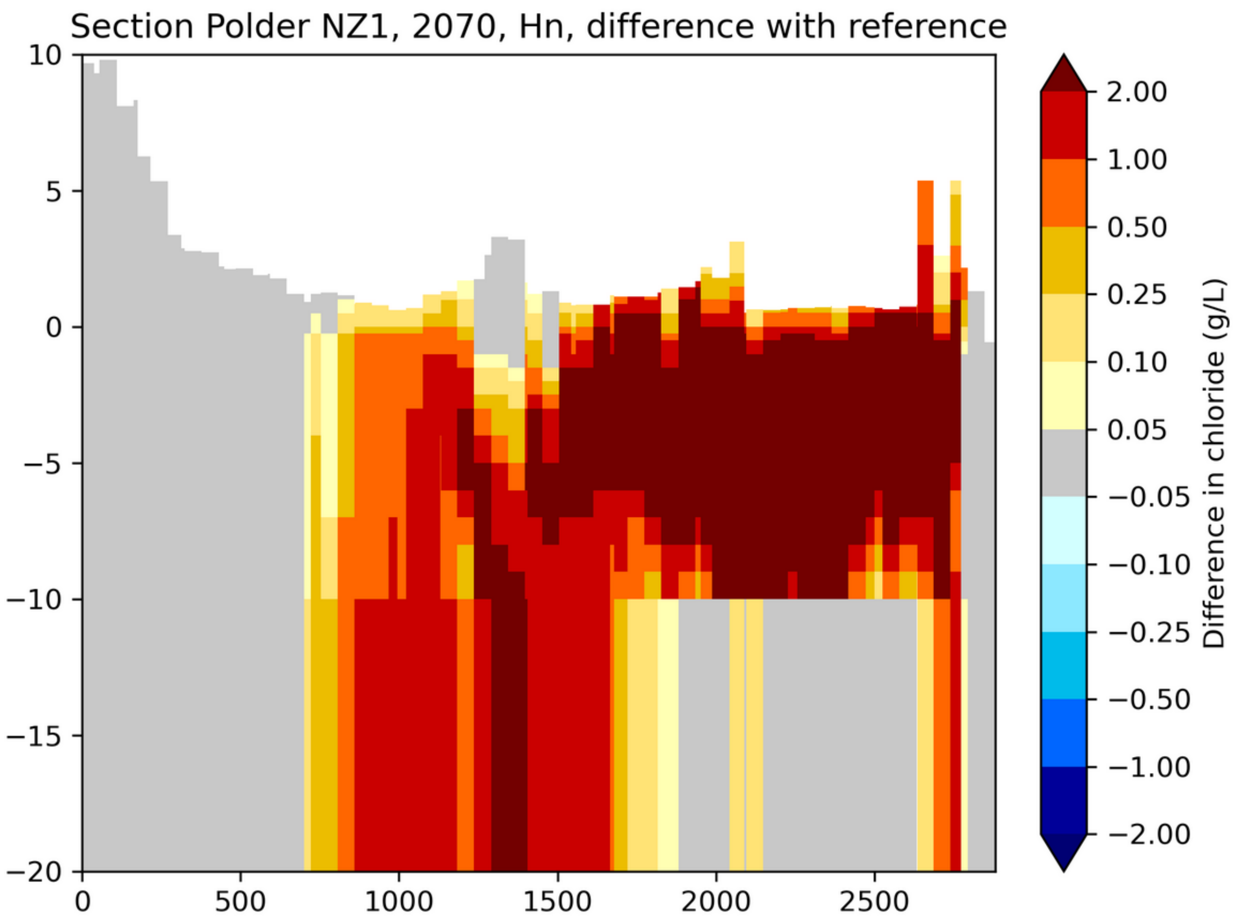

Figure C178: Location cross section polder NZ1 2070 Hn difference with reference (Deltares, 2024-a)

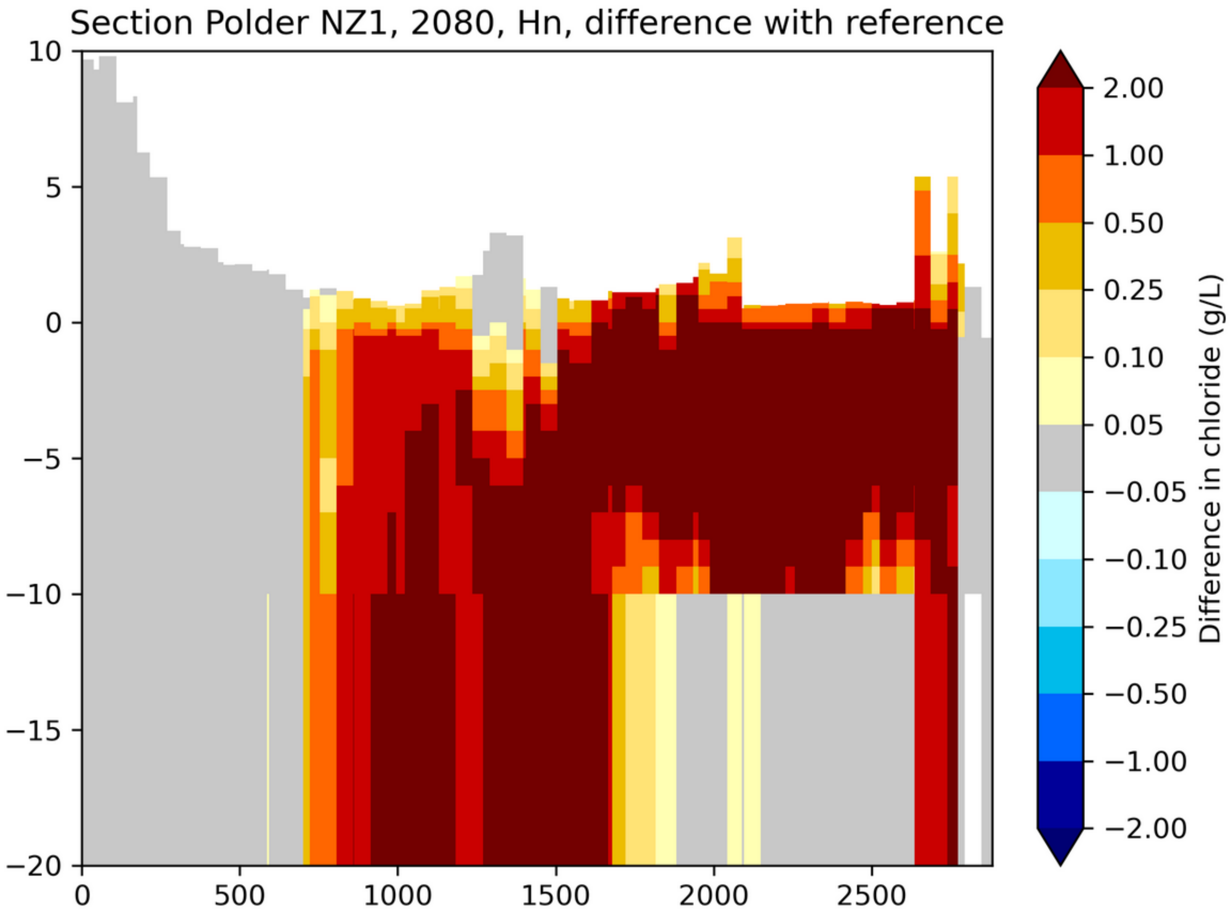

Figure C179: Location cross section polder NZ1 2080 Hn difference with reference (Deltares, 2024-a)

