Delta21's contribution to the European Water Framework Directive

Can Delta21 contribute to meet the goals of the European Water Framework Directive?
- a qualitative impact assessment

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About Ziltelande

Ziltelande is a fresh new consultancy firm. Our team is currently composed of six Dutch master students from various studies at Wageningen University (Figure 1). The main disciplines are in ecology, marine biology and hydrology. The following part will introduce each individual and explain how they will complement each other.

Figure 1: From left to right: Koen, Jacco, Sofia, Wout, Lisa and Collin.

Collin studies Biology with a focus on aquatic ecology and has a personal interest in birds. He has experience with the Water Framework Directive and has knowledge on fish migration. He is highly task orientated and is good in finishing the last tasks. Lisa is our manager and has a background in biology with a focus on molecular ecology. She is good in coordinating and shaping ideas and always keeps the goal in mind. Wout studies Forest and Nature Conservation and has his focus on mammal-plant interaction and ecological dynamics. He is skilled in GIS and R and is a real team player. Sofia is a marine biologist and has the most expertise of our team on saltwater species. She likes to implement ideas and sees the small details that can improve a plan. She is our secretary. Jacco studies Earth and Environment and his disciplinary knowledge is on hydrology and spatial planning. He is skilled in GIS and is our creative mind. Besides, he is good in networking and knows how to get in touch with stakeholders. Koen is a hydrologist with a background in ecology. He is the controller and is good in analytically and critically assessing new ideas and shaping them into concrete plans.

Ziltelande is composed of various disciplines that are all needed to carry out our project. Our strengths lie in our motivation and collaborative mindset.

Executive Summary

Delta21 is a project that provides an alternative plan for flood protection for the Haringvliet delta whilst also assisting in the energy transition and aiding nature restoration and development. It has the ambition to re-open the Haringvliet sluices to restore the historical nature and its values in the area. The study area consists of three separate areas, Haringvliet West, Haringvliet East and Hollands Diep which can be split up in two water types: an estuary with moderate tidal influence (O2) and a freshwater tidal system (R8). Both have their own characteristics and quality requirements. Delta21 expects that its implementation will have a positive impact on the Dutch compliance to the European Water Framework Directive (WFD) guidelines for water quality.

This report was commissioned to provide an analysis of the impact of Delta21 in the study area and to assess whether the prognosed effects of Delta21 are positive and larger than the prognosed effects under current 'kier' management according to the WFD guidelines. The WFD score is based on two main assessment criteria, ecology and chemical quality. Under current management, the ecological quality is classified as poor, according to the WFD. The ecological quality includes assessments on biology, hydromorphology and physiochemical properties. Within the biological quality, the fish population is classified as poor. Therefore, the fish quality is mainly responsible for not adhering to the WFD goals. Rijkswaterstaat is responsible for the implementation of measures to reach the WFD goals. Therefore, Rijkswaterstaat is currently implementing new measures such as the 'kierbesluit' to improve the overall quality with which it aims to meet the WFD goals.

The main source of information used was literature. Comparisons between similar water types (e.g. Westerschelde), historical data and the current situation were used to estimate the impact of Delta21 and the 'kierbesluit'. Additionally, supporting interviews on specific topics were conducted with experts in the field and the team visited the study area.

In general, it is expected that both the 'kierbesluit' and Delta21 have a positive influence on the overall quality of the research areas. However, due to its larger impact on the entire research area, the Delta21 project is expected to have a stronger positive effect than the current 'kierbesluit', by altering habitats almost all in favour of positive indicator species for the biological quality assessments. The hydromorphology will also benefit from the Delta21 indicating an increase in the quality after realisation.

It is important to take into consideration that this report focussed on the qualitative part of the WFD assessment. In order to generate more reliable predictions, the quantitative analysis should be performed. What should also be considered is the uncertainty related to the effects of both climate change and management in the research area. Any positive effects attained through Delta21 implementations might disappear under certain predicted climate change scenarios. More intense droughts might affect the catchment area resulting in closure of the dam for several consecutive months in the summer period. This would have a large negative impact on the biology in the catchment. Also, the research area partly consists of a Natura2000 area, other (strict) law enforcements such as the Nature Law (2017) should therefore be taken into consideration. It is recommended to further study the adherence of Delta21 to these other laws in order to forestall any negative legal consequences for the project.

Samenvatting

Delta21 is een project dat een integraal alternatief plan voor waterbescherming biedt, waarin tevens de energietransitie en natuurherstel en ontwikkeling worden ondersteund. Het heeft de ambitie om de Haringvlietsluizen te heropenen om zo de historische natuur en bijbehorende waarden in het gebied te herstellen. Het volledige studiegebied bestaat uit drie losse gebieden, het Haringvliet West, het Haringvliet Oost en het Hollands Diep. Deze gebieden kunnen worden verdeeld in twee water types: Estuarium met matig getijverschil (O2) en Zoet getijdenwater (R8). Beide types hebben hun eigen karakteristieken en kwaliteitseisen. Delta21 verwacht dat de implementatie van het plan positief kan bijdragen aan het behalen van de Nederlandse doelen van Europese Kader Richtlijn Water (KRW) voor waterkwaliteit.

In deze rapportage wordt de kwalitatieve impact van Delta21 op het onderzoekgebied geanalyseerd en wordt uitgezocht of de voorspelde effecten van het Delta21 plan een groter positief effect hebben op het behalen van KRW-doelen dan het huidige 'kier' beleid. De KRW-scores zijn gebaseerd op twee boordelingscriteria; ecologische en chemische kwaliteit. Onder het huidige beleid is de ecologische kwaliteit volgends KRW-richtlijnen beoordeeld als ontoereikend. De ecologische kwaliteitsbeoordeling bevat onder ander de onderdelen biologie, hydromorfologie en algemene fysisch-chemische eigenschappen. Binnen de biologische kwaliteit wordt de viskwaliteit als matig geclassificeerd. Derhalve is de viskwaliteit de voornaamste reden waarom niet aan KRW-doelen voldaan wordt. Rijkswaterstaat is de verantwoordelijke partij voor de implementatie van maatregelen om aan de KRW-doelen te voldoen. Momenteel probeert zij met nieuwe maatregelen als het kierbesluit aan deze doelen te bewerkstelligen.

De informatie in dit verlag komt voornamelijk uit literatuur. Vergelijkingen tussen soortgelijke watertypes (bv. Westerschelde), historische data en de informatie over de huidige situatie zijn gebruikt om de prognose te schrijven over de impact van Delta21 en het kierbesluit op het onderzoeksgebied. Daarnaast zijn er ondersteunende interviews afgenomen met experts en heeft het team het onderzoeksgebied bezocht.

De verwachting is dat het kierbesluit en Delta21 beiden een positief effect hebben op de kwaliteit van het onderzoeksgebied, volgens de richtlijnen van het KRW. Echter verwachten wij dat het positieve effect groter is voor Delta21, omdat deze een positieve invloed heeft op verscheidene habitats, welke van belang zijn voor indicator soorten van de biologische kwaliteitsmeting van het KRW. Daarnaast zal de hydromorfologie ook profiteren van de realisatie van Delta21, wat een algehele kwaliteit stijging van het gebied tot gevolg zal hebben.

Het is belangrijk om in acht te nemen dat dit een kwalitatieve rapportage betreft. Om preciezere en meer betrouwbare voorspellingen te genereren zou een kwantitatieve analyse uitgevoerd moeten worden. Wat daarnaast ook overwogen moet worden is de onzekerheid betreffende de effecten van klimaatverandering en het beheer van het gebied. Positieve effecten van het Delta21 plan kunnen mogelijk worden tenietgedaan onder bepaalde klimaat scenario's. Intensere droogte kan het gehele stroomgebied beïnvloeden waardoor de sluis mogelijk meerdere maanden gesloten moet blijven, wat een sterk negatief effect zou hebben op de biologie in het stroomgebied. Daarnaast ligt een deel van het onderzoeksgebied in Natura2000 gebied, waardoor andere strikte wet- en regelgeving, als de Natuurwet (2017), tevens in acht moet worden genomen. Het wordt aangeraden om de mate waarin Delta21 aan deze regelgeving voldoet verder te onderzoeken om eventuele negatieve wettelijke gevolgen te ondervangen.

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1. Introduction

The Dutch coast has always been the battlefield of the contest between the Dutch people and the water. The result: major changes to the Dutch coast, with as most recent big changes the Delta Works, which were constructed after the dike failure of 1953. In that time, acute water safety had the highest priority. Nowadays, long term water safety has become a multi-disciplinary approach, in which sea level rise, climate change and nature are valued more important in the decision-making processes. Delta21 presents a plan to ensure the water safety of the Dutch people, with considering as much other interests as possible. Part of the Delta21 plan is to fully open the Haringvliet sluices and bring back the salty tide in the former estuary. This report will do a preliminary research on the effects of the Delta21 project on water quality in the Haringvliet and Hollands Diep, according to the Water Framework Directive (WFD).

1.1 Delta21 and Haringvliet estuary

Delta21 is a plan that proposes an alternative measure to ensure water safety. Due to climate change, global seawater levels are expected to rise between 26 and 110 cm by 2100, while extreme discharges of the Rhine will increase as well, threatening water safety in the lower delta of the Netherlands (Lenderink, Buishand, & van Deursen, 2007; Oppenheimer et al., 2019; te Linde, Aerts, Bakker, & Kwadijk, 2010). In the Delta21 project, pumps will be used to remove excess water out of the Dutch river delta during exceptionally high water levels due to storm-surges in combination with high river discharges. These pumps are located at the Energy Storage Lake which will be created next to Maasvlakte II as shown in Figure 2a. There will be a dam with a weir between this Energy Storage Lake and Goeree-Overflakkee, creating a Tidal Lake in front of the Voorne coastal area. Delta21 aims to contribute to the energy transition through the Energy Storage Lake. The pumps of the lake will be used to lower the water level when excess energy is available and generate hydropower when energy demand is high. This way, the Energy Storage Lake is used as a battery. Apart from this, the lake could be used for the generation of solar energy and salt-fresh water generators, possibly in combination with each other. Furthermore, the possibilities of aquaculture in the lake is under consideration (Delta21, 2019).

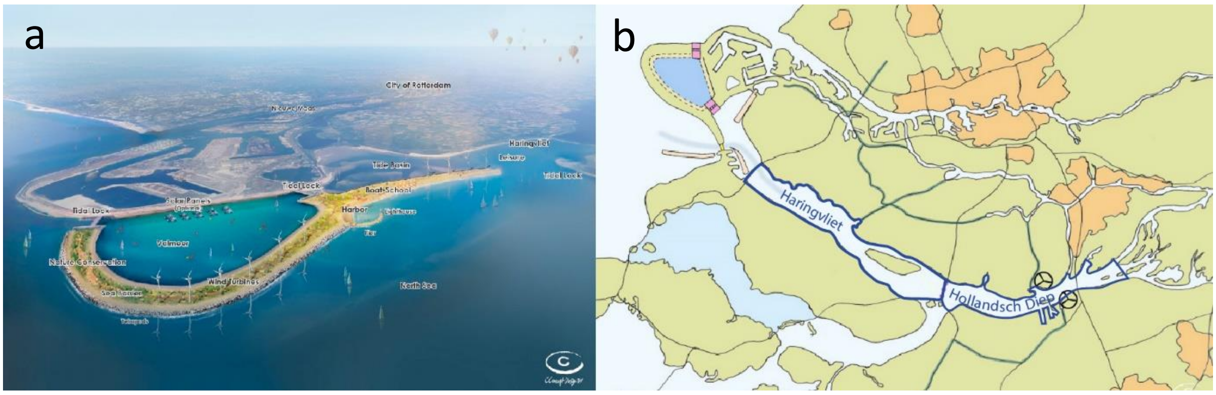

Figure 2: Artist impression of the Delta21 project with the energy storage lake. b) Location of the Haringvliet and Hollands Diep with respect to the Delta21 project (Delta21, 2019).

The Delta21 plan area lies in valuable nature areas. The most important impact will be in the Natura2000 protected pro-delta, in which the Energy Storage Lake is planned. In such cases, nature compensation and creation in other areas is required by Natura2000 legislation (European Commission, 2008). This compensation is, at least partially, planned in the Haringvliet and Hollands Diep (Figure 2b). The sluices of the Haringvliet dam will be opened entirely and only be (partly) closed if urgent conditions require it, letting saltwater enter the Haringvliet and restoring tidal influences

(Delta21, 2018a, 2019). The expected effects of Delta21 on water safety, energy transition and nature conservation are partially, described in several reports (Delta21, 2017, 2018a, 2018b).

Figure 3: Haringvliet sluices on ajar. Picture: Rijkswaterstaat.

Originally, the Haringvliet was an open estuary, with both saltwater influences from the open sea as well as freshwater inflow from the Rhine and Meuse. As a reaction to the storm surge of 1953, the coastline was shortened to protect the Dutch people by constructing dams, such as the Haringvliet dam. The brackish intertidal system disappeared, together with most of the species richness in the area (Tönis, Stam, & van de Graaf, 2002; van Dijk, 2019). The main goal for the restoration of estuarine dynamics is to gradually re-establish the estuarine processes and functions. This results in the (re)installation of typical estuarine habitats and biological communities, which are rare on a European scale (Ysebaert et al., 2016). In 2018, the sluice policy changed as stated in the 'kierbesluit' (also mentioned in this report as 'kier' management or simply 'kier'). The Haringvliet is now opened for a limited period per year (Figure 3). Though, the impact of this is not yet fully understood, the Delta21 project aims to further increase the opening, with the intention to improve the nature value even more (Wijsman et al., 2018). A more detailed description of the project area and history is provided in Appendix I.

1.2 Problem definition and research questions

The development and studies of the Delta21 project has mainly focused on flood risk protection. The implementation of the Delta21 project currently lacks predictions of its effects on aquatic biotope health and biodiversity in the Haringvliet and Hollands Diep. This study will assess these effects using the guidelines of the European Water Framework Directive (WFD), which goals are set for 2027. An introduction to the WFD is given in Appendix II. We strongly recommend reading this when you are unfamiliar with the WFD. Additionally, during communication with the commissioner (Delta21), it occurred to us that Rijkswaterstaat (RWS), the Dutch Ministry of Infrastructure and Water, is not able to comply to all objectives of the WFD before 2027. Therefore, we will discuss whether the implementation of Delta21 could contribute to compliance to the objectives.

1.2.1 Research question

We formulated the following main research question: *What are the qualitative effects of the Delta21 project on the water quality of the Haringvliet and Hollands Diep according to the guidelines of the European Water Framework Directive?*

1.2.2 Sub questions

To answer the main research question, we formulated the following sub questions:

1. Which water type will develop after realisation of the Delta21 project in the Haringvliet delta according to the Water Framework Directive guidelines?
2. What is the highest achievable water quality in the Haringvliet delta according to the Water Framework Directive guidelines for this water type, once the Delta21 project has been realized?
3. What is the current ecological status according to the Water Framework Directive in the Haringvliet delta?

4. What is the expected impact of the ‘kier’ management versus the impact of the Delta21 project on the water quality (chemical and ecological quality) in the Haringvliet delta, according to the Water Framework Directive?
5. What are our recommendations, after implementation of the Delta21 project, to contribute to the goals of the Water Framework Directive in the Haringvliet delta?
6. Could the implementation of Delta21 contribute to the compliance of Rijkswaterstaat to the Water Framework Directive goals in 2027?

1.3 Structure of the report

This report starts with explaining the guidelines of the WFD, its standards and the reference situations of the waterbodies in Chapter 2, which will answer question 1 & 2. Secondly, the current situation of the Haringvliet and Hollands Diep is described in Chapter 3, which answers question 3. In Chapter 4 the predicted future situation is described for 2050, both for the ‘kierbesluit’ as well as a full opening of the Haringvliet dam as projected by Delta21. This chapter answers question 4. We will discuss our study and recommendations in Chapter 5, answering question 5 & 6. Finally, we close our report with a conclusion in Chapter 6. This study will assess the ecological impacts based on the criteria from the WFD. We will consider four situations for which we will define the water quality according to the WFD:

1. The optimal reference situation for the Haringvliet and Hollands Diep, according to the Water Framework Directive. (Chapter 2)
2. The current situation in 2018, without the effects of the ‘kierbesluit’. (Chapter 3)
3. The expected situation in 2050, with the effects of the ‘kierbesluit’. (Chapter 4)
4. The expected situation in 2050, with the effects of fully opening the Haringvliet dam, according to the Delta21 project. (Chapter 4)

This report will focus on a qualitative ecological assessment and will set a baseline for additional quantitative research on the ecological impacts of Delta21 on the Haringvliet and Hollands Diep. For the current situation we will use the existing quality assessments. For the expected situations in 2050 we will use existing research and translate this to an expected assessment of the WFD. Climate change and sea level rise are not entrained in the final assessment but will be mentioned when their influences are expected to be of importance. Additional to our reference list, we describe our most used references. As our report is a preliminary research, having the most used references summarised makes it easier for other organisations to build upon it. Some additional information is attached in the several Appendices.

2. Reference Ecological Status

This chapter is written according to the guidelines composed by the STOWA (2018). This directive is based on natural water types. Therefore, the measure used in this chapter is the Good Ecological Status (GES). For more explanation, see Appendix II.

2.1 Introduction

The historical situation of the Haringvliet, before construction of the 1970 dam, would be classified as an estuary with moderate tidal range (O2) (Meijer & Weel, 2007; Peelen, 1967; STOWA, 2018). The classification is based on different abiotic factors influencing the water system. The characteristics for the specific water type O2 are shown in Table 1.

Table 1: Characterisation of water type O2 according to the Water Framework Directive (STOWA, 2018).

WFD parameter	**Range**	**Unit**
Salinity	Variable	g Cl/L
(average) Tidal range	1-5	m
Discharge freshwater	100 – 200	m^3/s
Wave height	0 – 0,4	m
Water depth	0 – 30	m
Mineral sludge*	0 – 10	%
Mineral sand	100 – 90	%
**Fraction <63 µm*		

There are multiple classifications for tidal waters; salt, brackish and fresh tidal systems within the Water Framework Directive. Salt levels in the Haringvliet and Hollands Diep will decrease gradually while moving inwards. The research area of this study is the Haringvliet and Hollands Diep and therefore this study will only consider brackish and freshwater tidal systems since a saltwater tidal system will not occur in our research area. It is predicted that Hollands Diep will have a salinity of <300 mg/L at the east part of the of the water, depending on rivers discharge and the tide (Peelen, 1967; Wijsman et al., 2018; Wolff, 1973). Within the WFD, waters with a salinity of <1000 mg/L are characterised as fresh tidal water on sand/clay (R8), see Table 2.

