3 Radiological aspects

This chapter describes the radiological environmental aspects considered in this EIR. In order to better interpret the results of these considerations, a brief introduction on the concept of radiation and its radiological impact is first provided. First, an overview of the situations considered in this EIR will be provided. This is partly a repeat of Chapter 1.

3.1 Scenarios considered

The determination of the effects of the Project is broken down into a number of scenarios, for items 2 and 3 see also § 1.7:

1. Baseline situation: this involves describing the situation as it currently exists. This is based on the situation before the Project, i.e. 2014. And to get a better idea of the average situation, the years 2012 and 2013 are also included.
2. Project (LTO scenario):
    a. Operational phase of the Project between 2015 and 2018: this refers to the phase of the Project where the adaptations and changes resulting from the Project are implemented. This phase will last from 2015 to 2018. These adjustments are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
    b. Operational phase in future situation (period 2019 - 2025): this refers to the phase of the Project where all changes and modifications to the Project have been implemented. The nuclear power plant will then be operated as normal. This phase will last from 2019 to 2025.
3. Zero alternative: this refers to the situation where the Project is <u>not</u> completed and therefore the operation of KCD-1 and KCD-2 will stop in 2015.

As also shown in § 1.1.3, the termination of electricity generation is followed by the Post Operational Phase, after which dismantling starts. Decommissioning is subject to its own specific licensing process, which includes an environmental impact assessment. Since this is a separate procedure, the dismantling of KCD-1 and KCD-2 is not part of this EIR.

§ 3.1.1 through § 3.1.3 describe these situations in more detail and discuss the methodology used that is specific to the situation at hand. This methodology was applied for both the baseline situation, as well as the Project Situation (the LTO scenario) and the Zero Alternative.

3.1.1 Baseline situation

The baseline situation is defined as the period 2012-2014. In 2015, work on the Project started. As a result, 2014 is the last year without impact from the Project. However, within normal operation, fluctuations in production occur. As a result, there are also fluctuations in the discharges and impact of the nuclear power plant on the environment. To get a better idea of the average situation, not only 2014 was considered, but also the two preceding years, namely 2012 and 2013.

The effects of KCD in the Baseline Situation were determined by examining what the measured and reported effects were in the period 2012-2014. Where possible, the data were broken down to look at the contribution of KCD-1 and KCD-2 and the combined contribution of KCD-3 and KCD-4. This provides insight into the contribution of KCD-1 and KCD-2 to the Baseline Situation. Where possible, an average effect was determined for the Baseline Situation, for both KCD-1 and KCD-2 together and KCD-3 and KCD-4. These averages were then used to determine the impacts during the operational phase of the Project between 2015 and 2018, the operational phase in the future situation (period 2019 - 2025), as well as for the Zero Alternative.

3.1.2 Project (LTO scenario):

Two phases can be distinguished in the scenario in which the LTO Project takes place; the operational phase of the Project between 2015 and 2018 and the operational phase in the future situation (period 2019 - 2025).

3.1.2.1 Operational phase of the Project between 2015 and 2018

During this phase, the LTO measures are implemented. Depending on the type of operations, the LTO measures can be carried out during regular operations or only during an outage (annual, during which fuel is also exchanged). In particular, the technical LTO measures can only be carried out during an outage to ensure the continuous safety of both the plant and the employees. During regular operations, many activities are also carried out.

For each environmental aspect (see § 3.3), the impact was determined for the baseline situation. Based on the description of the measures (see also § 1.6.1) and the effect during the baseline situation, it is estimated how each environmental aspect is affected by the measures. For example, will direct radiation increase, decrease, or remain the same relative to the baseline situation during the Project's operational phase between 2015 and 2018?

Because actual impacts from the 2015-2018 period are known at the time this EIR is prepared, the estimate made is then compared to the reported impacts.

3.1.2.2 Operational phase in the future situation (period 2019 - 2025)

After the operational phase of the Project is completed between 2015 and 2018, i.e. both implementation of the measures of the Project and regular operation, KCD-1 and KCD-2 will continue to be regularly operated during 2019-2025. Analogous to the operational phase of the Project between 2015 and 2018, the description of the measures and emissions during the baseline situation is used to estimate the effect of the measures on emissions during the operational phase in the future situation (period 2019 - 2025).

This estimate is then used to also determine the cumulative effect resulting from the 10 years longer operation.

3.1.3 Zero alternative

In determining the effects during the baseline situation, a distinction was made, to the extent possible, between the effects of KCD-1 and KCD-2 together and of KCD-3 and KCD-4 together.

Under the Zero Alternative, operation of KCD-1 and KCD-2 stops in 2015. However, the nuclear reactors and the fuel basin will still need to be cooled, so there will still be impacts from KCD-1 and KCD-2, although they will be lower than in the baseline situation. In this phase, called the Post Operational Phase, KCD-1 and KCD-2 are prepared for dismantling.

3.2 Radiation and its radiological impact

This section provides a brief introduction to the concept of radiation and the radiological impact it can have. This involves the use of a number of terms and definitions that are explained in advance [e.g., ARBIS]. Next, § 3.2.2 explains the concept of nuclear fission, its application in nuclear power, and radiation aspects.

3.2.1 Terms and definitions

Accidental discharges	These are radioactive discharges that occur as a result of an accident at the plant
Activity	The activity A of a certain amount of radionuclides in a given energy state and at a given time is the quotient of dn and dt, where dn represents the expected value of the number of spontaneous nuclear transitions from that energy state during the time interval dt: $A = dn/dt$ The unit of activity is becquerel
ALARA	As Low As Reasonably Achievable Term from radiation protection indicating that radiation levels should be kept as low as reasonable
Becquerel	The unit of activity; one becquerel corresponds to one disintegration per second: $1\ Bq = 1\ s^{-1}$
Exposure	The fact of being exposed to ionizing radiation. A distinction is made between: • External exposure: exposure to radiation sources located outside the organism; • Internal exposure: exposure to radiation sources located within the organism, • Total exposure: the sum of external and internal exposure.

Collective dose	The collective dose (S) of a population or group exposed to a source, an act, or an occupational activity referred to in these regulations and resulting in exposure is given by the following expression: $S = \sum_i H_i P_i$ where H_i represents the average of the doses sustained and the follow-on doses for the entire organism, for an organ or for a tissue, by the P_i members of the i-th subset of the population or group considered.
Dose limitation	Limitation imposed on the expected individual doses that could be caused by a source, activity or particular task; it is used in optimization, during radiation protection planning.
Dose conversion factor	Factors to calculate the radiation exposure of individual organs and of the whole body from radioactive substances within the body. The dose factors depend on the radionuclide, on the mode of entry (inhalation/ingestion), on the chemical compound of the radionuclide (soluble/insoluble) as well as on the person's age
Dose limit	The maximum values of doses resulting from the exposure of occupationally exposed persons, pupils and students, as well as other persons of the public, to ionizing radiation, as determined in these regulations; they apply to the sum of the relevant doses resulting from external exposures during a given period and of the follow-on doses for 50 years (for children, up to the age of 70 years) resulting from recorded doses during the same period.
Dose rate	The term dose rate is used to indicate the amount of (effective) dose per unit time, usually in µSv/hour. The dose rate can only be used for direct radiation because follow-on doses are not taken into account. The dose rate usually represents the committed effective dose assuming beta and gamma radiation (WR=1) and homogeneous whole-body irradiation (WT=1).
Effective dose (E)	The sum of the weighted equivalent doses in all body tissues and organs listed in Annex II of the ARBIS due to internal and external irradiation. It is defined by: $E = \sum W_T H_T \sum W_T \sum W_R D_{T,R}$ where: • $D_{T,R}$ is the average dose absorbed by the organ or tissue T as a result of the radiation R; • w_R is the radiation weighting factor, and • w_T the tissue weighting factor for the tissue or organ T. The relevant w_T and w_R values are listed in annex II of the ARBIS. The unit of effective dose is the sievert (Sv).

Committed effective dose [E(τ)]:
The sum of the equivalent committed doses in the various tissues or organs [$H_T(\tau)$] resulting from a intake, multiplied by the corresponding tissue weighting factor wT. It is defined by:

$$E(T) = \sum_T W_T H_T(T)$$

wherein τ indicates the number of years over which integration is performed. The unit of committed effective dose is the sievert.

Equivalent dose (H_T)
The absorbed dose in a tissue or organ T, weighted for the type and quality of radiation R. It is obtained by:

$$H_{T,R} = W_R D_{T,R}$$

where:

- $D_{T,R}$ represents the average absorbed dose in tissue or organ T due to radiation R, and
- W_R is the corresponding radiation weighting factor.

When the radiation field consists of multiple radiation types and energies with different w_R values, the total equivalent dose H_T is obtained by:

$$H_T = \sum W_R D_{T,R}$$

The relevant w_R values are listed in annex II of the ARBIS. The unit of equivalent dose is the sievert (Sv);

Committed dose equivalent [$H_T(\tau)$]
The integral over time of the equivalent dose rate in tissue or organ T which will be incurred by an individual as a result of a intake at time t_0. It is obtained by:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} H_T(t)\,dt$$

Wherein: HT(τ) represents the corresponding equivalent dose rate in the organ or tissue T at time τ and τ represents the time interval, expressed in years, over which integration is performed.
When τ is not specified, it is assumed to be 50 years for adults and the number of years remaining until the age of 70 for children. The unit of committed dose equivalent dose is the sievert.

FHA
(Fuel Handling Accident): This is an accident where it is assumed that a fuel element comes loose during handling and as a result of the fall, all fuel rods are damaged.

Absorbed dose (D)
The energy absorbed per unit mass:
D = d€/dm
Where:

- d€ is the average energy transferred to matter in a volume element by ionizing radiation, and
- dm is the mass of this volume element

Radiation Controlled Area (RCA)
An area, which for reasons of protection against ionizing radiation, is subject to regulation and whose access is also regulated. Here, staff exposure is monitored because of the possible occurrence of an increased radiation or contamination level

Health risk	The estimated risk of a shortened life span and reduced quality of life for a population due to exposure to ionizing radiation. This definition includes the consequences and the probability of effects on life expectancy and quality of life due to both somatic effects and cancer (fatal or non-fatal), and genetic effects in future generations, as well as any other effect attributable to ionizing radiation.
Gray (Gy)	The unit of absorbed dose; one gray corresponds to one joule per kilogram: 1 Gy = 1 $J \cdot kg^{-1}$
Limit value	Policy-based standard that aims to ensure a minimum level of protection of systems
Half-life	The time period over which half of the nuclei of a radionuclide decays
LOCA	(Loss Of Cooling Accident): This is an accident where the normal cooling of the core by the primary circuit is lost. A special safety injection system is included in the design to deal with this accident.
Intake	The radionuclide activity absorbed by the organism from the surrounding environment.
Primary circuit	In a PWR reactor, the primary circuit is the circuit that provides direct cooling to the core. The function is to transfer the heat developed in the core to the steam generator where the heat is transferred to the secondary circuit. In a PWR reactor, pressurized water is used so that the water remains liquid despite reaching a temperature of about 300°.
Radioactive contamination	Contamination of a material, surface, environment or person by radioactive substances. In the specific case of the human body, this radioactive contamination includes both external contamination of the skin and internal contamination, regardless of the pathway through which the ingestion occurs.
Radioactive substance	Any substance containing one or more radionuclides whose activity or concentration should not be neglected for reasons of radiation protection.
Risk	The product of the probability of the occurrence of an accidental situation and the undesirable effect of that accidental situation
Routine discharges	These are the radioactive discharges that take place when the plant is in normal operation.
Secondary circuit	The secondary circuit transfers the heat from the primary circuit to the turbine and the tertiary circuit (where it is discharged into the Scheldt). Water from the primary circuit is pumped to the steam generator where it comes into contact with the water of the secondary circuit (via narrow tubes) and releases its heat to that water. The water will then be taken to the turbine via the secondary circuit where, via expansion, the thermal energy will be converted into mechanical energy and then the remaining heat will be dissipated.
Sievert (Sv)	The unit of the equivalent dose and the effective dose. For photons and electrons of any energy, one sievert corresponds to one joule per kilogram: 1 Sv = 1 $J.kg^{-1}$.

3.2.2 Radiation and radiological impact

3.2.2.1 Atom

An atom is the smallest building block of any chemical element that is still recognizable as such. Figure 3-1 Schematic representation of an oxygen-16 atom31 shows an oxygen atom.

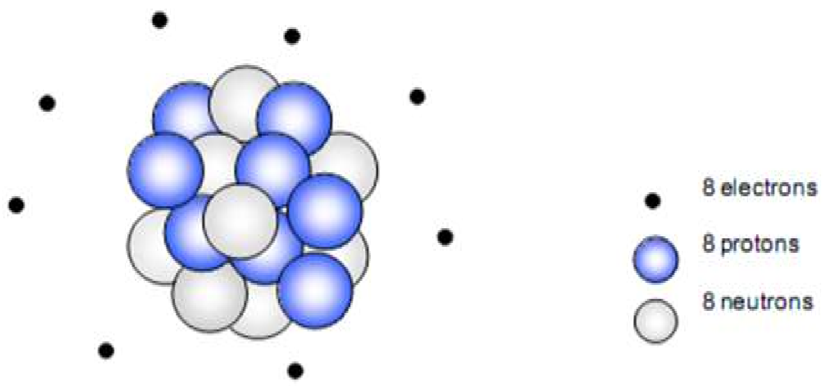

Figure 3-1 Schematic representation of an oxygen-16 atom31

Here we see that the atom itself can be further divided into three building blocks: electrons, protons and neutrons. All protons and neutrons together are called the atomic nucleus. The electrons are electrically negatively charged, the protons are positively charged, and the neutrons are electrically neutral. The atom as a whole does not have an electrical charge, as atoms always have the same number of protons and electrons.

The chemical behavior of an atom is determined entirely by the electrons that surround atom's nucleus. As a consequence, two atoms with an equal number of protons and electrons but a different number of neutrons have the same chemical behavior. These are called isotopes of a chemical element. However, the physical properties (e.g., melting point) of these two isotopes may differ.

To write down the different isotopes, the mass number and the atomic number are used. The atomic number is the number of protons in a nucleus; the mass number is the sum of the number of neutrons and protons in a nucleus. An isotope of a chemical element has the same atomic number, but a different mass number. As a general notation, there is ${}_{\text{atomic number}}^{\text{mass number}}X$, where X stands for the chemical element in question (e.g., H, He, Li, U, etc.). Since the notation X is uniquely linked to the atomic number, it is commonly omitted (e.g., oxygen (O) always has 8 protons). In this way, we arrive at the notation of the mass number, for example ^{16}O, ^{235}U or ^{238}U. Alternatively, isotopes are often noted using the X-mass number, e.g. O-16, U-235, U-238, etc.

3.2.2.2 Binding energy per nucleon

To understand how fission works, it is not the chemical behavior and electrons that are important, but the behavior of the nucleus itself. The nucleus consists of a number of protons and a number of neutrons. The fact that the nucleus does not disintegrate despite being made up of mutually repelling protons (as these are positively charged) is down to how nuclear forces work. These nuclear forces will try to hold the nucleus together and are the same for neutrons and protons.

When the average binding energy per nucleon (this is the common name for protons and neutrons) is plotted as a function of the number of nucleons we get the results shown in Figure 3-2.

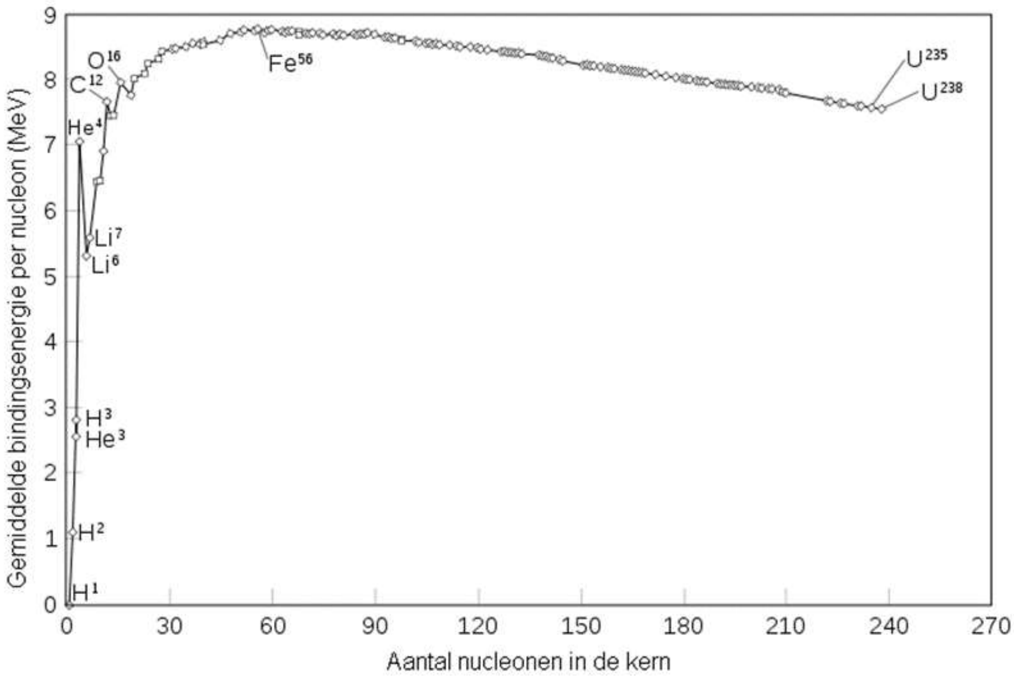

Figure 3-2 Average binding energy of a nucleon as a function of the total number of nucleons

The binding energy per nucleon is the energy that needs to be added to the nucleus to release a nucleon. The above graph shows two things. On the one hand, one notices that the binding energy for low mass numbers is smaller than for large numbers, this trend continues until Fe-56. Beyond Fe-56, the energy per nucleon decreases. It is this phenomenon that is used in both nuclear fusion and nuclear fission. Nuclear fission involves splitting heavy elements into several lighter nuclei. The difference in energy is then released and used to produce electricity. In nuclear fusion, the idea is to bind two lighter elements into one heavier element.

All current commercially operated nuclear reactors use the principle of nuclear fission.

3.2.2.3 Nuclear fission in practice

The Belgian plants use U-235 as a fuel in nuclear fission. Figure 3-3 shows that when a neutron is fired at U-235, U-236 is formed. This U-236 is unstable and disintegrates into two distinct nuclei and a number (2 to 3) of loose neutrons during which energy is released. This process is used in a nuclear power plant.

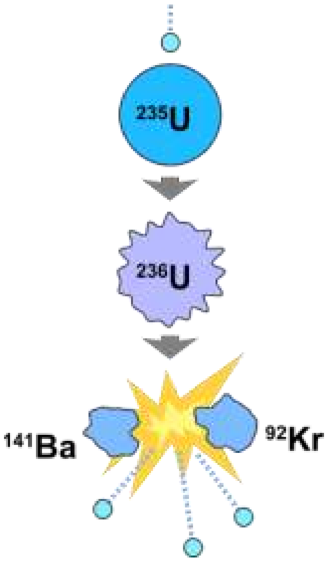

Figure 3-3 Fission of U-235

The neutrons released, after moderation, are used to split a new U-235 to achieve a chain reaction. However, more neutrons are created during fission than are consumed. To keep the chain reaction under control, the excess neutrons are captured using substances such as cadmium (typically located in the control rods) and boron (typically dissolved in water).

3.2.2.4 Radioactivity

The above paragraphs explained what an atom and a nucleon are. Another important aspect of understanding what happens in a nuclear power plant is understanding radioactivity. There are 3 main types of radioactivity. Alpha radiation (α), beta radiation (β) and gamma radiation (γ). Radioactivity is based on an imbalance between the ratio of neutrons to protons which means that the strong nuclear force, which tries to hold the nucleus together, is not able to restrain the electromagnetic force, which wants to make the nucleus fall apart. As a result, the core will try to redress this balance. Below are the 3 most common mechanisms for this purpose (Figure 3-4):

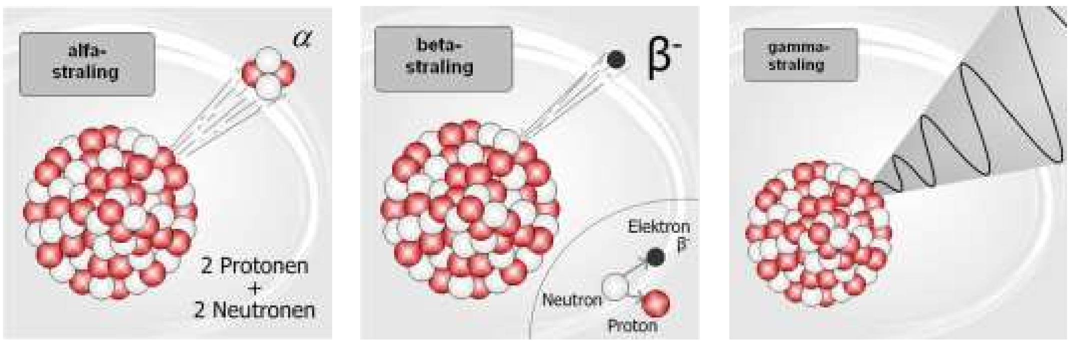

Figure 3-4 Graphical representation of alpha, beta and gamma radiation

In the case of alpha radiation, a helium nucleus (2 protons and 2 neutrons) is emitted to decay into a more stable nucleus. In the case of beta radiation, an electron is emitted to convert a neutron into a proton. In the case of gamma radiation, the neutrons and protons evolve into a more stable state by emitting an energy-rich photon without changing the nucleus.

Radioactivity is a natural phenomenon. Most atoms are stable (without outside action they will continue to exist forever). Other atoms have a structure or excess energy that makes them unstable. These are radionuclides, which can be of natural or artificial origin. Their nuclei spontaneously transform until they find a balanced structure. Each transformation releases radiation (photons or particles): they are radioactive. This invisible phenomenon is irreversible: after one or more transformations, the radionuclide stabilizes once and for all into a stable nuclide.

The unit of measurement of radioactivity is the Becquerel (Bq).

3.2.2.5 Radioactive decay

Radioactive decay where ionizing radiation is emitted is a natural phenomenon. For example, soil contains radionuclides such as potassium-40 and uranium-238 (also written as ^{40}K and ^{238}U), which are all so-called primordial radionuclides. Primordial radionuclides were created when planet Earth was formed, about 4.5 billion years ago and still exist today. In the upper layers of the atmosphere, the interaction of high-energy cosmic rays (e.g., from the sun) leads to nuclear reactions in which relatively short-lived (relative to the Earth's lifetime, <10,000 years) radionuclides such as tritium (^{3}H) and carbon-14 (^{14}C) are continuously formed.

All of these radionuclides are unstable and eventually decay to a more stable product, called radioactive decay. The probability of decay depends on the half-life, which is characteristic of a radionuclide; for example, the half-life of ^{40}K is 1.25 billion years while the half-life of ^{3}H is 12.3 years. This means that 50% of ^{40}K decays in 1.25 billion years, after 2.50 billion years only 25% of the original ^{40}K remains. As a result of its long half-life, ^{40}K is still naturally present since the creation of the Earth (ca. 4.5 billion years ago).

3.2.2.6 Radiation

During the decay of radionuclides, (generally) a great deal of energy is released. As a result, the radiation is able to change the atoms of the matter it penetrates by causing them to absorb energy and thereby lose a unit of electric charge, transforming them into ions. In other words, the radiation is ionizing (ionizing radiation).

As stated earlier, there are different types of ionizing radiation; particulate and electromagnetic (gamma) radiation. Particle radiation usually involves emitting an electron (beta or β) or a helium-4 nucleus (alpha or α). As the emitted particles have a high charge, there is strong interaction with matter, therefore the distance which the particles can travel is relatively short. Alpha radiation does not carry as far, compared to beta radiation, but because of the strong interaction, alpha particles cause a lot of ionization and potential damage. Electromagnetic radiation (photons) has no charge and mass and therefore can travel much greater distances (Figure 3-5), however, the ionization density is much lower as a result compared to beta and especially alpha radiation. High-energy electromagnetic radiation resulting from radioactive decay is normally referred to as gamma radiation (γ-radiation).

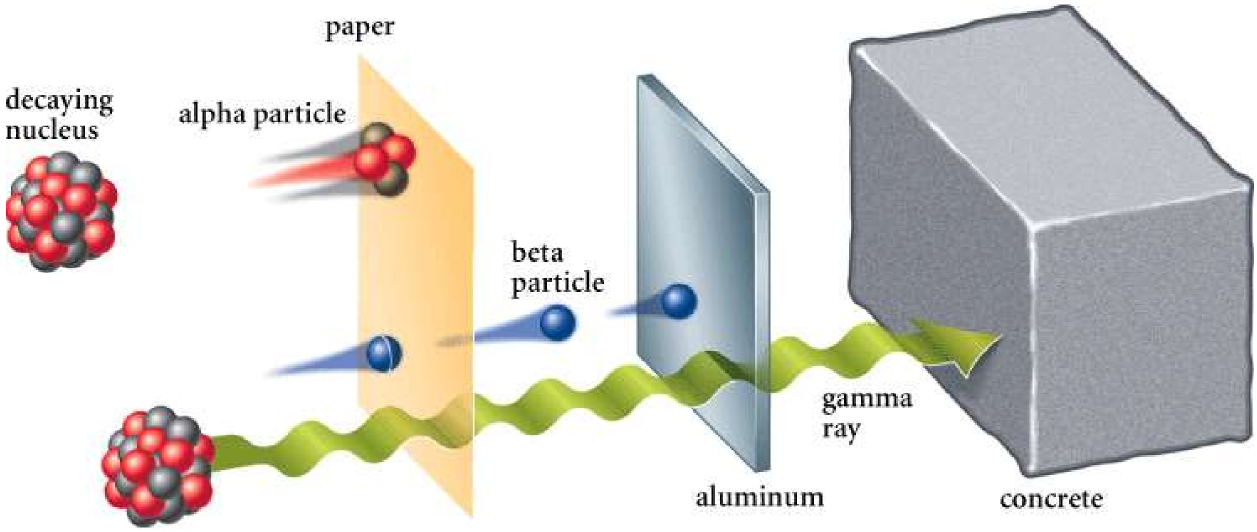

Figure 3-5 Distances alpha, beta and gamma radiation can travel

The ionization of atoms because of interaction with ionizing radiation causes an atom to lose one electron, making it positively charged, and thus chemically reactive. Induced ionizations are typically expressed in the unit of energy per mass (Joule per kilogram, J/kg). In radiation protection, the unit Gray (Gy) is often used, where 1 Gy equals 1 J/kg.

3.2.2.7 Impact of radiation exposure

Ionized atoms can cause damage and adverse biological effects in human cells. The biological effect of ionizing radiation varies as a function of the nature and energy of the radiation, the duration of exposure, and the body part exposed. The energy of the radiation and the duration of exposure together determine the radiation dose. The same amount of radiation can be incurred by being exposed to high-energy radiation for a short time, or by being exposed to low-energy radiation for a long time. The biological effect of radiation, in addition to the amount of energetic radiation, depends on the type of tissue. Tissue consisting of rapidly dividing cells is more sensitive to radiation than tissue consisting of less rapidly dividing cells.

To express the damage to tissues, this dose is often converted to an effective dose by multiplying the energy absorbed (in Gy or J/kg) by a radiation weighting factor (20 for alpha radiation and 1 for beta/gamma radiation) and a tissue weighting factor. The radiation weighting factor is used to indicate how much the radiation interacts with human tissue. As indicated earlier, alpha radiation has a high charge, and therefore a lot of interaction. As a result, there is a lot of ionization in the affected tissue, with potential damage. Beta and gamma radiation, on the other hand, have a lower interaction. Therefore, alpha radiation has a higher radiation weighting factor than beta and gamma radiation. The tissue weighting factor is an indication of the sensitivity of tissue to ionization.

The effective dose is expressed in the unit sievert (Sv). Because the dose is usually very low, the term millisievert (1 mSv = 0.001 Sv) or microsievert (1 µSv = 0.001 mSv = 0.000 001 Sv) is usually used.

Exposure to ionizing radiation can lead to damaged DNA. This damage is taking place continuously. In almost all cases, however, the human body is able to repair the damage without consequences. However, in a few cases the body cannot sufficiently repair the damage, which will usually lead to the cell dying. The death of a single cell does not cause problems and is a natural phenomenon. However, if the body is exposed to a very high dose radiation (several hundred millisieverts), cell death can cause serious damage such as (temporary) sterility, cataracts and burns. Such effects are described as deterministic and are extremely rare.

Although most damage is successfully repaired by the body or eventually dies off, damage can lead to uncontrolled growth of the damaged cell creating a cancerous tumor, which is called a stochastic effect. Another type of stochastic effect is genetic defects for offspring. The probability of stochastic effects due to radiation increases with increasing radiation dose. Based on statistical data, the International Commission on Radiological Protection (ICRP) conducted research that determined the risk of cancer as well as genetic disorders due to exposure to ionizing radiation. Table 3-1 shows an estimate of stochastic effects due to exposure to ionizing radiation in percent per Sv. However, these risk numbers are only valid for higher doses well above the background dose. The values for staff and the general public differ slightly because children have an increased risk of effects, and because of this are not allowed to work with ionizing radiation.

Table 3-1 Probability of stochastic effects at low doses and dose rates [ICRP, 2007]

	Cancer	Hereditary defects	Total damage
Employees	4.1%/Sv	0.1%/Sv	4.2%/Sv
Population	5.5%/Sv	0.2%/Sv	5.7%/Sv

3.2.2.8 Exposure modes

Humans are exposed to different types of radioactivity throughout their lives:

- Natural radioactivity comes from the cosmos (cosmic rays) and is also present in the earth's crust (telluric rays), in groundwater, in the oceans and even in our bodies.
- Artificial radioactivity, which may or may not be linked to radioactive discharges into the environment and is very low in normal operations, is generated by human activities such as the operation of nuclear reactors for generating electricity, providing nuclear medicine, medical imaging and sterilization of surgical equipment or certain food products.

The average dose for residents of Belgium is about 3.98 mSv per year. Of this, more than 61% is due to natural radiation (Figure 3-6); the artificial radiation is almost entirely caused by medical applications. However, the natural dose strongly depends on your location; for example, natural background radiation is higher in Wallonia compared to Flanders due to the different soil composition.

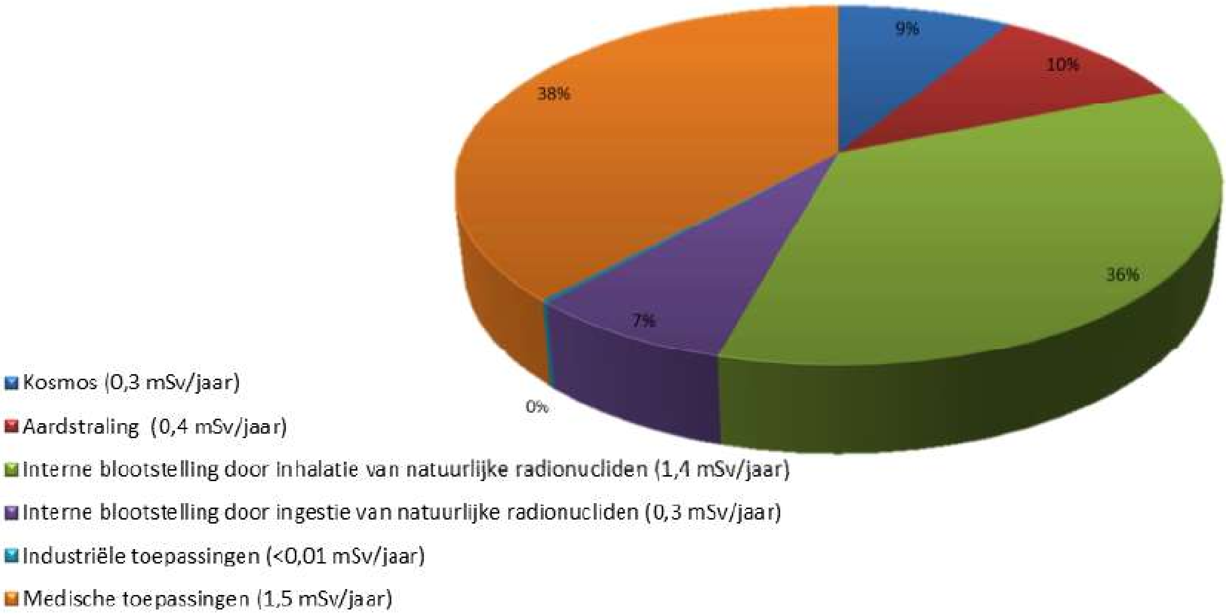

Figure 3-6 Average annual dose for a member of the Belgian population [FANC, 2018]

Exposure can be through external or internal exposure, see also the following figures (Figure 3-7) [FANC, 2014].

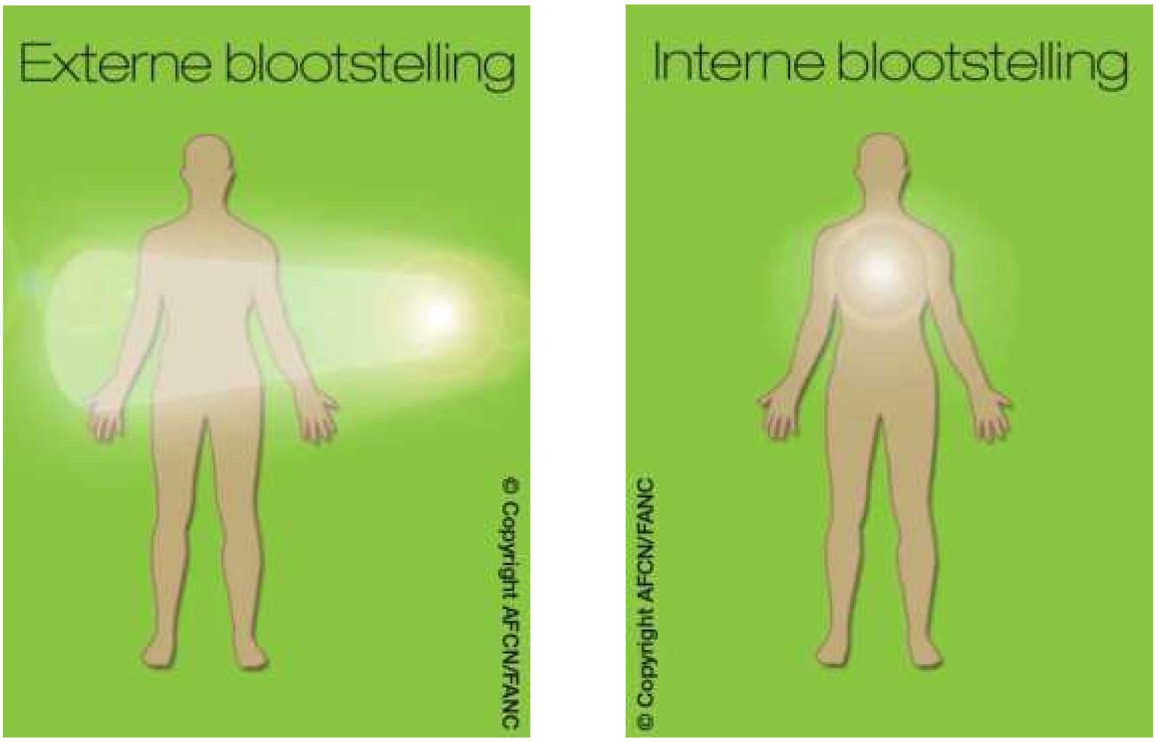

Figure 3-7 External (left) and internal (right) exposure to ionizing radiation [FANC, 2014]

External exposure involves exposure to ionizing radiation whose source is outside the organism. For example, a medical diagnosis using X-rays. For internal exposure, the source of ionizing radiation is located within the organism. For example, a medical diagnosis where radioactive isotopes are injected into the patient's body [FANC, 2014].

3.2.2.9 Radiation exposure from a nuclear power plant

Class 1 nuclear facilities - such as the Doel nuclear power plant - are licensed to make radioactive discharges. This permit includes discharge limits which the facility must achieve. These discharge limits are set at the lowest reasonable level possible (ALARA- As Low As Reasonably Achievable). What is "reasonable" has been assessed on a case-by-case basis, taking into account technical (best available technologies, international best practices, etc.), economic and societal factors. In any case, the discharge limits authorized are compatible with the legal limits set out in the Royal Decree of 20 July 2001 on the general regulation for the protection of the population, workers and the environment against the danger of ionizing radiations [ARBIS]. The discharge limits allowed are so low that they can result in only a fraction of the regulatory limit for the most exposed local population. The license specifies the nature of the radioactive substances that can be discharged (radiological composition of the discharges, and the discharge modalities (maximum and average radioactive concentration of the discharges, maximum amount of radioactivity emitted over a given period, etc.) [FANC, 2014].

Operators are required to comply with discharge limits for radioactive discharges. During the discharges, controls are permanently performed in real time to determine whether the discharge limits (maximum and average concentration of discharges, maximum amount of radioactivity emitted, etc.) are respected. For this purpose, radiological monitoring equipment has been set up at each pipeline for liquid discharges and at each chimney for gaseous discharges, see Figure 3-8 [FANC, 2014].

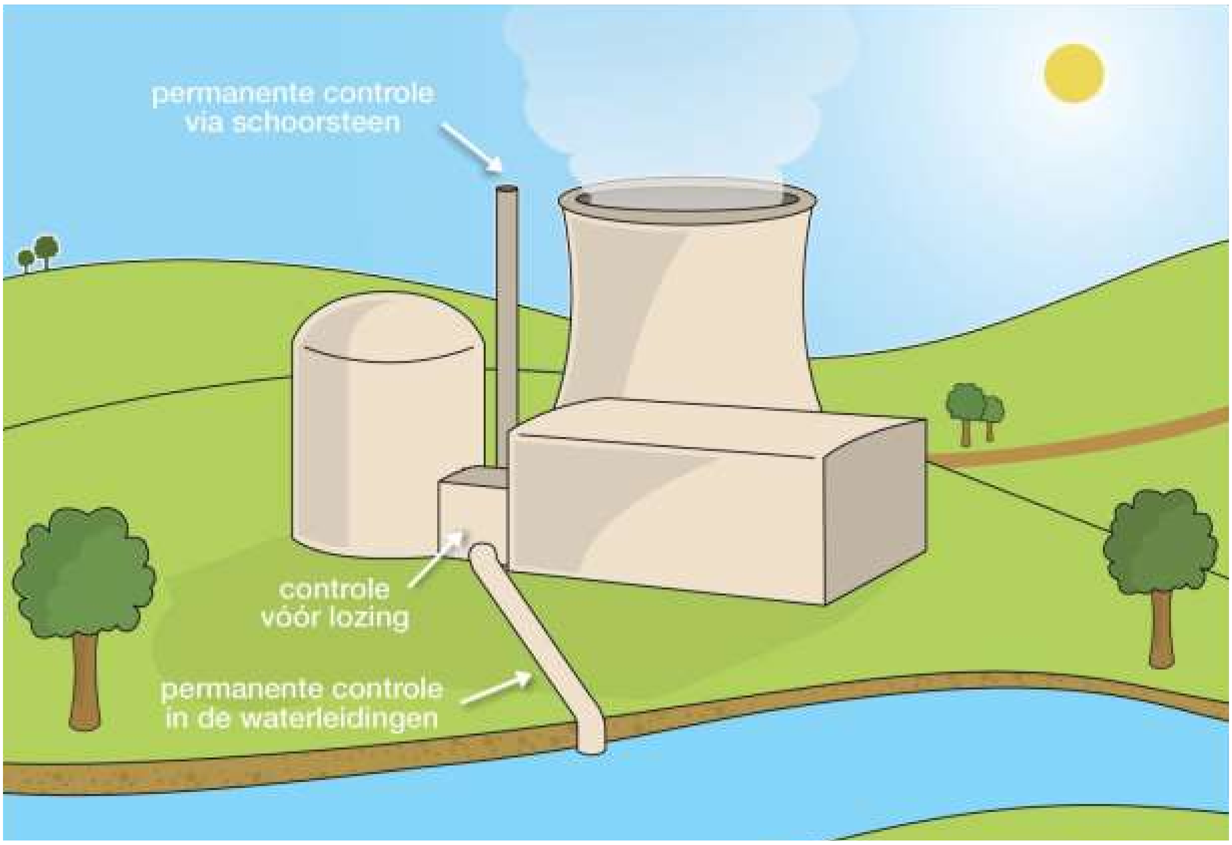

Figure 3-8 Schematic overview of discharge checks by operators

This equipment continuously measures the activity of the discharges and the results are sent directly to the control desks where staff monitor the discharges. If a deviation from one of the controlled parameters is detected, the discharge is automatically interrupted.

The operator records the actual quantities of radioactive material discharged. This registration is sent to FANC on a monthly basis.

The population living or residing in the vicinity of a nuclear facility may be exposed to radioactive materials from systems' discharges. The ionizing radiation exposure of the population in the sphere of influence of a nuclear power plant depends on the following factors [FANC, 2014]:

- The geographic location of the place of residence, particularly the distance from the power plant and the location relative to the most common wind directions;
- The diet, especially the consumption of local agricultural products, produce from the garden or home pickings, and produce from fishing and hunting;
- The use of water, especially for domestic use and for irrigation.

The modes of exposure to radioactivity for the public, from both liquid and gaseous discharges is shown in the following figure (Figure 3-9) [FANC, 2014].

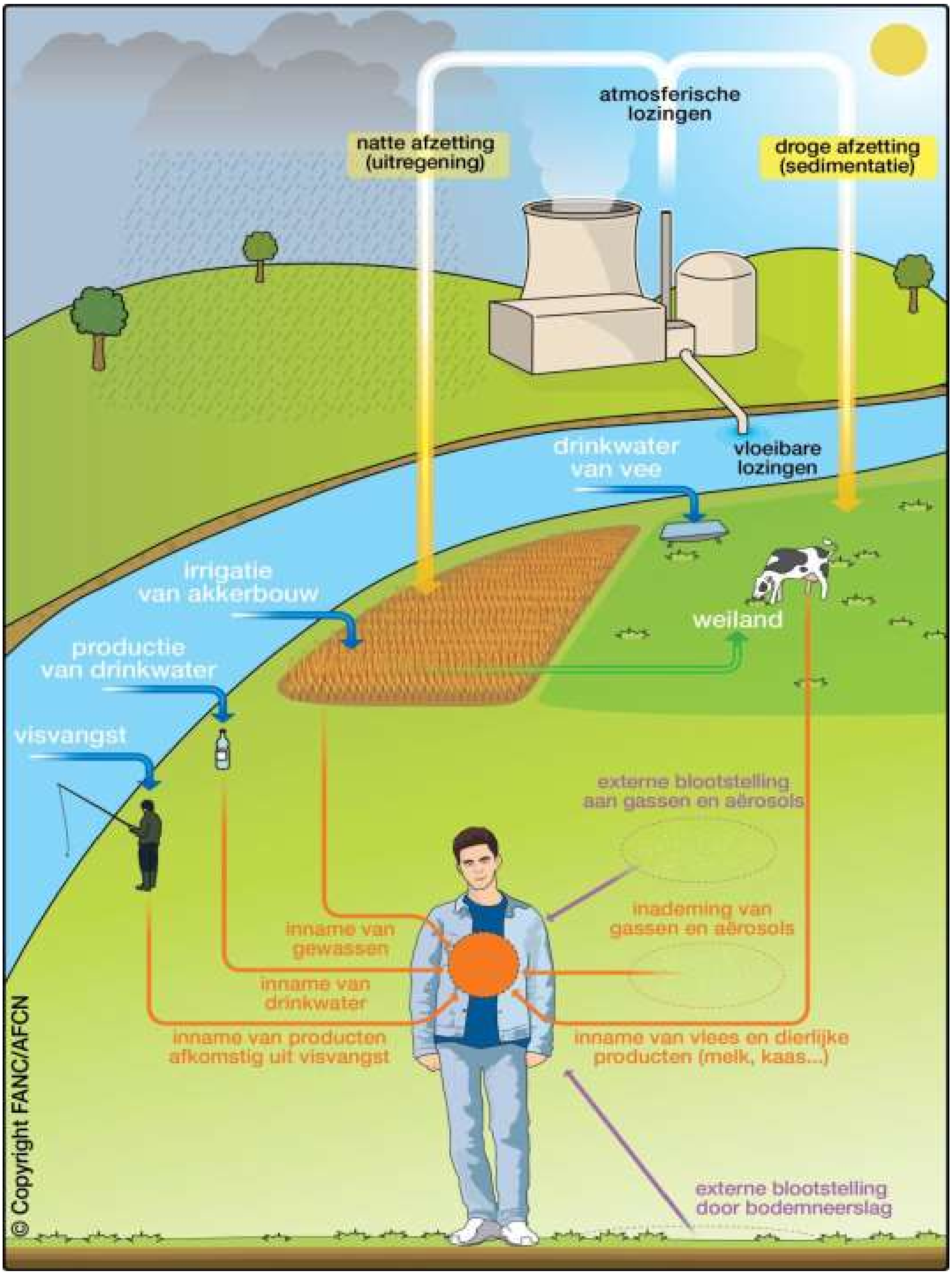

Figure 3-9 Modes of exposure to radioactivity to the public from liquid and gaseous discharges

The main exposure modes for the population in the vicinity of a nuclear power plant are:

- Direct radiation;
- Liquid discharges:
  - Internal Exposure:
    - Use of the liquid discharge water for:
      - Production of drinking water;
      - Consumption of aquatic plants and animals;
    - Irrigation of plant products for:
      - Human consumption (fruits, vegetables, cereals,...);
      - Animal consumption (animal feed);
  - External exposure:
    - Swimming;
    - Nautical sports;
    - Professional Shipping;
    - Being present on the banks and dredge sludge;
- Gaseous discharges:
  - Internal Exposure:
    - Inhalation of gas and aerosols;
    - Consumption of contaminated fruits, vegetables and cereals due to deposition of radionuclides;
    - Consumption of local foods (milk, meat, eggs) from livestock with contaminated feed;
  - External exposure:
    - Exposure to gas and aerosols;
    - Exposure to depositions on the ground surface.

In addition, the exposure and sensitivity of individuals to ionizing radiation depends on the age of the person. Six different age categories are defined in ARBIS:

- Babies: aged <1 year;
- Children aged between 1-2 years;
- Children aged between 2-7 years;
- Children aged between 7-12 years;
- Children aged between 12-17 years;
- Adults: aged > 17 years.

3.2.2.10 Radiological impact

Models for theoretical reference groups have been calculated, to determine the radiological impact of radioactive discharges into the environment.

The committed effective dose due to radioactive discharges is calculated based on FANC-accredited guidelines [NRC, 1977] from the United States Nuclear Regulatory Commission (US-NRC) and the calculation methodology established by FANC [FANC, 2013a]. In this process, the scattering of radioactive elements is first determined based on weather models, and then the intake of radionuclides is modeled based on different vectors, as shown in Figure 3-8. The dose calculations are performed based on data published by the International Commission on Radiological Protection [ICRP, 2007].

The reference groups (composed of fictitious individuals) are located at typical distances from the power plant and include different age groups. The location of the reference group as well as the age determines the exposure mode (wind direction, diet, living habits) and the sensitivity of the individuals [FANC, 2014].

These models take into account unfavorable assumptions for calculating the impact on the reference group. The total activity discharged over the course of a year (both liquid and gaseous discharges) is considered, as well as the transmission to exposed persons. The calculations assume a "critical individual". This is a person who:

- permanently resides in the same location, with the highest concentration of radioactivity;
- feeds largely on produce from the garden with the highest deposition and
- feeds on products from local agriculture, hunting and fishing.

The dose determined in this way is the most conservative (maximum) dose that a member of the population may incur as a result of the operation of a nuclear power plant. This results in an overestimate of the real exposure.

3.2.2.11 Limits

During the regular operation of a nuclear power plant, several paths can lead to exposure to ionizing radiation. The maximum exposure is limited according to the ARBIS [ARBIS] based on international standards where specific dose limits apply to the whole body (D) and specifically to eyes(D_{eye}), skin(D_{skin}) and extremities($D_{\text{extremity}}$) such as hands, forearms and feet. The limits were determined for both occupationally exposed workers (≥ 18 years), exposed students working at a nuclear site (16-18 years) and members of the public and were designed so that maximum exposure would not pose an unacceptable risk.

Table 3-2 Dose limits from ARBIS [ARBIS]

	D [mSv/yr]	D_{eye} [mSv/yr]	D_{skin} [mSv/yr]	$D_{extremity}$ [mSv/yr]
Population	1	15	50	-
Exposed students (16-18 years)	6	150	150	150
Occupationally exposed worker	20	150	200	500

In addition to the dose limits established in the ARBIS, specific limits have been established for the operation of the different units of the Doel nuclear power plant. These limits are defined in the Technical Specifications that are part of the safety report; the specific limits are shown in relevant sections. Where possible, the impact of the LTO has been assessed against both the ARBIS and the current Technical Specifications.

3.2.2.12 Radiological surveillance

To verify the dose calculations, samples are collected annually from the vicinity of KCD on behalf of both the regulator FANC and Electrabel. The samples are analyzed in specialized laboratories to assess the impact of radioactivity on flora and fauna in the vicinity of KCD.

3.2.2.12.1 Radiological surveillance on Belgian territory

Radiological surveillance on Belgian territory is performed in two ways [FANC, 2013a]:

- Through periodic measurements where samples are taken and analyzed;
- Through continuous measurements of the automatic TELERAD network for measuring local environmental radioactivity.

FANC carries out periodic radioactivity measurements in the environment. This allows the evaluation of natural and artificial radioactivity levels in the environment as well as in the food chain [FANC,2013a]. Various types of samples are taken: water, sediment, air, grass, vegetables, milk, fish, meat, etc. [FANC, 2014]. The program consists of nearly 4,500 annual samplings and 28,000 analyses of alpha, beta and gamma radioactivity [FANC, 2013a].

In addition to these periodic samplings, there is permanent monitoring of the territory with the TELERAD network. This is an automatic measurement and alarm network consisting of:

- 192 measuring stations for the measurement of gamma radiation in the vicinity (128 on the territory and 64 on the fences of the nuclear power plants);
- 8 stations for measuring gamma radiation in watercourses;
- 7 stations for measuring aerosols in the air.

These measuring stations are spread throughout the Belgian territory, with a greater density around the nuclear power plants, see also Figure 3-10 [FANC, 2014]. The figure shows not only the locations of the TELERAD measuring stations, but also the average background level on Belgian territory. Depending on the composition of the soil and remnants of the Chernobyl disaster and aboveground nuclear weapons explosions, the background level varies widely within Belgium; the radiation dose due to direct radiation from naturally occurring activity around KCD is about 0.70 to 0.75 mSv per year, this is in line with the average dose for residents of Belgium as shown in Figure 3-10 (cosmos and terrestrial radiation) [FANC, 2018].

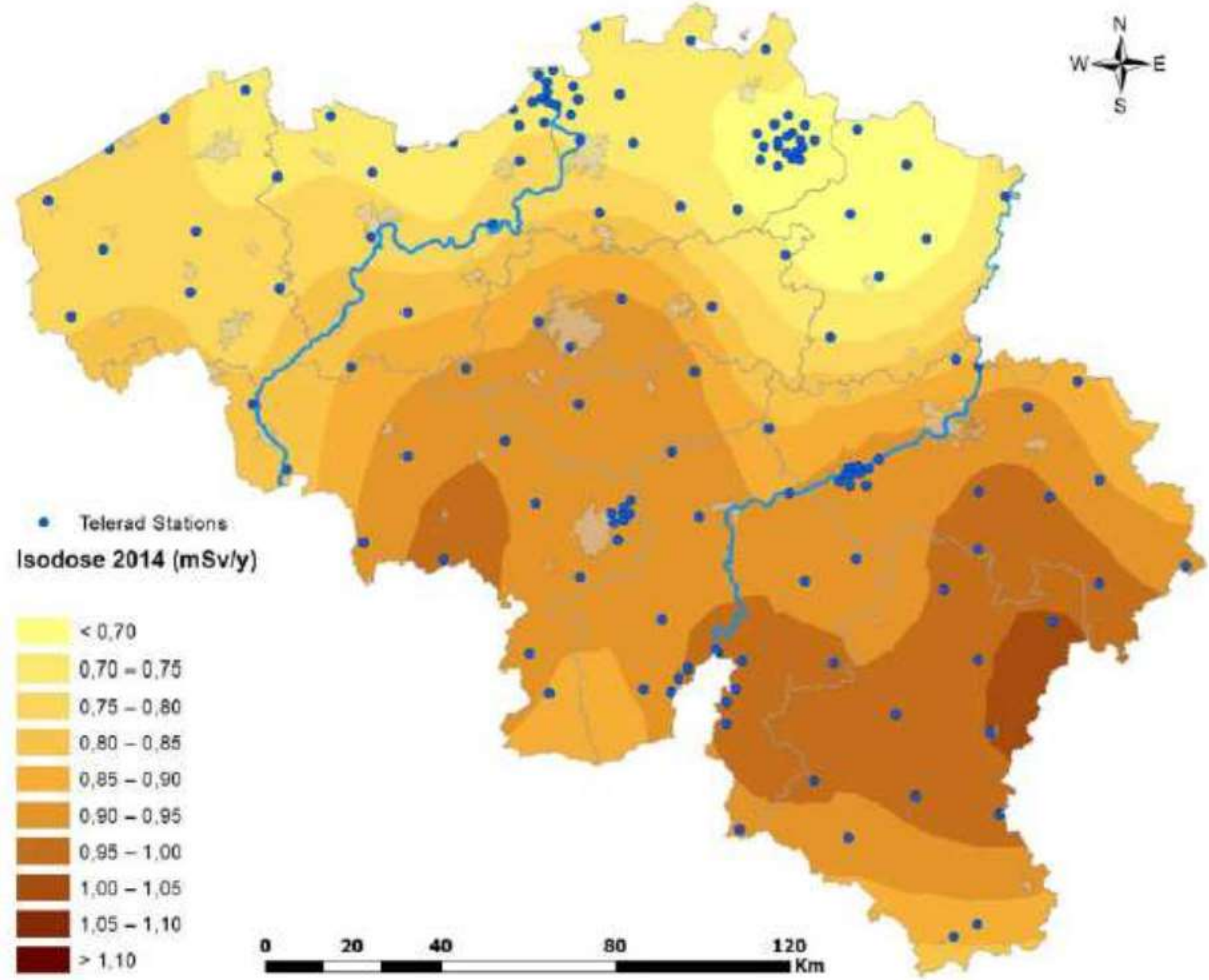

Figure 3-10 Dose map based on the 2014 TELERAD measurements.

The measuring stations continuously monitor total radioactivity in the air, atmospheric particles and the water of the rivers Meuse, Sambre and Molse Nete. The measuring stations are connected to a central system, which is automatically alerted if abnormal increases in radioactivity are detected.

3.2.2.12.2 Targeted radiological surveillance

Gaseous and liquid discharges spread radioactive substances into the environment. Substances discharged into surface water will flow with the current and partially deposit in the sediment at the bottom of the surface water. In water, algae and aquatic organisms can absorb radioactivity. Some of the radioactive substances may end up on land, for example through irrigation, after which they may be absorbed by plants and animals. In this way, they enter the food chain [FANC, 2014]. Figure 3-11 shows the sampling points in the vicinity of the nuclear power plant [FANC, 2014].

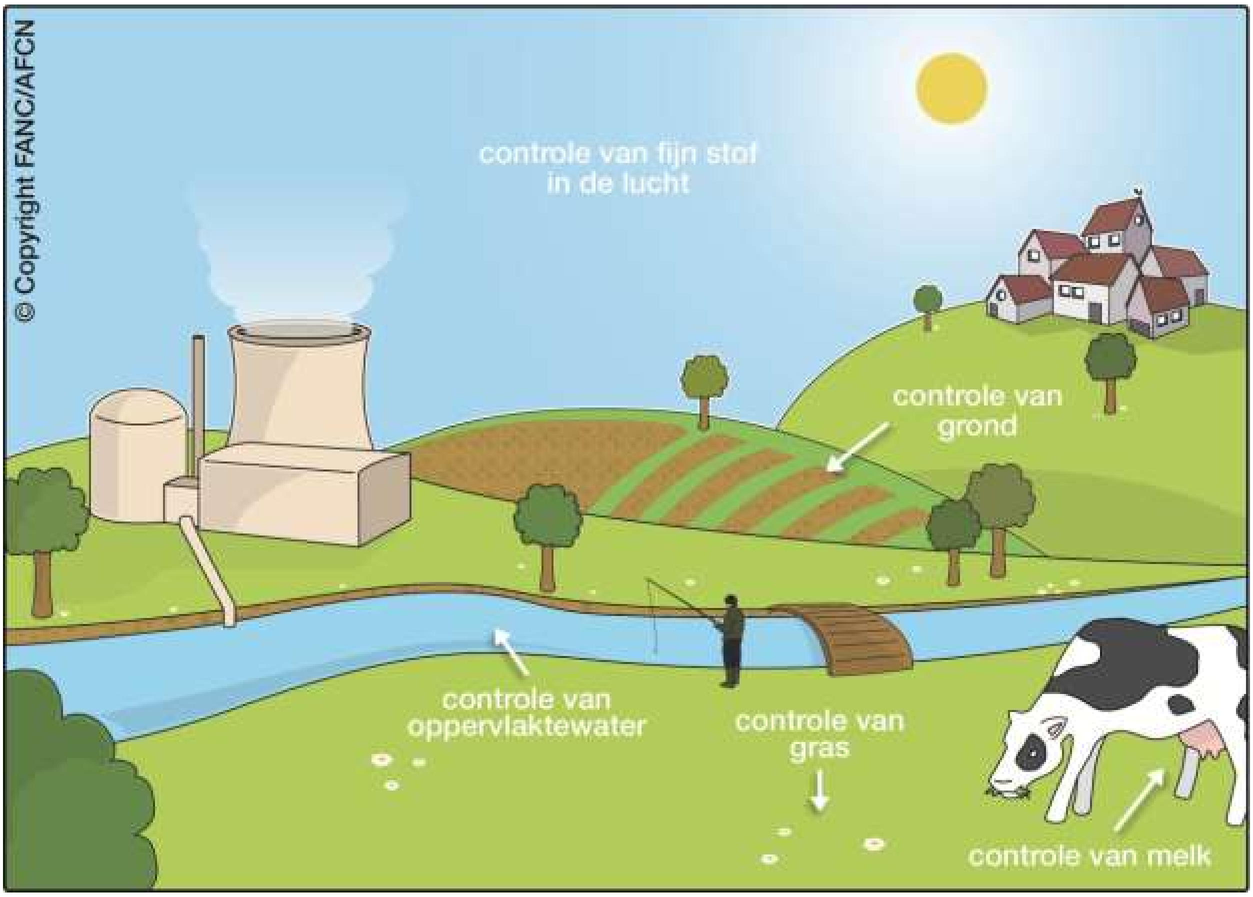

Figure 3-11 Sampling of the environment.

3.2.2.13 Nuclear safety

Due to the potential effects, strict regulations have been established for handling radioactive materials and ionizing radiation. For the Belgian territory, the Royal Decree of 20 July 2001 on the general regulation for the protection of the population, the workers and the environment against the danger of ionizing radiations [ARBIS] has been established for this purpose. According to this Decree, there are three basic principles that must be met before handling ionizing radiation:

- The justification principle;
- The optimization principle and
- Respecting the dose limits.

All activities resulting in exposure to ionizing radiation must be justifiable by the benefits they provide. If an activity (e.g., energy production) can be justified, the activity should comply with the principle "as low as reasonably achievable" (ALARA). In addition to these optimization principles, there are also strict dose limits set by international and European standards that must be met at all times, both for occupationally exposed workers and for the general public, see § 3.2.2.11.

Because of the potential risks of nuclear power plants, safe operation is monitored already at the time of construction. Three key safety functions have been identified that must be met at all times:

- Controlling reactivity;

- Cooling the fissile materials and
- Containment of the radioactive substances and fissile materials.

Nuclear safety at a nuclear power plant is based on the concept of defense in depth. This concept is a combination of different levels consisting of architectural, technical and organizational facilities. For each level, protective measures with different strategies have been established to ensure the safety of the reactor, both during regular operation and abnormal and accident conditions. This included measures to prevent failure from both human action and technical causes (prevention) and to mitigate any consequences due to failure (mitigation).

An example of defense in depth is the containment of activity. Nuclear fission of uranium produces radioactive fission products. These fission products are trapped in the uranium matrix of the fuel rod, as schematically shown as barrier 1 from Figure 3-12. To prevent the release of fission products from the fuel rods, the uranium pellets are enclosed in a fuel element (barrier 2). The fuel elements are then enclosed in the reactor vessel with a closed cooling system (barrier 3) which is held in a steel and concrete jacket called the containment (barriers 4&5).

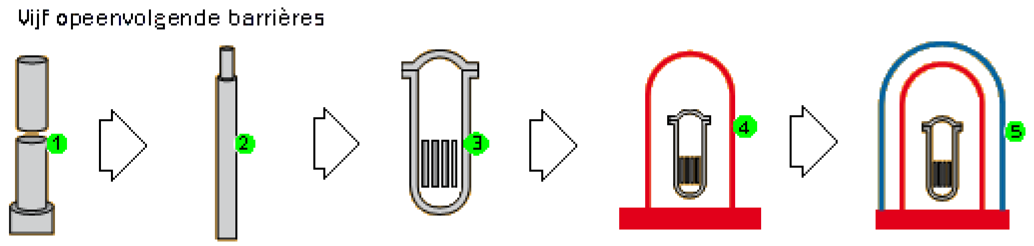

Figure 3-12 The containment of radioactivity in the nuclear power plant, based on five barriers to meet the nuclear safety function with the defense in depth concept.

3.3 Expected radiological environmental aspects

The potentially significant environmental impacts for the Project and the Zero Alternative are indicated below:

- Direct radiation at the site boundary
- Radiation exposure of (non-)occupationally exposed staff;
- Radioactive gaseous discharges
- Radioactive liquid discharges
- Radioactive waste
- Spent fuel elements
- Accident situations

All aspects except accident situations are considered during normal operation. Accident situations can lead to significant impact through direct radiation and/or discharges. However, these aspects are considered accident situations and are considered jointly in that section.

These impacts are considered in more detail in § 3.4.1 - § 3.4.8.

3.4 Environmental Assessment

3.4.1 Direct radiation at the site boundary

Virtually all of the radioactivity at the Doel Nuclear Power Station (KCD) site is in the reactor cores and spent fuel elements, radioactive waste, and facilities where radioactive material is processed and temporarily stored, such as the Water and Waste Treatment Building (WAB). Both the reactor buildings (RGB), the fuel container building (FCB), and the WAB contain several layers of shielding to absorb virtually all ionizing radiation emitted.

Nevertheless, the various systems as well as work on the KCD site can potentially lead to an increased dose at the site boundary, the point closest to KCD where any member of the population may be. Direct radiation can be caused by:

- residual radiation from the buildings;
- transports of radioactive materials between buildings, for example, waste from the power plant to the water and waste treatment building (WAB building);
- transportation of spent fuel from a unit to the fuel container building (FCB).

The direct radiation emitted from all sources at the site contributes to the dose to both members of the public and employees. The impact of the dose sustained on field staff is described separately in § 3.4.2. The committed effective dose for members of the population is composed of three components:

- Direct radiation at the site boundary
- The committed dose due to liquid discharges;
- The committed dose due to atmospheric discharges.

The committed effective dose due to liquid discharges (§ 3.4.4) and atmospheric discharges (§ 3.4.3) are described separately. Nevertheless, the committed effective dose for members of the population should be below 1 mSv per year at all times, regardless of the source of the dose [ARBIS] [1]. As a result, the total dose due to the operation of KCD is described and explained in the conclusion (§ 3.4.8) . The current section only describes the impact of direct radiation due to the operation of the units. This includes the transport of nuclear material at the site.

As described earlier, several sources can contribute to the effective dose to members of the population. Virtually all of the dose from direct radiation originating from KCD will consist of γ-photons. As a result, the dose due to an exposure to direct radiation will have a one-time contribution. In other words, once a person leaves the radiation field, that person will not incur further dose. The committed dose, which

[1] It should be noted that this limit does not take into account legitimate medical treatments or exposure to natural radiation.

represents the total dose that a person will incur over a 50-year period as a result of a single exposure/contamination, is therefore equal to the dose incurred immediately. As a result, the dose due to direct radiation is described as dose while dose due to discharges are described as committed dose. In all cases it is the effective dose, taking into account the type of ionizing radiation causing the dose (e.g. gamma radiation) and the organs in the body that are exposed. For direct radiation, whole-body irradiation is assumed.

For a point source, it can be assumed that the dose rate decreases quadratically with distance (Figure 3-13), i.e., doubling the distance from the source will result in a fourfold (2^2) decrease in the dose rate. Given the distance of the units (KCD-1, KCD-2, KCD-3, and KCD-4) from the location where a member of the population may be exposed (the site boundary), the sources listed above can be considered a point source for simplification. Although the WAB and FCB are closer to the site boundary, the dose rate coming from these buildings will also decrease almost quadratically with distance.

This leads to the conclusion that the highest dose outside the KCD site due to direct radiation will, by definition, be found at the site boundary. For reasons of conservatism, the site boundary dose is therefore used as the starting value, i.e. the dose described in this section assumes a person who will be somewhere on the site boundary throughout the year. The road over the dike along the site is not accessible to the public, so effectively a person will not be able to be at the site boundary at the level of KCD-1 and KCD-2, which increases the conservatism in this assessment.

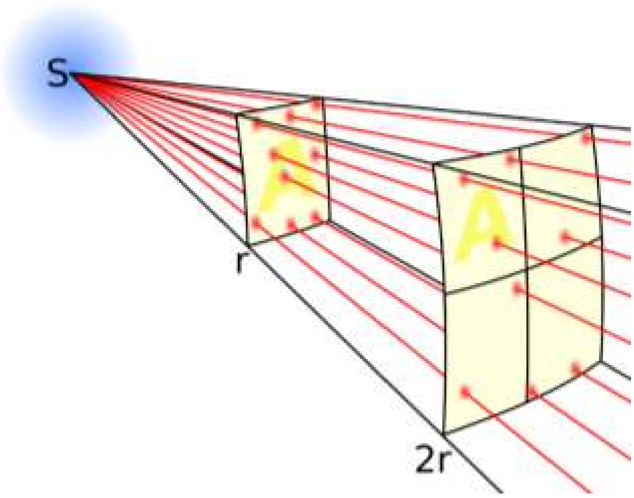

Figure 3-13 Quadratic decrease in radiation field with increase in distance *r* from source(*S*) [Bos, 2000].

3.4.1.1 Methodology

The dose at the site boundary is measured by 24 thermoluminescence dosimeters (TLDs) set up at the site boundary (Figure 3-14). TLDs consist of small crystals where the associated electrons enter an excited state through interaction with ionizing radiation. After the crystals are heated (to several hundred degrees Celsius), the excited atoms revert back to the ground state and emit visible light in the process. The amount of light photons emitted is proportional to the absorbed dose in the crystal and therefore can be used to determine the dose very accurately. Because of these properties, TLDs are used in many countries as official dosimeters for occupationally exposed workers, including Belgium[2].

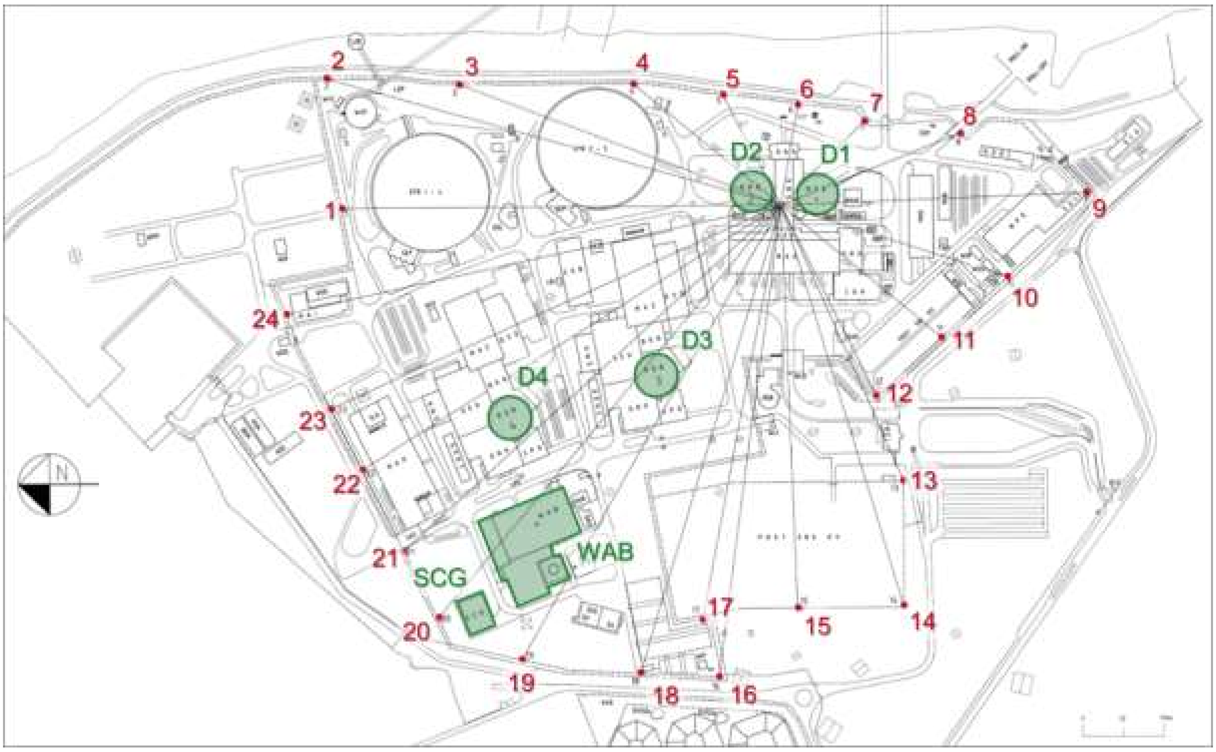

Figure 3-14 Location of TLD measuring stations at the site boundary of KCD, from [Electrabel, 2015]

The TLDs installed are replaced quarterly and read by an approved service. Based on these results, the average dose rate at the site boundary can be determined. An expectation of the environmental impact due to direct radiation is issued for the period 2015-2025 based on the annually reported results of the TLDs and compared to the baseline situation (2012-2014) [Electrabel, 2013][Electrabel, 2014][Electrabel, 2015a][Electrabel, 2016][Electrabel, 2017][Electrabel, 2018].

However, TLDs (like all other types of dosimeters) cannot distinguish between natural background radiation (incl. cosmic radiation, radiation from building materials used in buildings) and radiation actually coming from the installation.

The natural background radiation varies depending on location; for example, the dose from cosmic rays increases with increasing altitude while natural radionuclides in the soil can lead to increased dose from the ground. The latter effect in particular is clearly visible in the measurement results of the TELERAD network (see § 3.2.2.12.1), a network of 250 measuring stations managed by the FANC and located in Belgium, both around nuclear facilities and throughout the Belgian territory[3].

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[2] https://fanc.fgov.be/nl/professionelen/bescherming-van-de-werknemers/diensten-voor-externe-dosimetrie/types-dosismeter (visited on: 8 January 2020)

[3] https://fanc.fgov.be/nl/het-telerad-netwerk (visited on: 8 January 2020)

The TELERAD network measurement data show a clear difference in natural background radiation in the Ardennes compared to Flanders.

Based on the TELERAD network, FANC concluded that the average background radiation in Belgium is 1 mSv per year, while the average background radiation in Flanders is 0.8 to 0.9 mSv per year and the average background radiation in the north of Belgium is 0.7 mSv per year [FANC, 2018]. For the current assessment, a background dose of 0.7 mSv per year is assumed, which corresponds to the lowest established average and is thus the most conservative approach.

To illustrate, the average dose for members of the Belgian population is 4.0 mSv per year (Figure 3-6) of which industrial applications (including nuclear power generation) contribute less than 0.01 mSv (0.25% of the average dose) per year [FANC, 2018].

3.4.1.2 Baseline situation

The average dose as measured with the TLD dosimeters in 2014 at the site boundary is shown in Figure 3-15 [Electrabel, 2015a]. Most measurement points are below the average background level of northern Belgium (0.7 mSv per year) indicating that the background level around KCD is low. The average dose at the site boundary (0.71 mSv per year) is also in line with the average background dose in northern Belgium and well below the average for Belgium. This means that the average dose at the site boundary of KCD is around the background dose.

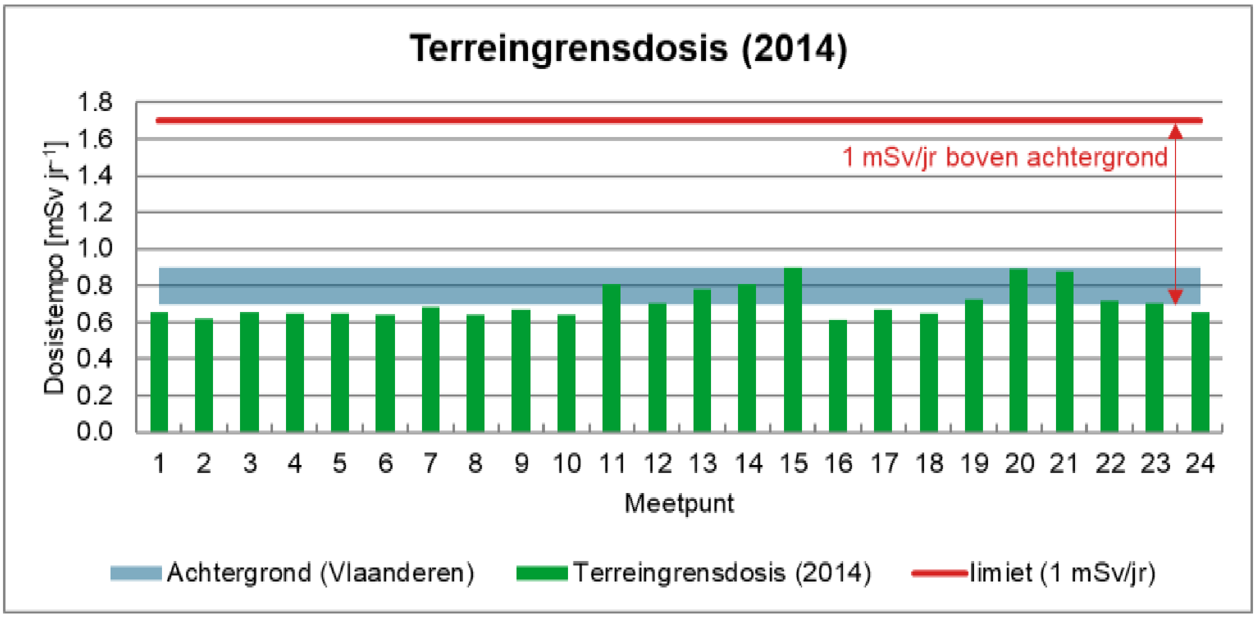

Figure 3-15 Dose measured at the site boundary of KCD in 2014 compared to the average background dose around KCD as reported for northern Belgium (0.7 mSv/yr) and Flanders (0.9 mSv/yr) [FANC, 2018]. The limit here is defined as 1 mSv per year plus the average dose in northern Belgium (0.7 mSv/yr).

Nevertheless, a few measuring points in 2014 show an increase over most measuring points. For example, points 20 and 21 show an increased dose up to 0.89 mSv per year. These points are located around the fuel container building (FCB) and the water and waste treatment building (WAB building), indicating that these facilities contribute to the dose at the site boundary. However, under the assumption of a background dose rate of 0.7 mSv per year (Northern Belgium), the effective dose with the assumption that a person is somewhere on the site boundary throughout the year is 0.19 mSv per year as a result of direct radiation from the FCB and/or WAB and thus remains well below the limit of 1 mSv per year.

Measuring points 4 through 8 are closest to KCD-1 and KCD-2. No increase in site boundary dose was observed for these measuring points, showing that the shielding of the units is sufficient to absorb the ionizing radiation emitted.

Measuring points 11 through 15 show an increase in dose relative to the background levels. However, these points are relatively far from the units and other nuclear zones, so the origin of this increase is unknown at this time. As an additional radiographic analysis of welds at the high-voltage pylons as well as transport of radioactive material across the site has been inconclusive, it is possible that these monitoring posts are located on soil with increased naturally occurring activity. Nevertheless, out of conservatism, it is assumed that the measured dose in these monitoring stations is due to the operation of KCD.

The measured site boundary dose during the period from 2012 to 2014 is shown in Table 3-3 for the entire site (KCD) [Electrabel, 2013][Electrabel, 2014][Electrabel, 2015a]. This data shows that the observations from 2014 are also valid for the previous years. The data shows that, despite minor differences, the dose remains relatively constant and is around the average background level of Flanders.

Table 3-3 The site boundary dose measured between 2012 and 2014 for the entire site (KCD). The values are given without background correction.

Measuring point	2012 [mSv/yr]	2013 [mSv/yr]	2014 [mSv/yr]
1	0.67	0.67	0.66
2	0.62	0.62	0.62
3	0.69	0.70	0.66
4	0.68	0.67	0.65
5	0.64	0.67	0.65
6	0.67	0.67	0.64
7	0.70	0.72	0.68
8	0.63	0.67	0.64
9	0.69	0.70	0.67
10	0.66	0.67	0.64
11	0.83	0.81	0.81
12	0.74	0.73	0.70
13	0.81	0.82	0.78
14	0.87	0.88	0.81
15	0.92	0.88	0.90
16	0.64	0.65	0.61
17	0.72	0.70	0.67
18	0.68	0.69	0.65
19	0.79	0.78	0.73
20	0.89	0.92	0.89
21	0.86	0.85	0.88

Measuring point	2012 [mSv/yr]	2013 [mSv/yr]	2014 [mSv/yr]
22	0.71	0.71	0.72
23	0.69	0.70	0.70
24	0.66	0.67	0.66

The highest site boundary dose was measured around point 15 and point 20, so the dose from these points was considered representative for the operation of the entire site. The measurement points in the immediate vicinity of KCD-1 and KCD-2 (4-8) show no increase over the background level, which implies that the shielding of the buildings of KCD-1 and KCD-2 is such that it has no direct contribution on the dose to the population due to direct radiation at the site boundary.

The dose attributable to the operation of KCD was determined as the measured dose at the highest measuring point at the site boundary (points 15 and 20) during the baseline situation, leading to an average dose of 0.90 mSv per year. After adjusting for background (0.7 mSv per year), the dose due to the operation of KCD from direct radiation is 0.2 mSv per year. The measuring points in the immediate vicinity of KCD-1 and KCD-2 show no increase compared to the background level. As the dose coming from the FCB is due to the operation of the various units, it is not possible to assign a specific dose to the operation of the different units.

3.4.1.3 Impact assessment

The potential impacts of direct radiation on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  This scenario is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): operation after implementation of the LTO measures.
- Zero alternative, the Project is <u>not</u> completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the period (2012-2014; baseline situation) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[4].

[4]For further explanation on this assumption, see § 1.1.3

3.4.1.3.1 Operational phase of the Project between 2015 and 2018

The LTO synthesis report contains the integrated action plan [Electrabel, 2015c]. During the period 2015-2018, these measures will be implemented and that period is referred to within this Project as the "operational phase of the Project between 2015 and 2018." Also during this period, KCD-1 and KCD-2 are operated by Electrabel.

Depending on the type of work, the LTO measures can be carried out during regular operations or can only be carried out during an outage. In particular, the technical LTO measures can only be implemented during an outage.

Despite the fact that in addition to regular operation, many activities are carried out in the radiologically controlled areas, direct radiation at the site boundary due to KCD-1 and KCD-2 is expected to be as high as in the baseline situation during the operational phase of the Project between 2015 and 2018. This is because as described earlier in this paragraph that the shielding of the buildings is sufficient to absorb the emitted ionizing radiation.

Given the timing of this study, the site boundary dose during the Project's operational phase between 2015 and 2018 is already known. The site boundary doses of all monitoring points around the KCD site during the operational phase of the Project between 2015 and 2018 are shown in Table 3-4 [Electrabel, 2016] [Electrabel, 2017] [Electrabel, 2018] [Electrabel, 2019].

Table 3-4 The site boundary dose measured between 2015 and 2018 for the entire site (KCD). The values are given without background correction.

Measurement Point	2015 [mSv/yr]	2016 [mSv/yr]	2017 [mSv/yr]	2018 [mSv/yr]
1	0.65	0.67	0.68	0.70
2	0.62	0.62	0.63	0.64
3	0.67	0.69	0.71	0.67
4	0.65	0.67	0.66	0.65
5	0.67	0.68	0.68	0.67
6	0.65	0.67	0.70	0.72
7	0.70	0.70	0.70	0.81
8	0.64	0.65	0.66	0.64
9	0.67	0.69	0.71	0.68
10	0.67	0.69	0.67	0.68
11	0.85	0.81	0.79	0.80
12	0.78	0.70	0.70	0.69
13	0.80	0.77	0.71	0.71
14	0.80	0.81	0.78	0.77
15	1.01	0.90	0.86	0.82
16	0.62	0.60	0.63	0.62
17	0.67	0.68	0.69	0.68
18	0.66	0.67	0.67	0.67
19	0.78	0.74	0.76	0.78
20	0.95	0.99	0.96	0.97

Measurement Point	2015 [mSv/yr]	2016 [mSv/yr]	2017 [mSv/yr]	2018 [mSv/yr]
21	0.83	0.88	0.88	0.88
22	0.71	0.72	0.72	0.68
23	0.70	0.71	0.73	0.71
24	0.64	0.67	0.71	0.68

Table 3-4 shows that during the operational phase of the Project between 2015 and 2018, the site boundary dose is almost the same as the site boundary dose in the baseline situation (2012-2014). Only measurement point 20, adjacent to the FCB and the WAB, shows a consistent significant increase in dose during the Project's operational phase between 2015 and 2018 compared to the baseline situation.

Although no clear source can be identified, the increase is presumably due to work carried out on all units, given the location of this measurement point near the FCB and the WAB, which is where the spent fuel elements and all the waste from the site are transported. However, additional analysis has revealed that, in the period 2015-2018, no additional transports took place compared to the baseline situation (2012-2014), so the increase in dose is likely to come directly from the FCB where the spent fuel elements are stored. As a result, it can be stated (extremely conservatively) that the increase in dose from the FCB will result from the operation of KCD-1 and KCD-2 and thus this Project.

To determine the (maximum) dose contribution of this Project, the average measured dose of measurement point 20 during the baseline situation (0.90 mSv per year) was subtracted from the average measured dose of measurement point 20 during the Project's operational phase between 2015 and 2018 (0.97 mSv per year). The remaining dose of 0.07 mSv per year, as described earlier, is conservatively assumed to be the maximum dose at the site boundary resulting from this Project. It should be noted that this dose is probably a strong overestimate of the real dose.

With these conservative assumptions, the total annual dose at the site boundary due to operation (0.2 mSv per year; see § 3.4.1.2) and this Project (0.07 mSv per year) is max. 0.27 mSv per year. The dose remains well within the dose limit of 1 mSv per year and is comparable to the annual dose at the site boundary during the baseline situation (0.2 mSv per year).

Therefore, the implementation of the LTO has had very limited impact on direct radiation at the site boundary.

3.4.1.3.2 Operational phase in the future situation (period 2019 - 2025)

During the period 2019-2025, KCD-1 and KCD-2 will continue to operate and this period within this Project is referred to as the "operational phase in future situation (period 2019 - 2025)". The maximum expected dose at the site boundary is expected to be similar to the operational phase between 2015 and 2018. The expected site boundary dose from KCD during the operational phase is shown in Figure 3-16.

