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# Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)

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# Executive Summary

AkzoNobel has been producing salt by solution mining in the Twente region since 1933. Solution mining is a technique whereby salt is produced from the subsurface by dissolving it in water that is pumped down into a salt layer, thereby creating holes called “caverns”. Many caverns in this region have reached their end of productive life or will do so in the near future. AkzoNobel aims to use some of these caverns for the storage of gas oil. Prior to the selection of specific caverns, the suitability for storage was assessed at site level, which resulted in a preselection of eleven caverns that were considered potentially suitable for gas oil storage (see “*Voornemen gasolieopslag in zoutcavernes in regio Twente*“; AkzoNobel, 2010). Important issues to be addressed in more detail for these preselected caverns relate to the technical suitability of a salt cavern for storage, and the risks associated with it. For this purpose, a generic technical risk assessment was done for gas oil storage in salt caverns in Twente (Van Duijne et al., 2012). This risk assessment was done by applying the bow-tie methodology, and is based on the subsurface containment concept and its underlying assumptions, which encompasses the whole suite of barriers and monitoring measures that ensure that gasoil does not disperse outside the boundaries of the storage system. It resulted in a checklist with requirements for a cavern to adhere to for it to be labeled suitable for storage of gas oil. This checklist is used in this cavern-specific risk assessment, in which the suitability for storage of gas oil is assessed for four selected caverns within the Marssteden concession by looking in detail at the local geology around the caverns, their geometry, their well configuration, their volumes, and in which the effects of seven hazard scenarios associated with the top event “breach of confinement” are quantified.

In this report, for each selected cavern, additional information is given on the current status, the geometry, and the local geological conditions around the cavern. Next, for each cavern the suitability checklist (see section 7.4 in Van Duijne et al., 2012) is filled in and reviewed to show that the selected cavern fulfills the requirements to be used for gasoil storage. A suitable cavern in this context means that it adheres to the conditions that are required to ensure that the gasoil remains confined to the storage system. Having verified the suitability of the four selected caverns, then for each cavern, and for each potential leakage scenario connected to the top event "breach of confinement", the effects of leakage (magnitude, extent of contamination) are quantified using multiphase flow modeling (STOMP).

**Characteristics, geology and hydrogeology of the location**
The Marssteden storage concession is located between in the municipality of Enschede, at the west side of Enschede in the catchment area of the Twentekanaal. AkzoNobel has selected four caverns to be used for gasoil storage: caverns 367, 372, 469 and 472 (see Figure ES1). Relief in the area is subtle and no moraines or clay lenses are present. Phreatic groundwater levels lie between 0 and 2 m below the surface and fluctuate approximately 1 m throughout the year (De Louw, 2006). Several surface water streams can be found in the vicinity of the area of which some have EU Water Framework Directive objective ("Azelerbeek" and "Bornsebeek"). North of the Marssteden concession, an area of the Ecological Main Structure of the Netherlands (EHS) is present. Several groundwater abstraction wells for drinking water and two groundwater protection areas are located at close proximity to the selected caverns (< 5 km) as well as several swimming water locations.

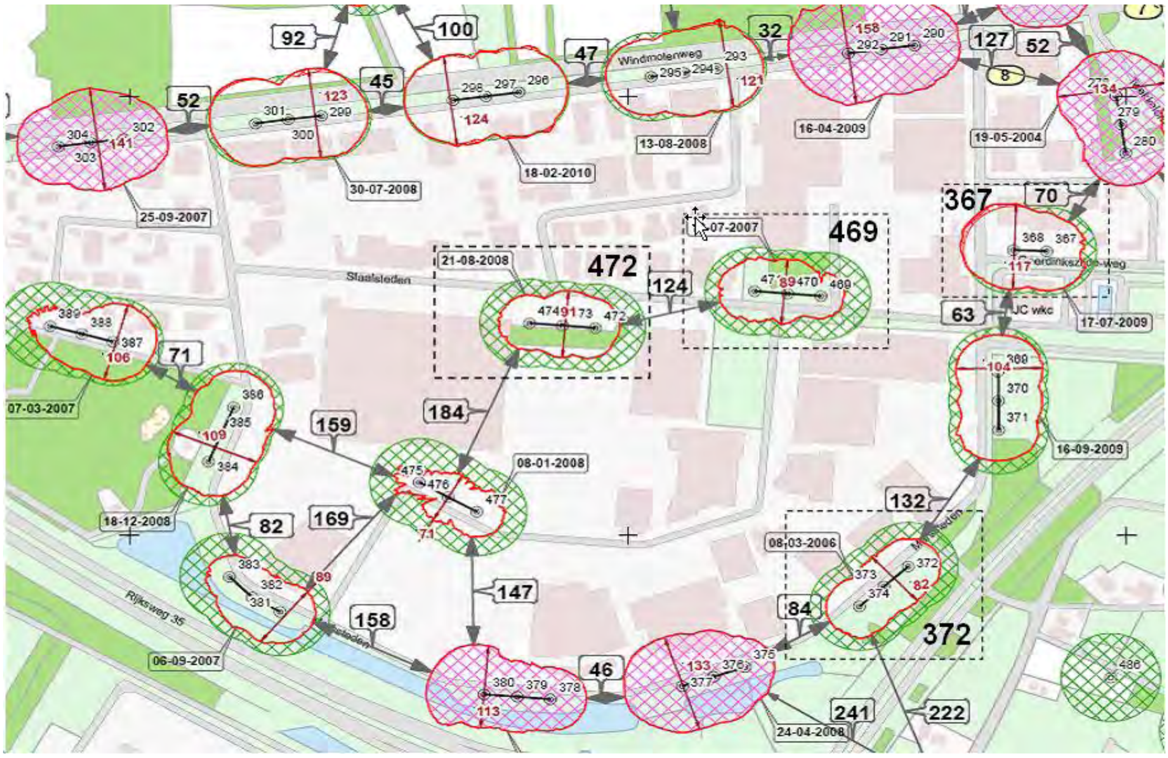

*Figure ES1: Overview of the area of the Marssteden concession of AkzoNobel with the position of the salt caverns. Caverns in dashed rectangles are selected for gas oil storage.*

The geology of the Twente area is a key factor in the natural containment of gasoil in salt caverns, with emphasis on the hydrogeological properties of the geological layers, the tectono-stratigraphic history of the region and the characteristics of faults present in the area. The subsurface of the Marssteden area consists of an alternation of aquifers (high permeability) and aquitards (low permeability). The shallowest aquifer (first 10 to 60 m below the surface) is unconsolidated and sandy, and has a high permeability. At the base of this aquifer a 50-100 meters thick layer of marine clays is found with a very low permeability. These marine clays constitute the hydrogeological base of the groundwater system. At larger depth the only aquifer present is the Muschelkalk formation, at a depth of approximately 250 meters. Furthermore, the subsurface above the Rot salt layers consists of Rot ciaystone with a thickness of approximately 150 meters.

Although tectonic activity has affected the Twente area during geologic history, leading to the development of both large scale faults (like the Gronau fault zone north of Hengelo and the Boekelo fault zone, southwest of Enschede) and small scale faults, the Marssteden concession area itself has been hardly affected. Only the southwestern part of the area, closest to the Boekelo fault zone, seems to be affected and faults are present her with an offset between 4 and 20 meters. However, these faults do not offset the entire stratigraphy. From literature and detailed studies it can be concluded that the salt caverns themselves are unlikely to have been directly affected by faults. If faults are present in the salt itself, the permeability across faults is known not to change significantly due to the viscoplastic nature of salt, which tends to heal such high-permeable zones. Nevertheless, there may be faults present in the overburden that may form a fluid migration pathway between aquifers at different depths that are otherwise separated by aquitards.

**Preliminary cavern selection**

Prior to this detailed risk assessment, a cavern selection process was performed, excluding high risk caverns from the selection. Excluding criteria encompassed:

- a history of some form of subsidence;
- a too thin salt roof above the cavern
- a too small distance between adjacent caverns (i.e. too thin salt pillar);
- an irregular cavern shape or too small cavern volume;
- development of the cavern into units of the Main Röt Evaporite salt layer younger than unit A;
- presence of major faults with possible leakage risks.

**Possible leakage scenarios and leakage modeling**

Seven leakage scenarios have been identified (see Table ES1), covering all possible causes for leakage and their consequences. Each scenario has a different depth and period of leakage, as the time span until the discovery of a leak and until full mitigation has been achieved differs, depending on the location of the leak (well or cavern). Scenario 1, "no breach of confinement", is the base case (expected evolution scenario).

| | Scenario's | leakage depth | period of leakage |
|---|---|---|---|
| **1** | no breach of confinement *(base case)* | 435 m -surf. | 3 months |
| **2** | leakage from cavern into Röt Claystone | 395 m -surf. | 3 months |
| **3** | scenario 2 with old permeable well in vicinity | 395 m -surf. | 3 months |
| **4** | leakage from well into Muschelkalk Formation (below hydrogeological base) | 156 m -surf. | 1 month |
| **5** | scenario 4 with old permeable well in vicinity | 156 m -surf. | 1 month |
| **6** | leakage from well into North Sea Supergroup (below hydrogeological base) | 60 m -surf. | 1 month |
| **7** | scenario 6 with old permeable well in vicinity | 60 m -surf. | 1 month |
| **8** | leakage from well above hydrogeological base directly into groundwater | 20 m -surf. | 1 month |

*Table ES1: Hazard scenarios associated with the top event "breach of confinement for the cavern-specific risk analysis.*

A computer model called STOMP (Subsurface Transport Over Multiple Phases) was used to calculate the vertical migration of gasoil from the leakage location, following a limited period of leakage of 1 month for a leak in the well, and 3 months for a leak at cavern level. Model input parameters are shown in Table ES2.

**Results of the cavern-specific risk assessment**

*Cavern 367*

Cavern 367 (wells 367 and 368) is located in the eastern part of the Marssteden concession area (see Figure ES1). Characteristics of this cavern, based on the two basic sources of subsurface data that are available (i.e. sonar survey data and gamma-ray log data) are shown in Table ES3.

| description host rock | | | | properties host rock | | | | properties permeable faults | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Geological Formation | Lithology | depth top layer | layer thickness | particle density | total porosity | geological permeability | hydraulic conductivity | total porosity | geological permeability | hydraulic conductivity |
| | | (m - surf.) | (m) | (kg/m$^3$) | (fraction) | (mD) | (m/d) | (fraction) | (mD) | (m/d) |
| North Sea Supergroup above hydrogeol. base | sand | 0 | 28 | 2082 | 0,41 | 1,00E+05 | 1,00E+00 | -- | -- | -- |
| North Sea Supergroup below hydrogeol. base | clay | 28 | 10 | 1746 | 0,1 | 1,00E-02 | 1,00E-08 | -- | -- | -- |
| | consolidated sand | 38 | 10 | 2200 | 0,3 | 5,00E+02 | 5,00E-04 | -- | -- | -- |
| | claystone | 48 | 10 | 1746 | 0,1 | 1,00E-02 | 1,00E-08 | -- | -- | -- |
| | consolidated sand | 58 | 10 | 2200 | 0,29 | 5,00E+02 | 5,00E-04 | -- | -- | -- |
| | claystone | 68 | 10 | 1746 | 0,1 | 1,00E-02 | 1,00E-08 | -- | -- | -- |
| Altena Group / Niedersachsen Group | claystone | 78 | 40 | 1746 | 0,07 | 1,00E-02 | 1,00E-08 | 0,17 | 1,00E-01 | 1,00E-07 |
| Muschelkalk | dolomitic marl | 118 | 20 | 2243 | 0,27 | 1,00E+00 | 1,00E-06 | 0,37 | 1,00E+02 | 1,00E-04 |
| | clayey marl | 138 | 20 | 2243 | 0,29 | 1,00E-02 | 1,00E-08 | 0,39 | 5,00E-01 | 5,00E-07 |
| | dolomitic marl | 158 | 30 | 2243 | 0,27 | 1,00E+00 | 1,00E-06 | 0,37 | 1,00E+02 | 1,00E-04 |
| | clayey limestone | 188 | 20 | 2243 | 0,14 | 1,00E+01 | 1,00E-05 | 0,24 | 1,00E+03 | 1,00E-03 |
| | marl, anhydrites | 208 | 20 | 2610 | 0,24 | 1,00E-01 | 1,00E-07 | 0,34 | 1,00E+01 | 1,00E-05 |
| Upper Röt Claystone | claystone | 228 | 170 | 1860 | 0,07 | 1,00E-02 | 1,00E-08 | 0,17 | 1,00E-01 | 1,00E-07 |
| Upper Röt Evaporite | anhydrite | case spec. | | 2320 | 0,01 | 1,00E-05 | 1,00E-10 | 0,11 | 1,00E-04 | 1,00E-09 |
| Main Röt Evaporite | rock salt, claystone | case spec. | | 2150 | 0,005 | 1,00E-05 | 1,00E-10 | 0,005 | 1,00E-05 | 1,00E-10 |

*Table ES2: Input parameter values for properties of each rock/soil type in the STOMP model.*

| **Characteristics for cavern 367** | |
|---|---|
| top Upper Röt Evaporite (average) | 398m below surface |
| thickness Upper Röt Evaporite (average) | 12m |
| top Main Röt Evaporite (average) | 410m below surface |
| thickness Main Röt Evaporite (average) | 71m |
| cavern length | 130m |
| cavern width | 110m |
| cavern height (average) | 37m |
| location gas oil well | 93m from west rim cavern |
| fault F2: distance from gas oil well | 65m west of well |
| fault F2: depth range of offset | 78 to 228m below surface |
| old well: distance from gas oil well | 36m west of well |

*Table ES3: Overview of the characteristics of cavern 367.*

The cavern is fully situated in the Röt Salt A Member (lowermost salt layer), except for a small upward protrusion at the location of well 367, which appears to just penetrate the base of Salt B. Salt D is overlain by 12 m of impermeable anhydrite. Above that another ±165 m of impermeable claystone separates the cavern from the Muschelkalk Formation. A fault, located 65 m to the west of the gasoil injection well and above the cavern, runs through the impermeable Upper Röt Claystone Member, the (locally) permeable Muschelkalk and the low permeable Altena/Niedersachsen groups (Geowulf, 2010). Since it runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Moreover, the fault is not in direct contact with the cavern. The current volume of the cavern is approx. 200,000 m$^3$, based on results from sonar surveys. These also indicate that the roof of the cavern is undulating, which results in so- called "pockets" in the roof in which gasoil may get trapped when the oil is being withdrawn from the cavern. A total pocket volume of 13,000 m$^3$ is estimated from sonar. AkzoNobel aims to leach the roof before filling the cavern with gasoil entirely, to create a flat roof with as little pockets as possible. Caverns 278 and 369 (of which the latter is still producing brine) are located in close proximity to this cavern (60 and 70 m respectively). After termination of production, the width of the salt pillar between cavern 367 and cavern 369 will still be over 50 m (i.e. twice the width as required for mechanical stability).

*Cavern 372*

Cavern 372 (wells 372, 373 and 374) is located near the southeastern edge of the Marssteden concession (see Figure ES1). Characteristics of this cavern, based on the two basic sources of subsurface data that are available (i.e. sonar survey data and gamma-ray log data) are shown in Table ES4. The cavern is fully situated in the Röt Salt A Member and Röt D is overlain by 13 m of impermeable anhydrite (Röt E). Above that another ±160 m of impermeable claystone separates the cavern from the more permeable Muschelkalk Formation.

| **Characteristics for cavern 372** | |
|---|---|
| top Upper Röt Evaporite (average) | 398m below surface |
| thickness Upper Röt Evaporite (average) | 12m |
| top Main Röt Evaporite (average) | 407m below surface |
| thickness Main Röt Evaporite (average) | 68m |
| cavern length | 180m |
| cavern width | 100m |
| cavern height (average) | 38m |
| location gas oil well | centre of cavern |
| fault Fboekelo: distance from gas oil well | 135m west of well |
| fault Fboekelo: depth range of offset | 78 to >480m below surface |
| old well: distance from gas oil well | 40m west of well |

*Table ES4: Overview of the characteristics of cavern 372.*

The nearest fault to this cavern is part of the Boekelo fault zone and is located 135 m to the southwest of the gasoil injection well, ±60 m from the edge of the cavern. It runs through the impermeable Upper Röt Claystone Member, the (locally) permeable Muschelkalk and the low permeable Altena/Niedersachsen groups (Geowulf, 2010). Its throw is estimated by Geowulf (2010) to be between 4 and ±15 m. Since the fault runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Moreover, the fault is not in direct contact with the cavern.

The current volume of the cavern is approx. 149,000 $m^3$, based on results from sonar surveys. These also indicate that the roof of the cavern is undulating, which results in so-called "pockets" in the roof in which gasoil may get trapped when the oil is being withdrawn from the cavern. A total pocket volume of 2,000 $m^3$ is estimated from sonar. AkzoNobel aims at leaching the roof following the last withdrawal of gasoil, which implies a longer period necessary to deliver the last quantity of oil (approximately 250 days). Caverns 369 and 375, of which cavern 369 is still producing brine, are located in close proximity to this cavern (125 and 85 m respectively). At the end of production of cavern 375, the width of the salt pillars between cavern 372 and the neighboring caverns will still be at least 85 m, which is more than three times the width as required for mechanical stability.

*Cavern 469*

Cavern 469 (wells 469, 470 and 471) is located in the center part of the Marssteden concession (see Figure ES1). Characteristics of this cavern, based on the two basic sources of subsurface data that are available (i.e. sonar survey data and gamma-ray log data) are shown in Table ES5. The cavern is fully situated in the Röt Salt A Member and Röt D is overlain by 11 m of impermeable anhydrite (Rot E). Above that another ±164 m of impermeable claystone separates the cavern from the more permeable Muschelkalk Formation.

Two faults are located near this cavern. One is located 80 m south of well 470 (the gasoil injection well) and it actually crosses the cavern (Gewowulf, 2010). Its throw is estimated to be between 2 and ±6 m. A second fault is located 35 m west of well 470, and above the cavern. Its throw is estimated to be less than 8 m. Since both faults run through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Furthermore, although the first fault might be in direct contact with the cavern, the estimated throw is much less than the thickness of the salt layers (Salt A-D), and therefore it is unlikely that containment has been compromised by this fault.

| **Characteristics for cavern 469** | |
|---|---|
| top Upper Röt Evaporite (average) | 398m below surface |
| thickness Upper Röt Evaporite (average) | 11m |
| top Main Röt Evaporite (average) | 409m below surface |
| thickness Main Röt Evaporite (average) | 65m |
| cavern length | 160m |
| cavern width | 110m |
| cavern height (average) | 35m |
| location gas oil well | centre of cavern |
| fault F1: distance from gas oil well | 40m west of well |
| fault F1: depth range of offset | 78 to 474m below surface |
| fault F2: distance from gas oil well | 35m west of well |
| fault F2: depth range of offset | 78 to 228m below surface |
| old well: distance from gas oil well | 40m west of well |

*Table ES5: Overview of the characteristics of cavern 469.*

The current volume of the cavern is 105.000 $m^3$, based on results from sonar surveys. These also indicate that the roof of the cavern is undulating, which results in so-called "pockets" in the roof in which gasoil may get trapped when the oil is being withdrawn from the cavern. A total pocket volume of 2,000 $m^3$ is estimated from sonar. AkzoNobel aims at leaching the roof before filling the cavern with gasoil entirely, to create a flat roof with as little pockets as possible. Oil storage cavern 472 is located in close proximity to this cavern, at a distance of 124 m, which is still four times more than the width (25m) as required for mechanical stability.

*Cavern 472*

Cavern 472 (wells 472, 473 and 474) is located in the central part of the Marssteden concession (see Figure ES1). Characteristics of this cavern, based on the two basic sources of subsurface data that are available (i.e. sonar survey data and gamma-ray log data) are shown in Table ES6. The cavern is fully situated in the Röt Salt A Member and Röt D is overlain by 13 m of impermeable anhydrite (Röt E). Above that another ±163 m of impermeable claystone separates the cavern from the more permeable Muschelkalk Formation.

The nearest fault to this cavern runs just east of this cavern, is identified in well 474 and actually crosses the cavern (geowulf, 2010). Its throw is estimated to be between 2 and 6 meters. As it runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Because the estimated throw is much less than the thickness of the salt layer (salt A-D), the containment is unlikely to be compromised by this fault.

The current volume of the cavern is approx. 143,000 $m^3$, based on results from sonar surveys. These also indicate that the roof of the cavern is undulating, which results in so-called "pockets" in the roof in which gasoil may get trapped when the oil is being withdrawn from the cavern. A total pocket volume of 2,400 m^ is estimated from sonar. AkzoNobel aims at leaching the roof following the last withdrawal of gasoil, which implies a longer period necessary to deliver the last quantity of oil (approximately 150 days).

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| **Characteristics for cavern 472** | |
|---|---|
| top Upper Röt Evaporite (average) | 397m below surface |
| thickness Upper Röt Evaporite (average) | 13m |
| top Main Röt Evaporite (average) | 410m below surface |
| thickness Main Röt Evaporite (average) | 62m |
| cavern length | 170m |
| cavern width | 80m |
| cavern height (average) | 17m |
| location gas oil well | centre of cavern |
| fault F1: distance from gas oil well | 70m west of well |
| fault F1: depth range of offset | 78 to >480m below surface |
| old wells: distance from gas oil well | 40m west and east of well |

*Table ES6: Overview of the characteristics of cavern 472*

Oil storage cavern 469 is located in close proximity to this cavern, at a distance of 124 m, which is still five times more than the width (25m) as required for mechanical stability. Furthermore, brine production cavern 475 is located at a distance of 184 m. After termination of brine production in 2017 this cavern and cavern 472 will still be more than 150 m away from each other, which is five times more than the width (25 m) as required for mechanical stability.

**Compliance with conditions and requirements**

All four caverns have been found to comply with the initial conditions and assumptions underlying the containment concept. Furthermore, both the unconditional and the conditional requirements that must be complied with are fulfilled and the reference material relevant to the checklist is presented. Consequently, the risk associated with storage of gasoil in these caverns, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2012).

Once breach of confinement occurs, gasoil leaks from the storage system into the surrounding rock. STOMP modeling results indicate that the residual risk associated with leakage of gasoil from any point below the hydrogeological base does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gasoil does not reach the nearby structures with a higher porosity and permeability (fault and/or 'old' well). Leakage from the gasoil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, STOMP modeling results indicate that the spread of the gasoil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden

**Conclusion**
Deltares concludes that all four caverns are suitable for cyclic (i.e., non-permanent) gasoil storage.

# 1 Introduction

In this report, which was compiled by Deltares (no contribution from TNO), a cavern-specific risk assessment is made for four caverns on the Marssteden concession that have been selected for gas oil storage. The risk assessment is made by applying the methodology explained in the report titled "*Generic Risk Assessment of Gas Oil Storage in Salt Caverns in the Twente region based on the Second Use Containment Concept (2UC)*" by Van Duijne et al. (2012), and is based on the subsurface containment concept and its underlying assumptions as explained in Chapter 4 of that report. In the underlying report, the technical suitability of the four caverns selected for gas oil storage is addressed, and the risks associated with it are assessed. Prior to the assessment for the individual caverns, the characteristics of the location, the geology and the hydrogeology of the Marssteden concession are briefly reviewed. Also, the selection procedure, which resulted in the four caverns under consideration, is briefly explained.

As part of the cavern-specific risk assessment, first the hazard scenarios associated with the top event "breach of confinement" are investigated for the four caverns, and their probabilities are quantified using the generic risk quantification method for gas oil storage in salt caverns as explained in Chapter 7 of the report by Van Duijne et al. (2012). Next, for each selected cavern, additional information is given on the history, current status, geometry, volumetrics, and the local geological conditions around the cavern. Next, for each cavern the cavern suitability checklist (see section 7.4 in Van Duijne et al., 2012) is filled in and reviewed to show that the selected cavern fulfills the requirements to be used for gas oil storage. A suitable cavern in this context means that it adheres to the conditions that are required to ensure that the gas oil remains confined to the storage system. Having verified the suitability of the four selected caverns, then for each cavern, and for each hazard scenario connected to the top event "breach of confinement", the effects of leakage (magnitude, extent of contamination) are quantified using multiphase flow modeling (STOMP).

# 2 Marssteden concession

## 2.1 Location

The Marssteden concession is located between the cities of Hengelo and Enschede (in the municipality of Enschede) in the catchment of the Twentekanaal. AkzoNobel has selected four caverns to be used for gas oil storage (see Figure 2.1 for location; AkzoNobel, 2010): cavern 367 with two wells (wells 367, 368), cavern 372 with three wells (wells 372, 373, 374), cavern 469 with three wells (wells 469, 470, 471), and cavern 472 with three wells (472, 473, 474). Relief in the area is subtle (no large differences in elevation), and no moraines or clay lenses are present in this area. Phreatic groundwater levels lie between 0 and 2 m below the surface and fluctuate approximately 1 m throughout the year (De Louw, 2006). Several surface water streams can be found in the vicinity of the concessions of which some have EU Water Framework Directive objective (“Azelerbeek” and “Bornsebeek”). North of the Marssteden concession, an area of the Ecological Main Structure of the Netherlands (EHS) is present. Several groundwater abstraction wells for drinking water and two groundwater protection areas are located at close proximity to the selected caverns (< 5 km). Several swimming water locations can be found in the vicinity of the Marssteden concession (Figure 2.2).

## 2.2 Geology and hydrogeology

Basically the stratigraphic units as described in section 3.2.1 of the report of Van Duijne et al. (2012) on the general geology of the Twente area are also present in the Marssteden concession, and in a horizontal to sub-horizontal position. Information on their depth of occurrence, their thickness and their hydrogeological characteristics (bulk porosity, permeability) is provided in Table 3.1 of that report (Van Duijne et al., 2012). For further information on the general geology and hydrogeology of the Twente region the reader is referred to Chapter 3 of that report. Here, the focus is on the geology and hydrogeology of the Marssteden concession.

The Marssteden concession can be subdivided in a southern and a northern part based on the presence of tectonic elements. Detailed studies by Geowulf (2010, 2012) on the presence of discontinuities in the otherwise gently dipping strata resulted in a map of the Twente-Rijn concession with tectonic areas and fault zones, and in depth and subcrop maps of stratigraphic formation boundaries, in which the offset of individual faults is displayed at that particular stratigraphic level. Furthermore, one cross-section was constructed that runs from SW to NE through the Marssteden area. All maps and the cross-section can be found in Appendix A. In these maps, which are primarily based on well data, the Marssteden storage concession is labeled “Area 3B Marssteden”, and the boundary is indicated by a black line in the SE corner of the map. The main tectonic element in this area is the Boekelo Fault zone (labeled “Fboekelo”), which runs NW-SE through the southern part of the Marssteden concession (see Van Duijne et al., 2012, Chapter 4, Figure 4.3). In depth, it runs from below the stratigraphic level of the caverns up and into the deposits of the North Sea Supergroup, and has a maximum throw in the range of 5-20m within the Marssteden area. Furthermore, in the northern part, where the caverns selected for gas oil storage are located, two smaller normal faults (labeled “F1”, “F2” on the maps) are identified, also with a maximum displacement in the range of 5-20m. However, these faults do not offset the entire stratigraphy. Fault F1 has an offset at cavern level of 4-6 meters, whereas fault F2 has no offset at cavern level. Geowulf (2010) concluded that the containment of the gas oil is not likely to be directly affected by these faults due to the self-healing nature of salt. A more detailed analysis of these faults, i.e., their geographical and stratigraphic location in relation to the caverns, and their throw, will be reviewed later in this report for each selected cavern individually.

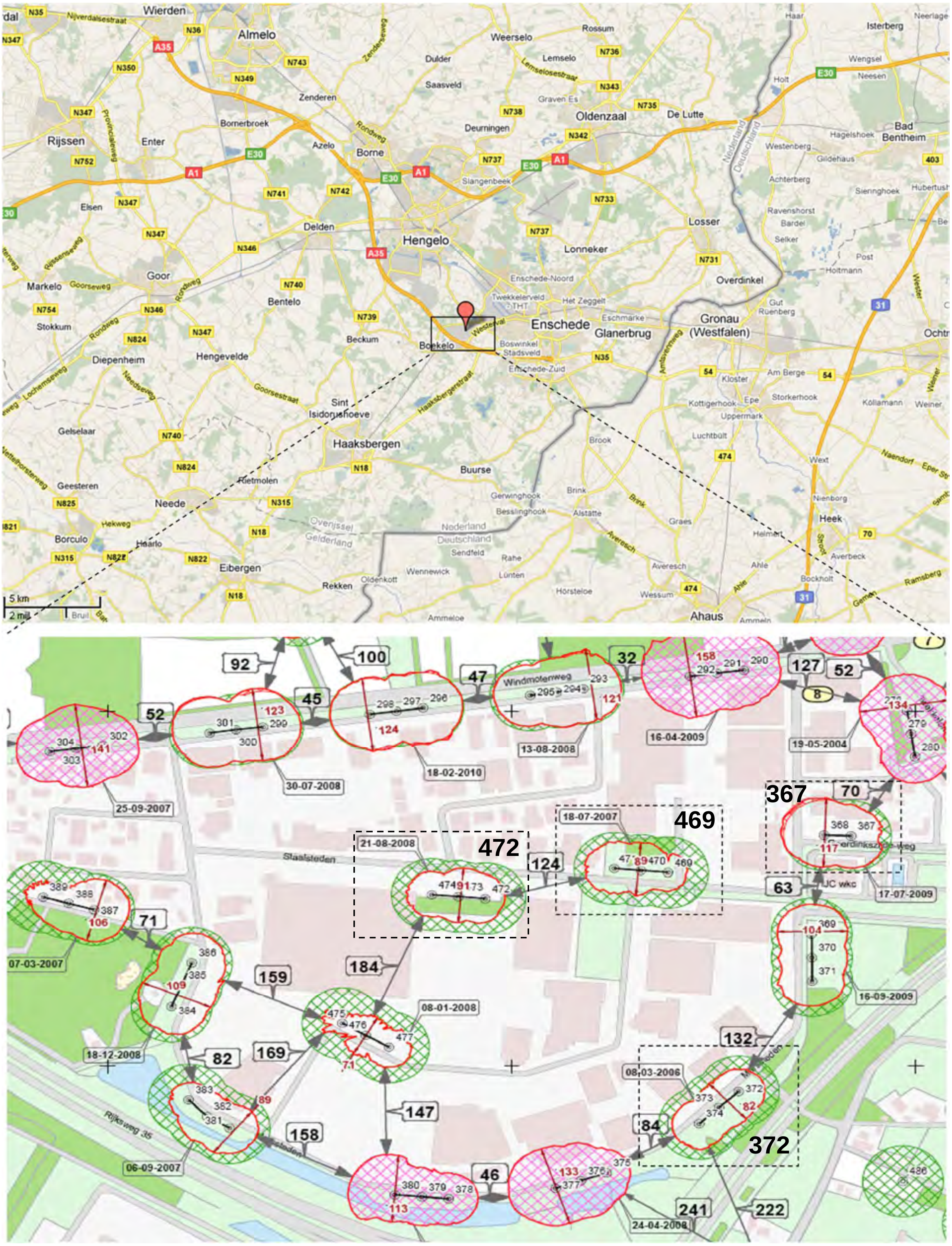


Figure 2.1: Overview of the area of the Marssteden concession of AkzoNobel with the position of the salt caverns. Caverns in dashed rectangles are selected for gas oil storage.

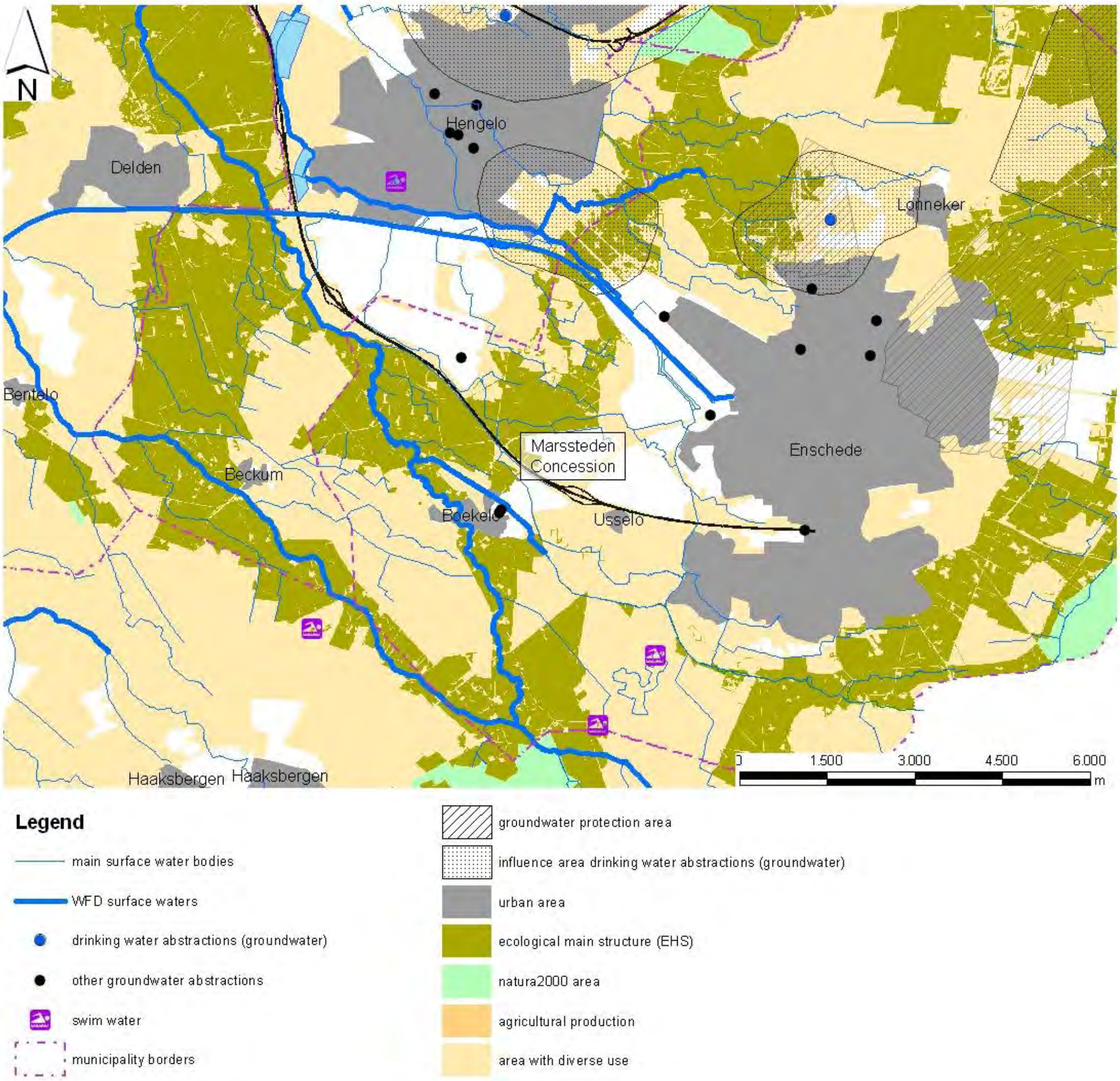


*Figure 2.2: Overview of the land and water functions of the area surrounding the Marssteden Concession (source: Waterbeheerplan 2010-2015).*

# 3 Preliminary cavern selection

As part of the permitting procedure for storage of gas oil, a cavern selection process was performed (AkzoNobel, 2010). In this preliminary selection process, the caverns in the Marssteden concession were checked for compliance with a number of technical requirements set by AkzoNobel. A detailed risk analysis was not yet performed at this stage. Technical requirements that caverns must comply with according to AkzoNobel included:

- no history of subsidence;
- fulfilling geomechanical stability criteria (e.g. minimum thickness of salt roof above the cavern, minimum distance between caverns);
- suitable cavern geometry (shape, volume);
- cavern fully contained within unit A of the Main Röt Evaporite;
- minimal presence of faults;
- good accessibility

Afterwards, the 11 pre-selected caverns that fulfilled the technical requirements were ranked based on operational footprint (impact on the environment, proximity to nature, etc.) and compatibility with spatial planning. Primary conclusion from this preliminary cavern selection process was that four salt caverns in the Marssteden concession are most suitable for gas oil storage: cavern 367 with two wells (wells 367, 368), cavern 372 with three wells (wells 372, 373, 374), cavern 469 with three wells (wells 469, 470, 471), and cavern 472 with three wells (472, 473, 474). For further details on the cavern selection process the reader is referred to the “Startnotitie MER”, published under the title “*Voornemen gasolieopslag in zoutcavernes in regio Twente*“ by the Ministry of Economic Affairs, Agriculture and Innovation (AkzoNobel, 2010).

# 4 Leakage scenarios

## 4.1 Leakage scenarios

Seven leakage scenarios (see Table 4.1) have been identified for the selected caverns, all of which result in a deviation from the base case, which is that of a closed storage system (cavern and wells) that ensures containment of the gas oil. Together these scenarios cover all the possible causes of leakage and their consequences. Scenarios include amongst others leakage at different depths from the well or the cavern, i.e., below and above the hydrogeological base, the presence of degraded permeable cementation in a neighboring well of the same cavern or older caverns in the Marssteden concession, and the presence of permeable faults in the immediate vicinity of the cavern or the well that may serve as a vertical migration path to shallower stratigraphic levels. STOMP was used to calculate the migration of the LNAPL (gas oil) from the cavern for these leakage scenarios, and for the base case of enduring containment. For each scenario, a maximum period of leakage is defined after which mitigation measures stop the leakage. This is further discussed in the next section.

| Scenario's | | leakage depth | period of leakage |
|---|---|---|---|
| **1** | no breach of confinement *(base case)* | 435 m -surf. | 3 months |
| **2** | leakage from cavern into Röt Claystone | 395 m -surf. | 3 months |
| **3** | scenario 2 with old permeable well in vicinity | 395 m -surf. | 3 months |
| **4** | leakage from well into Muschelkalk Formation (below hydrogeological base) | 156 m -surf. | 1 month |
| **5** | scenario 4 with old permeable well in vicinity | 156 m -surf. | 1 month |
| **6** | leakage from well into North Sea Supergroup (below hydrogeological base) | 60 m -surf. | 1 month |
| **7** | scenario 6 with old permeable well in vicinity | 60 m -surf. | 1 month |
| **8** | leakage from well above hydrogeological base directly into groundwater | 20 m -surf. | 1 month |

*Table 4.1 Hazard scenarios associated with the top event "breach of confinement for the cavern-specific risk analysis.*

## 4.2 Timing of mitigation measures

For the generic assessment of the effects (Chapter 6 of Van Duijne et al., 2012) of gas oil leakage, conservative calculations were made using STOMP in which the period of gas oil leakage was set to 30 years. However, in reality a breach of confinement of the gas oil system will be noticed and mitigating measures (technical, human-error-proof, see sections 5.10 and 5.11 of Van Duijne et al., 2012) will be taken as soon as the leak is detected, i.e., much sooner than after 30 years. Below, the steps that must be taken to stop a leakage from the storage system are described, together with a conservative estimate of the timing of each of the steps, which , when added together, gives the time that elapses before full mitigation is achieved:

a. A pressure measurement (or any other suitable measurement employed by AkzoNobel) indicates an anomaly, and is followed by an investigation (week 1), during which the pressure in the gas oil system is maintained, e.g. by brine injection, to prevent destabilization of the cavern;

b. If investigation points out that the breach of confinement (leakage) is in one of the wells, a workover installation is mobilized (week 2);

c. The well is temporarily repaired using a packer and pressure is monitored to assess whether or not the leakage of gas oil has stopped (week 3). At this stage, the exact location of the leakage is found if the leak is in the well.

d. The leak in the well is permanently repaired and after testing the gas oil storage activities can be continued (week 4). At this point in time one month has passed.

e. When during step b no leak is found in the wells, then in a worst-case scenario the gas oil must be removed from the cavern. Duration of this process depends on the amount of gas oil stored. In the case of the caverns being completely filled with oil up to the maximum allowable amount, this process takes about three months.

Considering the above, it is safe to assume that leakage from a cavern will continue for a period of three months, whereas leakage from a well will continue for one month. These maximum periods of leakage have been used in the STOMP model calculations for quantification of the effects of gas oil leakage (next section).

### 4.3 Numerical modeling of multiphase flow: STOMP

White et al. (1995) and Lenhard et al. (1995) developed a computer model called STOMP (Subsurface Transport Over Multiple Phases) to predict the effectiveness of environmental restoration studies involving multiple phases. It is a three-dimensional, three-phase, compositional engineering simulator for modeling contaminant migration and remediation technologies for the cleanup of subsurface sites contaminated with organic compounds. The STOMP model code is based on the Richards equation (see Section 6.3.1 in Van Duijne et al., 2011) and on the constitutive relations developed by Lenhard and Parker (1987) and Kaluarachchi and Parker (1992). Flow and transport are solved numerically using an integrated-volume finite-difference scheme to discretize the governing equations. For further details on the theory of multiphase flow and the STOMP model the reader is referred to Chapter 6 of Van Duijne et al., 2012.

For the purpose of the cavern-specific STOMP calculations of the four selected caverns, the local subsurface of the Twente area was digitized in a cross-sectional (2D) model domain based on the conceptual model as presented in Chapter 3 of Van Duijne et al. (2012). In the horizontal direction, the resolution of the model domain is 10 m. Vertically, the resolution of the model domain varies depending on the level of detail that is required in the result (high for the interval in the subsurface containing the caverns and the interval above the hydrogeological base, lower in-between) and the amount of knowledge that exists of the geological layers. The layers that represent the Upper Röt Claystone, the Muschelkalk Formation, the Altena Group, the Niedersachsen Group, and the North Sea Supergroup below the hydrogeological base have a resolution of 10 m. The Main Röt Evaporite Member, the Middle Röt Claystone Member and the Upper Röt Evaporite Member have a much higher resolution, as does the layer above the hydrogeological base (2 m). The schematization of the cavern-specific situation is described for each cavern separately: the cavern dimensions, the local depth and thickness of the Main Röt Evaporite Member, the local depth and thickness of the Upper Röt Evaporite Member, and the local characteristics of the North Sea Supergroup above the hydrogeological base (sections 5.1, 6.1, 7.1, and 8.1).

The location and the properties of potentially permeable faults and “old” wells with reduced integrity in the vicinity of the cavern need to be schematized separately. The location of the faults in the area with respect to the caverns as well as the depth over which the faults occur are specified for each cavern separately in sections 5.2, 6.2, 7.2, and 8.2. Furthermore, despite various studies that have been reported in literature (e.g. Bense and Person, 2006; Folch and Mas-Pla, 2007; Anderson and Bakker, 2008; Magri et al., 2009; Saar, 2010), no assumptions can be made on porosity and permeability values of faults. Generally, for faults that are permeable, the permeability can be considered several orders of magnitude higher than that of the surrounding host rock, and depends primarily on the amount of fault throw and the clay-content of the lithologies flanking the fault zone. Therefore, the porosity and permeability of a permeable fault in this study was estimated based on the porosity and permeability of the host rock, the clay content of the host rock and the throw of the fault (see Chapter 3 of Van Duijne et al., 2012). Because the subsurface in the Marssteden area consists of an alternation of clay-rich and sandy formations, the permeability of faults varies strongly with depth (see Table 4.2 for values). Furthermore, for “old” wells in the vicinity of the cavern that may have a reduced integrity, the schematization of the permeable casing/cement is similar for all wells: the porosity of the cement around the well is 0.8 and the permeability is $1.00 \times 10^6$ mD (hydraulic conductivity of 10 m/d), and the zone of increased permeability runs from 30 m above the roof of the cavern to the surface (worst-case scenario). The location of the nearest “old” well is determined for each cavern individually.

Simulation of multiphase flow behavior with the STOMP model requires input data on the properties of the subsurface, the formation water, the brine and the gas oil (see Table 4.2). Subsurface data required include:

- Hydraulic properties of the subsurface: porosity and intrinsic permeability of each defined rock/soil type. Intrinsic permeability was either directly declared or calculated through the hydraulic conductivity at reference conditions (atmospheric pressure and 20°C The values for the porosity and permeability were obtained as described in Section 3.3.2 of Van Duijne et al. (2012). (Verweij and Simmelink, 2002; Bouw and Oude Essink, 2003; Pöppelreiter et al., 2005; Doe and Osnes, 2006; Bear, 1972; Domenico and Schwartz, 1998; Dufour, 1998; De Louw, 2006).

- Mechanical properties of the subsurface: particle density for each defined rock/soil type. The values for particle density were obtained from the website simetric.co.uk/si_materials.htm. Based on these values and the values for porosity the specific storativity, compressibility, and a tortuosity function for each defined rock/soil type are calculated by the STOMP model.

- Saturation properties of the subsurface according to the saturation-capillary pressure function for each defined rock/soil type. For this function, the water retention curve by Van Genuchten is used (van Genuchten, 1980). The Van Genuchten function was chosen because it assumes that the wetting fluid drains from a porous medium whenever the capillary pressure is greater than zero.

In Table 4.2 the values that were used for these input parameters of subsurface characteristics are listed. Data required of the water and gas oil phases include:

- The aqueous relative permeability for each defined rock/soil type; For this purpose the Mualem function is chosen since the aqueous relative permeability is dependent on the saturation function (van Genuchten) and the Mualem function is strictly applicable to the Van Genuchten function (Mualem, 1976).

- The NAPL relative permeability for each defined rock/soil type; for this purpose the Mualem function is used as well, because of its dependency on the Van Genuchten function.

- The physical properties of the gas oil: the gas oil that will be injected has a density of 820 to 860 kg/m$^3$ (average of 840 kg/m$^3$) and a viscosity of $1.64\times10^{-3}$ Pa.s to $3.87\times10^{-3}$ Pa.s (average of $2.76\times10^{-3}$ Pa.s). These values were obtained from Appendix 2 of the gas oil 10ppm product specifications provided by the North Sea Group.

*Table 4.2 Input parameter values of the properties of each rock/soil type in the STOMP model.*

| description host rock | | | | properties host rock | | | | properties permeable faults | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Geological Formation | Lithology | depth top layer | layer thickness | particle density | total porosity | geological permeability | hydraulic conductivity | total porosity | geological permeability | hydraulic conductivity |
| | | (m - surf.) | (m) | (kg/m$^3$) | (fraction) | (mD) | (m/d) | (fraction) | (mD) | (m/d) |
| North Sea Supergroup above hydrogeol. base | sand | 0 | 28 | 2082 | 0,41 | 1,00E+05 | 1,00E+00 | -- | -- | -- |
| North Sea Supergroup below hydrogeol. base | clay | 28 | 10 | 1746 | 0,1 | 1,00E-02 | 1,00E-08 | -- | -- | -- |
| | consolidated sand | 38 | 10 | 2200 | 0,3 | 5,00E+02 | 5,00E-04 | -- | -- | -- |
| | claystone | 48 | 10 | 1746 | 0,1 | 1,00E-02 | 1,00E-08 | -- | -- | -- |
| | consolidated sand | 58 | 10 | 2200 | 0,29 | 5,00E+02 | 5,00E-04 | -- | -- | -- |
| | claystone | 68 | 10 | 1746 | 0,1 | 1,00E-02 | 1,00E-08 | -- | -- | -- |
| Altena Group / Niedersachsen Group | claystone | 78 | 40 | 1746 | 0,07 | 1,00E-02 | 1,00E-08 | 0,17 | 1,00E-01 | 1,00E-07 |
| Muschelkalk | dolomitic marl | 118 | 20 | 2243 | 0,27 | 1,00E+00 | 1,00E-06 | 0,37 | 1,00E+02 | 1,00E-04 |
| | clayey marl | 138 | 20 | 2243 | 0,29 | 1,00E-02 | 1,00E-08 | 0,39 | 5,00E-01 | 5,00E-07 |
| | dolomitic marl | 158 | 30 | 2243 | 0,27 | 1,00E+00 | 1,00E-06 | 0,37 | 1,00E+02 | 1,00E-04 |
| | clayey limestone | 188 | 20 | 2243 | 0,14 | 1,00E+01 | 1,00E-05 | 0,24 | 1,00E+03 | 1,00E-03 |
| | marl, anhydrites | 208 | 20 | 2610 | 0,24 | 1,00E-01 | 1,00E-07 | 0,34 | 1,00E+01 | 1,00E-05 |
| Upper Röt Claystone | claystone | 228 | 170 | 1860 | 0,07 | 1,00E-02 | 1,00E-08 | 0,17 | 1,00E-01 | 1,00E-07 |
| Upper Röt Evaporite | anhydrite | case spec. | | 2320 | 0,01 | 1,00E-05 | 1,00E-10 | 0,11 | 1,00E-04 | 1,00E-09 |
| Main Röt Evaporite | rock salt, claystone | case spec. | | 2150 | 0,005 | 1,00E-05 | 1,00E-10 | 0,005 | 1,00E-05 | 1,00E-10 |

Besides these input parameters, boundary and initial conditions are required. Application of boundary and initial conditions requires an appropriate conceptualization of the physical problem and translation of that conceptualization into boundary and initial condition form. The initial conditions are defined for time step T=0 and consist of a hydrostatic pressure at the lower boundary of the model domain and a pressure gradient in the vertical direction towards the upper boundary of the model domain. The pressure in the lowermost layer is calculated from the depth and the water density ($5.2\times10^6$ Pa). At the upper boundary the pressure is identical to atmospheric pressure ($1.01325\times10^6$ Pa) so that an unsaturated zone is created in the phreatic model layer. Another initial condition is the NAPL pressure. In the lowermost model layer, a NAPL pressure is defined to obtain a layer that is completed saturated with NAPL ($5.2\times10^6$ Pa). In the rest of the model, the NAPL pressure is defined as zero. The boundary conditions are constant for the whole simulation period, and only at the upper boundary (the uppermost layer) the aqueous pressure is defined to be equal to the atmospheric pressure (this is the hydrostatic pressure) together with a zero flux for the NAPL.

Model results are visualized at time t=150 years after the initial breach of confinement for all scenarios. For the scenario that is found to pose the highest risk (most severe in terms of magnitude of leakage and leakage flow rate), model output is visualized at multiple moments in time after gas oil leakage occurs: 1 day, 1 week, 1 month, 3 months, 1 year, 5 year, 30 year, 60 year, 100 year and 150 year after leakage.

# 5 Cavern 367

## 5.1 Status

Cavern 367 contains two wells (367, 368), and is located in the eastern part of the Marssteden concession (see Figure 2.1). Both wells were drilled in the last quarter of 1991, and are in good condition, as indicated in section B4 of the Storage Plan. Brine production started in April 1992, and stopped in 2010. Currently, the span of the cavern is ±130 m in E-W direction (along the line of the cross-section used in the STOMP risk modeling; see section 5.5), and ±110 m in the direction perpendicular to that. Because the final decision on which well will be used for gas oil injection has not been made yet, well 368 is assumed to be the gas oil injection well. Wells 367 and 368 are 36 m apart along the line of the cross-section used in the STOMP modeling, and the distance from either of the wells to the edge of the cavern is 57 m. A detailed overview of the cavern and the wells, and its position in relation to the stratigraphy, is included in Appendix B. It is based on the two basic sources of subsurface data that are available: sonar survey data and gamma-ray log data.

Caverns 278 and 369 are located in close proximity to this cavern, at distances of 60 and 70 m respectively. Cavern 278 went out of production in November 2006. However, cavern 369 is still producing brine and will continue to do so until the end of 2013. A recent sonar measurement indicates that the thickness of the salt pillar between this cavern and cavern 367 is about 70m. At the end of production, when this cavern has reached its final geometry, the width of the salt pillars between cavern 367 and the neighboring caverns will still be 50 m or more, which is twice the width (25m) as required for mechanical stability.

## 5.2 Geology

The Main Röt Evaporite A-D members have a total thickness of ±70 m at the location of this cavern, with the base located at a depth of 477 m and the top located at 407 m below the surface (see Appendix B). Members A and C have significant thicknesses (respectively 30-40 m and 15-20 m), while layers B and D are relatively thin (respectively ±5 m and ±2 m). The cavern has a height of max. 20m and is fully situated in the Main Röt A Member (lowermost salt layer), except for a small upward protrusion at the location of well 367, which appears to just penetrate the base of the Main Röt B Member. Main Röt Evaporite A-D members are overlain by 12 m of Main Röt Evaporite E Member, which consists entirely of impermeable anhydrite. Above that another ±165 m of impermeable claystone (Intermediate Röt Claystone and Upper Röt Claystone members) separates the cavern from the more permeable Muschelkalk Formation.

Properties of the subsurface (porosity, permeability) in the immediate vicinity of this cavern are essentially similar to those stated in Table 4.2. The nearest fault to this cavern is fault “F2” (see map with tectonic areas and fault zones in Appendix A), which is located 65 m to the west of the gas oil injection well, and above the cavern. It runs from >480m depth (below the cavern) to 80 m depth through the impermeable Main Röt Evaporite, the impermeable Upper Röt Claystone Member, the (locally) permeable Muschelkalk and the low permeable Altena/Niedersachsen groups (Geowulf, 2010). Its throw is estimated by Geowulf (2010) to be zero at the base of the Muschelkalk and deeper and 8 meters at the top of the Muschelkalk. Geowulf base their estimate on interpolated well tops, i.e., no direct observation has been done e.g. from seismic, probably because the fault throw is too small to be seen on seismic (sub-seismic scale). Since the fault runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Moreover, the fault is not in direct contact with the cavern.

## 5.3 Volumetrics

The current volume of the cavern is approx. 200,000 $m^3$. It is calculated based on results from sonar (sound navigation and ranging) surveys, which produce a three-dimensional image of the cavern by emitting a sound pulse and recording the time lapse before the pulse, which is reflected by the cavern wall, is received again by the receiver. A layer of brine is left at the bottom of the cavern during storage to shield the gas oil from the permeable sump material and formations below the cavern into which it may potentially migrate. Close inspection of the sonar data reveals that a maximum depth of the oil-brine interface of 465m is allowable without exposing the sump to gas oil, i.e., the cavern can be filled with gas oil up to a level where the oil-brine interface is at 465m depth below surface. At this maximum depth, the volume of gas oil that can be stored is ca. 163,000 $m^3$. Furthermore, the sonar measurements indicate that the roof of the cavern is undulating, which results in so-called “pockets” in the roof in which gas oil gets trapped. A total pocket volume of 13,000 $m^3$ is estimated from sonar (see Appendix B). Mitigation measures to ensure that all the oil that is stored in the cavern is retrieved at the end of the storage period are discussed in section D of the Storage Plan on residual oil after abandonment.

## 5.4 Suitability for storage

This checklist is based on see section 7.4 in Van Duijne et al., 2012.

***Initial conditions and assumptions underlying the containment concept that the cavern must comply with to be suitable for storage***

1. The cavern will be used for storage of gas oil.
   *Valid, see “Voornemen gasolieopslag in zoutcavernes in regio Twente” (AkzoNobel, 2010).*

2. Gas oil will be stored for a maximum period of 30 years.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

3. Gas oil is injected and extracted to the cavern via a well which includes a casing secured by cement and a packer close to the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B4*

4. Brine is extracted (as gas oil is injected) and injected (as gas oil is extracted) to the cavern by a well.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

5. The cavern is surrounded by Röt A salt at the sides and above.
   *Valid, see Section 5.1.*

6. The bottom of the cavern is covered by brine as a control measure. This ensures that the gas oil will not reach the bottom of the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

7. The whole cycle of injection, storage and extraction is an isolated process with no contamination to the surroundings layers.
   *Valid, see Environmental Impact Assessment (AkzoNobel, in preparation).*

8. The maximum hydraulic conductivity of the salt is $1.6x10^{-5}$ m/d.
   *Valid, see Table 3.1 in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

9. A cavern for which the storage activity is completed is refilled with brine and adheres to the conditions set by the good salt mining practice.
   *Valid, see Storage Plan (AkzoNobel, in preparation), sections D2, D5*

***Unconditional requirements that the cavern must comply with to be suitable for storage***

1. There are no known indicators for unfavorable containment conditions for the specific cavern, such as:

   - Cavern instability
   - Low pressure
   - Leakage
   - Roof collapse
   - Loss of wellhead pressure/failed pressure test
   - Degraded caprock integrity
   - Fractures
   - Presence of unfavorable insoluble layers
   - Filling with aqueous fluids from surrounding rock (capable of leaching salt)
   - Overpressure/overfilling of the cavern/operational procedure
   - Well/casing/plug problems/failure, including blowout.

   *True, these known indicators for unfavorable containment conditions have not occurred for cavern 367.*

2. The cavern is solely situated within the Main Röt Evaporite A rock salt layer.
   *True, see Section 5.1 of this report.*

3. There is no permeable layer within the Main Röt Evaporite salt layers.
   *True, see Section 3.2.1 on stratigraphy in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

4. The cavern is at least overlain by 5 m of Röt C.
   *True, see Section 5.1 of this report.*

5. The roof of the cavern is favorable for gas oil extraction at the end of the storage period.
   *True, see Storage Plan (AkzoNobel, in preparation), Section D4.*

6. The geometry of the cavern does not favor stress concentration.

*True, see Storage Plan (AkzoNobel, in preparation), Section B5.1*

7. The distance between different salt caverns within a row of caverns is at least 25 m.
*True, see Section 5.1 of this report.*

8. Parallel rows of caverns are separated by a pillar that is at least 70 m thick, or a report exists which proves that the cavern under investigation is stable.
*True, see Section 5.1, and Storage Plan (AkzoNobel, in preparation), Section B5.1.*

9. The pressure in the cavern is equal to or above the hydrostatic pressure.
*True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

10. The pressure in the cavern does not exceed the minimum in-situ (lithostatic) stress.
*True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

11. The maximum temperature change due to brine/gas oil injection is 20°C inside the cavern.
*True, see "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

12. Brine and gas oil is not injected with a temperature below 5 °C.
*True, see Storage Plan (AkzoNobel, in preparation), Section B1.*

13. There is no vertical casing displacement.
*True, see Storage Plan (AkzoNobel, in preparation), Section B4.*

14. There is no methane release from the cavern-bearing salt formation.
*True, no methane release from the cavern-bearing salt formation has been observed during regular brine production.*

***Conditional requirements that must be met for the cavern to be suitable for storage***

1. An MIT (Mechanical Integrity Test) is performed prior to storage to assess the integrity of the wells
*Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation)*

2. The cementation, casing and packer are of good quality.
*Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

3. The cement in the cement annulus is not degraded and was properly bonded to the casing and the surrounding rock during cementation in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern).
*Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

4. In case of failure of the casing and/or packer, replacement is installed and checked.

*Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. In case of serious failure of the cement in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern), replacement is installed and checked.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. Faults present in underlying and/or overlying strata that are possibly in contact with the cavern have a throw that does not exceed the minimum thickness of the Main Röt Evaporite A rock salt layer. Faults that do have a throw that exceeds the minimum thickness of the Main Röt Evaporite A rock salt layer that are possibly in contact with the cavern must be further investigated with the aim to assess their potential to form a leakage path for gas oil from the cavern to shallow depths above the hydrogeological base.
   *No faults are present that are potentially in contact with the cavern (see section 5.2 of this report).*

***Monitoring requirements that must be implemented to minimize risk and work towards ALARP***

1. The oil and brine pressure is monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

2. Pressure is monitored in the well annulus.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

3. Composition of annular fluid is monitored for the presence of gas oil components.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

4. The gas oil level is periodically monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. The brine inflow/outflow is monitored (temperature, flow rate, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. The gas oil inflow/outflow is monitored (temperature, flow rate, composition, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

7. The shape and extent of the cavern is monitored using sonar before initial gas oil injection, during storage at intervals of 5 years, and after gas oil extraction.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

8. Casing and cement bond evaluation is performed at regular basis (e.g. every 10 – 20 years).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

## 5.5 Risks

*Model setup*
For the model schematization of the case of cavern 367, the scenario's, boundary conditions, and input parameters of the properties of the subsurface and the water and gas oil are for the largest part taken from the general schematization for the Marssteden area (see Van Duijne et al., 2012, Chapter 4, Table 4.2). Case specific input properties are required for the cavern dimensions, the depth and thickness of the Main Röt Evaporite, the depth and thickness of the Upper Röt Evaporite, the position of faults with respect to the cavern, and the occurrence of "old" permeable wells and their position with respect to the cavern. These specifications for cavern 367 are summarized in Table 5.1 (see also section 5.1 and 5.2). Only the closest well and closest fault are included in the simulation, thus representing the worst case for this cavern.

*Results*
The results of the STOMP modeling for cavern 367 are visualized as a series of two-dimensional cross sections in Appendix B. In the base case scenario, the gas oil does not cause a breach of the containment of the cavern; the gas oil remains within the salt cavern for the modeled time span of 150 years.

*Table 5.1: Overview of the characteristics of cavern 367 used as input for the cavern-specific STOMP model.*

| **Characteristics for cavern 367** | |
|---|---|
| top Upper Röt Evaporite (average) | 398m below surface |
| thickness Upper Röt Evaporite (average) | 12m |
| top Main Röt Evaporite (average) | 410m below surface |
| thickness Main Röt Evaporite (average) | 71m |
| cavern length | 130m |
| cavern width | 110m |
| cavern height (average) | 37m |
| location gas oil well | 93m from west rim cavern |
| Fault F2: distance from gas oil well | 65m west of well |
| Fault F2: depth range of offset | 78 to 228m below surface |
| old well: distance from gas oil well | 36m west of well |

In scenario's 2 to 7 the gas oil does not penetrate more than 5 to 10m into the surrounding rock away from the point of leakage. In none of these scenarios the gas oil LNAPL reaches the fault or the 'old' permeable well. However, in the figure of scenario 7 it can be seen that there is a small effect of the 'old' permeable well that lies at a distance of 36 m from the gas oil well: due to the pressure reduction that occurs locally, the gas oil LNAPL shows some preferential flow in the direction of the 'old' permeable well.

In case of leakage above the hydrogeological base (scenario 8), there is a direct risk of contamination of the phreatic groundwater. The characteristics of the gas oil LNAPL are summarized in Table 5.2. The following observations can be made for this scenario:

- After 1 year the gas oil LNAPL reaches the phreatic groundwater level.
- After 1 month the maximum saturation of gas oil in the pores of the sediments is reached. Afterwards, the saturation of gas oil in the pores is reduced due the continued spreading of the LNAPL away from the point of leakage, which causes the gas oil to dilute as it becomes partially trapped in the pores.
- After the gas oil LNAPL has reached the phreatic groundwater, it spreads out on top of the groundwater surface (up to 90 m after 150 years). However, due to the relatively small scale of the phenomenon in comparison to the large scale of the figure, this spread of the LNAPL is not visible in the figures of the STOMP results in the Appendix. Therefore, in *Figure 5.1* a close-up of the contaminated zone is displayed that shows how the gas oil LNAPL spreads out on top of the phreatic groundwater level in more detail. Figure 5.2 the lateral spread of the gas oil LNAPL after 1 week, 1 month and 5 years is visualized in plan view over the topography of the Marssteden Concession area.

*Table 5.2 Results for scenario 8 of the cavern-specific STOMP modeling of cavern 367.*

| Characteristics of gas oil LNAPL | scenario 8; time horizons | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 day | 1 week | 1 month | 3 months | 1 year | 5 year | 30 year | 60 year | 150 year |
| top LNAPL (m - surf.) | 20,00 | 18,00 | 14,00 | 8,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| bottom LNAPL (m - surf) | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 20,00 | 18,50 | 14,00 |
| spread LNAPL (m) | 10,00 | 10,00 | 30,00 | 30,00 | 30,00 | 50,00 | 70,00 | 75,00 | 90,00 |
| max. gas oil saturation in LNAPL (%) | 0,01 | 0,01 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| max. saturation phreatic grw (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| Total oil volume ($m^3$) | 0,10 | 0,62 | 1,49 | 1,49 | 1,48 | 1,47 | 1,47 | 1,46 | 1,46 |

## 5.6 Conclusions

Cavern 367 adheres to the initial conditions and assumptions underlying the containment concept as defined by Deltares/TNO in Van Duijne et al. (2012). Furthermore, both the unconditional and the conditional requirements that must be complied with according to Deltares/TNO (see checklist) are met and the reference material relevant to the checklist was presented. Consequently, the risk associated with storage of gasoil in this cavern, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2011). Information on the effects after breach of confinement for this cavern was presented in the previous paragraph and is briefly summarized below.

Once breach of confinement occurs, gas oil leaks from the storage system into the surrounding rock. STOMP modeling results indicate that leakage of gas oil from any point below the hydrogeological base (ie. That means all the aquifers below the hydrological base) does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (fault and/or ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden concession. The gas oil contamination does not come near any surface water body, ecologically valuable area or drinking water abstraction point.

In order to further minimize the risk and work towards ALARP, AkzoNobel is working on a risk management plan that includes effective monitoring and mitigation measures. As part of this plan, AkzoNobel aims to perform the monitoring of the storage system conform the requirements set by Deltares/TNO in their monitoring checklist.

In view of the above, Deltares concludes that cavern 367 is suitable for cyclic (i.e. non-permanent) gas oil storage.

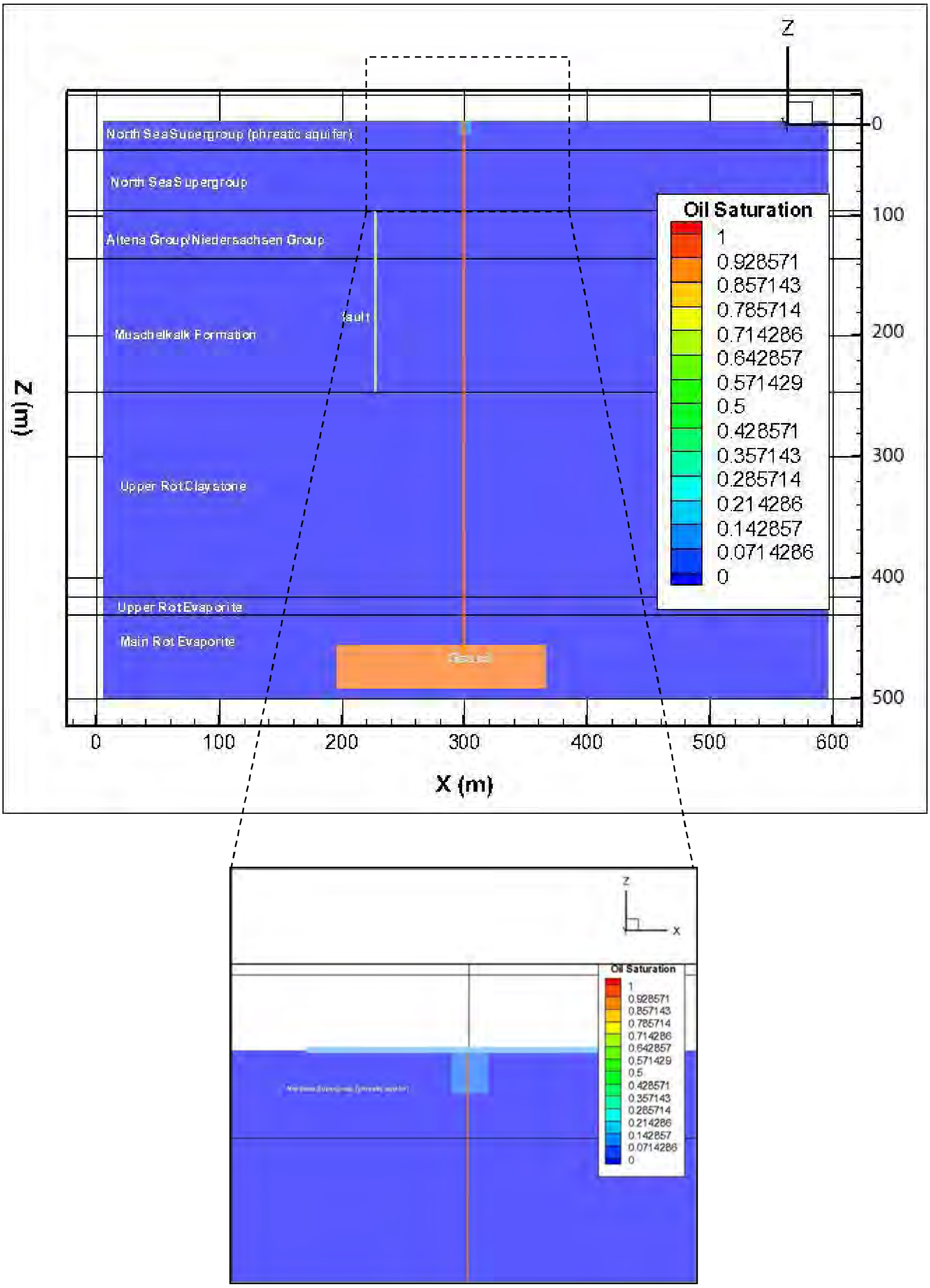


*Figure 5.1: Cavern 367, Scenario 8: leakage from the well above the hydrogeological base. Effects of leakage after 150 years. Lower figure is a close-up of the rectangle in the upper figure, and shows the spread of the gas oil LNAPL on top of the phreatic groundwater level in higher detail. The horizontal width of the lower figure is 170 m.*

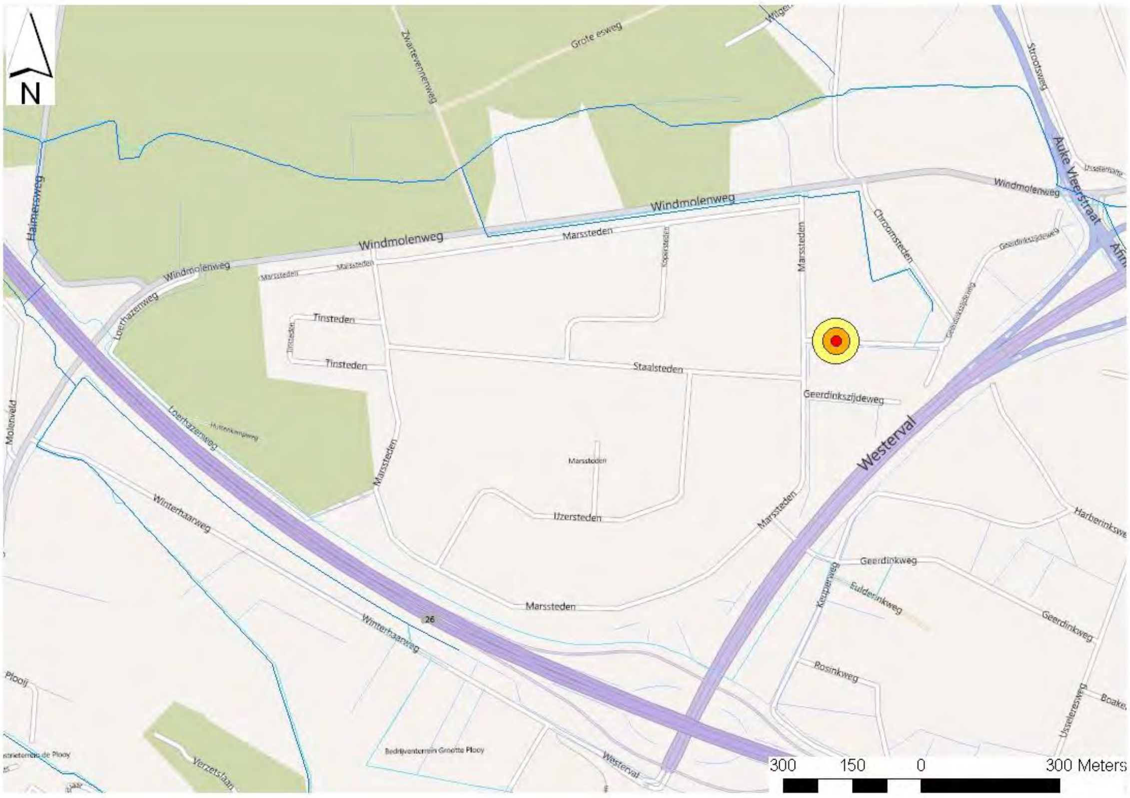


*Figure 5.2: Map of the Marssteden Concession area displaying the area over which gas oil will spread in the phreatic groundwater in case of leakage scenario 8 for cavern 367: spread after 1 week (red), 1 month (orange) and 5 years (yellow).*

# 6 Cavern 372

## 6.1 Status

Cavern 372 contains three wells (372, 373, 374), and is located near the southeastern edge of the Marssteden concession (see Figure 2.1). All three wells were drilled in the first half of 1993, and are in good condition, as indicated in Section B4 of the Storage Plan (AkzoNobel, in preparation). Brine production started in June 1993, and stopped in 2012. Span of the cavern is ±180 m in NE-SW direction (along the line of the cross-section used in the STOMP risk modeling; see section 6.5), and ±100 m in the direction perpendicular to that. Because the final decision on which well will be used for gas oil injection has not been made yet, well 373 is assumed to be the gas oil injection well. It is located at the center of the cavern. Distance from well 373 to wells 372 and 374 is 40 m along the line of the cross-section used in the STOMP risk modeling. Distance from the injection well to the edge of the cavern is 100 m. A detailed overview of the cavern and the wells, and its position in relation to the stratigraphy, is included in Appendix B. It is based on the two basic sources of subsurface data that are available: sonar survey data and gamma-ray log data.

Caverns 369 and 375 are located in close proximity to this cavern, at distances of 125 and 85 m respectively. Cavern 375 went out of production in March 2008. However, cavern 369 is still producing brine, and will continue to do so until the end of 2013. A recent sonar measurement indicates that the thickness of the salt pillar between this cavern and cavern 367 is about 125m. At the end of production, when all caverns have reached their final geometry, the width of the salt pillars between cavern 372 and the neighboring caverns will still be at least 85 m, which is more than three times the width (25m) as required for mechanical stability.

## 6.2 Geology

The Main Röt Evaporite A-D members have a total thickness of ±70 m at the location of this cavern, with the base located at a depth of 477 m and the top located at 407 m below the surface. Members A and C have significant thicknesses (respectively 30-35 m and 20-25 m), while members B and D are relatively thin (respectively ±5 m and ±3 m). The cavern has a height of max. 17 m and is fully situated in the Main Röt Evaporite A Member (lowermost salt layer).. Main Röt Evaporite A-D members are overlain by 13 m of Main Röt Evaporite E Member, which consists entirely of impermeable anhydrite. Above that another ±160 m of impermeable claystone (Intermediate Röt Claystone and Upper Röt Claystone members) separates the cavern from the more permeable Muschelkalk Formation.

Properties of the subsurface (porosity, permeability) in the immediate vicinity of this cavern are essentially similar to those stated in Table 4.2. The nearest fault to this cavern is the “Fboekelo” fault (see map with tectonic areas and fault zones in Appendix A), which is located 135 m to the southwest of the gas oil injection well, ±60 m from the edge of the cavern. It runs from >480m depth (below the cavern) to 80 m depth through the impermeable Main Röt Evaporite, the impermeable Upper Röt Claystone Member, the (locally) permeable Muschelkalk and the low permeable Altena/Niedersachsen groups (see cross-section in Appendix A; Geowulf, 2010). Its throw is estimated by Geowulf (2010) to be ± 15 m at the base of the Main Röt Evaporite member, 12 m at the top of the Main Röt Evaporite member, and 4 meters at the top of the Muschelkalk. Geowulf base their estimate on interpolated well tops, i.e., no direct observation has been done e.g. from seismic, probably because the fault throw is too small to be seen on seismic (sub-seismic scale). Since the fault runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Moreover, the fault is not in direct contact with the cavern.

## 6.3 Volume

The current volume of the cavern is 149,000 $m^3$. It is calculated based on results from sonar (sound navigation and ranging) surveys, which produce a three-dimensional image of the cavern by emitting a sound pulse and recording the time lapse before the pulse, which is reflected by the cavern wall, is received again by the receiver. A layer of brine is left at the bottom of the cavern during storage to shield the gas oil from the permeable sump material and formations below the cavern into which it may potentially migrate. Close inspection of the sonar data reveals that a maximum depth of the oil-brine interface of 468m is allowable without exposing the sump to gas oil, i.e., the cavern can be filled with gas oil up to a level where the oil-brine interface is at 468m depth below surface. At this maximum depth, the volume of gas oil that can be stored is ca. 127,000 $m^3$. Furthermore, the sonar measurements indicate that the roof of the cavern is undulating, which results in so-called “pockets” in the roof in which gas oil gets trapped. A total pocket volume of 2,000 $m^3$ is estimated from sonar (see Appendix B). Mitigation measures to ensure that all the oil that is stored in the cavern is retrieved at the end of the storage period are discussed in section D of the Storage Plan.

## 6.4 Suitability for storage

This checklist is based on see section 7.4 in Van Duijne et al., 2012.

***Initial conditions and assumptions underlying the containment concept that the cavern must comply with to be suitable for storage***

1. The cavern will be used for storage of gas oil.
   *Valid, see “Voornemen gasolieopslag in zoutcavernes in regio Twente” (AkzoNobel, 2010).*

2. Gas oil will be stored for a maximum period of 30 years.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

3. Gas oil is injected and extracted to the cavern via a well which includes a casing secured by cement and a packer close to the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B4*

4. Brine is extracted (as gas oil is injected) and injected (as gas oil is extracted) to the cavern by a well.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

5. The cavern is surrounded by Röt A salt at the sides and above.
   *Valid, see Section 5.1 of this report.*

6. The bottom of the cavern is covered by brine as a control measure. This ensures that the gas oil will not reach the bottom of the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

7. The whole cycle of injection, storage and extraction is an isolated process with no contamination to the surroundings layers.
   *Valid, see Environmental Impact Assessment (AkzoNobel, in preparation).*

8. The maximum hydraulic conductivity of the salt is $1.6x10^{-5}$ m/d.
   *Valid, see Table 3.1 in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

9. A cavern for which the storage activity is completed is refilled with brine and adheres to the conditions set by the good salt mining practice.
   *Valid, see Storage Plan (AkzoNobel, in preparation), sections D2, D5*

***Unconditional requirements that the cavern must comply with to be suitable for storage***

1. There are no known indicators for unfavorable containment conditions for the specific cavern, such as:

   - Cavern instability
   - Low pressure
   - Leakage
   - Roof collapse
   - Loss of wellhead pressure/failed pressure test
   - Degraded caprock integrity
   - Fractures
   - Presence of unfavorable insoluble layers
   - Filling with aqueous fluids from surrounding rock (capable of leaching salt)
   - Overpressure/overfilling of the cavern/operational procedure
   - Well/casing/plug problems/failure, including blowout.

   *True, these known indicators for unfavorable containment conditions have not occurred for cavern 372.*

2. The cavern is solely situated within the Main Röt Evaporite A rock salt layer.
   *True, see Section 6.1 of this report.*

3. There is no permeable layer within the Main Röt Evaporite salt layers.
   *True, see Section 3.2.1 on stratigraphy in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

4. The cavern is at least overlain by 5 m of Röt C.
   *True, see Section 6.1 of this report.*

5. The roof of the cavern is favorable for gas oil extraction at the end of the storage period.
   *True, see Storage Plan (AkzoNobel, in preparation), Section D4.*

6. The geometry of the cavern does not favor stress concentration.
   *True, see Storage Plan (AkzoNobel, in preparation), Section B5.1*

7. The distance between different salt caverns within a row of caverns is at least 25 m.
   *True, see Section 6.1 of this report.*

8. Parallel rows of caverns are separated by a pillar that is at least 70 m thick, or a report exists which proves that the cavern under investigation is stable.
   *True, see Section 6.1 of this report, and Storage Plan (AkzoNobel, in preparation), Section B5.1.*

9. The pressure in the cavern is equal to or above the hydrostatic pressure.
   *True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

10. The pressure in the cavern does not exceed the minimum in-situ (lithostatic) stress.
    *True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

11. The maximum temperature change due to brine/gas oil injection is 20°C inside the cavern.
    *True, see "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

12. Brine and gas oil is not injected with a temperature below 5 °C.
    *True, see Storage Plan (AkzoNobel, in preparation), Section B1.*

13. There is no vertical casing displacement.
    *True, see Storage Plan (AkzoNobel, in preparation), Section B4.*

14. There is no methane release from the cavern-bearing salt formation.
    *True, no methane release from the cavern-bearing salt formation has been observed during regular brine production.*

***Conditional requirements that must be met for the cavern to be suitable for storage***

1. An MIT (Mechanical Integrity Test) is performed prior to storage to assess the integrity of the wells
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation)*

2. The cementation, casing and packer are of good quality.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

3. The cement in the cement annulus is not degraded and was properly bonded to the casing and the surrounding rock during cementation in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

4. In case of failure of the casing and/or packer, replacement is installed and checked.

*Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. In case of serious failure of the cement in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern), replacement is installed and checked.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. Faults present in underlying and/or overlying strata that are possibly in contact with the cavern have a throw that does not exceed the minimum thickness of the Main Röt Evaporite A rock salt layer. Faults that do have a throw that exceeds the minimum thickness of the Main Röt Evaporite A rock salt layer that are possibly in contact with the cavern must be further investigated with the aim to assess their potential to form a leakage path for gas oil from the cavern to shallow depths above the hydrogeological base.
   *No faults are present that are potentially in contact with the cavern (see section 6.2 of this report).*

***Monitoring requirements that must be implemented to minimize risk and work towards ALARP***

1. The oil and brine pressure is monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

2. Pressure is monitored in the well annulus.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

3. Composition of annular fluid is monitored for the presence of gas oil components.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

4. The gas oil level is periodically monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. The brine inflow/outflow is monitored (temperature, flow rate, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. The gas oil inflow/outflow is monitored (temperature, flow rate, composition, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

7. The shape and extent of the cavern is monitored using sonar before initial gas oil injection, during storage at intervals of 5 years, and after gas oil extraction.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

8. Casing and cement bond evaluation is performed at regular basis (e.g. every 10 – 20 years).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

## 6.5 Risks

*Model setup*

For the model schematization of the case of cavern 372, the scenario's, boundary conditions, and input parameters of the properties of the subsurface and the water and gas oil are for the largest part taken from the general schematization for the Marssteden area (see Van Duijne et al., 2012,, Chapter 4, Table 4.2). Case specific input properties are required for the cavern dimensions, the local depth and thickness of the Main Röt Evaporite, the local depth and thickness of the Upper Röt Evaporite, the position of faults with respect to the cavern, and the occurrence of "old", permeable wells and their position with respect to the cavern. These specifications for cavern 372 are summarized in Table 6.1 Table 6.1: Overview of the characteristics of cavern 372 used as input for the cavern-specific STOMP model.(see also sections 6.1 and 6.2). Only the closest well and closest fault are included in the simulation, thus representing the worst case for this cavern.

*Table 6.1: Overview of the characteristics of cavern 372 used as input for the cavern-specific STOMP model.*

| **Characteristics for cavern 372** | |
|---|---|
| top Upper Röt Evaporite (average) | 398m below surface |
| thickness Upper Röt Evaporite (average) | 12m |
| top Main Röt Evaporite (average) | 407m below surface |
| thickness Main Röt Evaporite (average) | 68m |
| cavern length | 180m |
| cavern width | 100m |
| cavern height (average) | 38m |
| location gas oil well | centre of cavern |
| Fault Fboekelo: distance from gas oil well | 135m west of well |
| Fault Fboekelo: depth range of offset | 78 to >480m below surface |
| old well: distance from gas oil well | 40m west of well |

*Results*

The results of the STOMP modeling for cavern 372 are visualized as a series of two dimensional cross sections in appendix C. In the base case scenario, no breach of confinement occurs; the gas oil remains within the salt cavern for the modeled time span of 150 years. In scenario's 2 to 7 the gas oil does not penetrate more than 5 to 10m into the surrounding rock away from the point of leakage. In none of these scenarios the gas oil LNAPL reaches the fault or the 'old' permeable well. However, in the figure of scenario 7 it can be seen that there is a small effect of the 'old' permeable well that lies at a distance of 40 m from the gas oil well: due to the lower permeability in the old well, locally the gas oil LNAPL shows some preferential flow in the direction of the 'old' permeable well.

In case of leakage above the hydrogeological base (scenario 8), there is a direct risk of contamination of the phreatic groundwater. The characteristics of the gas oil LNAPL are summarized in Table 5.2. The following observations can be made for this scenario:

- After 1 year the gas oil LNAPL reaches the phreatic groundwater level.
- After 1 month the maximum saturation of gas oil in the pores of the sediments is reached. Afterwards, the saturation of gas oil in the pores is reduced due the continued spreading of the LNAPL away from the point of leakage, which causes the gas oil to dilute as it becomes partially trapped in the pores.
- After the gas oil LNAPL has reached the phreatic groundwater, it spreads out on top of the groundwater surface (up to 90 m after 150 years). However, due to the relatively small scale of the phenomenon n comparison to the large scale of the figure, this spread of the LNAPL is not visible in the figures of the STOMP results in the appendix. Therefore, in *Figure 5.1* a close-up of the contaminated zone is displayed that shows how the gas oil LNAPL spreads out on top of the phreatic groundwater level in more detail. Figure 5.2 the lateral spread of the gas oil LNAPL after 1 week, 1 month and 5 years is visualized from the top view over the topography of the Marssteden Concession area.