Table 2: Characterisation of water type R8 according to the Water Framework Directive (STOWA, 2018).

WFD parameter	**Range**	**Unit**
Gradient	< 1	m/km
Stream velocity	< 50	cm/s
Geology >50%	gravel	m
Width	> 25	m
Surface area river basin	> 200	m^2
Permanence	N.A.	
(average) Tidal range	0.3 – 1.9	m

Currently, Haringvliet East/Hollands Diep is classified as water type R8 (fresh tidal water) (Factsheet, 2018; STOWA, 2018) and Haringvliet West is classified as water type O2 (estuary with moderate tidal range) (Factsheet, 2018; STOWA, 2018). However, the characteristics for the specific water type R8 argue in favour of the R8 type (Table 2), a freshwater body with tidal influences for Haringvliet West. We think that this inconsistency in characterisation can be attributed to the subdivision of the Haringvliet in Haringvliet West and Haringvliet East. The division is made approximately on the line

Spui-Middelharnis. In Haringvliet West salt might intrude the waterbody through the sluices inducing an O2 water type. Based on the current assessments and available literature, we decided to describe the current situation of the Haringvliet West as an O2 water type (Compendium voor de Leefomgeving, 2016; Factsheet, 2018), Haringvliet East and Hollands Diep are combined and described as an R8 (Table 3). After implementation of the 'kierbesluit' or Delta21 the current water types in the research area will remain the same. However, the border between O2 and R8 might shift. This is further explained in Chapter 4.

Table 3: The Haringvliet is separated into West and East on the line Spui-Middelharnis. The western part is an O2 water type, the eastern part and the Hollands Diep are both an R8 water type.

Waterbody	Water type
Haringvliet West	O2 (estuary)
Haringvliet East and Hollands Diep	R8 (freshwater with tidal influences)

2.2 Abiotic factors

2.2.1 Hydromorphology

The hydromorphological requirements to conform to the reference situation standards, for a 'high' quality assessment, are relatively simple for water type R8. Water type O2 requires, at a minimum, 80% natural shoreline. Natural shoreline is defined as a natural transition from land to water which does not limit the surface area of the water with anthropogenic alterations (STOWA, 2018). This inhibition may be caused by, for example, dikes, shore defences or impolderment (STOWA, 2018). Water type R8 should have a river discharge between 600 and 5341 m^3/s and a flow speed between 0.001 and 1.5 m/s (STOWA, 2018). The ideal situation for adherence to the WFD would see the Haringvliet sluices opened completely in order to fully restore tidal influences in the Haringvliet Delta. Fresh tidal water (R8) has a tidal range between 0.3 and 1.9 meter. The estuary (O2) is described by STOWA as a water body with a tidal wave of 1 to 5 meter. Water types R8 and O2 have no further required specifications for tidal elements or river discharge (STOWA, 2018). Hydromorphological quality requirements are the conditions which determine the difference between a GES and a reference ('high') quality assessment. The abovementioned requirements are not immediately relevant for the Haringvliet delta, as it is currently classified as a heavily modified water body and thus cannot score higher than a GEP rating.

2.2.2 Physiochemical properties: salt- and freshwater occurrence

A fully opened Haringvliet sluice would cause maximal salt intrusion into the Haringvliet Delta. This is desirable for restoration of natural estuarian habitats like estuary water type O2. Water type O2 has no specific salt requirements, whereas fresh tidal water type R8 has a maximum salt content of 300 mg Cl/L to meet the 'high' criteria of the WFD (STOWA, 2018). These values are seasonal averages advised to be measured at about 30cm under the surface (Rijkswaterstaat, 2014b).

2.2.3 Physicochemical properties: oxygen, transparency, acidity, nitrogen, phosphorus

The fresh tidal water type R8 has six physicochemical quality requirements to fulfil in order to satisfy the 'high' requirements. Daily water temperature should not exceed 23 °C. Oxygen levels should be in between 70% and 110%. PH levels should be between 6.5 and 8.5. Concerning nutrients: nitrogen levels should not exceed 2 mg 'total nitrogen'/L, whereas total phosphorus levels should not exceed 0.06 mg/L. 'Total nitrogen' includes all nitrogen containing molecules in the water. Salt levels should not exceed 300 mg Cl/L (STOWA, 2018).

The estuary water type O2 has three physicochemical quality requirements to fulfil in order to satisfy the 'high' requirements. Daily water temperature should not exceed 21°C. Oxygen saturation should not be lower than 80%. Concerning nutrients, winter levels for dissolved inorganic nitrogen should not exceed 0.22 mg N/L or 15.6 µmol N/L. These values are winter values which are only valid with a salinity of 30 or higher. For lower salinity values the norm for mg nitrogen per litre can be calculated using the following formula: 2.59 - 0.071 * Salinity (STOWA, 2018). Transparency used to be applied but has been removed as a quality for type R8 and O2 because no clear range could be applied. A low transparency could indicate too many algae but could also indicate sediments. The latter is considered as positive because of more sediment dynamics (STOWA, 2018; van der Molen, Boers, & Evers, 2006).

2.2.4 Other specific pollutants

The WFD defines maximum levels for a wide range of polluting substances totalling approximately 100 chemicals (Rijkswaterstaat, 2015). In order to fulfil the requirements for a 'high' rating, these threshold values should not be exceeded for a single substance on the list. As the list is very long, only those exceeding their thresholds or those that are expected to exceed their threshold are discussed in upcoming chapters.

2.3 Biology

The four parameters used by the WFD to assess the biology of a waterbody are: fish, macrofauna, water plants and phytoplankton (STOWA, 2018). The species composition in an estuary is mainly influenced by waterflow, turbidity, salinity, temperature in combination with oxygen levels, sediment type, water depth and whether the soil runs dry. The Haringvliet East/Hollands Diep will be a freshwater body influenced by the tides as explained before. Its species composition will mainly consist of species which are adjusted to the tides. This implies that they need to be able to survive variations in currents, instable substrates and they need to survive running dry (STOWA, 2018).

2.3.1 Fish

Amongst the present fish species are species which entire life cycle is completed in an estuary; these species are called estuarian resident species. Other species use the estuary as nursery, these are called marine juvenile species. The migrating fish species that use the estuary as passage are called diadromous species and can be subdivided into catadromous (spawn in marine environment) and anadromous (spawn in fresh water) fish species. These diadromous species depend on the passage from the sea to the river or vice versa to complete their life cycle. Estuarian fish species composition and abundance is dynamic and seasonal depending. During certain seasons, species might use the estuary to spawn or forage, these species are classified as seasonal guest. Additionally, there are freshwater fish species which forage in the estuary. This categorisation is based on the classification by Elliott & Hemingway (2002) and used in the WFD and the categories are called guilts.

Table 4 is retrieved from the WFD guidelines (STOWA, 2018), translated and adjusted for this report. It displays the number of fish species present per category if the Haringvliet would optimally function as estuary. There would be 9,6 diadromous species, 11,2 estuarian resident species, 8,8 nursery species, 5,6 seasonal guests and 8,8 freshwater species during sampling for the 'high - good' standard. These exact sampling rules and calculations can be found in the STOWA (2018) guidelines.

Table 4: Displays the species composition for an O2 water, according to the number of species per guilt that needs to be present to meet the accompanying statuses of the WFD. EQR is the Ecological Quality Ratio as described in Appendix II. Table is retrieved from STOWA (2018).

Number of	**Reference**	**High - Good**	**Good - Moderate**	**Moderate - Poor**	**Poor - Bad**
Diadromous species	12	9,6	7,2	4,8	2,4
Estuarian resident species	14	11,2	8,4	5,6	2,8
Nursery species	11	8,8	6,6	4,4	2,2
Seasonal guest species	7	5,6	4,2	2,8	1,4
Freshwater species	11	8,8	6,6	4,4	2,2
EQR	1	0,8	0,6	0,4	0,2

In the freshwater body, rheophile and eurytopic species are present. These terms encompass fish species which are respectively living in flowing water and species which live in both flowing and nonflowing water types. Moreover, some diadromous species are present. They live in the sea or in the estuary, but spawn for example in these fresh waters. Species specifically mentioned in the WFD are European Flounder (*Platichthys flesus*), European smelt (*Osmerus eperlanus*) and Twait shad (*Alosa fallax*). Moreover, the waterbody functions as migrating route for anadromous species such as the Sea trout (*Salmo trutta trutta*) and Allis shad (*Alosa alosa*).

Table 5 is retrieved from the WFD guidelines (STOWA, 2018), translated and adjusted for this report. For the Hollands Diep we use the GEP, similar to the Factsheet (2018). If the Hollands Diep would function optimally according to the guidelines as a freshwater body, there would be 15-16 rheophilic fish species, 10-11 diadromous species and 4-5 limnophilous species (species that live in nonflowing water).

Table 5: A display of the number of fish species per category per status for an R8 water type. EQR is the Ecological Quality Ratio as described in Appendix II. Table is retrieved from STOWA (2018).

Number of	**High**	**Good**	**Moderate**	**Poor**	**Bad**
Reophilous species	>16	15 – 16	12 – 14	10 – 11	<10
Diadromous species	>11	10 – 11	7 – 9	5 – 6	<5
Limnophilous species	>5	4 – 5	2 – 3	1	0
EQR	0.9	0.7	0.5	0.3	0.1

For an assessment of the fish species in the waterbody, the WFD also describes abundancies of certain species. However, our report focusses specifically on a qualitative analysis, not quantitative. Therefore, we will not elaborate further on this guideline.

2.3.2 Macrofauna

The term macrofauna is used for invertebrates visible with the naked eye. This macrofauna is measured differently for both water types. The exact method and calculations can be found in (STOWA, 2018). Estuarine habitats (O2) have a low species diversity for the macrofauna. For the macrofauna community species richness and density increases with increasing salinity (Heip et al., 2006; Soetaert, Vincx, Wittoeck, & Tulkens, 1995; Ysebaert et al., 2003). The majority of the species which remain along the gradient are from marine origin as they are better adapted to salt fluctuations. Additionally, the species composition changes from filter feeders, such as the Common cockle (*Cerastoderma edule*) and the Blue mussel (*Mytilus edulis*), to deposit feeders, such as the Sandworm (*Alitta virens*) and Mud shrimp (*Corophium*). Other factors influencing the species composition are water currents and the soil running dry (Heip et al., 2006; Soetaert et al., 1995; Ysebaert et al., 2003).

To assess the quality of the estuary, three indices are used. First the species richness expressed in number of species or taxa for a sample or dataset. Second the Shannon index (log2), this is a measure for expressing species or taxa diversity in a sample or dataset. Thirdly, a software program called AMBI, which is developed to assess the quality of benthic macroinvertebrates communities (AZTItecnalia, 2019). The STOWA (2018) report and the report by Gittenberger & van Loon (2011)contain lists and tables with all possible present macrofauna species. They describe whether a species occurrence is necessary and what the optimal estuary density is for some specific species. The list used is static, this means that the situation is either good or not.

In a freshwater body with tidal influences (R8), the macrofauna species are assessed according to the standards developed by Peeters, de Lange, de la Haye, & Reeze (2010). The fresh tidal waters can be distinguished from brackish waters as there is a larger species diversity in insects and Oligochaeta. Their characteristic species are Swollen spire snail (*Mercuria confusa*) and larvae of the mosquito (*Thalassosmittia thalassophila*). As stated before, specific measures and guidelines are developed for the R8 water type as there is no reference situation available. To determine the reference situation, Peeters et al. (2010) did a data-analysis on 900 samples from 15 years of collecting. After sampling, all organisms need to be identified upon species name. Next, multiple sub standards are calculated based upon the EQR (Ecological Quality Ratio). This means that the number of found genera, are divided by the reference genera number. The exact calculation can be found in the report (Peeters et al., 2010).

2.3.3 Water flora

Water flora is an important aspect of the estuary ecosystem facilitating habitats for both fish and macrofauna. Not only do these groups need the plants as habitat, for some species the salt marsh flora is necessary for the completion of their life cycle (Hughes, Hughes, & Smith, 2013). Within the water type O2, two quality assessments occur regarding the vegetation, salt marsh vegetation species and more specifically seagrasses. The WFD distinguishes the salt marsh vegetation zones and seagrasses from each other in their quality assessment regarding the reference situation. This report only focusses on the reference quality. However, within the STOWA (2018) document the quantity of these habitats also has an impact on the ideal reference situation. The distribution of different vegetation zones is a direct measure regarding the quality of the salt marshes.

The quality assessment for water flora is based on a balanced distribution of the habitat types occurring in the estuary. The seagrass habitat consists of Common eelgrass (*Zostera marina*) and Dwarf eelgrass (*Zostera noltii*). Regarding the quality assessment of the salt marshes in general, five vegetation zones are distinguished. The vegetation zones consist of the following stadia; pioneer, low, middle and climax. The climax stadium consists of either Couch grass (*Elytrigia atherica*) or Reed (*Phragmitis australis*). Each zone should contribute to the total vegetation habitat with a percentage of the cover between 5% and 35%. Furthermore, the abundance of climax vegetation with Couch grass may not occur more than 50% in order to reach the reference quality. For a complete assessment of the overall quality of the vegetation, the quantity and quality are inseparable. Reference conditions (MEP) are set specifically for each water type O2 occurring in the Netherlands. The quantitative quality is based on the percentage covered by either one of the vegetation zones, explained in detail in the report from (Wielakker, Bak, & Reitsma, 2011). The quality of seagrass cover is based on the composition of Common eelgrass (*Zostera marina*) and Dwarf eelgrass (*Zostera noltii*) related to one another. Within the quality assessment shown below (Table 6), there are three coverage categories distinguished. They range from 5-20%, 21-60% up to 61-100% seagrass coverage. Each category has its unique different reference situation for the seagrass cover. The ideal composition for Common eelgrass (*Zostera marina*) related to Dwarf eelgrass (*Zostera noltii*) is shown in Table 6 as well (Wielakker et al., 2011).

Table 6: Optimal area distribution (%) for seagrass coverage. Based on the reference condition (REF), and the 'Good' Ecological Status (GES). The table is adapted from Wielakker et al. (2011).

	REF			**GET**			**REF**	**GET**
Seagrass cover (%)	5-20	21-60	60-100	5-20	21-60	60-100	Average cover	Average cover
Common eelgrass	50	40	10	70	30	0	30	20
Dwarf eelgrass	10	40	50	30	50	20	60	40

Since for seagrass the final quality assessment also depends on both quantity and quality inseparable, it is important to mention the quantitative aspect as well. The reference condition for seagrass coverage in water type O2 is set at a total surface area coverage of >7,5% seagrass fields, dominated by Common eelgrass (*Zostera marina*) and Dwarf eelgrass (*Zostera noltii*) (STOWA, 2018).

For most water types, this is based on the database from a real water system within countries that are part of the European Union. However, for the water flora reference in water type O2 there is neither a database nor a reference site present in the European Union. Therefore, the validation has been based on the judgement of expert concerning this water type (STOWA, 2018). For the R8 water type, the quality of the water flora is based on the occurrence of certain vegetation types. As shown in Table 7, a different abundance related to the total area has a different outcome regarding the quality. When almost no vegetation occurs regarding to the coverage of submerged, floating and emerged plants (<0,5%), the quality is bad. However, a domination of 50-100% coverage scores moderate, indicating that a balanced occurrence of these different vegetation groups is desired for the reference situation. Moreover, the reference situation for water type R8 is that 10% of the suitable habitat area is covered by emerging, submerging or floating water plants. Table 7 lists the different quality requirements for the flora. Within this water type also the bank region is assessed on its quality. The quality of the ecological status for the bank zone is based on the percentage of the total area that is covered by rush vegetation. This is compared in relation to the total that vegetation can cover on the shore. The reference value for this is a coverage of 30% with rush vegetation (STOWA, 2018).

Table 7: Quality assessment water flora R8 water type (cover percentage and area percentage on the overgrown area (STOWA, 2007).

	Reference value	**High**	**Good**	**Moderate**	**Poor**	**Bad**
Submerged, floating and emerged plants	30%	5 - 25%	2 - 5% 25 - 50%	1 - 2% 50 - 100%	0.5 - 15%	< 0.5%
Bank plants	30%	> 25%	15 - 25%	7 - 15%	2 - 7%	< 2%

In the sixth appendix of STOWA (2018) document there is a list with all water plants that are characteristic for certain water types. For each specific water type, the impact based on the abundance of that species is described in this document. Based on the relative abundance of the possible characteristic water plants, a score can be given to each water. This score is based on the relative amount and abundance of these different plants. Reference conditions for the plant species composition is based on a value. This value is a direct index of the quality and species composition and is based on five repeated measurements. How the measurements are conducted is explained in the document from STOWA (2018). For water type R8 this value is 38 (STOWA, 2018). For water type R8 the validation for water flora is mainly based on field studies and literature descriptions. These descriptions are based on reference areas such as the Schelde and Elbe. Research from Zonneveld (1960) in the Biesbosch has also been of great importance to create reference sites for this water type (STOWA, 2018).

2.3.4 Phytoplankton

The parameter phytoplankton is only assessed in marine waters, estuaries and lakes. Estuaries form due to their fluctuations in salinity extreme circumstances for phytoplankton. This salinity gradient largely determines phytoplankton quantity and composition. Species richness is highest in deep salt parts of the water, lowest in brackish water zone and increases again in freshwater zones. The majority of the species are diatoms. Due to the high turbidity in estuaries, the phytoplankton bloom (yearly increase in biomass) is late in the parts with high salinity. In the freshwater areas, the phytoplankton is dominated by cyanobacteria and green algae. The estuary (O2) is sampled during the summer period between 1st of March until the 30th of September. The assessment is based on the chlorophyll-a concentrations. The phytoplankton is not identified up to species levels, it is a quantitative assessment. Table 8 shows that 12 µg/L is the maximum chlorophyll-α concentration to get the status 'high'. The GEP would be a maximum of 18 µg/L chlorophyll-α. The reference situation (1,00) is based upon models which use data from the Ems-Dollard area (Baptist & Jagtman, 1997).

Table 8: Boundaries for chlorophyll-A for transitional and coastal waters and M32 (90 percentile). Retrieved from the STOWA (2018).

Type	EKR	1.00	0.80	0.60	0.40	0.20	0.00
M32, O2		8	12	18	36	72	144

2.4 Chemical quality

The chemical quality is assessed using 33-45 different chemicals. For each chemical separately, the 'Rijksinstituut voor Volksgezondheid en Milieu' (RIVM) has set a norm which should not be exceeded. The list is too long to cover all chemicals in this report, however they can be found in (*Richtlijn 2013/39/EU van het Europees Parlement en de Raad*, 2013). Each chemical with its corresponding norms can be found in the database of the RIVM (RIVM, 2019). In this report, only chemicals which exceed the norm or might exceed the norm will be discussed based on the (Factsheet, 2018). The norms of those chemicals are shown in Appendix IV.