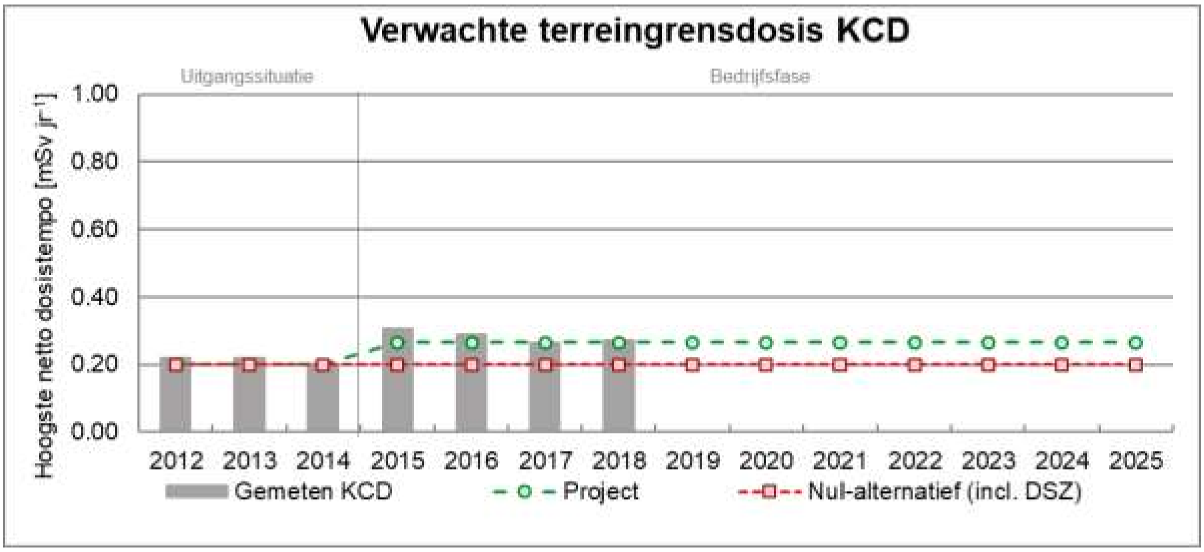

Figure 3-16 Expected site boundary dose from KCD. The values are given after background correction (0.7 mSv per year). The vertical bars show the actual measured values for the conservatively chosen measurement point.

Figure 3-16 shows that, after the baseline situation (2012-2014) the dose from direct radiation increases slightly due to the conservative approach during the operational phase of the Project between 2015 and 2018 as well as in the future operational situation between 2019 and 2025. This is described in § 3.4.1.3.1 and § 3.4.1.3.2, respectively.

The dose shown is a large overestimation of a realistic dose which a person may incur off-site. For example, the dose was calculated for a person who is located on the site boundary for the entire Project. As an illustration, correction factors are applied in Dutch legislation to correct the dose for the destination area to arrive at a more realistic dose, for example, a through road within an industrial area would be multiplied by a factor of 0.01 because individuals will only travel here for a (very) short time[5].

However, the total dose that a member of the population outside of KCD may incur consists of three factors: direct radiation and the committed effective dose from atmospheric (§ 3.4.3) and liquid discharges (§ 3.4.4). The impact assessment of these factors is described in later sections, the total dose due to the operation of KCD is given in § 3.4.8.

The annual dose due to direct radiation, even for a person located somewhere on the site boundary throughout the year, is well within the legal limit and on the basis of these data it can be concluded that the continued operation of KCD-1 and KCD-2, after implementation of the LTO measures, will not have a significant impact on the environment.

Cumulative effect of the Project

The cumulative dose that a person would incur from direct radiation due to the operation of KCD if they were to be continuously at the site boundary is 2.9 mSv (11 years at 0.27 mSv per year). To illustrate, this

[5] https://wetten.overheid.nl/BWBR0040581/ (date of visit: 24 February 2020)

cumulative dose is well below the average background dose of Belgium (43.8 mSv) during this Project, of which 26.9 mSv is due to natural radiation and 16.8 mSv is due to medical applications [FANC, 2018].

3.4.1.3.3 Zero alternative

KCD-1 and KCD-2 will be taken offline in 2015 if no LTO occurs. Immediately after that, the Post Operational Phase (POP) will start. In that case, it can only be stated that the observed increase in dose near the FCB (0.07 mSv per year), will not occur. This annual increase is expected to come from the additional spent fuel elements produced and stored.

The fact that KCD-1 and KCD-2 will be operated for 10 years less under the Zero Alternative than under the Project results in less fuel in the FCB. As a result, the dose rate will remain at 0.20 mSv/year under the Zero Alternative.

Since no decision has yet been taken in Belgium on reprocessing or final disposal of spent fuel elements, and it is not likely that such a decision will be implemented before 2025, the LTO will not result in earlier removal of the fuel elements from the FCB and the associated dose reduction.

Post Operational Phase of KCD-1 and KCD-2

If no LTO were to take place, KCD-1 and KCD-2 will be shut down and the Post Operational Phase (POP) will be started. At the time KCD-1 and KCD-2 will transition to the POP, this will not directly affect the radiation level at the site boundary. As described earlier, the dose contribution at the site boundary is primarily determined by direct radiation from the FCB, where the spent fuel elements are stored.

During the Post Operational Phase (POP) of KCD-1 and KCD-2, direct radiation will continue to contribute to the effective dose at the site boundary. However, there will be no difference in the duration of the POP phase after the LTO (Project) and after immediate shutdown (Zero Alternative). In the case of the Project, the Post Operational Phase will start only 10 years later. As a result, the only difference is that the direct radiation due to KCD-1 and KCD-2 becomes zero 10 years earlier under the Zero Alternative than under the Project. In Figure 3-16, direct radiation during the POP phase is added at the Zero alternative.

3.4.1.4 Cross-border effects

As described earlier, almost all dose originating from direct radiation from KCD consists of γ photons whose dose rate decreases as the distance increases. As a result, the dose rate outside the site decreases with increasing distance from the site boundary. The nearest border with the Netherlands is about 2.5 km away. Measurement point 20, the representative measuring point for the entire site (see § 3.4.1.2), on the site boundary lies in the direction of the Dutch border. It is likely that most radiation will come from FCB, which is about 50 meters from the measurement point 20. The average dose rate of measuring point 20 over the years 2012-2014 was about 0.2 mSv per year (with background correction). To determine the dose rate at a given distance, the law of squares is used:

$$\dot{D}(r_2) = \dot{D}(r_1) \cdot \frac{r_1^2}{r_2^2}$$

Where $\dot{D}(r_1)$ is the dose rate at distance r_1 from the source and $\dot{D}(r_2)$ is the dose rate at distance r_2. Although the squared law is only valid for a point source, the source within KCD can be considered a point source given the large distance (2.5 km) compared to the actual size of the source (several tens of meters).

The distance from the source (FCB) to the Dutch border (2,500 + 50 m) is about a factor of 51 (r_2/r_1) larger compared to the distance from the source to the site boundary (50 m). Based on these data, the dose rate at the Dutch border was calculated as 0.000078 mSv per year (Table 3-5).

Table 3-5 Quadratic decrease in dose rate towards the Dutch border.

		FCB
r_1	: Distance to site boundary [m]	50
r_2	: Distance to Dutch border [m]	2,550
$\dot{D}(r_1)$	: Dose rate at site boundary [mSv·jr^{-1}]	0.20
$\dot{D}(r_2)$	: Dose rate at Dutch border [mSv·jr^{-1}]	0.000078

This does not include the absorption of radiation up to the boundary, so the actual radiation dose due to direct radiation will be even lower.

The Dutch Decree of 23 October 2017, establishing rules for the protection of individuals against the dangers of exposure to ionizing radiation (Basic Safety Standards on Radiation Protection Decree; Bbs), Article 9.2.1 states that the maximum dose for a member of the Dutch population resulting from the operation of a nuclear facility may not exceed 0.1 mSv per year. This is the Dutch dose limit due to direct radiation, liquid and gaseous discharges. As can be seen from the above, the dose as direct radiation at the Dutch border from the Project is well below this level. The impact of the entire project, including liquid and gaseous discharges is described in § 3.4.8.

As the dose rate will continue to decrease quadratically as the distance from the KCD increases, the operation of KCD will also have no impact on more distant countries (including France, Germany, Luxembourg and the United Kingdom).

3.4.1.5 Monitoring

FANC manages the TELERAD network with over 250 measuring stations on the Belgian territory, which continuously measure radioactivity in the air and in water[6]. Around KCD, a relatively large number of measuring stations are set up (Figure 3-17) which continuously measure the dose. Any deviations in the dose will immediately trigger an alarm once a warning threshold is exceeded. A similar network of measurement stations is also located on Dutch territory (the National Radioactivity Monitoring Network[7]).

[6] https://fanc.fgov.be/nl/het-telerad-netwerk (visited on: 19 February 2020)

[7] https://www.rivm.nl/nationaal-meetnet-radioactiviteit (visited on: 19 February 2020)

Figure 3-17 Measuring stations of the TELERAD network around KCD.

3.4.1.6 Mitigating measures

Based on the available data, direct radiation at the site boundary originating from KCD does not have a significant impact on the environment and no mitigation measures are required.

3.4.1.7 Knowledge gaps

The available knowledge is sufficient to determine the effects of direct radiation at the site boundary coming from KCD under this plan. It should be noted, however, that the measured values of the site boundary dose are in the order of the background radiation. There is no unambiguous explanation for the slightly higher values of measurement points 11-15, relative to the other measurement points around the site. These gaps in knowledge do not interfere with decision making because out of conservatism, the highest readings at the site boundary were assumed to be from KCD-1 and/or KCD-2.

3.4.1.8 Conclusions

As a result of this Project, effects of direct radiation at the site boundary originating from KCD-1 and KCD-2 will occur 10 years longer. Although the construction of the various LTO measures (2015-2018) could possibly have resulted in a slightly increased dose, it is not visible in the site boundary dose measurement due to the shielding of KCD-1 and KCD-2. However, due to the increase in the spent fuel elements in the FCB and given the conservative assumptions, the maximum expected dose at the site boundary will be 0.07 mSv per year higher during the Project period than under the Zero alternative. Based on this, it can be concluded that this Project has no significant impact on the environment with respect to direct radiation.

The operation of KCD as well as the LTO Project has no significant measurable impact on the Dutch territory so that further cross-border effects as a result of direct radiation can also be excluded.

3.4.2 Radiation exposure of employees

Nearly 2,000 people work at the Doel nuclear power plant every day. These are both in-house and external employees. A large proportion of these people do not come into contact with radioactivity [Electrabel 2019a].

On the other hand, some employees may be exposed to ionizing radiation during their work. If there is a risk that an employee's effective dose exceeds 1 mSv per year, these individuals are called occupationally exposed workers [ARBIS][8]. Work is done throughout the year, however, especially during outages, a lot of work takes place in the radiologically controlled areas.

During an outage period, a larger number of employees work in and around the plants for maintenance and inspection work. This includes both KCD staff and external staff from specialized companies.

As radiation exposure can pose a health risk, legal limits and requirements have been defined and laid down in the Royal Decree ARBIS [ARBIS]. Employees who do not come into contact with radiation are subject to the same radiation requirements as members of the public (including local residents). The effective dose limit for members of the public is set at 1 millisievert per year [ARBIS, Article 20.1.4].

For occupationally exposed workers, important requirements are to have adequate knowledge of radiation protection and to track the radiation dose incurred per individual. Also, every occupationally exposed employee must be under medical supervision by a licensed radiation physician. The maximum allowable regulatory standard for occupationally exposed workers is 20 mSv per 12 consecutive sliding months [ARBIS, Article 20.1.3]. Electrabel itself applies as a maximum limit that is half this legal limit. Every occupationally exposed employee may incur a maximum of 10 mSv per year.

The United Nations has a committee UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). This committee provides scientific knowledge for radiation protection and assesses the effects of ionizing radiation on a global level. In that context, it has published a study that includes exposure from occupational activities [UNSCEAR, 2000]. Table 3-6 shows the number of occupationally exposed workers and the corresponding average annual effective dose for each work area [UNSCEAR, 2000]. This shows that workers exposed to natural ionizing radiation sources, such as airline and mining staff, among others, incur an average effective annual dose which is three times that of workers exposed to man-made sources. Nuclear power plants are part of the nuclear fuel chain, so nuclear power plant employees are shown in this category in the table below.

Table 3-6 Average effective dose per work area

Source / work area	Number of exposed employees [-]	Average effective dose [mSv/year]
Man-made sources		
Nuclear fuel chain (incl. uranium mining)	800,000	1.8
Industrial use of radiation	700,000	0.5
Defense activities	420,000	0.2

[8] https://fanc.fgov.be/nl/beroepshalve-blootgestelde-personen (visited on: April 2020)

Medical use of radiation	2,320,000	0.3
Education/Veterinary Medicine	360,000	0.1
Total	*4,600,000*	*0.6*
Natural sources		
Air travel (crew)	250,000	3.0
Mining (other than coal)	760,000	2.7
Coal mining	3,910,000	0.7
Processing of minerals	300,000	1.0
Above-ground workplaces (radon)	1,250,000	4.8
Total	*6,500,000*	*1.8*

3.4.2.1 Methodology

The radiation exposure for professionally exposed employees (both Electrabel employees and externals) is continuously monitored, in particular through the use of personal dosimeters. The as-low-as-reasonable-as-possible (ALARA) principle is applied to all works. The dose sustained is tested against KCD's internal limit for each employee. The company uses half the legal dose as its limit, i.e. 10 mSv per year. Even if a very exceptional situation occurs (such as a clerical error), the employee's annual dose will remain below the legal limit.

Dose data is published annually in the environmental statements [Electrabel, 2012][Electrabel, 2013a][Electrabel, 2014a][Electrabel, 2015b][Electrabel, 2016a][Electrabel, 2017a][Electrabel, 2018a]. This report compares these annually published dose data with the internal KCD limit and issues a forecast for the 2015-2025 period based on the multiple years.

To determine the radiation exposure for non-professionally exposed employees at the site, available dose data from so-called "blind monitors" are used (TLDs) which are installed at representative locations within the KCD site, but outside the radiologically controlled areas, and are read regularly. For non-professionally exposed workers, the legal limit is 1 mSv per year [ARBIS, Article 20.1.4], equal to the dose limit for the general population.

3.4.2.2 Baseline situation

In both 2012, 2013, and 2014, the maximum dose for all employees was below the KCD internal limit of 10 mSv per year and thus also well below the legal limit of 20 mSv per 12 consecutive sliding months.

The average dose for both internal and external employees is shown in Table 3-7 [Electrabel, 2012][Electrabel, 2013a][Electrabel, 2014a]. The collective dose depends very much on the works performed during outages, for example, during the outage of KCD-1 and KCD-3 in 2012, there were many unexpected work activities, so the collective dose for KCD and for KCD-1 is higher compared to the other years. Of course, because more work is performed, there are also more occupationally exposed workers in 2012.

Table 3-7 Effective dose of employees at KCD during the baseline situation

Year	KCD			KCD-1 and KCD-2
	Total number of exposed persons	**Average effective dose [mSv/year]**	**Collective [human.mSv/year]**	**Collective [human.mSv/year]**
2012	3,402	0.47	1,612	521
2013	3,134	0.14	449	203
2014	3,145	0.31	981	336

The average effective dose of employees at KCD is about six times lower than the average effective dose for employees in the nuclear industry, according to data published by UNSCEAR (1.8 mSv/year) [UNSCEAR, 2000] (Table 3-6).

No individual dose records are kept for non-professionally exposed internal and external employees. To ensure that employees stay below the legal limit of 1 mSv per year, so-called blind monitors can be used. The blind monitors are TLD dosimeters which are installed in representative locations within the KCD site, but outside the radiologically controlled areas. The results of the blind monitors are used to determine the background level for the TLD personal dosimeters.

The measurements from the blind monitors show an average dose of 0.63 mSv/year over the period 2012-2014. This dose rate is below the average background level around KCD (0.7 mSv per year, see also § 3.4.1.1), which is due to the shielding of the buildings from natural radiation (including ground and cosmic rays). As an illustration, a study investigating the dose from > 50,000 blind monitors in Belgium revealed an average dose rate of 0.67 mSv per year [Electrabel, 2020a]. As a result, the average exposure of KCD's non-professionally exposed employees is negligible [Electrabel, 2020a].

The highest dose measured by blind monitors was 0.87 mSv per year or 0.17 mSv per year after correction for the background radiation. As a result, the annual dose that an employee who would spend 2000 hours per year at this point would receive (0.04 mSv) is well below the legal limit (1 mSv per year). These results confirm that the units, WAB and FCB at the site have sufficient radiological shielding to protect non-professionally exposed employees.

3.4.2.3 Impact assessment

The potential consequences of radiation exposure to employees are assessed for both scenarios to be addressed:

- Implementation of the Project
  This scenario is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): regular operation after implementation of the LTO measures;
- Zero alternative, the Project is <u>not</u> completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the baseline situation (2012-2014) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[9].

3.4.2.3.1 Operational phase of the Project between 2015 and 2018

The LTO synthesis report contains the integrated action plan to operate KCD-1 and KCD-2 for ten years longer than envisioned in the 2003 Nuclear Phase-Out Act. During the period 2015-2018, these measures will be implemented and that period is referred to within this Project as the "operational phase of the Project between 2015 and 2018." During this period, KCD-1 and KCD-2 are operated by Electrabel.

Depending on the type of work, the LTO measures can be carried out during regular operations or an outage. In particular, the technical LTO measures can only be carried out during an outage to ensure the continuous safety of both the plant and the employees. As many activities are performed in addition to regular operation, it is expected that the exposure to ionizing radiation for occupationally exposed internal and external employees will be higher during the operational phase of the Project, between 2015 and 2018 than in the baseline situation. Conversely, the dose sustained by the non-professionally exposed staff is not expected to change significantly during this period compared to the baseline situation.

Given the timing of this study, the employees' exposure during the Project's operational phase between 2015 and 2018 is already known. The effective dose to employees for both KCD-1 and KCD-2 as well as the entire site (KCD) during the operational phase of the Project between 2015 and 2018 is shown in Table 3-8 [Electrabel, 2016a] [Electrabel, 2017a] [Electrabel, 2018a] [Electrabel, 2019a]. As during the baseline situation, the maximum dose of all occupationally exposed workers, also for the years 2015-2017, was well below the legal limit of 20 mSv per 12 consecutive sliding months. In 2018, work was performed during which one employee sustained a dose higher than the internal 10 mSv/year limit. This was a planned activity that was discussed with the parties involved, to ensure that the annual dose remained well below the legal limit.

[9] For further information about this assumption, see § 1.1.3

Table 3-8 Effective dose of employees at KCD during the operational phase of the Project between 2015 and 2018

Year	KCD			KCD-1 and KCD-2
	Total number of exposed persons	Average effective dose [mSv/year]	Collective [human.mSv/year]	Collective [human.mSv/year]
Baseline situation (2012-2014)	3,227	0.31	1,014	353
2015	3,544	0.34	1,219	602
2016	3,582	0.26	916	473
2017	3,594	0.42	1,493	784
2018	3,961	0.45	1,789	1,347

As more work for the LTO measures is done in the reactor building, more than 400 additional occupationally exposed workers are required for this work. As a result, the collective dose of all occupationally exposed workers is, as expected, higher than during the baseline situation.

Nevertheless, the average effective dose of occupationally exposed workers at KCD factors remains lower than the average effective dose for workers in the nuclear industry, according to data published by UNSCEAR (1.8 mSv/year) [UNSCEAR, 2000].

For the non-professionally exposed internal and external staff, as in the previous section, the so-called blind monitors can be used, which are installed in representative locations within the KCD site, but outside the radiologically controlled areas. They show an average of 0.61 mSv/year over the period 2015-2018 [ENGIE, 2020], similar to the baseline situation. The highest dose measured of 0.61 mSv per year has decreased slightly compared to the baseline situation. The conclusion is that the construction work has no impact on the dose for non-occupationally exposed workers.

Based on these data, it can be concluded that the construction of the LTO measures caused a slight increase in the collective dose for occupationally exposed workers. Since the individual doses are well below the legal limit, this phase has no significant negative impact. For non-professionally exposed employees, this phase also has no significant negative impact.

3.4.2.3.2 Operational phase in the future situation (period 2019 - 2025)

After the operational phase of the Project between 2015 and 2018, the units (KCD-1 and KCD-2) will continue to be operated. Also during this regular operation (2019-2025), work will take place during outages and employees will be exposed to ionizing radiation. Despite the fact that the extent of this exposure is highly dependent on the type of operations in the reactor buildings, the annual collective dose is expected to be similar to the annual collective dose during the baseline situation (2012-2014). It has been assumed that the annual collective dose during the operational phase in the future situation (period 2019 - 2025) will be equal to that in the baseline situation (see the green line in Figure 3-18).

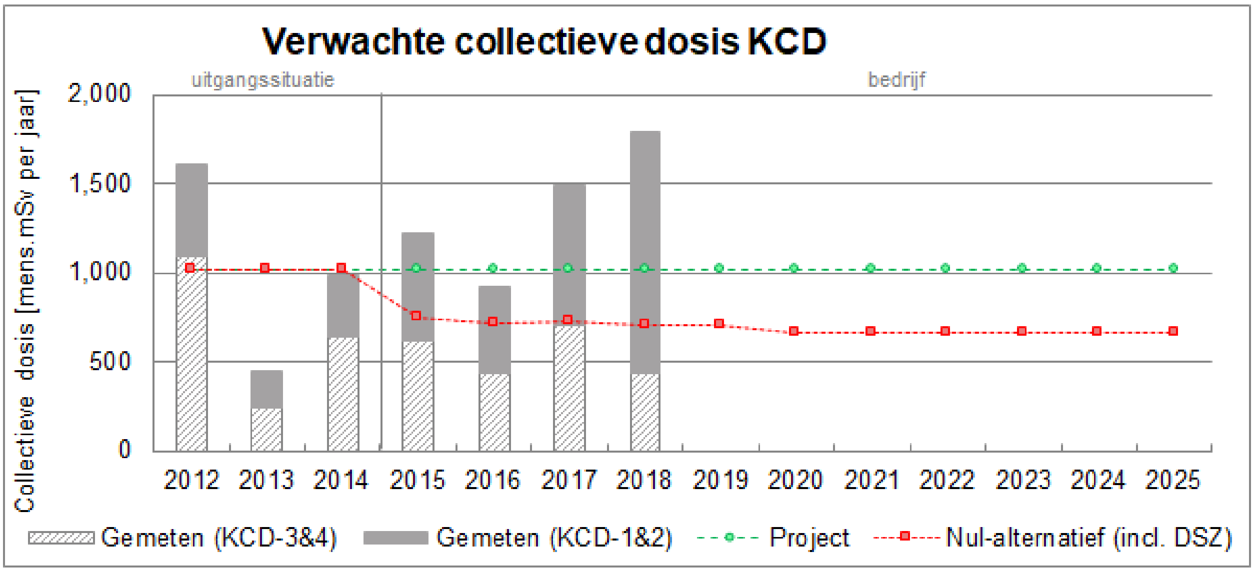

Figure 3-18 Expected collective dose for occupationally exposed employees of KCD, for both the Project and Zero alternative. The vertical bars show the actual collective dose measured, where available.

In the operational phase in the future situation (period 2019 - 2025), no impact is expected for the non-occupationally exposed employees, as previously confirmed during the operational phase of the Project between 2015 and 2018.

Based on these results, the conclusion is that this Project has no significant impact on the exposure of staff, both those who are occupationally exposed and non-occupationally exposed.

3.4.2.3.3 Zero alternative

If no LTO takes place, both KCD-1 and KCD-2 will be permanently shut down in 2015. In that case, employees will no longer be exposed to ionizing radiation as a result of energy generation by KCD-1 and KCD-2. In that case, the annual collective dose for occupationally exposed employees is caused by the operation of only KCD-3 and KCD-4 and the POP work at KCD-1 and KCD-2. Because of the radiological shielding of KCD-1 and KCD-2, discontinuing these units will have little effect on the annual dose of non-professionally exposed employees. In Figure 3-18, direct radiation during the POP phase is added at the Zero alternative.

Post Operational Phase of KCD-1 and KCD-2

After KCD-1 and KCD-2 are shut down, the reactor cores and fuel pools will still need to be cooled to remove the residual heat. Maintenance and inspection work still needs to be done. The duration of the Post Operational Phase (POP) will be no different between the Project and the Zero Alternative. If the Project is implemented, the POP will start 10 years later. As a result, the collective dose per year during the POP phase will be the same for both scenarios.

Electrabel made an estimate of the radiation exposure of occupationally exposed workers during the four POP phases. This estimate was made on the basis of POP work that has taken place at German nuclear power plants over the last 10 years. Electrabel assumed that the radiation exposure of occupationally exposed workers will follow a similar trend as at these German nuclear power plants. Based on this estimate, the expected collective dose during the POP for KCD-1 and KCD-2 has been calculated and is shown in Figure 3-19. The following time schedule was used for this purpose (see paragraph 1.1.3 for the work carried out in the various phases):

- POP phase 1 takes place in the 1st year of the POP period;
- POP phase 2 will take place after the 1st year of the POP period;
- POP phase 3 will take place during the 2nd, 3rd and 4th years of the POP period;
- POP phase 4 will take place in the 5th year of the POP period.

It should be noted that the dose burden for occupationally exposed workers is related to the work being performed at any given time. Therefore, the schedule of KCD-1 and KCD-2 may differ somewhat from the planning of the considered German nuclear power plants, which means that not all similar works will be carried out at the same time. As a result, especially in POP phase 3, the trend of decreasing radiation exposure may fluctuate somewhat.

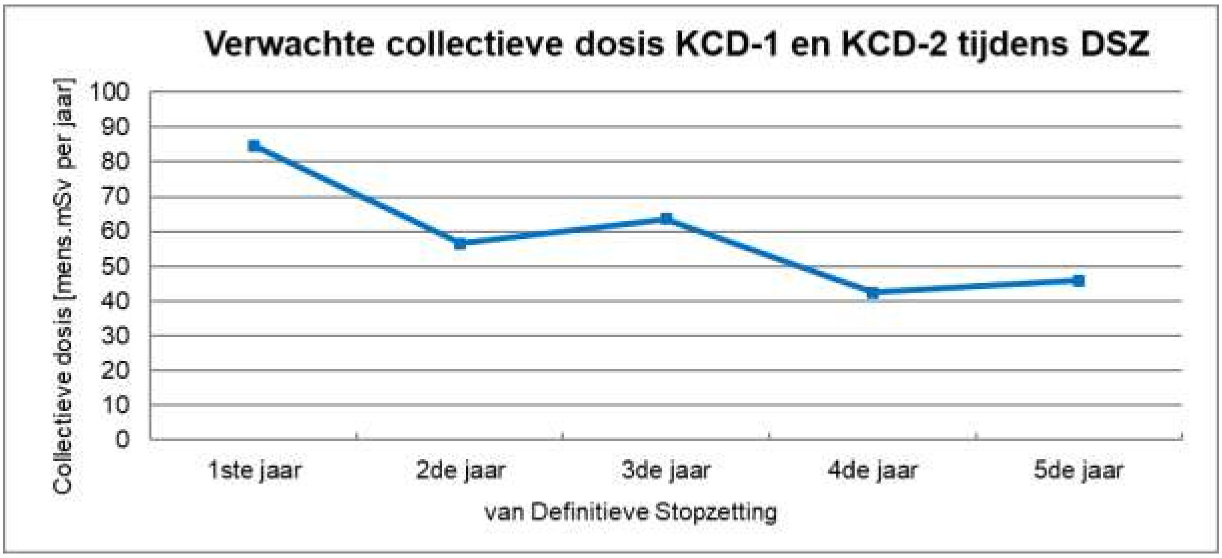

Figure 3-19 Expected collective dose for occupationally exposed workers due to operations at KCD-1 and KCD-2 during the POP.

Stopping KCD-1 and KCD-2 will have little effect on the annual dose of non-professionally exposed employees because of the radiological shielding of these units.

3.4.2.4 Cross-border effects

All employees, regardless of where they live, are subject to Belgian law. So no cross-border effects are applicable.

3.4.2.5 Monitoring

ARBIS legally regulates the minimum monitoring to be done by the employer and is supervised by FANC. Personal dosimetry is performed by an independent institute recognized by FANC. Blind monitors also monitor the exposure of non-exposed personnel.

3.4.2.6 Mitigating measures

The infrastructure of KCD-1 and KCD-2 to protect against radiation exposure is such that the applicable criteria are amply met. Therefore, no additional mitigation measures are required.

3.4.2.7 Knowledge gaps

The available knowledge is sufficient to determine the effects of radiation exposure resulting from implementation of the Project. There are no gaps in knowledge that impede proper impact assessment.

3.4.2.8 Conclusions

As a result of the Project (LTO of KCD-1 and KCD-2), employees will be exposed for an additional 10 years. Electrabel has halved its internal limit compared to the legal limit, so that in principle no professionally exposed employee exceeds the annual legal limit. Because of the radiological shielding of all units, WAB and FCB, there will be no significant difference between the Project and the Zero Alternative with respect to the annual dose (1 mSv per year [ARBIS, Section 20.1.4]) of non-occupationally exposed employees. From this, it can be concluded that this Project will not have a significant impact on employees with respect to the dose sustained.

All employees, regardless of where they live, are subject to Belgian law. So no cross-border effects are applicable.

3.4.3 Radioactive gaseous discharges

During the operation of KCD, several radionuclides end up in the gas phase. Virtually all radionuclides present in the gas phase come from the primary cooling circuit; these are mainly gaseous fission products (incl. ^{85}Kr, ^{133}Xe, and ^{131}I), tritium(^{3}H), carbon-14 (^{14}C), and to a limited extent aerosols containing both activation and fission products (including. ^{60}Co and ^{137}Cs).

Radionuclides present in the gas phase are collected in the dedicated *Gaseous waste* (GW) circuit. The gases are passed through an activated carbon filter and an absolute filter into a tank until a preset volume is reached, after which the tank is sealed and put into decay mode. During this period, all short-lived radionuclides are allowed to decay, greatly reducing the activity of the potential discharge. After decay, the remaining activity in the gases is measured. Then, based on the remaining activity, using iodine and aerosol filters, the gases are discharged to the environment in a controlled manner in accordance with the discharge limits. In this process, the gases are passed through various filters (including HEPA and activate carbon filters) to minimize the amount of activity discharged [Tractebel, 2010]. However, especially aerosols and iodine are captured by the filters. The filtering efficiency for noble gases, tritium (^{3}H) and carbon-14 (^{14}C) is very low due to the properties of these elements.

Gaseous radionuclides may also be released within the radiologically controlled areas through leaks or venting of process systems that contain primary cooling water. To prevent unwanted discharges to the environment of these released radionuclides, all radiologically controlled areas are under negative pressure with respect to the outside air, to ensure the air always flows towards the potentially contaminated area. This also means that unexpectedly released radionuclides enter the buildings' ventilation systems, where they are filtered and eventually discharged through the ventilation shaft.

Almost immediately after discharge through the ventilation shaft, the discharged radionuclides will disperse, depending on the wind direction and wind force, with the activity concentration being greatly diluted. Depending on their chemical properties, the discharged radionuclides may behave differently and end up in the environment. For example, aerosols will primarily precipitate, possibly enhanced by rain, while noble gases will disperse further. For this purpose, the ventilation flow rate of the shaft is closely monitored to ensure effective diffusion.

The atmospheric discharges can contribute to the committed effective dose for humans and flora and fauna. To determine the impact of atmospheric discharges on the environment, both the total discharged activity and the calculated committed effective dose should be examined, taking into account the various radiological effects of the discharged radionuclides (including distinction between gamma- and alpha-emitting radionuclides).

3.4.3.1 Methodology

After decay, the gases are discharged through the ventilation shaft. Prior to discharge, the activity concentration is monitored. Should a predetermined activity limit be exceeded, the discharge is interrupted automatically. The measured activity values are also recorded to demonstrate that the units meet the imposed limits, which are summarized in Table 3-9 [Electrabel, 2013a] [Electrabel, 2014a] [Electrabel, 2015b][Electrabel, 2016a] [Electrabel, 2017a] [Electrabel, 2018a]. Because most gaseous activity is discharged directly from the units, there is a limit both for the entire site (KCD-1, KCD-2, KCD-3, KCD-4 and the WAB) and for the various units (KCD-1 and KCD-2 are considered together). Tritium (^{3}H; gaseous) is mainly discharged from the water and waste treatment building (WAB building), therefore ^{3}H is only licensed for the entire site.

Table 3-9 Licensed activities for discharges of gases from KCD

Nuclide	Discharge limit KCD-1 and KCD-2 per 12 months	Discharge permit KCD per 12 months
Noble gases	1 480 TBq $^{133}Xe_{eq}$	2960 TBq $^{133}Xe_{eq}$
Iodine 131 (^{131}I)	7.4 GBq	14.8 GBq
Aerosols	74 GBq[10]0	148 GBq
Tritium (^{3}H)	-	88.8 TBq

To test the discharged activity against the limit, the activity of discharged noble gases should be reset to ^{133}Xe:

$$^{133}\mathrm{Xe}_{\mathrm{eq}} = R(^{133}\mathrm{Xe}) + \sum\left(\frac{\gamma_{\text{noble gas}}}{\gamma_{^{133}\mathrm{Xe}}}\right) \cdot R(\text{noble gas})$$

Where R is the activity concentration and γ is the dose conversion factor of the various radionuclides. The data for gaseous discharge emissions are from Electrabel's annual reports.

A bi-gaussian dispersion model is used for the atmospheric dispersion calculation. This involves calculating the dispersion and dilution of radionuclides from an emission point based on different dispersion coefficients. The coefficients used for the calculation were determined from experimental studies of atmospheric conditions in 1968, 1969 and 1971 [Tractebel, 2010].

[10] TBq means TerraBecquerel; GBq means GigaBecquerel
1 Tbq = 1000 GBq = 10^{9} Bq

In addition to dispersion, followed by inhalation of radionuclides and direct radiation, radionuclides can also precipitate on soil and contribute to direct radiation as well as ingestion through contaminated foods. Deposition on the soil was studied in dry weather and in case of precipitation. For dry deposition, a deposition rate was experimentally determined for each unit. For deposition by precipitation, an deposition rate for the entire site was determined and a correction for wind speed is applied [Tractebel, 2010].

To determine the impact of the discharged radionuclides, the committed effective dose (total incurred dose over a 50-year period from a single ingestion) is calculated annually from atmospheric dispersion models and absorption models based on the United States Nuclear Regulatory Commission calculation method [NRC, 1977]. Here, the dose contribution of the following scenarios is calculated:

- Direct exposure to a cloud of noble gases and
- Contamination due to discharges of iodine, aerosols, gaseous tritium and ^{14}C through:
  - Inhalation of air;
  - Exposure of the body to deposits on the ground and
  - Exposure through ingestion of contaminated foods (milk, meat, and plant foods).

The dose is calculated for six different age categories (<1 year, 1-2 years, 2-7 years, 7-12 years, 12-17 years and >17 years) as published by the International Commission on Radiological Protection (ICRP) [ICRP, 1995] based on typical consumption values derived from NRC Regulatory Guide 1.109 [NRC, 1977]. This methodology has been adapted by FANC to the Belgian context and documented in Méthodes et hypothèses relatives au calcul de doses à la population dues aux rejets de routine pour les établissement nucléaires de classe I en Belgique [FANC, 2013a].

The calculated dose is tested annually against the limit values for the different age categories (Table 3-10), which were calculated by performing a similar calculation on the licensed discharge limits of KCD [Tractebel, 2014a].

Table 3-10 Committed effective dose due to atmospheric discharges by KCD related to discharge limits.

	Committed effective dose resulting from licensed discharges of KCD [mSv/yr]					
	<1 year	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**>17 years**
Gaseous discharges	0.13	0.17	0.14	0.12	0.13	0.12

In addition to the direct comparison of gaseous discharges, the committed effective dose due to atmospheric discharges is combined with the committed effective dose due to liquid discharges (§ 3.4.4) and the effective dose due to direct radiation (§ 3.4.1). This total dose to a member of the population as a result of the operation of KCD is then tested against the dose limit of 1 mSv per year from the ARBIS [ARBIS]. The latter equation is described for the total dose (§ 3.4.8).

In order to detect abnormal radioactive contamination of the food chain, moss, grass and soil samples are taken annually on behalf of Electrabel and analyzed in a radioanalytical laboratory for the presence of radionuclides using both γ-spectrometry and specialized methods for the detection of ^{3}H and ^{14}C. Samples of each material (moss, grass, and soil) are taken from two locations around KCD where the highest deposition is expected. In addition, a reference sample is taken 20 km from KCD in the least common wind direction (Figure 3-20).

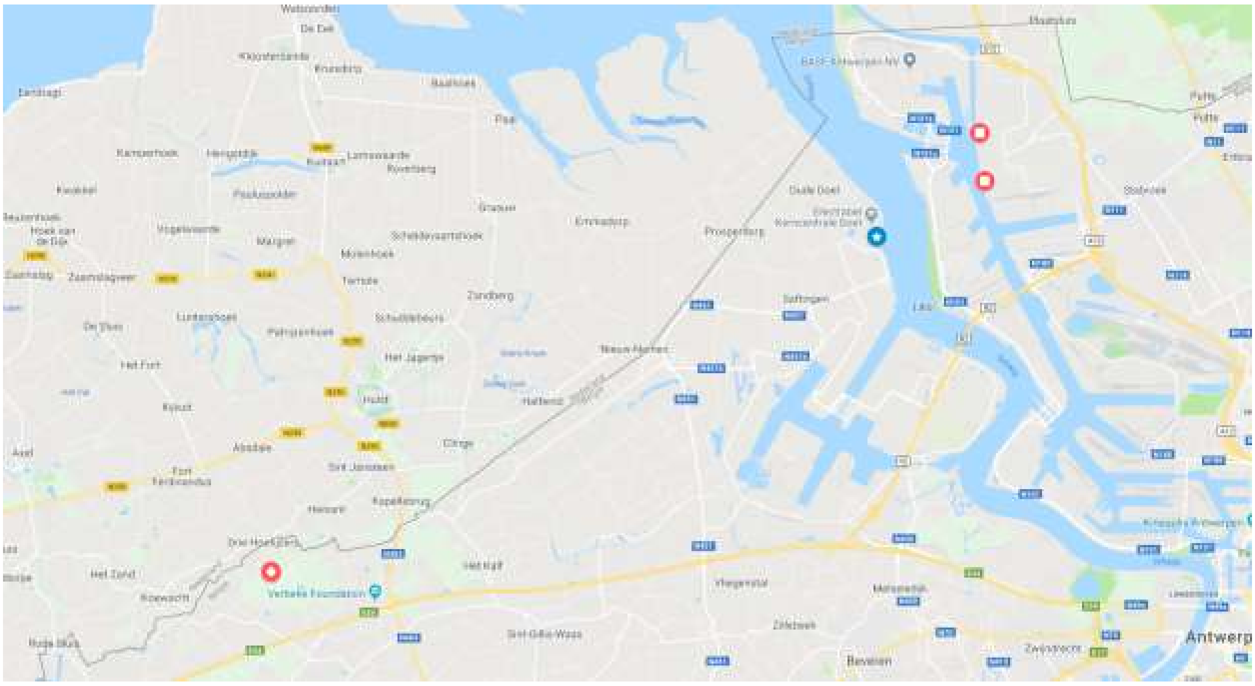

Figure 3-20 Location of grass, moss and soil sample sites. In Belgium, the wind predominantly comes from the southwest[11].

3.4.3.2 Baseline situation

The annually reported activity which has been discharged to the atmosphere is shown in Table 3-11 [Electrabel, 2013][Electrabel, 2014][Electrabel, 2015a]. The discharged activities are shown for both the entire site (KCD-1, KCD-2, KCD-3, KCD-4 and WAB) and specifically for KCD-1 and KCD-2. Most of the gaseous activity is discharged directly from the different units, only a fraction of the discharged activity comes from the water and waste treatment building (WAB building), of which it can be assumed that 50% is allocated to the operation of KCD-1 and KCD-2 [Tractebel, 2019c]. The total discharged activity($A_{KCD1\&2}$) was calculated by adding the activity directly discharged from the two units (A_{KCD1} en A_{KCD2}) to 50% of the total activity discharged by the WAB (A_{WAB}):

$$A_{\mathrm{KCD1\&2}} = A_{\mathrm{KCD1}} + A_{\mathrm{KCD2}} + \frac{2}{4} \cdot A_{\mathrm{WAB}}$$

The total activity discharged from both the entire site (KCD-1, KCD-2, KCD-3, KCD-4 and WAB) as well as the calculated activity discharged from KCD-1 and KCD-2 is shown in Table 3-11.

[11] https://www.meteo.be/nl/unpublish/algemeen-klimaat-belgie/parameters (visited on: 16 January 2020)

Table 3-11 Discharged activity from aerosols, iodine-131, noble gases and tritium in the atmosphere over the years 2012 - 2014

	Aerosols [GBq]		Iodine-131 [GBq]		Noble gases [TBq]		Tritium [TBq]	
Year	**KCD-1&2**	**KCD**	**KCD-1&2**	**KCD**	**KCD-1&2**	**KCD**	**KCD-1&2**	**KCD**
2012	0.0585	0.0844	0.0174	0.0362	24.8	35.8	2.62	3.25
2013	0.0604	0.0841	0.0110	0.0320	18.7	29.2	1.58	2.39
2014	0.0598	0.0887	0.0190	0.0317	19.9	30.1	1.79	2.65
Discharge limit	74	148	7.4	14.8	1 480	2 960	-	88.8

Most of the discharged activity comes from noble gases (including various isotopes of xenon and krypton) followed by tritium (^3H). Nevertheless, all activities discharged, including iodine-131 and aerosols, are well below the licensed discharge limits. However, the data does show a slight spread between different years, which is caused by various factors such as production time and works.

Based on the discharge data, the committed effective dose was calculated for six different age groups. The results for the annual dose are summarized in Table 3-12 [Tractebel, 2014][Tractebel, 2014a][Tractebel, 2015a]. The calculations show that the committed effective dose is also well below the committed effective dose based on the licensed discharge limits. Because the committed effective dose is calculated on the basis of the discharged activity, it shows a similar distribution.

Table 3-12 Overview of the annual committed effective dose per age category, over the years 2012-2014 due to atmospheric discharges of KCD vs. committed effective dose based on licensed discharge limits

	Committed effective dose due to atmospheric discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
2012	0.0060	0.020	0.013	0.011	0.0099	0.0098
2013	0.0056	0.019	0.012	0.010	0.0097	0.0094
2014	0.0058	0.019	0.013	0.010	0.0099	0.0094
Based on license limits	0.13	0.17	0.14	0.12	0.13	0.12

For all age groups, carbon-14 (^{14}C) makes by far the largest contribution to the committed effective dose, as shown graphically in Figure 3-21.Figure 3-21 However, the discharged carbon-14 activity is estimated based on technical literature from similar plants [Schwibach, 1978] due to the lack of measurement data at KCD. This has been approved by FANC [Electrabel, 1981]. Both aerosols and iodine-131 make a very limited (≤ 1%) contribution to the committed effective dose.

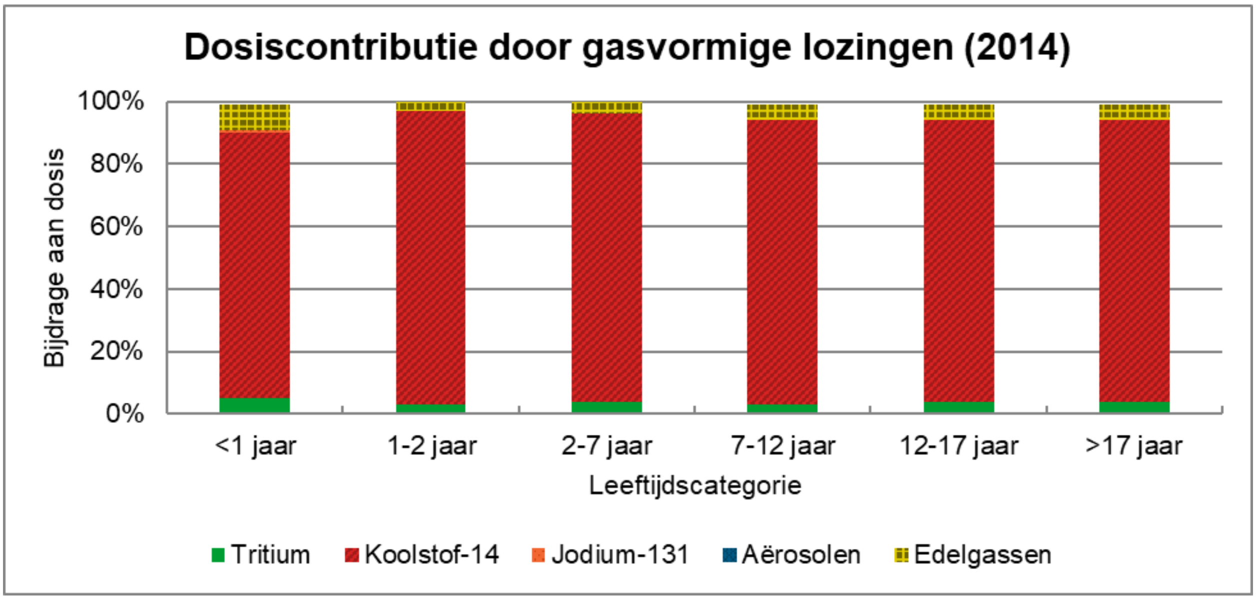

Figure 3-21 Contribution of different types of radionuclides to the committed effective dose due to atmospheric discharges in 2014.

Based on Electrabel's internal monitoring program with the help of SCK-CEN no radionuclides were found in significantly measurable concentrations, with the exception of ^{14}C and ^{137}Cs. The measured activity concentrations for ^{137}Cs in the different samples taken in the vicinity of KCD are shown in Table 3-13. The different samples all show significantly measurable ^{137}Cs activity, both around KCD and in the reference sample. The reference sample is taken approximately 20 km from KCD in the least common wind direction. Although ^{137}Cs is found almost everywhere as a result of the above-ground nuclear weapons explosions and the Chernobyl accident [FANC, 2018], in one of the samples around KCD a clearly increased activity was found compared to the reference sample, both in the moss and in the soil. Nevertheless, based on Electrabel's internal monitoring program, the radionuclide concentrations of the samples measured are very low and confirm that KCD's radiological liquid and atmospheric discharges have no significant measurable impact on the human population (see also § 3.4.3.5).

Recent studies, performed by the IAEA in the MODARIA II program, have shown that if regular discharges have a negligible radiological impact on humans, this implies that there is then also no harmful impact on flora and fauna [Tractebel, 2020c]. A further analysis of effects on flora and fauna therefore has no added value in the context of the Project and Zero Alternative. The results of the radiological surveillance program, which analyzed various flora and fauna samples, confirm that the Doel nuclear power plant has no measurable radiological impact on the atmosphere (see § 3.4.4.5).

The activity concentration of ^{14}C in moss and grass around KCD matches the concentration in the reference sample as well as the average naturally occurring activity concentration of ^{14}C in living organisms (0.227 Bq/g) [Chopin, 2013]. No significantly measurable ^{14}C activity was found in the soil samples.

Table 3-13 Activity concentration of ^{137}Cs in samples analyzed in the vicinity of KCD (2014).

	Moss [Bq/kg]	Grass [Bq/kg]	Soil [Bq/kg]
Sample-1	3.41 ± 0.54	< 1.2	7.4 ± 1.0
Sample-2	1.31 ± 0.38	< 1.8	1.73 ± 0.36
Reference Sample	0.29 ± 0.23	< 1.0	0.97 ± 0.33

3.4.3.3 Impact assessment

The potential impacts of gaseous discharges on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  It is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): regular operation after implementation of the LTO measures;
- Zero alternative, the Project is not completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the baseline situation (2012-2014) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[12].

3.4.3.3.1 Operational phase of the Project between 2015 and 2018

During the period 2015-2018, the LTO measures will be implemented and this is referred to within this Project as the "operational phase of the Project between 2015 and 2018." During this phase, not only will the LTO measures be implemented but the units will also be operated similar to the baseline situation.

Depending on the type of work, the LTO measures can be carried out during regular operations or an outage. In particular, the technical LTO measures can only be carried out during an outage to ensure the continuous safety of both the plant and the employees.

Although many activities are performed in addition to regular operations, the radioactive gaseous discharges during the Project's operational phase between 2015 and 2018 are expected to be similar to the baseline situation.

Given the timing of this study, the radioactive gaseous discharges during the Project's operational phase between 2015 and 2018 are already known. During this period, gases based on residual activity are released to the environment in a controlled manner via iodine and aerosol filters in accordance with the

[12]For further information about this assumption, see § 1.1.3

current permit. The activity discharged to the atmosphere over the years 2015 - 2018 is shown in Table 3-14.

Table 3-14 Discharged activity from aerosols, iodine-131, noble gases and tritium in the atmosphere over the years 2015-2018

	Aerosols [GBq][10]		Iodine-131 [GBq]		Noble gases [TBq]		Tritium [TBq]	
Year	**KCD-1&2**	**KCD**	**KCD-1&2**	**KCD**	**KCD-1&2**	**KCD**	**KCD-1&2**	**KCD**
Baseline situation (2012-2014)	0.0596	0.0857	0.0158	0.0333	21.2	31.7	2.00	2.76
2015	0.0668	0.0928	0.0324	0.0568	46.3	56.3	2.46	3.31
2016	0.0620	0.0841	0.0141	0.0265	37.9	48.2	3.57	4.45
2017	0.0447	0.0592	0.0037	0.0063	17.6	27.4	1.32	2.17
2018	0.0299	0.0412	0.0202	0.0231	45.5	55.1	2.69	3.64
Discharge limit	74	148	7.4	14.8	1480	2960	-	88.8

Especially in 2015, an increase in the total discharged activity of noble gases from KCD-1 and KCD-2 was observed. This increase in reported noble gas activity in 2015 is attributable to additional activity during the prolonged shutdown of KCD-1. The increase in iodine discharges in 2015 is attributable to a greater number of filter tests conducted [Electrabel, 2016]. The increase in discharged tritium activity in 2016 is due to incorrect sampling which resulted in a conservative value (strong overestimate) being reported [Electrabel, 2017]. Despite the increases, the discharged activity each year is well below the permit limit. The other discharged activities are at the same level as in the baseline situation while the discharged activity in 2018 is well below the baseline situation.

Based on the discharge data, the committed effective dose was calculated for six different age groups. The results for atmospheric discharges are summarized in Table 3-15 [Tractebel, 2019a] [Tractebel, 2017] [Tractebel, 2018] [Tractebel, 2019]. The calculations show that the effective dose is also well below the licensed limit. Because the committed effective dose is calculated on the basis of the discharged activity, it shows a similar distribution. Because the largest contribution to the committed effective dose is the discharge of ^{14}C and noble gases contribute about 10% (Figure 3-21) , the impact of the increased discharge of noble gases in 2015 is negligible for the committed effective dose.

Table 3-15 Overview of the annual committed effective dose per age category, over the years 2015-2018 due to gaseous discharges of KCD vs. committed effective dose based on licensed discharge limits

	Committed effective dose due to atmospheric discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
2015	0.0064	0.020	0.013	0.011	0.010	0.0099
2016	0.0063	0.020	0.013	0.011	0.010	0.010
2017	0.0057	0.019	0.013	0.010	0.0097	0.0092
2018	0.0063	0.020	0.013	0.011	0.010	0.010
Based on license limits	0.13	0.17	0.14	0.12	0.13	0.12

Both the discharged activity and the committed effective dose due to gaseous discharges originating from both KCD-1 and KCD-2 and from the entire site during the Project's operational phase between 2015 and 2018 do not deviate from the baseline situation (2012-2014), as expected. As a result, the Project's operational phase between 2015 and 2018 has a negligible environmental impact.

3.4.3.3.2 Operational phase in the future situation (period 2019 - 2025)

During the period 2019-2025, KCD-1 and KCD-2 will continue to operate and this period within this Project is referred to as the "operational phase in future situation (period 2019 - 2025)". Figure 3-22 shows a graphical representation of the expected discharged gaseous discharges from KCD, for both the Project and the Zero Alternative. It is expected that the total discharged gaseous activity in this phase will not change compared to the baseline situation. This expectation is based on the reported total of noble gases, aerosols, iodine and tritium discharged during the baseline situation (2012-2014) and measurement data from the period 2015-2018. The annual discharged activity is well within the discharge limit for the entire site.

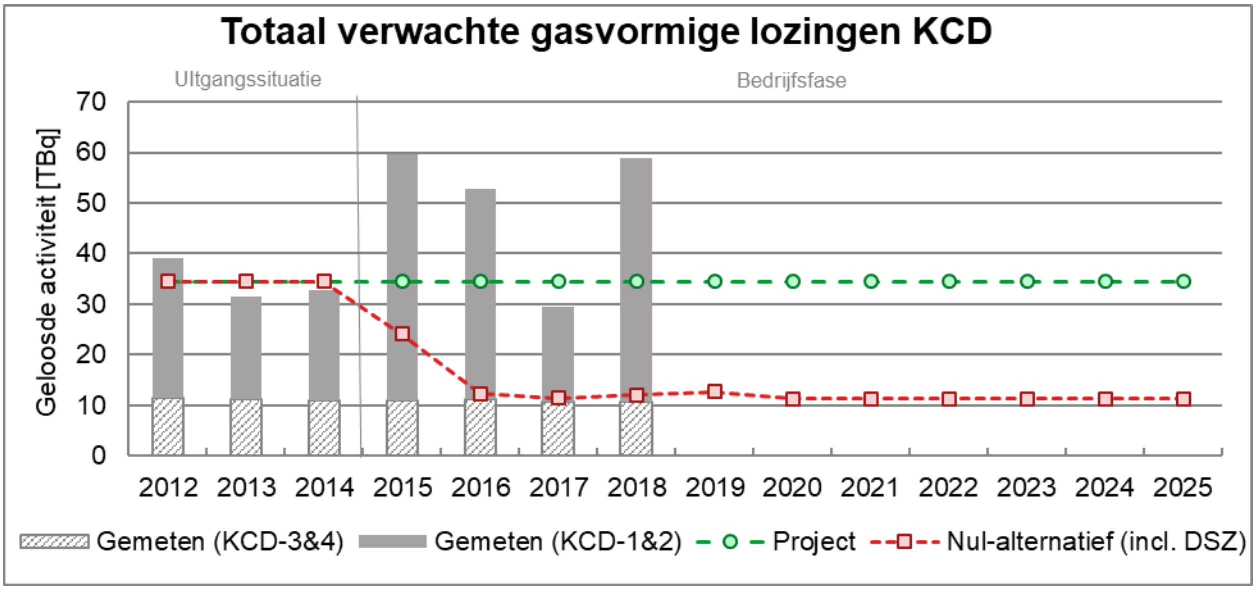

Figure 3-22 Expected gaseous discharged activity, both for the Project and the Zero alternative relative to available measurement results

As the expected total annual activity discharged after the start of the LTO Project will not deviate from the baseline situation, the committed effective dose resulting from the operation of KCD will not deviate from the baseline situation either, which is summarized in Table 3-16. This table shows the expected annual committed effective dose for the Project (LTO) by age group as the average over the years 2012-2014, as listed in Table 3-12.

Table 3-16 Expected annual committed effective dose from atmospheric discharge during operation of KCD due to the Project

	Committed effective dose as a result of atmospheric discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
Project (LTO)	0.0058	0.019	0.013	0.011	0.0098	0.0095
Based on license limits	0.13	0.17	0.14	0.12	0,13	0.12

The committed effective dose due to gaseous discharges is well below the dose limit of 1 mSv per year, a dose which is internationally considered to be the dose at which no significant effects will occur [IAEA, 2014]. The gaseous discharges contribute in part to the total dose which a member of the population receives at most as a result of the operation of KCD. The total dose is described in § 3.4.8.

Since the amount of discharged activity during the regular operation after implementation of the LTO measures is expected to be at the same level as the baseline situation, which also means that the committed effective dose for a member of the population due to atmospheric discharges will not increase, the atmospheric discharges during the operational phase in future situation (period 2019 - 2025) will not have a significant impact on the environment.

Cumulative effect of the Project

The expected cumulative dose due to this Project can be seen as the difference between the committed effective dose that would occur in the event that the Project does not proceed (and only KCD-3 and KCD-4 are operated) and the committed dose that would occur in the event of the Project (and so KCD-1 through KCD-4 are operated).

The expected cumulative dose due to this Project was thus calculated by subtracting the committed effective dose for the entire site under the Zero Alternative (0.0064 mSv/yr, Table 3-18) from the total annual dose due to this Project (0.0095 mSv/yr, Table 3-16). The remaining annual dose (0.0032 mSv/yr) is the dose due to the operation of KCD-1 and KCD-2. By multiplying this dose by the intended operating period, the total cumulative dose due to this Project can be obtained (Table 3-17).

The expected cumulative dose for an adult (>17 years) due to the LTO of KCD-1 and KCD-2 is 0.035 mSv. Although the highest committed effective dose due to gaseous discharges is incurred by children 1-2 years of age, the LTO covers a longer period (10 years) and children will fall into at least 2 or more age classes during the LTO Project. The highest possible cumulative dose for children is 0.044 mSv (Table 3-17).

Table 3-17 Expected committed effective dose due to the LTO of KCD-1 and KCD-2 from gaseous discharges

	Adult [mSv]	**Child [mSv]**

Cumulative committed effective dose resulting from the Project	0.035	0.044

As an illustration, the average dose for one transatlantic flight is about 0.040 to 0.050 mSv, similar to the maximum contribution from this Project due to gaseous discharges. The dose is also much lower than the average background dose in Belgium (39.81 mSv per 10 years) [FANC, 2018] which leads to the conclusion that for the person most exposed to dose, the cumulative dose due to this Project is very low.

Because the discharged activity and committed effective dose due to gaseous discharges during regular operation after implementation of LTO measures is not expected to deviate from the baseline situation, these atmospheric discharges will not have a significant impact on the environment.

3.4.3.3.3 Zero alternative

If no LTO takes place, both KCD-1 and KCD-2 will be discontinued. Therefore, under the Zero Alternative, no discharge of activity to the atmosphere will occur as a result of the operation of KCD-1 and KCD-2.

The committed effective dose due to the operation of KCD, without KCD-1 and KCD-2, can be compared to the baseline situation of the entire site from which the dose contribution due to KCD-1 and KCD-2 has been subtracted. The annual committed effective dose due to gaseous discharges from the operation of KCD-3 and KCD-4 only is shown in Table 3-18. Figure 3-22 includes the expected gaseous discharges during POP as part of the Zero Alternative.

Table 3-18 Expected annual committed effective dose due to atmospheric discharges during operation of KCD due to the Zero Alternative(Excluding POP KCD-1 and KCD-2)

	Committed effective dose due to atmospheric discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
Zero alternative	0.0038	0.013	0.0085	0.0070	0.0066	0.0064

Post Operational Phase of KCD-1 and KCD-2

After the shutdown, the reactor cores and the fuel basin will still need to be cooled, generating gaseous discharges which, after passing through several filters, will be discharged. Most gaseous emissions are expected during POP phase 1 due to, among other things, the opening of the primary circuit. In addition, a limited number of gaseous discharges are expected during the remaining POP phases. All gaseous radionuclides are collected in the Gaseous Waste circuit (GW). In several filter stages, gaseous radionuclides will be trapped and filtered air will be released through the ventilation shaft.

In preparation for the POP, Electrabel has estimated how much gaseous activity will be released during the POP. This estimate was made on the basis of the POP work that has taken place at German nuclear power plants during the last 10 years. It has been assumed by Electrabel that the gaseous discharges will follow a similar trend as the gaseous discharges from these German nuclear power plants. Based on this estimate, the total expected gaseous discharges during POP for KCD-1 and KCD-2 were calculated. The results are shown in Figure 3-23. The following time schedule was used for this purpose (see paragraph 1.1.3 for the work carried out in the various phases):

- POP phase 1 takes place in the 1st year of the POP period;
- POP phase 2 will take place after the 1st year of the POP period;
- POP phase 3 will take place during the 2nd, 3rd and 4th years of the POP period;
- POP phase 4 will take place in the 5th year of the POP period.

It should be noted that the type and amount of gaseous discharges depend on the work being performed at any given time. Therefore, the schedule of KCD-1 and KCD-2 may differ somewhat from the planning of the considered German nuclear power plants, which means that not all similar works will be carried out at the same time. As a result, the trend of decreasing gaseous discharges may fluctuate somewhat.

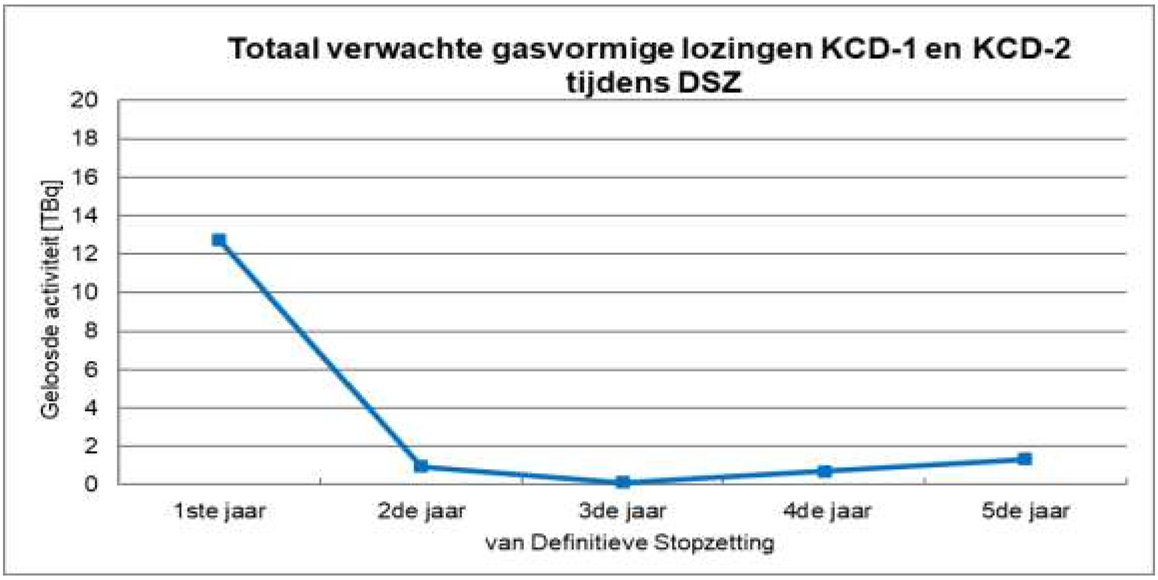

Figure 3-23 Total expected gaseous discharges due to works at KCD-1 and KCD-2 during the POP.

The duration of the Post Operational Phase (POP) and associated work will not differ between the Project and the Zero Alternative. As a result, the discharged activity and committed effective dose during POP will not differ between the two scenarios. However, in the case of the Project, the phase of POP will start only 10 years later.

3.4.3.4 Cross-border effects

The gaseous discharges are discharged into the atmosphere and carried and diluted by the wind. Depending on the wind, the discharged radionuclides reach the border with one or more of the surrounding countries.

Dose effects at the Dutch border

Of all the national borders, the Dutch border is located closest to KCD; approximately 3 km, see Figure 3-23.

Figure 3-24 Location of KCD in relation to the Belgian-Dutch border and measuring points

Based on the atmospheric discharges of the whole KCD and of KCD-1 and KCD-2 in 2014, the committed effective dose was calculated at the nearby Dutch border zone at about 3 km from KCD-1 and KCD-2 in the northwest direction for six different age categories using a method accepted by FANC. The results for the annual committed dose are summarized in Table 3-19 and Table 3-20, respectively [Tractebel, 2020b]. The calculations for the year 2014 show that the committed effective dose is well below the committed effective dose based on the licensed discharge limits and thus well below the limit of 1 mSv per year. The gaseous discharges do not vary over the years in the baseline situation to such an extent that this would cause the committed effective dose to vary significantly at the Dutch border.

Table 3-19 Committed effective dose at the Dutch border due to atmospheric discharges by all of KCD in 2014

	Committed effective dose due to atmospheric discharges at KCD [mSv/yr]					
	<1 year	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**>17 years**
2014	0.00075	0.0024	0.0016	0.0013	0.0012	0.0012
Based on license limits	0.016	0.018	0.016	0.015	0.0150	0.015

Table 3-20 Committed effective dose at the Dutch border due to atmospheric discharges by KCD-1 and KCD-2 in 2014

	Committed effective dose due to atmospheric discharges by KCD-1 and KDC-2 [mSv/yr]					
	<1 year	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**>17 years**
2014	0.00026	0.00076	0.00052	0.00042	0.00042	0.00040
Based on license limits	0.0075	0.0086	0.0076	0.0068	0.0071	0.0067

The Dutch Decree of 23 October 2017, establishing rules for the protection of individuals against the dangers of exposure to ionizing radiation, Article 9.2.1 states that the maximum dose for a member of the Dutch population resulting from the operation of a nuclear facility may not exceed 0.1 mSv per year. Although this is the Dutch dose limit for gaseous and liquid discharges as well as direct radiation, the dose due to gaseous discharges from the LTO of KCD-1 and KCD-2, as described in this section, is well below this limit. The impact of the entire Project, including liquid discharges and direct radiation is described in § 3.4.8.

Dose effects at the border with other surrounding countries

For the other surrounding countries, France, Germany, Luxembourg and the United Kingdom, the committed effective dose was also calculated based on the distances from the respective country borders to KCD. These national borders are located at significantly greater distances from KCD than the Dutch border, i.e., approximately 97 km, 117 km, 177 km, and 195 km, respectively. Calculations according to the diffusion models commonly used for this purpose, show that the committed effective dose at the borders with France, Germany, Luxembourg and the United Kingdom is significantly lower and thus also remains well below the limit of 1 mSv per year [Tractebel, 2020b]. The result of these calculations is shown in Table 3-21 for KCD-1 and KCD-2 and in Table 3-22 for KCD

Table 3-21 Committed effective dose due to atmospheric discharges by KCD-1 and KCD-2 based on the discharge limits for land borders with France, Germany, Luxembourg and the United Kingdom.

	Committed effective dose due to atmospheric discharges by KCD-1 and KCD-2 [mSv/yr]					
	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
France	0.00078	0.00089	0.00079	0.00071	0.00074	0.00070
Germany	0.00069	0.00079	0.00070	0.00063	0.00066	0.00062
Luxembourg	0.00053	0.00061	0.00054	0.00048	0.00051	0.00049
United Kingdom	0.00050	0.00057	0.00051	0.00046	0.00048	0.00045

Table 3-22 Committed effective dose due to atmospheric discharges by KCD based on the licensed limits for the borders with France, Germany, Luxembourg and the United Kingdom.

	Committed effective dose due to atmospheric discharges at KCD [mSv/yr]					
	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
France	0.0011	0.0013	0.0011	0.0097	0.0010	0.00096
Germany	0.00097	0.0011	0.00098	0.00086	0.00091	0.00085
Luxembourg	0.00075	0.00087	0.00075	0.00066	0.00070	0.00065
United Kingdom	0.00070	0.00082	0.00071	0.000062	0.00066	0.00061

3.4.3.5 Monitoring

The radiological surveillance program on the Belgian territory is carried out periodically by FANC. Measurements are performed, especially for the areas near the nuclear sites. In this way it is possible to evaluate whether the quality of the environment in terms of radioactivity remains of sufficient quality. To monitor radioactive substances released into the atmosphere from gaseous discharges, the following samples are periodically performed and analyzed:

- ambient air (aerosols in the atmosphere, gases);
- rainwater (precipitation of aerosols and gases in the atmosphere);
- soil (atmospheric deposition);
- grass (atmospheric deposition, transmission of radioactivity via the roots from the soil);
- milk (transmission of radioactivity from the feed to the cattle).

This is done at various distances from a nuclear site. Currently, for radiological surveillance on Belgian territory, more than 4,660 annual samplings are carried out, on which 28,000 analyses of alpha, beta, and gamma radioactivity are performed.

The Doel site is located on the Scheldt, which is part of the Scheldt and Nete Basin. More than 1,230 samples are taken annually in the entire basin on which more than 3,730 radioactivity measurements are made. The radiological surveillance program of the Scheldt Basin in the vicinity of the Doel site is shown in Table 3-23.

Table 3-23 Radiological monitoring program of the Scheldt and Nete basins FANC, 2019a]

Compartment	Type of measurement	Frequency of sampling
Atmosphere		
Dust particles	γ spectrometry: ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb	Every 4 weeks
	Total β spectrometry (on paper filters, after 5 days of decay)	Daily
Surface deposition (bins)	γ spectrometry (untreated water): ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb, ^{131}I	Every 4 weeks
	Total β spectrometry, α total, ^{3}H, ^{90}Sr (filtered water)	Every 4 weeks
	Total β spectrometry, α total (filter precipitation)	Every 4 weeks
Soil		
Perennial pasture (colluvium-0.125 m² at ~15 cm depth + short-cut grass)	γ spectrometry: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra, ^{228}Th	Annually

In FANC's synthesis reports [FANC,2013] [FANC,2014] [FANC,2015] [FANC,2016] [FANC,2017] [FANC,2018a] [FANC,2019a] FANC concludes that the Doel nuclear power plant has no measurable radiological impact on the atmosphere.

3.4.3.6 Mitigating measures

Based on the available data, the gaseous discharges from KCD-1 and KCD-2 have no significant impact on the environment and no mitigation measures are required.

3.4.3.7 Knowledge gaps

The available knowledge is therefore sufficient to determine the effects of the gaseous radioactive discharges of this intention. Despite the fact that exact data are not always available on which of the four units sends the discharges to the WAB. For the current assessment, 50% of the discharged atmospheric activity originating from the WAB was assumed to be due to the operation of KCD-1 and KCD-2, and therefore that portion was allocated to them [Tractebel, 2019c].

3.4.3.8 Conclusions

As a result of the Project (LTO of KCD-1 and KCD-2), gaseous discharges will be made for 10 more years. The LTO of KCD-1 and KCD-2 will not have a negative impact on the environment compared to the baseline situation because the expected annual discharged activity will be similar to the annual discharged activity before the LTO Project. The committed effective dose which members of the public may potentially incur as a result of gaseous discharges is well below the dose limit and will have no significant impact on the population.

Under the Zero Alternative, the final shutdown of KCD-1 and KCD-2 will result in fewer gaseous radioactive discharges, however, the difference compared with the baseline situation and the Project is negligible.

The operation of KCD has no significant measurable impact on the Dutch territory and the territory of the other countries bordering Belgium so that further cross-border effects due to atmospheric discharges can be excluded.

3.4.4 Radioactive liquid discharges

During the operation of KCD, radioactive substances may end up in the river Scheldt.

The vast majority of the activity is in the so-called primary cooling system, a closed circuit in which cooling water is passed through the core to cool the core after which the heat produced is transferred to steam generators. In steam generators, heat is transferred to the secondary cooling water without direct contact between the primary and secondary cooling water. As a result, all activity will remain in the primary cooling water and the secondary cooling water will not contain increased activity. The cooled primary cooling water can then be reused to cool the core.

The secondary cooling water is converted to steam in the steam generator, which then drives a turbine to generate electricity. Because the secondary cooling water has no direct contact with the primary cooling water at any time, the secondary cooling water will not contain radioactive elements. Nevertheless, the residual heat from the secondary cooling water is transferred to tertiary cooling water, which is eventually discharged into the Scheldt. This double barrier (primary-secondary and secondary-tertiary) prevents radioactivity from being discharged into the Scheldt via the cooling water.

Despite this, the Doel nuclear power plant does discharge radioactivity into the Scheldt. This is mostly process water that is collected within the facility, for example, primary water during works on systems with primary cooling water, water collected through floor drains within the radiologically controlled area or shower or laundry water. To minimize the amount of radioactivity discharged, all potentially contaminated water is collected within the plant and transported through underground galleries to the Water and Waste Treatment Building (WAB Building).

In the WAB, water is collected based on properties and origin and reused where possible [Tractebel, 2010a]. The activity present is removed from the water as much as possible using methods such as evaporation, after which the radioactive concentrates are disposed of as solid radioactive waste. The remaining, almost inactive, condensates are collected in a control tank from where it is finally discharged into the Scheldt.

However, before the condensates are discharged, samples are taken which are analyzed in designated laboratories to determine the residual radioactivity of the condensates, primarily by gamma spectrometry and tritium (^{3}H) analyses. Once it has been determined that any discharge complies with the permit limits, which have been specifically established for KCD based on legal limits and further technical limitations, the condensates are discharged via a single discharge point into the Scheldt. Control measurements are also performed during the discharge. All discharged activity is recorded and continually tested against the current discharge limits [Electrabel, 2013a].

The discharged activity will be carried away via the current of the Scheldt and eventually discharge into the North Sea, although some of the discharged activity will deposit locally. Dilution will cause the activity concentration in the water to decrease rapidly as the distance from the discharge point increases. Nevertheless, the discharge can lead to an committed effective dose (the total dose that a person incurs over a period of at least 50 years as a result of a single intake) for humans as well as flora and fauna. To determine the impact of liquid discharges on the environment, both the total discharged activity as well as the committed effective dose to the population should be examined.

3.4.4.1 Methodology

Before being discharged into the Scheldt, the condensates are sampled and analyzed. Here, both total activity and tritium (^{3}H) are measured. If the measured activity remains below the internal limits, the condensates are discharged into the Scheldt via the discharge point. These limits are shown in Table 3-24. As all liquids that are potentially radioactively contaminated are collected in the water and waste treatment building (WAB building), this limit is valid for the entire site and thus related to the operation of KCD-1, KCD-2, KCD-3, KCD-4 as well as the WAB.

The limit for ^{3}H is higher than the limit for total activity excluding tritium. This difference is due to the fact that ^{3}H is mainly present as tritiated water (HTO or [^{3}H]HO) and therefore cannot be separated from uncontaminated water. Because ^{3}H decays under pure emission of β particles with a relatively low energy (≤ 18.6 keV), ^{3}H has a relatively low dose conversion coefficient
(1,8 10^{-11} Sv Bq^{-1} for the ingestion of water), i.e. ^{3}H has a limited environmental impact compared to most other radionuclides.

The data of liquid discharged radioactivity into the Scheldt for the baseline situation (2014) as well as the previous years (2012-2013) is taken from the annual reports of Electrabel [Electrabel,2013a] [Electrabel, 2014a] [Electrabel, 2015b]. The licensed discharge limits are shown in Table 3-24 [Electrabel, 2013a].

Table 3-24 Licensed activities for discharges of water from KCD

Nuclide	Discharge permit KCD [TBq/12 months]
all (excl. ^{3}H)	1.48
^{3}H	103.6

Along the Scheldt River and the preceding Nete Basin, there are several facilities that discharge liquid discharges containing potential radionuclides into the river water. These nuclides may come from nuclear sites such as SCK-CEN, Belgoprocess, Belgonucleaire and FBFC International in Mol and Dessel. Several non-nuclear sites also potentially discharge radionuclides into the Scheldt, such as hospitals of large agglomerations (e.g. Antwerp) and the former food phosphate factory near Tessenderlo (Figure 3-25). All radionuclides will be strongly diluted and eventually carried away by the current of the Scheldt along KCD into the North Sea. As a result of these installations, several radionuclides are expected to be present in the Scheldt around KCD, such as ^{3}H, ^{7}Be, ^{40}K, ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{99}Tc, ^{103}Ru, ^{106}Ru, ^{110m}Ag, ^{131}I, ^{134}Cs, ^{137}Cs, ^{141}Ce, ^{144}Ce, ^{226}Ra, ^{228}Ra, ^{228}Th, ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Am [FANC, 2015]. It should be noted that in particular the elements naturally present in the soil (^{40}K and to a limited extent ^{226}Ra and ^{228}Th) are responsible for the radioactivity present in the Scheldt [FANC, 2015].

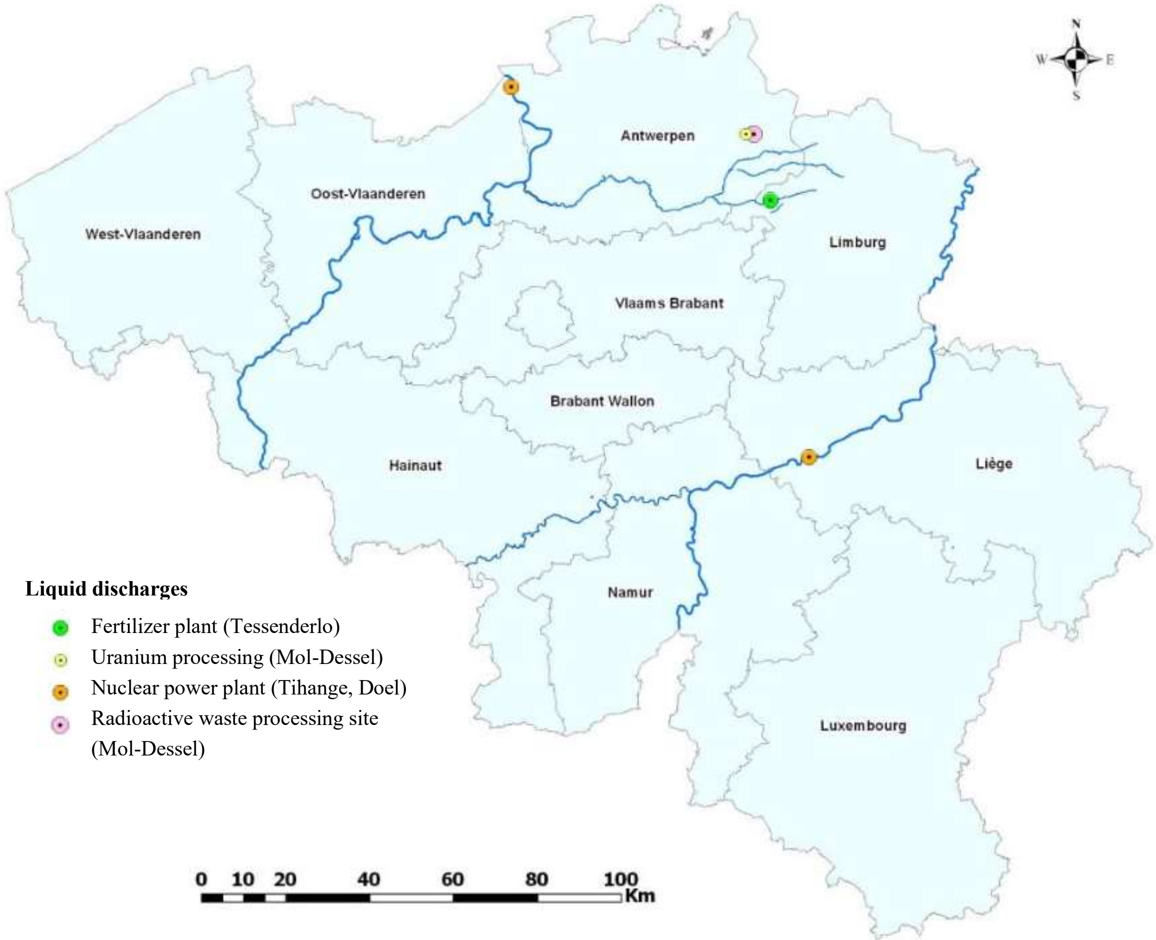

Figure 3-25 Location of nuclear facilities which may discharge radioactive liquid discharges [FANC, 2015].

Although the activity discharged will dilute greatly due to the large volume of water and the flow of the Scheldt, the discharged activity in the Scheldt may result in an effective, but extremely limited, committed dose to members of the population. Different exposure pathways can be considered here:

- Ingestion (internal exposure):
  - Drinking Water;

- Fish;
- Milk and meat from cattle that were contaminated by drinking water and
- Food contaminated by irrigation water;

- External exposure:
  - Professional Shipping;
  - Being present on banks and
  - Present on material coming from dredging activities.

As cattle does not drink water from the Scheldt, milk and meat intake is not considered. As the Scheldt water is not used for irrigation either, due to its high salinity, the ingestion of food contaminated by irrigation water is also not considered [Tractebel, 2015a].

To determine the committed effective dose for these exposure pathways, a guideline prepared by the United States Nuclear Regulatory Commission (US-NRC)(Regulatory guide 1.109) is applied [NRC, 1977]. This is done for six different age categories (<1 year, 1-2 years, 2-7 years, 7-12 years, 12-17 years and >17 years), as published by the International Commission on Radiological Protection (ICRP) [ICRP, 1995]. This methodology has been adapted by FANC to the Belgian context and documented in Méthodes et hypothèses relatives au calcul de doses à la population dues aux rejets de routine pour les établissement nucléaires de classe I en Belgique [FANC, 2013a].

Based on the measured data on the amount of activity discharged, the ingestion of different radionuclides through the various exposure pathways for the age groups can be calculated. For this calculation, a person who is on the banks with the highest activity deposition and ingesting foods with the highest contamination rate throughout the year is assumed. As a result, the calculated dose will be a strong overestimate compared to a realistic dose.

The maximum allowable dose which a member of the public may receive as a result of the operation of a nuclear facility is 1 mSv per year [ARBIS]. However, the committed effective dose to a member of the population from the operation of KCD consists of three components: liquid discharges, atmospheric discharges, and direct radiation. According to the previously mentioned, FANC-approved method, the maximum committed effective dose is calculated based on the liquid discharge limits, which are shown in Table 3-25 [Electrabel, 2015a].

Table 3-25 Committed effective dose due to liquid discharges by KCD related to the discharge limits.

	Committed effective dose resulting from licensed discharges of KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
Liquid discharges	0.008	0.005	0.20	0.18	0.23	0.23

In addition to recording the radioactivity discharged into the Scheldt, an annual sampling and analysis campaign of the environment around the Doel site is carried out on behalf of Electrabel. This involves sampling sediment and fucus (seaweed) from the Scheldt at two locations where the highest activity concentration is expected, approximately 1 km and 6.5 km from the discharge point. For verification, a sample is also taken approximately 50 km upstream (Figure 3-26). The collected samples are processed in a radioanalytical laboratory and analyzed for the presence of radionuclides. The results of these campaigns provide an understanding of the actual absorption of radionuclides into the environment.

Figure3-26 Location of sediment and fucus sampling in the Scheldt River

3.4.4.2 Baseline situation

The annually reported activity which, after treatment in the water and waste treatment building (WAB building), was discharged into the Scheldt is shown in Table 3-26 [Electrabel, 2013a][Electrabel, 2014a][Electrabel, 2015b]. Table 3-26 shows both the total discharged activity from the entire site (KCD-1, KCD-2, KCD-3, KCD-4 and the WAB) and the calculated activity discharged from the operation of KCD-1 and KCD-2. It was assumed that the total discharged activity due to the operation of KCD-1 and KCD-2($A_{\mathrm{KCD1\&2}}$) consists of the sum of the possible activity discharged directly from the units through the secondary cooling water (A_{KCD1} and A_{KCD2}) as well as 1/3rd [Tractebel, 2019d] of the total of the site discharged activity from the WAB (A_{WAB}),which is attributed to KCD-1 and KCD-2:

$$A_{\mathrm{KCD1\&2}} = A_{\mathrm{KCD1}} + A_{\mathrm{KCD2}} + \frac{1}{3} \cdot A_{\mathrm{WAB}}$$

The annual discharged activity varies depending on many factors, such as the work performed and production period, therefore it is not possible to make an accurate prediction of the activity that will be discharged. Despite this, the discharged activities during the baseline situation (2012-2014) are well below the licensed discharge limits.