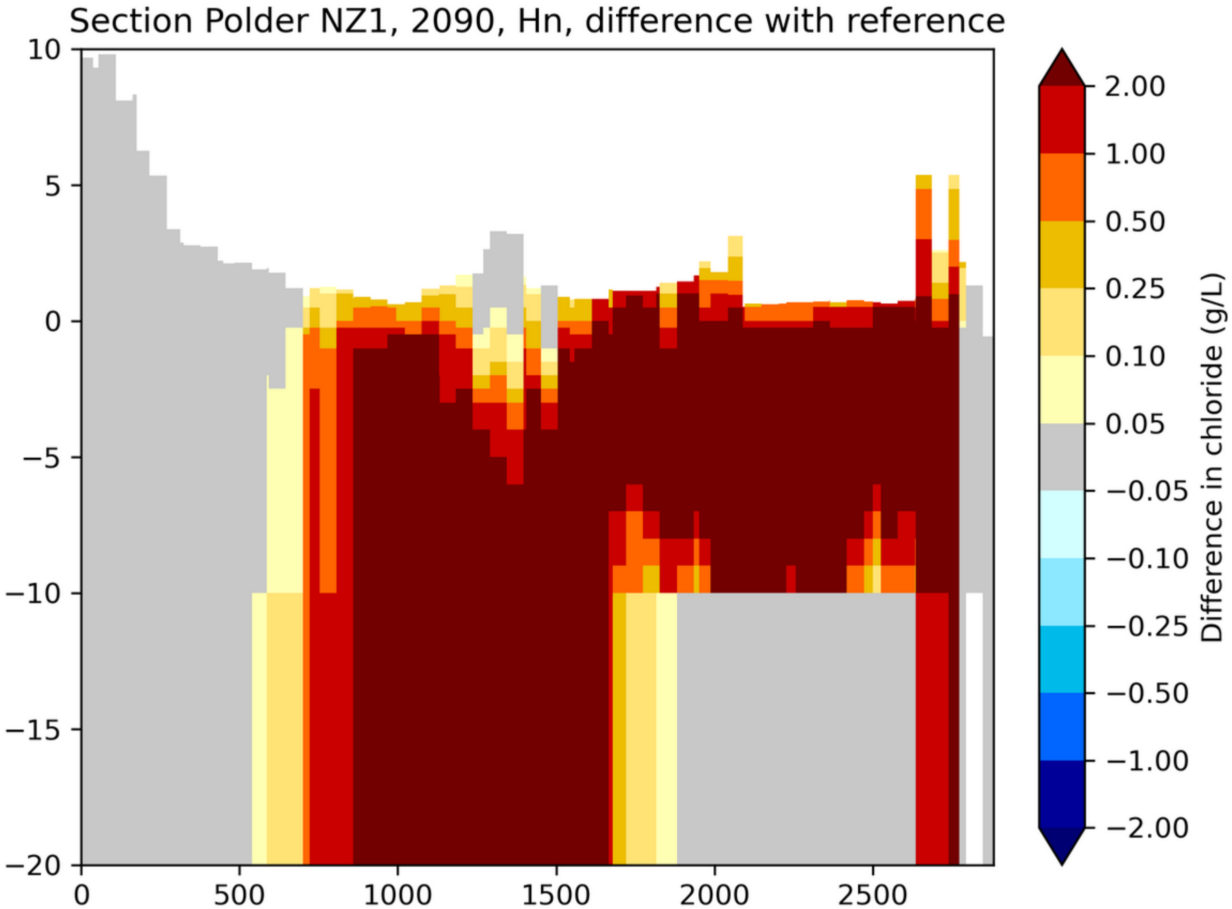

Figure C180: Location cross section polder NZ1 2090 Hn difference with reference (Deltares, 2024-a)

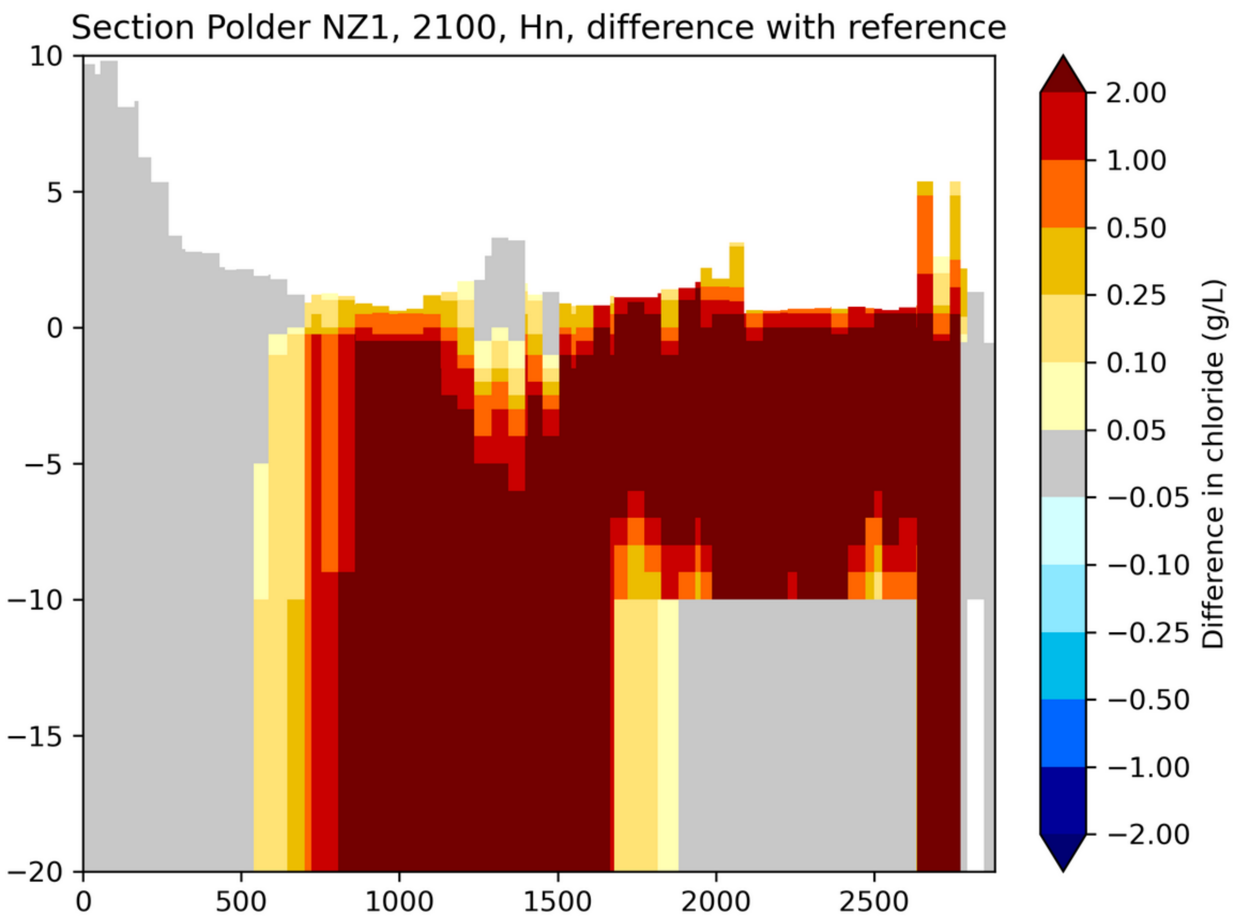

Figure C181: Location cross section polder NZ1 2100 Hn difference with reference (Deltares, 2024-a)

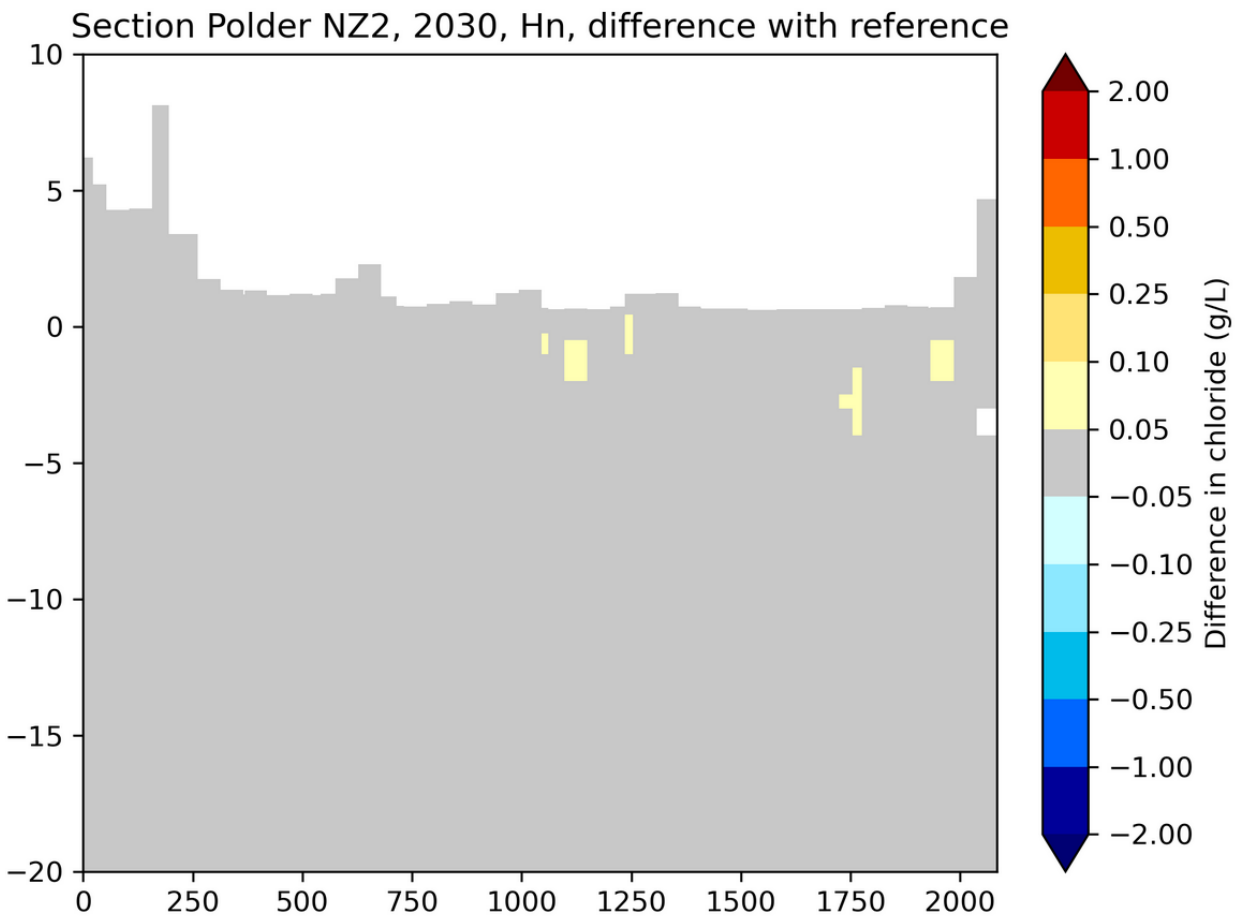

Figure C182: Location cross section polder NZ2 2030 Hn difference with reference (Deltares, 2024-a)