2.5 Chapter summary

The Haringvliet can be subdivided into Haringvliet West and Haringvliet East. Haringvliet West is currently classified as an O2. Haringvliet East and Hollands Diep are combined and classified as an R8. Each quality element from both Ecological quality and Chemical quality of the WFD is discussed and its classification standard is explained. If the measure is not explained very extensively, references to documents with background information are given.

3. Current Ecological Status

The reference condition of the Water Framework Directive (WFD) applies to almost completely undisturbed conditions in natural waters. However, almost all waterbodies in the Netherlands are classified as heavily modified waters. Due to human interventions it is not feasible to reach the reference condition for natural waterbodies. For these waters the 'Good Ecological Potential' (GEP) applies. Both the Haringvliet and Hollands Diep are currently classified as heavily modified (STOWA, 2018), therefore the Ecological Potential (EP) will be used as a measure for the quality in Chapter 3 and 4. For more detailed explanation, see Appendix II.

3.1 Abiotic factors

3.1.1 Hydromorphology

The average depth in the Haringvliet (West and East) is about 8 meters (Rijkswaterstaat, 2011). Deeper tidal channels remain from before the dam construction and are up to 40 meters deep (Figure 4). They are separated by large sandy shallows (Rijkswaterstaat, 2011; van Dijk, 2019). The bathymetry has mostly changed in those deep gullies with sedimentation rates of 0.2 cm/year (Rijkswaterstaat, 2011). A more complete description of the morpho dynamic processes can be found in Wijsman et al. (2018) and Ysebaert et al. (2016).

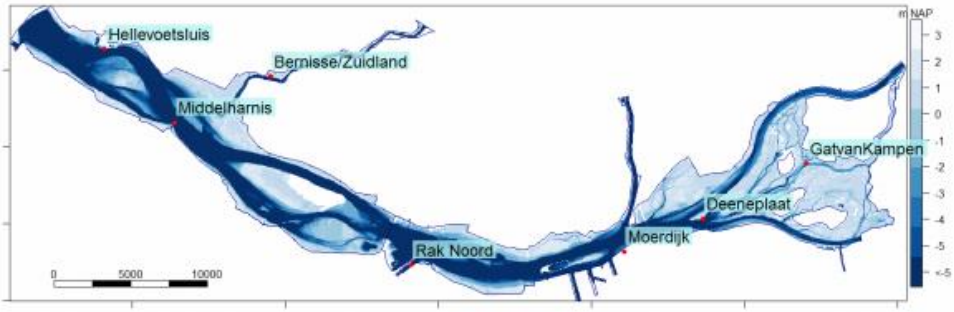

Figure 4: Bathymetry of the Haringvliet and Hollands Diep as presented by Wijsman et al. (2018).

The reduction of the tide results in altered sedimentation erosion processes (Tönis et al., 2002). The lack of tide results in the waves caving at the same height of the coast. Because of this, there are steep shores and many shores are protected. It does not reach the WFD criteria of natural shores for O2 water types.

Discharge

R8 water types should have a discharge higher than 600 m^3/s according to the WFD (STOWA, 2018). The discharge through the eastern Haringvliet in the current situation is estimated differently between authors and is set at about 300 to 750 m^3/s and increases to Haringvliet East and Hollands Diep by diversion of flow towards the Volkerak and Spui channel (Noordhuis, 2017; Ysebaert et al., 2016). Rijkswaterstaat (2011) estimates a Haringvliet discharge of 500 m^3/s for high discharges at Lobith and a Haringvliet discharge of 0 m^3/s for low discharges at Lobith. This curious discharge of 0 m^3/s can be explained by the closure of the dam low discharges. Rijkswaterstaat also gives a more detailed description of the changes over the year. Ysebaert et al. (2016) presents a nice overview of the flow diversion.

The northern Rhine channels ('Nieuwe Waterweg') are not closed off from the sea, affecting the discharge through the Haringvliet. During low discharges, there will be relatively less water flowing through the Haringvliet. The exact discharge is based on the sluice management which is linked to the discharge at Lobith. Figure 5 shows the sluice management before the 'kierbesluit'; LPH84. The LPH84 management (Lozings Programma Haringvlietsluizen 1984) allows the Haringvliet sluice to open only at low tide for discharges higher than 1500 m^3/s at Lobith. The opening will gradually increase with higher discharges (van Hees & Peters, 1998). Literature does not agree on whether the sluice will be closed for a major or a minor part of the year. However, it is clear that the sluice will be closed for longer periods of time. This will counteract tidal restoration in the Haringvliet and negatively affect the adherence to WFD guidelines.

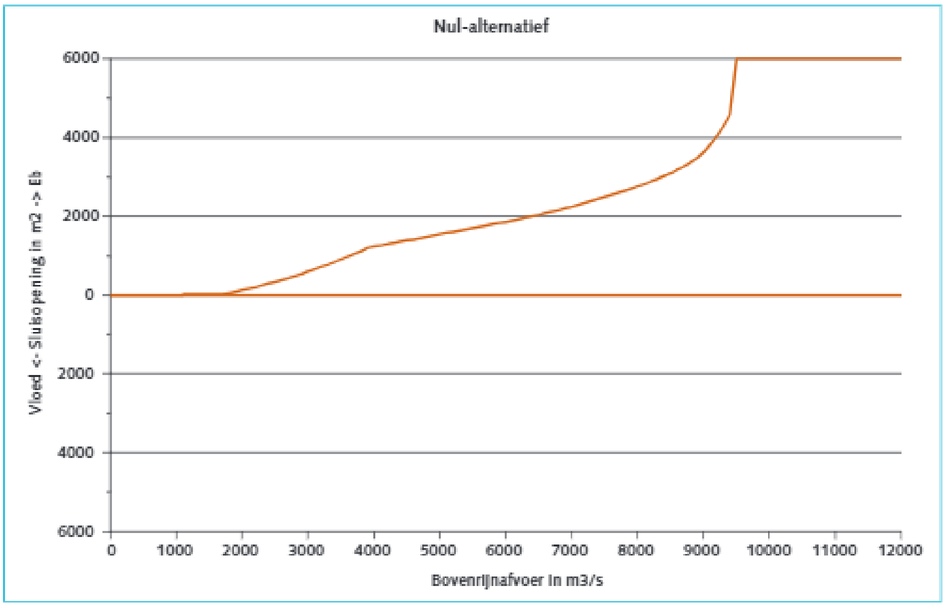

Figure 6: The Haringvliet sluice opening curve in m^2 under LPH84 management (pre-'kier' management). The x-axis shows the discharge at Lobith and the y-axis shows the sluice opening surface area in m^2 for low tide (van Hees & Peters, 1998).

Tide

The opening of the sluices also influences the tidal wave (Figure 6). There is a tidal wave of 2,35 meter outside the Haringvliet sluice and about 30 cm inside the sluices (Noordhuis, 2017; Rijkswaterstaat, 2011). The tidal wave enters the Haringvliet via the 'Nieuwe Waterweg', resulting in a tidal wave of 65 cm at both Hellevoetsluis and Willemstad and 90 cm at Dordrecht (Noordhuis, 2017). The WFD states that an R8 type should have 0.3 meter to 1.9 meter tidal wave height. This is in line with the current situation. O2 types should have 1 to 5 meters tidal waves. This goal is currently not met in Haringvliet West (STOWA, 2018).

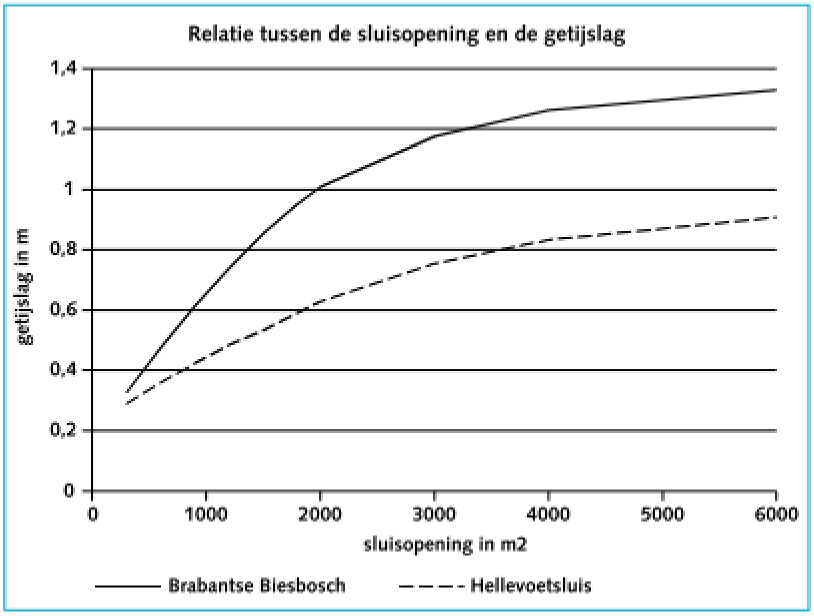

Figure 5: Relation between tidal wave and sluice opening. The maximum opening of the Haringvliet is 6000m2 (van Hees & Peters, 1998).

Flow velocity

The flow velocity is variable over the whole area and depends on the depth and connectivity. The waters close to the sluices have a velocity of about 3.8 m/s, when the sluices are maximally opened (Noordhuis, 2017). Flow velocity will reduce to less than 1 m/s by the closure of the Haringvliet (Wijsman et al., 2018). The flow speed has to be between 0.001 and 1.5 m/s for water type R8, according to the WFD (STOWA, 2018). This goal is most likely met for the Haringvliet and Hollands Diep.

3.1.2 Physiochemical properties: salt- and freshwater occurrence

The saltwater occurrence is dependent on the entrance of saltwater, mostly during high tide, and the total discharge of the river. Furthermore, the heavier saltwater will form a tongue below the freshwater and will mostly flow in the deeper areas (Figure 7 (Jacobs, Steenkamp, & de Goederen, 2003)). The dark blue pits are currently filled with brackish water (>150 – 5000 mg/L) which is only flushed out at high tides (Groenenboom, Tiessen, van der Kaaij, & Plieger, 2016; Noordhuis, 2017).

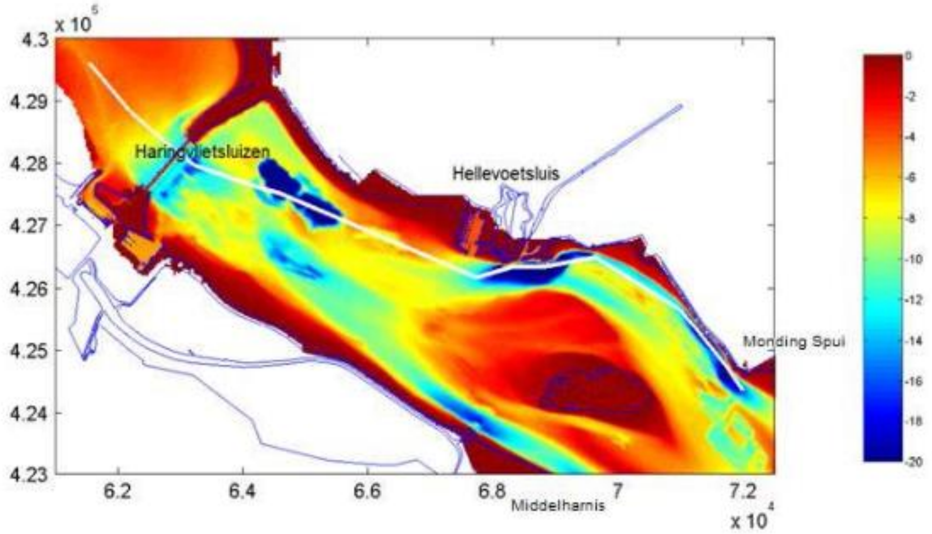

Figure 7: Depth in the western Haringvliet (Jacobs et al., 2003).

Water type R8 has a WFD criterion of 1g to 0.4g Cl/L seasonal average for a 'bad' classification and <0.3 g seasonal average Cl/L for a 'high' classification, whereas water type O2 has no specific saltwater requirements (STOWA, 2018). Thus, the natural border between water type O2 and R8 is mainly determined through salt concentration in the water and consequently by the intrusion distance of the salt tongue into the Haringvliet. Under the 'kier' management the 0.3 g Cl/L isohaline is not allowed to penetrate any further than the line Spui-Middelharnis (Wijsman et al., 2018). Thus, the O2 classification in the Haringvliet West, as well as the R8 classification in the Haringvliet East and Hollands Diep meet their respective WFD salinity level requirements.

3.1.3 Physicochemical properties: oxygen, acidity, nitrogen, phosphorus

Acidity

The acidity is lower in brackish water than in fresh water (pH 6 and 7.5 respectively) The acidity will decrease more if the saltwater can intrude further into the Haringvliet (Noordhuis, 2017). A lower pH will result in a slower breakdown of pollutants. Completely saltwater however, will have a higher pH of around 8. Phytoplankton blooms can cause extremely high pH values (Paalvast, 2016). Current acidity levels are good (Factsheet, 2018).

Oxygen, Phosphorus and Nitrogen

Pre-'kier' management oxygen levels are good according to WFD criteria (Factsheet, 2018) and van Hees & Peters (1998) rate the chance of hypoxia at 0. Saltwater intrusion is negligible, and the waves and discharge provide enough movement to mix the water and inhibit stratification in both Haringvliet (West and East) and Hollands Diep. The phosphate and maximum chlorophyll concentrations have been decreasing in the last decades. They were respectively 0.08 mg/L and 9 ug/L in the Haringvliet (exact location unknown) in 2017 (Noordhuis, 2017). Those concentrations are expected to increase with increasing discharge and therefore fluctuate throughout the year. Factsheet (2018) rates the nitrogen and DIN (Dissolved Organic Nitrogen) moderate for both Haringvliet (West and East) and Hollands Diep. According to WFD guidelines, the Haringvliet West is rated moderate (O2) and the Haringvliet East combined with Hollands Diep (R8) are rated good quality for Physicochemical quality (Table 10) (Factsheet, 2018).

Table 9: Physicochemical indicators in Haringvliet West, Haringvliet East and Hollands Diep (Factsheet, 2018).

Parameter	**Haringvliet West**	**Haringvliet East and Hollands Diep**
Physicochemical quality	moderate	good
DIN	moderate	-
Nitrogen	-	moderate
Phosphorus	-	good
Oxygen	good	good
pH	-	good
Temperature	good	good
Salinity	-	good

3.1.4 Other specific pollutants

Other specific pollutants were rated bad for Haringvliet East and Hollands Diep in 2015. Four pollutants exceeded their limit in 2015 for the Eastern Haringvliet and Hollands Diep, this number increased to seven in 2018. The exceeding pollutants were ammonium, bezonanthracene, cobalt, copper, selenium, uranium and silver. In Haringvliet West, there are three pollutants which exceed their limit in 2018. Those are dichloorvos, cobalt and copper (Factsheet, 2018).

3.2 Biology

3.2.1 Fish

In the current situation there is a clear difference in the fish communities on both sides of the Haringvliet dam. There is a saltwater community outside the dam and a freshwater community on the inside. The community in the Haringvliet cannot be called an estuarine community, even though there is some opportunity for exchange with the sea. Fish migration can only occur through the fish sluices and during the begin and end phase of the purging of freshwater into the sea. Especially big and strong fish species can enter the Haringvliet at this moment (Noordhuis, 2017). On the inside of the Haringvliet dam there is a lack of saline gradient. This results in the 'flushing' of fish species, both for in- and outwards migrating fish as they do not have enough time to adjust to different salinity levels (Hop, Vriese, Quak, & Breukelaar, 2011; Noordhuis, 2017; Withagen, 2000).

The possibility to enter and exit the Haringvliet has a big influence on migrating fish species. They prefer to enter and leave via the same waterway. Thus, the difference between high discharge flow through the Haringvliet and low discharge flow, which is mostly done via the Nieuwe Waterweg could pose a problem. There are fish sluices in the Haringvliet dam, but it is unclear how effective they are

(Hop et al., 2011). Withagen (2000) stated that the flow velocities in the sluices are too high for most fish species. Moreover, those fish species need a gradual fresh saltwater gradient to acclimatize, which is currently not present. The presence of freshwater will inhibit saltwater community to develop and there will be no appropriate food base for those species (Noordhuis, 2017).

The fish community is rated as 'poor' in Haringvliet West as well as in Haringvliet East/Hollands Diep (Compendium voor de Leefomgeving, 2016; Factsheet, 2018).

3.2.2 Macrofauna

The current macrofauna community in the Haringvliet is common for a freshwater system, although there are a few species that can thrive well in a brackish water system. All the species that can be found in the Haringvliet are quite insensitive to pollution and eutrophic circumstances. This shows that it cannot be assumed that the Haringvliet is a clean environment (Rijkswaterstaat, 2011). Especially omnivores can be found in and on the shallow bottom of the Haringvliet. In the top layer of the lakebed mosquito larvae and New Zealand mud snails (*Potamopyrgus antipodarum*) are very abundant. Pea cockle (*Pisidium casertanum*) and Asian clam (*Corbicula fluminea*) are the most abundant filter feeders (Rijkswaterstaat, 2011). Depending on the season *Palaemon longirostris* is present in the Haringvliet. This crustacean migrates to brackish waters during spring to reproduce. At the end of the summer they move upstream to freshwaters. The Chinese mitten crab (*Eriocheir sinensis*) shifts to saltwater to reproduce, this migration is however restricted due to the Haringvliet dam. The Louisiana crawfish is also commonly found in the Haringvliet (Rijkswaterstaat, 2011). Other species often found in the Haringvliet are the Common shrimp (*Crangon crangon*), European green crab (*Carcinus maenas*), Chesapeake blue crab (*Callinectes sapidus*) and the brackish water loving *Rhithropanopeus harrisii* (Rijkswaterstaat, 2011). Against the foreshore defences Amphipods, Chelicorophoim, Quagga mussel (*Dreissena rostriformis bugensis*) and New Zealand mud snails live on the stones. There abundance is however quite low on the stones at the 'Beninger Slikken', this could be a result of local environmental factors, such as the wave action and current, not being ideal (Rijkswaterstaat, 2011). In the deep waterbed the Quagga mussel and the New Zealand mud snail are the most abundant. Until 2009 the Zebra mussel (*Dreissena polymorpha*) was the most abundant mussel, but they were replaced with the Quagga mussel quickly. The waterbed of deep waters inhabits more Polychaete and Pea cockle than then other biotope and mosquito larvae are far less abundant in deep water than in the shallow water (Rijkswaterstaat, 2011).