Table 3-26 Discharged activity of both tritium (^{3}H) and all other nuclides excluding tritium from liquid discharges during 2012-2014

Year	Total (excl. ^{3}H) [GBq]		Tritium [TBq][13]	
	KCD-1&2	KCD	KCD-1&2	KCD
2012	2.02	5.77	15.86	47.57
2013	1.24	3.49	12.20	36.61
2014	0.89	2.44	12.23	36.70
discharge limit	-	1,480	-	103.60

Almost all of the discharged activity consists of tritium, a radionuclide which is virtually impossible to remove and, partly because of this, is considered separately. Although tritium accounts for the majority of the total discharged activity in terms of activity, tritium has a relatively low dose conversion coefficient relative to many other radionuclides. Partly because of this, it is important to monitor other radionuclides in addition to tritium in order to better estimate the actual environmental impact (dose).

Figure 3-27 shows a graphical representation of the discharged activity of various radionuclides in 2014. These data show that, in addition to ^{3}H, mainly activation products (both ^{110m}Ag, ^{58}Co, ^{60}Co, ^{51}Cr and ^{55}Fe) are discharged, although some fission products (incl. ^{106}Ru) have been discharged. For Figure 3-27, the seven radionuclides with the highest activity were selected. It should be noted that the activity (in Bq) is given by multiplying the number of particles(N) by the decay constant(λ): $A=N\cdot\lambda$. Radionuclides with a short half-life, and therefore a high decay constant ($\lambda=\ln(2)/T_{½}$), for an equal number of particles, therefore give a higher activity initially. As a result, Figure 3-27 shows particularly short-lived radionuclides and long-lived radionuclides (e.g. ^{137}Cs), are only discharged with very low activities. As already described for tritium, the activity does not equal the expected environmental impact/dose. The radiological composition of the discharges in other years (2012 and 2013) show a similar composition.

[13] TBq means TerraBecquerel; GBq means GigaBecquerel
1 Tbq = 1000 GBq = 10^{9} Bq

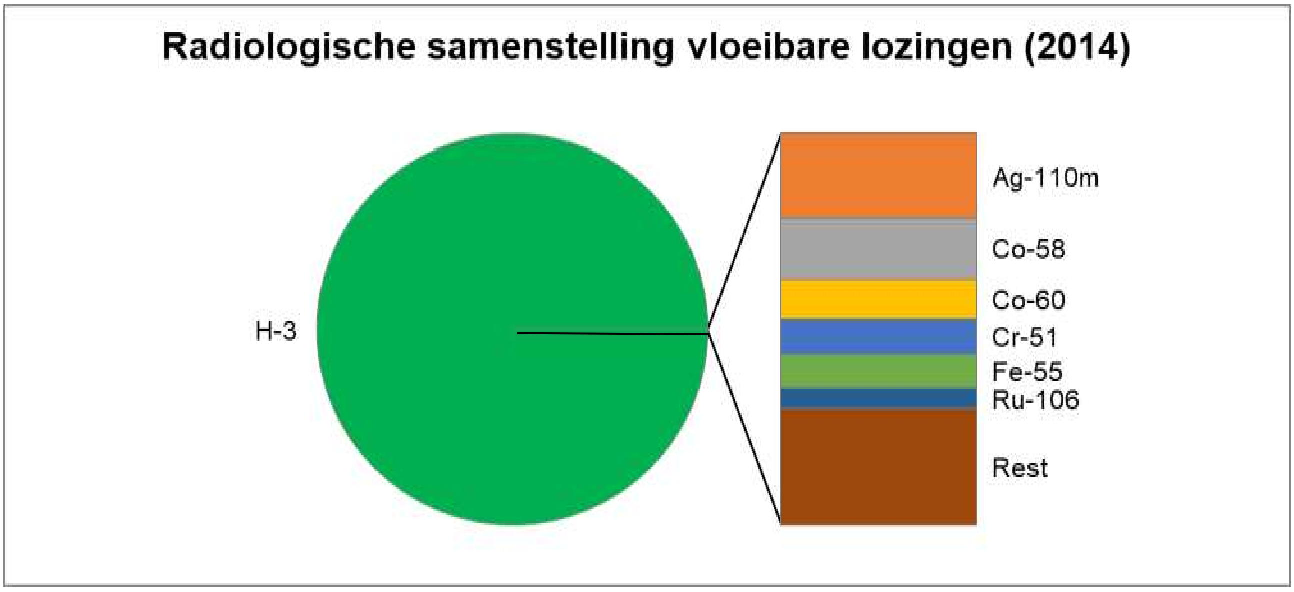

Figure 3-27 Radiological composition of liquid discharges in 2014, based on discharged activity.

Based on the discharge data, the committed effective dose of the entire site for six different age categories is calculated annually, which are summarized in Table 3-27 [Tractebel, 2014][Tractebel, 2014a][Tractebel, 2015a]. The calculations were performed in accordance with the previously mentioned method approved by FANC. For comparison, the licensed limit values calculated from the licensed liquid discharge limits to Table 3-27 have also been added. Like the discharged activity, the committed effective dose shows a spread which depends on many factors, such as the type of work during outages.

Table 3-27 Overview of the annual committed effective dose per age category, due to liquid discharges of KCD vs. committed effective dose based on licensed discharge limits for the period 2012-2014

	Committed effective dose due to liquid discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
2012	0.00061	0.00063	0.0011	0.00093	0.00093	0.0011
2013	0.00046	0.00047	0.00077	0.00067	0.00066	0.00077
2014	0.00046	0.00052	0.00064	0.00052	0.00049	0.00060
Based on license limits	0.008	0.005	0.20	0.18	0.23	0.23

In particular, for young children (< 2 years), ^{3}H has the highest contribution (> 90 %) to the collective dose, while for older children (> 7 years) and adults, β- and γ-emitters make a significant contribution (Figure 3-28). Discharged α-emitting radionuclides do not result in a significant committed dose for the different age categories (maximum 1%).

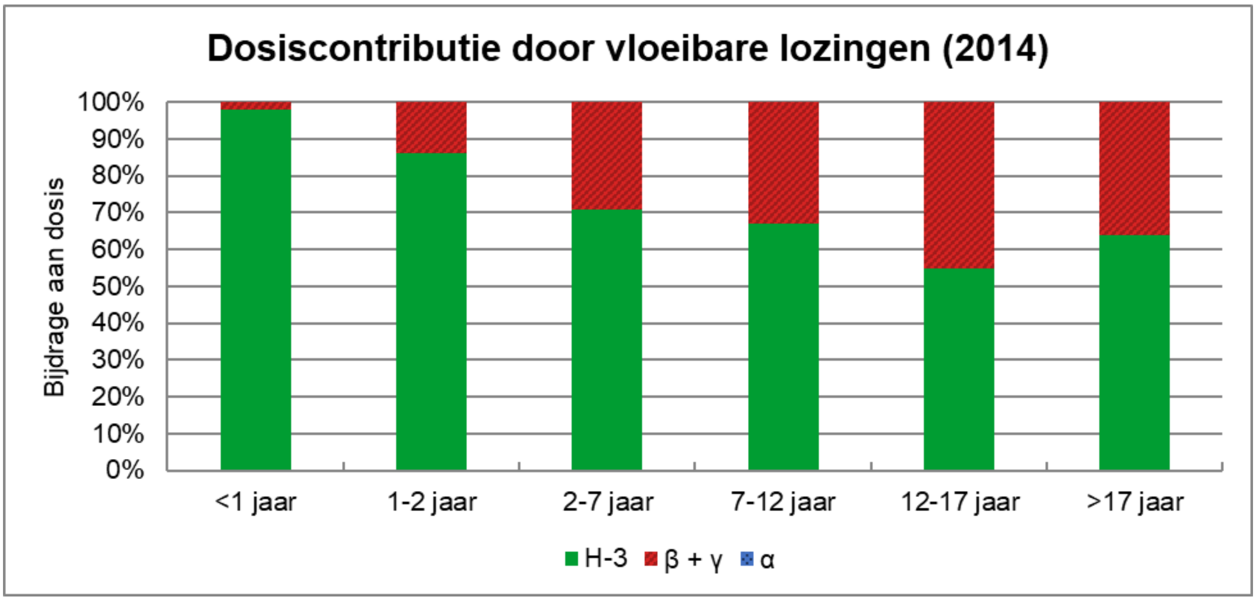

Figure 3-28 Contribution of different types of radionuclides to the committed effective dose due to liquid discharges in 2014.

Based on Electrabel's internal monitoring program, with the help of SCK-CEN, sediment and fucus (seaweed) samples are taken annually for verification in the vicinity of KCD (Figure 3-26). They are analyzed for the presence of ^{60}Co, ^{95}Nb, ^{110m}Ag, ^{131}I, ^{134}Cs and ^{137}Cs, the fucus was also analyzed for the presence of ^{3}H and ^{14}C. In the results of Electrabel's 2014 internal monitoring program, with the exception of ^{14}C (fucus), ^{60}Co (sediment) and ^{137}Cs (sediment and fucus), none of the analyzed radionuclides were detected in the samples analyzed.

In two of the sediment samples, an increase in ^{137}Cs activity was found compared to the detection limit. This includes both a sample from the vicinity of KCD (sediment-2) as well as the reference sample. Because of the small increase in ^{137}Cs activity, the exact origin cannot be determined because ^{137}Cs is still present in the environment due to above-ground nuclear weapons explosions and the Chernobyl accident [FANC, 2018]. Nevertheless, Electrabel's internal monitoring program concludes that the measured activity concentration is very low and consistent with the Belgian surveillance program of radioactive discharges of the KCD and these discharges have no significant measurable impact on the human population (see also § 3.4.4.5).

Recent studies, performed by the IAEA in the MODARIA II program, have shown that if regular discharges have a negligible radiological impact on humans, this implies that there is then also no harmful impact on flora and fauna [Tractebel, 2020c]. A further analysis of effects on flora and fauna therefore has no added value in the context of the Project and Zero Alternative. The results of the radiological surveillance program, which analyzed various flora and fauna samples, confirm that the Doel nuclear power plant has no measurable radiological impact on the Scheldt (see § 3.4.4.5).

In addition to ^{60}Co and ^{137}Cs, ^{14}C was also detected in the fucus, the activity concentration of which corresponds to the natural ^{14}C activity in living organisms [Chopin, 2013]. The sediment was not analyzed for ^{14}C. The results of the analysis of the environmental samples are shown in Table 3-28.

Table 3-28 Results of the sediment and fucus analysis from the vicinity of KCD (2014).

	^{14}C [Bq/g]	^{60}Co [Bq/kg]	^{137}Cs [Bq/kg]
Sediment-1	-	< 1.1	< 1.7
Sediment-2	-	2.5 ± 0.4	7.3 ± 1.2
Sediment-ref	-	< 0.9	3.3 ± 0.6
Fucus-1	0.29 ± 0.05	< 0.35	0.35 ± 0.16
Fucus-2	0.22 ± 0.04	< 0.37	< 0.32
Fucus-ref	0.22 ± 0.03	< 0.43	< 0.53

3.4.4.3 Impact assessment

The potential impacts of liquid discharges on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  It is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): further operation after implementation of the LTO measures.
- Zero alternative, the Project is <u>not</u> completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the period (2012-2014; baseline situation) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[14].

3.4.4.3.1 Operational phase of the Project between 2015 and 2018

The LTO synthesis report contains the integrated action plan to operate KCD-1 and KCD-2 for ten years longer than envisioned in the 2003 Nuclear Phase-Out Act. This action plan was submitted to FANC for review [Electrabel, 2015c]. FANC, together with Bel V, analyzed this plan and that analysis showed that the Project is feasible and the safety of KCD-1 and KCD-2 remains guaranteed during the period of Long Term Operation [FANC, 2015a]. During the period 2015-2018, the measures of the action plan will be implemented and that period is referred to within this Project as the "operational phase of the Project between 2015 and 2018." During this period, KCD-1 and KCD-2 are operated by Electrabel.

Depending on the type of work, the LTO measures can be carried out during regular operations or only during an outage. In particular, the technical LTO measures can only be carried out during an outage to ensure the continuous safety of both the plant and the employees. Because many activities are also carried

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[14] For more information on this assumption, see §1.1.3

out during regular operation, it is expected that the discharges of radionuclides into the Scheldt during the operational phase of the Project between 2015 and 2018 will not deviate significantly from the discharged activity during the baseline situation.

Given the timing of this study, the amount of activity discharged into the Scheldt during the operational phase of the Project between 2015 and 2018 is already known. The discharged activity from both KCD-1 and KCD-2 and the entire site (KCD) during the operational phase of the Project between 2015 and 2018 is shown in Table 3-29 [Electrabel, 2016a] [Electrabel, 2017a] [Electrabel, 2018a] [Electrabel, 2019a]. For both tritium and all radionuclides excluding tritium, the actual discharged activity does not deviate significantly from the average discharged activity during the baseline situation. The data shows a slight spread between years. The fluctuations can be caused by various factors, such as the nature of the work and total production time. The discharged activities are well below the permit limit throughout the period (Table 3-24).

Table 3-29 Discharged activity of both tritium (^{3}H) and all other nuclides excluding tritium from liquid discharges in the operational phase of the Project between 2015 and 2018

	Total (excl. ^{3}H) [GBq]		Tritium [TBq]	
	KCD-1&2	KCD	KCD-1&2	KCD
Baseline situation (2012-2014)	1.39	3.90	13.43	40.29
2015	0.97	2.63	6.80	20.41
2016	1.28	3.76	13.94	41.81
2017	1.52	4.25	12.65	37.93
2018	1.08	3.40	11.71	35.14
Discharge limit	-	1,480	-	103.60

Table 3-30 shows the annual committed effective dose for six different age groups. They were calculated based on the discharged liquid activities [Tractebel, 2017] [Tractebel, 2018] [Tractebel, 2019] [Tractebel, 2019a]. Like the discharged activity, the committed effective dose shows a spread which depends on many factors, such as the type of work during outages on all units.

Table 3-30 Overview of the annual committed effective dose per age category, due to liquid discharges of KCD vs. committed effective dose based on licensed discharge limits for the period 2015-2018

	Committed effective dose due to liquid discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
2015	0.00026	0.00033	0.00046	0.00040	0.00040	0.00046
2016	0.00053	0.00061	0.00086	0.00072	0.00071	0.00084
2017	0.00048	0.00059	0.00084	0.00069	0.00070	0.00082
2018	0.00044	0.00053	0.00074	0.00062	0.00061	0.00072
Based on license limits	0.008	0.005	0.20	0.18	0.23	0.23

Both the discharged activity and the committed effective dose due to liquid discharges originating from both KCD-1 and KCD-2 and from the entire site during the Project's operational phase between 2015 and

2018 do not deviate from the baseline situation (2012-2014), as expected. As a result, the construction of the LTO measures did not have a significant impact on the environment.

3.4.4.3.2 Operational phase in the future situation (period 2019 - 2025)

After the operational phase of the Project between 2015 and 2018, the units (KCD-1 and KCD-2) will continue to be operated. Also during this operation (2019-2025), work will take place during outages and activity will be discharged into the Scheldt.

LTO measures relate reducing the probability and effects of an accident situation. The measures have no effect on the amount of activity discharged during normal operation. Therefore, in principle, there will be no difference between the operation during the baseline situation and the operational phase in the future situation (period 2019 - 2025) and it is expected that the discharged activity will be similar to the discharged activity during the period (2012-2014) of the baseline situation.

The expected annual discharged activity, both for tritium (^3H) and all other nuclides during the operational phase in future situation (period 2019 - 2025) is shown graphically in Figure 3-29

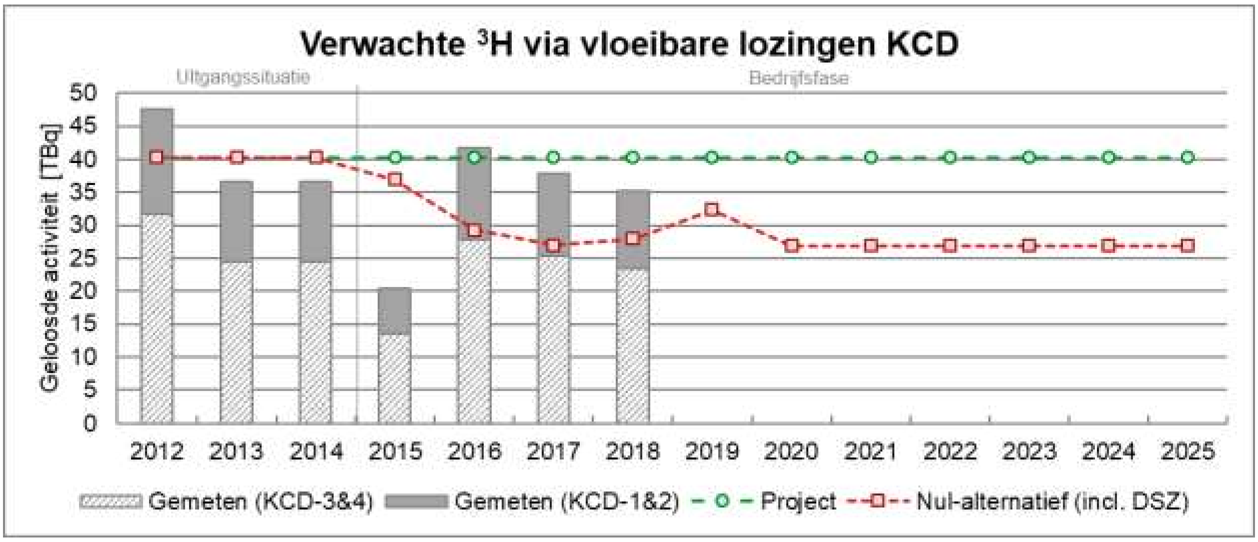

Figure 3-29 Expected ^3H activity discharged into the Scheldt as a result of the operation of KCD, both for the Project and the Zero alternative. The vertical bars show the actual measured activity, where available.

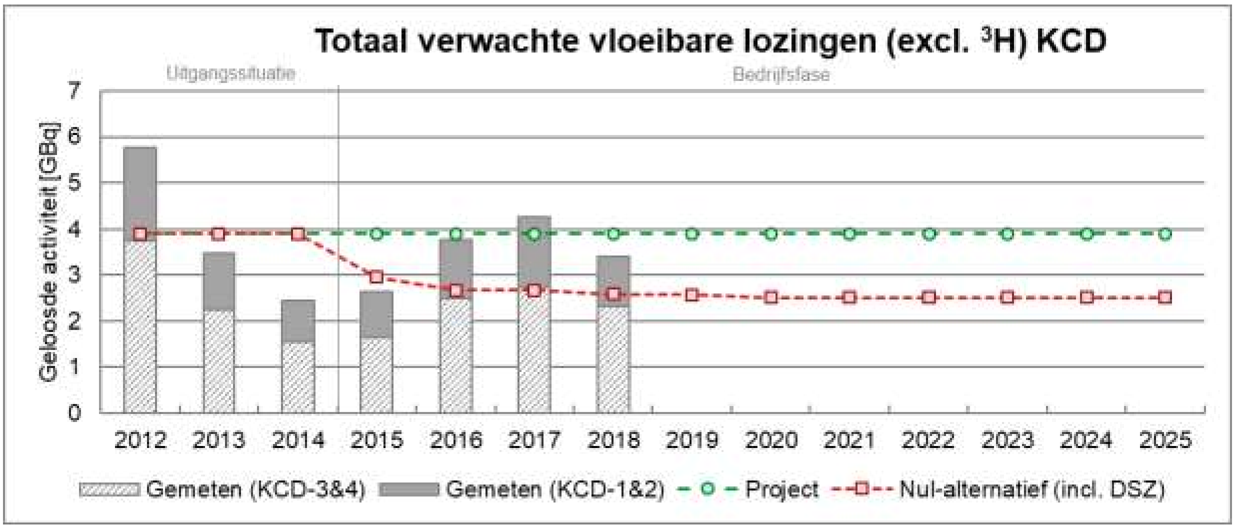

Figure 3-30 Expected activity discharged (excl. ^{3}H) into the Scheldt as a result of the operation of KCD, both for the Project and the Zero alternative. The vertical bars show the actual measured activity, where available.

Because the total annual activity discharged into the Scheldt after implementation of the Project will not deviate from the baseline situation, the committed effective dose due to the operation of KCD will also not deviate from the baseline situation, which is summarized in Table 3-31 (the average of the baseline situation). The committed effective dose due to liquid discharges is well below the dose limit of 1 mSv per year, a dose which is internationally considered to be the dose at which no significant effects will occur [IAEA, 2014]. Liquid discharges contribute in part to the total dose to which a member of the population may be exposed as a result of the operation of KCD. The total dose is described in § 3.4.8.

Table 3-31 Expected annual committed effective dose from liquid discharges during operation of KCD due to the Project

	Committed effective dose due to liquid discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
Project (LTO)	0.00051	0.00054	0.00082	0.00070	0.00068	0.00080
Based on license limits	0.008	0.005	0.20	0.18	0.23	0.23

Cumulative effect of the Project

The expected cumulative dose due to this Project can be seen as the difference between the committed effective dose that would occur in the event that the Project does not proceed (and only KCD-3 and KCD-4 are operated) and the committed dose that would occur in the event of the Project (and so KCD-1 through KCD-4 are operated).

The expected cumulative dose due to this Project was thus calculated by subtracting the committed effective dose for the entire site under the Zero Alternative (0.00053 mSv/yr, Table 3-33) from the total annual dose due to this Project (0.00080 mSv/yr, Table 3-31). Table 3-31 The remaining annual dose (0.00027 mSv/yr) is the dose due to the operation of KCD-1 and KCD-2. By multiplying this dose by the intended operating period, the total cumulative dose due to this Project can be obtained (Table 3-32).

The expected cumulative dose to an adult (>17 years) due to the Project is 0.0031 mSv due to KCD-1 and KCD-2. Although the highest committed effective dose due to liquid discharges is incurred by children 2-7 years of age, the LTO covers a longer period and children will fall into at least 2 or more age classes during the this period. The highest possible cumulative dose for children is 0.0030 mSv due to KCD-1 and KCD-2. It is noted that there is hardly any difference between the expected cumulative dose for adult and the highest expected dose for a child (Table 3-32).

Table 3-32 Expected cumulative committed effective dose due to longer operation of KCD-1 and KCD-2 by liquid discharges

	Adult [mSv]	Child [mSv]
Cumulative committed effective dose resulting from the Project	0.0031	0.0030

This cumulative dose due to liquid discharges is very small and will not result in significant measurable effects. To illustrate, the average dose for one transatlantic flight is approximately 0.040 a 0.050 mSv[15], a simple X-ray of the jaw 9 µSv and a typical CT scan 0.978 mSv [FANC, 2018]. The dose is also much lower than the average background dose in Belgium (43.79 mSv during the Project) [FANC, 2018]. It should be noted that the frequently used risk number of 5.5% probability of cancer per Sv (1,000 mSv or 1,000,000 µSv) [ICRP, 2007] is only valid for higher doses and cannot be used to determine any risks from (very) low doses.

Because the discharged activity and committed effective dose due to liquid discharges during the operation after implementation of LTO measures is not expected to deviate from the baseline situation, these liquid discharges will not have a significant impact on the environment.

3.4.4.3.3 Zero alternative

If no Project takes place, both KCD-1 and KCD-2 will be permanently shut down in 2015. The committed effective dose due to the operation of KCD, without KCD-1 and KCD-2, is compared to the baseline situation of the entire site from which the dose contribution due to KCD-1 and KCD-2 is subtracted, leaving only the routine discharges from KCD-3 and KCD-4. The annual discharged activity into the Scheldt if the Project will not occur is shown graphically in Figure 3-29 (^{3}H) en Figure 3-30 (total excluding ^{3}H). The annual committed effective dose due to liquid discharges from the operation of only KCD-3 and KCD-4, i.e., without KCD-1 and KCD-2, is shown in Table 3-33.

Table 3-33 Expected annual committed effective dose due to liquid discharges during operation of KCD due to the Zero Alternative(Excluding POP KCD-1 and KCD-2)

	Committed effective dose due to liquid discharges at KCD [mSv/yr]					
Age category	**< 1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**> 17 years**
Zero alternative	0.00034	0.00036	0.00054	0.00046	0.00044	0.00053

15 https://www.rivm.nl/stralingsbelasting-in-nederland/invloed-van-menselijk-handelen/vliegverkeer (visited on: 20 February 2020)

Post Operational Phase of KCD-1 and KCD-2

After the shutdown of KCD-1 and KCD-2, the Post Operational Phase will be initiated. Preparations for the dismantling of KCD-1 and KCD-2 are taking place during the period. Liquid radioactive waste is expected to be generated during POP phases 2, 3 and 4. These include:

- Process water used during chemical decontamination;
- Process water from the primary circuit and other circuits in the radiologically controlled area;
- Process water from the fuel basin and associated circuits.

All these flows are captured and processed in the WAB. The activity present is removed from the water as much as possible using methods such as evaporation, after which the radioactive concentrates are disposed of as solid radioactive waste.

In preparation for the POP, Electrabel has estimated how much liquid activity will be released during the POP. This estimate was made on the basis of POP work that has taken place at German nuclear power plants over the last 10 years. It has been assumed by Electrabel that the liquid discharges will follow a similar trend as the liquid discharges from these German nuclear power plants. Based on this estimate, the total expected liquid discharges during POP for KCD-1 and KCD-2 were calculated and are shown in Figure 3-31 and Figure 3-32. The following time schedule was used for this purpose (see paragraph 1.1.3 for the work carried out in the various phases):

- POP phase 1 takes place in the 1st year of the POP period;
- POP phase 2 will take place after the 1st year of the POP period;
- POP phase 3 will take place during the 2nd, 3rd and 4th years of the POP period;
- POP phase 4 will take place in the 5th year of the POP period.

It should be noted that liquid discharges are related to the activities carried out at a given time. Therefore, the schedule of KCD-1 and KCD-2 may differ somewhat from the planning of the considered German nuclear power plants, which means that not all similar works will be carried out at the same time. As a result, the trend of decreasing liquid discharges may fluctuate somewhat.

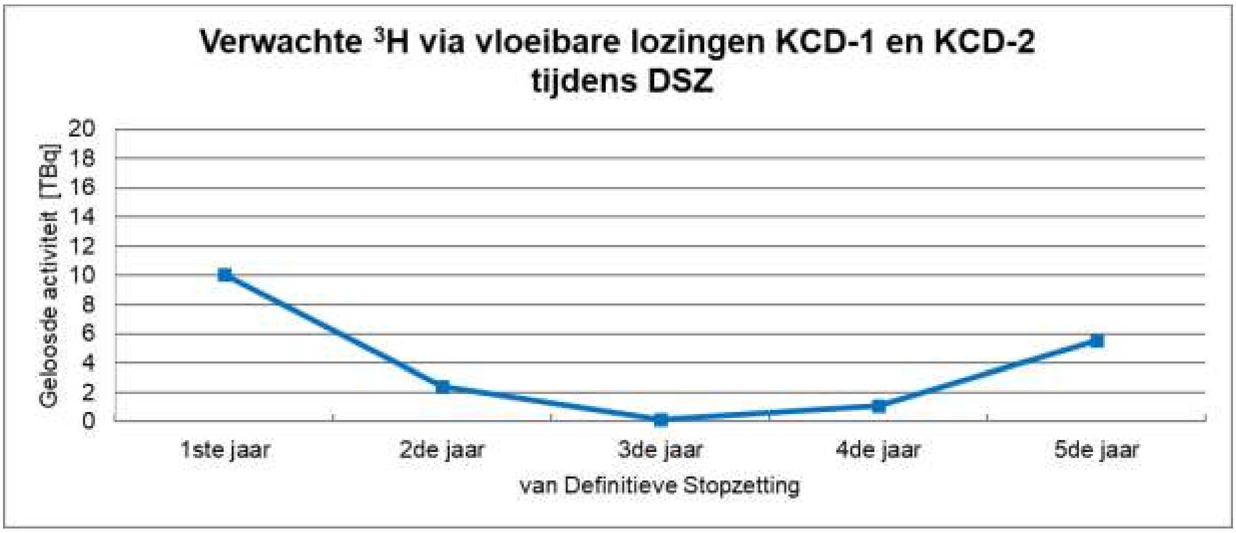

Figure 3-31 Expected ^{3}H via liquid discharges due to works at KCD-1 and KCD-2 during the POP.

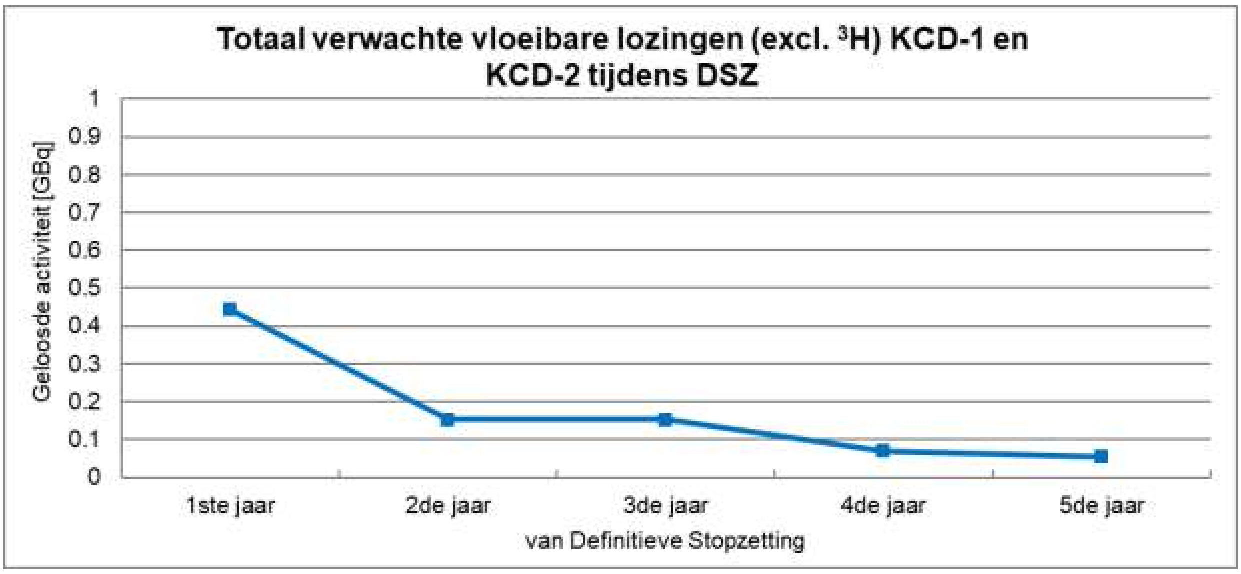

Figure 3-32 Total expected liquid discharges (excl. ^3H) due to works at KCD-1 and KCD-2 during the POP.

The duration of the POP and associated work that will be performed will not differ between the Project and the Zero Alternative. As a result, the discharged activity and committed effective dose will not differ between the two scenarios. In the case of the Project, the Post Operational Phase will start only 10 years later.

3.4.4.4 Cross-border effects

The liquid discharges into the Scheldt, which flows into the North Sea via Dutch territory.

Dose effects at the Dutch border

The Belgian-Dutch border is about 6 km downstream from the KCD discharge point, so the discharged radionuclides will reach Dutch territory relatively soon after the discharge. A conservative estimate is that the radioelement exposure from liquid discharges at the Dutch border is the same as for the most exposed person at the site boundary of KCD. This is conservative because the Dutch border is at a greater distance and therefore the released radionuclides are diluted up to the border and there is lower exposure.

Based on the liquid discharges of the entire KCD and of KCD-1 and KCD-2 in 2014, the committed effective dose was calculated at the Dutch border for six different age categories using a method accepted by FANC. The results for the annual committed dose are summarized in Table 3-34 andTable 3-35, respectively [Tractebel, 2020b]. The calculations for the year 2014 show that the committed effective dose is well below the committed effective dose based on the licensed discharge limits and thus well below the limit of 1 mSv per year. The liquid discharges do not vary over the years in the baseline situation to such an extent that this would cause the committed effective dose to vary significantly at the Dutch border.

Table 3-34 Committed effective dose at the Dutch border due to liquid discharges by all of KCD in 2014

	Committed effective dose due to liquid discharges at KCD [mSv/yr]					
	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
2014	0.00046	0.00052	0.00064	0.00052	0.00049	0.00060
Based on license limits	0.0080	0.0050	0.20	0.18	0.23	0.23

Table 3-35 Committed effective dose at the Dutch border due to liquid discharges by KCD-1 and KCD-2 in 2014

	Committed effective dose due to liquid discharges at KCD-1 and KCD-2 [mSv/yr]					
	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
2014	0.00014	0.00016	0.0002	0.00016	0.00016	0.00020
Based on license limits	0.0027	0.0017	0.066	0.060	0.076	0.076

The Dutch Decree of 23 October 2017, establishing rules for the protection of individuals against the dangers of exposure to ionizing radiation, Article 9.2.1 states that the maximum dose for a member of the Dutch population resulting from the operation of a nuclear facility may not exceed 0.1 mSv per year. Although this is the Dutch dose limit for gaseous and liquid discharges as well as direct radiation, the dose due to liquid discharges from the LTO of KCD-1 and KCD-2, as described in this section, is well below this limit. The impact of the entire Project, including liquid discharges and direct radiation is described in § 3.4.8.

Dose effects at the border with other surrounding countries

For the other surrounding countries (France, Germany, Luxembourg and the United Kingdom), doses due to radioactive liquid discharges into the Scheldt are more difficult to assess than for atmospheric discharges because the transport route to these land borders is complex and because the distribution of radioactive discharges in water is more local and subject to local conditions than for atmospheric discharges. Given the distance of KCD from the border of the other countries, doses due to liquid discharges can be considered negligible [Tractebel, 2020b].

3.4.4.5 Monitoring

The radiological surveillance program on the Belgian territory is carried out periodically by FANC. Measurements are performed, especially for the areas near the nuclear sites. In this way it is possible to evaluate whether the quality of the environment in terms of radioactivity remains of sufficient quality. To monitor radioactive substances released due to liquid discharges, the following samples are periodically performed and analyzed:

- the water itself (concentration of radioactivity in the watercourse);
- the sediment (deposition of radioactivity in the bed of the watercourse);
- the algae, the aquatic plants (transfer of radioactivity from the water to the aquatic flora);
- the fish, crustaceans (transfer of radioactivity from the water to the aquatic fauna).

This is done upstream and downstream of the discharge point, at different distances from a nuclear site. Upstream sampling can serve as a reference to evaluate the radiological footprint of the facility in question with respect to the natural background radiation of the environment.

Currently, for radiological surveillance program on Belgian territory, more than 4,660 annual samplings are carried out, on which 28,000 analyses of alpha, beta, and gamma radioactivity are performed.

The Doel site is located on the Scheldt, which is part of the Scheldt and Nete Basin. More than 1,230 samples are taken annually in the entire basin on which more than 3,730 radioactivity measurements are made. The radiological surveillance program of the Scheldt Basin in the vicinity of the Doel site is shown in Table 3-36.

Table 3-36 Radiological monitoring program of the Scheldt and Nete basins FANC, 2019a]

Compartment	**Type of measurement**	**Frequency of sampling**
Soil		
Perennial pasture (colluvium-0.125 m² at ~15 cm depth + short-cut grass)	γ spectrometry: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra, ^{228}Th	Annually
River		
Water	γ spectrometry: ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb, ^{226}Ra	Every 2 weeks
	Total β spectrometry, α total, ^{3}H, ^{40}K	Every 2 weeks
Sediments	γ spectrometry: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra, ^{228}Th	Every 4 weeks
Shrimp (estuary downstream of Doel (Kieldrecht))	γ spectrometry: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra, ^{228}Th	Quarterly
Musselids, algae (North Sea - Hoofdplaat & Kloosterzande)	^{90}Sr, $^{238-(239+240)}$Pu, ^{241}Am, organic ^{3}H, (^{99}Tc for the algae)	Quarterly

In FANC's synthesis report [FANC,2013] [FANC,2014] [FANC,2015] [FANC,2016] [FANC,2017] [FANC,2018a] [FANC,2019a] FANC concludes that the Doel nuclear power plant has no measurable radiological impact on the Scheldt.

3.4.4.6 Mitigating measures

The facilities of KCD-1 and KCD-2 serving the liquid discharges are such that the applicable criteria are amply met. Therefore, no additional mitigation measures are required.

3.4.4.7 Knowledge gaps

The available knowledge is therefore sufficient to determine the effects of the radioactive liquid discharges of this intention. Despite the fact that exact data are not always available on which of the four units sends the discharges to the WAB. For the current assessment, 1/3rd of the discharged liquid activity originating from the WAB was assumed to be due to the operation of KCD-1 and KCD-2, and therefore that portion was allocated to them [Tractebel, 2019c].

3.4.4.8 Conclusions

As a result of the Project, discharges of radioactively contaminated liquid discharges will be carried out for over 10 years longer. The LTO of KCD-1 and KCD-2 will not have a negative impact on the environment because the expected annual liquid discharged activity will remain similar to the annual discharged activity for the implementation of the LTO Project. The committed effective dose which members of the public may potentially incur as a result of liquid discharges is well below the dose limit and will have no significant impact on the population.

Under the Zero Alternative, the final shutdown of KCD-1 and KCD-2 will result in fewer liquid radioactive discharges, however, the difference compared with the baseline situation and the Project is negligible.

The Project has no significant measurable impact on the Dutch territory and the territory of the other countries bordering Belgium so that further cross-border effects due to liquid discharges can also be excluded.

3.4.5 Radioactive waste

Many different waste streams are generated during operation, most of which are non-radioactive and disposed of as non-radioactive (conventional) waste. Only a portion of the waste streams contain significant amounts of radionuclides and should therefore be disposed of as radioactive waste. In this paragraph, only the fraction of radioactive waste is considered. The environmental impact of non-radioactive waste is considered in paragraph 2.9.

Safe management of radioactive waste for disposal in Belgium is the responsibility of the National Agency for Radioactive Waste and Enriched Fissile Materials (NIRAS) and its subsidiary Belgoprocess. By isolating the waste from the environment until the activity of the waste has decreased to below the limit values applicable in Belgium (through decay), this management requirement is met. These values are based on international guidelines such as ICRP, IAEA and Belgian legislation.

The costs associated with the management and storage of the waste are borne according to the "polluter pays" principle. Those who produce the waste, proportional to the quantities produced, pay for the management and storage.

The treatment of radioactive waste is highly dependent on its activity and lifetime, so waste in Belgium is classified into three categories[16],[17] as also shown schematically in Table 3-37:

- Category A: low and medium level short-lived radioactive waste
  Category A waste is waste that contains nuclides in low activity concentrations and with short half-lives (30 years or less). The lifetime of radioactive waste depends on the half-life of the different isotopes present in the waste). Examples include contaminated personal protective

[16] https://fanc.fgov.be/nl/classificatie-van-afval-belgie (visited on: November 2019).
[17] https://www.niras.be/soorten-radioactief-afval (visited on: November 2019).

equipment (including gloves), cleaning materials, filters, and replaced parts (including pipe sections).

- Category B: low and medium level long-lived radioactive waste
  Category B waste is waste contaminated with long half-life alpha emitters at higher concentrations than Category A waste. It may also contain varying amounts of beta and gamma-ray nuclides.
  As for a nuclear power plant, these include resins and, when a nuclear power plant is decommissioned, some parts of the reactor.

- Category C: highly radioactive long-lived waste.
  Category C waste is highly radioactive waste containing large amounts of alpha, beta and gamma emitting nuclides. Due to its high activity, most of it gives off more than 20 W/m3 of heat.

Table 3-37 Category classification overview for radioactive waste.

	Low-active waste	Medium-active waste	High-active waste
Short-lived waste ($t_{1/2}$ < 30 years)	Category A	Category A	Category C
Long-lived waste ($t_{1/2} \geq$ 30 years)	Category B	Category B	Category C

About 95% of all waste generated in Belgium consists of category A and B waste[18]. High-level waste (Category C) is produced only in limited volumes, for example in research reactors and medical isotope production. No Category C waste is generated during the operation of KCD.

Spent fuel elements coming from KCD's nuclear units are also highly radioactive. As no decision has yet been taken in Belgium as to whether spent fuel elements might be reprocessed at a later date (which will reduce the total volume of highly radioactive waste), spent fuel elements are not considered waste for the time being. As a result, the impact of LTO with respect to spent fuel elements (potential Category C waste) is described in § 3.4.6.

The radioactive waste is further divided into two categories from the point of view of KCD. The first category is unconditioned waste and the second category is conditioned waste. The difference between these two categories is that the first type of waste is sent to Belgoprocess in an unconditioned form, while the second type is conditioned by KCD on site and only then sent to Belgoprocess. The unconditioned waste is further treated and conditioned at Belgoprocess so that it meets the requirements for disposal.

One of the basic principles in radioactive waste is to avoid (selection at source) or minimize the amount of radioactive waste as much as possible. If radioactive waste cannot be avoided, the processing process is aimed at reducing the final amount of waste to be disposed of. Reducing the amount of low and intermediate-level radioactive waste is a responsibility of every person within the KCD organization.

All waste from the nuclear part of the facilities is initially considered radioactive waste. However, some of this waste is potentially non-radioactive and can be disposed of as regular and/or industrial waste after

[18] https://fanc.be/nl/classificatie-van-afval-belgie (visited on: December 2019)

prior decontamination and clearance. Every effort is being made to reduce the fraction of radioactive waste. Therefore, priority is given to decontaminating waste where possible and clearing it, in accordance with the legal criteria [ARBIS].

The regulatory clearance criteria [ARBIS] are based on international guidelines [IAEA, 2014][EU, 2013], which were established based on international studies [IAEA, 2005]. Radionuclide concentrations have been determined which, under unfavorable conditions, could lead to a maximum committed effective dose of 10 µSv/year, a dose which is considered trivial. The clearance concept was developed to prevent the regulatory system for radioactive materials from being overloaded by (very) large quantities of waste that have practically no radioactivity left in them, for example through decontamination or decay, so that it does not pose a significant risk to the population.

Of the remaining share, the radioactive waste not to be released, the volumes are reduced to the maximum extent. Different processing methods can be used for this purpose depending on the physical and radiological properties of the waste. Radioactive waste is mainly processed in the facilities of the WAB building (water and waste treatment building). The facilities in the WAB are intended to further treat and process the waste from all nuclear KCD units. The facilities include facilities for decontamination, waste clearance measurements, liquid waste evaporation and conditioning facilities.

The different groups of waste, where the volumes are reduced to the maximum, are:

- Combustible waste
  Combustible waste, after volume reduction in the WAB, is disposed of as unconditioned waste for incineration at Belgoprocess. At Belgoprocess, the quantity of waste is further reduced by incineration. The residual fraction (ashes), containing the collected radioactive materials, is conditioned.

- Non-combustible waste
  Non-combustible waste or compactable waste is broken down into different waste streams. Among other things, the various metals will be separated from the other various compactable wastes with the objective always being to be able to reduce each individual waste stream as much as possible. At Doel's facilities, compactable waste is compressed a first time (using a 16-ton or 100-ton press), after which it is disposed of as unconditioned waste to Belgoprocess. There, it is compressed for a second time in their facilities using a 1000 ton press. The compacted waste is then conditioned.

- Filters
  To remove any radioactive particles from the air as much as possible, the air from the RCA is continuously filtered using pre-filters, activate carbon filters (for iodine) and absolute filters (see § 3.4.3). The ventilation filters from these installations are, depending on their physical properties, also processed as combustible or compactable waste and transported to Belgoprocess as non-conditioned waste.

  The liquid filters from the circuits of the nuclear part of the plants are also compressed and conditioned in a concrete mixture, if possible.

- Liquid waste
  The volume of radioactive liquid waste is reduced mainly by evaporation. The radioactive substances present in the liquid are collected in the 'concentrate' and the non-radioactive part of the liquids, the condensates, can be discharged after prior checks (see § 3.4.4). The 'concentrate' is further processed into conditioned waste at the Doel conditioning plant. After acceptance by NIRAS, the conditioned waste is transported to Belgoprocess for disposal. Acceptance is the set of checks performed by NIRAS to determine whether the waste complies with the applicable acceptance criteria.

- Resin
  Radioactive resins from ion exchangers, for purifying circuits, are not compacted but, like the concentrate, processed into conditioned waste. The resins are mixed with a concrete mixture.

- Protective clothing
  The use of disposable protective clothing (radioactive waste) in the nuclear parts of the facilities is minimized by using washable protective clothing. This reusable personal protective equipment (PPE) is cleaned in the WAB building's specialized laundry facility. The laundry water is discharged after filtering and prior checks.

All radioactive waste is always treated in accordance with the requirements of NIRAS. The requirements set by NIRAS which the waste must comply with are included in the various ACRIAs (AcceptanceCRiteriA) and comply with the applicable legislation. The acceptance criteria depend on the type of waste and the waste category to which the waste belongs. Both the systems and the treatment methods used to characterize and produce radioactive waste meet the requirements set by NIRAS. For example, all radioactive waste will be identified and documented in accordance with applicable regulations prior to transfer to Belgoprocess.

Radioactive waste management at NIRAS can be divided into the following steps[19]:

- Acceptance and transport
  After acceptance by NIRAS, the waste is transported to Belgoprocess in Dessel for further processing.

- Processing and temporary storage
  At Belgoprocess, unconditioned radioactive waste is processed and conditioned into packages. All packages must meet the requirements for concentration, containment and durability, thus allowing for safe long-term management. Pending surface disposal, the waste is temporarily stored in packages in special buildings. The stored packages are monitored over time to verify that they remain in compliance with the applicable acceptance criteria. Via the choice of material and wall thicknesses, the buildings provide adequate protection from ionizing radiation according to the radiological characteristics of the waste.

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[19] https://www.niras.be/het-afvalbeheer-nu-en-op-lange-termijn (visited on: January 2020)

- Surface storage
  For category A radioactive waste, NIRAS prepares long-term surface disposal. The barrels are encased in a concrete container, which in turn is encased in a concrete layer underground. NIRAS must ensure sufficient storage capacity to store all radioactive waste in Belgium.

- Geological disposal
  At present, NIRAS considers storage in a geological repository as the best solution for the final disposal of the highly radioactive and/or long-lived waste (categories B and C). The waste is then isolated in a stable layer deep underground, behind a whole series of barriers. These barriers provide containment, in case of failure of these barriers delayed or diffused release. In what form and to what extent the radioactive waste will be placed there has not been determined at this time. In particular, for fuel elements (Category C), there are the options of reprocessing or non-reprocessing. However, the Belgian government has yet to make a decision on this.

3.4.5.1 Methodology

All solid radioactive waste is collected at the WAB building where it is treated, packaged and finally disposed of. The amount of radioactive waste is typically expressed in volumes. The volumes disposed of are reported in the annual environmental statements of KCD [Electrabel, 2012][Electrabel, 2013a][Electrabel, 2014a][Electrabel, 2015b][Electrabel, 2016a][Electrabel, 2017a][Electrabel, 2018a]. The reporting shows the total amount of low and medium level waste on an annual basis for the entire Doel site. For this EIR, it has been assumed that a 1/3rd of the annual amount of waste can be attributed to the combination of the KCD-1 and KCD-2.

The main radiological environmental aspect of waste is ionizing radiation. As long as the waste is at the KCD site, it contributes to the dose at the site boundary. However, this is part of direct radiation at the site boundary and is included in this topic (see § 3.4.1).

Disposal of the waste to Belgoprocess for further processing results in a very small dose to the environment along the transport route. After acceptance by NIRAS, transports complies with the ADR guidelines for radioactive transports. The dose consequence for the environment is zero. This environmental aspect is not considered further in this EIR.

A comparison between the quantities of radioactive waste due to exploitation before and after the implementation of the Project was evaluated.

3.4.5.2 Baseline situation

The total volume of low and medium-level radioactive waste disposed of through the WAB to Belgoprocess in the baseline situation is shown in Table3-38 [Electrabel, 2012][Electrabel, 2013a][Electrabel, 2014a].

Table3-38 Volume disposed low and medium level radioactive waste for KCD-1 and KCD-2 and KCD during the baseline situation

Year	Volume KCD-1&2 [m³]	Volume KCD [m³]
2012	41.6	124.7
2013	42.0	125.9
2014	15.6	46.8
Average (2012-2014)	33.0	99.1

Most of the radioactive waste is generated during operation and the annual regular outages, during which major maintenance of facilities and fuel exchange takes place. Variations in waste quantities depend on planned maintenance activities and projects. Such activities also cause variations in the quantities of radioactive waste processed and disposed of in the WAB. This is the reason why there may be differences in annual quantities.

For this environmental impact assessment, it is conservatively assumed that waste released from KCD will result in the maximum committed effective dose of 10 µSv per year.

3.4.5.3 Impact assessment

The potential impacts of radioactive waste on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  It is divided into two phases, each of which is covered in a separate §.
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): operation after implementation of the LTO measures.
- Zero alternative, the Project is <u>not</u> completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the period (2012-2014; baseline situation) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[20].

[20]For further explanation on this assumption, see § 1.1.3

3.4.5.3.1 Operational phase of the Project between 2015 and 2018

As projects impact the total volume of low and medium level waste, the implementation of the various projects in the construction phase will have increased the share of the total volume of low and medium level waste disposed of from the KCD-1 and KCD-2 facilities in line with expectations (Table 3-39). Given the timing of this study, the quantities of low and medium level radioactive waste generated and disposed of during the construction phase are already known. However, not all waste from the construction phase was incorporated into the WAB during this period; it is anticipated that this will be incorporated in 2019 and 2020. On the other hand, the average volume of low and medium level waste disposed of annually KCD over the period 2015-2018 is in line with the annual average in the baseline situation (2012-2014). The annual quantities disposed of are shown in Table 3-39. [Electrabel, 2016a] [Electrabel, 2017a] [Electrabel, 2018a] [Electrabel, 2019a].

Table 3-39 Volume of disposed low and medium level radioactive waste for KCD-1 and KCD-2 and KCD during the operational phase of the Project between 2015 and 2018

Year	Volume KCD-1&2 [m^3]	Volume KCD [m^3]
Baseline situation (2012-2014)	33.0	99.1
2015	36.1	108.2
2016	33.5	100.5
2017	31.7	95.1
2018	30.4	91.1
Average (2015-2018)	32.9	98.7

3.4.5.3.2 Operational phase in the future situation (period 2019 - 2025)

Although the amount of radioactive waste produced and disposed of each year varies greatly due to many factors, based on the baseline situation it can be stated that approximately 33 m^3 of low and medium level radioactive waste is disposed of annually to NIRAS as a result of the operation of KCD-1 and KCD-2 (Figure 3-33). In other words, the total annual amount of waste disposed of will not deviate from the baseline situation in the period 2019 - 2025. When the Project's work is complete, the amount of radioactive waste from KCD-1 and KCD-2 is not expected to differ from the baseline situation.

Cumulative effect of the Project

The previous paragraph and § 3.4.5.2 show the annual radioactive waste volumes for the period 2015-2025. Adding these gives the cumulative amount of radioactive waste resulting from the LTO Project for the period 2015-2025; this is 363 m^3.

3.4.5.3.3 Zero alternative

In the case of the Zero Alternative, no LTO, the reactors will be shut down and the Post Operational Phase (POP) will be initiated in 2015. During the POP and subsequent dismantling, both radioactive and conventional waste will be generated. The annual amount of waste that will be generated is expected to be more than during regular operation. This follows from the obligation to return the site to its original condition (greenfield) and remove all materials (radioactive and conventional).

The amount of radioactive waste produced annually is expected to decrease. As stated earlier in this EIR, low and medium-level radioactive waste is generated primarily during outages and fuel exchanges.

Because there will be no more fuel exchanges, there will be a decrease in the amount of radioactive waste produced annually.

However, radioactive waste will continue to be produced during the various POP phases as systems are decommissioned at different times. For example, the cooling systems remain operational for the purpose of removing residual heat. Such systems must be available and maintained even after final shutdown, only after all fuel elements have been removed can they be permanently shut down. It varies per POP phase which systems still need to be available and thus which can be permanently discontinued.

As indicated earlier, POP operations and dismantling under the Zero Alternative start 10 years earlier than under the Project. Since the work to be done is the same for both cases, it is likely that the environmental impacts will be the same in both situations. Therefore, no radioactive waste resulting from the operation of KCD-1 and KCD-2 will be produced from 2015 onwards.

As a result of the POP work, waste will be generated. For this EIR, it has been conservatively assumed that the quantities of waste disposed of during the POP phases 1, 2 and 3 are equal to the quantities due to operation (see Figure 3-33). It is assumed that upon completion of the POP, no more radioactive waste will be produced.

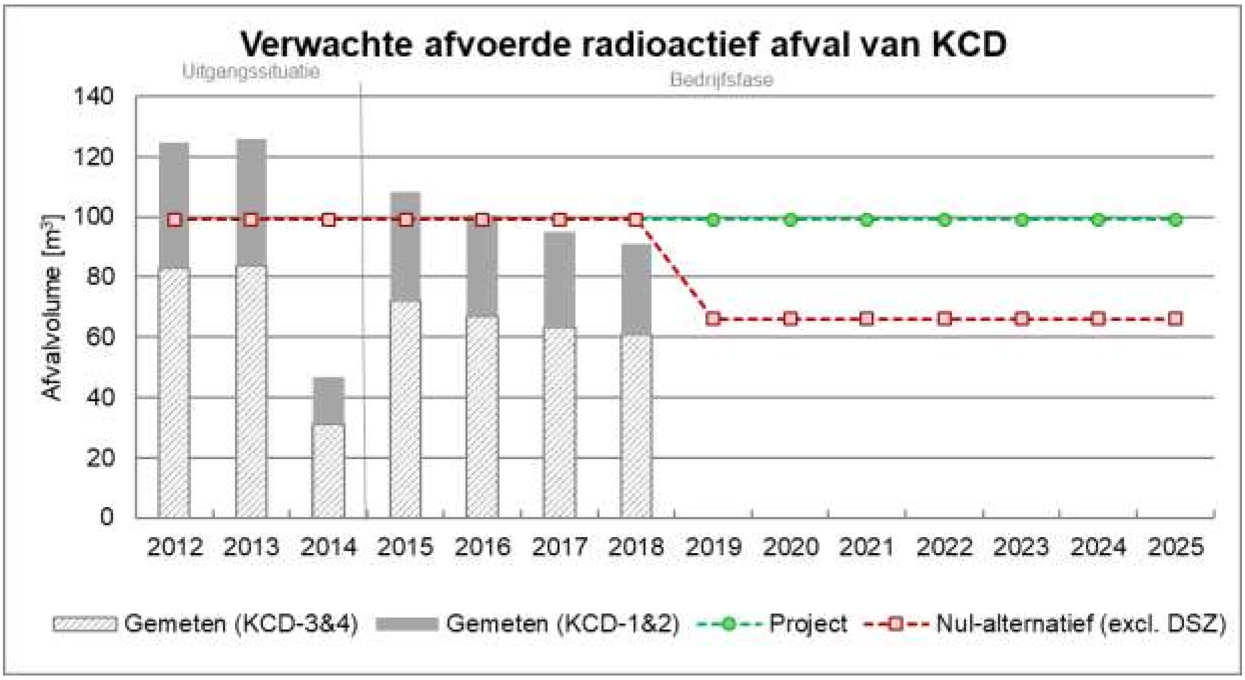

Figure 3-33 Total volume (KCD-1 through KCD-4) of low- and intermediate-level radioactive waste disposed of and expected quantities, for both the Project and Zero alternative. The vertical bars show the actual values measured, where available.

Post Operational Phase of KCD-1 and KCD-2

During the Post Operational Phase, the main share of radioactive waste generated is from operational activities. This therefore falls within the existing and validated categories of radiological waste and the associated processes for treating the waste.

The annual amount of radioactive waste during the various POP phases is expected to be less than the annual amount during operation. In addition, the quantities of radioactive waste will also decrease due to the reduced need for maintenance and interventions on the gradually decommissioned circuits and facilities. The exception is radioactive waste, generated by the specific activities on behalf of POP. The main waste streams are shown below:

- Rinsing fluids used in chemical decontamination
- Resins from the ion exchangers, which are used in chemical decontamination
- Filters used in chemical decontamination
- Non-fissile highly radiating components from the reactor vessel
- Wastewater from emptying the circuits and the deactivation basin

This waste will be treated as much as possible in the same way as the radioactive waste produced during operation. Therefore, the waste from the POP activities is also treated in the WAB where possible.

3.4.5.4 Cross-border effects

All waste generated will be processed and stored on Belgian territory until a final solution is found. NIRAS manages the radioactive waste isolated from the environment until the activity of the waste is reduced by decay to below the exemption values applicable in Belgium. As a result, no cross-border impacts are anticipated.

3.4.5.5 Monitoring

The waste streams within KCD are monitored and recorded by Electrabel. The volumes of low- and medium-level radioactive waste disposed of from KCD are monitored by NIRAS and Belgoprocess, under the supervision of Federal Agency for Nuclear Control (FANC).

3.4.5.6 Mitigating measures

To minimize the total volume of low and medium level radioactive waste, solid waste is processed (pressed and shredded) in the water and waste treatment building WAB and solid waste is incinerated (at Belgoprocess). Using these technologies leads to a strong volume reduction of waste.

3.4.5.7 Knowledge gaps

The available knowledge is sufficient to determine the radioactive waste impacts of this plan. Despite the fact that the exact origin of the disposed waste from the water and waste treatment building is not always unambiguously assignable to a particular unit. Total waste generation also depends on many factors and is therefore very difficult to predict. For this EIR, it has therefore been assumed that a 1/3rd of the annual amount of waste can be attributed to the combination of the KCD-1 and KCD-2.

3.4.5.8 Conclusions

As a result of the KCD-1 and KCD-2 LTOs, low and medium level waste will be generated for an additional 10 years (2015-2025). The nature of the planned activities in the operational phase of the Project between 2015 and 2018 differs from the nature of the regular activities in the baseline situation. It is therefore plausible, and demonstrated by practical figures for the years 2015-2018, that differences exist in the quantities of waste generated. The radiation impact at the site boundary from radioactive waste cannot be determined separately because the thermoluminescence dosimeters detect radiation from all sources present at the site combined, however, it can be concluded in general terms that this Project has no significant impact on the environment with respect to direct radiation (see § 3.4.1).3.4.1

In contrast, under the Zero Alternative, less low-level and medium-level radioactive waste is generated over the entire 2015-2025 operating period compared to this Project. During the POP period, in addition to radioactive waste originating from the operational activities, which amount decreases as the POP progresses, one-off radioactive waste streams are also produced at the specific POP activities. It is expected that the quantities of radioactive waste over the entire period of the POP will be lower on an annual basis than the quantities during operation.

All generated low- and medium-level waste (category A and B) will be processed and stored on the Belgian territory in the surface repository. As a result, no cross-border impacts are anticipated. The latter is confirmed in the opinion of the European Commission[21].

3.4.6 Spent fuel elements

The reactors of KCD-1 and KCD-2 contain nuclear fuel elements. In these elements, fission of the low-enriched uranium present in them (between 3 and 5%) takes place, releasing heat. This heat is used to produce electricity through the nuclear power plant's systems. Due to the fission reaction, the fuel elements become exhausted and need to be replaced. After four 12-month cycles, they are removed from the core. Although the spent fuel elements still consist largely of uranium, some of the uranium has been split into fission products, some of which are still radioactive.

Due to the high activity and the residual heat generated as a result, the spent fuel elements must be stored in the shared fuel pool in the Nuclear Auxiliary Services Building (GNH). The elements are stored in the GNH for a period of several years. After this cool-down period, the elements are placed in a Dual Purpose Cask (DPC)[22], which is then sealed. The DPC is designed to provide shielding against ionizing radiation. The DPC is then transported to the fuel container building (FCB), where the DPC is stored under controlled conditions until a decision is made on a suitable final destination (final geological disposal and/or reprocessing).

In 1993, the Belgian government introduced a moratorium on the reprocessing of spent fuel elements. This means that the Belgian government has not yet made a decision whether or not these fuel elements will be reprocessed:

- Reprocessing
  The uranium is separated from the plutonium and fission products. The plutonium and uranium are reused to make new fuel elements. The fission products are vitrified: this vitrified high-level waste is then stored, awaiting final disposal. Through reprocessing, the volume of high-level

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[21] https://op.europa.eu/nl/publication-detail/-/publication/682dfad5-257f-11eb-9d7e-01aa75ed71a1/language-nl (visited on December 2020)

[22] A Dual Purpose Cask can be used for interim storage as well as for transport on and off-site.

radioactive waste that is stored can be greatly reduced. This will reduce the capacity required in a final repository with related cost and safety benefits. It leads to an increase in low and medium level waste which requires an increased capacity of the appropriate disposal facilities.

- No reprocessing
  The spent fuel elements are considered waste in their entirety and stored pending final disposal.

Pending the decision of the Belgian government, all spent fuel elements should be stored on-site [EU, 2013] and are not considered radioactive waste for the time being. As a result, with each year of operation, the number of spent fuel element stored on the site increases.

The main environmental impact of spent fuel elements is radiological radiation. As all spent fuel elements remain at the KCD site until a decision is made regarding reprocessing, only radiological radiation can be considered. However, this is part of direct radiation at the site boundary and is included in this topic (see § 3.4.1). The radiation share at the site boundary from spent fuel elements cannot be determined because the thermoluminescence dosimeters installed at the site boundary detect radiation from all sources present at the site together, and cannot distinguish the source of the radiation.

3.4.6.1 Methodology

A cycle of KCD-1 and KCD-2 lasts for a maximum of 12 months, after which the fuel elements in the core are reclassified to compensate for the decrease in fuel in an element. Per average cycle, about a quarter of the nuclear fuel elements are replaced with new elements. The exact number of new elements depends on various factors such as the consumption rate, power distribution across the reactor core and the amount of electricity produced. Due to work, disruption, and other factors, the duration of cycles and outages can vary greatly, so too can the number of fuel elements consumed per cycle [Tractebel, 2015]. The spent fuel elements are placed in the fuel basin for a minimum of 3 years before being disposed of in the FCB. Within this EIR, it is assumed that over several years, the annual average number of fuel elements consumed will equal the annual average number of fuel elements removed.

The number of fuel elements disposed of is taken from Electrabel's published environmental statements [Electrabel, 2013a][Electrabel, 2014a][Electrabel, 2015b][Electrabel, 2016a][Electrabel, 2017a][Electrabel, 2018a]. In it, the number of fuel elements per year is published; therefore, the methodology applies an annual approach.

3.4.6.2 Baseline situation

The number of fuel elements consumed varies greatly from year to year; the number depends, for example, on energy production and the duration of cycles. As the fuel elements are replaced on average annually, there may be no elements removed in a given year or the removed elements from multiple cycles may be removed in a year. The number of fuel elements removed per plant is shown in Table 3-40 [Electrabel, 2013a] [Electrabel, 2014a] [Electrabel, 2015b].

To average out these strong annual variations, the multi-year average is used instead of the average value over the baseline situation [Electrabel, 2012], shown in Table 3-40.Table 3-40 The number of fuel elements disposed of in the baseline situation is in line with the multi-year averages shown in Table 3-40.Table 3-40

Table 3-40 Annual fuel elements removed from KCD-1, KCD-2, and KCD during the baseline situation, which have been transported to the FCB from the associated fuel basin.

	KCD-1	KCD-2	KCD
Multi-year average	32	32	168
2012	36	22	162
2013	0	32	32
2014	36	28	120

3.4.6.3 Impact assessment

The potential impacts of the consumption of fuel elements on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  It is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): operation after implementation of the LTO measures.
- Zero alternative, the Project is not completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on long term average data (baseline situation) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[23].

3.4.6.3.1 Operational phase of the Project between 2015 and 2018

KCD-1 and KCD-2 will be in operation during the operational phase of the Project between 2015 and 2018 as in the baseline situation (2012-2014). Assuming the multi-year average fuel consumption as shown in Table 3-40, KCD-1 (32 per year) and KCD-2 (32 per year) together will produce 256 spent fuel assemblies during the operational phase of the Project between 2015 and 2018 (4 years).Table 3-40 This production is not due to the performance of various LTO measures during the operational phase of the Project between 2015 and 2018 but solely due to the continuation of the operation of KCD-1 and KCD-2 during this phase.

Given the timing of this study, the amount of fuel elements consumed during the operational phase of the Project between 2015 and 2018 is already known. This is shown for all units of KCD in Table 3-41 [Electrabel, 2016a][Electrabel, 2017a][Electrabel, 2018a][Electrabel, 2019a]. The data shows a spread between years, which depends on production time, scheduled and unscheduled outages.

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[23] For further explanation on this assumption, see § 1.1.3

Table 3-41 Annual number of fuel elements consumed from KCD-1, KCD-2 and KCD during the operational phase of the Project between 2015 and 2018 as transported to the FCB.

	KCD-1	KCD-2	KCD
Multi-year average	32	32	168
2015	60	0	156
2016	28	40	108
2017	28	32	120
2018	0	28	124

Because the long-term average consumption of fuel assemblies in the Construction Phase (2015-2018) is the same as that of the baseline situation (2012-2014), the impact of the fuel assemblies on the environment (due to radiation) will be determined by the number of additional stored spent fuel assemblies and transport to the FCB. This is addressed in § 3.4.1 and § 3.4.2 because the radiation monitoring measurements also record the radiation coming from this transport.

3.4.6.3.2 Operational phase in the future situation (period 2019 - 2025)

After completion of the operational phase of the Project between 2015 and 2018, KCD-1 and KCD-2 will continue to operate during the normal operational phase (2019-2025) as in the baseline situation (2012-2014).

The expected numbers of fuel elements consumed during the operational phase in the future situation (period 2019 - 2025) are shown in Figure 3-34

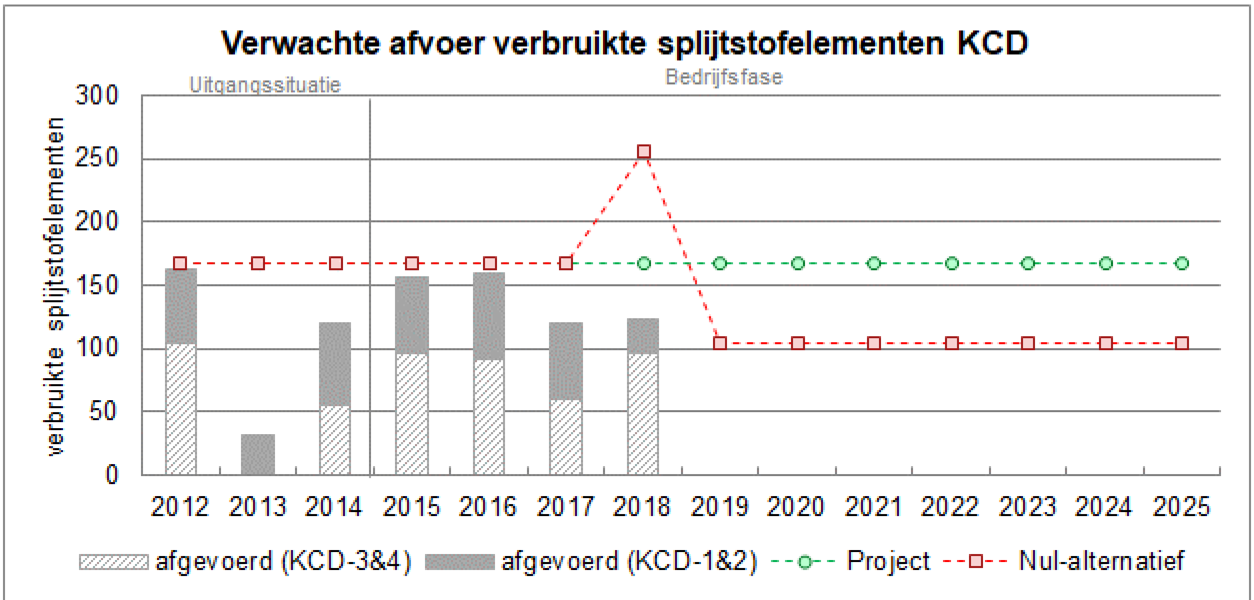

Figure 3-34 Expected consumption of fuel elements as a result of KCD operation, both for the Project and the Zero Alternative, as transported to the FCB. The vertical bars show the actual fuel elements consumed, where available.

Therefore, since the consumption rate of fuel elements in normal operation (2019-2025) remains the same as in the baseline situation (2012-2014), its impact on the environment during the operational phase in the future situation (period 2019 - 2025) will also be determined by the number of additional stored spent fuel elements and the transport movements to transport them to the FCB. This results in the annual increase during the operational phase in the future situation (period 2019 - 2025) being equal to that in the baseline situation.

Cumulative effect of the Project

Assuming the multi-year average fuel consumption as shown in Table 3-40, KCD-1 and KCD-2 together will produce approximately 448 spent fuel elements during the operational phase in future situation (period 2019 - 2025).Table 3-40 Together with the fuel elements consumed by KCD-1 and KCD-2 in 2015-2018 (216) (see Table 3-40), the Project will result in a consumption of approximately 664 additional fuel elements.

As a result of the operation of all units, the available capacity of the FCB will be reached before the end of the life of the units, assuming the LTO G2 project goes ahead. To increase storage capacity, a new storage building in the Spent Fuel Storage Facility (SF^2) project is under construction at the time of writing. The environmental impact assessment of the new storage is described in a separate environmental impact assessment report. However, the existing capacity of the FCB is sufficient for the fuel elements produced as a result of the operation of KCD-1 and KCD-2 resulting from the Project. As a result, the SF^2 project is only relevant to the operation of KCD-3 and KCD-4 and independent of the Project (LTO of KCD-1 and KCD-2).

3.4.6.3.3 Zero alternative

Within the Zero Alternative, operation of both KCD-1 and KCD-2 ceases in 2015. At that time, no more fuel elements will be consumed. Only those elements present in the reactor vessel or fuel basin at the time of the shutdown should be disposed of after sufficient residual heat removal. Therefore, the effect of spent fuel on the environment will be lower in the Zero alternative than in the baseline situation. The annual increase due to the Zero Alternative will be zero.

Post Operational Phase of KCD-1 and KCD-2

During the operation of KCD-1 and KCD-2, a quarter of the fuel elements in the reactor are replaced each year. The spent fuel elements are transferred from the reactor to the fuel basin. This is (approximately) equal to the number of fuel assemblies transferred to the FCB each year after allowing them to cool down for at least 3 years. As a result, the number of fuel elements present in the fuel basin will remain about the same over the years of operation.

In POP phase 1, all fuel elements present in the reactor are transferred to the fuel basin. Sufficient capacity is available in the fuel basin to safely house all elements from the reactor in addition to the fuel elements already present. Each year, sufficient cooled fuel elements are placed in Dual Purpose Casks (DPC) and transferred to the FCB.

At some point during POP Phase 3, only those fuel elements will be present in the fuel pool that were present in the reactor core at the end of operation. All other fuel elements are sufficiently cooled and moved to the FCB at that time. These fuel elements still present in the fuel basin will also be transferred to the FCB in the final period of POP phase 3. This is the reason why more elements are transported to the FCB in 2018 than in other years. After this, there will be no more fuel elements at KCD-1 and KCD-2. The above is shown in Figure 3-35, using the following time schedule (see paragraph 1.1.3 for the work performed in the different phases):

- POP phase 1 takes place in the 1st year of the POP period;
- POP phase 2 will take place after the 1st year of the POP period;
- POP phase 3 will take place during the 2nd, 3rd and 4th years of the POP period;
- POP phase 4 will take place in the 5th year of the POP period.

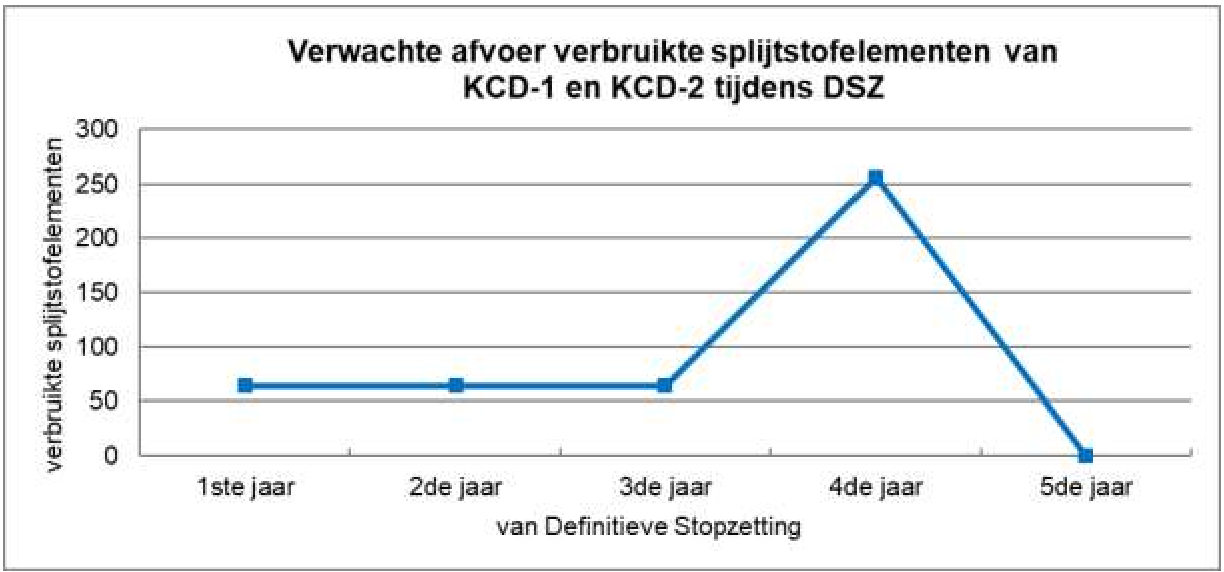

Figure 3-35 Anticipated disposal of spent fuel elements from KCD-1 and KCD-2 during POP.

It is expected that the occupationally exposed workers involved in the waste fuel elements (especially during POP Phase 3) will incur a greater dose compared to the other POP work. The effects for all occupationally exposed employees at KCD-1 and KCD-2 are described in § 3.4.2. Figure 3-34 shows the number of spent fuel elements disposed of during the POP phase under the Zero alternative.

3.4.6.4 Cross-border effects

Since the Belgian government has yet to take a decision regarding further processing of spent fuel elements (e.g. reprocessing or direct final disposal), they are not considered radioactive waste for the time being. Possible transportation of these elements to other countries for reprocessing, resulting in possible environmental impacts, are therefore not considered in this EIR.

3.4.6.5 Monitoring

The number of spent fuel elements is reported annually. Additional monitoring compared to the current situation is therefore not required.

3.4.6.6 Mitigating measures

The infrastructure of KCD-1, KCD-2, and FCB for spent fuel elements is adequately equipped to amply meet the applicable criteria. Therefore, no additional mitigation measures are required.

3.4.6.7 Knowledge gaps

Currently, the Belgian government has not yet made a decision regarding the final destination of spent fuel elements (including reprocessing or direct geological final disposal). Therefore, the long-term effects beyond the site boundary of KCD cannot be determined at the time of preparing this environmental impact assessment.

3.4.6.8 Conclusions

Since the consumption rate of fuel elements both in the operational phase of the Project between 2015 and 2018 and operational phase in the future situation (period 2019 - 2025) is the same as that of the baseline situation (2012-2014), the increase per year of operation will be identical in all cases. Within the Zero Alternative, the consumption rate of spent fuel elements stops, reducing its impact on the environment. The radiation impact at the site boundary from spent fuel elements cannot be determined separately because the thermoluminescence dosimeters detect radiation from all sources present at the site combined, however, it can be concluded in general terms that this Project has no significant impact on the environment with respect to direct radiation (see § 3.4.1).

The current available capacity of the fuel container building is sufficient for the additional fuel elements consumed as a result of the Project (LTO of KCD-1 and KCD-2).

3.4.7 Accident situations

In addition to managing obsolescence, increasing the nuclear safety of the KCD-1 and KCD-2 is the main goal of LTO. As a result of the modifications made as part of the LTO, a positive impact in terms of accident events is expected during the continued operation.

Nuclear power plants must be operated safely so that people and the environment are protected from the harmful effects of ionizing radiation. To meet this goal, a nuclear power plant must essentially perform the following three fundamental safety functions [Decision, 2011]:

1. controlling reactivity;
2. removing heat from the core and
3. containing the radioactive substances.

These three fundamental safety functions apply to all phases of the life cycle of a nuclear power plant. To ensure these fundamental safety functions, each nuclear power plant must take measures:

- to control the exposure of humans to ionizing radiation and the release of radioactive substances or (irradiated) fissile materials into the environment;
- to reduce the probability of events that could lead to loss of control of the reactor core, nuclear chain reaction, radioactive sources or other sources of ionizing radiation;
- to mitigate the effects of such events should they occur.

For nuclear installations, it is common to implement this by applying the concept of layered protection (Defense-in-Depth, DiD). This concept is a combination of architectural, technical and organizational measures. It is applied both during design and commissioning, and during operation, decommissioning and final dismantling of the plant.

The concept of layered protection includes six layers [Decision, 2011]:

a) minimize the impact of external hazards of natural origin, including extreme hazards, and unintentional man-made hazards;
b) prevent avoidable operating incidents or failures;

c) manage avoidable operating incidents and detect defects;
d) design-based accidents are managed;
e) the conditions of design increases are managed, while also preventing accidents from escalating to serious accidents and limiting the consequences of serious accidents;
f) enable emergency management, in accordance with Article 16 Internal Emergency Plan of the Royal Decree on Safety Requirements for Nuclear Facilities and, for power reactors, Article 31 Internal Emergency Plan of the Royal Decree on Safety Requirements for Nuclear Facilities.

The overall goal of the Defense in Depth concept is to ensure that a single (material or human) error at one of the layers or a combination of errors at multiple layers does not compromise the functioning of the next layer. The independence of the different layers is essential to achieve this goal. This nuclear safety concept was already taken into account during the design of KCD-1 and KCD-2. For this purpose, the safety standards of the "United States Nuclear Regulatory Commission" (US-NRC) were adhered to. The above safety philosophy is the starting point for these safety standards.

To ensure safety, analyses were performed for a wide range of Design-Based accidents (DBAs) and unit design were modified where necessary. Design-based accidents are hypothetical events that could occur at the facility in question and, thanks to the safety systems included in the design, would not result in unacceptable releases of radioactivity to the environment.

Periodic safety review

International guidelines strongly encourage continuous improvement of nuclear safety. One type is a Periodic Safety Review (PSR). This results in improvement proposals with the aim of increasing nuclear safety and possibly also the reliability and availability of the nuclear installation. In Belgium, the Royal Decree of 25 January 1974 and the Royal Decree of 30 November 2011 (Article 14 periodic reviews) on safety regulations for nuclear facilities stipulate that the operator must conduct a periodic safety assessment, at intervals of no more than ten years [Decree, 2011]. At the time of the LTO decision for KCD-1 and KCD-2, three safety reviews were conducted, also known as decennial safety review. The fourth safety assessment was conducted as part of the Project.

The first PSR (1984) [Electrabel, 2012a] led to the most extensive modifications. Similar to the then new units KCD-3 and KCD-4, the bunkered Emergency Systems Building (GNS) for KCD-1 and KCD-2 was commissioned. The GNS design is based on extensive external accident studies, such as earthquakes, gas explosions and aircraft impacts. The GNS emergency systems are designed to ensure the following functions, namely preservation of:

- water inventory in the reactor circuit;
- sub-criticality of the reactor;
- removal of residual heat;
- Emergency control room.

Some other important improvements made relate to the:

- improving the seismic resistance of the main nuclear systems;
- increasing the fire resistance of the control room and reducing the risk of contamination in the control room from toxic and radioactive gases;

- replacing the safety valves on the reactor circuit with hydraulically controlled safety valves to provide overpressure protection;
- installing passive catalytic hydrogen recombiners in the reactor buildings to avoid or reduce the risk of hydrogen explosion;
- replacing the four isolation valves in the main steam line, to improve the reliability of the fast isolation of the main steam lines.

The second PSR was completed in 1995 [Electrabel, 2012a]. From then on, the structural approach to aging and wear was started. In addition, among others the following improvements were made:

- upgrading the low-pressure safety injection pumps to increase their reliability;
- further upgrading seismic resistance of the units;
- perform Probabilistic Safety Assessment (PSA), to identify potential weaknesses in the facilities. This demonstrated the beneficial effect of the modified accident procedures and the installation of catalytic hydrogen recombiners in the reactor buildings.

In the third PSR [Electrabel, 2012a], the focus was on confirmation of the initial safety level, evaluation of plant obsolescence, and internal and external operating experience. Some examples of significant improvements:

- replacing the cooling coils of the ventilation systems in the reactor building and electricity supply building;
- applying a new coating on the external concrete shell of the reactor buildings.

In addition to the improvements from the PSRs, numerous technical, procedural and organizational improvements have been made as a result of [Electrabel, 2012a]:

- internal inspections, maintenance, internal operating experience management;
- external sources such as external operating experience management, studies and research, international memberships;
- nuclear incidents and major accidents such as Three Miles Island, Chernobyl and Fukushima (project Belgian Stress Tests - BEST, triggered by the Fukushima nuclear incident).

3.4.7.1 Methodology

The maximum permissible risks are included in the safety report; as a result of changes to the plant, accident analyses must ensure that the impact of the change on nuclear safety maintains at least the same level of safety as before implementation [FOBZ, 2011]. The risk assessments should assume accidents with both an internal and external potential event to be considered. Examples of accidents include:

- equipment failure;
- loss of coolant accidents (LOCA);
- loss of internal electricity supplies;
- human errors;
- accidents such as fires, explosions and floods with internal causes;
- extreme meteorological conditions;

- flooding;
- earthquakes;
- loss of external power supply;
- aircraft crash and
- failure of nearby industrial activities and transportation (domino effect).

The risk of an accident depends on two factors; the probability of its occurrence and the consequences of the event.

Based on the probability of occurrence, potential events are classified as follows:

I normal operating conditions and operating transients[24] (expected during normal operation)[25];
II incidents that occur occasionally (up to once a year);
III infrequent accidents (one time during the entire operating period);
IV limiting accidents (basically never) [Tractebel, 2015].

Class I and II events must not result in the loss of integrity of barriers holding back radioactive products; Class II events must, at most, result in an automatic shutdown of the reactor. A Class III event, which must occur no more than once during the duration of operation, may result in minor damage that does not allow the reactor to be restarted immediately. A Class IV event may result in the discharge of radioactive products, although the probability of these accidents occurring is very low. Should an accumulation of incidents still result in such an accident, the discharge resulting from the accident must comply with the applicable limits.

To determine the probability of the various accidents, a so-called probabilistic safety study (Probalistic Safety Analysis; PSA) must be performed. Here, based on statistical data, the probability of those accident scenarios that may lead to a radiological accident is calculated. Core Damage Frequency (CDF) is a widely used indicator to demonstrate compliance with nuclear safety goals [IAEA,2010]. The core damage frequency is a measure of the risk that given the way a reactor is designed and operated, the fuel in the reactor could be damaged by an accident[26]. After the probability is calculated, the radiological consequences of the accident scenario must also be determined, mainly by dispersion calculations of released radioactive materials.

The dispersion of radioactivity and the resulting committed effective dose are calculated based on an FANC-approved methodology prepared by the United States Nuclear Regulatory Commission [NRC, 1977]. The results must comply with the Royal Decree authorizing the construction of a nuclear power plant at Doel and the associated general data under Article 37 of the Euratom Treaty [Electrabel, 1981].

[24] Operating transient: a deviation by which one of the operating parameters of a nuclear power plant (including power, pressure, temperature, coolant flow rate) deviates from the set value and by the automatic controls of the nuclear power plant.