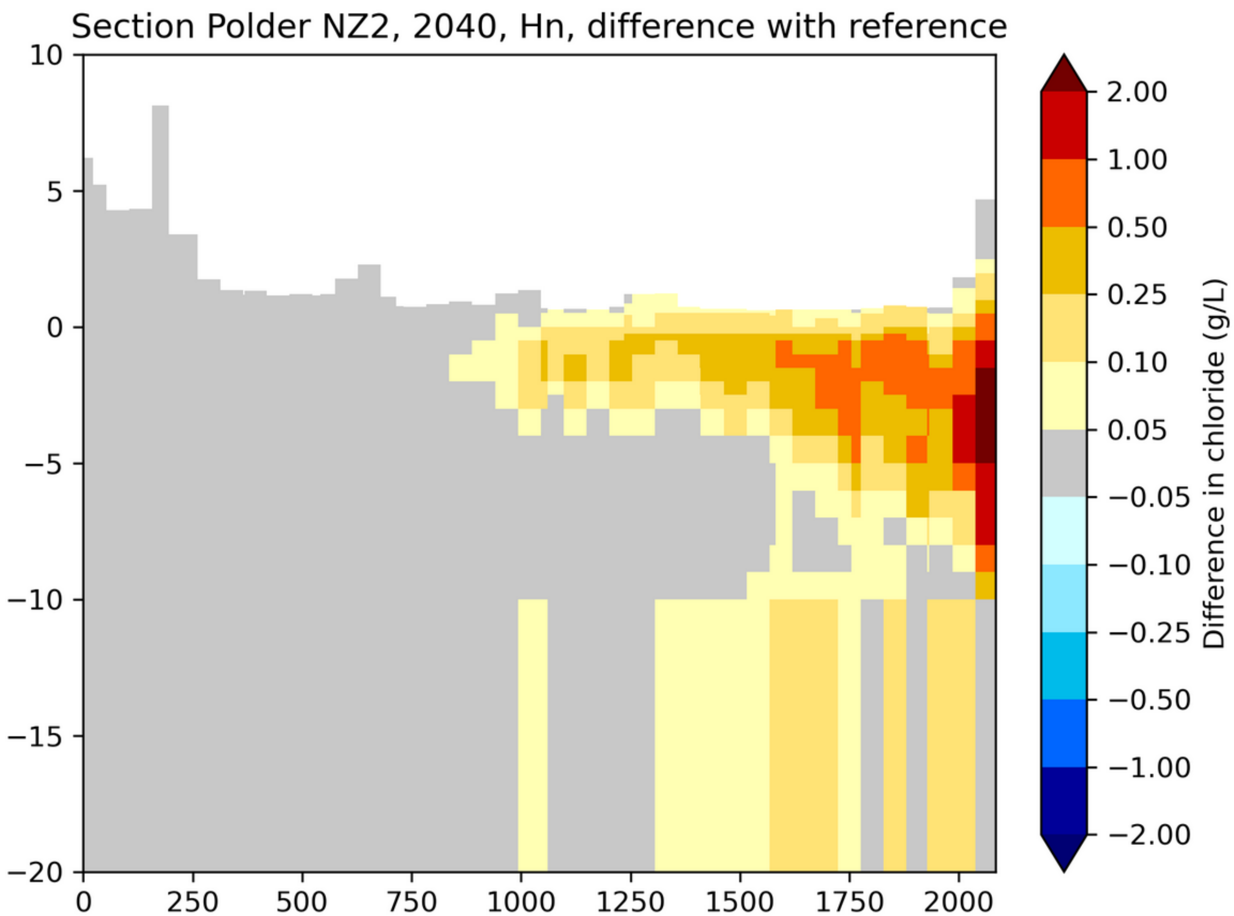

Figure C183: Location cross section polder NZ2 2040 Hn difference with reference (Deltares, 2024-a)

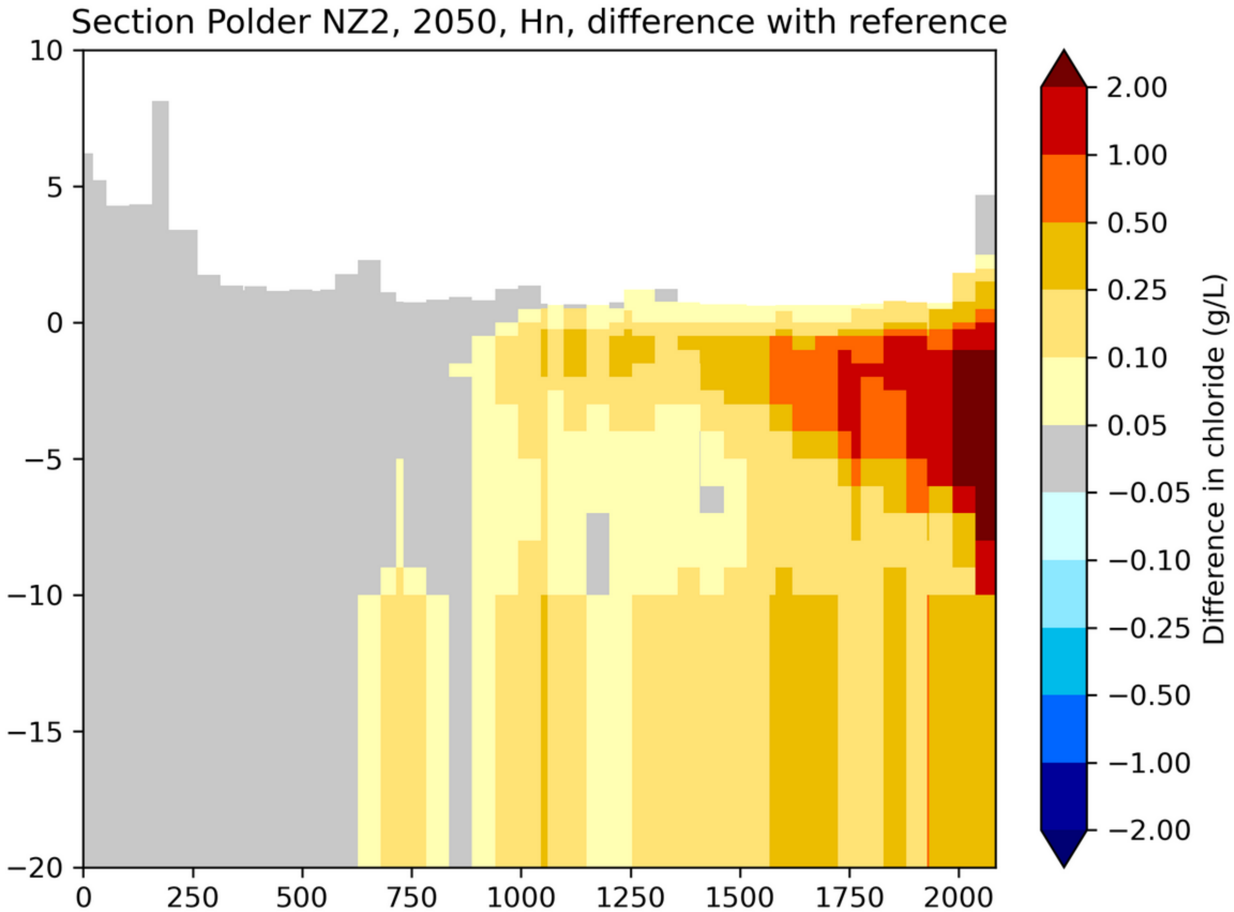

Figure C184: Location cross section polder NZ2 2050 Hn difference with reference (Deltares, 2024-a)