The macrofauna is stated as 'good' in Haringvliet West and 'moderate' in Haringvliet East/Hollands Diep (Compendium voor de Leefomgeving, 2016; Factsheet, 2018).

3.2.3 Water flora

On the outside of the Haringvliet dam, the defence constructions have formed habitats for various seaweeds, for example Lesser grass-kelp (*Blidingia minima*) and Bladderwrack (*Fucus vesiculosus*) (van Dijk, 2019). The areas along the Haringvliet that lay outside the dykes, were brackish marsh ('kwelder') areas with reed and rush. After the closure of the Haringvliet these areas became fresh. The rush fields have disappeared after this change in combination with grazing by water birds. Due to the disappearance of the function of these reed and rush fields, the area became rougher. Currently these areas are being grazed by cattle or horses, who are being assisted by geese resting in this area during their migration. These areas consist of vast, moist to dry, nutrient-rich grassland. The less intensively grazed areas consist of reeds and willow struts (Rijkswaterstaat, 2011).

The water flora was assessed as 'good' in both Haringvliet West and Haringvliet East/Hollands Diep (Compendium voor de Leefomgeving, 2016; Factsheet, 2018). However, when looking at the Factsheet (2018), it occurred to us that the GEP for Haringvliet West is set at ≥0.00.

3.2.4 Phytoplankton

Both the WFD assessments of 2015 and 2018 concluded that phytoplankton was good in Haringvliet West (Compendium voor de Leefomgeving, 2016; Factsheet, 2018). This means that the concentrations of chlorophyll-α are equal to or lower than the set maximum. Both Hollands Diep and Haringvliet East are regarded as R8 (fresh flowing water), therefore phytoplankton is not measured.

3.3 Chemical quality

The monitoring of Factsheet in 2018 found for non-ubiquitous chemicals only fluoranthene exceeded the limit in the Haringvliet East/Hollands Diep. The ubiquitous chemical benzo(a)pyrene, benzo(b)fluaranthene, benzo(a)pyrene and mercury were also exceeding the limit. The Haringvliet West did not exceed the WFD limits except for the ubiquitous chemicals benzo(g,h,i)perylene, mercury and tributyltin (only in 2015) (Factsheet, 2018).

3.4 Chapter summary

In 2018, the Haringvliet East area and the Hollands Diep had a classification of water type R8 according to the WFD, which is a fresh tidal water on sand/clay. The Haringvliet West area has a water type O2, an estuary with a mediocre tidal range (Noordhuis, 2017). The ecological quality in both Hollands Diep and Haringvliet have the status ‘poor’ and their corresponding chemical quality is ‘insufficient’ (Table 11). This is caused by the status of the quality element fish. All other quality elements in the Ecological quality are ‘good’ or ‘moderate’, however due to the assessment procedure (Appendix II) the final status for the waterbody is equal to the lowest biological quality element. Additionally, there are chemicals exceeding the given norm, therefore its chemical quality status is ‘insufficient’ (Factsheet, 2018).

Table 10: Current status according to the Water Framework Directive of the Haringvliet West and Haringvliet East/Hollands Diep (Factsheet, 2018).

2018	**Haringvliet West**	**Haringvliet East/Hollands Diep**
Chemical quality	insufficient	insufficient
Ecological quality	poor	poor

4. Expected Ecological Status

In this fourth chapter we compare the expected situation 30 years after the implementation of the 'kierbesluit' and the Delta21 project with the current situation. We use literature on the historical situation and literature from comparable estuaries the Westerschelde and Ems-Dollard to describe the expected situation of the Haringvliet and Hollands Diep.

4.1 Introduction

Thus far, we have focused on the current situation of the Haringvliet West, Haringvliet East/Hollands Diep, and the possible reference situations according to the guidelines of the Water Framework Directive (WFD). When the sluices open, the entire situation in the waterbody will change. The water types of the Haringvliet West (O2) and Haringvliet East/Hollands Diep (R8) according to which they are assessed now will not change. But the Haringvliet West, which is now an O2 water body with primarily freshwater, will change to an estuary with its own specific characteristics. We will not be able to exactly predict what will happen. Nevertheless, using the available literature and a hint of our own imagination, we will try to envision the expected situation in the waterbody according to the guidelines of the WFD.

There are multiple sources of literature combined to envision the expected situation in the Haringvliet and Hollands Diep. Literature on the historical situation has its advantage that a similar situation is likely to occur, however its disadvantage is that the WFD was not developed yet. Therefore, we combine this information with literature written about the prognosis of the 'kier' management and information from the Westerschelde and Ems-Dollard estuaries. The Ems-Dollard and Westerschelde are both estuaries classified as O2 in the WFD (STOWA, 2018), similar to Haringvliet West. Additionally, if the sluices were to be opened, nature would need time to re-establish and to find its new equilibrium. This might take a lot of time, and with time other effects such as climate change and sea level rise will also have progressed and influenced the situation. Therefore, we decided to use an approximate timespan of 30 years to assess the expected effects.

4.2 Abiotic factors

4.2.1 Hydromorphological properties

Discharge

'Kierbesluit'

Van Hees & Peters (1998) expect the discharge to increase if the sluices are opened further. The water division between the Haringvliet and the 'Nieuwe Waterweg' will change in favour of the Haringvliet. However, the exact increase is not currently known. The 'kier' sluice management is presented in Figure 8. The sluices are only opened with discharges above 1100m^3/s for low tide and discharges above 1500m^3/s for high tide. The sluices open gradually with increasing discharge, up to the maximum opening of 6000 m^2 at discharges of around 9500m^3/s (Noordhuis, 2017).

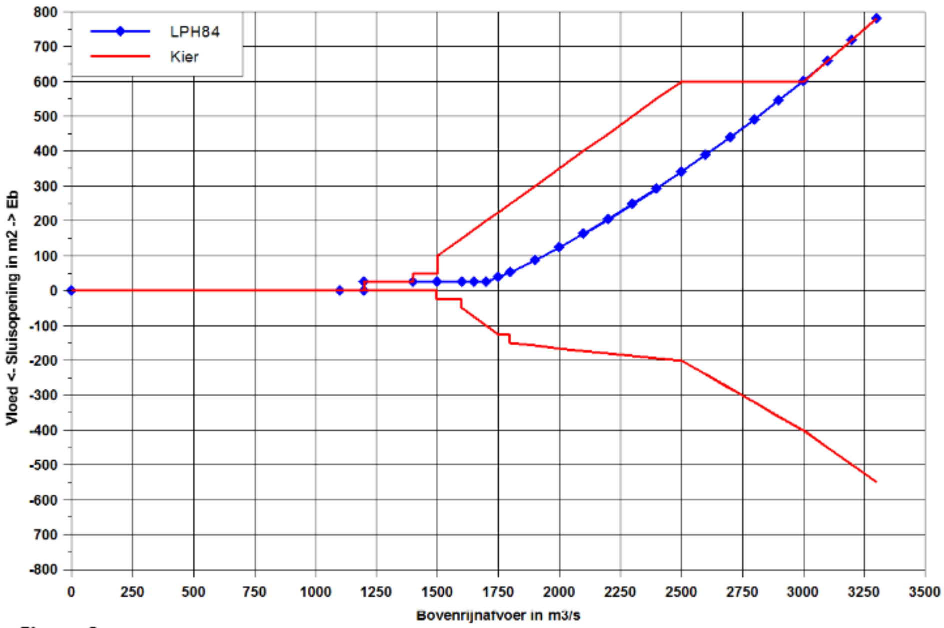

Figure 9: Sluice management programs LPH84 (blue, pre-'kier' management), 'kier' (red). The X-axis shows the discharge at Lobith and the Y-axis shows the sluice opening in m2 for high tide (positive axis) and low tide (negative axis) (Paalvast, 2016 adopted from Van Leeuwen et al., 2004).

Based on this policy, the opening throughout the year can be predicted. Figure 9 shows the times that the sluices would have been closed and opened under the 'kierbesluit' policy in the period 1900-2010. This excludes the preparation time for low discharge periods in which all saltwater is washed out beforehand. About 60% of the years during this time period, the sluices were closed completely for more than 30 days, which occurred mostly in fall (Noordhuis, 2017). Climate change and changing discharges are not included in these simulations. The derivation of this figure and the exact open and closed days for both high and low tide can be found in more detail in Paalvast (2016).

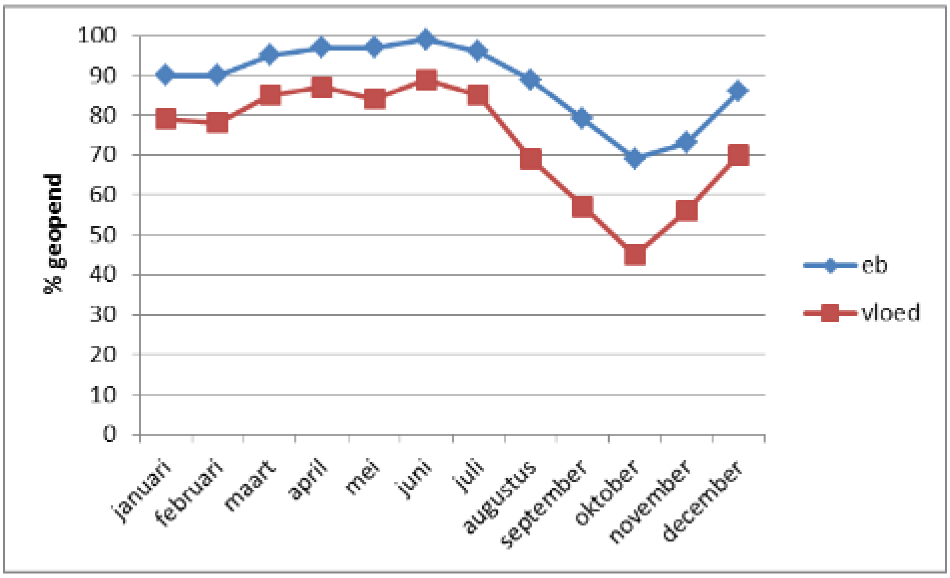

Figure 8: Graph showing the percentage of time that the Haringvliet sluice would have been opened per month for the period 1900-2010. Red represents flood conditions whereas blue represents ebb conditions. From Noordhuis (2017).

The 'kier' management will slightly improve the WFD criteria to have a discharge of 600 m^3/s (STOWA, 2018), but this criterion will still not be reached for certain periods in a year (see the discussion about current discharge in 2.2.1). The implementation of the POA (Permanent Oostelijke Aanvoer) project may help reach the WFD criteria. The POA entails a change in water provisioning for the 'Groene Hart' area of the Netherlands (between Rotterdam, the Hague, Amsterdam and Utrecht). The POA will ease the discharge pressure on the 'Nieuwe Waterweg' and increase discharge through the Haringvliet (Roels, 2018; WNF, 2012). The extra discharge may help keep the 'kier' open for longer periods of time.

Delta21

For the Delta21 scenario, the sluices will be fully opened when the discharge is higher than 1000 m^3/s at Lobith and closed during high tides with lower discharges. This will allow the saltwater to intrude up to Strijensas/Rode Vaart. The sluices will be closed for an average 10 days/year (Delta21, 2019). Noordhuis (2017) expect an average discharge of 1130 m^3/s for a controlled tide scenario. The Delta21 plan will have even higher discharges, because the sluices will be opened more often. Van Hees & Peters (1998) state that the discharge before 1970 was 1100 m^3/s. This higher expected discharge in Noordhuis (2017) can be attributed to other sluices limiting discharge via Volkerak (Ysebaert et al., 2016). The average discharge could further increase when considering the extra discharge of up to 400 m^3/s from the Hollandse IJssel (Delta21, 2019). This will mostly affect the 'Nieuwe Waterweg', but it will also affect the division of water upstream. The WFD criteria for the discharge (600 m^3/s) (STOWA, 2018) will be met more often with the Delta21 project than both the current situation and the 'kier' management.

Climate change

The previous scenarios do not consider changes in river discharges due to climate change. Vellinga, Pier, Katsman, Caroline; Sterl & Beersma (2008) model that the average discharge of the Rhine might decrease up to 40% in summer (Aug-Oct) by 2050 according to the KNMI '06 W+ scenario (te Linde et al., 2010; Vellinga et al., 2008). This is the most extreme among four scenarios, which considers a fast-global warming and a temperature increase of 2.3 °C in 2050 (KNMI, 2015). An average summer discharge of 700 m^3/s at Lobith will completely change the predictions, resulting in closure of the sluices for a longer period, as low river discharges (<1000 m^3/s) will become a common practice (te Linde et al., 2010; Vellinga et al., 2008). A fast warming climate will have negative consequence for the WFD criteria of 600 m^3/s for R8 (STOWA, 2018). This has effect on both the 'kier' scenario as the Delta21 scenario, but the former will experience the most degradation.

Tide

'Kierbesluit'

'Kier' management will most likely only have a small effect on the tidal regime in the Haringvliet and Hollands Diep. According to Noordhuis (2017), the tidal wave outside the Haringvliet sluice will decrease with 6 cm. It will increase 1 cm at Hellevoetsluis and increase with 3 and 5 cm in Willemstad and the Biesbosch respectively. The 'kier' management will therefore not meet the WFD goal for O2 types to reach a tidal wave of 1 to 5 meters (STOWA, 2018). These changes are not significant enough to change the positive WFD assessment for water type R8.

Delta21

The tide will change because of the opening of the sluices, but also because of the change in discharge. Historical tidal ranges were about 1.9 meters at the Biesbosch and 2.25 meters at Moerdijk (Wijsman et al., 2018; Wolff, 1973). Van Hees & Peters (1998) estimate the tidal wave to increase to 1.40 at the Haringvliet dam, increase to 0.90 meter at Middelharnis, and to 1.35 at the Biesbosch. A more recent study models the tidal amplitude for Middelharnis and in between Willemstad and Moerdijk (a bit more east than Biesbosch) at 1.40 m and 1.10 m respectively but this also includes a tidal wave passing from the Volkerak into the Eastern Haringvliet (Ysebaert et al., 2016). This roughly in line with the 0.3-1.9 meter tidal range requirement for a freshwater estuary and 1-5 meter requirement for a saltwater estuary according to the WFD (STOWA, 2018). Meaning that both water types will conform to WFD standards. Those estimations do not take into account the closure of the Haringvliet of 10 days/year and the extra discharge from the Hollandse IJssel. Both will decrease the tidal wave. Besides, the Energy Storage Lake in front of the estuary and the narrow entrance will also affect the tidal wave but it remains unclear if this will be negative or positive without further modelling studies.

Climate change

Sea level is expected to rise 40 cm by 2050 compared to the beginning to this century (KNMI, 2015). The tidal wave will have less friction in a deeper Haringvliet. Therefore, a rising sea level will increase the tidal wave as can already be noticed currently (Vellinga et al., 2008).

Flow speed and shorelines

The discharge and tidal wave will change the flow speeds and sediment input. The tidal channels might widen a slightly and will reduce sedimentation, which is expected to have a positive influence on nature (van Hees & Peters, 1998; Ysebaert et al., 2016). A sea level rise based on climate change will not affect the morphological processes too much. The whole area will become higher and it will take longer before a morphological balance is reached (Wijsman et al., 2018). The WFD states that the O2 type should have at least 80% natural shorelines (STOWA, 2018). The current coast is often protected, and this goal is not met. The tidal change will result in more fluctuating water levels allowing for more natural coasts. Therefore, the opening of the sluices will have a positive influence. Wijsman et al. (2018) states it will still fall short on completely restoring the natural building and erosion of intertidal areas. The extra sediment input from the Hollandse IJssel is not taken into account and could help to reach this goal (WNF, 2012). Increasing dynamics will lead to higher flow velocities, which could erode the polluted sediments that are present in the Haringvliet and Hollands Diep (Ysebaert et al., 2016). These impacts are further discussed in Chapter 5.

4.2.2 Physiochemical properties: salt- and freshwater occurrence

'Kierbesluit'

Under 'kier' management, the 300 mg Cl/L seasonal average salinity boundary is not allowed to advance any further than the line between Middelharnis and Spui. Adaptive management will be used to manage this. If this 300 mg Cl/L isohaline threatens to advance further, the Haringvliet sluices throughput will be reduced to limit salt intrusion (Noordhuis, 2017; Wijsman et al., 2018). Because of the effects of climate change, sea level rise and more extreme river discharges, there may be periods the Haringvliet sluices will have to be closed further or for longer periods of time in order to limit salt penetration (Vellinga et al., 2008; Wijsman et al., 2018). This closure may in turn obstruct the realisation of WFD goals as it effectively stops tidal influences in the Haringvliet and Hollands Diep and in doing so inhibits development and conservation of tidal water types.

Delta21

To ascertain the changes to salinity in the delta area, as caused by the Delta21 plan, one may look at the reference situation before the Haringvliet dam construction, as described by, for example, Peelen (1967). While this can be used as a starting point there are several reasons why this would not be fully accurate. These reasons include changed salinity levels along the coast and different river mouth morphology due to the Haringvliet dam (Wijsman et al., 2018). Modelling studies may then fill the knowledge gap, but to this day no modelling studies have been performed on the effect of Delta21 on salinity levels in the Haringvliet delta. However, there have been modelling studies on the delta area which include, so called, 'storm surge barrier' scenarios. The defining characteristic of these scenarios is opened sluices under all but the most extreme conditions. Bol & Kraak (1998) and Ysebaert et al. (2016) used 1D models to predict salt penetration in the Haringvliet delta for such scenarios. Both studies find that saltwater does not penetrate much further than the island of Tiengemeten. However, 1D modelling is limited in its application to salt tongue movement as this is inherently a 3D and layered affair which is difficult to model. Wijsman et al. (2018) therefore does not use a model but uses expert judgement to predict salt penetration in a storm surge barrier scenario (Figure 10). This scenario most closely resembles the situation under the Delta21 plan. However, Delta21 conditions would differ from Wijsman et al. (2018) predictions due to the presence of the Energy Storage Lake and Tidal Lake in the pro-delta. These effects are not yet fully known but may include salt and fresh water mixing in the Tidal Lake which, in turn, may cause less salt intrusion into the Haringvliet. Besides this, Delta21 may implement a threshold under the Haringvliet bridge near Willemstad in order to hamper further salt penetration, although this plan is not yet definitive. Sea level rise and extreme river discharges caused by climate change may influence salt intrusion under Delta21 as well. During the summer months, under low discharge conditions and high tide, the 300 mg Cl/L isohaline may move further inland, past the planned freshwater intake points at Strijensas and Rode Vaart (Vellinga et al., 2008; Wijsman et al., 2018). As freshwater security is a priority in Delta21. This could negatively affect the establishment of or established tidal nature values and thus negatively impact adherence to WFD targets (Delta21, 2019). The increase in discharge through the Haringvliet which may be realized through the implementation of the POA plan (see 4.2.1) may help push back the salt tongue in the Haringvliet. Safeguarding the freshwater supply a bit longer before any weir closure may become necessary.