[25] So, strictly speaking, these incidents cannot be considered an accident.

[26] https://www.nrc.gov/reading-rm/basic-ref/glossary/core-damage-frequency.html (visited on: Febr. 2021)

The required safety studies are documented in the safety report [VR-KCD] and are periodically updated, based on updated insights and standards. In KCD-1 and KCD-2, Loss Of Coolant Accidents (LOCA) and fuel handling accidents (FHA) are the so-called reference accidents; accidents that can have the greatest conceivable radiological consequences [Electrabel, 1981] [VR-KCD]. The impact assessment in the following sections therefore focuses on these accidents.

In line with the international regulatory framework, the radiological consequences of normal operation, accidents considered during the design of power plants and so-called Beyond Design Base Accident (BDBA) should be evaluated. Also, this international regulatory framework provides that more realistic assumptions may be considered when calculating the radiological consequences of beyond design base accidents than for design base accidents. A beyond design base accident is an accident that goes beyond a design-based accident. The probability of a beyond-design base accident occurring is still much lower than the probability of a design-based accident. For this reason, the design for the beyond-design base accidents considers only how to reduce the residual risk by reasonable means (technical, organizational).

For KCD-1 and KCD-2, one beyond design base accident was analyzed that is representative of all other beyond design base accidents of internal and external origin, including the scenario considered by Electrabel of an aircraft crashing into the nuclear power plant. This is a scenario of a very serious accident (i.e., with core meltdown) where the first event is the total loss of electrical power (both internal and external) without taking into account recovery actions or interventions by operators or the emergency plan. This scenario is called complete station blackout (CSBO). In this case, the accident was assumed to evolve where the fuel rods in the reactor core melted, vessel ruptured, the pressure in the primary containment reached the design pressure of the filtered vent, and all radioactive gaseous material present was released into the environment through the filters of the Filtered Containment Vent (FCV). Radiological consequences have been evaluated for this representative outdoor beyond design base accident (CSBO) with a very low probability of occurrence [Tractebel, 2020e].

Accident analyses in the context of the LTO Project
To assess the impact, most relevant projects and their potential impact on nuclear safety of KCD-1 and KCD-2 are briefly described. It was also checked for the reference accidents (LOCA and FHA) whether, and if so, which proposed changes within the LTO Project could affect the radiological consequences of the accident in question. Radiological consequences were then determined for the situation where the changes are implemented [Tractebel, 2020d].

3.4.7.2 Baseline situation

To enable the life time extension of KCD-1 and KCD-2, the LTO (Long Term Operation) project was started. One of the elements of this project is the implementation of the fourth PSR to reassess and further improve the nuclear safety of the plant.

At the same time, the European Nuclear Safety Regulators Group (ENSREG) decided that following the Fukushima Daiichi nuclear power plant accident, a full and transparent risk and safety assessment should be conducted for all nuclear power plants in Europe. In Belgium, the Belgian Stress Tests (BEST) project came out of this evaluation. The BEST project has been added to the LTO Project.

The LTO project (including PSR 4 and BEST) has led to several design improvements [Electrabel, 2012a], such as:

- Installing two emergency sealing water primary pumps (RJ) per unit instead of one in the emergency systems building (GNS) ;
- Making the Refueling Water Storage Tanks (RWST) of KCD-1 and KCD-2 earthquake-proof to increase the robustness of these units;
- Improving automatic fire suppression in the turbine hall;
- Equipping a motor on the large isolation valves between the stationary cooling circuit (SC) systems;
- Improving the physical separation of the 6 kV power cables of the GNS in the Electrical Auxiliary Services (GEH) Building;
- Installing a Filtered Containment Vent (FCV);
- Tightening the procedures for scram testing (formal pre-job briefing) and organising annual testing on the control of the partial scram breakers.

All design improvements, as mentioned in Long Term Operation Technical Report of Doel 1&2 [Electrabel, 2012a] are planned and executed in the period 2012-2018[27]. Design improvements will be implemented incrementally, starting now, in parallel with actions due to obsolescence. The study phase, qualification, manufacture, delivery, construction and installation of the material and buildings must be taken into account. The first few years are used for preparations, so the effective construction period is from 2015 to 2018.

The most relevant change with respect to the accident analyses concerns the installation of a filtered pressure relief system or Filtered Containment Vent (FCV), to protect the containment from overpressure in the event of a nuclear meltdown accident, avoiding unacceptable radiological consequences for the environment [Tractebel, 2020d]. The baseline situation is defined as the period 2012-2014. During 2015 through 2018, the LTO measures are implemented. So, in the baseline situation, FCV is not yet available.

KCD-3, KCD-4 and WAB have their own periodic safety evaluation cycle. In the day-to-day operation of these facilities, there is a constant focus on continuous improvement and ensuring safety [Electrabel, 2013a].

3.4.7.3 Impact assessment

The potential impacts of accident situations (design-based accidents and beyond design base accident) on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  It is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.

[27] During the 2019 maintenance outage (which lasted until early 2020), the final work for the benefit of LTO was completed. In particular, as not all the radioactive waste from the construction phase has been processed and this affects the totals of the years after 2018, this EIR assumes that no LTO work will be carried out after 2019.

  - Operational phase in future situation (period 2019 - 2025): regular operation after implementation of the LTO measures;
- Zero alternative, the Project is not completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the baseline situation (2012-2014) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[28].

3.4.7.3.1 Operational phase of the Project between 2015 and 2018

The LTO synthesis report contains the integrated action plan, which was submitted to FANC for review [Electrabel, 2015c]. FANC, together with Bel V, analyzed this plan and that analysis showed that the Project is feasible and the safety of KCD-1 and KCD-2 remains guaranteed during the period of Long Term Operation [FANC, 2015a]. Depending on the type of work, the LTO measures can be carried out during normal operations or can only be carried out during an outage. These outages are extended where necessary. In particular, the technical LTO measures can only be implemented during an outage. During the period 2015-2018, these measures will be implemented and that period is referred to within this Project as the "operational phase of the Project between 2015 and 2018." § 1.5 indicates a number of design improvements that came out of the LTO (incl. PSR 4) and BEST [Electrabel, 2012a] projects as part of the action plan. The safety improvement for these is indicated below:

- Installing two emergency sealing water primary pumps (RJ) per unit instead of one in the emergency systems building (GNS) ;
  These additional RJ pumps provide a backup for the emergency sealing water primary pumps already in place. The probabilistic safety study shows that this significantly reduces the probability of a core meltdown; in other words, it significantly reduces the probability of an accident situation where a core meltdown can occur.

- Making the Refueling Water Storage Tanks (RWST) of KCD-1 and KCD-2 earthquake-proof to increase the robustness of these units;
  Making the RWSTs earthquake-resistant further increases the robustness of the entire plant. These tanks are a design control, to have borated water available in case of accidental situations. This water can be used to cool the reactor core and prevent a nuclear chain reaction.

- Improving automatic fire suppression in the turbine hall.
  In addition to improving the automatic fire suppression system, additional fire separation walls will be installed in the basement of the turbine hall. This prevents the possible horizontal spread of oil. Together with the increase in efficiency of the extinguishing systems, this significantly reduces the risk of an oil fire in the turbine hall.

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[28] For further information about this assumption, see § 1.1.3

- Equipping a motor on the larger isolation valves between the stationary cooling circuit (SC) systems.
  This (automatic) motor allows the large isolation valves to be closed more quickly, which, if desired, allows a SC system to be isolated more quickly.

- Improving the physical separation of the 6 kV power cables from the GNS in the Electrical Auxiliary Services (GEH) Building.
  This physical separation will significantly reduce the likelihood of multiple power cables failing at the same time due to fire. This increases the reliability of the GNS's safety systems.

- Installing a Filtered Containment Vent (FCV).
  During an extreme accident (with a very small likelihood of occurrence) overpressure in the reactor building could occur. To prevent overpressure, an exhaust from the reactor building must be present. In order to discharge as little radioactivity as possible at the same time, in that possible situation, the air is passed through a filter.

- Tightening the procedures for scram testing (formal pre-job briefing) and organising annual testing on the control of the partial scram breakers.
  Tightening up the procedures of scram tests will reduce the likelihood of errors during such tests. This increases the reliability of the scram system[29].

The remaining LTO measures in the action plan contribute to the safety improvements of KCD-1 and KCD-2. All of these measures together reduce the likelihood of an accidental situation.

In addition to various safety improvements, as part of the integrated action plan, the management of obsolescence and the qualification of unit components has been perfected with the aim of ensuring the availability and reliability of the KCD-1 and KCD-2.

It is assumed that the measures will not be completed until the end of the 2015-2018 period so that no credit can be taken for these measures in this period.

3.4.7.3.2 Operational phase in the future situation (period 2019 - 2025)

After implementation of all LTO measures, the nuclear safety of KCD-1 and KCD-2 has improved. This reduced the likelihood of an accident situation involving a radioactive discharge, which also reduces the likelihood of a potential environmental impact.

As part of the Project, the probabilistic safety assessment (PSA) has been updated and the indicator for the core damage frequency (CDF) has also been updated. Compared to the baseline situation, the CDF is more than halved. Here, the smaller the CDF, the smaller the risk of an accident involving core damage and the safer the nuclear power plant. It should be noted that the CDF was already below the IAEA target in the baseline situation. Due to the LTO measures, KCD-1 and KCD-2 are approaching the guideline values for new reactors, according to IAEA SSG-3 [IAEA, 2010].

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[29] The scram system causes the nuclear chain reaction to stop.

The reference design-based accidents, valid for KCD-1 and KCD-2, LOCA (rupture of a primary circuit) and FHA (fuel handling accident at the fuel basin) were analyzed again as part of the Project [Tractebel, 2020d]. This was also done for the reference beyond design base accident case Complete Station Black-Out (CSBO) [Tractebel,2020e]. The conservatively determined[30] effective dose resulting from these accidents are shown in Table 3-42.

Table 3-42 Effective dose and the thyroid dose at the site boundary of KCD due to the occurrence of LOCA and FHA, compared to dose limits as described in the general data under Article 37 of the Euratom Treaty, which are a part of the license, in mSv. Both determined for the pessimistic (conservative) model. And the reference beyond design base accident CSBO.

Reference accident		**Dose at the site boundary [mSv]**	**License limits [mSv]**
LOCA	Effective dose	1.96	20.4
	Thyroid dose	38.5	38.5
FHA at the fuel basin	Effective dose	1.44	5.7
	Thyroid dose	16,9	24.7
CSBO	Effective dose	13.2	none
	Thyroid dose	5.5	none

The above table shows that the committed effective doses resulting from both reference design-based accidents are within the set limits. It is also noted that the doses for the beyond design base accident CSBO are lower than the limits applicable at the site boundary as described in the general data under Article 37 of the Euratom Treaty as part of the license [Electrabel, 1981].

At the same time, KCD-3, KCD-4, WAB and FCB are operated and they are not part of the Project. Therefore, the probability of a possible accident situation involving a radioactive discharge does not change. So neither is the likelihood of a potential environmental impact. Summed for the entire site, the probability of a potential environmental impact becomes lower.

3.4.7.3.3 Zero alternative

If no LTO takes place, both KCD-1 and KCD-2 will be permanently discontinued. For the removal of the residual heat, the fuel elements will still need to be cooled, initially using the reactor cooling circuit. The reactors will be unloaded permanently. The fuel elements are transferred to the fuel basin and cooled using the cooling circuits of this basin. This transition phase until dismantling begins will occur under both the Zero Alternative (no Project) and the Project.

In both situations, the transition phase is the same in terms of duration and preparations for dismantling. The only difference is the timing of the Post Operational Phase. Also, there will be no difference with respect to nuclear safety between the Zero Alternative (no Project) and the Project. This also applies to an

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[30] According to the applicable guidelines including Safety Guidance on the application of conservative and less conservative approaches for the analysis of radiological consequences, Bel V, June 2017.

incident with a possible radioactive release and the associated environmental impact. The only difference is that under Zero Alternative, the risk of a potential accident is no longer present.

At the same time, KCD-3, KCD-4, WAB, and FCB are operated and the probability of a potential accidental radioactive discharge situation for these facilities does not change. So neither is the likelihood of a potential environmental impact. When aggregated for the entire site, the probability of an environmental impact occurring due to an accident situation will be lower under the Zero Alternative (no Project) than under the baseline situation because KCD-1 and KCD-2 will not be operated further.

Post Operational Phase of KCD-1 and KCD-2

During POP phase 1, all fuel assemblies are transferred from both reactors to the fuel basin. Phase 1 ends when all fuel elements have been transferred. From that point on, only the residual heat is removed via the fuel basin cooling circuits. When both reactors are empty, the reactor accidents described in the safety report are no longer relevant [VR-KCD]. The only accident that does remain relevant is the fuel handling accident (FHA) at the fuel basin.

As fuel elements are still present during Phase 2 and Phase 3 of the Post Operational Phase, the only relevant accident during both of these phases remains the FHA. As shown in Table 3-42, the effective dose at the site boundary and the thyroid dose due to this accident remain below the limits.

In POP phase 4, no more fissile material is present at either reactor and so the FHA is no longer possible.

3.4.7.4 Cross-border effects

Although the probability is very low, the consequences of major accidents will be cross-border in nature. The effects on the Netherlands are especially relevant, as this national border is close by and the most common wind direction (southwest) will carry any released radionuclides towards Dutch territory. As the project measures reduces the probability and possible consequences of accidents, this reduction will also apply to the Dutch territory.

In the accident analyses carried out within the framework of the Project, the possible radiological consequences of the accident in question at the Dutch border were examined for the reference accidents (LOCA and FHA) [Tractebel, 2020d]. Table 3-43 shows the conservative results, determined according to the applicable guidelines, are presented and which show that both reference accidents meet the corresponding limits at the Dutch border [Tractebel, 2020d]. This was also done for the reference beyond design base accident case Complete Station Black-Out (CSBO) [Tractebel,2020e].

Table 3-43 Effective dose and the thyroid dose at the Dutch border due to the occurrence of LOCA and FHA, compared to dose limits as described in the general data under Article 37 of the Euratom Treaty, which are a part of the license, in mSv. Both determined for the pessimistic (conservative) model. And the reference beyond design base accident CSBO.

Reference accident		Dose at the Dutch border [mSv]	License limits [mSv]
LOCA	Effective dose	0.28	2.7
	Thyroid dose	5.4	5.4
FHA at the fuel basin	Effective dose	0.46	1.5
	Thyroid dose	5.4	8.0
CSBO	Effective dose	0.45	none
	Thyroid dose	0.19	none

The above table shows that the committed effective doses resulting from both reference design-based accidents are within the set limits. For the reference beyond design base accident CSBO, doses at the Dutch border are lower than the limits applicable to the Dutch border described in the general data under Article 37 of the Euratom Treaty, as part of the license [Electrabel, 1981]. It should also be noted that the doses are lower than those imposed for evacuation, sheltering and stable iodine ingestion in the Royal Decree on Emergency Planning [Decree, 2018] (see Table 3-44).

Table 3-44 Dose reference level for nuclear and radiological emergency plans.

Protective Measure	Dose criteria and integration period	Target group	Guideline [mSv]
Find shelter	Effective dose in 24 hours		5
Ingestion of stable iodine	Equivalent dose to the thyroid	Children, pregnant and breastfeeding women	10
		Adult	50
Evacuation	Effective dose in 7 days		50

Depending on the severity of the accident and weather conditions, radionuclides may also be carried to other European countries. On 13 August 2020, under the new law on the postponement of the shutdown of KCD-1 and KCD-2, the Federal Public Service Economy notified the authorities of the countries located within a 1,000 km radius around KCD-1 and KCD-2. For the countries of France, Germany, Luxembourg, and the United Kingdom (bordering Belgium), dose calculations were performed based on the calculations done for the Dutch border based on the design-based accidents FHA and LOCA. These calculations show that the doses would be reduced by a factor of about 65 for France, 80 for Germany,120 for Luxembourg and 130 for the United Kingdom compared to the results at the Dutch border. For other countries that are further than 1000 km away from KCD-1 and KCD-2 (such as Sweden, Austria, Poland, Czech Republic, Denmark, and Ireland), the impacts are limited by the impacts evaluated at the Luxembourg border, i.e., at least 120 times lower than at the Dutch border, thus implying a non-significant radiological impact due to the design-based accidents [Tractebel, 2020d].

The radiological consequences of the reference beyond design base accident CSBO were also mapped. This evaluation shows that the doses would be reduced approximately by a factor of 55 for France, 67 for Germany, 103 for Luxembourg, and 114 for the United Kingdom compared to the results at the Dutch border, resulting in significantly lower results. For other countries that are further than 1000 km away from KCD-1 and KCD-2 (such as Sweden, Austria, Poland, Czech Republic, Denmark, and Ireland), the impacts are limited by the impacts evaluated at the Luxembourg border, i.e., at least 103 times lower than at the Dutch border, thus implying a non-significant radiological impact due to the beyond design base accident [Tractebel, 2020e].

3.4.7.5 Monitoring

Any change in the plant is coordinated with FANC, where calculations are performed to determine the effect of the modification on nuclear safety. Only after approval of FANC may the relevant change be carried out.

3.4.7.6 Mitigating measures

Electrabel can and must meet the accident criteria in force in Belgium. To this end, KCD-1 and KCD-2, as well as KCD-3, KCD-4, WAB and the FCB, are equipped with various safety features and have an emergency plan which must be consistent with the national nuclear and radiological emergency plan. No additional mitigation measures under the Project are therefore necessary.

3.4.7.7 Knowledge gaps

There are no gaps in knowledge that affect the alternatives considered and thus do not impede decision making.

3.4.7.8 Conclusions

After implementation of the LTO measures (the Project), nuclear safety improved. Updating the probabilistic safety assessment (PSA) reveals that the core damage frequency (CDF) has been more than halved. This results in a lower probability of an accident situation involving radioactive discharges during the operational phase than in the baseline situation. In particular, the Filtered Containment Vent reduces the likelihood of any radioactive discharge resulting from a possible accident situation.

The reference accidents loss of coolant (LOCA), fuel handling accident (FHA) at the fuel basin, and complete station blackout (CSBO) were analyzed again for the Project. For all three reference accidents, the dose is lower than the applicable limits described in the general data under Article 37 of the Euratom Treaty as part of the license [Electrabel, 1981]. It should also be noted that the doses for the reference beyond design base accident are lower than those imposed for evacuation, sheltering and stable iodine ingestion in the Royal Decree on Emergency Planning [Decree, 2018] (see Table 3-44).

For countries that are further away from KCD than the Netherlands, the dose factors are smaller than dose at the Dutch border, which therefore implies that there is a non-significant radiological impact due to the reference accidents.

For the Zero Alternative, the likelihood of an accidental environmental impact due to the KCD site will be even lower than for the Project, because KCD-1 and KCD-2 will not be operated further.

Thanks to KCD's emergency organization and the National Nuclear and Radiological Emergency Plan, the potential consequences in the event of a possible accident situation are managed.

3.4.8 Total committed effective dose

3.4.8.1 Methodology

This paragraph determines the maximum, total committed effective dose to which a member of the population may be exposed, as a result of the operation of KCD. This total committed effective dose comes from four sources, described separately in earlier paragraphs:

- Direct radiation (§3.4.1),
- Committed effective dose resulting from gaseous discharges (§ 3.4.3);
- Committed effective dose resulting from radioactive liquid discharges (§3.4.4)

The maximum dose that a member of the population may receive is calculated for a so-called "critical individual," which is a person who may incur the maximum dose based on very conservative assumptions. It is assumed, for example, that the person will be at the site boundary where the highest dose rate is measured throughout the year, while at the same time the person will also be at the site with the highest airborne activity and also at the site with the highest activity deposition.

The total committed effective dose due to liquid and atmospheric discharges are based on dose calculations according to the method published by the United States Nuclear Regulatory Commission (US-NRC) [NRC, 1977] and adapted by FANC to the Belgian context and recorded in *Méthodes et hypothèses relatives au calculating de doses à la population dues aux rejets de routine pour les établissement nucléaires de classe I en Belgique* [FANC, 2013a].

The direct dose is based on measurements at the site boundary. The total committed effective dose to the population due to operation is tested against the legal limit from the ARBIS of 1 mSv per year [ARBIS]. As described earlier, this limit of 1 mSv applies to the dose resulting from the operation of a nuclear facility and is in addition to the natural background radiation (about 4.0 mSv per year [FANC, 2018]).

3.4.8.2 Baseline situation

The total committed effective dose due to whole site operation (KCD) for an adult critical individual is summarized in Table 3-45. The committed effective dose due to liquid and atmospheric discharges are based on dose calculations according to the method published by the United States Nuclear Regulatory Commission (US-NRC) [NRC, 1977]. The direct dose is based on the highest measurement at the site boundary (Table 3-3). This measured dose was corrected for the natural background radiation as determined by FANC for the north of Belgium (0.7 mSv per year) [FANC, 2018]. The dose determined in this way is the most conservative (maximum) dose that a member of the population may incur as a result of the operation of a nuclear power plant. This results in an overestimate of the real exposure.

Table 3-45 Committed effective dose for an adult resulting from the operation of KCD during the baseline situation (2012-2014).

Year	Direct [mSv/yr]	Gaseous [mSv/yr]	Liquid [mSv/yr]	Total [mSv/yr]
2012	0.22	0.0098	0.0011	0.23
2013	0.22	0.0094	0.00077	0.23
2014	0.20	0.0094	0.00060	0.21

The total committed effective dose for an adult is determined by the direct radiation at the site boundary. The discharges into both the Scheldt and the atmosphere only provide a marginal contribution to the total committed effective dose.

The total committed effective dose for the different age groups due to the operation of KCD-1 and KCD-2 is summarized in Table 3-46; this is the summation of the committed effective dose for direct radiation, liquid and gaseous discharges (§ 3.4.1, § 3.4.3, § 3.4.4). As direct radiation at the site boundary is the highest contributor to the total dose, and it is independent of age, the doses differ only marginally between age classes.

Table 3-46 Total committed effective dose to a critical individual resulting from the operation of KCD-1 and KCD-2 during the baseline situation.

	Total committed effective dose KCD-1 and KCD-2 [mSv/yr]					
Year	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
2012	0.22	0.23	0.22	0.22	0.22	0.22
2013	0.22	0.23	0.22	0.22	0.22	0.22
2014	0.20	0.21	0.21	0.21	0.21	0.21

The total committed effective dose for the different age groups due to the operation of KCD (KCD-1, KCD-2, KCD-3, KCD-4, WAB and FCB) is summarized in Table 3-47. Similarly, for the total dose from the site, the direct dose at the site boundary makes the highest contribution, resulting in only marginal differences in the total dose between the age classes. The committed effective dose remains well below the legal limit of 1 mSv per year for all years.

Table 3-47 Total committed effective dose for an adult resulting from the operation of KCD during the baseline situation.

	Total committed effective dose KCD [mSv/yr]					
Year	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
2012	0.23	0.24	0.23	0.23	0.23	0.23
2013	0.22	0.24	0.23	0.23	0.23	0.23
2014	0.21	0.22	0.22	0.21	0.21	0.21
Based on license limits	1	1	1	1	1	1

3.4.8.3 Impact assessment

The potential impacts of gaseous discharges on the environment are assessed for both scenarios to be addressed:

- Implementation of the Project
  It is broken down into two phases, each of which is covered in a separate section:
  - Operational phase of the Project between 2015 and 2018: the construction of the LTO measures. These are made particularly during outages. Electrabel also operates both KCD-1 and KCD-2 during this period.
  - Operational phase in future situation (period 2019 - 2025): regular operation after implementation of the LTO measures;
- Zero alternative, the Project is not completed and the operation of KCD-1 and KCD-2 stops in 2015.

The impact of the LTO of KCD-1 and KCD-2 is based on data collected from the baseline situation (2012-2014) and is determined for the period 2015-2025. Where possible, available data were used to test the expected effects against real data from the 2015-2018 period. For the purposes of evaluating the Project and the Zero Alternative, it is assumed that the environmental impacts of KCD-3, KCD-4, and the WAB will remain the same as in the baseline situation through 2025. This is a conservative assumption[31].

3.4.8.3.1 Operational phase of the Project between 2015 and 2018

As a condition of the LTO of KCD-1 and KCD-2, a package of measures to improve the safety of the units was prepared. These LTO measures are implemented in the period from 2015 to 2018, the period defined in this Project as the operational phase of the Project between 2015 and 2018.

During the operational phase of the Project between 2015 and 2018, the two units will remain in operation, the measures will be implemented mainly during outages. Because the work is primarily done during outages, no significant increase in atmospheric and liquid discharges is expected. Although the shielding of the reactor buildings will be sufficient to prevent a significant dose at the site boundary, local transports, for example to the water and waste treatment building, will potentially result in a slightly increased dose at the site boundary.

Given the nature of this Project, the dose sustained during the operational phase of the Project between 2015 and 2018 is already known. It is summarized in Table 3-48 and, with the exception of direct radiation, shows no significant change from the baseline situation.

As described earlier, the dose due to direct radiation is slightly increased compared to the baseline situation, which is presumably caused by additional internal transports of radioactively contaminated material.

[31] For further explanation on this assumption, see § 1.1.3

Table 3-48 Committed effective dose for an adult resulting from the operation of KCD during the operational phase of the Project between 2015 and 2018.

Year	Direct [mSv/yr]	Gas [mSv/yr]	Liquid [mSv/yr]	Total [mSv/yr]
2015	0.31	0.0099	0.00046	0.32
2016	0.29	0.010	0.00084	0.29
2017	0.26	0.0093	0.00082	0.27
2018	0.27	0.010	0.00072	0.27

The total committed effective dose for the different age groups due to the operation of KCD-1 and KCD-2 is similarly summarized in Table 3-49. In Table 3-50 this is summarized as a result of the operation of KCD (KCD-1, KCD-2, KCD-3, KCD-4, WAB and FCB).

Table 3-49 Total committed effective dose to a critical individual resulting from the operation of KCD-1 and KCD-2 during the baseline situation.

	Total committed effective dose KCD-1 and KCD-2 [mSv/yr]					
Year	**<1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**>17 years**
2015	0.31	0.31	0.31	0.31	0.31	0.31
2016	0.29	0.30	0.29	0.29	0.29	0.29
2017	0.27	0.27	0.27	0.27	0.27	0.27
2018	0.27	0.28	0.28	0.28	0.28	0.28

Table 3-50 Total committed effective dose for an adult resulting from the operation of KCD during the operational phase of the Project between 2015 and 2018.

	Total committed effective dose KCD [mSv/yr]					
Year	**<1 year**	**1-2 years**	**2-7 years**	**7-12 years**	**12-17 years**	**>17 years**
2015	0.31	0.33	0.32	0.32	0.32	0.32
2016	0.30	0.31	0.30	0.30	0.30	0.30
2017	0.27	0.28	0.28	0.27	0.27	0.27
2018	0.28	0.29	0.29	0.28	0.28	0.28
Based on license limits	1	1	1	1	1	1

As with the baseline situation, for both the site KCD and for KCD-1 and KCD-2 combined, direct radiation at the site boundary is the highest contributor to the total committed effective dose, resulting in only marginal differences in the total dose between the age classes. The committed effective dose remains well below the legal limit of 1 mSv per year for all years.

3.4.8.3.2 Operational phase in the future situation (period 2019 - 2025)

After the operational phase of the Project between 2015 and 2018, the units will be operated in a further operational phase in the future situation (period 2019 - 2025). Therefore, it is likely that the dose during the operational phase in the future situation will not be significantly different from the operational phase of the Project between 2015 and 2018. The total committed effective dose of KCD is shown graphically in Figure 3-36.

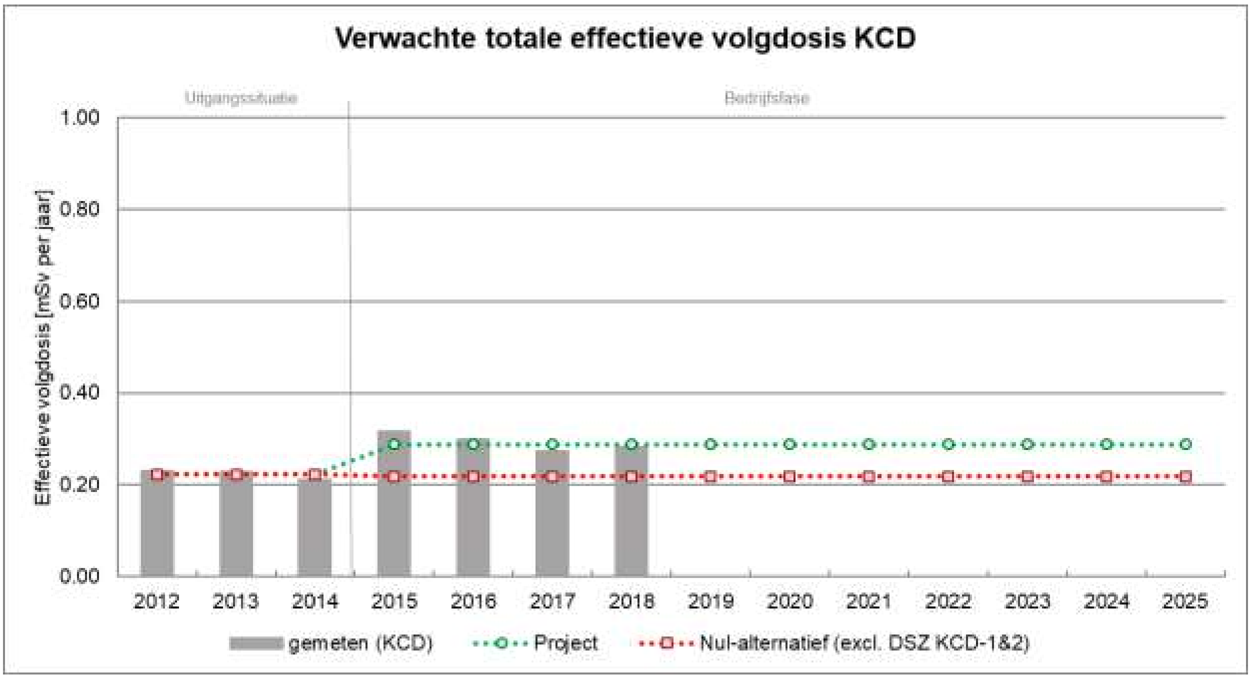

Figure 3-36 Expected total committed effective dose of KCD due to direct radiation, liquid and gaseous radioactive discharges, for the Project and the Zero Alternative.

Cumulative impact of the Project

Based on the previous descriptions, the maximum cumulative dose due to this Project is expected to be 3.3 mSv (11 years at 0.30 mSv/yr (average over 2015-2018). Because the various dose calculations use extremely conservative methods, the calculated cumulative dose resulting from this Project is a strong overestimate of a real dose.

Nevertheless, the calculated cumulative dose of 3.3 mSv is well below the induced cumulative dose limit[32] (11 years × 1 mSv=11 mSv) and no significant effects are expected. To illustrate, the average Belgian background dose over the period of this Project is over 43 mSv [FANC, 2018].

3.4.8.3.3 Zero alternative

Under the Zero Alternative, KCD-1 and KCD-2 will be shut down and the Post Operational Phase will begin. The difference between the Project and the Zero alternative is determined by the increase in direct radiation dose at the site boundary, which is likely caused by the greater number of spent fuel elements

[32] This is not a legal limit. The legal limit is 1 mSv per year [ARBIS].

stored at the FCB. On the other hand, the shutdown of KCD-1 and KCD-2 will stop the gaseous and liquid discharges resulting from the operation of these units.

As described in § 3.4.1 through § 3.4.6, the POP has no or temporary limited impacts on the environmental aspects considered. In general, it can be said that the annual radiological impact of POP is smaller than that of operating the unit in question.

This will take place under both scenarios. Under the Project scenario, it will occur 10 years later than under the Zero alternative. It is likely that the Post Operational Phase of KCD-1 and KCD-2 will be similar under both scenarios, so the environmental impacts are not expected to differ between the two scenarios.

3.4.8.4 Cross-border effects

Dose effects at the Dutch border

The Dutch Decree of 23 October 2017, establishing rules for the protection of individuals against the dangers of exposure to ionizing radiation, Article 9.2.1 states that the maximum dose for a member of the Dutch population resulting from the operation of a nuclear facility may not exceed 0.1 mSv per year. This is the Dutch dose limit due to direct radiation, liquid and gaseous discharges. Table 3-51 shows the total committed effective dose for the Dutch population due to the operation of KCD, based on what has been described for cross-border effects under direct radiation (§ 3.4.1), gaseous discharges (§ 3.4.3) and liquid discharges (§ 3.4.4).

Table 3-51 The committed effective dose due to the operation of KCD for the Dutch population was determined to be 0.027 mSv per year.

Direct [mSv/yr]	Gaseous [mSv/yr]	Liquid [mSv/yr]	Total [mSv/yr]
0.000078	< 0.027	0.00042	< 0.027

The above table shows that as a result of the operation of KCD the exposure limit for the population applicable in the Netherlands is met.

Dose effects at the border with other surrounding countries

For the other surrounding countries, France, Germany, Luxembourg and the United Kingdom, the committed effective dose was also calculated based on the distances from the respective country borders to KCD. These national borders are located at significantly greater distances from KCD than the Dutch border, i.e., approximately 97 km, 117 km, 177 km, and 195 km, respectively. Given these distances, the contribution of direct radiation to the total dose is reduced to zero. Calculations according to the diffusion models commonly used for this purpose, show that the committed effective dose at the borders with France, Germany, Luxembourg and the United Kingdom is significantly lower and thus also remains well below the limit of 1 mSv per year. The result of these calculations, both due to atmospheric discharges and liquid discharges, for the different age groups is shown in Table 3-52 for KCD.

Table 3-52 Total committed effective dose due to atmospheric discharges and liquid discharges by KCD based on the licensed limits for the borders with France, Germany, Luxembourg and the United Kingdom.

	Committed effective dose due to atmospheric discharges at KCD [mSv/yr]					
	<1 year	1-2 years	2-7 years	7-12 years	12-17 years	>17 years
France	0.0011	0.0013	0.0011	0.0097	0.0010	0.00096
Germany	0.00097	0.0011	0.00098	0.00086	0.00091	0.00085
Luxembourg	0.00075	0.00087	0.00075	0.00066	0.00070	0.00065
United Kingdom	0.00070	0.00082	0.00071	0.000062	0.00066	0.00061

3.4.8.5 Gap in knowledge

The existing uncertainties in knowledge with respect to total dose are described under direct radiation (§ 3.4.1), committed effective dose due to atmospheric discharges (§ 3.4.3) , and committed effective dose due to liquid discharges (§ 3.4.4).3.4.13.4.33.4.4

However, the available knowledge is sufficient to determine the effects of the total dose of this intention. The gaps in knowledge therefore do not affect the assessment and therefore do not hinder the decision making.

3.4.8.6 Conclusions

Based on the estimated dose due to the Project and the Zero alternative, it can be concluded that the legal limit for the population [ARBIS] is met, so there is no significant impact on humans and the environment.

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4 Conclusion

4.1 Non-radiological aspects

This section draws the overall conclusion regarding non-radiological environmental impacts based on the previous Chapter 2.

The table below indicates whether significant impacts were identified for the Project and the Zero Alternative. For the Project, impacts are first assessed from the 2015-2018 operational phase, together with the works related to LTO, compared to the situation without operation of KCD. The operational phase in the future situation (period 2019-2025) represents the effects of LTO from KCD-1 and KCD-2 relative to the baseline situation. The impact assessment of the zero alternative is not significantly different from that of the project. However, in the zero alternative, effects will decrease as early as 2015 rather than as late as 2025.

A plus (+) or minus (-) sign indicates whether the expected effect has a positive or negative impact on the environment. If an effect is negligible, this is indicated by a v. If an impact may be cross-border, this is indicated with a 'G'.

Table 4-1 Identification of potential non-radiological effects of KCD-1 and KCD-2

	Project		
	Operational phase 2015-2018 vs situation without operation KCD	**Operational phase in the future situation (period 2019 - 2025) compared to baseline situation**	**Zero alternative vs. situation without operation KCD**
Soil	- 1 / v	- 1 / v	- 1 / v
Water	- 3 to -1 / v	No additional impacts relative to operational phase 2015-2018	No effect quantification
Noise[1]	- 3 to -1 / v	- 3 to -1 / v	- 3 to -1 / v
Air	v	v	v
Biodiversity	-2 to -1/v	No additional impacts relative to operational phase 2015-2018	-2 to -1/v
Landscape, architectural heritage & archaeology	v	v	v
Human - health	v	v	v
Human - Mobility	- 1/ v	- 1	v
Waste	No assessment	No assessment	The amount of waste will be less

Key:
-3: considerably negative
-2: negative
-1: slightly negative
v: negligible

The effects are explained in more detail below.

4.1.1 Normal operation

4.1.1.1 Soil

The impact of the works that have taken place as part of the modifications for LTO can be assessed as slightly negative to negligible, for the soil section.There are no additional effects of the LTO situation expected, compared to the baseline situation.

The effects of the POP are also assessed as slightly negative to negligible. The difference between the POP in 2015 (= zero alternative) or in 2025 is somewhat limited.

However, it cannot be excluded that incidents with an impact on soil hygiene may occur in the future. However, KCD 1 and KCD-2are currently equipped with both technical and organisational measures to prevent or counteract possible contamination as much as possible. The continued operation of the nuclear

[1] The assessment was done according to the assessment framework. This is an interpretation according to the range of scores obtained. It is assessed separately for the day period and the night period. For the night period, the final scores are -3 to V and for the day period, -2 to V. If the consideration is applied to the operational phases compared to the baseline situation 2013-2014, the noise impacts are negligible for all phases.

power plant will always be carried out in accordance with the latest available good practices, thus significantly reducing the risk of soil contamination. As far as accidental emissions are concerned, the reporting system (for incidents, among others) will be strictly followed at all times in order to identify, analyse and remedy critical points.

The operation of the Doel 1 and 2 units has no impact on the salt deposition in the environment, and thus on soil use and soil suitability.

No additional mitigating measures or recommendations are considered necessary.

4.1.1.2 Water

The water supply, the infiltration and discharge characteristics and the emissions to the water system will not differ significantly in the LTO situation from the emissions in the baseline situation. There are no additional effects of the LTO situation compared to the baseline situation.

The project includes a re-licensing of the existing KCD systems of KCD-1 and KCD-2 and the water balance for the base years 2013-2014 is considered representative for the production in the following years of the re-licensing period. Therefore, no relevant changes in water consumption and water balance are expected compared to the baseline situation.

The main impact of KCD on the water system compared to the situation without operation of KCD is the discharge of wastewater and cooling water into the Scheldt. The impact of wastewater discharge is assessed as negligible because the average concentration increase in the Scheldt due to the activities of KCD compared to the environmental quality standard (EQS) is less than 0.1%. On the other hand, a frequent operation of KCD's sanitary wastewater collection wells into the Scheldt is expected to have a negative effect. The discharge of the cooling water has a negative to considerably negative impact as a result of the temperature increases.

No mitigating measures are set from the Water section. The following recommendations are made:

- To monitor active chlorine in cooling water based on the shock dosage of NaOCl, it is recommended to perform the monitoring of active chlorine with an online measuring sensor, with a detection limit up to approx. 10 µg/L (instead of 100 µg/L in the existing condition). This in order to be able to refine the control of the dosage of NaOCl with the aim of a lower NaOCl consumption, lower active chlorine levels in the discharged cooling water and less AOX formation.
- Considering the considerable amount of paved surface of KCD, the frequency and volume of flooding of the collection wells for sanitary waste water from the site to the Scheldt in the baseline situation and in the operational phase 2015-2018, the fact that the environmental quality standards for N, P and COC for the Scheldt are not met in the baseline situation and in the operational phase 2015-2018 and the expected periods of intense rain in winter and heavy thunderstorms and water shortages in summer due to climate change, the Water section recommends examining the feasibility of the following measures at concept level and according to the Best Available Technology:
    - Source-specific measure: for new projects, analyse the impact of disconnecting rainwater from sanitary wastewater and the possibilities for reuse of rainwater, infiltration or buffering

according to BAT. The climate-scaled showers must be taken into account. The high-impact scenario provides a good frame of reference for making KCD more climate-proof;
    - End-of-pipe measure: analysis of the installation of additional collection volume for sanitary waste water according to BAT with the aim of reducing the operation of the sanitary waste water collection wells.

4.1.1.3 Noise

In general, it can be said that no distinctive noise effects are expected for the different operational phases compared to the baseline situation 2013-2014. The deviations in the assessment points are limited to less than 0.5 dB(A) for all operational phases compared to the situation in 2013-2014. This means that the noise effects and assessment already to be determined for the situation 2013-2014 will be maintained for the coming years.

The specific noise level from the continuous sources of the KCD at the western, southern and northern assessment points (= direction where there is still some habitation) is considered to be 'minor negative'. In addition, at these assessment points (200 m from the plot boundary) for the specific noise level, the applicable guide value during the day, evening and night period is met.

Although the nearby houses are not among the assessment points (as they are more than 200 m away from the plot boundary), a limited noise increase to a maximum of 1.5 dB(A) on the original ambient noise level is obtained there, as a result of which the maximum noise effect can be considered 'minor significant'.

In the east, a 'negative' effect is obtained for the assessment point, located in the nature reserve along the Scheldt and determined mainly by the noise contribution of the cooling towers

In 2010, a remediation study was already carried out with regard to the noise impact from the cooling towers. In a study carried out by Technum (Studie geluidsanering koeltorens (Cooling towers noise remediation study); 090-390-0225 14/06/2012) the falling water was identified as the cause of the noise emission. In addition, a number of possible measures were proposed to reduce the noise contribution to the surrounding area:

- Source-specific measures:
    - Reduction of falling height
    - Floating, noise-dampening mats
- Transfer-restriction measures
    - Silencers around the cooling towers
    - Noise barriers along the cooling towers

The feasibility of the remediation measures was investigated by the constructor Hamon Thermal Europe and the engineering firm Tractebel. The modification of the cooling tower is not justified from an economic and safety point of view. All this was presented to the monitoring committee which accepted the studies and the decisions.

The cross-border effect on Dutch homes is expected to be limited to a maximum of 30 dB(A) for the specific noise level from KCD's continuous noise sources. It can then be assumed that KCD will not cause an increase in the ambient noise levels at the houses under consideration in the Netherlands.

Additional mitigating measures will therefore not be formulated for the future operational phases.

4.1.1.4 Air

KCD-1 and KCD-2's effects on air quality are:

- in the basic alternative to be assessed as negligible, both during the operational phase and during the Post Operational Phase;
- in the Zero alternative to be assessed as negligible, both during the operational phase and during the Post Operational Phase;

The continued operation of the Doel 1 and Doel 2 power plants for a period of 10 years can also be assessed as negligible.

With regard to direct CO_2 emissions, no significant difference is expected between the zero and the basic alternative.

However, it is assumed that in the zero alternative more electricity is imported than in the LTO situation. Consequently, indirect CO_2 emissions will be higher in the Zero alternative than in the LTO situation (basic alternative). In that respect, the LTO situation is more positive for the climate than the Zero alternative (assuming that everything else remains the same). However, the assumptions contain a great deal of uncertainty.

Given the absence of significant impacts, no mitigating measures or recommendations are proposed.

4.1.1.5 Biodiversity

The impacts of eutrophication and acidification, rest disturbance, water intake, cooling water discharge, and chemicals will not be significantly different in the LTO situation compared to the baseline situation. There are no additional effects of the LTO situation compared to the operational phase in the baseline situation.

The nitrogen deposits of KCD in the present project do not have a significant negative effect compared to the situation without operation of KCD on eutrophication of the surrounding European habitat types in the Special Protection Area - Habitats 'Schelde- en Durmeëstuarium van de Nederlandse grens tot Gent' and of the vegetation on the mudflats and salt marshes in the (partly overlapping) VEN area 'Slikken en schorren langsheen de Schelde'. The acidifying depositions from KCD assessed in the current project will not have a significant adverse effect on ecosystems in the study area compared to the situation without operation of KCD. Therefore, no significant negative effects are expected from acidification as a result of the operational activities of the KCD on the surrounding European habitat types in the Special Protection Area - Habitats 'Schelde- en Durmeëstuarium van de Nederlandse grens tot Gent' and of the mud and salt marsh vegetation in the (partly overlapping) VEN area 'Slikken en schorren langsheen de Schelde'.

To the east of the KCD, the 55 dB nuisance contour extends into the Special Protection Area - Birds 'Schorren en polders van de Beneden-Schelde', also designated as the VEN area 'Slikken en schorren langs de Schelde' and as a Ramsar area. Rest disturbance due to the operation of KCD along the reed beds and mudflats on the banks of the Scheldt, near the KCD, is assessed as negative compared to the situation without operation of KCD. North of the KCD the 50 dB and 45 dB nuisance contours do not reach the protected nature reserve 'Schor Ouden Doel' (negligible effect). To the west and south of KCD, the nuisance contour of 50 dB is largely limited to the KCD site itself and there is only a slight overlap with the Special Protection Area - Birds 'Schorren en polders van de Beneden-Schelde'. The rest disturbance caused by the operation of KCD in the polder areas to the west and south of KCD is assessed as a slightly negative effect compared to the situation without operation of KCD.

For the Doel 1 and 2 cooling water intake, mechanical treatment takes place outside the dike, at the level of the water intake, by means of grids on the inlet. Fish and crustaceans cannot enter the cooling water circuit in this way. Therefore, no mortality of fish or crustaceans will be observed at this intake. At the cooling water intake for Doel 3 and 4, a fish protection system was installed at the water intake with a fish-friendly filter system and a drain channel. Sound waves keep fish away from the intake. As a result of these measures, it can be said that no significant negative effects are to be expected with regard to mortality of fish and crustaceans at the level of water intake.

The impact of the KCD's cooling water discharge on the aquatic communities in the Lower Scheldt is not considered to be considerably negative compared to the situation without operation of KCD.

During the operation of KCD, the following effluents are produced: sanitary wastewater, industrial wastewater and cooling water. The discharge of nutrients into the Scheldt can cause eutrophication. The discharge of hazardous materials into the Scheldt can cause ecotoxicological effects:

For the nutrient parameters nitrate+nitrite+ammonium and orthophosphate, an annual average negligible contribution is calculated in the Water section. Therefore, no significant eutrophying impact is expected on an annual average basis from the discharge of the KCD to the Scheldt, compared to the situation without operation of KCD. In the Water section, frequent operation of the sanitary waste water collection wells was found. Although the load is rather limited, these operations can create peaks of nutrient concentrations in the Scheldt at the level of KCD, in the area within the breakwater where the discharge of the sanitary and industrial wastewater and cooling water of the KCD takes place.

Sodium hypochlorite (NaOCl) is added to the cooling water to prevent biofouling. The NaOCl reacts to form chlorides. The levels of active chlorine in KCD's discharged cooling water are below 100 µg/l. It can be concluded that at times of discharge of active chlorine, acute toxicological effects for aquatic organisms can occur locally around the discharge point for a short period of time (slightly negative effect).

4.1.1.6 Landscape, architectural heritage & archaeology

The impact of the works that have taken place as part of the modifications for LTO can be assessed as negligible for the Landscape, architectural heritage & archaeology section. There are no additional effects of the LTO situation expected, compared to the baseline situation.

The effects of the POP and for the Zero Alternative are also negligible.

For the Landscape, architectural heritage & archaeology section, no monitoring and evaluation measures are needed.

4.1.1.7 Human - health

The LTO of Doel 1 and 2, including the construction and operation of the plants, as well as the activities during the Post Operational Phase have no relevant health effects compared to the zero alternative.

Given the absence of significant impacts, no mitigating measures or recommendations are proposed.

4.1.1.8 Human - Mobility

The traffic volumes caused by the transport of KCD on the access road to KCD is significant at peak times and negligible beyond.

The impact of the works that have taken place as part of the modifications for LTO can be assessed as slightly negative at most, for the mobility section. Relative to the baseline situation there is a slight increase in the number of transports, respectively due to construction traffic. In the LTO situation, a slight increase in the number of transports is also expected due to the additional number of employees. The effect is assessed as slightly negative. During the POP, there will be a gradual decrease in staff, together with a limited increase in material transports. The knock-on effect on traffic flows is assessed as negligible. In the Zero alternative, a reduction in the workforce would be expected from 2015 onwards, which would have a negligible impact on traffic flows. In the LTO situation, this decline will only occur after 2025.

On the basis of the impact assessment, no mitigating measures are considered necessary. However, some recommendations are proposed:

- Further focus on sustainable modes such as cycling. This can be further expanded by constructing sufficiently comfortable bicycle sheds (covered). Initiatives regarding company bicycles, bicycle allowances, shower facilities and bicycle sharing can also contribute to making travel to and from work more sustainable.
- Focus on carpooling. This has a positive impact on traffic generation and parking needs. By encouraging carpooling within the company (e.g. reserved car-pool parking spaces, car-pool fee, car-pooling system) both among permanent employees and contractors, the nuclear power plant can reduce the traffic intensities produced and make them more sustainable.

4.1.1.9 Waste

The work carried out as part of the LTO adjustments generated a certain amount of waste. Additional waste streams will also be created in the POP. In addition, waste is also generated during normal operation of the nuclear power plant. However, KCD makes every effort to reduce the impact of non-radioactive waste on the environment. However, a POP in 2015 (= zero alternative) would have produced less total waste than an LTO of Doel 1 and 2 to 2025.

KCD has an environmental management system for its waste streams in accordance with the international standard ISO14001 and the European EMAS Regulation. In addition, the regulations laid down in VLAREMA and VLAREBO are followed. No additional mitigating measures or recommendations are considered necessary.

4.1.2 Accident situations

The maximum impact distances of a non-radiological incident at KCD-1 and KCD-2 do not extend beyond the site boundaries. The probability of a potential environmental impact does not change significantly as a result of LTO works or as a result of the longer operation of KCD-1 and KCD-2. No significant negative impact is expected on the IHDs of surrounding SPA areas.

4.1.3 Overall Conclusion

The impact of the effects will not be significantly different in the LTO situation from the effects in the baseline situation. No additional impacts are caused by LTO compared to the baseline.

The impact of the operation of KCD on the environment was studied for the period 2015-2018 compared to the situation without operation of KCD. It can be concluded that the impact on the environment for most environmental aspects is negligible to limited compared without operation of KCD. This does not apply to the discharge of cooling water. The discharge of the cooling water has a negative to considerably negative impact as a result of the temperature increases. The effect of temperature increase on the aquatic communities in the Lower Scheldt is considered not considerably negative. A frequent operation of the site's sanitary wastewater collection wells into the Scheldt was found to have a negative effect. To the east of the KCD, the 55 dB nuisance contour reaches into the Special Protection Area - Birds 'Schorren en polders van de Beneden-Schelde', also designated as the VEN area 'Slikken en schorren langs de Schelde' and as a Ramsar area. Rest disturbance due to the operation of KCD along the reed beds and mudflats on the banks of the Scheldt, near the KCD, is assessed as negative.

4.2 Radiological aspects

This section draws the overall conclusion regarding radiological environmental impacts based on the previous Chapter 3.

The table below indicates whether significant impacts were identified for the Project and the Zero Alternative. It shows the impact relative to the baseline situation (the average situation for the years 2012-2014), with both KCD-1 and KCD-2 in operation for the Project, and both KCD-1 and KCD-2 out of operation for the Zero Alternative. A plus (+) or minus (-) sign indicates whether the expected effect has a positive or negative impact on the environment. If an effect is negligible, this is indicated by a v. If an impact may be cross-border, this is indicated with a 'G'.

Table 4-2 Identification of potential radiological impacts of KCD relative to the baseline situation

	Project		Zero alternative
	Operational phase of the Project between 2015 and 2018	Operational phase in the future situation (period 2019 - 2025)	

Direct radiation at the site boundary	- (G: v)	- (G: v)	v (G: v)
Radiation exposure of (non-) occupationally exposed employees	v	v	v
Radioactive gaseous discharges	v (G: v)	v (G: v)	v (G: v)
Radioactive liquid discharges	v (G: v)	v (G: v)	v (G: v)
Radioactive waste	v	v	(+):
Spent fuel elements	v	v	(+):
Accident situations	v (G: v)	+ (G: +)	+ (G: +)

The effects are explained in more detail below. For all environmental aspects, as a result of the Project, potential impacts originating from KCD-1 and KCD-2 will occur for 10 more years.

4.2.1 Normal operation

4.2.1.1 Direct radiation

(See § 3.4.1)

The construction of the various LTO measures (2015-2018) will result in a slightly increased dose compared to the baseline situation, prior to the Project (2012-2014), but it will not have an impact on the environment. Thereafter, in the period of continued operation (2019-2025), the maximum expected dose at the site boundary is slightly increased compared to that in the baseline situation. Nevertheless, it can be concluded that this Project has no significant impact on the environment with respect to direct radiation.

Within the Zero Alternative, direct radiation due to KCD-1 and KCD-2 decreases to zero 10 years earlier, compared to implementation of the Project. However, the difference in site boundary dose between the Project and the Zero Alternative is small.

The operation of KCD as well as the LTO Project has no significant measurable impact on the Dutch territory so that further cross-border effects as a result of direct radiation can also be excluded.

4.2.1.2 Radiation exposure of employees

(see § 3.4.2)

In principle, no occupationally exposed employee will exceed the annual legal limit. Electrabel's internal limit is half the legal limit. Because of the radiological shielding of all units, WAB and FCB, there is no significant difference between the Project and the Zero Alternative with respect to the annual dose of non-occupationally exposed employees (1 mSv per year [ARBIS, Section 20.1.4]). From this, it can be concluded that this Project and the Zero Alternative will not have a significant impact on employees with respect to the dose sustained.

4.2.1.3 Radioactive gaseous discharges

(see § 3.4.3)

The Project will have no measurable impact on the environment because the annual discharged activity will remain the same as the annual discharged activity for the LTO Project. The committed effective dose which members of the public may potentially incur as a result of gaseous discharges is well below the dose limit and has no significant impact on the population.

Under the Zero Alternative, the final shutdown of KCD-1 and KCD-2 will result in fewer gaseous radioactive discharges, however, the difference compared with the baseline situation and the Project is negligible.

The Project has no significant measurable impact on the Dutch territory so further cross-border effects due to atmospheric discharges can also be excluded.

4.2.1.4 Radioactive liquid discharges

(see § 3.4.4)

The LTO of KCD-1 and KCD-2 (the Project) will not have a negative impact on the environment because the annual discharged activity will remain the same as the annual discharged activity before implementation of the Project. The committed effective dose which members of the public may potentially incur as a result of liquid discharges is well below the dose limit and has no significant impact on the population.

Under the Zero Alternative, the final shutdown of KCD-1 and KCD-2 will result in fewer liquid radioactive discharges, however, the difference compared with the baseline situation and the Project is negligible.

The Project has no significant measurable impact on the Dutch territory so further cross-border effects due to liquid discharges can also be excluded.

4.2.1.5 Radioactive waste

(see § 3.4.5)

As a result of the KCD-1 and KCD-2 life extensions, low and medium level waste will be generated for an additional 10 years (2015-2025). The nature of the planned activities in the operational phase of the Project between 2015 and 2018 differs from the nature of the regular activities in the baseline situation. It is therefore plausible, and demonstrated by practical figures for the years 2015-2018, that differences exist in the quantities of waste generated.

In contrast, under the Zero Alternative, no low and medium level radioactive waste directly related to the operation of KCD-1 and KCD-2 would be generated over the entire 2015-2025 period.

All the waste produced will be processed and stored on the Belgian territory at the surface disposal facility. As a result, no cross-border impacts are anticipated.

4.2.1.6 Spent fuel elements

(see § 3.4.6)

Since the consumption rate of fuel elements both in the operational phase of the Project between 2015 and 2018 and operational phase in the future situation (period 2019 - 2025) is the same as that of the baseline situation (2012-2014), the increase per year of operation will be identical in all cases. Within the Zero Alternative, the consumption rate of spent fuel elements decreases to zero, reducing its impact on the environment. The radiation impact at the site boundary from spent fuel elements cannot be determined separately because the thermoluminescence dosimeters detect radiation from all sources present at the site combined, however, it can be concluded in general terms that this Project has no significant impact on the environment with respect to direct radiation (see § 3.4.1).

The current available capacity of the fuel container building is sufficient for the additional fuel elements consumed as a result of the Project (LTO of KCD-1 and KCD-2). The SF^2 project aims to further increase capacity, which will be required for KCD-3 and KCD-4.

In contrast, under the Zero Alternative, no new spent fuel elements are produced over the entire 2015-2025 period.

4.2.2 Accident situations

(see § 3.4.7)

It was concluded that after implementation of the LTO measures (the Project), nuclear safety improved. This results in a lower probability of an accident situation involving radioactive discharges during the operational phase than in the baseline situation. In particular, the Filtered Containment Vent significantly reduces any radioactive discharges resulting from a possible accident situation.

In the Zero Alternative, the likelihood of an environmental impact occurring due to an accident situation will be lower than in the baseline situation because KCD-1 and KCD-2 will not be operated further.

Thanks to KCD's emergency organization and the National Nuclear and Radiological Emergency Plan, the potential consequences in the event of a possible accident situation are managed.

4.2.3 Overall Conclusion

(see § 3.4.8)

The total committed effective dose is below the legal limit for effective follow-on dose to the population for both the Zero Alternative and the Project.

In summary, it can be concluded that for both the Project and the Zero alternative, the impact on the environment for most environmental aspects is negligible compared to the baseline situation. There is a minor impact due to the environmental aspects of radioactive waste and spent fuel elements, which is factored into the direct radiation at the site boundary. Under both the Project and the Zero Alternative, the likelihood of an accident situation involving radioactive discharges is lower than under the Baseline situation.

As a result of the operation of KCD-1 and KCD-2, fuel elements are consumed and radioactive waste is generated. Under the Zero Alternative, operation of KCD-1 and KCD-2 ceases and only radioactive waste is generated by operations for the Post Operational Phase.

The radiological impact due to the Post Operational Phase will be smaller than during the operation of the unit in question.

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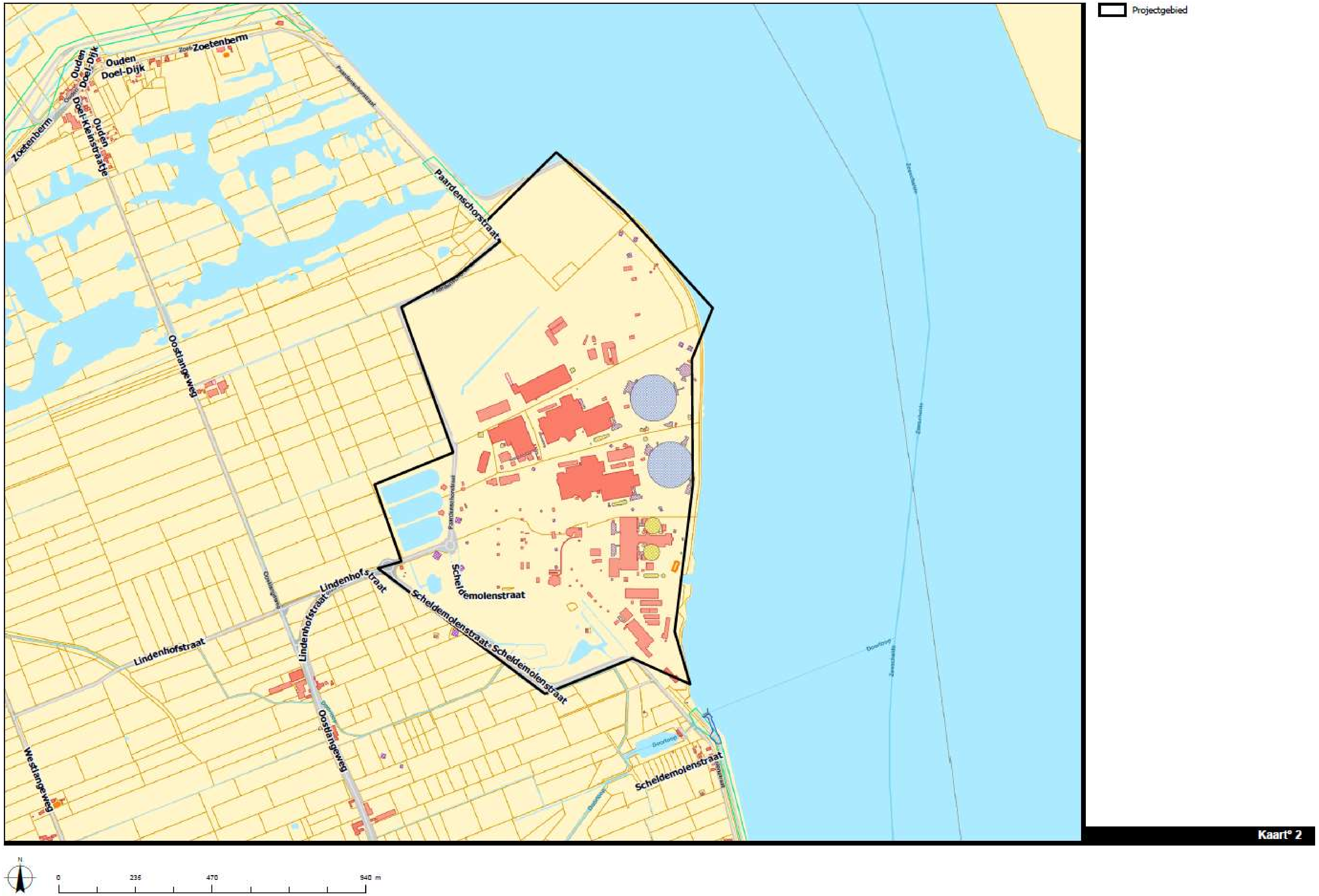

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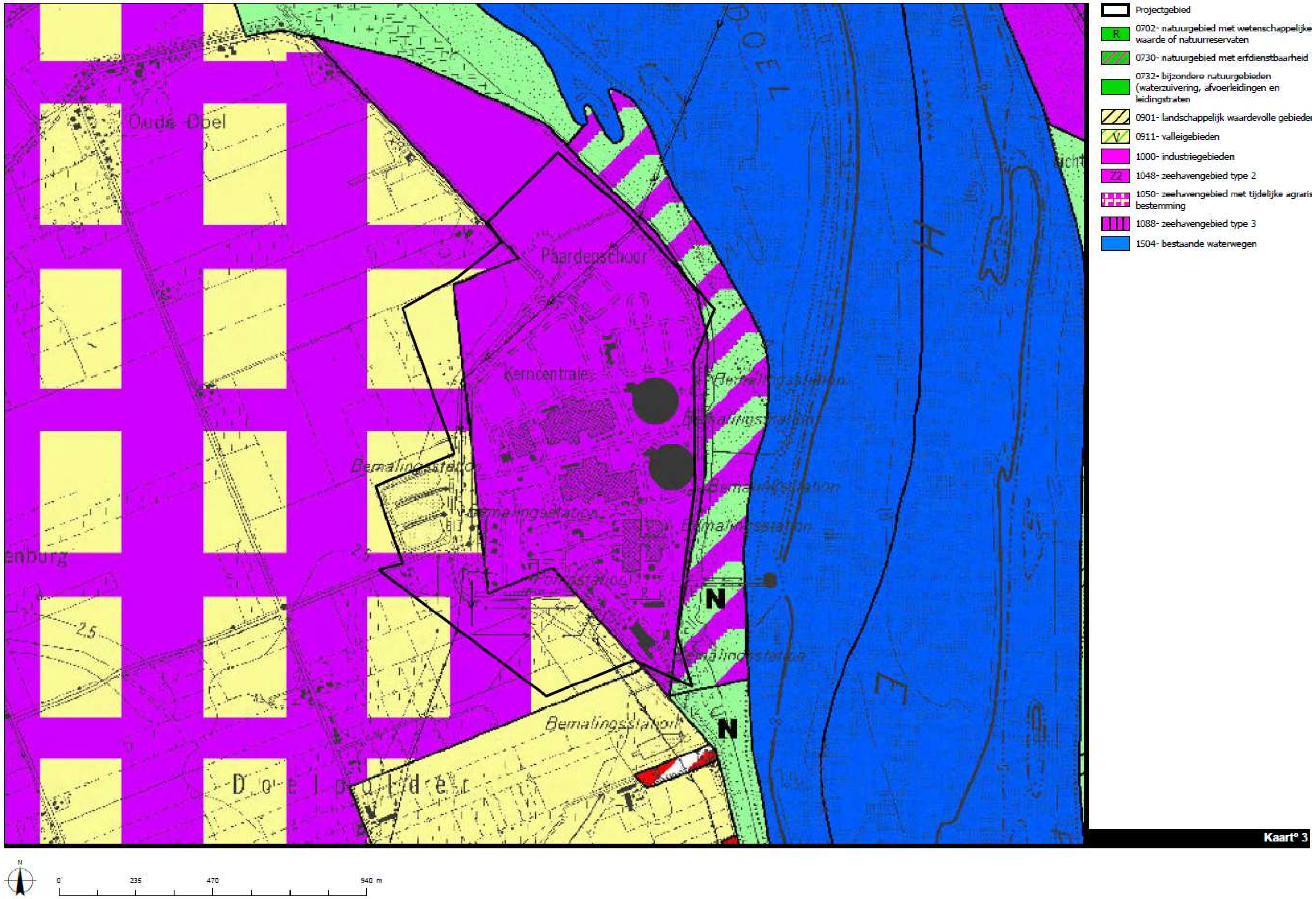

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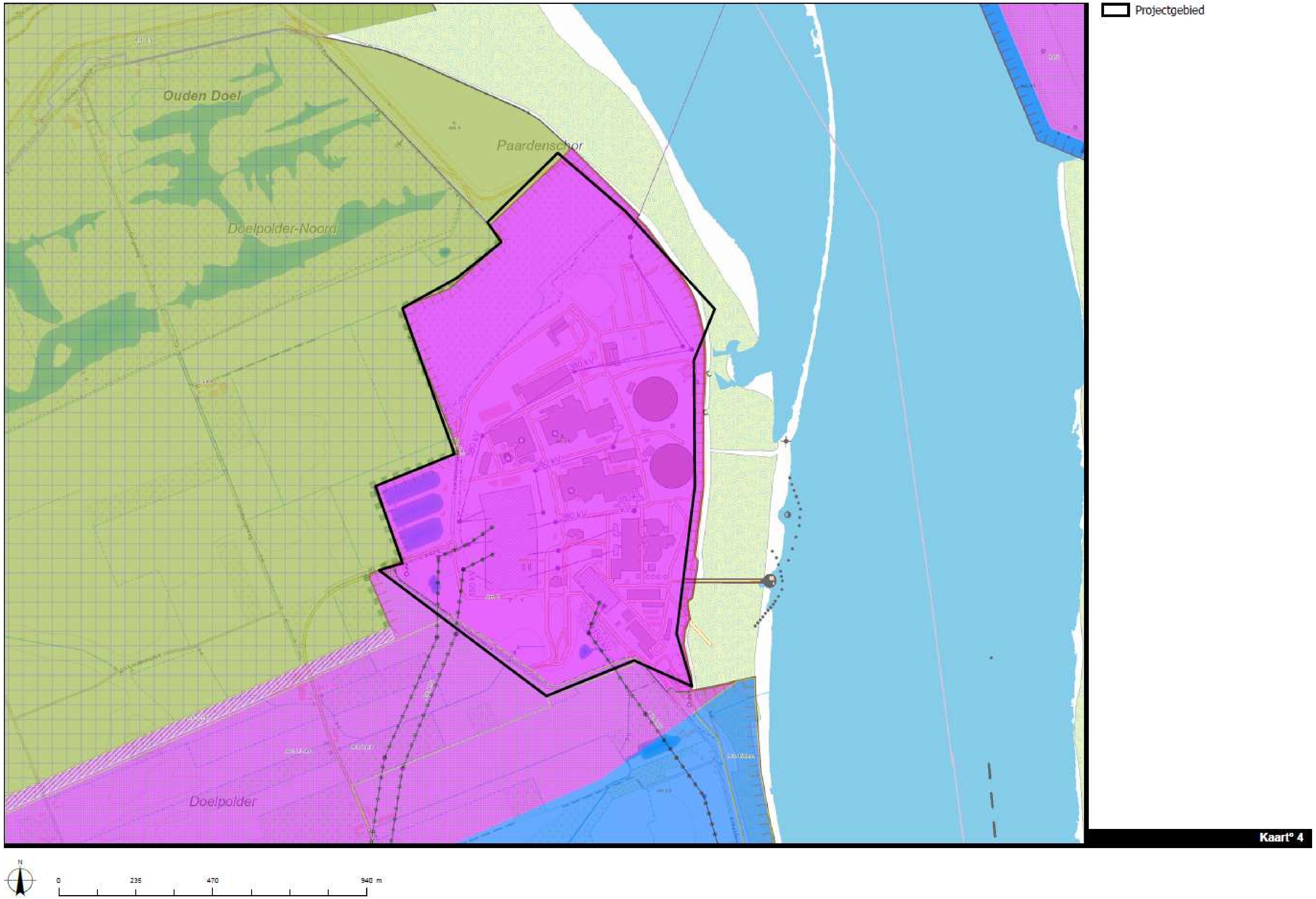

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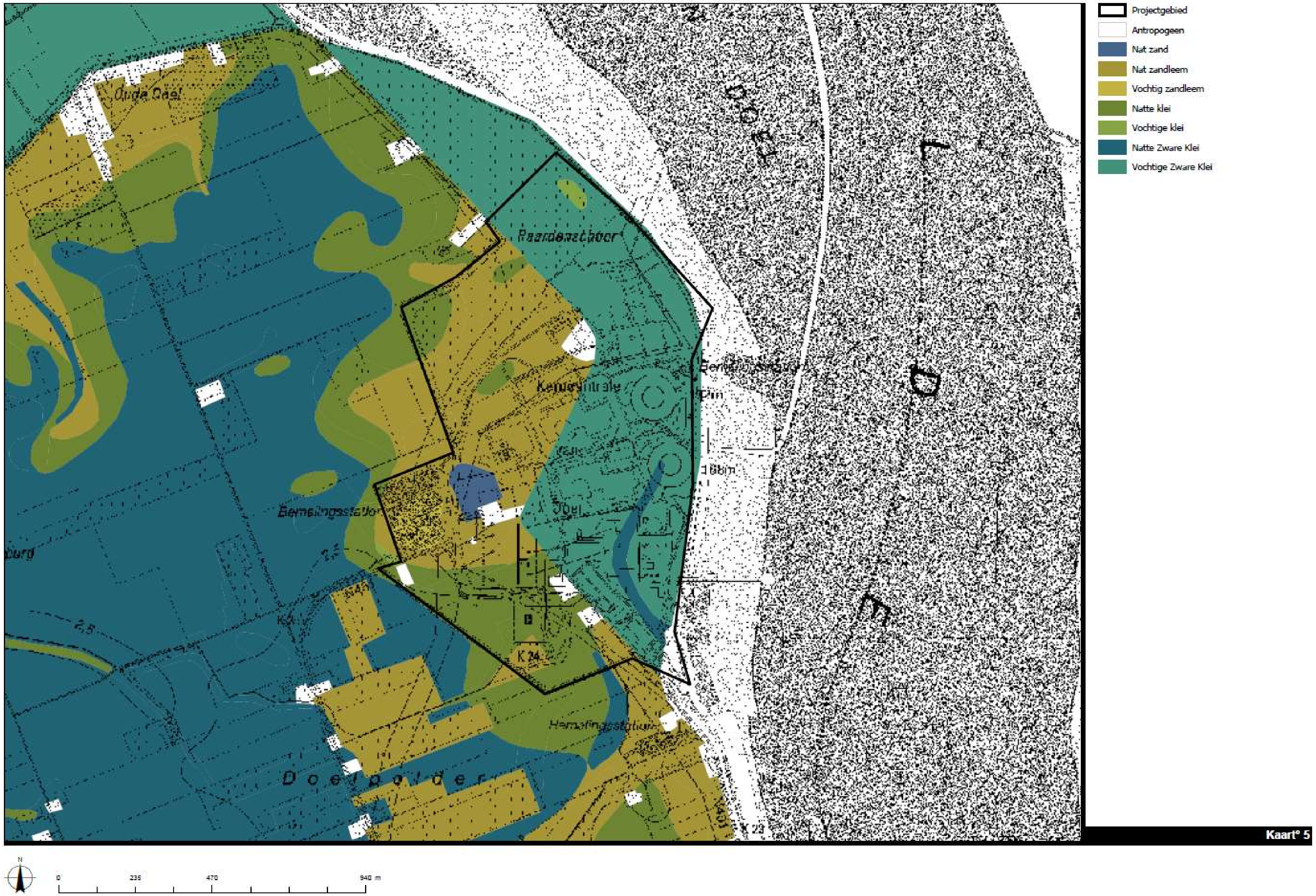

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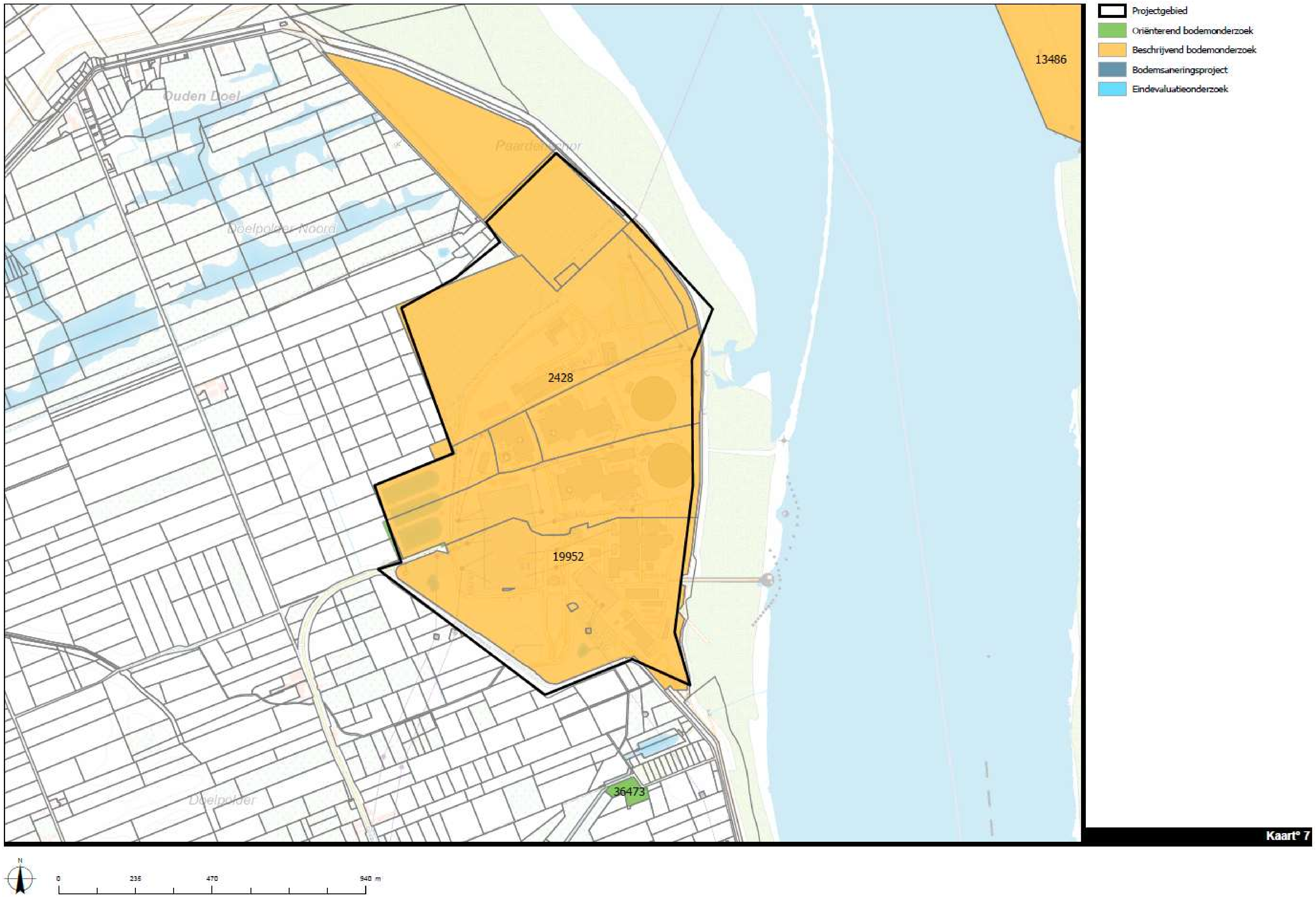

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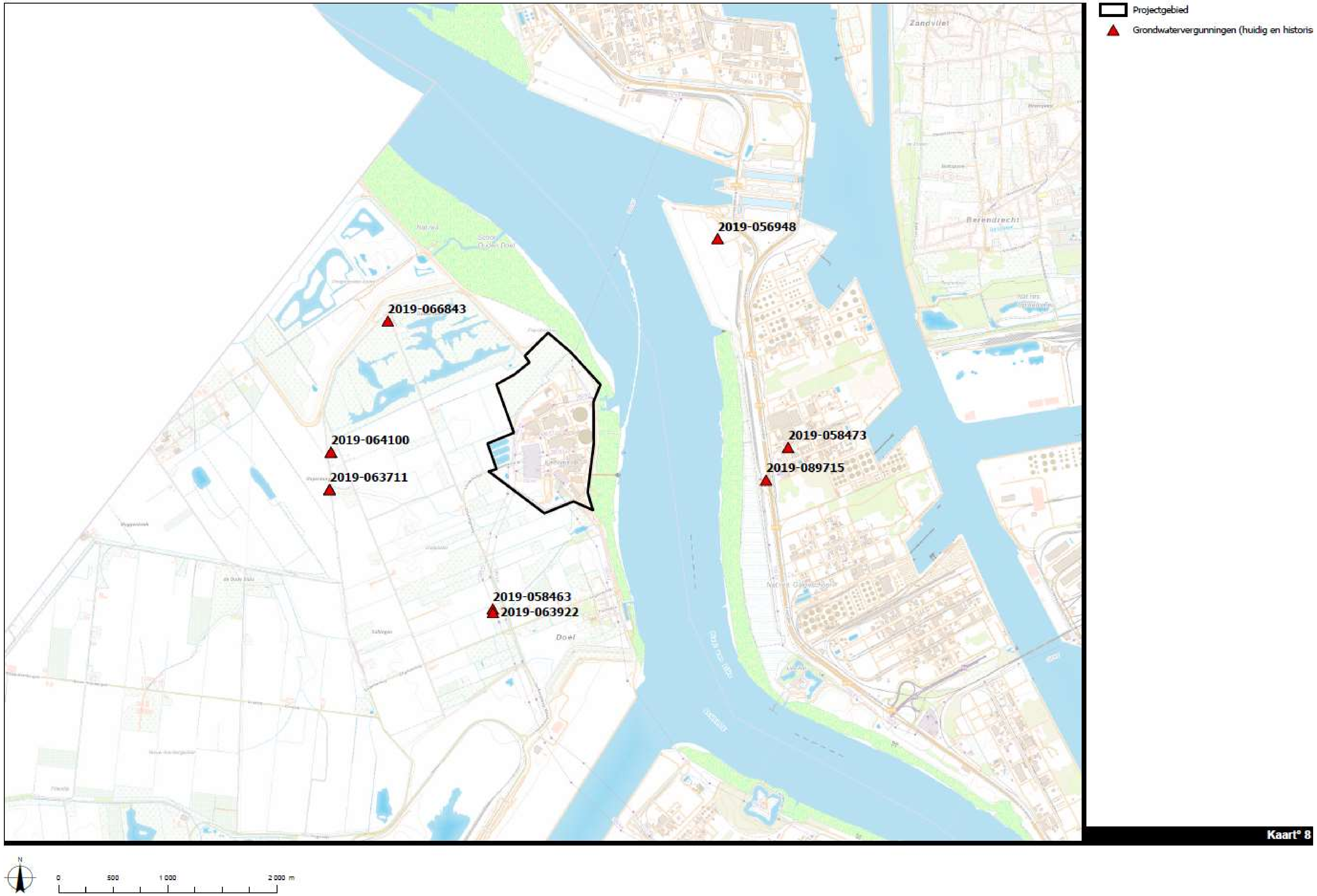

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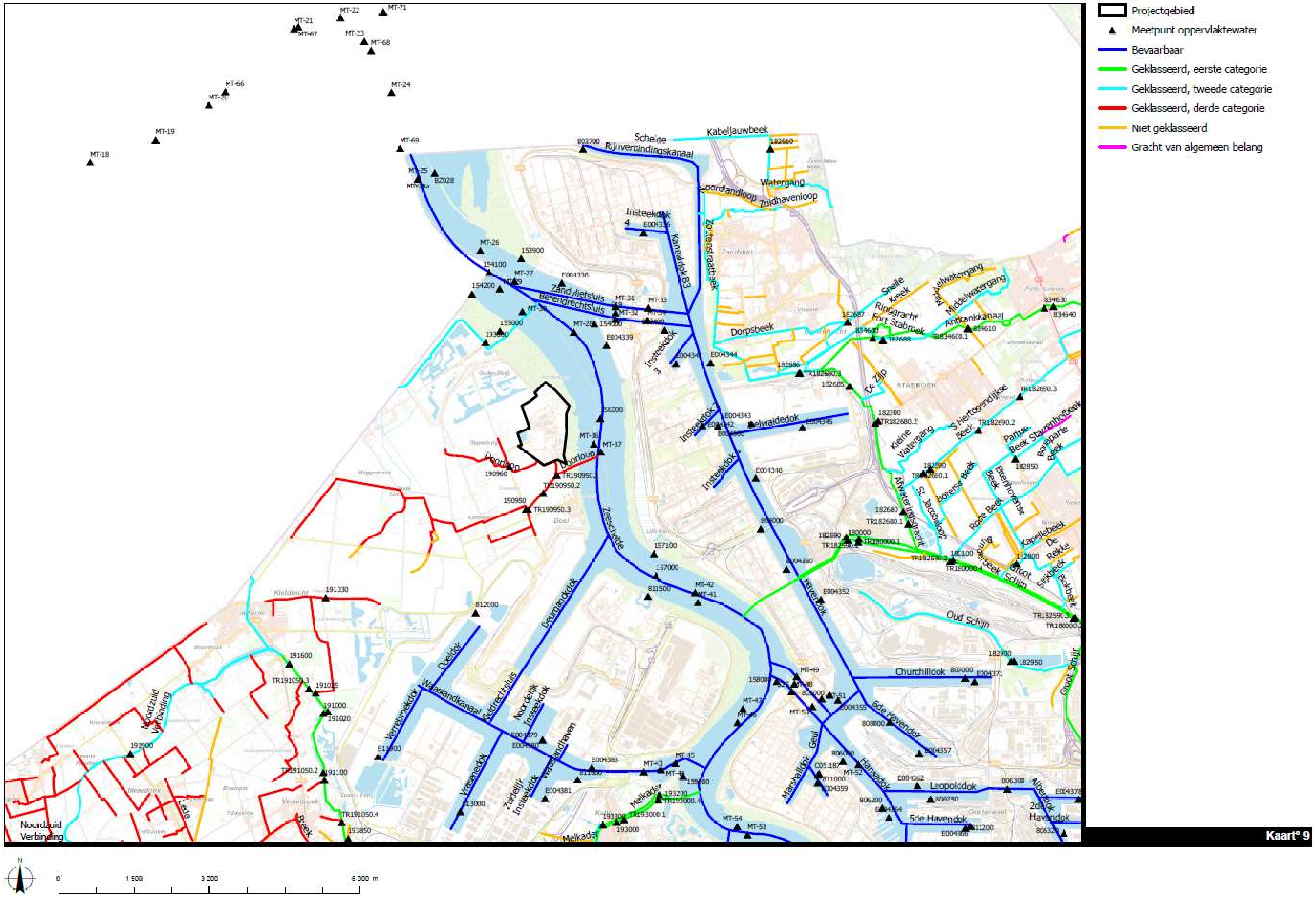