*Table 6.2 Results for scenario 8 of the cavern-specific STOMP modeling for cavern 372*

| **Characteristics of gas oil LNAPL** | **scenario 8; time horizons** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 day | 1 week | 1 month | 3 months | 1 year | 5 year | 30 year | 60 year | 150 year |
| top LNAPL (m - surf.) | 20,00 | 18,00 | 14,00 | 8,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| bottom LNAPL (m - surf) | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 20,00 | 18,50 | 14,00 |
| spread LNAPL (m) | 10,00 | 10,00 | 30,00 | 30,00 | 30,00 | 50,00 | 70,00 | 75,00 | 90,00 |
| max. gas oil saturation in LNAPL (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| max. saturation phreatic grw (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| Total oil volume ($m^3$) | 0,10 | 0,62 | 1,49 | 1,49 | 1,48 | 1,47 | 1,47 | 1,46 | 1,46 |

## 6.6 Conclusions

Cavern 372 adheres to the initial conditions and assumptions underlying the containment concept as defined by Deltares/TNO in Van Duijne et al. (2012). Furthermore, both the unconditional and the conditional requirements that must be complied with according to Deltares/TNO (see checklist) are met and the reference material relevant to the checklist was presented. Consequently, the risk associated with storage of gasoil in this cavern, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2012). Information on the effects after breach of confinement for this cavern was presented in the previous paragraph and is briefly summarized below.

Once breach of confinement occurs, gas oil leaks from the well or the cavern into the surrounding rock. STOMP modeling results indicate that leakage of gas oil from any point below the hydrogeological base (ie. That measn all the aquifers below the hydrological base) does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (fault and/or ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden concession. The gas oil contamination does not come near any surface water body, ecologically valuable area or drinking water abstraction point.

In order to further minimize the risk and work towards ALARP, AkzoNobel is working on a risk management plan that includes effective monitoring and mitigation measures. As part of this plan, AkzoNobel aims to perform the monitoring of the storage system conform the requirements set by Deltares/TNO in their monitoring checklist.

In view of the above, Deltares concludes that cavern 372 is suitable for cyclic (i.e., non-permanent) gas oil storage.

Deltares

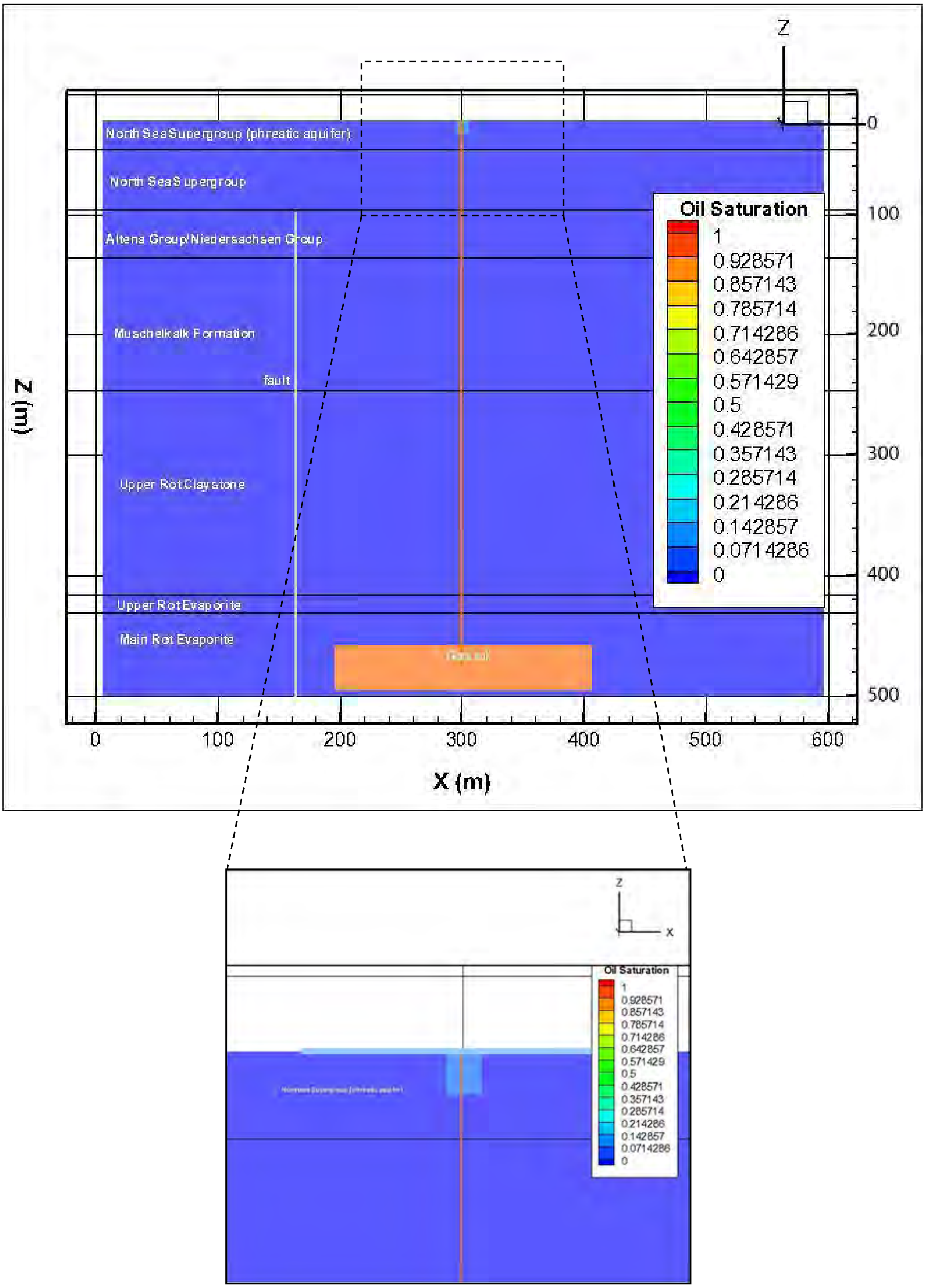


*Figure 6.1: Cavern 372, Scenario 8: leakage from the well above the hydrogeological base. Effects of leakage after 150 year. Lower figure is a close-up of the rectangle in the upper figure, and shows the spread of the gas oil LNAPL on top of the phreatic groundwater level in higher detail. Horizontal width of lower figure is 170 m.*

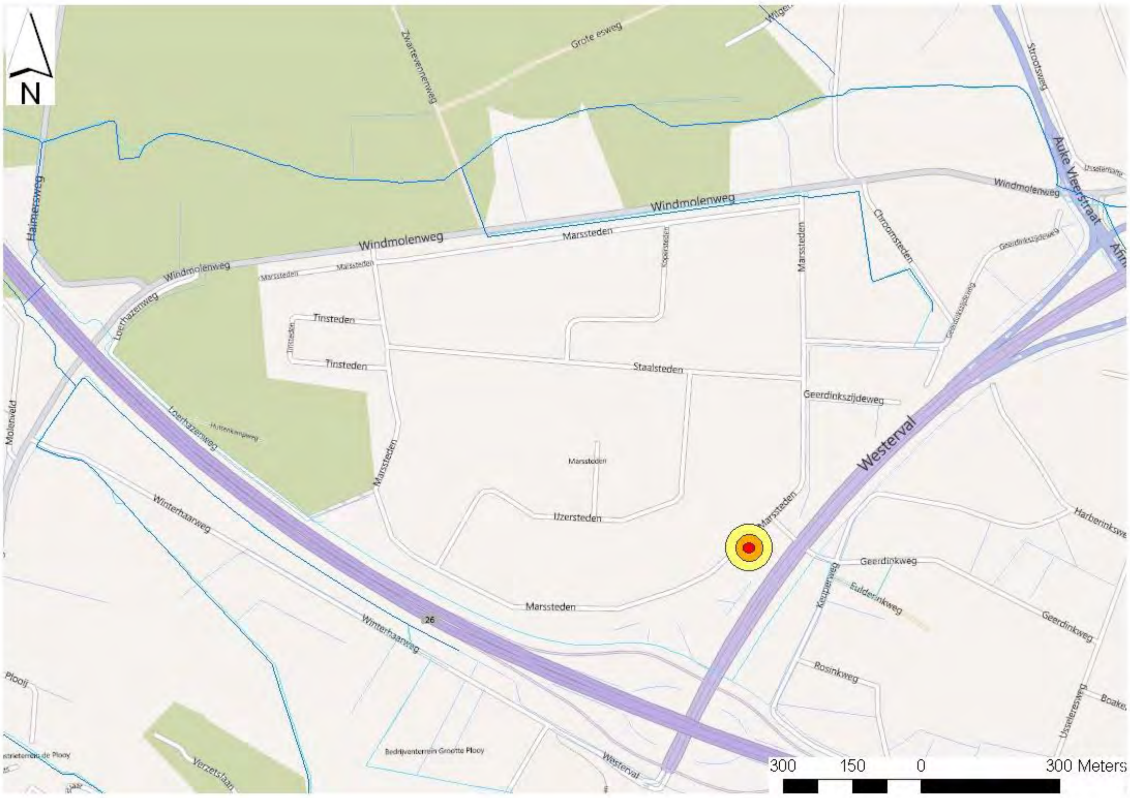


Figure 6.2: Map of the Marssteden Concession area displaying the area over which gas oil will spread in the phreatic groundwater in case of leakage scenario 8 for cavern 372: spread after 1 week (red), 1 month (orange) and 5 years (yellow).

# 7 Cavern 469

## 7.1 Status

Cavern 469 contains three wells (469, 470, 471), and is located in the central part of the Marssteden concession (see Figure 2.1). All three wells were drilled in the period between November 1997 and January 1998, and are in good condition, as indicated in Section B4 of the Storage Plan (AkzoNobel, in preparation). Brine production started in July 1998, and stopped in 2011. Span of the cavern is ±160 m in E-W direction (along the line of the cross-section used in the STOMP risk modeling; see section 7.5), and ±110 m in the direction perpendicular to that. Since the final decision on which well will be used for gas oil injection has not been taken, well 470 is assumed to be the gas oil injection well. It is located at the center of the cavern. Distances from well 470 to wells 469 and 471 are 40 m along the line of the cross-section used in the STOMP risk modeling. Distance from the injection well to the edge of the cavern is 100 m. A detailed overview of the cavern and the wells, and its position in relation to the stratigraphy, is included in Appendix B. It is based on the two basic sources of subsurface data that are available: sonar survey data and gamma-ray log data.

Oil storage cavern 472 is located in close proximity to this cavern, at a distance of 124 m, which is almost five times more than the width (25m) as required for mechanical stability.

## 7.2 Geology

The Main Röt Evaporite A-D members have a total thickness of ±65 m at the location of this cavern, with the base located at a depth of 472 m and the top located at 407 m below the surface. Members A and C have significant thicknesses (respectively 30 m and 20 m), while members B and D are relatively thin (respectively ±4 m and ±2 m). The cavern has a height of max. 23 m and is fully situated in the Main Röt A Member (lowermost salt layer). Main Röt Evaporite A-D members are overlain by 11 m of Main Röt Evaporite E Member, which consists entirely of impermeable anhydrite. Above that another ±164 m of impermeable claystone (Intermediate Röt Claystone and Upper Röt Claystone members) separates the cavern from the more permeable Muschelkalk Formation.

Properties of the subsurface (porosity, permeability) in the immediate vicinity of this cavern are essentially similar to those stated in Table 4.2. Furthermore, two faults are located near this cavern. Fault “F1” is located 80 m south of well 470 (the gas oil injection well). It runs from > 480 m depth (below the cavern) to 80 m depth, and under the assumption that the position of the fault is correctly interpreted by Geowulf (2010) it actually crosses the cavern. Its throw is estimated by Geowulf (2010) to be ± 6 m at the base of the Main Röt Evaporite member, ± 4 m at the top of the Main Röt Evaporite member, and ± 2 meters at the top of the Muschelkalk. Fault “F2” is located 35 m west of well 470, and above the cavern. It runs from >480 m depth (below the cavern) to 80 m depth through the impermeable Main Röt Evaporite, the impermeable Upper Röt Claystone Member, the (locally) permeable Muschelkalk and the low permeable Altena/Niedersachsen groups (Geowulf, 2010). Its throw is estimated by Geowulf (2010) to be zero at the base of the Muschelkalk and deeper and 8 meters at the top of the Muschelkalk. Geowulf base their estimate on interpolated well tops, i.e., no direct observation has been done e.g. from seismic, probably because the fault throw is too small to be seen on seismic (sub-seismic scale). Since faults F1 and F2 run through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Furthermore, Fault F2 is not in direct contact with the cavern. For fault F1, the possibility that it is in direct contact with the cavern cannot be excluded. However, because the estimated throw is much less than the thickness of the Main Röt Evaporite A-D members, the containment is unlikely to be compromised by this fault.

## 7.3 Volume

The current volume of the cavern is ca. 150,000 $m^3$. It is calculated based on results from sonar (sound navigation and ranging) surveys, which produce a three-dimensional image of the cavern by emitting a sound pulse and recording the time lapse before the pulse, which is reflected by the cavern wall, is received again by the receiver. A layer of brine is left at the bottom of the cavern during storage to shield the gas oil from the permeable sump material and formations below the cavern into which it may potentially migrate. Close inspection of the sonar data reveals that a maximum depth of the oil-brine interface of 460m is allowable without exposing the sump to gas oil, i.e., the cavern can be filled with gas oil up to a level where the oil-brine interface is at 460m depth below surface. At this maximum depth, the volume of gas oil that can be stored is ca. 105,000 $m^3$. Furthermore, the sonar measurements indicate that the roof of the cavern is undulating, which results in so-called “pockets” in the roof in which gas oil gets trapped. A total pocket volume of 2,000 $m^3$ is estimated from sonar (see Appendix B). Mitigation measures to ensure that all the oil that is stored in the cavern is retrieved at the end of the storage period are discussed in section D of the Storage Plan.

## 7.4 Suitability for storage

This checklist is based on see section 7.4 in Van Duijne et al., 2012.

***Initial conditions and assumptions underlying the containment concept that the cavern must comply with to be suitable for storage***

1. The cavern will be used for storage of gas oil.
   *Valid, see “Voornemen gasolieopslag in zoutcavernes in regio Twente” (AkzoNobel, 2010).*

2. Gas oil will be stored for a maximum period of 30 years.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

3. Gas oil is injected and extracted to the cavern via a well which includes a casing secured by cement and a packer close to the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B4*

4. Brine is extracted (as gas oil is injected) and injected (as gas oil is extracted) to the cavern by a well.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

5. The cavern is surrounded by Röt A salt at the sides and above.
   *Valid, see Section 7.1 of this report*

6. The bottom of the cavern is covered by brine as a control measure. This ensures that the gas oil will not reach the bottom of the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

7. The whole cycle of injection, storage and extraction is an isolated process with no contamination to the surroundings layers.
   *Valid, see Environmental Impact Assessment (AkzoNobel, in preparation).*

8. The maximum hydraulic conductivity of the salt is $1.6x10^{-5}$ m/d.
   *Valid, see Table 3.1 in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

9. A cavern for which the storage activity is completed is refilled with brine and adheres to the conditions set by the good salt mining practice.
   *Valid, see Storage Plan (AkzoNobel, in preparation), sections D2, D5*

***Unconditional requirements that the cavern must comply with to be suitable for storage***

1. There are no known indicators for unfavorable containment conditions for the specific cavern, such as:

   - Cavern instability
   - Low pressure
   - Leakage
   - Roof collapse
   - Loss of wellhead pressure/failed pressure test
   - Degraded caprock integrity
   - Fractures
   - Presence of unfavorable insoluble layers
   - Filling with aqueous fluids from surrounding rock (capable of leaching salt)
   - Overpressure/overfilling of the cavern/operational procedure
   - Well/casing/plug problems/failure, including blowout.

   *True, these known indicators for unfavorable containment conditions have not occurred for cavern 469.*

2. The cavern is solely situated within the Main Röt Evaporite A rock salt layer.
   *True, see Section 7.1 of this report.*

3. There is no permeable layer within the Main Röt Evaporite salt layers.
   *True, see Section 3.2.1 on stratigraphy in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

4. The cavern is at least overlain by 5 m of Röt C.
   *True, see Section 7.1 of this report.*

5. The roof of the cavern is favorable for gas oil extraction at the end of the storage period.
   *True, see Storage Plan (AkzoNobel, in preparation), Section D4.*

6. The geometry of the cavern does not favor stress concentration.

*True, see Storage Plan (AkzoNobel, in preparation), Section B5.1*

7. The distance between different salt caverns within a row of caverns is at least 25 m.
*True, see Section 7.1 of this report.*

8. Parallel rows of caverns are separated by a pillar that is at least 70 m thick, or a report exists which proves that the cavern under investigation is stable.
*True, see Section 7.1 of this report, and Storage Plan (AkzoNobel, in preparation), Section B5.1.*

9. The pressure in the cavern is equal to or above the hydrostatic pressure.
*True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

10. The pressure in the cavern does not exceed the minimum in-situ (lithostatic) stress.
*True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

11. The maximum temperature change due to brine/gas oil injection is 20°C inside the cavern.
*True, see "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

12. Brine and gas oil is not injected with a temperature below 5 °C.
*True, see Storage Plan (AkzoNobel, in preparation), Section B1.*

13. There is no vertical casing displacement.
*True, see Storage Plan (AkzoNobel, in preparation), Section B4.*

14. There is no methane release from the cavern-bearing salt formation.
*True, no methane release from the cavern-bearing salt formation has been observed during regular brine production.*

***Conditional requirements that must be met for the cavern to be suitable for storage***

1. An MIT (Mechanical Integrity Test) is performed prior to storage to assess the integrity of the wells
*Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation)*

2. The cementation, casing and packer are of good quality.
*Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

3. The cement in the cement annulus is not degraded and was properly bonded to the casing and the surrounding rock during cementation in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern).
*Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

4. In case of failure of the casing and/or packer, replacement is installed and checked.

*Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. In case of serious failure of the cement in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern), replacement is installed and checked.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. Faults present in underlying and/or overlying strata that are possibly in contact with the cavern have a throw that does not exceed the minimum thickness of the Main Röt Evaporite A rock salt layer. Faults that do have a throw that exceeds the minimum thickness of the Main Röt Evaporite A rock salt layer that are possibly in contact with the cavern must be further investigated with the aim to assess their potential to form a leakage path for gas oil from the cavern to shallow depths above the hydrogeological base.
   *Two faults are probably present in the vicinity of the cavern (Geowulf, 2010), one of which is possibly in contact with the cavern. However, its throw does not exceed the minimum thickness of the Main Röt A salt (see section 7.2).*

***Monitoring requirements that must be implemented to minimize risk and work towards ALARP***

1. The oil and brine pressure is monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

2. Pressure is monitored in the well annulus.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

3. Composition of annular fluid is monitored for the presence of gas oil components.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

4. The gas oil level is periodically monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. The brine inflow/outflow is monitored (temperature, flow rate, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. The gas oil inflow/outflow is monitored (temperature, flow rate, composition, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

7. The shape and extent of the cavern is monitored using sonar before initial gas oil injection, during storage at intervals of 5 years, and after gas oil extraction.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

8. Casing and cement bond evaluation is performed at regular basis (e.g. every 10 – 20 years).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

## 7.5 Risks

*Model setup*
For the model schematization of the case of cavern 469, the scenario's, boundary conditions, and input parameters of the properties of the subsurface and the water and gas oil are for the largest part taken from the general schematization for the Marssteden area (see Van Duijne et al., 2012, Chapter 4, Table 4.2).

*Table 7.1: Overview of the characteristics of cavern 469 used as input for the cavern-specific STOMP model.*

| **Characteristics for cavern 469** | |
|---|---|
| top Upper Röt Evaporite (average) | 398m below surface |
| thickness Upper Röt Evaporite (average) | 11m |
| top Main Röt Evaporite (average) | 409m below surface |
| thickness Main Röt Evaporite (average) | 65m |
| cavern length | 160m |
| cavern width | 110m |
| cavern height (average) | 35m |
| location gas oil well | centre of cavern |
| fault F1: distance from gas oil well | 40m west of well |
| fault F1: depth range of offset | 78 to 474m below surface |
| fault F2: distance from gas oil well | 35m west of well |
| fault F2: depth range of offset | 78 to 228m below surface |
| old well: distance from gas oil well | 40m west of well |

Case specific input properties are required for the cavern dimensions, the local depth and thickness of Main Röt Evaporite, the local depth and thickness of Upper Röt Evaporite, the position of faults with respect to the cavern, and the occurrence of the "old" permeable wells and their position with respect to the cavern. These specifications for cavern 469 are summarized in Table 7.1 (see also sections 7.1 and 7.2). Only the closest well and closest fault are included in the simulation, thus representing the worst case for this cavern.

*Results*
The results of the STOMP modeling for cavern 469 are visualized as a series of two dimensional cross sections in Appendix D. In the base case scenario, no breach of confinement occurs; the gas oil remains within the salt cavern for the modeled time span of 150 years. In scenario's 2 to 7 the gas oil does not penetrate more than 5 to 10m into the surrounding rock away from the point of leakage. In none of these scenarios the gas oil LNAPL reaches the fault or the 'old' permeable well. However, in the figure of scenario 7 it can be seen that there is a small effect of the 'old' permeable well that lies at a distance of 36 m from the gas oil well: due to the lower permeability in the old well, the gas oil LNAPL shows some preferential flow in the direction of the 'old' permeable well.

In case of leakage above the hydrogeological base (scenario 8), there is a direct risk of contamination of the phreatic groundwater. The characteristics of the gas oil LNAPL are summarized in Table 5.2. The following observations can be made for this scenario:

- After 1 year the gas oil LNAPL reaches the phreatic groundwater level.
- After 1 month the maximum saturation of gas oil in the pores of the sediments is reached. Afterwards, the saturation of gas oil in the pores is reduced due the continued spreading of the LNAPL away from the point of leakage, which causes the gas oil to dilute as it becomes partially trapped in the pores.
- After the gas oil LNAPL has reached the phreatic groundwater, it spreads out on top of the groundwater surface (up to 90 m after 150 years). However, due to the relatively small scale of the phenomenon n comparison to the large scale of the figure, this spread of the LNAPL is not visible in the figures of the STOMP results in the appendix. Therefore, in *Figure 5.1* a close-up of the contaminated zone is displayed that shows how the gas oil LNAPL spreads out on top of the phreatic groundwater level in more detail.Figure 5.2 the lateral spread of the gas oil LNAPL after 1 week, 1 month and 5 years is visualized from the top view over the topography of the Marssteden concession.

*Table 7.2 Results for scenario 8 of the cavern-specific STOMP modeling for cavern 469.*

| **Characteristics of gas oil LNAPL** | **scenario 8; time horizons** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 day | 1 week | 1 month | 3 months | 1 year | 5 year | 30 year | 60 year | 150 year |
| top LNAPL (m - surf.) | 20,00 | 18,00 | 14,00 | 8,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| bottom LNAPL (m - surf) | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 20,00 | 18,50 | 14,00 |
| spread LNAPL (m) | 10,00 | 10,00 | 30,00 | 30,00 | 30,00 | 50,00 | 70,00 | 75,00 | 90,00 |
| max. gas oil saturation in LNAPL (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| max. saturation phreatic grw (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| Total oil volume ($m^3$) | 0,10 | 0,62 | 1,49 | 1,49 | 1,48 | 1,47 | 1,47 | 1,46 | 1,46 |

## 7.6 Conclusions

Cavern 469 adheres to the initial conditions and assumptions underlying the containment concept as defined by Deltares/TNO in Van Duijne et al. (2012). Furthermore, both the unconditional and the conditional requirements that must be complied with according to Deltares/TNO (see checklist) are met and the reference material relevant to the checklist was presented. Consequently, the risk associated with storage of gasoil in this cavern, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2012). Information on the effects after breach of confinement for this cavern was presented in the previous paragraph and is briefly summarized below.

When a shift from the base case to an unstable situation occurs, gas oil leaks from the well or the cavern into the surrounding rock. STOMP modeling results indicate that leakage of gas oil from any point below the hydrogeological base does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (fault and/or ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden concession. The gas oil contamination does not come near any surface water body, ecologically valuable area or drinking water abstraction point.

In order to further minimize the risk and work towards ALARP, AkzoNobel is working on a risk management plan that includes effective monitoring and mitigation measures. As part of this plan, AkzoNobel aims to perform the monitoring of the storage system conform the requirements set by Deltares/TNO in their monitoring checklist.

In view of the above, Deltares concludes that cavern 469 is suitable for cyclic (i.e., non-permanent) gas oil storage.

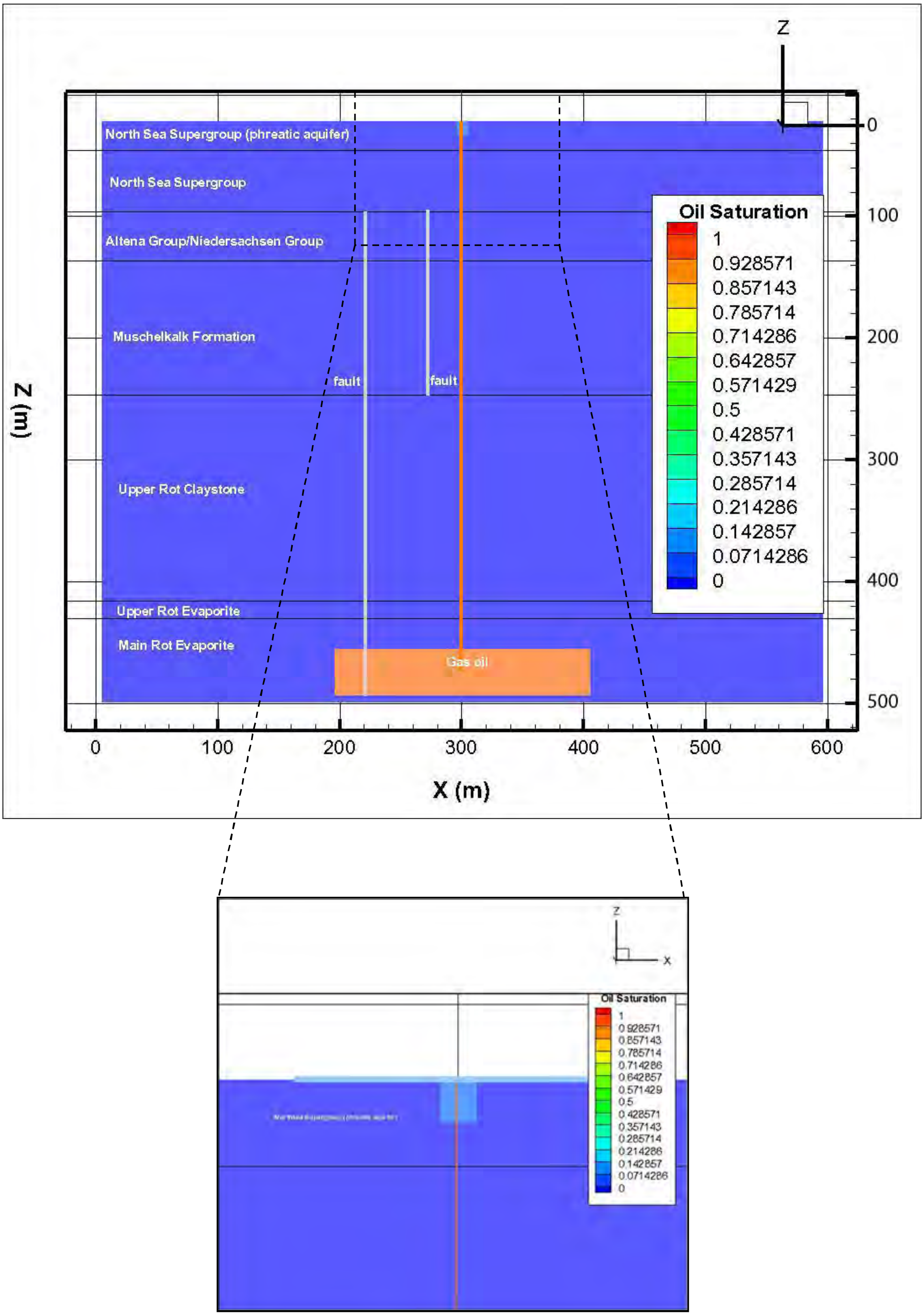


*Figure 7.1: Cavern 469, Scenario 8: leakage from the well above the hydrogeological base. Effects of leakage after 150 year. Lower figure is a close-up of the rectangle in the upper figure, and shows the spread of the gas oil LNAPL on top of the phreatic groundwater level in higher detail.*

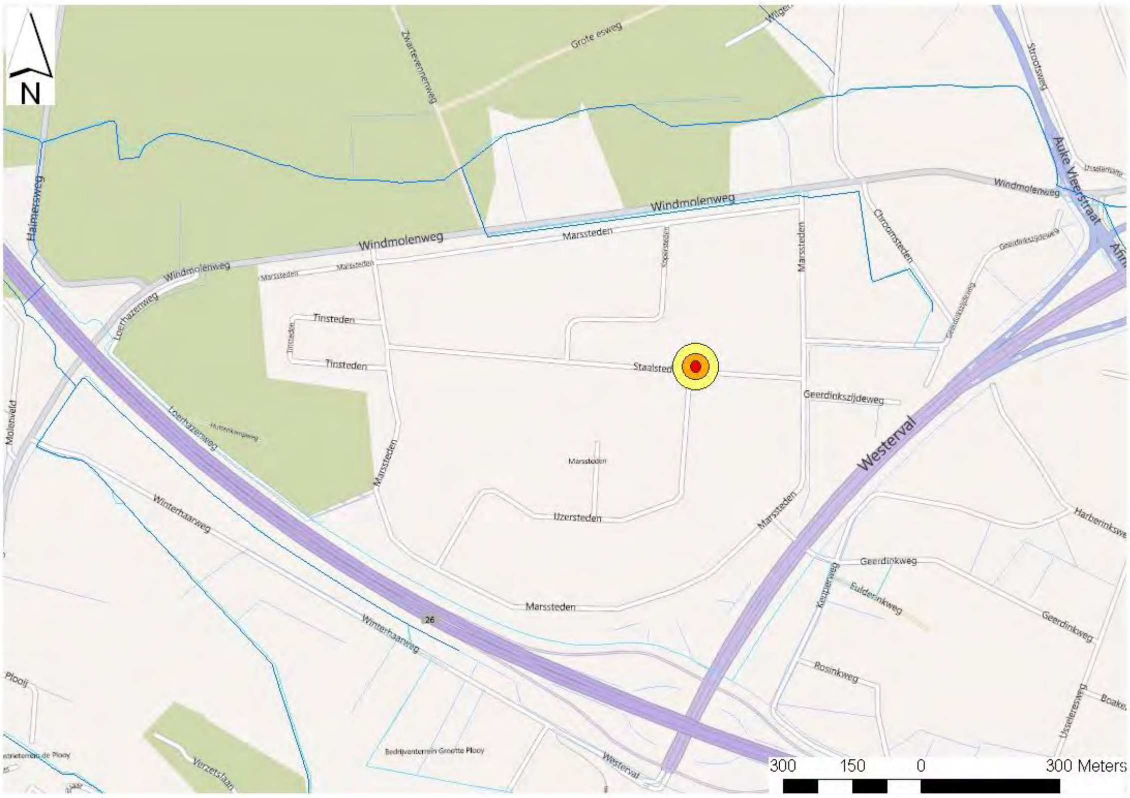


*Figure 7.2: Map of the Marssteden Concession area displaying the area over which gas oil will spread in the phreatic groundwater in case of leakage scenario 8 for cavern 469: spread after 1 week (red), 1 month (orange) and 5 years (yellow).*

# 8 Cavern 472

## 8.1 Status

Cavern 472 contains three wells (472, 473, 474), and is located in the central part of the Marssteden concession (see Figure 2.1), just west of cavern 469. All three wells were drilled in the period between November 1997 and January 1998, and are in good condition, as indicated in Section B4 of the Storage Plan (AkzoNobel, in preparation). Brine production started in July 1998, and stopped in 2011. Span of the cavern is ±170 m in E-W direction (along the line of the cross-section used in the STOMP risk modeling; see section 8.4), and ±80 m in the direction perpendicular to that. Since the final decision on which well will be used for gas oil injection has not been taken, well 473 is assumed to be the gas oil injection well. It is located at the center of the cavern. Distance from well 473 to wells 472 and 474 is 40 m along the line of the cross-section used in the STOMP risk modeling. Distance from the injection well to the edge of the cavern is 70 m to the east and about 100 m to the west. A detailed overview of the cavern and the wells, and its position in relation to the stratigraphy, is included in Appendix B. It is based on the two basic sources of subsurface data that are available: sonar survey data and gamma-ray log data.

Oil storage cavern 469 is located in close proximity to this cavern, at a distance of 124 m, which is still five times more than the width (25m) as required for mechanical stability. Furthermore, brine production cavern 475 is located at a distance of 184m, and is planned to continue producing brine until the end of 2017. However, at this point in time the width of the salt pillar between this cavern and cavern 472 will still be more than 150m, which is six times more than the width (25m) as required for mechanical stability.

## 8.2 Geology

The Main Röt Evaporite A-D members have a total thickness of ±62 m at the location of this cavern, with the base located at a depth of 472 m and the top located at 410 m below the surface. Members A and C have significant thicknesses (respectively 30 m and 23 m), while members B and D are relatively thin (respectively ±5 m and ±4 m). The cavern has a height of max.17 m and is fully situated in the Main Röt A Member (lowermost salt layer). Main Röt Evaporite A-D members are overlain by 13 m of Main Röt E Member, which consists entirely of impermeable anhydrite. Above that another ±163 m of impermeable claystone (Intermediate Röt Claystone and Upper Röt Claystone members) separates the cavern from the more permeable Muschelkalk Formation.

Properties of the subsurface (porosity, permeability) in the immediate vicinity of this cavern are essentially similar to those stated in Table 4.2. Furthermore, one fault is located near this cavern. Fault F1 runs just east of this cavern, it is identified in well 474, and there it cuts out a section of 3.3 m of Muschelkalk (normal fault) at a depth of 140 m below surface. It runs from 480 m below surface (below the cavern) to 80 m below surface, and under the assumption that the position of the fault is correctly interpreted by Geowulf (2010) it actually crosses the cavern. Its throw is estimated by Geowulf (2010) to be ± 6 m at the base of the Main Röt Evaporite member, ± 4 m at the top of the Main Röt Evaporite member, and ± 2 meters at the top of the Muschelkalk. Geowulf base their estimate on interpolated well tops, i.e., no direct observation has been done e.g. from seismic, probably because the fault throw is too small to be seen on seismic (sub-seismic scale). Since fault F1 runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. As mentioned, the possibility that it is in direct contact with the cavern cannot be excluded. However, because the estimated throw is much less than the thickness of the Main Röt Evaporite A-D members, the containment is unlikely to be compromised by this fault.

## 8.3 Volume

The current volume of the cavern is ca. 143,000 $m^3$. It is calculated based on results from sonar (sound navigation and ranging) surveys, which produce a three-dimensional image of the cavern by emitting a sound pulse and recording the time lapse before the pulse, which is reflected by the cavern wall, is received again by the receiver. A layer of brine is left at the bottom of the cavern during storage to shield the gas oil from the permeable sump material and formations below the cavern into which it may potentially migrate. Close inspection of the sonar data reveals that a maximum depth of the oil-brine interface of 462m is allowable without exposing the sump to gas oil, i.e., the cavern can be filled with gas oil up to a level where the oil-brine interface is at 462m depth below surface. At this maximum depth, the volume of gas oil that can be stored is ca. 134,000 $m^3$. Furthermore, the sonar measurements indicate that the roof of the cavern is undulating, which results in so-called “pockets” in the roof in which gas oil gets trapped. A total pocket volume of 2,400 $m^3$ is estimated from sonar (see Appendix B). Mitigation measures to ensure that all the oil that is stored in the cavern is retrieved at the end of the storage period are discussed in section D of the Storage Plan (AkzoNobel, in preparation).

## 8.4 Suitability for storage

This checklist is based on see section 7.4 in Van Duijne et al., 2012.

***Initial conditions and assumptions underlying the containment concept that the cavern must comply with to be suitable for storage***

1. The cavern will be used for storage of gas oil.
   *Valid, see “Voornemen gasolieopslag in zoutcavernes in regio Twente” (AkzoNobel, 2010).*

2. Gas oil will be stored for a maximum period of 30 years.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

3. Gas oil is injected and extracted to the cavern via a well which includes a casing secured by cement and a packer close to the cavern.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B4*

4. Brine is extracted (as gas oil is injected) and injected (as gas oil is extracted) to the cavern by a well.
   *Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

5. The cavern is surrounded by Röt A salt at the sides and above.
   *Valid, see Section 8.1 of this report*

6. The bottom of the cavern is covered by brine as a control measure. This ensures that the gas oil will not reach the bottom of the cavern.

*Valid, see Storage Plan (AkzoNobel, in preparation), Section B1*

7. The whole cycle of injection, storage and extraction is an isolated process with no contamination to the surroundings layers.
   *Valid, see Environmental Impact Assessment (AkzoNobel, in preparation).*

8. The maximum hydraulic conductivity of the salt is $1.6x10^{-5}$ m/d.
   *Valid, see Table 3.1 in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

9. A cavern for which the storage activity is completed is refilled with brine and adheres to the conditions set by the good salt mining practice.
   *Valid, see Storage Plan (AkzoNobel, in preparation), sections D2, D5*

***Unconditional requirements that the cavern must comply with to be suitable for storage***

1. There are no known indicators for unfavorable containment conditions for the specific cavern, such as:

   - Cavern instability
   - Low pressure
   - Leakage
   - Roof collapse
   - Loss of wellhead pressure/failed pressure test
   - Degraded caprock integrity
   - Fractures
   - Presence of unfavorable insoluble layers
   - Filling with aqueous fluids from surrounding rock (capable of leaching salt)
   - Overpressure/overfilling of the cavern/operational procedure
   - Well/casing/plug problems/failure, including blowout.

   *True, these known indicators for unfavorable containment conditions have not occurred for cavern 472.*

2. The cavern is solely situated within the Main Röt Evaporite A rock salt layer.
   *True, see Section 8.1 of this report.*

3. There is no permeable layer within the Main Röt Evaporite salt layers.
   *True, see Section 3.2.1 on stratigraphy in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

4. The cavern is at least overlain by 5 m of Röt C.
   *True, see Section 8.1 of this report.*

5. The roof of the cavern is favorable for gas oil extraction at the end of the storage period.
   *True, see Storage Plan (AkzoNobel, in preparation), Section D4.*

6. The geometry of the cavern does not favor stress concentration.
   *True, see Storage Plan (AkzoNobel, in preparation), Section B5.1*

7. The distance between different salt caverns within a row of caverns is at least 25 m.
   *True, see Section 8.1 of this report.*

8. Parallel rows of caverns are separated by a pillar that is at least 70 m thick, or a report exists which proves that the cavern under investigation is stable.
   *True, see Section 8.1 of this report, and Storage Plan (AkzoNobel, in preparation), Section B5.1.*

9. The pressure in the cavern is equal to or above the hydrostatic pressure.
   *True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

10. The pressure in the cavern does not exceed the minimum in-situ (lithostatic) stress.
    *True, see Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

11. The maximum temperature change due to brine/gas oil injection is 20°C inside the cavern.
    *True, see "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012).*

12. Brine and gas oil is not injected with a temperature below 5 °C.
    *True, see Storage Plan (AkzoNobel, in preparation), Section B1.*

13. There is no vertical casing displacement.
    *True, see Storage Plan (AkzoNobel, in preparation), Section B4.*

14. There is no methane release from the cavern-bearing salt formation.
    *True, no methane release from the cavern-bearing salt formation has been observed during regular brine production.*

***Conditional requirements that must be met for the cavern to be suitable for storage***

1. An MIT (Mechanical Integrity Test) is performed prior to storage to assess the integrity of the wells
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation)*

2. The cementation, casing and packer are of good quality.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

3. The cement in the cement annulus is not degraded and was properly bonded to the casing and the surrounding rock during cementation in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B4.*

4. In case of failure of the casing and/or packer, replacement is installed and checked.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. In case of serious failure of the cement in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern), replacement is installed and checked.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section B5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. Faults present in underlying and/or overlying strata that are possibly in contact with the cavern have a throw that does not exceed the minimum thickness of the Main Röt Evaporite A rock salt layer. Faults that do have a throw that exceeds the minimum thickness of the Main Röt Evaporite A rock salt layer that are possibly in contact with the cavern must be further investigated with the aim to assess their potential to form a leakage path for gas oil from the cavern to shallow depths above the hydrogeological base.
   *One fault could be present in the vicinity of the cavern (GeoWulf, 2010), and is possibly in contact with the cavern, but its throw does not exceed the minimum thickness of the Main Röt A salt (see section 7.2).*

***Monitoring requirements that must be implemented to minimize risk and work towards ALARP***

1. The oil and brine pressure is monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

2. Pressure is monitored in the well annulus.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

3. Composition of annular fluid is monitored for the presence of gas oil components.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

4. The gas oil level is periodically monitored.
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

5. The brine inflow/outflow is monitored (temperature, flow rate, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

6. The gas oil inflow/outflow is monitored (temperature, flow rate, composition, pressure).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

7. The shape and extent of the cavern is monitored using sonar before initial gas oil injection, during storage at intervals of 5 years, and after gas oil extraction.

*Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

8. Casing and cement bond evaluation is performed at regular basis (e.g. every 10 – 20 years).
   *Yes, see Storage Plan (AkzoNobel, in preparation), Section 5.2.2., and Risk Management Plan (AkzoNobel, in preparation).*

## 8.5 Risks

*Model setup*
For the model schematization of the case of cavern 472, the scenario's, boundary conditions, and input parameters of the properties of the subsurface and the water and gas oil are for the largest part taken from the general schematization for the Marssteden area (see Van Duijne et al., 2012, Chapter 4, Table 4.2).

*Table 8.1: Overview of the characteristics of cavern 472 used as input for the cavern-specific STOMP model.*

| **Characteristics for cavern 472** | |
|---|---|
| top Upper Röt Evaporite (average) | 397m below surface |
| thickness Upper Röt Evaporite (average) | 13m |
| top Main Röt Evaporite (average) | 410m below surface |
| thickness Main Röt Evaporite (average) | 62m |
| cavern length | 170m |
| cavern width | 80m |
| cavern height (average) | 17m |
| location gas oil well | centre of cavern |
| fault F1: distance from gas oil well | 70m west of well |
| fault F1: depth range of offset | 78 to >480m below surface |
| old wells: distance from gas oil well | 40m west and east of well |

Case specific input properties are required for the cavern dimensions, the local depth and thickness of Main Röt Evaporite, the local depth and thickness of Upper Röt Evaporite, the position of faults with respect to the cavern, and the occurrence of the "old", permeable wells and their position with respect to the cavern. These specifications for cavern 472 are summarized in Table 8.1(see also sections 8.1 and 8.2). Only the closest well and closest fault are included in the simulation, thus representing the worst case for this cavern.

*Results*
The results of the STOMP modeling for cavern 472 are visualized as a series of two dimensional cross sections in appendix E. In the base case scenario, breach of confinement does not occur; the gas oil remains within the salt cavern for the modeled time span of 150 years. In scenario's 2 to 7 the gas oil does not penetrate more than 5 to 10m into the surrounding rock away from the point of leakage. In none of these scenarios the gas oil LNAPL reaches the fault or the 'old' permeable well. However, in the figure of scenario 7 it can be seen that there is a small effect of the 'old' permeable wells that lie at a distance of 40 m from the gas oil well: due to the lower permeability in the old well, the gas oil LNAPL shows some preferential flow in the direction of the 'old' permeable wells.

In case of leakage above the hydrogeological base (scenario 8), there is a direct risk of contamination of the phreatic groundwater. The characteristics of the gas oil LNAPL are summarized in Table 5.2. The following observations can be made for this scenario:

- After 1 year the gas oil LNAPL reaches the phreatic groundwater level.
- After 1 month the maximum saturation of gas oil in the pores of the sediments is reached. Afterwards, the saturation of gas oil in the pores is reduced due the continued spreading of the LNAPL away from the point of leakage, which causes the gas oil to dilute as it becomes partially trapped in the pores.
- After the gas oil LNAPL has reached the phreatic groundwater, it spreads out on top of the groundwater surface (up to 90 m after 60 years). However, due to the relatively small scale of the phenomenon n comparison to the large scale of the figure, this spread of the LNAPL is not visible in the figures of the STOMP results in the appendix. Therefore, in Figure 8.1 a close-up of the contaminated zone is displayed that shows how the gas oil LNAPL spreads out on top of the phreatic groundwater level in more detail. In Figure 8.2 the lateral spread of the gas oil LNAPL after 1 week, 1 month and 5 years is visualized from the top view over the topography of the Marssteden Concession area.

*Table 8.2 Results for scenario 8 of the cavern-specific STOMP modeling for cavern 472.*

| **Characteristics of gas oil LNAPL** | **scenario 8; time horizons** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 day | 1 week | 1 month | 3 months | 1 year | 5 year | 30 year | 60 year | 150 year |
| top LNAPL (m - surf.) | 20,00 | 18,00 | 14,00 | 8,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| bottom LNAPL (m - surf) | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 22,00 | 20,00 | 18,00 | 14,00 |
| spread LNAPL (m) | 10,00 | 10,00 | 30,00 | 30,00 | 30,00 | 50,00 | 70,00 | 90,00 | 90,00 |
| max. gas oil saturation in LNAPL (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| max. saturation phreatic grw (%) | 0,01 | 0,06 | 0,08 | 0,04 | 0,04 | 0,11 | 0,05 | 0,05 | 0,03 |
| Total oil volume ($m^3$) | 0,10 | 0,62 | 1,49 | 1,49 | 1,48 | 1,47 | 1,47 | 1,46 | 1,46 |

## 8.6 Conclusions

Cavern 472 adheres to the initial conditions and assumptions underlying the containment concept as defined by Deltares/TNO in Van Duijne et al. (2012). Furthermore, both the unconditional and the conditional requirements that must be complied with according to Deltares/TNO (see checklist) are met and the reference material relevant to the checklist was presented. Consequently, the risk associated with storage of gasoil in this cavern, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2012). Information on the effects after breach of confinement for this cavern was presented in the previous paragraph and is briefly summarized below.

When a shift from the base case to an unstable situation occurs, gas oil leaks from the well or the cavern into the surrounding rock. STOMP modeling results indicate that leakage of gas oil from any point below the hydrogeological base does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (fault and/or ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden concession. The gas oil contamination does not come near any surface water body, ecologically valuable area or drinking water abstraction point.

In order to further minimize the risk and work towards ALARP, AkzoNobel is working on a risk management plan that includes effective monitoring and mitigation measures. As part of this plan, AkzoNobel aims to perform the monitoring of the storage system conform the requirements set by Deltares/TNO in their monitoring checklist.

In view of the above, Deltares concludes that cavern 472 is suitable for cyclic (i.e., non-permanent) gas oil storage.

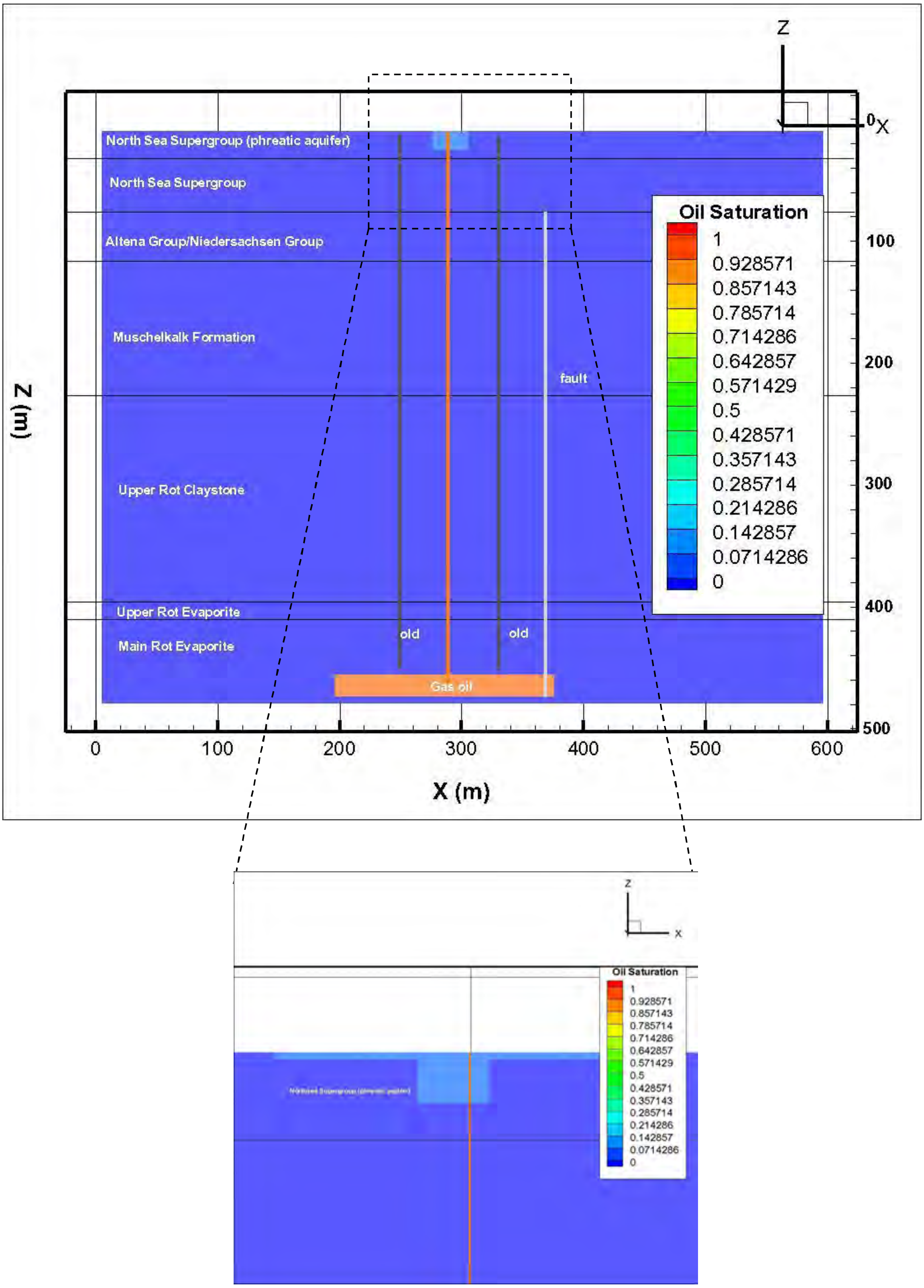


*Figure 8.1: Cavern 472, Scenario 8: leakage from the well above the hydrogeological base. Effects of leakage after 150 year. Lower figure is a close-up of the rectangle in the upper figure, and shows the spread of the gas oil LNAPL on top of the phreatic groundwater level in higher detail.*

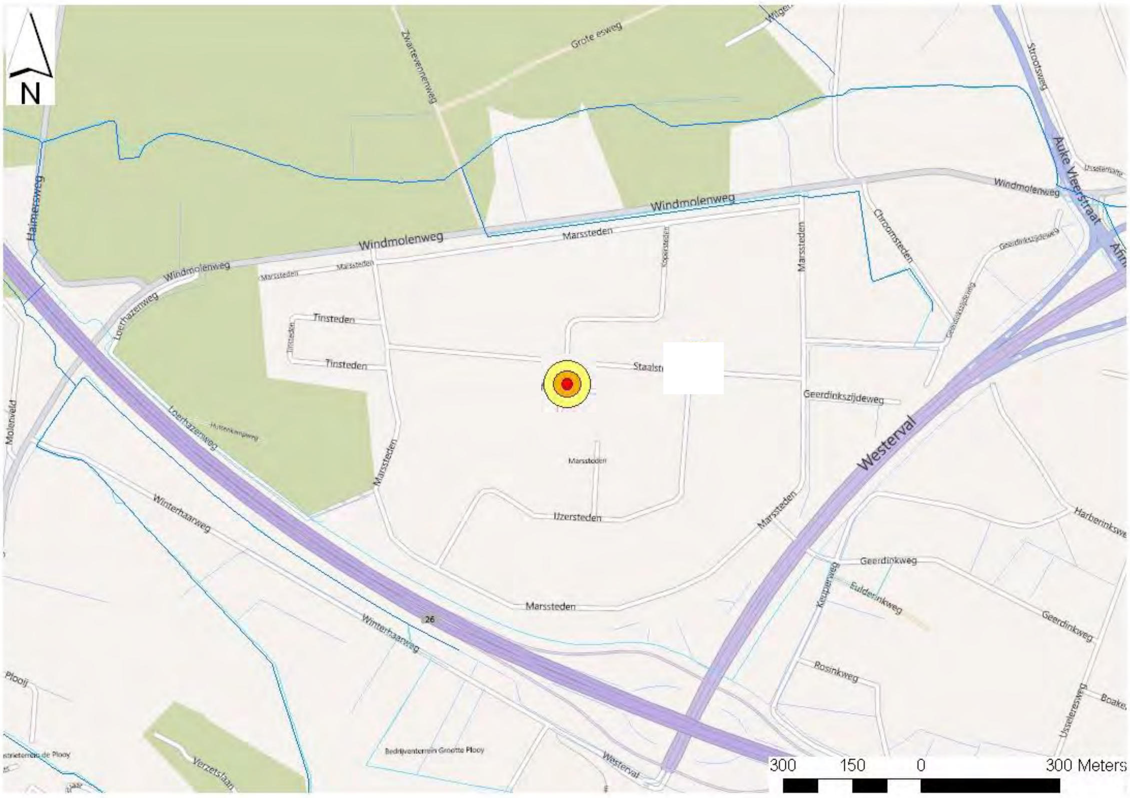


*Figure 8.2: Map of the Marssteden Concession area displaying the area over which gas oil will spread in the phreatic groundwater in case of leakage scenario 8 for cavern 469: spread after 1 week (red), 1 month (orange) and 5 years (yellow).*

# 9 Conclusions of the cavern-specific risk assessment

All four selected caverns comply with the initial conditions and assumptions underlying the containment concept as defined by Deltares/TNO. Furthermore, for all four caverns both the unconditional and the conditional requirements that must be complied with according to Deltares/TNO (see checklist) are met and the reference material relevant to the checklist was presented. Consequently, the risk associated with storage of gasoil in this cavern, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible.

In case of a breach of confinement, gas oil leaks from the well or the cavern into the surrounding rock. From the STOMP modeling results it could be concluded that leakage of gas oil from any point below the hydrogeological base does not pose a risk of contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (faults and ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden Concession area. The gas oil contamination does not come near any surface water body, ecologically valuable area or drinking water abstraction.

In order to further minimize the risk and work towards ALARP, AkzoNobel is working on a risk management plan that includes effective monitoring and mitigation measures. As part of this plan, AkzoNobel aims to perform the monitoring of the storage system conform the requirements set by Deltares/TNO in their monitoring checklist. Furthermore, although the contamination of gas oil in case of a breach of the containment will probably not spread very fast, Deltares strongly advises to prepare remediation of the groundwater and soil surrounding the contaminated area as soon as possible when leakage of gas oil above the hydrogeological base is detected.

In view of the above, Deltares concludes that all four caverns are suitable for cyclic (i.e., non-permanent) gas oil storage for a period of 30 years.

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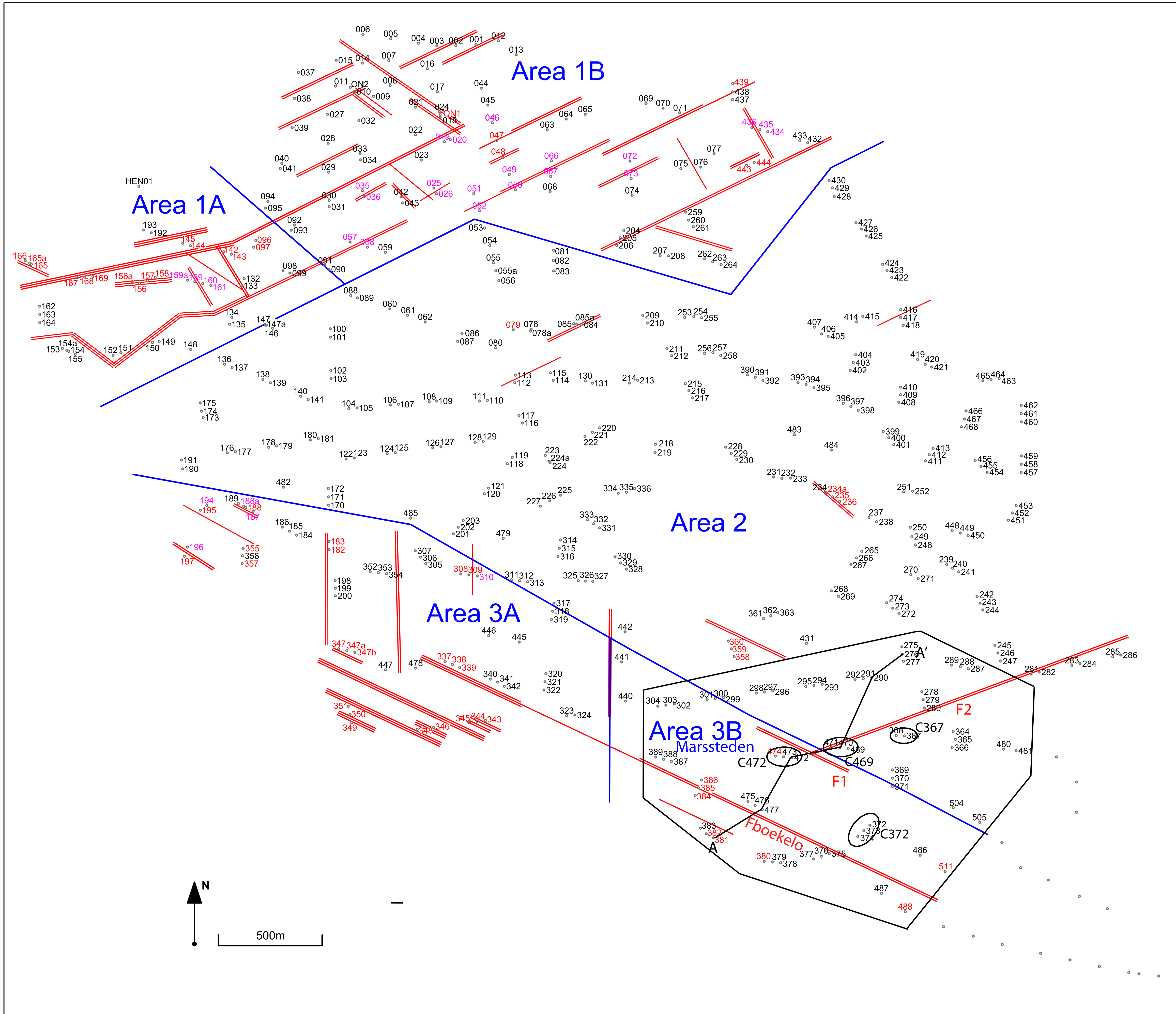
# Appendix A: Local geology of the Marssteden concession

# Map A-2: Tectonic areas and fault zones




Map A-2:
Tectonic areas and fault zones

for detail is referred to the depth maps (Attachment C).

Legend:

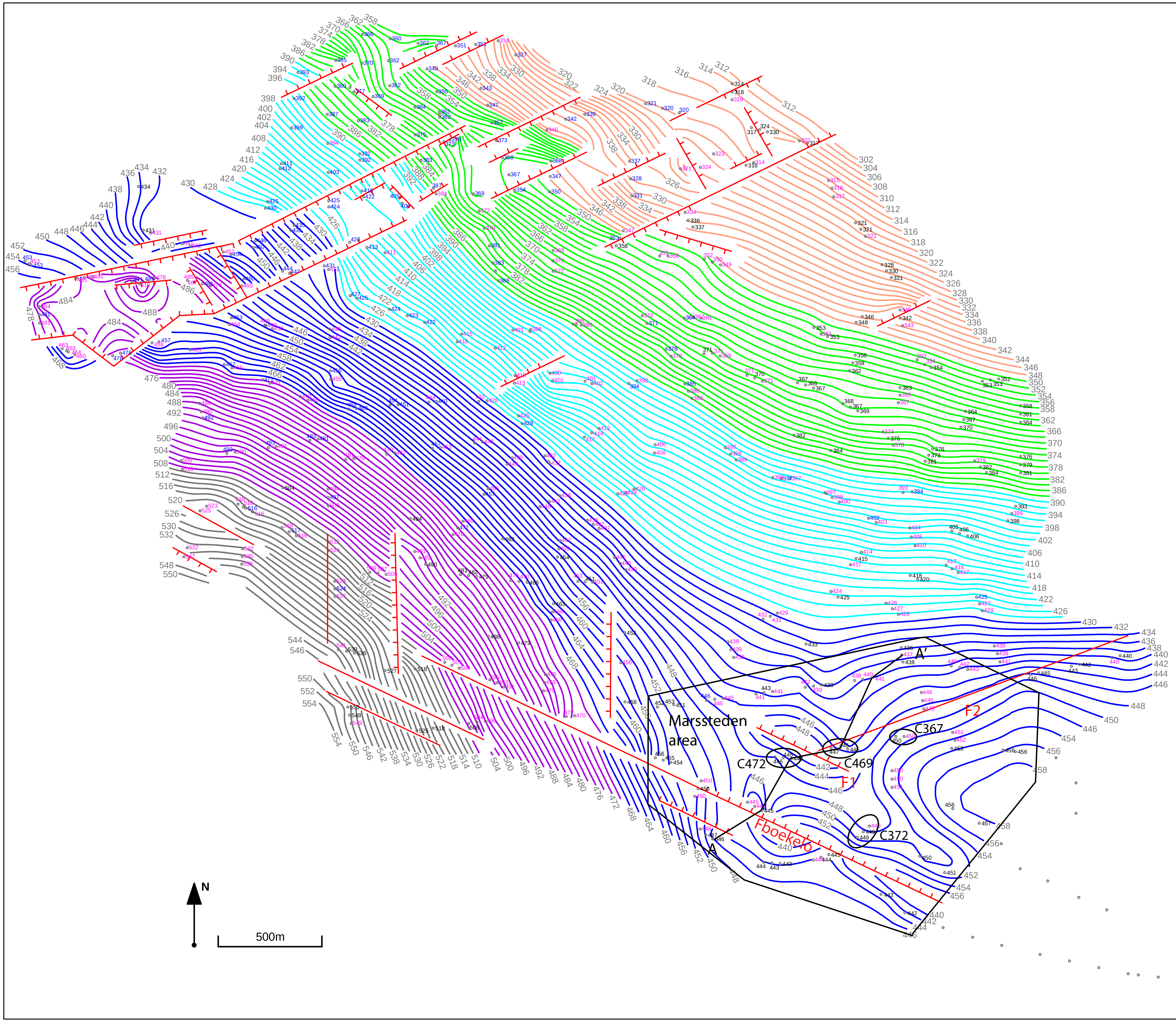
- well location
- 100 well name
- 100 fault identified in well
- 100 fault identified in Series

fault lines with maximum present day offset

- / offset <5m
- // offset 5 - 20m
- /// offset >20m

prepared by:
GEOWULF*Laboratories*
attachment to report GL11.901

Map C-1: Depth Top Solling Fm.: RNSO




Map C-1: Depth Top RNSO

Legend:

- ∘ well location

depth in meters below NAP

- 20.4 source GR log
- 20.4 source 'orig. log' & cored
- 20.4 source base A2 or 'original log' and not cored

isolines (2m interval)

- ≤ 348m
- 350 - 388m
- 390 - 428m
- 430 - 468m
- 470 - 508m
- ≥ 510m

normal fault

- offset
- no offset at this level

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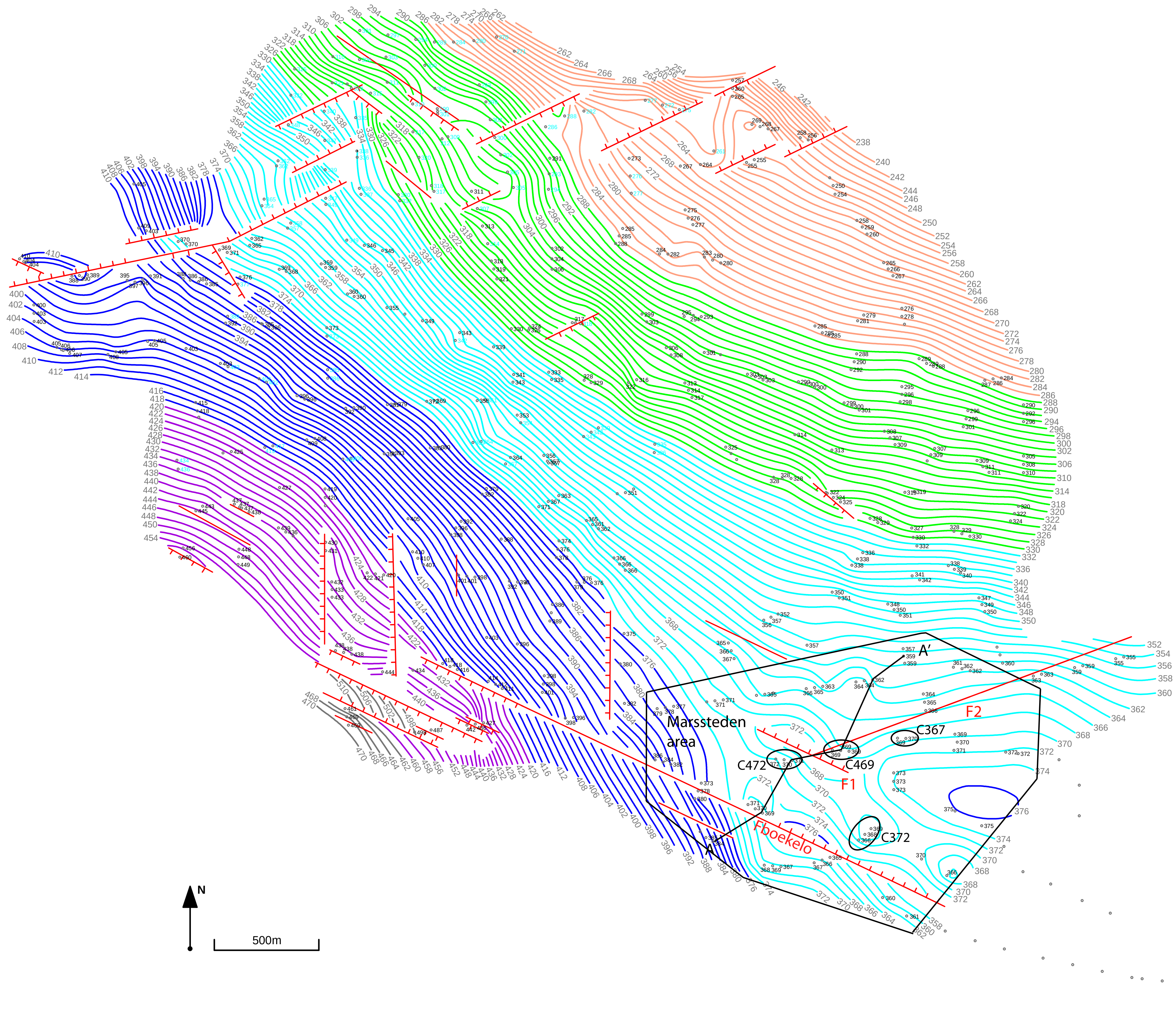
Map C-2: Depth Top Main Röt Evaporite Mb.: RNRO1




Map C-2: Depth Top RNRO1

Legend:

∘ well location

depth in meters below NAP

20.4 source GR log

20.4 derived depth

isolines (2m interval)

- ≤ 286m
- 288 - 330m
- 332 - 374m
- 376 - 418m
- 420 - 460m
- ≥ 462m

normal fault

- offset
- no offset at this level

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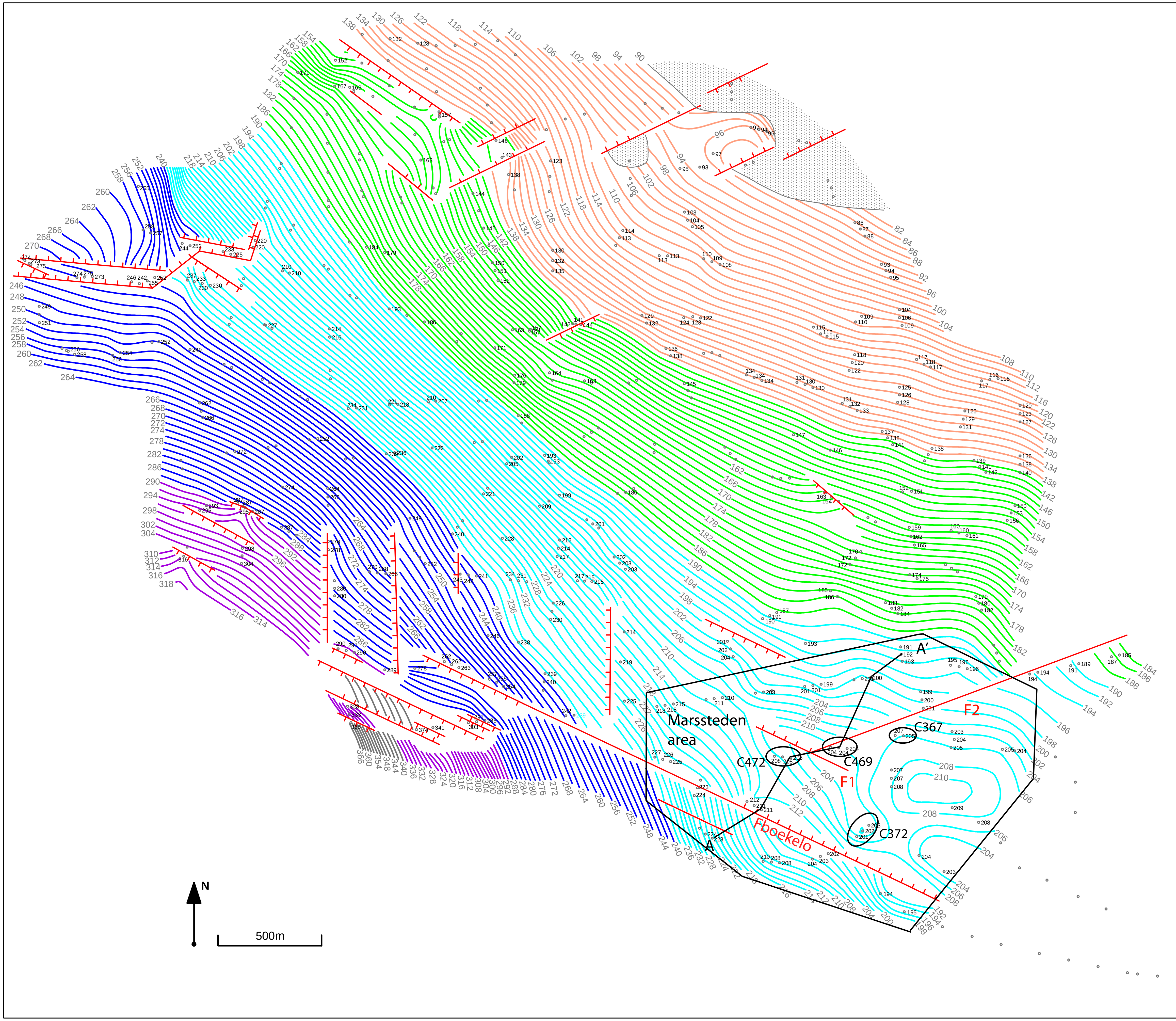


Map C-3: Depth Base RNMU

Legend:

well location

depth in meters below NAP

20.4 source GR log

eroded

isolines (2m interval)

≤ 138m

140 - 188m

190 - 238m

240 - 288m

290 - 338m

≥ 340m

normal fault

offset

no offset at this level

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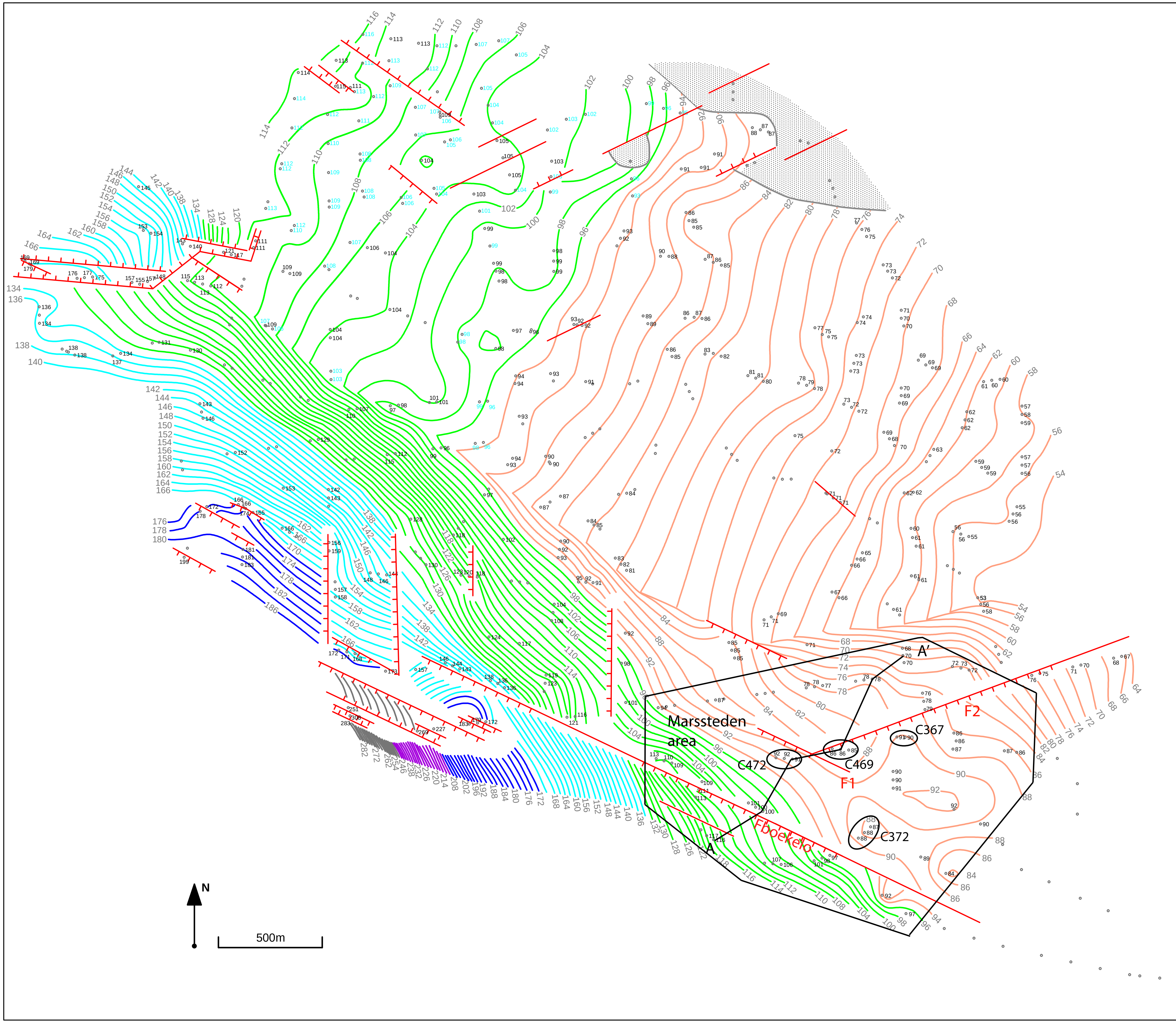
Map C-4: Depth Top MMuschelkalk Fm: RNMU




Map C-4: Depth Top RNMU

Legend:

- well location
- depth in meters below NAP
  - 20.4 source GR log
  - 20.4

isolines (2m interval)

- ≤ 94m
- 96 - 132m
- 134 - 170m
- 172 - 208m
- 210 - 246m
- ≥ 248m

normal fault

- offset
- no offset at this level

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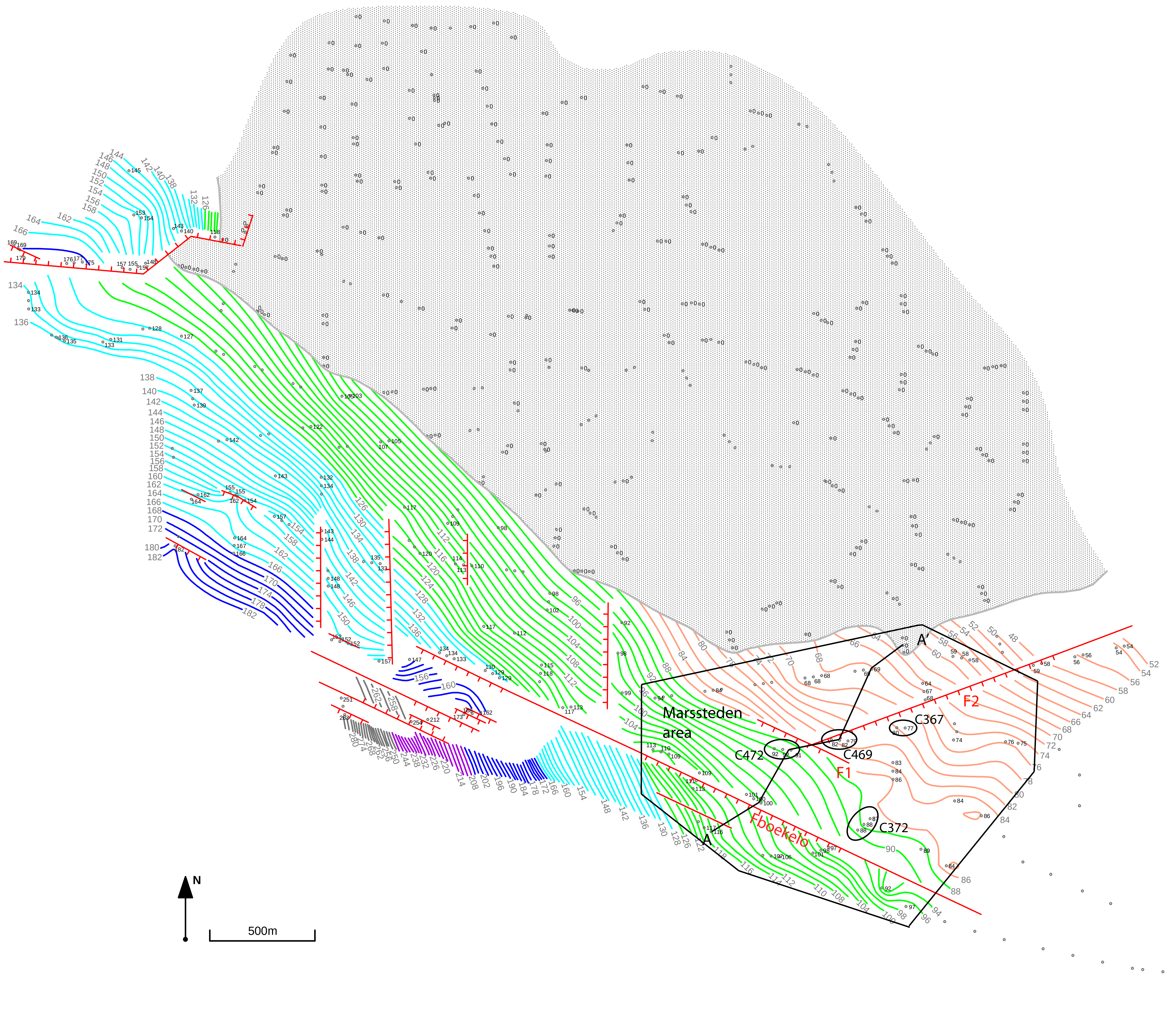
Map C-7: Depth Base Niedersachsen Gp.: SK




Map C-7: Depth Base SK

Legend:

- well location
- depth in meters below NAP
- 20.4 source GR log
- 0 datapoint with no SK
- eroded

isolines (2m interval)

- ≤ 86m
- 88 - 126
- 128 - 166m
- 168 - 206m
- 208 - 246m
- ≥ 248m

normal fault

- offset
- no offset at this level

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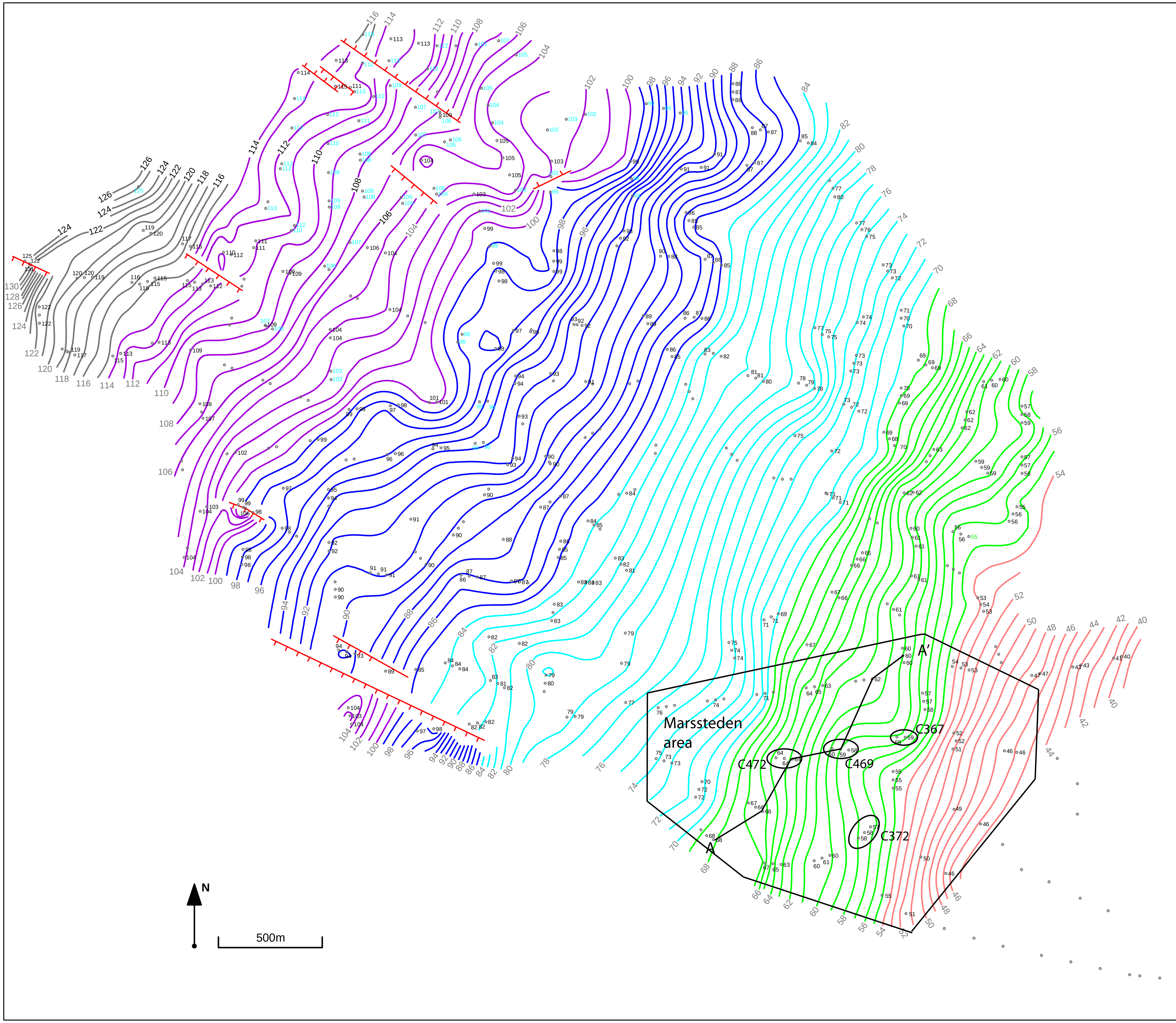


Map C-9: Depth Base N

Legend:

well location

depth in meters below NAP

20.4 source GR log

20.4 source 'boorboek'

isolines (1m interval)