Figure 10: 300 mg Cl/L salinity predictions from Wijsman et al. (2018) based on expert judgement. The purple area represents the uncertainty region for the 300 mg Cl/L salinity boundary under normal discharge and high tide conditions for the storm surge barrier scenario. The red area represents the same boundary under low discharge and high tide conditions.

The salinity level is an important factor in determining whether an area conforms to water type O2 or R8 in the WFD system. While an estuary system is inherently dynamic in its salinity levels, average isohaline locations can be estimated for fully developed systems. Figure 11a/b/c shows these average locations for the 300 mg Cl/L isohaline for different scenarios as estimated by Wijsman et al. (2018). Based on the estimations from Wijsman et al. (2018) it seems the Haringvliet East may, at least partially, exceed the salinity levels set for a R8 type and should therefore perhaps be changed to an O2 water type classification. Haringvliet West and the Hollands Diep seem to conform to salinity level requirements set for their water type. However, the salt tongue will of course flow back and forth through the system (Figure 10) and accurate predictions about its position cannot be made without further modelling studies.

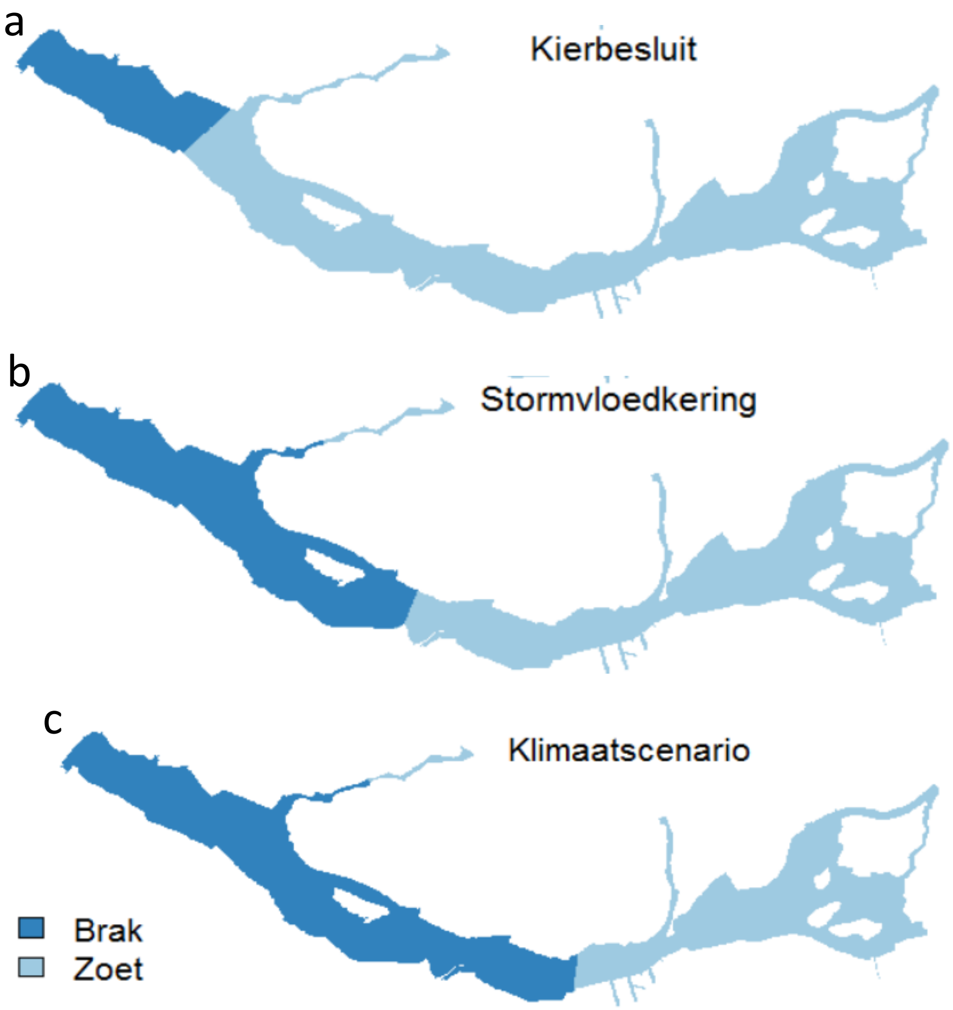

Figure 11: Averaged locations for the 300 mg Cl/L isohaline as estimated by Wijsman et al. (2018). Dark blue represents brackish water, whereas light blue represents fresh water. From top to bottom the estimation for the 'kierbesluit' scenario, the storm surge barrier scenario and a climate scenario (KNMI, warm, 2050).

4.2.3 Physicochemical properties: oxygen, transparency, acidity, nitrogen, phosphorus

Oxygen

'Kierbesluit'

The risk of hypoxia is negligible because no saltwater intrudes, and the waves are strong enough to mix the water. This is also shown in the current good rating for the WFD criteria (Factsheet, 2018). Once saltwater has intruded, opening the sluices more often will likely lead to reduced hypoxia risk. Hypoxia occurs when salt/freshwater stratification lasts for at least 30 days with constant warm summer weather (van Hees & Peters, 1998). They estimate the chance of hypoxia for 'kier' management at 1/100 years and the broken tide (mostly opened at low tide only) at 1/7 years. The current oxygen level could be slightly improved by a higher discharge and more mixing by the tide. However, the chances for a decline in oxygen levels are higher. The 'kier' management will allow saltwater to intrude and could close the dams afterwards. This problem is tackled by the flushing before closing the damn in the current 'kier' management plans. The effectiveness of the flushing has yet to be tested. The change in discharge is very low and the 'kier' management is expected to have negligible effect on the R8 area.

Delta21

Chances for hypoxia may be a lot lower for the Delta21 scenario because the sluices will be open more often, in accordance with the storm surge barrier management from van Hees & Peters (1998). If the sluices close, it will mostly be at the beginning of winter and rarely 30 days in a row (see Paalvast (2016) for further detail). Besides, the WFD criteria oxygen level can improve by a higher discharge and faster flow speed due to the tide in the O2 area. A higher discharge could also improve the oxygen levels in the R8 areas.

Climate change

Both scenarios will change if low discharge becomes more common due to a fast warming climate. The 'kier' management will be similar or worse than the broken tide (1/7 years) and hypoxia will become common. If all the saltwater is still flushed out before dam closure, it will take extensive closure of the dams in most years, reducing the benefits of the open sluices. The Delta21 scenario will also experience hypoxia risks, but this is relatively small in 2050. This will however become a larger issue at the end of the century if global warming follows the quick warming scenario and dams will still be closed at high tide for low discharge levels at Lobith. Higher water temperatures will further exacerbate the oxygen levels in summer (see paragraph temperature below).

Phosphorus and Nitrogen

'Kierbesluit'

Ysebaert et al. (2016) relates the nitrogen concentrations to the discharge. The adapted management, which resembles the 'kier' the best, has a lower nitrogen concentration for the Haringvliet (East and West) due to the mixing of low nutrient concentration seawater. However, the discharge decrease is not in line with the 'kier' scenario and the mixing is therefore not expected to have a significant impact. Apart from the saltwater mixing and changes in discharge, Factsheet (2018) estimates to improve the DIN level in the O2 area to good quality in 2027 and the nitrogen level in the R8 type to good in 2027 as well. This in line with the current trend of phosphorus decline which is an autonomic development and is likely to keep declining based on the accelerating decrease of the last years (Noordhuis, 2017). The phosphorus and nitrogen input from neighbouring countries has also been decreasing for the Rhine and the Meuse (Deltares, 2016). The sum of those processes results in an expected decrease of the phosphorus, nitrogen and DIN WFD criteria for both water types.

Delta21

Van Hees & Peters (1998) state that higher discharge will result in a higher input of nutrients. A shorter residence time will result in higher nutrient concentrations. Ysebaert et al. (2016) has modelled a storm surge barrier management scenario and finds a slight nitrogen decrease for the Haringvliet. The mixing of Haringvliet waters with seawater with low nitrogen and phosphorus concentrations seems to have more impact than the higher discharge. The declining nitrogen and phosphorus input trend reduce the effect of higher discharge and will further tip the balance to a net expected decrease in phosphorus and nitrogen levels in the Haringvliet. The nitrogen levels in the Hollands Diep will decrease a little less under Delta21 than under the 'kier' management because of the higher discharge.

Climate change

A decrease in discharge due to climate change will have a positive impact on the WFD criteria for both scenarios. A lower discharge would mean less nutrient input. More importantly, a lower discharge and sea level rise would push more nutrient-poor seawater into the Haringvliet. This has the biggest impact on the Delta21 scenario since the sluices will be open for most of the time.

Temperature

Another WFD criteria is the temperature which should not exceed 23 °C in R8 water and 21 °C in O2 water (STOWA, 2018). This target is already met for most of the days but both river temperatures as sea level water have been increasing and is expected to continue increasing (Compendium voor de Leefomgeving, 2017; Singer, Millat, Staneva, & Kröncke, 2017). River water has gone up from 0 to 6 days/year exceeding 25 °C in the Rhine at Lobith (comparing 1911-1920 and 2005-2016). This increase has been 1 to 4 days/year for the Meuse. The main cause has been the dumping of cooling water (Compendium voor de Leefomgeving, 2017). Those developments could cause the temperature to become a problem.

A higher tidal wave will result in more mixing between shallow and deep water. The intrusion of colder sea water is an important aspect as well. Besides, a higher discharge will also increase the flow velocity and result in more mixing. Those effects are most pronounced on the Delta21 scenario, in which the system is more dynamic and cold sea water could further intrude. Both 'kierbesluit' management and Delta21 are expected to show decreasing temperature quality for water type R8. The negative impact will be bigger on the 'kier' scenario, which has a lower discharge and less mixing by the tidal wave. This would stop the tidal wave and discharge, reduce mixing, and allows for less cold sea water intrusion.

Acidity

The current level of acidity in the R8 water is good. It might increase or decrease a bit as the nitrogen and phosphor levels decrease. Algae blooms, caused by temperature changes or nutrient input, could also affect the acidity levels. Nutrient input is expected to decrease and temperature to increase, so the occurrence of blooms remains uncertain. A warm climate scenario will have the most influence on the acidity. The effect of an elevated CO_2 level causing the pH to decrease is not considered. This is expected to increase the pH by 0.4 for sea water (Birchenough et al., 2015).

4.2.4 Other specific pollutants

Dichlorvos

Dichlorvos has been used as insecticide and was reduced around 1996 and prohibited in 2004 (Rijkswaterstaat, 2012; Wilting, Evers, & Eys, 1996). It is still allowed for veterinarian uses. It is collected in minor rivers and builds up concentrations in the major water bodies. It is only noted if it exceeds 0.01 µg/L, but this threshold is too low to monitor the occurrence properly for most areas. Also, it is not included in the emission monitor. Therefore, it is hard to say something about the actual distribution. Norm exceedance is declining, and it appears that there is a declining trend (van Duijnhoven & Bakker, 2011; Verschoor et al., 2019). Factsheet (2018) expects to score 'sufficient' in 2027 for this chemical. This effect is the same for both the 'kier' management and Delta21.

Cobalt

418 kilo/year is annually polluted by sewage plants. Another estimated 1200 kilo/year is estimated to be polluted by diffuse sources. Locally, welding and shipyards can have a high impact. Norm exceeding locations are nearly all located close to heavy industry (van Duijnhoven & Bakker, 2011). It is not expected that input will in- or decrease. This is in line with the fluctuating industrial pollution levels (Rijkswaterstaat, 2018). In contrast, atmospheric deposition has been decreasing in the Netherlands and Europe in the last decades, but this is a minor source (Rijkswaterstaat, 2019a). Cobalt is classified as a problem in freshwater and 'needs attention' in saltwater. An increase in salinity would thus reduce the problem. Therefore, the 'kier' management is expected to improve slightly and Delta21 to improve more in the Eastern Haringvliet. The western Haringvliet might improve slightly in the Delta21 scenario.

Ammonium

Ammonium occurs as a natural process in the presence of other nitrogen chemicals (van Duijnhoven & Bakker, 2011). It is therefore related to the WFD goal of nitrogen and DIN. Both scenarios will have a slight improvement. A current problem is the injection of manure when soil is cracked by drought (van Duijnhoven & Bakker, 2011). This could worsen if droughts become more frequent, but this effect is rather speculative. Atmospheric ammonium pollution has been decreasing in both Europe and the Netherlands over the last decades (Rijkswaterstaat, 2019a). The RWS Factsheet (2018) expects to improve the current situation to reach the WFD goal in 2027.

Uranium and Silver

Currently, uranium and silver norms are exceeded for the Haringvliet East and the Hollands Diep. However, van Duijnhoven & Bakker (2011) expect that the WFD norms will not be exceeded if the norms get corrected for background concentrations. Unfortunately, current background concentrations are unknown for both fresh- and saltwater. Factsheet (2018) expects to adhere to the WFD goal for silver but not for uranium in 2027. Industrial pollution of silver has declined more than 100-fold from 1995 to 2016 (Rijkswaterstaat, 2018).

Copper

Copper is found in high concentrations in the water bottom in the Eastern Haringvliet. Due to the planned dredging the copper concentration is expected to reach the WFD target (Factsheet, 2018; Rijkswaterstaat, 2014a). Besides, copper input by the Rhine and the Meuse as well as industrial copper pollution in the Netherlands, have been declining over the last decades (Deltares, 2016; Rijkswaterstaat, 2018). This trend is not found in atmospheric deposition (Rijkswaterstaat, 2019a).

Benzo(a)anthracene

See description 4.4 PAH

Selenium

Selenium is mostly polluted via atmospheric deposition (Klein, Kruijne, & de Rijk, 2013). Selenium has only been added to the WFD after 2009 and has not been monitored as much before. (Rijkswaterstaat, 2018) measured the total emission for 2010-2015 and 2016. No clear pattern can be recognised from these three measurements. The RWS Factsheet (2018) expects that the WFD goals will not be met in 2027.

4.3 Biology

4.3.1 Fish

Currently, the quality of the fish in the Haringvliet and Hollands Diep is the lowest of all ecological assessments. Being ‘poor’ from 2015 onwards, even estimated that in 2021 the quality still will be ‘poor’. This quality applies for both water types on Haringvliet East/Hollands Diep (R8) and Haringvliet West (O2) (Factsheet, 2018). Therefore, the fish assessment is responsible for the overall poor quality. However, when Delta21 will be realised the status of the water may change (STOWA, 2018).

‘Kierbesluit’

Currently, with the ‘kierbesluit' the sluices are only open with a very narrow opening during some parts of the year, depending on the discharge and weather conditions. The impact of this narrow opening has been predicted for future scenarios. It is expected that this only creates a very small tidal system of 11 million m^3 in the Delta. This is not enough to facilitate (permanent) habitats for estuary residence species to increase the quality measure according to the WFD. Moreover, only with high discharges from the river, the fresh and saltwater will be able to mix due to stratification (Baptist et al., 2007). Figure 12 shows that there will be a minimal increase in biotopes with the current management.

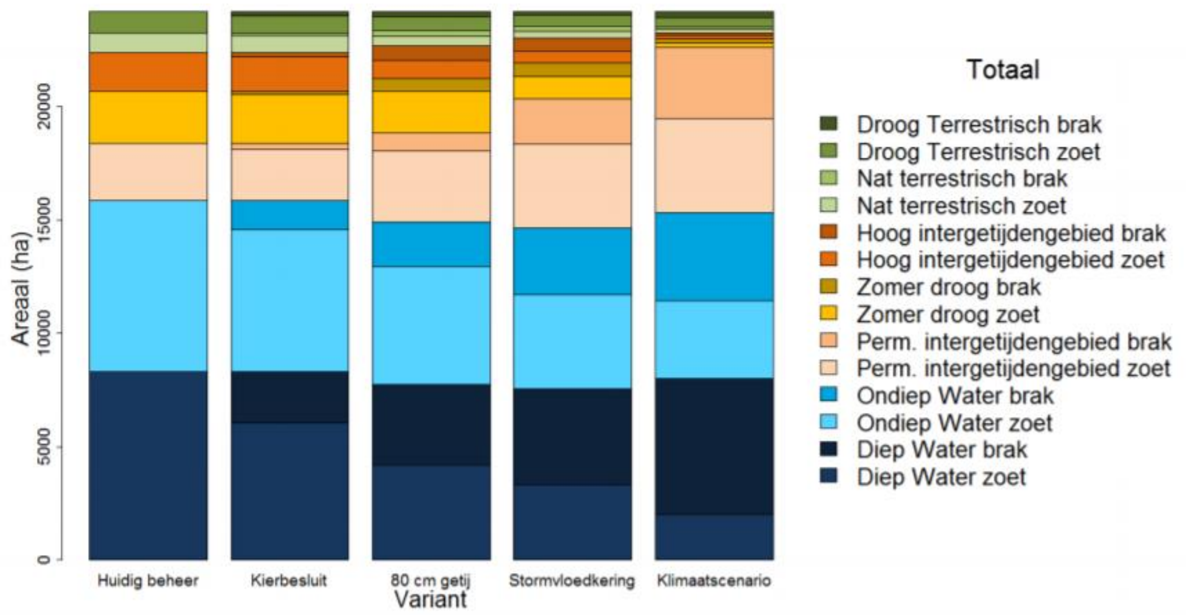

Figure 12: The impact of 'kierbesluit' on the occurrence of ecotypes relevant for the indicator fish species (Wijsman et al., 2018).

Another important factor this report takes into consideration with the 'kierbesluit' scenario is climate change. While assessing the expected impacts of climate change, this report focusses on the impact in 2050. There will be an increased demand for freshwater in the catchment. Additionally, there will be an increase in discharge fluctuations throughout the year. This results in periods that the Haringvliet sluices needs to be closed in order to guarantee freshwater supply. As mentioned earlier, the closing of the sluices will have a big impact on the estuary. Especially the diadromous species traveling from saltwater into the fresh river around the period of September – October will be negatively influenced; this also applies on the scenario when Delta21 is realised (van Kleuenen, Noordhuis, & Arts, 2018).

Delta21

Estuaries with moderate intertidal influence, historically hosted feeding and spawning grounds for the target species such as salmon (*Salmo salar*) and sturgeon (*Acipenser sturio*) which nowadays have almost entirely disappeared since the decline in suitable habitat. The system that will develop after realization of the Delta21 project will facilitate a more gradual transfer between fresh, brackish and saltwater. The impact of complete removal of the Haringvliet barrier has been predicted. According to Baptist et al. (2007) there will be enough mixing between fresh and saltwater since the inlet of saltwater is much higher. Therefore, it is expected that there will establish a permanent estuary facilitating habitats with a volume of at least 150 million m³ in the Haringvliet delta. Therefore, an increase in the quality of fish species according to the WFD is expected (Baptist et al., 2007; Catthrijsse, Mees, & Hostens, 1998; STOWA, 2018).