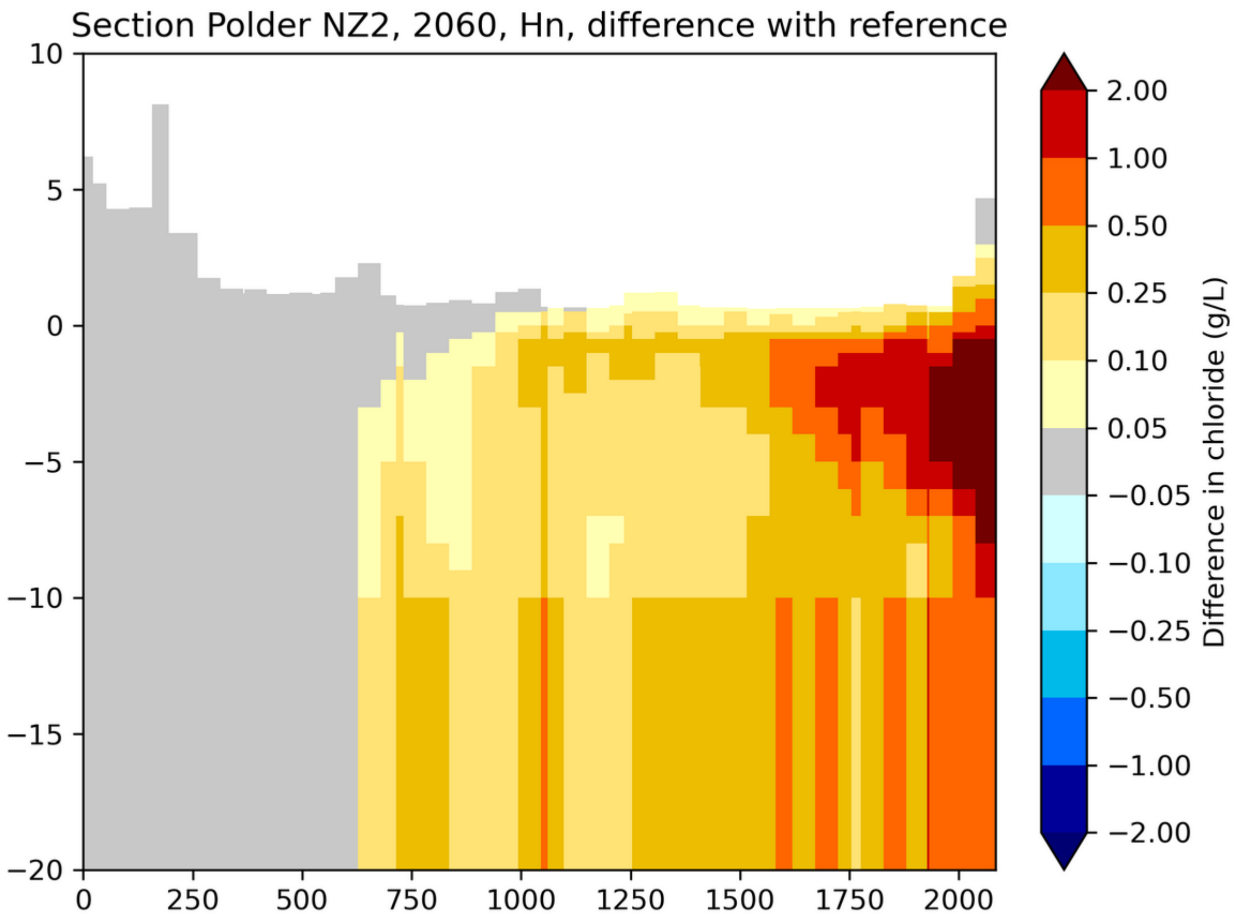

Figure C185: Location cross section polder NZ2 2060 Hn difference with reference (Deltares, 2024-a)

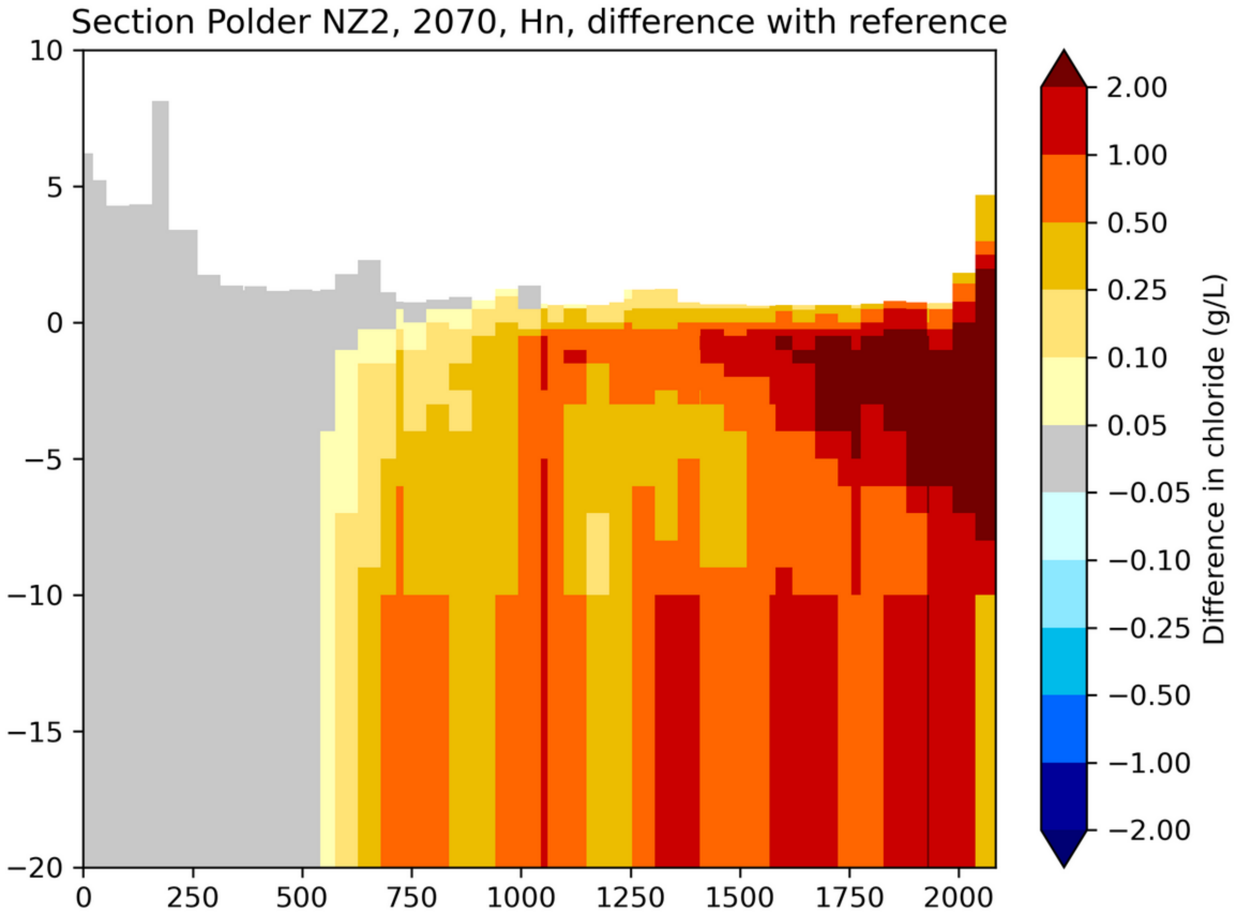

Figure C186: Location cross section polder NZ2 2070 Hn difference with reference (Deltares, 2024-a)

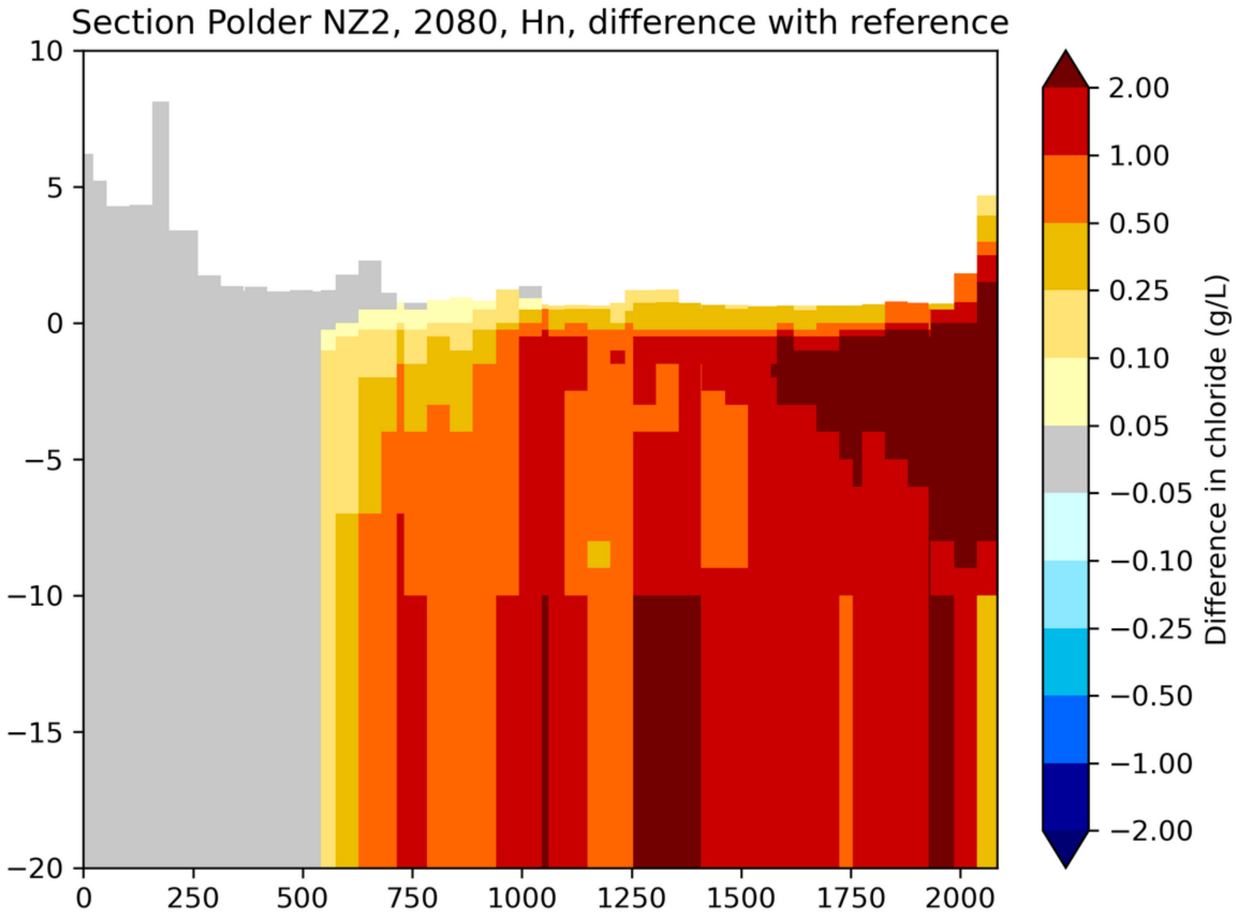

Figure C187: Location cross section polder NZ2 2080 Hn difference with reference (Deltares, 2024-a)