≤ 54m

55 - 69m

70 - 84m

85 - 99m

100 - 114m

≥ 115m

normal fault

offset

no offset at this level

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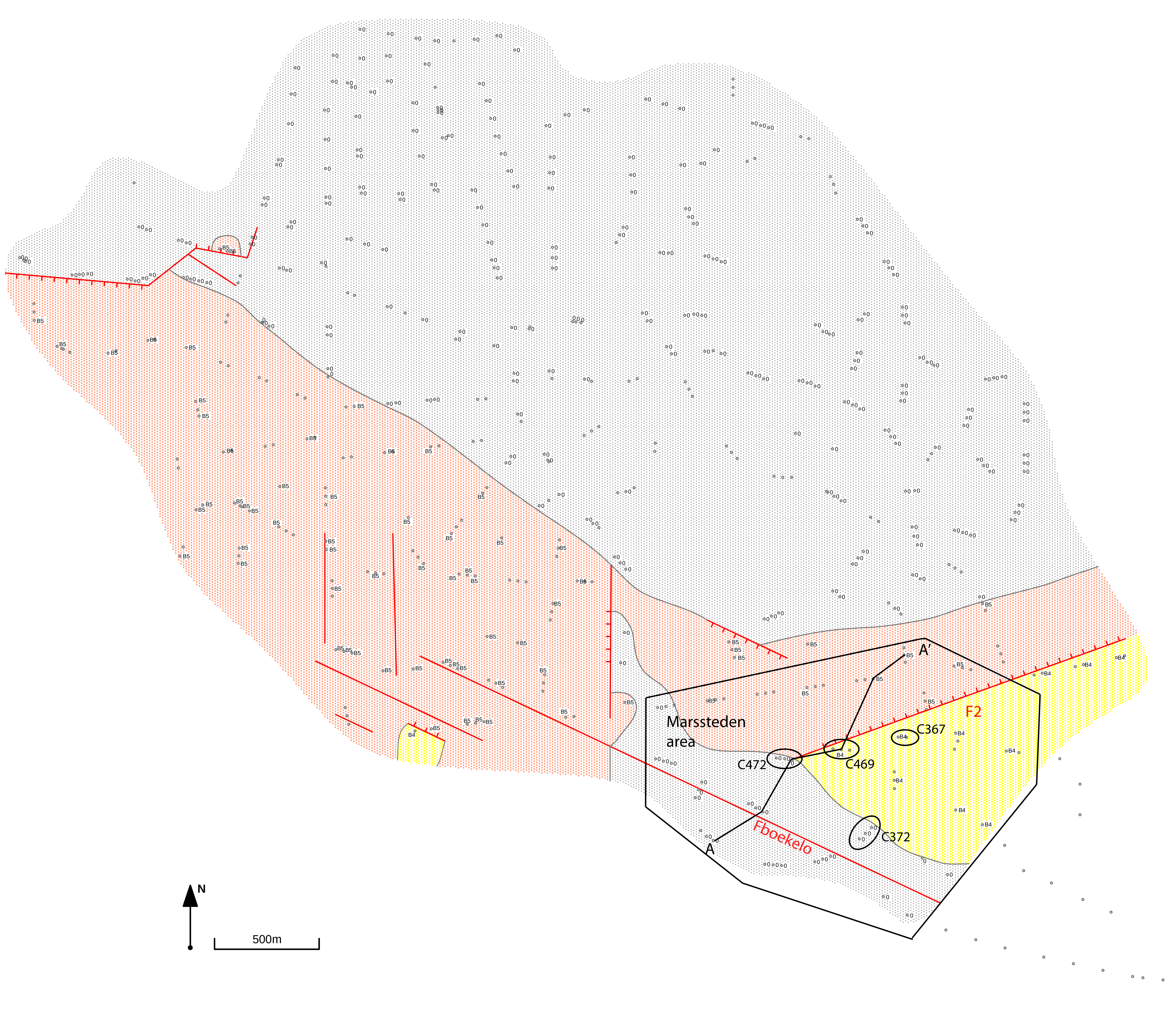


Map C-5:
Subcrop Base AT Unconformity

Legend:

- well location
- datapoint with AT eroded
- AT eroded

Unit underlying Base AT

- unit name
- RNMU-B4
- RNMU-B5

normal fault

- offset
- no offset at this level

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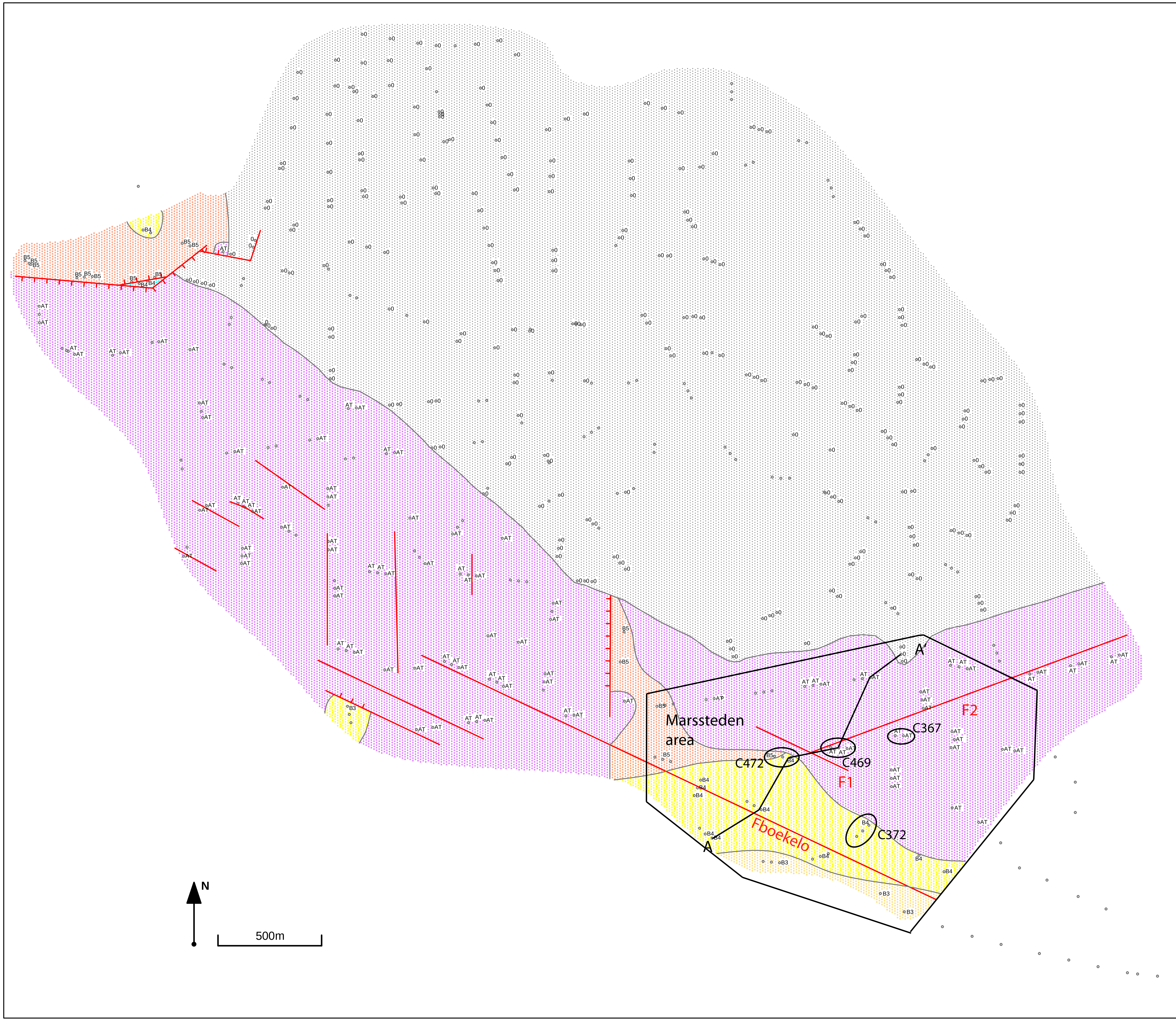


Map C-6:
Subcrop Base SK Unconformity

Legend:

- well location
- datapoint with SK eroded
- SK eroded

Unit underlying base SK

- unit name
- RNMU-B3
- RNMU-B4
- RNMU-B5
- AT

normal fault

- offset
- no offset at this level

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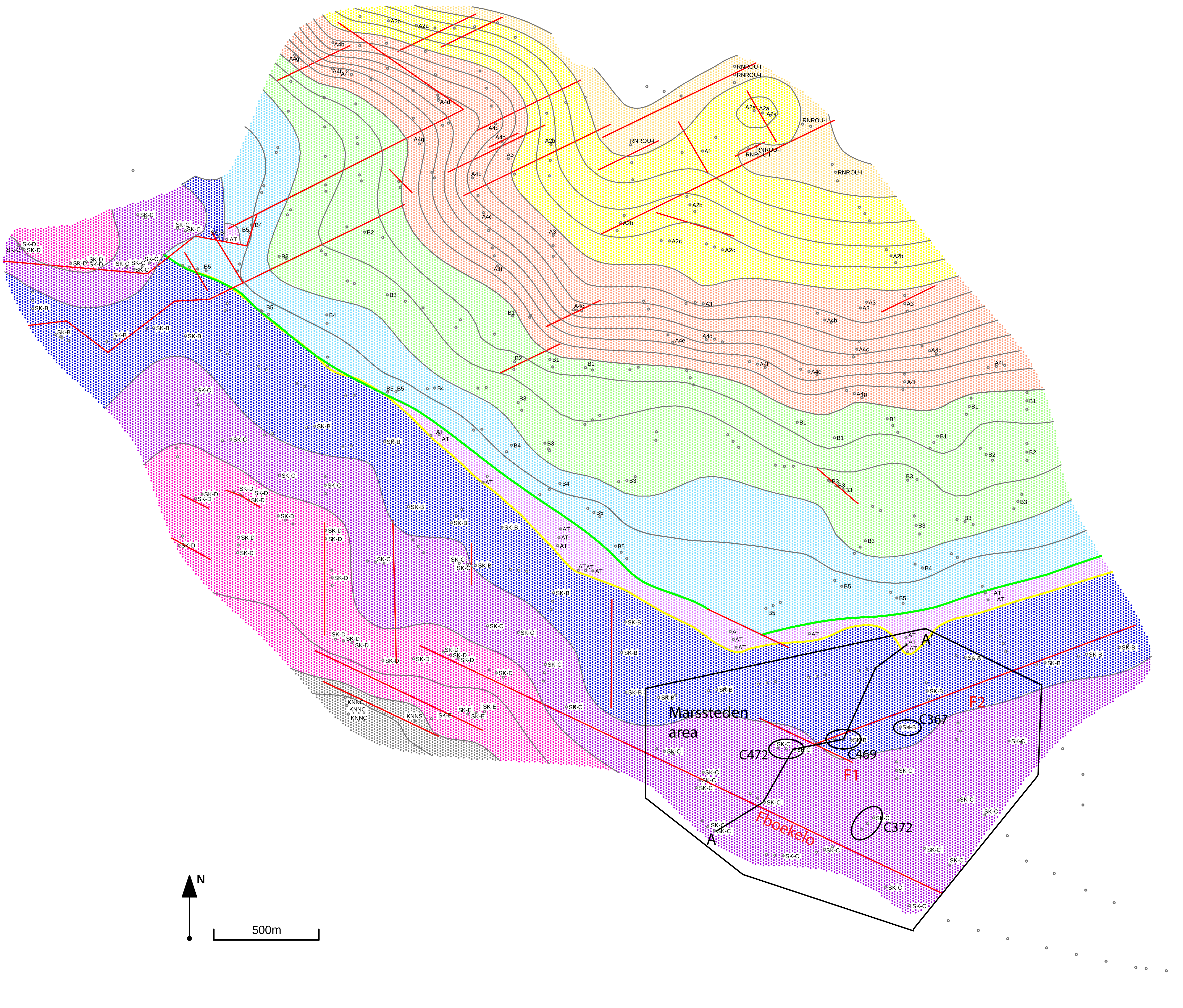


Map C-8:
Subcrop Base N Unconformity
(contour lines not edited to fault lines)

Legend:

- well location
- AT = 0 (see map C-5)
- SK = 0 (see map C-6)

Unit underlying base N

- B unit name

in order of decreasing erosion:

- RNROU
- RNMU-A1 & A2
- RNMU-A3 & A4
- RNMU-B1, B2 & B3
- RNMU-B4 & B5
- AT
- SK-A & B
- SK-C
- SK-D & E
- KN

- main normal fault at deeper level(s)

prepared by:
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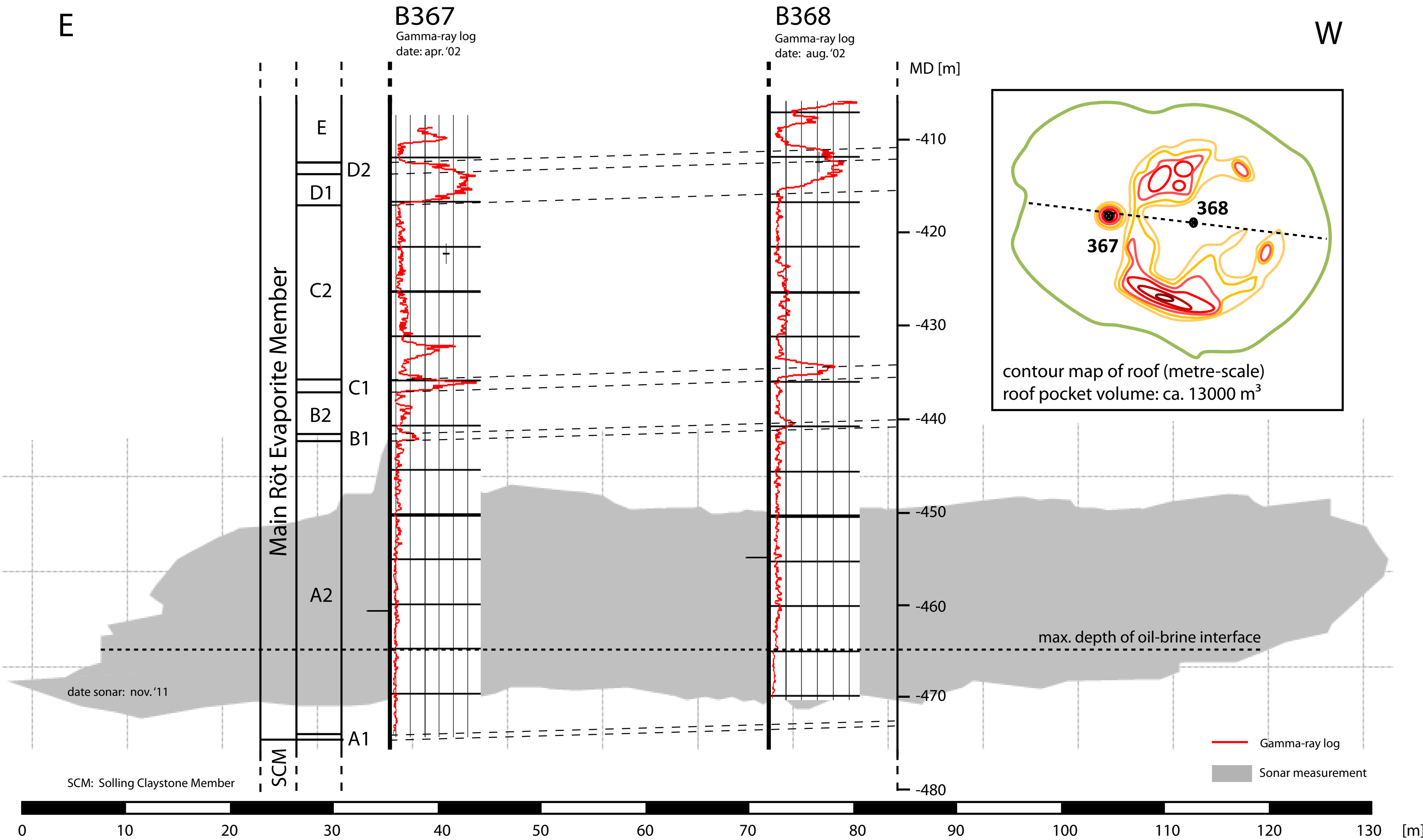
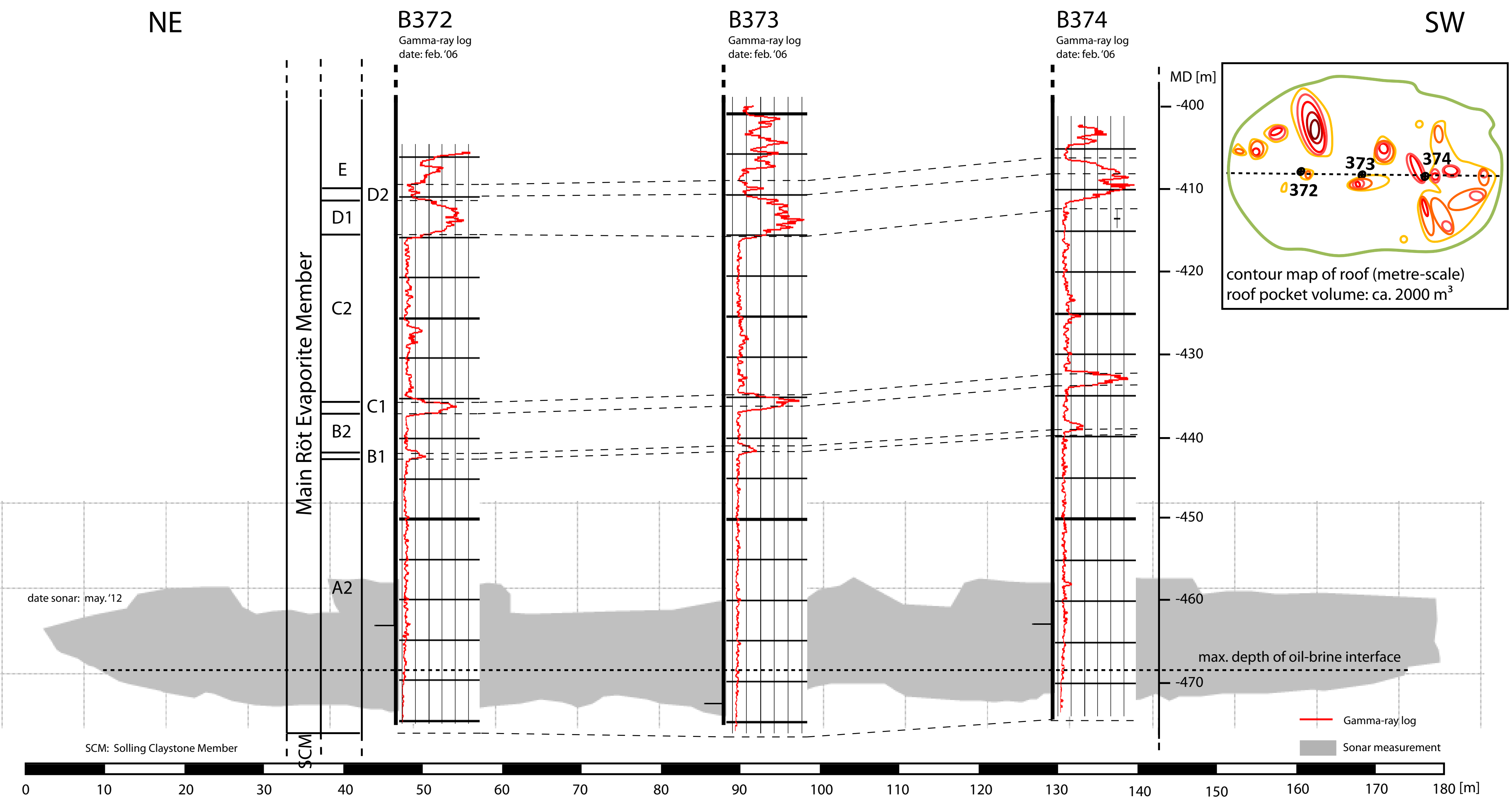
A
A′
B381
B477
B472
B470
B290
B276
SW
NE
<- 273m ->
<- 289m ->
<- 236m ->
<- 372m ->
<- 186m ->
N2
N1
SK
AT
RNMU-B
RNMU-A
RNROU
RNRO2
RNROM
RNRO1
SH
(SH)
EK
(K)
(K)-SH
(K)-(SH)
EK-SH
Fboekelo
F1
F2
AkzoNobel
LEGEND

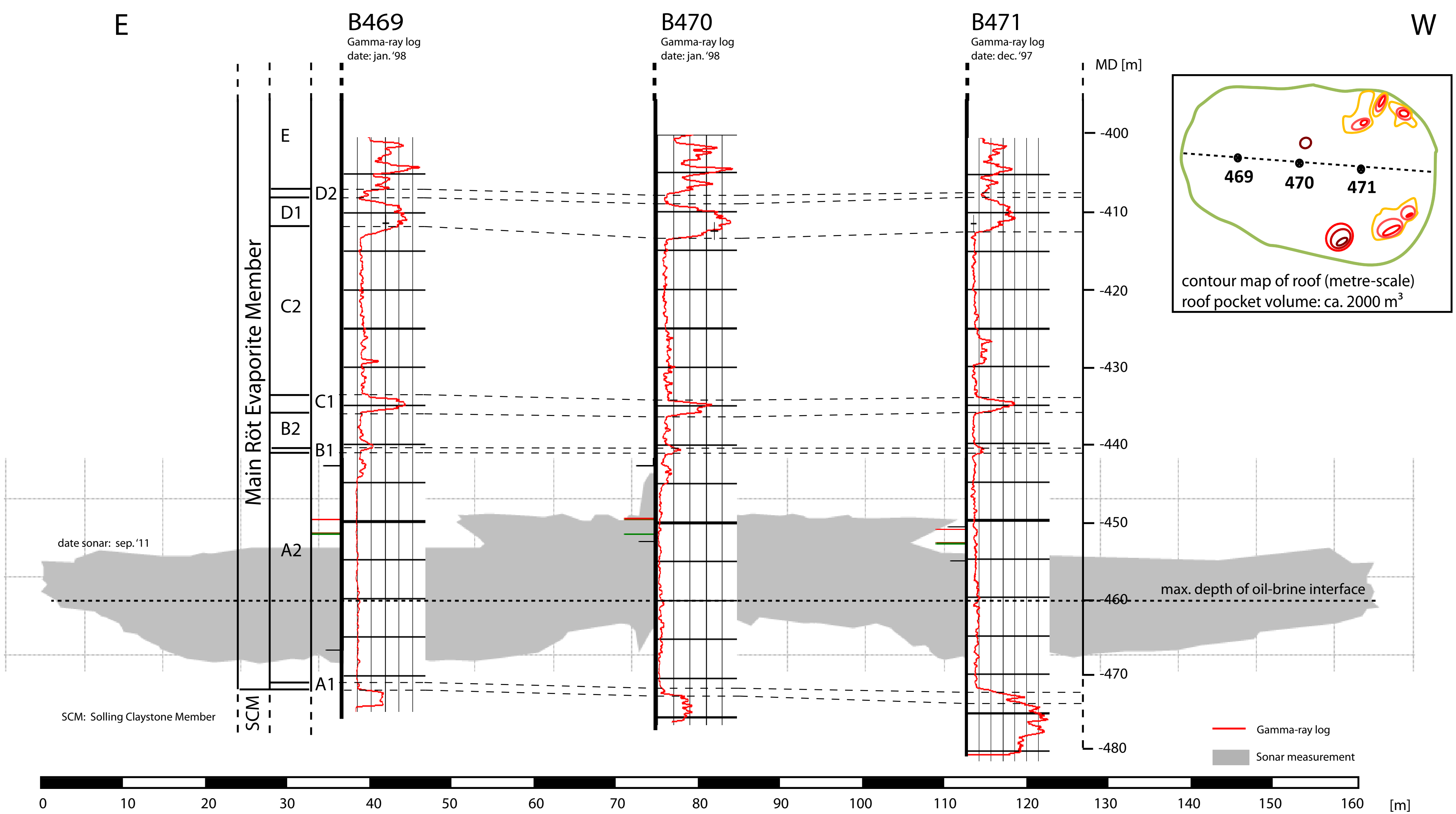
# Appendix B: Geometry and volumes of selected caverns



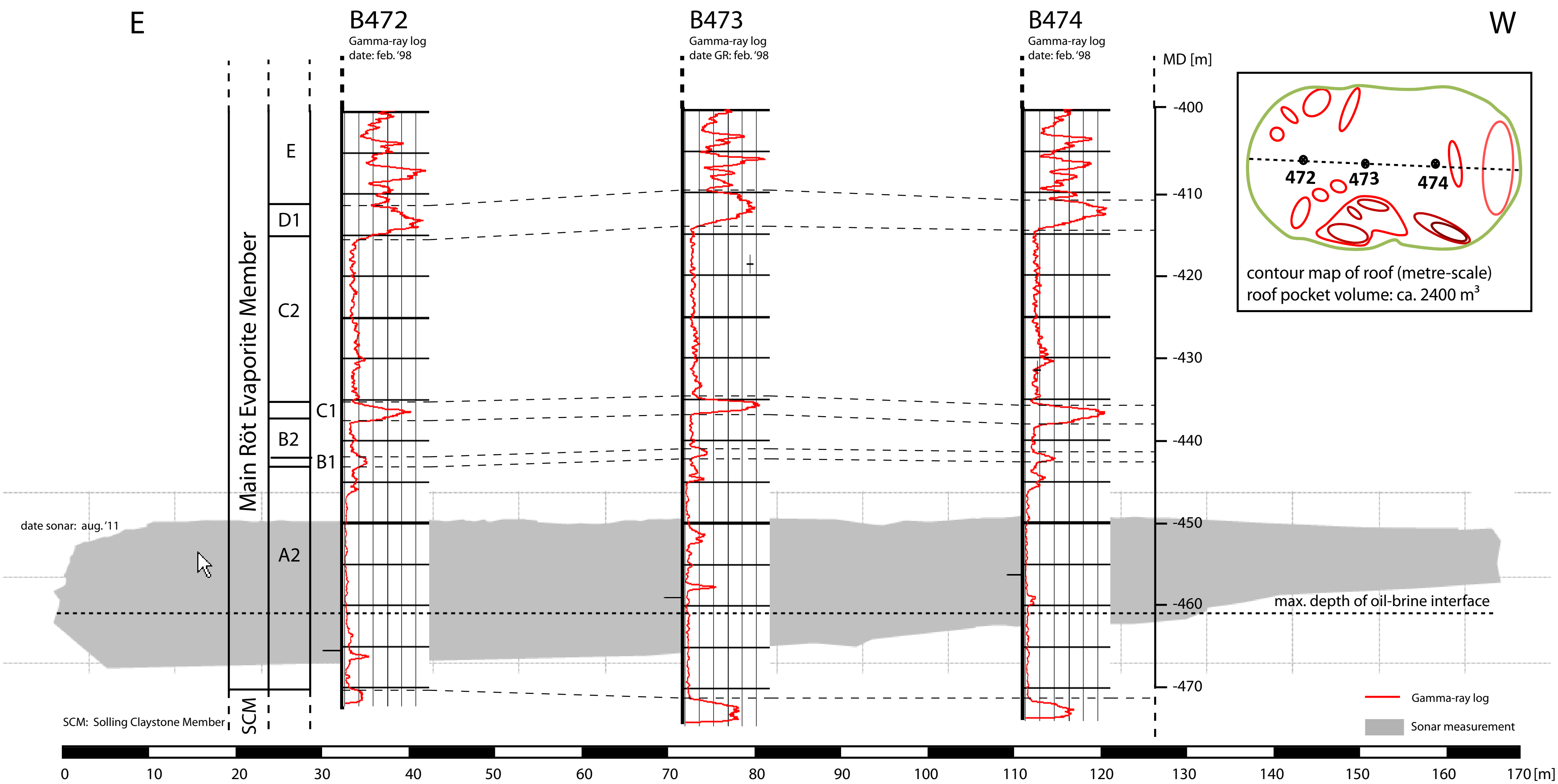
E
W
B367
Gamma-ray log
date: apr. '02
B368
Gamma-ray log
date: aug. '02
MD [m]
Main Röt Evaporite Member
E
D2
D1
C2
C1
B2
B1
A2
A1
SCM
-410
-420
-430
-440
-450
-460
-470
-480
max. depth of oil-brine interface
date sonar: nov. '11
SCM: Solling Claystone Member
0
10
20
30
40
50
60
70
80
90
100
110
120
130
[m]
368
367
contour map of roof (metre-scale)
roof pocket volume: ca. 13000 m³
Gamma-ray log
Sonar measurement



NE
B372
Gamma-ray log
date: feb. '06
B373
Gamma-ray log
date: feb. '06
B374
Gamma-ray log
date: feb. '06
SW
MD [m]
-400
-410
-420
-430
-440
-450
-460
-470
contour map of roof (metre-scale)
roof pocket volume: ca. 2000 m³
372
373
374
Main Röt Evaporite Member
E
D2
D1
C2
C1
B2
B1
A2
SCM
date sonar: may. '12
max. depth of oil-brine interface
SCM: Solling Claystone Member
Gamma-ray log
Sonar measurement
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180 [m]



E
W
B469
Gamma-ray log
date: jan.'98
B470
Gamma-ray log
date: jan.'98
B471
Gamma-ray log
date: dec.'97
MD [m]
Main Röt Evaporite Member
SCM
E
D2
D1
C2
C1
B2
B1
A2
A1
date sonar: sep.'11
max. depth of oil-brine interface
SCM: Solling Claystone Member
-400
-410
-420
-430
-440
-450
-460
-470
-480
469
470
471
contour map of roof (metre-scale)
roof pocket volume: ca. 2000 m³
Gamma-ray log
Sonar measurement
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
[m]



E
W
B472
Gamma-ray log
date: feb. '98
B473
Gamma-ray log
date GR: feb. '98
B474
Gamma-ray log
date: feb. '98
MD [m]
-400
-410
-420
-430
-440
-450
-460
-470
Main Röt Evaporite Member
E
D1
C2
C1
B2
B1
A2
SCM
SCM: Solling Claystone Member
date sonar: aug. '11
max. depth of oil-brine interface
472
473
474
contour map of roof (metre-scale)
roof pocket volume: ca. 2400 m³
Gamma-ray log
Sonar measurement
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170 [m]

# Appendix C: STOMP model results for cavern 367

The following figures are shown in this appendix:

Scenario 1: no loss of containment / breach of confinement.
Effects of leakage after 150 years

Scenario 2: leakage from cavern in Röt Claystone.
Effects of leakage after 150 years

Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity.
Effects of leakage after 150 years

Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation.
Effects of leakage after 150 years

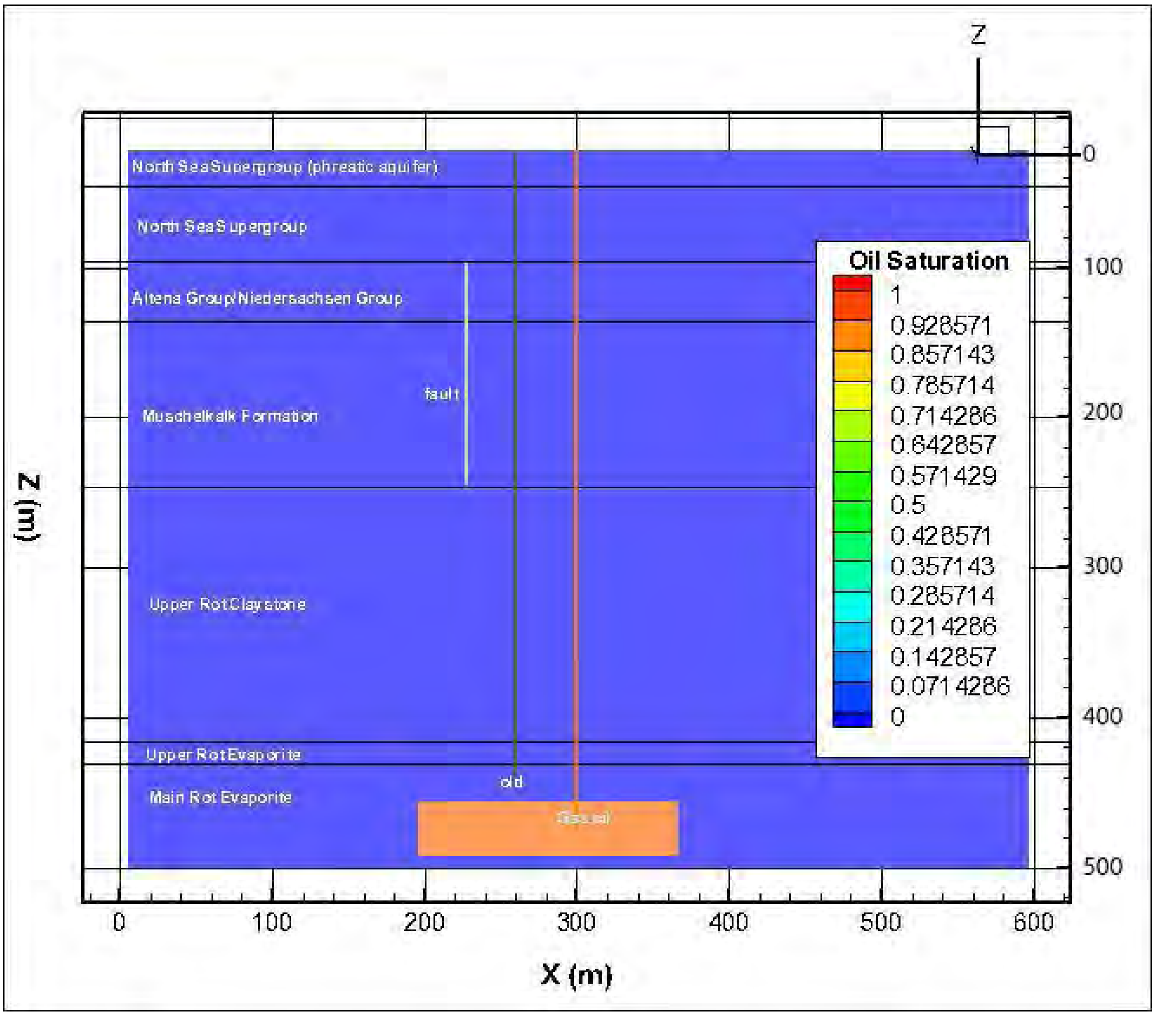
Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup
Effects of leakage after 150 years

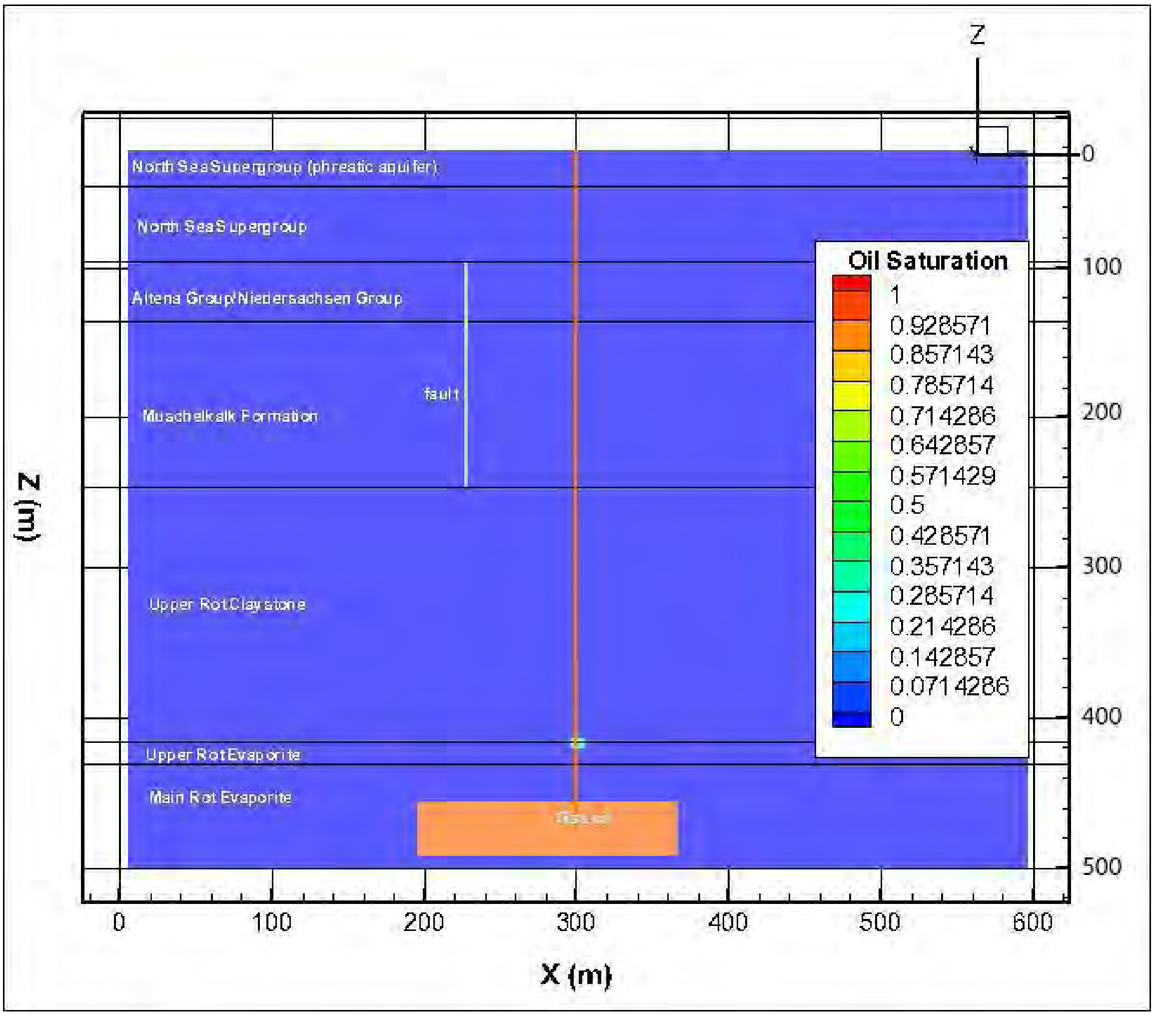
Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 8: leakage from well above hydrogeological base
Effects of leakage after 1 week, 1 month, 3 months, 1 years, 5 years, 30 years, 60 years, 150 years

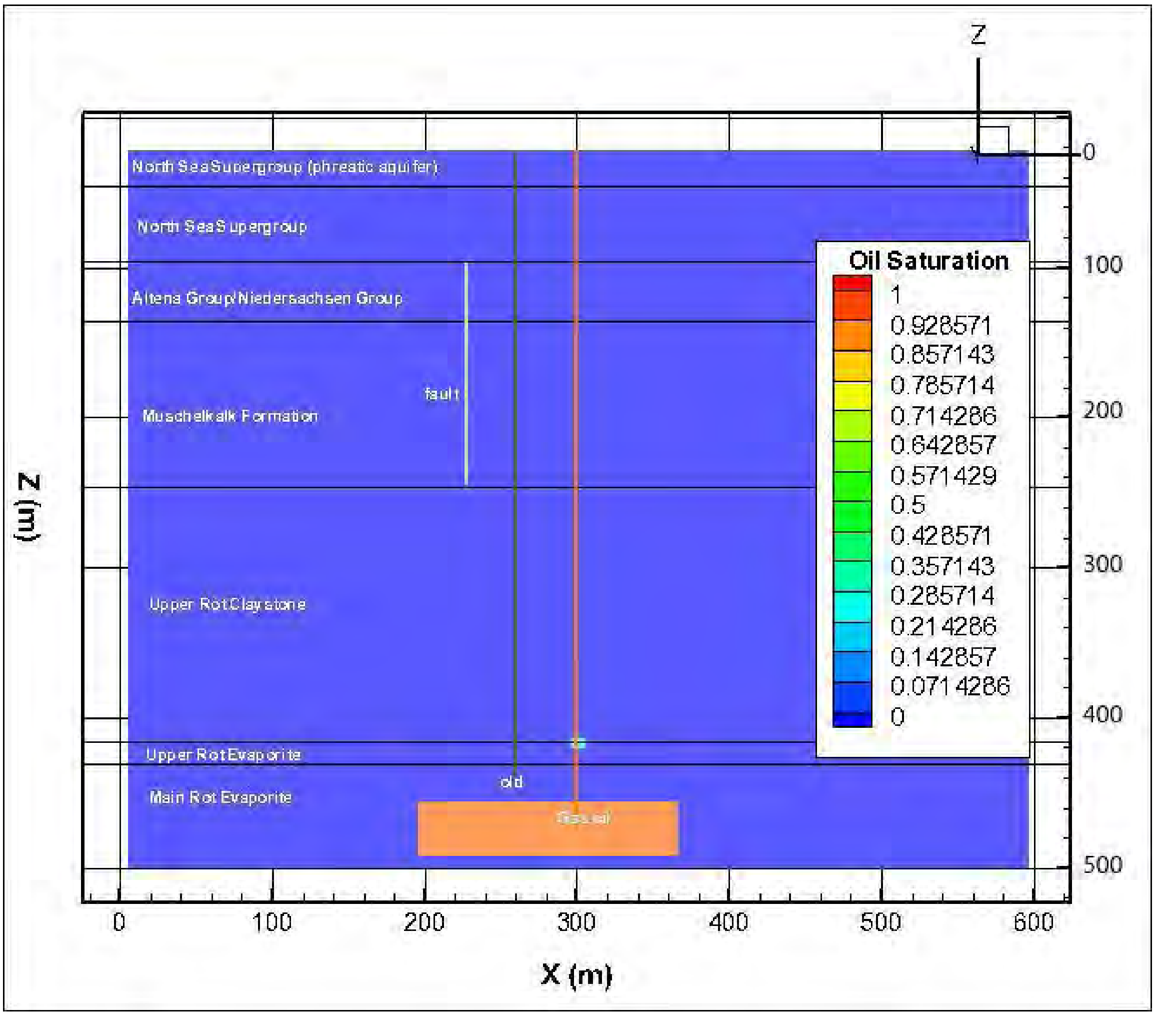
**Cavern 367-368, Scenario 1: no loss of containment / breach of confinement. Effects of leakage after 150 years.**



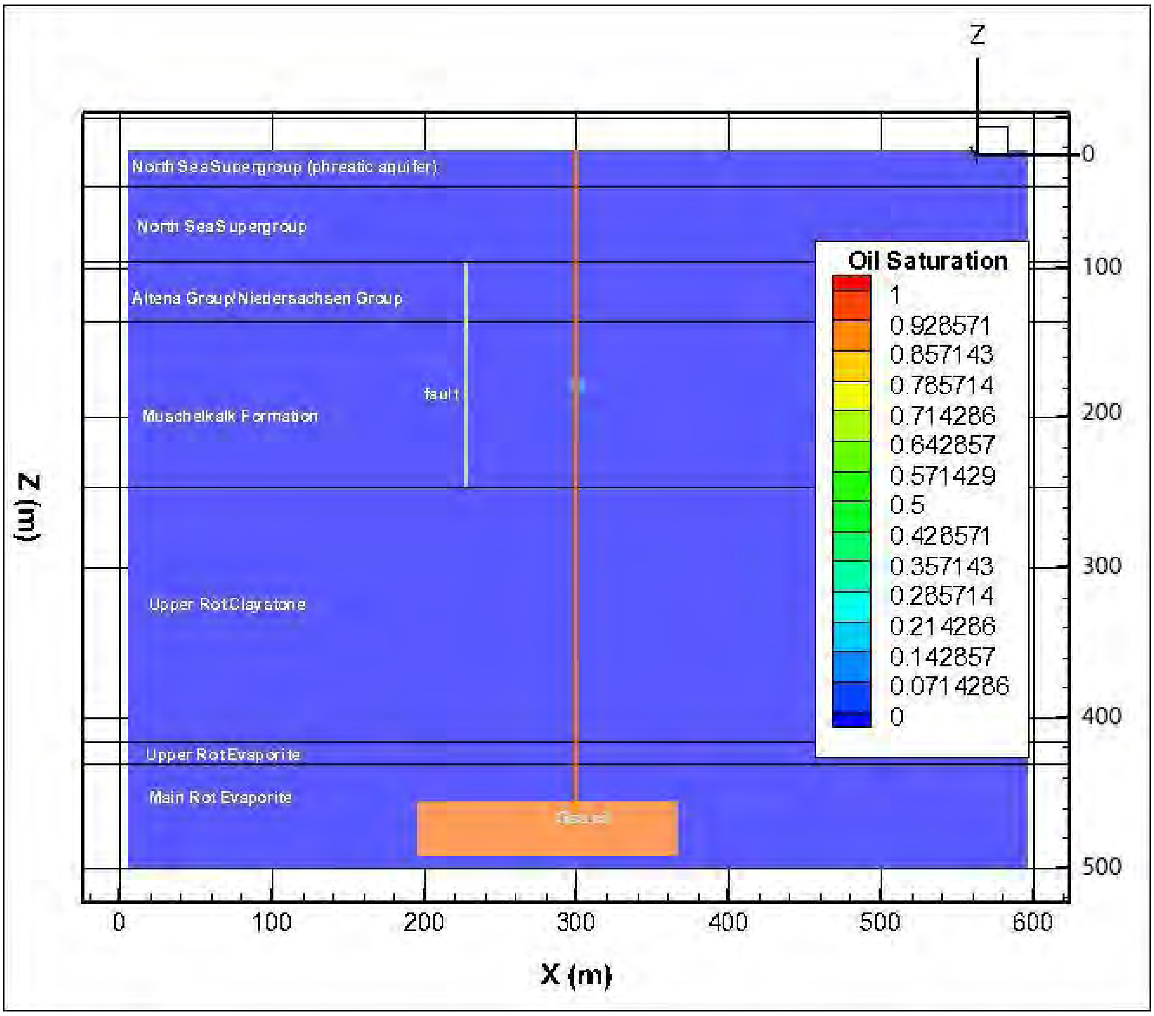
**Cavern 367-368, Scenario 2: leakage from cavern in Röt Claystone. Effects of leakage after 150 years.**



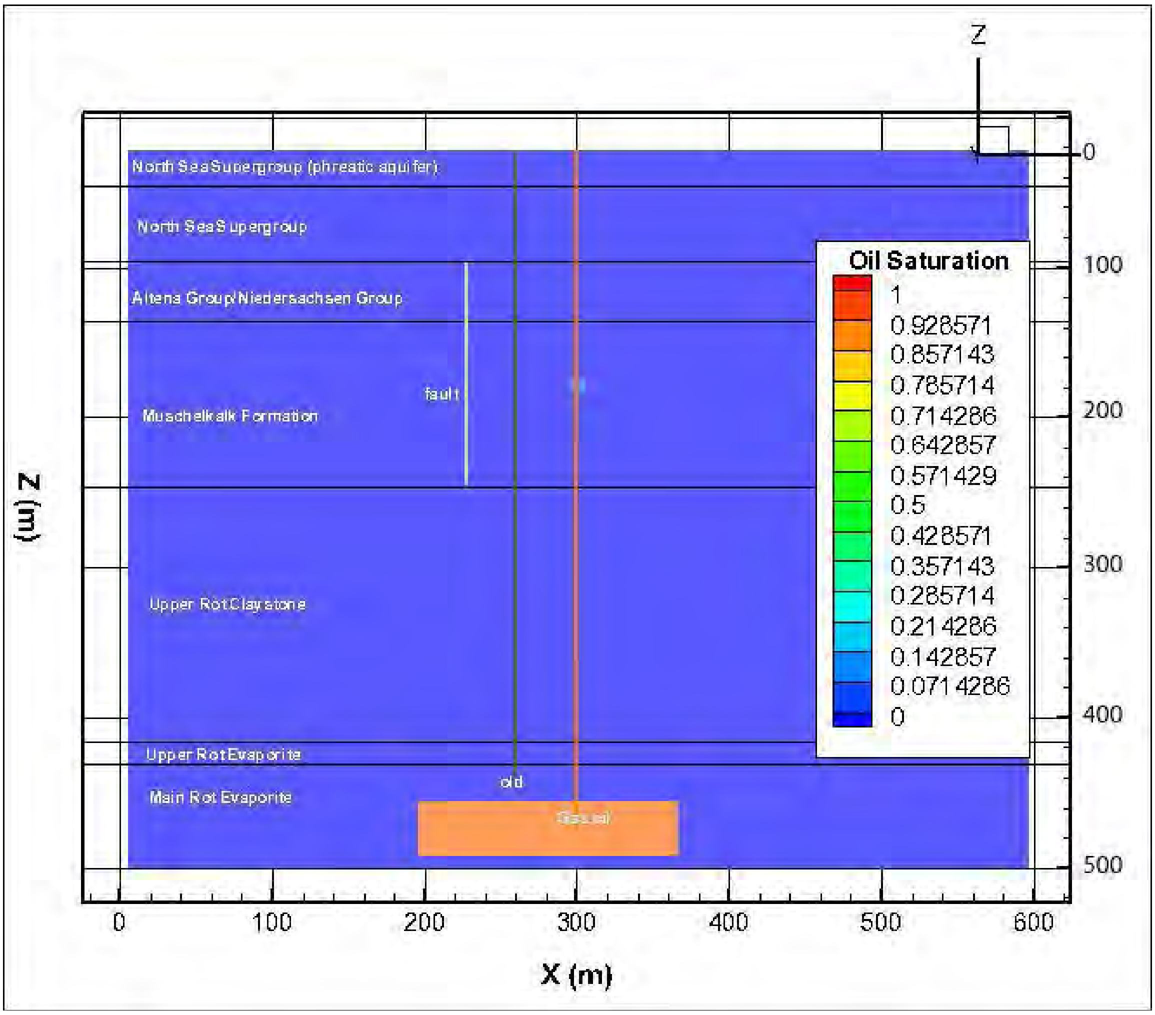
**Cavern 367-368, Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity. Effects of leakage after 150 years.**



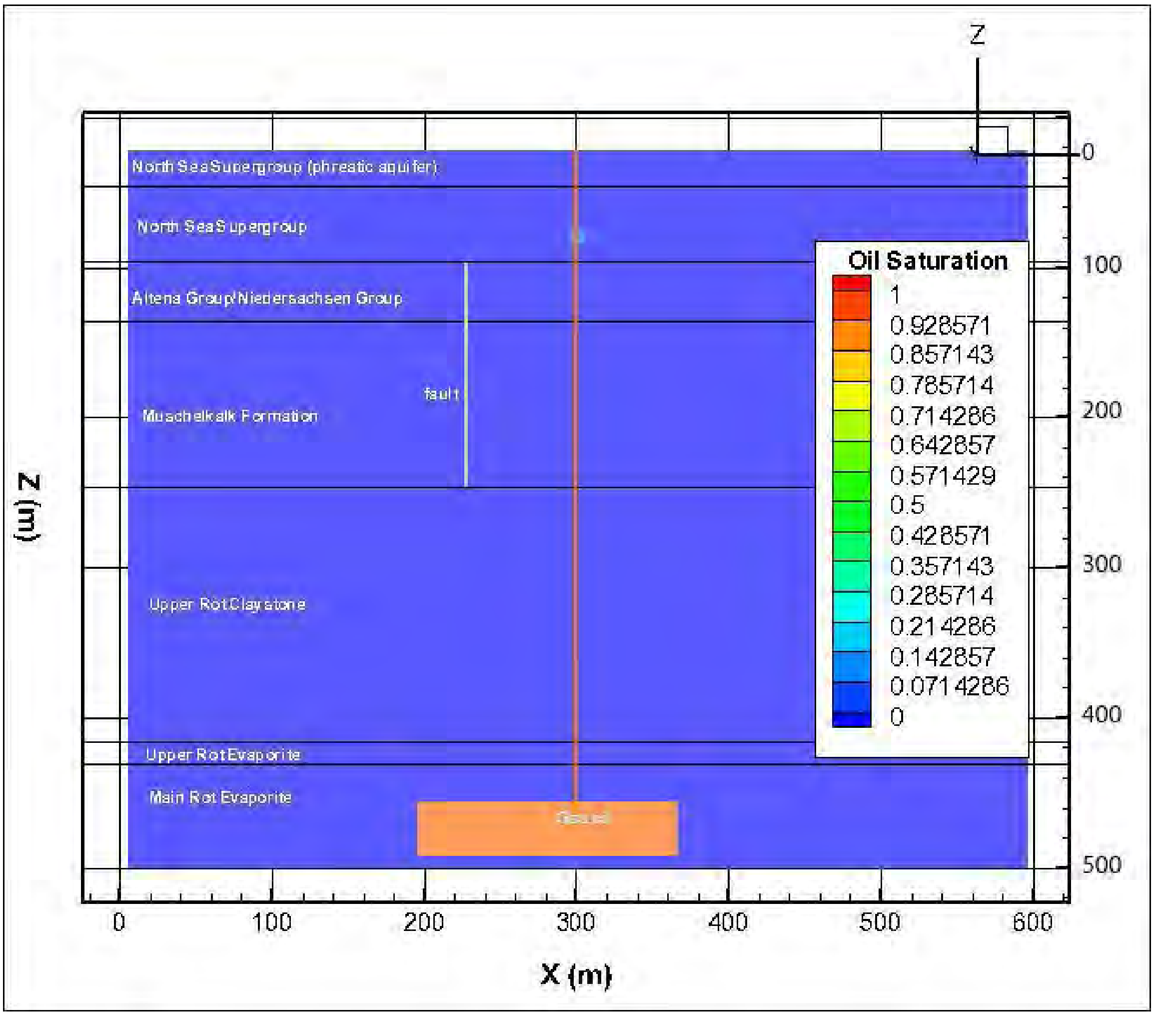
**Cavern 367-368, Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation. Effects of leakage after 150 years.**



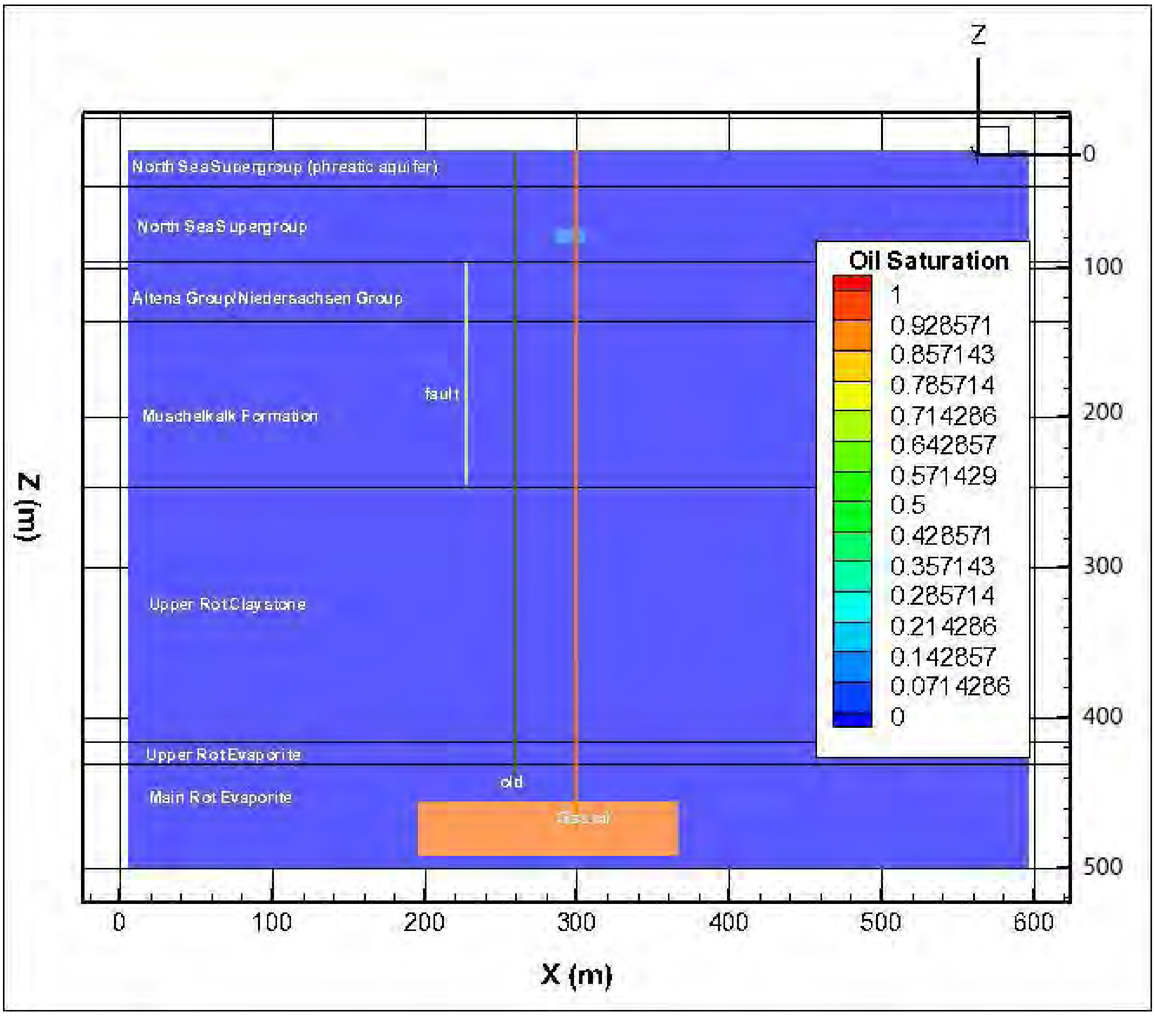
**Cavern 367-368, Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years.**



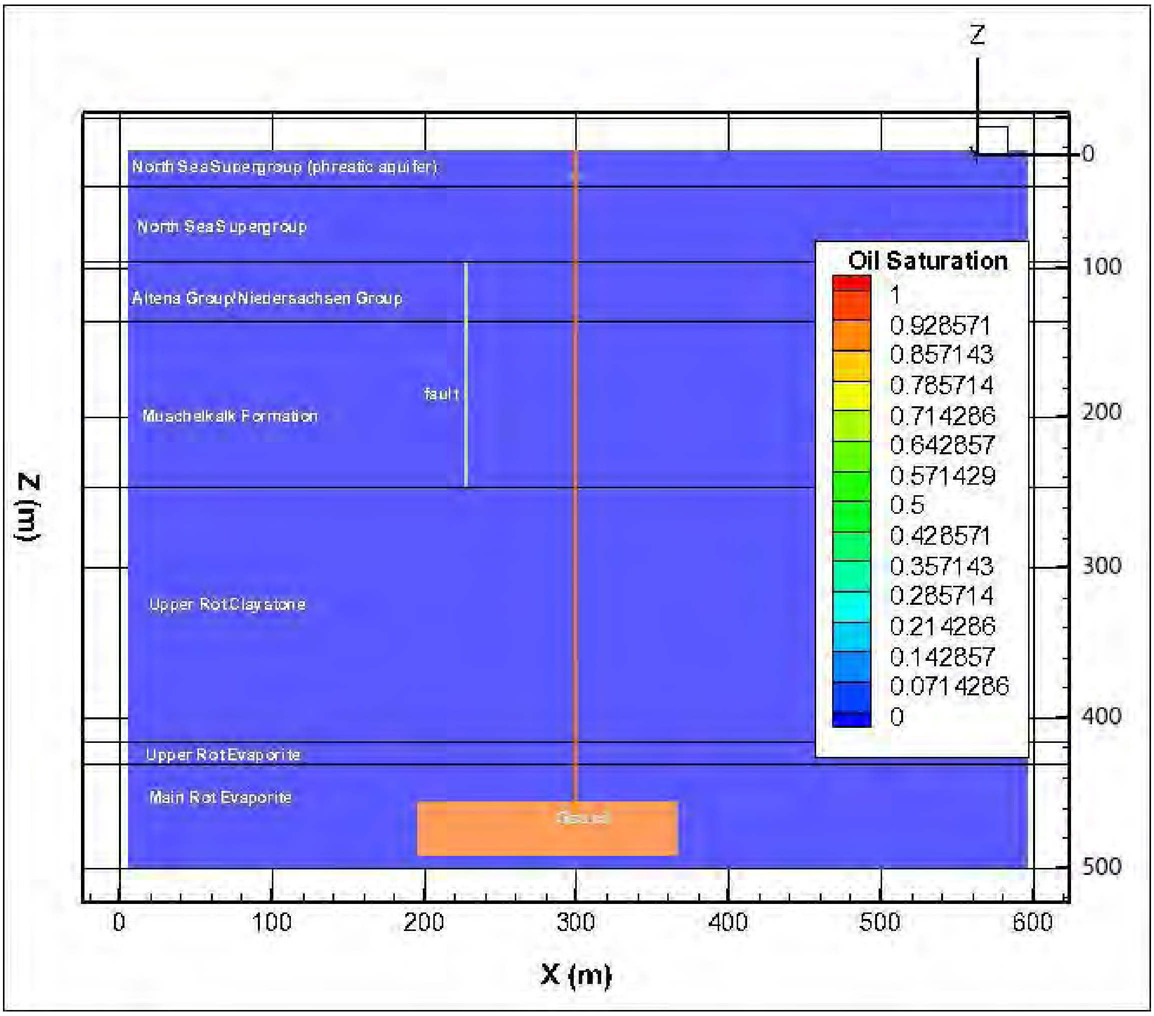
**Cavern 367-368, Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup. Effects of leakage after 150 years.**



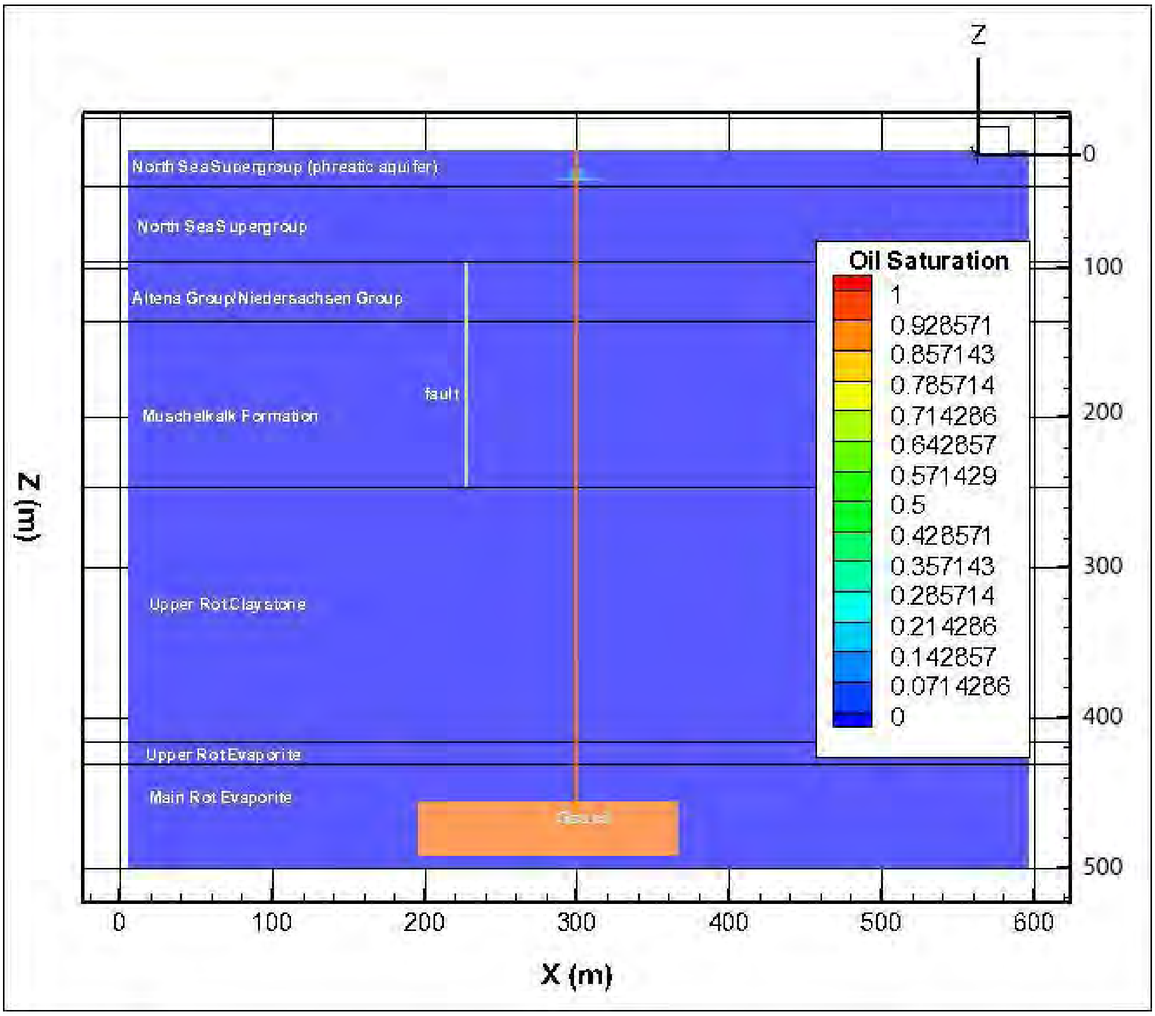
**Cavern 367-368, Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years.**



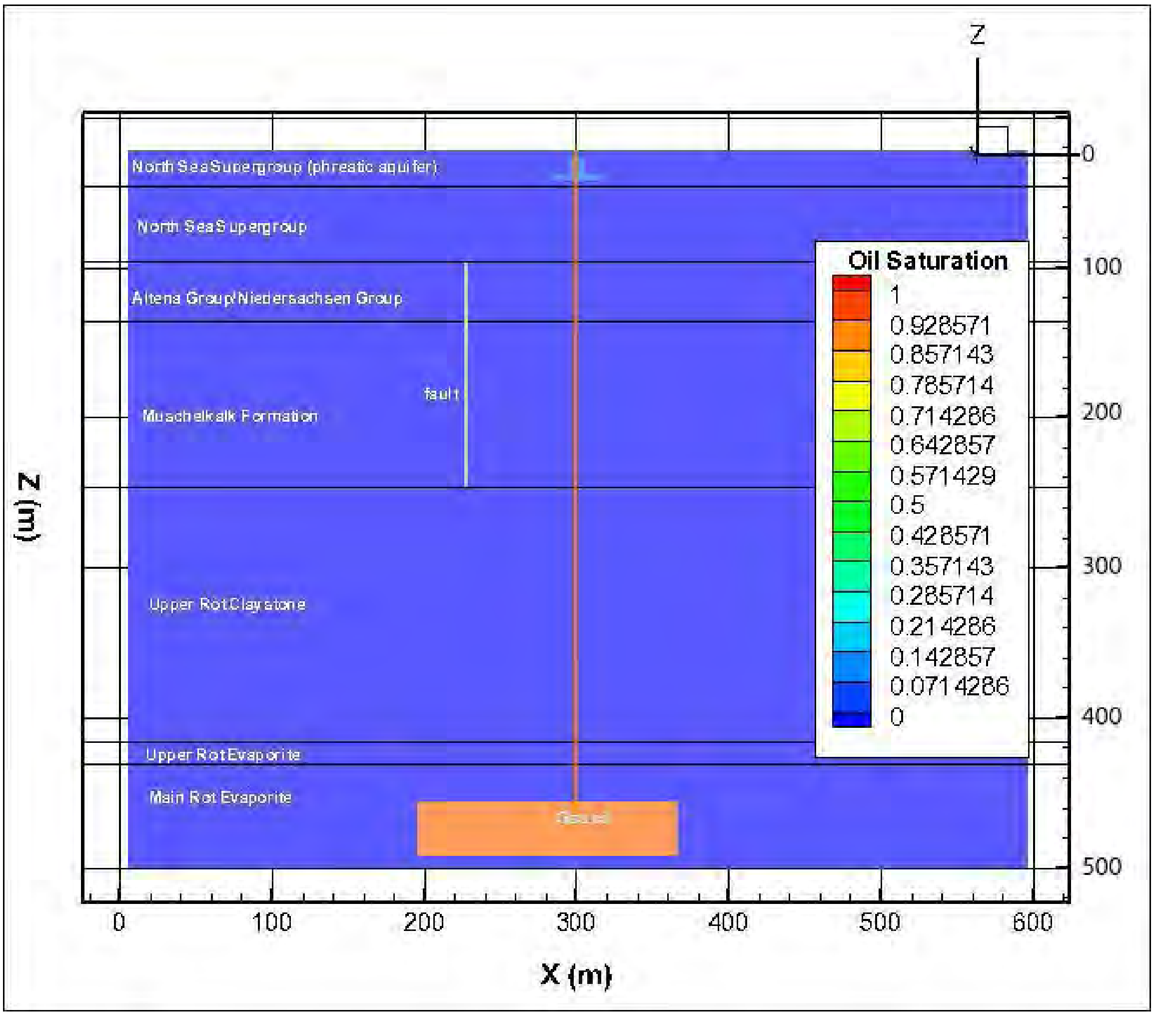
**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 week.**



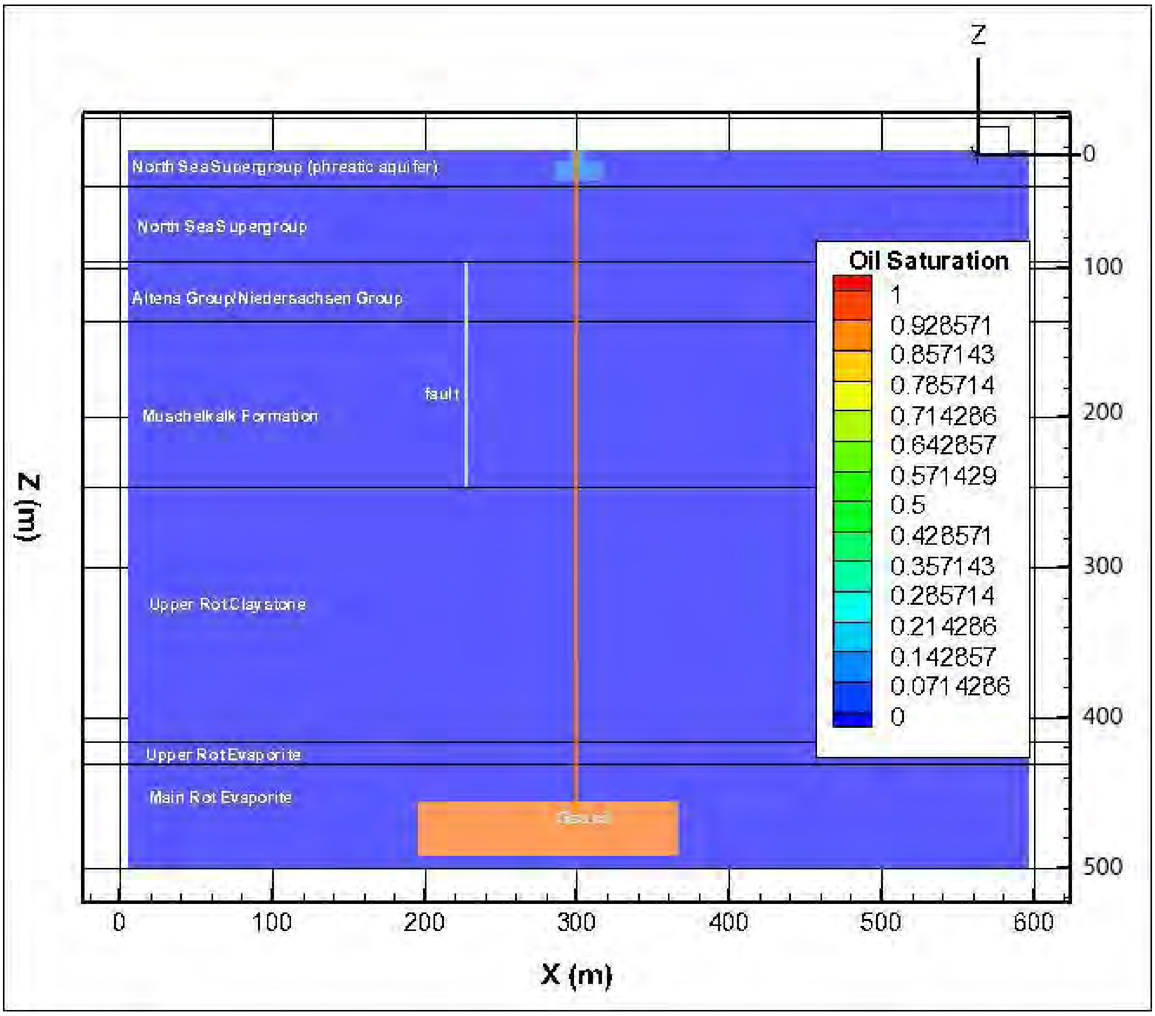
**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 month.**



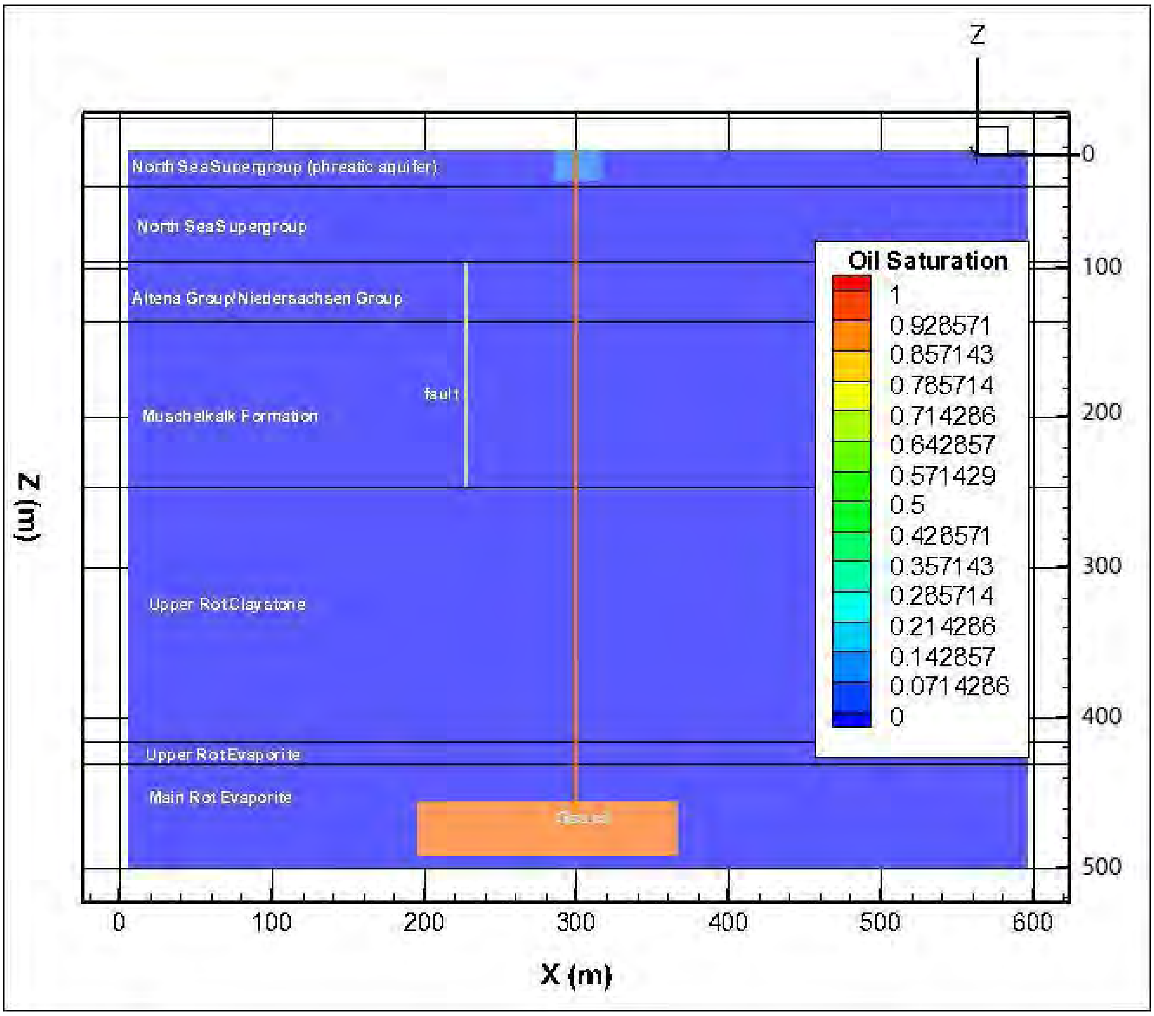
**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 3 months.**



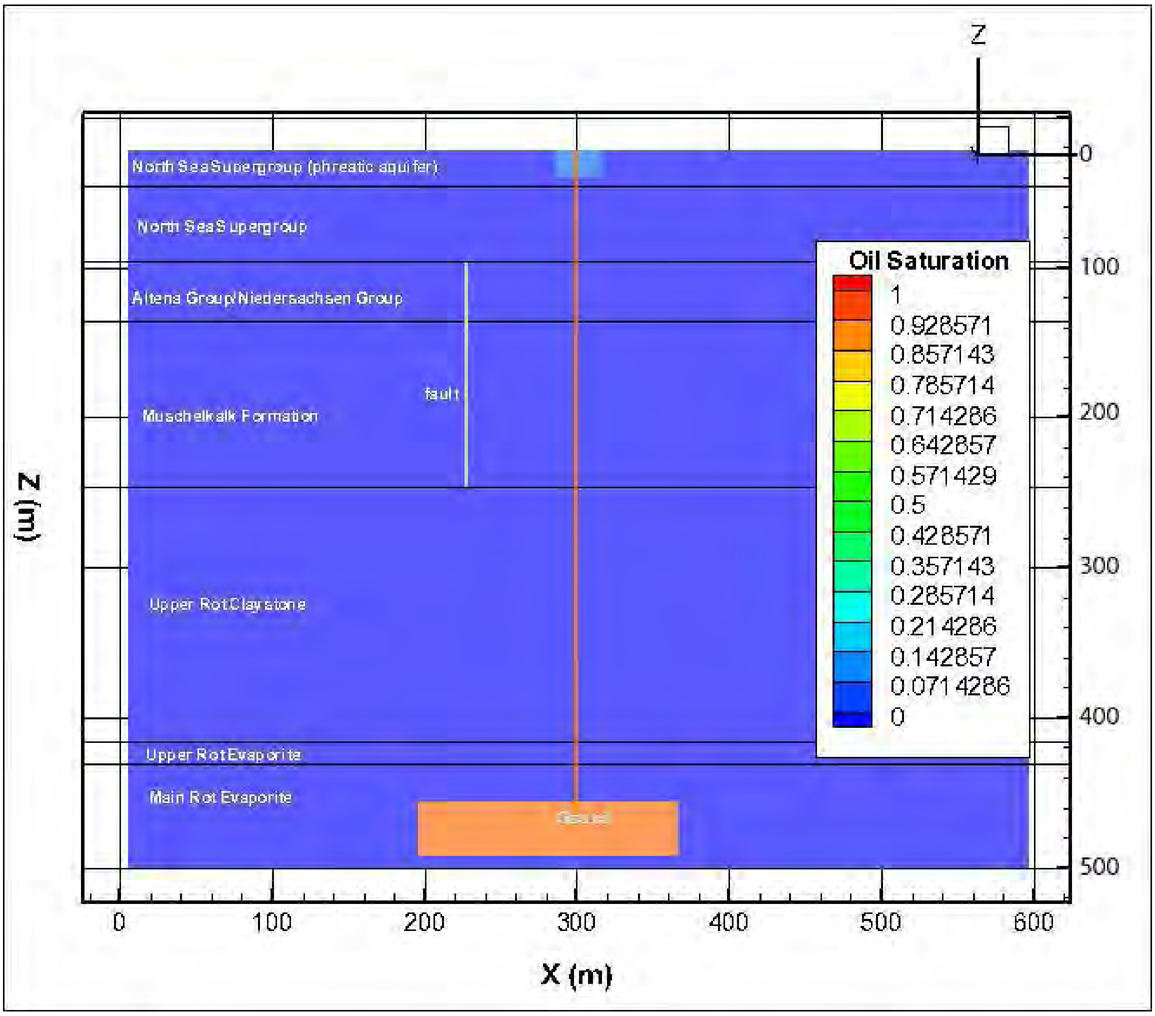
**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 year.**



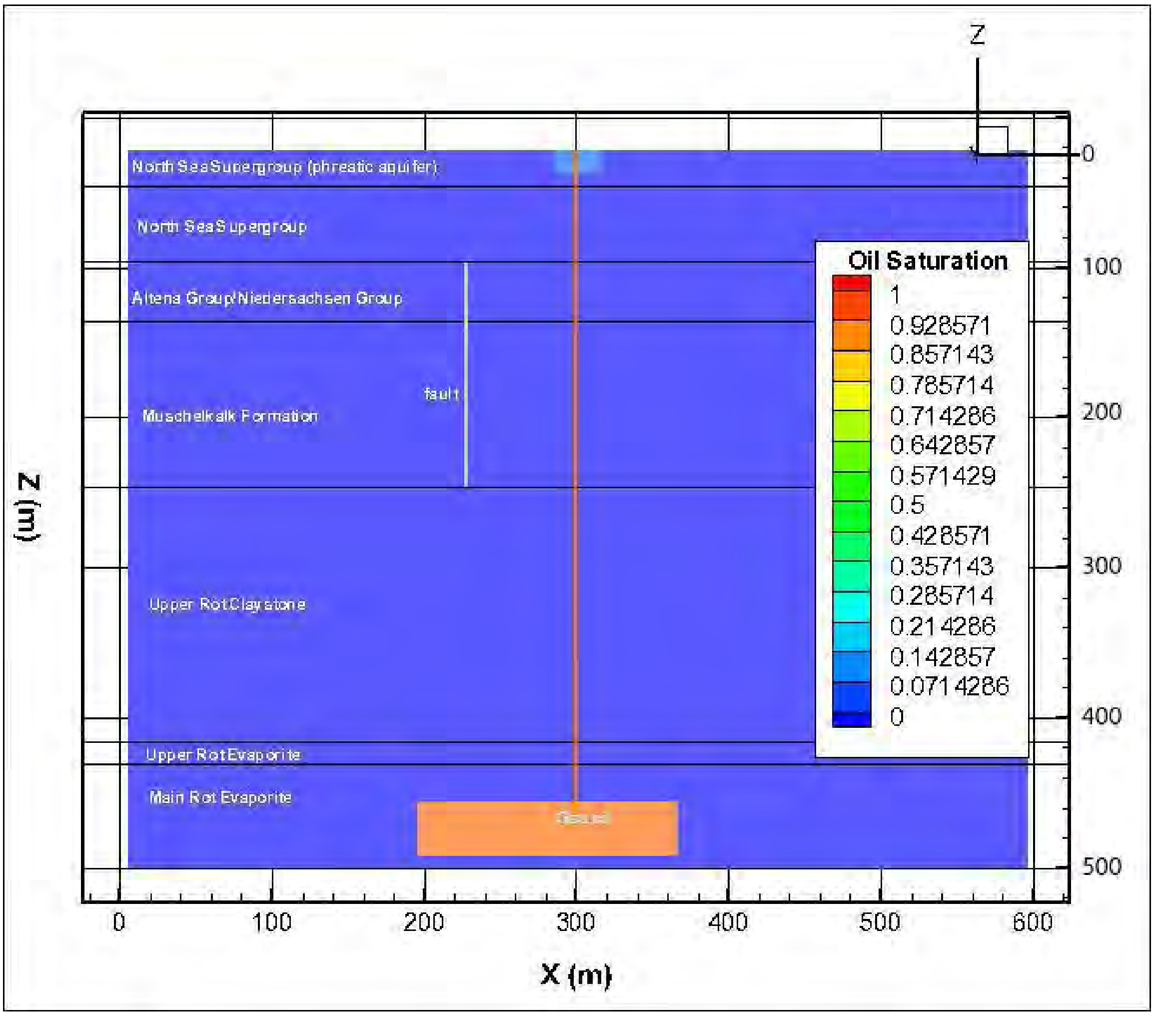
**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 5 years.**