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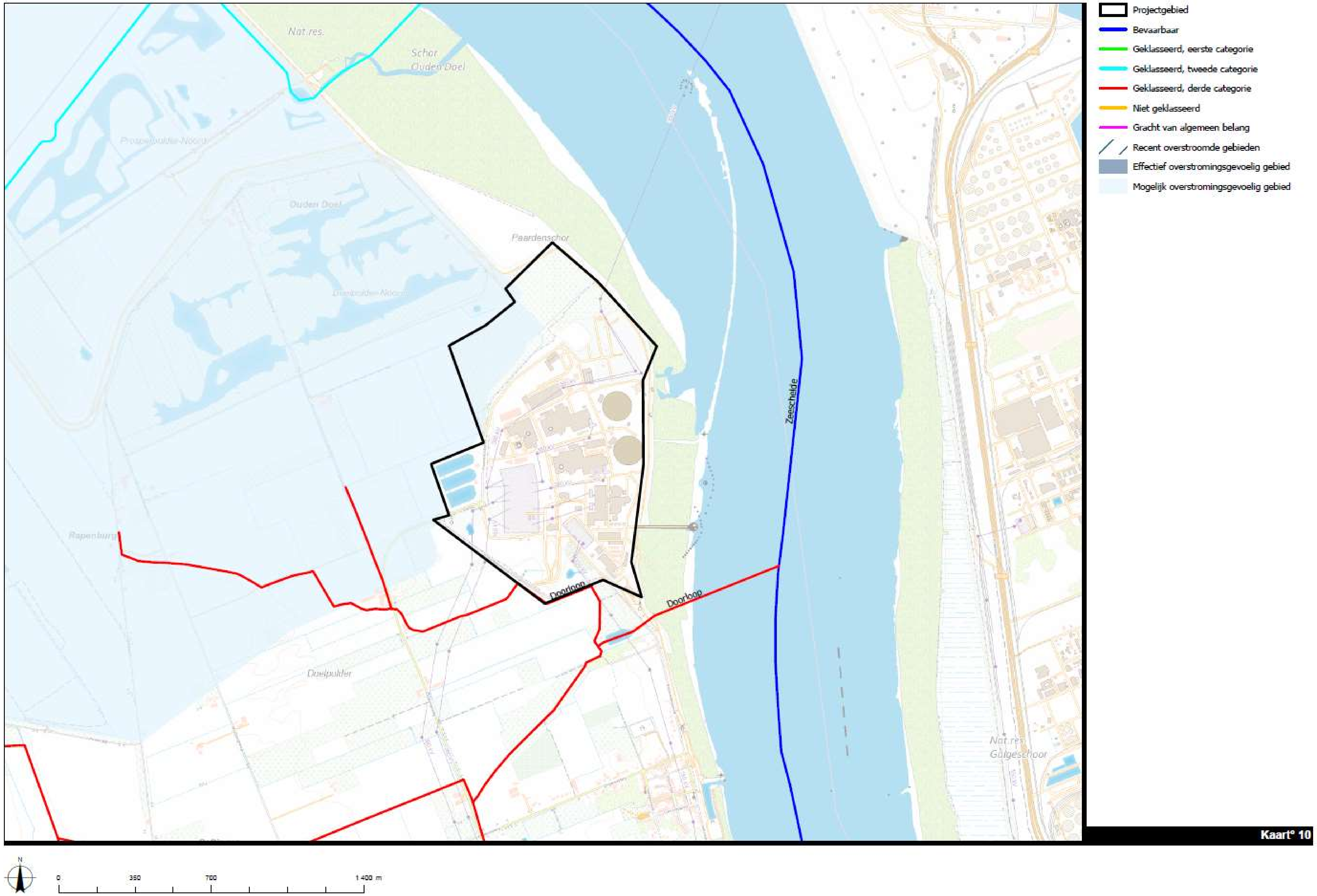

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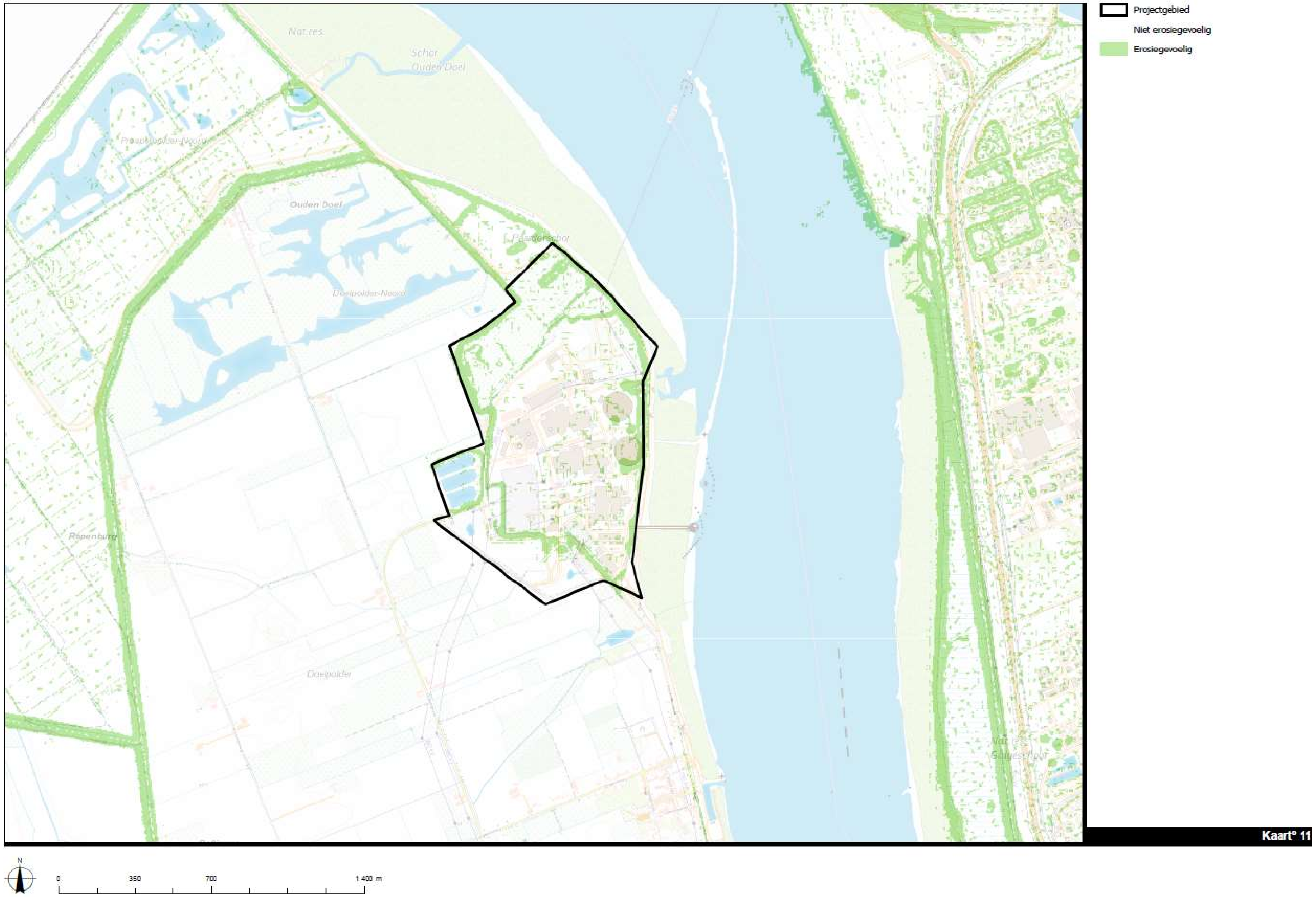

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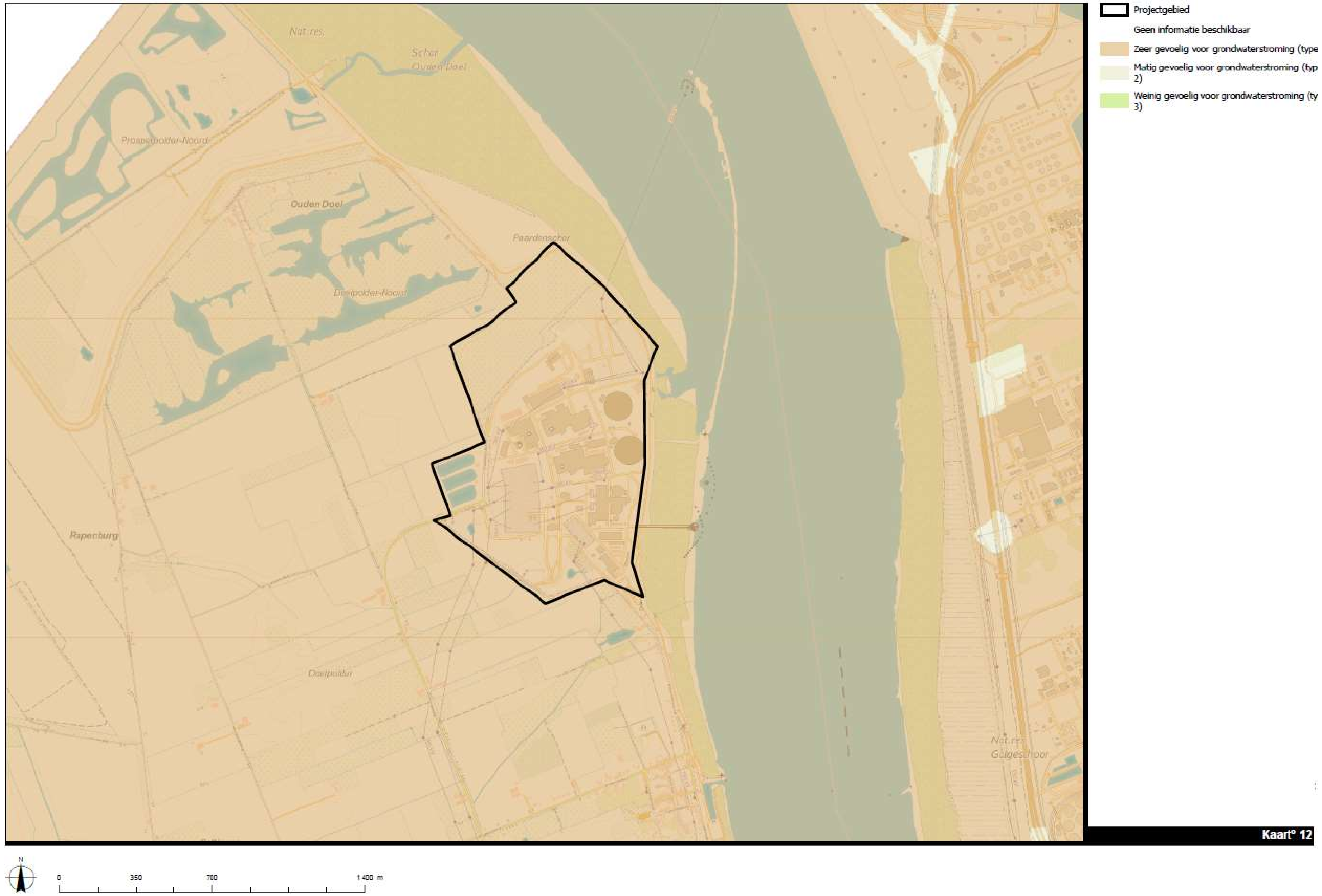

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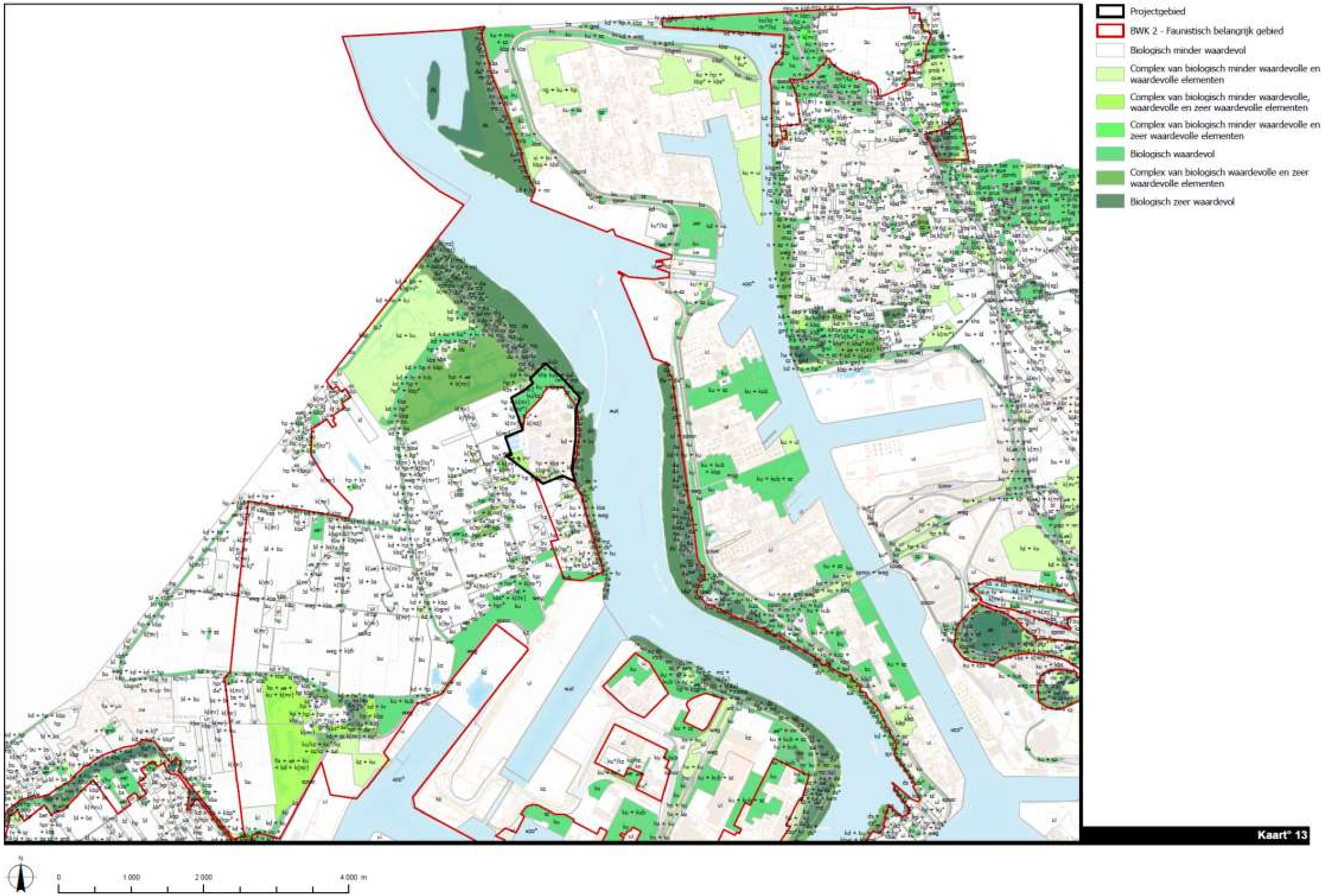

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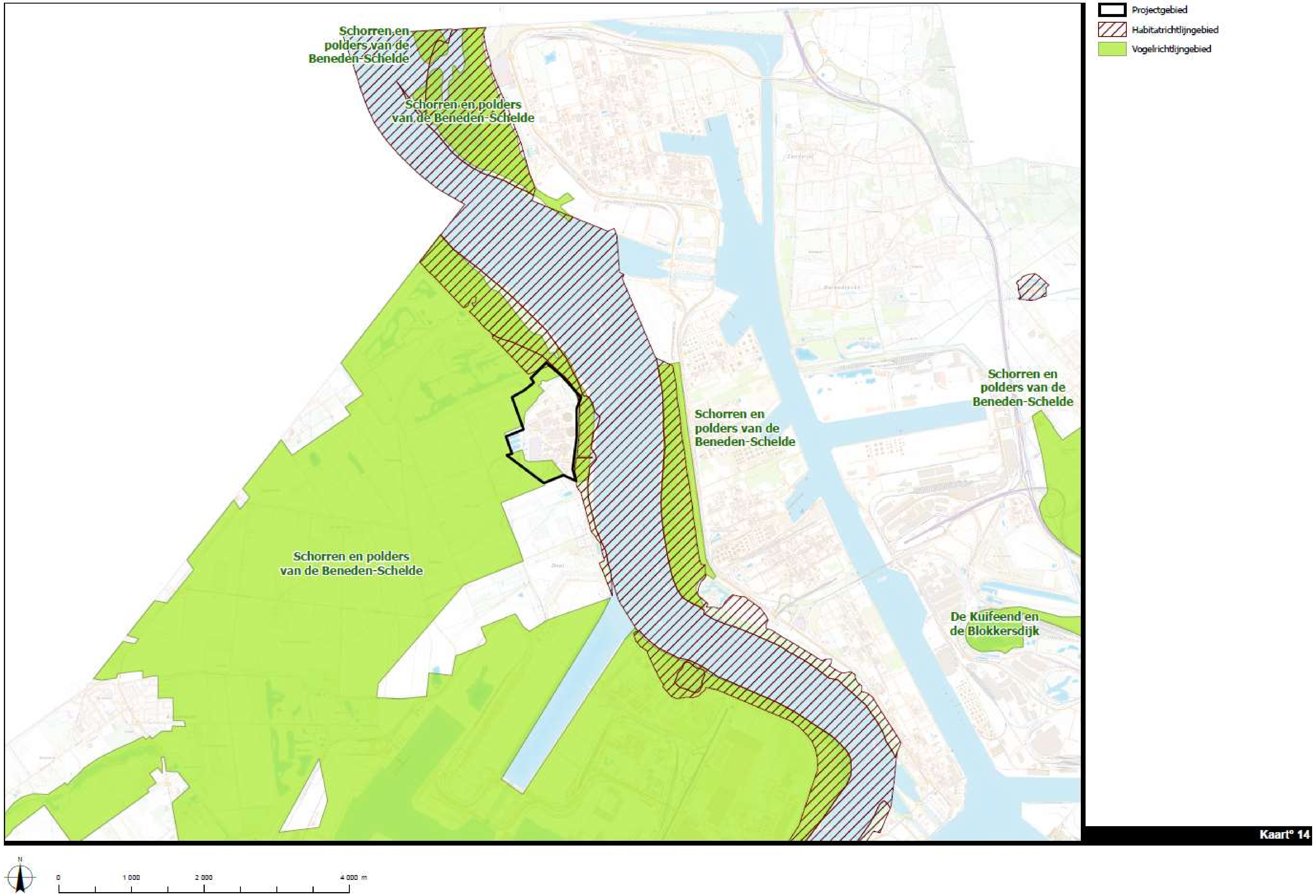

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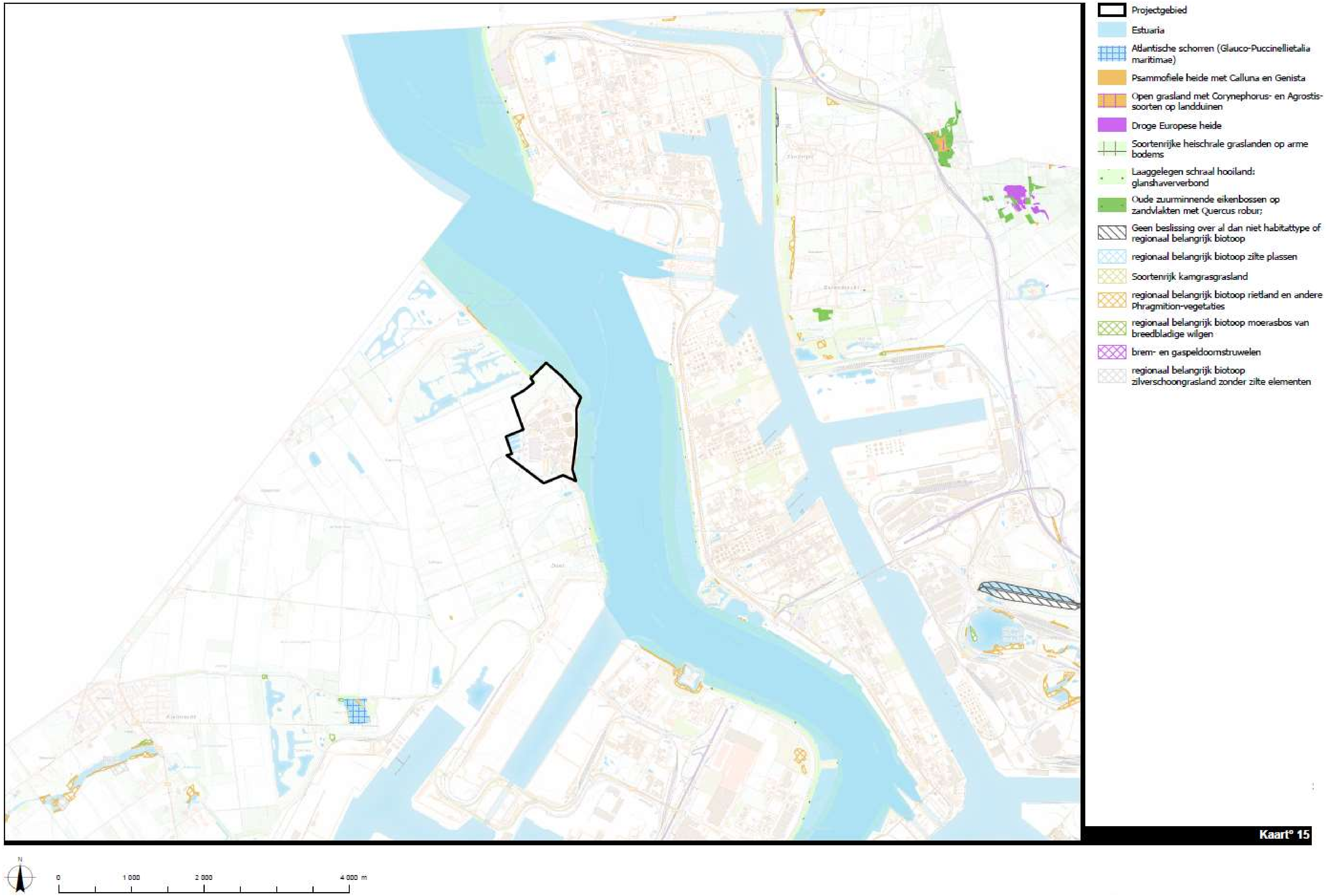

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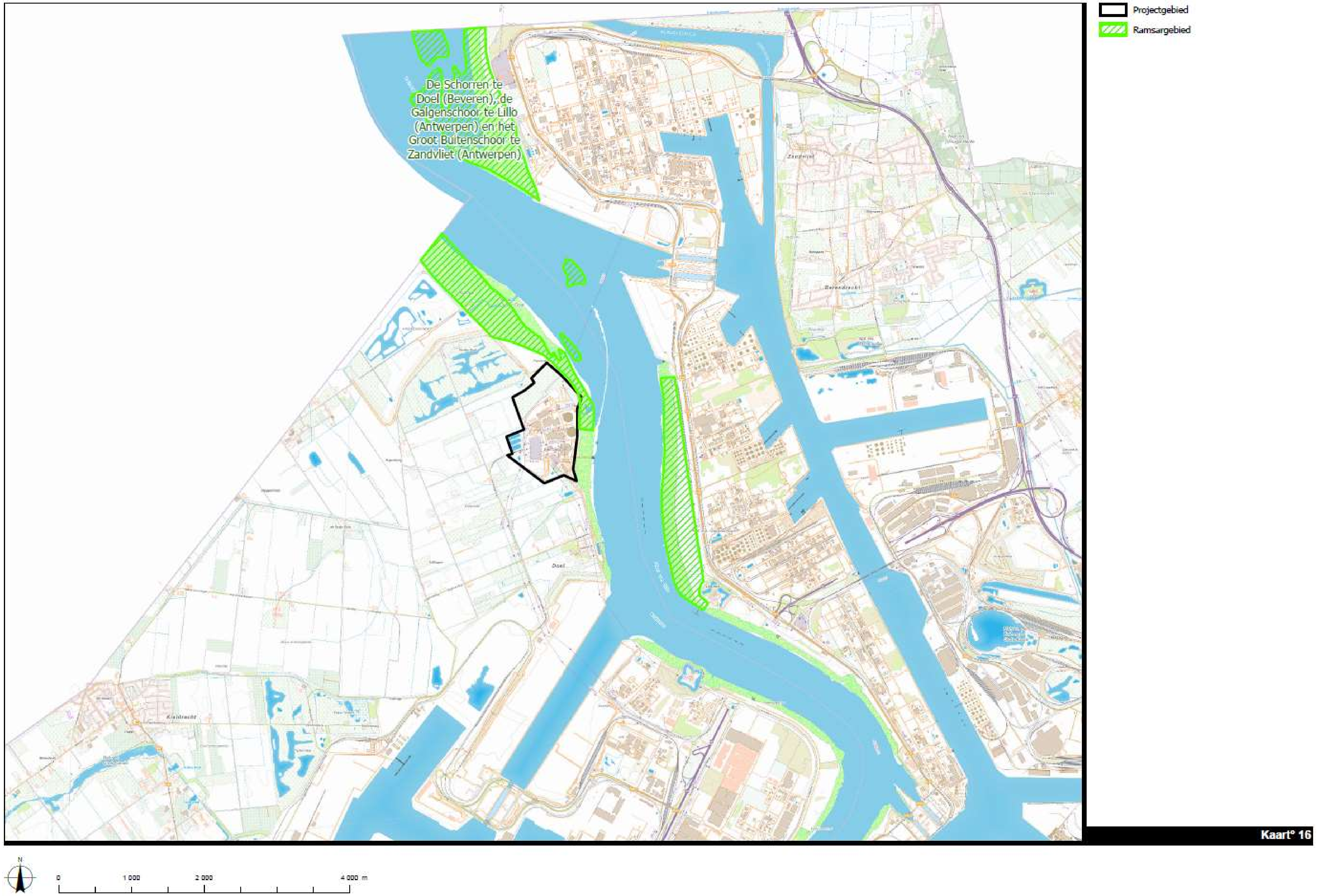

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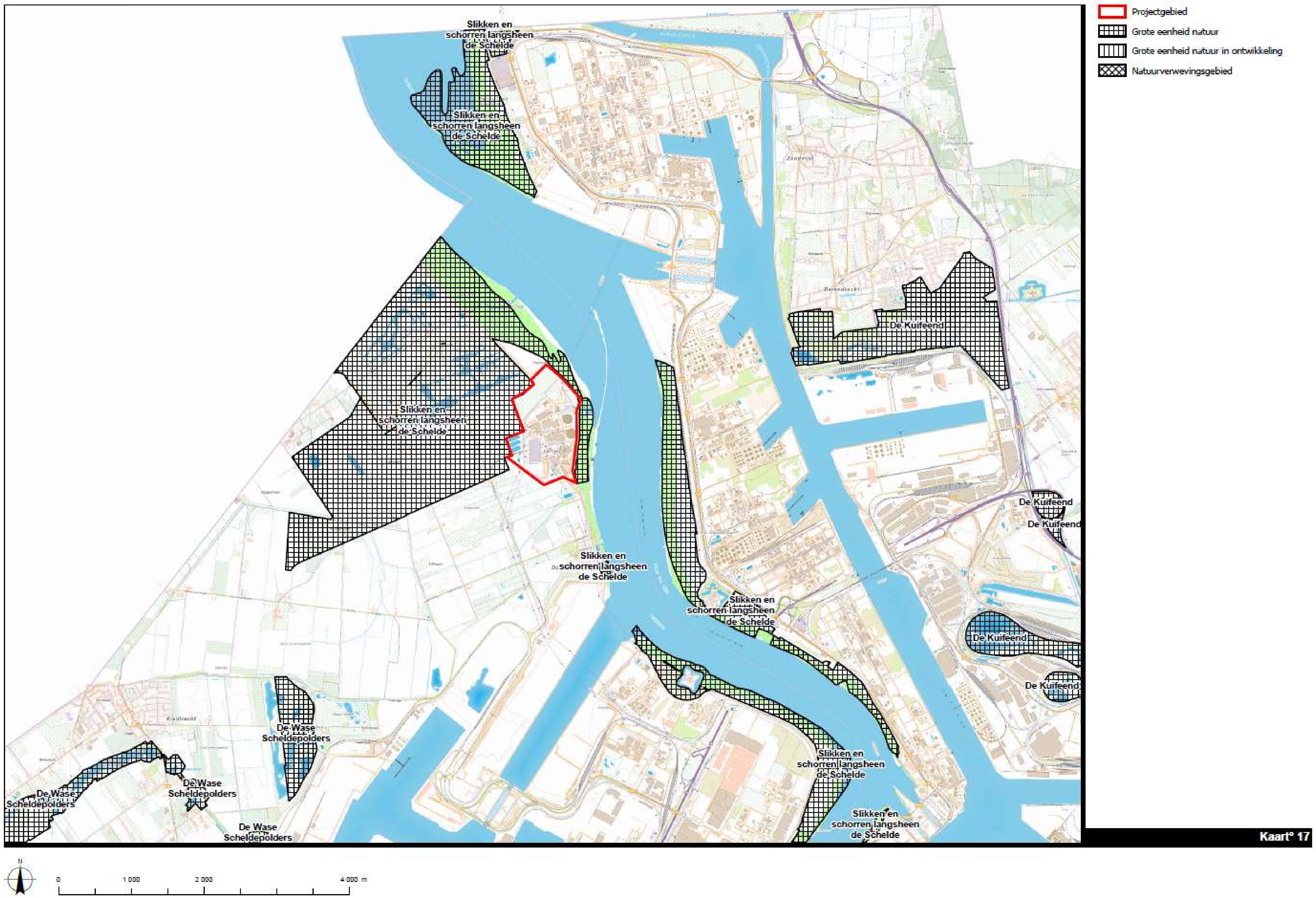

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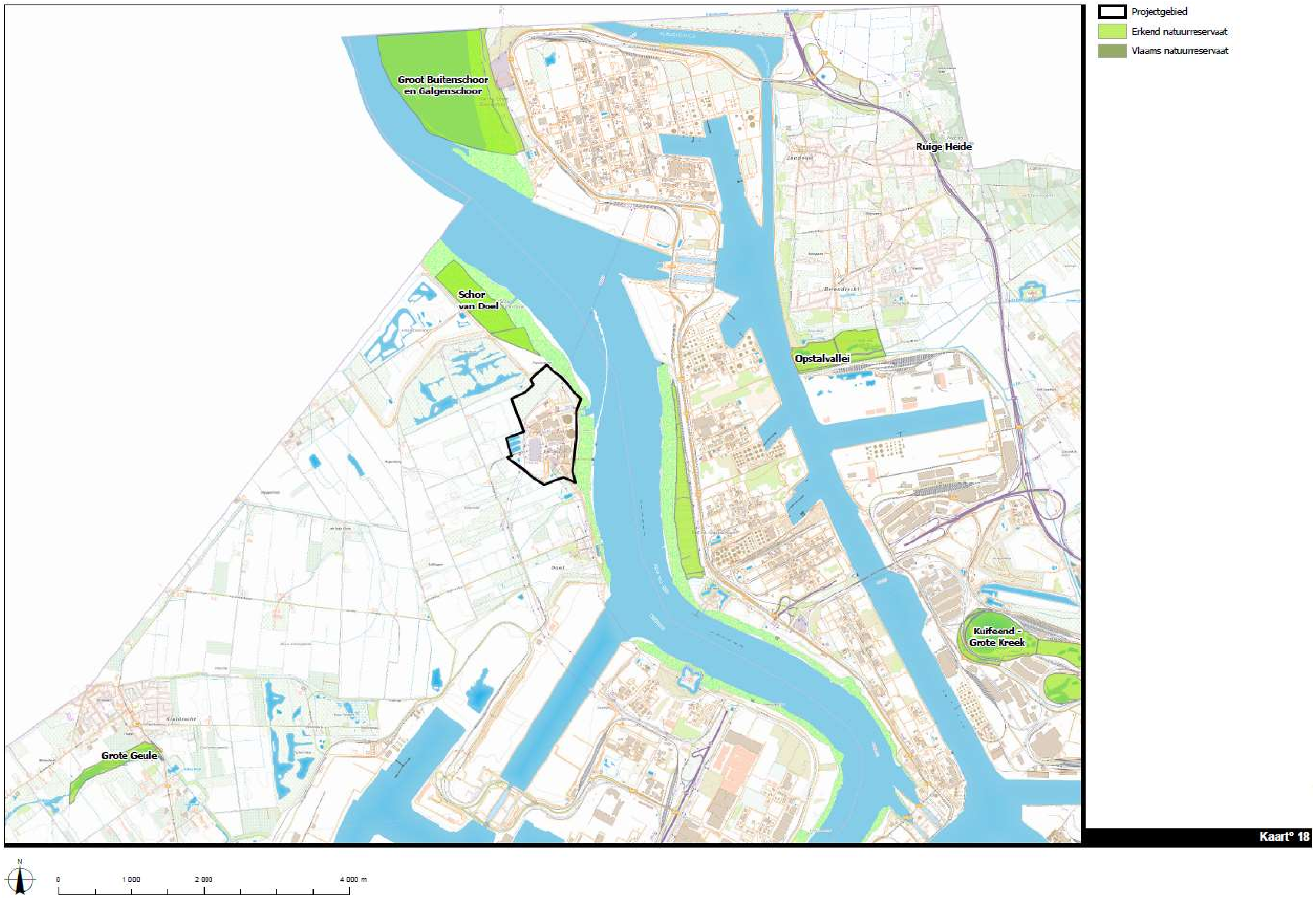

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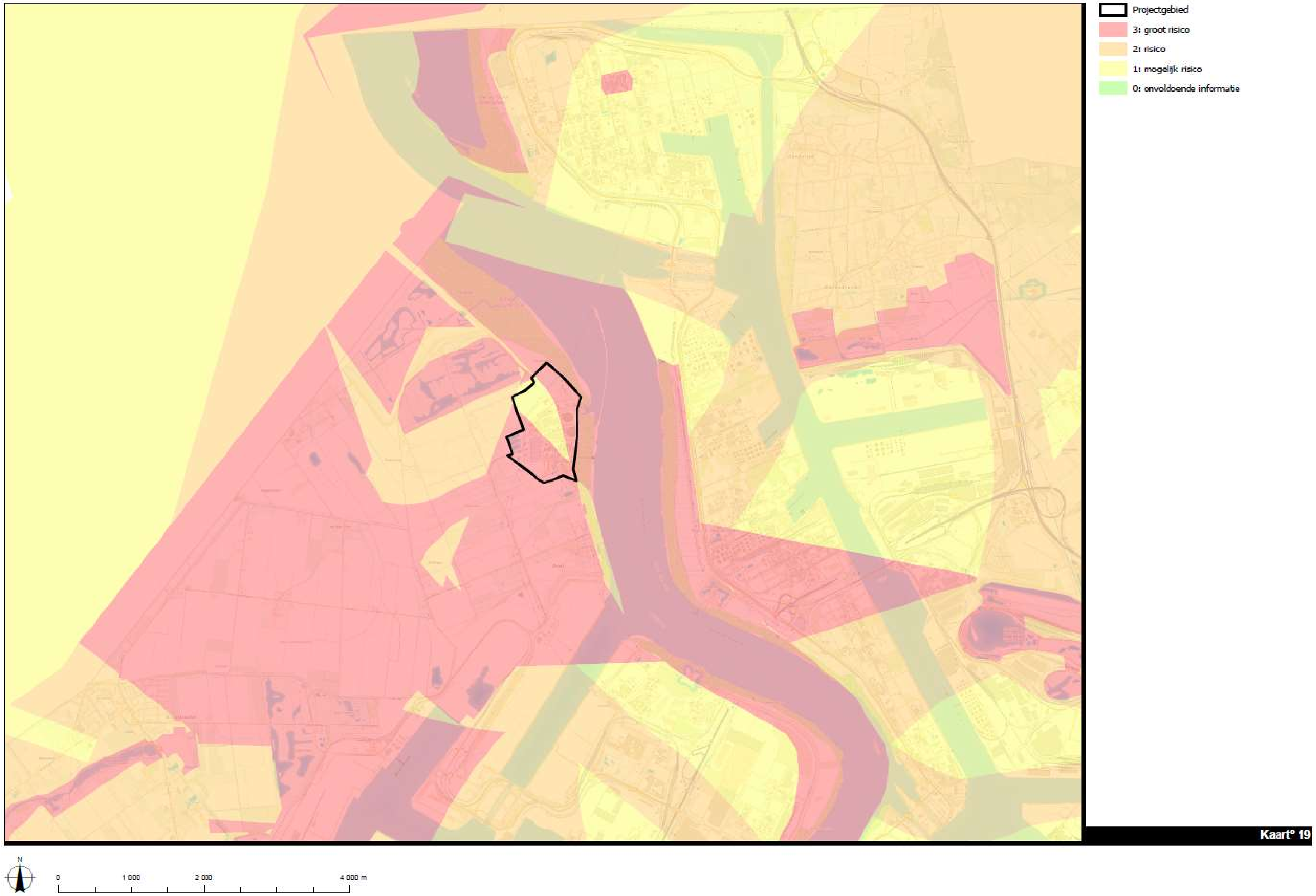

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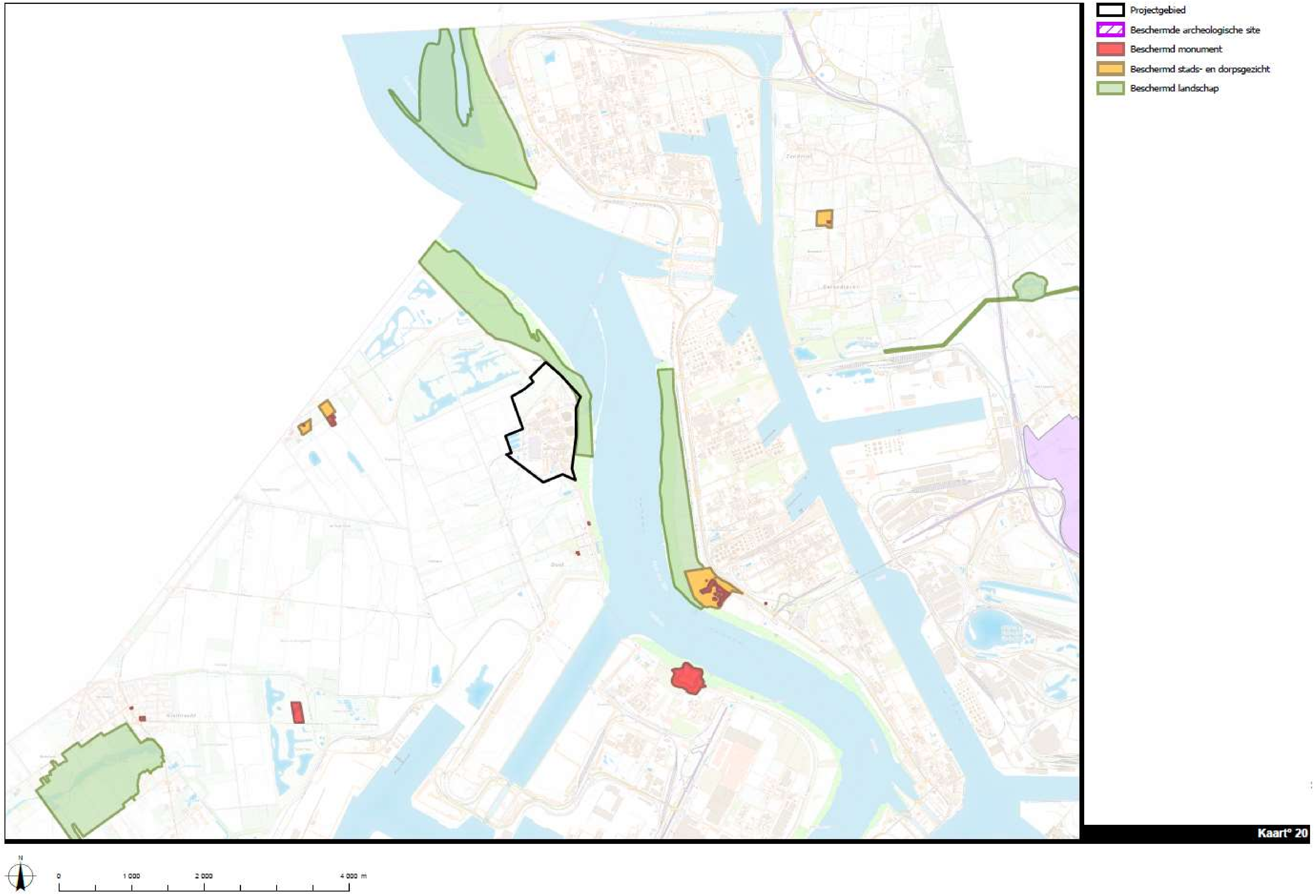

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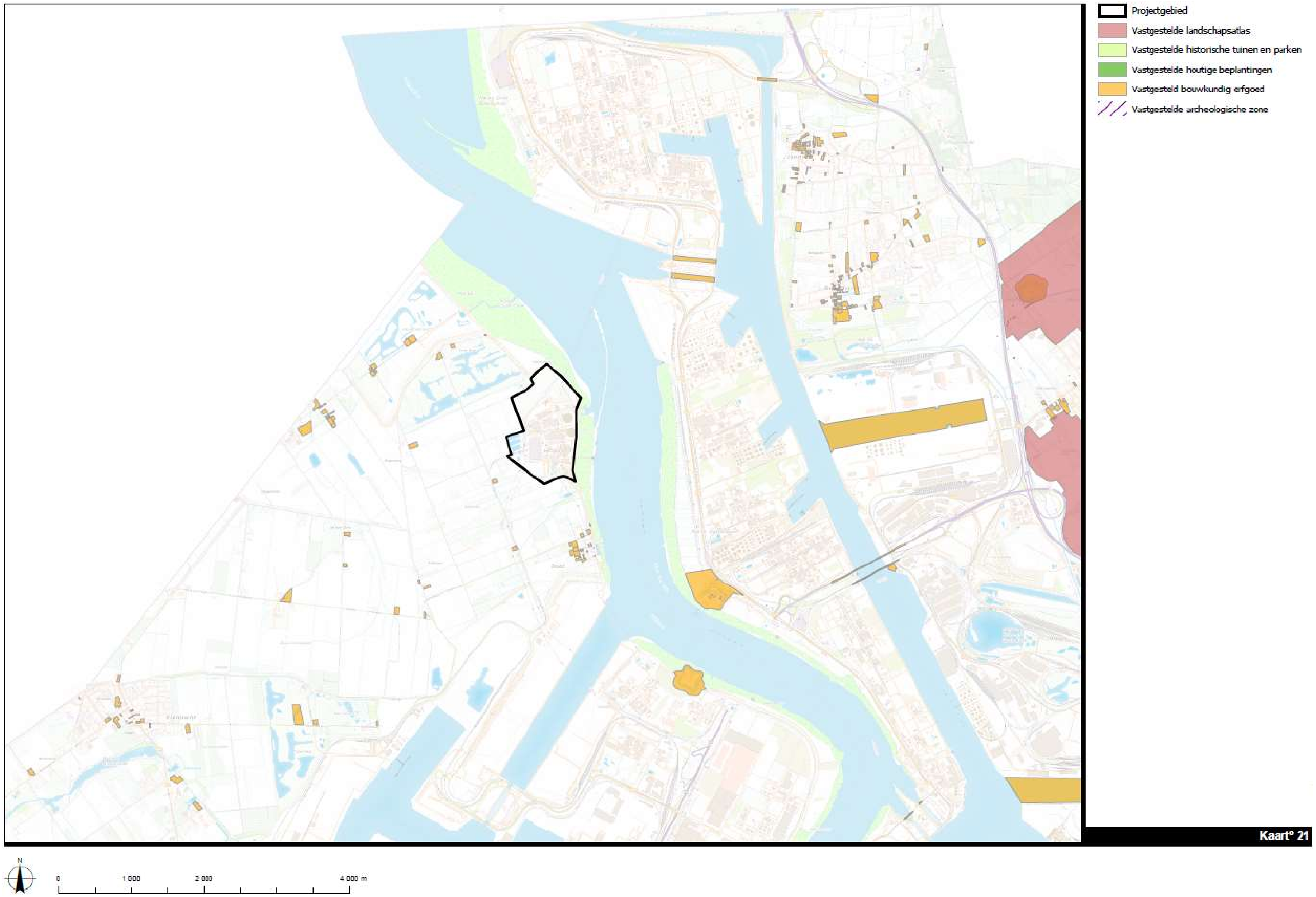

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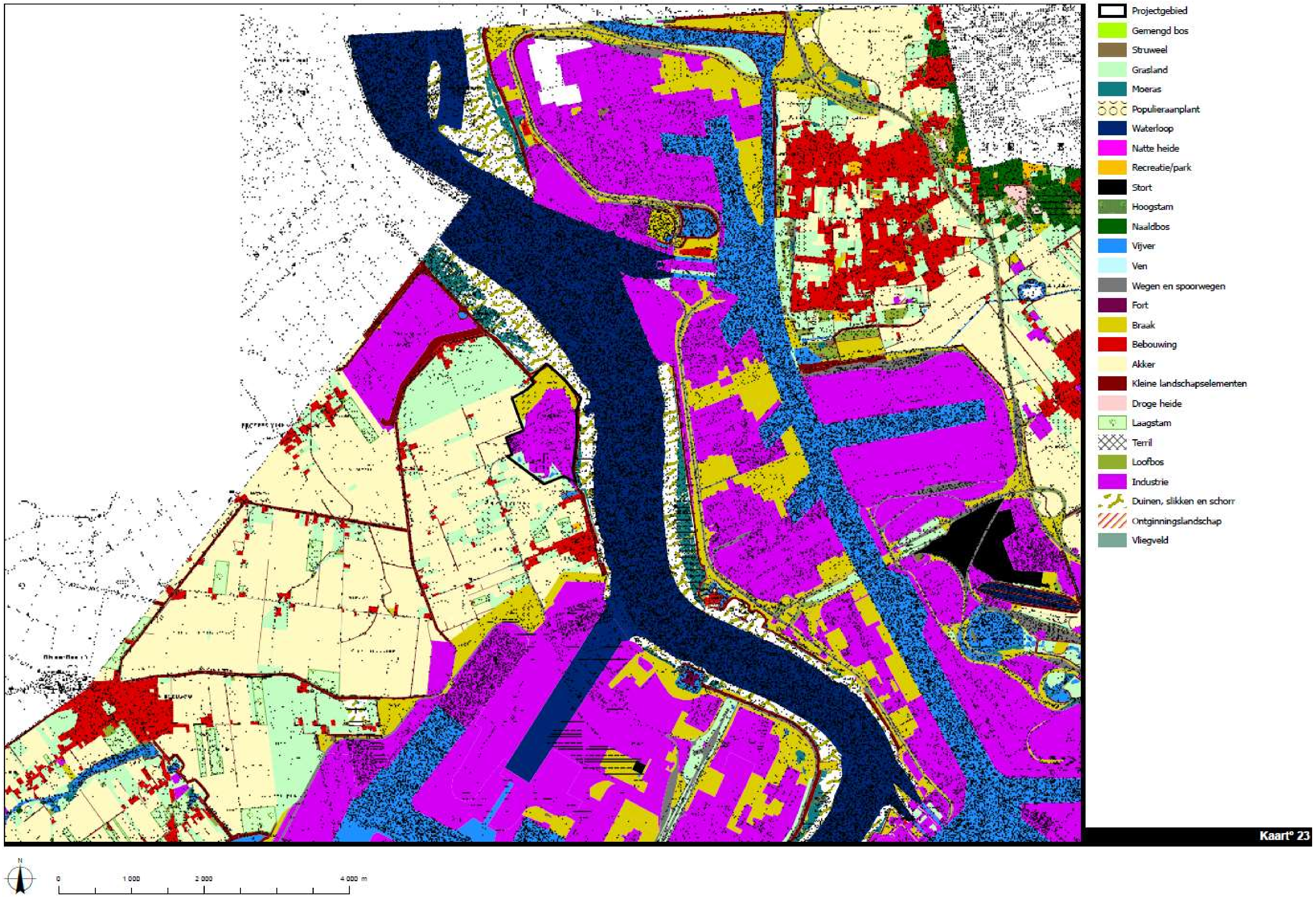

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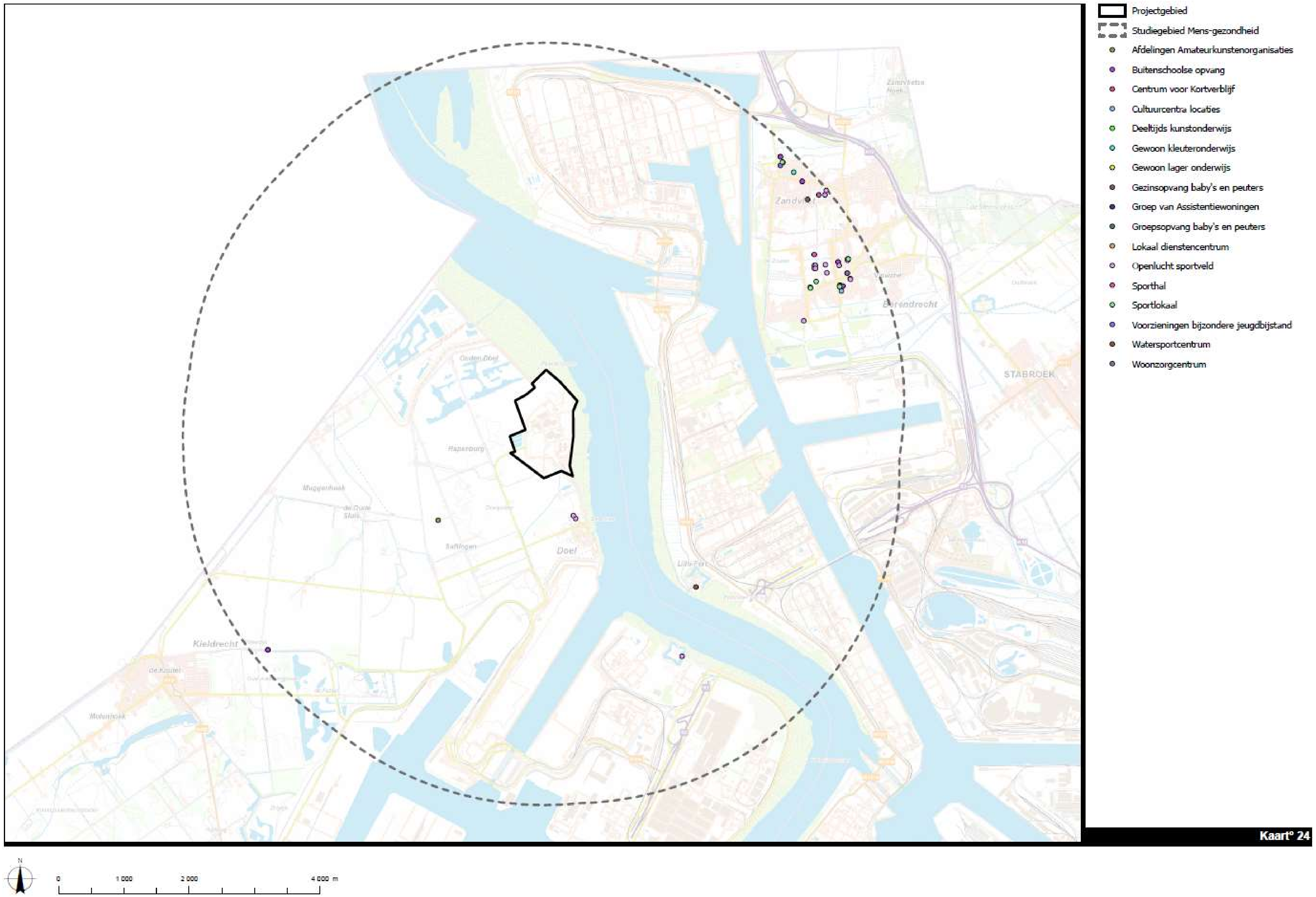

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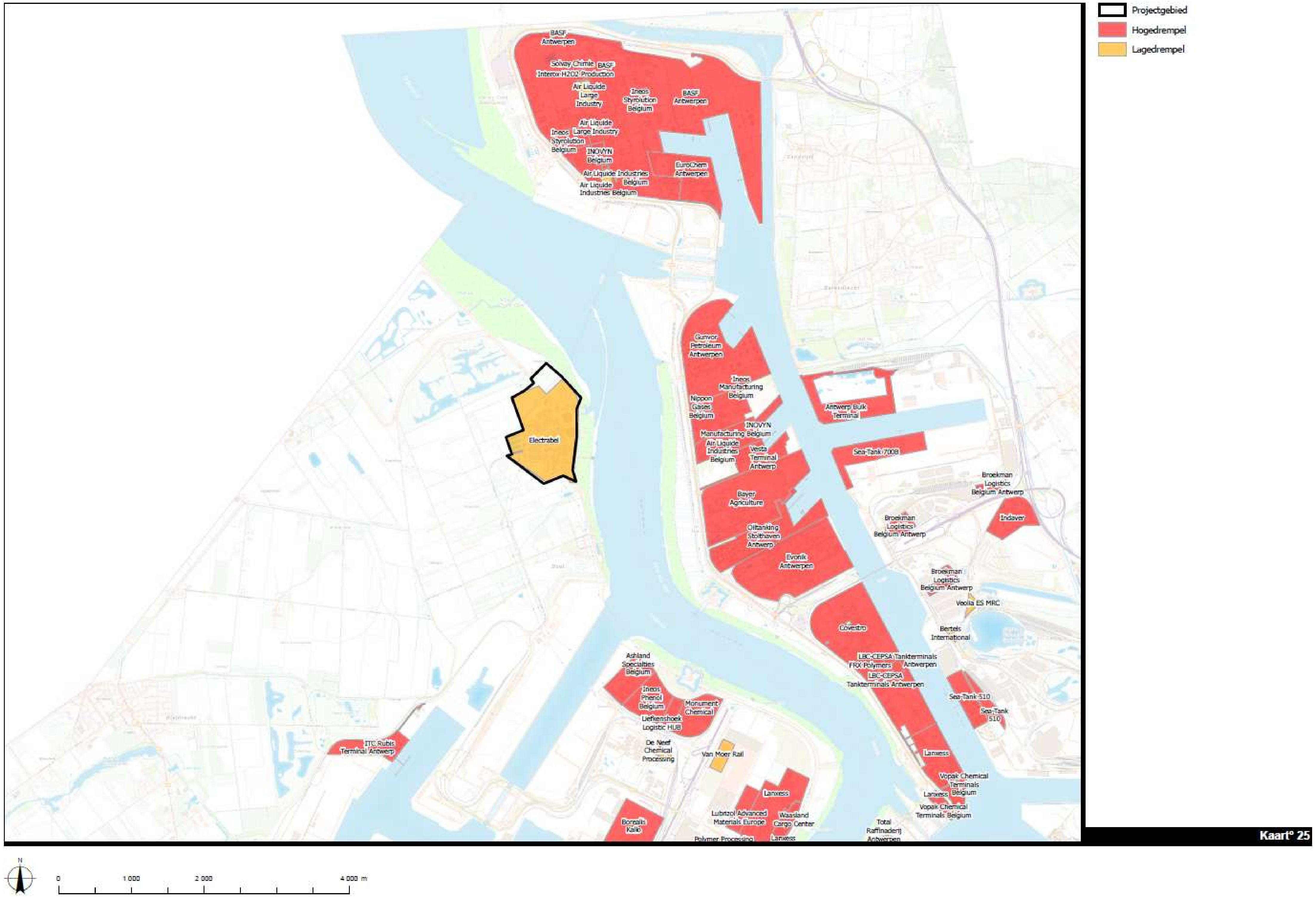

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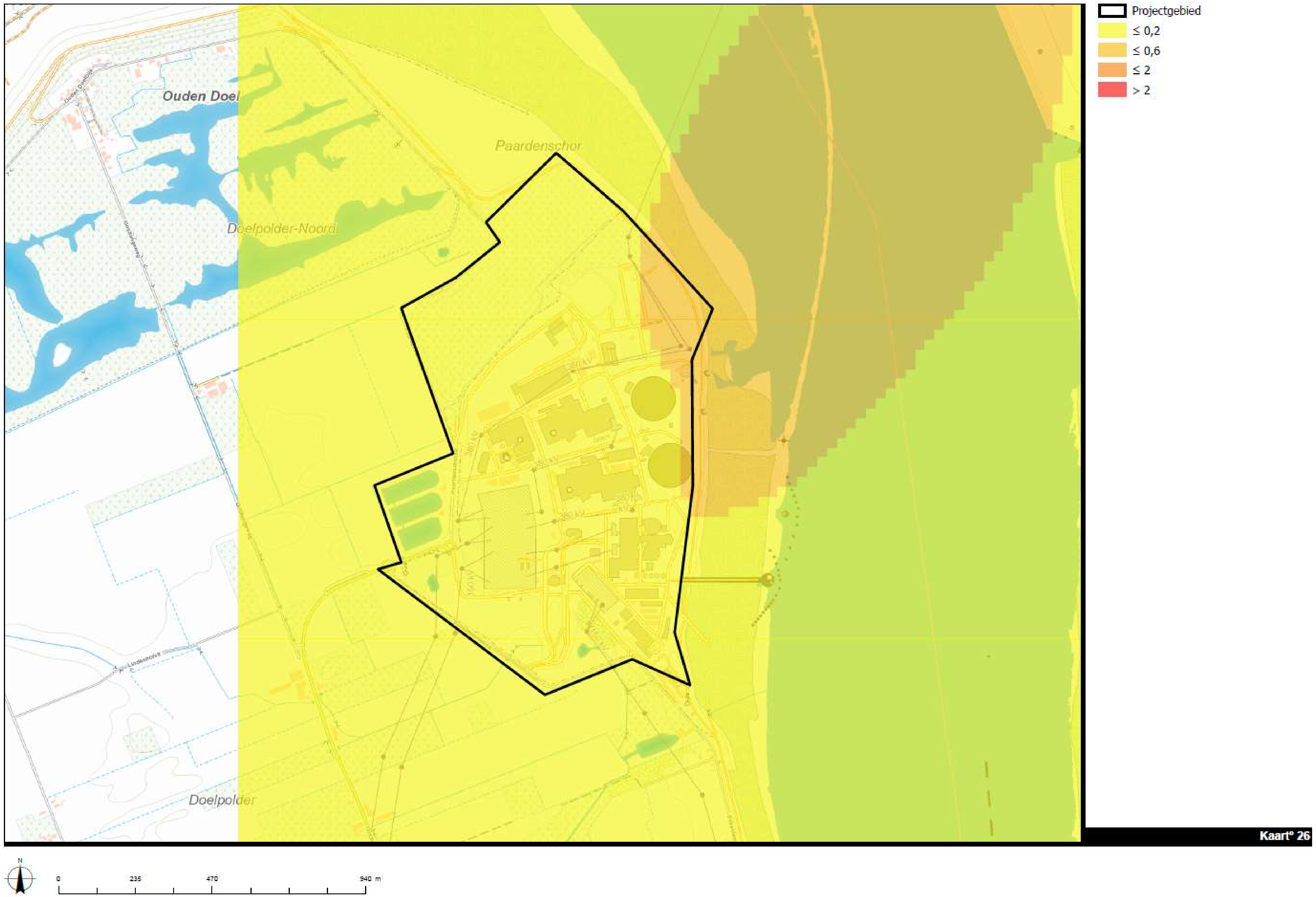

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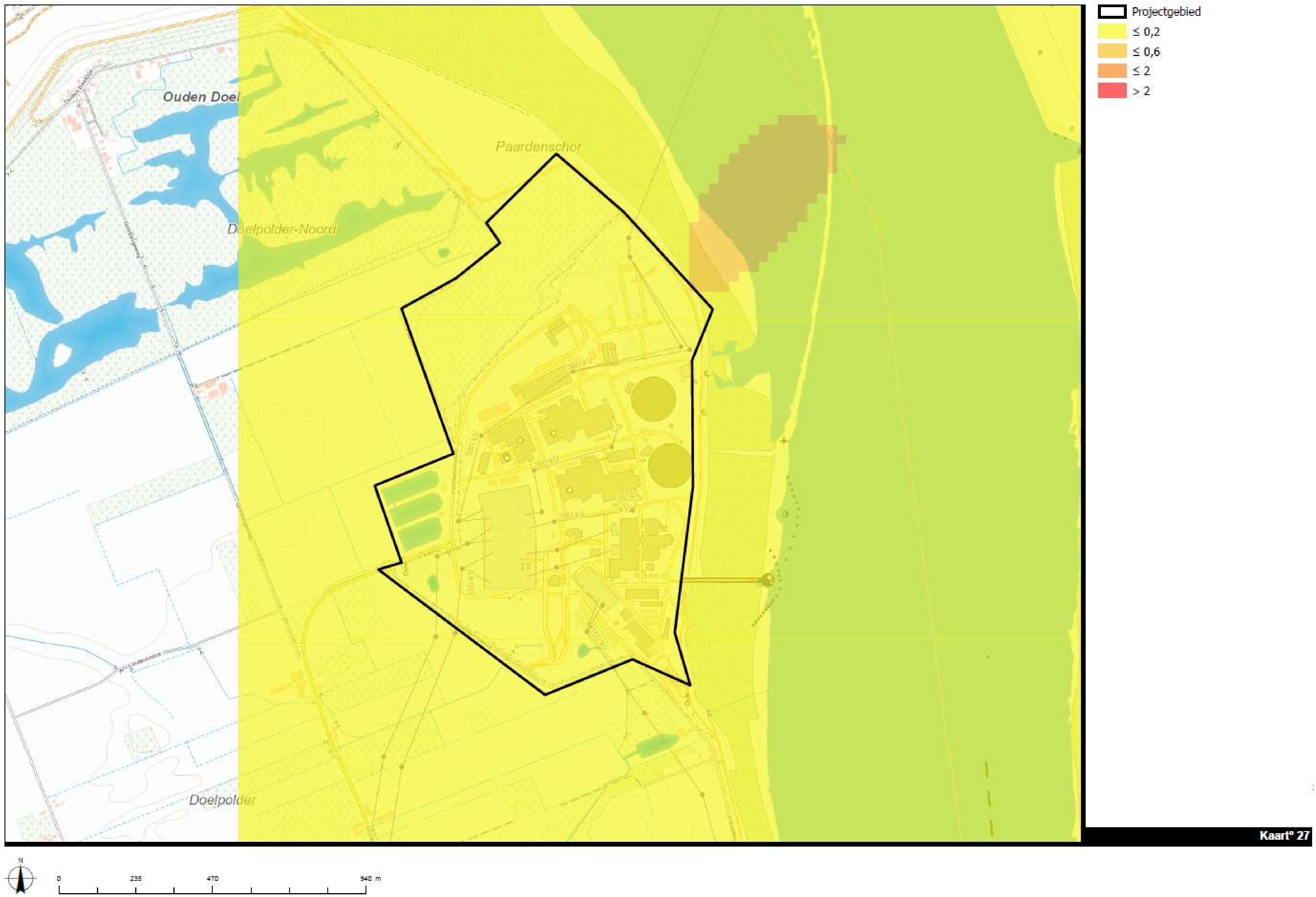

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Imagine the result

Verslag 5 uitgevoerde monitoringscampagnes (periode juni 2011 – maart 2012) naar de temperatuursinvloed van het koelwater van de kerncentrale van Doel op de Schelde

Electrabel NV

Projectnummer BE0111001590| finaal | 12-06-2012




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Projectomschrijving

Verslag 5 uitgevoerde monitoringscampagnes (periode juni 2011 – maart 2012) naar de temperatuursinvloed van het koelwater van de kerncentrale van Doel op de Schelde

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Inhoudsopgave

1 INLEIDING

Electrabel baat in Doel een kerncentrale uit, waarbij het gebruik van koelwater vereist is. Het koelwater wordt uit de Schelde opgepompt en daarna teruggestort, en voert op die manier grote hoeveelheden warmte af naar de Schelde. Die temperatuursverhoging is van belang voor het leven in en rond het Schelde-estuarium.

Voor de lozing van koelwater van elektrische centrales zijn in de VLAREM sectorale voorwaarden opgelegd. Voor de temperatuur van het geloosde koelwater gelden volgende emissiegrenswaarden:

- Maximum 33°C als ogenblikkelijke waarde
- Maximum 32°C als daggemiddelde
- Maximum 30°C als voortschrijdend 30-dagengemiddelde

In het kader van de hervergunning van de milieuvergunning van de kerncentrale werd in 2010 een milieueffectenrapport (MER) opgemaakt, waarin ondermeer de impact van de koelwaterlozing op de temperatuur van de Schelde werd beschreven en beoordeeld. De impact werd geëvalueerd door toepassing van het model CORMIX[1]. Dit is een softwaresysteem voor de analyse en voorspelling van lozingen in diverse waterlichamen.

De grootste invloed van de lozing van het koelwater bleek zich te situeren ter hoogte van de Plaat van Doel stroomafwaarts van het lozingspunt. Gezien het temperatuurverloop er lokaal niet gekend is en de modelresultaten verder gevalideerd en gepreciseerd dienen te worden, is in het MER voorgesteld ter hoogte van de Plaat van Doel een monitoring van de temperatuur van de Schelde uit te voeren. Deze monitoring dient toe te laten de evolutie van de temperatuur te verifiëren op de Plaat van Doel gedurende de getijdencyclus en dit in het bijzonder bij de kentering bij laagwater en het model te valideren. De kennis van deze evolutie is vooral wenselijk bij de hoogste Scheldetemperaturen in warme periodes. Daartoe is in het MER voorgesteld op verschillende dagen temperatuurmetingen van het Scheldewater uit te voeren.

In het vergunningsbesluit voor de verdere vergunning van de kerncentrale van Doel is deze aanbeveling gevolgd en is opgenomen dat er een monitoringsprogramma dient uitgevoerd te worden om de invloed van het koelwater van de kerncentrale op de Schelde na te gaan en de modelresultaten verder te valideren en te preciseren.

[1] CORMIX: Cornell Mixing Zone Expert System

Voorliggend verslag geeft de resultaten weer van de 5 uitgevoerde monitoringscampagnes ter invulling van deze eis. De monitoringscampagnes werden uitgevoerd conform het monitoringsprogramma opgemaakt op 24 mei 2011, conform het ‘voorstel voor verdere monitoring’ opgenomen in het verslag van monitoringscampagnes 1 en 2 (d.d. 05/09/2011) en conform de opmerkingen en voorstellen van de bevoegde overheden aangegeven vóór aanvang van de 1ste monitoringscampagne en op het overleg van 12 september 2011.

2 BESCHRIJVING MEETMETHODE

2.1 Monitoringsdata en -omstandigheden

De monitoringscampagnes van de periode juni 2011 tot maart 2012 werden uitgevoerd op volgende data:

Monitoringscampagne	1	2	3	4	5
Monitoringsdata	16/06/2011	02/08/2011	29/09/2011	07/02/2012	07/03/2012
Type periode	Gematigde temperaturen	Warme temperaturen	Warme temperaturen	Koude temperaturen	Koude temperaturen
Buitenluchttemperatuur	13,4 tot 19,3°C	17,1 tot 28,0°C	16,3 tot 27,6°C	-11,3 tot -6,4°C	2,2 tot 5,3°C
Weersomstandigheden	Bewolkt, felle regenbuien	Zonnig met sporadisch lichte sluier-bewolking	Zonnig, licht bewolkt	Droog, veel wind, zeer koud	Buien

2.2 Meetmateriaal en monitoringsdiepte

De monitoringscampagnes werden uitgevoerd aan de hand van een klein werkschip, dat voor de duur van 1 dag gehuurd wordt. Ter hoogte van alle meetpunten werd de temperatuur en het zuurstofgehalte opgemeten aan de hand van een Hach HQ40d meettoestel met twee sondes met telkens een zuurstof- en temperatuurelektrode, met één sonde op een constante diepte van 0 m tot 0,5 m onder de waterspiegel en de andere sonde op een constante diepte van 2 m tot 2,5 m onder de waterspiegel. De diepte van beide sondes werd constant gehouden door de kabels van de sondes op afgemeten lengte vast te hechten aan een vlottende jerrycan of aan een metalen staaf met gewicht, bevestigd aan de zijkant van het werkschip. Alle metingen werden uitgevoerd bij (relatieve) stilstand van het werkschip.

Hach HQ40d meettoestel aangesloten aan twee meetsondes

Kabels van beide meetsondes bevestig aan de zijkant van het werkschip en op constante diepte gehouden met een vlottende jerrycan

2.3 Monitoringslocaties

De meetpunten van de diverse campagnes worden weergegeven op de plannen in bijlage 1. Afhankelijk van het doel van de diverse monitoringslocaties werden metingen op diverse plaatsen uitgevoerd:

- Monitoringscampagne 1 werd uitgevoerd bij gemiddelde temperaturen, met het doel om in de periode rond de kentering bij laagwater gegevens te verzamelen ter hoogte van de Plaat van Doel, in een zone tot ca. 1300 m stroomafwaarts van het lozingspunt (i.e. de zone die binnen de strekdam gelegen is).
  - ➔ Bovendien werden er metingen uitgevoerd bij afgaand water nog verder stroomafwaarts van het lozingspunt (tot op ca. 3,7 km);
  - ➔ Bij opkomend tij aan de overzijde van de strekdam (wanneer het koelwater over de strekdam begint te stromen); langsheen de strekdam en tussen het lozingspunt en de captatiepunten;
  - ➔ Twee dwarsprofielmetingen bij opkomend tij, van de ene oever naar de overzijde van de Schelde.
- Monitoringscampagne 2 werd uitgevoerd bij warme (buitenlucht)temperaturen, met het doel om in de periode rond de kentering bij laagwater gegevens te verzamelen in de zone binnen de strekdam.
  - ➔ Er werden ook metingen uitgevoerd bij afgaand water verder stroomafwaarts (tot op ca. 5 km van het lozingspunt);
  - ➔ Bij opkomend tij aan de overzijde van de strekdam; tussen het lozingspunt en de captatiepunten.
- Monitoringscampagne 3 werd uitgevoerd bij warme (buitenlucht)temperaturen, met het doel om gedurende 12 h gegevens te verzamelen *enkel* in de zone binnen de strekdam, voor representatieve toetsing aan de daggemiddelde (en 1h kentering) modelresultaten.
  - ➔ Bij hoogwater werd bovendien de temperatuurstoename in de zone op 150-300 m stroomafwaarts van het lozingspunt (mengzone) opgevolgd, met als doel de overlevingskans van exoten in deze zone in te schatten.
- Monitoringscampagnes 4 en 5 werden uitgevoerd bij koude temperaturen en waren gericht op het beantwoorden van de vraag of de temperatuurverhoging van die aard is dat exoten kunnen overleven en verder ontwikkelen. Daarom werd nagegaan of op bepaalde plaatsen de temperatuur in belangrijke mate verhoogd blijft gedurende de getijdencyclus:
  - ▪ binnen de strekdam, in de zone dicht bij het lozingspunt en bij opkomend water;
  - ▪ buiten de strekdam, stroomopwaarts, in de zone tussen het lozingspunt en de captatiepunten bij hoogwater en afgaand water.

- ➔ Bovendien werden er in de zone binnen de strekdam, tot ca. 1300 m stroomafwaarts van het lozingspunt ook metingen uitgevoerd in de periode rond de kentering bij laagwater (zoals bij de eerdere campagnes).

Naast de temperatuur werd eveneens telkens het zuurstofgehalte gemeten (zie bijlage 2). De metingen tonen geen zuurstofverarming van het Scheldewater ten gevolge van de lozing van warm koelwater, eerder een lichte aanrijking (bij doorstroming van het koelwater doorheen het koelproces wordt het water sterk belucht). De resultaten van de zuurstofmetingen worden in voorliggend verslag niet verder in detail besproken.

Bijkomend is gebruik gemaakt van data die reeds continu door Electrabel verzameld worden in het kader van de goede werking van het koelwatersysteem van de kerncentrale:

- ➔ datareeksen van temperatuur en zuurstofgehalte ter hoogte van de intake (captatiepunt) en het lozingspunt;
- ➔ datareeksen van buitenluchttemperaturen ter hoogte van de centrale.

3 RESULTATEN VAN DE MONITORINGSCAMPAGNES

In onderstaande tabel worden de specificaties van de uitgevoerde monitorings-campagnes weergegeven.

Parameter		1 16/06/11	2 02/08/11	3 29/09/11	4 07/02/12	5 07/03/12
Gemiddelde temperatuur Schelde	Achtergrondwaarde zoals gemeten tijdens monitorings-campagnes (1)	19,3°C	19,5°C	18,6°C	3,4°C	6,8°C
Gemiddelde temperatuur Schelde bij intake koelwater	Achtergrondwaarde zoals gemeten door Electrabel bij intake (2)	19,4°C	19,8°C	18,9°C	3,7°C	7,0°C
Gemiddelde lozingstemperatuur		30,5°C	31,1°C	30,4°C	17,1°C	23,1°C
Temperatuursverschil (ΔT) Scheldewater en koelwater bij lozing		11,2°C	11,6°C	11,8°C	13,7°C	16,3°C
Lozingsdebiet	Maximaal vergund debiet (alle eenheden in dienst)	195.760 m³/h (3) (54,4 m³/s)				
Begin en einde monitoring		7h00 tot 19h00	7h00 tot 19h00	7h00 tot 19h00	7h00 tot 17h00	7h00 tot 16h00
Laagwater		10h57	12h39	11h53	9h39	9h11
Hoogwater		16h46	18h14	17h25	15h21	14h52

(1) Gemeten bij afgaand water en stroomopwaarts van de lozing; aan de overzijde van de Schelde; of bij opkomend water stroomafwaarts van de lozing.

(2) Bij deze waarde is de bijdrage van de lozing van het koelwater reeds geïncorporeerd.

(3) Gedurende de wintercampagnes was het lozingsdebiet 40.000 m³/h lager dan bij de overige campagnes omwille van de uitschakeling van één pomp.

In bijlage 2 worden de meetresultaten alle uitgevoerde monitoringscampagnes weergegeven. De meetlocaties worden visueel voorgesteld in bijlage 1.

Om de meetresultaten van de punten gelegen binnen de strekdam (het gebied waarop de focus van de monitoring ligt) grafisch voor te kunnen stellen, worden de meetresultaten van dit gebied opgedeeld in drie of vier zones, volgens afstand tot het lozingspunt. De ligging van deze invloedszones wordt geschetst op de plannen in bijlage 1.

Voor elk van deze invloedszones werd de temperatuur uitgezet in functie van de tijd, voor de gehele monitoringsduur (max. 12 h). De beide monitoringsdiepten (0 tot 0,5 m; 2 tot 2,5 m) worden telkens samen op één grafiek voorgesteld. Deze grafieken werden opgemaakt voor alle monitoringscampagnes afzonderlijk (bijlage 3), en voor de gegevens per invloedszone van alle campagnes samen (bijlage 4).

4 MODELLERING

Met het oog op de validering en verdere precisering van de modelresultaten bekomen bij uitvoering van het MER worden de gemeten temperatuursgegevens getoetst ten opzichte van de modelresultaten bekomen bij een lozingstemperatuur en achtergrondtemperatuur van de Schelde zoals gemeten tijdens de monitoringcampagnes.

Voor de modellering wordt de CORMIX software toegepast (zie MER). Dit softwaresysteem, dat gebruik maakt van inputgegevens (zoals de geometrie van het systeem, de lozingskarakteristieken…) laat de voorspelling van de lozingspluim (temperatuurspluim) toe (omvang en reikwijdte).

Volgende scenario's worden gemodelleerd:

- ➔ Ogenblikkelijke waarde bij de kentering met een bathymetrie overeenkomstig beperkte verspreiding Plaat van Doel: voor alle 5 uitgevoerde monitoringscampagnes telkens bij de desbetreffende lozingstemperatuur en de gemeten achtergrondwaarde van het Scheldewater, 1 uur bij kentering bij laagwater (geringe menging).
- ➔ Daggemiddelde waarde over 24 h (een volledige cyclus): enkel voor monitoringscampagne 3, bij de desbetreffende lozingstemperatuur en de gemeten achtergrondwaarde van het Scheldewater. Enkel bij monitoringscampagne 3 werden immers voldoende meetgegevens verzameld voor representatieve toetsing aan de gemodelleerde daggemiddelde waarden.

Voor de simulatie van de bijdrage van de koelwaterlozing op de temperatuur van de Schelde worden de gegevens toegepast die in onderstaande tabel zijn samengevat. Als debiet wordt het maximum vergund lozingsdebiet gehanteerd.

Parameter		**Waarde**	**Bron**
Gemiddelde temperatuur Schelde	16/06/2011	19,3°C	Monitoring 1
	02/08/2011	19,5°C	Monitoring 2
	29/09/2011	18,6°C	Monitoring 3
	07/02/2012	3,4°C	Monitoring 4
	07/03/2012	6,8°C	Monitoring 5
Snelheden	Opkomend water Aanname model	1,25 à 2 m/s 1,63 m/s	Wat. Lab
	Afgaand water	1,5 m/s	Wat. Lab
	Kentering	0,05 m/s	Wat. Lab
Waterpeil	Gemiddeld hoogwater	5,18 m TAW	Wat. Lab
	Gemiddeld laagwater	0,04 m TAW	Wat. Lab
	Gemiddelde halftijhoogte	2,61 m TAW	Wat. Lab
Lozingsdebiet		195.760 m³/h (54,4 m³/s)	Electrabel

Bathymetrie (*)	Breedte	1.100 m	MER
	Diepte	8 m	MER
Bathymetrie Plaat van Doel (*)	Breedte	300 m	MER
	Diepte	3 m	MER
Kenmerken lozingspunt	Breedte	20 m	Electrabel
	Hoogte	1 m	Electrabel
	Oppervlakkige lozing Loodrecht op de Schelde		CORMIX user's manual
Lozingstemperatuur	16/06/2011	30,5°C	Electrabel
	02/08/2011	31,1°C	Electrabel
	29/09/2011	30,4°C	Electrabel
	07/02/2012	17,1°C	Electrabel
	07/03/2012	23,1°C	Electrabel
Heat loss Coefficient		33 W/m²/C	CORMIX user's manual

(*) Nota: De gemiddelde diepte van de Schelde is 7,8 m en de breedte is ongeveer 1.100 m. Deze gegevens werden aangenomen voor de simulatie ingeval van opkomend water, voor de berekening van het daggemiddelde. Gezien de specifieke ligging van het lozingspunt aan de kop van de Plaat van Doel wordt voor de situatie bij afgaand water aangenomen dat het grootste volume water afkomstig van de koelwaterlozing via deze plaat wegstroomt. Om dit in rekening te brengen werd voor de simulatie aldaar een breedte van 300 m en een diepte van 3 m in aanmerking genomen. Deze aanname werd in rekening gebracht bij de kentering. Bij de berekening van het daggemiddelde werd deze aanname bij eb telkens ook vergeleken met de gemiddelde diepte en breedte van de Schelde gezien gedurende de eerste uren van eb en stroomafwaarts van de Plaat van Doel een ruimere verspreiding kan verwacht worden.

5 BESPREKING VAN DE RESULTATEN

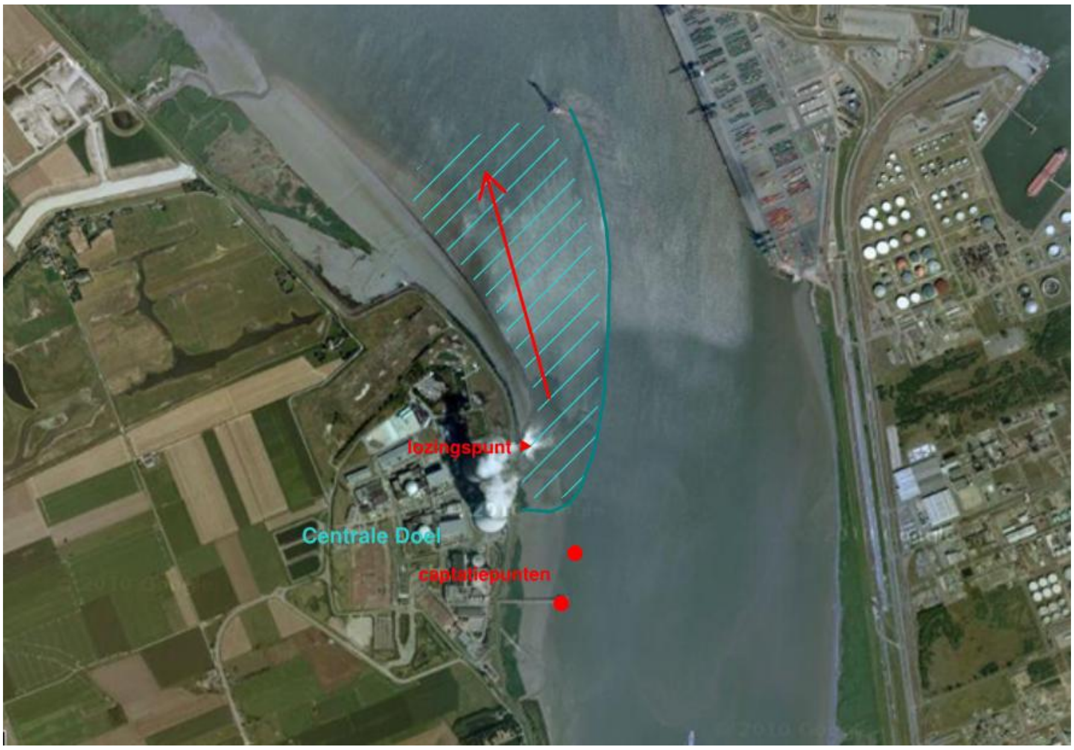
5.1 Vaststellingen

Bij de monitoringscampagnes werden diverse zaken waargenomen. Deze worden per periode in de getijdencyclus besproken in onderstaande paragrafen.