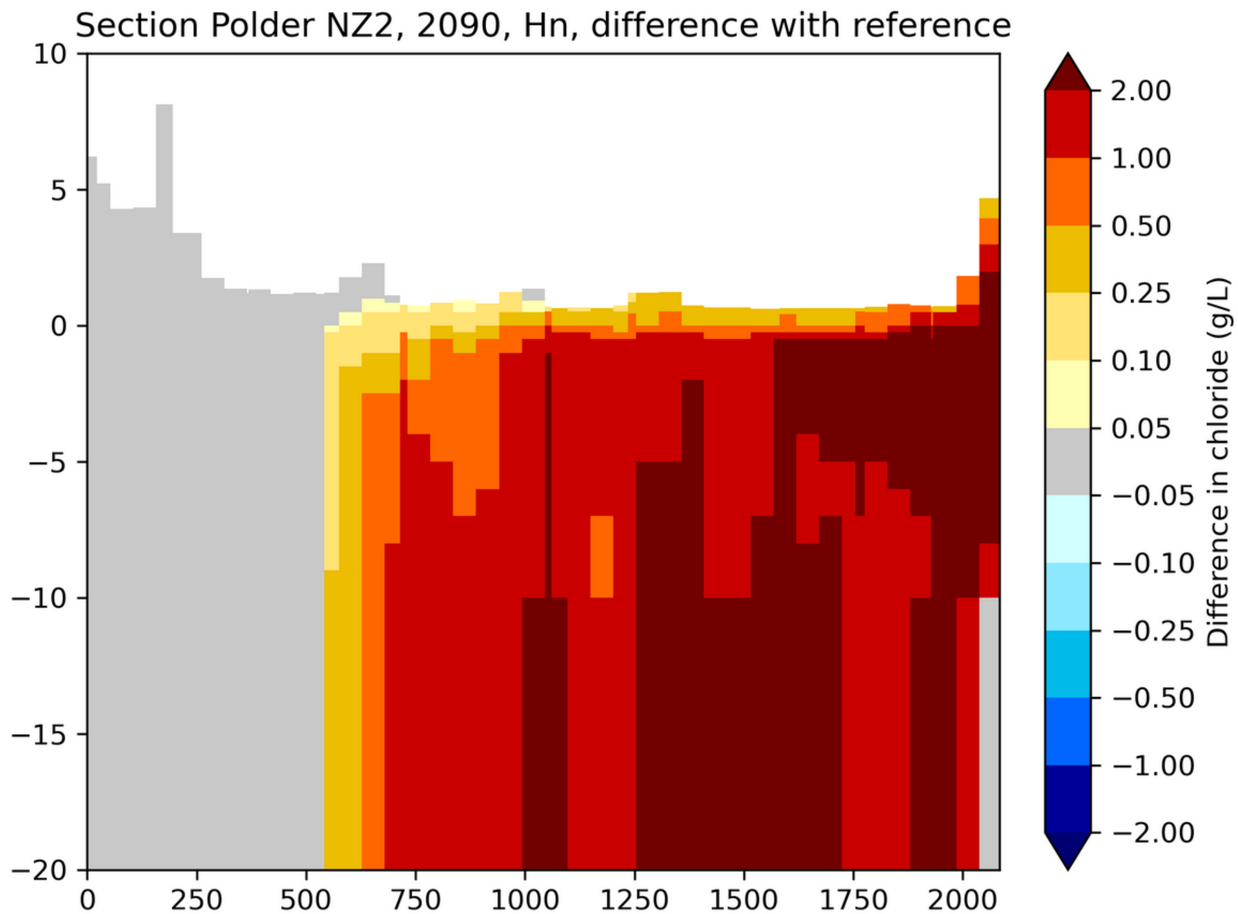

Figure C188: Location cross section polder NZ2 2090 Hn difference with reference (Deltares, 2024-a)

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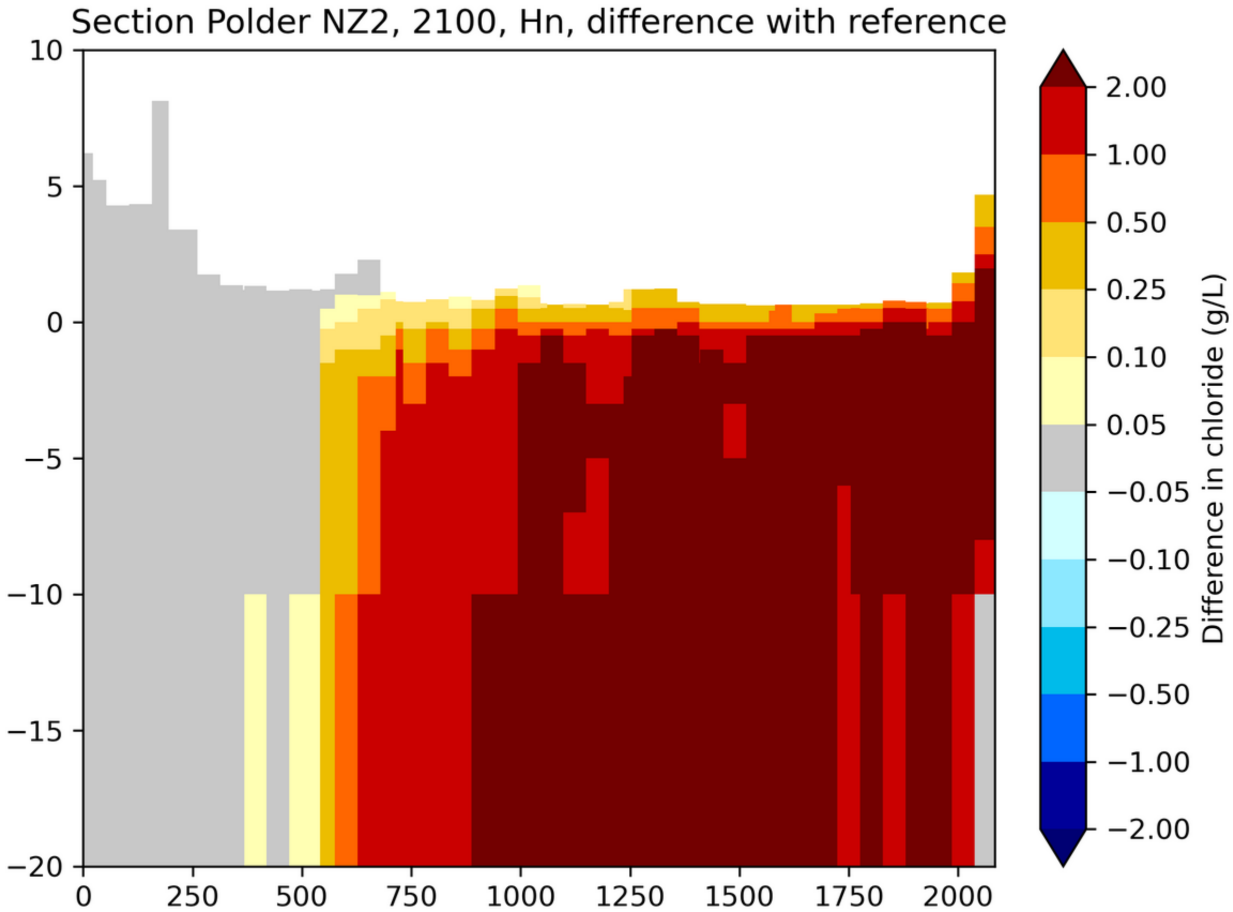

Figure C189: Location cross section polder NZ2 2100 Hn difference with reference (Deltares, 2024-a)