After realisation of the Delta21 project, the properties of the delta will be comparable to the Westerschelde. The Westerschelde historically is known for its bad water quality, however the water quality of the Westerschelde has been improving since the 1980s. Onwards, this had a positive impact on the fish species. Already in 2001, the effects of these improvements were noticeable. A more stable and natural salinity gradient going from fresh river water to salt marine water is needed for the indicator diadromous and estuarian residence species. Such a salinity gradient can be found in the Westerschelde (van Dijk, 2019). The species composition and abundance of indicator species for O2 increased, with a higher abundance of diadromous such as the European plaice (*Pleuronectes platessa*)

("Schelde nieuwsbrief," 2001). Nonetheless, the current EQR of the Westerschelde is still poor (STOWA, 2018; Ysebaert, de Mesel, & Herman, 2008).

The reference condition for fish species is mainly based on the historical situation and its fish population, the expected situation will most likely be like the Westerschelde. The water quality of the Westerschelde cannot directly be compared to the Haringvliet delta since the Schelde is one of the most polluted rivers in Europe ("Schelde nieuwsbrief," 2001; STOWA, 2018; Wouters, 1994). As mentioned in Chapter 2 & 3, there are five 'guilds' that relate to the quality assessment for the fish. Two of the guilds will especially benefit from the Delta21 project (Baptist et al., 2007). The diadromous species, such as the sea lamprey (*Petromyzon marinus*) and sea trout (*Salmo trutta*) will benefit highly. With an estimated brackish area of 1500 ha, this area will facilitate both a feeding ground and a zone to acclimatize before these species travel upstream or to open sea (Paalvast, Iedema, & Ohm, 1998).

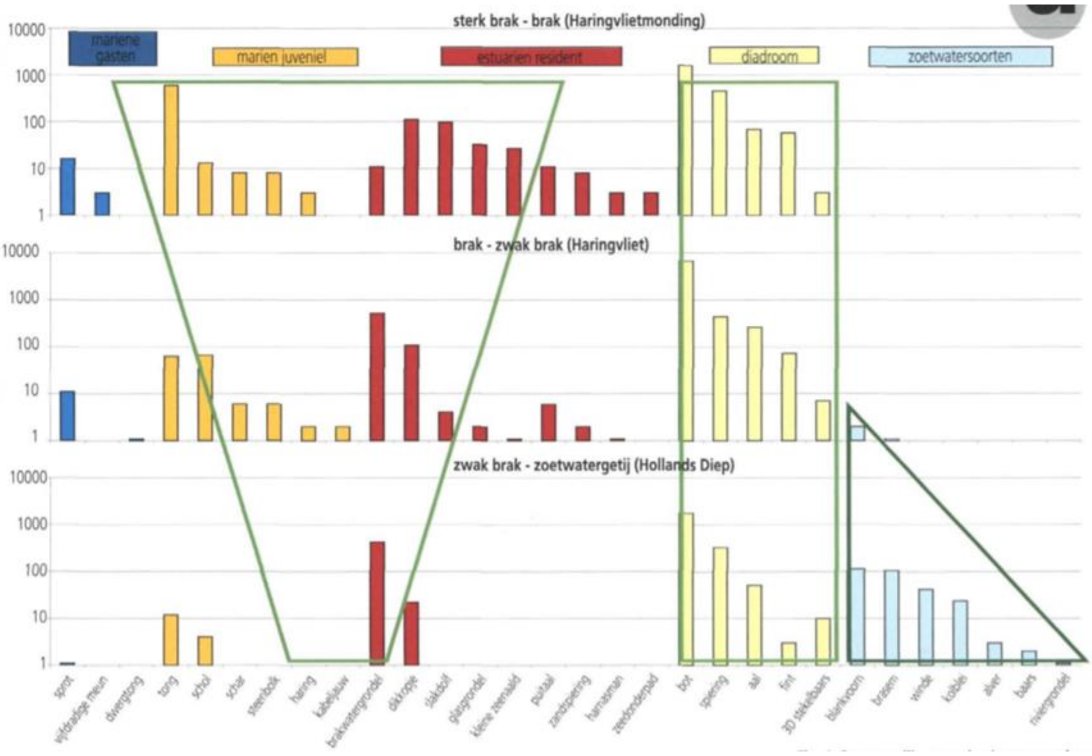

Figure 13: Species composition and abundance of O2 water type indicator species before the realisation of the Haringvliet dam structure (Jager et al., 2004).

Before the realisation of the Delta21 project all five guilds were present in the estuary of the Haringvliet, both the abundance and species composition from the Haringvliet is shown in Figure 13. The figure ranges from a strong brackish condition on top until a moderate brackish condition at the bottom. As shown, the occurrence of freshwater species will only be in the moderate brackish parts of the estuary. The quantitative assessment of the WFD quality is based on the abundance of two representative species per guild. These specific species per guild are stated in Chapter 2.7 of the STOWA (2018) document. Figure 13 shows that, historically, almost all these representative species were present in the Haringvliet Delta in moderate to relative high abundances. This indicates that the quality of the fish, according to the WFD, would have been of at least moderate or good quality before the realisation of the dam in 1971 (Jager, Kranenbarg, & Vethaak, 2004; STOWA, 2018).

Since this report mainly focusses on the quality aspect of the WFD assessment, it would be inappropriate to give a specific score to the fish quality after realisation of the Delta21 project. Furthermore, the abundance of these fish species also depends on what happens with climate change impacts. There will be an increase in discharge fluctuations as mentioned in Chapter 4.2.1. Respectively, this has a huge impact on the estuary in the Haringvliet delta (Baptist et al., 2007; Wijsman et al., 2018). Since the historical fish populations in the Haringvliet were assessed to be of moderate to good quality according to the WFD, it is expected that this will occur after realisation of Delta21 as well. The impact of only the 'kierbesluit' will most likely be too small to improve the insufficient quality of the fish in the Haringvliet delta. As mentioned above, the developing estuary area will be too small for estuarian residence species to settle. Also, the rheophile diadromous species will not have a stable transition area to acclimatize before they shift from fresh to saltwater and vice versa. Since the estuarian residence and diadromous guilds are of big importance in the assessment for the overall quality, it is expected that the poor quality will stay the same.

4.3.2 Macrofauna

In the Westerschelde the polyhaline zone contains 93 taxa. This zone is dominated by suspension feeders, surface deposit feeders and sub-surface deposit feeders, decreasing in abundance with decreasing salinity (Heip et al., 2006; Ysebaert et al., 2003). The poly-mesohaline zone contained 86 taxa and the mesohaline zone contained 59 taxa. This zone is dominated by omnivores, showing a decrease in abundance with increasing salinity (Heip et al., 2006; Ysebaert et al., 2003). The species diversity and biomass are the highest in the intertidal zone compared to the subtidal zone (Ysebaert et al., 2003). The most common species that are found in the Westerschelde are the polychaete *Heteromastus filiformis*, *Pygospio elegans* and *Nereis diversicolor*, the small saltwater clam *Macoma balthica*, the amphipod *Bathyporeia spp.*, and the mud snail *Hydrobia ulvae* (Ysebaert et al., 2003). In the meso-oligohaline zone the salinity has big seasonal variation. As a result, benthic communities also change a lot, with the communities rarely advancing beyond early succession stages (Heip et al., 2006).

In fresh tidal waters (R8), species are accustomed to tidal movements, by being adapted to dry and wet periods, and variation in currents. Due to these extreme circumstances, these areas are relatively species poor, but they do have certain characteristic species and communities (Peeters et al., 2010). The macrofauna community is different from brackish and saltwater communities, as they have a high diversity of insects (larvae) and Oligochaeta. There are only a few characteristic freshwater species, which are the Swollen spire snail (*Mercuria confusa*) and the mosquito larvae *Thalassosmittia thalassophila* (Peeters et al., 2010). The deep gullies do not contain many species, outside the Zebra mussel (*Dreissena polymorpha*), a few current loving Oligochaeta (*Propappus volki*) and larvae of Chironomidae (*Kloosia pusilla*) (Peeters et al., 2010). In areas with a high current velocity and unstable beddings, the conditions are bad. In areas with a lower current velocity, more species can thrive. Here you can find freshwater mussels, for example species of Unionidae and Anodontinae (Peeters et al., 2010).

'Kierbesluit'

The Quagga mussel will disappear from the West part of the Haringvliet when more salt intrudes with the tide (Noordhuis, 2017). The soil fauna will be composed of species that have a wide salinity tolerance, quick development and can quickly colonize. A part of the species also needs to be able to withstand the salt tongue coming through their area four times a day and the accompanying sedimentation and resubmission of particles (Noordhuis, 2017). Almost every year there will be periods with a low river discharge (<1500 m^3/s). During these periods the Haringvliet sluices will be closed, resulting in the Haringvliet becoming mostly fresh water again. The top water layer will become fresh within one day, the lower layers within three to four days. The dynamic of the salt tongue coming through four times a day will disappear. As a result, no permanent salt or brackish macrofauna community can be established in areas that are less than 8 meters in depth (Noordhuis, 2017). The low river discharge periods will on average occur five times a year. The sluices will be closed on average 20 days during such a period, resulting in the sluices being closed for on average 100 days a year. So, on average five times per year the saltwater will be replaced completely in areas with a depth less than 8 meters. This will inhibit the ability of stable salt and brackish macrofauna to inhabit the Haringvliet, expect in the deep gullies (>8 m in depth) (Noordhuis, 2017).

Currently, the status of Haringvliet-West is good (Factsheet, 2018). With the 'kierbesluit' Haringvliet-West will become a saltwater area. However, five times a year this area will become fresh again due to the closing of the Haringvliet sluices. This constant change from salt to fresh water and vice versa will inhibit the ability for a stable macrofauna community to develop. On the other hand, van Hees & Peters (1998) stated that the macrofauna community will increase slightly with the 'kierbesluit'. However, this is under the assumption that the sluices will be opened permanently. They did not consider the closing to the sluices multiple times a year. Therefore, we expect the macrofauna to deteriorate with the 'kierbesluit'. The macrofauna status for the Haringvliet East and Hollands Diep (R8) is moderate (Compendium voor de Leefomgeving, 2016; Factsheet, 2018). We expect the status to remain the same under the 'kierbesluit', as the saltwater will not be allowed to intrude further than the line Spui – Middelharnis (Wijsman et al., 2018).

Delta21

For the 'kierbesluit' the salt gradient is not allowed any further than the Spui (Wijsman et al., 2018). For the Delta21 project it is expected to reach much further, possibly up to Strijenas/Rode Vaart under high tide and low discharge conditions (Wijsman et al., 2018). Therefore, salt and brackish water communities will develop further upstream. According to the Delta21 project the sluices will be closed when the river discharge is less than 1000 m^3/s (Delta21, 2019). The average river discharge is expected to be 1130 m^3/s (Noordhuis, 2017), resulting in the sluices being closed for an average of 10 days a year (Delta21, 2019).

Fresh water rinsing will be a much smaller problem for the macrofauna community in Haringvliet West with the Delta21 plan, than with the 'kierbesluit'. Van Hees & Peters (1998) stated that the macrofauna community will strongly increase in a situation similar to the Delta21 plan and as the freshwater rinsing will not be a problem, we expect the macrofauna community to increase in their status in Haringvliet West. The prognosis for macrofauna in the Haringvliet East and Hollands Diep, the R8 waterbody, is very difficult to determine. As explained in previous chapter 4.2.2, predictions regarding the saltwater influx is very difficult. The macrofauna community, depends on salt concentrations and the changes between saltwater and freshwater. We expect that this might negatively affect the current status of macrofauna.

4.3.3 Water flora

Historically, the Haringvliet consisted of large regions with mudflats with habitats for estuary flora. The mudflats were mainly dominated by two vegetation types, reeds (*Phragmites australis*) and rushes (biezen) habitat. Also, seagrass fields historically occurred in high abundances in the Haringvliet. These fields were composed of both Dwarf eelgrass (*Zostera noltii*) and Common eelgrass (*Zostera marina*), which is nowadays a threatened species. These two vegetation types are part of the quality assessment of the WFD. The historical vegetation zones in the Haringvliet delta show similarities to the current vegetation in the Westerschelde (STOWA, 2018; van de Rijt & Coops, 1993). The typical vegetation of the Haringvliet and Hollands Diep almost completely disappeared in the years after the realisation of the dam. Removing the tide from the area had massive impact, together with grazing from birds this resulted in the disappearance of the reed and rushes (Rijkswaterstaat, 2011). However, from 1979 onwards there has been active management in order to reverse this impact. In areas with low grazing pressure from either geese or cows, there is development of stretching reed fields again (Rijkswaterstaat, 2011).

‘Kierbesluit’

Both the current situation and the similar area Westerschelde, are classified with the status ‘good’, it is expected that this will remain the same. The good quality has been stable for over a decade. Moreover, the benefits of the Delta21 project, such as the increasing impact of the tide can only positively influence the water flora of an estuary since the shifting water levels is preferable for these occurring estuary species (de Boois, 1982). Also, when the ‘kierbesluit' measure will continue until 2050, the impact on the water flora ecotypes can be neglectable. In the part of Hollands Diep, which is classified as R8, the tide increases. This will create better opportunities for more rushes to develop in the intertidal area of the shore. Since the abundance of rushes (in %) is a direct measure for the quality of R8 the quality will most likely stay the same since it is already at the highest achievable quality of a heavily modified waterbody (STOWA, 2018). The quality of the water flora both in the Haringvliet and Hollands Diep will most likely stay the same in both the ‘kierbesluit’ scenario as after realisation of Delta21 (Paalvast et al., 1998).

Delta21

With the realisation of Delta21 estuary flora vegetation can rehabilitate in the benthic regions of the Haringvliet delta again. Also, the species composition of the bank vegetation will shift towards estuary cultures. The restoration of the tidal system will create opportunities for species that were once present. Species such as the Sea clubrush (*Scirpus maritimus*) and Common clubrush (*Schoenoplectus lacustris*) were historically among the most abundant shore vegetation in the Haringvliet estuary. After the realisation of the Haringvliet dam, most of these estuary species disappeared. The above-mentioned species were only found sporadically along the shores of the Haringvliet delta after 1970, only the reed (*Phragmites australis*) managed to still inhabit parts of the shallower banks (van de Rijt & Coops, 1993). As mentioned in Chapter 3.2.3, the quality and quantity assessment for water type O2 is based on different vegetation types and their relative abundance compared to the total suitable growing area. It is predicted that after realisation of Delta21, there will be an overall increase in tidal waves in the Haringvliet delta. This will have a strong positive impact on the proportion of natural banks, creating more suitable area for the water flora to occur. This has a positive influence on the quantity aspect according to the WFD. It is also expected that seagrass species will reoccur in the area since they have been abundant in the area prior to the dam and Dwarf eelgrass (Zostera noltii) is currently abundant in the Westerschelde (Rijkswaterstaat, 2011; STOWA, 2018; Ysebaert et al., 2016).

The Westerschelde will also be used to scale the outcomes for water flora after realisation of Delta21. Consistently from 2015 onwards, the quality of the Westerschelde has been good. It is important to realise that after the Delta21 project there will be periods of ‘zoetspoeling' occurring on average 10 days a year (Delta21, 2019). The effects of climate change by the year of 2050 will be more severe. As mentioned in Chapter 4.2.1., there can be periods of continuous closure of the sluices for the months September-October. This means that the physical properties for the water plants in the Haringvliet will shift very abrupt from brackish to temporarily fresh (te Linde et al., 2010; Vellinga et al., 2008). When the water shifts from brackish to fresh water, temporarily, the salinity shifts. However, the species that mainly occur in the estuary also thrive in freshwater systems. Therefore, a temporarily shift towards freshwater will most likely not significantly impact or decrease the quality of the estuary habitats (te Linde et al., 2010; Vellinga et al., 2008).

4.3.4 Phytoplankton

As stated, before in Chapter 3.2.4, the phytoplankton is monitored for the WFD measuring the chlorophyll-α concentration in the estuary. In estuaries (O2) phytoplankton is not identified up to species levels.

Before the closure of the Haringvliet, there was a relatively large discharge from the Rhine in the summer. This caused a low residual time for the phytoplankton and resulted in poor plankton development. As the phytoplankton generation time can vary from one to a few days. After closure of the Haringvliet, this residual time increased to 30-40 days in summer and this caused a drastic species change (Peelen, 1974). As the ecosystem was still in development, Peelen (1974) did not discuss phytoplankton quantities, rather species composition.

'Kierbesluit'

During the 'kier' management, the fluctuations in salinity will affect the species composition and phytoplankton quantities in the Haringvliet (Paalvast, 2016). Noordhuis (2017) shows in graphs that there is a large peek up to approximately 25 µg/L in chlorophyll concentration outside of the sluices between March and May. This is lower within the Haringvliet and shows a smaller peak in July up to approximately 10 µg/L. This is supported by STOWA (2018) stating that the lower water layers with higher salinity have a higher primary production. This might mean an increase in phytoplankton levels under the circumstances of influx of saltwater under the 'kier' management. However, in 'kier' management documents (Wijsman et al., 2018) is stated that the saltwater shall not pass by the line Middelharnis-Spui and the sluices will only be opened if the discharge exceeds a certain threshold. This limits the influx of saltwater. Additionally, STOWA (2018) states that phytoplankton primary production is lowest in the brackish water zone. When combining this information, we cannot make a clear prognosis whether the quality will increase or decrease under the 'kier' management according to the standards of the WFD. We expect minor changes to occur.

Delta21

After opening the Haringvliet sluices, this previously mentioned strong chlorophyll peak in the saltwater (Noordhuis, 2017), might increase the average chlorophyll concentrations in the Haringvliet as the saltwater can intrude into the estuarian. On the other hand, the turbidity in estuaries is shown to delay the phytoplankton bloom and in brackish waters it is even delayed until the summer. Moreover, the discharge from the rhine might flush out the phytoplankton and the large brackish zone is expected to affect the phytoplankton primary production negatively (STOWA, 2018). Both the Westerschelde and the Ems-Dollard are given the status 'good' according to the GEP. They both score ≥0,6 on the scale, so below 18 µg/L chlorophyll-α. Therefore, even though the water system entirely changes from an R8 to an O2, we expect the system to balance to a 'good' status.