5.1.1 Afgaand water

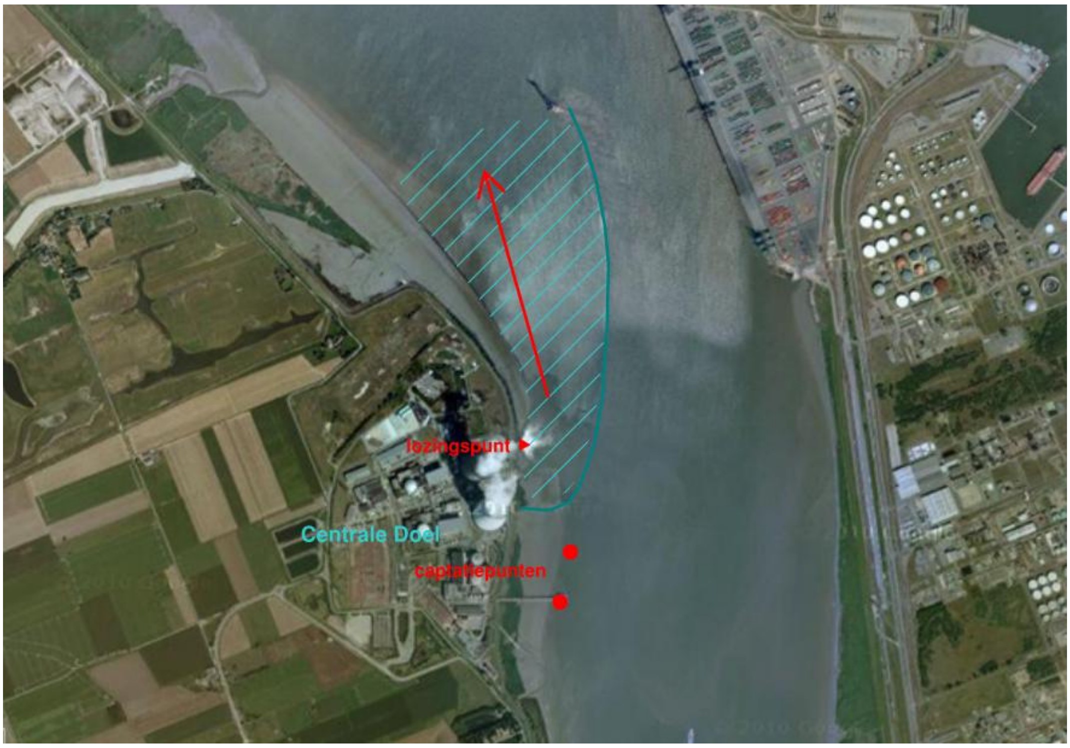
- ➔ Bij afgaand water vormt zich een pluim in de zone binnen de strekdam, waarbij de temperatuur afneemt in functie van de afstand van het lozingspunt.
- ➔ In de zone tot 200 à 300 m van het lozingspunt blijft de temperatuur nagenoeg gelijk aan de lozingstemperatuur; dit is de mengzone.
- ➔ Aan het einde van de strekdam, op een afstand van ongeveer 1300 m stroomafwaarts van het lozingspunt bedraagt de temperatuurstoename (ΔT) ca. 1°C.
- ➔ De strekdam blijft in de periode na hoogwater nog lange tijd onder water, waardoor het koelwater zich theoretisch over de gehele breedte en diepte van de Schelde kan verspreiden, en het koelwater voortdurend vermengd wordt met vers en koel Scheldewater vanaf stroomopwaartse richting. De zone met waarneembare temperatuursverhoging blijft op die manier beperkt tot een kegel binnen de strekdam (gearceerde zone in Figuur 1).

Figuur 1: Zone met waarneembare temperatuursverhoging bij afgaand water, strekdam onder water



- Vanaf het moment dat de strekdam boven het wateroppervlak komt te liggen (ca. 1,5 uur voor kentering) is er geen toestroom meer mogelijk van vers, koel Scheldewater vanaf stroomopwaartse richting tot in de zone binnen de strekdam, en is er stroomafwaarts geen verdere verspreiding meer mogelijk over de gehele breedte en diepte van de Schelde. De zone met waarneembare temperatuursverhoging wordt dan gedefinieerd als het volledige gebied binnen de strekdam (gearceerde zone in Figuur 2).

Figuur 2: Zone met waarneembare temperatuursverhoging bij afgaand water, strekdam boven water



- Er is een duidelijke thermische stratificatie waarneembaar, waarbij het warmere, minder dense koelwater aan de oppervlakte drijft. Het temperatuursverschil tussen het water aan de oppervlakte en het water op grotere diepte neemt af met toenemende afstand tot het lozingspunt.
- Op een diepte van 2 tot 2,5 m is enkel dicht bij het lozingspunt (< 300 m) een sterke temperatuurstoename waarneembaar. In deze zone komt immers een goede verticale menging voor door de turbulentie veroorzaakt door het instromend koelwater, de geringe waterdiepte en de grillige morfologie. Vermoedelijk komt er ter hoogte van het lozingspunt een diepere zone voor, iets verder stroomafwaarts gevolgd door een duin.

5.1.2 Kentering bij laagwater

- ➔ Bij kentering (doodtij) bij laagwater hoopt het koelwater zich op binnen de strekdam waardoor de temperatuur oploopt in dit gebied. De temperatuur neemt af naargelang men zich verder van het lozingspunt verwijdert.
- ➔ Op een afstand van 400 tot 500 m stroomafwaarts van het lozingspunt bedraagt de temperatuurstoename (ΔT) van het Scheldewater tijdens de kentering aan de oppervlakte gemiddeld 10 à 12°C (bij een ΔT bij lozing van 11 tot 16°C); op een diepte van 2 tot 2,5 m bedraagt deze gemiddeld 6 à 7°C. De temperatuurstoename aan de oppervlakte blijft hoger dan 5°C tot op een afstand van ca. 850 m. Op een diepte van 2 tot 2,5 m is ΔT beperkt tot ca. 3°C op een afstand van 800 m. Op 1250 m afstand stroomafwaarts van het lozingspunt bedraagt ΔT 0,5 à 1°C.

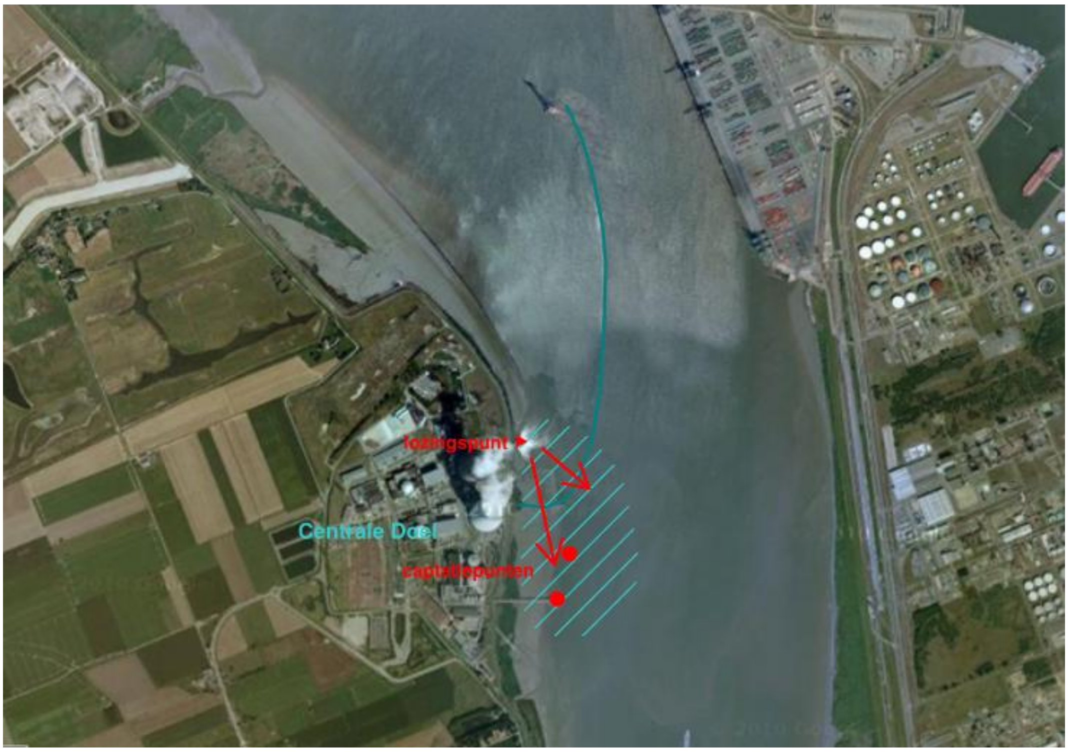
5.1.3 Opkomend water

- ➔ Bij opkomend water wordt de lozingspluim gelegen binnen de strekdam geleidelijk teruggedrongen naar het lozingspunt toe.
- ➔ Naarmate het waterpeil opnieuw stijgt, komt de strekdam vervolgens opnieuw onder water te liggen. Het net geloosde koelwater en opgehoopte water binnen de strekdam wordt uitgespoeld en stroomt over de breedte van de dam, stroomopwaarts.
- ➔ Binnen de strekdam is er na verloop van tijd amper nog een temperatuurstoename meetbaar:
  - Bij monitoringscampagnes 1, 3, 4 en 5 werd in de periode voor hoogwater op ca. 200 m van het lozingspunt (de kortst mogelijke afstand tot het lozingspunt bij hoogwater) geen temperatuursverhoging meer opgemeten. Bij de campagnes 1 en 3 werd deze nagenoeg volledige uitspoeling op minder dan een half uur voor hoogwater vastgesteld; bij campagnes 4 en 5 (winter) al ruim 2,5 uur voor hoogwater.
  - Bij monitoringscampagne 2 werd een dergelijke nagenoeg complete uitspoeling binnen de strekdam niet waargenomen. Wel treedt er een sterke daling van ΔT op in het gebied voorbij de mengzone (i.e. voorbij ca. 200 m van het lozingspunt); er werd nog slechts een ΔT van 1 tot 3°C, voornamelijk oppervlakkig, vastgesteld.

- ➔ Stroomopwaarts, buiten de strekdam, is de impactzone beperkt van omvang; er blijkt zich ten zuiden van het lozingspunt een wolk te vormen → het koelwater wordt min of meer kortgesloten tussen het lozingspunt en de captatiepunten (gearceerde zone in Figuur 3).
- ➔ De impactzone bij opkomend water is meetbaar tot op maximaal 500 m van het lozingspunt in oostelijke richting en reikt maximaal tot 800 m stroomopwaarts van het

lozingspunt (zuidelijke richting). Binnen deze zone bedraagt de temperatuurstoename 1 tot 3°C; uitzonderlijk werd een hogere ΔT gemeten (maximaal 6°C).

Figuur 3: Maximale zone met waarneembare temperatuursverhoging bij opkomend water



5.1.4 Afgaand water, vlak na hoogwater kentering

Na kentering bij hoogwater stroomt het koelwater opnieuw stroomafwaarts.

➔ Bij campagnes 4 en 5 (winter) werd het terugdringen van de impactzone buiten de strekdam door het afgaand water gemonitord:

- Bij campagne 4 werd 1 uur na hoogwater op 300 m stroomopwaarts van het lozingspunt (i.e. het dichtst mogelijke punt voor meting buiten de strekdam) geen temperatuursverhoging meer waargenomen.
- Bij campagne 5 werd al een kwartier na hoogwater geen temperatuursverhoging buiten de strekdam meer gemeten.

➔ De thermische pluim stroomopwaarts buiten de strekdam verdwijnt dus helemaal.

➔ Korte tijd na hoogtij stijgt de watertemperatuur in de zone binnen de strekdam opnieuw. De cyclus herhaalt zich, zoals beschreven vanaf § 5.1.1.

5.1.5 Globaal temperatuurverloop per invloedszone over 12 uur

Uit de grafieken waarin de meetgegevens van alle campagnes uitgezet zijn in functie van de tijd (bijlage 4), kan afgeleid worden dat er in de zone van 300-600 m stroomafwaarts van het lozingspunt een sterke temperatuurstoename plaatsvindt vanaf 1,5 uur voor laagwater tot 3 uur na laagwater. In de zones verder stroomafwaarts van het lozingspunt neemt ΔT steeds verder af en neemt de periode waarin een duidelijke temperatuurstoename waarneembaar is eveneens steeds verder af:

- ➔ Op 600-850 m stroomafwaarts is er een duidelijke temperatuurstoename vanaf 1 uur voor laagwater tot 2,5 uur na laagwater.
- ➔ Op 850-1000 m stroomafwaarts is er een duidelijke temperatuurstoename vanaf 1 uur voor laagwater tot 2 uur na laagwater.
- ➔ Op 1000-1250 m stroomafwaarts is er een duidelijke temperatuurstoename vanaf minder dan 1 uur voor laagwater tot minder dan 2 uur na laagwater.

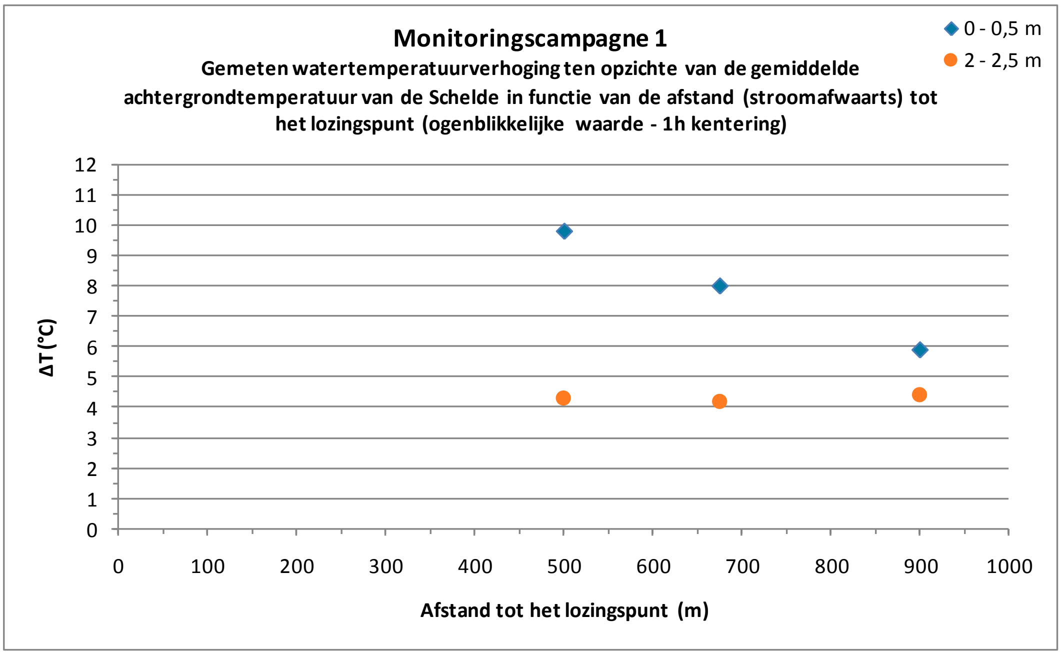
5.2 Toetsing gemeten waarden aan de gemodelleerde waarden

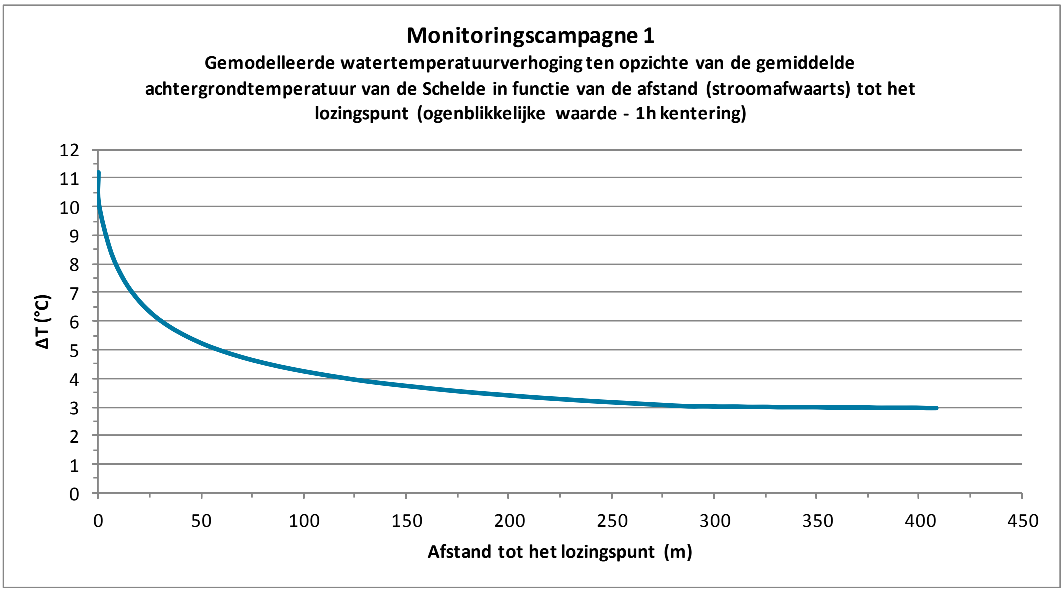
Allereerst dient opgemerkt te worden dat het CORMIX model geen rekening houdt met de thermische stratificatie die duidelijk waargenomen werd bij de monitoring; het model houdt slechts rekening met een waterkolom van 3 meter diep waarin de thermische pluim gemengd wordt. De modelresultaten worden vergeleken met de gemeten waarden op 2 diepten: 0-0,5 m en 2-2,5 m (afzonderlijk uitgezet op de grafieken).

5.2.1 Gemodelleerde en gemeten watertemperatuursverhoging – 1 uur kentering bij laagwater

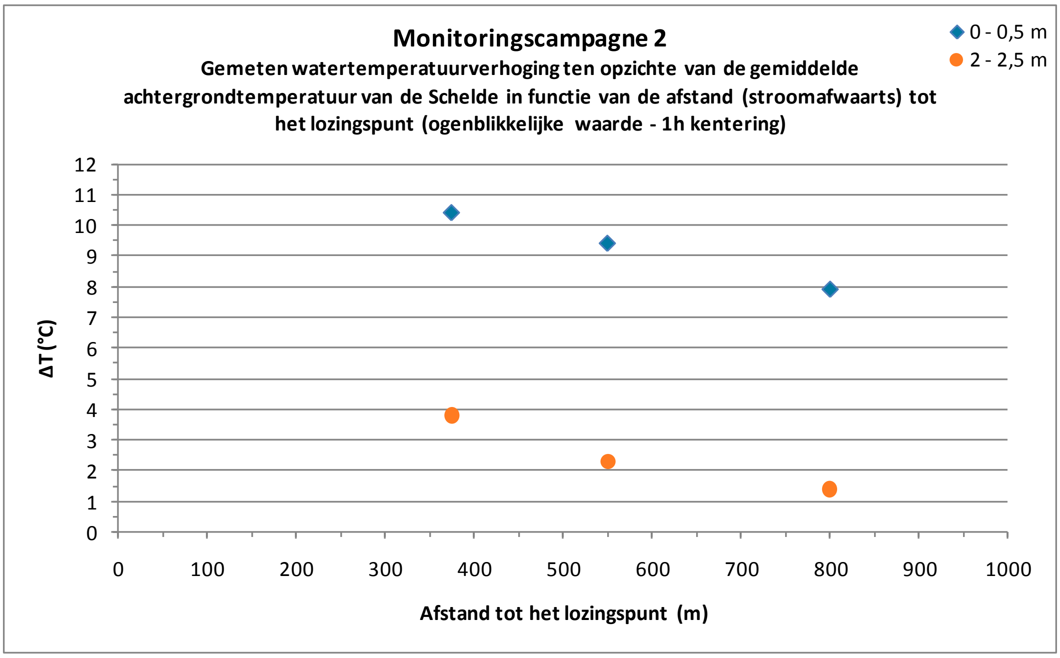
Onderstaande figuren tonen per monitoringscampagne de gemodelleerde en gemeten watertemperatuursverhoging ten opzichte van de achtergrondtemperatuur van de Schelde in functie van de afstand stroomafwaarts tot het lozingspunt, 1 uur bij kentering bij laagwater.

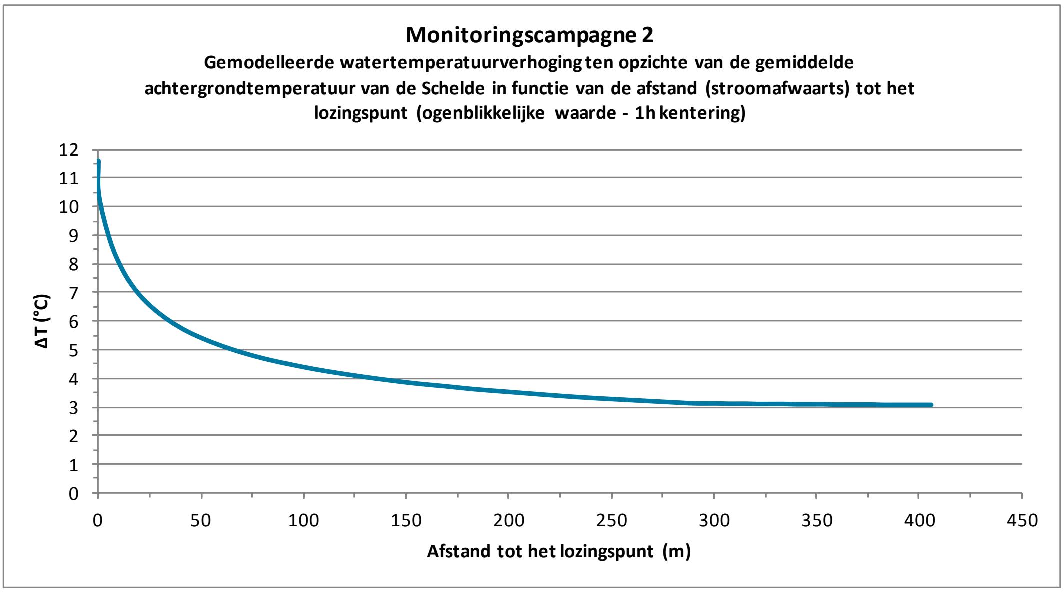
Monitoringscampagne 1



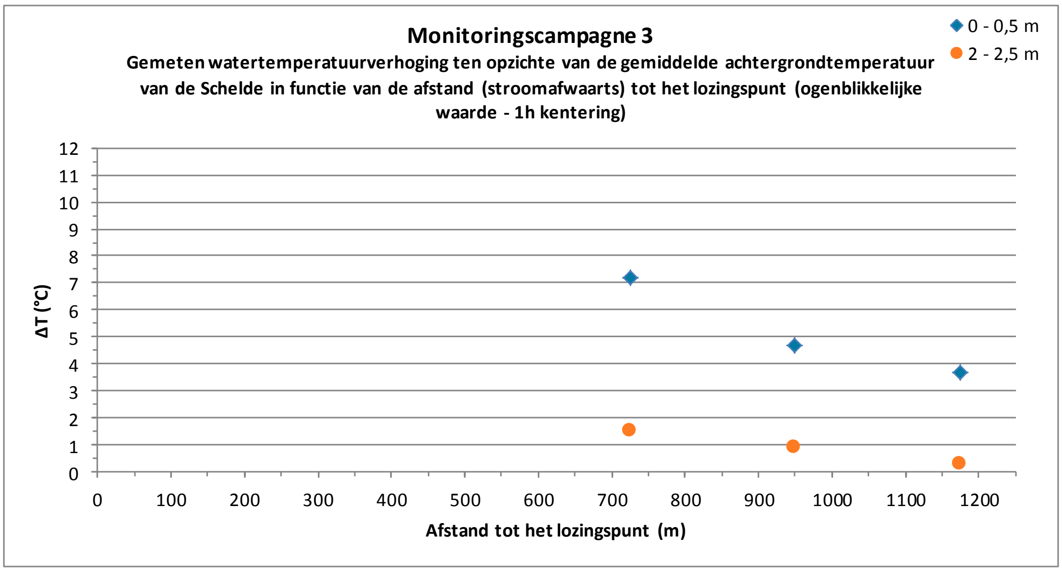


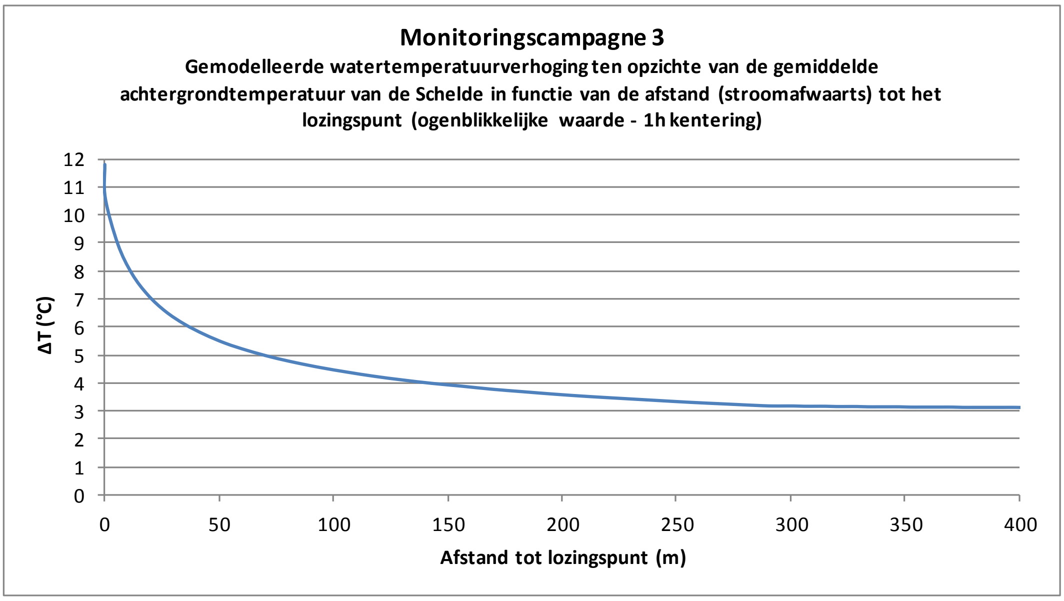
Monitoringscampagne 2



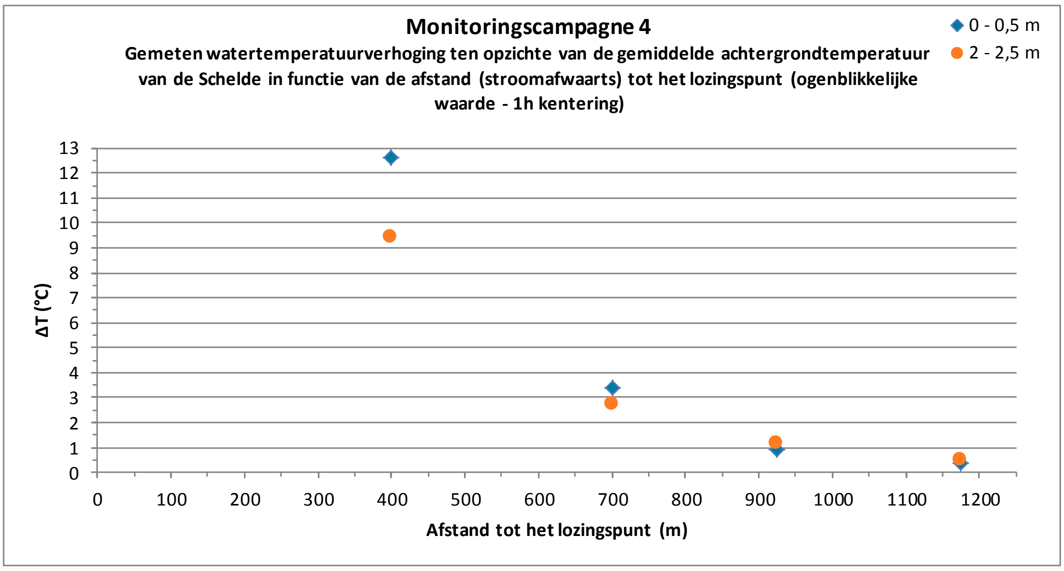


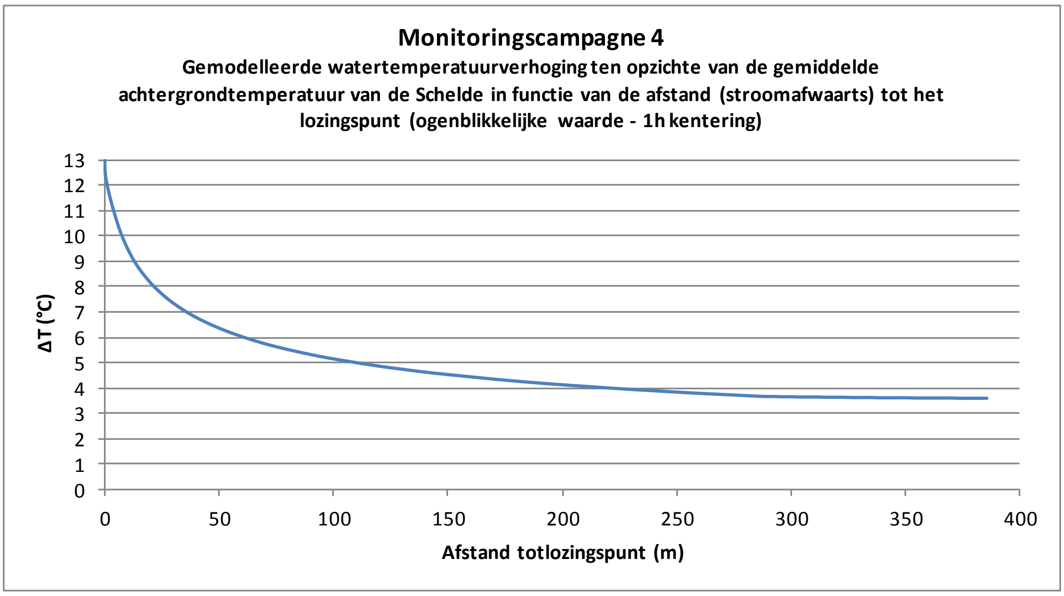
Monitoringscampagne 3



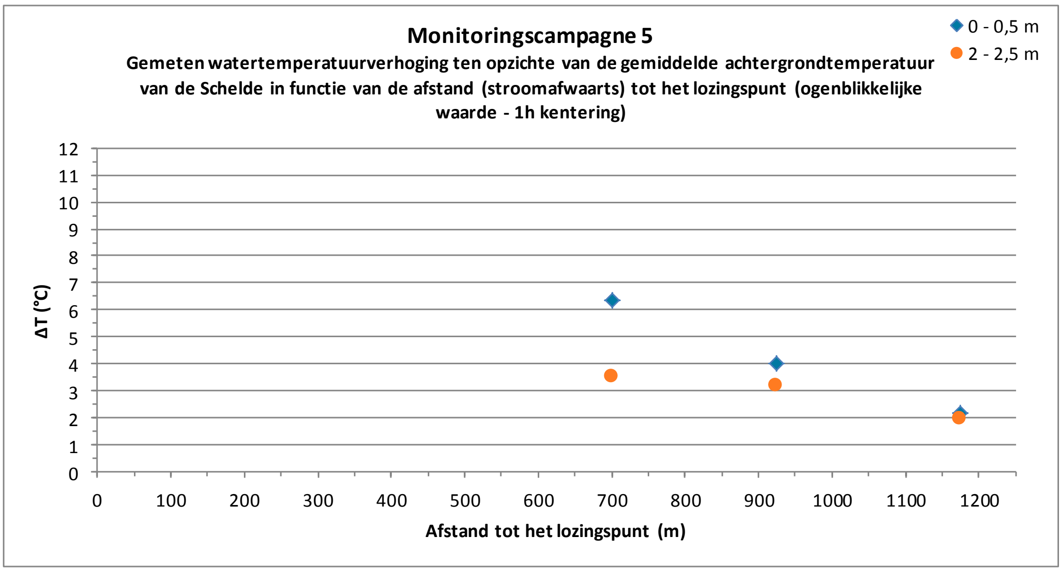


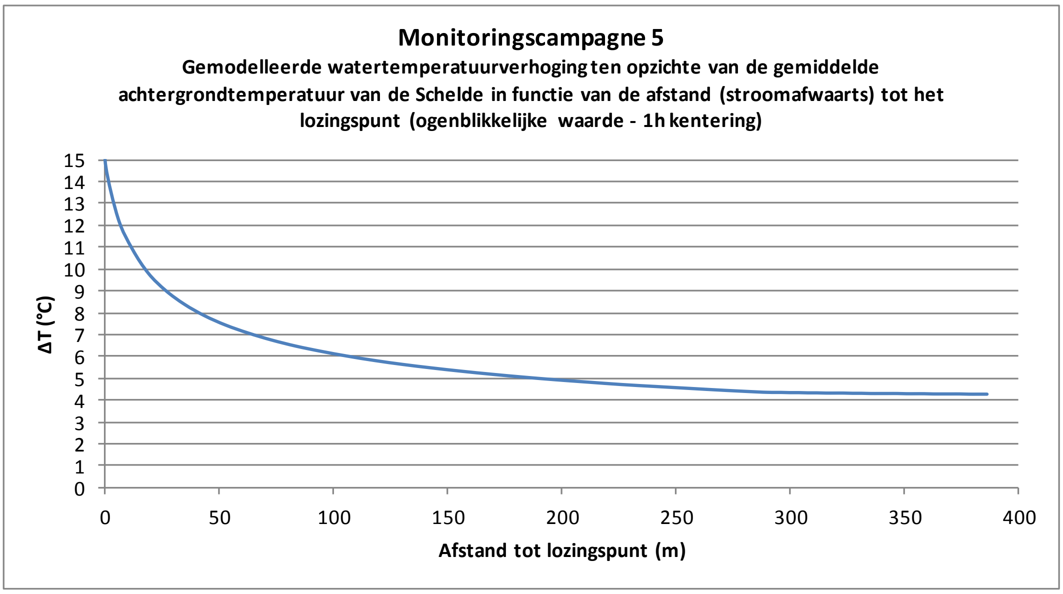
Monitoringcampagne 4





Monitoringscampagne 5





Bespreking

Uit de vergelijking van de gemeten waarden met de gemodelleerde waarden blijkt dat de temperatuurstoename op 400 à 500 m bij kentering bij laagwater zoals gemeten bij de monitoringscampagnes groter is dan zou blijken uit de modellering. Vooral aan de oppervlakte is wegens de stratificatie het verschil groot. Het model laat niet toe tijdens de kentering de temperatuursverhoging na te gaan op grotere afstanden. Voor de voorspelling van de ogenblikkelijke watertemperatuursverhoging bij kentering blijkt het CORMIX model dus niet geschikt te zijn, vooral omwille van de specificiteit van de morfologie en de waterbewegingen stroomafwaarts het lozingspunt. Evenmin geeft het CORMIX model de mogelijkheid de stratificatie-invloed in te schatten. Voor dergelijke specifieke plaatsgebonden modellering is er geen ander bestaand model beschikbaar.

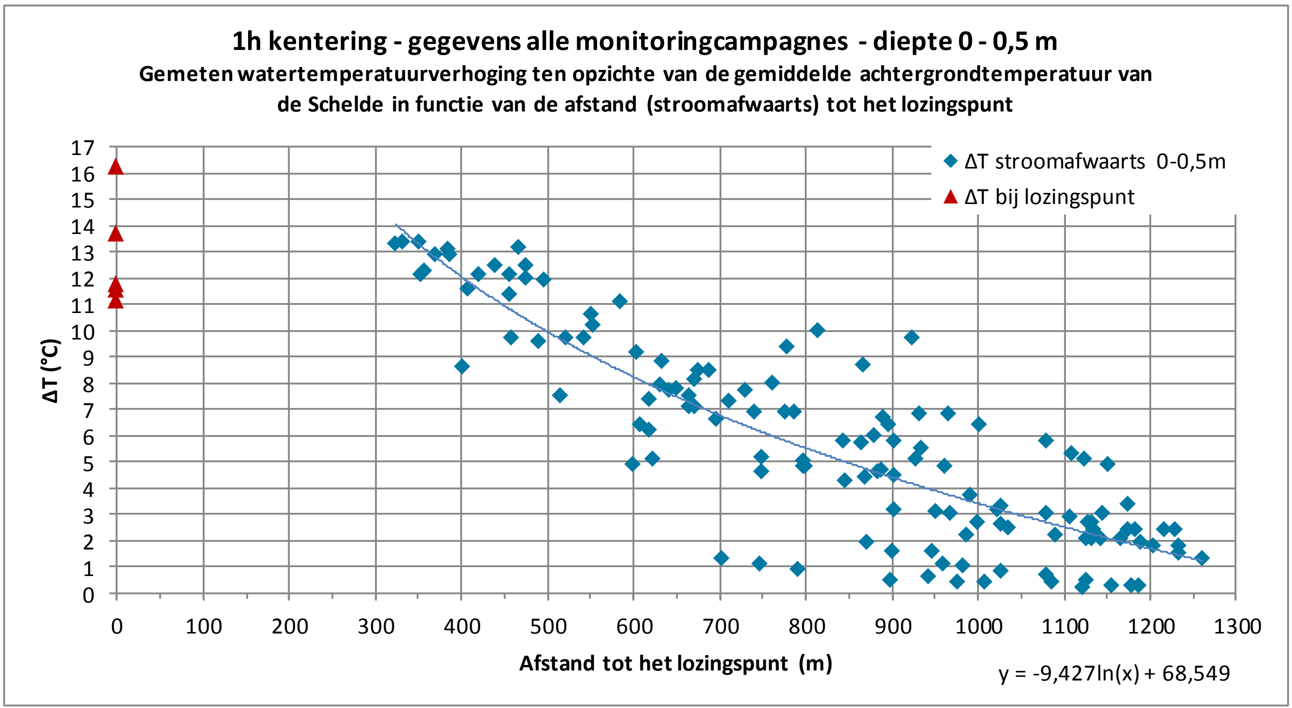
De daling van ΔT met de afstand tot het lozingspunt wordt beter voorspeld op basis van de gemeten waarden van de 5 uitgevoerde monitoringscampagnes. Alle opgemeten temperaturen (1 uur bij kentering bij laagwater, in de zone binnen de strekdam en voorbij de mengzone) werden daarom uitgezet ten opzichte van de afstand tot het lozingspunt, voor beide monitoringsdieptes afzonderlijk (zie onderstaande grafieken). Uit deze grafieken kan het verband tussen ΔT en de afstand tot het lozingspunt (bij kentering) afgeleid worden.

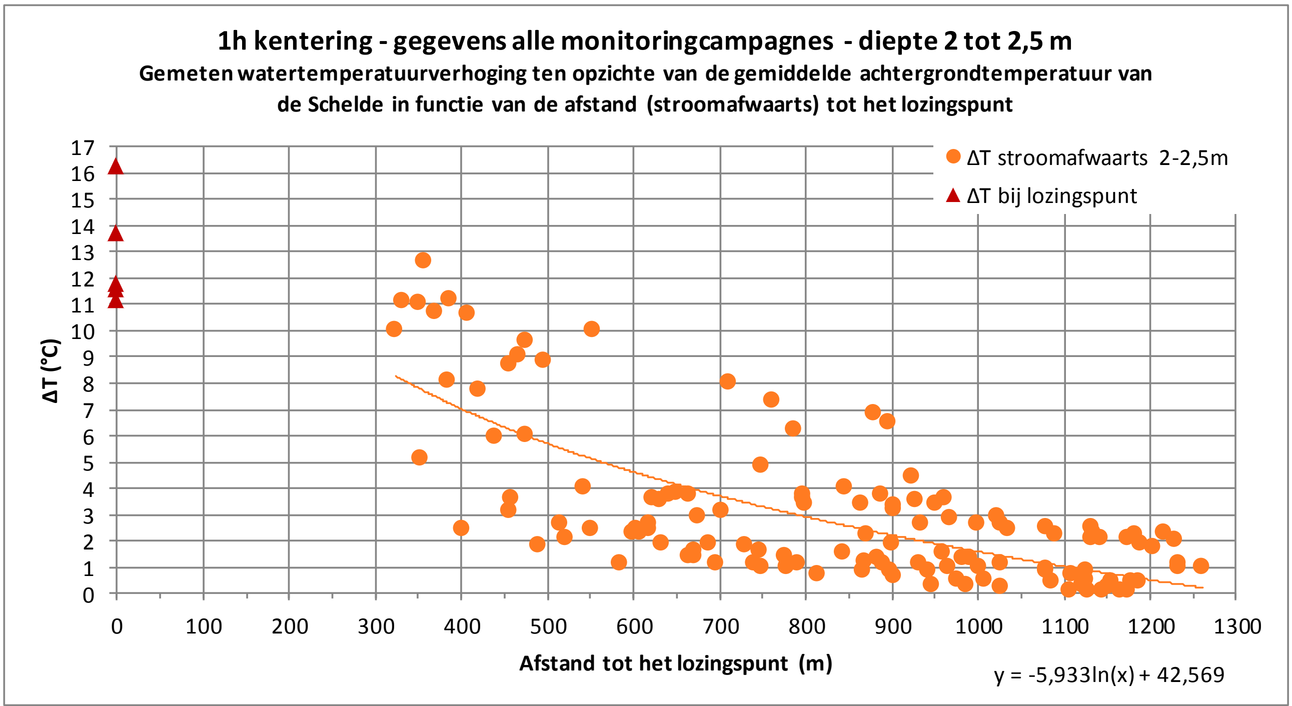
De logaritmische functies die het verband tussen ΔT (y) en de afstand tot het lozingspunt (x) voor elk van de monitoringsdieptes afzonderlijk en 1 uur bij kentering bij laagwater het best beschrijven, zien er als volgt uit:

Diepte	Logaritmische functie
Diepte 0 – 0,5 m	$\boldsymbol{y = -9,427.\ln x + 68,549}$
Diepte 2 – 2,5 m	$\boldsymbol{y = -5,933.\ln x + 52,569}$

Hieruit blijkt dat de lozing tijdens kentering van het getij tot de volgende stijging van de watertemperatuur leidt (in het gebied stroomafwaarts van het lozingspunt, binnen de strekdam, buiten de mengzone):

Afstand tot lozingspunt	ΔT op diepte 0-0,5 m	ΔT op diepte 2-2,5 m
500 m	10,0 °C	5,7 °C
750 m	6,1 °C	3,3 °C
1000 m	3,4 °C	1,6 °C
1250 m	1,3 °C	0,3 °C





De waargenomen variaties in ΔT worden verondersteld voornamelijk het gevolg te zijn van volgende factoren:

- Temperatuursverschil tussen het Scheldewater en het koelwater bij lozing: Bij de wintercampagnes (campagnes 4 en 5) lag ΔT bij lozing 2 tot 5°C hoger dan bij de overige monitoringscampagnes, gezien het lagere lozingsdebiet (zie hoofdstuk 3, opmerking 3 bij de tabel). Bijgevolg wordt net voorbij de mengzone (300-400 m stroomafwaarts) een hogere ΔT opgemeten.

- Buitenluchttemperatuur en windsnelheid: Bij lage buitenluchttemperaturen en/of hoge windsnelheid koelt het geloosde water sneller af naar de lucht dan op warme en windstille dagen. De lozingspluim is bijgevolg kleiner in omvang (minder ver uitgestrekt van het lozingspunt vandaan).
- Omwille van de grillige morfologie en waterbewegingen stroomafwaarts van het lozingspunt treden er tot op ca. 600 m stroomafwaarts sterke temperatuursvariaties op → temperatuursmetingen uitgevoerd op enkele meters van elkaar kunnen daardoor meer dan 5°C verschil aangeven.

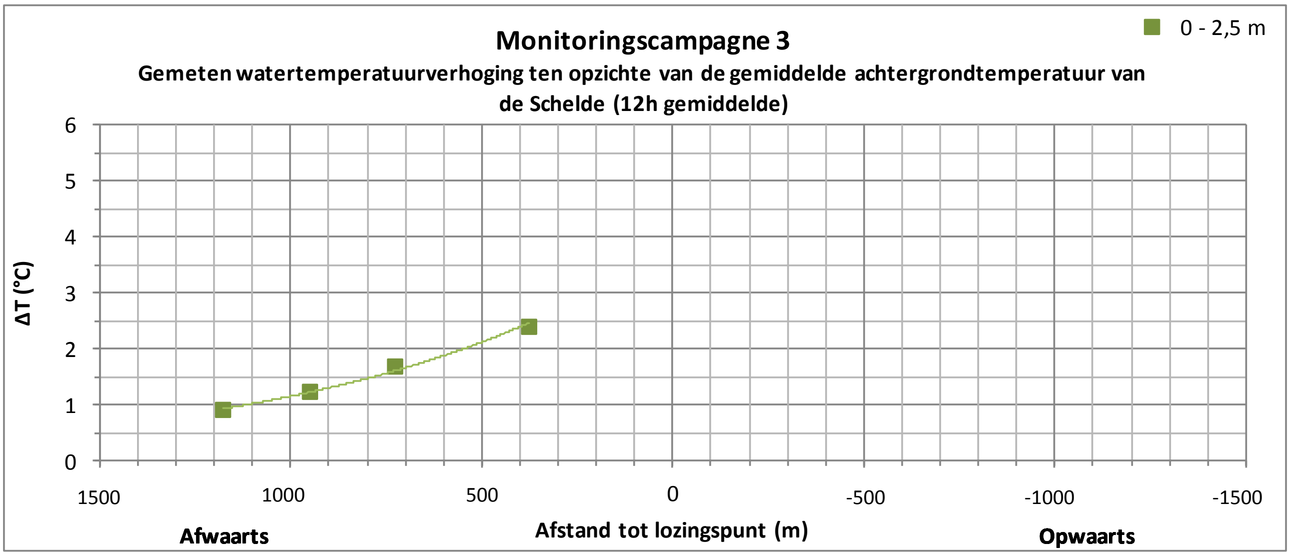
5.2.2 Gemodelleerde en gemeten watertemperatuursverhoging – daggemiddelde

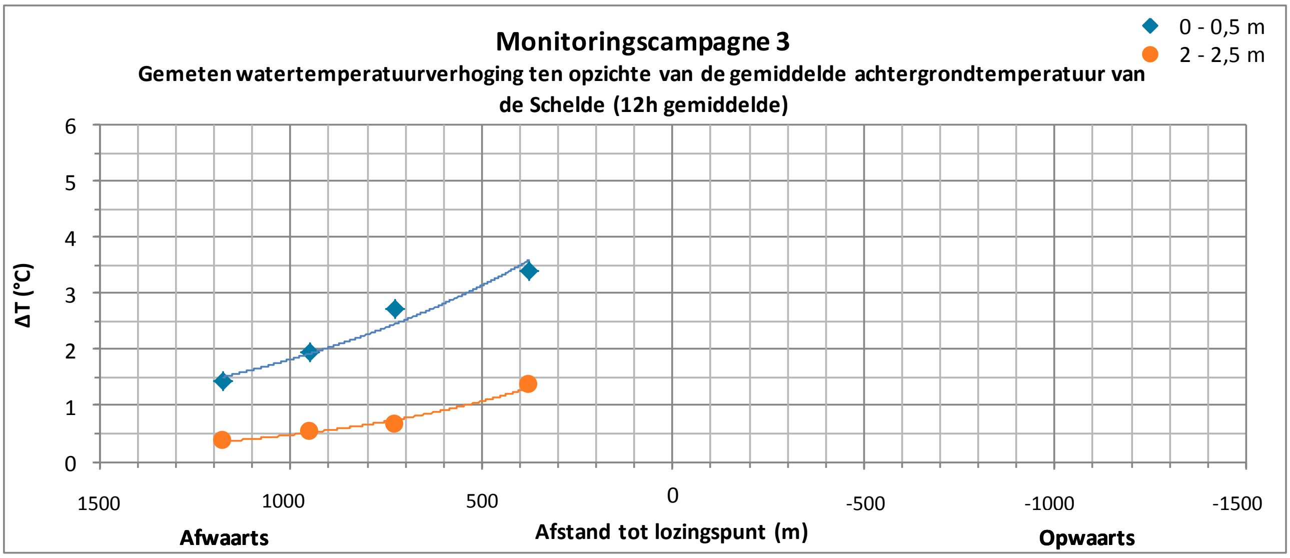
Onderstaande figuren tonen de gemodelleerde en gemeten watertemperatuursverhoging ten opzichte van de achtergrondtemperatuur van de Schelde in functie van de afstand stroomop en -afwaarts tot het lozingspunt, daggemiddelde waarden. Enkel campagne 3 werd zodanig uitgevoerd dat een representatieve toetsing van de gemeten waarden aan de daggemiddelde modelresultaten mogelijk is. De eerste figuur toont de gemeten temperaturen, gemiddeld over 0 tot 2,5 m diepte, terwijl de tweede figuur de gemeten waarden voor de twee gemonitorde dieptes afzonderlijk weergeeft (0-0,5 m en 2-2,5 m).

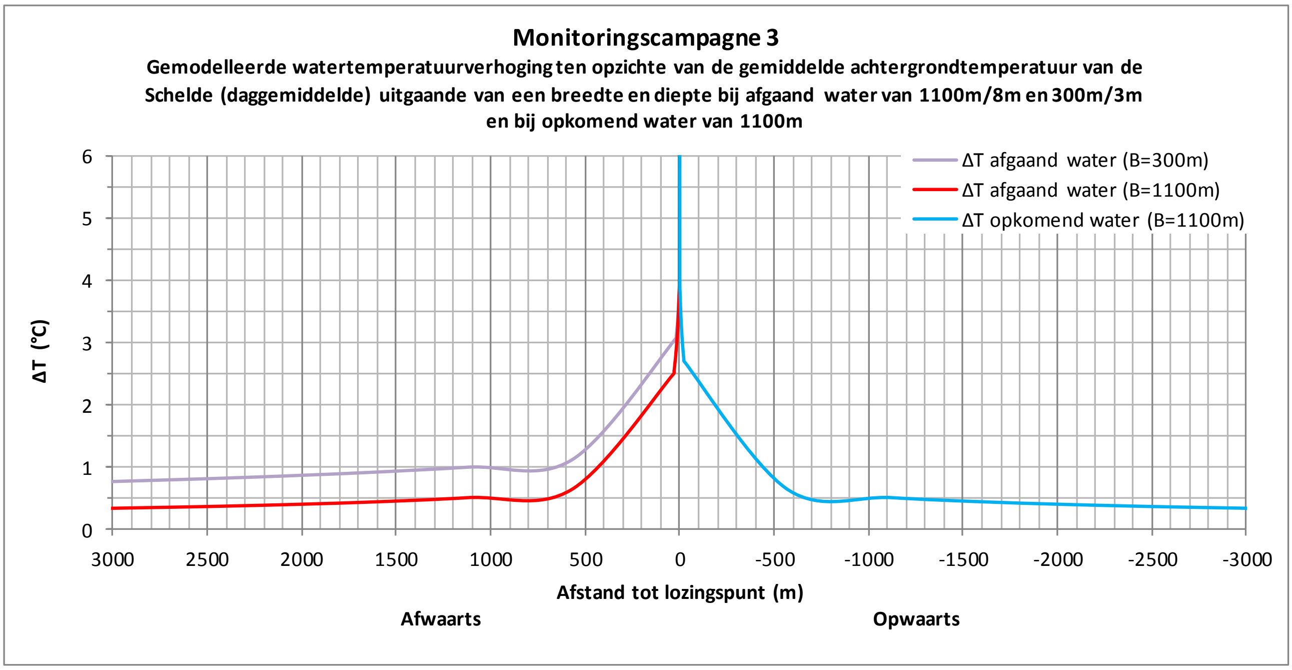
Uit de vergelijking van de gemeten waarden bij afgaand water met de gemodelleerde waarden bij afgaand water en bij een breedte en diepte van de Schelde van 300m/3m (Plaat van Doel, waarlangs het grootste volume water afkomstig van de koelwaterlozing wegstroomt) blijkt dat de temperatuur in werkelijkheid iets minder sterk exponentieel afneemt dan gemodelleerd. Gemiddeld voor beide dieptes (0-2,5 m) bedraagt de gemodelleerde temperatuurstoename stroomafwaarts 1,3°C op 500 m en 1°C op 1000 m van het lozingspunt. De gemeten gemiddelde waarde van de toename bedraagt 2,1°C op 500 m en 1,2°C op 1000 m. Uit de vergelijking van de gemodelleerde waarden met de gemeten waarden gemiddeld voor beide dieptes (0-2,5 m), blijkt dus een discrepantie van minder dan 1°C.

Wat betreft de oppervlakkige (0-0,5 m) watertemperaturen zijn de verschillen groter. Op 500 m afstand van het lozingspunt geven de modelresultaten een grotere onderschatting van de werkelijke waarden op 0-0,5 m (1,3°C gemodelleerd t.o.v. 3,1°C gemeten). Op grotere diepte is de gemeten waarde quasi gelijk aan de gemodelleerde waarde (1,3°C gemodelleerd t.o.v. 1,1°C gemeten). Op grotere afstand van het lozingspunt neemt de discrepantie tussen de gemodelleerde en gemeten waarden steeds verder af.

Er kan globaal gezien besloten worden dat het CORMIX model voor de daggemiddelde waarden een representatief beeld van de werkelijkheid geeft en voor dergelijke voorspellingen bruikbaar is.


Monitoringscampagne 3
Gemeten watertemperatuurverhoging ten opzichte van de gemiddelde achtergrondtemperatuur van de Schelde (12h gemiddelde)
0 - 2,5 m
ΔT (°C)
Afstand tot lozingspunt (m)
Afwaarts
Opwaarts


Monitoringscampagne 3
Gemeten watertemperatuurverhoging ten opzichte van de gemiddelde achtergrondtemperatuur van de Schelde (12h gemiddelde)
0 - 0,5 m
2 - 2,5 m
ΔT (°C)
Afstand tot lozingspunt (m)
Afwaarts
Opwaarts


Monitoringscampagne 3
Gemodelleerde watertemperatuurverhoging ten opzichte van de gemiddelde achtergrondtemperatuur van de Schelde (daggemiddelde) uitgaande van een breedte en diepte bij afgaand water van 1100m/8m en 300m/3m en bij opkomend water van 1100m
ΔT afgaand water (B=300m)
ΔT afgaand water (B=1100m)
ΔT opkomend water (B=1100m)
ΔT (°C)
Afstand tot lozingspunt (m)
Afwaarts
Opwaarts

5.3 Overlevingskans van exoten

Tijdens de monitoringscampagnes werd ook nagegaan of de temperatuurverhoging van die aard is dat exoten kunnen overleven en verder ontwikkelen in welbepaalde zones. Bijgevolg werd nagegaan of op bepaalde plaatsen de temperatuur in belangrijke mate verhoogd blijft gedurende de getijdencyclus (Figuur 4):

- Aandachtszone 1: binnen de strekdam, in de zone dicht bij het lozingspunt en bij opkomend water;
- Aandachtszone 2: buiten de strekdam, stroomopwaarts, in de zone tussen het lozingspunt en de captatiepunten bij hoogwater en afgaand water.

Figuur 4: Aandachtszones met betrekking tot overlevingskans van exoten

➔ Uit de metingen blijkt dat de thermische pluim stroomopwaarts buiten de strekdam (aandachtzone 2) bij afgaand water relatief snel volledig verdwijnt.

➔ Binnen de strekdam (aandachtzone 1) wordt bij opkomend water waargenomen dat nagenoeg de volledige thermische pluim die zich binnen de strekdam had gevormd, wordt uitgespoeld. Na verloop van tijd (na laagwater) is er amper nog een temperatuurstoename meetbaar, behalve in de zone dicht bij het lozingspunt.

Vermoedelijk blijft de temperatuur in de zone dicht bij het lozingspunt (< 200 m, zowel stroomop- als stroomafwaarts) gedurende de gehele getijdencyclus sterk verhoogd tot nagenoeg gelijk aan de lozingstemperatuur; dit is de mengzone. In deze zone heerst een hoge stroomsnelheid en turbulentie, veroorzaakt door het instromend koelwater en de geringe waterdiepte. De omvang van de zone wordt ingeschat op ongeveer 6 ha (= 0,06 km²).

In deze zone, die overeenkomt met de mengzone, hebben warmteminnende exoten bijgevolg mogelijk een verhoogde overlevingskans in koude periodes. De hoge turbulentie maakt de zone echter voor vele soorten veel minder geschikt. Buiten de mengzone is de temperatuurstoename steeds beperkt in de tijd en is er elke dag een belangrijke periode waarbij er geen of een zeer beperkte (< 1°C) temperatuurstoename heerst. De aanwezigheid van warmteminnende exoten wordt buiten de mengzone aldus niet bevorderd.

6 Conclusies

6.1 Watertemperatuurverhoging bij kentering bij laagwater

Zoals in eerder hoofdstuk reeds aangetoond, blijkt het CORMIX model niet geschikt voor de voorspelling van de ogenblikkelijke watertemperatuursverhoging bij kentering bij laagwater. Op basis van de gemeten waarden van de 5 uitgevoerde monitoringscampagnes werden daarom voor beide monitoringsdieptes (0-0,5 m en 2-2,5 m) formules afgeleid die het verband tussen ΔT (y) en de afstand tot het lozingspunt (x) 1 uur bij kentering bij laagwater beschrijven:

Diepte	Logaritmische functie
Diepte 0 – 0,5 m	$\boldsymbol{y = -9,427.\ln x + 68,549}$
Diepte 2 – 2,5 m	$\boldsymbol{y = -5,933.\ln x + 52,569}$

Aan de hand van deze formules kan voor elke afstand tot het lozingspunt de temperatuurstoename voorspeld worden, en omgekeerd.

- ΔT bedraagt tijdens de kentering op 500 m stroomafwaarts 10°C aan de oppervlakte, en 5,7°C op 2-2,5 m diepte.
- Op 750 m afstand bedraagt ΔT aan de oppervlakte 6,1°C en 3,3°C op 2-2,5 m diepte.
- Op 1 km afstand bedraagt ΔT aan de oppervlakte 3,4°C en 1,6°C op 2-2,5 m diepte.
- ΔT daalt naar 1°C op een afstand van 1300 m aan de oppervlakte, en op een afstand van 1100 m op 2-2,5 m diepte.

6.2 Daggemiddelde watertemperatuurverhoging

Uit de bespreking van de resultaten blijkt dat het CORMIX model een representatieve voorspelling geeft voor de daggemiddelde watertemperatuurverhoging van het Scheldewater bij afgaand water.

Op basis van het model, afgetoetst aan de metingen, kunnen volgende daggemiddelde watertemperatuurverhogingen afgeleid worden:

- Stroomafwaarts:
  - Op 500 m bedraagt ΔT 1 tot 2°C;
  - Vanaf 750 m afstand bedraagt ΔT ca. 1°C of minder.
- Stroomopwaarts:
  - Op 500 m bedraagt ΔT 0,5 tot 1°C;
  - Vanaf 750 m bedraagt ΔT ongeveer 0,5°C of minder.

6.3 Overlevingskans van exoten

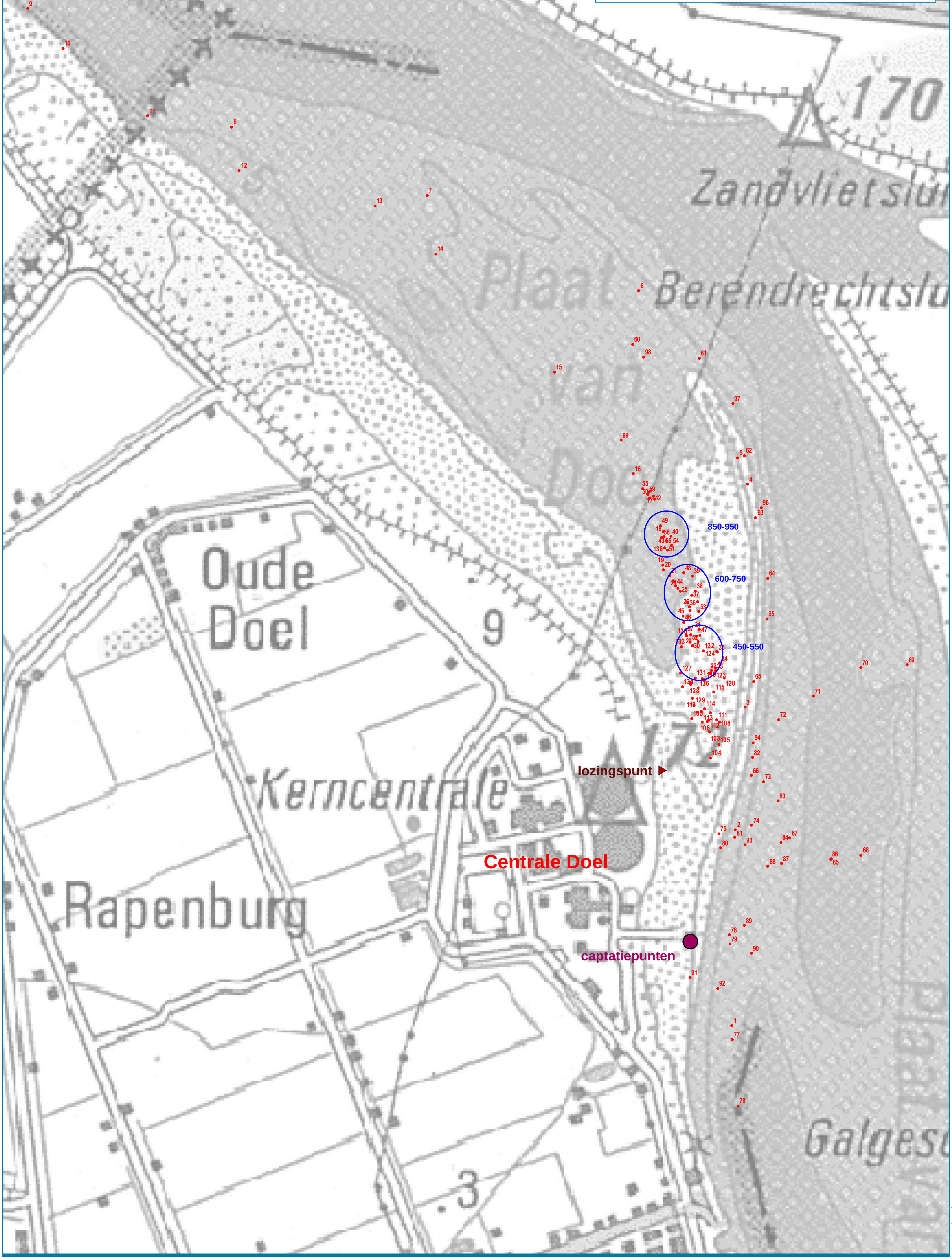
Vermoedelijk blijft de temperatuur in de zone dicht bij het lozingspunt (< 200 m, zowel stroomop- als stroomafwaarts) gedurende de gehele getijdencyclus sterk verhoogd tot nagenoeg gelijk aan de lozingstemperatuur; dit is de mengzone. De omvang van de zone wordt ingeschat op ongeveer 6 ha (= 0,06 km²).

In deze zone, die overeenkomt met de mengzone, hebben warmteminnende exoten mogelijk een verhoogde overlevingskans in koude periodes. De hoge turbulentie maakt de zone echter voor vele soorten veel minder geschikt. Buiten de mengzone is de temperatuurstoename steeds beperkt in de tijd en is er elke dag een belangrijke periode waarbij er geen of een zeer beperkte (< 1°C) temperatuurstoename heerst. De aanwezigheid van warmteminnende exoten wordt buiten de mengzone aldus niet bevorderd.

BIJLAGEN

Bijlage 1 Ligging van de meetpunten

Monitoringscampagne 1

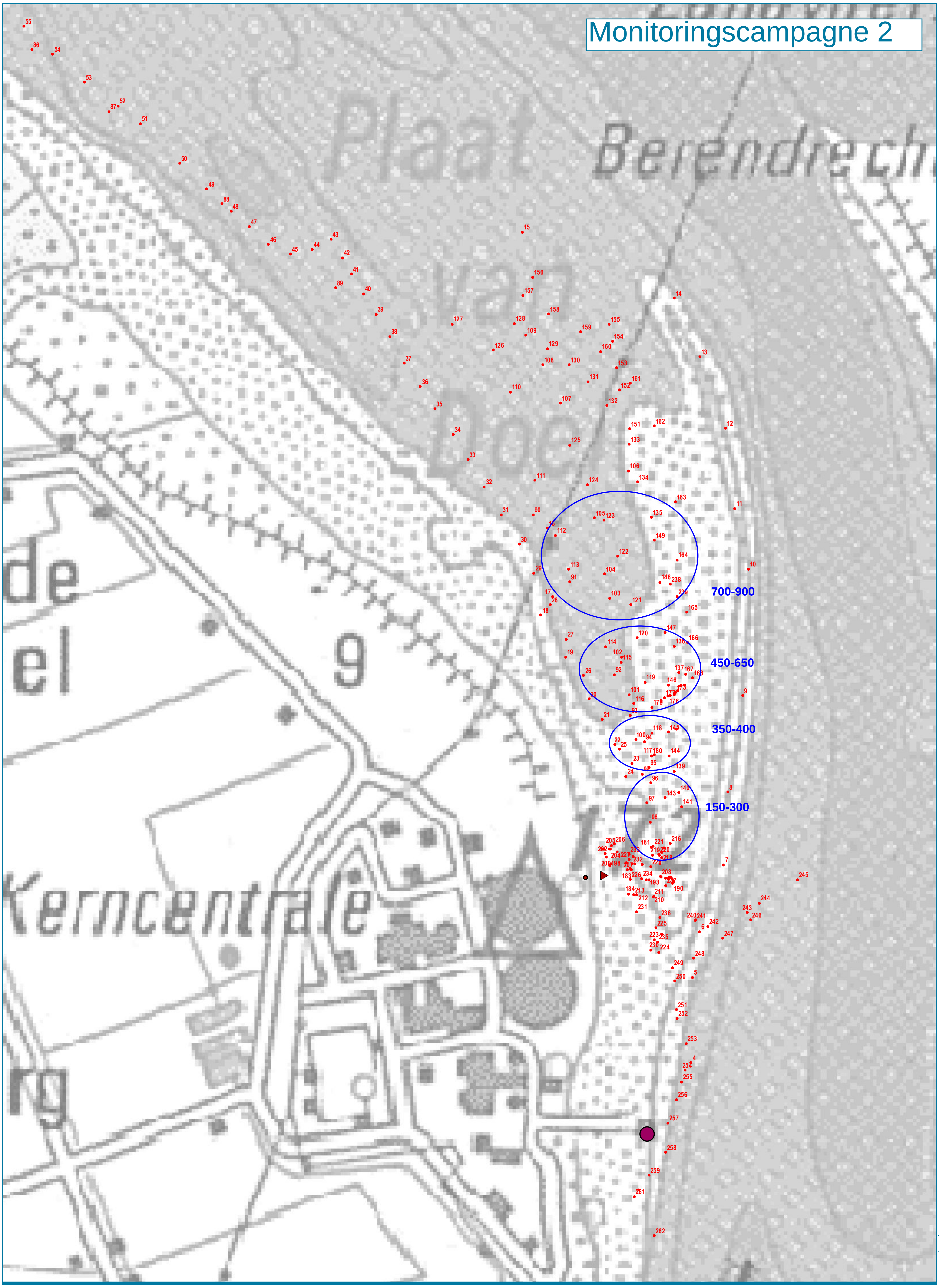


www.geovlaanderen.be

N

1:13.000

ARCADIS



www.geovlaanderen.be

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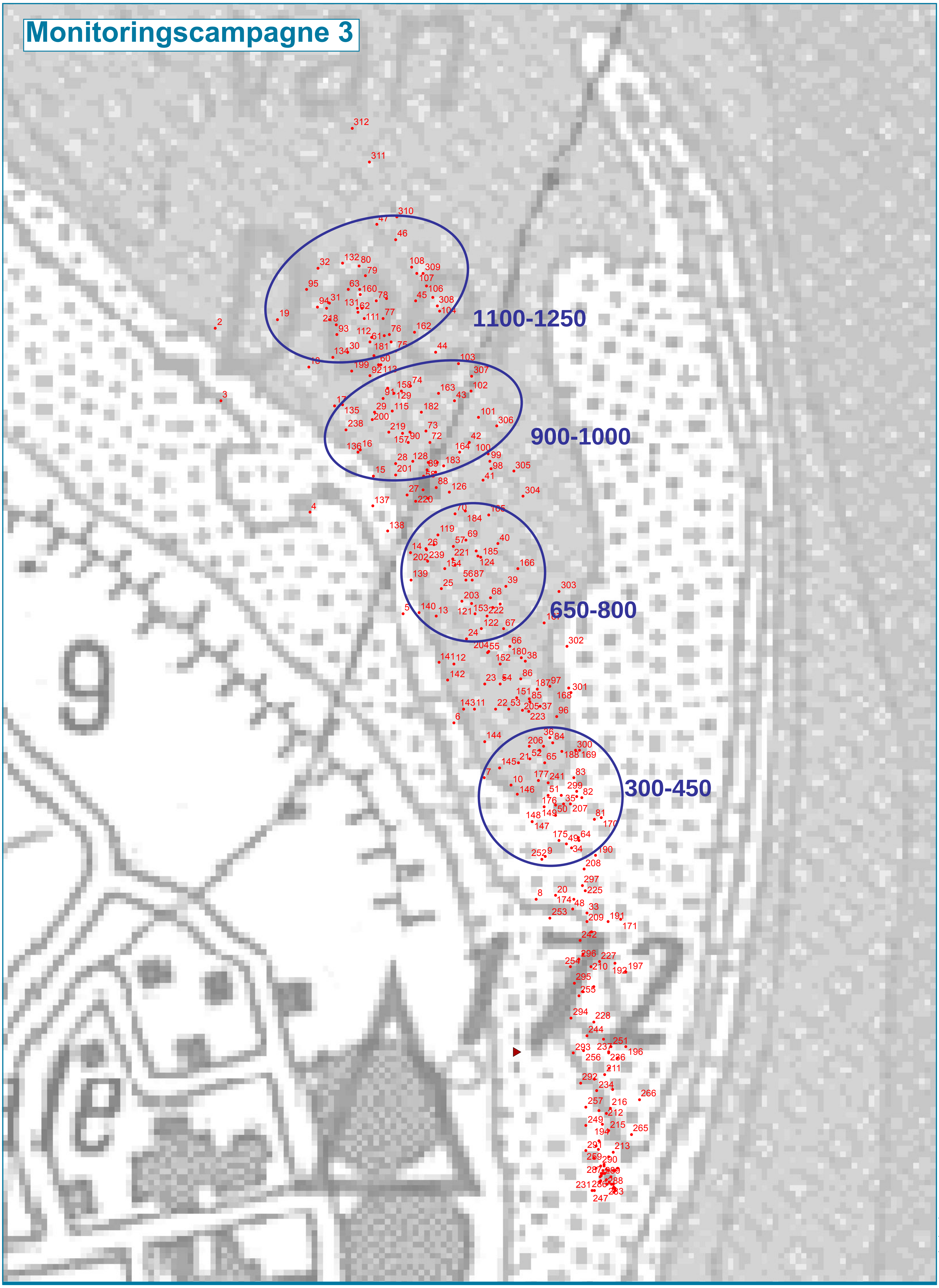
Monitoring 2

ARCADIS



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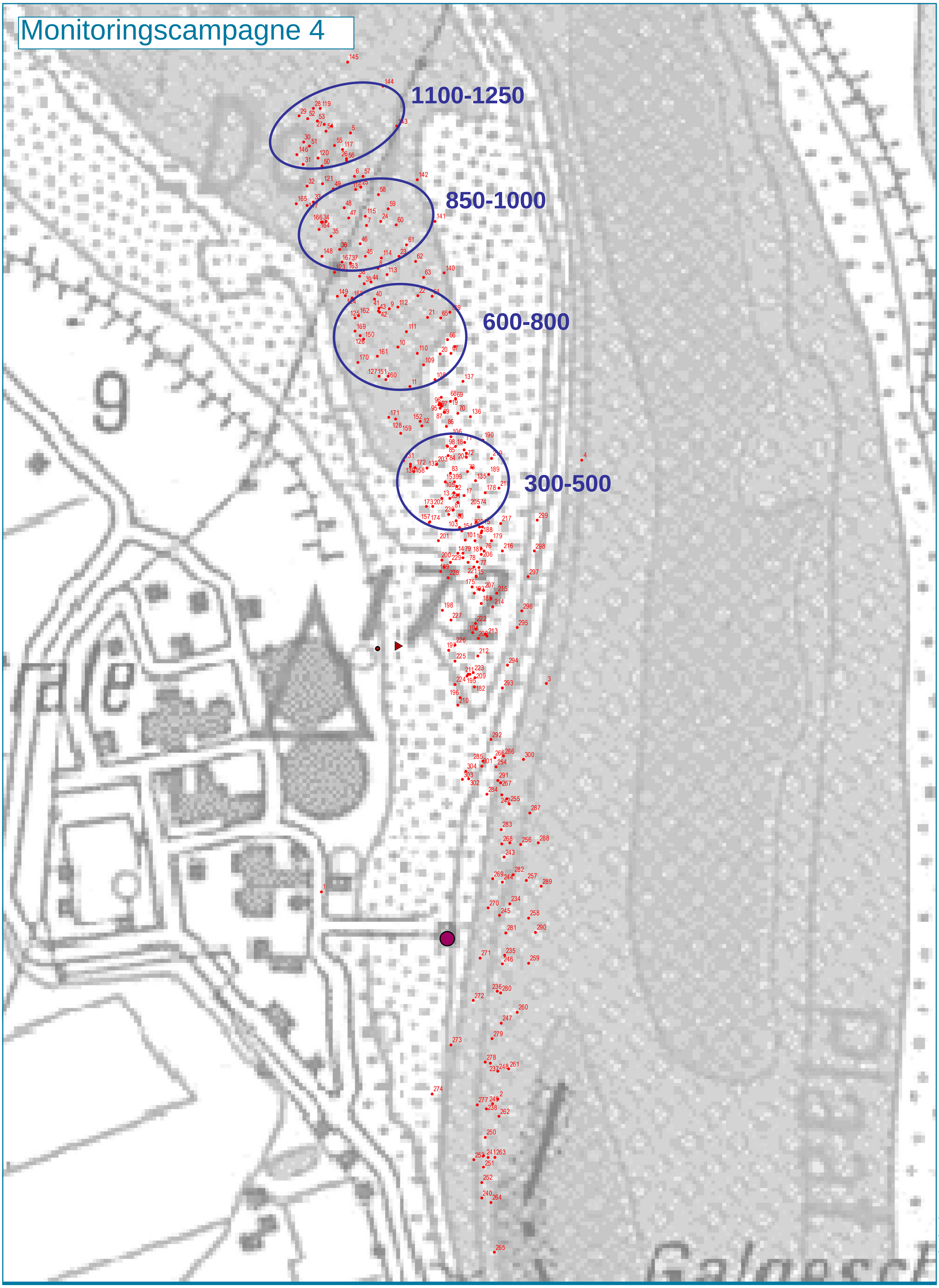
Monitoring 3

ARCADIS

Monitoringscampagne 4



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Monitoring 4

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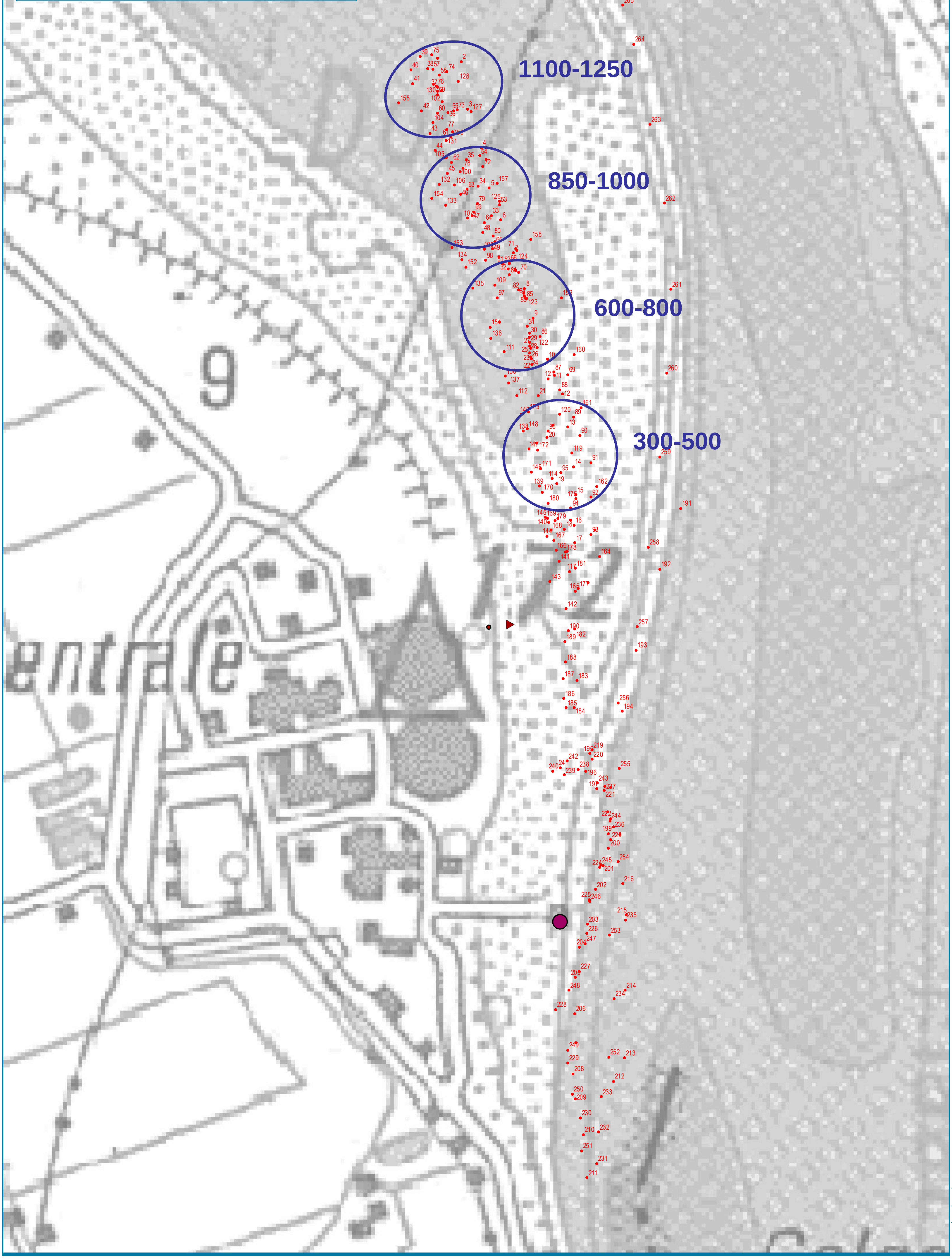
Monitoringscampagne 5



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Monitoring 5

ARCADIS

Bijlage 2 Meetresultaten

Monitoringscampagne 1 (16/06/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
7:43	1	143.008,69	223.221,33	6,73	19,4	6,64	19,4	1014	
7:47	2	143.022,48	223.964,90	6,94	19,4	6,72	19,4	394	
7:49	3	143.057,95	224.430,30	6,94	19,4	6,73	19,4	436	
7:54	4	143.068,37	225.277,70	6,80	19,3	6,74	19,3	1153	
7:58	5	143.031,34	225.377,89	6,93	19,2	6,81	19,2	1238	
8:04	6	142.654,75	226.012,59	7,16	19,2	7,01	19,2	1827	
8:10	7	141.850,50	226.373,54	7,20	19,2	6,99	19,2	2345	
8:16	8	141.107,75	226.634,36	7,23	19,8	7,04	19,8	2919	
8:22	9	140.332,89	227.084,49	7,40	19,5	7,31	19,5	3740	
8:28	10	140.467,30	226.934,05	7,45	19,6	7,29	19,6	3538	
8:33	11	140.787,32	226.677,57	7,14	19,7	7,04	19,7	3139	
8:39	12	141.136,49	226.469,28	7,04	19,7	6,91	19,6	2765	
8:45	13	141.651,87	226.334,91	6,94	19,6	6,83	19,6	2389	
8:51	14	141.883,84	226.152,82	6,88	19,7	6,75	19,6	2128	
9:00	15	142.334,93	225.703,39	6,98	21,0	6,82	20,8	1560	
9:07	16	142.634,01	225.317,23	6,99	21,3	6,88	21,2	1133	
9:12	17	142.715,20	225.220,70	6,89	21,6	6,49	19,8	1035	
9:21	18	142.748,70	225.098,27	7,00	22,5	6,42	20,2	914	
9:26	19	142.746,20	224.970,33	6,99	22,8	6,44	20,3	786	
9:31	20	142.748,51	224.953,63	7,18	23,5	6,43	20,1	769	
9:35	21	142.772,87	224.931,35	7,22	23,7	6,42	20,1	749	
9:41	22	142.786,77	224.910,93	6,47	20,7	6,40	20,1	731	
9:43	23	142.789,09	224.907,22	6,86	22,2	6,45	20,3	727	
9:47	24	142.804,16	224.883,09	7,26	23,8	6,41	20,2	705	
9:53	25	142.812,28	224.871,95	6,66	21,7	6,39	20,0	696	
9:57	26	142.847,04	224.812,56	7,24	24,5	6,43	20,5	644	
10:03	27	142.849,35	224.797,73	6,69	22,0	6,38	20,0	631	
10:11	28	142.874,77	224.699,42	7,13	25,6	6,45	20,8	544	
10:14	29	142.861,94	224.664,21	7,40	27,3	6,46	21,0	506	
10:16	30	142.858,46	224.664,21	6,84	23,6	6,43	20,5	505	
10:21	31	142.884,10	224.725,37	7,33	26,3	6,42	20,5	571	
10:27	32	142.930,35	224.569,54	7,75	29,7	6,63	22,9	449	
10:31	33	142.946,62	224.569,51	7,75	29,0	6,65	22,9	458	
10:33	34	142.962,90	224.597,31	7,60	28,9	6,42	21,1	490	
10:38	35	142.953,68	224.639,98	7,72	29,0	6,50	21,4	522	
10:42	36	142.879,60	224.831,07	7,25	26,4	6,21	20,7	671	
10:45	37	142.856,39	224.855,20	7,49	27,8	6,48	21,2	688	
10:48	38	142.870,36	224.871,87	7,51	27,9	6,30	19,9	708	
10:50	39	142.858,82	224.929,38	7,50	27,3	7,53	26,6	761	
10:52	40	142.777,71	225.079,68	7,33	25,7	7,29	25,8	897	
10:54	41	142.690,84	225.246,70	6,55	20,3	6,31	19,9	1061	
10:56	42	142.711,72	225.231,83	6,63	20,1	6,51	20,1	1046	
11:01	43	142.760,27	225.063,02	7,39	25,3	7,40	26,1	879	laagwater
11:04	44	142.794,89	224.890,52	7,41	26,6	7,44	27,3	711	
11:05	45	142.822,61	224.777,37	7,61	28,5	6,72	21,7	605	
11:09	46	142.824,89	224.753,26	7,64	28,8	6,88	21,2	582	
11:11	47	142.887,55	224.704,96	7,65	29,5	7,60	29,3	553	
11:14	48	142.826,31	224.940,55	7,46	27,6	7,32	27,1	766	
11:17	49	142.737,12	225.120,53	7,16	24,8	6,58	21,9	935	
11:21	50	142.697,82	225.252,25	6,76	20,6	6,47	20,1	1066	
11:25	51	142.763,71	225.027,79	7,24	25,1	6,35	20,8	844	
11:30	52	142.851,54	224.706,87	7,64	29,0	6,84	23,3	543	
11:35	53	142.883,03	224.793,98	7,23	27,2	6,44	21,9	636	
11:39	54	142.778,83	225.044,46	7,39	26,6	7,20	25,6	862	
11:42	55	142.668,78	225.261,57	6,71	20,5	6,62	20,6	1076	
11:46	56	142.751,00	225.077,87	7,34	25,2	7,22	24,9	894	
11:51	57	142.834,12	224.708,74	7,68	29,3	7,61	29,2	541	
11:57	58	142.742,87	225.076,03	7,24	25,2	7,04	24,8	891	
12:00	59	142.688,50	225.239,28	6,87	20,6	6,84	20,8	1053	
12:06	60	142.632,39	225.808,64	6,51	19,6	6,34	19,5	1624	
12:09	61	142.884,34	225.756,38	6,56	19,5	6,43	19,5	1582	
12:13	62	143.055,74	225.387,14	6,94	21,2	6,79	21,0	1254	
12:16	63	143.099,57	225.151,57	6,96	21,6	6,81	21,7	1046	
12:19	64	143.144,55	224.919,72	6,88	22,0	6,74	21,9	860	
12:23	65	143.091,77	224.528,52	6,72	21,9	6,58	21,8	523	
12:26	66	143.083,16	224.170,66	6,87	23,8	6,80	23,8	387	
12:29	67	143.229,23	223.933,11	6,29	19,9	6,16	19,9	590	
12:32	68	143.499,86	223.867,87	6,19	19,6	6,09	19,6	864	
12:39	69	143.675,01	224.590,83	6,66	19,5	6,57	19,5	1059	
12:43	70	143.498,42	224.579,92	6,57	19,6	6,38	19,6	894	
12:45	71	143.318,23	224.472,60	6,83	20,7	6,60	20,6	685	