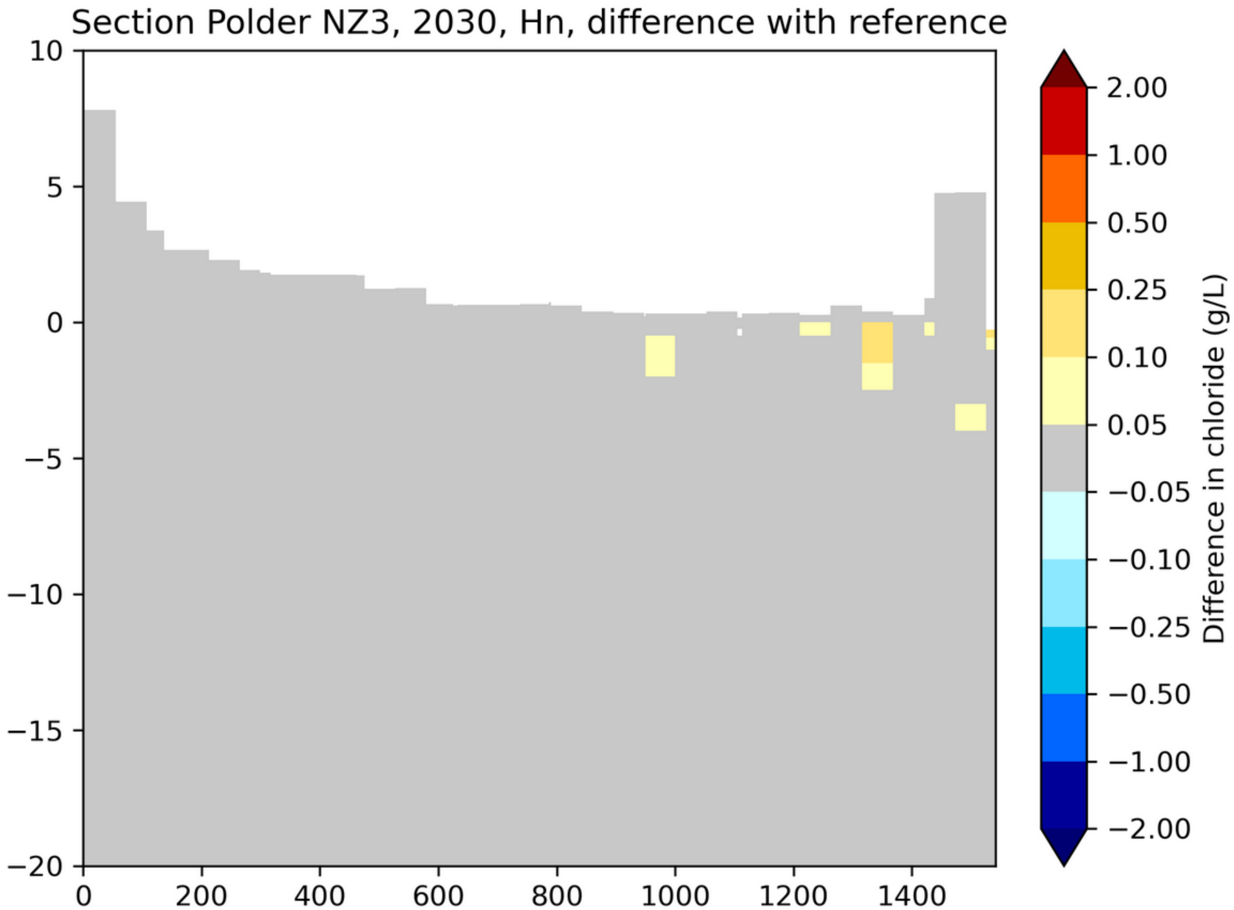

Figure C190: Location cross section polder NZ3 2030 Hn difference with reference (Deltares, 2024-a)

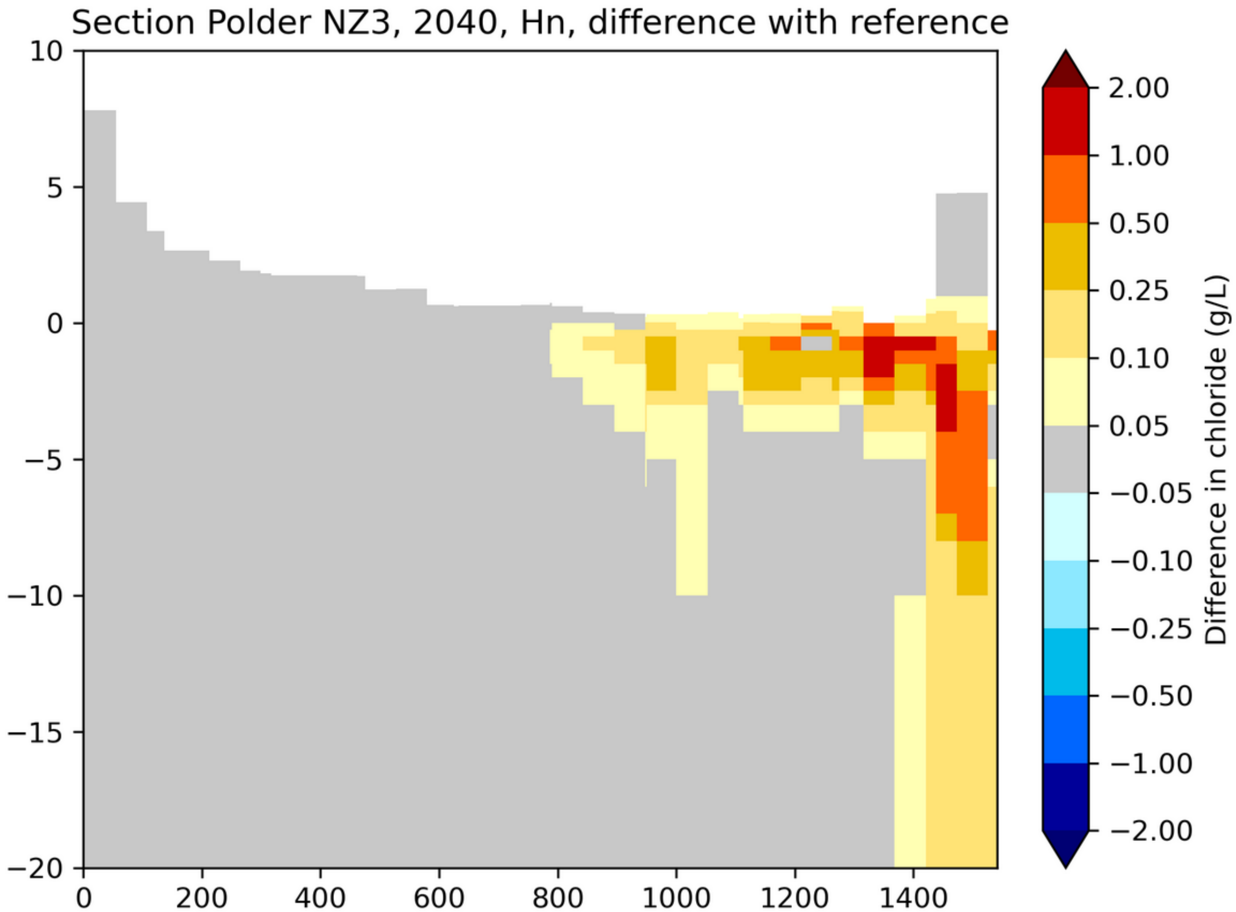

Figure C191: Location cross section polder NZ3 2040 Hn difference with reference (Deltares, 2024-a)

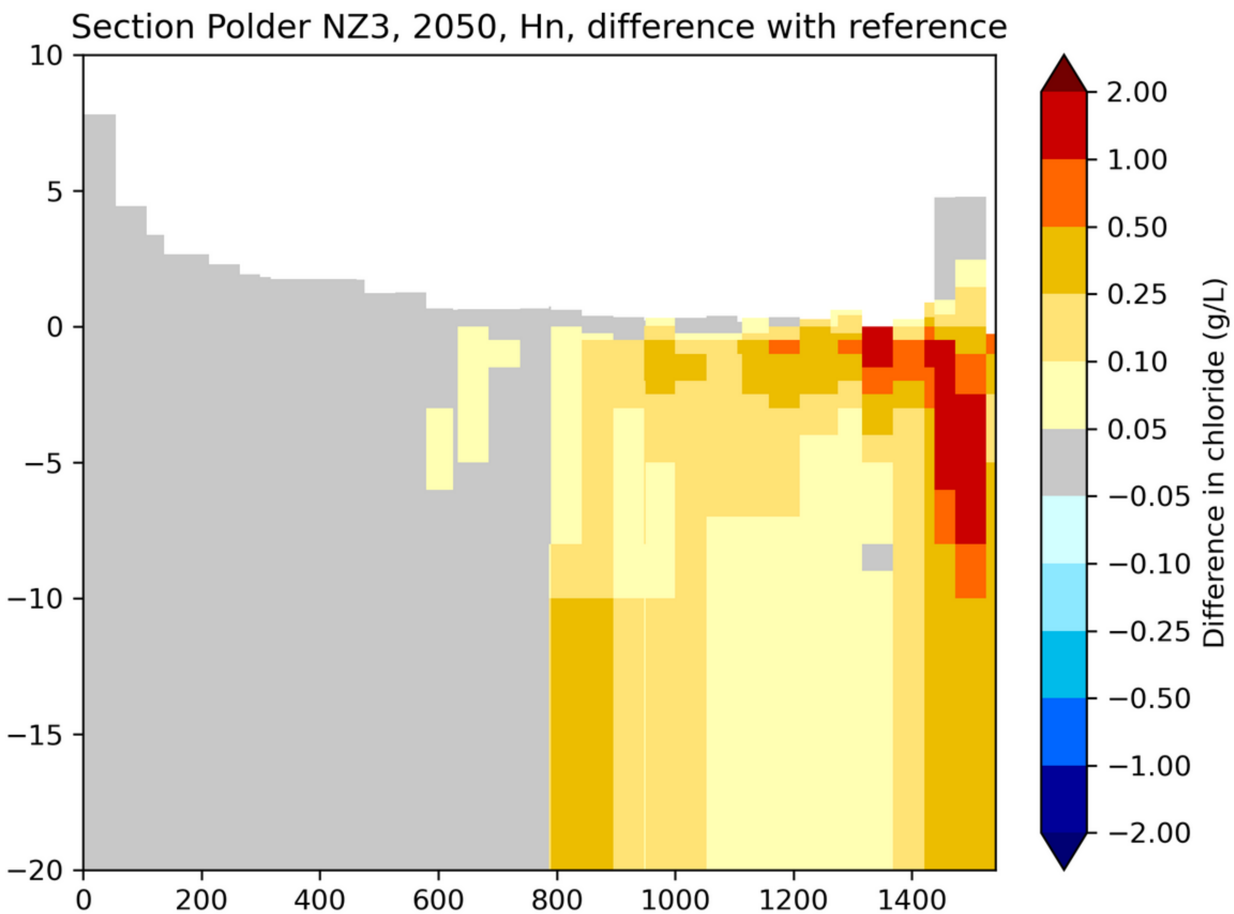

Figure C192: Location cross section polder NZ3 2050 Hn difference with reference (Deltares, 2024-a)