4.4 Chemical quality

Tributyltin

Tributyltin was used on ship paint to prevent shells to attach to the ship. It has been banned for use in 1993 for small ships (<25m) and in 2003 for bigger ships. It barely dissolves and attaches to fine sediment. Regularly used ship routes and surroundings of shipyards often have polluted sediment (WaddenZee, 2019). It is therefore a ubiquitous sediment. Factsheet (2018) expect to keep the sufficient status in the Eastern Haringvliet but not in the Western Haringvliet.

PAH

Poly aromatic hydrocarbon (PAH) are polluted by incomplete combustion and pollution sources are small and bigger energy plants (van Duijnhoven & Bakker, 2011). The WFD considers benzo(a)pyrene, benzo(e)acephenanthrylene, benzo(g,h,i)perylene, and fluoranthene in the chemical quality and benzo(a)anthracene in the other specific pollutants in biological quality. Industrial pollution has spiked in 2010 (1990-2016) and declined afterwards (Rijkswaterstaat, 2018). Deltares (2016) noted a decline in input (up to 3-fold) for all PAH's in the Rhine and for some in the Meuse over the last decades (1990-

2014). Atmospheric deposition has been decreasing both in the Netherlands and in Europe (1990-2017) (Rijkswaterstaat, 2019a).

The chemicals mentioned before barely dissolve and are easily bound to sludge. Sewage systems can sieve up to 90% for benzo(a)pyrene and benzo(e)acephenanthrylene and 60% for benzo(g,h,i)perylene. The remainder is excreted into surface water. These chemicals build up in sediment and are all considered ubiquitous chemicals except for fluoranthene and are not expected to change if sediments do not change (Baltussen & Geurts van Kessel, 2014; Factsheet, 2018). Only benzo(b)fluaranthene and benzoanthracene might make the 2027 WFD goal because of mitigation measures (Factsheet, 2018). Higher dynamics are expected to increase erosion. This could flush out some of the polluted sediments (Ysebaert et al., 2016). The exact erosion gullies are difficult to predict so this is not considered for the WFD predictions.

Mercury

Mercury is a ubiquitous chemical and the water quality for mercury adheres to the WFD goals. It binds strongly to sediment and both Haringvliet and Hollands Diep are polluted (Pieters & Kotterman, 2003; Slooff, van Beelen, Annema, & Janus, 1994). Only the mercury in eel exceeds the WFD limits (van Duijnhoven & Bakker, 2011). Mercury input by the Rhine and the Meuse have been declining over the last decades as well industrial pollution within the Netherlands (Deltares, 2016; Rijkswaterstaat, 2018). The EU has also made the legislation stricter in 2016 (EU, 2016). Based on those decreases, a slight improvement is expected. However, Factsheet (2018) expects that the WFD goals will not be made in 2027. Like, the PAH (4.4), increasing dynamics might flush out some of the polluted sediments.

4.5 Summary

We have summarized the information from this chapter in the factsheets in Table 11 and 12. The complete factsheet with all quality elements can be found in Appendix III. This factsheet is based on the WFD assessment of 'Waterkwaliteitsportaal' (Factsheet, 2018). In addition, we have added our prognoses for 2050 under 'kier' management and after implementation of the Delta21 project. As we did a qualitative analysis and not a quantitative, we cannot predict the status of each quality element. However, we indicated expected increase, decrease and no change in quality by using respectively +, - and 0 signs.

Haringvliet West

The 'kierbesluit' does not seem to have a large effect on the overall WFD quality of the Haringvliet West. There is a positive effect in 2050 for other specific pollutants, but this is attributed to current legislation instead of the 'kierbesluit'. There is a slight positive effect expected on the quality element fish, as they will be able to migrate past the Haringvliet dam. On the other hand, a slightly negative effect is expected on macrofauna due to the saltwater and freshwater changes. Therefore, we do not expect a large positive of negative net effect (Table 11).

The effect of Delta21 on the Haringvliet West, appears to be larger. We expect a positive effect on the quality element fish, since the fish will be able to migrate freely when the dam is opened. Moreover, we expect a positive effect on macrofauna and water flora when the estuary is restored. The combination of these factors will lead to an expected positive net effect (Table 11).

Table 11: Final impact assessment of quality elements for Haringvliet West based on the Factsheet (2018). For legend colours, see Appendix III.

Haringvliet West			2018	Kier	Delta 21
Final assessment	Ecological quality	Ecology total		0	+
		Hydromorphology		0	+
		Physicochemical quality		-	0
		Other specific pollutants		+	+
		Biology total		0	+
	Chemical quality	Chemical total		0	0
		Ubiquitous chemicals		0	0
		Non-ubiquitaire chemicals		NA	NA

Haringvliet East/Hollands Diep

Both the 'kierbesluit' and Delta21 implementation appear to have a positive effect on the WFD status of the Haringvliet East/Hollands Diep. Here again some increasing quality elements (e.g. chemicals) are autonomic and cannot be attributed to the 'kier' management nor Delta21 implementation. Nevertheless, there seems to be an overall net positive effect. This effect occurs stronger for the Delta21 scenario even though the macrofauna seems to be negatively affected. The quality elements fish, water flora and river discharge increase stronger for Delta21 than under 'kier' management (Table 12).

Table 12: Final assessment of quality elements for Haringvliet East and Hollands Diep based on the Factsheet (2018). For legend colours, see Appendix III.

Haringvliet East/Hollands Diep			2018	Kier	Delta 21
Final assessment	Ecological quality	Ecology total		+	+
		Hydromorphology		0	+
		Physicochemical quality		+	+
		Other specific pollutants		+	+
		Biology total		0	+
	Chemical quality	Chemical total		0	0
		Ubiquitous chemicals		0/+	0/+
		Non-ubiquitaire chemicals		0	0

Based on these summary tables, it implies a larger overall positive effect for Haringvliet East/Hollands Diep under both kier and Delta21 for the WFD quality elements than the Haringvliet West. However, we attribute this to the different WFD assessments for both water types. Haringvliet West is assessed as O2 and Haringvliet East/Hollands Diep as R8. When considering all separate quality elements in Appendix III, it becomes clear that some factors weigh different or are not applicable for one water type, whereas it is for the other.

5. Discussion and Recommendations

After assessing the reference, current and expected situation in the Haringvliet and Hollands Diep, we will put our study in a broader perspective.

5.1 Limitation

In this report we write prognoses for the Haringvliet West and the combination of the Haringvliet East and Hollands Diep, under the 'kier' management and under the effects of the implementation of the Delta21 project. One should keep in mind that these prognoses are based on available literature and largely dependent on assumptions. Additionally, as a team of students, we are no experts on the Water Framework Directive (WFD), nor do we have many years of experience in our respective fields. For this report we look to the year 2050 as a comparison point for the two different plans. In those 30 years, multiple aspects (e.g. politics, climate) can change and several scenarios are possible. Moreover, we took 2018 as the current situation for the created factsheet, but every year has its year specific effects that might affect the outcome of the WFD assessment of that year.

Saltwater intrusion, tidal heights, discharge and related sluice closure which form the boundary conditions for ecological development are estimated in this study. Uncertainty about the discharge and sluice closure is mostly based on climate change and is discussed in Chapter 5.2. The effects of the tide and saltwater intrusion were estimated by several models (see 4.2.1). They all underline the uncertainty in the saltwater predictions. More important, the effects of the Energy Storage Lake, the optional POA, the new dam and morphological changes outside Haringvliet are not included in those modelling studies. Additionally, the expected ecological situation is mainly based on data of the Westerschelde and historical data. Each estuary has its own unique species composition and since the Haringvliet dam is placed, the circumstances have changed.

5.2 Climate change

Climate change has a potentially large influence on the prognoses for the Haringvliet (West and East) and Hollands Diep in the future. Some effects are covered in the chapters; however, we would like to elaborate on certain aspects which are not covered in the previous chapters.

5.2.1 Dam closure

Salt intrusion

Salt intrusion into the Haringvliet East/Hollands Diep could technically be detrimental for achieving its R8 WFD goals. However, the transition between O2 and R8 is a dynamic process that flows back and forth. Further salinity intrusion caused by, for example, sea level rise will not damage the R8 water type so much as it will moves the transition zone between the two water types. Salt intrusion deep into the Eastern Haringvliet may eventually threaten the freshwater inlets, causing the Tidal Lake weir to be closed to stop saltwater inflow. This closure, combined with the action of flushing out the saltwater, may undo all the effects of saltwater intrusion. If the sluices are closed while saltwater is still inside, oxygen levels might decrease as a result of stratification as explained in 4.2.3. If this situation lasts too long, it will be detrimental for the ecology. Furthermore, closure of the sluices will have a negative impact on nitrogen, DIN, phosphor concentrations, some specific pollutants and hydromorphological goals. All these criteria in turn will influence the ecological values of the system as well.

Protecting the fresh water supply in different ways can help avoid the sluice closure and associated risks and will help safeguard long term adherence to the WFD guidelines. The salt tongue threshold under the Haringvliet bridge may help hold back the saltwater in order to protect the freshwater inlets. The exact implementation of this remains unclear and needs further modelling studies. The freshwater supply may also be protected through the realisation of large freshwater reservoirs inland, capable of handling long term water provisioning. The buffer function of these reservoirs may reduce the need for sluice closure and thus protect ecosystem functioning.

Ship navigation

The Haringvliet and Hollands Diep are important for domestic shipping (Baptist et al., 2007; van Hees & Peters, 1998). The situation before and after the 'kier' management have taken ship navigation into account by setting a minimum depth at Moerdijk. If this minimum depth is threatened to not be reached, the sluices will be closed (Wijsman et al., 2018). This will become a bigger problem with lower discharges due to climate change. A solution, which avoids closing the sluices, is deepening the fairway. Van Hees & Peters (1998) mentioned that increased dynamics by opening the sluices will lead to less sedimentation in the long term.

5.2.2 Effects on biology

Except for changing discharge and salt intrusion, climate change effects have not been discussed regarding its effects on ecology. Acidity, temperature change, higher CO_2 concentration and different precipitation levels might have their impact on the current biology. New species might colonise the area and some current ones might disappear due to the changing environment. These effects are too complicated and beyond the scope of this study to discuss into detail. However, it should be included in further research regarding Delta21.

5.2.3 Long term effects

This report has considered predictions up to 2050. However, a project like Delta21 functions on a much larger time scale than 30 years. Therefore, climate change predictions for 2100 and beyond can help assess the Delta21 plan. Continuing on the more extreme W+ scenario (4 °C in 2100 globally), the summer discharges will further decrease up to 60% (700 m^3/s) at Lobith (KNMI, 2015; Vellinga et al., 2008). The peak discharge will also increase up to 38% (Vellinga et al., 2008). All discharge predictions assume no change in water use or inundations upstream. Sea level rise will be 100 cm in 2100 (KNMI, 2015). Both discharge changes and sea level rise will lead to a more frequent closure of the sluices if policy remains the same. Together with the temperature, acidity, and CO_2 concentration, those climate change effects will have a profound impact on the ecology.

5.3 Chemicals and pollutants

Expected changes in pollutants are mostly independent of the 'kierbesluit' or Delta21. Soil remediation is possible by identifying, reducing and restricting current emissions or by cleaning polluted sediments. Reduction and restriction are both political decisions that will come at the cost of other industries. In this way, point sources could be added next to the catchment or could be removed from the catchment and diffuse sources legislation could be less or stricter. Also, new pollutants could increase in their concentrations. Van Duijnhoven & Bakker (2011) discusses several steps in achieving an emission reduction for cobalt, which are similar for other chemicals.

PAHs, tributyltin and mercury have high concentrations in the sediment. Factsheet (2018) discusses several options under the 'kier' management but concludes that those are either too expensive or the effectiveness is marginal and therefore no feasible measures can be suggested. As explained in Chapter 4.4, increasing dynamics could result in flushing out of polluted sediment, but could also uncover the polluted sediments and entrain them. Such changes might alter decision making for soil remediation in the future.

5.4 Nature legislation

Regulations and law enforcements within the Haringvliet are not only related to the WFD. The research area includes a Natura2000 area and other regulations are of equal importance. In the Netherlands, since January 2017, the New Nature Law ('Nieuwe Natuurwet') was enforced. This law replaces three former laws including regulations on protected areas such as Natura2000 and protected species (Hunink & Zollinger, 2016).

5.4.1 Natura2000

The Delta21 project and its realisation needs to adhere to these law enforcements as well. A permit is needed in order to alter the protected habitat types in a Natura2000 area. Haringvliet West in specific hosts one of the largest marsh-meadow fields (*Altheaea officinalis*) (habitat type 6430). In this area important protected bird species such as the Bluethroat (*Luscinia svecica*) can thrive. The impact of Delta21 on the Natura2000 area in Haringvliet West will most likely alter the composition of its habitat types. A specific impact assessment of Delta 21 on habitat types, according to the Natura2000 guidelines, is needed in order to get permission to realise Delta21 (Ministry of Agriculture Nature and Food Quality, 2010).

Within the New Nature Law there are other enforcements that apply on the research area Haringvliet West & East. More specifically, birds and habitat guidelines also apply on the Natura2000 areas in order to maintain specific protected species, like the bluethroat (*Luscinia svecica*). Protected areas for these birds occur in the Haringvliet west. For every implemented change, including shifting habitats types, any possible negative impacts need to be assessed. The implementations cannot be realised if they appear to be damaging to the protected flora and fauna. Exceptions can be made, only if these exceptions serve the purpose of big and important public interest. This should be taken in consideration for the Delta21 plan (Osieck, 1998).

The protection of vulnerable mammals is also included in the Natura2000 law enforcements, a total of 44 species are protected. Within the pro-delta, the two protected Natura2000 seal species are of importance, the common seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*). For the common seal (*Phoca vitulina*) specifically, the goal is to realise a stable permanent population of at least 200 individuals before 2021. The 'Voordelta' is the biggest contributing area to achieve these goals in the South-West of the Netherlands. Impacting the habitat for seals in the 'Voordelta' is therefore prohibited since this has impact on the conservation objectives. Delta21 would change the occurrence of seal habitats in the 'Voordelta' and therefore this enforcement applies on the Delta21 project. However, exceptions can again be realised if topics serve a bigger purpose of important public interest (Ministry of Infrastructure and Water management, 2016).

5.4.2 Fish measures

Rijkswaterstaat is responsible for implementing the measures which aim to increase the fish populations and therefore its quality. Currently, measures are implemented to support the reintroduction of rheophile species that are entering the system again via the sluice opening from the 'kierbesluit'. Tree trunks are placed on the river bottom to create structure functioning both as habitat for macrofauna and as shelter for the fish species. This has a positive effect on the success rate of spawning fish species. Additionally, natural banks are renewed in the research area over a transect of 9km. This measure both tackles erosion of the banks but also brings opportunities for fish species to spawn and thus increase the possibility that indicator species, such as the salmon and sea trout, will be successfully reintroduced. Natural banks have a strong positive impact on all aspects regarding the ecological quality status. Therefore, it is recommended to further increase the abundance of natural banks in both the Haringvliet (West and East) and Hollands Diep (Rijkswaterstaat, 2019b).

Another important factor influencing the success of the reintroduced fish species is fishing. Currently, there are still fisheries active both in front of the dam and behind the dam. Reducing the fisheries in the direct transition zone between fresh and saltwater will increase the success rate of rheophile fish species traveling upstream significantly (Ysebaert et al., 2016). Therefore, we recommend that fishing activities are excluded in the direct transition area until at least ‘het Spui'. This is especially important during the migration period of indicator species (Griffioen, Winter, & van Hal, 2017).

5.5 Catchment perspective

If the Delta21 project would be implemented, an historically important estuary for migrating fish species would be realised again. This would have a positive influence on species such as the salmon (*Salmo salar*) and sea trout (*Salmo trutta*). However, the successful reintroduction to the system also depends on the situation upstream. For example, the migration from the salmon in the catchment of the Meuse is still negatively impacted by fisheries and hydraulic power stations in both the Netherlands and Germany. The impact on the indicator fish species for both water type O2 & R8 therefore also depends on the functioning of the upstream catchment (Compendium voor de Leefomgeving, 2018). High mortality rates of young migrating salmon (*Salmo salar*) and European eel (*Anguilla anguilla*) occur when they are traveling via the main current from the river Meuse.

Changes in land use upstream also have a big impact on the estuary and lower catchment of the Meuse. Due to the overall increase of global surface temperature, crops will relatively use more water for the same yield. Especially in summer this can result in a big increase of water use in the upper catchment both reducing overall discharge and altering the overall water quality (Bresser et al., 2005). Predictions and models on the impact of climate change are based on current management for land use and therefore its use of water. Nonetheless, since there most likely will be a higher demand for irrigation, the effects predicted by these models can be more severe (Nechifor & Winning, 2019).

5.6 Rijkswaterstaat and Water Framework Directive

It is difficult to make an exact prediction for how much the Delta21 plan helps with achieving RWS’s WFD goals for 2027, based on this qualitative analysis. However, based on our factsheet is seems that Delta21 does have a stronger positive effect on the progress toward the WFD goals then the current ‘kier’ management. It must be said that it is unlikely that Delta21 can have an actual effect before 2027 given the scale of the project but implementation of the plan may help prove that RWS is on track to fix the problems, which may be accepted as well under WFD guidelines. The prognoses of this report are based on the current GEP values. After implementation of Delta21, the opening of the sluices might have such a large impact on the water quality, that the GEP values are adjusted for the waterbodies (van der Wal, 2018). This may result in higher Ecological Quality Ratio values, without actually leading to a higher classification.

6. Conclusion

The implementation of the Delta21 project currently lacks predictions of its qualitative effects on water quality in the Haringvliet (West and East) and Hollands Diep. In this study we used literature to estimate these effects according to the guidelines of the European Water Framework Directive (WFD). We did this by comparing the expected effects of both the scenarios of Delta21 implementation and the current 'kier' management by 2050. Additionally, we discussed whether the implementation of Delta21 could contribute to compliance of Rijkswaterstaat to the objectives of the Water Framework Directive in 2027.

The net effects for both the Delta21 scenario and 'kierbesluit' scenario appear to be positive according to our assessment. The Delta21 scenario is expected to have a stronger positive effect, mainly due to its relatively larger potential positive contribution to the biology and hydromorphology subcategories. Therefore, we expect that the implementation of Delta21 might contribute to the compliance of Rijkswaterstaat to the WFD goals of 2027. However, this positive effect could be cancelled out by the threshold for sluice closure in the current sluice management policy, if the management is not adapted in response to the effects of climate change. We recommend performing more detailed, qualitative studies regarding the effects of the Energy Storage Lake and Tidal Lake on the estuarian characteristics of the Western Haringvliet.

References

Most used references

1. (van Hees & Peters, 1998)
    a. This report contains a thorough research into the effects of the Haringvliet sluice management in 1998 and proposes some alternative management options and deliberates on the effects of these alternatives.