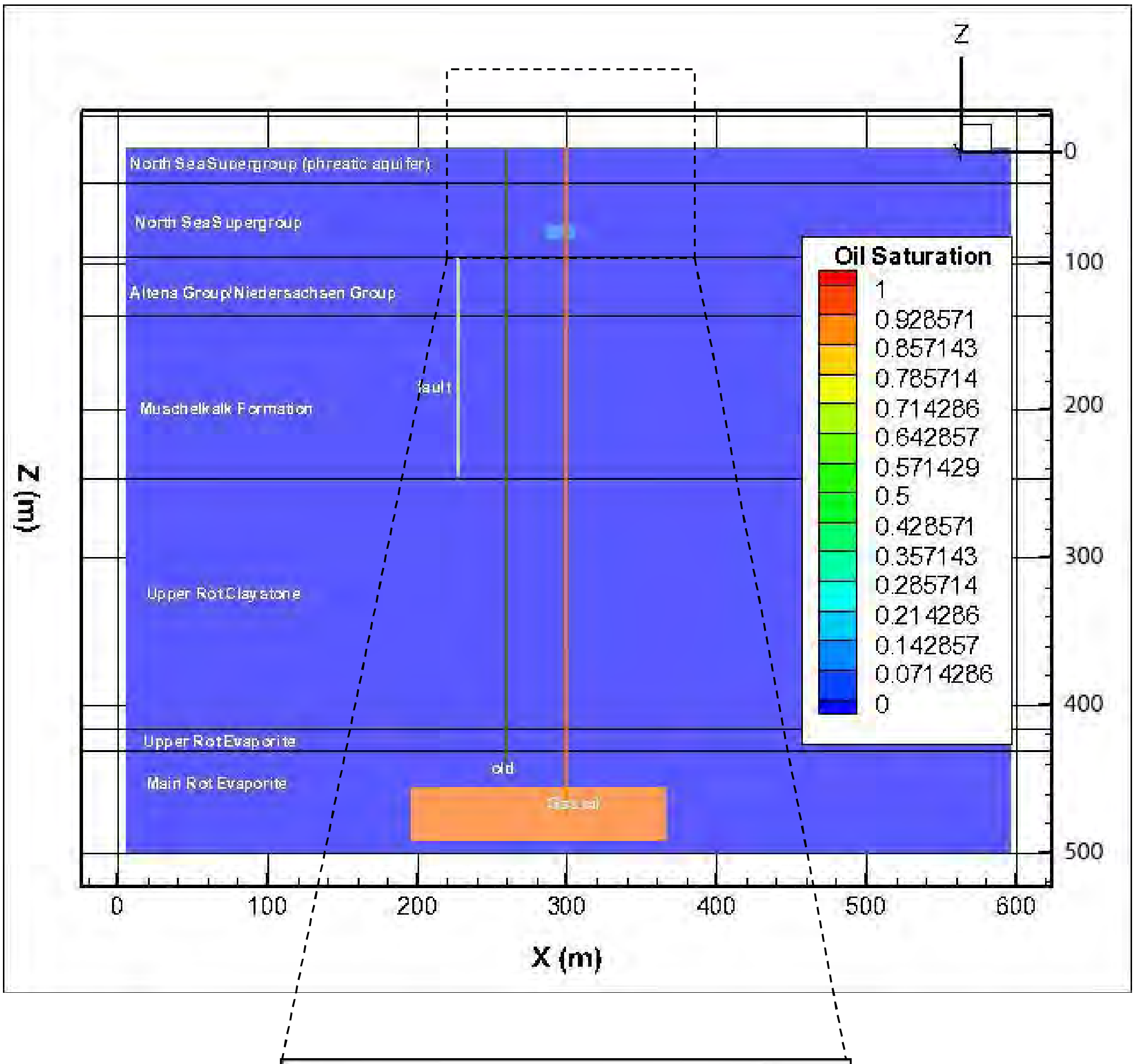
**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 30 years.**

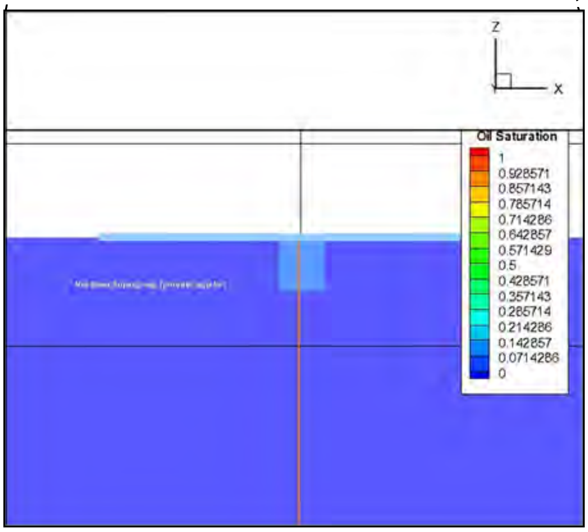


**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 60 years.**



**Cavern 367-368, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 150 years. Lower figure shows the form of the LNAPL in and on top of the phreatic groundwater level in detail.**



# Appendix C: STOMP model results for cavern 372

The following figures are shown in this appendix:

Scenario 1: no loss of containment / breach of confinement.
Effects of leakage after 150 years

Scenario 2: leakage from cavern in Röt Claystone.
Effects of leakage after 150 years

Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity.
Effects of leakage after 150 years

Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation.
Effects of leakage after 150 years

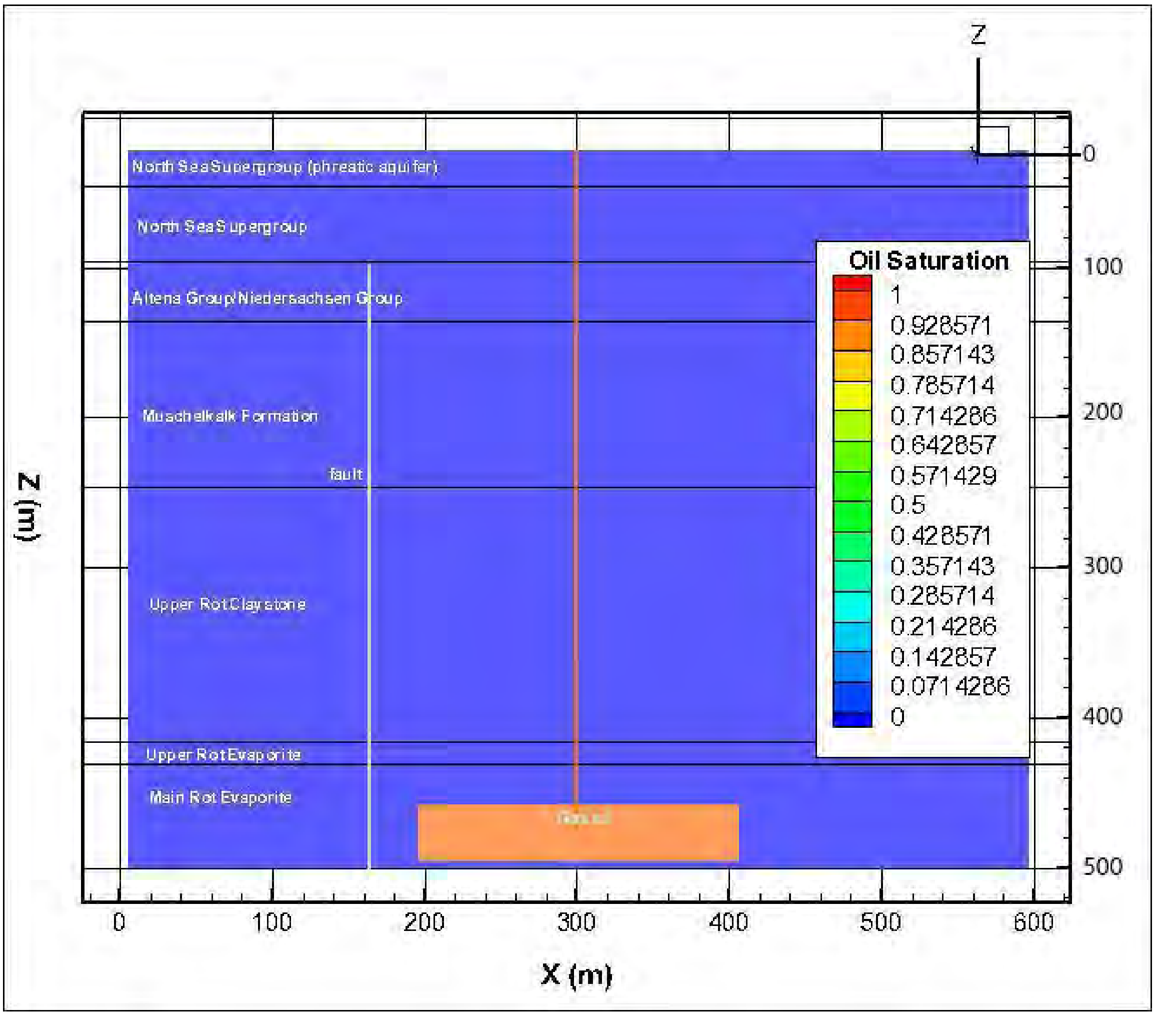
Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup
Effects of leakage after 150 years

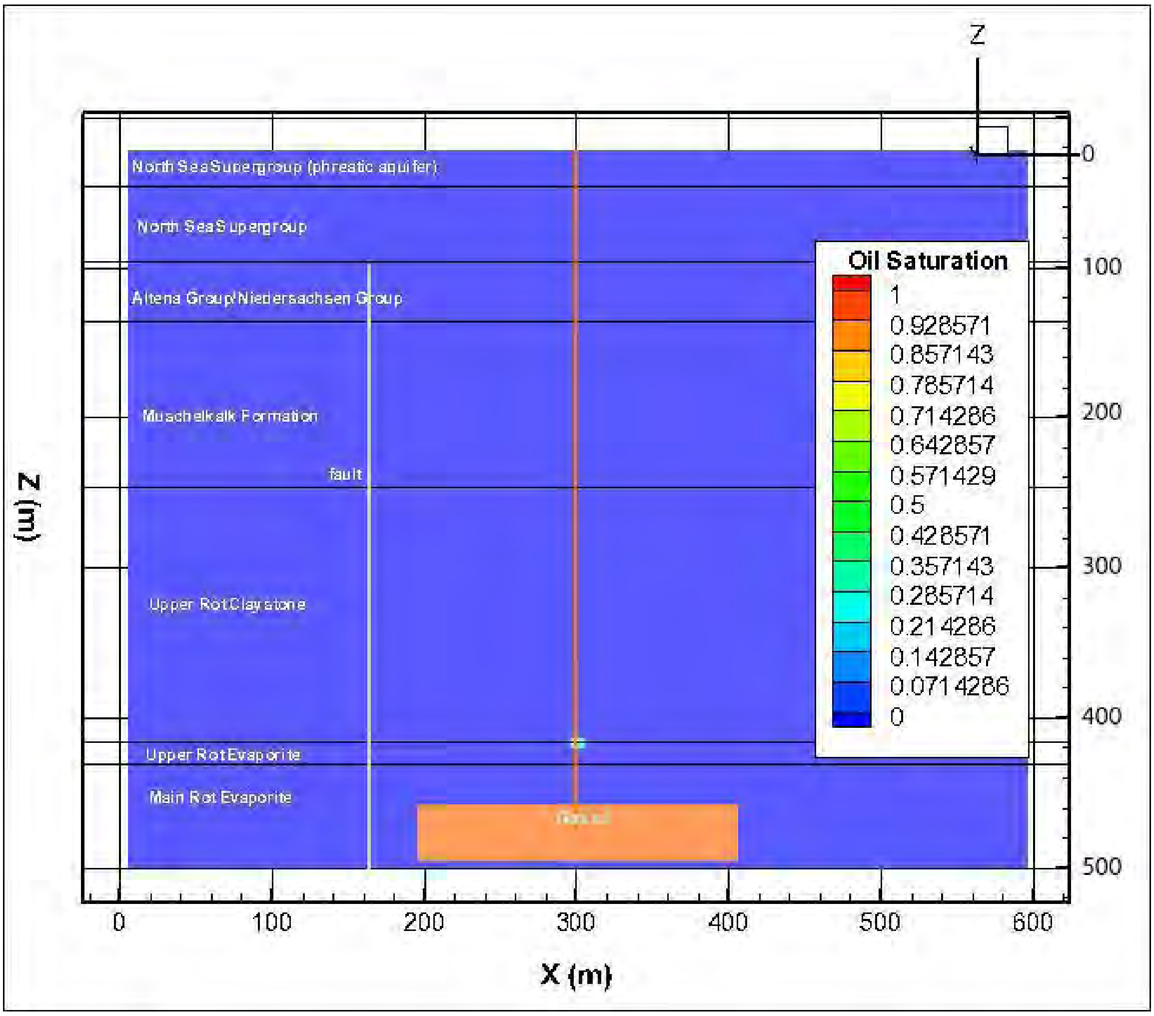
Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 8: leakage from well above hydrogeological base
Effects of leakage after 1 week, 1 month, 3 months, 1 year, 5 years, 30 years, 60 years, 150 years

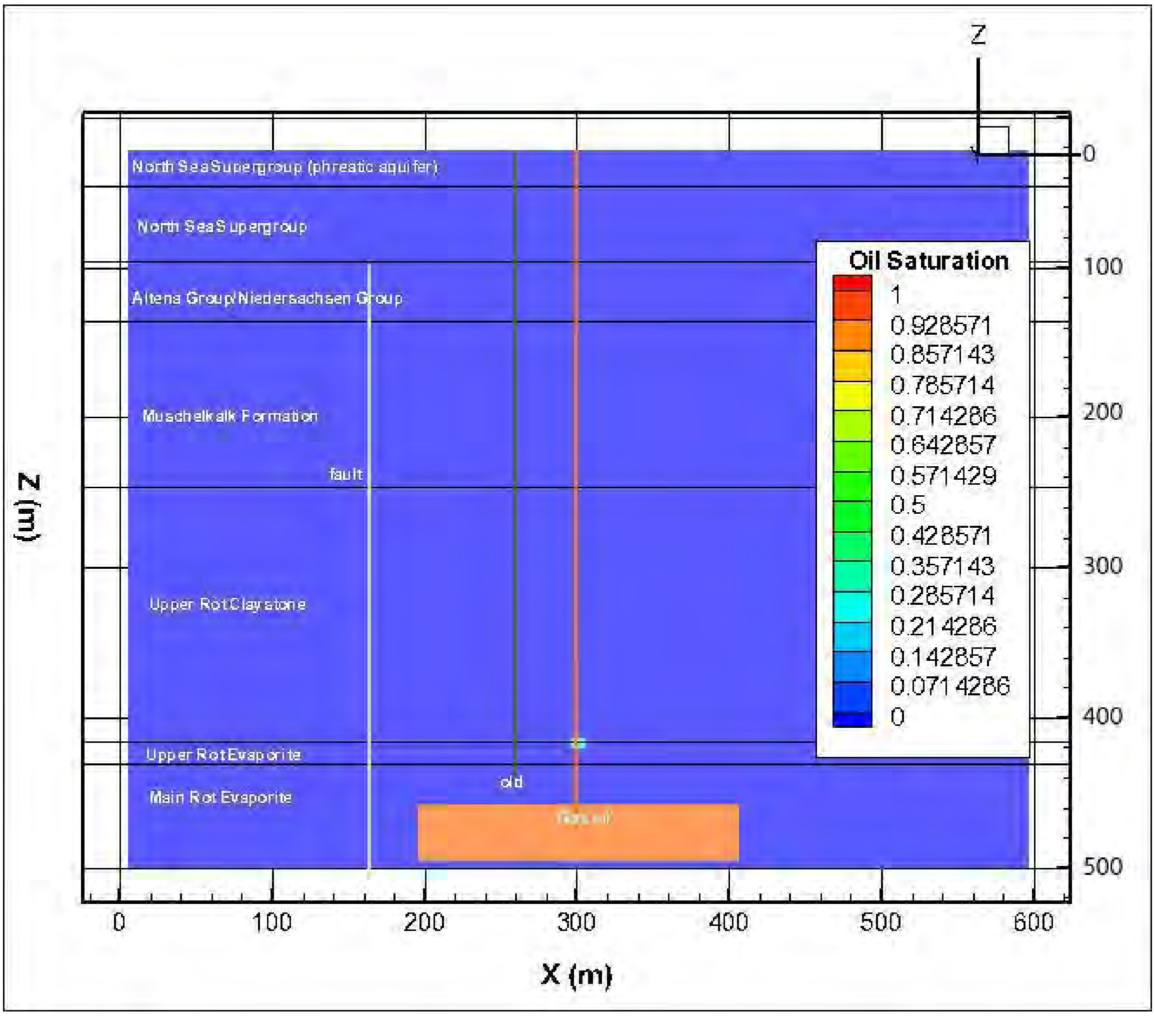
**cavern 372-373-374, Scenario 1: no loss of containment / breach of confinement. Effects of leakage after 150 years.**



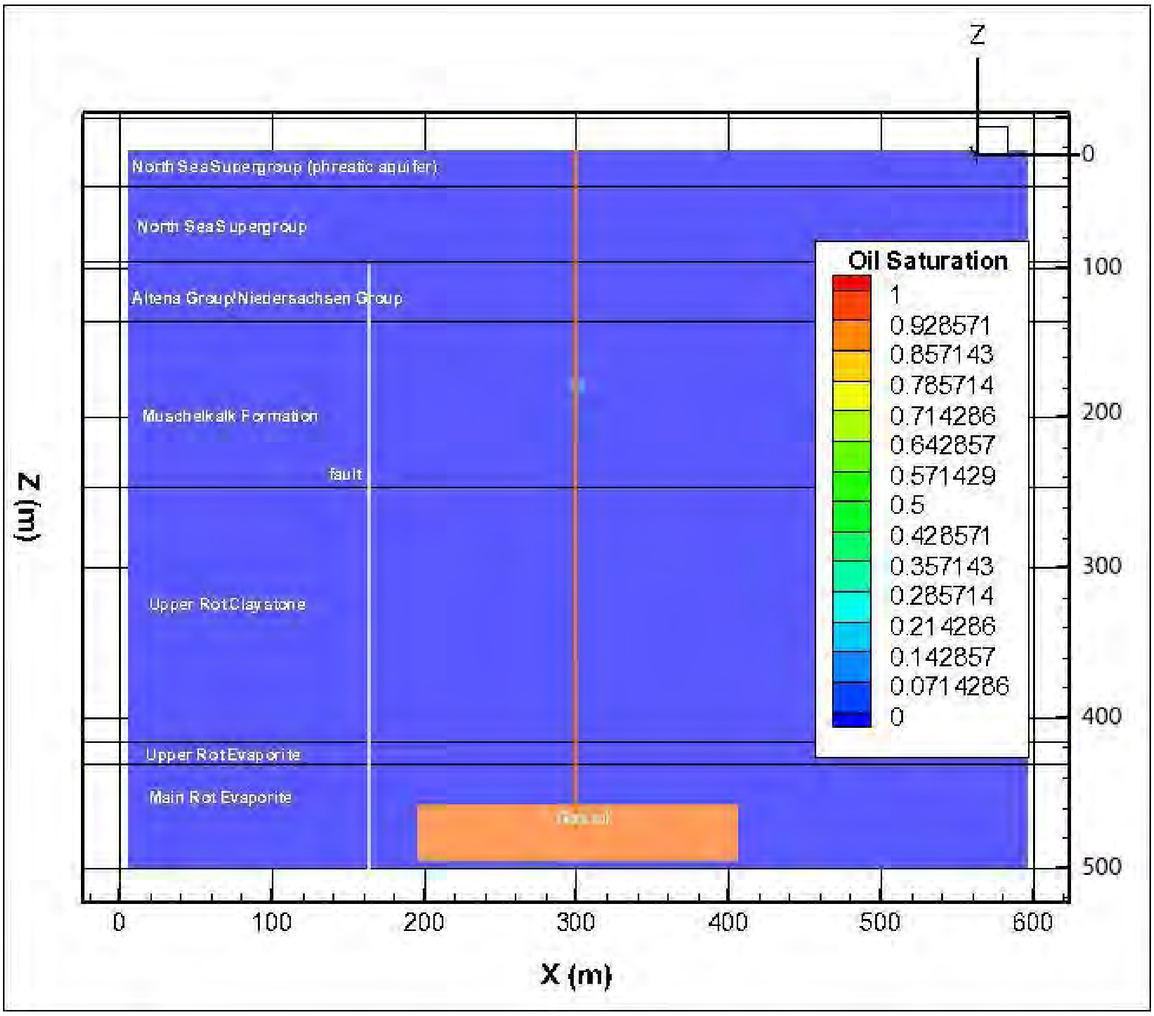
**Cavern 372-373-374, Scenario 2: leakage from cavern in Röt Claystone. Effects of leakage after 150 years.**



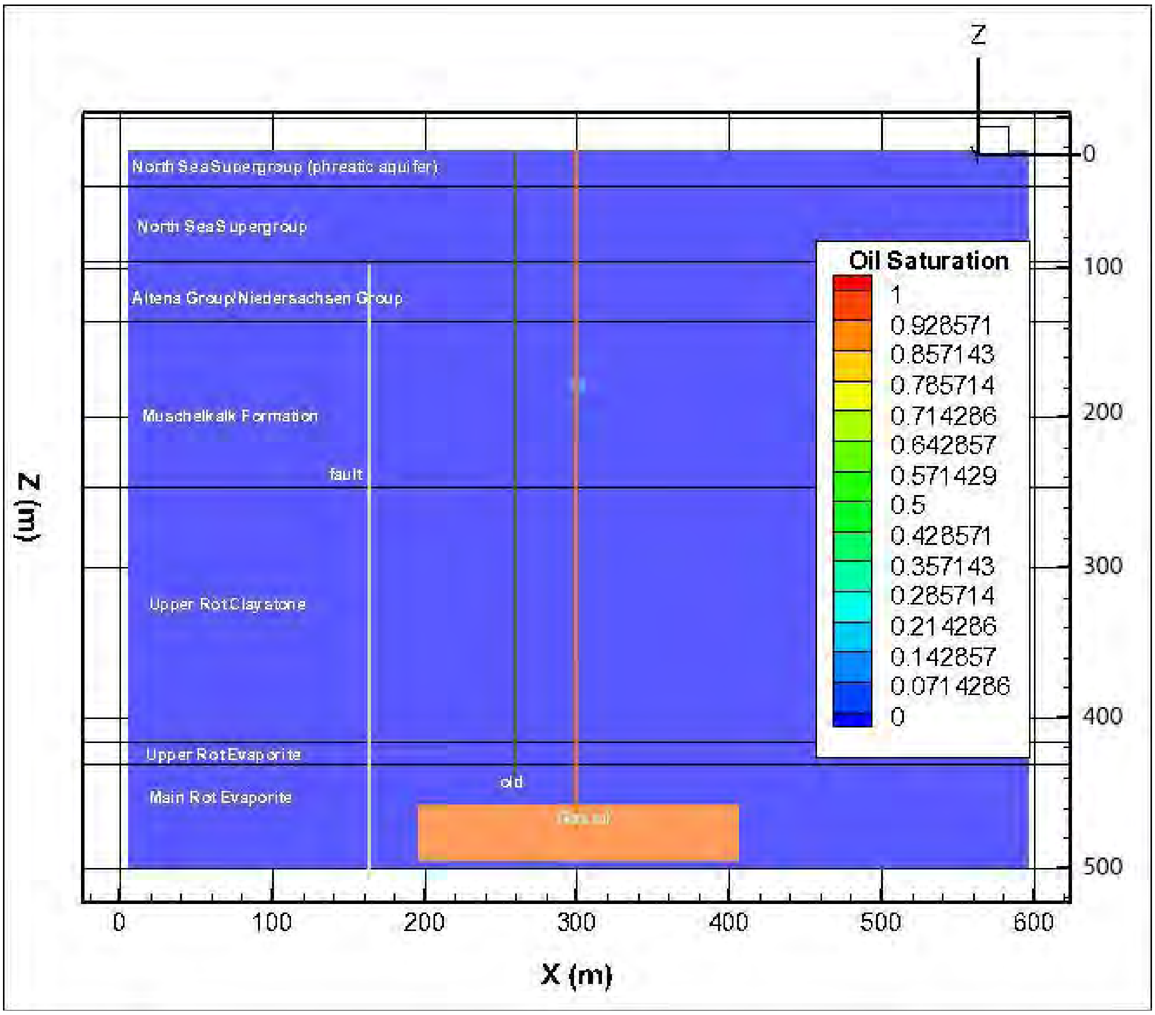
**Cavern 372-373-374, Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity. Effects of leakage after 150 years.**



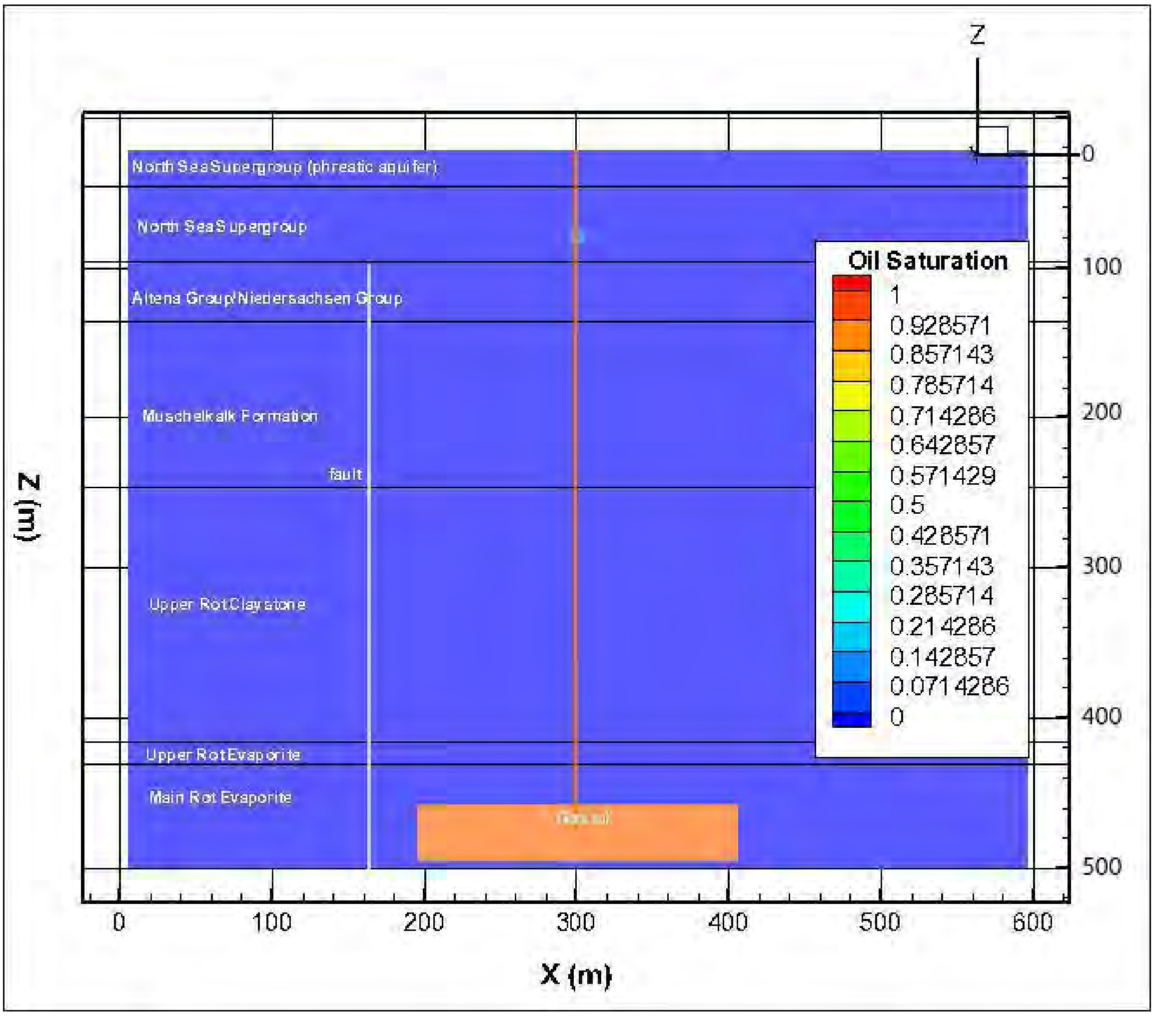
**Cavern 372-373-374, Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation. Effects of leakage after 150 years.**



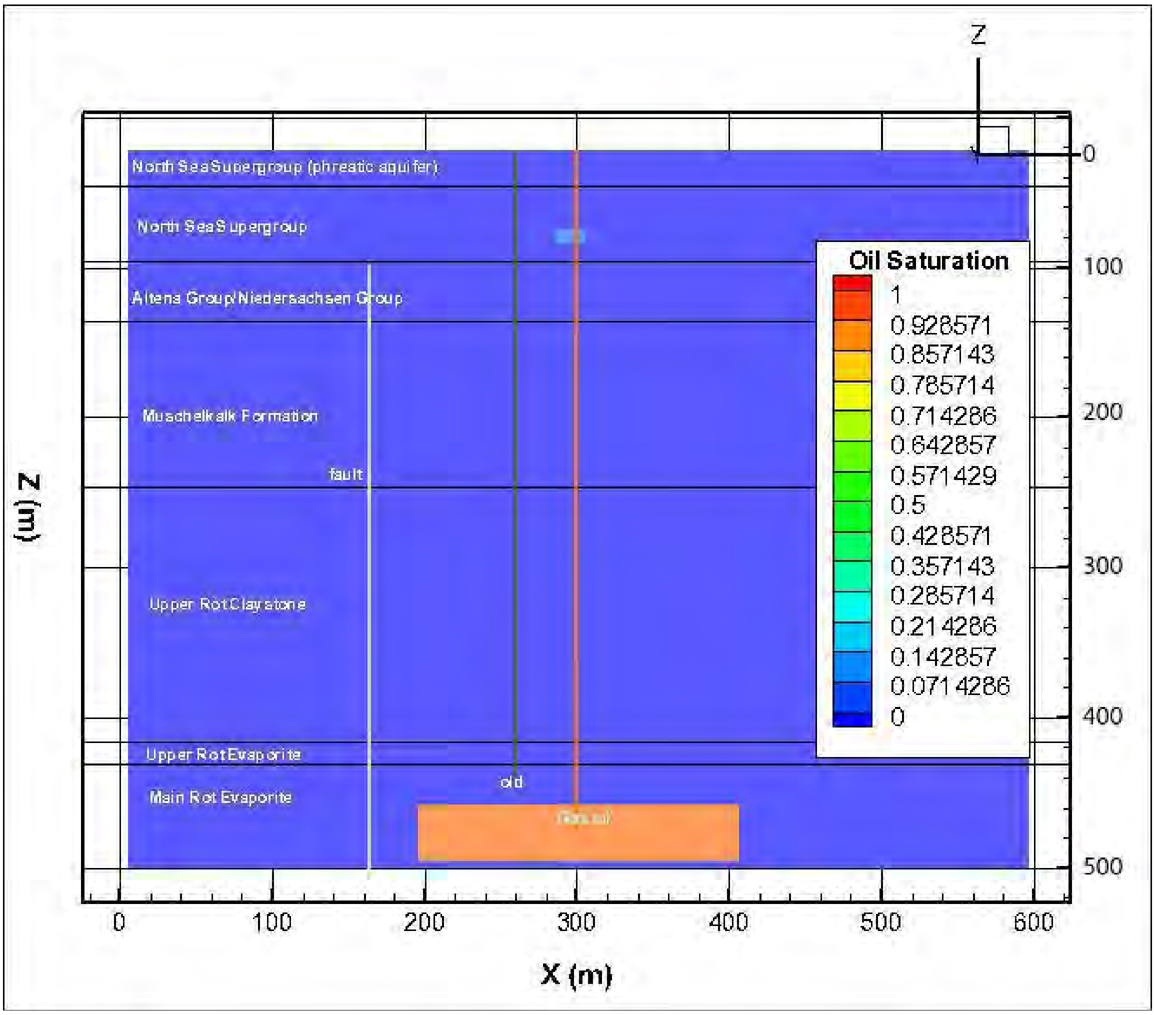
**Cavern 372-373-374, Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years.**



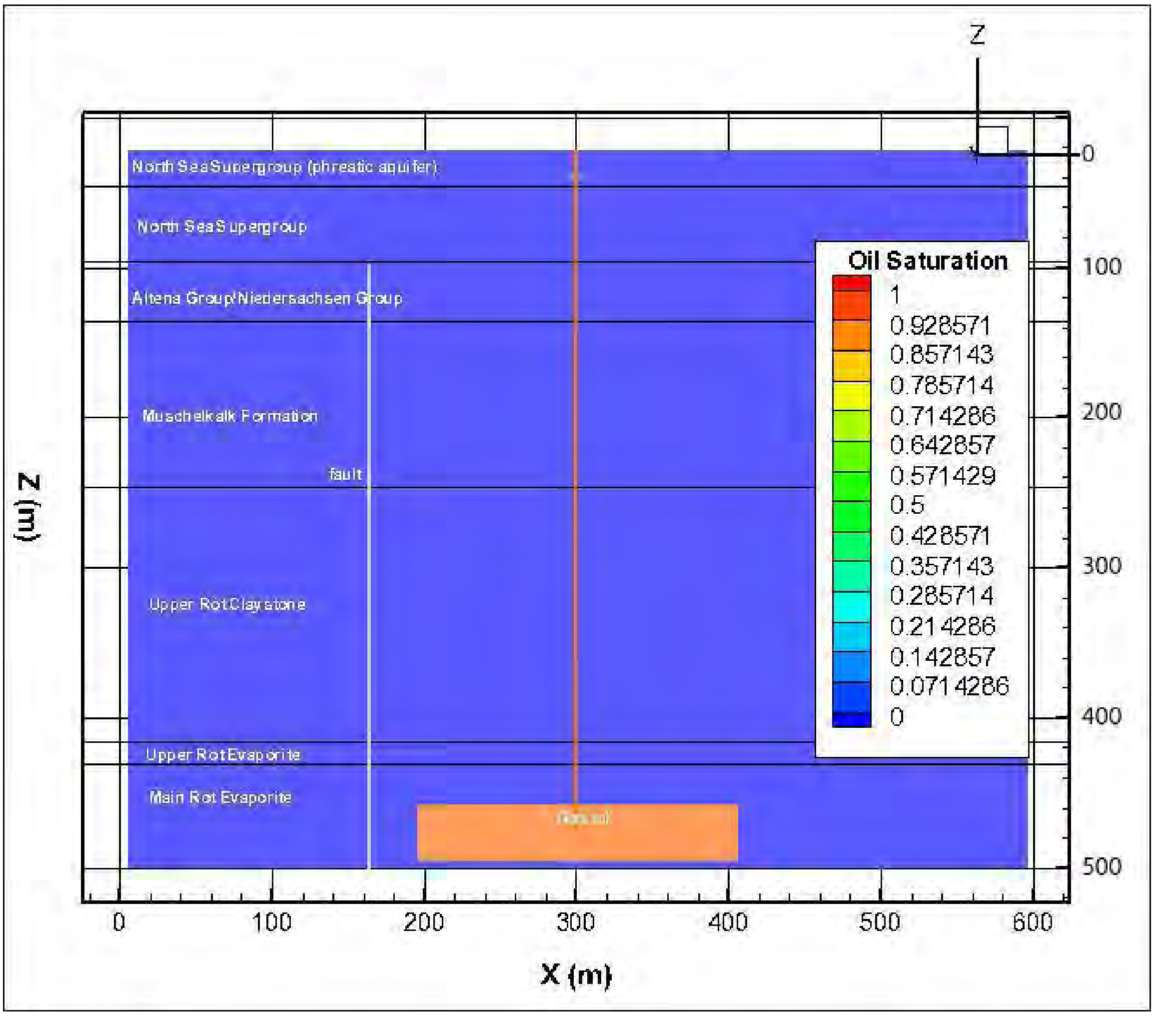
**Cavern 372-373-374, Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup. Effects of leakage after 150 years.**



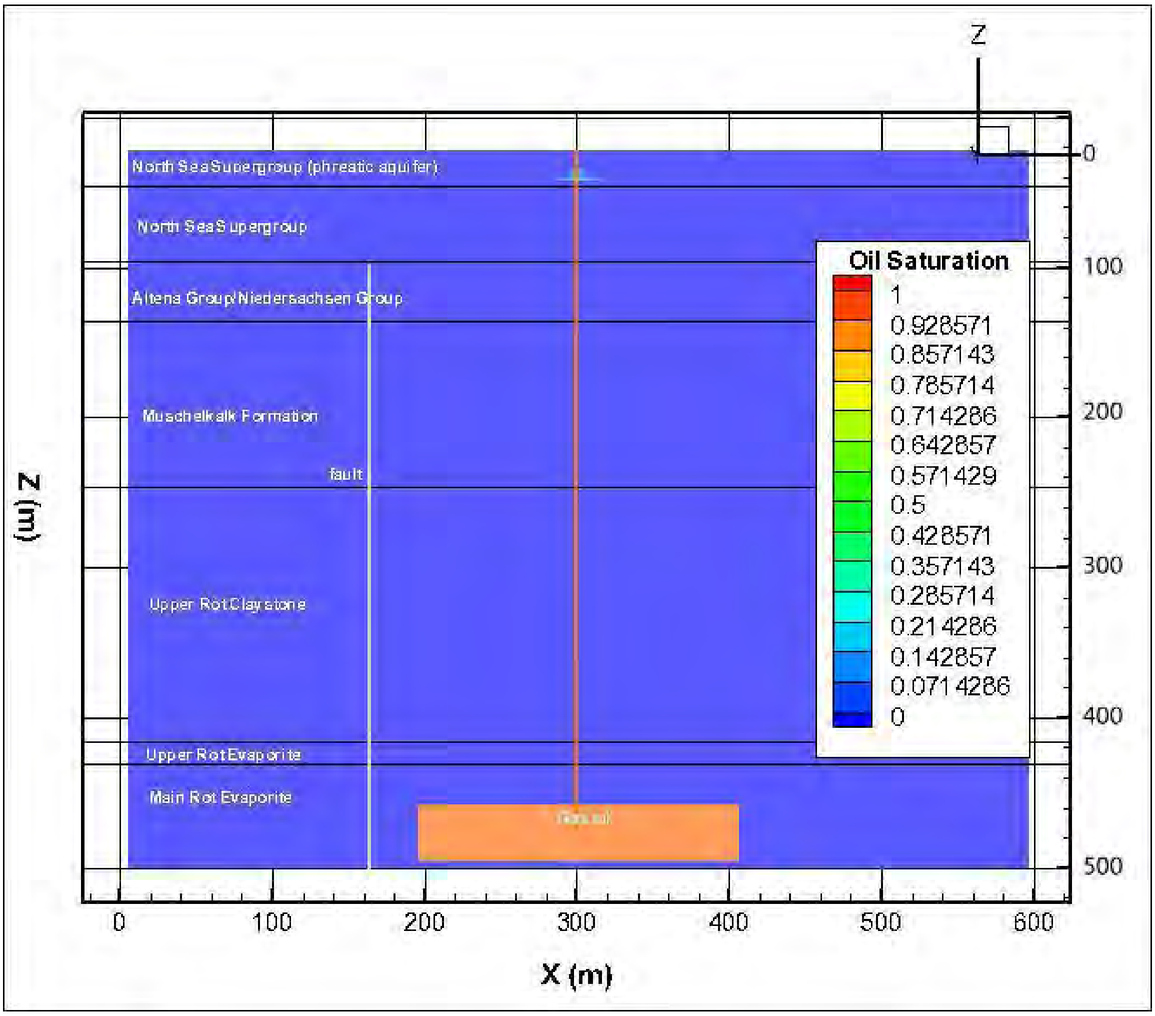
**Cavern 372-373-374, Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years.**



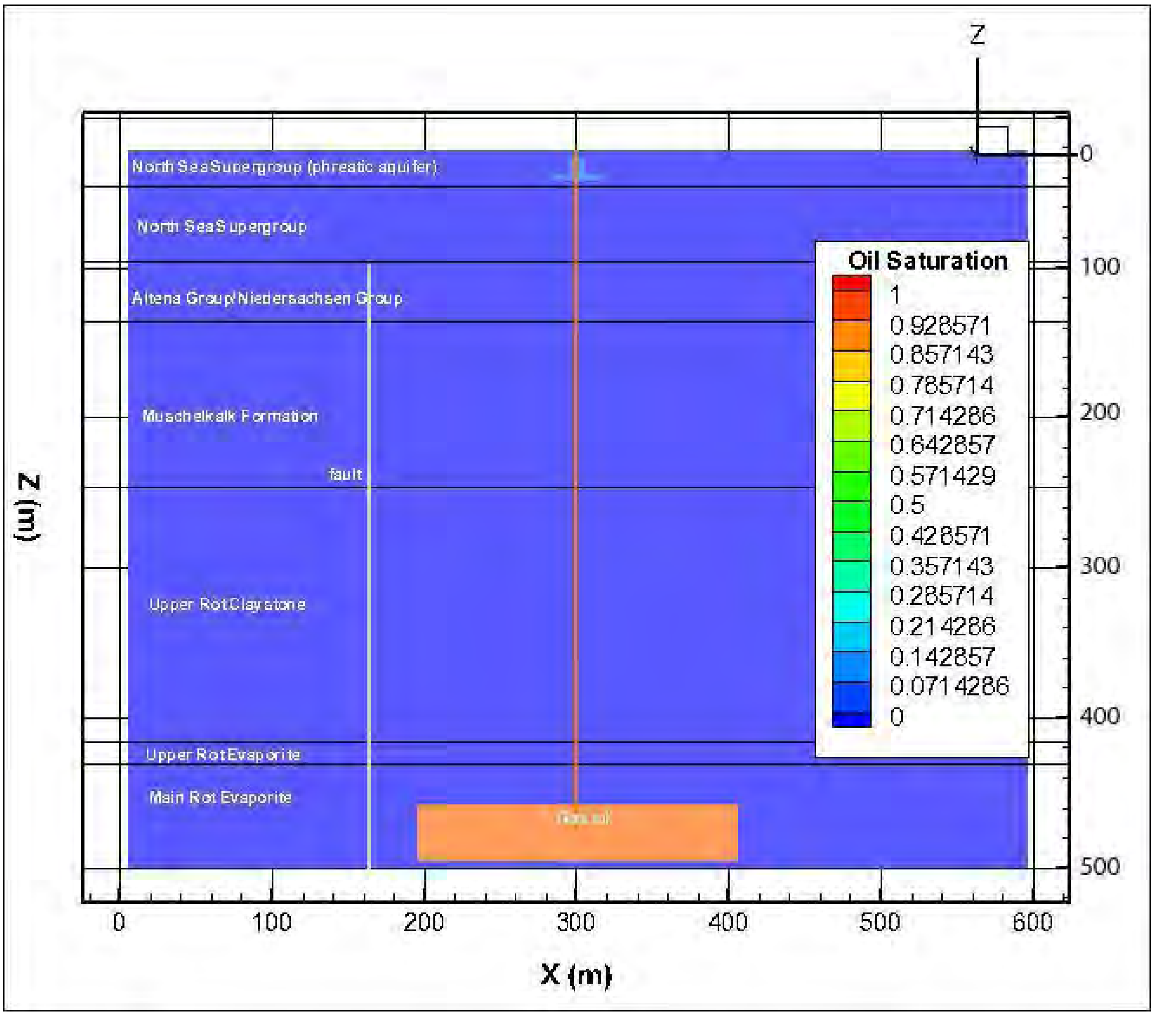
**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 week.**



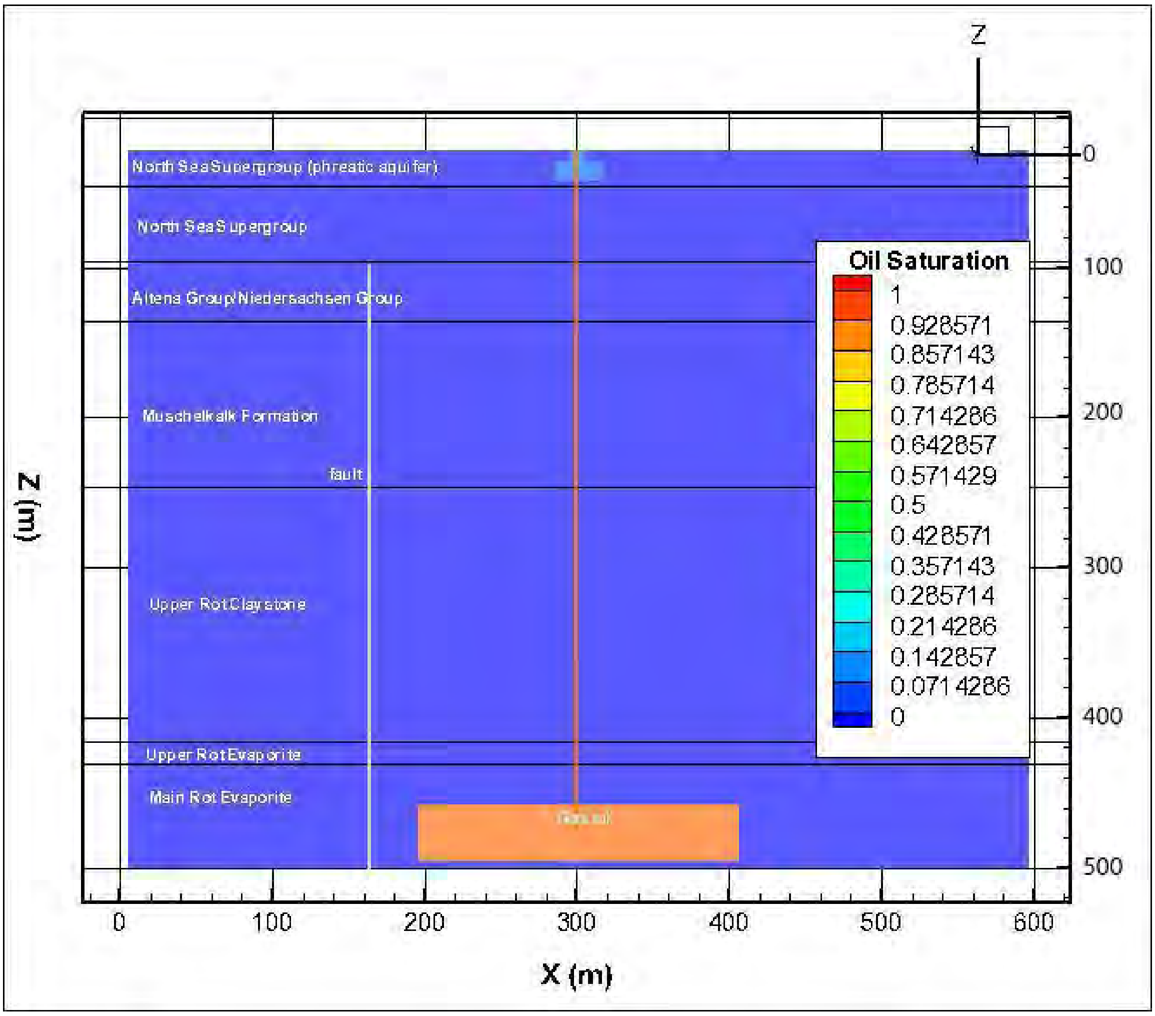
**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 month.**



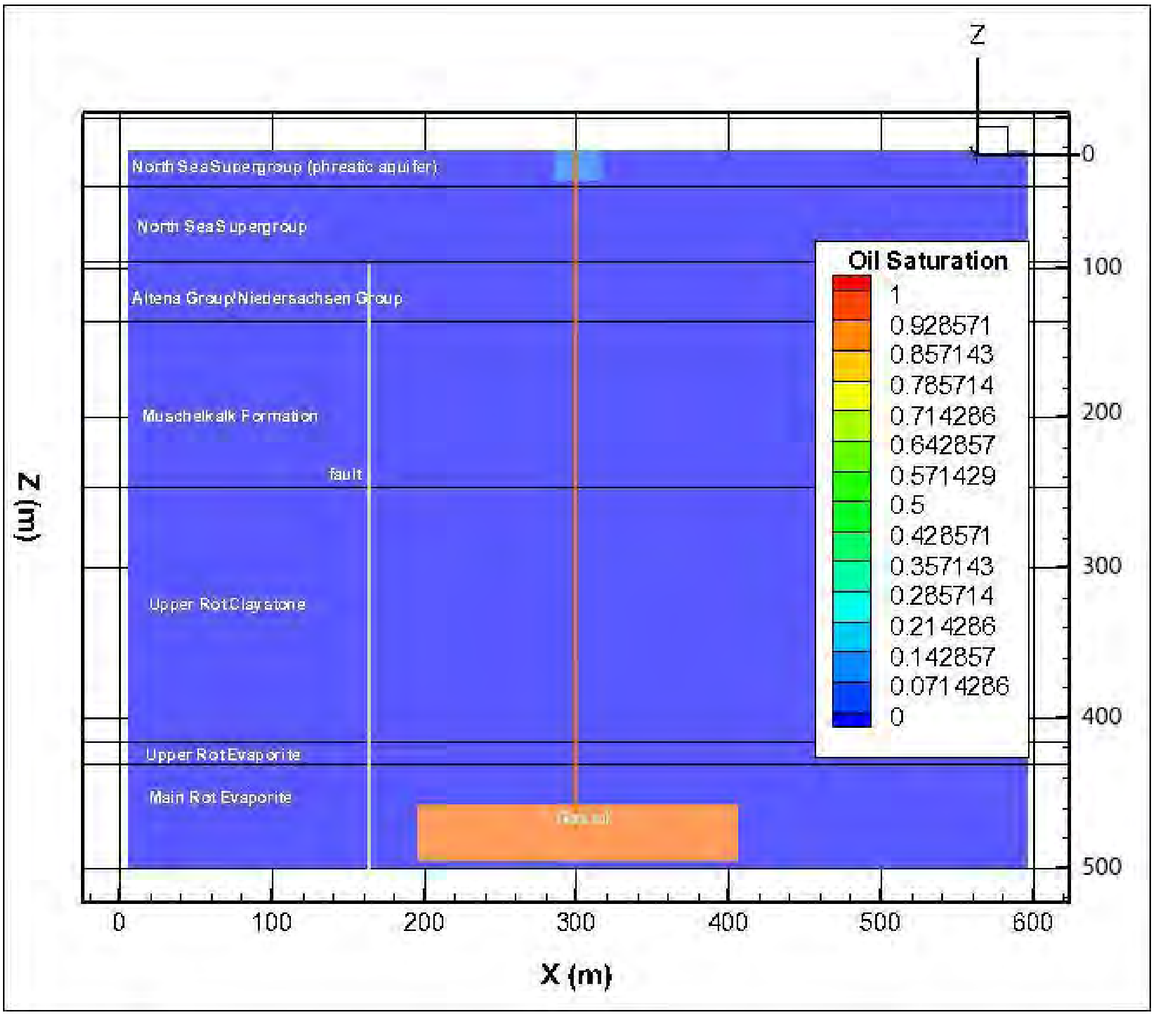
**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 3 months.**



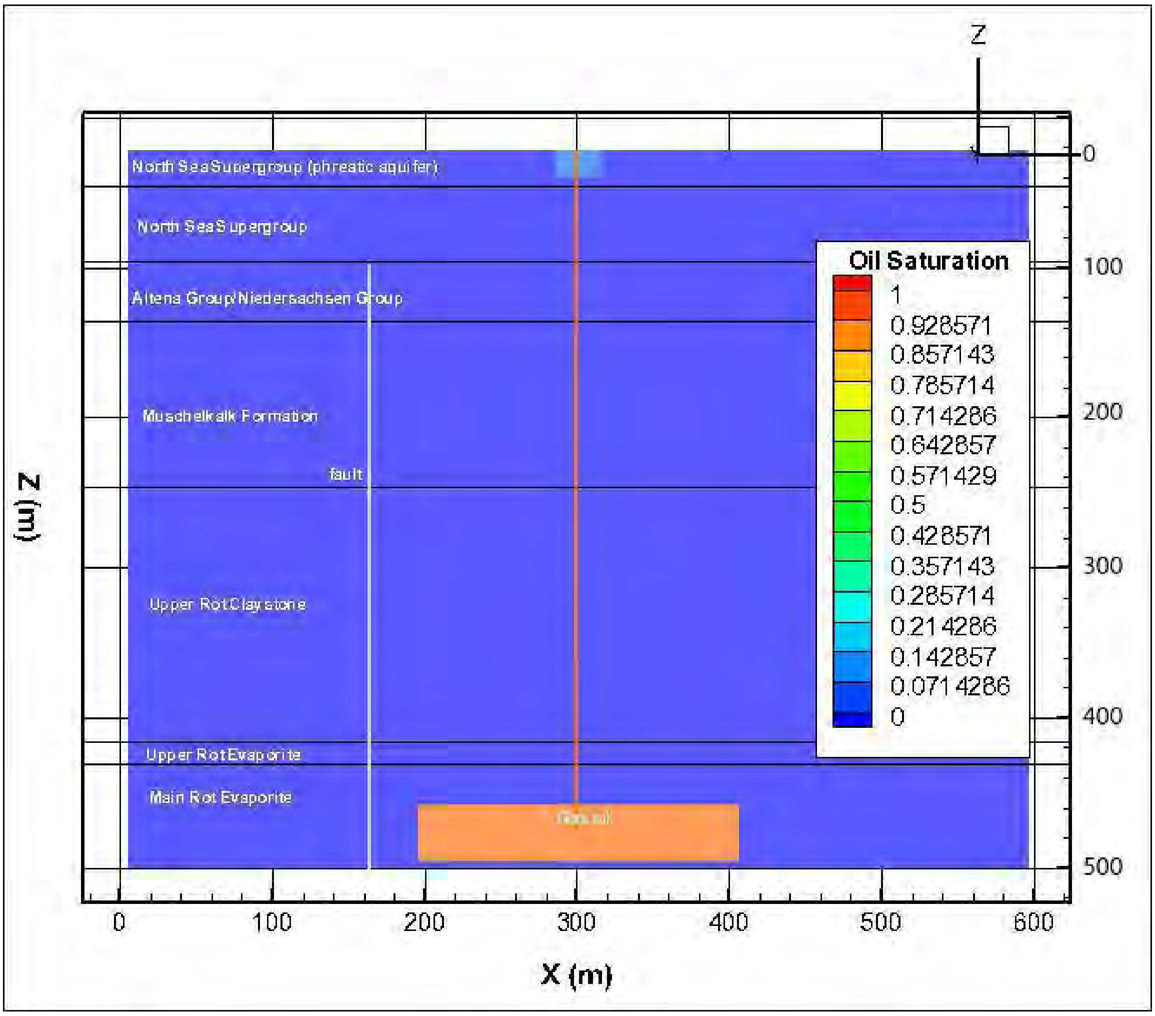
**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 years.**



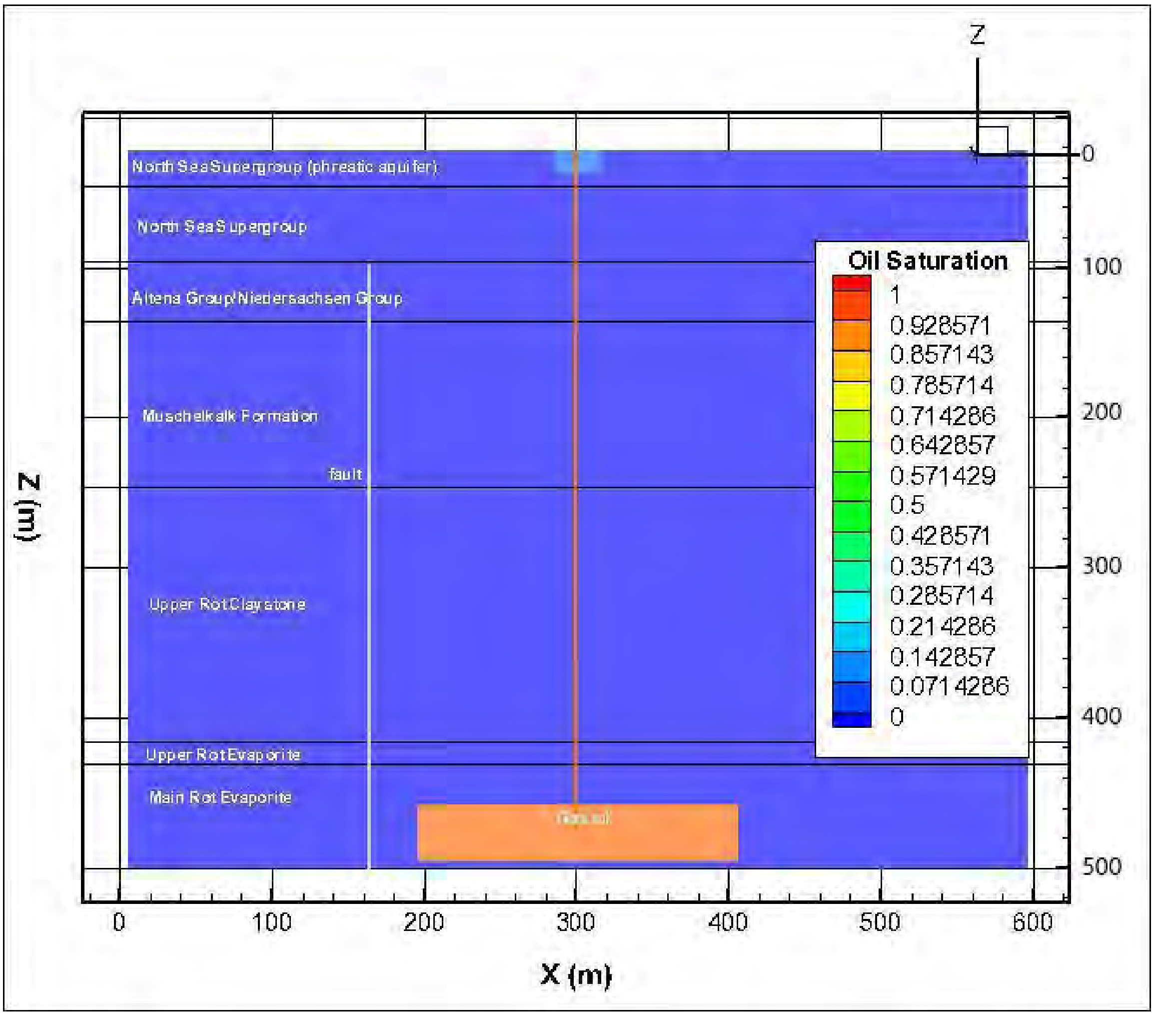
**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 5 years.**



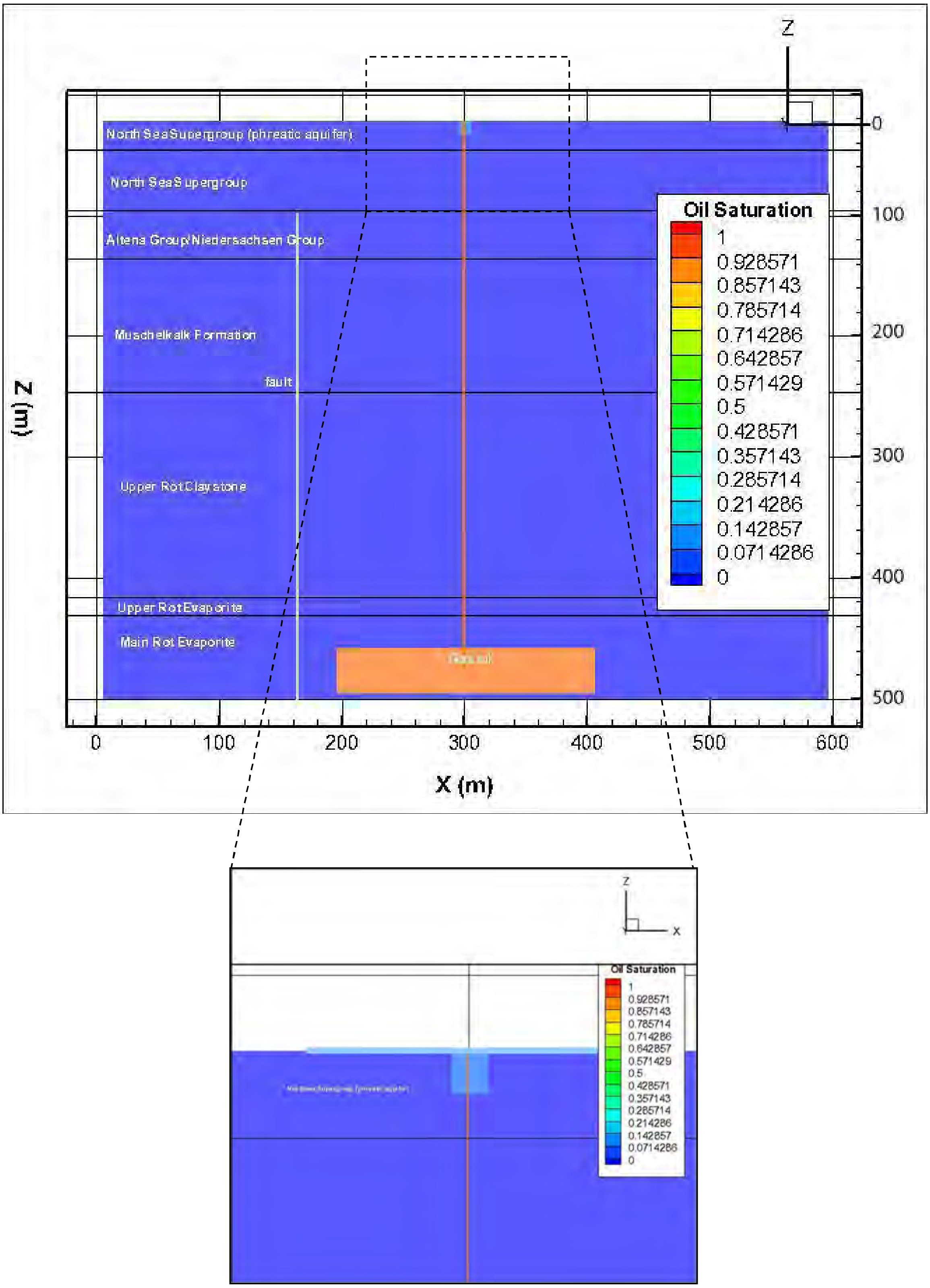
**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 30 years.**



**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 60 years.**



**Cavern 372-373-374, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 150 years. Lower figure shows the form of the LNAPL in and on top of the phreatic groundwater level in detail.**



# Appendix D: STOMP model results for cavern 469

The following figures are shown in this appendix:

Scenario 1: no loss of containment / breach of confinement.
Effects of leakage 150 year

Scenario 2: leakage from cavern in Röt Claystone.
Effects of leakage 150 year

Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity.
Effects of leakage 150 year

Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation.
Effects of leakage 150 year

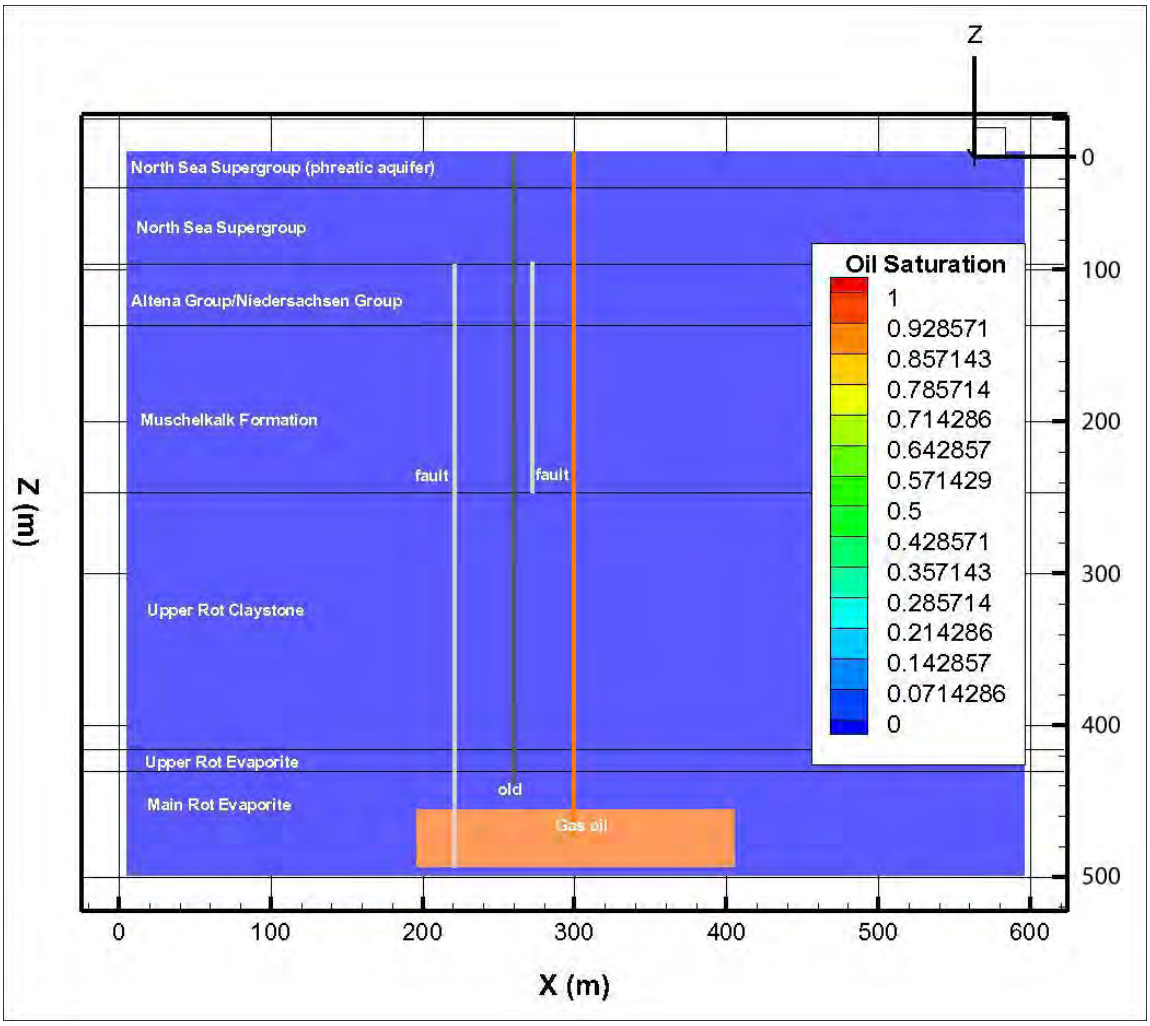
Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage 150 year

Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup
Effects of leakage after 150 years

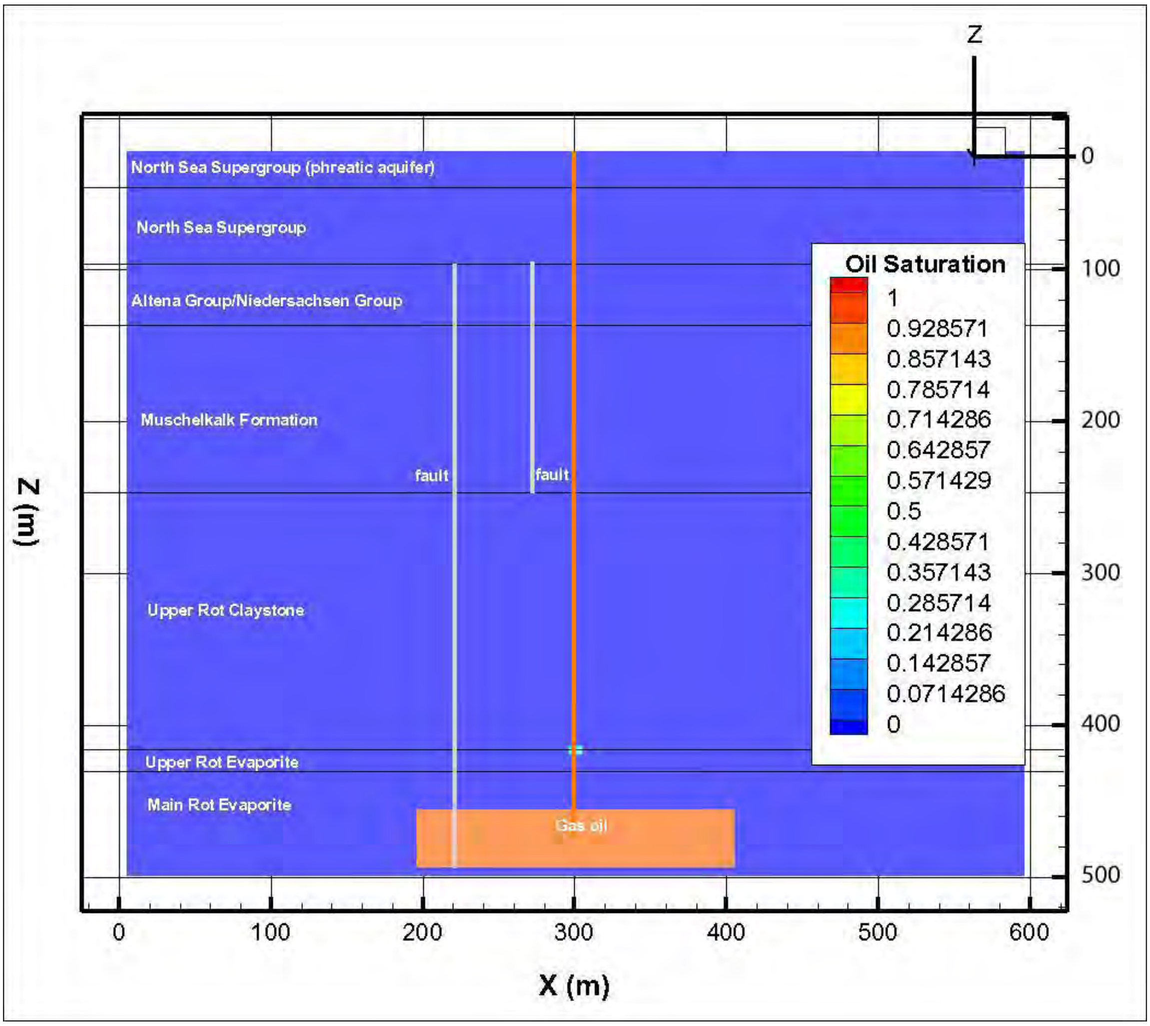
Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 8: leakage from well above hydrogeological base
Effects of leakage after 1 week, 1 month, 3 months, 1 year, 5 years, 30 years, 60 years, 150 years

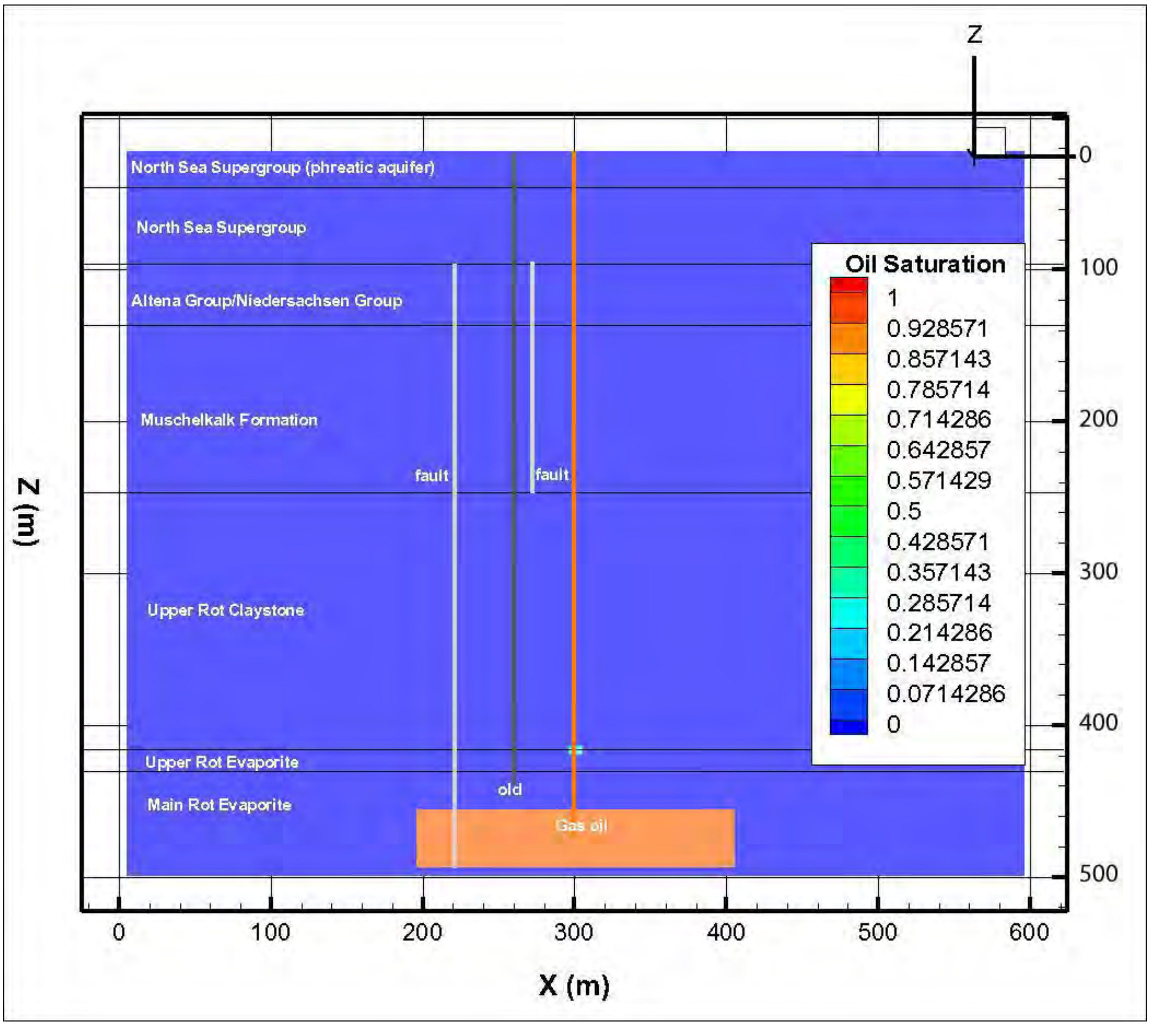
**Cavern 469-470-471, Scenario 1: no loss of containment / breach of confinement. Effects of leakage after 150 years.**



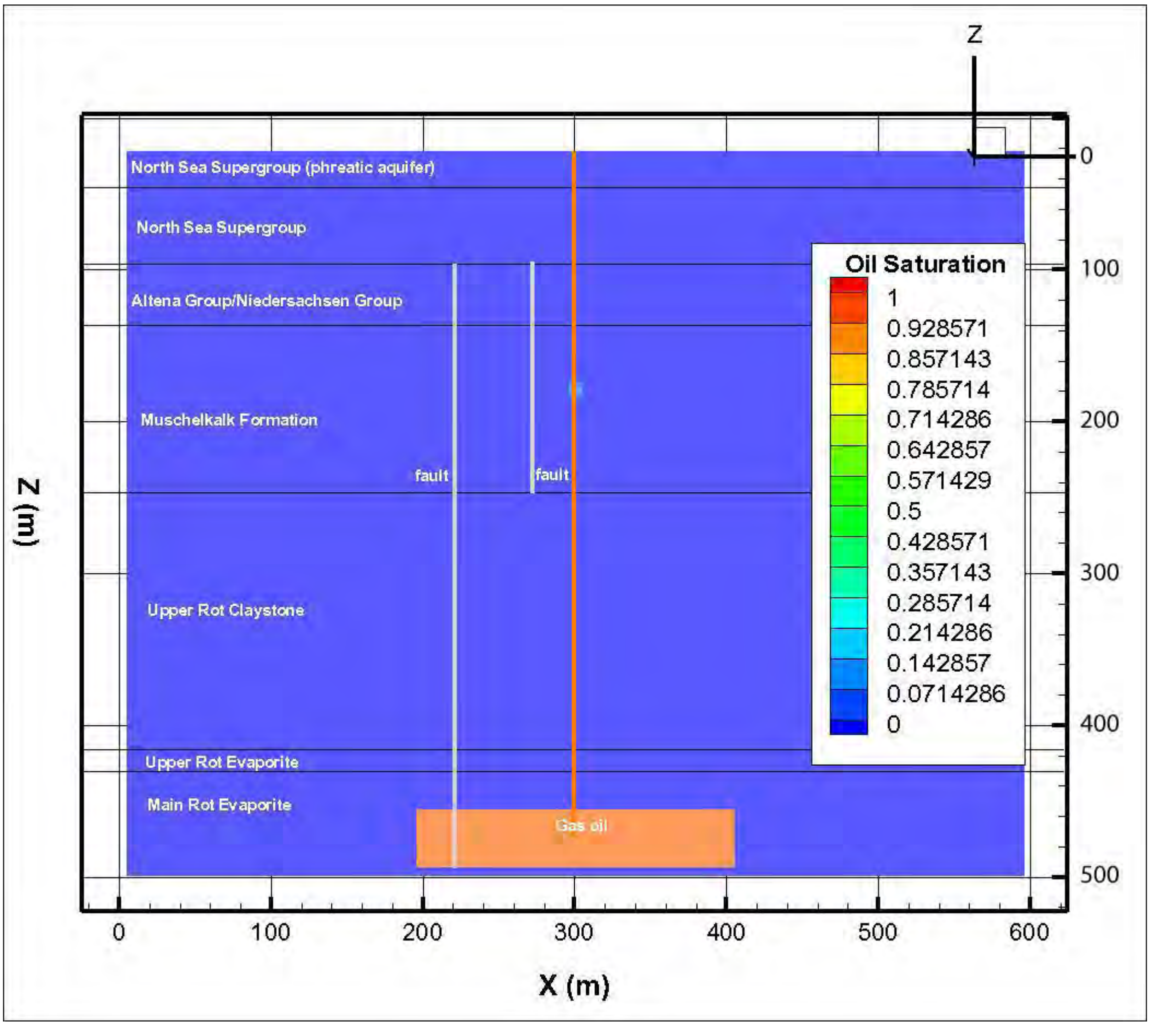
**Cavern 469-470-471, Scenario 2: leakage from cavern in Röt Claystone. Effects of leakage after 150 years.**



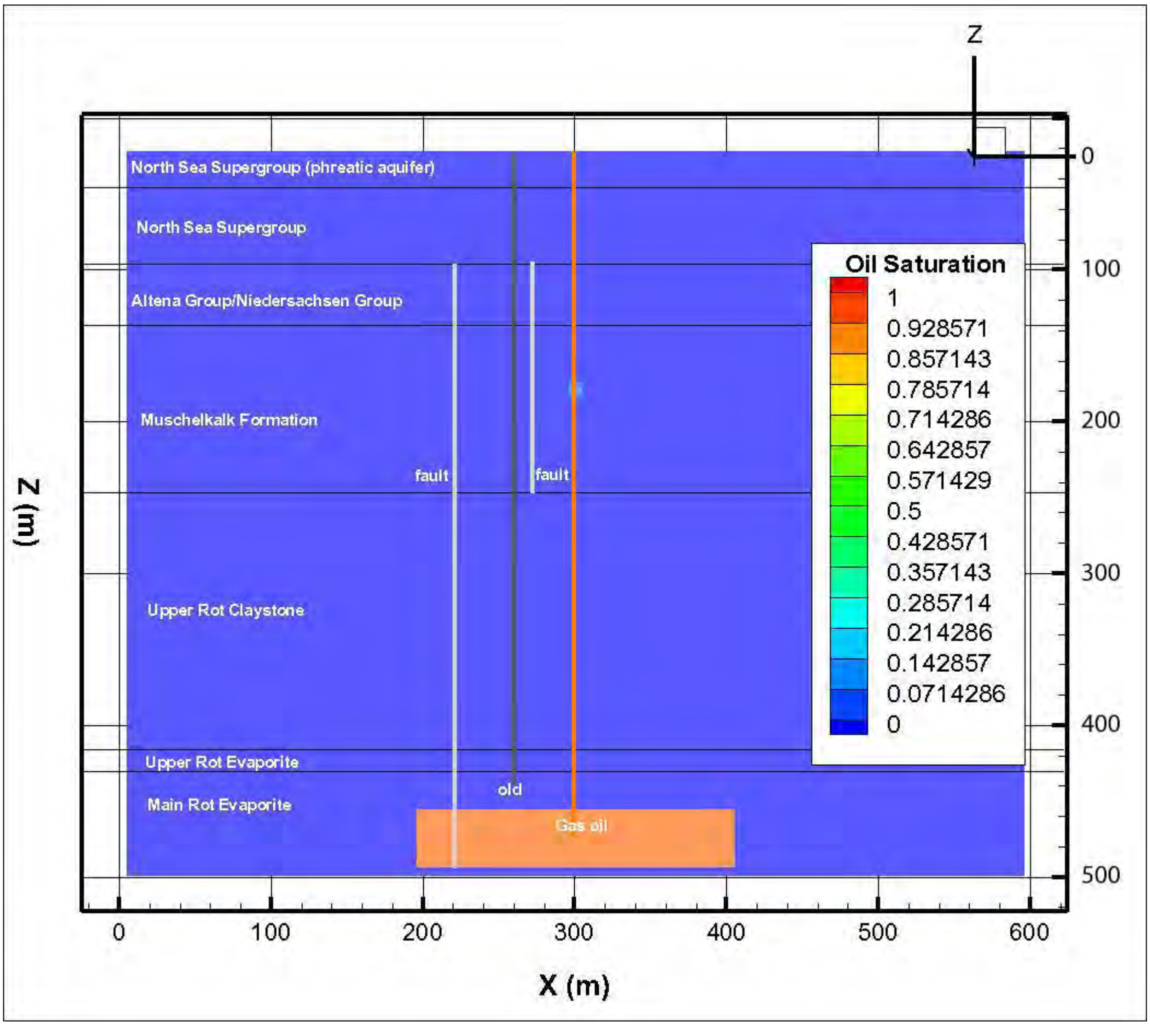
**Cavern 469-470-471, Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity. Effects of leakage after 150 years.**



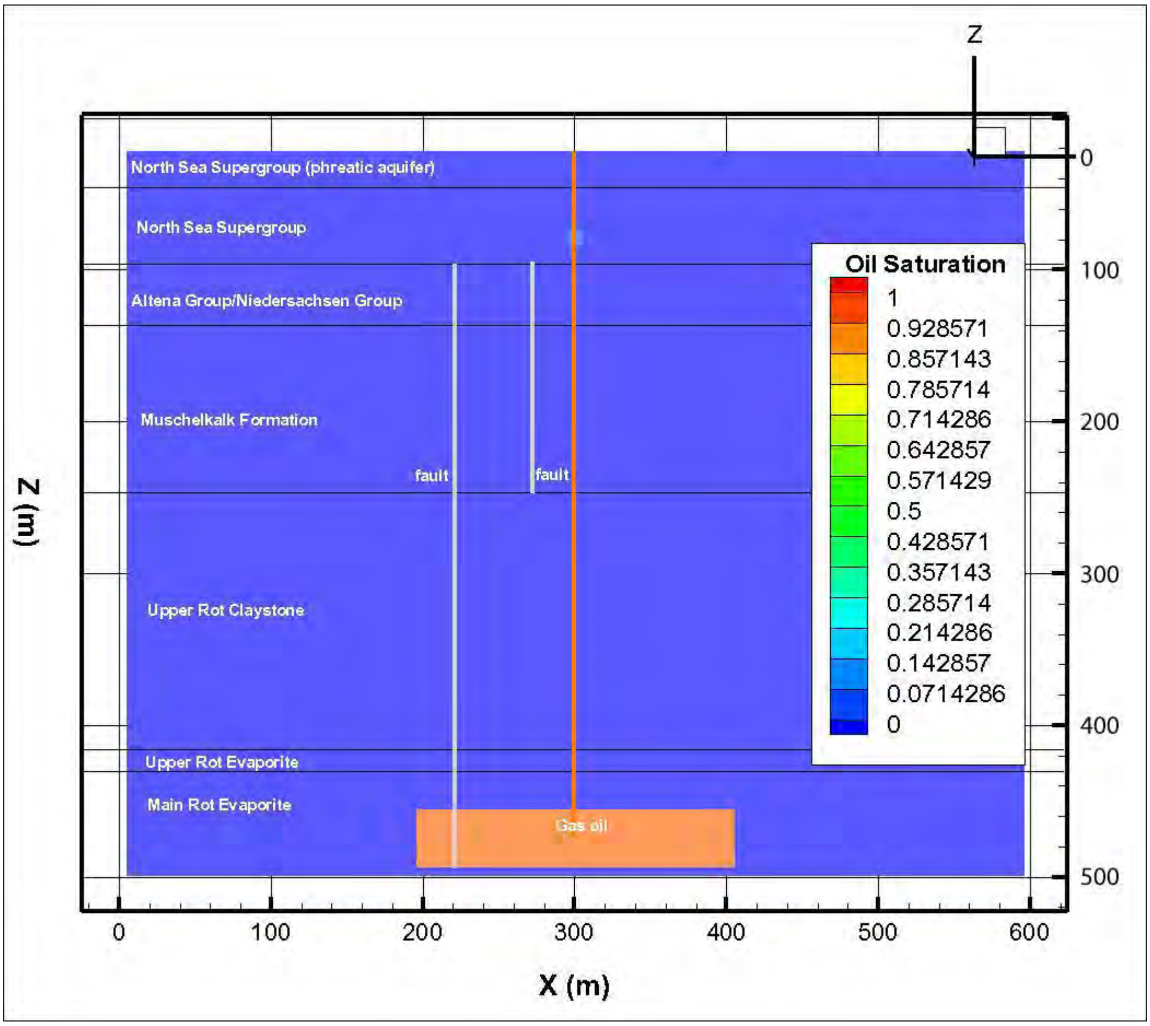
**Cavern 469-470-471, Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation. Effects of leakage after 150 years.**