Monitoringscampagne 1 (16/06/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
12:48	72	143.185,68	224.383,77	6,81	21,0	6,70	20,9	528	
12:51	73	143.129,60	224.148,34	7,29	25,7	7,18	25,4	435	
12:54	74	143.084,07	223.981,51	6,74	22,7	6,54	21,8	438	
12:58	75	142.959,71	223.950,15	6,40	21,0	6,33	21,0	354	
13:04	76	142.999,86	223.566,26	6,62	21,0	6,56	21,0	690	
13:06	77	143.010,94	223.167,56	6,55	20,9	6,45	20,9	1066	
14:32	78	143.032,68	222.915,35	6,69	20,0	6,59	19,9	1314	
14:39	79	143.000,98	223.531,03	6,81	20,6	6,51	20,3	722	
14:44	80	142.965,45	223.896,38	6,88	21,7	6,72	21,5	395	
14:47	81	143.020,11	223.937,10	7,12	24,0	6,83	22,8	408	
14:51	82	143.086,73	224.239,26	6,91	19,4	6,80	19,4	394	
14:55	83	143.184,10	224.074,10	6,92	19,3	6,83	19,4	500	
14:57	84	143.194,35	223.916,46	6,86	20,9	6,76	20,4	566	
15:01	85	143.385,98	223.855,02	6,98	19,5	6,86	19,5	765	
15:04	86	143.383,65	223.853,17	7,05	19,4	6,90	19,4	764	
15:06	87	143.196,58	223.836,73	7,02	19,5	6,90	19,4	610	
15:08	88	143.145,44	223.825,67	7,16	23,7	6,88	22,0	576	
15:14	89	143.055,69	223.601,41	6,79	20,7	6,58	20,5	686	
15:16	90	143.083,42	223.495,68	6,70	20,7	6,61	20,3	791	
15:20	91	142.849,75	223.403,28	6,72	19,6	6,64	19,6	798	
15:23	92	142.955,43	223.362,34	6,64	19,7	6,57	19,6	863	
15:30	93	143.059,58	223.907,37	7,01	19,8	7,13	22,2	458	
15:36	94	143.089,14	224.294,88	7,17	19,2	7,08	19,2	408	
15:43	95	143.143,20	224.765,81	7,48	19,1	7,27	19,1	732	
15:51	96	143.120,52	225.188,63	7,47	19,1	7,31	19,1	1089	
15:57	97	143.011,87	225.583,74	7,42	19,3	7,28	19,3	1433	
16:04	98	142.672,98	225.760,37	7,54	19,3	7,37	19,3	1575	
16:07	99	142.587,74	225.445,26	7,48	19,1	7,41	19,1	1264	
16:10	100	142.697,77	225.226,29	7,53	19,1	7,51	19,0	1040	
16:14	101	142.841,26	224.827,41	7,58	19,0	7,50	18,9	658	
16:17	102	142.926,85	224.558,42	7,61	19,0	7,53	19,0	438	
16:19	103	142.924,22	224.335,90	7,54	19,0	7,46	19,0	273	
16:21	104	142.927,58	224.237,62	7,49	19,1	7,39	19,0	237	
16:25	105	142.959,01	224.287,64	7,57	19,0	7,46	19,1	282	
16:29	106	142.916,15	224.376,70	7,56	19,0	7,49	19,0	291	
16:35	107	142.876,70	224.412,00	7,56	19,0	7,47	19,0	289	
16:41	108	142.961,45	224.372,94	7,62	19,0	7,54	18,9	324	
16:46	109	142.892,96	224.413,82	7,54	19,1	7,49	19,0	301	hoogwater
16:50	110	142.926,64	224.410,07	7,57	19,2	7,51	18,9	321	
16:54	111	142.952,16	224.382,21	7,53	19,0	7,49	19,0	322	
16:56	112	142.920,79	224.380,41	7,65	20,9	7,41	19,8	297	
17:00	113	142.896,39	224.373,03	7,68	22,5	7,54	21,5	274	
17:05	114	142.904,59	224.424,94	7,59	21,4	7,36	19,7	317	
17:09	115	142.940,70	224.487,93	7,54	20,5	7,45	19,1	388	
17:15	116	142.946,63	224.578,79	7,55	19,3	7,57	19,0	466	
17:19	117	142.904,74	224.534,34	7,44	21,1	7,41	19,8	406	
17:23	118	142.859,34	224.463,95	7,46	21,4	7,38	20,6	322	
17:28	119	142.890,64	224.413,84	7,57	22,1	7,51	22,0	299	
17:35	120	142.979,10	224.541,66	7,53	21,6	7,50	21,3	454	
17:40	121	142.932,69	224.582,51	7,58	21,8	7,50	21,4	462	
17:47	122	142.895,46	224.538,07	7,62	22,6	7,44	22,1	404	
17:50	123	142.944,27	224.558,39	7,42	19,9	7,35	19,7	447	
17:52	124	142.951,36	224.641,82	7,62	21,9	7,41	20,2	522	
17:56	125	142.880,54	224.679,01	7,57	22,3	7,32	19,9	526	
18:01	126	142.850,13	224.523,29	7,62	22,4	7,54	21,9	371	
18:05	127	142.814,17	224.560,43	7,58	22,3	7,37	19,7	393	
18:11	128	142.852,44	224.515,87	7,58	22,0	7,46	21,5	365	
18:17	129	142.866,28	224.437,96	7,49	21,6	7,37	19,4	304	
18:25	130	142.837,60	224.701,32	7,50	19,9	7,42	19,5	534	
18:34	131	142.868,74	224.541,80	7,42	19,6	7,34	19,7	395	
18:39	132	142.901,41	224.645,61	7,46	19,2	7,38	19,1	503	
18:42	133	142.816,64	224.660,55	7,63	20,6	7,46	20,2	490	
18:44	134	142.821,07	224.508,49	7,62	22,1	7,50	22,0	346	
18:47	135	142.855,75	224.387,92	7,48	21,1	7,25	19,6	257	
18:54	136	142.881,47	224.502,84	7,29	19,2	7,22	19,2	367	
18:56	137	142.850,34	224.677,19	7,38	19,2	7,29	19,2	515	
19:00	138	142.753,26	225.035,22	7,42	19,2	7,32	19,2	851	
19:02	139	142.693,12	225.222,59	7,51	19,1	7,40	19,1	1037	

lozingspunt	142.696,32	224.186,02

Monitoringscampagne 2 (02/08/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
7:17	1	142.908,75	222.362,93	6,93	19,6	6,94	19,6	1835	
7:30	2	142.979,27	222.937,67	7,07	19,5	7,22	19,4	1280	
7:37	3	142.790,91	222.861,91	7,35	19,4	7,52	19,3	1327	
7:40	4	142.961,73	223.720,22	7,38	19,4	7,49	19,3	536	
7:44	5	142.965,50	223.935,32	7,37	19,3	7,48	19,3	368	
7:46	6	142.983,09	224.050,26	7,44	19,3	7,50	19,4	317	
7:49	7	143.043,72	224.218,92	7,54	19,3	7,53	19,3	349	
7:52	8	143.054,42	224.402,48	7,62	19,3	7,53	19,3	418	
7:55	9	143.091,93	224.645,35	7,60	19,3	7,59	19,3	606	
7:59	10	143.106,28	224.964,28	7,63	19,4	7,57	19,4	880	
8:01	11	143.071,65	225.116,38	7,58	19,4	7,57	19,4	1003	
8:03	12	143.048,68	225.318,53	7,60	19,5	7,62	19,6	1186	
8:05	13	142.983,88	225.498,48	7,65	19,6	7,63	19,7	1344	
8:07	14	142.919,04	225.646,92	7,64	19,7	7,60	19,7	1478	
8:12	15	142.537,17	225.812,49	7,69	19,4	7,59	19,4	1634	
8:28	16	142.599,98	225.066,96	7,26	19,4	7,24	19,4	886	
8:33	17	142.612,52	224.894,50	7,12	19,4	7,09	19,4	713	
8:35	18	142.583,41	224.848,16	7,53	22,5	7,47	21,5	672	
8:38	19	142.645,98	224.742,38	7,51	23,6	7,06	20,0	559	
8:41	20	142.705,08	224.636,61	7,38	22,4	7,38	22,1	451	
8:43	21	142.737,53	224.584,64	7,42	22,4	7,19	20,8	401	
8:46	22	142.769,97	224.521,55	7,38	22,0	7,25	20,7	344	
8:48	23	142.812,89	224.475,14	7,24	19,8	7,20	19,6	312	
8:51	24	142.797,74	224.441,78	7,40	21,9	7,22	20,1	275	
8:53	25	142.781,57	224.510,40	7,39	21,7	7,25	20,3	335	
8:57	26	142.691,22	224.695,97	7,42	22,0	7,32	21,0	510	
8:59	27	142.647,21	224.786,89	7,39	22,2	7,47	22,3	603	
9:01	28	142.606,68	224.874,09	7,46	23,1	7,35	22,2	694	
9:03	29	142.566,14	224.953,89	7,34	23,5	7,24	20,1	779	
9:05	30	142.529,07	225.026,26	7,36	22,7	7,24	19,9	857	
9:08	31	142.483,88	225.100,50	7,35	22,4	7,22	20,3	939	
9:10	32	142.441,00	225.171,03	7,32	22,6	7,23	20,5	1018	
9:12	33	142.400,45	225.239,70	7,27	22,8	7,23	20,1	1094	
9:14	34	142.362,20	225.302,81	7,27	22,5	7,24	19,9	1166	
9:16	35	142.317,01	225.367,77	7,29	22,9	7,23	20,2	1241	
9:18	36	142.279,92	225.423,45	7,34	23,0	7,24	20,3	1306	
9:19	37	142.239,36	225.482,85	7,28	22,8	7,23	19,9	1375	
9:22	38	142.202,29	225.549,67	7,41	23,0	7,27	20,1	1450	
9:24	39	142.168,70	225.605,34	7,35	23,2	7,24	20,0	1514	
9:26	40	142.136,26	225.657,32	7,46	23,5	7,29	20,5	1574	
9:28	41	142.106,13	225.707,43	7,43	23,2	7,29	20,5	1632	
9:30	42	142.082,96	225.748,26	7,39	23,0	7,27	20,6	1678	
9:32	43	142.055,16	225.794,66	7,29	23,2	7,24	20,2	1732	
9:34	44	142.007,51	225.768,77	7,47	23,1	7,14	20,3	1726	
9:36	45	141.952,90	225.757,74	7,49	23,0	7,27	20,8	1739	
9:38	46	141.897,19	225.781,92	7,46	22,5	7,10	19,9	1785	
9:40	47	141.848,49	225.826,51	7,03	20,4	7,10	19,7	1847	
9:42	48	141.803,25	225.865,52	7,19	20,9	7,11	19,7	1902	
9:44	49	141.741,79	225.921,25	7,41	22,1	7,12	19,6	1980	
9:46	50	141.673,36	225.986,25	7,40	22,5	7,19	19,6	2071	
9:48	51	141.573,66	226.086,54	7,39	22,3	7,21	19,6	2207	
9:50	52	141.517,99	226.131,14	7,37	22,1	7,18	20,0	2274	
9:52	53	141.433,31	226.190,63	7,13	21,1	7,23	19,7	2369	
9:53	54	141.353,30	226.261,22	7,16	20,8	7,22	19,6	2472	
9:55	55	141.280,25	226.331,81	7,19	20,6	7,23	19,5	2571	
9:58	56	141.150,35	226.424,74	7,22	20,8	7,23	19,5	2721	
9:59	57	141.088,89	226.478,63	7,19	20,2	7,23	19,4	2800	
10:01	58	141.036,74	226.536,20	7,17	20,4	7,23	19,5	2877	
10:02	59	140.986,88	226.582,65	7,13	20,3	7,21	19,5	2944	
10:03	60	140.943,98	226.617,95	7,13	20,2	7,20	19,5	2997	
10:05	61	140.908,04	226.647,68	7,13	20,2	7,19	19,5	3043	
10:07	62	140.812,98	226.738,72	7,16	20,3	7,20	19,5	3172	
10:09	63	140.763,16	226.801,85	7,19	20,6	7,20	19,5	3253	
10:11	64	140.660,02	226.913,29	7,17	20,5	7,19	19,4	3404	
10:12	65	140.584,66	226.983,90	7,15	20,4	7,19	19,4	3505	
10:15	66	140.493,11	227.074,93	7,12	20,1	7,21	19,4	3633	
10:17	67	140.437,48	227.136,23	7,14	20,0	7,21	19,4	3716	
10:19	68	140.343,65	227.251,36	7,23	20,5	7,22	19,4	3864	
10:20	69	140.248,68	227.375,79	7,26	20,5	7,23	19,5	4021	
10:22	70	140.174,49	227.442,69	7,19	20,3	7,23	19,4	4119	
10:24	71	140.078,37	227.567,11	7,26	20,8	7,27	19,5	4276	

Monitoringscampagne 2 (02/08/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
10:26	72	140.038,99	227.619,10	7,16	20,2	7,28	19,4	4341	
10:28	73	139.948,71	227.758,35	7,18	20,2	7,30	19,4	4507	
10:29	74	139.878,11	227.875,32	7,26	19,9	7,34	19,4	4643	
10:30	75	139.841,05	227.919,89	7,28	20,1	7,34	19,4	4700	
10:32	76	139.761,18	228.033,17	7,23	20,0	7,33	19,5	4839	
10:34	77	139.695,18	228.124,15	7,25	19,9	7,34	19,5	4951	
10:35	78	139.611,89	228.268,96	7,25	19,9	7,33	19,5	5117	
10:38	79	139.569,13	228.363,62		19,9	7,35	19,4	5218	
10:44	80	139.729,88	228.055,48		20,1	7,36	19,5	4876	
10:53	81	140.000,62	227.587,65	7,47	20,6	7,35	19,9	4340	
10:56	82	140.136,05	227.377,86	7,55	21,3	7,41	20,4	4092	
11:01	83	140.438,43	227.019,40	7,54	21,8	7,48	21,0	3623	
11:03	84	140.574,02	226.876,37	7,45	21,4	7,42	20,6	3427	
11:07	85	140.892,79	226.558,71	7,46	21,7	7,46	20,6	2980	
11:11	86	141.301,06	226.272,43	7,48	21,9	7,50	21,3	2510	
11:13	87	141.494,73	226.116,35	7,35	21,5	7,36	21,0	2274	
11:17	88	141.780,05	225.884,09	7,53	21,9	7,42	21,2	1930	
11:20	89	142.066,59	225.672,26	7,59	23,4	7,64	22,9	1614	
11:28	90	142.564,03	225.100,39	7,43	25,8	7,10	20,7	924	
11:30	91	142.655,54	224.931,51	7,67	28,9	7,05	20,7	747	
11:35	92	142.767,89	224.697,72	7,65	29,6	7,06	21,0	517	
11:37	93	142.808,41	224.595,67	7,63	30,0	7,27	23,5	425	
11:39	94	142.844,33	224.528,86	7,58	30,0	7,11	23,2	373	
11:41	95	142.855,86	224.463,94	7,59	30,2	7,23	24,0	320	
11:43	96	142.860,45	224.425,00	7,56	30,2	7,21	24,3	290	
11:45	97	142.851,09	224.374,94	7,55	30,0	7,31	25,1	244	
11:46	98	142.859,15	224.326,72	7,48	29,0	7,28	25,5	215	
11:50	99	142.838,41	224.447,28	7,40	28,6	7,21	24,9	297	
11:51	100	142.823,43	224.534,45	7,54	29,6	7,15	23,9	371	
11:53	101	142.806,16	224.647,59	7,45	29,0	7,08	22,2	474	
11:55	102	142.786,54	224.742,20	6,91	23,1	7,06	20,9	563	
11:58	103	142.756,55	224.890,57	6,90	22,6	7,02	20,4	707	
11:59	104	142.743,85	224.951,79	7,11	23,7	6,99	20,5	767	
12:02	105	142.717,34	225.092,76	6,94	22,2	6,95	20,2	907	
12:03	106	142.804,62	225.211,31	6,88	21,3	6,92	19,9	1031	
12:06	107	142.632,95	225.382,15	6,91	21,9	6,95	20,0	1198	
12:08	108	142.588,96	225.478,64	6,89	21,3	6,94	19,8	1297	
12:09	109	142.544,93	225.552,87	6,91	21,3	6,93	19,7	1375	
12:14	110	142.506,40	225.410,14	7,47	26,5	7,04	20,0	1239	
12:18	111	142.568,78	225.187,53	7,42	26,5	7,03	20,2	1010	
12:20	112	142.620,87	225.048,94	7,56	28,2	7,02	20,3	866	
12:22	113	142.653,27	224.963,04	7,57	28,9	7,07	20,5	778	
12:27	114	142.747,08	224.768,20	7,62	30,6	7,14	20,6	584	
12:29	115	142.785,36	224.729,21	7,53	30,1	7,11	21,9	550	
12:32	116	142.817,75	224.625,32	7,54	30,9	7,15	22,6	456	
12:34	117	142.868,68	224.495,45	7,62	31,6	7,14	24,6	354	
12:39	118	142.862,95	224.551,08	7,31	28,1	7,02	21,9	401	laagwater
12:41	119	142.845,70	224.679,06	7,18	27,0	7,01	22,1	515	
12:43	120	142.826,10	224.790,34	7,18	25,7	7,12	21,9	618	
12:45	121	142.809,97	224.873,81	7,24	26,1	6,97	20,6	697	
12:47	122	142.777,60	224.996,24	7,62	29,5	6,87	20,2	814	
12:48	123	142.742,88	225.087,15	6,94	22,7	6,91	20,1	902	
12:50	124	142.701,19	225.176,22	7,32	25,1	6,91	19,9	990	
12:52	125	142.656,03	225.276,41	7,14	23,6	6,91	19,9	1091	
12:58	126	142.463,57	225.515,90	6,98	21,3	6,92	19,8	1350	
13:00	127	142.359,13	225.580,95	7,19	21,8	7,15	20,0	1435	
13:04	128	142.515,93	225.582,58	7,17	22,3	7,20	20,5	1408	
13:06	129	142.600,63	225.519,41	7,42	25,9	7,14	20,6	1337	
13:07	130	142.655,16	225.478,54	7,54	28,0	6,96	20,0	1293	
13:08	131	142.701,56	225.435,83	7,48	27,7	7,01	20,0	1250	
13:10	132	142.750,26	225.376,42	7,52	28,7	6,91	20,0	1192	
13:12	133	142.805,87	225.278,06	7,53	29,6	6,89	20,4	1098	
13:14	134	142.827,81	225.183,47	7,49	30,0	6,86	20,4	1006	
13:15	135	142.862,53	225.094,40	7,41	29,2	7,08	23,9	923	
13:21	136	142.919,02	224.769,82	7,54	31,5	6,97	22,8	625	
13:22	137	142.930,54	224.703,05	7,58	31,9	6,90	22,9	568	
13:24	138	142.925,70	224.560,27	7,56	31,9	6,94	22,3	439	
13:26	139	142.919,74	224.454,59	7,59	32,0	7,75	30,3	349	
13:27	140	142.931,29	224.400,79	7,61	31,7	7,62	30,1	318	
13:28	141	142.938,21	224.365,56	7,44	30,4	7,44	28,8	301	
13:32	142	142.864,85	224.243,27	7,47	30,7	7,33	27,5	178	

Monitoringscampagne 2 (02/08/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
13:34	143	142.896,41	224.387,86	7,65	31,2	7,65	29,6	284	
13:35	144	142.907,01	224.493,54	7,61	31,1	6,96	23,7	373	
13:36	145	142.904,78	224.552,88	7,58	30,8	7,07	23,9	422	
13:38	146	142.904,94	224.671,56	7,61	31,2	7,01	23,3	528	
13:40	147	142.895,82	224.803,23	7,25	27,1	7,07	22,9	649	
13:42	148	142.883,22	224.931,19	7,33	27,9	7,01	22,4	768	
13:43	149	142.869,42	225.036,91	7,50	29,9	7,33	26,0	868	
13:45	150	142.845,23	225.177,88	7,49	29,8	7,03	22,3	1003	
13:47	151	142.807,09	225.317,00	7,28	25,5	7,30	22,4	1136	
13:48	152	142.781,68	225.415,32	6,90	21,2	7,01	20,5	1232	
13:49	153	142.774,78	225.470,95	6,88	20,7	6,99	20,2	1287	
13:50	154	142.764,42	225.537,73	6,86	20,5	6,94	20,0	1353	
13:51	155	142.755,19	225.580,38	6,84	20,3	6,91	19,9	1396	
13:55	156	142.562,56	225.699,33	6,92	20,6	6,90	19,9	1519	
13:57	157	142.538,11	225.653,01	6,81	20,3	6,80	19,7	1475	
13:58	158	142.603,08	225.606,56	6,82	20,4	6,80	19,7	1424	
13:59	159	142.683,15	225.561,95	6,79	20,3	6,81	19,7	1376	
14:00	160	142.734,19	225.511,81	6,80	20,3	6,84	19,8	1326	
14:02	161	142.808,40	225.431,97	6,83	20,3	6,87	19,9	1251	
14:04	162	142.868,66	225.324,34	6,85	20,2	6,92	19,9	1151	
14:07	163	142.921,83	225.133,26	7,31	24,8	6,98	21,2	974	
14:08	164	142.926,27	224.986,77	7,29	25,0	7,21	22,8	833	
14:10	165	142.950,48	224.855,08	7,32	25,0	7,26	22,3	716	
14:11	166	142.952,70	224.779,04	7,38	27,2	7,32	22,4	646	
14:13	167	142.947,95	224.699,32	7,18	24,2	7,20	21,4	572	
14:15	168	142.965,36	224.690,03	7,26	23,8	7,24	21,1	571	
14:16	169	142.945,59	224.671,51	7,28	23,7	7,38	22,2	546	
14:18	170	142.937,45	224.671,52	7,38	25,1	7,35	22,9	542	
14:19	171	142.935,14	224.669,66	7,38	25,1	7,27	22,6	539	
14:22	172	142.928,14	224.656,69	7,43	25,7	7,22	22,7	525	
14:24	173	142.922,33	224.652,99	7,42	25,7	7,11	22,3	519	
14:26	174	142.918,85	224.647,44	7,42	26,2	7,22	23,4	512	
14:29	175	142.909,55	224.645,59	7,44	26,5	7,19	23,3	507	
14:31	176	142.903,73	224.643,75	7,43	26,6	7,10	22,7	503	
14:34	177	142.895,60	224.640,05	7,21	25,3	7,29	23,7	496	
14:36	178	142.886,29	224.632,63	6,76	20,8	6,87	20,2	485	
14:38	179	142.863,03	224.615,99	6,84	20,5	6,89	20,1	461	
14:40	180	142.861,70	224.493,61	7,21	24,2	7,02	21,4	349	
14:43	181	142.861,39	224.263,67	7,47	26,6	7,62	27,3	182	
14:45	182	142.809,03	224.209,96	7,65	29,4	7,69	29,1	115	
14:46	183	142.802,07	224.206,27	7,70	29,9	7,74	29,6	108	
14:49	184	142.804,30	224.145,07	7,56	30,2	7,58	29,8	115	
14:54	185	142.848,50	224.180,24	7,61	29,3	7,60	28,3	152	
14:56	186	142.855,47	224.180,24	7,60	28,8	7,51	27,5	159	
15:02	187	142.906,60	224.187,58	7,54	28,5	7,30	25,2	210	
15:04	188	142.911,25	224.187,58	7,66	29,1	7,16	24,1	215	
15:07	189	142.913,57	224.183,86	7,57	28,3	7,61	27,5	217	
15:11	190	142.914,71	224.172,73	7,25	26,3	7,35	25,4	219	
15:18	191	142.903,10	224.183,88	7,59	28,1	7,32	25,0	207	
15:21	192	142.898,46	224.185,74	7,39	27,0	7,44	25,8	202	
15:25	193	142.886,85	224.187,61	7,52	27,3	7,57	26,4	191	
15:31	194	142.839,26	224.219,19	7,72	28,8	7,80	28,6	147	
15:32	195	142.819,51	224.221,08	7,70	29,4	7,76	29,0	128	
15:35	196	142.798,60	224.224,82	7,64	29,1	7,67	28,8	109	
15:38	197	142.760,26	224.221,17	7,71	30,3	7,57	28,4	73	
15:40	198	142.756,77	224.217,45	7,59	29,2	7,63	28,7	68	
15:42	199	142.745,20	224.247,15	7,69	30,1	7,74	29,8	78	
15:45	200	142.748,67	224.237,86	7,71	30,1	7,67	29,4	74	
15:47	201	142.740,56	224.258,27	7,72	30,1	7,77	30,0	85	
15:49	202	142.755,66	224.258,25	7,70	30,0	7,72	29,8	93	
15:52	203	142.775,39	224.250,81	7,69	29,9	7,73	29,6	102	
15:56	204	142.757,99	224.258,25	7,69	29,8	7,66	29,3	95	
16:01	205	142.761,49	224.267,52	7,70	29,9	7,72	29,6	104	
16:04	206	142.768,46	224.271,22	7,69	29,7	7,71	29,6	112	
16:09	207	142.811,35	224.206,26	7,60	28,6	7,64	28,4	117	
16:11	208	142.884,52	224.189,47	7,39	27,8	7,36	26,5	188	
16:12	209	142.915,88	224.180,16	7,39	27,6	7,24	25,2	220	
16:17	210	142.865,86	224.137,57	7,32	27,1	7,37	27,0	176	
16:19	211	142.867,03	224.139,42	7,35	27,9	7,22	25,9	177	
16:23	212	142.825,22	224.143,19	7,34	28,8	7,11	25,0	136	
16:27	213	142.817,08	224.143,20	7,17	25,5	7,20	24,6	128	

Monitoringscampagne 2 (02/08/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
16:30	214	142.883,41	224.220,99	7,29	26,0	7,23	24,0	190	
16:32	215	142.888,08	224.237,67	7,22	25,4	7,00	21,1	199	
16:38	216	142.909,03	224.272,88	7,29	25,5	6,92	20,1	230	
16:41	217	142.893,91	224.261,77	7,06	22,8	6,99	20,3	212	
16:43	218	142.888,09	224.250,64	7,05	22,9	6,99	20,1	202	
16:47	219	142.882,27	224.243,24	7,33	25,4	7,02	19,9	195	
16:48	220	142.881,11	224.245,10	6,89	21,5	6,97	20,2	194	
16:50	221	142.866,04	224.265,52	7,03	20,7	7,10	19,7	187	
16:53	222	142.816,05	224.239,63	7,61	26,5	7,71	25,9	131	
16:56	223	142.869,20	224.030,02	7,34	26,1	7,28	24,6	233	
16:58	224	142.880,77	223.998,48	7,23	24,8	7,23	24,0	263	
16:59	225	142.873,89	224.059,68	7,27	25,0	7,33	24,9	218	
17:03	226	142.809,00	224.182,15	7,32	25,9	7,53	26,7	113	
17:04	227	142.805,58	224.232,23	7,02	21,1	6,99	21,1	119	
17:06	228	142.860,17	224.213,61	7,03	20,4	7,11	19,9	166	
17:08	229	142.887,82	224.044,82	7,41	24,9	7,45	24,8	238	
17:10	230	142.859,87	224.004,07	7,29	25,2	7,33	24,0	245	
17:12	231	142.825,15	224.100,54	7,24	24,5	7,31	22,9	155	
17:14	232	142.812,54	224.221,08	7,34	24,7	7,09	20,7	121	
17:15	233	142.805,61	224.245,20	7,12	20,7	7,09	20,3	124	
17:16	234	142.836,88	224.183,97	7,11	20,3	7,17	19,9	141	
17:18	235	142.877,33	224.024,44	7,33	24,0	7,37	23,2	243	
17:20	236	142.883,22	224.085,63	7,22	20,3	7,38	23,6	212	
17:24	237	142.897,28	224.167,21	7,28	20,2	7,27	19,8	202	
17:39	238	142.909,93	224.925,59	7,44	20,3	7,52	19,6	770	
17:40	239	142.927,30	224.894,05	7,43	20,2	7,52	19,5	745	
17:57	240	142.973,82	224.079,94	7,60	22,8	7,46	19,7	297	
17:58	241	142.972,66	224.078,09	7,55	22,8	7,48	21,8	297	
18:01	242	143.004,02	224.063,20	7,49	22,5	7,54	21,9	331	
18:02	243	143.103,97	224.098,31	7,56	20,1	7,51	19,8	417	
18:03	244	143.134,22	224.122,38	7,55	19,9	7,55	19,6	443	
18:04	245	143.229,55	224.181,59	7,56	20,0	7,55	19,7	533	
18:06	246	143.112,08	224.079,75	7,53	22,6	7,56	19,5	429	
18:07	247	143.041,15	224.033,50	7,46	22,7	7,58	21,8	377	
18:09	248	142.967,90	223.983,53	7,44	22,5	7,47	21,8	339	
18:11	249	142.915,57	223.959,49	7,33	22,8	7,43	21,5	315	
18:14	250	142.921,34	223.926,10	7,33	22,4	7,44	22,9	344	hoogwater
18:15	251	142.924,74	223.853,78	7,28	22,7	7,34	20,9	403	
18:16	252	142.927,02	223.831,52	7,30	21,4	7,36	20,9	423	
18:17	253	142.950,17	223.768,45	7,31	21,2	7,30	20,3	489	
18:18	254	142.946,60	223.701,70	7,25	20,9	7,30	20,3	545	
18:19	255	142.938,43	223.672,03	7,21	21,0	7,32	20,0	568	
18:20	256	142.925,58	223.627,55	7,20	21,2	7,29	20,2	604	
18:21	257	142.903,42	223.568,24	7,06	21,0	7,24	20,2	652	
18:22	258	142.897,51	223.494,08	7,18	21,5	7,22	20,1	721	
18:23	259	142.856,77	223.436,65	7,12	20,7	7,21	20,0	766	
18:24	260	142.829,99	223.399,60	7,19	20,3	7,27	19,9	798	
18:25	261	142.818,36	223.382,93	7,18	20,3	7,28	19,8	812	
18:26	262	142.869,34	223.284,58	7,21	20,3	7,27	19,9	918	

lozingspunt	142.696,32	224.186,02

Monitoringscampagne 3 (29/09/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
7:25	1	142.908,97	222.362,89	6,28	18,6	6,20	18,7	1835	
7:54	2	142.294,99	225.265,78	7,02	20,9	6,65	18,6	1152	
7:57	3	142.302,97	225.158,22	7,22	22,1	6,54	19,3	1049	
8:01	4	142.435,14	224.992,99	7,12	22,9	6,95	22,3	848	
8:05	5	142.573,16	224.842,59	7,04	22,2	6,97	22,4	668	
8:10	6	142.648,43	224.681,15	7,24	22,2	6,97	21,8	497	
8:12	7	142.693,62	224.599,50		20,6	7,01	22,3	413	
8:17	8	142.770,04	224.419,52	6,57	19,1	6,60	19,6	245	
8:18	9	142.784,07	224.482,55	6,55	18,9	6,52	18,8	309	
8:20	10	142.733,10	224.588,32	6,56	18,7	6,52	18,7	404	
8:21	11	142.678,66	224.701,51	6,59	18,6	6,65	19,0	516	
8:23	12	142.648,56	224.768,31	6,70	19,3	6,71	19,4	584	
8:24	13	142.621,94	224.838,81	7,03	21,7	6,71	19,8	657	
8:25	14	142.583,74	224.933,43	7,18	22,9	6,91	21,0	756	
8:27	15	142.529,31	225.046,63	6,78	20,6	6,62	19,6	877	
8:28	16	142.509,62	225.085,60	6,28	21,2	6,68	19,7	919	
8:30	17	142.471,38	225.150,55	6,81	21,0	6,57	19,1	990	
8:31	18	142.433,13	225.208,09	6,77	20,7	6,56	19,0	1055	
8:33	19	142.386,77	225.278,63		20,3	6,57	19,0	1136	
8:47	20	142.799,09	224.425,05	6,81	21,6	6,42	19,3	260	
8:51	21	142.743,61	224.621,68	6,80	21,3	6,49	19,0	438	
8:52	22	142.710,03	224.701,47	6,79	21,3	6,43	18,9	516	
8:53	23	142.693,82	224.738,57	6,73	21,3	6,51	19,2	553	
8:55	24	142.667,19	224.805,37	6,82	21,5	6,49	19,2	620	
8:56	25	142.630,13	224.879,59	6,90	22,1	6,50	19,2	697	
8:57	26	142.606,98	224.938,96	6,94	22,2	6,49	19,3	758	
8:59	27	142.579,21	225.018,74	6,67	20,9	6,45	19,1	841	
9:00	28	142.561,86	225.065,12	6,69	21,0	6,45	19,1	889	
9:01	29	142.530,60	225.141,20	6,56	20,1	6,47	19,2	969	
9:03	30	142.491,24	225.230,26	6,71	20,5	6,43	19,0	1064	
9:05	31	142.463,47	225.302,62	6,56	19,9	6,39	18,8	1141	
9:06	32	142.447,28	225.354,56		19,4	6,40	18,8	1195	
9:17	33	142.845,53	224.399,02		25,2	6,33	20,3	260	
9:18	34	142.822,42	224.495,48	7,12	24,4	6,29	19,3	334	
9:20	35	142.810,90	224.560,40	6,89	22,9	6,30	19,2	392	
9:21	36	142.790,12	224.658,70	6,64	21,6	6,31	19,2	482	
9:22	37	142.776,25	224.705,08	6,43	20,1	6,29	19,0	525	
9:24	38	142.754,27	224.771,87	6,41	19,7	6,28	18,9	589	
9:26	39	142.725,38	224.883,17	6,30	19,0	6,28	18,8	698	
9:27	40	142.713,86	224.946,23	6,29	18,8	6,28	18,7	760	
9:28	41	142.691,92	225.040,83	6,28	18,7	6,28	18,6	855	
9:30	42	142.671,09	225.096,49	6,28	18,7	6,26	18,6	911	
9:31	43	142.649,11	225.157,72	6,29	18,7	6,27	18,6	973	
9:32	44	142.621,33	225.230,07	6,29	18,7	6,27	18,6	1047	
9:34	45	142.591,24	225.306,15	6,30	18,7	6,28	18,6	1125	
9:35	46	142.562,33	225.397,05	6,31	18,6	6,28	18,6	1218	
9:36	47	142.534,49	225.419,34	6,33	18,6	6,31	18,6	1244	
9:46	48	142.824,62	224.404,61	7,89	27,1	6,72	22,5	253	
9:49	49	142.815,46	224.501,05	7,66	27,4	6,39	20,8	337	
9:50	50	142.799,26	224.543,72	7,38	26,3	6,35	20,3	372	
9:51	51	142.787,68	224.573,41	7,22	25,6	6,35	20,1	398	
9:52	52	142.761,04	224.627,22	7,10	25,0	6,34	19,9	446	
9:54	53	142.729,78	224.701,44	7,28	25,3	6,32	19,8	517	
9:55	54	142.717,05	224.738,54	7,16	24,9	6,27	19,5	553	
9:56	55	142.698,53	224.784,93	7,02	23,9	6,24	19,4	599	
9:58	56	142.666,16	224.892,52	6,88	23,3	6,26	19,4	707	
9:59	57	142.647,64	224.942,62	6,76	22,3	6,28	19,4	758	
10:01	58	142.603,65	225.046,52	6,91	22,9	6,30	19,4	865	
10:03	59	142.550,40	225.176,40	6,69	22,0	6,32	19,5	1001	
10:04	60	142.536,51	225.211,65	6,60	21,5	6,30	19,4	1038	
10:05	61	142.523,78	225.245,05	6,78	22,0	6,33	19,5	1073	
10:06	62	142.506,43	225.289,58	6,69	21,6	6,31	19,4	1120	
10:07	63	142.491,37	225.322,98	6,50	21,1	6,28	19,2	1155	
10:16	64	142.834,06	224.506,59	7,23	25,4	6,39	21,1	349	
10:19	65	142.783,10	224.621,63	6,96	23,7	6,31	20,3	444	
10:24	66	142.731,07	224.794,15	7,07	24,2	6,23	19,6	609	
10:25	67	142.721,81	224.820,13	6,48	21,8	6,21	19,5	635	
10:27	68	142.702,13	224.866,51	7,01	23,4	6,19	19,4	681	
10:29	69	142.666,24	224.951,86	6,54	21,7	6,20	19,3	766	
10:30	70	142.650,03	224.990,83	6,47	21,1	6,20	19,3	806	
10:31	71	142.623,42	225.066,89	6,77	22,3	6,22	19,3	884	

Monitoringscampagne 3 (29/09/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
10:32	72	142.613,01	225.096,57	6,62	21,8	6,23	19,3	914	
10:33	73	142.607,23	225.113,27	6,83	22,5	6,24	19,3	932	
10:34	74	142.584,09	225.180,06	6,83	22,5	6,26	19,4	1000	
10:36	75	142.562,10	225.232,01	6,45	21,1	6,27	19,4	1055	
10:37	76	142.552,84	225.256,13	6,38	20,5	6,26	19,3	1080	
10:38	77	142.543,58	225.280,25	6,38	20,5	6,24	19,3	1105	
10:39	78	142.533,16	225.306,23	6,37	20,1	6,23	19,2	1132	
10:41	79	142.516,96	225.343,34	6,33	20,0	6,17	19,0	1171	
10:42	80	142.507,69	225.358,19	6,62	21,2	6,17	19,0	1187	
10:53	81	142.856,17	224.538,08	7,03	25,5	6,30	20,9	387	
10:54	82	142.837,63	224.569,63	6,96	25,3	6,30	20,7	409	
10:55	83	142.826,05	224.599,32	6,87	24,9	6,32	20,8	433	
10:56	84	142.794,76	224.651,28	6,84	24,4	6,23	19,9	476	
10:58	85	142.761,16	224.712,52	6,60	22,9	6,25	19,8	530	
10:59	86	142.747,26	224.745,92	6,83	24,0	6,29	19,8	562	
11:03	87	142.675,45	224.892,51	7,19	24,9	6,26	19,4	707	
11:06	88	142.622,21	225.029,81	6,58	22,0	6,26	19,4	847	
11:07	89	142.608,31	225.055,79	6,81	22,9	6,27	19,4	874	
11:08	90	142.580,49	225.096,62	6,76	22,5	6,32	19,4	918	
11:10	91	142.543,41	225.161,58	6,43	20,9	6,32	19,4	987	
11:11	92	142.523,71	225.194,98	6,83	22,4	6,33	19,4	1024	
11:12	93	142.475,02	225.256,24	6,88	22,4	6,33	19,5	1093	
11:13	94	142.446,04	225.297,08	6,70	21,7	6,39	19,5	1139	
11:14	95	142.429,81	225.323,07	6,78	22,0	6,38	19,5	1168	
11:25	96	142.800,62	224.690,21	6,70	24,8	6,27	20,3	515	
11:26	97	142.790,23	224.734,73			6,22	20,1	557	
11:33	98	142.703,56	225.057,51	6,14	20,1	6,09	19,0	872	
11:34	99	142.701,25	225.068,64	6,15	20,1	6,08	18,9	883	
11:35	100	142.698,94	225.079,76	6,18	20,0	6,08	18,9	894	
11:37	101	142.685,08	225.133,56	6,19	20,2	6,08	18,9	948	
11:38	102	142.673,52	225.172,52	6,34	20,8	6,11	18,9	987	
11:42	103	142.654,99	225.213,34	6,56	21,9	6,08	18,8	1028	
11:44	104	142.627,23	225.291,26	6,45	21,5	6,07	18,7	1107	
11:45	105	142.616,80	225.311,67	6,43	21,3	6,07	18,7	1128	
11:46	106	142.607,53	225.328,37	6,56	21,6	6,07	18,7	1146	
11:48	107	142.593,62	225.346,94	6,37	20,7	6,07	18,7	1165	
11:49	108	142.585,50	225.356,22	6,70	22,0	6,08	18,7	1175	
11:51	109	142.508,80	225.322,95	6,98	23,5	6,13	18,8	1152	
11:52	110	142.512,24	225.295,13	7,00	23,7	6,21	19,1	1124	laagwater
11:54	111	142.515,70	225.280,29	7,01	23,9	6,32	19,3	1109	
11:55	112	142.526,12	225.252,46	7,09	24,4	6,41	19,5	1080	
11:56	113	142.540,00	225.211,65	7,17	24,8	6,37	19,6	1037	
11:58	114	142.550,40	225.176,40	7,13	25,0	6,40	19,6	1001	
11:59	115	142.557,32	225.143,01	7,18	25,4	6,36	19,6	967	
12:00	116	142.572,38	225.109,61	7,12	25,4	6,36	19,7	932	
12:01	117	142.587,42	225.068,80	7,12	25,3	6,32	19,7	889	
12:02	118	142.602,46	225.026,13	7,03	25,2	6,36	19,6	845	
12:04	119	142.624,43	224.959,34	7,03	25,5	6,35	20,0	777	
12:06	120	142.649,92	224.914,80	7,16	26,3	6,38	20,4	730	
12:08	121	142.674,24	224.857,28	7,18	26,7	6,38	20,2	672	
12:09	122	142.689,29	224.820,17	7,25	27,4	6,29	20,5	634	
12:11	123	142.705,59	224.851,67	6,98	25,7	6,29	20,0	666	
12:14	124	142.683,63	224.927,73	6,92	25,5	6,29	19,7	742	
12:16	125	142.681,32	224.935,15	6,62	23,2	6,35	19,6	749	
12:18	126	142.641,95	225.022,36	6,82	24,0	6,41	19,9	838	
12:20	127	142.621,08	225.052,06	6,71	23,0	6,44	19,8	869	
12:22	128	142.610,65	225.066,91	6,84	23,2	6,47	19,9	885	
12:25	129	142.559,68	225.168,97	6,77	22,3	6,58	19,9	992	
12:27	130	142.529,56	225.224,64	6,86	22,1	6,63	20,2	1052	
12:29	131	142.505,27	225.295,14	6,63	20,7	6,60	19,1	1125	
12:31	132	142.483,30	225.361,93	6,79	20,4	6,75	20,0	1195	
12:32	133	142.459,97	225.295,21	6,79	20,6	6,66	19,0	1134	
12:35	134	142.469,16	225.222,88	6,77	20,8	6,62	19,0	1061	
12:37	135	142.483,00	225.152,39	7,13	22,4	6,63	19,3	990	
12:39	136	142.506,13	225.081,89	7,02	22,6	6,73	19,9	916	
12:42	137	142.528,08	225.002,12	7,23	24,3	6,65	20,6	833	
12:44	138	142.550,10	224.965,01	7,06	24,6	6,58	20,2	793	
12:46	139	142.584,84	224.892,64	7,11	25,5	6,58	20,7	715	
12:48	140	142.596,39	224.844,41	7,14	26,2	6,64	20,7	666	
12:50	141	142.626,49	224.770,19	7,23	27,2	6,84	21,9	588	
12:52	142	142.639,23	224.744,21	7,22	27,3	6,96	22,5	561	

Monitoringscampagne 3 (29/09/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
12:54	143	142.662,40	224.701,53	7,27	27,7	6,98	23,9	517	
12:56	144	142.693,70	224.653,28	7,15	27,2	6,72	22,5	467	
12:58	145	142.715,72	224.614,30	7,24	27,7	6,66	22,6	429	
13:02	146	142.742,38	224.575,33	7,41	28,7	6,79	22,9	392	
13:04	147	142.764,39	224.534,50	6,76	24,8	6,82	23,4	355	
13:06	148	142.764,39	224.534,50	6,77	25,0	6,87	24,3	355	
13:07	149	142.799,28	224.558,56	6,74	24,6	7,08	25,8	387	
13:10	150	142.759,90	224.645,77	7,20	27,3	6,70	22,8	464	
13:12	151	142.741,42	224.718,11	7,18	26,6	6,73	22,0	534	
13:13	152	142.717,09	224.768,21	7,14	26,3	6,84	21,9	583	
13:15	153	142.680,02	224.842,44	7,17	26,3	6,56	21,0	657	
13:18	154	142.634,82	224.909,26	6,22	19,5	6,30	19,3	726	
13:20	155	142.618,60	224.944,51	6,12	19,2	6,16	19,1	762	
13:22	156	142.610,57	225.013,13	6,10	19,1	6,04	19,0	832	
13:24	157	142.582,83	225.111,45	6,07	19,1	6,01	19,0	932	
13:26	158	142.570,14	225.172,66	6,08	19,1	5,99	19,0	995	
13:28	159	142.544,70	225.254,29	5,94	19,1	5,89	18,9	1079	
13:30	160	142.509,95	225.315,53	5,85	19,1	5,84	18,9	1145	
13:32	161	142.548,27	225.309,92	5,85	19,0	5,87	18,8	1134	
13:34	162	142.590,01	225.259,79	5,84	19,1	5,85	18,9	1079	
13:36	163	142.625,89	225.168,88	5,86	19,0	5,86	18,9	985	
13:38	164	142.657,13	225.081,68	5,86	19,1	5,87	18,9	897	
13:40	165	142.699,98	224.988,90	5,92	19,0	5,92	18,9	803	
13:42	166	142.742,84	224.909,10	5,94	19,1	5,95	18,9	725	
13:44	167	142.782,23	224.829,31	6,00	19,1	5,97	18,9	649	
13:46	168	142.818,11	224.732,84	6,01	19,1	5,99	18,9	560	
13:48	169	142.834,24	224.640,10	6,04	19,2	6,01	19,0	475	
13:50	170	142.866,63	224.539,92	6,05	19,2	6,05	19,0	393	
13:52	171	142.895,47	224.389,68	7,57	28,9			285	
13:54	172	142.855,83	224.289,60	7,34	28,8	6,54	22,2	190	
13:55	173	142.839,63	224.337,84	7,19	27,8	6,75	23,0	209	
13:57	174	142.825,81	224.419,45	7,24	26,9	6,10	19,9	267	
14:00	175	142.803,85	224.506,63	6,18	20,1	6,14	19,7	338	
14:02	176	142.781,85	224.556,73	6,17	19,8	6,26	19,7	380	
14:04	177	142.773,77	224.595,68	6,05	19,5	6,28	19,7	417	
14:06	178	142.775,00	224.640,18	5,95	19,3	5,93	19,2	461	
14:07	179	142.760,00	224.716,23	5,92	19,1	5,91	19,1	534	
14:10	180	142.748,47	224.777,44	5,91	19,1	5,87	19,0	594	
14:19	181	142.555,15	225.245,00	6,08	19,2	5,96	18,8	1068	
14:22	182	142.600,30	225.141,10	6,04	19,2	5,94	18,8	960	
14:24	183	142.632,71	225.061,31	6,07	19,4	5,92	18,8	878	
14:26	184	142.665,14	224.994,51	5,98	19,1	5,91	18,8	809	
14:27	185	142.688,27	224.925,87	5,99	19,1	5,92	18,8	740	
14:29	186	142.717,22	224.857,22	5,99	19,1	5,91	18,9	672	
14:32	187	142.771,64	224.731,05	5,94	19,1	5,91	19,0	550	
14:34	188	142.808,68	224.638,28	5,95	19,1	5,92	19,0	466	
14:35	189	142.830,66	224.571,49	5,94	19,1	5,90	19,0	408	
14:36	190	142.858,42	224.484,30	5,95	19,1	5,91	19,0	339	
14:38	191	142.876,87	224.386,00	5,95	19,2	5,92	19,1	269	
14:39	192	142.887,25	224.324,79	7,54	29,0	7,27	27,4	236	
14:42	193	142.878,90	224.169,04	7,40	29,8	7,13	27,0	183	
14:44	194	142.868,33	224.085,61	7,34	29,9	6,91	25,6	199	
14:47	195	142.883,51	224.137,51	7,26	29,1	7,14	26,9	193	
14:48	196	142.903,34	224.200,53	7,20	27,8	5,82	19,8	208	
14:51	197	142.903,49	224.311,79	5,86	20,2	5,82	19,6	242	
15:02	198	142.463,43	225.278,51	6,40	19,1	6,39	18,7	1117	
15:03	199	142.497,01	225.202,44	6,33	19,0	6,39	18,7	1036	
15:05	200	142.527,10	225.130,08	6,31	19,0	6,39	18,7	959	
15:07	201	142.561,83	225.048,43	6,29	19,1	6,39	18,7	873	
15:09	202	142.608,14	224.937,11	6,26	19,1	6,35	18,7	756	
15:11	203	142.660,30	224.861,01	6,21	19,2	6,25	18,7	676	
15:14	204	142.699,69	224.786,78	6,20	19,3	6,23	18,7	601	
15:16	205	142.749,52	224.699,56	6,17	19,2	6,14	18,7	516	
15:17	206	142.780,81	224.645,74	6,21	19,3	6,14	18,8	467	
15:19	207	142.821,35	224.560,38	6,17	19,3	6,12	18,8	395	
15:21	208	142.840,97	224.463,93	6,06	19,3	6,03	18,8	313	
15:24	209	142.845,51	224.386,04	7,44	28,3	6,18	20,1	250	
15:26	210	142.851,23	224.319,28	7,43	29,5	7,16	26,9	204	
15:28	211	142.871,92	224.159,78	6,94	26,5	6,85	26,2	178	
15:29	212	142.874,16	224.102,29	7,30	29,0	6,37	24,6	197	
15:30	213	142.884,54	224.044,79	7,31	30,0	5,93	20,5	235	

Monitoringscampagne 3 (29/09/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
15:32	214	142.881,00	224.007,71	7,28	29,6	5,91	20,2	257	
15:34	215	142.877,61	224.076,32	7,17	29,1	6,15	21,1	212	
15:36	216	142.879,98	224.109,70	6,72	25,7	6,45	22,8	199	
15:38	217	142.890,54	224.183,86	6,77	25,9	6,05	20,2	194	
15:51	218	142.473,88	225.271,08	6,61	19,3	6,64	18,7	1108	
15:54	219	142.551,47	225.111,50	6,60	19,0	6,60	18,6	937	
15:55	220	142.591,98	225.009,45	6,63	19,0	6,59	18,6	830	
15:57	221	142.646,45	224.924,07	6,63	19,0	6,59	18,6	740	
15:59	222	142.697,44	224.838,70	6,62	19,0	6,59	18,6	653	
16:02	223	142.758,81	224.697,69	6,54	19,2	6,58	18,6	515	
16:04	224	142.807,43	224.573,38	6,50	19,2	6,52	18,6	403	
16:05	225	142.843,25	224.432,40	6,46	19,3	6,53	18,6	287	
16:06	226	142.852,46	224.371,20	6,46	19,4	6,52	18,6	242	
16:07	227	142.864,01	224.326,68	6,40	19,3	6,48	18,6	219	
16:08	228	142.855,76	224.237,68	7,41	27,1	6,71	23,2	168	
16:12	229	142.870,57	224.026,27	6,78	24,1	6,69	23,2	236	
16:13	230	142.865,89	224.002,17	6,80	24,2	6,67	23,0	250	
16:14	231	142.853,09	223.987,35	6,87	24,7	6,66	22,7	253	
16:15	232	142.855,48	224.035,56	6,74	23,6	6,52	21,1	219	
16:16	233	142.863,65	224.061,51	6,78	24,0	6,63	22,9	209	
16:19	234	142.860,27	224.135,69	6,90	25,1			171	
16:21	235	142.877,77	224.191,29	6,49	20,1	6,35	19,7	182	
16:22	236	142.877,77	224.193,15	6,53	19,6	6,55	19,2	182	
16:23	237	142.869,67	224.211,70			6,60	19,1	175	
16:38	238	142.488,75	225.115,30	7,05	19,0	6,95	18,7	952	
16:40	239	142.609,28	224.920,42	6,97	18,9	6,93	18,7	740	
16:43	240	142.722,87	224.747,81	6,98	18,9	6,94	18,7	562	
16:44	241	142.787,71	224.591,95	7,04	18,9	6,97	18,7	416	
16:46	242	142.835,01	224.358,24	6,89	18,9	6,88	18,7	221	
16:47	243	142.839,56	224.282,21	6,88	18,9	6,85	18,7	173	
16:48	244	142.845,28	224.217,30	6,86	18,9	6,82	18,8	152	
16:49	245	142.863,71	224.106,01	7,01	22,4	6,92	21,8	186	
16:50	246	142.886,83	224.016,97	6,96	22,4	6,86	21,5	255	
16:52	247	142.856,58	223.987,35	6,92	22,5	6,93	22,2	255	
16:53	248	142.858,95	224.020,72	6,93	22,7	6,90	21,5	232	
16:56	249	142.843,93	224.083,79	6,88	21,5	6,87	21,1	180	
16:58	250	142.856,81	224.152,38	6,97	22,0	6,81	19,4	164	
17:02	251	142.881,27	224.200,56	6,95	19,4	6,85	19,2	186	
17:07	252	142.778,26	224.478,85	7,22	18,8	7,19	18,5	304	
17:08	253	142.790,92	224.391,68	7,20	18,8	7,16	18,6	226	
17:09	254	142.821,02	224.319,32	6,97	19,0	7,09	18,7	183	
17:10	255	142.833,74	224.276,65	6,92	19,1	6,97	18,8	165	
17:12	256	142.840,60	224.195,05	6,96	21,5	7,05	22,6	145	
17:13	257	142.843,97	224.111,60	6,98	21,5	6,99	21,2	165	
17:14	258	142.858,99	224.054,10	6,93	21,8	6,98	20,9	209	
17:15	259	142.862,47	224.048,53	6,94	21,6	6,96	21,0	216	
17:17	260	142.870,57	224.024,41	6,92	21,6	6,99	20,3	238	
17:18	261	142.874,05	224.018,85	6,91	21,5	6,98	20,2	244	
17:20	262	142.877,53	224.016,99	6,93	20,9	7,06	20,3	248	
17:22	263	142.884,50	224.016,98	7,00	21,1	7,04	20,6	253	
17:25	264	142.891,48	224.020,68	7,02	21,1	7,09	20,2	256	hoogwater
17:27	265	142.911,30	224.070,72	7,03	21,1	7,10	20,7	244	
17:30	266	142.922,99	224.122,62	7,12	22,0	7,04	21,1	235	
17:32	267	142.877,56	224.037,38	7,07	20,9	6,97	20,6	234	
17:33	268	142.884,47	223.996,58	6,87	20,8	6,99	20,1	267	
17:34	269	142.884,47	223.996,58	6,79	21,1	6,99	20,0	267	
17:36	270	142.885,63	223.991,01	6,69	21,5	7,04	19,7	272	
17:37	271	142.886,79	223.991,01	6,54	21,4	7,08	19,5	273	
17:40	272	142.887,95	223.987,30	6,48	21,3	6,83	19,6	276	
17:41	273	142.885,62	223.985,45	6,56	21,1	6,85	19,3	276	
17:43	274	142.886,79	223.987,30	6,52	20,6	6,89	19,2	275	
17:45	275	142.884,47	223.991,02	6,40	19,9	6,84	19,1	271	
17:47	276	142.885,63	223.992,87	6,51	19,5	6,85	19,0	270	
17:49	277	142.882,15	223.996,58	6,62	19,3	6,89	19,0	265	
17:51	278	142.878,67	224.000,30	6,71	19,2	6,88	19,0	260	
17:54	279	142.871,72	224.013,29	6,74	19,1	6,87	19,0	246	
17:56	280	142.867,07	224.013,29	6,76	19,2	6,82	18,9	243	
17:58	281	142.869,39	224.013,29	6,76	19,1	6,84	18,9	245	
18:00	282	142.875,18	223.996,59	6,85	19,2	6,81	19,0	261	
18:03	283	142.875,18	223.996,59	6,88	19,3	6,89	19,1	261	
18:05	284	142.864,73	224.000,32	6,92	19,3	6,88	19,0	251	

Monitoringscampagne 3 (29/09/2011)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
18:07	285	142.865,89	224.002,17	6,97	19,4	6,94	19,2	250	
18:08	286	142.864,74	224.007,73	6,95	19,4	6,92	19,1	245	
18:10	287	142.867,07	224.009,58	6,93	19,3	6,92	19,1	246	
18:12	288	142.874,03	224.004,01	6,98	19,3	6,99	19,1	254	
18:15	289	142.869,40	224.017,00	6,95	19,3	6,94	19,1	242	
18:16	290	142.865,92	224.024,42	6,96	19,2	6,98	19,1	234	
18:17	291	142.843,88	224.046,70	6,90	19,2	6,89	18,9	203	
18:18	292	142.835,89	224.146,85	6,92	19,2	6,94	19,0	145	
18:19	293	142.825,49	224.191,36	6,93	19,3	6,97	19,1	129	
18:20	294	142.822,08	224.243,29	6,95	19,3	6,97	19,1	138	
18:22	295	142.826,80	224.295,21	7,26	21,5	7,10	20,0	170	
18:23	296	142.833,81	224.330,43	7,29	22,7	7,29	22,3	199	
18:24	297	142.838,61	224.439,83	7,10	21,4	6,98	19,7	291	
18:25	298	142.832,90	224.510,30	7,10	21,8	7,07	19,6	352	
18:27	299	142.830,67	224.578,91	7,11	21,8	7,08	19,6	415	
18:28	300	142.828,43	224.640,11	7,10	21,3	7,15	19,4	473	
18:29	301	142.821,58	224.725,42	7,10	20,3	7,22	19,2	554	
18:31	302	142.815,87	224.794,03	7,12	20,1	7,24	19,2	620	
18:32	303	142.804,36	224.875,64	7,15	20,5	7,22	19,7	698	
18:34	304	142.751,12	225.016,64	7,12	20,7	7,25	19,6	832	
18:35	305	142.737,24	225.053,75	7,11	20,7	7,19	19,4	869	
18:36	306	142.711,78	225.120,54	7,12	20,4	7,24	19,2	935	
18:37	307	142.674,71	225.194,77	7,12	20,6	7,22	19,4	1009	
18:39	308	142.623,75	225.298,68	7,16	20,1	7,28	19,3	1115	
18:40	309	142.602,91	225.346,92	7,15	20,0	7,31	19,3	1165	
18:41	310	142.563,54	225.430,43	7,20	20,0	7,37	19,1	1251	
18:43	311	142.523,01	225.512,07	7,20	19,9	7,35	19,1	1337	
18:45	312	142.497,53	225.562,18	7,21	19,9	7,34	19,1	1390	

lozingspunt	142.696,32	224.186,02

Monitoringscampagne 4 (07/02/2012)

Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
7:34	1	142.570,29	223.644,69	10,27	3,8	11,01	3,8	556	
7:45	2	142.963,54	223.184,27			10,97	3,9	1037	
7:51	3	143.070,51	224.107,58			10,98	3,8	382	
7:53	4	143.150,16	224.604,44			10,98	3,9	617	
8:05	5	142.635,41	225.332,04	10,71	3,9	11,13	3,7	1148	
8:07	6	142.644,57	225.235,60	10,55	3,6	11,14	3,8	1051	
8:09	7	142.671,13	225.126,16	10,52	3,6	11,15	3,7	940	
8:11	8	142.696,55	225.031,55	10,51	3,7	11,14	3,8	846	
8:13	9	142.721,98	224.940,65	10,44	4,7	11,13	4,6	755	
8:15	10	142.740,45	224.855,33	10,43	5,0	11,07	5,3	671	
8:17	11	142.768,20	224.768,14	10,37	5,7	11,05	5,8	587	
8:19	12	142.793,64	224.680,95	10,14	11,2	10,68	8,9	504	
8:23	13	142.838,72	224.519,56	9,91	13,4	10,73	12,1	363	
8:26	14	142.874,57	224.397,12	9,76	16,0	10,50	14,6	276	
8:28	15	142.915,16	224.345,15	9,73	15,5	10,46	15,3	271	
8:30	16	142.911,78	224.424,89	9,70	16,0	10,41	13,0	322	
8:32	17	142.888,68	224.525,05	9,80	13,5	10,63	10,2	390	
8:34	18	142.869,08	224.634,49	9,83	12,7	10,68	11,2	481	
8:36	19	142.857,60	224.734,63	9,98	10,8	10,84	6,2	572	
8:38	20	142.834,52	224.840,36	10,25	5,0	10,93	5,7	669	
8:40	21	142.806,75	224.921,99	10,32	4,5	10,95	5,1	744	
8:41	22	142.784,75	224.970,24	10,35	4,1	10,96	4,8	789	
8:43	23	142.743,05	225.057,45	10,39	4,0	11,06	4,3	873	
8:45	24	142.702,50	225.135,39	10,43	3,8	11,12	4,0	949	
8:47	25	142.658,47	225.211,48	10,45	3,7	11,14	3,8	1026	
8:49	26	142.627,20	225.274,57	10,47	3,6	11,16	3,7	1091	
8:50	27	142.577,36	225.350,67	10,49	3,6	11,17	3,7	1171	
8:51	28	142.553,02	225.385,93	10,47	3,6	11,18	3,8	1208	
8:53	29	142.521,64	225.369,29	10,53	3,6	11,19	3,7	1196	
8:54	30	142.532,01	225.311,79	10,49	3,7	11,19	3,8	1138	
8:55	31	142.530,78	225.261,72	10,48	3,7	11,19	3,9	1088	
8:56	32	142.538,84	225.213,50	10,49	3,9	11,21	4,1	1039	
8:57	33	142.552,73	225.178,25	10,49	4,1	11,16	4,3	1003	
8:59	34	142.571,25	225.133,72	10,47	4,4	11,15	4,7	956	
8:59	35	142.592,11	225.102,16	10,44	4,7	11,17	4,9	922	
9:01	36	142.611,81	225.072,47	10,42	4,9	11,11	5,3	890	
9:02	37	142.635,00	225.042,76	10,40	5,2	11,14	5,6	859	
9:02	38	142.655,87	225.013,07	10,40	5,3	11,10	5,6	828	
9:03	39	142.666,30	224.996,36	10,39	5,6	11,09	5,7	811	
9:04	40	142.688,32	224.962,95	10,36	5,7	11,06	5,9	777	
9:05	41	142.698,75	224.942,54	10,35	5,8	11,06	6,1	757	
9:06	42	142.699,90	224.933,27	10,27	8,1	11,01	7,5	747	
9:07	43	142.697,58	224.935,12	10,20	8,6	10,90	8,2	749	
9:09	44	142.681,41	225.000,05	10,29	5,7	10,97	6,0	814	
9:10	45	142.668,71	225.057,55	10,34	5,3	11,03	5,6	872	
9:10	46	142.657,13	225.085,38	10,36	5,0	11,03	5,3	900	
9:11	47	142.631,66	225.142,90	10,36	4,5	11,02	4,9	959	
9:12	48	142.621,24	225.165,17	10,38	4,4	11,04	4,7	982	
9:13	49	142.596,91	225.207,85	10,40	4,2	11,07	4,5	1027	
9:14	50	142.572,59	225.257,96	10,44	4,1	11,13	4,2	1079	
9:15	51	142.544,77	225.302,50	10,44	3,9	11,14	4,2	1127	
9:16	52	142.540,22	225.363,70	10,46	3,7	11,16	3,8	1188	
9:17	53	142.562,28	225.358,10	10,45	3,7	11,13	3,8	1180	
9:18	54	142.580,83	225.335,83	10,44	3,7	11,16	3,8	1156	
9:18	55	142.600,53	225.304,27	10,58	3,6	11,16	3,7	1122	
9:19	56	142.627,20	225.270,86	10,45	3,8	11,14	3,8	1087	
9:20	57	142.663,15	225.235,57	10,46	3,8	11,14	3,9	1050	
9:21	58	142.697,94	225.194,73	10,48	3,8	11,14	3,9	1009	
9:22	59	142.718,81	225.163,18	10,43	3,8	11,13	3,9	977	
9:23	60	142.737,34	225.127,92	10,43	4,0	11,10	4,2	943	
9:24	61	142.760,51	225.083,38	10,45	3,9	11,14	4,2	900	
9:25	62	142.780,20	225.046,27	10,41	4,1	11,10	4,2	864	
9:26	63	142.797,58	225.011,01	10,40	4,1	11,12	4,4	831	
9:27	64	142.817,27	224.968,34	10,41	4,3	11,13	4,5	792	
9:28	65	142.835,79	224.920,10	10,39	4,5	11,03	5,0	747	
9:30	66	142.851,98	224.871,86	10,39	4,7		6,5	703	
9:30	67	142.858,91	224.842,18	10,06	11,9	10,91	6,3	676	
9:33	68	142.869,23	224.742,04	9,89	13,5	10,82	12,2	582	
9:32	69	142.869,23	224.740,18	9,82	14,0		13,2	581	
9:33	70	142.873,83	224.708,65	9,77	14,3	10,56	14,7	552	
9:35	71	142.888,84	224.643,73	9,70	15,3		12,2	497	

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9:36	72	142.893,44	224.610,35	9,71	16,6	10,42	12,4	468	
9:36	73	142.895,72	224.578,82	9,62	15,9	10,49	9,3	441	
9:38	74	142.921,18	224.500,90	9,65	16,3	10,39	14,6	387	
9:39	75	142.929,25	224.456,39	9,64	15,7	10,37	16,0	357	laagwater
9:40	76	142.932,66	224.402,61	9,59	16,6	10,32	15,9	321	
9:41	77	142.920,99	224.365,54	9,58	16,8	10,32	16,7	288	
9:42	78	142.896,61	224.376,70	9,58	16,8	10,33	16,5	277	
9:42	79	142.886,18	224.397,11	9,56	17,0		15,0	284	
9:44	80	142.870,02	224.469,45	9,58	16,8	10,32	14,5	332	
9:44	81	142.864,24	224.493,56	9,58	16,8	10,40	14,4	350	
9:45	82	142.865,46	224.532,50	9,55	16,5		11,5	386	
9:46	83	142.857,38	224.575,16	9,61	15,5		11,1	421	
9:47	84	142.852,79	224.614,11	9,66	15,5		12,1	456	
9:48	85	142.850,50	224.636,37	9,59	15,9	10,55	9,4	476	
9:48	86	142.848,23	224.679,02	9,65	15,2	10,60	10,3	516	
9:49	87	142.843,63	224.710,55	9,73	14,0	10,64	10,6	545	
9:50	88	142.839,00	224.725,39	9,72	14,3	10,63	11,8	558	
9:51	89	142.837,84	224.725,39	9,75	14,1	10,55	12,9	558	
9:52	90	142.835,52	224.729,10	9,74	14,2	10,48	14,1	561	
9:53	91	142.834,36	224.729,10	9,76	14,2	10,42	13,5	560	
9:54	92	142.833,20	224.729,11	9,80	13,8	10,50	12,9	560	
9:55	93	142.833,20	224.730,96	9,73	13,4	10,52	13,7	562	
9:57	94	142.832,04	224.727,25	9,84	11,0	10,47	11,6	558	
9:58	95	142.832,04	224.727,25	9,88	10,6	10,58	11,3	558	
9:59	96	142.832,04	224.727,25	9,93	11,2	10,64	11,9	558	
10:00	97	142.834,35	224.719,83	9,91	11,9	10,55	11,6	551	
10:02	98	142.851,66	224.634,51	9,71	15,4	10,39	13,0	475	
10:04	99	142.866,65	224.556,61	9,68	15,0	10,28	14,0	408	
10:05	100	142.874,72	224.510,24	9,62	16,3	10,32	14,1	370	
10:07	101	142.890,87	224.426,77	9,62	16,3	10,38	13,4	310	
10:08	102	142.886,17	224.387,84	9,61	16,6	10,25	14,4	277	
10:09	103	142.878,13	224.454,60	9,58	16,7	10,36	13,4	324	
10:11	104	142.874,74	224.526,93	9,62	16,1	10,55	12,2	385	
10:11	105	142.871,28	224.545,47	9,63	16,0	10,34	13,7	400	
10:13	106	142.858,66	224.656,75	9,62	16,2	10,46	13,2	498	
10:15	107	142.837,87	224.743,93	9,65	15,2	10,45	13,1	576	
10:17	108	142.822,82	224.782,90	9,77	13,7	10,50	12,1	610	
10:19	109	142.798,47	224.816,31	9,85	12,7	10,58	11,6	639	
10:20	110	142.784,57	224.842,29	9,83	13,1	10,59	12,6	662	
10:22	111	142.760,24	224.890,53	9,80	13,3	10,57	11,4	707	
10:23	112	142.740,57	224.944,34	9,79	13,3	10,83	12,8	760	
10:24	113	142.716,28	225.016,69	10,20	5,8	10,74	6,0	831	
10:25	114	142.704,71	225.053,79	10,22	5,3	10,91	5,4	868	
10:26	115	142.668,84	225.146,56	10,40	4,7	11,03	4,9	961	
10:27	116	142.646,85	225.205,93	10,44	4,6	11,11	4,7	1021	
10:29	117	142.617,94	225.294,98	10,49	4,2	11,15	4,4	1112	
10:30	118	142.593,62	225.346,93	10,48	4,2	11,18	4,3	1165	
10:31	119	142.568,12	225.385,91	10,52	4,5	11,23	4,6	1207	
10:33	120	142.563,32	225.276,51	10,53	4,2	11,24	4,4	1099	
10:34	121	142.573,69	225.219,01	10,53	4,5	11,25	4,6	1040	
10:36	122	142.580,54	225.135,56	10,49	5,3	11,19	5,3	957	
10:38	123	142.600,13	225.022,42	10,38	7,9	11,16	8,0	842	
10:40	124	142.624,45	224.970,46	10,25	9,2	10,96	9,2	788	
10:41	125	142.645,29	224.920,36	10,09	10,6	10,85	10,6	736	
10:42	126	142.656,85	224.881,41	10,00	12,4	10,71	12,3	697	
10:44	127	142.698,54	224.790,49	9,85	13,6	10,57	13,5	604	
10:45	128	142.735,58	224.695,86	9,76	14,6	10,47	14,6	511	
10:47	129	142.769,12	224.590,12	9,69	15,2	10,38	15,2	411	
10:49	130	142.769,13	224.595,68	9,65	15,2	10,32	15,2	416	
10:52	131	142.754,03	224.603,12	9,63	15,2	10,31	15,3	421	
10:54	132	142.806,29	224.586,36	9,61	15,8	10,35	15,7	415	
10:56	133	142.879,33	224.482,42	9,61	16,0	10,29	14,8	348	
10:59	134	142.917,52	224.378,52	9,56	16,4	10,33	16,5	293	
11:02	135	142.913,12	224.558,40	9,57	16,2	10,35	15,7	431	
11:05	136	142.901,70	224.701,20	9,59	16,1	10,31	14,4	555	
11:06	137	142.885,54	224.779,10	9,72	14,0	10,46	13,8	623	
11:08	138	142.868,22	224.857,01	9,79	12,2	10,97	11,1	693	
11:09	139	142.856,71	224.933,05	10,26	4,4	10,88	4,8	764	
11:11	140	142.844,06	225.020,22	10,44	4,7	11,14	4,8	847	
11:13	141	142.823,31	225.135,22	10,50	4,8	11,20	5,3	958	
11:15	142	142.783,94	225.227,99	10,56	4,5	11,25	4,6	1046	
11:17	143	142.738,81	225.346,73	10,46	3,8	11,15	3,9	1161	
11:19	144	142.707,57	225.435,78	10,44	3,8	11,12	3,8	1250	

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11:21	145	142.628,67	225.489,67	10,42	3,8	11,08	3,8	1305	
11:26	146	142.516,87	225.284,00	10,39	3,8	11,10	3,8	1113	
11:28	147	142.538,78	225.170,85	10,42	3,8	11,14	3,9	997	
11:30	148	142.572,30	225.057,69	10,55	4,0	11,38	4,5	880	
11:32	149	142.605,86	224.968,63	10,57	5,2	11,32	5,4	788	
11:34	150	142.664,97	224.873,98	10,41	7,9	11,12	8,0	689	
11:36	151	142.719,45	224.790,46	10,03	11,0	10,77	11,5	605	
11:38	152	142.790,17	224.690,22	9,86	13,5	10,63	13,2	513	
11:41	153	142.846,90	224.556,63	9,68	15,1	10,41	14,9	400	
11:43	154	142.882,77	224.447,18	9,64	15,7	10,29	15,5	321	
11:45	155	142.909,38	224.367,41	9,63	15,5	10,38	15,4	280	
11:47	156	142.843,16	224.367,50	9,66	16,0	10,37	16,0	233	
11:49	157	142.811,93	224.467,67	9,59	15,5	10,25	15,5	304	
11:51	158	142.776,07	224.578,98	9,67	14,2	10,41	13,9	401	
11:52	159	142.747,15	224.664,32	9,89	11,7	10,55	11,8	481	
11:55	160	142.714,79	224.783,05	10,25	8,0	10,89	8,0	597	
11:56	161	142.695,11	224.834,99	10,43	4,3	11,05	4,6	649	
11:58	162	142.653,42	224.925,91	10,39	3,9	11,08	4,1	741	
12:00	163	142.628,01	225.026,08	10,39	3,9	11,08	3,9	843	
12:02	164	142.565,42	225.117,04	10,37	3,8	11,07	3,9	940	
12:04	165	142.514,39	225.174,59	10,37	3,8	11,07	3,8	1005	
12:06	166	142.573,57	225.133,71	10,38	3,8	11,07	3,8	956	
12:08	167	142.616,42	225.044,64	10,35	3,8	11,06	3,8	862	
12:10	168	142.639,54	224.964,88	10,37	3,8	11,08	3,8	781	
12:12	169	142.645,24	224.890,69	10,39	3,8	11,10	3,8	707	
12:14	170	142.652,12	224.822,07	10,43	3,8	11,15	3,8	638	
12:16	171	142.720,48	224.699,59	10,47	3,8	11,24	4,0	514	
12:18	172	142.779,57	224.588,25	10,53	4,1	11,25	4,2	411	
12:21	173	142.803,84	224.501,06	10,54	5,0	11,23	8,1	333	
12:22	174	142.810,77	224.465,82	10,30	9,4	11,03	9,3	302	
12:25	175	142.905,83	224.322,91	9,94	12,0	10,68	11,5	250	
12:27	176	142.928,07	224.447,12	10,37	4,2	11,06	4,4	349	
12:30	177	142.893,46	224.619,62	10,41	3,8	11,08	3,9	476	
12:32	178	142.935,16	224.532,41	10,39	3,8	11,09	3,9	421	
12:34	179	142.948,95	224.424,84	10,41	3,8	11,14	4,0	348	
12:36	180	142.947,62	224.296,89	10,49	3,9	11,19	4,0	275	
12:37	181	142.934,73	224.217,17	10,53	4,1	11,23	4,1	240	
12:38	182	142.911,34	224.100,38	9,88	15,0	10,71	14,5	231	
12:40	183	142.893,94	224.124,51	9,75	15,1	10,43	15,0	207	
12:42	184	142.915,00	224.228,32	9,76	15,6	9,69	11,7	223	
12:43	185	142.926,69	224.285,79	10,09	5,2	10,83	5,0	251	
12:43	186	142.920,93	224.317,32	10,31	4,2	10,89	4,4	260	
12:45	187	142.926,84	224.395,20	10,44	4,0	11,04	4,0	311	
12:46	188	142.926,91	224.443,41	10,36	3,9	11,05	4,0	346	
12:48	189	142.942,18	224.573,19	10,40	3,8	11,07	3,9	459	
12:50	190	142.929,51	224.649,24	10,37	3,8	11,06	3,9	519	
12:51	191	142.906,19	224.588,08	10,36	3,8	11,07	3,8	454	
12:54	192	142.915,32	224.467,53	10,39	3,8	11,10	3,8	357	
12:56	193	142.910,46	224.308,07	10,42	3,8	11,13	3,8	246	
12:57	194	142.906,85	224.220,92	10,47	3,8	11,18	3,8	213	
12:59	195	142.897,43	224.128,21	10,06	13,4	10,80	13,5	209	
13:00	196	142.879,94	224.076,32	9,87	15,3	10,59	14,9	214	
13:02	197	142.854,52	224.182,05	9,86	14,3	10,48	13,6	158	
13:04	198	142.839,54	224.271,08	9,85	15,4	10,61	15,0	167	
13:05	199	142.836,17	224.356,38	10,30	5,4	10,30	5,3	220	
13:06	200	142.838,53	224.382,34	10,27	4,6	10,97	4,5	242	
13:07	201	142.830,46	224.425,00	10,41	4,1	11,09	4,2	274	
13:09	202	142.817,79	224.501,04	10,41	3,8	11,10	4,0	338	
13:10	203	142.827,21	224.595,60	10,41	3,9	11,08	3,9	430	
13:12	204	142.887,66	224.627,04	10,44	3,9	11,11	3,9	481	
13:14	205	142.920,01	224.500,90	10,39	3,8	11,09	3,9	386	
13:16	206	142.926,86	224.408,18	10,41	3,8	11,10	3,8	320	
13:18	207	142.931,38	224.315,46	10,40	3,8	11,12	3,8	268	
13:20	208	142.919,62	224.207,92	10,42	3,8	11,13	3,8	224	
13:21	209	142.912,53	224.120,78	10,34	9,8	11,94	6,5	226	
13:22	210	142.874,10	224.059,64	10,15	12,7	11,04	13,5	218	
13:23	211	142.900,92	224.128,21	10,15	12,7	10,66	13,2	213	
13:24	212	142.918,40	224.168,98	10,19	4,5	10,90	4,4	223	
13:25	213	142.939,37	224.213,46	10,33	4,1	10,97	4,2	245	
13:26	214	142.952,24	224.278,34	10,53	3,9	11,01	4,0	272	
13:27	215	142.960,41	224.308,00	10,38	3,9	11,06	4,0	291	
13:29	216	142.973,32	224.402,55	10,44	3,9	11,09	3,9	352	
13:30	217	142.969,92	224.463,75	11,61	3,8	11,11	3,9	390	

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13:31	218	142.965,37	224.541,64	10,52	3,8	11,22	3,8	446	
13:34	219	142.949,20	224.608,42	10,62	3,7	11,30	3,7	492	
13:36	220	142.922,28	224.456,40	10,46	3,8	11,16	3,8	352	
13:38	221	142.915,16	224.347,00	10,43	3,8	11,13	3,8	272	
13:40	222	142.913,85	224.241,31	10,44	3,8	11,15	3,8	224	
13:41	223	142.907,89	224.131,91	10,44	3,8	11,14	3,8	218	
13:43	224	142.868,36	224.106,00	10,13	12,3	10,84	11,9	190	
13:44	225	142.867,27	224.157,93	10,10	11,6	10,23	11,5	173	
13:45	226	142.867,32	224.193,16	10,30	4,5	10,97	4,4	171	
13:46	227	142.859,26	224.248,80	10,40	4,0	11,03	4,2	175	
13:48	228	142.852,42	224.343,38	10,55	3,8	11,13	4,0	222	
13:49	229	142.857,11	224.376,75	10,53	3,8	11,23	3,8	249	
13:51	230	142.853,77	224.484,31	10,85	3,6	11,39	3,7	337	
13:52	231	142.856,15	224.519,53			11,41	3,7	370	
14:20	232	142.983,03	223.851,80	10,54	5,1	11,32	4,9	440	
14:22	233	142.989,87	223.753,52	10,57	5,0	11,22	5,2	523	
14:24	234	142.989,69	223.618,15	10,47	5,5	11,21	4,8	639	
14:26	235	142.977,92	223.503,20	10,53	4,8	11,24	4,5	739	
14:27	236	142.961,54	223.423,48	10,56	4,5	11,26	4,5	807	
14:30	237	142.946,22	223.264,03	10,54	4,5	11,27	4,3	955	
14:31	238	142.937,95	223.162,06	10,50	4,2	11,21	4,2	1052	
14:33	239	142.930,84	223.058,23	10,53	4,2	11,19	4,2	1152	
14:34	240	142.927,22	222.963,66	10,50	4,2	11,20	4,2	1244	
14:36	241	142.941,29	223.054,50			11,21	4,2	1158	
14:46	242	142.971,43	223.861,09	10,71	4,6	11,35	4,6	426	
14:49	243	142.977,05	223.722,01	10,68	5,0	11,35	4,7	542	
14:50	244	142.973,49	223.666,38	10,60	4,4	11,27	4,3	589	
14:52	245	142.966,42	223.592,22	10,67	3,9	11,35	4,0	652	
14:54	246	142.973,24	223.484,66	10,70	4,0	11,39	3,9	754	
14:56	247	142.970,74	223.353,01	10,57	5,3	11,28	4,6	877	
14:58	248	142.963,62	223.245,47	10,55	4,7	11,32	4,3	978	
15:00	249	142.951,91	223.173,16	10,61	4,5	11,29	4,3	1045	
15:02	250	142.935,54	223.099,01	10,64	4,2	11,33	4,1	1113	
15:03	251	142.930,80	223.032,26	10,65	4,1	11,37	4,1	1177	
15:05	252	142.927,27	222.998,89	10,62	4,2	11,33	4,1	1209	
15:06	253	142.909,91	223.048,98	10,71	4,2	11,32	4,3	1157	
15:14	254	142.958,73	223.922,30	10,76	4,8	11,46	5,3	372	
15:16	255	142.988,83	223.840,67	10,80	4,4	11,55	3,7	453	
15:17	256	143.014,27	223.749,77	10,75	4,2	11,53	3,8	540	
15:19	257	143.026,94	223.670,02	10,77	4,1	11,33	4,7	613	
15:21	258	143.031,48	223.586,57	10,66	4,8	11,38	4,4	687	hoogwater
15:23	259	143.031,34	223.486,44	10,61	4,7	11,34	4,7	776	
15:26	260	143.005,63	223.377,07	10,63	4,4	11,34	4,1	866	
15:28	261	142.986,87	223.251,00	10,73	3,9	11,43	3,9	979	
15:30	262	142.965,81	223.145,33	10,74	4,0	11,39	3,8	1075	
15:31	263	142.956,40	223.054,48	10,79	3,9	11,44	3,9	1161	
15:33	264	142.948,13	222.954,36	10,71	4,0	11,39	3,8	1257	
15:35	265	142.954,95	222.843,09	10,71	3,9	11,44	3,6	1368	
15:45	266	142.956,43	223.942,70	10,71	4,9	11,41	4,9	356	
15:46	267	142.969,14	223.887,06	10,67	4,9	11,36	4,0	405	
15:49	268	142.972,44	223.751,69	10,77	4,1	11,43	4,2	515	
15:51	269	142.951,42	223.673,83	10,78	3,8	11,46	3,9	572	
15:52	270	142.940,88	223.608,94	10,79	3,8	11,48	3,8	627	
15:54	271	142.923,30	223.497,71	10,84	3,7	11,49	3,7	725	
15:56	272	142.908,06	223.403,16	10,83	3,7	11,51	3,7	811	
15:57	273	142.859,13	223.304,95	10,82	3,7	11,50	3,8	896	
15:59	274	142.817,15	223.195,60	10,75	3,7	11,49	3,7	998	
16:02	275	129.175,56	226.711,13	10,79	3,6	11,48	3,6	13755	
16:04	276	129.524,26	226.502,05	10,81	3,6	11,57	3,6	13374	
16:05	277	142.917,05	223.171,36	10,78	3,7	11,54	3,6	1038	
16:07	278	142.934,60	223.265,90	10,80	3,7	11,51	3,6	950	
16:08	279	142.949,78	223.317,80	10,77	3,7	11,53	3,6	904	
16:10	280	142.969,67	223.419,77	10,78	3,7	11,55	3,7	814	
16:12	281	142.980,31	223.553,26	10,79	3,6	11,53	3,7	694	
16:13	282	142.996,75	223.683,04	10,81	3,6	11,52	3,7	586	
16:15	283	142.970,16	223.783,21	10,81	3,6	11,51	3,6	487	
16:16	284	142.938,90	223.861,14	10,86	3,6	11,63	3,6	405	
16:17	285	142.929,70	223.935,32	10,92	3,5	11,62	3,6	343	
16:19	286	142.976,19	223.946,38	10,90	3,5	11,62	3,6	368	
16:22	287	143.034,11	223.820,21	10,83	3,6	11,54	3,6	498	
16:23	288	143.052,61	223.753,43	10,87	3,6	11,55	3,6	560	
16:25	289	143.059,45	223.657,00	10,90	3,6	11,61	3,6	642	
16:27	290	143.046,54	223.555,03	10,92	3,6	11,62	3,6	722	