2. (Rijkswaterstaat, 2011)
    a. This report gives a description of the current macrofauna species composition and hydromorphological conditions in the entire Haringvliet (West and East).

3. (Noordhuis, 2017)
    a. This report summarizes the outlines of the hydraulic properties of the Haringvliet for several management strategies. Gives an overview of important research papers and reports and provides a basis for forecasting potential nature developments for several hydraulic scenarios.

4. (Wijsman et al., 2018)
    a. This report describes the potential of tidal nature reservation for the scenarios: (1) Current management (2) 'kierbesluit', (3) 80 cm tidal range, (4) Storm surge barrier and (5) Storm surge barrier with climate change.

5. (STOWA, 2018)
    a. This report describes the specific criteria and standards for optimal quality of the Dutch natural water types. The O2 water type can be found on page 247 and the R8 water type can be found on page 177.

6. (Wolff, 1973)
    a. This article describes the historical situation of the Haringvliet estuary before the dam. The focus of the article is on macrofauna. However, it contains a lot of information on other aspects such as salinity of the Haringvliet estuary as well.

7. (Factsheet, 2018)
    a. This Factsheet gives an overview of all KRW qualifications. Page 402 – 449 states the current and expected situation of water quality in the Haringvliet West (NL94_11) (page 428-440), Haringvliet East/Hollands Diep (NL94_1) (page 402-413). We used their figures as a basis to visualize and frame our own expectations.

8. (Compendium voor de Leefomgeving, 2016)
    a. This website shows per waterbody the WFD status on an interactive map. Each quality element separately can be checked. The data is from 2015.

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Appendix I: Background: Historic developments, interests and ecological challenges

The Haringvliet is located in the Dutch Southwestern Delta. Originally, the Haringvliet was an open estuary, with both saltwater influences from the open sea as well as freshwater inflow from the Rhine and Meuse. A dynamic transition between fresh and saltwater was dominating the area. The estuaries were daily impacted by the tides and due to these unique conditions, the dynamic area was high in species richness (Figure 14, 800 ad) (Ferguson & Wolff, 1984).

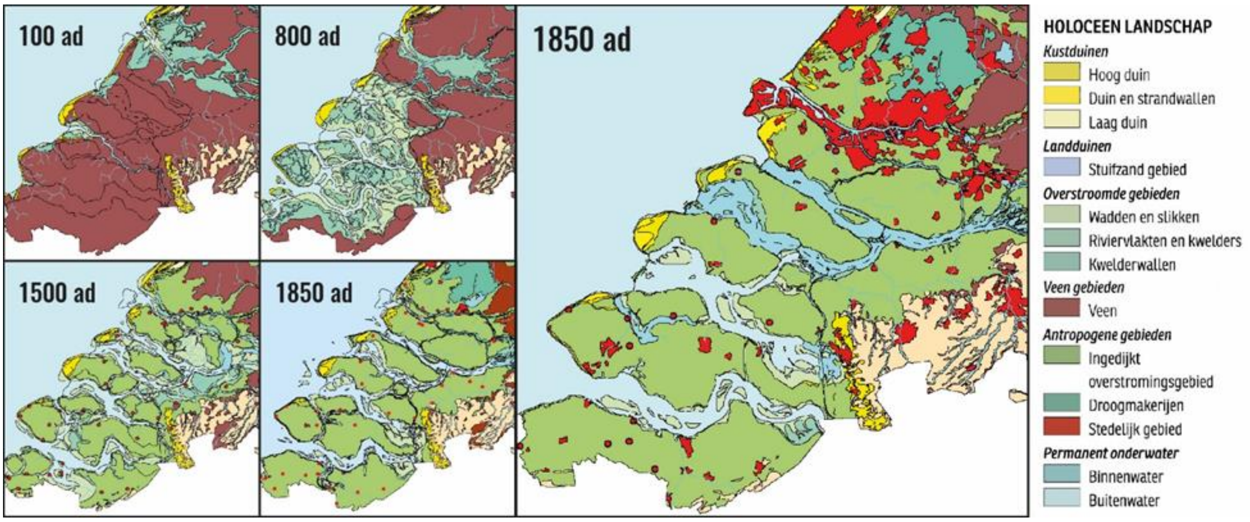

Figure 14: Historical evolution of the Southwestern Dutch Delta (Vos, P. & S. de Vries 2013: 2e generatie palaeogeografische kaarten van Nederland (versie 2.0). Deltares, Utrecht. Op 18-11-2019 gedownload van www.cultureelerfgoed.nl.)

As a reaction to the devastating flood of 1953, the coastline was shortened as a measure for flood protection for the people. Two of the original four open estuaries were completely closed during the construction of the Delta Works (Haringvliet and Grevelingen). The Eastern Scheldt was closed partially, and the Western Scheldt was left open, as it is the entrance to the ports of Antwerp (Tönis et al., 2002; Ysebaert et al., 2016). The Haringvliet estuary was closed at two locations, one dam was constructed 30 km upstream (Volkerak dam, 1969) and one at the river mouth (Haringvliet dam, 1970). The dikes of the Maasvlakte and the Slufter bounds the estuary in the north, the Brielse Gat dam and the sandy coast of Voorne bounds it in the east, the Haringvliet dam and its sluices in the southeast, and wide sandy beaches of Goeree in the south (Tönis et al., 2002). Current measures for providing water safety include dyke reinforcement and projects like 'Ruimte voor de Rivier'.

The realisation of the Delta Works had an impact on the tidal currents and the wave impact in the Harlingvliet (Tönis et al., 2002). It had a big impact on the morphology of the estuary. The waters landwards of the Haringvliet dam turned into fresh waters, resulting in the disappearance of the brackish intertidal system. A small estuary remained seaward of the dam (Tönis et al., 2002; van Dijk, 2019). Most of the species richness in the area also disappeared. Most of the occurring species lost their habitats due to the stable water levels, and the migrating fish species cannot pass the estuary anymore. Part of the solution could be reopening the tidal inlets as an attempt to improve and recover the environment in the Haringvliet (Tönis et al., 2002). This is currently implemented by opening the Haringvliet Sluices, as stated in the 'kierbesluit' (Wijsman et al., 2018). The Delta21 project aims to take this implementation further by opening the Haringvliet dam completely.

Appendix II: Introduction to the Water Framework Directive

The European Water Framework Directive (WFD) is a document first published in December 2000 with guidelines regarding European water management. All the EU member states have to conform their water management legislations to meet the requirements of the WFD. The main objective of the WFD is to achieve the status ‘good’ for all European waters by 2015 (Mostert, 2003). These standards were not fully met in 2015, therefore its new deadline is postponed to 2027 (“Kaderrichtlijn Water - BIJ12,” 2019).

Within the current framework of the WFD, waters are classified based on several characteristics. Three main categories can be distinguished based on their character. The first category comprises the natural waters such as lakes, rivers, tidal- and coastal waters. The second category comprises the heavily modified waterbodies, by for example hydromorphological interventions. All anthropogenically created waterbodies, in locations where there was no water before, belong to the third category, the artificial waters (STOWA, 2018). These main categories are subdivided into smaller operational areas, the water types. According to the STOWA (2018) only the larger waters belonging to the category natural waters are reported to the European Commission. Therefore, the STOWA guidelines are described for 9 lake types, 12 river types and 4 tidal- and coastal waters.

The waterbodies are assessed according to multiple criteria. The two main categories of criteria are chemical quality and ecological quality. The chemical quality is assessed by set norms for 33 chemicals and can be either ‘insufficient’ (exceeding the norm) or ‘sufficient’ (remain below the norm). The ecological quality is subdivided into Biology, Physiochemical quality, other relevant chemicals and hydromorphology. These subcategories of criteria are subdivided again. For biology: Fish, macrofauna, water flora and phytoplankton. Physiochemical quality: phosphorus, nitrogen, oxygen, transparency, acidity, salinity, temperature and dissolved inorganic nitrogen. See Table 13 for an overview.

Table 13: Gives an overview of the standards the water is tested upon.

Main categories	Subcategories	Quality elements
Chemical quality		33 chemicals
Ecological quality	Biology	Fish
		Macrofauna
		Water flora
		Phytoplankton
	Physiochemical quality	8 parameters
	Other Relevant	+- 100 chemicals
	Hydromorphology	

Each of these categories will get an EQR (Ecological Quality Ratio, or EKR in Dutch) value assigned, based on their compliance to WFD standards. This value can fall between 0, for the lowest possible quality, and 1.0, for the highest possible quality (the natural reference situation). This range from 0 to 1.0 is subdivided into 5 classes: ‘bad’ (0-0.2), ‘poor’ (0.2-0.4), ‘moderate’ (0.4-0.6), ‘good’ (0.6-0.8) and ‘high’ (0.8-1.0). The minimum requirement for WFD adherence is GES (Good Ecological Status or GET in Dutch), which starts at an EQR of 0.6.

The range from 0 to 1.0 is applicable only to natural waters. However, in the Netherlands, most waterbodies are modified or heavily modified. Because these non-natural waters are usually significantly hydromorphologically changed, an EQR of 1.0 is not achievable. Therefore, a modified waterbody is not compared to the natural reference situation (EQR 1.0), but to its Maximum Ecological Potential (MEP). A modified waterbody's MEP is determined by its managing party by assessing all theoretically possible measures and determining the subsequent maximum EQR. From this MEP value a GEP (Good Ecological Potential) value is determined by assessing the maximum EQR value achievable when executing all practically possible measures. This GEP value is now the new minimum EQR value required for that particular modified waterbody to adhere to WFD criteria. The lower ratings of moderate, poor and bad are now subdivided equally over this EQR value. If all EQR values for a modified waterbody are above 0.6 there is no ground to speak of a modified waterbody anymore and the waterbody will be assessed by GES standards going forward. A schematic overview of the steps followed to classify the waterbody can be found in Figure 15 (Ecostat, 2003).

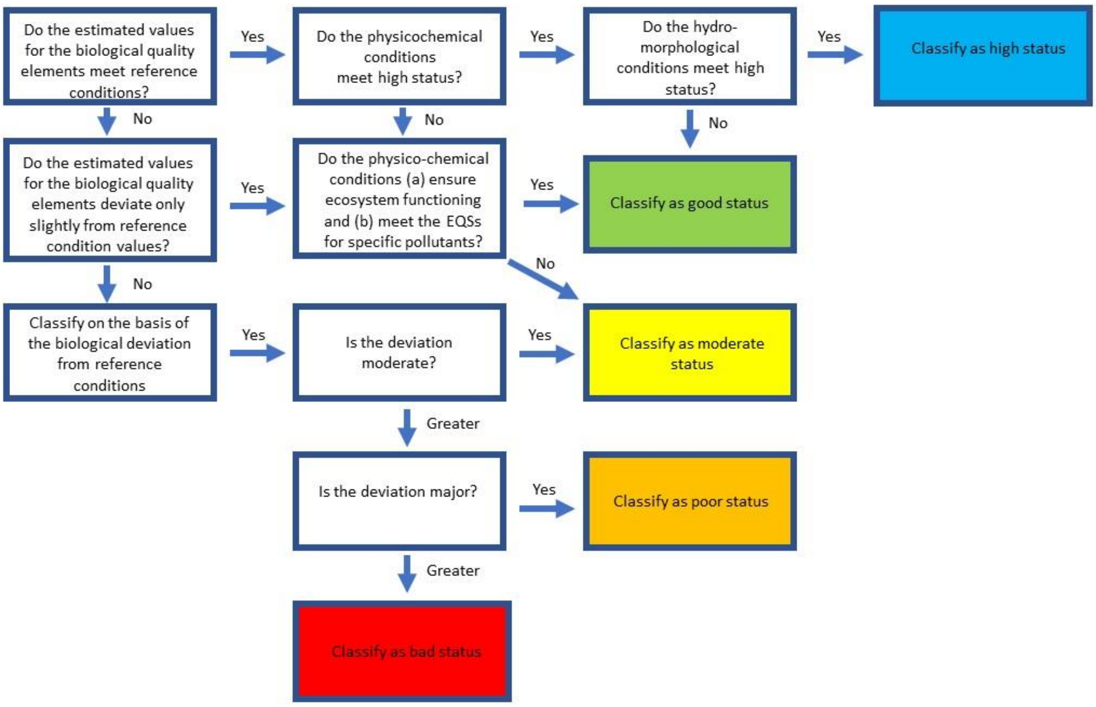

Figure 15: Ecological assessment of waterbodies (Ecostat, 2003). EQS stands for Environmental quality standard for further explanation see Environmental Quality Standard – an overview (2019).

Appendix III: Factsheets

The factsheets (Table 14, 15 and 16) are a visual summary of Chapter 4. Within this chapter, the values mentioned in these tables are explained. In Chapter 4 we do not only mention in more detail how the quality will improve; we also give an explanation on how this is happening. Therefore, it would be incorrect to draw conclusions from solely the tables.

Table 14: Legend explaining the colours and abbreviations of the factsheets.

Legenda				
	Ecological status	**Chemical status**	**Symbol**	**Compared to situation 2018**
	High	Sufficient	--	Large deterioration
	Good		-	Deterioration
	Moderate		0	No expected difference
	Poor		+	Improvement
	Bad	Insufficient	++	Large improvement
NA	No data / not assessed	No data / not assessed	NA	No data / not assessed

Table 15: Factsheet with current situation and prognoses for Haringvliet West. Adapted from Factsheet (2018).

			Haringvliet West			
			GEP (O2)	**2018**	**2050**	
					Kier	**Delta 21**
Ecological quality	Hydromorphology	Natural shoreline	≥ 80%		0	+
	Physiochemical quality	Phosphorus total (SA) (mg P/l)	NA	NA	NA	NA
		Nitrogen total (SA) (mg N/l)	NA	NA	NA	NA
		DIN (winter period) (mg N/l)	≤ 2,57		+	++
		Salinity (SA) (mg Cl/l)	NA	NA	NA	NA
		Maximum Temperature (gr.C)	≤ 25,0		--	0
		Acidity (SA) (-)	NA	NA	NA	NA
		Oxygen saturation (SA) (%)	≥ 60		-/--	0/-
		Transparency (SA) (m)	NA	NA	NA	NA
	Other specific pollutants	Dichlorvos			+	+
		Cobalt			0	+
		Copper			+	+
	Biology	Fish (EKR) GEP	≥ 0,60		0/+	+
		Macrofauna (EKR) GEP	≥ 0,25		-	+
		Water flora (EKR) GEP	≥ 0,00		0	+
		Phytoplankton (EKR) GEP	≥ 0,60		0	0
Chemical quality	Ubiquitous chemicals	Benzo(ghi)perylene			0	0
		Mercury			+	+
		Tributyltin (cation)			-	-
	Non-ubiquitous chemicals	None			NA	NA

Table 16: Factsheet with current situation and prognoses for Haringvliet East/Hollands Diep. Adapted from Factsheet (2018).

			Haringvliet East/Hollands Diep			
			GEP (R8)	2018	2050 Kier	2050 Delta 21
Ecological quality	Hydromorphology	River discharge (m3/s)	600-5341		+	++
		Flow velocity (m/s)	0.001 - 1.5		0	+
	Physiochemical quality	Phosphorus total (SA) (mg P/l)	≤ 0,14		+	+
		Nitrogen total (SA) (mg N/l)	≤ 2,50		+	+
		DIN (winter period) (mg N/l)		NA	NA	NA
		Salinity (SA) (mg Cl/l)	≤ 300		0	-
		Maximum Temperature (gr.C)	≤ 25,0		-	0
		Acidity (SA) (-)	6,0 - 8,5		+	+
		Oxygen saturation (SA) (%)	70 - 120		0/+	+
		Transparency (SA) (m)		NA	NA	NA
	Other specific pollutants	Dichlorvos		NA	NA	NA
		Cobalt			0	0
		Copper			++	++
		Ammonium			+	+
		Benzo(a)anthracene			+	+
		Selenium			0	0
		Uranium			0	0
		Silver			+	+
	Biology	Fish (EKR) GEP	≥ 0,19		0/+	+
		Macrofauna (EKR) GEP	≥ 0,40		0	-
		Water flora (EKR) GEP	≥ 0,32		0	+
		Phytoplankton (EKR) GEP		NA	NA	NA
Chemical quality	Ubiquitous chemicals	Benzo(a)pyrene			0	0
		Benzo(e)acephenanthrylene			+	+
		Benzo(ghi)perylene			0	0
		Mercury			+	+
		Tributyltin (cation)			0	0
	Non-ubiquitous chemicals	Fluoranthene			0	0

Appendix IV: Other specific pollutants

This table show the norms for the other specific pollutants within the ecology and the chemical quality that are exceeded, recently exceeded or expected to exceed in the Haringvliet (East and West) and Hollands Diep (Factsheet, 2018). JG-MKN is the Dutch norm for yearly average environmental quality norm ('jaargemiddelde milieukwaliteitsnorm') and is set for long-term exposure. The MAC-MKN is the maximal acceptable concentration ('Maximaal Aanvaardbare Concentratie') and is meant for short term exposure. More explanation can be found on (RIVM, 2019).

		JG-MKN (µg/l)				MAC-MKN (µg/l)				Sediments (mg/kg)	Entrained particles (log Kp l/kg)	Biota (µg/kg)
		Dissolved		Total		Dissolved		Total				
		Fresh water	Salt water	Fresh water	Salt water	Fresh water	Salt water	Fresh water	Salt water			
Other specific pollutants	Dichlorvos	-		0.0006	0.00006	-		0.0007	0.00007	-	0.9	-
	Cobalt	0.2		-		1.36	0.21	-		12	3.59	-
	Copper	2.4	1.1	-		-		-		73	4.7	-
	Ammonium	-		304	-	-		608	-	-	-	-
	Benzo(a)anthracene	0.00023		0.00064	0.00027	0.1	0.01	0.28	0.012	0.4	4.86	3
	Selenium	0.0052	-	-		0.059	2.6	-		-	2.77	-
	Uranium	0.17	-	-		8.6	-	-		-	2.41	-
	Silver	0.01	0.081	-		0.01	0.081	-		5.5	5	-
Ubiquitous chemicals	Benzo(a)pyrene	-		0.00017		-		0.27	0.027	3	5.04	5
	Benzo(e)acephenanthrylene	-		*		-		0.017		0.81	4.98	*
	Benzo(ghi)perylene	-		*		-		0.0082	0.00082	8	5.7	*
	Mercury	0.00007		-		0.07		-		10	5.23	20
	Tributyltin (kation)	-		0.0002		-		0.00015		10	3.17	-
Non-ubiquitous chemicals	Fluoranthene	-		0.0063	0.063	-		0.12		3	4.23	30

- : No norm

* : Not assessed, value of Benzo(a)pyrene is used an assumed to be equivalent