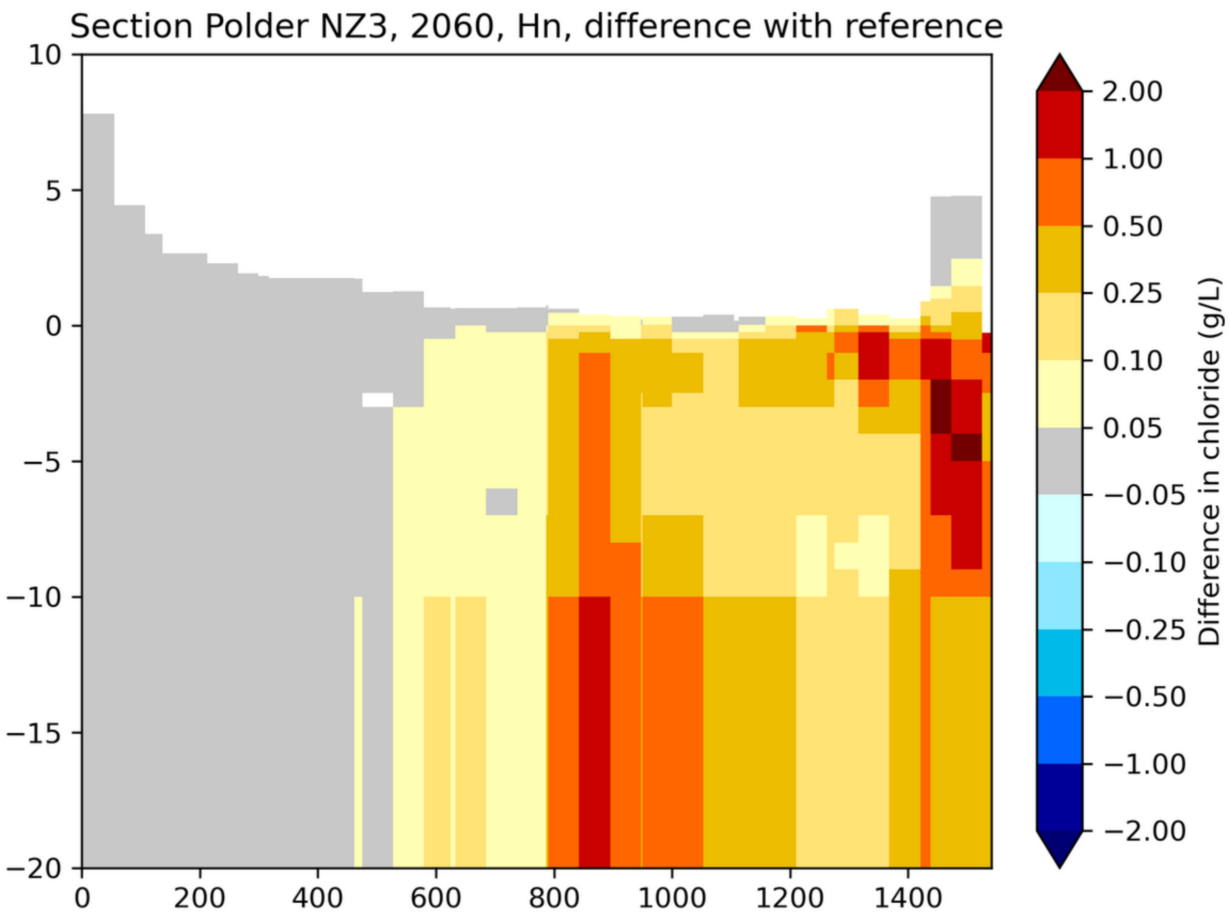

Figure C193: Location cross section polder NZ3 2060 Hn difference with reference (Deltares, 2024-a)

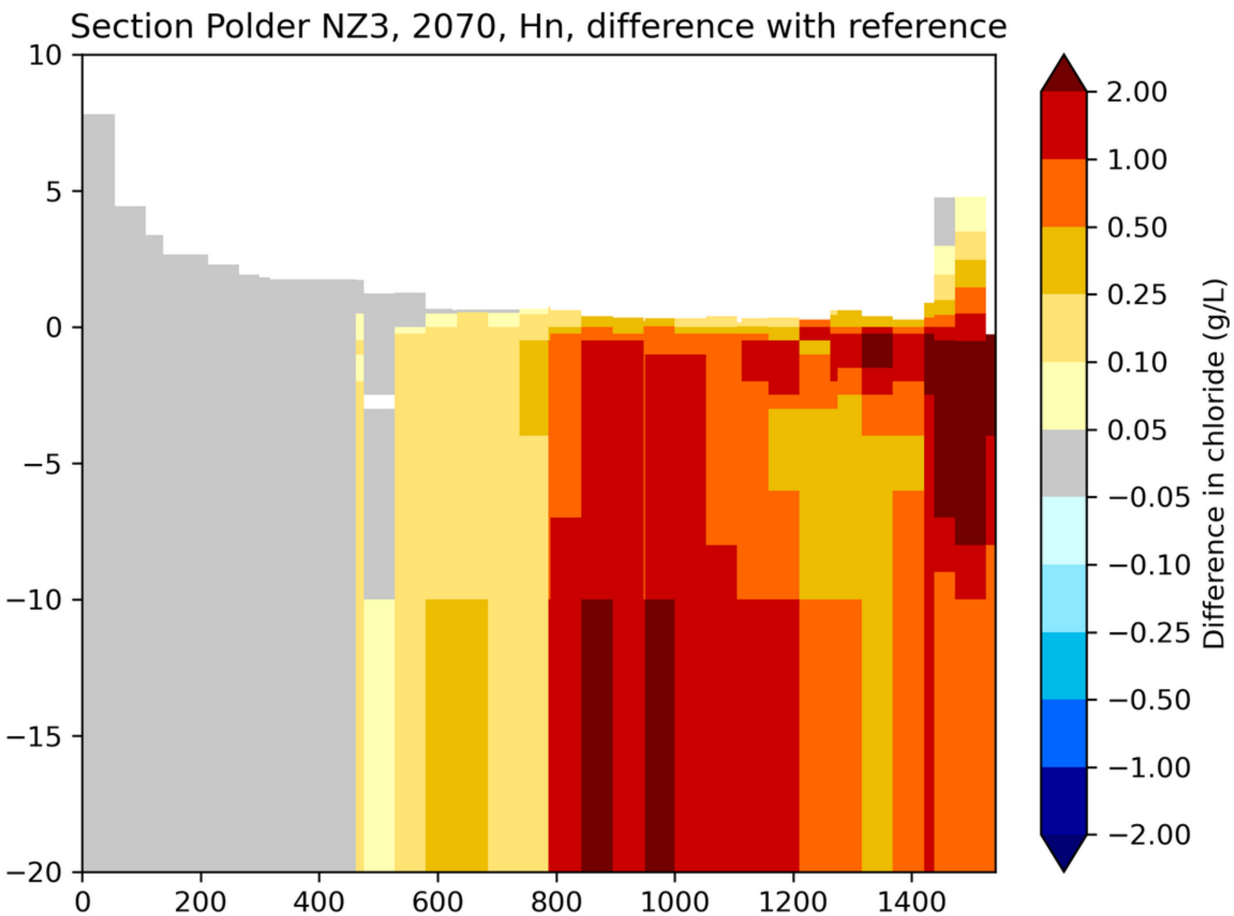

Figure C194: Location cross section polder NZ3 2070 Hn difference with reference (Deltares, 2024-a)