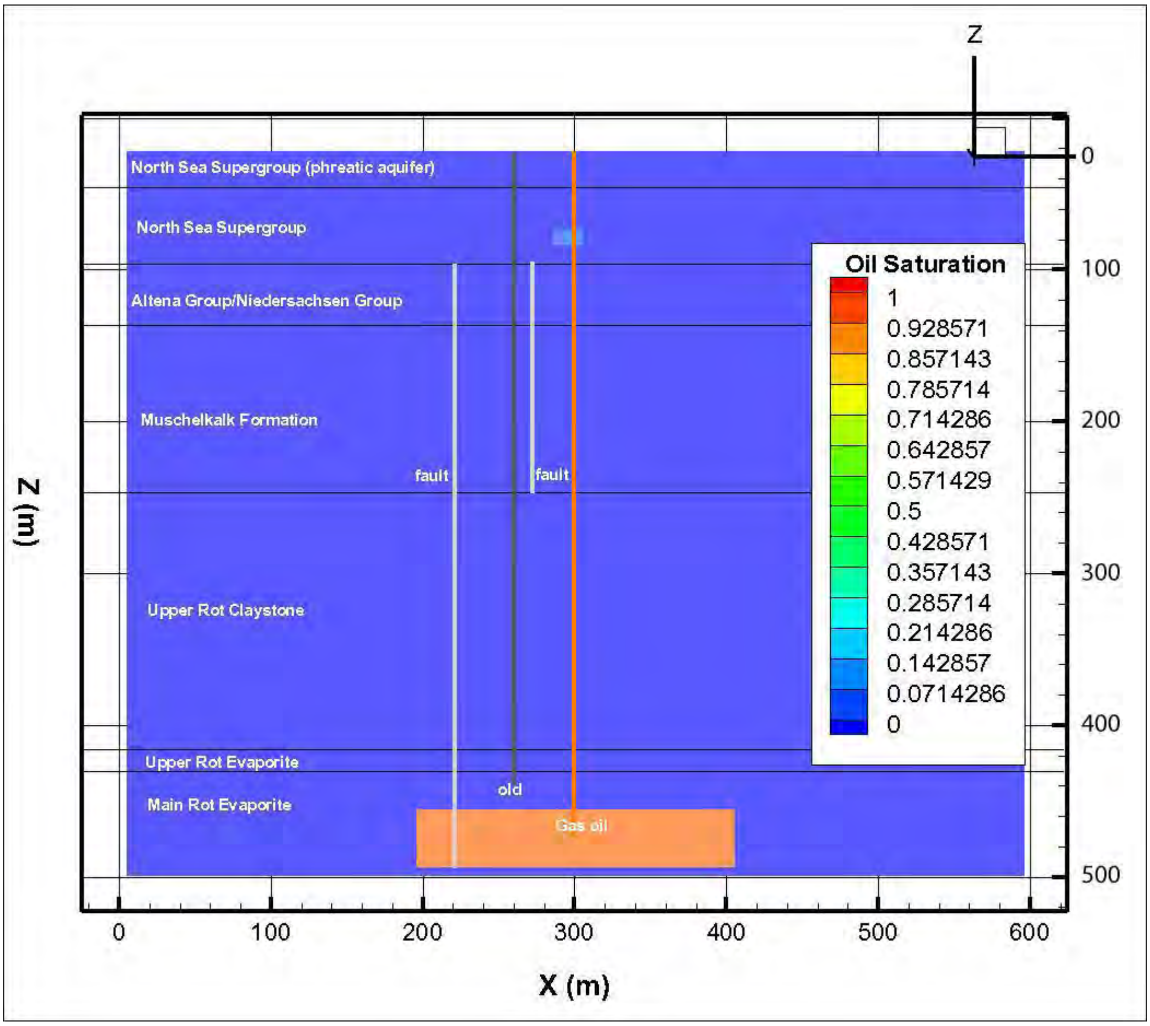
**Cavern 469-470-471, Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years.**



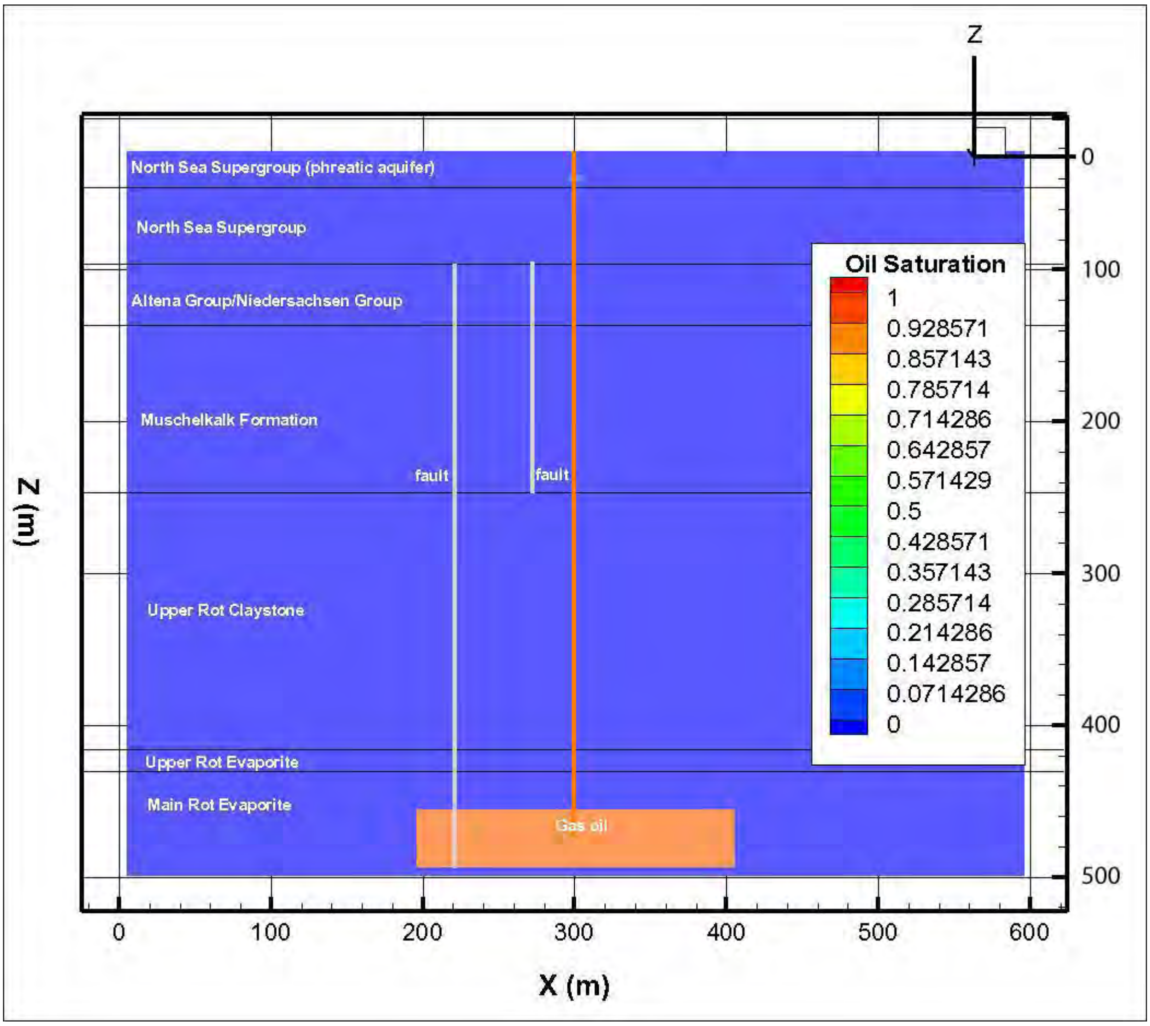
**Cavern 469-470-471, Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup. Effects of leakage after 150 years.**



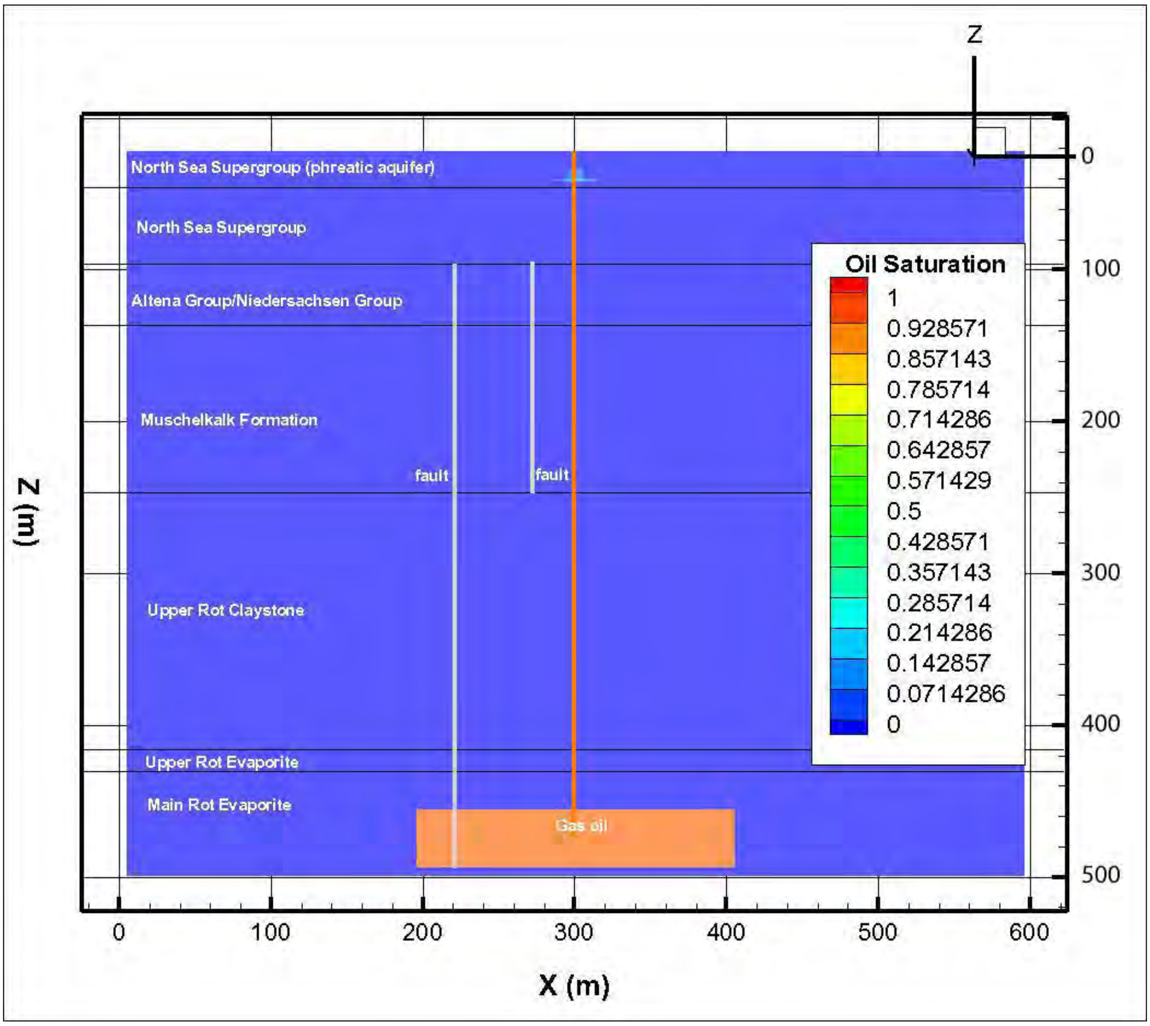
**Cavern 469-470-471, Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years.**



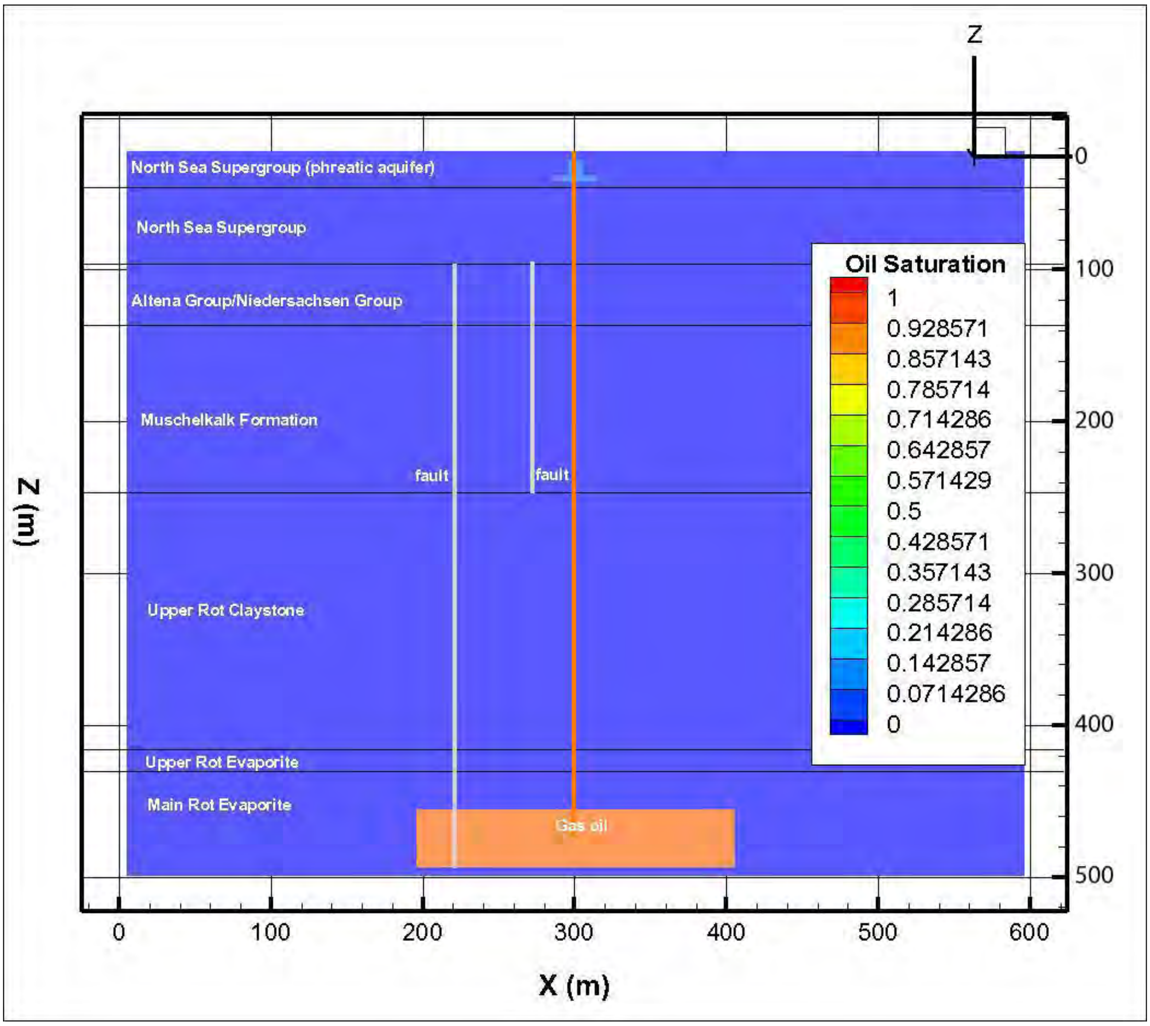
**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 week.**



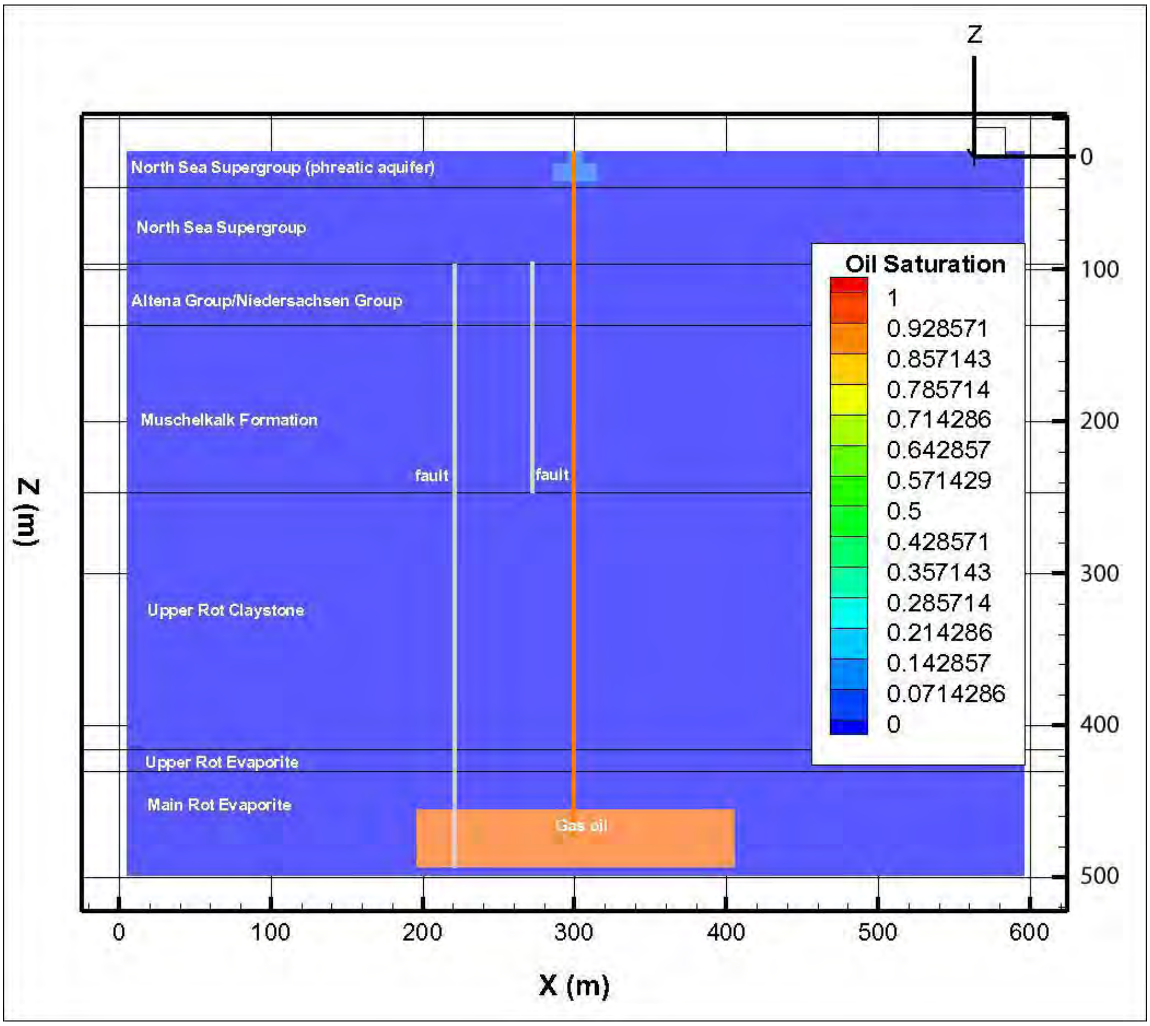
**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 month.**



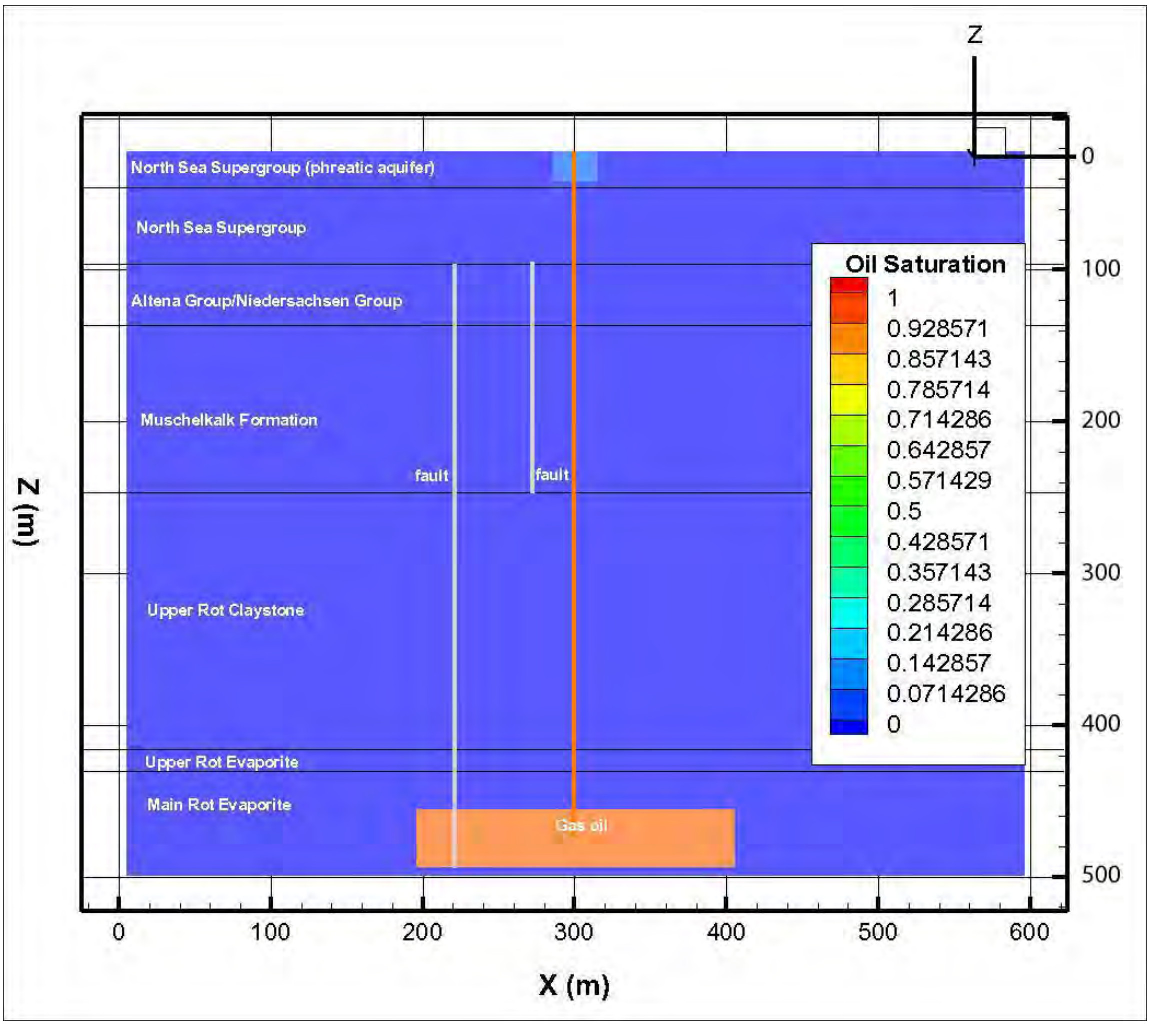
**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 3 months.**



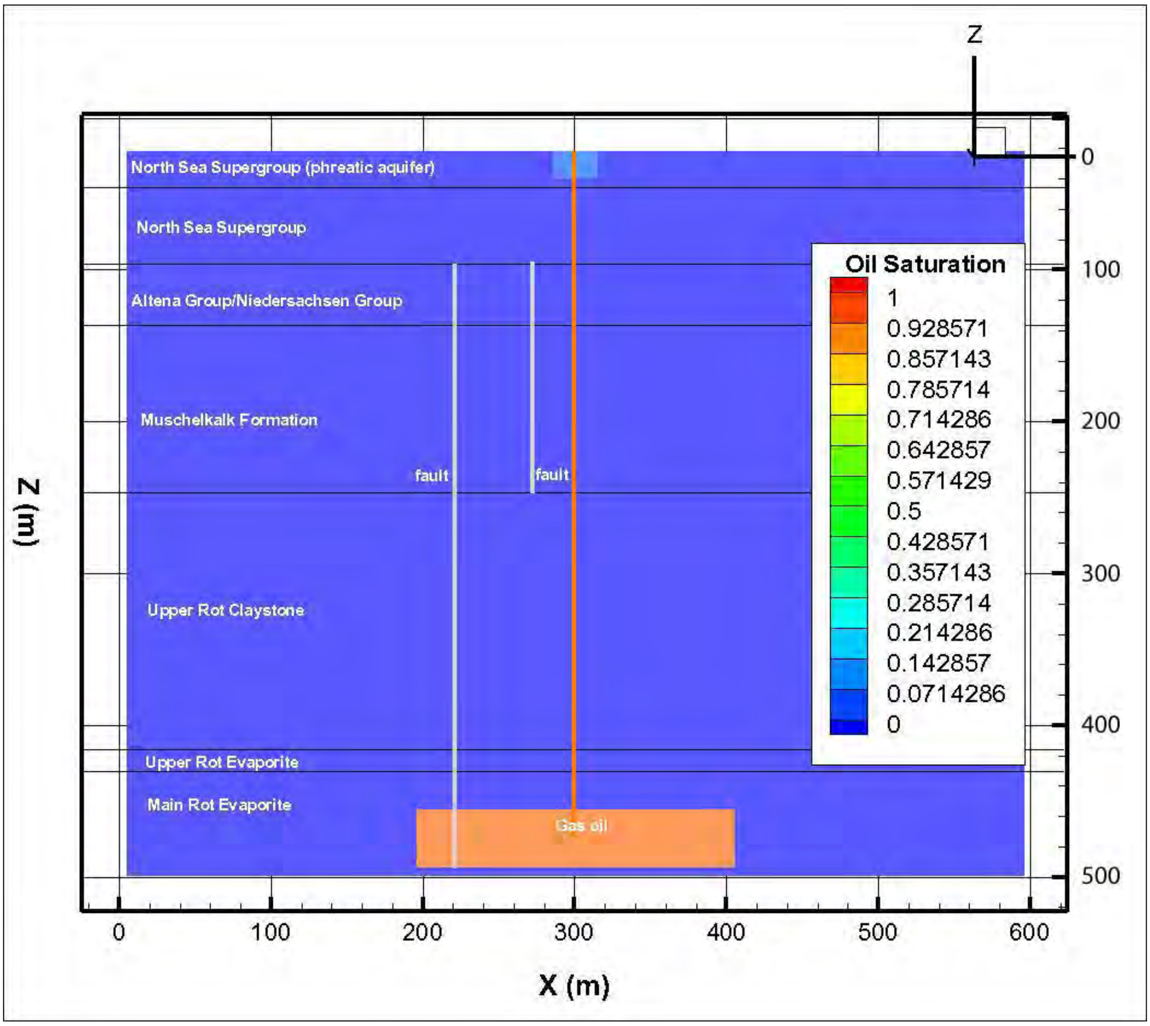
**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 year.**



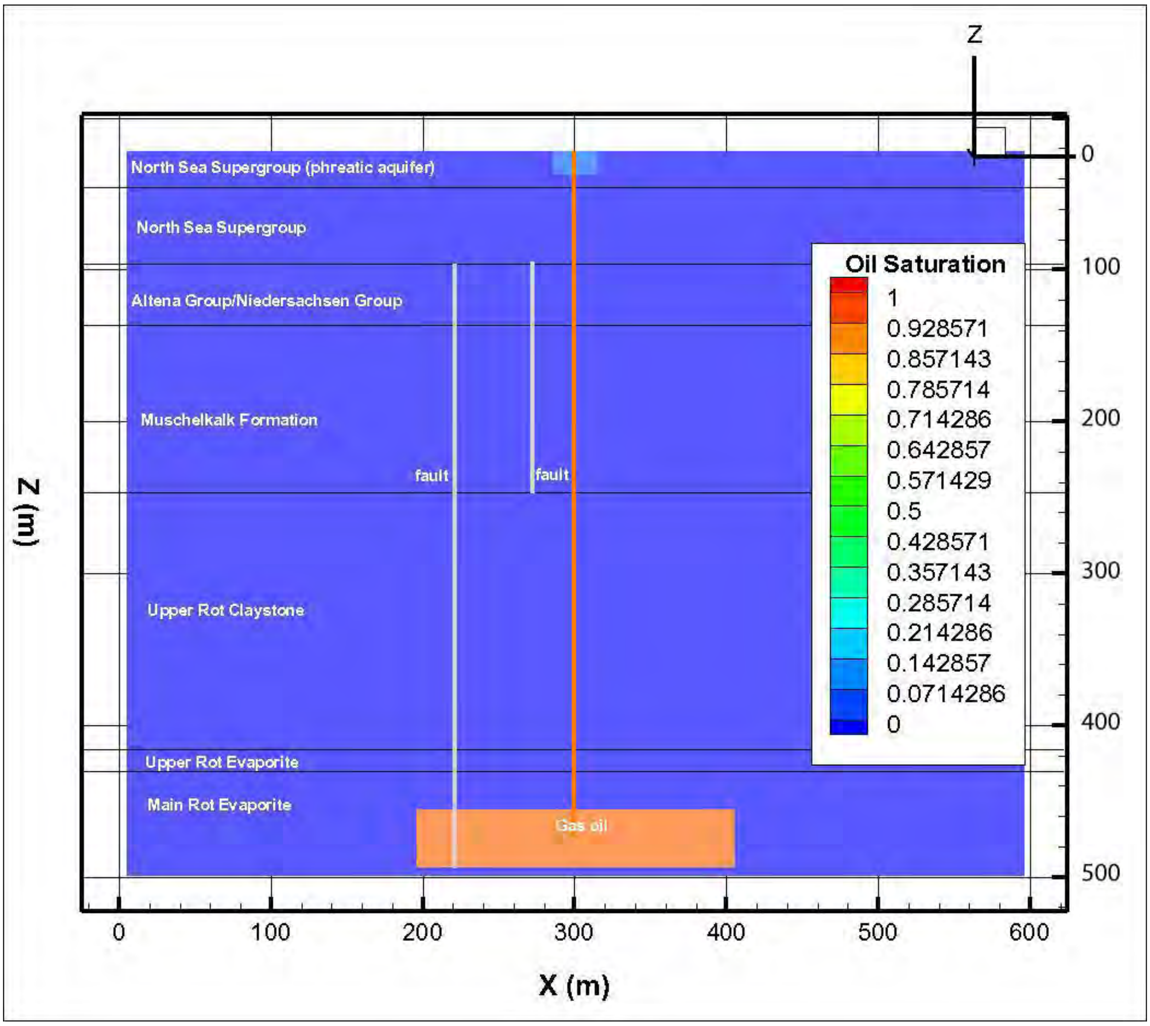
**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 5 years.**



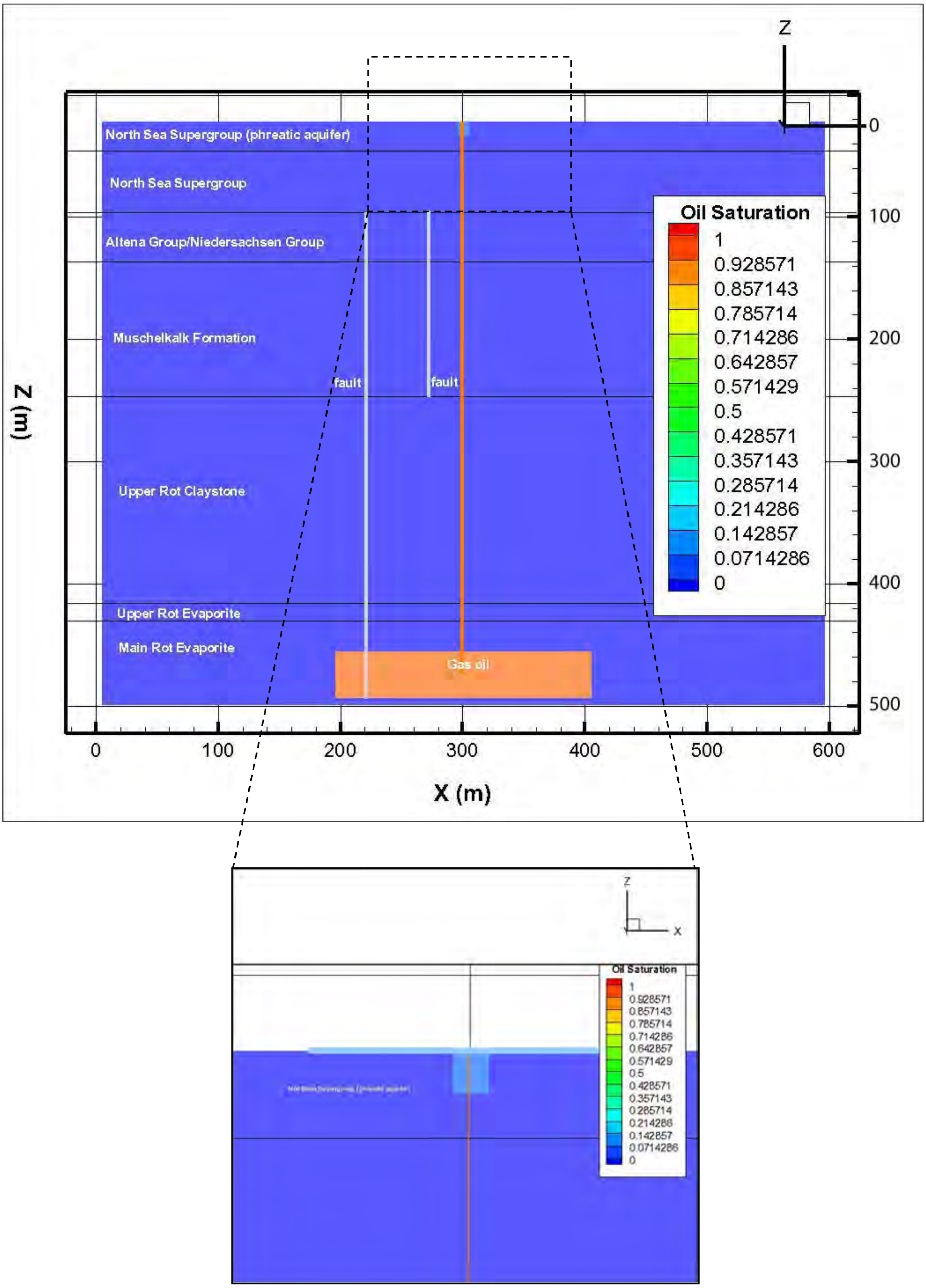
**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 30 years.**



**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 60 years.**



**Cavern 469-470-471, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 150 years. Lower figure shows the form of the LNAPL in and on top of the phreatic groundwater level in detail.**



# Appendix E: STOMP model results for cavern 472

The following figures are shown in this appendix:

Scenario 1: no loss of containment / breach of confinement.
Effects of leakage after 150 years

Scenario 2: leakage from cavern in Röt Claystone.
Effects of leakage after 150 years

Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity.
Effects of leakage after 150 years

Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation.
Effects of leakage after 150 years

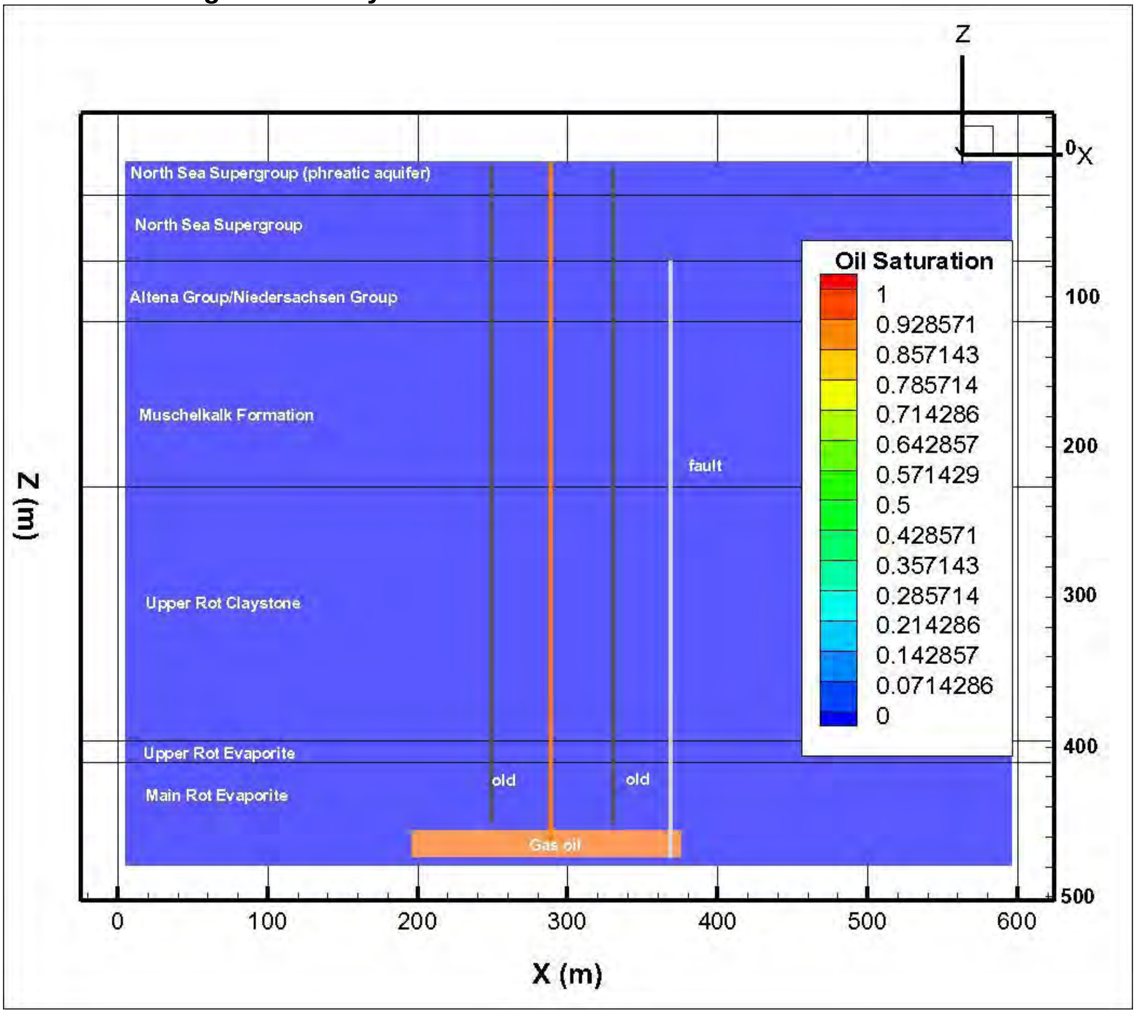
Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup
Effects of leakage after 150 years

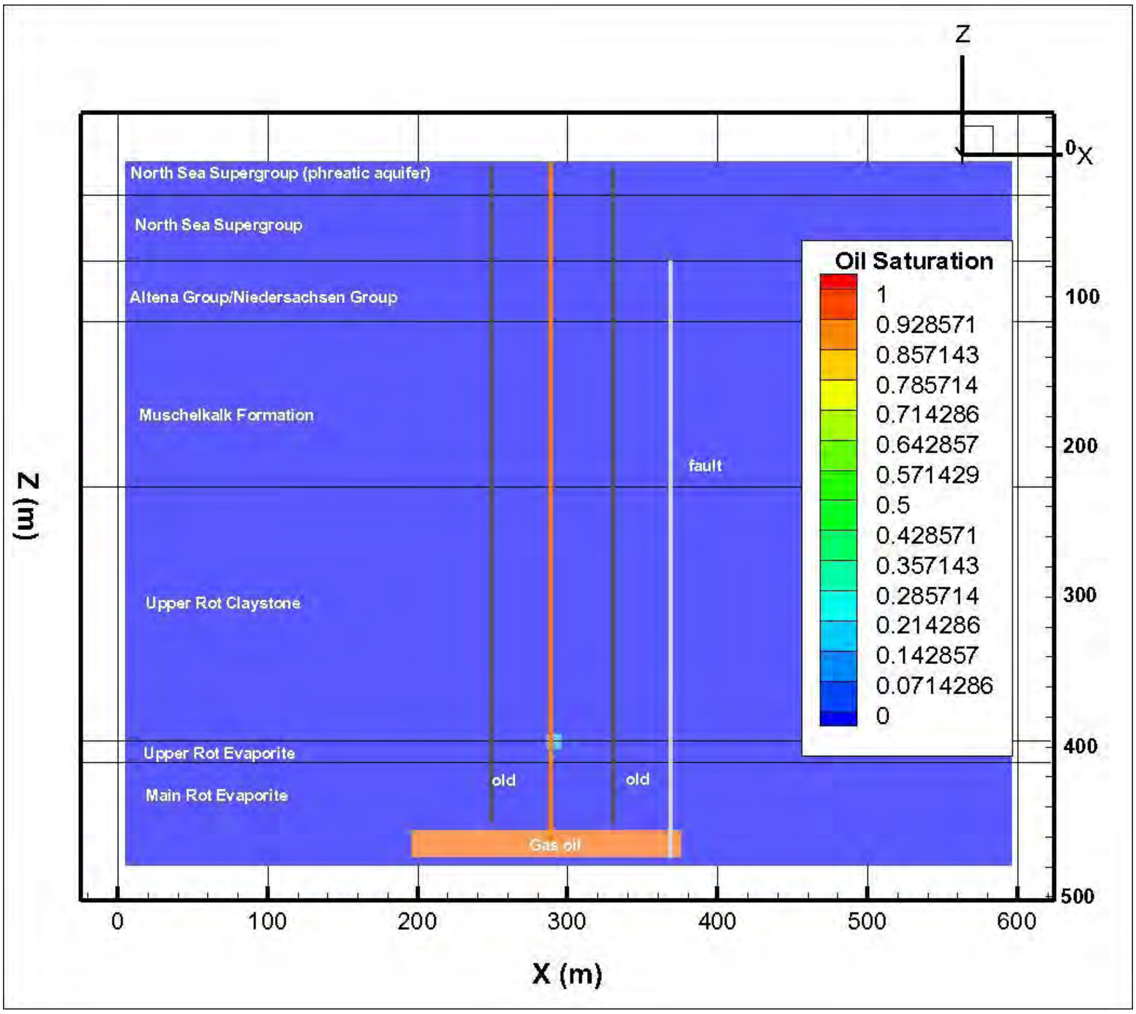
Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years

Scenario 8: leakage from well above hydrogeological base
Effects of leakage after 1 week, 1 month, 3 months, 1 year, 5 years, 30 years, 60 years, 150 years

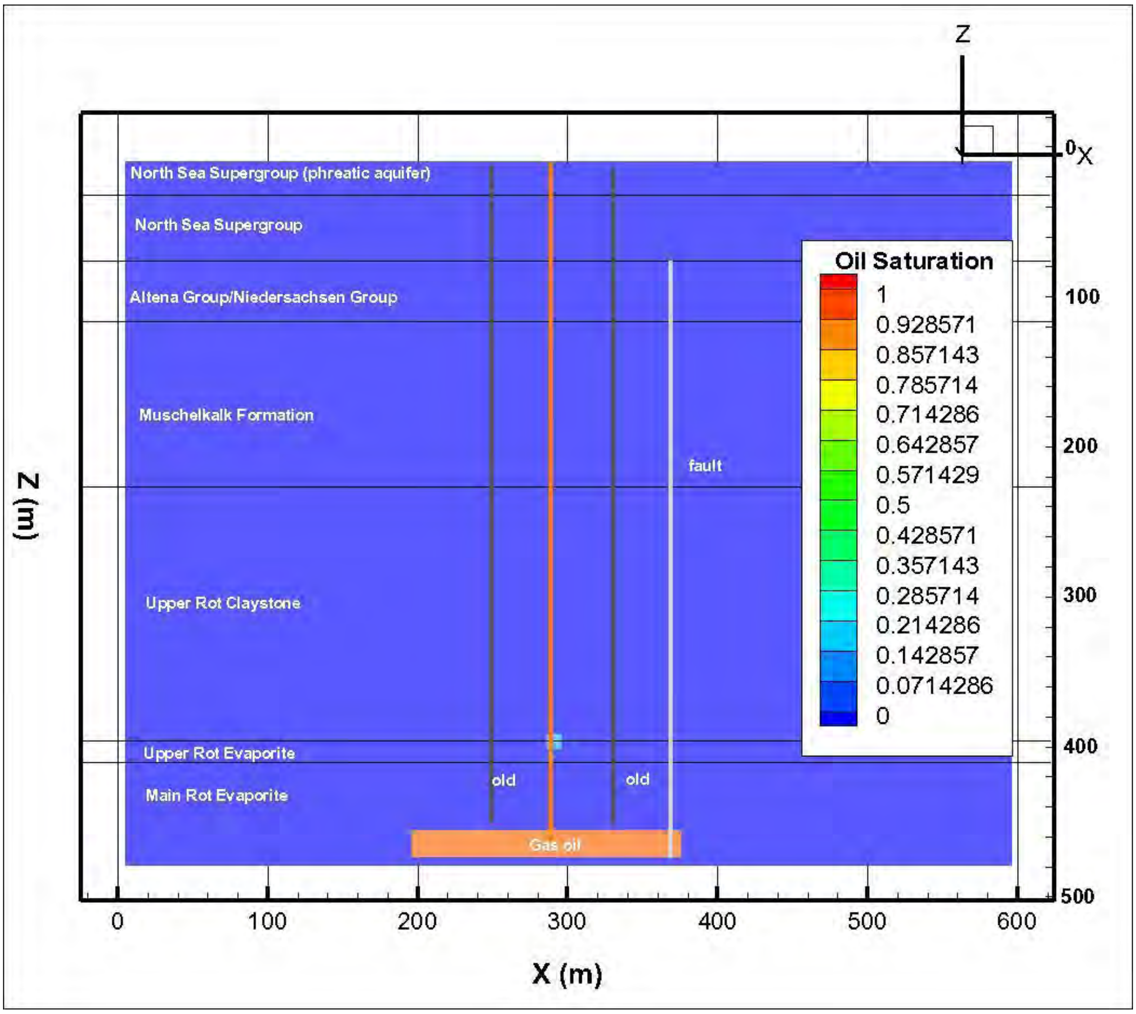
**Cavern 472-473-474, Scenario 1: no loss of containment / breach of confinement. Effects of leakage after 150 years.**



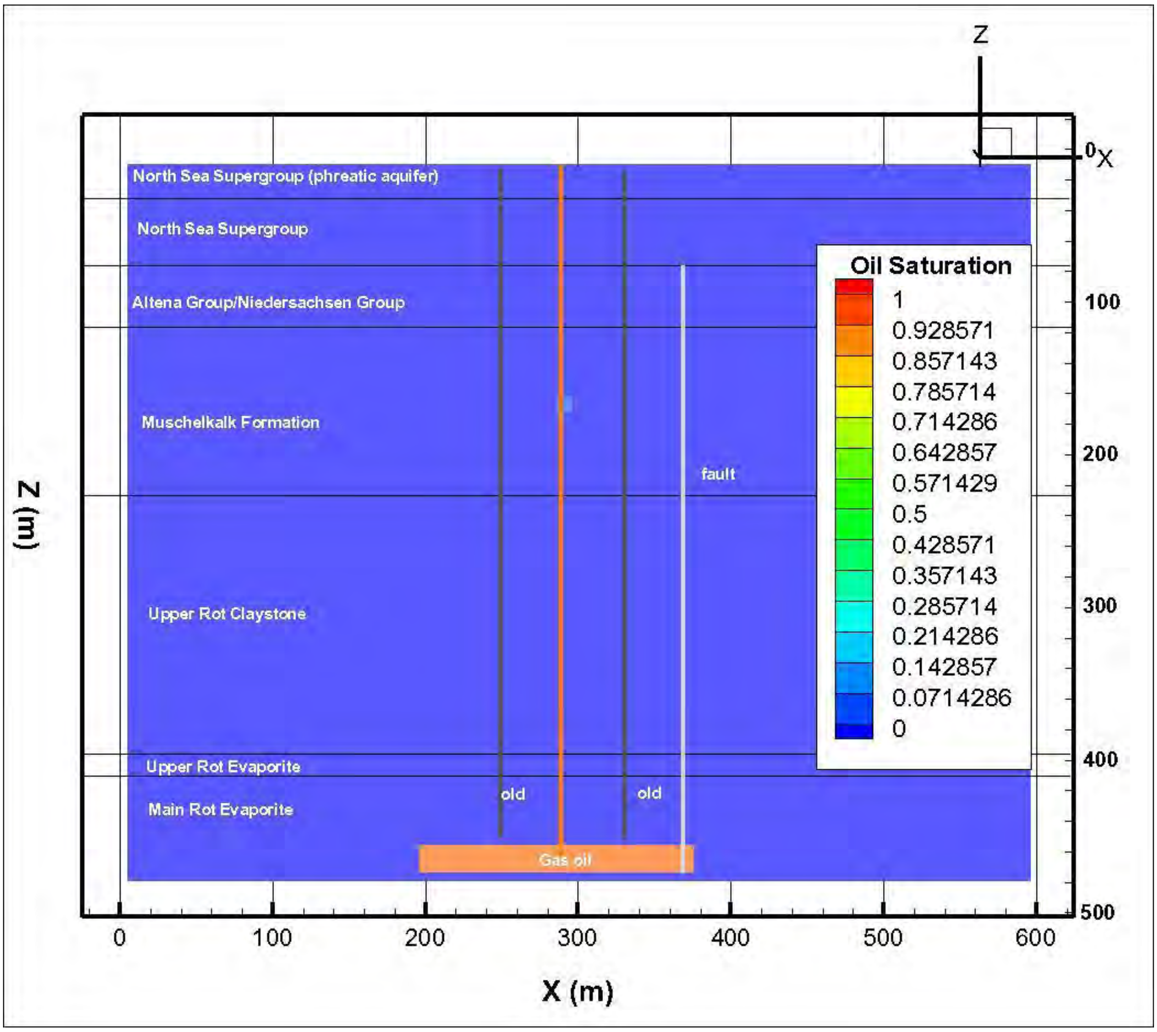
**Cavern 472-473-474, Scenario 2: leakage from cavern in Röt Claystone. Effects of leakage after 150 years.**



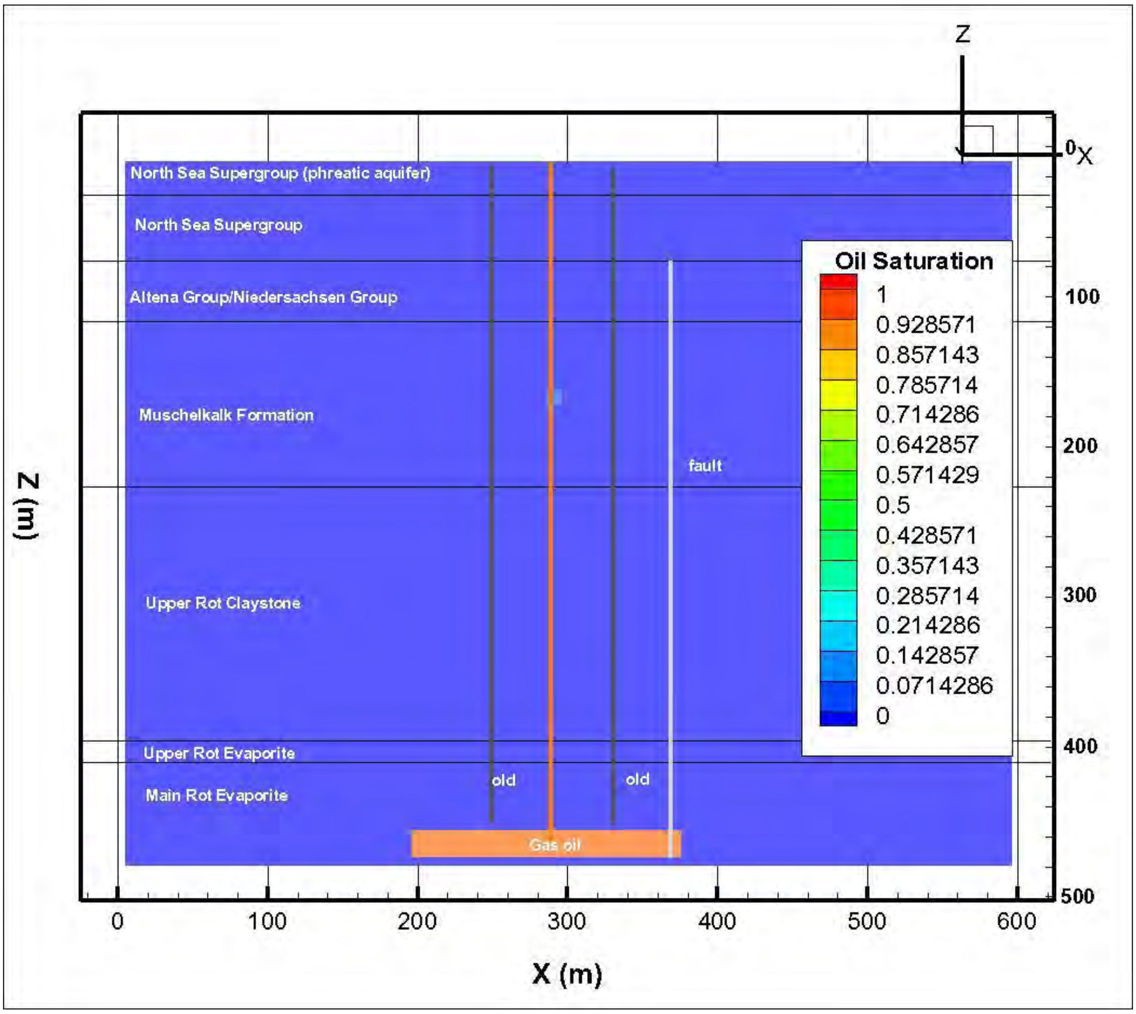
**Cavern 472-473-474, Scenario 3: leakage from cavern in Röt Claystone with old permeable well in vicinity. Effects of leakage after 150 years.**



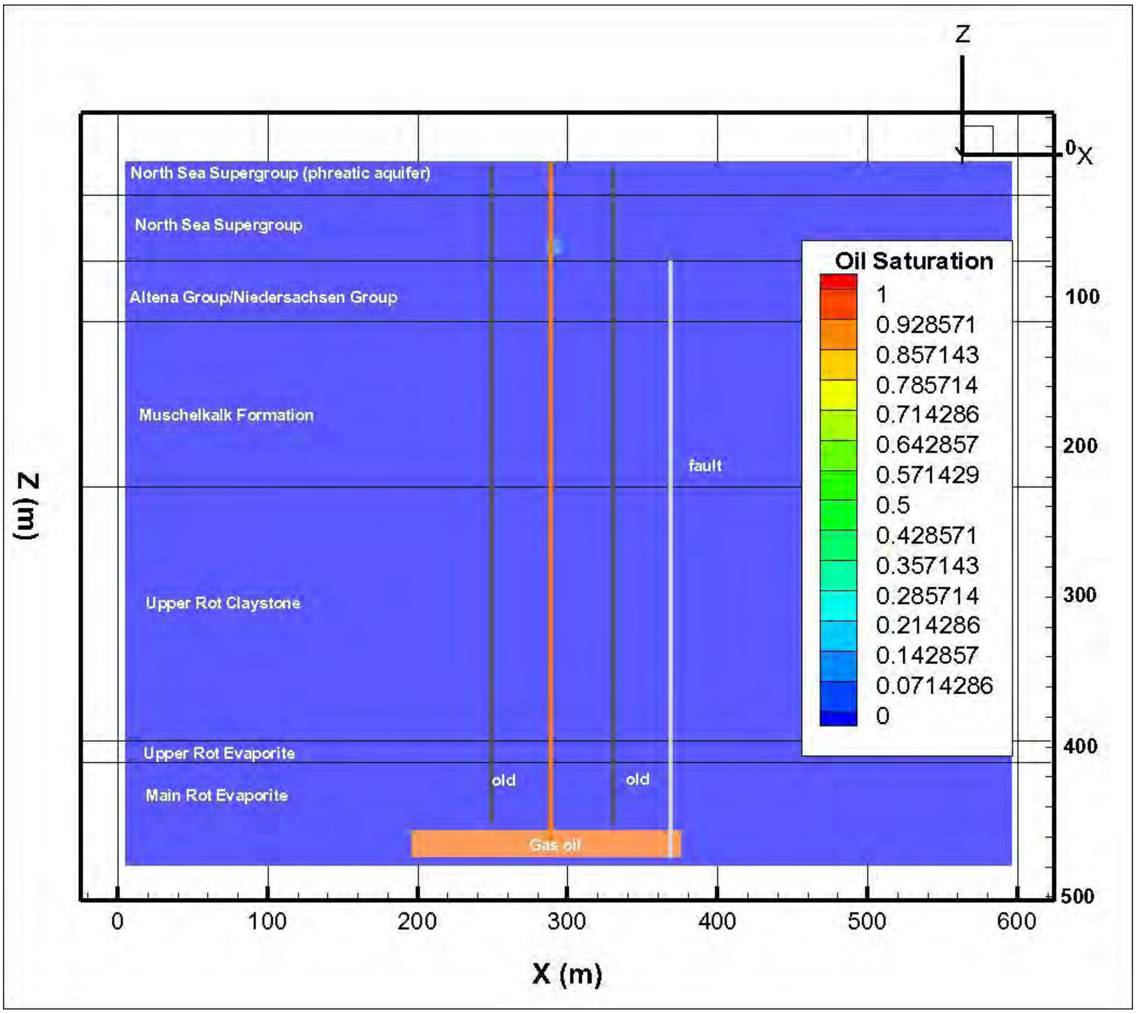
**Cavern 472-473-474, Scenario 4: leakage from well below hydrogeological base in Muschelkalk Formation. Effects of leakage after 150 years.**



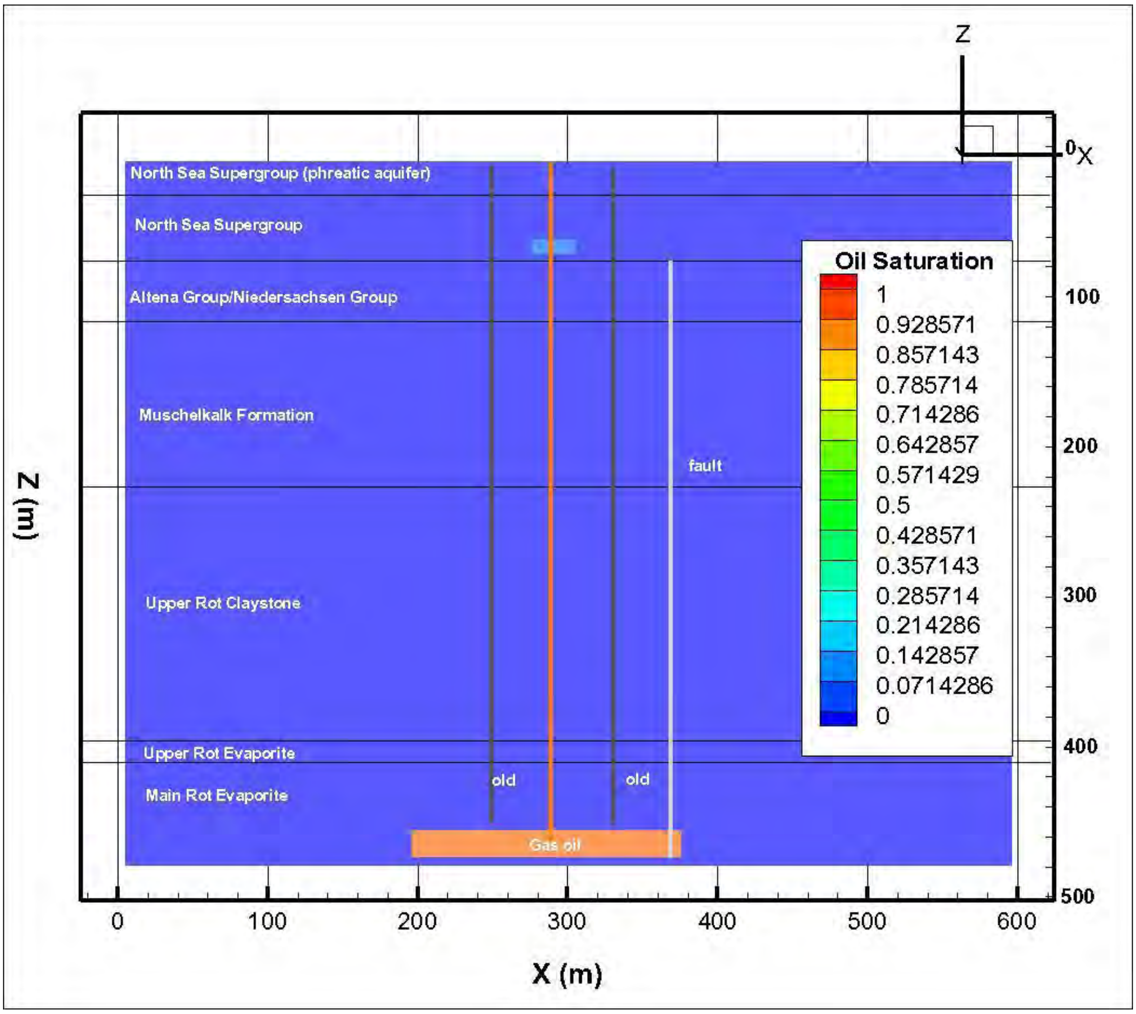
**Cavern 472-473-474, Scenario 5: leakage from well below hydrogeological base in Muschelkalk Formation with old permeable well in vicinity. Effects of leakage after 150 years.**



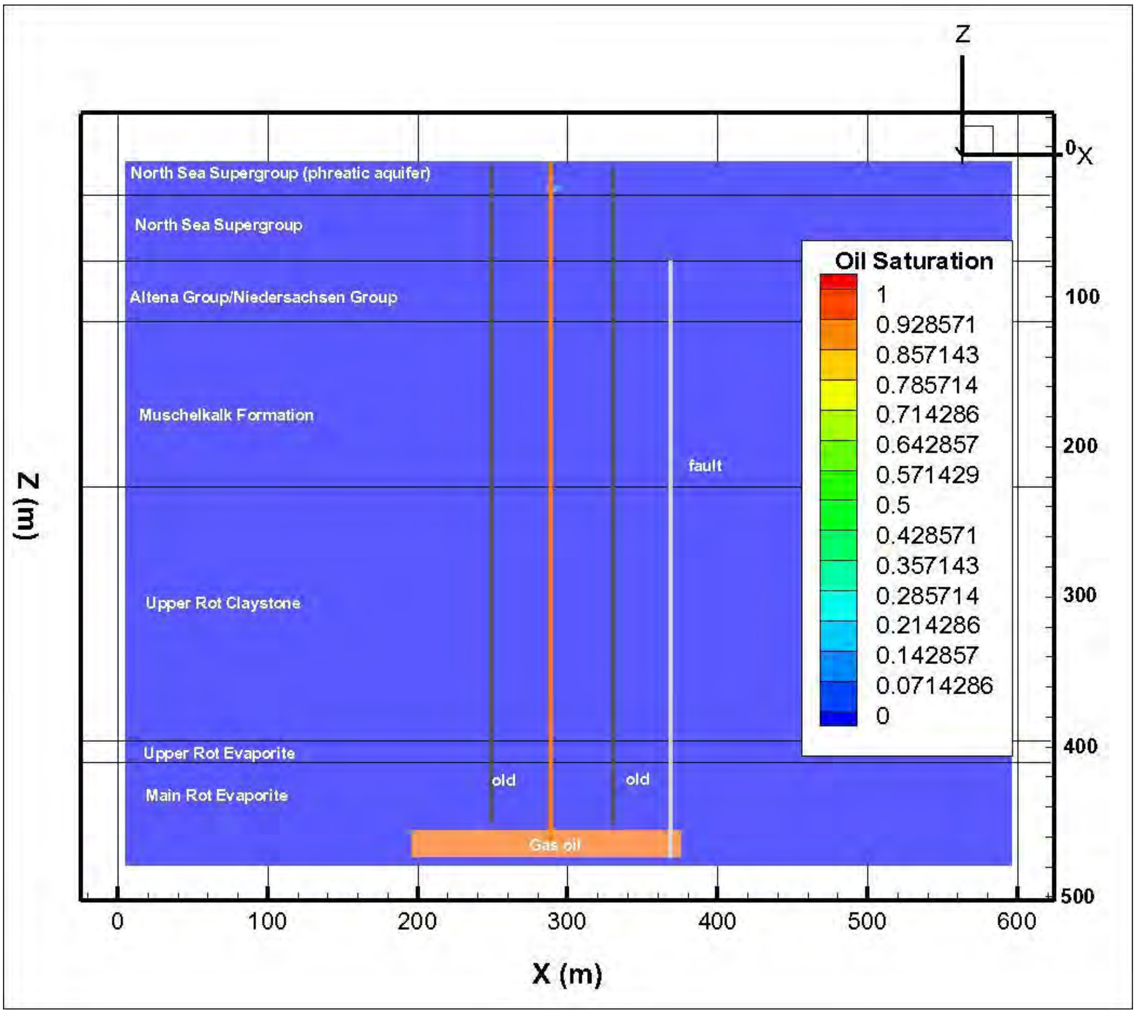
**Cavern 472-473-474, Scenario 6: leakage from well below hydrogeological base in Northsea Supergroup. Effects of leakage after 150 years.**



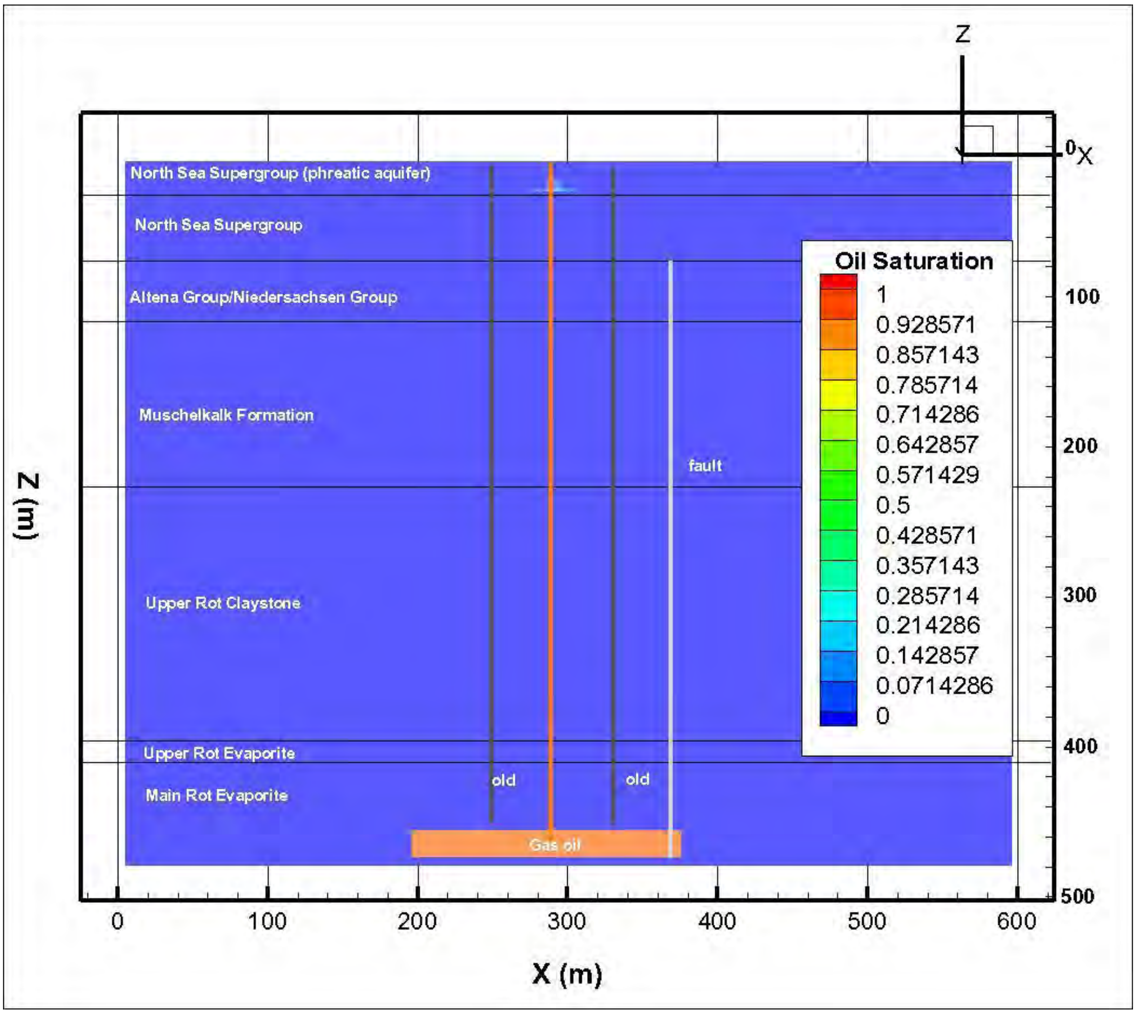
**Cavern 472-473-474, Scenario 7: leakage from well below hydrogeological base in Northsea Supergroup with old permeable well in vicinity. Effects of leakage after 150 years.**



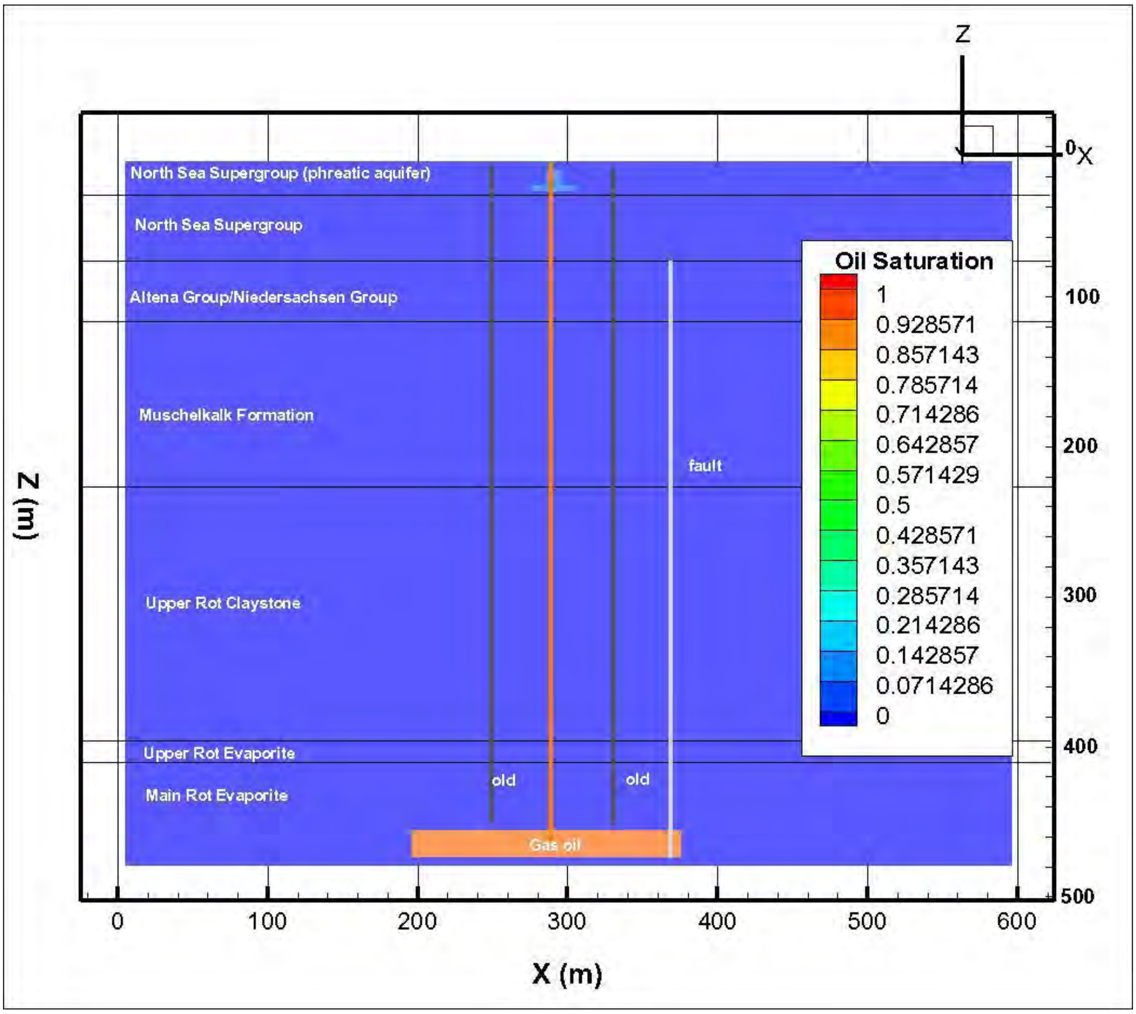
**Cavern 472-473-474, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 week.**



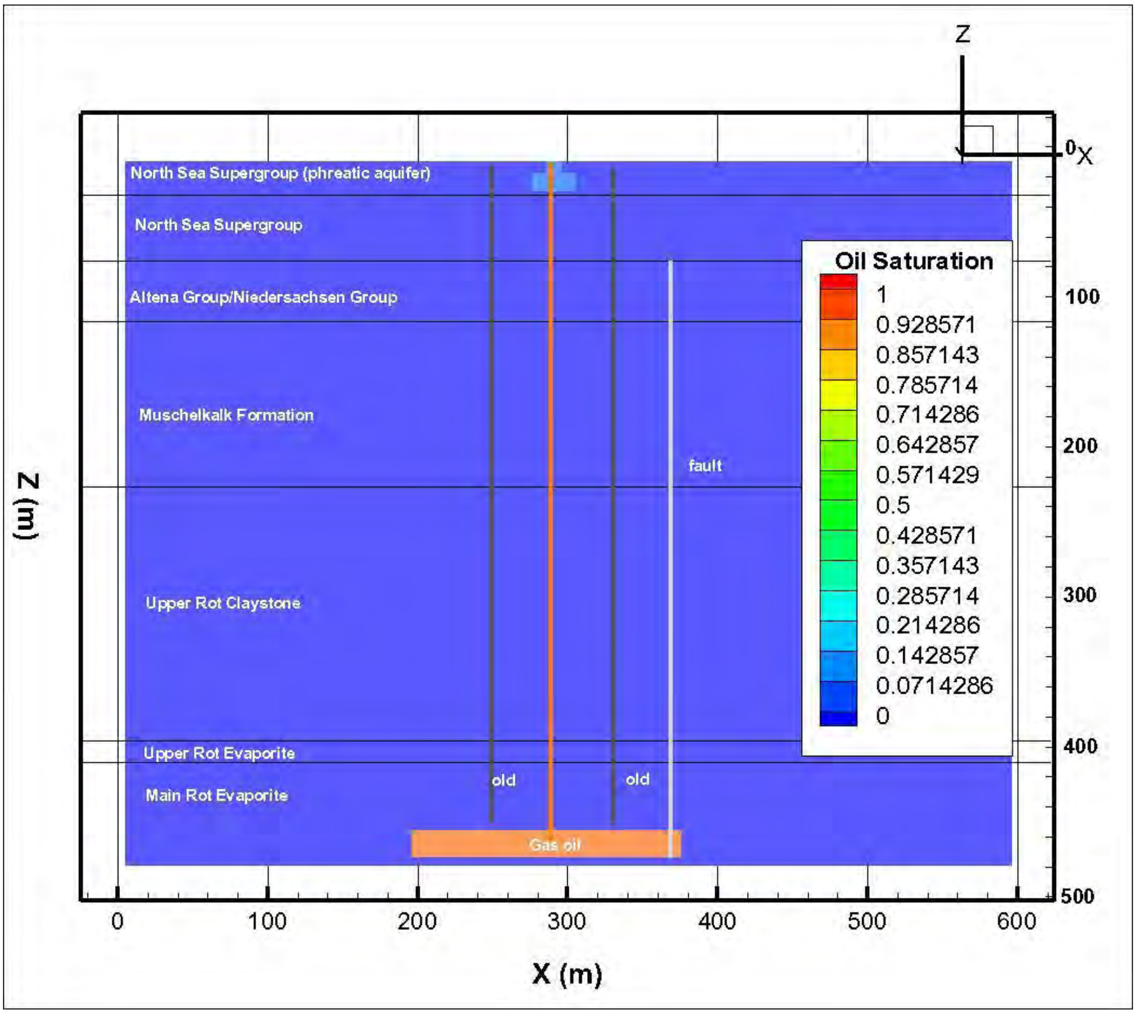
**Cavern 469-471-472, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 month.**



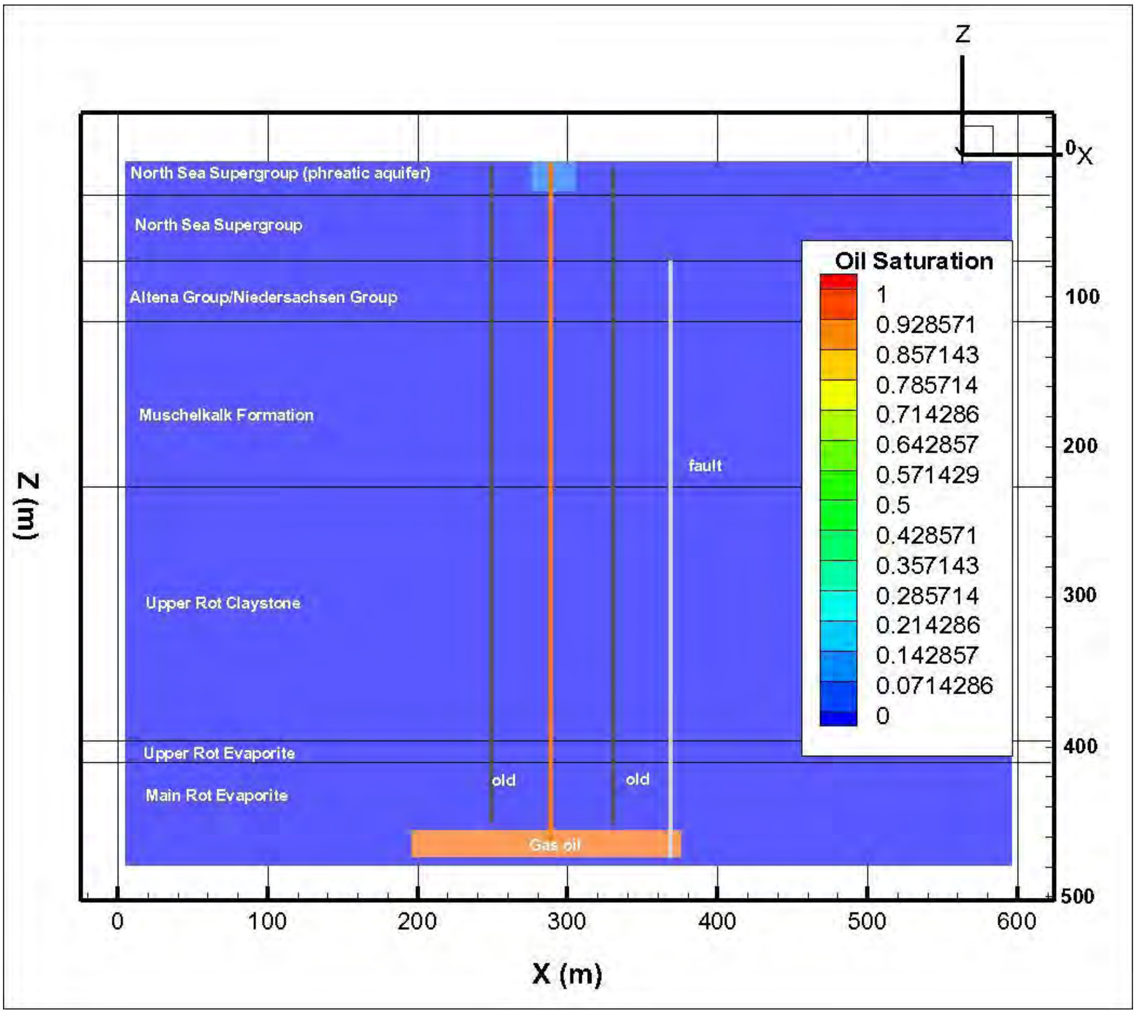
**Cavern 472-473-474, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 3 months.**



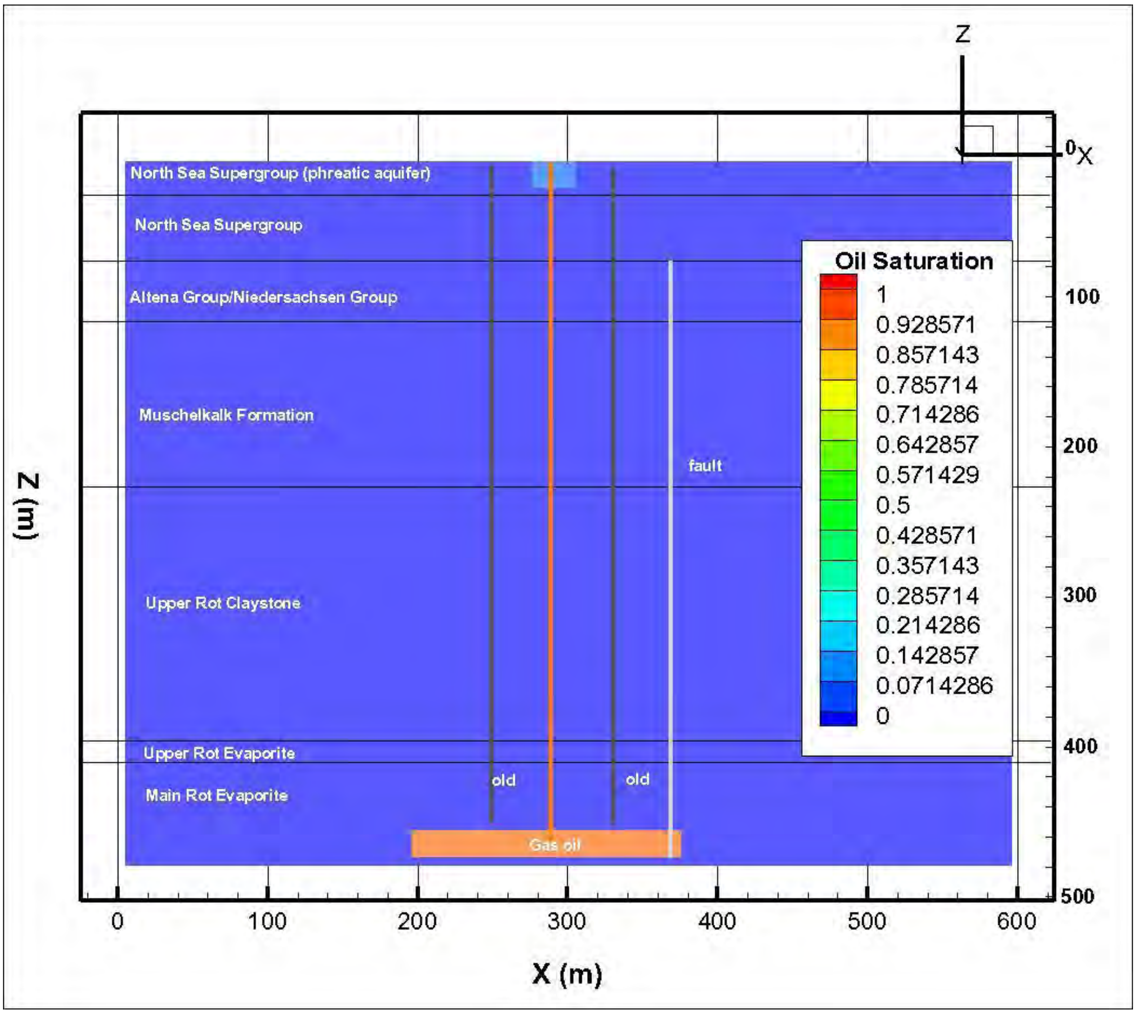
**Cavern 469-471-472, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 1 year.**



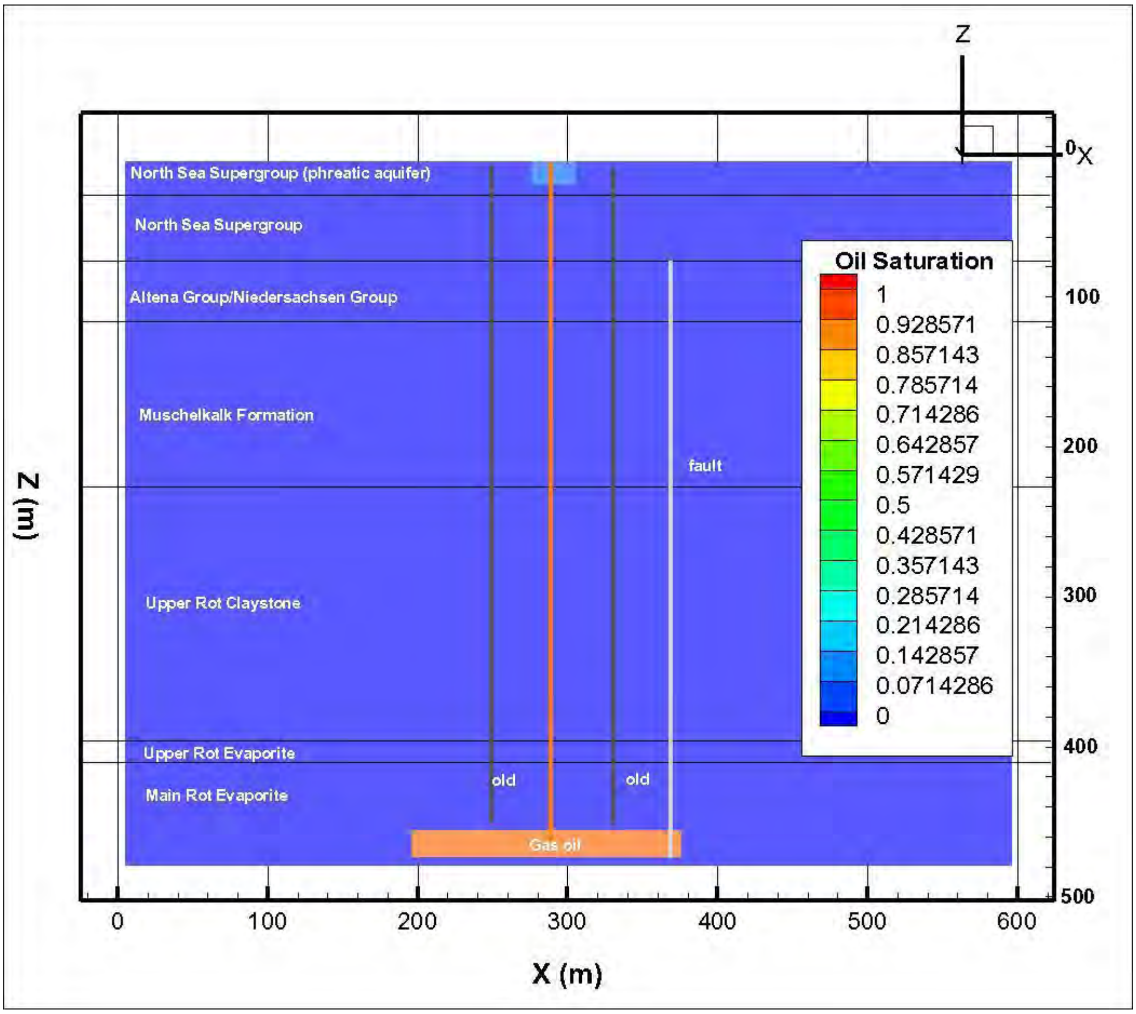
**Cavern 469-471-472, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 5 years.**



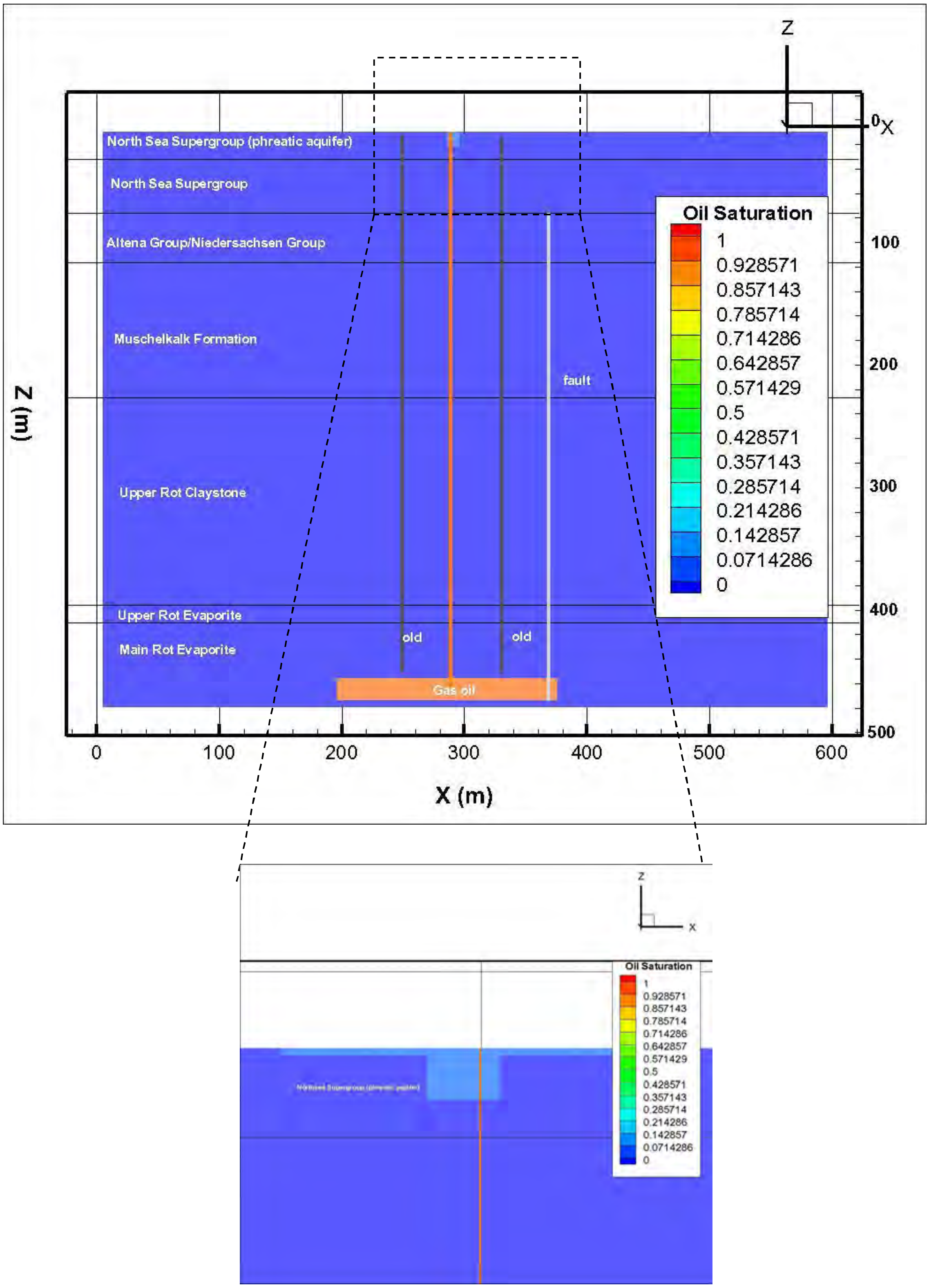
**Cavern 472-473-474, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 30 years.**



**Cavern 472-473-474, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 60 years.**



**Cavern 472-473-474, Scenario 8: leakage from well above hydrogeological base. Effects of leakage after 150 years. Lower figure shows the form of the LNAPL in and on top of the phreatic groundwater level in detail.**



# Cavern-specific risk assessment
# *Cavern 381*

AkzoNobel
Tomorrow's Answers Today

## Executive summary

AkzoNobel has been producing salt by solution mining in the Twente region since 1933. Solution mining is a technique whereby salt is produced from the subsurface by dissolving it in water that is pumped down into a salt layer, thereby creating holes called “caverns”. Many caverns in this region have reached their end of productive life or will do so in the near future. AkzoNobel aims to use some of these caverns for the storage of gas oil. Prior to the selection of specific caverns, the suitability for storage was assessed at site level, which resulted in a preselection of eleven caverns that were considered potentially suitable for gas oil storage (see “*Voornemen gasolieopslag in zoutcavernes in de regio Twente*“; AkzoNobel, 2010). Important issues to be addressed in more detail for these preselected caverns relate to the technical suitability of a salt cavern for storage, and the risks associated with it. For this purpose, a generic technical risk assessment was done for gas oil storage in salt caverns in Twente (Van Duijne et al., 2012a). This risk assessment was done by applying the bow-tie methodology, and is based on the subsurface containment concept and its underlying assumptions, which encompasses the whole suite of barriers and monitoring measures that ensure that gasoil does not disperse outside the boundaries of the storage system. It resulted in a checklist with requirements for a cavern to adhere to for it to be labeled suitable for storage of gas oil.