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16:32	291	142.963,34	223.892,63	10,93	3,4	11,60	3,5	397	
16:33	292	142.948,36	223.983,51	10,89	3,5	11,63	3,5	323	
16:34	293	142.972,91	224.098,44	11,04	3,5	11,63	3,6	290	
16:35	294	142.984,59	224.148,49	10,90	3,5	11,67	3,6	291	
16:36	295	143.006,78	224.231,91	10,93	3,5	11,70	3,6	314	
16:37	296	143.016,12	224.268,98	10,91	3,6	11,70	3,6	330	
16:38	297	143.030,17	224.344,99	10,96	3,5	11,70	3,7	370	
16:38	298	143.044,18	224.402,46	10,94	3,6	11,69	3,7	410	
16:39	299	143.050,08	224.471,06	10,93	3,6	11,69	3,6	454	
16:47	300	143.020,33	223.938,91	10,97	3,4	11,66	3,5	407	
16:50	301	142.927,36	223.924,20	10,94	3,4	11,66	3,5	349	
16:51	302	142.898,28	223.896,42	10,90	3,5	11,64	3,5	353	
16:52	303	142.884,34	223.894,59	10,86	3,5	11,61	3,5	347	
16:52	304	142.892,49	223.913,12	10,87	3,5	11,59	3,5	336	

lozingspunt	142.696,32	224.186,02

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Uur	Meetlocatie	X (m)	Y (m)	O_2 ondiep (mg/l)	T ondiep (°C)	O_2 diep (mg/l)	T diep (°C)	Afstand tot lozingspunt (m)	Opmerking
7:37	1	142.997,35	222.399,85	9,44	7,0	9,50	7,0	1811	
8:01	2	142.635,55	225.426,61	10,08	6,9	9,91	7,1	1242	
8:03	3	142.649,34	225.322,75	9,93	7,1	9,89	7,1	1138	
8:06	4	142.679,42	225.237,41	9,84	7,3	9,85	7,3	1052	
8:08	5	142.696,72	225.150,23	9,78	8,4	9,84	8,6	964	
8:10	6	142.722,17	225.079,73	9,73	9,8	9,80	9,6	894	
8:12	7	142.749,95	225.007,37	9,65	8,9	9,69	8,9	823	
8:13	8	142.774,24	224.929,45	9,62	10,5	9,69	10,0	748	
8:15	9	142.792,73	224.864,53	9,54	11,2	9,62	9,9	685	
8:17	10	142.823,97	224.773,62	9,43	15,1	9,62	9,7	601	
8:18	11	142.840,18	224.738,37	9,26	17,1	9,62	9,4	571	
8:20	12	142.857,55	224.697,55	9,22	17,7	9,56	9,0	536	
8:21	13	142.869,07	224.625,21	9,12	18,3	9,52	9,4	472	
8:23	14	142.881,73	224.538,04	9,04	20,1	9,61	10,8	398	
8:25	15	142.886,29	224.476,84	9,02	20,1	9,55	11,4	347	
8:26	16	142.882,72	224.410,09	9,02	21,1	9,55	11,7	291	
8:28	17	142.883,82	224.371,15	8,92	21,7	9,60	11,4	263	
8:30	18	142.861,79	224.400,85	8,87	21,4	9,57	12,1	271	
8:32	19	142.844,50	224.501,01	9,01	20,0	9,60	11,4	348	
8:33	20	142.823,73	224.603,02	8,99	19,7	9,55	11,6	436	
8:35	21	142.804,11	224.693,91	9,14	16,1	9,60	10,5	519	
8:37	22	142.790,27	224.762,54	9,25	15,7	9,69	9,4	584	
8:39	23	142.789,12	224.775,52	9,20	11,3	9,80	9,3	597	
8:41	24	142.787,97	224.779,23	9,55	11,7	9,79	9,1	600	
8:43	25	142.785,66	224.788,51	9,42	13,2	9,76	9,1	609	
8:45	26	142.787,99	224.797,78	9,33	14,2	9,63	9,4	619	
8:46	27	142.785,68	224.803,34	9,34	11,9	9,89	10,4	624	
8:49	28	142.784,53	224.810,76	9,40	14,7	9,59	10,3	631	
8:51	29	142.784,54	224.821,89	9,34	14,5	9,60	10,5	642	
8:52	30	142.784,55	224.831,16	9,33	14,6	9,60	10,6	651	
8:54	31	142.779,93	224.846,00	9,30	14,3	9,59	10,5	665	
8:56	32	142.738,29	224.972,15	9,47	13,7	9,57	13,0	787	
8:57	33	142.701,28	225.089,03	9,47	11,3	9,56	10,1	903	
8:59	34	142.672,33	225.153,97	9,59	9,8	9,69	9,6	968	
9:00	35	142.646,86	225.211,49	9,66	9,4	9,75	9,4	1027	
9:02	36	142.606,35	225.315,39	9,77	8,9	9,82	8,9	1133	
9:03	37	142.583,20	225.371,05	9,78	8,7	9,84	8,7	1190	
9:04	38	142.562,35	225.411,88	9,82	8,6	9,90	7,9	1233	
9:05	39	142.544,97	225.437,87	9,83	8,1	9,89	7,8	1261	
9:06	40	142.525,18	225.408,22	9,88	8,3	9,95	7,8	1234	
9:07	41	142.528,62	225.378,55	9,90	8,6	9,95	8,5	1204	
9:08	42	142.548,28	225.319,18	9,92	8,9	9,96	8,9	1143	
9:10	43	142.566,79	225.269,09	9,90	9,0	9,93	9,0	1091	
9:11	44	142.578,36	225.231,99	9,82	9,4	9,90	9,2	1053	laagwater
9:12	45	142.605,00	225.181,88	9,77	9,5	9,82	9,4	1000	
9:13	46	142.633,97	225.135,48	9,72	9,9	9,80	10,2	952	
9:15	47	142.659,46	225.089,09	9,61	12,6	9,79	10,0	904	
9:16	48	142.682,64	225.051,97	9,54	12,5	9,70	10,2	866	
9:17	49	142.703,50	225.016,71	9,48	12,3	9,69	10,4	831	
9:18	50	142.717,41	224.998,14	9,46	11,8	9,61	10,4	812	
9:19	51	142.726,68	224.983,30	9,47	11,6	9,56	10,5	798	
9:20	52	142.740,62	224.983,28	9,48	11,8	9,58	10,4	798	
9:23	53	142.718,74	225.113,11	9,59	11,9	9,68	10,3	927	
9:25	54	142.675,91	225.220,72	9,77	9,3	9,69	9,2	1035	
9:27	55	142.619,13	225.319,08	9,71	9,2	9,81	9,1	1136	
9:28	56	142.592,48	225.363,62	9,76	9,2	9,85	9,0	1182	
9:29	57	142.572,80	225.410,01	9,80	9,2	9,94	8,8	1230	
9:30	58	142.586,72	225.397,01	9,93	9,2	9,87	9,1	1216	
9:31	59	142.583,18	225.354,37	9,76	9,2	9,89	8,9	1174	
9:32	60	142.583,12	225.313,57	9,77	9,5	9,83	9,3	1133	
9:33	61	142.592,34	225.261,64	9,72	9,8	9,85	9,3	1081	
9:34	62	142.614,33	225.205,97	9,72	10,0	9,79	9,7	1023	
9:35	63	142.647,93	225.146,59	9,64	11,6	9,75	10,4	962	
9:37	64	142.686,16	225.074,22	9,61	11,5	9,67	10,5	888	
9:38	65	142.709,33	225.031,53	9,57	11,1	9,64	10,8	846	
9:40	66	142.740,63	224.985,13	9,51	11,6	9,59	10,2	800	
9:41	67	142.753,38	224.970,28	9,51	11,6	9,59	10,2	786	
9:43	68	142.754,54	224.968,42	9,38	14,1	9,46	10,2	785	
9:45	69	142.869,23	224.740,18	9,33	14,6	9,52	10,3	581	
9:47	70	142.761,51	224.964,70	9,30	14,2	9,63	10,7	781	
9:49	71	142.754,61	225.016,64	9,61	10,7	9,55	11,3	833	

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9:53	72	142.682,84	225.196,61	9,71	10,2	9,74	10,6	1011	
9:54	73	142.626,11	225.320,93	9,73	9,4	9,78	9,2	1137	
9:56	74	142.604,16	225.404,40	9,97	9,2	9,89	9,0	1222	
9:58	75	142.570,52	225.441,54	9,94	9,1	9,99	8,6	1262	
9:59	76	142.580,88	225.372,91	9,85	9,3	9,96	8,9	1192	
10:01	77	142.603,98	225.278,31	9,89	9,6	9,91	9,3	1096	
10:02	78	142.638,70	225.192,96	9,75	11,0	9,86	10,7	1009	
10:04	79	142.671,11	225.115,03	9,66	11,0	9,76	11,0	929	
10:05	80	142.704,70	225.044,52	9,69	10,5	9,71	10,5	859	
10:07	81	142.740,59	224.959,17	9,55	11,9	9,65	11,5	774	
10:09	82	142.761,45	224.925,76	9,40	14,0	9,57	10,5	743	
10:11	83	142.771,90	224.918,33	9,29	15,2	9,56	10,9	736	
10:13	84	142.774,21	224.912,77	9,27	15,6	9,59	10,9	731	
10:15	85	142.776,53	224.907,20	9,25	15,7	9,58	11,1	726	
10:17	86	142.807,78	224.823,71	9,23	15,9	9,45	15,3	647	
10:19	87	142.837,87	224.745,79	9,16	17,3	9,31	17,0	577	
10:20	88	142.851,76	224.706,83	9,07	17,8	9,29	17,0	544	
10:21	89	142.881,88	224.647,45	9,09	17,7	9,20	16,8	497	
10:22	90	142.895,76	224.606,63	9,07	18,9	9,14	18,0	466	
10:23	91	142.920,08	224.547,26	8,92	19,9	9,03	17,2	425	
10:25	92	142.919,97	224.471,23	8,85	20,9	9,24	15,5	362	
10:26	93	142.919,86	224.389,64	8,85	20,9	9,28	18,8	302	
10:29	94	142.875,80	224.447,19	8,91	19,7	9,08	16,0	317	
10:30	95	142.853,83	224.525,10	8,94	19,3	9,19	16,9	374	
10:33	96	142.826,08	224.616,00	8,99	18,5	9,21	16,9	449	
10:39	97	142.713,80	224.909,14	9,47	12,6	9,72	10,6	723	
10:41	98	142.688,36	224.990,77	9,75	10,8	9,84	9,9	805	
10:43	99	142.662,96	225.096,50	9,96	9,6	10,07	9,4	911	
10:44	100	142.632,88	225.185,55	10,13	9,0	10,23	8,9	1002	
10:46	101	142.612,08	225.261,61	10,17	7,5	10,20	7,7	1079	
10:48	102	142.593,61	225.339,52	10,12	7,3	10,16	7,4	1158	
10:50	103	142.573,92	225.376,63	10,06	7,2	10,10	7,2	1197	
10:52	104	142.572,64	225.293,19	10,13	7,2	10,15	7,3	1114	
10:54	105	142.602,73	225.215,26	10,20	7,5	10,24	7,6	1033	
10:55	106	142.620,06	225.155,90	10,28	8,6	10,34	8,4	973	
10:56	107	142.649,00	225.083,54	10,15	9,2	10,24	8,9	899	
10:58	108	142.686,07	225.014,88	9,73	11,5	10,16	9,9	829	
11:00	109	142.709,20	224.936,96	9,41	14,5	9,96	9,4	751	
11:01	110	142.719,54	224.855,36	9,36	15,0	9,58	11,9	670	
11:03	111	142.729,90	224.790,44	9,23	16,6	9,62	11,0	605	
11:05	112	142.757,65	224.693,98	9,16	17,2	9,35	15,2	512	
11:07	113	142.800,48	224.590,08	9,09	17,9	9,24	16,8	417	
11:09	114	142.835,23	224.512,15	9,02	19,1	9,31	15,0	354	
11:10	115	142.847,88	224.424,98	8,92	20,5	9,62	16,4	283	
11:12	116	142.867,53	224.352,63	8,88	20,5	9,41	12,8	239	
11:14	117	142.872,12	224.308,12	8,85	21,6	9,27	16,7	214	
11:16	118	142.875,76	224.421,23	8,94	19,6	9,37	13,1	296	
11:18	119	142.878,28	224.567,72	9,02	17,9	9,37	16,1	423	
11:20	120	142.851,68	224.653,05	9,09	17,8	9,24	17,4	492	
11:22	121	142.826,23	224.730,97	9,08	17,4	9,23	16,3	560	
11:24	122	142.801,93	224.799,61	9,16	16,8	9,37	16,4	623	
11:26	123	142.778,85	224.907,20	9,18	16,6	9,80	10,3	726	
11:28	124	142.756,93	225.012,92	9,34	15,0	9,55	13,9	829	
11:30	125	142.718,75	225.120,53	9,69	7,7	9,66	7,9	935	
11:32	126	142.689,83	225.211,43	9,82	7,3	9,82	7,4	1025	
11:34	127	142.657,46	225.317,17	9,74	7,1	9,78	7,1	1132	
11:36	128	142.628,52	225.383,97	9,78	7,1	9,79	7,1	1200	
11:37	129	142.583,29	225.434,10	9,83	7,1	9,78	7,1	1253	
11:39	130	142.583,19	225.361,78	9,74	7,1	9,80	7,1	1181	
11:41	131	142.602,78	225.254,20	9,81	7,1	9,83	7,1	1072	
11:43	132	142.587,54	225.157,80	9,80	7,1	9,84	7,1	978	
11:44	133	142.601,42	225.111,42	9,92	7,1	9,87	7,1	930	
11:46	134	142.636,09	224.992,70	9,84	7,1	9,98	7,3	809	
11:47	135	142.660,40	224.929,61	9,91	7,1	9,98	7,4	744	
11:49	136	142.699,74	224.820,15	9,64	13,7	10,01	7,8	634	
11:51	137	142.739,10	224.721,82	9,43	15,2	10,06	10,0	538	
11:53	138	142.771,48	224.616,08	9,23	17,0	9,61	14,0	437	
11:55	139	142.806,16	224.495,50	9,18	16,8	9,34	15,9	328	
11:56	140	142.826,96	224.415,73	9,15	17,0	9,33	16,2	264	
11:58	141	142.850,08	224.330,40	8,96	20,6	9,21	16,5	211	
12:00	142	142.865,04	224.226,54	8,98	19,9	9,19	18,6	174	
12:03	143	142.829,11	224.285,93	8,86	21,5	9,25	17,1	166	
12:05	144	142.823,44	224.386,07	8,87	20,1	9,17	15,9	237	

Monitoringscampagne 5 (07/03/2012)

12:07	145	142.820,01	224.426,87	9,07	17,0	9,37	15,6	271	
12:09	146	142.788,78	224.527,04	9,20	16,4	9,62	10,6	353	
12:10	147	142.784,20	224.577,12	9,67	8,1	9,81	7,8	401	
12:11	148	142.779,62	224.621,63	9,82	7,4	9,84	7,5	444	
12:12	149	142.766,88	224.653,17	9,82	7,3	9,90	7,6	472	
12:14	150	142.732,15	224.736,66	10,00	7,4	10,00	7,5	552	
12:16	151	142.698,61	224.844,26	9,92	7,1	9,92	7,2	658	
12:20	152	142.645,36	224.975,99	9,80	7,1	9,84	7,2	792	
12:21	153	142.615,22	225.018,69	9,80	7,1	9,81	7,1	837	
12:23	154	142.571,24	225.126,30	9,81	7,1	9,81	7,1	949	
12:29	155	142.498,36	225.335,94	9,85	7,1	9,85	7,1	1167	
12:31	156	142.616,74	225.272,73	9,89	7,1	9,89	7,1	1090	
12:32	157	142.714,15	225.159,48	9,87	7,1	9,87	7,1	974	
12:35	158	142.787,16	225.036,99	9,83	7,1	9,86	7,1	856	
12:37	159	142.854,36	224.908,95	9,79	7,1	9,82	7,1	740	
12:39	160	142.883,23	224.784,67	9,77	7,1	9,81	7,1	627	
12:40	161	142.898,17	224.667,82	9,79	7,1	9,81	7,1	522	
12:43	162	142.932,78	224.495,32	9,82	7,1	9,81	7,1	389	
12:44	163	142.929,17	224.398,90	9,81	7,1	9,88	7,3	315	
12:45	164	142.938,38	224.341,41	9,84	7,2	9,88	7,2	288	
12:48	165	142.886,00	224.265,45	9,44	15,0	9,76	14,5	206	
12:49	166	142.843,14	224.354,52	9,36	10,3	9,56	8,5	223	
12:50	167	142.838,52	224.376,78	9,71	8,1	9,79	7,9	238	
12:50	168	142.831,59	224.399,04	9,84	7,7	9,81	7,7	252	
12:51	169	142.824,65	224.425,01	9,78	7,5	9,81	7,5	271	
12:53	170	142.813,11	224.482,51	9,75	7,2	9,79	7,2	319	
12:55	171	142.809,70	224.534,43	9,81	7,1	9,84	7,1	366	
12:56	172	142.802,79	224.575,24	9,83	7,1	9,87	7,1	404	
12:59	173	142.783,15	224.658,71	9,89	7,1	9,92	7,1	481	
13:00	174	142.836,55	224.628,97	9,89	7,1	9,93	7,1	465	
13:03	175	142.886,28	224.467,57	9,85	7,1	9,91	7,1	340	
13:05	176	142.912,75	224.283,96	9,84	7,1	9,90	7,1	238	
13:06	177	142.891,82	224.271,01	9,90	7,1	9,89	7,1	213	
13:08	178	142.864,05	224.350,78	9,95	7,1	9,91	7,1	235	
13:10	179	142.840,91	224.419,42	9,91	7,1	9,92	7,1	275	
13:11	180	142.825,86	224.458,38	9,99	7,1	9,96	7,1	302	
13:14	181	142.884,91	224.315,52	9,99	7,1	9,98	7,1	229	
13:16	182	142.884,73	224.182,01	9,68	14,3	9,70	13,3	188	
13:17	183	142.889,22	224.068,89	9,51	13,9	9,66	13,6	226	
13:18	184	142.883,33	224.009,56	9,38	15,9	9,58	13,6	257	
13:19	185	142.864,74	224.009,58	9,39	16,0	9,62	12,6	244	
13:19	186	142.860,12	224.029,99	9,39	15,4	9,56	14,3	226	
13:20	187	142.859,02	224.072,64	9,44	14,2	9,57	14,0	198	
13:21	188	142.863,72	224.109,72	9,70	13,5	9,50	13,3	184	
13:21	189	142.862,62	224.154,22	9,52	13,9	9,60	12,9	169	
13:22	190	142.869,62	224.178,32	9,55	14,9	9,63	14,4	173	
13:41	191	143.116,27	224.446,87	10,37	6,8	10,42	6,9	494	
13:43	192	143.070,78	224.313,41	10,33	6,9	10,34	6,9	396	
13:45	193	143.018,27	224.135,47	10,37	6,9	10,29	6,9	326	
13:47	194	142.987,88	224.002,00	10,24	6,9	10,29	6,9	345	
13:50	195	142.916,89	223.909,38	10,06	9,4	10,10	8,1	354	
13:51	196	142.908,70	223.870,45	9,94	9,8	10,15	7,5	380	
13:51	197	142.931,88	223.831,48	9,92	8,8	10,18	8,5	426	
13:52	198	142.956,22	223.781,38	10,03	8,7	10,13	7,7	481	
13:53	199	142.957,31	223.733,16	9,92	9,6	10,10	8,7	523	
13:54	200	142.958,43	223.701,64	9,88	9,6	10,07	9,2	551	
13:55	201	142.946,76	223.662,71	9,92	9,0	10,05	8,2	580	
13:56	202	142.929,26	223.610,82	9,92	8,9	10,10	8,2	621	
13:57	203	142.911,73	223.534,81	9,82	8,2	10,00	8,1	686	
13:58	204	142.894,23	223.484,77	9,96	7,9	10,04	7,8	729	
14:00	205	142.884,85	223.418,03	10,01	7,6	10,07	7,6	791	
14:01	206	142.883,58	223.338,29	10,05	7,5	10,12	7,6	868	
14:02	207	142.886,98	223.275,24	10,08	7,5	10,12	7,5	931	
14:03	208	142.879,91	223.206,64	10,06	7,5	10,14	7,4	996	
14:04	209	142.885,64	223.151,00	10,05	7,5	10,12	7,5	1052	
14:06	210	142.902,97	223.073,10	9,95	7,5	10,08	7,5	1132	
14:08	211	142.910,97	222.978,52	9,92	7,6	10,07	7,5	1226	
14:12	212	142.969,36	223.189,83	10,17	7,6	10,20	7,6	1033	
14:14	213	142.993,83	223.241,72	10,13	7,6	10,19	7,6	990	
14:18	214	142.994,03	223.390,06	10,13	7,6	10,19	7,6	850	
14:21	215	142.997,74	223.555,09	10,15	7,9	10,21	7,8	699	
14:23	216	142.989,70	223.623,71	10,13	8,0	10,22	7,9	634	
14:24	217	142.982,87	223.731,27	10,12	8,3	10,26	7,7	537	

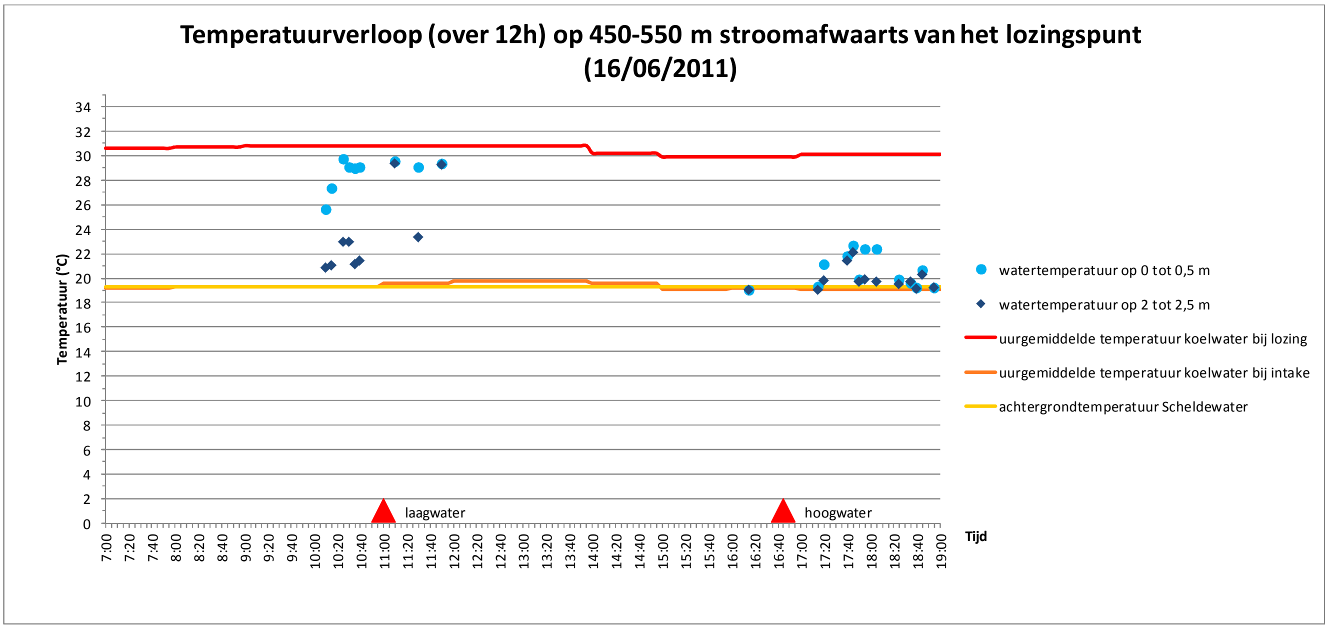
Monitoringscampagne 5 (07/03/2012)

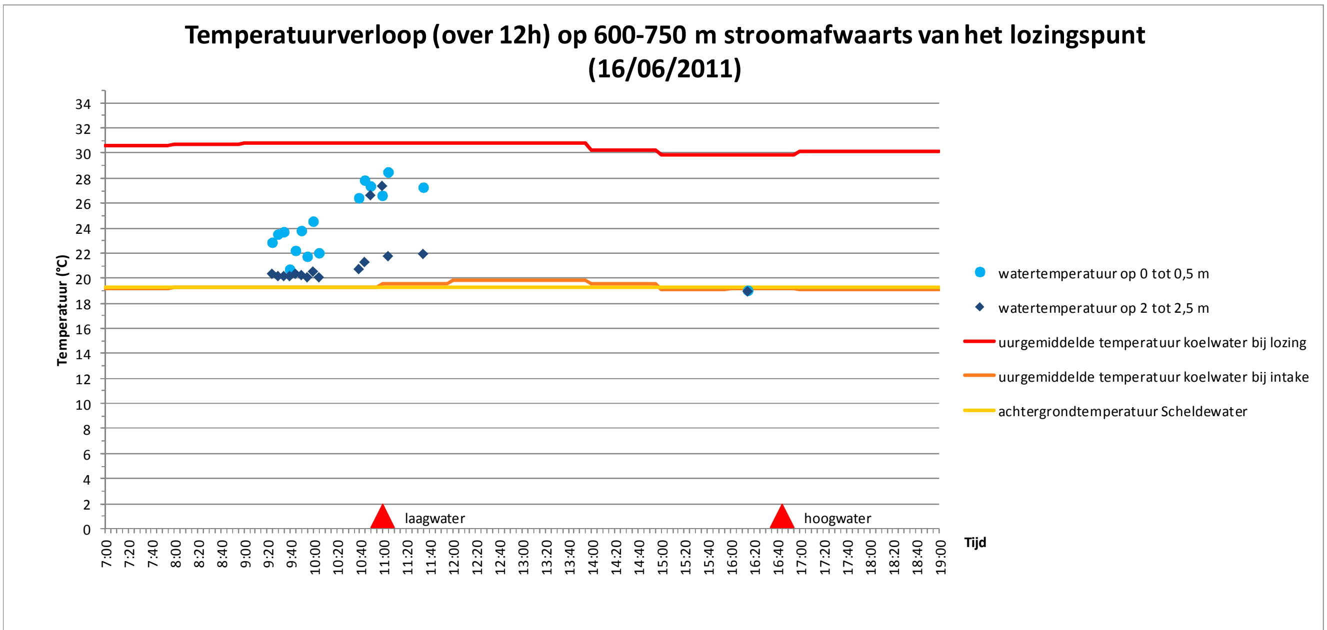
14:27	218	142.963,26	223.835,14	10,13	8,6	10,20	8,4	441	
14:29	219	142.922,71	223.916,79	10,06	8,7	10,09	8,8	352	
14:30	220	142.922,68	223.896,39	10,04	8,5	10,06	8,3	368	
14:32	221	142.949,31	223.827,74	10,13	8,3	10,23	7,6	439	
14:33	222	142.963,17	223.766,53	10,12	7,8	10,25	7,6	497	
14:34	223	142.963,10	223.720,17	10,23	7,5	10,24	7,5	537	
14:35	224	142.938,62	223.659,01	10,17	7,5	10,28	7,4	580	
14:37	225	142.915,29	223.588,58	10,17	7,3	10,23	7,3	636	
14:38	226	142.910,54	223.514,42	10,18	7,3	10,29	7,2	705	
14:40	227	142.894,16	223.430,99	10,27	7,2	10,30	7,1	781	
14:42	228	142.841,76	223.347,62	10,19	7,3	10,24	7,3	851	
14:44	229	142.869,49	223.230,76	10,19	7,3	10,25	7,2	971	
14:46	230	142.897,21	223.110,19	10,20	7,2	10,28	7,1	1094	
14:48	231	142.931,93	223.010,01	10,21	7,1	10,25	7,1	1199	
14:50	232	142.936,67	223.078,61	10,26	7,1	10,36	7,0	1133	
14:52	233	142.942,59	223.156,49	10,26	7,1	10,37	7,0	1059	hoogwater
14:55	234	142.970,77	223.371,55	10,32	7,1	10,39	7,0	859	
14:58	235	142.995,40	223.543,97	10,39	7,0	10,42	7,0	708	
15:00	236	142.968,95	223.747,98	10,38	7,0	10,44	7,0	516	
15:02	237	142.950,48	223.837,01	10,37	7,0	10,42	7,0	432	
15:03	238	142.891,28	223.874,18	10,35	7,1	10,50	7,0	368	
15:04	239	142.861,06	223.863,10	10,33	7,0	10,58	6,9	363	
15:05	240	142.835,51	223.870,55	10,33	7,1	10,56	6,9	345	
15:05	241	142.852,94	223.877,94	10,34	7,0	10,46	7,0	346	
15:06	242	142.868,07	223.892,76	10,37	7,0	10,48	7,0	340	
15:07	243	142.934,23	223.844,45	10,43	7,0	10,48	7,0	416	
15:10	244	142.962,00	223.760,97	10,44	7,0	10,42	7,1	501	
15:12	245	142.940,95	223.664,57	10,36	7,0	10,42	7,1	576	
15:14	246	142.917,61	223.584,87	10,42	7,0	10,45	7,0	641	
15:16	247	142.907,02	223.492,17	10,41	7,0	10,48	7,0	725	
15:18	248	142.872,03	223.390,23	10,45	6,9	10,48	7,0	815	
15:20	249	142.868,36	223.258,58	10,43	6,9	10,46	7,0	943	
15:22	250	142.878,69	223.162,14	10,41	6,9	10,45	6,9	1040	
15:25	251	142.899,43	223.037,87	10,41	6,9	10,46	6,9	1166	
15:30	252	142.958,97	223.243,62	10,40	7,0	10,48	7,0	978	
15:33	253	142.960,50	223.510,64	10,42	7,0	10,50	7,0	725	
15:36	254	142.979,31	223.671,94	10,42	7,0	10,49	7,0	587	
15:39	255	142.981,90	223.875,91	10,42	7,0	10,50	7,0	422	
15:41	256	142.979,77	224.020,55	10,43	7,1	10,54	7,1	328	
15:43	257	143.020,66	224.187,39	10,47	7,1	10,53	7,1	324	
15:45	258	143.045,29	224.361,66	10,48	7,1	10,54	7,1	391	
15:47	259	143.071,11	224.560,04	10,48	7,1	10,55	7,2	529	
15:49	260	143.086,46	224.743,60	10,48	7,1	10,55	7,2	681	
15:51	261	143.094,83	224.927,17	10,48	7,2	10,55	7,2	841	
15:53	262	143.081,14	225.116,33	10,49	7,2	10,55	7,2	1007	
15:55	263	143.048,85	225.288,82	10,46	7,3	10,59	7,3	1158	
15:57	264	143.013,08	225.465,03	10,89	6,7	10,89	6,7	1318	
15:58	265	142.989,97	225.550,36	10,86	6,6	10,94	6,6	1396	

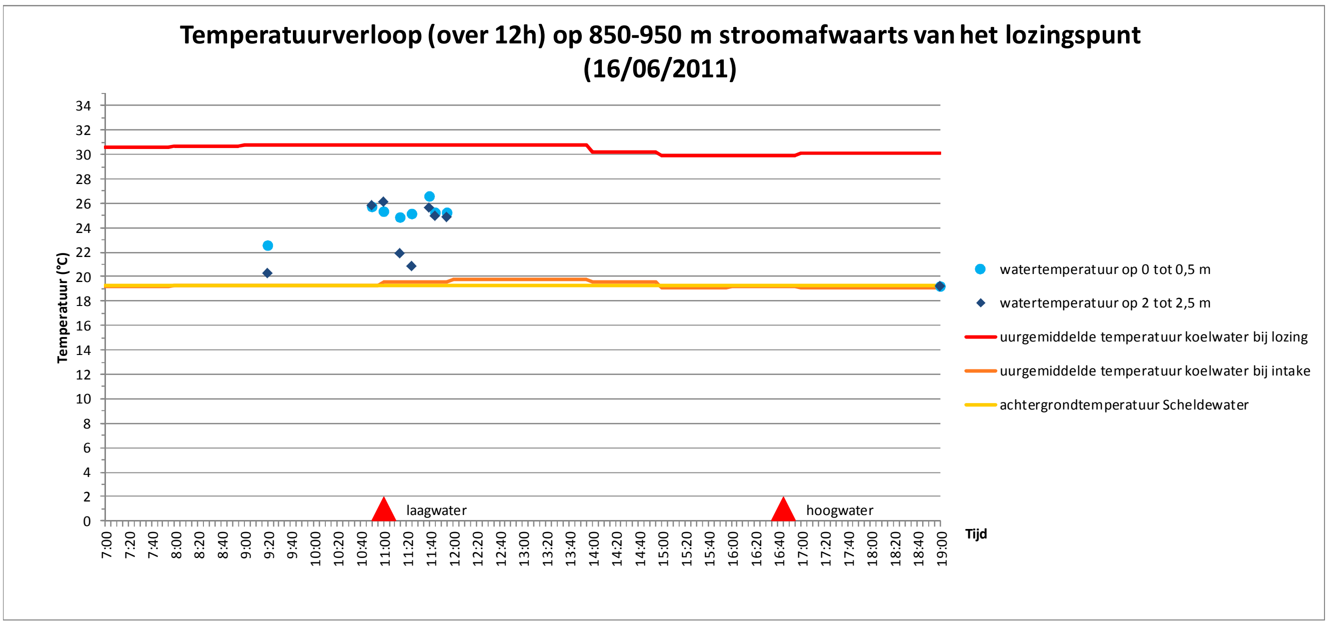
lozingspunt	142.696,32	224.186,02

Bijlage 3 Grafische voorstelling van het temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (afzonderlijke monitoringscampagnes)

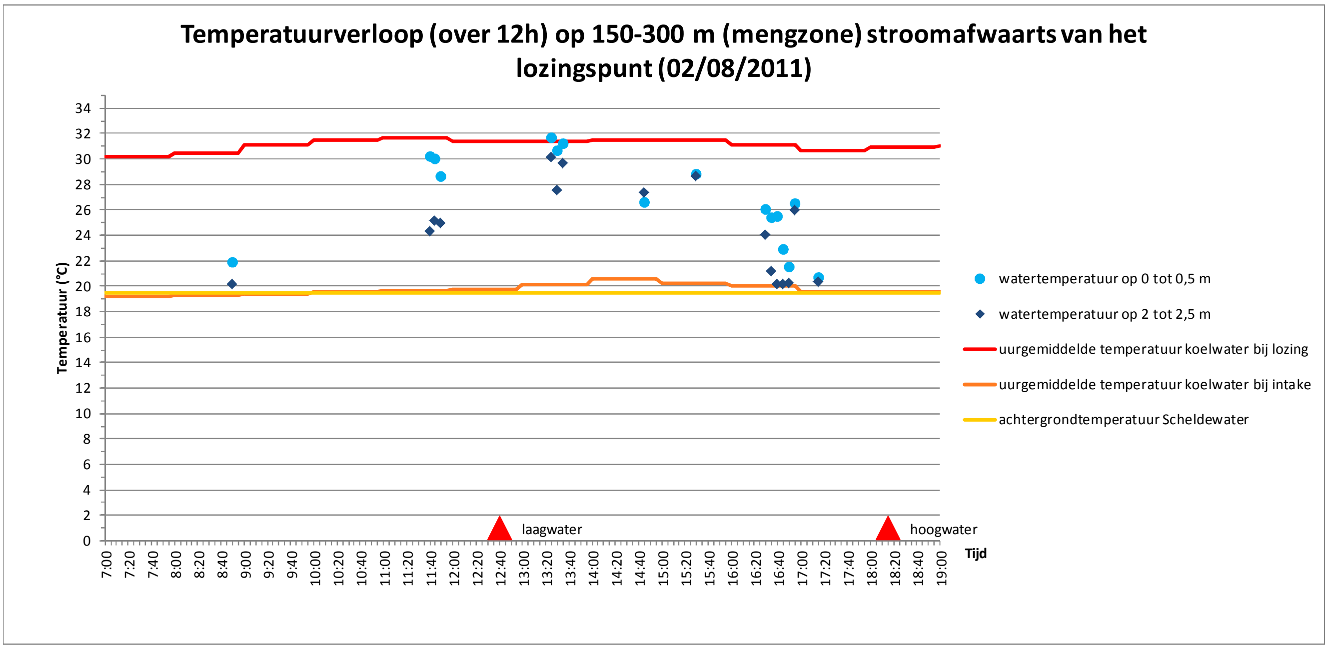
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 1)

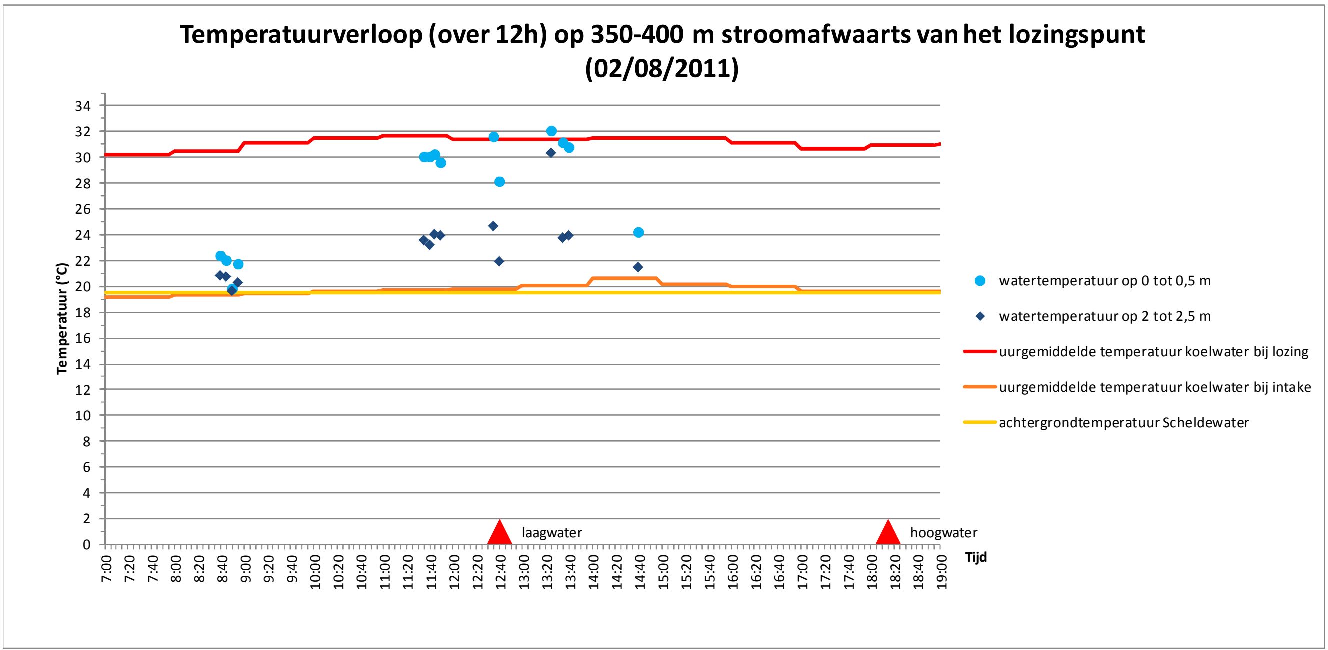


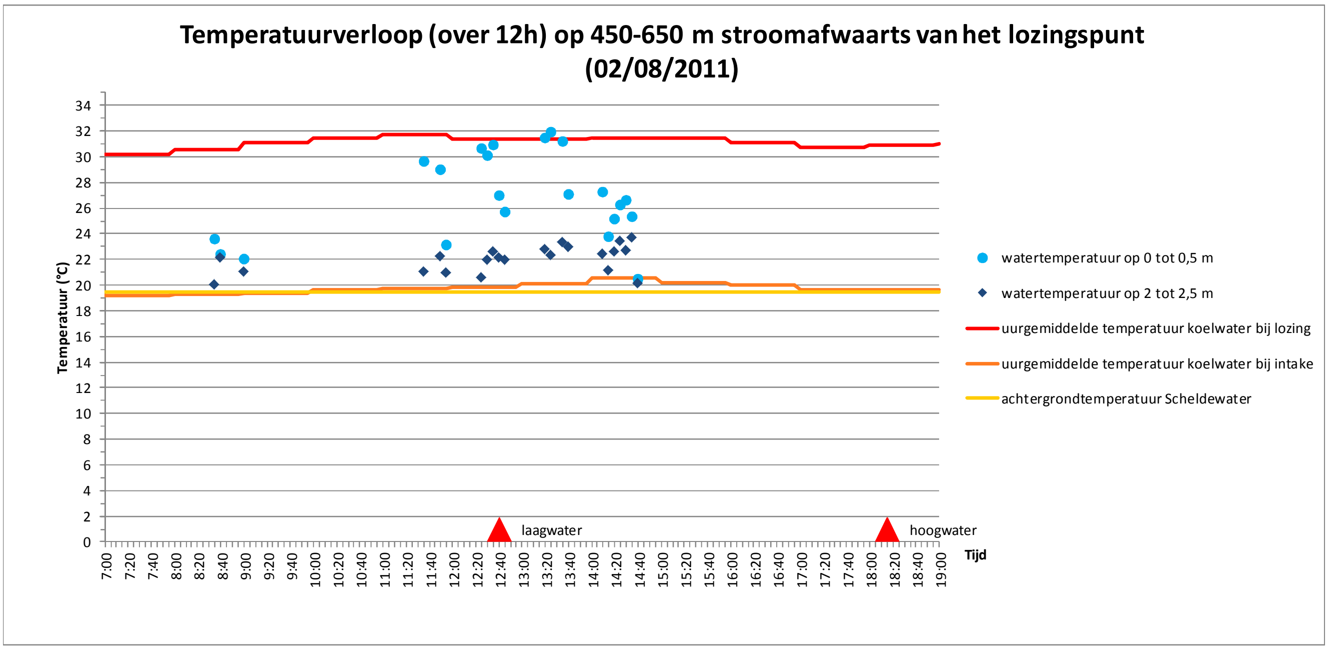




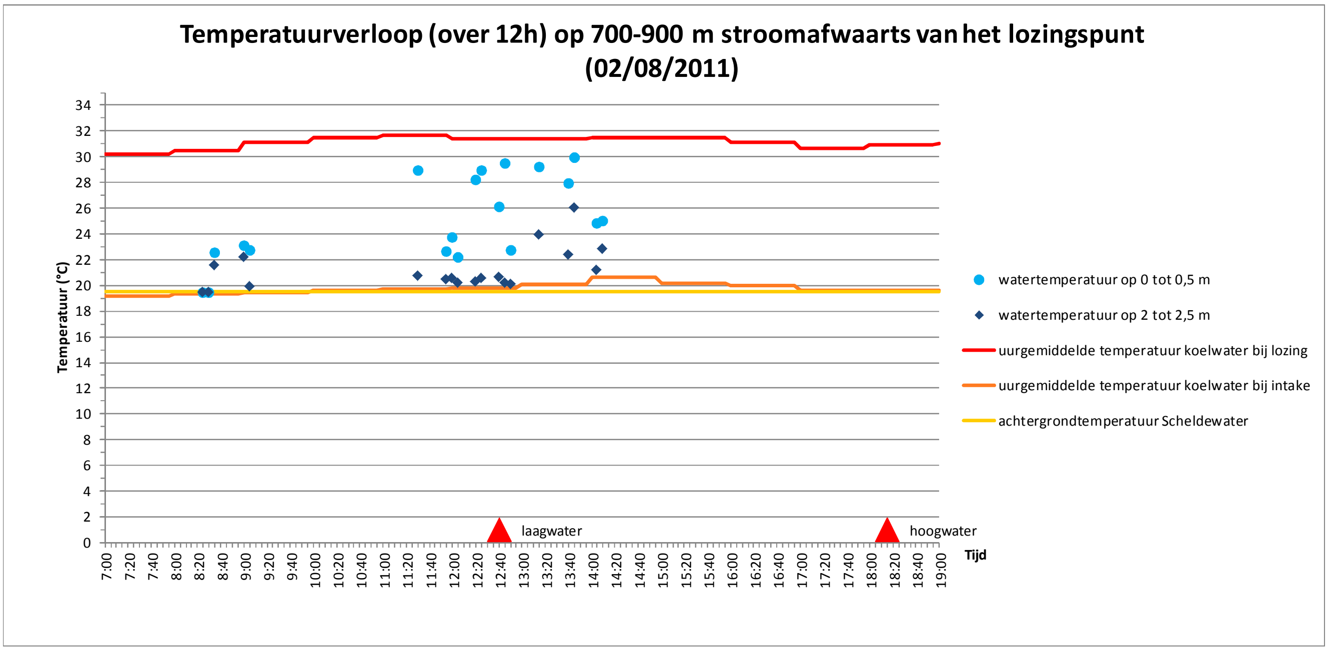
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 2)



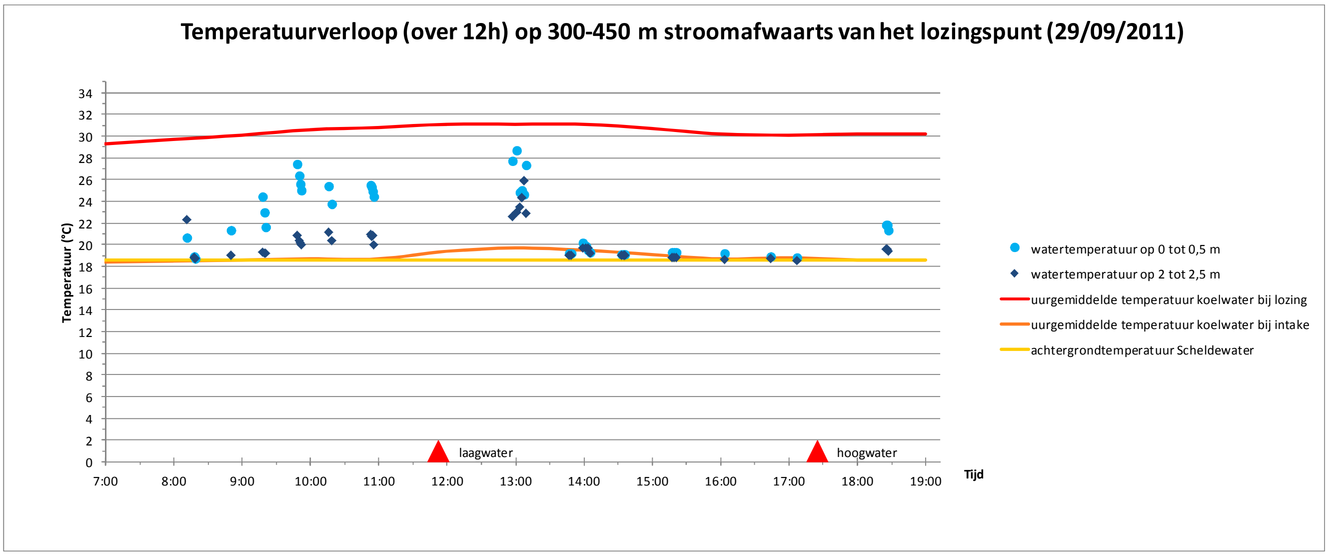


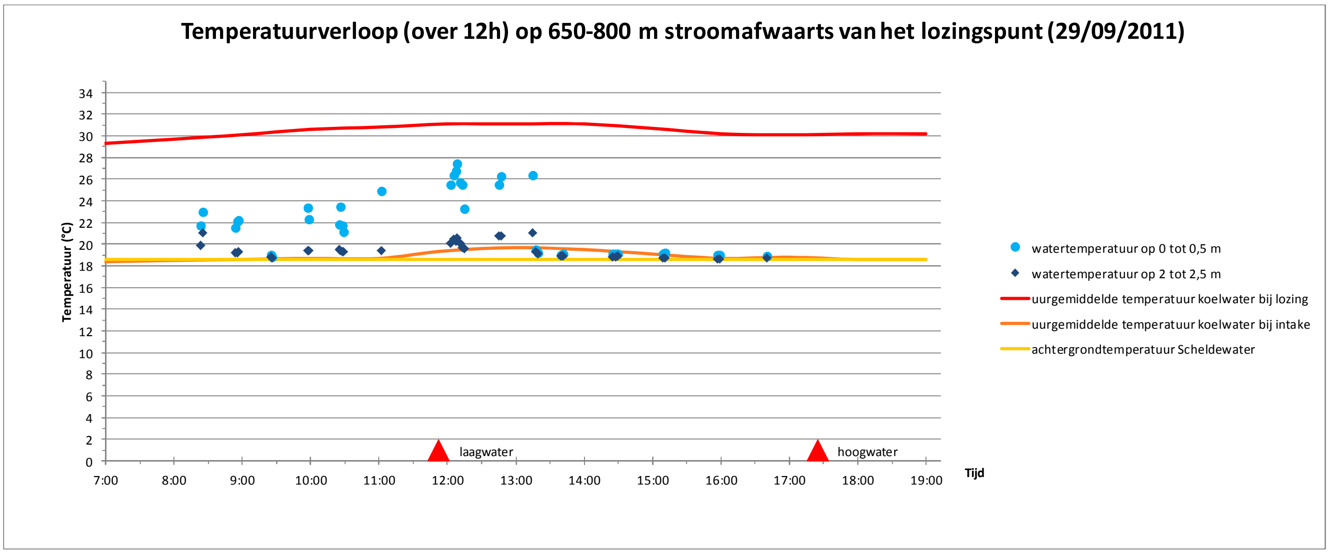


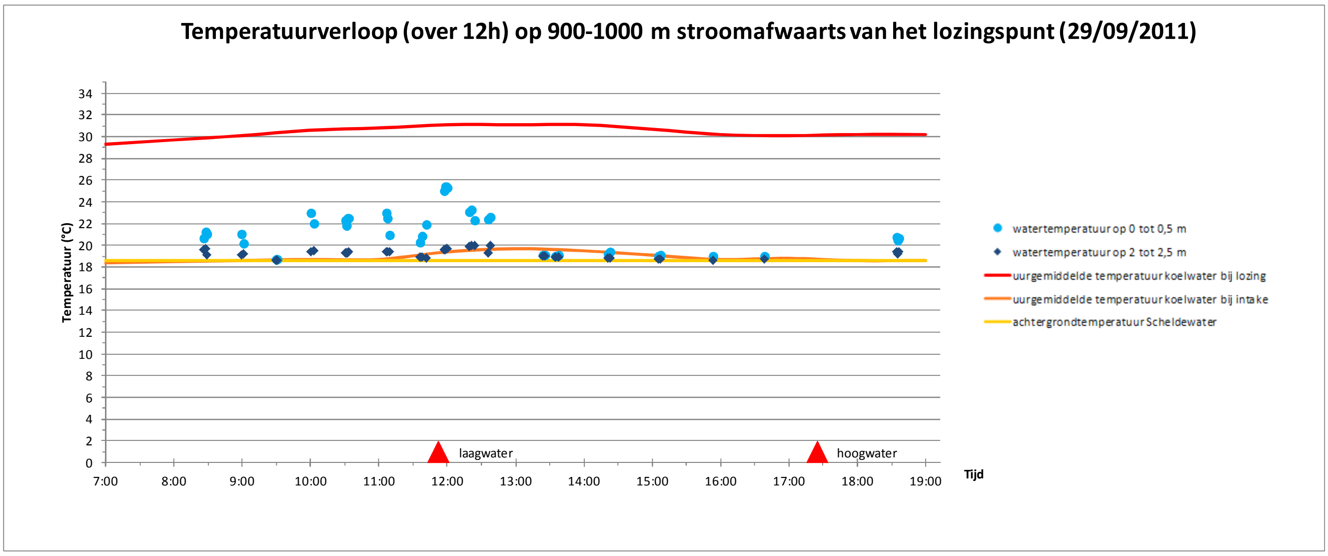
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 2)



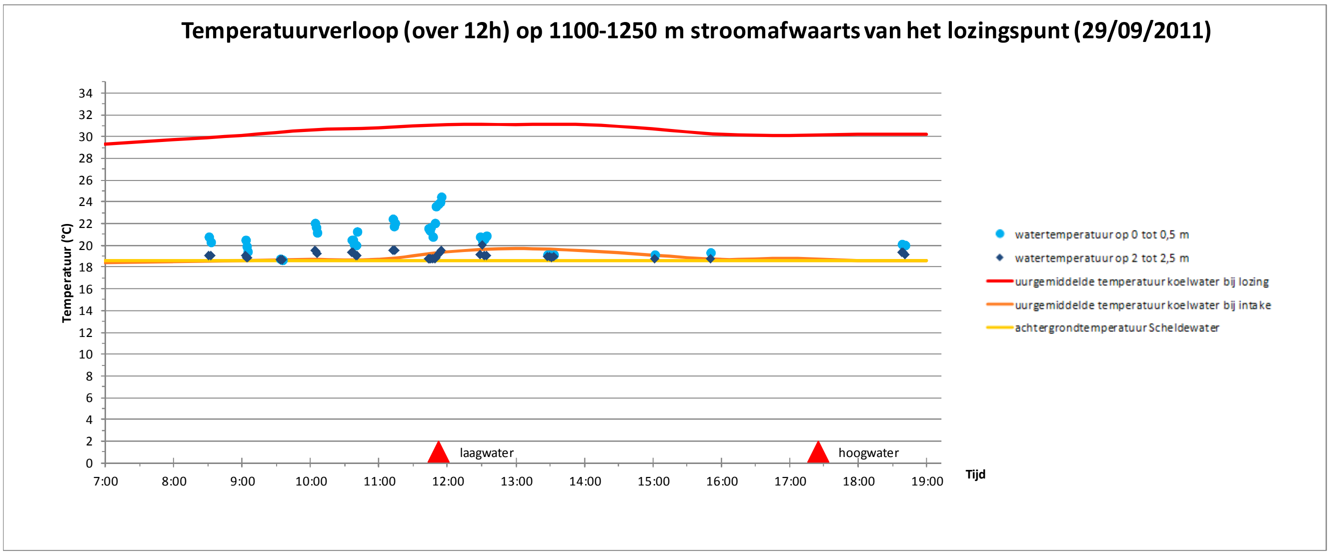
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 3)



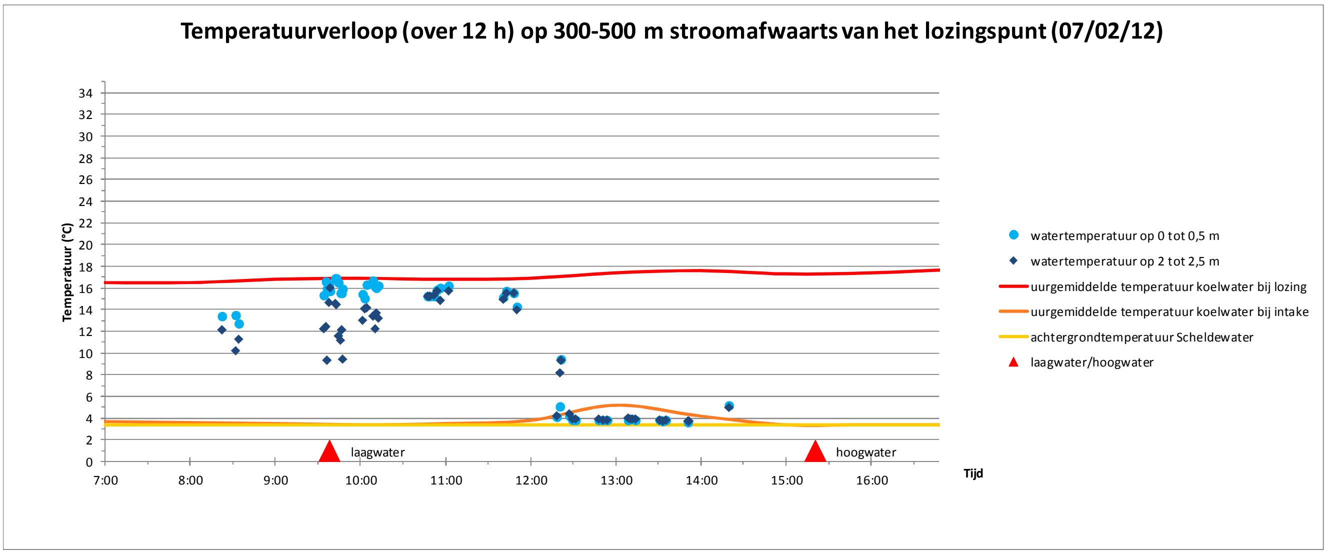


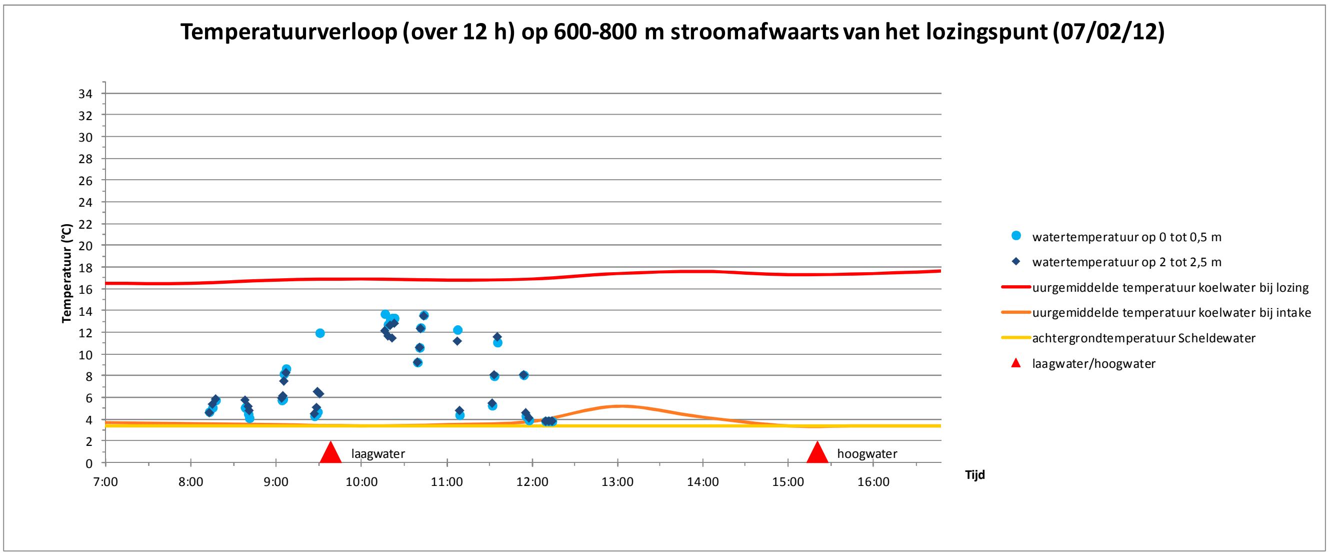


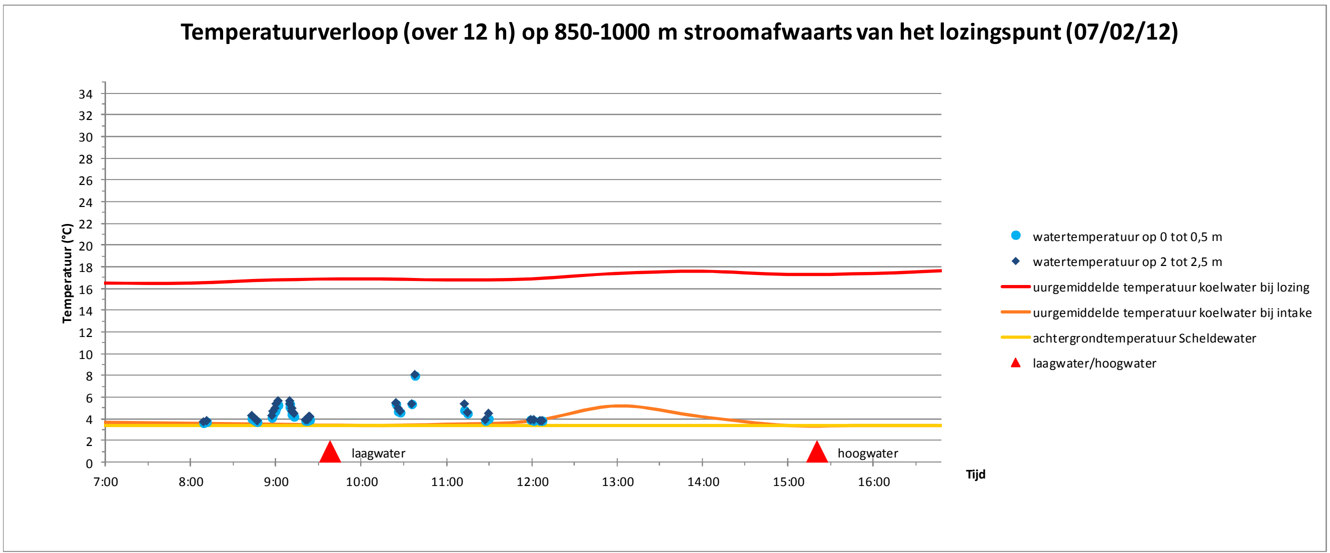
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 3)



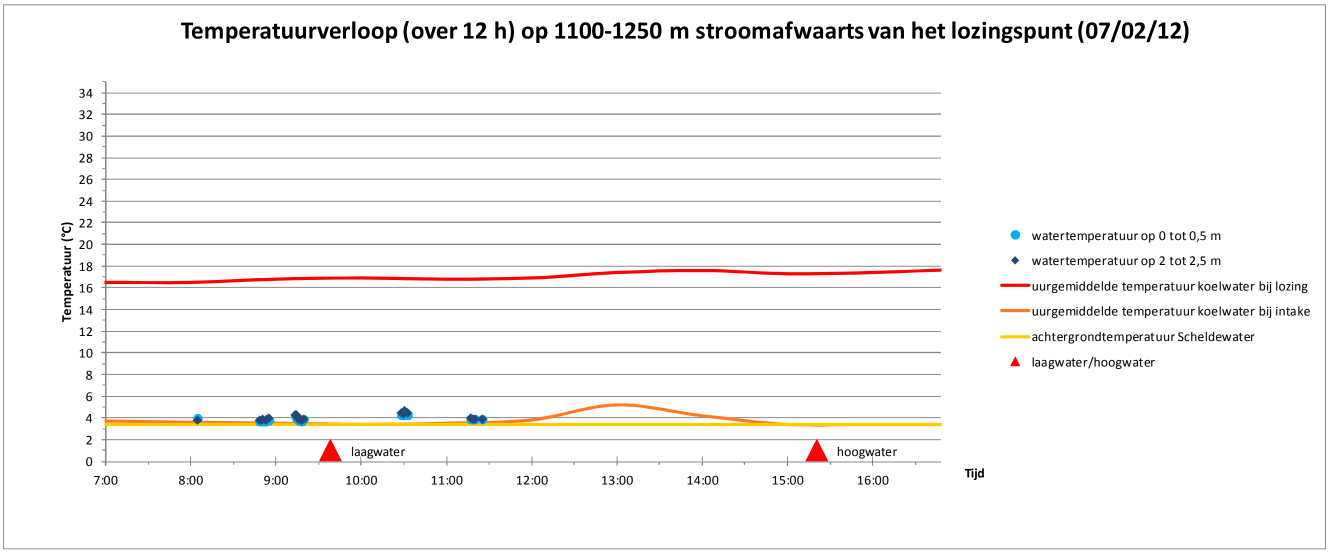
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 4)



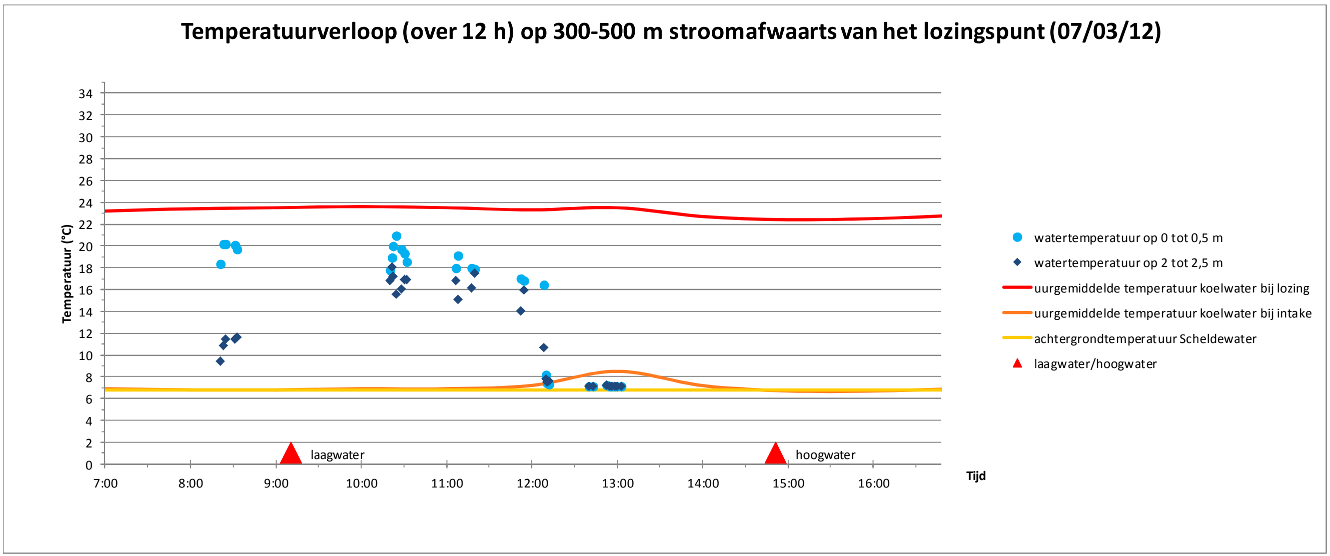


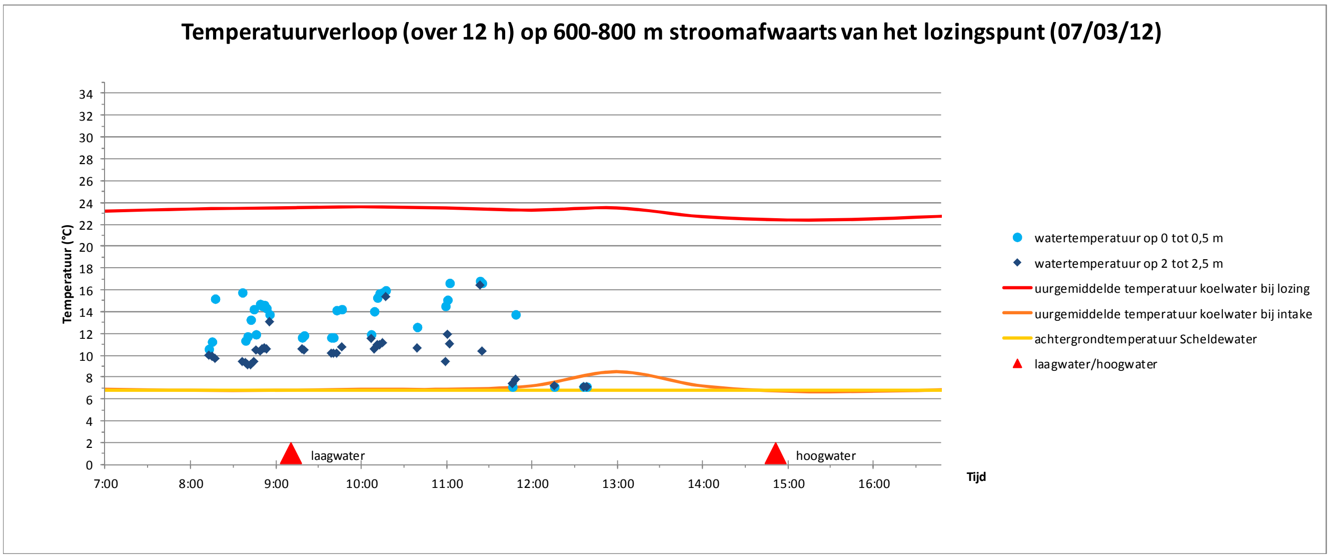


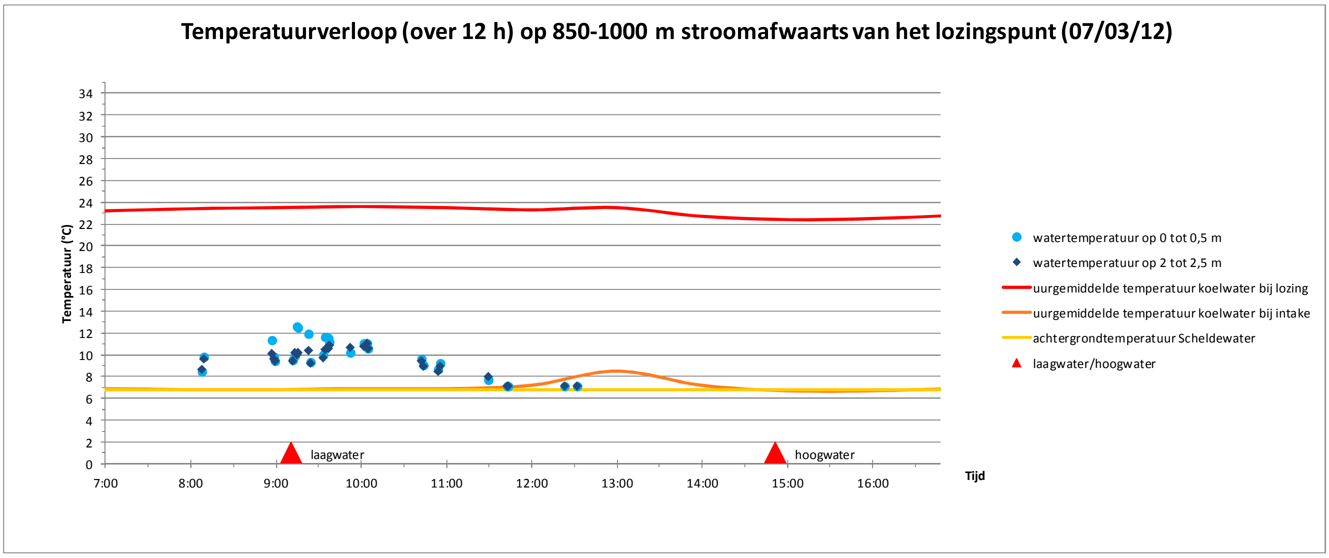
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 4)



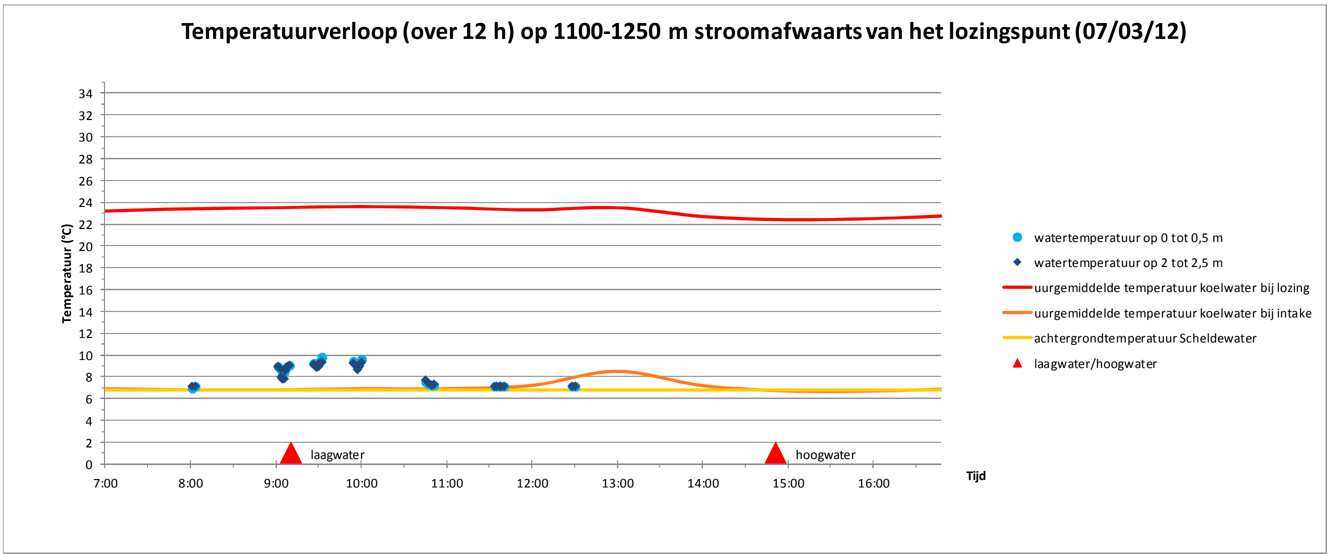
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 5)





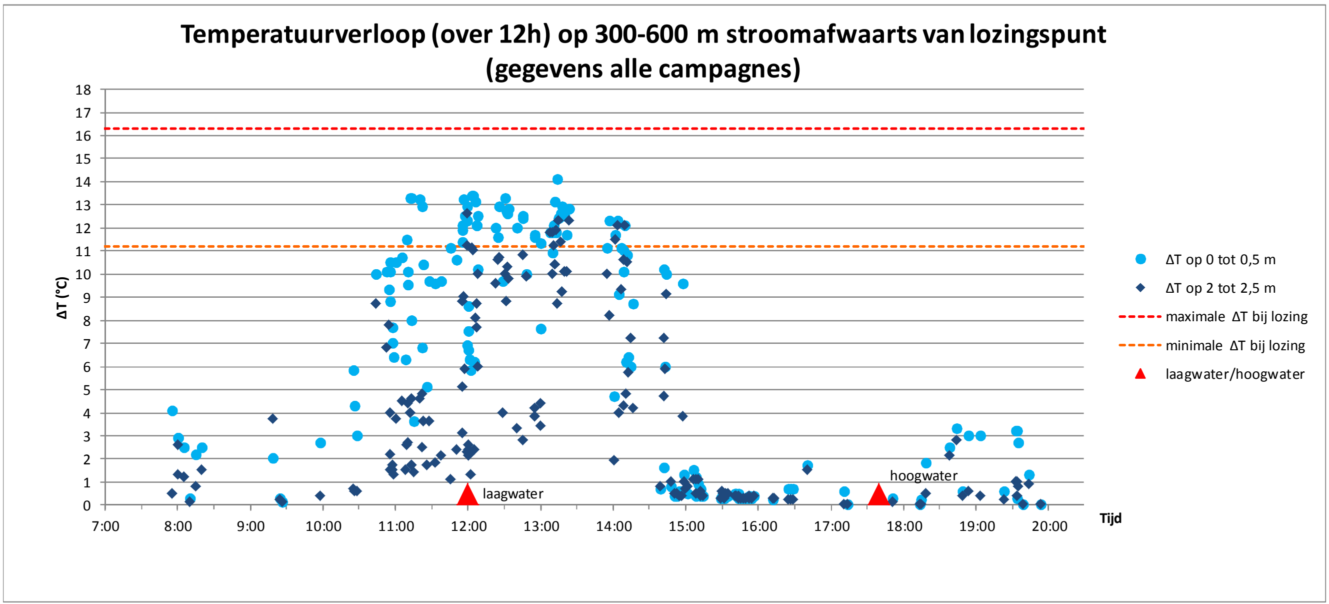


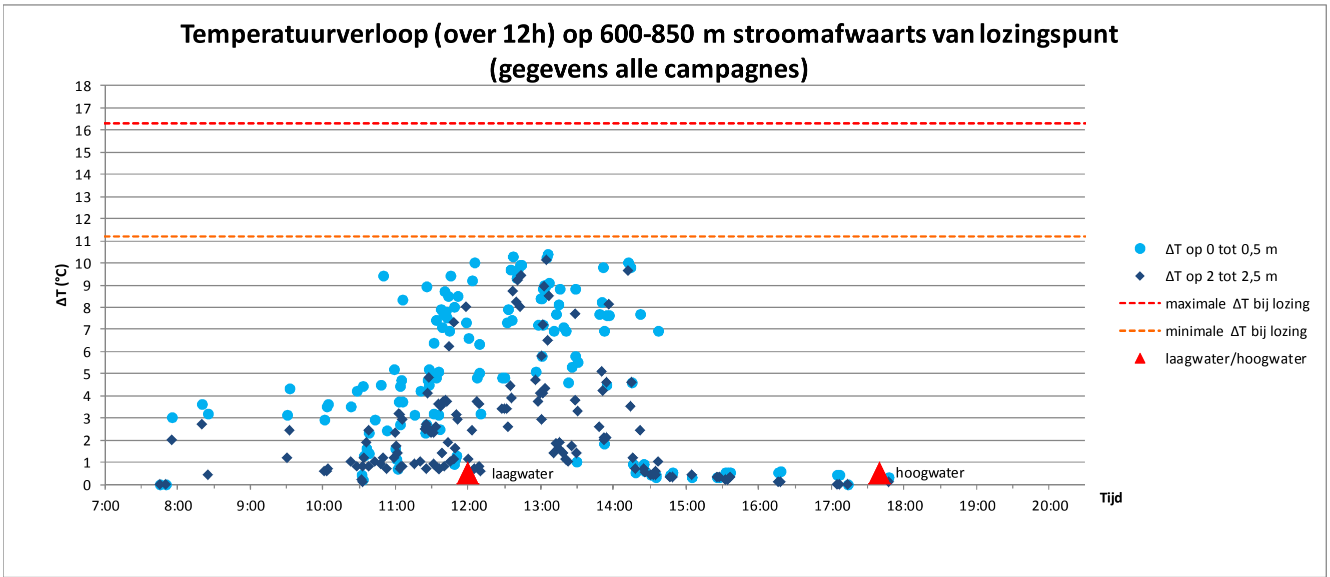
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (monitoringscampagne 5)

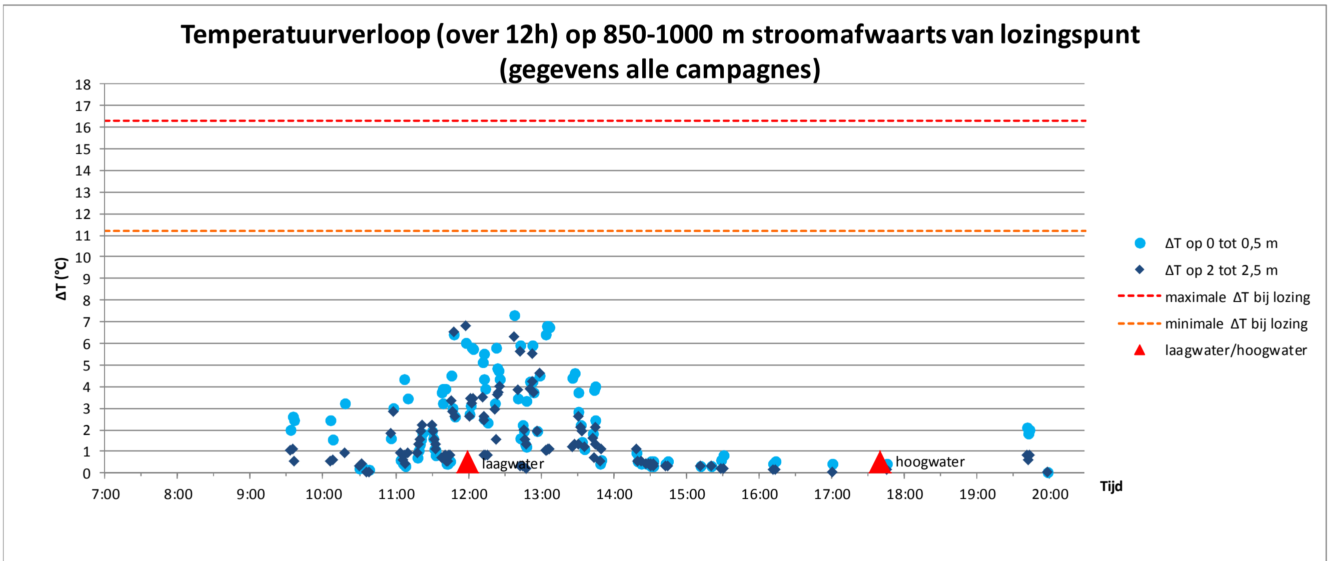


Bijlage 4 Grafische voorstelling van het temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (gegevens alle monitoringscampagnes)

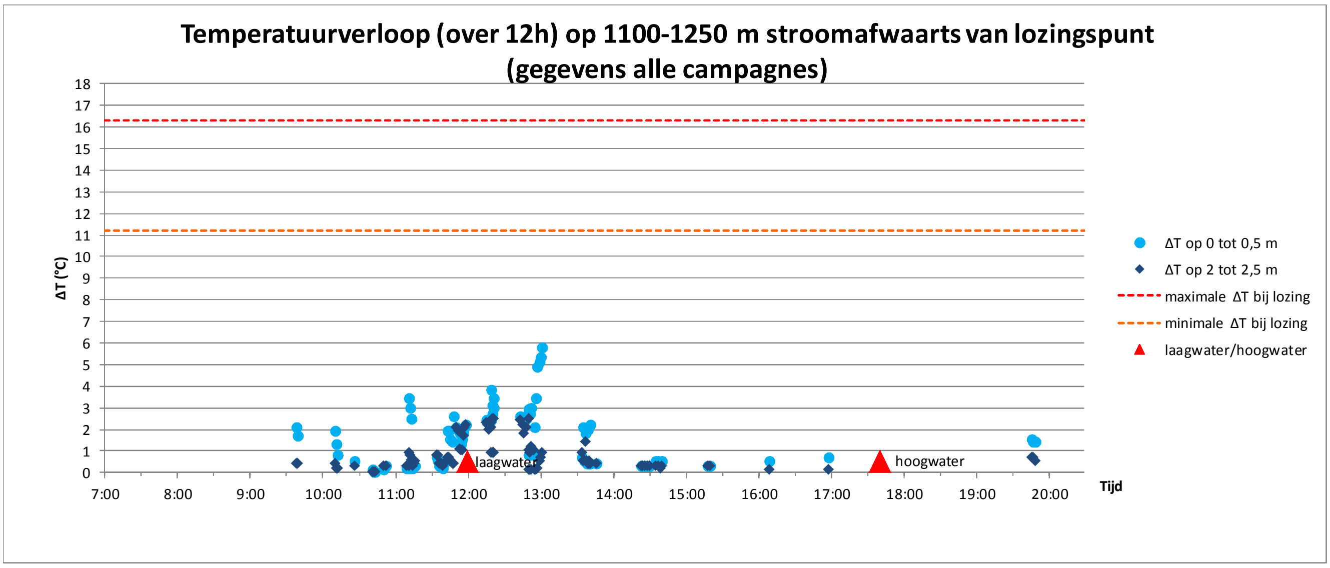
Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (gegevens alle meetcampagnes)







Temperatuurverloop in functie van de tijd voor diverse afstanden tot het lozingspunt (gegevens alle meetcampagnes)



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