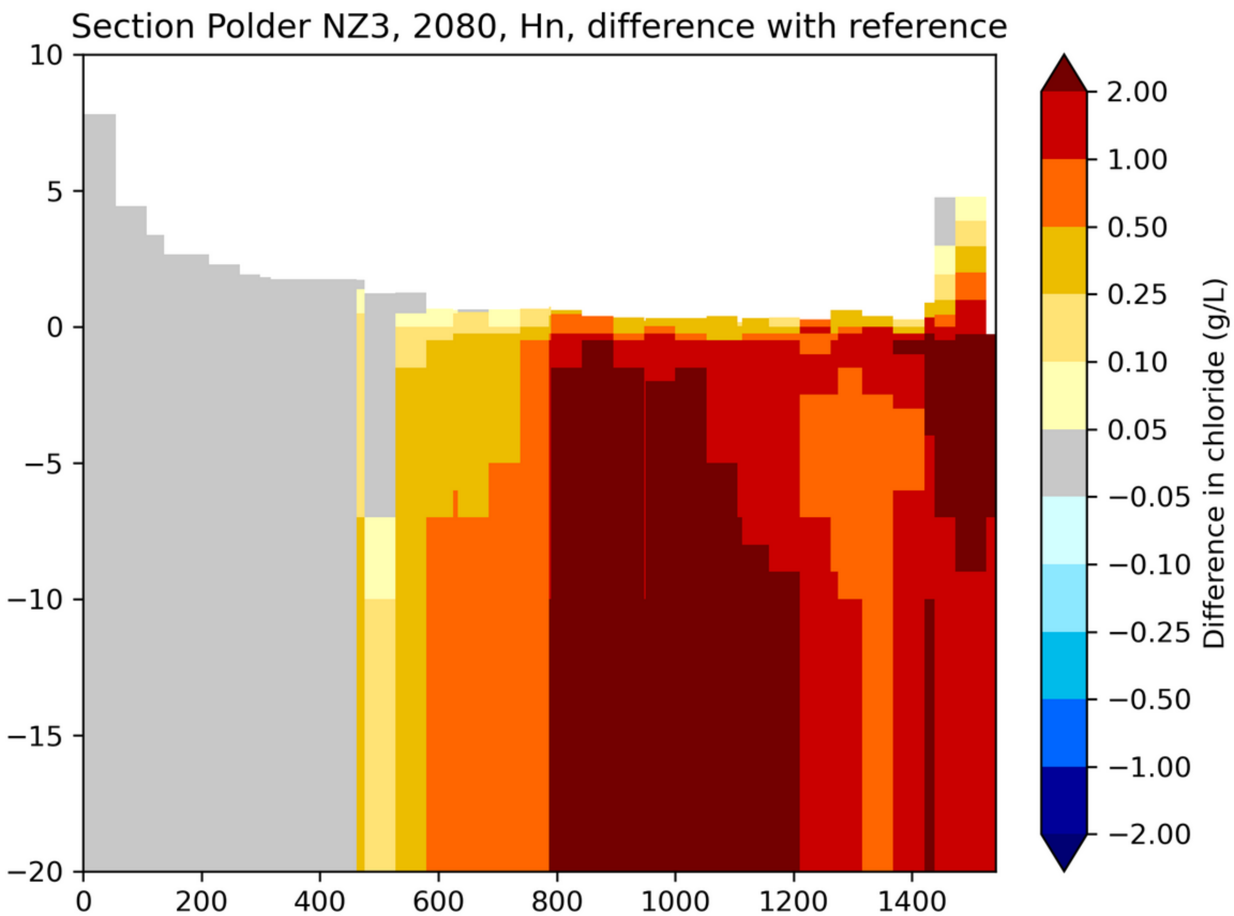

Figure C195: Location cross section polder NZ3 2080 Hn difference with reference (Deltares, 2024-a)

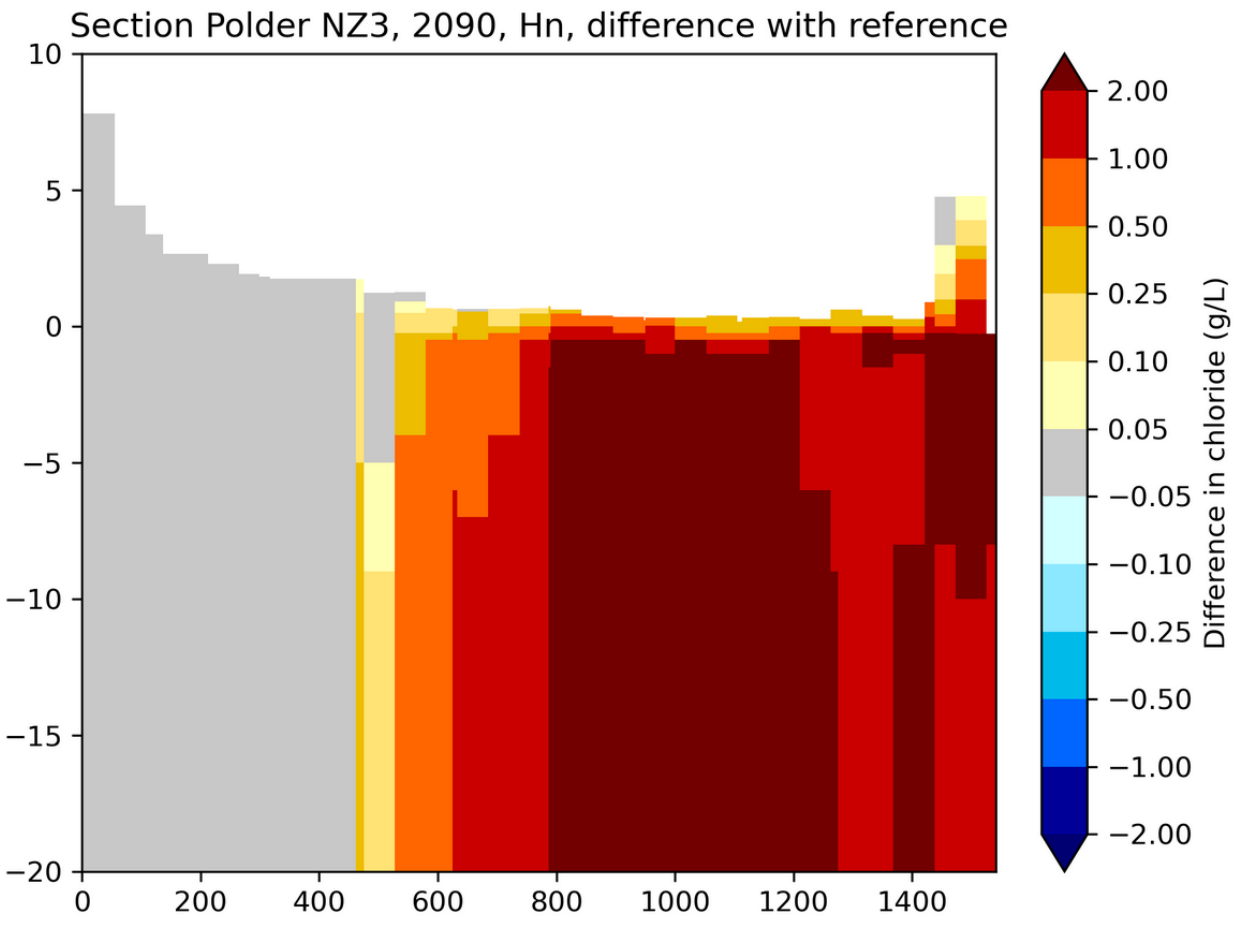

Figure C196: Location cross section polder NZ3 2090 Hn difference with reference (Deltares, 2024-a)

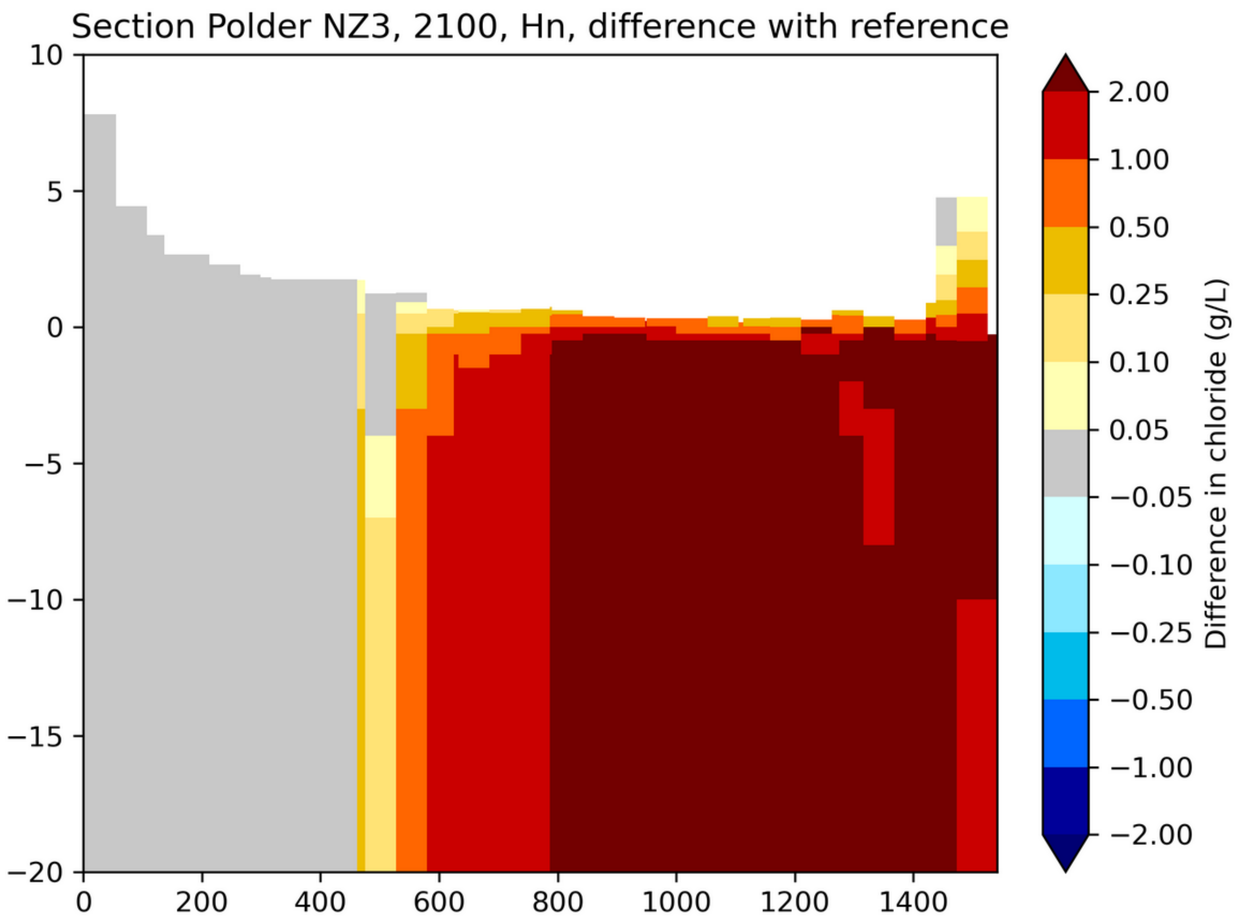

Figure C197: Location cross section polder NZ3 2100 Hn difference with reference (Deltares, 2024-a)