Four cavers were selected for storage of gas oil and were subjected to this checklist in a cavern-specific risk assessment (Van Duijne et al., 2012b) by Deltares that was submitted as attachment to the storage plan in early January 2013.

In December 2012 a fifth cavern was added to the selection: cavern 381. Its suitability for storage of gas oil was assessed in a similar manner as the other four caverns, i.e., by performing a cavern-specific risk assessment that involves subjecting it to the checklist for suitability for storage of gasoil, and by looking in detail at the local geology around the cavern, the geometry, the well configuration, and the volume. As such, the results from this cavern-specific risk assessment for cavern 381 are detailed in this report. Additional information is given on the current status, the geometry, and the local geological conditions around cavern 381. Next, the suitability checklist (see section 7.4 in Van Duijne et al., 2012a) is filled in and reviewed to show that the selected cavern fulfills the requirements to be used for gasoil storage. A suitable cavern in this context means that it adheres to the conditions that are required to ensure that the gasoil remains confined to the storage system.

Contrary to the other four caverns, for this cavern no multiphase flow modeling (STOMP) was done to explicitly quantify the effects of leakage (magnitude, extent of contamination). The reason for this is that the results of a similar modeling exercise for the other four caverns showed that the effects of leakage are extremely very limited, and also very comparable between the four caverns. Since the situation in and around cavern 381 is very comparable to that of the other caverns, no change in modeled effects of leakage is to be expected.

**Characteristics, geology and hydrogeology of the location**
Cavern 381 is located in the Marssteden storage concession, located in the municipality of Enschede, at the west side of Enschede in the catchment area of the Twentekanaal. Relief in the area is subtle and no moraines or clay lenses are present. Phreatic groundwater levels lie between 0 and 2 m below the surface and fluctuate approximately 1 m throughout the year (De Louw, 2006). Several surface water streams can be found in the vicinity of the

area of which some have EU Water Framework Directive objective ("Azelerbeek" and "Bornsebeek"). North of the Marssteden concession, an area of the Ecological Main Structure of the Netherlands (EHS) is present. Several groundwater abstraction wells for drinking water and two groundwater protection areas are located at close proximity to the selected caverns (< 5 km) as well as several swimming water locations.

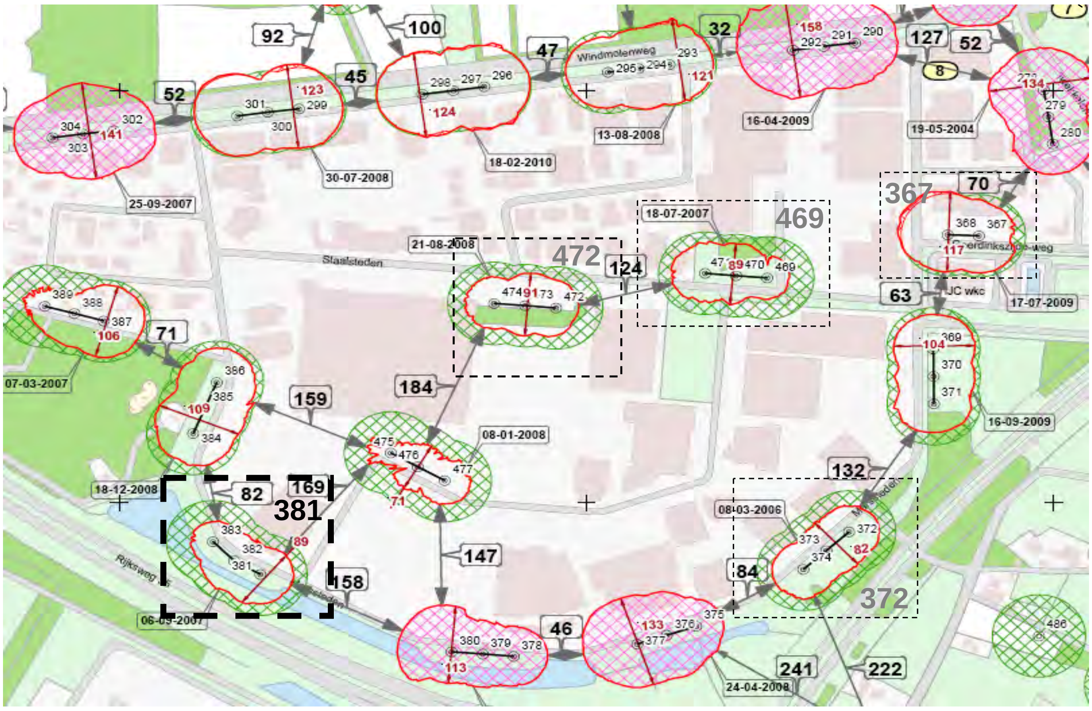



*Figure ES1: Overview of the area of the Marssteden concession of AkzoNobel with the position of the salt caverns. Caverns in dashed rectangles are selected for gas oil storage. Caverns 367, 372, 469 and 472 are discussed in Van Duijne et al. (2012b), cavern 381 is discussed in this report.*

The geology of the Twente area is a key factor in the natural containment of gasoil in salt caverns, with emphasis on the hydrogeological properties of the geological layers, the tectono-stratigraphic history of the region and the characteristics of faults present in the area. The subsurface of the Marssteden area consists of an alternation of aquifers (high permeability) and aquitards (low permeability). The shallowest aquifer (first 10 to 60 m below the surface) is unconsolidated and sandy, and has a high permeability. At the base of this aquifer a 50-100 meters thick layer of marine clays is found with a very low permeability. These marine clays constitute the hydrogeological base of the groundwater system. At larger depth the only aquifer present is the Muschelkalk formation, at a depth of approximately 250 meters. Furthermore, the subsurface above the Rot salt layers consists of Rot claystone with a thickness of approximately 150 meters.

Although tectonic activity has affected the Twente area during geologic history, leading to the development of both large scale faults (like the Gronau fault zone north of Hengelo and the Boekelo fault zone, southwest of Enschede) and small scale faults, the Marssteden concession area itself has been hardly affected. Only the southwestern part of the area, closest to the Boekelo fault zone, seems to be affected and faults are present here with an offset between 4 and 20 meters. However, these faults do not offset the entire stratigraphy. From literature and detailed studies it can be concluded that the salt caverns themselves are unlikely to have been directly affected by faults. If faults are present in the salt itself, the permeability across faults is known not to change significantly due to the viscoplastic nature of salt, which tends to heal such high-permeable zones. Nevertheless, there may be faults present in the overburden that may form a fluid migration pathway between aquifers at different depths that are otherwise separated by aquitards.

**Preliminary cavern selection**
Prior to this detailed risk assessment, a cavern selection process was performed, excluding high risk caverns from the selection. Excluding criteria encompassed:

- a history of some form of subsidence;
- a too thin salt roof above the cavern
- a too small distance between adjacent caverns (i.e. too thin salt pillar);
- an irregular cavern shape or too small cavern volume;
- development of the cavern into units of the Main Röt Evaporite salt layer younger than unit A;
- presence of major faults with possible leakage risks.

**Possible leakage scenarios and leakage modeling**
Seven leakage scenarios have been identified (see Table ES1), covering all possible causes for leakage and their consequences. Each scenario has a different depth and period of leakage, as the time span until the discovery of a leak and until full mitigation has been achieved differs, depending on the location of the leak (well or cavern). Scenario 1, "no breach of confinement", is the base case (expected evolution scenario).

| Scenario's | leakage depth | period of leakage |
|---|---|---|
| **1** no breach of confinement *(base case)* | 435 m -surf. | 3 months |
| **2** leakage from cavern into Röt Claystone | 395 m -surf. | 3 months |
| **3** scenario 2 with old permeable well in vicinity | 395 m -surf. | 3 months |
| **4** leakage from well into Muschelkalk Formation (below hydrogeological base) | 156 m -surf. | 1 month |
| **5** scenario 4 with old permeable well in vicinity | 156 m -surf. | 1 month |
| **6** leakage from well into North Sea Supergroup (below hydrogeological base) | 60 m -surf. | 1 month |
| **7** scenario 6 with old permeable well in vicinity | 60 m -surf. | 1 month |
| **8** leakage from well above hydrogeological base directly into groundwater | 20 m -surf. | 1 month |

*Table ES1: Hazard scenarios associated with the top event "breach of confinement for the cavern-specific risk analysis.*

**Results of the cavern-specific risk assessment**

Cavern 381 (wells 381, 382 and 383) is located in the southwestern corner of the Marssteden concession (see Figure ES1). Characteristics of this cavern, based on the two basic sources of subsurface data that are available (i.e. sonar survey data and gamma-ray log data) are shown in Table ES2. The cavern is fully situated in the Röt Salt A Member and Röt D is overlain by 12 m of impermeable anhydrite (Röt E). Above that another ±160 m of impermeable claystone separates the cavern from the more permeable Muschelkalk Formation.

The nearest fault to this cavern runs just northeast of this cavern, is identified in wells 381 and 382, and actually crosses the cavern (Geowulf, 2010). Its throw is estimated to be less than 2 meters. As it runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. Because the estimated throw is much less than the thickness of the salt layer (salt A-D), the containment is unlikely to be compromised by this fault.

The current volume of the cavern is approximately 160,000 $m^3$. It is calculated based on results from sonar (sound navigation and ranging) surveys. A layer of brine is left at the bottom of the cavern during storage to shield the gas oil from the permeable sump material and formations below the cavern into which it may potentially migrate. Close inspection of the sonar data reveals that a maximum depth of the oil-brine interface of 465 m is allowable without exposing the sump to gas oil, i.e., the cavern can be filled with gas oil up to a level where the oil-brine interface is at 465 m depth below surface. At this maximum depth, the volume of gas oil that can be stored is approximately 150,000 $m^3$. Furthermore, the sonar measurements indicate that the roof of this cavern is very regular, i.e., the number of so-called "pockets" in the roof in which gas oil gets trapped is low. A total pocket volume of only a few hundred $m^3$ is estimated from sonar.

| **Characteristics for cavern 381** | |
|---|---|
| top Upper Röt Evaporite (average) | 410m below surface |
| thickness Upper Röt Evaporite (average) | 12m |
| top Main Röt Evaporite (average) | 424m below surface |
| thickness Main Röt Evaporite (average) | 51m |
| cavern length | 165m |
| cavern width | 105m |
| cavern height (average) | 16m |
| location gas oil well | centre of cavern |
| fault Fsw: distance from gas oil well | 30m northeast of well |
| fault Fsw: depth range of offset | 95 to >490m below surface |
| old wells: distance from gas oil well | 40m northwest and southeast of well |

*Table ES2: Overview of the characteristics of cavern 381*

Brine production cavern 384 is located at a distance of 72 m, which is almost three times the distance (25 m) as required for mechanical stability. Brine production cavern 475 is located at a distance of over 150 m and also cavern 378 (no brine production anymore) is located at a distance of over 150 m. Also after termination of brine production in caverns 384 this will still be more than 50 m away from cavern 381, which is at least two times more than the width (25 m) as required for mechanical stability and also the distance to cavern 475 will remain over 125 m.

**Compliance with conditions and requirements**
Cavern 381 has been found to comply with the initial conditions and assumptions underlying the containment concept. Furthermore, both the unconditional and the conditional requirements that must be complied with are fulfilled and the reference material relevant to the checklist is presented. Consequently, the risk associated with storage of gasoil in this caverns, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2012a).

Contrary to the other four caverns, for this cavern no multiphase flow modeling (STOMP) was done to explicitly quantify the effects of leakage (magnitude, extent of contamination). The reason for this is that the results of a similar modeling exercise for the other four caverns showed that the effects of leakage are extremely limited, and also very comparable between the four caverns. Since the situation in and around cavern 381 is very comparable to that of the other caverns, no change in modeled effects of leakage is to be expected.

STOMP modeling results for cavern 472, which is closest to cavern 381, and comparable in terms of geology, geometry, and well layout, indicate that leakage of gas oil from any point below the hydrogeological base does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (fault and/or ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden concession.

**Conclusion**

It can be concluded that cavern 381 is suitable for cyclic (non-permanent) gas oil storage.

# Index

# 1 Introduction

In December 2012 Deltares issued a report titled "*Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)"* (Van Duijne et al., 2012b). It details the results of a cavern-specific risk assessment for four caverns in the Marssteden concession selected for gas oil storage. The risk assessment was made by applying the methodology explained in the report titled "*Generic Technical Risk Assessment of Gas Oil Storage in Salt Caverns in the Twente region based on the Second Use Containment Concept (2UC-CC)* (Van Duijne et al., 2012a), and was based on the subsurface containment concept and its underlying assumptions as explained in Chapter 4 of that report. In the report containing the cavern-specific risk assessment, the technical suitability of the four caverns selected for gas oil storage was addressed, and the risks associated with it were assessed.

Around the same time in December 2012, AkzoNobel decided to add cavern 381 in the Marssteden concession to the caverns selected for gas oil storage. In the underlying report, the technical suitability of this fifth cavern is addressed, and the risks associated with it are assessed. Prior to the actual risk assessment for this cavern, the characteristics of the location, the geology and the hydrogeology of the Marssteden concession are briefly reviewed. Furthermore, the selection procedure that resulted in the selection of this fifth cavern under consideration is briefly explained.

As part of the cavern-specific risk assessment, the hazard scenarios associated with the top event "breach of confinement" are investigated for this fifth cavern, and their probabilities are quantified using the generic risk quantification method for gas oil storage in salt caverns as explained in Chapter 7 of the report by Van Duijne et al. (2012a). Additional information is given on the history, current status, geometry, and volumetrics of the cavern, and on the local geological conditions around the cavern. Furthermore, the cavern suitability checklist (see Section 7.4 in Van Duijne et al., 2012a) is filled in and reviewed to show that the selected cavern fulfills the requirements to be used for gas oil storage. A suitable cavern in this context means that it adheres to the conditions that are required to ensure that the gas oil remains confined to the storage system.

Contrary to the other four caverns, for this cavern no multiphase flow modeling (STOMP) was done to explicitly quantify the effects of leakage (magnitude, extent of contamination). The reason for this is that the results of a similar modeling exercise for the other four caverns showed that the effects of leakage are extremely limited, and also very comparable between the four caverns. Since the situation in and around cavern 381 is very comparable to that of the other caverns, no change in modeled effects of leakage is to be expected.

# 2 Marssteden concession

## 2.1 Location

The Marssteden concession is located between the cities of Hengelo and Enschede (in the municipality of Enschede) in the catchment of the Twentekanaal. AkzoNobel selected four caverns in this concession to be used for gas oil storage in 2012. A fifth cavern was added to this selection in January 2013: cavern 381 with three wells (wells 381, 382 and 383). It is situated in the southwest corner of the concession (see Figure 2.1 for location; AkzoNobel, 2010).

Relief in the area is subtle (no large differences in elevation), and no moraines or clay lenses are present in this area. Phreatic groundwater levels lie between 0 and 2 m below the surface and fluctuate approximately 1 m throughout the year (De Louw, 2006). Several surface water streams can be found in the vicinity of the concessions of which some have EU Water Framework Directive objective ("Azelerbeek" and "Bornsebeek"). North of the Marssteden concession, an area of the Ecological Main Structure of the Netherlands (EHS) is present. Several groundwater abstraction wells for drinking water and two groundwater protection areas are located at close proximity to the selected caverns (< 5 km). Several swimming water locations can be found in the vicinity of the Marssteden concession (Figure 2.2).

## 2.2 Geology and hydrogeology

Stratigraphic units as described in Section 3.2.1 of the report of Van Duijne et al. (2012a) on the general geology of the Twente area are also present in the Marssteden concession, and in a horizontal to sub-horizontal position. Information on their depth of occurrence, their thickness and their hydrogeological characteristics (bulk porosity, permeability) is provided in Table 3.1 of that report (Van Duijne et al., 2012a). For further information on the general geology and hydrogeology of the Twente region the reader is referred to Chapter 3 of that report. Here, the focus is on the geology and hydrogeology of the Marssteden concession.

The Marssteden concession can be subdivided in a southern and a northern part based on the presence of tectonic elements. Detailed studies by Geowulf (2010, 2012) on the presence of discontinuities in the otherwise gently dipping strata resulted in a map of the Twente-Rijn concession with tectonic areas and fault zones, and in depth and subcrop maps of stratigraphic formation boundaries, in which the offset of individual faults is displayed at that particular stratigraphic level. Furthermore, one cross-section was constructed that runs from SW to NE through the Marssteden area. All maps and the cross-section can be found in Appendix A. In these maps, which are primarily based on well data, the Marssteden storage concession is labeled "Area 3B Marssteden", and the boundary is indicated by a black line in the SE corner of the map. The main tectonic element in this area is the Boekelo Fault zone (labeled "Fboekelo"), which runs NW-SE through the southern part of the Marssteden concession (see Van Duijne et al., 2012a, Chapter 4, Figure 4.3). In depth, it runs from below the stratigraphic level of the caverns up and into the deposits of the North Sea Supergroup, and has a maximum throw in the range of 5-20m within the Marssteden area. Furthermore, in the northern part, where the caverns selected for gas oil storage are located, two smaller normal faults (labeled "F1", "F2" on the maps) are identified, also with a maximum displacement in the range of 5-20m. However, these faults do not offset the entire stratigraphy. Fault F1 has an offset at cavern level of 4-6 meters, whereas fault F2 has no offset at cavern level.

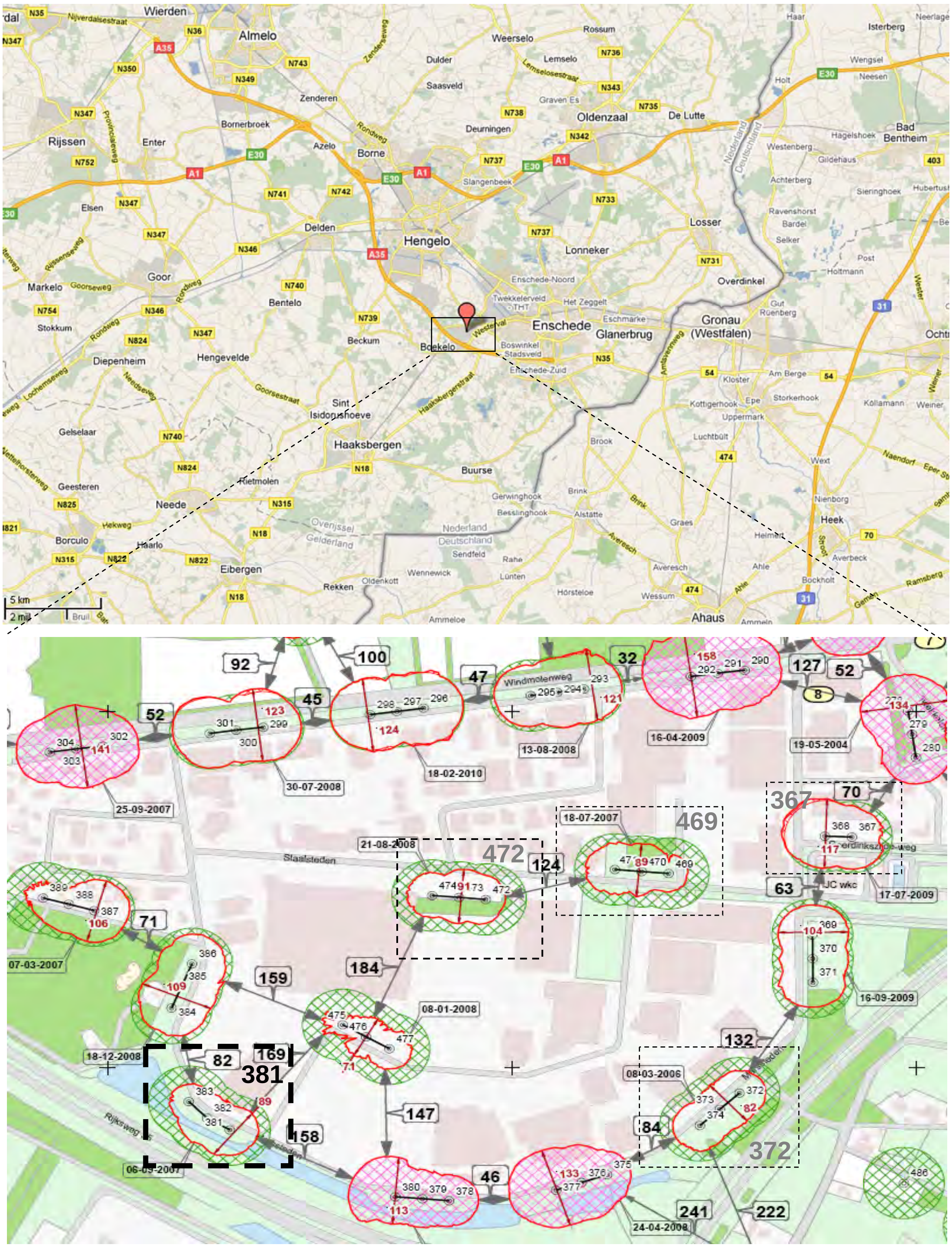



*Figure 2.1: Overview of the area of the Marssteden concession of AkzoNobel with the position of the salt caverns. Caverns in dashed rectangles are selected for gas oil storage. Caverns 367, 372, 469 and 472 are discussed in Van Duijne et al. (2012a), cavern 381 is discussed in this report.*

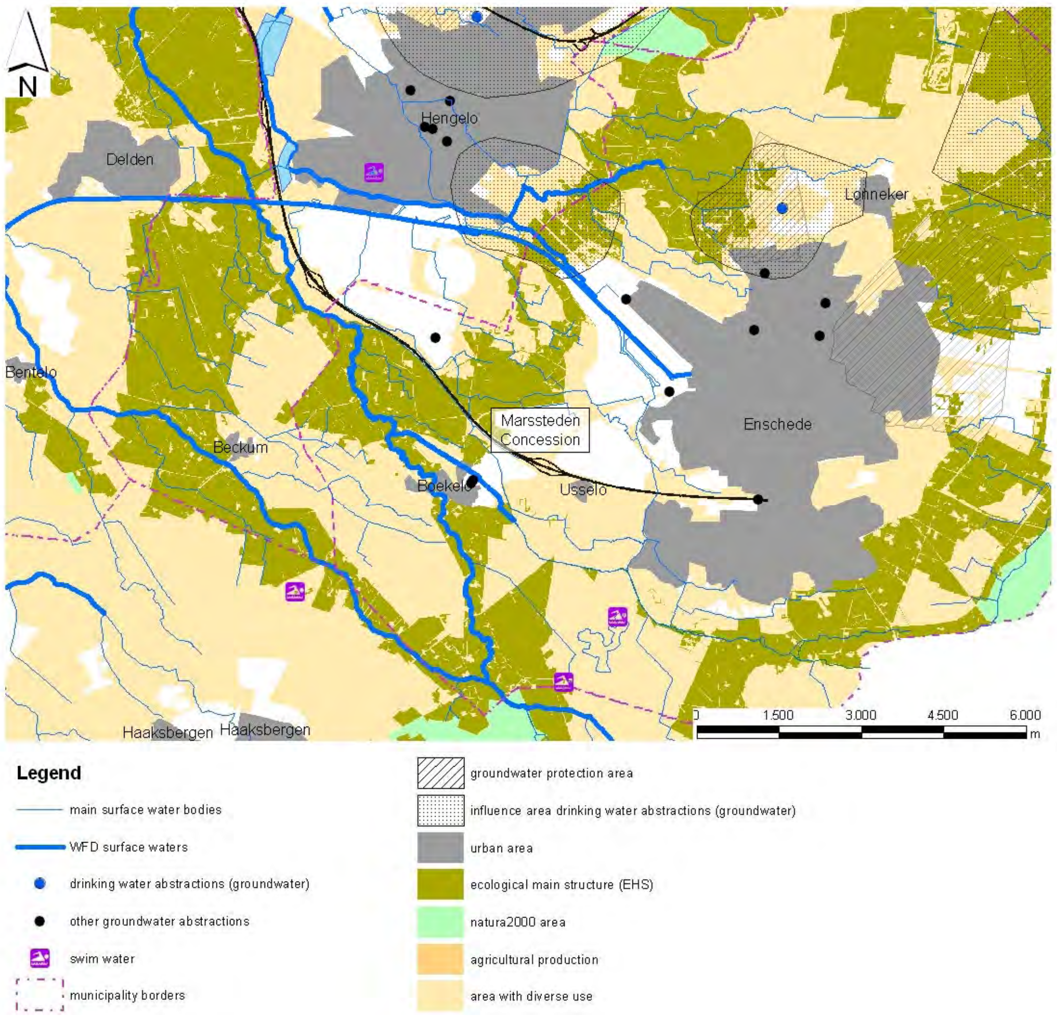



*Figure 2.2: Overview of the land and water functions of the area surrounding the Marssteden Concession (source: Waterbeheerplan 2010-2015).*

In the southwestern part of the area, one small normal fault is located (labeled “Fsw”), which has no offset at cavern level. Geowulf (2010) concluded that the containment of the gas oil is not likely to be directly affected by these faults due to the self-healing nature of salt. A more detailed analysis of these faults, i.e., their geographical and stratigraphic location in relation to the caverns, and their throw, will be reviewed later in this report for cavern 381 individually.

# 3 Preliminary cavern selection

As part of the permitting procedure for storage of gas oil, a cavern selection process was performed (AkzoNobel, 2010). In this preliminary selection process, the caverns in the Marssteden concession were checked for compliance with a number of technical requirements set by AkzoNobel. A detailed risk analysis was not yet performed at this stage. Technical requirements that caverns must comply with according to AkzoNobel included:

- no history of subsidence;
- fulfilling geomechanical stability criteria (e.g. minimum thickness of salt roof above the cavern, minimum distance between caverns);
- suitable cavern geometry (shape, volume);
- cavern fully contained within unit A of the Main Röt Evaporite;
- minimal presence of faults;
- good accessibility

Afterwards, the 11 pre-selected caverns that fulfilled the technical requirements were ranked based on operational footprint (impact on the environment, proximity to nature, etc.) and compatibility with spatial planning. Primary conclusion from this preliminary cavern selection process was that four salt caverns in the Marssteden concession are most suitable for gas oil storage: cavern 367 with two wells (wells 367, 368), cavern 372 with three wells (wells 372, 373, 374), cavern 469 with three wells (wells 469, 470, 471), and cavern 472 with three wells (472, 473, 474).

Several caverns were labeled potentially suitable for future use, mainly because their volume was not yet sufficient for oil storage. Of these potentially suitable caverns, the one that was deemed most suitable for storage, cavern 381, was selected to be included in the Environmental Impact Assessment (EIA) and the spatial plan (‘Inpassingsplan’) that was issued by the national government (ministry of Economic Affairs).

In December 2012, the volume of cavern 381 was measured, and found to have reached a volume of roughly 160.000 $m^3$, thus making it suitable for storage of gas oil.

For further details on the cavern selection process the reader is referred to the “Startnotitie MER”, published under the title “*Voornemen gasolieopslag in zoutcavernes in regio Twente*“ by the Ministry of Economic Affairs, Agriculture and Innovation (AkzoNobel, 2010).

# 4 Leakage scenarios

## 4.1 Leakage scenarios

Seven leakage scenarios (see Table 4.1) have been identified for the selected caverns, all of which result in a deviation from the base case, which is that of a closed storage system (cavern and wells) that ensures containment of the gas oil. Together these scenarios cover all the possible causes of leakage and their consequences. Scenarios include amongst others leakage at different depths from the well or the cavern, i.e., below and above the hydrogeological base, the presence of degraded permeable cementation in a neighboring well of the same cavern or older caverns in the Marssteden concession, and the presence of permeable faults in the immediate vicinity of the cavern or the well that may serve as a vertical migration path to shallower stratigraphic levels. For each scenario, a maximum period of leakage is defined after which mitigation measures stop the leakage. This is further discussed in the next section.

| Scenario's | leakage depth | period of leakage |
|---|---|---|
| **1** no breach of confinement *(base case)* | 435 m -surf. | 3 months |
| **2** leakage from cavern into Röt Claystone | 395 m -surf. | 3 months |
| **3** scenario 2 with old permeable well in vicinity | 395 m -surf. | 3 months |
| **4** leakage from well into Muschelkalk Formation (below hydrogeological base) | 156 m -surf. | 1 month |
| **5** scenario 4 with old permeable well in vicinity | 156 m -surf. | 1 month |
| **6** leakage from well into North Sea Supergroup (below hydrogeological base) | 60 m -surf. | 1 month |
| **7** scenario 6 with old permeable well in vicinity | 60 m -surf. | 1 month |
| **8** leakage from well above hydrogeological base directly into groundwater | 20 m -surf. | 1 month |

*Table 4.1 Hazard scenarios associated with the top event "breach of confinement for the cavern-specific risk analysis.*

## 4.2 Timing of mitigation measures

For the generic assessment of the effects of gas oil leakage (Chapter 6 of Van Duijne et al., 2012a), conservative calculations were made using STOMP in which the period of gas oil leakage was set to 30 years. However, in reality a breach of confinement of the gas oil system will be noticed and mitigating measures (technical, human-error-proof, see sections 5.10 and 5.11 of Van Duijne et al., 2012a) will be taken as soon as the leak is detected, i.e., much sooner than after 30 years. Below, the steps that must be taken to stop a leakage from the storage system are described, together with a conservative estimate of the timing of each of the steps, which, when added together, gives the time that elapses before full mitigation is assumed to be achieved:

a. A pressure measurement (or any other suitable measurement employed by AkzoNobel) indicates an anomaly, and is followed by an investigation (week 1), during which the pressure in the gas oil system is maintained, e.g. by brine injection, to prevent destabilization of the cavern;
b. If investigation points out that the breach of confinement (leakage) is in one of the wells, a workover installation is mobilized (week 2);

c. The well is temporarily repaired using a packer and pressure is monitored to assess whether or not the leakage of gas oil has stopped (week 3). At this stage, the exact location of the leakage is found if the leak is in the well.
d. The leak in the well is permanently repaired and after testing the gas oil storage activities can be continued (week 4). At this point in time one month has passed.
e. When during step b no leak is found in the wells, then in a worst-case scenario the gas oil must be removed from the cavern. Duration of this process depends on the amount of gas oil stored. In the case of the caverns being completely filled with oil up to the maximum allowable amount, this process takes about three months.

Considering the above, it is assumed that leakage from a cavern will continue for a period of three months, whereas leakage from a well will continue for one month.

## 4.3 Numerical modeling of multiphase flow: STOMP

As no multiphase flow modeling with STOMP has been done for cavern 381 to explicitly quantify the effects of leakage (magnitude, extent of contamination), we refer to the cavern-specific risk assessment by Van Duijne et al. (2012a) for a technical description of the modeling approach that was adopted.

## 4.4 Comparison of the results of the numerical modeling for the four selected caverns

The results of the multiphase flow modeling with STOMP were visualized at time t=150 years after the initial breach of confinement for all scenarios. For the scenario that was found to pose the highest risk (most severe in terms of magnitude of leakage and leakage flow rate), being scenario 8 (leakage from well above hydrogeological base directly into groundwater model), output was visualized at multiple moments in time after gas oil leakage occurs: 1 day, 1 week, 1 month, 3 months, 1 year, 5 year, 30 year, 60 year, 100 year and 150 year after leakage.

When the results of the scenarios are compared for each individual cavern, the following conclusions can be drawn with respect to differences and similarities:

1. Differences in the geological situation around the caverns are solely due to the presence and location of faults. The geological situation of cavern 381 is most comparable to cavern 472, as will be discussed in Chapter 5 in more detail;
2. For all leakage scenarios, the subsurface volume that is actually affected by leakage is in the immediate vicinity of the well and never related to the presence of an old well or a fault;
3. Differences in the modeling results between the individual caverns are hardly visible.
4. Leakage from a well above hydrogeological base directly into groundwater (scenario 8) poses the highest risk. The surface area and volume of gasoil leaked in this scenario is similar for all four selected caverns.

As the geology of cavern 381 is highly comparable to the geological situation for the other four caverns, and as the well and cavern configuration (age, geometry, depth, etc.) is highly comparable to that of the other four caverns, it is highly likely that the results of a STOMP-modeling for cavern 381 would produce the same results as for the other four caverns. As such, it was decided to not perform a STOMP-modeling exercise for cavern 381.

# 5 Cavern 381

## 5.1 Status

Cavern 381 contains three wells (381, 382 and 383) and is located in the southwestern corner of the Marssteden concession (see Figure 2.1). All three wells were drilled in the period between April and July 1998. Although no USIT measurement for casing integrity and quality of the cement bonding has been performed yet, they are assumed to be in good condition, because they are considerably younger than the wells of caverns 367 and 372. For the wells of caverns 367 and 472 USIT measurements have indicated that casing integrity is good. Cement bonding is also generally good, but moderate in some sections. USIT measurements in the three wells of cavern 381 are planned to be done in the coming months.

Brine production started in June 1998, and stopped in November 2012. Span of the cavern is ±165 m in SE-NW direction, and ±105 m in the direction perpendicular to that. Since the final decision on which well will be used for gas oil injection has not been taken, well 382 is assumed to be the gas oil injection well because it has the highest roof position. This well is located at the center of the cavern. Distance from well 382 to wells 381 and 383 is 40 m. Distance from the gasoil injection well to the edge of the cavern is 75 m to the northwest and about 90 m to the southeast. A detailed overview of the cavern and the wells, and its position in relation to the stratigraphy, is included in Appendix B. It is based on the two basic sources of subsurface data that are available: sonar survey data and gamma-ray log data.

Brine production caverns 384 and 475 are located at distances of 72 m and 154 m respectively. Cavern 384 is planned to continue producing brine until Q4 2014, cavern 475 until Q2 2016. At this point in time the width of the salt pillar between this cavern and any neighboring caverns is still over 70 m, which is almost 3 times more than the width (25m) as required for mechanical stability. Regular sonar measurements of these caverns are part of the risk management plan to ensure that the pillar remains intact.

## 5.2 Geology

The Main Röt Evaporite A-D members have a total thickness of ±51 m at the location of this cavern, with the base located at a depth of 472 m and the top located at 422 m below the surface. Members A and C have thicknesses of 23 m and 15 m respectively in well 381 (SE part of the cavern), and thicknesses of 25 m and 19 m respectively in well 383 (NW part of the cavern. Members B and D are both between ±5 m and ±10 m, whereby especially Salt D is thicker than in many other caverns in the Marssteden. Salt B shows a significant thickening in a southeastern direction, so opposite to the trend observed in Salt C. The cavern has a height of max.17 m and is fully situated in the Main Röt A Member (lowermost salt layer). Main Röt Evaporite A-D members are overlain by 12 m of Main Röt E Member, which consists entirely of impermeable anhydrite. Top Röt dips in SW direction. Above the Main Röt Evaporite ±160 m of impermeable claystone (Intermediate Röt Claystone and Upper Röt Claystone members) separates the cavern from the more permeable Muschelkalk Formation.

Properties of the subsurface (porosity, permeability) in the immediate vicinity of this cavern are essentially similar to those stated in Table 4.2 in the Cavern-specific risk assessment by Van Duijne et al. (2012b).

Cavern 381 is the only selected cavern located south of the fault that cross-cuts the Marssteden area (Fboekelo). Near the southeastern edge of the Marssteden area this fault has a significant throw of approximately 10 to 15 m at top Röt level, but near the western edge of the Marssteden area, i.e. close to cavern 381, this fault shows no significant offset at this level (less than 2 m; see contour maps of formation boundaries and cross-section in Appendix A).

Fault Fsw is located in the southwestern corner of the Marssteden area (see contour maps of formation boundaries and cross-section in Appendix A). It runs parallel to Fboekelo and more or less parallel to the longitudinal axis of cavern 381. It cuts out a section of approximately 2 m of Muschelkalk (normal fault) at a depth of approximately 200 m below surface in wells 381 and 382 (no data available for well 383). It runs from over 490 m below surface (below the cavern) to 95 m below surface (Laramide Unconformity), and under the assumption that the position of the fault is correctly interpreted by Geowulf (2010) it actually crosses the cavern through its northeastern part. Its throw is estimated by Geowulf (2010) to be less than 2 m at the base of the Main Röt Evaporite member, nil at the top of the Main Röt Evaporite member, and ± 2 meters at the top of the Muschelkalk. Geowulf base their estimate on interpolated well tops, i.e., no direct observation has been done e.g. from seismic, probably because the fault throw is too small to be seen on seismic (sub-seismic scale). Since fault Fsw runs through a considerable interval of claystones, it is likely that large sections of it are impermeable due to clay-smear. As mentioned, the possibility that it is in direct contact with the cavern cannot be excluded. However, because the estimated throw is much less than the thickness of the Main Röt Evaporite A-D members, and because faults in the salt itself tend to heal due to the viscoplastic nature of salt, the containment is unlikely to be compromised by this fault. Furthermore, recent sonar measurements do not show any irregularities that might be related to this fault.

## 5.3 Volume

The current volume of the cavern is approximately 160,000 $m^3$. It is calculated based on results from sonar (sound navigation and ranging) surveys, which produce a three-dimensional image of the cavern by emitting a sound pulse and recording the time lapse before the pulse, which is reflected by the cavern wall, is received again by the receiver. A layer of brine is left at the bottom of the cavern during storage to shield the gas oil from the permeable sump material and formations below the cavern into which it may potentially migrate. Close inspection of the sonar data reveals that a maximum depth of the oil-brine interface of 465 m is allowable without exposing the sump to gas oil, i.e., the cavern can be filled with gas oil up to a level where the oil-brine interface is at 465 m depth below surface. At this maximum depth, the volume of gas oil that can be stored is approximately 150,000 $m^3$. Furthermore, the sonar measurements indicate that the roof of this cavern is very regular in comparison to the roofs of the other four caverns, i.e., the number of so-called "pockets" in the roof in which gas oil gets trapped is low. Only in the northwestern most part of the cavern, where the roof subsides about 2m over a section of about 10 m, a potential pocket can be observed. However, close inspection of the sonar in three dimensions reveals that the subsided roof section is actually a local phenomenon, i.e. the potentially isolated roof section to the northwest of it is connected to well 383 outside of the chosen plane of sight. A total pocket volume of a few hundred $m^3$ is estimated from sonar.

Mitigation measures to ensure that all the oil that is stored in the cavern is retrieved at the end of the storage period are discussed in section D of the Storage Plan (AkzoNobel, 2013).

## 5.4 Suitability for storage

### *5.4.1 Initial conditions and assumptions underlying the containment concept that the cavern must comply with to be suitable for storage*

1. The cavern will be used for storage of gas oil.
   *Valid, see "Voornemen gasolieopslag in zoutcavernes in regio Twente" (AkzoNobel, 2010).*

2. Gas oil will be stored for a maximum period of 30 years.
   *Valid, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013) Section B1*

3. Gas oil is injected and extracted to the cavern via a well which includes a casing secured by cement and a packer close to the cavern.
   *Valid, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B4*

4. Brine is extracted (as gas oil is injected) and injected (as gas oil is extracted) to the cavern by a well.
   *Valid, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B1*

5. The cavern is surrounded by Röt A salt at the sides and above.
   *Valid, see Section 5.2 of this report*

6. The bottom of the cavern is covered by brine as a control measure. This ensures that the gas oil will not reach the bottom of the cavern.
   *Valid, see Section 5.3 of this report and Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B1*

7. The whole cycle of injection, storage and extraction is an isolated process with no contamination to the surroundings layers.
   *Valid, see Environmental Impact Assessment (AkzoNobel, 2013).*

8. The maximum hydraulic conductivity of the salt is 1.6x10-5 m/d.
   *Valid, see Table 3.1 in "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012a).*

9. A cavern for which the storage activity is completed is refilled with brine and adheres to the conditions set by the good salt mining practice.
   *Valid, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), sections D2, D5.*

### 5.4.2 *Unconditional requirements that the cavern must comply with to be suitable for storage*

1. There are no known indicators for unfavorable containment conditions for the specific cavern, such as:

   - Cavern instability
   - Low pressure
   - Leakage
   - Roof collapse
   - Loss of wellhead pressure/failed pressure test
   - Degraded caprock integrity
   - Fractures
   - Presence of unfavorable insoluble layers
   - Filling with aqueous fluids from surrounding rock (capable of leaching salt)
   - Overpressure/overfilling of the cavern/operational procedure
   - Well/casing/plug problems/failure, including blowout.

   *True, these known indicators for unfavorable containment conditions have not occurred for cavern 381.*

2. The cavern is solely situated within the Main Röt Evaporite A rock salt layer.
   *True, see Section 5.3 of this report.*

3. There is no permeable layer within the Main Röt Evaporite salt layers.
   *True, see Section 3.2.1 on stratigraphy in "Generic Technical Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012a).*

4. The cavern is at least overlain by 5 m of Röt C.
   *True, see Section 5.2 of this report. Röt C thins in southeastern direction and in the most southeastern tip of the cavern it has a thickness of just 5 m. Here Salt B has a thickness of almost 10 m.*

5. The roof of the cavern is favorable for gas oil extraction at the end of the storage period.
   *True, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section D4.*

6. The geometry of the cavern does not favor stress concentration.
   *True, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B5.1*

7. The distance between different salt caverns within a row of caverns is at least 25 m.
   *True, see Section 5.1 of this report.*

8. Parallel rows of caverns are separated by a pillar that is at least 70 m thick, or a report exists which proves that the cavern under investigation is stable.
   *True, see Section 5.1 of this report, and Addendum to Storage Plan (AkzoNobel, in preparation), Section B5.1.*

9. The pressure in the cavern is equal to or above the hydrostatic pressure.
*True, see Addendum to Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

10. The pressure in the cavern does not exceed the minimum in-situ (lithostatic) stress.
*True, see Addendum to Storage Plan (AkzoNobel, in preparation), Section B1. The pressure in the cavern is close to halmostatic at all times during normal operation.*

11. The maximum temperature change due to brine/gas oil injection is 20°C inside the cavern.
*True, see "Generic Risk Assessment of gas oil storage in salt caverns in the Twente region based on the Second Use Containment Concept (2U-CC)" (Van Duijne et al., 2012a).*

12. Brine and gas oil is not injected with a temperature below 5 °C.
*True, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B1.*

13. There is no vertical casing displacement.
*True, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B4.*

14. There is no methane release from the cavern-bearing salt formation.
*True, no methane release from the cavern-bearing salt formation has been observed during regular brine production.*

### *5.4.3 Conditional requirements that must be met for the cavern to be suitable for storage*

1. An MIT (Mechanical Integrity Test) is performed prior to storage to assess the integrity of the wells
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B5.2.2., and Risk Management Plan (AkzoNobel, 2013)*

2. The cementation, casing and packer are of good quality.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B4.*

3. The cement in the cement annulus is not degraded and was properly bonded to the casing and the surrounding rock during cementation in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern).
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B4.*

4. In case of failure of the casing and/or packer, replacement is installed and checked.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation) and Storage Plan (AkzoNobel, 2013), Section B5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

5. In case of serious failure of the cement in the section of the well that penetrates the Main Röt Evaporite (roof of the cavern), replacement is installed and checked.

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*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section B5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

6. Faults present in underlying and/or overlying strata that are possibly in contact with the cavern have a throw that does not exceed the minimum thickness of the Main Röt Evaporite A rock salt layer. Faults that do have a throw that exceeds the minimum thickness of the Main Röt Evaporite A rock salt layer that are possibly in contact with the cavern must be further investigated with the aim to assess their potential to form a leakage path for gas oil from the cavern to shallow depths above the hydrogeological base.
*One fault could be present in the vicinity of the cavern (GeoWulf, 2010), and is possibly in contact with the cavern, but its throw of ca. 2m does not exceed the minimum thickness of the Main Röt A salt (see section 5.2 of this report).*

### *5.4.4 Monitoring requirements that must be implemented to minimize risk and work towards ALARP*

1. The oil and brine pressure is monitored.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

2. Pressure is monitored in the well annulus.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

3. Composition of annular fluid is monitored for the presence of gas oil components.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

4. The gas oil level is periodically monitored.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

5. The brine inflow/outflow is monitored (temperature, flow rate, pressure).
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

6. The gas oil inflow/outflow is monitored (temperature, flow rate, composition, pressure).
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

7. The shape and extent of the cavern is monitored using sonar before initial gas oil injection, during storage at intervals of 5 years, and after gas oil extraction.
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

8. Casing and cement bond evaluation is performed at regular basis (e.g. every 10 – 20 years).
*Yes, see Addendum to Storage Plan (AkzoNobel, in preparation), Storage Plan (AkzoNobel, 2013), Section 5.2.2., and Risk Management Plan (AkzoNobel, 2013).*

## 5.5 Risks

*Model setup*

No STOMP modeling has been done for cavern 381. Cavern-specific input properties such as the cavern dimensions, the local depth and thickness of Main Röt Evaporite, the local depth and thickness of Upper Röt Evaporite, the position of faults with respect to the cavern, and the occurrence of any “old”, permeable wells and their position with respect to the cavern are summarized in Table 5.1 for the sake of completeness (see also sections 5.1 and 5.2).

*Table 5.1: Overview of the characteristics of cavern 381.*

| **Characteristics for cavern 381** | |
|---|---|
| top Upper Röt Evaporite (average) | 410m below surface |
| thickness Upper Röt Evaporite (average) | 12m |
| top Main Röt Evaporite (average) | 424m below surface |
| thickness Main Röt Evaporite (average) | 51m |
| cavern length | 165m |
| cavern width | 105m |
| cavern height (average) | 16m |
| location gas oil well | centre of cavern |
| fault Fsw: distance from gas oil well | 30m northeast of well |
| fault Fsw: depth range of offset | 95 to >490m below surface |
| old wells: distance from gas oil well | 40m northwest and southeast of well |

*Results*

In Section 4.4 of this addendum it was concluded that it is highly likely that the results of a STOMP-modeling for cavern 381 would produce the same results as for the other four caverns. As such, it was decided to not perform a STOMP-modeling exercise for cavern 381. As cavern 381 is highly comparable to cavern 472 we present the results for that cavern below. For reference to figures the reader is referred to the report detailing the results of the cavern-specific risk assessment for cavern 472 (Van Duijne et al., 2012b).

In the base case scenario, breach of confinement does not occur; the gas oil remains within the salt cavern for the modeled time span of 150 years. In scenario’s 2 to 7 the gas oil does not penetrate more than 5 to 10 m into the surrounding rock away from the point of leakage. In none of these scenarios the gas oil LNAPL reaches the fault or the ‘old’ permeable well. However, in the figure of scenario 7 (see Van Duijne et al., 2012b) it can be seen that there is a small effect of the ‘old’ permeable wells that lie at a distance of 40 m from the gas oil well: due to the pressure reduction that occurs locally the gas oil LNAPL shows some preferential flow in the direction of the ‘old’ permeable wells.

In case of leakage above the hydrogeological base (scenario 8), there is a direct risk of contamination of the phreatic groundwater. The following observations can be made for this scenario for cavern 472 and are assumed applicable to cavern 381 as well:

- After 1 year the gas oil LNAPL reaches the phreatic groundwater level.
- After 1 month the maximum saturation of gas oil in the pores of the sediments is reached. Afterwards, the saturation of gas oil in the pores is reduced due the continued spreading of the LNAPL away from the point of leakage, which causes the gas oil to dilute as it becomes partially trapped in the pores.
- After the gas oil LNAPL has reached the phreatic groundwater, it spreads out on top of the groundwater surface (up to 90 m after 60 years).

## 5.6 Conclusions

Cavern 381 adheres to the initial conditions and assumptions underlying the containment concept as defined by Deltares/TNO in Van Duijne et al. (2012a). Furthermore, both the unconditional and the conditional requirements that must be complied with according to Deltares/TNO (see checklist) are met and the reference material relevant to the checklist was presented. Consequently, the risk associated with storage of gasoil in this cavern, defined as the probability of occurrence of a breach of confinement (the top event) times the effect, is very low to negligible. Information on the probability of occurrence of a breach of confinement can be found in Chapter 7 of Van Duijne et al. (2012a). Effects after breach of confinement for this cavern are assumed to be similar to that of cavern 472.

When a shift from the base case to an unstable situation occurs, gas oil leaks from the well or the cavern into the surrounding rock. STOMP modeling results for cavern 472 indicate that leakage of gas oil from any point below the hydrogeological base does not pose a risk with respect to contamination of the upper, phreatic groundwater bodies near the Marssteden area. Due to the low porosity and permeability of the geological layers below this base, upward migration due to multiphase flow is largely prohibited and the gas oil does not reach the nearby structures with a higher porosity and permeability (fault and/or ‘old’ well). Leakage from the gas oil well above the hydrogeological base does cause a direct risk of contamination of the upper groundwater bodies. However, the spread of the gas oil in and on top of the phreatic groundwater will be limited to an area well within the Marssteden concession. The gas oil contamination does not come near any surface water body, ecologically valuable area or drinking water abstraction point.

In order to further minimize the risk and work towards ALARP, AkzoNobel is working on a risk management plan that includes effective monitoring and mitigation measures. As part of this plan, AkzoNobel aims to perform the monitoring of the storage system conform the requirements set by Deltares/TNO in their monitoring checklist.

In view of the above, it can be concluded that cavern 381 is suitable for cyclic (i.e., non-permanent) gas oil storage.

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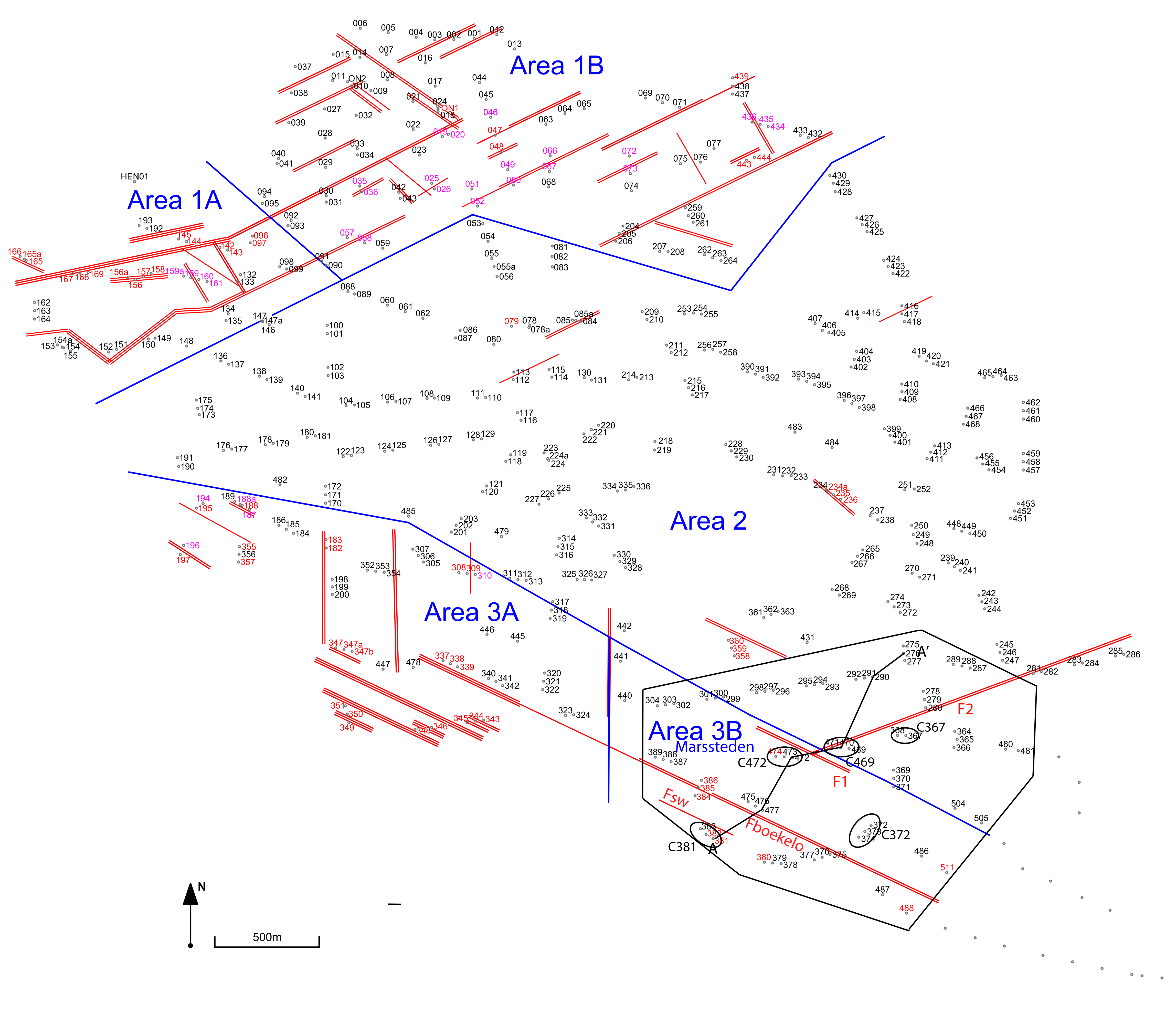
## Appendices




Map A-2:
Tectonic areas and fault zones

for detail is referred to the depth maps (Attachment C).

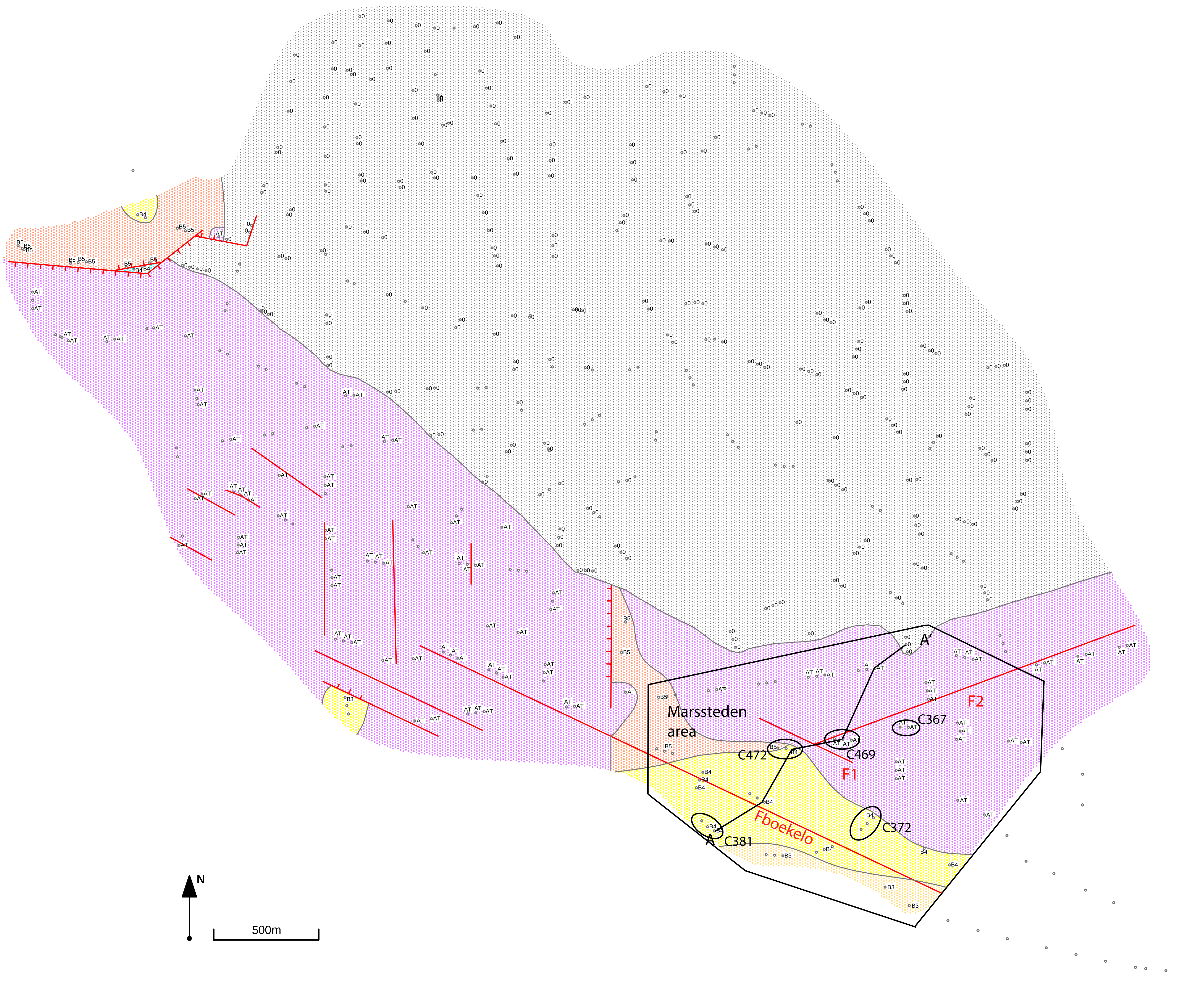
Legend:

- well location
- 100 well name
- 100 fault identified in well
- 100 fault identified in Series

fault lines with maximum present day offset

- / offset <5m
- // offset 5 - 20m
- /// offset >20m

prepared by:
GEOWULF*Laboratories*
attachment to report GL11.901




Map C-6:
Subcrop Base SK Unconformity

Legend:

- well location
- datapoint with SK eroded
- SK eroded

Unit underlying base SK

- B unit name
- RNMU-B3
- RNMU-B4
- RNMU-B5
- AT

normal fault

- offset
- no offset at this level

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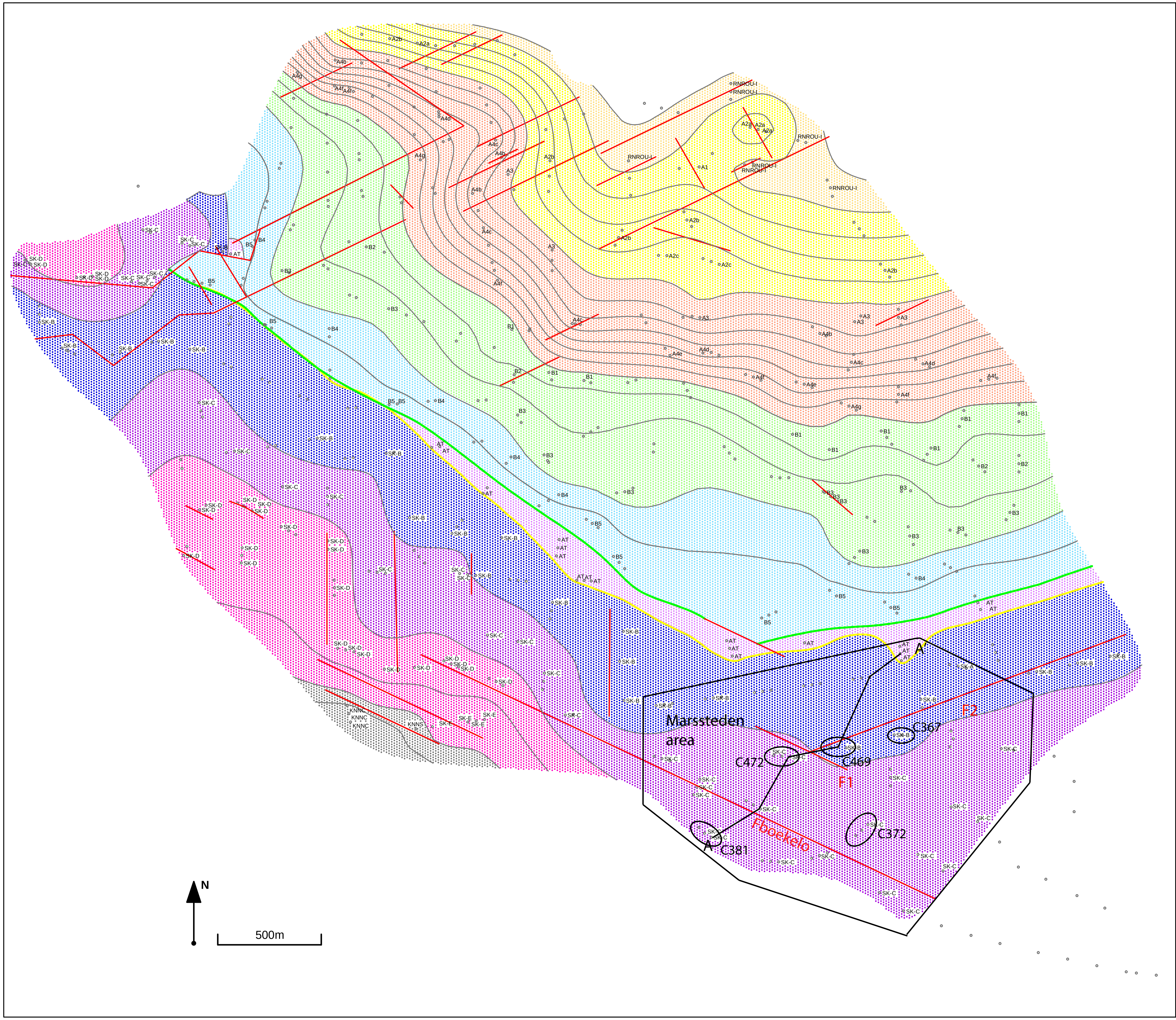


Map C-8:
Subcrop Base N Unconformity
(contour lines not edited to fault lines)

Legend:

- well location
- AT = 0 (see map C-5)
- SK = 0 (see map C-6)

Unit underlying base N

- B unit name

in order of decreasing erosion:

- RNROU
- RNMU-A1 & A2
- RNMU-A3 & A4
- RNMU-B1, B2 & B3
- RNMU-B4 & B5
- AT
- SK-A & B
- SK-C
- SK-D & E
- KN

- main normal fault at deeper level(s)

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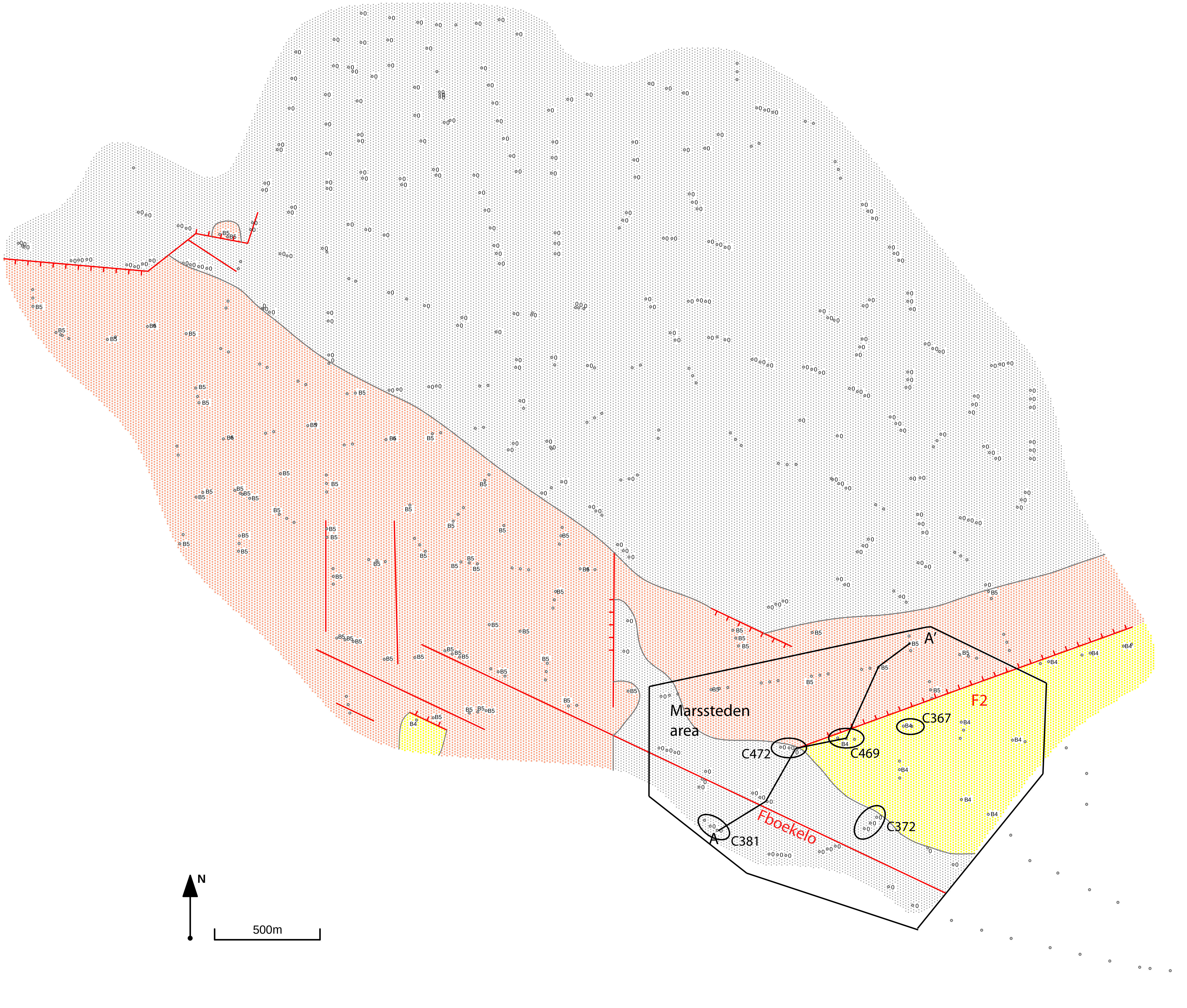


Map C-5:
Subcrop Base AT Unconformity

Legend:

- well location
- datapoint with AT eroded
- AT eroded

Unit underlying Base AT

- unit name
- RNMU-B4
- RNMU-B5

normal fault

- offset
- no offset at this level

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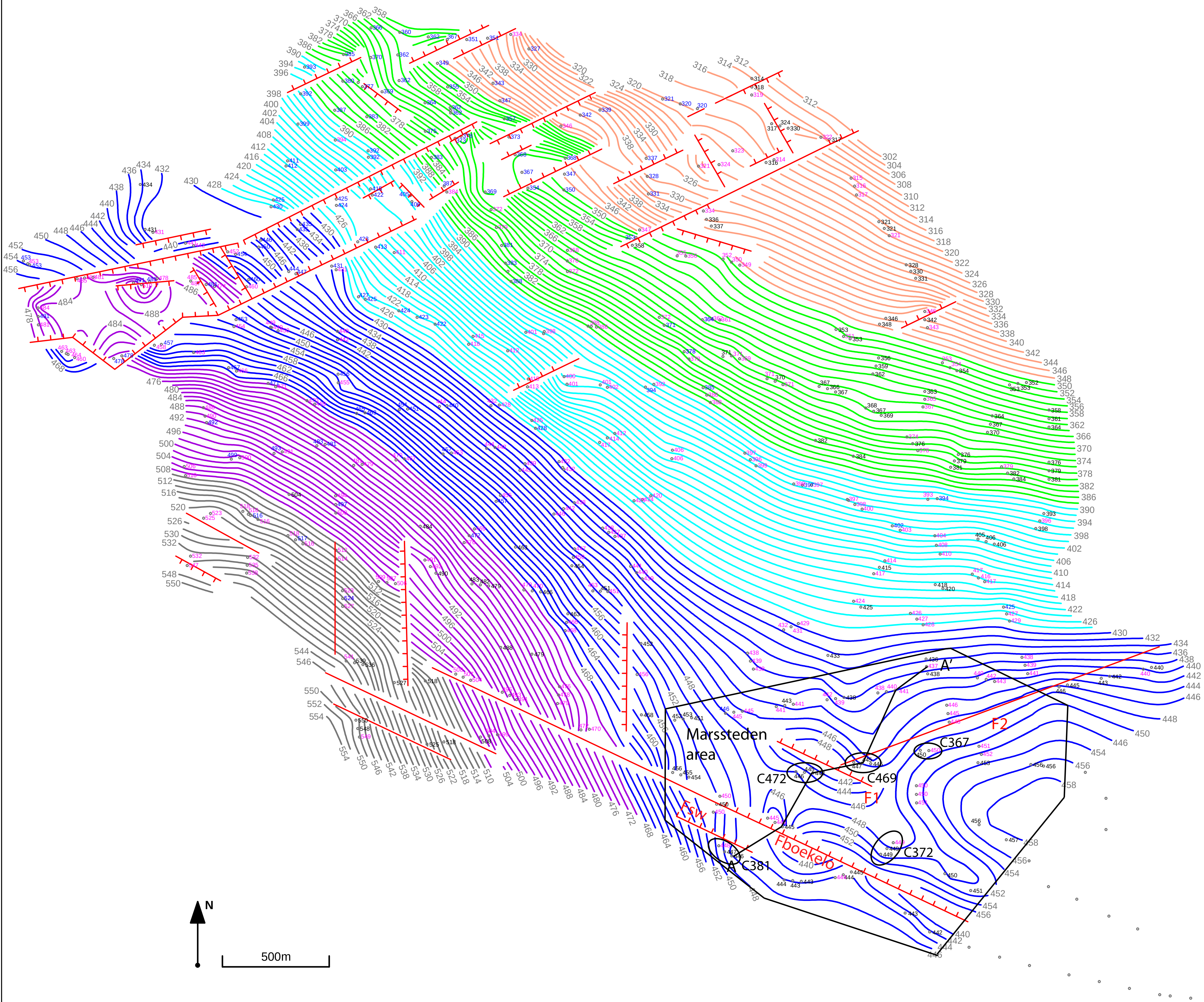
attachment to report GL11.901

Map C-1: Depth Top Solling Fm.: RNSO




Map C-1: Depth Top RNSO

Legend:

- well location

depth in meters below NAP

- 20.4 source GR log
- 20.4 source 'orig. log' & cored
- 20.4 source base A2 or 'original log' and not cored

isolines (2m interval)

- ≤ 348m
- 350 - 388m
- 390 - 428m
- 430 - 468m
- 470 - 508m
- ≥ 510m

normal fault

- offset
- no offset at this level

prepared by:
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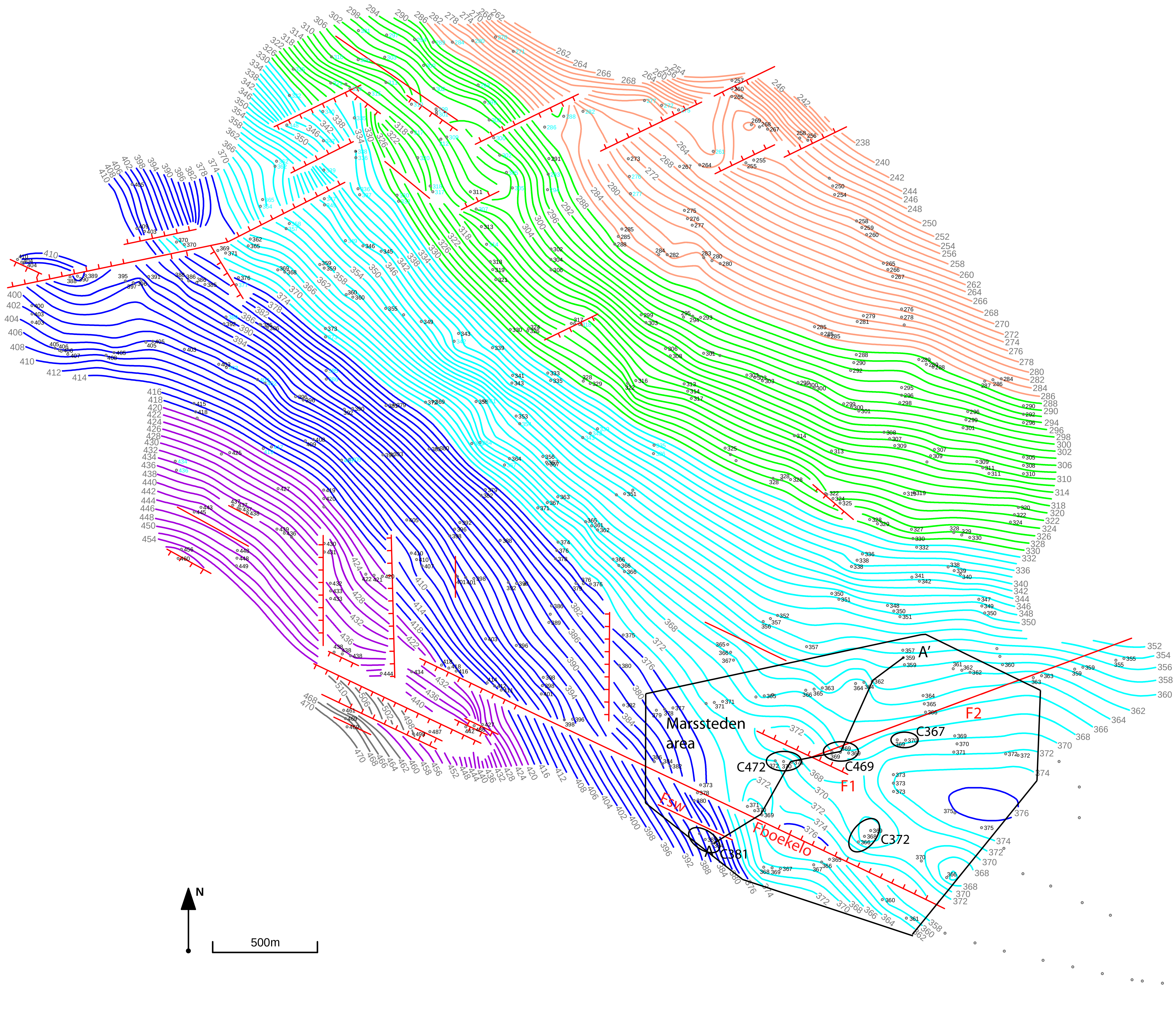
attachment to report GL11.901




Map C-2: Depth Top RNRO1

Legend:

well location

depth in meters below NAP

20.4 source GR log

20.4 derived depth

isolines (2m interval)

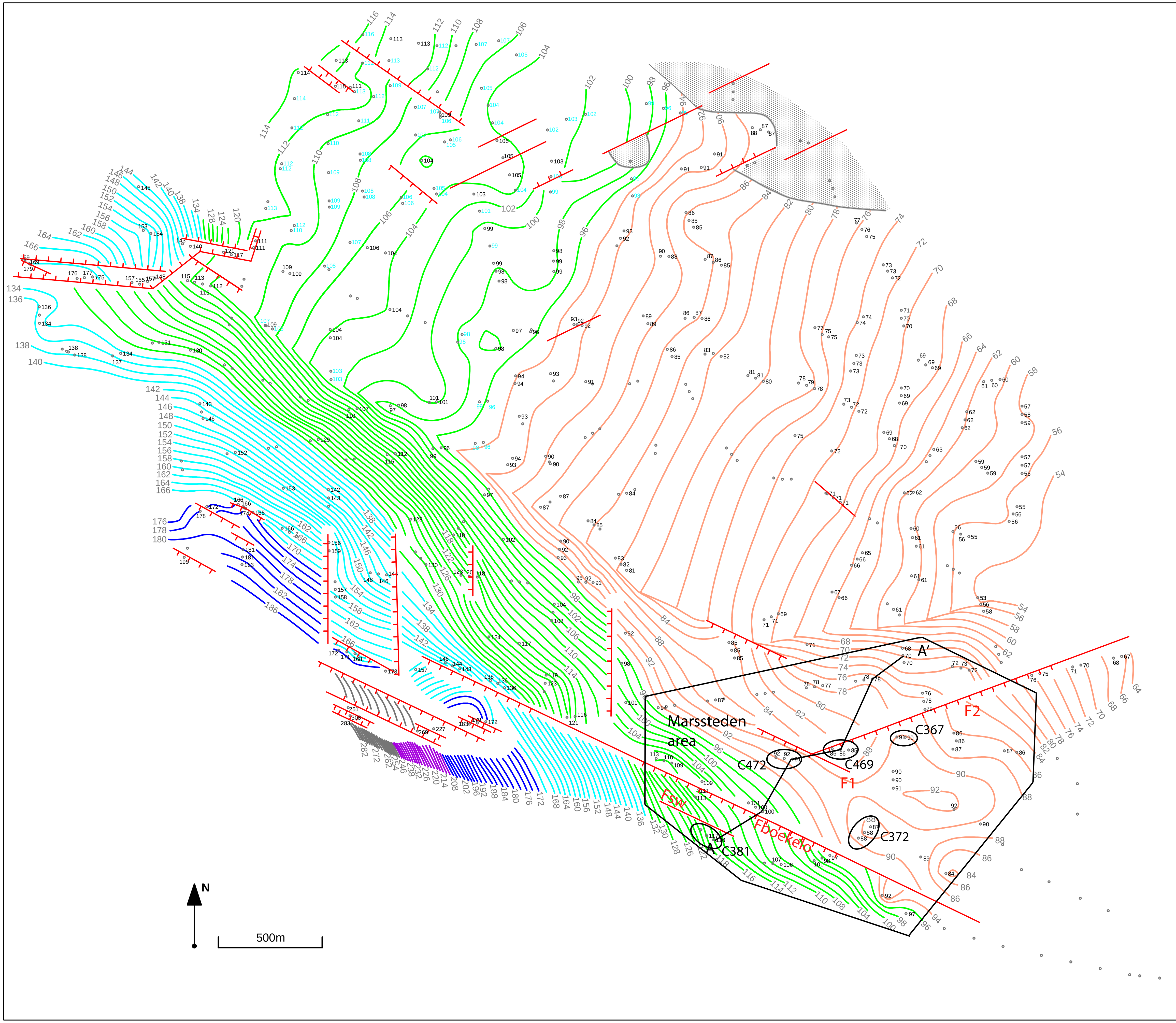
- ≤ 286m
- 288 - 330m
- 332 - 374m
- 376 - 418m
- 420 - 460m
- ≥ 462m

normal fault

- offset
- no offset at this level

prepared by:
GEOWULF*Laboratories*
attachment to report GL11.901

Map C-4: Depth Top MMuschelkalk Fm: RNMU




Map C-4: Depth Top RNMU

Legend:

well location

depth in meters below NAP

20.4 source GR log

20.4

isolines (2m interval)

≤ 94m

96 - 132m

134 - 170m

172 - 208m

210 - 246m

≥ 248m

normal fault

offset

no offset at this level

prepared by:
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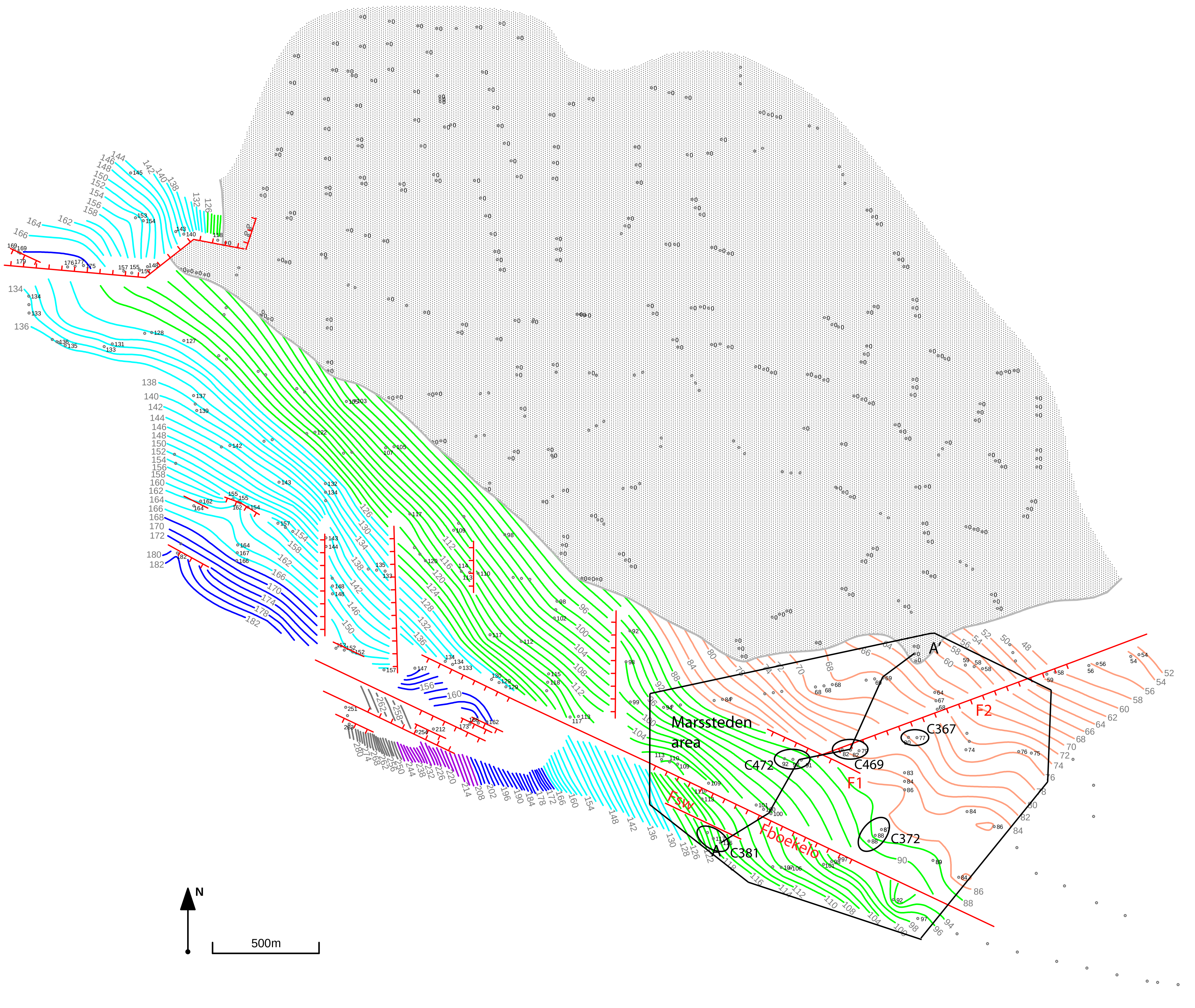
attachment to report GL11.901

Map C-7: Depth Base Niedersachsen Gp.: SK




Map C-7: Depth Base SK

Legend:

well location

depth in meters below NAP

20.4 source GR log

0 datapoint with no SK

eroded

isolines (2m interval)

≤ 86m

88 - 126

128 - 166m

168 - 206m

208 - 246m

≥ 248m

normal fault

offset

no offset at this level

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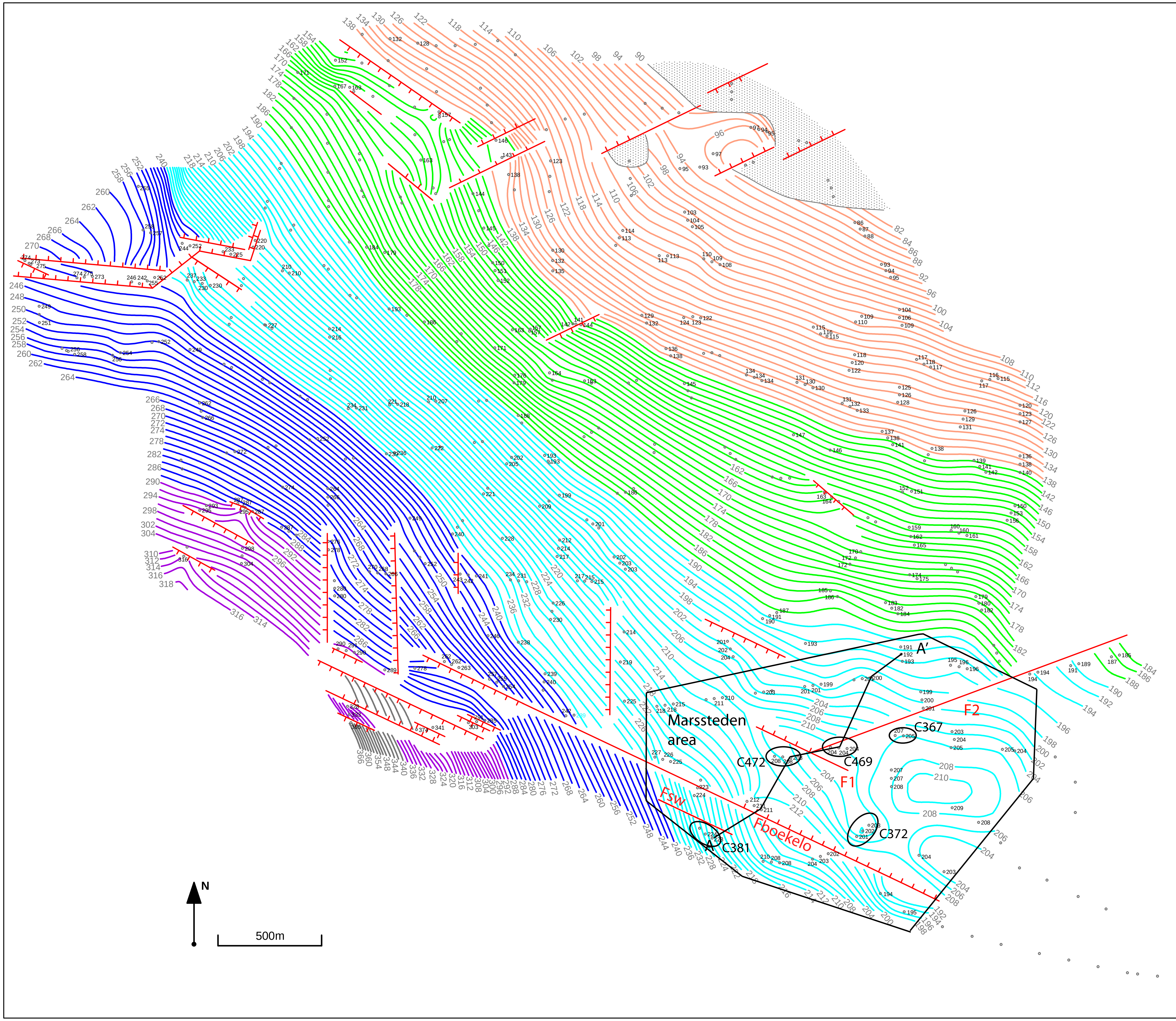


Map C-3: Depth Base RNMU

Legend:

- well location

depth in meters below NAP

- 20.4 source GR log
- eroded

isolines (2m interval)

- ≤ 138m
- 140 - 188m
- 190 - 238m
- 240 - 288m
- 290 - 338m
- ≥ 340m

normal fault

- offset
- no offset at this level

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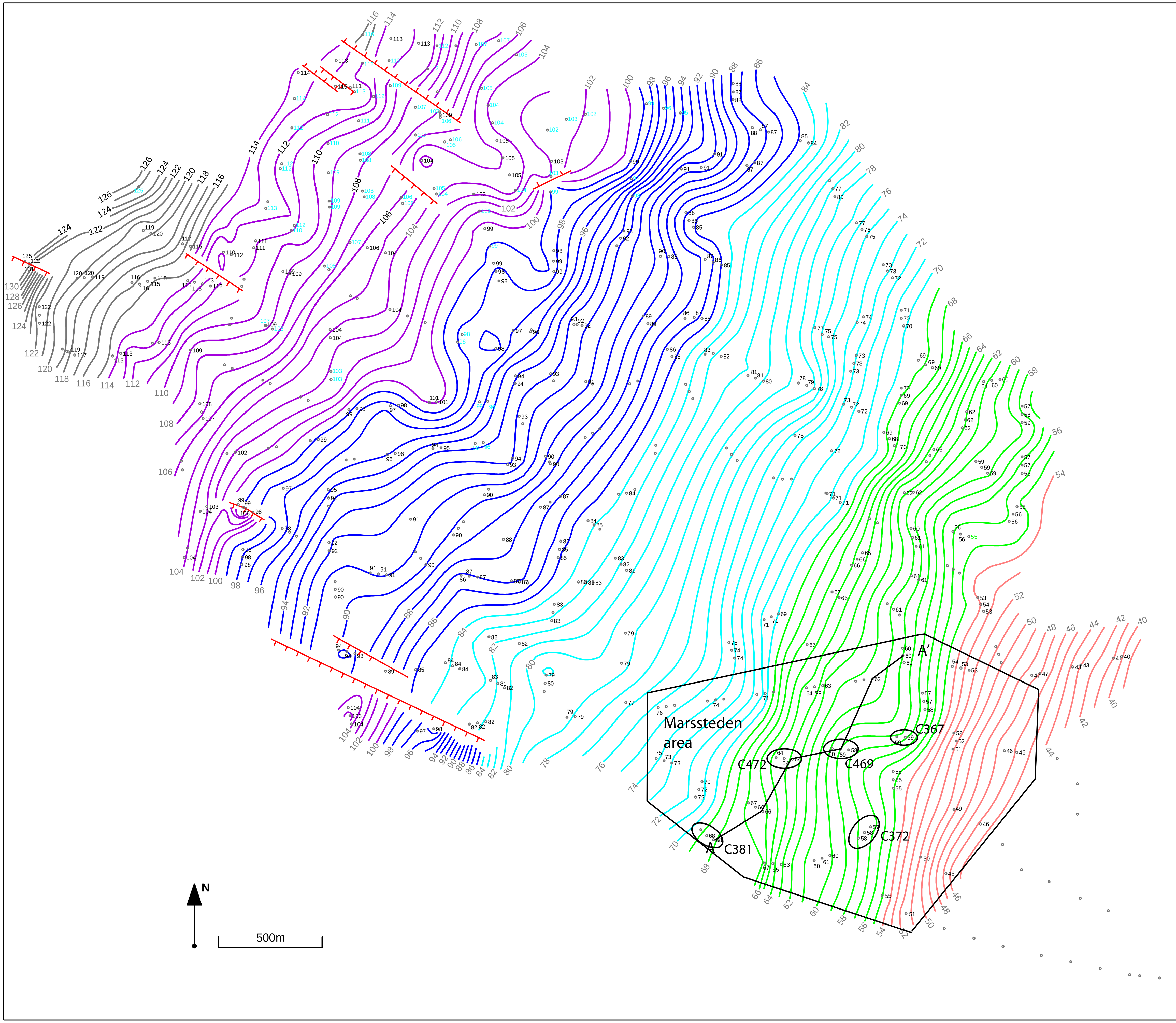
attachment to report GL11.901




Map C-9: Depth Base N

Legend:

well location

depth in meters below NAP

20.4 source GR log

20.4 source 'boorboek'

isolines (1m interval)

≤ 54m

55 - 69m

70 - 84m

85 - 99m

100 - 114m

≥ 115m

normal fault

offset

no offset at this level

prepared by:
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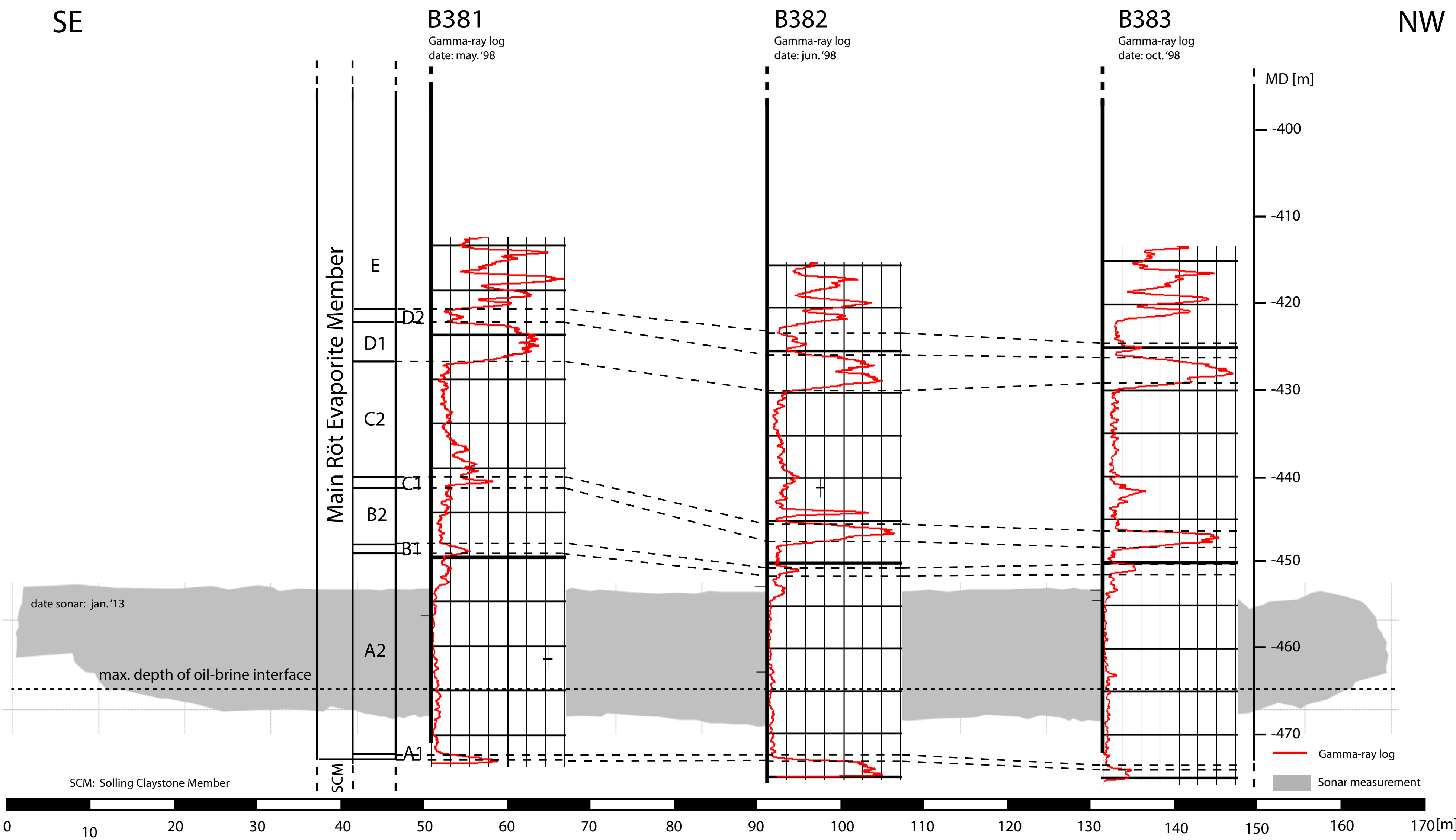
attachment to report GL11.901

A
A'
SW
NE
B381
B477
B472
B470
B290
B276
<- 273m ->
<- 289m ->
<- 236m ->
<- 372m ->
<- 186m ->
N2
N1
SK
AT
RNMU-B
RNMU-A
RNROU
RNRO2
RNROM
RNRO1
SH
(SH)
EK
(K)
(K)-SH
(K)-(SH)
EK-SH
Fsw
Fboekelo
F1
F2
AkzoNobel
LEGEND
vertical scale 1 : 1000
LITHOLOGY
clay / claystone
silt / siltstone
sand / sandstone
marl
limestone
calcareous dolomite
dolomite
anhydrite
halite
LITHOLOGICAL DETAIL
argillaceous
thin claystone bed
left side: silty
thin siltstone bed
siltstone bed
mid: slightly sandy
sandy
very sandy
right side: thin sandstone bed
sandstone bed
calcareous
thin limestone bed
dolomitic
thin dolomite bed
anhydritic
thin anhydrite bed
anhydrite nodule
thin halite bed
FOSSILS AND OTHER GEOLOGICAL DETAIL
glauconite
shell fragments
ostracods
plant fragments
continental red beds
OTHER
unconformity
stratigraphic boundary
Tertiary fault
Sub-Hercynian fault
Kimmerian fault
prepared by
GEOWULF Laboratories
attachment to report GL11.901
info@geowulf.nl
See report for well location and discussion



SE
NW
B381
Gamma-ray log
date: may. '98
B382
Gamma-ray log
date: jun. '98
B383
Gamma-ray log
date: oct. '98
MD [m]
-400
-410
-420
-430
-440
-450
-460
-470
Main Röt Evaporite Member
E
D2
D1
C2
C1
B2
B1
A2
A1
SCM
date sonar: jan. '13
max. depth of oil-brine interface
SCM: Solling Claystone Member
Gamma-ray log
Sonar measurement
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170 [m]

# Clovis project
# 'Second opinion'
# Gesteentemechanische 3-D modellering
# v.1.2

| | |
|---|---|
| Voorbereiding: | Well Engineering Partners B.V., Hoogeveen |
| Auteur: | dr.ir. A.J.H.M. Duquesnoy |
| Versie: | 1.2 (definitief) |
| Publicatiedatum: | 4 januari 2013 |
| Goedkeuring: | T. Koopmans, AkzoNobel MTD |

# Inhoud

## Managementsamenvatting

In deze bureaustudie zijn alle gesteentemechanische aspecten aan bod gekomen, die van belang zijn voor een veilige en duurzame opslag van olie in zoutcavernes gelegen in de opslagvergunning Twenthe Rijn De Marssteden. Voor dit doel dient de lange-termijn stabiliteit en lekdichtheid van de opslagcavernes gewaarborgd te zijn. De lekdichtheid heeft een geologische en een puttechnische component. Alleen de geologische lekdichtheid is in deze studie onderzocht. Het betrouwbaar aantonen van de lekdichtheid van een boorput vormt een vakgebied op zich en valt buiten het bestek van deze 'second opinion'

In de gesteentemechanische beoordeling van IfG uit 2010 zijn vanuit een conservatieve benadering ('worst case') de cavernestabiliteit en caverne-integriteit semi-kwantitatief beoordeeld. Alle onderzochte kandidaat-opslagcavernes blijken op de korte en lange-termijn ruim aan de gesteentemechanische criteria voor stabiele zoutpijlers, een stabiel cavernedak en geologische lekdichtheid te voldoen. Ondanks alle positieve beschouwingen heeft IfG aanbevolen om aanvullend door middel van 3-D finite-elementen modellering rekentechnisch aan te tonen dat de caverneconfiguraties stabiel zijn.

Naar aanleiding van genoemde IfG aanbeveling heeft WEP aan de hand van de laatste stand van zaken in het caverneveld een eigen gesteentemechanische beoordeling gemaakt. De meest recente resultaten van holruimtemetingen en de toekomstige zoutproductie van AkzoNobel zijn daarin betrokken. Opnieuw zijn de stabiliteit van zoutpijlers en cavernedak, en de geologische lekdichtheid bestudeerd. Voor alle volledigheid zijn ook verkennende berekeningen uitgevoerd naar de sterkte en stabiliteit van de bodems van de opslagcavernes in een 'worst case' situatie. Geheel in lijn met de IfG bevindingen wordt nog steeds ruimschoots voldaan aan alle gesteentemechanische criteria voor cavernestabiliteit en integriteit.

Gezien alle eerdere positieve bevindingen van IfG, aangevuld met die van WEP, is het moeilijk voor te stellen, dat een bewerkelijke en complexe 3-D modellering tot wezenlijk andere resultaten zou leiden. De noodzaak en meerwaarde van een dergelijke modellering voor een veilige en duurzame olieopslag in de kandidaatcavernes is niet overtuigend aantoonbaar.

# 1 Inleiding

AkzoNobel is al enkele jaren bezig met het voorbereiden van olieopslag in zoutcavernes (ondergrondse holruimten) in de opslagvergunning Twenthe-Rijn De Marssteden, gelegen in de gemeente Enschede en in 2010 verleend door de minister van Economische Zaken (EZ). Momenteel stelt AkzoNobel een opslagplan op conform artikel 26, Mijnbouwbesluit.

In 2010 heeft AkzoNobel een gesteentemechanische beoordeling laten uitvoeren door IfG (refs.1, 2 en 3) naar de haalbaarheid van olieopslag in een zestal geselecteerde zoutcavernes in het gebied De Marssteden van de verleende opslagvergunning. De belangrijkste gesteentemechanische criteria voor de duurzame omzetting van een zoutcaverne naar een opslagcaverne voor dieselolie zijn de lange-termijn stabiliteit en de lekdichtheid (integriteit) van de caverne. De beoordeling door IfG heeft een aantal geotechnische aanbevelingen opgeleverd.

Een van de aanbevelingen betreft het uitvoeren van een drie-dimensionale gesteentemechanische modellering om de stabiliteit van de opslagcavernes aan te tonen, waarbij zowel de huidige cavernesituatie als de verdere ontwikkeling van omliggende pekelproducerende cavernes worden bestudeerd onder de conservatieve opslagvoorwaarde dat de putmonddruk van de olievoerende boring gelijk is aan nul (atmosferische druk).

AkzoNobel voert de zoutwinningsactiviteiten in het gebied van de opslagvergunning uit op basis van gesteentemechanische randvoorwaarden, die zijn vastgelegd in het winningsplan Twenthe-Rijn 2008-2025 (ref.4). In dat verband is het geometrische begrip ‘caverne-omhullende’ geïntroduceerd, waarbinnen men cavernes kan ontwikkelen met voldoende lange-termijn stabiliteit en integriteit. De omhullende heeft niet alleen betrekking op de afmetingen in het horizontale vlak, maar ook op de dikte van de zoutbodem en de maximale hoogte van de cavernes, die de dikte van het resterende zoutdak bepaalt.

Ondermeer naar aanleiding van overleg met Staatstoezicht op de Mijnen (SodM) heeft AkzoNobel besloten twee van de zes door IfG onderzochte kandidaat-opslagcavernes verder buiten beschouwing te laten in verband met de mogelijke nabijheid van een kleine breukzone in de Röt zoutformatie (ref.5). De ligging van de overgebleven kandidaten is getoond in de holruimtekaart van bijlage 1. Het betreft de cavernes 367-368, 372-373-374, 469-470-471 en 472-473-474, waaruit de winning van steenzout inmiddels is gestaakt.

Gezien de specifieke afmetingen van de kandidaatcavernes en hun positionering ten opzichte van elkaar en van naburige cavernes vraagt AkzoNobel zich af, of een bewerkelijke 3-D modellering in dit stadium wel voldoende toegevoegde waarde heeft.

In opdracht van AkzoNobel heeft Well Engineering Partners een inventariserende bureaustudie uitgevoerd naar de reeds beschikbare gesteentemechanische inzichten en het eventuele nut van een aanvullende gesteentemechanische 3-D modellering.

# 2 Gesteentemechanische analyses

## 2.1 IfG bevindingen

Onderzoeksinstituut IfG heeft in zijn beoordeling (ref.1) zowel de lange-termijn stabiliteit als de integriteit (lekdichtheid) van de kandidaat-opslagcavernes semi-kwantitatief onderzocht.

***Cavernestabiliteit***
IfG heeft de lange-termijn stabiliteit van de cavernes onderzocht aan de hand van de sterkte van de zoutpijlers tussen de cavernes en van het zoutdak boven de cavernes. Men heeft zich op essentiële punten voornamelijk gebaseerd op onderzoeksresultaten van de Bundesanstalt für Geowissenschaften und Rohstoffe (BGR). In een reeks onderzoeken heeft BGR zowel 2-D als 3-D finite-elementen modellering uitgevoerd op representatieve caverneconfiguraties in het Hengelo veld (refs. 6, 7, 8). Daarbij heeft BGR gebruik gemaakt van de uit laboratoriumonderzoek aan boorkernmonsters verkregen gesteentemechanische eigenschappen van het Röt zout en de Röt kleisteen met anhydrietlagen, die aansluitend boven het zout gelegen is en van de Solling zanderige kleisteen, die direct aansluitend onder het Rötzout ligt (refs. 9, 10, 11). Soms ligt nog een dunne basisanhydrietlaag tot 1 m dikte tussen de Solling kleisteen en het Rötzout. In bijlage 2 is de diepteligging van de cavernes getoond in de vorm van overlangse dwarsdoorsneden verkregen uit holruimtemetingen (sonars). De basisanhydrietlaag is aangeduid als A1. De maximale hoogte van de cavernes varieert tussen 15 – 25 m.

De olieopslag vindt normaalgesproken plaats onder halmostatische condities, dat wil zeggen met pekeldruk in de caverne (drukopbouw 0,12 bar/m). Men brengt in één boorput van de opslagcaverne een pekelkolom aan tot aan maaiveld, terwijl een tweede boorput een oliekolom bevat (drukopbouw 0,08 bar/m). Aangezien de olieopslag tot een referentiediepte van maximaal 470 m beneden maaiveld plaatsvindt, zoals getoond in de cavernedoorsnedes van bijlage 2, levert dit een putmonddruk van circa 19 bar op. De middelste, derde boorput naar een caverne wordt drukloos afgesloten. De bovengenoemde BGR modellering is representatief voor halmostatische condities, zodat de resultaten ook rechtstreeks toepasbaar zijn op de normale olieopslagpraktijk. De minst gunstige uitzonderingssituatie (‘worst case’) in gesteentemechanisch opzicht doet zich voor indien de druk van de olievoerende putmond (voor langere tijd) terugvalt tot atmosferische druk, waardoor er in de caverne een drukverlies van circa 19 bar optreedt en het omringende zout- en kleigesteente zwaarder wordt belast.

***Sterkte zoutpijlers***
IfG heeft voor de ‘worst case’ situatie, namelijk oliedruk in de cavernes, onderzocht hoe sterk de zoutpijlers tussen de betreffende cavernes worden belast. Daarbij heeft men de pijlergeometrie uit een holruimtekaart van medio 2010 als uitgangspunt genomen. De zoutwinning is echter in drie van de kandidaat-opslagcavernes na dat tijdstip voortgezet. De winning uit caverne 372-373-374 is gestopt eind mei 2012, uit caverne 469-470-471 in november 2011 en uit caverne 472-473-474 in augustus 2011. De holruimtekaart van bijlage 1 toont de recente situatie in oktober 2012. Hoewel de meeste cavernes breder zijn geworden liggen ze alle nog binnen de toegestane ‘omhullende’, zodat de zoutpijlers niet veel meer worden belast dan in 2010.

Bij bestudering van de breedte van de zoutpijlers rondom de kandidaat-opslagcavernes valt op dat de caverne 367-368 de minst brede pijlers heeft met twee naburige cavernes, namelijk 61 m en 70 m. Het dakoppervlak van deze opslagcaverne bedraagt ongeveer 14.000 $m^2$ en het effectieve pijleroppervlak om het gewicht van de bovenliggende gesteentelagen te dragen is minimaal 30.000 $m^2$, namelijk ongeveer een rechthoek van 200x215 $m^2$ minus het dakoppervlak. De oorspronkelijke lithostatische druk op een diepte van 470 m bedraagt ongeveer 100 bar (0,215 bar/m), maar door aanwezigheid van de caverne 367-368 worden de pijlers volgens een berekening van IfG met 130 bar belast. In de caverne staat minstens een oliedrukkolom van 470 m, ofwel er heerst een druk van minimaal 38 bar. Het drukverschil over de cavernewand bedraagt dus hoogstens 92 bar. De triaxiale sterkte van het zout op die diepte bedraagt volgens BGR onderzoek aan zoutmonsters (ref.9) minstens 300 bar, zodat de maximale benutting van de zoutsterkte 30% bedraagt. Bij de andere drie kandidaatcavernes ligt de benutting zeker lager dan 30%. Daarmee is naar het oordeel van IfG de lange-termijn stabiliteit van de pijlers rond de opslagcavernes zelfs gegarandeerd in het uitzonderlijke geval van een langdurige 'worst case'.

***Cavernedakstabiliteit***
Het cavernedak wordt door IfG beschouwd als een alzijdig ingeklemde ronde plaat, die belast wordt door de bovenliggende gesteenten, inclusief het gewicht van het zoutdak zelf, en die ontlast wordt door de vloeistofdruk in de caverne. De dakstabiliteit is onderzocht door de buigspanningen in het midden van de dakplaat te berekenen op een diepte van 450 m en met in de caverne een oliedruk van 36 bar ('worst case'). Voor de bepaling van de evenwichtsvoorwaarde heeft men een Mohr-Coulomb model toegepast. In de figuren van bijlage 2 is te zien hoe in de onderzochte cavernes het dragende cavernedak is opgebouwd. Het bestaat uit Röt zoutlagen (A2, B2, C2, D2) met tussenliggende steenbanken van kleisteen met anhydrietinsluitingen (B1, C1, D1) en aansluitend erboven een Röt kleisteenlaag (E) met in de onderste 10 à 12 m een anhydrietbank volgens loggegevens van de boorputten. Men heeft de Mohr-Coulomb parameters van de samenstellende gesteenten bepaald uit gesteentesterktes, die BGR met metingen aan kernmonsters al eerder heeft vastgesteld in termen van Drucker-Prager evenwichtsrelaties (ref.11). In een zeer conservatieve benadering heeft IfG voor het dragende dak alleen de sterkte van de Röt kleisteen beschouwd en bovendien in de berekening alleen de reststerkte na een breuk toegepast. De berekening heeft opgeleverd dat bij een verhouding van 0,37 tussen de dikte van het dragende Röt dak en de cavernedoorsnede het dak voldoende lange-termijn draagkracht heeft en stabiel is. Vervolgens heeft IfG op basis van de cavernestatus van medio 2010 geconcludeerd dat alle kandidaatcavernes ruim aan het stabiliteitscriterium voldoen.

***Caverne-integriteit***
De integriteit van een opslagcaverne heeft betrekking op de lekdichtheid van de caverne en de boorputten voor de opgeslagen vloeistof. Hierbij maakt IfG onderscheid tussen de geologische lekdichtheid van de zoutcaverne en de technische lekdichtheid van de boorputten en putmond. In deze 'second opinion' wordt alleen de geologische lekdichtheidsanalyse van IfG behandeld.

Het is uit jarenlange praktijkervaring met opslag van vloeistoffen in zoutcavernes bekend dat steenzout zelfs bij een wand- en dakdikte van slechts enkele meters al lekdicht kan zijn, indien de vloeistofdruk lager is dan de gesteentedruk ter plaatse. Metingen van IfG aan boorkernen (Stassfurt en Werra homogeen steenzout) hebben een intrinsieke permeabiliteit van $K < 10^{-20}$ $m^2$ en een porositeit < 0,5% te zien gegeven. Met behulp van de stromingsformule van Darcy voor een permeabel medium heeft IfG berekend hoeveel olielekkage kan optreden, en over welke periode, in het geval van opslag in de Hengelo cavernes. Men heeft een hoogste referentiediepte voor de olie/pekelovergang van 425 m genomen en voor de maximale cavernedruk een gradient van 0,15 bar/m, wat neerkomt op circa 70% van de heersende lithostatische druk. Dit percentage is lager dan gebruikelijk voor cavernes in zoutdomes, omdat de Hengelo cavernes een relatief groot plat dak hebben tot maximaal 20.000 $m^2$. Bij een oliegradient van 0,081 bar/m betekent dit een maximaal toelaatbare olievoerende putmonddruk van 29 bar. Verder heeft men aangenomen dat het cavernedak in totaal minstens een 30 m dikke afsluitende steenzoutlaag (B2+C2+D2) bevat met de bovengenoemde waarden voor de permeabiliteit en de porositeit. Verder heeft men verondersteld dat de Röt anhydrietbank (in laag E) doorlatend en poreus is zonder vloeistofdruk in de poriën.

De berekening geeft aan dat er een olielekkage van minder dan 1 liter per dag naar laag E optreedt, nadat eerst de hele onderliggende steenzoutlaag volledig doordrenkt is geraakt met olie. Gebaseerd op de zeer geringe permeabiliteit van het steenzout en vanwege de dikte van minimaal 30 m duurt het minstens 1000 jaar, voordat de olie gaat weglekken in de anhydrietbank.

IfG komt tot de conclusie dat de cavernes in geologisch opzicht lekdicht zijn, zolang de gesteentemechanische pijlerstabiliteit en dakstabiliteit zijn gewaarborgd en de vloeistofdruk beperkt blijft tot maximaal 70% van de lithostatische druk. In de praktijk is een caverne pas geschikt voor olieopslag indien ook de technische lekdichtheid voldoende is aangetoond.

***IfG aanbeveling tot 3-D modellering***
Ondanks alle positieve analyseresultaten ten aanzien van de gesteentemechanische stabiliteit van de kandidaat-opslagcavernes komt IfG toch tot de aanbeveling dat er een 3-D (finite-elementen) modellering nodig is om de lange-termijn stabiliteit aan te tonen, waarin ook de toekomstige verdere ontwikkeling van naburige pekelproducerende cavernes wordt betrokken.

## 2.2 Analyse WEP

WEP heeft door middel van een bureaustudie en met gebruikmaking van de meest recente gegevens over de status van de kandidaatcavernes en de verdere zoutproductieplanning van AkzoNobel, onderzocht of met voldoende zekerheid de stabiliteit en integriteit van de kandidaat-opslagcavernes beoordeeld kan worden op basis van de nu beschikbare geometrische en gesteentemechanische gegevens over deze cavernes en de omringende gesteenten.

***Zoutpijlerstabiliteit***
In aanvulling op de IfG sterkteanalyse zijn de BGR onderzoeksresultaten van belang. BGR heeft voor cavernes in parallelle rijen ondermeer berekend dat bij cavernes met een doorsnede van 120 m en een hoogte van 25 m de zoutpijler met naburige cavernes bij een benutting van 30% van de zoutsterkte 60 m moet bedragen (ref.7). Aan deze minimum breedte voldoen alle pijlers van de kandidaatcavernes. Daarnaast heeft BGR voor de situatie van parallelle rijen van cavernes op voldoende afstand van elkaar aangetoond, dat bij cavernes in dezelfde rij een tussenpijler van meer dan 20 m voldoende is om een tijdelijk pekeldrukverschil van 20 bar tussen naburige cavernes op te vangen (ref.8). Onder enig voorbehoud kan men stellen, dat caverne 367-368 in een (parallelle) rij van cavernes ligt, namelijk met de cavernes 278-279-280 en 369-370-371, omdat de afstand tot de andere buurcavernes zeer groot is (>130 m). In dat opzicht is de pijler van 61 m breedte tussen de cavernes 367-368 en 369-370-371 ruim voldoende voor lange-termijn stabiliteit in de 'worst case'.

***Dakstabiliteit***
In verband met gewijzigde afmetingen van de kandidaat-opslagcavernes sinds de rapportage van IfG heeft WEP voor de 'second opinion' een nieuwe berekening gemaakt van de verhouding tussen cavernedoorsnede en de Röt dakdikte. De cavernes hebben een ellipsvormig dak, zodat in navolging van IfG de spanwijdte (korte as) wordt genomen ter bepaling van de verhouding. Hierbij worden de waarden voor de spanwijdte S en dakdikte D ontleend aan de gegevens uit de bijlagen 1 en 2. Als onderkant van het dak is de gemiddelde diepte van het zoutdak van de caverne genomen. Als bovenkant van het dragende dak is van de Röt kleisteenlaag E nog 11 m anhydrietbank als dragend element meegenomen. In de volgende tabel zijn de nieuwe resultaten (status oktober 2012) samengevat. Het blijkt dat het dragende dak van caverne 367-368 het minste overschot heeft met het oog op het stabiliteitscriterium van 0,37.

| Opslagcaverne | Spanwijdte (m) | Dakdikte (m) | Verhouding D/S |
|---|---|---|---|
| 367-368 | 121 | 47 | 0,39 |
| 372-373-374 | 115 | 62 | 0,54 |
| 469-470-471 | 112 | 53 | 0,47 |
| 472-473-474 | 101 | 49 | 0,48 |

Het Röt cavernedak bestaat grotendeels uit steenzout (B2, C2). IfG heeft ook de Mohr-Coulomb parameters voor het Röt steenzout bepaald. Als men die toepast (berekening WEP) komt men tot een veel gunstiger criterium van 0,26 voor de minimaal gewenste dragende dakdikte voor de lange-termijn stabiliteit bij een bepaalde cavernedoorsnede.

Tenslotte vragen de uitwassingen in het cavernedak rond boring 367 (kleine koepel van circa 5 m hoogte) en in het dak rond boring 470 (koepel eveneens circa 5 m hoog) om extra aandacht. AkzoNobel is voornemens om voor het begin van de olieopslag nog circa 22.000 $m^3$ extra zout uit caverne 367-368 te winnen om het dak vlakker te krijgen. Het dakoppervlak is ongeveer 14.000 $m^2$, zodat met die zoutproductie het dak maximaal 2 m hoger komt te liggen en de D/S verhouding 0,37 wordt. Uit caverne 469-470-471 wil men met hetzelfde doel nog eens 100.000 $m^3$ zout uitlogen. Het dakoppervlak is momenteel ongeveer 16.500 $m^2$ groot, maar zal bij een dergelijke, grote productie zeker met 20% kunnen toenemen tot 20.000 $m^2$ met een spanwijdte van 120 m. Het dak komt ongeveer 5 m hoger te liggen en de D/S verhouding neemt af tot 0,40. De beoogde nalogingen zijn dus mogelijk zonder de dakstabiliteit wezenlijk te verminderen.

***Geologische lekdichtheid cavernes***

Aan de geologische lekdichtheidsanalyse van IfG valt niet veel toe te voegen. Een punt van aandacht zijn de gekozen permeabiliteit en porositeit voor het Rötzout. Het Rötzout vormt een geologisch jongere en minder diep gelegen zoutformatie dan de Werra en Stassfurt zouten. In de literatuur (refs.12, 13, 14) zijn voor met de Rötformatie vergelijkbare zoutafzettingen, die ook anhydriet en kleisteenlagen bevatten, de volgende eigenschappen gerapporteerd:

$6.10^{-20}\ m^2 < K < 2.10^{-19}\ m^2$ en $0{,}2\% < \varphi < 1\%$.

De door IfG toegepaste waarden zijn dus representatief te noemen.

***Sterkte en stabiliteit van de cavernebodems***

BGR heeft zowel 2-D als 3-D finite-elementen modellering uitgevoerd op representatieve caverneconfiguraties in het Hengelo veld (refs. 6, 7, 8). Hierbij heeft men altijd een zoutbodem van minimaal 5 m dikte en in enkele gevallen van 10 m dikte in het model aangebracht. Echter, in de kandidaat-opslagcavernes ontbreekt een dergelijke zoutbodem, uitgezonderd caverne 472-473-474. Uit de figuren van bijlage 2 blijkt dat de bodem van de andere cavernes hooguit enkele meters zout bevat. Ook hebben twee cavernes een laag basisanhydriet (A1) van ongeveer 1 m dikte. De bodem is hier en daar dikker vanwege de stapeling van niet-oplosbare bestanddelen in het Rötzout (de 'sump'). Onder de Rötformatie bevindt zich de Solling kleisteen. Hierna wordt globaal onderzocht in hoeverre de Solling kleisteen voldoende stabiel is in de 'worst case' van een (tijdelijk) drukloze olievoerende putmond. Dit incident kan zich bijvoorbeeld voordoen als een olietankwagen onverhoopt de boorkelder inrijdt. Ook als er een olielekkage langs het boorgat zou optreden, kan het noodzakelijk zijn de druk van de caverne af te halen in verband met metingen en een eventuele putreparatie.

BGR heeft gesteentemechanisch onderzoek verricht aan Solling boorkernmonsters uit de Hengelo boring 480 (ref.10). De boorkern is ongeveer 9 m lang en is door BGR omschreven als kleisteen, slikachtig, fijnzandig (eerste 2m), daarna sliksteen/fijnzandsteen. De sterkte (na breuk) van de onderzochte kleisteenmonsters is uitgedrukt in Drucker-Prager evenwichtsrelaties. De vochtigheidsgraad varieerde van 7 -16%, hetgeen duidt op een niet te verwaarlozen porositeit. Als de poriëndruk halmostatisch is, zijn onder normale opslagcondities de vloeistoffen in de caverne en in de Solling kleisteen in evenwicht. Zodra de cavernedruk met 18 bar daalt ('worst case') is dat niet meer het geval. Het hangt dan van de afdichtende eigenschappen van de sump en de dunne resterende zout/anhydrietlaag en van de permeabiliteit van de Solling kleisteen af, of eventueel wat porievloeistof weglekt naar de caverne. Op zich is dat geen probleem, omdat onder de olie toch al een pekellaag van minimaal enige meters aanwezig blijft. Een merkbare compactie van de kleisteen bij dit eventuele, relatief geringe drukverlies in de poriën is niet te verwachten.

Bij een oliekolom van 0,8 bar/10m tot een diepte van maximaal 470 m en een formatiedruk van 2,2 bar/10m + 30% vanwege de verhoogde pijlerbelasting (tributary load area) staat er onderin de caverne een horizontaal en vertikaal drukverschil (Ko=1 voor zout) van (2,2*47)*1,3 – (0,8*47) = 134,4 – 37,6 = 96,8 bar over de onderkant zoutwand.

Aan de rand van de caverne drukt de extra belaste zoutpijler zwaarder op de Solling kleisteen. Uitgaande van een aanvankelijk anisotrope spanningstoestand van de Solling kleisteen en een Poisson ratio van 0,33 (Ko =0,5) bedraagt de totaalspanning (1$^{e}$ Invariant) aan de top van de kleisteen precies aan de rand van de cavernebodem (-134,4 + 2,2*47-37,6) - 2*(2,2*47)*0,5 = - 172 bar (= drukspanning). Volgens bovengenoemd BGR onderzoek bedraagt de breuksterkte (wortel 2$^{e}$ Invariant) dan ongeveer 58,8 bar en de reststerkte 35,9 bar (Drucker-Prager, F4, voor Isigma = -17,2 MPa). De verschilspanning tussen minimum en maximum hoofdspanning mag dan maximaal 58,8*√3 = 101,8 bar bedragen. Op de overgang van zoutpijler naar Solling kleisteen bedraagt de verschilspanning tussen vertikaal en horizontaal maximaal 134,4 – 0,5*(2,2*47) = 82,7 bar, wat voldoende laag is voor een stabiele Solling kleisteen.

In het centrum van de cavernebodem is de belasting van de kleisteen anders, omdat hier geen extra pijlerdruk aanwezig is. Er staat dan een totaalspanning van ongeveer (103,4-37,6) – 2*51,7 = 65,8 – 103,4 = - 37,6 bar (=drukspanning) op de kleisteen en een verschilspanning tussen vertikaal en horizontaal van maximaal 65,8 – 51,7 = 14,1 bar. Volgens BGR (Drucker-Prager F4, voor Isigma = -3,76 MPa) is de breuksterkte (wortel 2$^{e}$ Invariant) dan ongeveer 38,6 bar en de reststerkte 18 bar, ofwel respectievelijk 67 bar en 31 bar in termen van verschilspanningen. De maximum verschilspannning in de top van de kleisteen bedraagt 14,1 bar, hetgeen dus ook op dit punt een stabiele kleisteen impliceert. Er bestaat geen risico op een omhoogkomende cavernebodem.

Bovenstaande berekeningen zijn overigens zeer conservatief, omdat er geen rekening gehouden is met iets hogere neerwaartse bodemdrukken als gevolg van de aanwezigheid van anhydriet, een dunne restantlaag steenzout, de sump van onoplosbare bestanddelen en een laag verzadigde pekel van minimaal enige meters onder de opgeslagen olie.

# 3 Conclusies en aanbevelingen

In de gesteentemechanische beoordeling van IfG uit 2010 zijn vanuit een conservatieve benadering ('worst case') de cavernestabiliteit en caverne-integriteit semi-kwantitatief beoordeeld. Alle onderzochte kandidaat-opslagcavernes blijken op de korte en lange-termijn ruim aan de gesteentemechanische criteria voor stabiele zoutpijlers, een stabiel cavernedak en geologische lekdichtheid te voldoen. Ondanks alle positieve beschouwingen heeft IfG aanbevolen om aanvullend door middel van 3-D finite-elementen modellering rekentechnisch aan te tonen dat de caverneconfiguraties stabiel zijn.

Naar aanleiding van genoemde IfG aanbeveling heeft WEP aan de hand van de laatste stand van zaken in het caverneveld een eigen gesteentemechanische beoordeling gemaakt. De meest recente resultaten van holruimtemetingen en de toekomstige zoutproductie van AkzoNobel zijn daarin betrokken. Opnieuw zijn de stabiliteit van zoutpijlers en cavernedak, en de geologische lekdichtheid bestudeerd. Voor alle volledigheid zijn ook verkennende berekeningen uitgevoerd naar de sterkte en stabiliteit van de bodems van de opslagcavernes in een ‘worst case’ situatie. Geheel in lijn met de IfG bevindingen wordt nog steeds ruimschoots voldaan aan alle gesteentemechanische criteria voor cavernestabiliteit en integriteit.

De lekdichtheid van een caverne heeft een geologische en een puttechnische component. Alleen de geologische lekdichtheid is in deze studie nader onderzocht en in orde bevonden. Echter, de technische lekdichtheid van de cavernes is uiteindelijk beslissend voor het welslagen van het opslagproject. Het betrouwbaar aantonen van de lekdichtheid van een boorput vormt een vakgebied op zich (refs12, 13). IfG heeft in de gesteentemechanische beoordeling van 2010 een aantal aanbevelingen gedaan hoe de boorputten op lekdichtheid te testen en maatregelen voorgesteld om ze geschikt te maken voor olieopslag. Het beoordelen van die aanbevelingen en maatregelen valt echter buiten het bestek van deze ‘second opinion’.

***Eindconclusie van deze ‘second opinion’***

Gezien alle eerdere positieve gesteentemechanische bevindingen van IfG, aangevuld met die van WEP, is het moeilijk voor te stellen, dat een bewerkelijke en complexe 3-D modellering tot wezenlijk andere resultaten zou leiden. De noodzaak en meerwaarde van een dergelijke modellering voor een veilige en duurzame olieopslag in de kandidaatcavernes is niet overtuigend aantoonbaar.

***Aanbevelingen***

De kandidaat-opslagcavernes worden deels omringd door cavernes, waaruit nog zout gewonnen wordt. Het is belangrijk, dat de ontwikkeling van die cavernes regelmatig wordt gecontroleerd. Uitgangspunt dient te zijn, dat ze binnen de toegelaten ‘omhullende’ blijven.

Het gebied van de opslagvergunning bevat nog een aantal cavernes, die tot nu toe slechts een beperkte hoogte hebben ontwikkeld. Deze cavernes zouden met het oog op mogelijk toekomstige uitbreiding van de opslagcapaciteit extra gecontroleerd kunnen worden op een vlakke dakontwikkeling en men zou de cavernehoogte tot minder dan 20 m kunnen beperken om met het oog op toekomstige olieopslag ruim voldoende dakstabiliteit te kunnen garanderen.

# Referenties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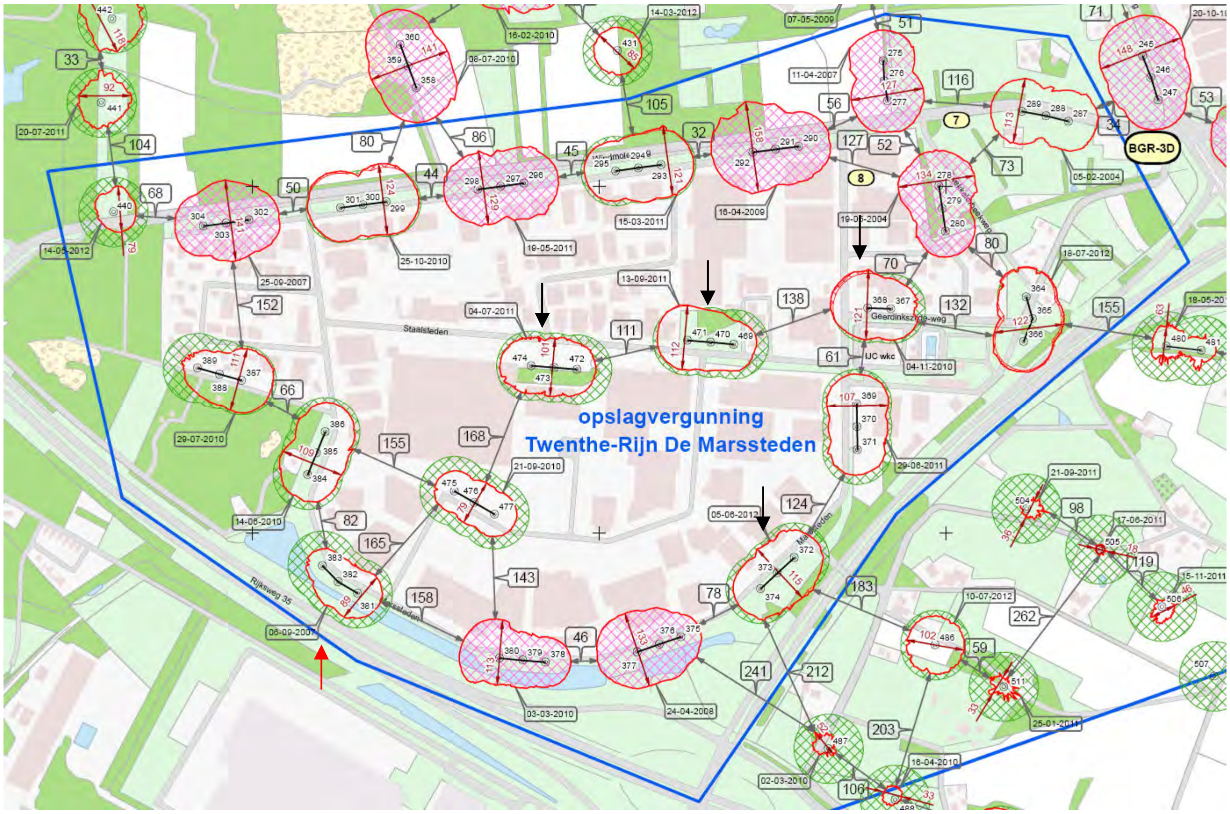
13. Tightness tests in salt-cavern wells, P. Bérest et al, SMRI Spring 2002 Meeting, Banff, Alberta, Canada.
14. An in situ creep test in advance of abandoning a salt cavern, B. Brouard et al., SMRI Fall 2004 Conference, Berlin, Germany.

# Bijlage 1: Holruimtekaart opslagvergunning Twenthe-Rijn De Marssteden

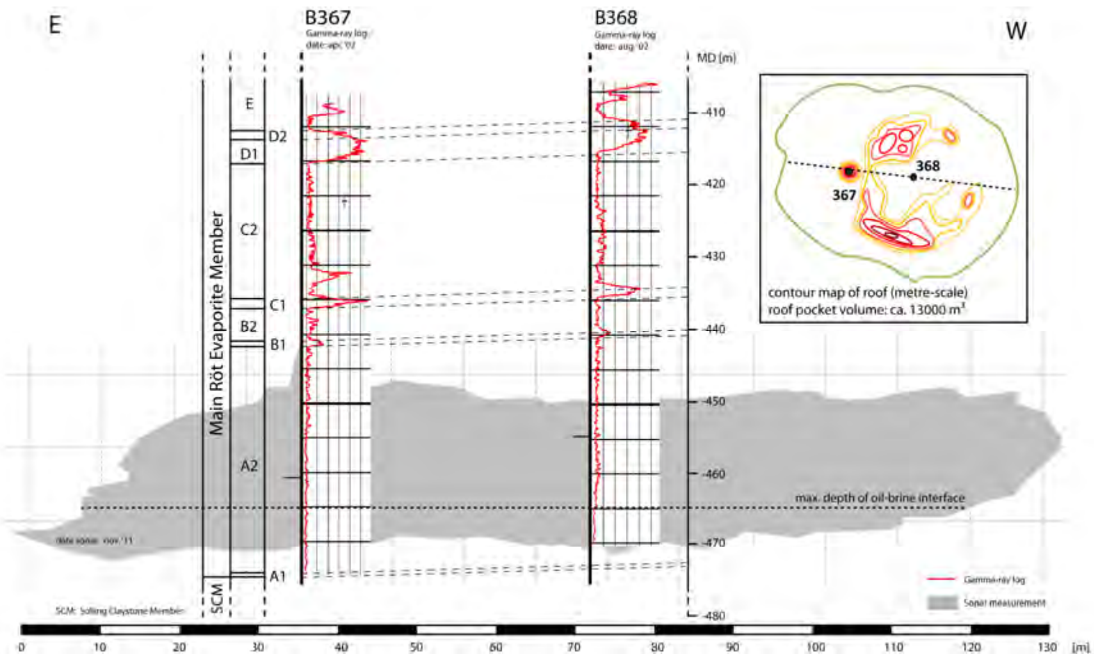



De holruimtekaart toont de ondergrondse situatie per oktober 2012. De rode contouren tonen de maximale afmetingen van een caverne in het horizontale vlak op de aangegeven meetdatum. De groen gearceerde vlakken geven de toegestane 'caverne omhullende' uit het winningsplan Twenthe-Rijn 2008-2025 aan (ref.4). De rood gearceerde vlakken tonen de afmetingen van de definitief uit bedrijf genomen zoutcavernes. De rode pijlen in de cavernes geven de grootste diameter (in m) loodrecht op de lange caverneas aan (de spanwijdte). De zwarte pijlen geven de kortste afstand (in m) tussen de maximum contour van belendende cavernes aan.

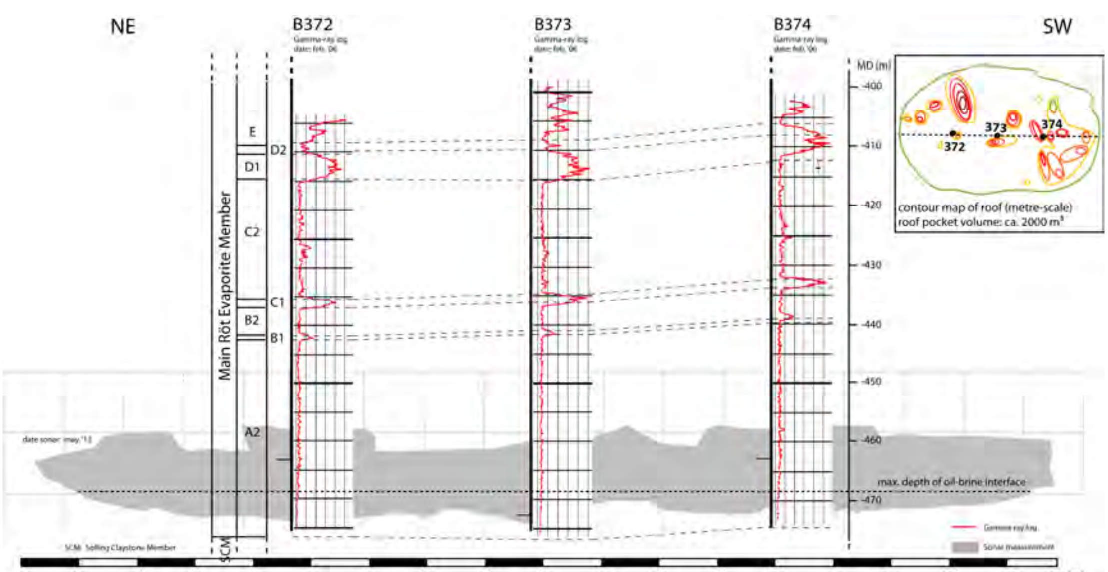
De volgende vier, voorlopig ook uit bedrijf genomen zoutcavernes zijn kandidaten voor ondergrondse olieopslag (zie zwarte pijlen):
caverne 367-368,
caverne 372-373-374,
caverne 469-470-471,
caverne 472-473-474.

In het MER en de Wabo-aanvraag is ook caverne 381-382-383 vermeld. Deze caverne is echter nog niet opgenomen in het opslagplan, dat AkzoNobel momenteel voorbereidt, en valt daarom buiten deze 'second opinion'. De caverne is aangeduid met een rode pijl.

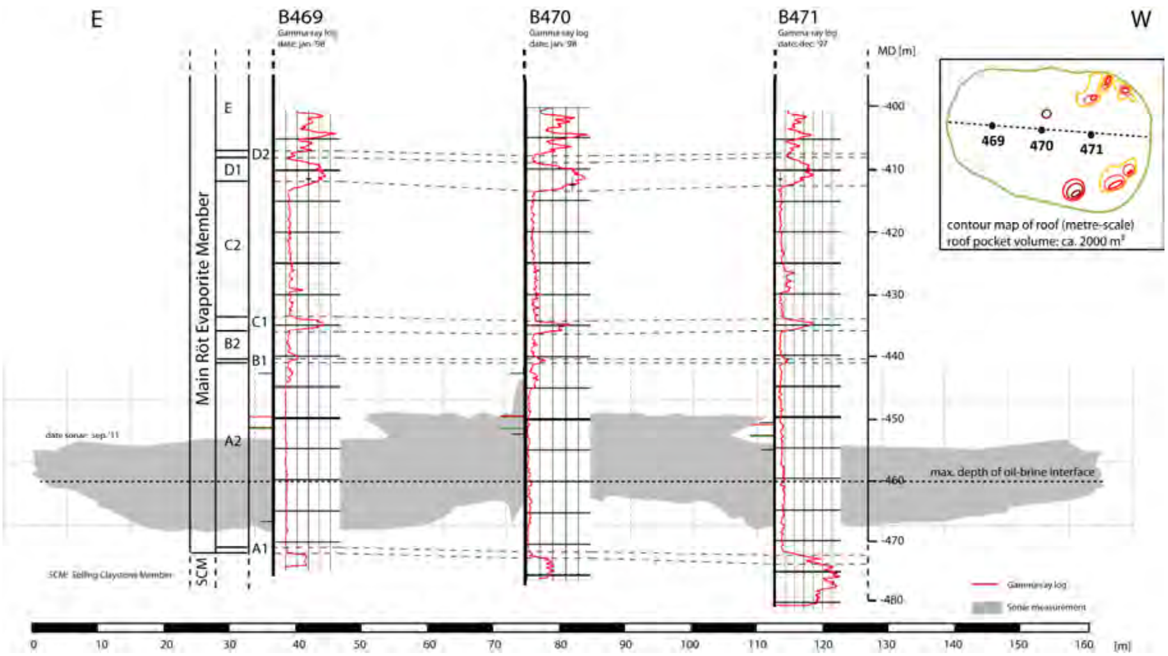
# Bijlage 2: Dwarsdoorsneden en bovenaanzichten opslagcavernes uit holruimtemetingen



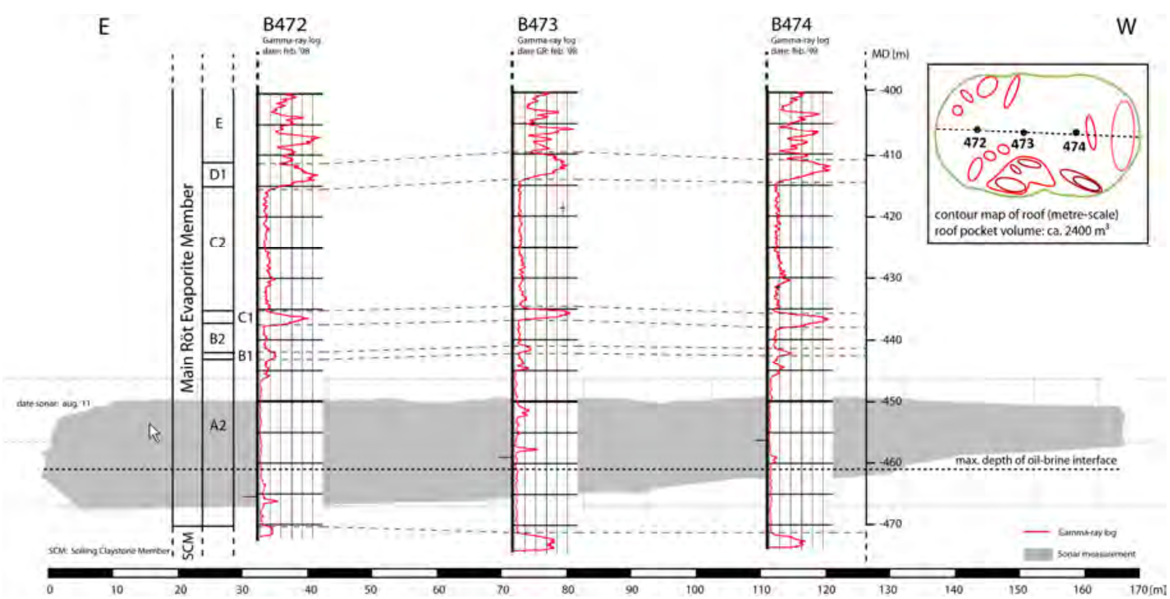

**Figuur 1: Caverne 367-368.** Einddatum uitlogen: 2 november 2010. Sonar november 2011.




**Figuur 2: Caverne 372-373-374.** Einddatum uitlogen 29 mei 2012. Sonar mei 2012.




**Figuur 3: Caverne 469-470-471.** Einddatum uitlogen 14 november 2011. Sonar september 2011.




**Figuur 4: Caverne 472-473-474.** Einddatum uitlogen 12 augustus 2011. Sonar augustus 2011.

# Clovis project

# Gesteentemechanische analyse caverne 381 v.1.1

| | |
|---|---|
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# Inhoud

## Managementsamenvatting

In een vorige bureaustudie (ref.1) zijn voor vier zoutcavernes, gelegen in de opslagvergunning Twenthe Rijn De Marssteden, de lange-termijn stabiliteit en lekdichtheid onderzocht met het oog op een veilige en duurzame opslag van dieselolie. Het onderzoek toonde aan dat een bewerkelijke gesteentemechanische 3-D modellering van de cavernes, zoals geadviseerd door IfG (ref.2), onvoldoende meerwaarde zou hebben. In deze studie wordt aanvullend een vijfde kandidaat-opslagcaverne, no.381, op geschiktheid onderzocht. De lekdichtheid van een caverne heeft een geologische en een puttechnische component. Alleen de geologische lekdichtheid is onderzocht.

WEP heeft aan de hand van de laatste stand van zaken in het caverneveld rondom caverne 381 een aantal essentiële gesteentemechanische en geologische factoren geanalyseerd. De meest recente resultaten van holruimtemetingen en de toekomstige zoutproductie van AkzoNobel zijn daarin betrokken. De stabiliteit van de zoutpijlers, cavernedak en cavernebodem, en de geologische lekdichtheid van caverne 381 zijn bestudeerd. De conclusies zijn dat er ruimschoots wordt voldaan aan alle gesteentemechanische en geologische criteria voor cavernestabiliteit en integriteit en dat ook bij deze caverne de toegevoegde waarde van een bewerkelijke gesteentemechanische 3-D modellering ontbreekt.

Gezien de huidige, ongelijkmatige dakgesteldheid van caverne no.384, die naast caverne 381 ligt, beveelt WEP bij voortgezette uitloging van caverne 384 aan om de verdere dakontwikkeling zorgvuldig te controleren.

Tenslotte merkt WEP op dat de door AkzoNobel terzijde geschoven caverne no.375, die eerder door IfG (ref.2) als opslagcaverne voor dieselolie in orde is bevonden, vermoedelijk toch geschikt is voor toekomstige olieopslag. Als AkzoNobel behoefte krijgt aan meer opslagcapaciteit zou WEP deze caverne volgens de in deze studie gevolgde analysemethodiek als eerstvolgende op geschiktheid kunnen analyseren. De aandacht zal dan met name gericht worden op het uitsluiten van bepaalde risico's, zoals de eventuele aanwezigheid van essentiële breuken in de Röt formatie in de onmiddellijke omgeving of ter plaatse van deze caverne, en een mogelijke hydraulische verbinding van de caverne met een naburige caverne.

# 1 Inleiding

In 2010 heeft AkzoNobel een gesteentemechanische beoordeling laten uitvoeren door het Institut für Gebirgsmechanik (IfG, refs.2, 3) naar de haalbaarheid van olieopslag in een zestal geselecteerde zoutcavernes in het gebied van de verleende opslagvergunning ‘Twenthe-Rijn De Marssteden’. De nu bestudeerde caverne 381 met boorputten 381-382-383 maakt geen deel uit van de IfG beoordeling en is niet opgenomen in het opslagplan, dat AkzoNobel heeft voorbereid. De caverne is al wel vermeld in het MER en de Wabo-aanvraag voor de olieopslag en wordt via een Addendum aan het opslagplan toegevoegd.

AkzoNobel voert de zoutwinningsactiviteiten in het gebied van de opslagvergunning uit op basis van gesteentemechanische randvoorwaarden, die zijn vastgelegd in het winningsplan Twenthe-Rijn 2008-2025 (ref.4). In dat verband is het geometrische begrip ‘caverne-omhullende’ geïntroduceerd, waarbinnen men cavernes kan ontwikkelen met voldoende lange-termijn stabiliteit en integriteit. De omhullende heeft niet alleen betrekking op de afmetingen in het horizontale vlak, maar ook op de dikte van de zoutbodem en de maximale hoogte van de caverne, die de dikte van het resterende zoutdak bepaalt.

AkzoNobel heeft twee van de zes door IfG onderzochte kandidaat-opslagcavernes niet in het opslagplan betrokken vanwege een kennelijk verwachte verstoring van de Röt zoutformatie door een nabijgelegen kleine breukzone (ref.5). De vervangende kandidaat-opslagcaverne 381 ligt waarschijnlijk wel buiten de directe invloedsfeer van die breukzone. Dit aspect wordt nader toegelicht in sectie 2.4. De winning van steenzout uit de caverne is inmiddels gestaakt. De ligging van de caverne is getoond op de holruimtekaart van bijlage 1.

In opdracht van AkzoNobel heeft Well Engineering Partners een korte bureaustudie uitgevoerd naar de geschiktheid van caverne 381 als opslagcaverne. De studie is uitgevoerd naar analogie van de bovengenoemde IfG beoordeling, waarbij een aantal essentiële gesteentemechanische en geologische factoren worden geanalyseerd. De belangrijkste criteria voor de duurzame omzetting van een zoutwinningscaverne naar een opslagcaverne voor dieselolie zijn de lange-termijn stabiliteit en de lekdichtheid (integriteit) van de caverne.

# 2 Gesteentemechanische analyse

Met gebruikmaking van de recentste gegevens over de status van de kandidaat-opslagcaverne 381 en zijn naburige cavernes en de verdere zoutproductieplanning van AkzoNobel in het betreffende gebied, heeft WEP onderzocht of met voldoende zekerheid de stabiliteit en integriteit van deze kandidaatcaverne vastgesteld kan worden. De lange-termijn stabiliteit is beoordeeld aan de hand van de sterkte van, respectievelijk, de zoutpijlers tussen de caverne en zijn buurcavernes, het zoutdak boven de caverne en de cavernebodem.

## 2.1 Sterkte zoutpijlers

De pijleranalyse is gebaseerd op de resultaten van BGR onderzoek. In een reeks onderzoeken heeft BGR zowel 2-D als 3-D eindige-elementen modellering uitgevoerd op representatieve caverneconfiguraties in het Hengelo veld (refs. 6, 7, 8). Daarbij heeft BGR gebruik gemaakt van de gesteentemechanische eigenschappen van het Röt zout en de Röt kleisteen met anhydrietlagen, die aansluitend boven het zout gelegen is en van de Solling zandige kleisteen, die direct aansluitend onder het Rötzout ligt (refs. 9, 10, 11). Soms ligt nog een dunne basisanhydrietlaag tussen de Solling kleisteen en het Rötzout.

In bijlage 2 is de ondergrondse situatie rond de caverne 381 getoond volgens de laatste sonarmetingen van december 2012 en februari 2013. De minimum afstand tussen caverne 381 en caverne 384 (met boorputten 384-385-386) bedraagt momenteel ongeveer 72 m. In bijlage 3 is de huidige diepteligging van de caverne 381 getoond in de vorm van een overlangse dwarsdoorsnede verkregen uit de sonarmetingen. De basisanhydrietlaag is aangeduid met A1. Deze laag is 1 à 2 m dik. De maximale hoogte van de caverne is circa 15 m en de referentiediepte is circa 460 m. Het cavernedak ligt 453 m beneden maaiveld en is bijzonder vlak, zoals de holruimteregistraties van bijlage 4 aantonen. De spanwijdte van het dak bedraagt, respectievelijk, 155 m (lange as) en 100 m (korte as), dus gemiddeld circa 127 m.

De olieopslag in caverne 381 vindt normaalgesproken plaats onder halmostatische condities, dat wil zeggen met pekeldruk in de caverne (drukopbouw 0,12 bar/m). Men brengt in één boorput van de caverne een pekelkolom aan tot aan maaiveld, terwijl een tweede boorput een oliekolom bevat (drukopbouw 0,08 bar/m). Aangezien de olieopslag op een referentiediepte van 460 m beneden maaiveld plaatsvindt levert dit een putmonddruk van 18,5 bar op. De bovengenoemde BGR modellering is representatief voor halmostatische condities, zodat de resultaten toepasbaar zijn op de normale olieopslagpraktijk. De minst gunstige uitzonderingssituatie ('worst case') in gesteentemechanisch opzicht doet zich voor indien de druk van de olievoerende putmond (voor langere tijd) terugvalt tot atmosferische druk, waardoor er in de caverne een drukverlies van 18,5 bar optreedt en het omringende zout- en kleigesteente zwaarder wordt belast. Dit incident kan zich bijvoorbeeld voordoen als een olietankwagen onverhoopt de boorkelder inrijdt. Ook als er een olielekkage langs het boorgat zou optreden, kan het noodzakelijk zijn de druk van de caverne af te halen in verband met metingen en een eventuele putreparatie.

***Analyse 'worst case' drukconditie***

Voor de 'worst case' situatie, namelijk oliedruk in de caverne 381, is onderzocht hoe sterk de zoutpijlers rondom de caverne worden belast. Het huidige dakoppervlak van de caverne bedraagt ongeveer 13.500 $m^2$ en het effectieve pijleroppervlak om het gewicht van de bovenliggende gesteentelagen te dragen is circa 49.000 $m^2$ ('tributary load area'), namelijk een rechthoek van 250x250 $m^2$ minus het dakoppervlak. De oorspronkelijke lithostatische druk op een diepte van 460 m bedraagt ongeveer 99 bar (0,215 bar/m), maar door aanwezigheid van de caverne worden de omringende pijlers met circa 126 bar belast. In de caverne staat minstens een oliedrukkolom van 460 m, oftewel er heerst een druk van minimaal 37 bar. Het drukverschil over de cavernewand bedraagt dus hoogstens 89 bar. De triaxiale sterkte van het zout op die diepte bedraagt volgens BGR onderzoek aan zoutmonsters (ref.9) minstens 300 bar, zodat de maximale benutting van de zoutsterkte minder dan 30% bedraagt. Daarmee is de lange-termijn stabiliteit van de pijlers rond de opslagcaverne ook nog gegarandeerd onder een langdurige 'worst case' drukconditie.

BGR heeft voor cavernes in parallelle rijen ondermeer berekend dat bij cavernes met een doorsnede van 120 m en een hoogte van 25 m de zoutpijler met naburige cavernes bij een benutting van 30% van de zoutsterkte 60 m moet bedragen (ref.7). Aan deze minimum breedte voldoen de pijlers van de kandidaatcaverne 381 meer dan voldoende. Daarnaast heeft BGR voor de situatie van parallelle rijen van cavernes op voldoende afstand van elkaar berekend, dat bij cavernes in dezelfde rij een tussenpijler van 20 m breedte nog juist voldoende is om een tijdelijk pekeldrukverschil van 20 bar tussen naburige cavernes op te vangen (ref.8). Onder enig voorbehoud kan men stellen, dat caverne 381 een (parallelle) rij vormt met caverne 384, aangezien de cavernes 378 (boorputten 378, 379, 380) en 475 (boorputten 475, 476, 477) op grote afstand liggen (>145 m). In dat opzicht waarborgt de huidige pijler van 72 m breedte tussen de cavernes 381 en 384 ruimschoots de lange-termijn stabiliteit in de 'worst case' situatie.

## 2.2 Stabiliteit cavernedak

Naar analogie van IfG (ref.2) beschouwt WEP het cavernedak van caverne 381 als een alzijdig ingeklemde ronde plaat, die belast wordt door de bovenliggende gesteenten, inclusief het gewicht van het zoutdak zelf, en die ontlast wordt door de vloeistofdruk in de caverne. In bijlage 4 is de maximale omvang van het cavernedak getoond. De gemiddelde spanwijdte van de ellipsvormige caverne bedraagt circa 127 m en wordt in een conservatieve benadering als bepalend voor de dragende dakplaatomvang beschouwd. In bijlage 3 is te zien hoe het dragende cavernedak is opgebouwd. Het bestaat uit Röt zoutlagen (A2, B2, C2, D2) met tussenliggende steenbanken van kleisteen met anhydrietinsluitingen (B1, C1, D1) en aansluitend erboven een Röt kleisteenlaag (E) met in de onderste 10 à 12 m een anhydrietbank volgens loggegevens van de boorputten. Als onderkant van het dak is de gemiddelde diepte van het zoutdak van de caverne genomen. Als bovenkant van het dragende dak is van de Röt kleisteenlaag E nog 11 m anhydrietbank als dragend element meegenomen, zodat de dikte van het dragende dak circa 41 m bedraagt.

De dakstabiliteit is volgens de IfG methode (ref.2) onderzocht door de buigspanningen in het midden van de dakplaat te berekenen op een diepte van 450 m en met in de caverne een oliedruk van 36 bar ('worst case'). Voor de bepaling van de evenwichtsvoorwaarde is een Mohr-Coulomb model toegepast. De Mohr-Coulomb parameters van de samenstellende gesteenten zijn bepaald uit gesteentesterktes, die BGR eerder heeft vastgesteld in termen van Drucker-Prager evenwichtsrelaties (ref.11). Het Röt cavernedak van caverne 381 bestaat grotendeels uit steenzout (A2, B2, C2, D2). Als men dit zout als hoofdzakelijk dragende dakelement beschouwd (75%) met de Röt kleisteen als aanvullend dragend element (25%) dan levert dit een minimaal vereiste verhouding van 0,29 (0,75*0,26+0,25*0,37) op tussen de dikte van het dragende Röt dak en de cavernespanwijdte ter waarborging van voldoende lange-termijn draagkracht en stabiliteit van het cavernedak.

Caverne 381 heeft een dragende dakdikte van 41 m en een gemiddelde spanwijdte van 127 m, zodat de verhouding 0,32 bedraagt. Gezien de minimaal vereiste verhouding van 0,29 voldoet het cavernedak dus voldoende aan het stabiliteitscriterium.

## 2.3 Stabiliteit cavernebodem

In de bovengenoemde BGR eindige-elementen modellering heeft men cavernes met een zoutbodem van minimaal 5 m dikte en in enkele gevallen van 10 m dikte geanalyseerd. Uit bijlage 3 blijkt dat de zoutbodem van de caverne 381 circa 4 m dik is en een laag basisanhydriet (A1) van ongeveer 1,5 m dikte bevat. Onder de Rötformatie bevindt zich de Solling kleisteen. Hierna wordt kort gecontroleerd of de Solling kleisteen voldoende stabiel is in de ‘worst case’ situatie van een (tijdelijk) drukloze olievoerende putmond, waarbij de druk in de caverne met 18,5 bar daalt.

Volgens BGR onderzoek aan boorkernmonsters uit de Hengelo boring 480 (ref.10) is de Solling kleisteen slikachtig of fijnzandig en heeft ze een niet te verwaarlozen porositeit. Als de poriëndruk halmostatisch is, zijn onder normale opslagcondities de vloeistoffen in de caverne en in de Solling kleisteen in evenwicht. Zodra de cavernedruk met 18,5 bar daalt is dat niet meer het geval. Het hangt dan van de afdichtende eigenschappen van de zout/basisanhydrietlaag en van de permeabiliteit van de Solling kleisteen af, of eventueel wat porievloeistof weglekt naar de caverne. Op zich is dat geen probleem, omdat onder de olie toch al een pekellaag van circa 3 m aanwezig blijft. Een merkbare compactie van de kleisteen bij dit eventuele, relatief geringe drukverlies in de poriën is niet te verwachten.

Bij een oliekolom van 0,8 bar/10m tot een diepte van maximaal 470 m en een formatiedruk van 2,15 bar/10m + 30% vanwege de verhoogde pijlerbelasting (tributary load area) staat er over de onderkant van de zoutwand van de caverne een horizontaal en vertikaal drukverschil van (2,15*47)*1,3 – (0,8*47) = 131,4 – 37,6 = 93,8 bar.

Analoog aan eerdere conservatieve stabiliteitsberekeningen (ref.1) kan men afleiden dat op de overgang van de extra belaste zoutpijler naar Solling kleisteen (met Ko= 0,5) de verschilspanning tussen vertikaal en horizontaal maximaal 131,4 – 0,5*(2,15*47) = 80,9 bar bedraagt, wat voldoende laag is voor een stabiele Solling kleisteen, want gebaseerd op breuksterkten uit BGR onderzoek (ref.10) mag het verschil tussen minimum en maximum hoofdspanning maximaal circa 100 bar bedragen.

In het centrum van de cavernebodem is de belasting van de kleisteen anders, omdat hier geen extra pijlerdruk aanwezig is. Er staat dan een verschilspanning tussen vertikaal en horizontaal van maximaal 14 bar. Op basis van BGR onderzoek mag de verschilspanning in de Solling kleisteen in dit belastingsgeval maximaal 31 bar bedragen, hetgeen ook nu een stabiele kleisteen impliceert. Er bestaat geen risico op een omhoogkomende cavernebodem.

## 2.4 Caverne-integriteit

De integriteit van een opslagcaverne heeft betrekking op de lekdichtheid van de caverne en de boorputten voor de opgeslagen vloeistof. Er bestaat onderscheid tussen de geologische lekdichtheid van de zoutcaverne en de technische lekdichtheid van de boorputten en putmond. In deze gesteentemechanische studie wordt alleen de geologische lekdichtheid bestudeerd.

TNO-NITG heeft op een overzichtskaart van de basis van het Rötzout in het Hengelo cavernenveld (ref.5, bijlage 4) een scharende breuklijn in noordwestelijke richting getoond, in het verlengde waarvan caverne 381 gelegen is. De breuk dempt op een afstand van ongeveer 400 m van de caverne 381 uit (volgens isolijnen met 20 m diepteverschil). Op detailkaarten van de basis en de top van zoutlaag A (ref.5, bijlagen 11 en 12, met isolijn-diepteverschil van 10 m) vindt men deze breuk niet terug. De bestudeerde caverne 381 en de naburige cavernes 378, 384 en 475 zijn aangelegd in zout A. Als er al sprake is van breuken in of nabij caverne 381, dan hebben deze een gering verzet (<2 m). Door het plastische gedrag van het zout zullen ze geen negatief effect hebben op de integriteit van de caverne. De sonarmetingen (bijlagen 3 en 4) geven een mooi gelijkmatig uitgeloogde caverne 381 te zien, die geen verbinding heeft met de bovenliggende steenbank B1, zodat in horizontale richting de caverne-integriteit gewaarborgd is. De steenbanken bestaan bovendien uit kleisteen met anhydrietinsluitingen, waardoor de permeabiliteit voor dieselolie zeer gering zal zijn.

Met behulp van de stromingsformule van Darcy voor een permeabel medium heeft IfG (ref.2) berekend hoeveel olielekkage in verticale richting kan optreden, en over welke periode, in het geval van olieopslag in een Hengelo caverne. Gebaseerd op onderzoek aan Stassfurt en Werra homogeen steenzout heeft IfG een intrinsieke permeabiliteit van $K < 10^{-20}$ $m^2$ en een porositeit $\varphi <$ 0,5% voor het zout toegepast. Het Rötzout vormt echter een geologisch jongere en minder diep gelegen zoutformatie dan de Werra en Stassfurt zouten. In de literatuur (refs.12, 13, 14) zijn voor met de Rötformatie vergelijkbare zoutafzettingen, die ook anhydriet en kleisteenlagen bevatten, de volgende eigenschappen gerapporteerd: $6.10^{-20}$ $m^2 < K < 2.10^{-19}$ $m^2$ en 0,2% < $\varphi$ < 1%. De door IfG toegepaste waarden zijn dus zondermeer representatief voor Hengelo cavernes.

Men heeft een hoogste referentiediepte voor de olie/pekelovergang van 425 m genomen (ref.3) en voor de maximale cavernedruk een gradient van 0,15 bar/m, wat neerkomt op circa 70% van de heersende lithostatische druk. Dit percentage is lager dan gebruikelijk voor cavernes in zoutdomes, omdat de Hengelo cavernes een relatief groot plat dak hebben tot maximaal 20.000 $m^2$. Bij een oliegradient van 0,081 bar/m betekent dit een maximaal toelaatbare olievoerende putmonddruk van 29 bar. Verder heeft men aangenomen dat het cavernedak in totaal minstens een 30 m dikke afsluitende steenzoutlaag (B2+C2+D2) bevat met de bovengenoemde waarden voor de permeabiliteit en de porositeit. Bovendien heeft men zeer conservatief verondersteld dat de Röt anhydrietbank (in laag E) doorlatend en poreus is zonder vloeistofdruk in de poriën. De berekening geeft aan dat er een olielekkage van minder dan 1 liter per dag naar laag E optreedt, nadat eerst de hele onderliggende steenzoutlaag volledig doordrenkt is geraakt met olie. Gebaseerd op de zeer geringe permeabiliteit van het steenzout en vanwege de dikte van minimaal 30 m duurt het minstens 1000 jaar, voordat de olie gaat weglekken in de anhydrietbank.

Bovengenoemde aannames zijn niet geheel representatief voor de kandidaat-opslagcaverne 381. De effectieve dikte van de zoutlagen in het cavernedak bedraagt ongeveer L= 20 m (i.p.v. 30 m). De olielekkage is omgekeerd evenredig met L, dus zal de lekkage ongeveer 1,5 liter per dag bedragen. De tijdsduur van oliedoorslag naar laag E wordt kwadratisch bepaald door L, dus de tijdsduur verkort naar 4/9*1000= 444 jaar. Daar staat tegenover, dat de feitelijke oliedruk in de caverne 10,5 bar lager is dan waarmee door IfG gerekend is. Oftewel, de oliedruk op een diepte van 425 m bedraagt 53,2 bar (i.p.v. 63,7 bar). De lekkage is recht evenredig met deze druk, dus 16,5 % minder dan 1,5 liter per dag, en de tijdsduur tot doorslag is omgekeerd evenredig met de druk, dus 16,5 % langer dan 444 jaar.

De conclusie is dat de caverne 381 in geologisch opzicht praktisch lekdicht is, zolang de gesteentemechanische pijlerstabiliteit en dakstabiliteit gewaarborgd zijn en de vloeistofdruk beperkt blijft tot maximaal 70% van de lithostatische druk. In de praktijk is een caverne uiteraard pas geschikt voor olieopslag indien ook de technische lekdichtheid van de boorputten en putmonden voldoende is aangetoond.

## 2.5 Productieplanning naburige cavernes

Tenslotte vraagt de toekomstige zoutproductie uit naburige cavernes de aandacht. Het betreft de cavernes 384 en 475 (zie bijlage 2).

AkzoNobel is voornemens om nog circa 43.500 $m^3$ zout (95.000 ton) uit caverne 384 te winnen. Hoewel het totale dakoppervlak ongeveer 14.000 $m^2$ groot is, is het gesplitst over twee niveau's. Het dak ligt rond boring 384 ongeveer 5 m hoger dan rond boring 386, zodat men moet trachten de zoutproductie te concentreren rond boring 386. Het dak komt daar dan ongeveer 6 m hoger te liggen. In het horizontale vlak zal de caverne niet veel in omvang toenemen, zodat de breedte van de zoutpijler tussen deze caverne en de kandidaat-opslagcaverne ongeveer gelijk blijft. Gezien de huidige, ongelijkmatige dakgesteldheid beveelt WEP aan de verdere dakontwikkeling zorgvuldig te controleren.

Uit caverne 475 kan AkzoNobel op basis van de huidige productiegegevens nog circa 115.000 $m^3$ zout (250.000 ton) uitlogen. Het dakoppervlak bedraagt volgens een sonarmeting van 21 september 2010 ongeveer 11.500 $m^2$, maar intussen is weer 100.000 ton zout (45.500 $m^3$) gewonnen. AkzoNobel is er echter niet zeker van dat deze hoeveelheid egaal over het gehele zoutdak van de caverne is gewonnen, aangezien de sonar uit 2010 een klein uitwassing rond boring 475 te zien gaf. In maart 2013 wordt de toestand van het dak opnieuw gecontroleerd met een sonarmeting, gevolgd door een workover van de boringen. Op basis van de meetresultaten gaat AkzoNobel besluiten of de geplande zoutproductie kan worden voortgezet. Als de productie inderdaad wordt voortgezet met in totaal nog 250.000 ton kan de dakomvang zeker met 25% toenemen tot circa 16.000 $m^2$ met een spanwijdte (korte as) van circa 115 m. Bij een gelijkmatige dakuitloging komt het dak ongeveer 7 m hoger te liggen en blijft de caverne geheel binnen zoutlaag A liggen. Ook blijft de caverne binnen de omhullende van het winningsplan, zodat de tussenpijler met caverne 381 zeer breed blijft (>130 m).

# 3 Conclusies en aanbevelingen

Naar analogie van een vorige studie (ref.1) heeft WEP een gesteentemechanische en geologische beoordeling gemaakt van de geschiktheid van caverne 381 als olieopslagcaverne. De meest recente resultaten van holruimtemetingen en de toekomstige zoutproductie van AkzoNobel zijn daarin betrokken. De stabiliteit van zoutpijlers, cavernedak en cavernebodem, en de geologische lekdichtheid zijn bestudeerd voor een 'worst case' situatie. De lange-termijn stabiliteit van caverne 381 blijkt ruimschoots gewaarborgd, ook in geval van de geplande voortgaande zoutproductie in enkele naburige cavernes.

De lekdichtheid van de caverne heeft een geologische en een puttechnische component. Alleen de geologische lekdichtheid van caverne 381 is in deze studie nader onderzocht en in orde bevonden. Echter, de technische lekdichtheid van de caverne (3 boorputten) is uiteindelijk beslissend voor het welslagen van het opslagproject. Het betrouwbaar aantonen van de lekdichtheid van een boorput vormt een vakgebied op zich (refs12, 13).

***Eindconclusie van de analyse***
Met het oog op een veilige en duurzame olieopslag in de kandidaatcaverne 381 is er, gezien alle positieve gesteentemechanische en geologische bevindingen, geen meerwaarde te verwachten van een additionele, bewerkelijke, gesteentemechanische 3-D eindige-elementen modellering.

***Aanbevelingen***
De kandidaat-opslagcaverne 381 wordt deels omringd door cavernes, waaruit nog zout gewonnen wordt. Het is belangrijk, dat de ontwikkeling van die cavernes regelmatig wordt gecontroleerd. Uitgangspunt dient te zijn, dat ze binnen de toegelaten omhullende blijven.

Gezien de huidige, ongelijkmatige dakgesteldheid van caverne 384 beveelt WEP bij voortgezette uitloging aan om de verdere dakontwikkeling zorgvuldig te controleren.

Tenslotte merkt WEP op dat de eerder door AkzoNobel terzijde geschoven caverne no.375, die door IfG (ref.2) als opslagcaverne voor dieselolie in orde is bevonden, vermoedelijk toch geschikt is voor toekomstige olieopslag. Als AkzoNobel behoefte krijgt aan meer opslagcapaciteit zou WEP deze caverne als eerstvolgende op geschiktheid kunnen analyseren volgens de in deze studie gevolgde methodiek van kritische factoren analyse (refs.2, 15). Met name risicofactoren, zoals de eventuele aanwezigheid van essentieel verstorende breuken in de Röt formatie in de onmiddellijke omgeving of ter plaatse van deze caverne, en een mogelijke hydraulische verbinding van de caverne met een naburige caverne, zullen dan nader onderzocht worden.
.

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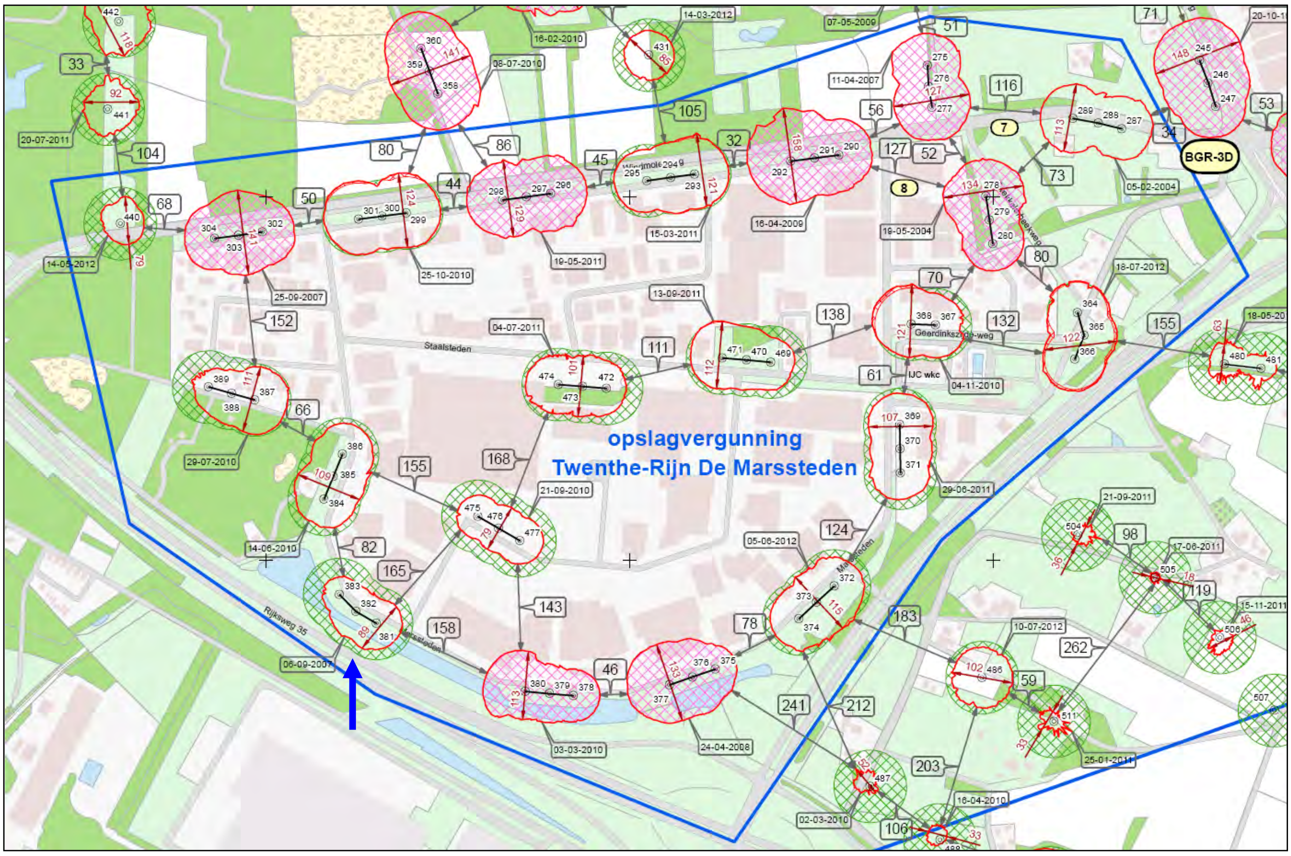
# Bijlage 1: Holruimtekaart opslagvergunning Twenthe-Rijn De Marssteden

**(peildatum oktober 2012)**

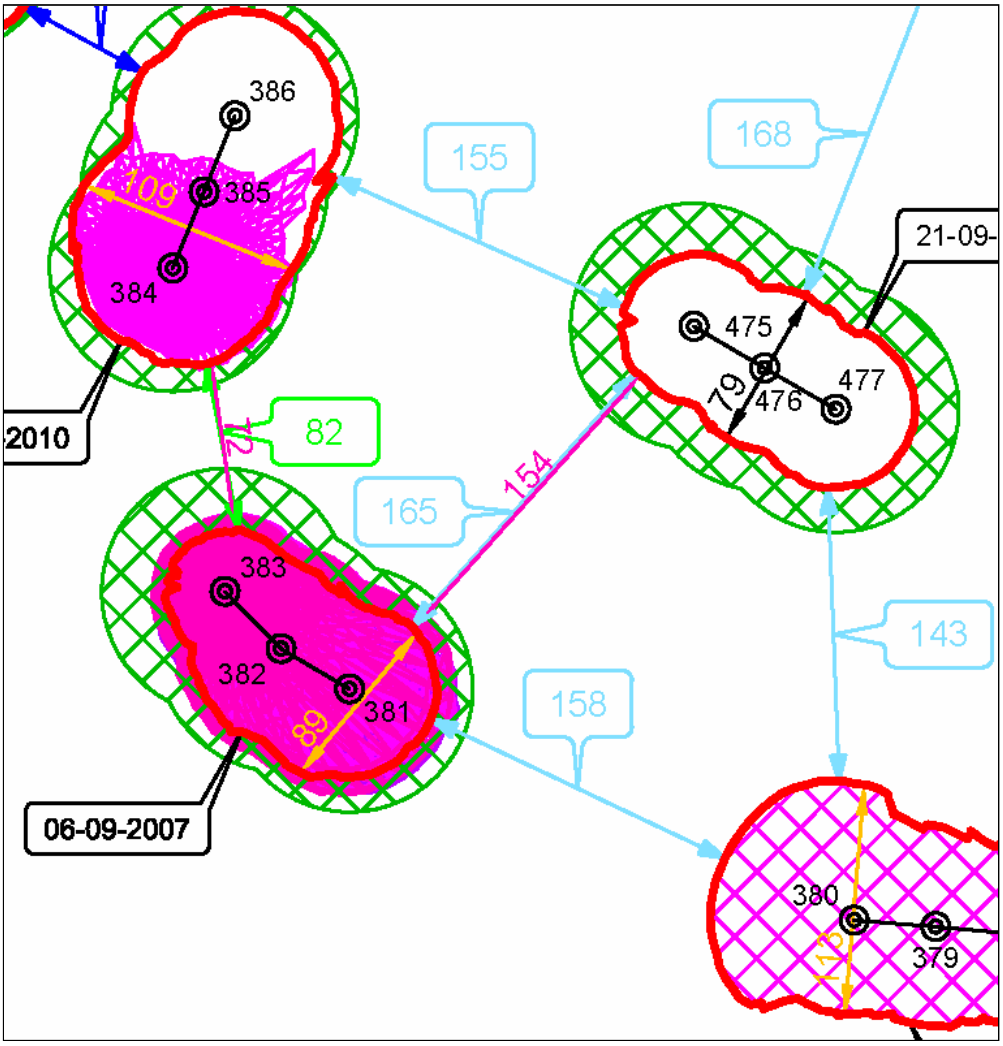



De holruimtekaart toont de ondergrondse situatie per oktober 2012. De rode contouren tonen de maximale afmetingen van een caverne in het horizontale vlak op de aangegeven meetdatum. De groen gearceerde vlakken geven de toegestane ‘caverne omhullende’ uit het winningsplan Twenthe-Rijn 2008-2025 aan (ref.4). De rood gearceerde vlakken tonen de afmetingen van de definitief uit bedrijf genomen zoutcavernes. De zwarte pijlen geven de kortste afstand (in m) tussen de maximum contour van naburige cavernes aan.

De blauwe pijl wijst naar de positie van de nieuwe kandidaat-opslagcaverne 381. De kaart toont nog de caverneomvang op basis van een sonarmeting uit 2007. In december 2012 en februari 2013 zijn nieuwe sonarmetingen verricht (zie bijlage 2).

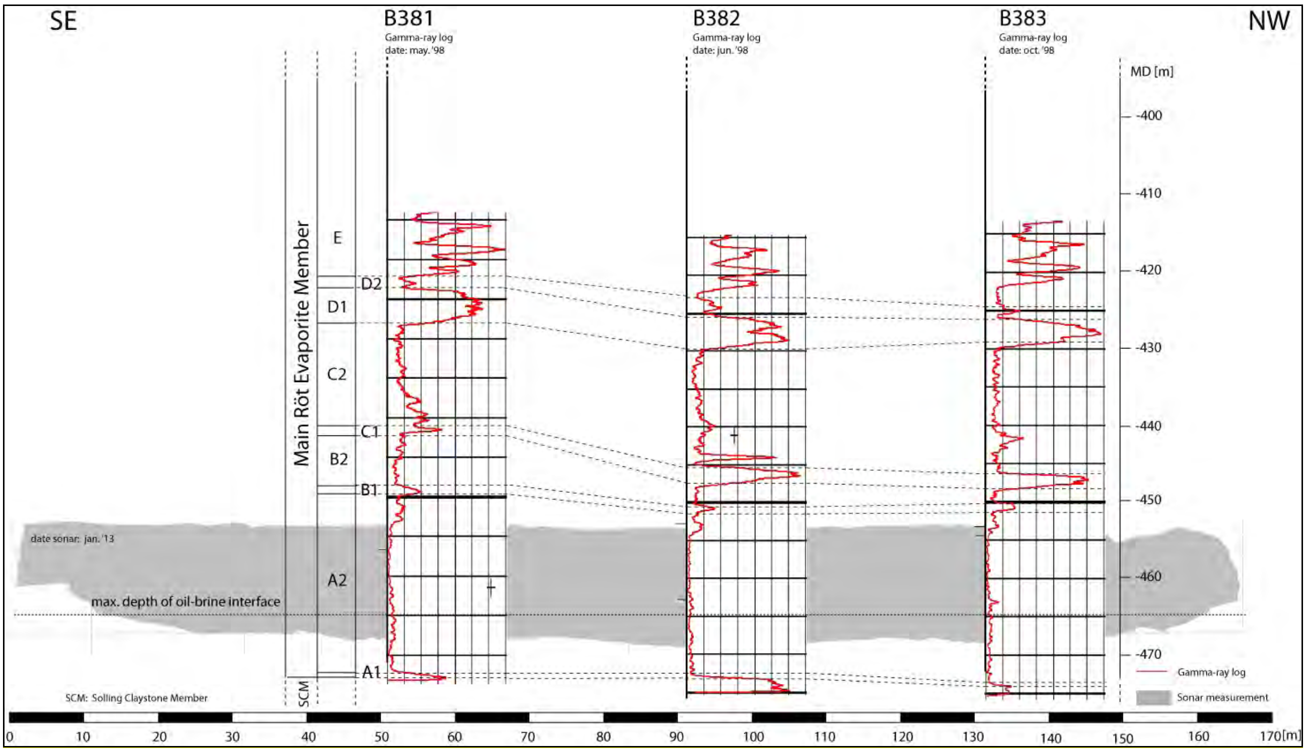
# Bijlage 2: Detail holruimtekaart omgeving caverne 381

**(peildatum februari 2013)**



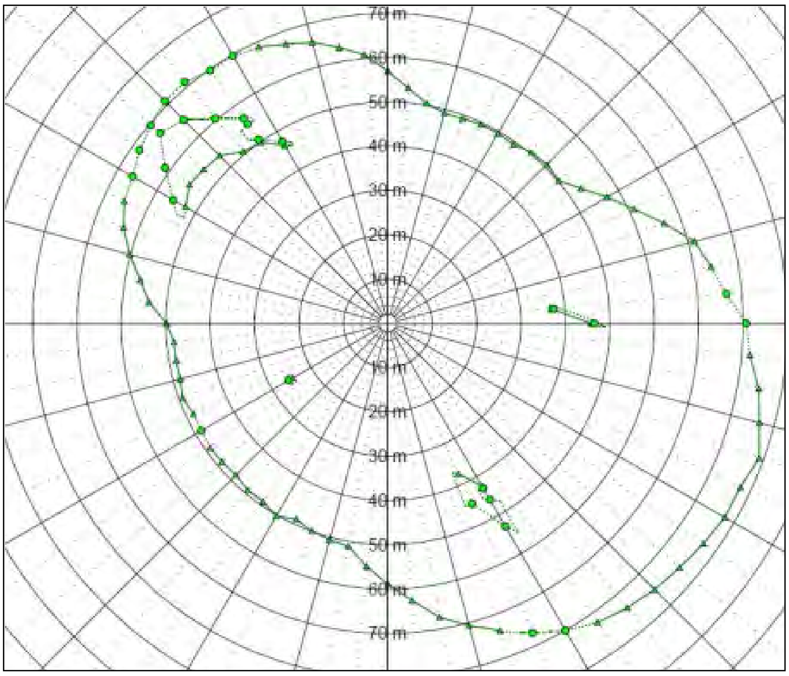

De paarse vlakken in de omhullenden (groen gearceerde vlakken) van de cavernes 381 en 384 tonen de resultaten van de laatste sonarmetingen van december 2012 en februari 2013 in de boorputten 381, 382, 383 en 384, geprojecteerd op de meest recente holruimtekaart van oktober 2012 (zie bijlage 1). De paarse getallen geven de nieuwste afstanden tussen de cavernes aan. De minimum afstand tussen de cavernes 381 en 384 bedraagt nu 72 m. Volgens planning wordt de caverne 475 binnenkort met sonar opnieuw gemeten. Zolang de afmeting van deze caverne binnen de getoonde omhullende blijft, is de afstand tot caverne 381 ruimschoots voldoende.

# Bijlage 3: Dwarsdoorsnede holruimtemetingen van caverne 381

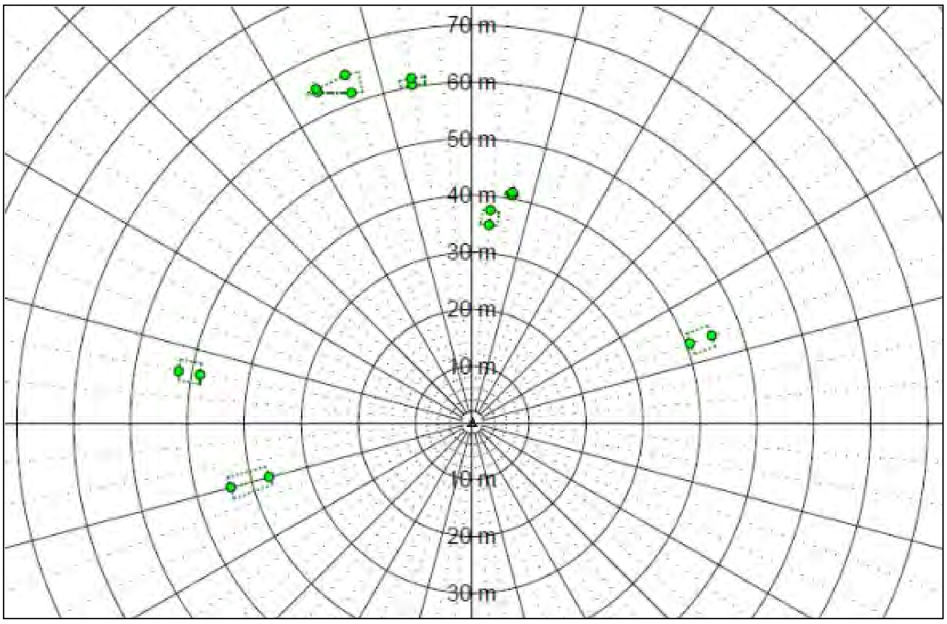



**Caverne 381.** Einde uitlogen: november 2012. Sonarmetingen: december 2012 en februari 2013.

# Bijlage 4: Horizontale snedes holruimtemetingen dakbereik caverne 381



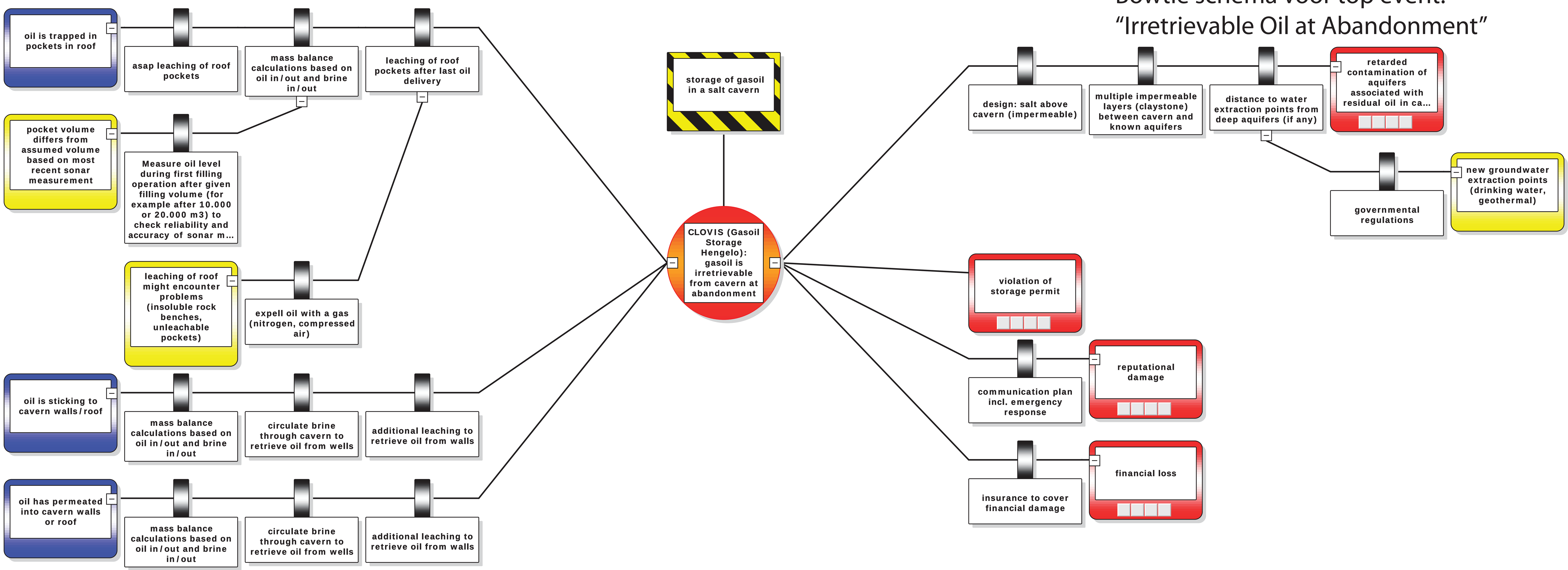

Gemeten dakcontour op een diepte van 454 m beneden maaiveld. In de noordwesthoek is een kleine uitstulping zichtbaar, die ook te zien is op de dwarsdoorsnede van bijlage 3.




Gemeten dakcontour op een diepte van 452 m beneden maaiveld. Er zijn geen pockets in het dak te zien. Het praktisch vlakke dak ligt op een diepte van circa 453 m beneden maaiveld.

# Opslagplan "Gasolieopslag de Marssteden"
## Bijlage 14
## Bowtie schema voor top event:
## "Breach of Confinement"

Opslagplan “Gasolieopslag de Marssteden”
Bijlage 15
Bowtie schema voor top event:
“Irretrievable Oil at Abandonment”



# Risicobeheersplan
# *Verspreiding van Olie in de Ondergrond*

AkzoNobel
Tomorrow's Answers Today

From Akzo Nobel Industrial Chemicals – Mining Technology Department
Date 09-01-2013
Subject Risicobeheersplan m.b.t. verspreiding van olie in de ondergrond

## Inleiding

AkzoNobel heeft, op basis van overleg met experts, input van TNO en Deltares, eigen inzicht en overleg met Staatstoezicht op de Mijnen (SodM), voor de olieopslag in zoutcavernes een zogenaamde "Bowtie" risico analyse uitgevoerd voor de twee belangrijkste gevaren:

1. Verspreiding van olie in de ondergrond als gevolg van lekkage van olie uit het opslagsysteem, i.e. vanuit de caverne of een van de boorgaten (zie Bijlage 14 bij het Opslagplan);
2. Achterblijven van een aanmerkelijke hoeveelheid olie na beëindiging van de olieopslag (zie Bijlage 15 bij het Opslagplan).

Voorliggend risicobeheersplan gaat in op het gevaar dat er tijdens de opslag olie weglekt vanuit het opslagsysteem ("breach of confinement") die zich verspreidt in de ondergrond. In soortgelijke vorm is ook een risicobeheersplan bij het Opslagplan bijgevoegd dat ingaat op het gevaar dat niet alle olie uit de caverne kan worden teruggehaald aan het einde van de opslag (Bijlage 17).

De risico analyse geeft een goed overzicht van de afzonderlijke bedreigingen ("threats") en de gevolgen daarvan ("consequences"). Barrières zijn benoemd die de kans dat een bedreiging daadwerkelijk optreedt verkleinen of die de gevolgen van een eventueel toch optredend gevaar beperken. Voor sommige barrières zijn escalatiefactoren benoemd (die de functionaliteit van een barrière verminderen) waarvoor vervolgens ook weer extra barrières zijn benoemd.

De benoemde barrières zijn ingedeeld in typen en zijn verder uitgewerkt. Sommige barrières vallen buiten de invloed van AkzoNobel, andere dienen nader te worden uitgewerkt in specifieke delen van voorliggend risicobeheersplan, zoals in het monitoringsplan of in het onderhoudsplan. Daarnaast zijn er nog enkele barrières die in overleg met Staatstoezicht op de Mijnen nader moeten worden ingevuld, zoals de uitvoering van tests die voorafgaand aan de olieopslag worden uitgevoerd en waarvoor geldt dat het wel of niet goed doorstaan ervan een cruciale factor is alvorens olieopslag in de cavernes kan worden gestart. Deze uitwerking zal gedaan worden in overleg met SodM.

AkzoNobel
Tomorrow's Answers Today

# Inhoudsopgave

# 1 Bowtie “Breach of Confinement”

## 1.1 Inleiding

In dit hoofdstuk beschrijven we op welke manier de risico’s m.b.t. de verspreiding van olie in de ondergrond als gevolg van lekkage van olie uit het opslagsysteem zijn geïnventariseerd, en welke stappen daarvoor zijn doorlopen. Het resultaat van de risico inventarisatie is weergegeven in de Bowtie “Breach of Confinement” (Bijlage 14).

## 1.2 Workshop met experts

In een in december 2010 door Deltares en AkzoNobel georganiseerde workshop is door experts uit de verschillende relevante vakgebieden (geologie van Twente, mechanisch gedrag van zout, oplosmijnbouw, ondergrondse opslag, risico analyse in relatie tot cavernestabiliteit en bodemdaling, well engineering, hydrogeologie, bodem- en water kwaliteit, en vloeistofstroming in poreuze media) een eerste inventarisatie gemaakt van de risico’s m.b.t. verspreiding van olie in de ondergrond als gevolg van het falen van het opslagsysteem voor het opslaan van olie in zoutcavernes in Twente. Een lijst van experts is opgenomen in Appendix C van Bijlage 11 van het Opslagplan. Ter voorbereiding op deze workshop werd de experts gevraagd om hun visie te geven op mogelijke gevaren en de gerelateerde risico’s in de vorm van lekscenario’s en hun mogelijke effecten. Aanvullend aan deze workshop is door Deltares en TNO een literatuurstudie gedaan om de geïnventariseerde risicoscenario’s te controleren en waar nodig aan te vullen.

## 1.3 Generieke Risico Inventarisatie door Deltares/TNO

Op basis van de tijdens de workshop gemaakte inventarisatie zijn de risico’s door Deltares en TNO in de vorm van een rapport (Bijlage 11 van het Opslagplan) verder technisch uitgewerkt op generiek niveau, d.w.z. op een niveau geldend voor zoutcavernes in de regio Twente. In het rapport wordt de aard en kans van optreden van de oorzaken die kunnen leiden tot een lekkage in detail beschreven, en worden de effecten gekwantificeerd d.m.v. een modelstudie van de verspreiding van olie in de ondergrond voor een generieke caverne in Twente. Vervolgens is voor een aantal voorname risicoscenario’s een semikwantitatieve risico analyse uitgevoerd. In de selectie van de scenario’s zijn de experts nauw betrokken, d.w.z., aan hen is gevraagd de selectie te controleren op relevantie en volledigheid, en om additionele scenario’s te beschrijven indien nodig. Op basis van de resultaten van de semikwantitatieve risico analyse is door Deltares en TNO een checklist samengesteld waarmee de geschiktheid van een caverne voor opslag van olie kan worden getoetst.

## 1.4 Caverne-Specifieke Risico Analyse door Deltares

Vervolgens is door Deltares voor 4 geselecteerde cavernes (cavernes met nummer 367, 372, 469, en 472) een caverne-specifieke risico analyse uitgevoerd op basis van alle over de cavernes beschikbare informatie over historie, status, vorm, inhoud, en lokale geologie. Hierin wordt ook nader ingegaan op de vorm van de cavernedaken, en de hoeveelheid olie die zich naar verwachting in de welvingen nestelt en die zonder specifieke mitigerende maatregelen niet terug kan worden gehaald. Voor iedere caverne is de geschiktheid getoetst aan de hand van de hierboven genoemde checklist. Tevens is voor iedere caverne een modelstudie gedaan waarin voor de voorname risicoscenario’s de effecten van optreden zijn gekwantificeerd in de vorm van hoeveelheid en verspreiding van olie in de ondergrond. De rapportage waarin deze risico analyse in detail word beschreven is in de vorm van een bijlage (Bijlage 12) opgenomen bij van het Opslagplan.

## 1.5 BowtieXP software

Op basis van alle beschikbare informatie over de risico's m.b.t. opslag van olie in zoutcavernes in Twente is vervolgens met de Bowtie XP software de Bowtie opgesteld voor de verspreiding van olie in de ondergrond als gevolg van lekkage van gasolie uit het opslagsysteem.

## 1.6 Bespreking met Staatstoezicht op de Mijnen

De conceptversie van de Bowtie is op 14 november 2012 gepresenteerd aan SodM en is gezamenlijk doorlopen. Belangrijkste conclusie was dat de concept-Bowtie een goed en gedetailleerd beeld gaf van de risico's en de barrières. Naar aanleiding van de opmerkingen van SodM is de Bowtie nog op diverse punten aangepast. Dit betrof m.n. het aanpassen van de naam van enkele hazards, en de opname van enkele additionele maatregelen. Tevens is een extra verdiepingsslag gemaakt door de toevoeging van 'escalatiefactoren' bij al benoemde barrières en de benoeming van extra barrières om de kans op het optreden van dergelijke escalaties te verminderen.

## 1.7 De Bowtie "Breach of confinement"

De definitieve Bowtie voor de verspreiding van olie in de ondergrond als gevolg van lekkage van gasolie uit het opslagsysteem (top event "Breach of Confinement") is weergegeven in Bijlage 14 bij het Opslagplan. Een tekstuele versie is als Bijlage 1 toegevoegd bij voorliggend risicobeheersplan.

# 2 Barrières

## 2.1 Inleiding

In dit hoofdstuk wordt een overzicht gegeven van alle barrières in de Bowtie “Breach of Confinement”. De verschillende typen barrières die er zijn worden beschreven, de aanwezige barrières worden gerangschikt naar type, en van iedere barrière wordt een gedetailleerde beschrijving gegeven.

## 2.2 Aanwezige barrières

In totaal zijn er 63 unieke barrières benoemd. Deze komen alle minimaal één en maximaal 12 keer voor in de Bowtie voor lekkage van gasolie uit het opslagsysteem. Bijlage 2a bij dit risicobeheersplan is een overzicht waarin wordt aangegeven hoe vaak elke barrière voorkomt en wat voor type het betreft (zie paragraaf 2.3). Bijlage 2b toont voor elke bedreiging en voor elke consequentie welk type barrières er zijn ingesteld. Indien een bedreiging veel verschillende typen barrières kent is dit een indicatie dat het risico dat deze bedreiging tot gevaar leidt op veel verschillende manieren geminimaliseerd wordt.

Twee barrières vallen op doordat ze erg vaak voorkomen:

***1.”Pressure monitoring system”***

Het drukmonitoringssysteem komt 12 keer voor in de Bowtie. Dit maakt enerzijds duidelijk dat het vroegtijdig signaleren van drukverandering een belangrijke barrière is bij het voorkomen van (verdere) lekkage, maar ook dat dit een barrière is met een gereduceerd onderscheidend vermogen. De snelheid van drukval bijvoorbeeld is een indicator met onderscheidend vermogen omdat deze direct gerelateerd is aan het drukverschil tussen de olie en de pekelkolom. Een snelle drukverandering zal optreden bij een lekkage met een groot debiet, terwijl een langzame lekkage een meer graduele drukverandering te weeg zal brengen. Echter, een snelle drukverandering zal ook optreden bij een plotselinge verandering van het olie-pekelspiegel niveau in de caverne als gevolg van een gedeeltelijke instorting van het cavernedak. Kortom: als er een drukverandering gemeten wordt, dan kan dit verschillende oorzaken hebben. Een dergelijke ‘waarschuwing’ zal dan ook direct opgevolgd worden door verdere metingen, zoals bijv. een olie-pekelspiegel meting, om duidelijk te maken wat de oorzaak is, wat de gevolgen zijn, en welke verdere maatregelen genomen moeten worden.

***2. “Oil-brine interface level measurement”***

Het doen van olie-pekelspiegel metingen komt 8 keer voor in de Bowtie. Dit maakt enerzijds duidelijk dat het vroegtijdig signaleren van een verandering van de oliespiegel een belangrijke barrière is bij het voorkomen van (verdere) lekkage, maar ook dat dit een barrière met een gereduceerd onderscheidend vermogen is. Ook hier is de snelheid waarmee de verandering plaatsvindt een belangrijke indicator om onderscheid te maken tussen een instantaan optredende oorzaak of een oorzaak in de vorm van een gradueel proces zoals lekkage. Anders gezegd: als er een olie-pekelspiegel verandering gemeten wordt, dan kan dit verschillende oorzaken hebben. Een dergelijke ‘waarschuwing’ zal dan ook direct opgevolgd moeten worden door verdere metingen om duidelijk te maken wat de oorzaak is, wat de gevolgen zijn, en welke verdere maatregelen genomen moeten worden.

Vanwege het belang van deze twee barrières zijn beiden in het monitoringsplan (zie Hoofdstuk 4.2) nader uitgewerkt. De andere barrières komen maximaal vijf keer voor, maar de meeste barrières komen elk slechts één of hooguit 2 keer voor.

In algemene zin geldt dat er op dit moment door gebrek aan ervaring met opslag van olie in de cavernes van AkzoNobel in Twente nog weinig bekend is over het gedrag van een dergelijk opslagsysteem, en dat juist door bijv. continue drukmetingen en periodieke olie-pekel spiegel metingen inzicht wordt verkregen in de natuurlijke variatie in deze belangrijke indicatoren en, door aanvullend follow-up onderzoek, in de oorzaak van veranderingen die groter zijn.

## 2.3 Typen barrières en gedetailleerde beschrijving

In totaal worden 8 typen barrières onderscheiden:

### 2.3.1 Administratieve barrières

Dit zijn barrières (4 stuks) die op een administratieve wijze zorgen voor extra controle en daarmee voorkomen dat eventuele bedreigingen daadwerkelijk een gevaar gaan vormen. Voorbeelden zijn de Mijnbouwwet- en regelgeving en de wet- en regelgeving op het gebied van grondwateronttrekking. Deze vallen buiten de invloed van AkzoNobel. Ook het interne systeem waarmee de in- en uitgaande stromen olie en pekel geregistreerd gaan worden is een administratieve barrière. Deze administratie is van groot belang om te weten hoeveel olie er nog in de caverne aanwezig is (bijvoorbeeld na beëindiging van de opslag), maar is ook van groot belang om de correlatie te kunnen maken tussen de sonarmetingen en de olie-pekelspiegel metingen. Indien de olie-pekelspiegel zich op een andere diepte bevindt dan op basis van de sonar en het geadministreerde olievolume verwacht kan worden, is sprake van een ongewenste situatie die nader onderzoek vereist.

Bijlage 3a toont de onderscheiden administratieve barrières.

### 2.3.2 Controle van de vrijkomende energie

Dit zijn barrières die de maximaal vrijkomende energie beperken. Dit zijn er slechts twee: 1) de aanwezigheid van brandblussers, zowel in het zouthuisje als in de tankwagens, en 2) het geïnstalleerde drukcontrolesysteem dat ervoor zorgt dat in geval van het ontstaan van een overdruksituatie automatisch de af-/toevoer van olie en de af-/toevoer van pekel afsluit.

Bijlage 3b toont de onderscheiden barrières die de vrijkomende energie beperken.

### 2.3.3 Ontwerpbarrières

Er zijn maar liefst 16 barrières die zijn opgenomen in het ontwerp van het opslagsysteem. Deels zijn dit van nature of vanuit de natuurkunde aanwezige barrières (zoals de grotere permeabiliteit van de onder de cavernes gelegen Solling formatie die voorkomt dat grote overdrukken in de cavernes kunnen ontstaan), deels zijn dit ontwerpaspecten die een rol hebben gespeeld bij de selectieprocedure waarmee de uiteindelijke opslagcavernes geselecteerd zijn, en deels zijn het technische ontwerpaspecten, die het ontstaan van een bedreiging (helpen te) voorkomen.

Bijlage 3c toont de onderscheiden barrières die voortkomen uit het ontwerp, of daaraan gerelateerde zaken.

### 2.3.4 Beschermende en afschermende barrières

Beschermende en afschermende barrières vormen een fysieke barrière voor het ontstaan van een gevaarlijke situatie, zoals betonnen blokken rondom het zouthuisje ter voorkoming van aanrijdingen, de zouthuisjes zelf en het hieromheen te plaatsen hekwerk.

Bijlage 3d toont de onderscheiden beschermende en afschermende barrières.

### 2.3.5 Barrières op het gebied van inspectie en onderhoud

Deze barrières omvatten de testen (USIT en MIT) die voorafgaand aan de olieopslag uit zullen worden gevoerd, de verschillende monitoringsactiviteiten zoals die plaatsvinden tijdens de olieopslagperiode en de beheer- en onderhoudsactiviteiten. Het slagen van testen voor de cavernes zal een harde eis zijn om opslag toe te staan. De USIT metingen zijn voor een aantal cavernes al met succes uitgevoerd, voor een aantal cavernes moeten deze nog worden uitgevoerd. De MIT's moeten voor alle cavernes nog worden uitgevoerd. Deze worden tweemaal uitgevoerd (eventueel na het millen), zowel vóór inbouw van de 5½" tubing (voor het aantonen van de integriteit van de verbinding zout-cement-7" casing) als ná inbouw van de 5½" tubing (voor het aantonen van de integriteit van de verbinding 7" casing-packer-5 ½" tubing).

De monitoringsactiviteiten zijn uitgewerkt in het monitoringsplan (zie Hoofdstuk 4.2). De beheer- en onderhoudsactiviteiten zijn uitgewerkt in het onderhoudsplan (zie Hoofdstuk 4.3).

Bijlage 3e toont de onderscheiden barrières op het gebied van inspectie en onderhoud.

### 2.3.6 Procedurele barrières

Er zijn zes procedurele barrières benoemd. Dit zijn barrières die procedureel zijn vastgelegd, bijvoorbeeld in het winningsplan van AkzoNobel (e.g. de "Good Salt Mining Practice"), of die gaan over te hanteren procedures bij de selectie van personeel voor het uitvoeren van onderhoud of metingen. Deze laatste zijn uitgewerkt in het onderhoudsplan (zie Hoofdstuk 4.3). Ook veiligheids-procedures die aan de orde moeten komen in het trainingsprogramma voor chauffeurs die namens Argos de laad- en losactiviteiten voor hun rekening gaan nemen, zijn hier genoemd. Deze zijn uitgewerkt in het trainings-programma (zie Hoofdstuk 4.4).

Bijlage 3f toont de onderscheiden procedurele barrières.

### 2.3.7 Barrières die de kans op het optreden van een bedreiging of de effecten na optreden verminderen

In deze categorie bevinden zich die barrières die duidelijk de kans op het optreden van een bepaalde bedreiging verminderen of die de gevolgen van het optreden ervan verminderen. Onder de eerste groep vallen bijvoorbeeld alle stappen van de selectieprocedure die doorlopen is om te komen tot de vijf geselecteerde cavernes, zoals de uitsluiting van instabiele cavernes en de volledige ligging in Zout A. Onder de tweede groep vallen barrières zoals de verwijdering van alle olie uit de caverne, de opstelling van een grondwater-monitorings- en saneringsplan in geval van lekkage en reparatie van een lek indien dit ontstaan is. Deze zaken zijn uitgewerkt in het Noodsituatie actieplan (zie Hoofdstuk 4.5). Een laatste barrière die ook onder deze categorie valt zijn de olie-pekelspiegel metingen. Deze hebben als doel om, in het geval van het optreden van drukveranderingen in het drukmonitoringssysteem, specifieker aan te geven wat er aan de hand is. Deze barrières verminderen dus niet zozeer de kans op het optreden van een bedreiging, maar verminderen wel het aantal potentiële oorzaken voor de gesignaleerde afwijking. Omdat dit een monitoringssysteem is, is het verder uitgewerkt in het monitoringsplan (zie Hoofdstuk 4.2).

Bijlage 3g toont de onderscheiden barrières die het vóórkomen van een bedreiging verminderen.

### 2.3.8 Barrières die een scheiding in plaats of tijd betreffen

In deze categorie vallen die barrières die het opslagsysteem of het ontstaan van een lekkage nadrukkelijk in plaats of tijd scheiden van het bedreigde aspect. Hieronder vallen de afstand tussen drink- en grondwateronttrekkingen en de opslagcavernes, zowel verticaal als horizontaal, maar ook het ontwerp van de put met een dubbele verbuizing.

Bijlage 3h toont de onderscheiden barrières die een scheiding in plaats of tijd betreffen.

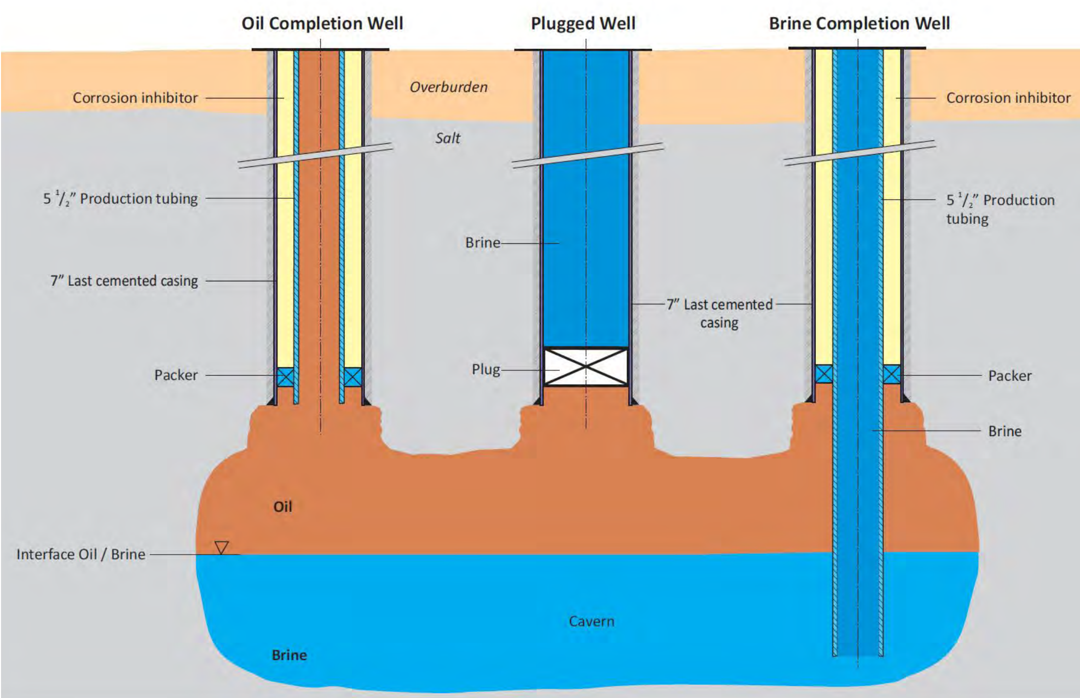
# 3 Overzicht van nog aan te leveren en te bespreken documenten

## 3.1 Inleiding

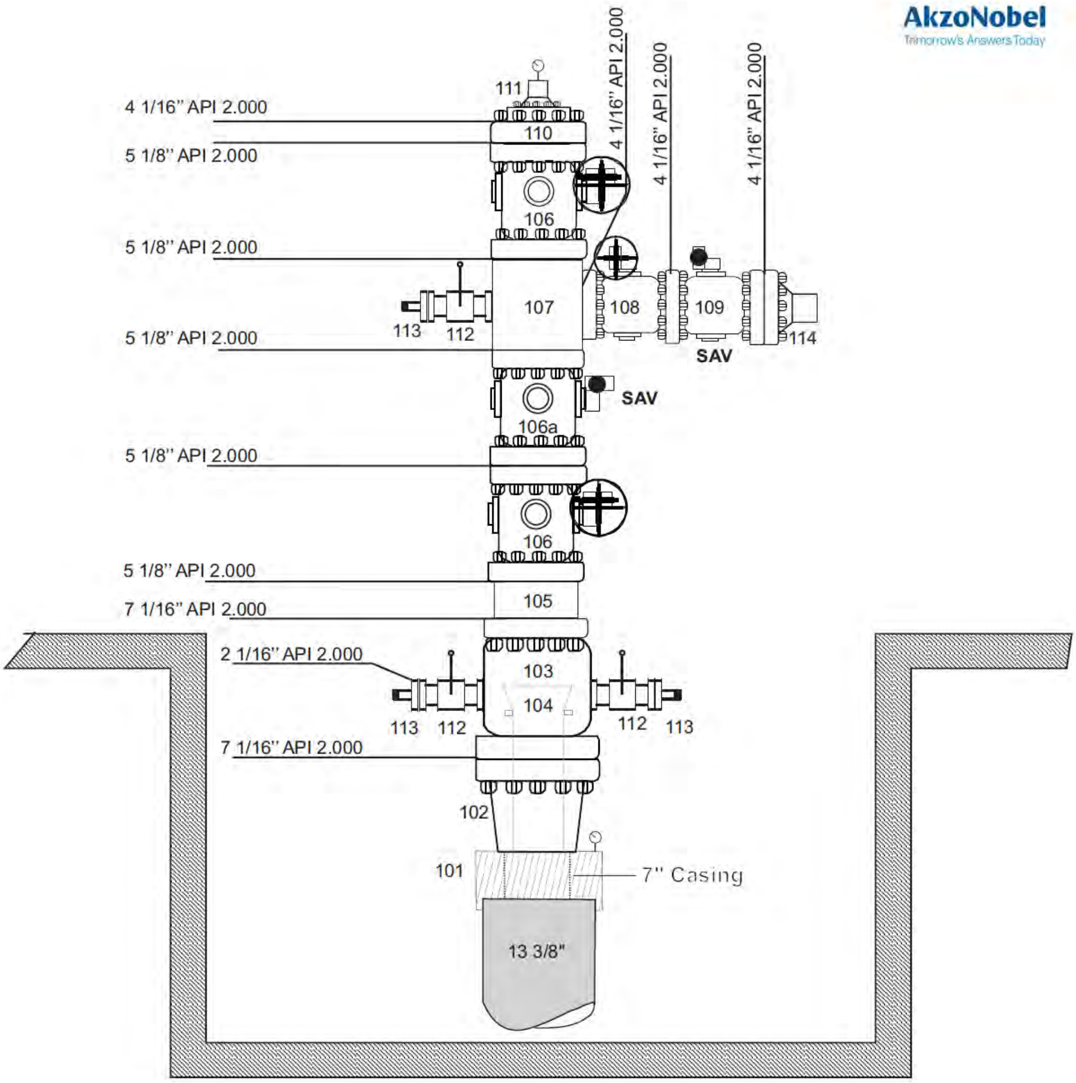
Het Voorlopig Ontwerp (VO) van het opslagsysteem (caverne, boorgaten, en boorgatafsluiter) is opgenomen in de hoofdtekst van het Opslagplan. In Figuur 3.1 en Figuur 3.2 is dit nogmaals weergegeven.

Het VO is op 21 december 2012 met SodM besproken. In 2013 zal dit ontwerp in overleg met SodM verder gespecificeerd worden. Het Definitief Ontwerp (DO) wordt ter goedkeuring aan SodM voorgelegd alvorens met de ombouw van de putten t.b.v. de olieopslag gestart wordt.

In dit hoofdstuk worden enkele veiligheidsaspecten van het ontwerp van de boorgaten en de boorgatafsluiters nader toegelicht en wordt aangegeven op welke punten nog nadere detaillering zal plaatsvinden.




*Figuur 3.1: ontwerp van het ondergrondse deel van het opslagsysteem (caverne, boorgaten, boorgatafsluiters)*




*Figuur 3.2: ontwerp van de boorgatafsluiter*

## 3.2 Nog aan te leveren en te bespreken documenten

### 3.2.1 Definitief Ontwerp boorputlocatie

**Betonblokken als bescherming tegen aanrijdingen**

De boorgatafsluiter kan beschadigd raken of zelfs afbreken indien er een (zware) vrachtwagen tegenaan rijdt. Op industrieterrein de Marssteden rijdt relatief veel (zwaar) vrachtverkeer. De olieopslag zal ervoor zorgen dat er nog meer zwaar vrachtverkeer bijkomt vanwege de aan- en afvoer van gasolie die met tankwagens plaats zal vinden. Daarom zijn maatregelen nodig die dit risico verminderen.

De belangrijkste barrière tegen aanrijdingen is de plaatsing van betonblokken rondom de zouthuisjes. Deze zorgen ervoor dat de impuls van de vrachtwagen verminderd wordt waardoor deze of niet meer tegen het huisje en de boorgatafsluiter aanrijdt, of dit met minder kracht doet, waardoor de gevolgen minder zijn. De exacte plaatsing van de betonblokken en de omvang hiervan zal nader bekeken worden en wordt in het DO van de locatie opgenomen.

Andere barrières tegen aanrijdingen zijn de plaatsing van borden met snelheids-beperkingen nabij de zouthuisjes, extra instructies voor de chauffeurs van de tankwagens m.b.t. het rijgedrag nabij de zouthuisjes, de zouthuisjes zelf en het te plaatsen hekwerk.

**Zouthuisjes en hekwerk**
De zouthuisjes zelf vormen voor diverse bedreigingen een barrière. Ten eerste vormen de huisjes de bescherming van de boorgatafsluiter tegen weersinvloeden en andere invloeden van buitenaf. De zouthuisjes zijn afgesloten met een slot, waarvan alleen mensen van het boorterrein van AkzoNobel evenals de chauffeurs van de olietankwagens een sleutel krijgen. Dit beschermt de putten tegen vandalisme. De procedures m.b.t. afsluiten van het huisje zullen met de chauffeurs worden afgestemd en worden opgenomen in het trainingsprogramma.

In ieder zouthuisje komt een brandblusser te hangen om in het geval van een calamiteit te kunnen blussen. In het veiligheidsrapport (VR) worden de procedures in het geval van een calamiteit verder uitgewerkt. De exacte plaatsing van de brandblussers wordt in het DO van de locatie opgenomen. In overeenstemming met de regels voor het transport van gevaarlijke stoffen, is ook iedere tankwagen uitgerust met een brandblusser, voor het geval de blusser in het huisje niet meer bereikbaar is.

Rondom ieder zouthuisje wordt een 2,5 m hoog hek geplaatst dat de locatie afsluit. De opening in dit hek wordt met een slot afgesloten. De mobiele pompinstallatie wordt binnen dit hek geplaatst, zodat ten tijde van laden en lossen ook deze beschermd is als er tijdelijk geen tankwagen en chauffeur aanwezig zijn. De procedures m.b.t. afsluiten van het hek zullen met de chauffeurs worden afgestemd en worden opgenomen in het trainings-programma.

Ten slotte hebben de huisjes een signaalfunctie voor de eronder gelegen caverne, waardoor een bedrijf dat onverhoopt nabij een zouthuisje (boor)activiteiten wil ontplooien gewezen wordt op de aanwezigheid van de ondergelegen caverne.

De exacte indeling van het zouthuisje en het hieromheen te plaatsen hek wordt in het DO van de locatie opgenomen.

**Boorkelder met rooster**
In het VO is de boorgatafsluiter in een kleine boorkelder geplaatst met een volume van minder dan 1 $m^3$. In het DO zal deze kelder vergroot worden tot 2 $m^3$. De maximale vrije uitstroom vanuit de olieput (zonder aanvoer van nieuwe pekel naar de caverne) is 1,7 $m^3$, gedreven door het hydrostatische drukverschil tussen de pekelkolom in de pekelput en de oliekolom in de olieput. De totale hoeveelheid vrij uitstromende olie kan dus worden opgevangen in de vergrote boorkelder.

Het is mogelijk dat er tijdens een aanrijding puin dreigt in de boorkelder terecht te komen, waardoor het volume hiervan kleiner wordt. Daarom wordt de boorkelder met een rooster afgedekt waardoor grof puin hier niet in kan vallen. Fijn puin kan er nog wel invallen, maar zal de inhoud van de kelder niet zo veel verminderen dat deze niet meer toereikend is voor de opvang van de vrij uitstromende olie (marge van 0,3 $m^3$).

De exacte indeling van de binnenkant van het zouthuisje en van de ruimte direct rond het boorgat wordt in het DO van de locatie opgenomen.

### 3.2.1 Definitief Ontwerp boorgaten en boorgatafsluiter

**Voorlopig Ontwerp van de boorgaten**

Het VO van de boorgaten en de boorgatafsluiter is weergegeven in Figuur 3.1 en 3.2. In dit ontwerp hebben zowel het olieboorgat als het pekelboorgat een dubbele verbuizing. In de casing hangt een binnenbuis waardoor de olie (of de pekel) omhoog of omlaag getransporteerd wordt, en daartussen zit een annulaire ruimte gevuld met pekel. Hierdoor zijn er altijd drie barrières tussen de olie (of de pekel) in de buis en het omliggende gesteente, namelijk de verbuizing van de 5½" binnenbuis, de gecementeerde 7" casing en het cement zelf. Ook tussen de olie in de caverne en het overliggende gesteente zijn, via het boorgat, altijd drie barrières aanwezig, nl. de packer (die de annulaire ruimte aan de onderzijde afsluit), de gecementeerde 7" casing, en het cement zelf.

De verwachting is dat het VO van de boorgaten niet meer zal wijzigen. Mocht dit wel het geval zijn dan zal dit gebeuren in overleg met SodM.

**Systeem voor overdrukcontrole**

Er wordt een systeem voor drukmonitoring geïnstalleerd dat in de boorgatafsluiters van zowel de olieput als de pekelput de druk meet. Dit systeem wordt ook voorzien van een overdrukbeveiliging die, in het geval van het ontstaan van overdruk, automatisch actie onderneemt door de olietoegang af te sluiten. De voorgestelde maximale drukken t.o.v. de werkdrukken zijn:

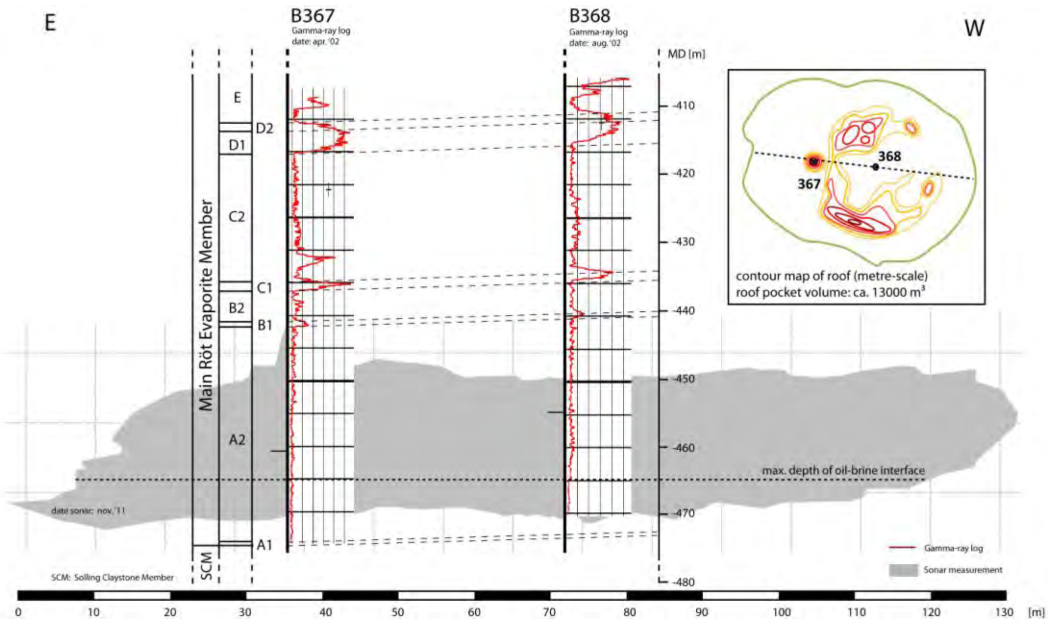
| **Locatie en situatie** | **Normale werkdruk** | **Signaaldruk** |
|---|---|---|
| Olieput; geen gebruik | 18 bar | 20 bar |
| Olieput; tijdens olietoevoer | 32 bar | 35 bar |
| Olieput; tijdens olieafvoer | 18 bar | 20 bar |
| Pekelput; geen gebruik | 1 bar | 5 bar |
| Pekelput; tijdens olietoevoer | 1 bar | 2 bar |
| Pekelput; tijdens olieafvoer | 4 bar | 5 bar |

**Diepteligging olie-pekelspiegel boven de cavernevloer**

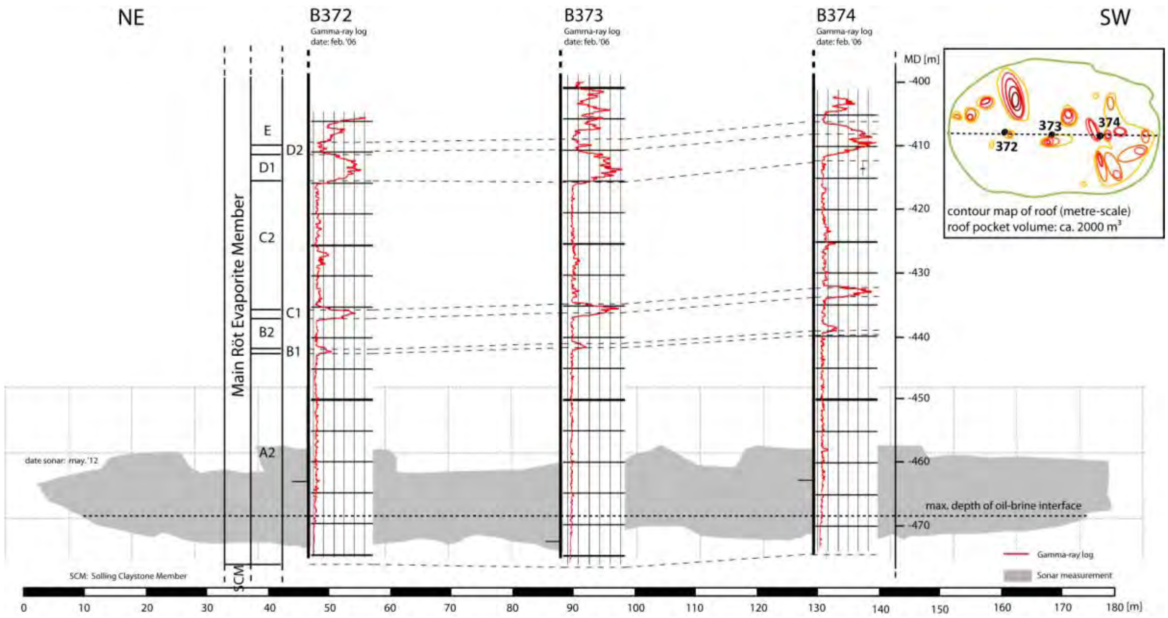
Het diepst bereikbare niveau van de olie-pekelspiegel is de onderzijde van de pekelbuis omdat er, als er wordt doorgegaan met olietoevoer, door de pekelbuis olie naar boven komt. Op dat moment sluiten automatisch de olietoevoer en de pekelafvoer (zie hierna). De diepte van de opening van de pekelbuis is tijdens de inbouw te kiezen. Deze dient echter wel afgestemd te zijn op de cavernegeometrie. Bij de bepaling van deze diepte is rekening gehouden met de volgende aspecten:

- Het volume aan olie, dus het cavernevolume boven het gekozen niveau. Dit dient tenminste 100.000 $m^3$ te zijn (contractuele verplichting);
- De diepteligging en het verloop van de cavernevloer;
- De samenstelling van de cavernevloer, i.e. bestaat deze uit ondoordringbaar zout of ligt er een doordringbare laag onoplosbaar materiaal (sump);
- De eventuele aanwezigheid van een nog intacte ondoordringbare zoutlaag tussen het diepste, ooit bereikte caverneniveau en de bovenzijde van de doordringbare Solling formatie.

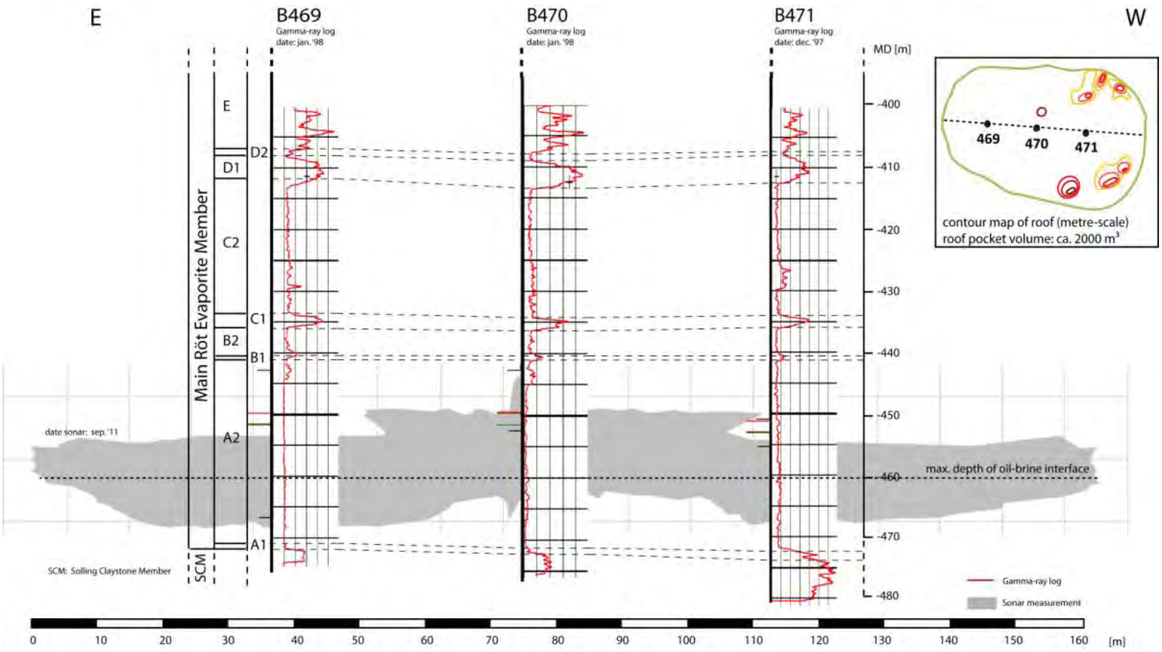
De voorlopig aan te houden olie-pekelspiegel niveaus zijn in de figuren 4.1, 4.2, 4.3, en 4.4 weergegeven:



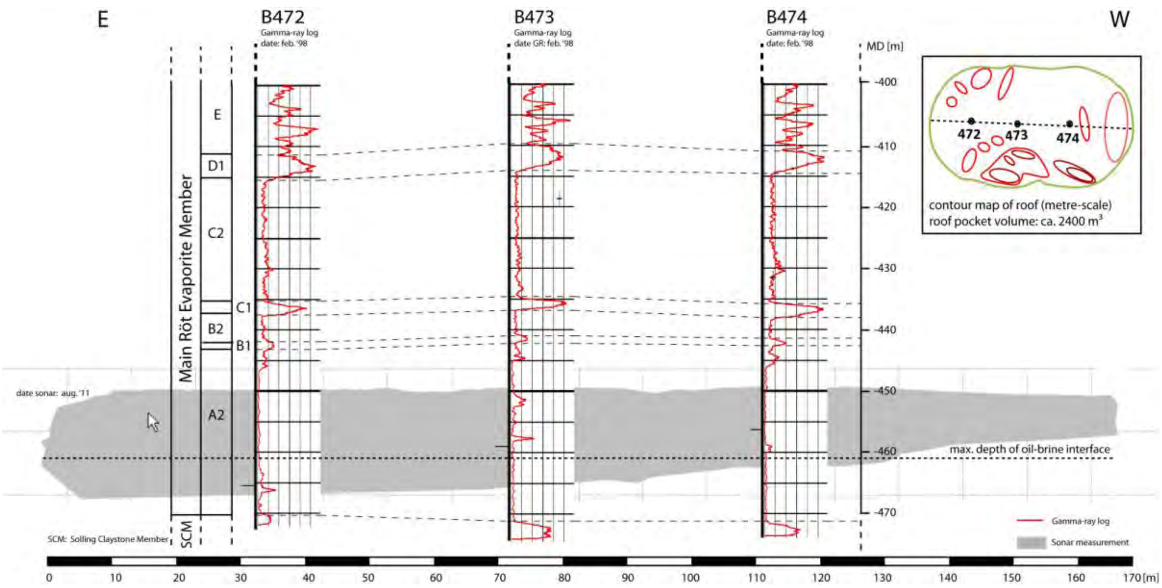

*Figuur 4.1: sonarbeeld van caverne 367 met daarin aangegeven de diepteligging van de olie-pekelspiegel.*




*Figuur 4.2: sonarbeeld van caverne 372 met daarin aangegeven de diepteligging van de olie-pekelspiegel.*




*Figuur 4.3: sonarbeeld van caverne 469 met daarin aangegeven de diepteligging van de olie-pekelspiegel.*




*Figuur 4.4: sonarbeeld van caverne 472 met daarin aangegeven de diepteligging van de olie-pekelspiegel.*

Alleen in het geval van caverne 472 ligt een klein deel van de cavernevloer in de olie. Uit oude sonarmetingen is echter vastgesteld dat er in dit deel van de caverne nog een dikke zoutlaag aanwezig is tussen de huidige cavernevloer en de top van de Solling formatie.

De diepteligging van de olie-pekelspiegel zal voorafgaand aan de eerste vulling van de cavernes aan SodM worden voorgelegd.

**Veiligheidsmaatregelen aan de boorgatafsluiter van de pekelput**
Diverse veiligheidsmaatregelen zijn geïmplementeerd in het ontwerp van de boorgatafsluiter van de pekelput. Deze boorgatafsluiter lijkt verregaand op de in Figuur 3.2 getoonde boorgatafsluiter. Dit houdt onder andere in dat er, in overeenstemming met de Mijnbouwwet- en regelgeving, tussen de pekel in de put en de buitenlucht minimaal twee kleppen aanwezig zijn, waarvan er één automatisch functioneert.

Een andere veiligheidsmaatregel m.b.t. de pekelput is dat, in het geval van overvullen, de automatische afsluiters van zowel de pekel- als de olieput worden afgesloten. Dit overvullen wordt gesignaleerd als er tijdens het vullen met olie (en tegelijkertijd aflaten van pekel) i.p.v. pekel olie door de pekelbuis omhoog komt. Dit signaleringssysteem wordt ingebouwd in de boorgatafsluiter van de pekelput, en moet een signaal geven aan de automatische afsluiters in zowel de pekel- als de olieput om af te sluiten.

Het exacte ontwerp van de beveiligingen aan de pekelput worden in het DO van de pekelput opgenomen.

**Veiligheidsmaatregelen aan de boorgatafsluiter van de olieput**
De maximale vrije uitstroom vanuit de olieput (zonder aanvoer van nieuwe pekel naar de caverne) is 1,7 $m^3$, gedreven door het hydrostatische drukverschil tussen de pekelkolom in de pekelput en de oliekolom in de olieput. Deze gehele hoeveelheid kan worden opgevangen in de boorkelder. De overdruk aan de kant van de olieput, die eerst ca. 17 bar is, neemt hierdoor af. De snelheid waarmee deze afneemt is afhankelijk van de grootte van het gat waardoor de uitstroom plaatsvindt. Indien deze maximaal is, d.w.z. 5½”, neemt de druk over een periode van 40 tot 70 seconden af naar atmosferische druk. De drukafname is dan 0,25-0,43 bar/s. Bij een kleiner gat is de drukafname kleiner omdat de uitstroom afhankelijk is van de grootte van het gat (proces vergelijkbaar met het leeglopen van een fietsband door een klein gaatje). Er zal daarom een systeem worden geïnstalleerd dat, in het geval van een gering drukverlies, de automatische afsluiter activeert. De implementatie van deze maatregel wordt verder uitgewekt in het DO van de olieput.

### 3.2.3 Uit te voeren testen en putaanpassingen

**USIT-metingen**
Met de Ultra Sonic Imager Tool (USIT) worden metingen uitgevoerd om de kwaliteit van het cement om de 7”-verbuizing en van het staal van de 7”-verbuizing zelf te bepalen. Het cement moet in ieder geval ter plaatse van de laatste gecementeerde casingschoen (LCCS) en in het traject direct boven de caverne (verbinding met het zout) van goede kwaliteit zijn ten behoeve van een vloeistofdichte verbinding tussen buis en gesteente. De USIT-metingen zijn al uitgevoerd voor de cavernes 372 en 469 en voor boorgat 367. De resultaten van deze metingen geven aan dat het cement en de cement bond in redelijk tot goede staat is. In boorgat 367 en in de boorgaten van caverne 372 moeten wel de LCCS vervangen worden vanwege de slechte kwaliteit van de cementverbinding op dit diepste niveau. Na het millen wordt de LCCS opnieuw ingebouwd, wat een goede boorgatintegriteit garandeert op het niveau van het cavernedak. Voor boorgat 368 en voor de boorgaten van caverne 472 moeten de USIT-metingen nog uitgevoerd worden, maar gezien de resultaten van de al uitgevoerde metingen is de verwachtingen dat ook deze in redelijk tot goede staat zullen zijn. Zodra ook de USIT-metingen in de andere boorgaten zijn uitgevoerd, worden alle USIT-resultaten aan SodM voorgelegd.

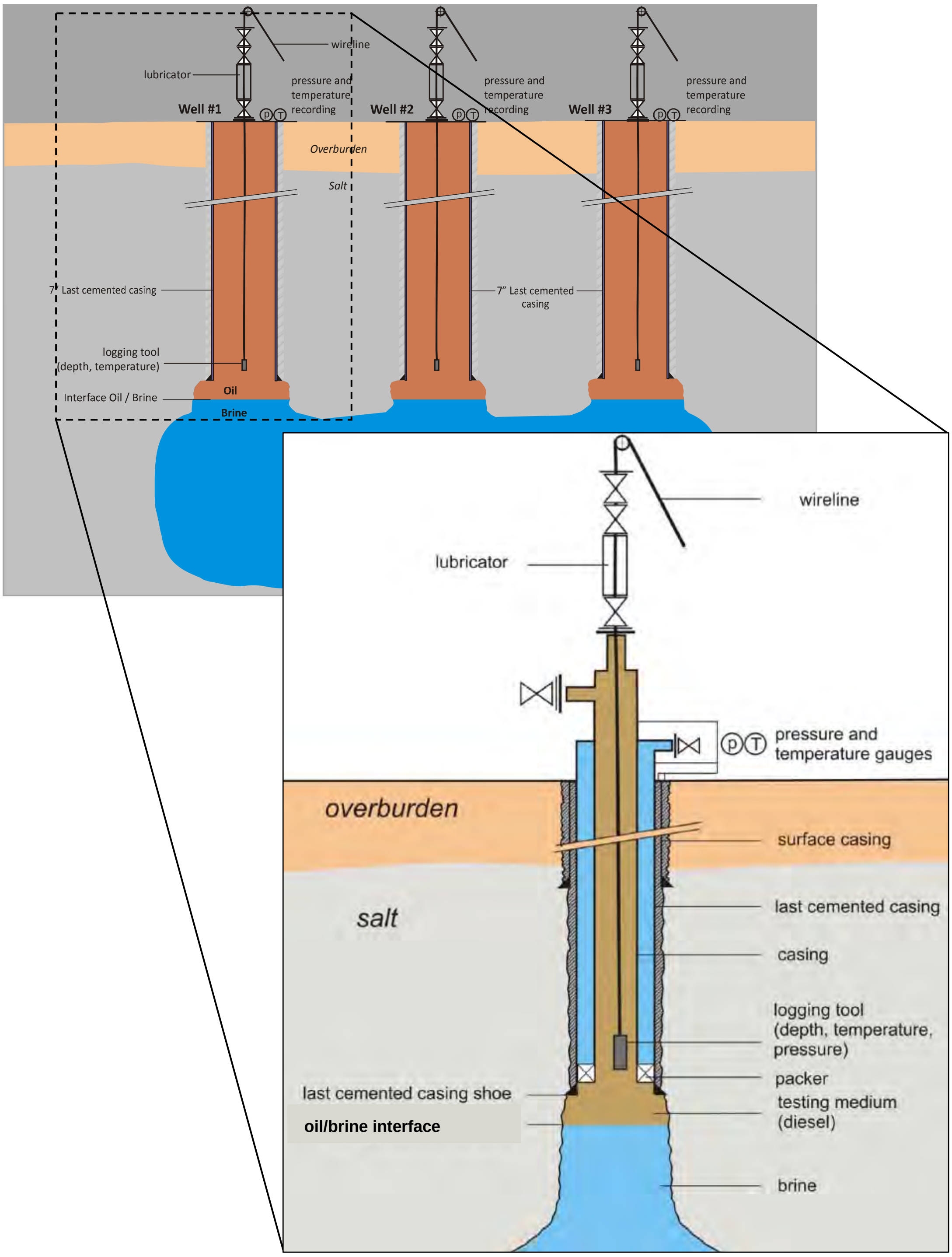
**Millen**

Tijdens de zogenaamde "milling" operatie wordt het onderste deel van de 7"-verbuizing en de LCCS weggemalen en daarna opnieuw ingebouwd. Dit is nodig als deze zich niet op de juiste diepte bevindt of als er tijdens de USIT gebleken is dat het cement ter plekke van de LCCS niet goed van kwaliteit is. De milling operatie wordt vooraf aangekondigd aan SodM en de resultaten ervan worden aan SodM doorgegeven.

**Mechanical Integrity Test (MIT)**

Tijdens de ombouw van de cavernes van pekelwinningscaverne naar olieopslagcaverne zal een zogenaamde Mechanical Integrity Test (MIT) worden uitgevoerd om de afsluiting van de onverbuisde cavernenek en van de packers te bepalen. Deze test wordt uitgevoerd na de milling operatie. Figuur 4.5 toont de test set-up. Hierbij wordt per boorgat een exact bekende hoeveelheid olie ingebracht in de onverbuisde nek, waarna de caverne onder druk gezet wordt met de pekelpomp. De maximaal haalbare druk verschilt per caverne en is onder andere afhankelijk van de lokale doorlatendheid van de Solling formatie onder de caverne. Zodra er geen pekel meer ingebracht wordt, zal de druk langzaam teruglopen. Na enkele dagen wordt de olie weer uit het boorgat gepompt en wordt deze hoeveelheid olie exact bepaald. Ieder verschil tussen de ingebrachte en terugverkregen hoeveelheid olie is een indicatie voor lekkage langs de aangebrachte packer of door het boorgat zelf. De MIT wordt per boorgat tweemaal uitgevoerd: zowel vóór inbouw van de 5½"-verbuizing (bepaling lekdichtheid van de LCCS-cement verbinding en de 7"-buis) als ná inbouw van de 5½"-verbuizing (bepaling lekdichtheid packers en de 5½"-buis).

De exacte definitieve procedure voor de uitvoering van de MIT, en de uitkomsten en interpretatie er van, worden aan SodM voorgelegd.




*Figuur 4.5: test set-up van de MIT (hydraulische lekdichtheidstest).*

# 4 Deelplannen risicobeheersing

## 4.1 Administratief plan

**Olie-pekel administratie**
AkzoNobel en Argos houden een olie- en pekeladministratie bij. Daarin wordt exact bijgehouden hoeveel olie er de caverne in en uit is gegaan en hoeveel pekel er de caverne in en uit is gegaan. Zo is er altijd een exact inzicht in de in de caverne aanwezige hoeveelheid olie. Dit is ook de hoeveelheid die er bij het volledig legen van de caverne weer uit moet komen. Een afwijking hiervan kan twee oorzaken hebben:

1. Olie in onbereikbare welvingen in het cavernedak.
2. Olielekkage tijdens opslag;

Voorafgaand aan de eerste vulling zal een verder uitgewerkt protocol voor de administratie aan SodM worden overlegd.

**Verificatie van geschat volume in aanwezige welvingen in het dak**
De nauwkeurige administratie van ingaande olie biedt, ten tijde van de eerste vulling, een belangrijke mogelijkheid om de laatste sonarmeting, die kort voor de eerste vulling gemaakt wordt, te toetsen, in het bijzonder op het volume aan olie dat zich nestelt in welvingen in het dak. Op basis van deze sonar kan worden bepaald op welke diepte de olie-pekelspiegel moet staan na een bepaalde hoeveelheid ingebrachte olie, bijvoorbeeld na 10.000 $m^3$, na 20.000 $m^3$, etc. Deze dieptes kunnen vergeleken worden met de daadwerkelijke diepteligging zoals bepaald m.b.v. de olie-pekelspiegel meting. De belangrijkste redenen voor afwijkingen zijn:

1. Aanwezigheid van extra welvingen in het dak die door de sonar niet worden "gezien". Dit zal al snel duidelijk worden, bij de eerste 10.000 $m^3$ olie die ingepompt wordt;
2. Een groter dan verwachte radius van de caverne (voortdurend langzamere daling van het olie-pekelspiegel niveau dan verwacht).

Op deze wijze ontstaat een goed inzicht in de betrouwbaarheid van de sonarmetingen, in de exacte caverne vorm, en in de aanwezigheid van welvingen in het dak en het volume aan olie dat zich hier in nestelt dat er zonder mitigerende maatregelen niet uit terug te halen is.

## 4.2 Monitoringsplan

**Monitoring van de druk**
De druk wordt op twee plaatsen gemeten: aan de boorgatafsluiter van de pekelput en van de olieput. Vanwege het ontwerp en de open verbinding tussen de pekelput en de pekel onderin de caverne en tussen de olieput en de olie bovenin de caverne, is het niet nodig om op meer plekken de druk te meten. Dit systeem wordt ook voorzien van een overdrukbeveiliging die, in het geval van het ontstaan van overdruk, actie onderneemt door de olietoegang af te sluiten. De voorgestelde maximale drukken t.o.v. de werkdrukken zijn:

| Locatie en situatie | Normale werkdruk | Signaaldruk |
|---|---|---|
| Olieput; geen gebruik | 18 bar | 20 bar |
| Olieput; tijdens olietoevoer | 32 bar | 35 bar |
| Olieput; tijdens olieafvoer | 18 bar | 20 bar |
| Pekelput; geen gebruik | 1 bar | 5 bar |
| Pekelput; tijdens olietoevoer | 1 bar | 2 bar |
| Pekelput; tijdens olieafvoer | 4 bar | 5 bar |

Het afsluiten van de putten d.m.v. de automatische afsluiters tijdens het vullen of legen wordt direct doorgegeven aan de controlekamer.

Als er niet gevuld of geleegd wordt, dient de druk aan de olieput rond de 18 bar te zijn (een en ander afhankelijk van het exacte olie-pekelspiegelniveau). Ter plaatse van de pekelput dient de druk dan 1 bar te zijn (atmosferische druk). Het verschil tussen beide bedraagt ca. 17 bar en is ook weer afhankelijk van het exacte olie-pekelspiegelniveau. Een verandering van de druk kan op verschillende zaken duiden, zoals:

- Uitzetten of krimpen van de inhoud van de caverne door temperatuurverandering (bijvoorbeeld als relatief koude olie in de caverne gebracht is);
- Lekkage van olie;
- Lekkage van pekel (bijvoorbeeld via de Solling formatie);
- Convergentie van de caverne;
- Instorten van een deel van het cavernedak;

De drukken worden met een hoge frequentie (uren) gemeten, en met een geringere frequentie uit de meetapparatuur uitgelezen, aanvankelijk dagelijks, om een beeld te krijgen van de natuurlijke variatie, en later wekelijks of maandelijks, zodat tijdig gereageerd kan worden bij het optreden van niet toelaatbare drukveranderingen. Wat beschouwd moet worden als ‘niet toelaatbaar’ moet werkenderwijs bepaald worden. Dit zal gebeuren in overleg met SodM.

De exacte wijze waarop de drukmetingen uitgevoerd worden, en een verder uitgewerkt drukmonitoringsprotocol, zullen aan SodM worden voorgelegd.

**Monitoring van het olie-pekelniveau**

Een verandering van het olie-pekelspiegel niveau kan op verschillende zaken duiden, zoals:

- Ongelijk uitzetten of krimpen van de inhoud van de caverne door temperatuur-verandering (bijvoorbeeld als relatief koude olie in de caverne gebracht is);
- Lekkage van olie;
- Lekkage van pekel (bijvoorbeeld via de Solling Formatie);
- Instorten van een deel van het cavernedak;

In de huidige pekelwinningcavernes wordt het olie-pekelspiegel niveau gemeten m.b.v. een zogenaamd “Blanket Control System” (BCS). Dit systeem heeft een resolutie van 10 cm. Een hogere resolutie (orde grootte 5-10 cm) kan bereikt worden door meerdere BCS systemen te installeren. In theorie is een nog hogere resolutie mogelijk met dit systeem, in de praktijk echter ontbreekt daarvoor de ruimte in de buis. Daarom wordt momenteel gekeken naar een manier om het niveau van de olie-pekelspiegel op een andere manier te meten. Een veelbelovende meetwijze lijkt het gebruik van dunne glasvezel te zijn. Deze is (samen met een verwarmingsdraad) om de 5½”-buis te wikkelen ter plaatse van het geplande niveau (en wellicht ook in de bovenste meters net onder het dak ten behoeve van een verbeterd inzicht in het volume van de welvingen). Glasvezel reageert snel op temperatuurveranderingen en omdat pekel een andere warmtegeleiding heeft dan gasolie kan de diepteligging van de olie-pekelspiegel zeer nauwkeurig worden bepaald bij kortdurende verwarming via de verwarmingsdraad. AkzoNobel onderzoekt in samenwerking met de meetdienst van Deltares of dit systeem op een efficiënte manier kan worden ingebouwd in een van de boorgaten van het opslagsysteem.

Ook dit systeem zal niet continu metingen verrichten. Het meten van het niveau zal met een nader te bepalen frequentie gebeuren door medewerkers van AkzoNobel. Vooralsnog wordt gedacht aan een dagelijkse meetfrequentie tijdens vullen/legen, en een maandelijkse meetfrequentie in statische toestand. In combinatie met de drukmetingen leveren de niveaumetingen zeer nuttige informatie over de situatie in de caverne.

De exacte wijze waarop de niveaumetingen uitgevoerd gaan worden, en een verder uitgewerkt monitoringsprotocol voor het olie-pekelspiegel niveau, zullen aan SodM worden voorgelegd.

**Monitoring van de temperatuur in de caverne**

Indien gekozen wordt voor de meting van het olie-pekelspiegel niveau m.b.v. glasvezel kunnen deze draden ook gebruikt worden voor het meten van de temperatuur in de caverne. Het meten van de temperatuur zal met een nader te bepalen frequentie gebeuren door medewerkers van AkzoNobel. Vooralsnog wordt gedacht aan een maandelijkse meetfrequentie.

De exacte wijze waarop de temperatuurmetingen uitgevoerd gaan worden zal aan SodM worden voorgelegd.

**Monitoring van de afgesloten put**

De afsluiting in de tijdelijk afgesloten put zal periodiek onderzocht worden op lekdichtheid. Dit kan door aan de bovenzijde van deze put de daar aanwezige vloeistof (pekel of anti-corrosievloeistof) te testen op de aanwezigheid van olie. Door een vloeistof te gebruiken die zwaarder is dan gasolie, komt eventueel hierin gelekte gasolie direct bovendrijven en kan eenvoudig worden gezien of de tijdelijke plug lekt.

Het controleren van de vloeistof in de afgesloten put zal met een nader te bepalen frequentie gebeuren door medewerkers van AkzoNobel. Vooralsnog wordt gedacht aan een driemaandelijkse meetfrequentie.

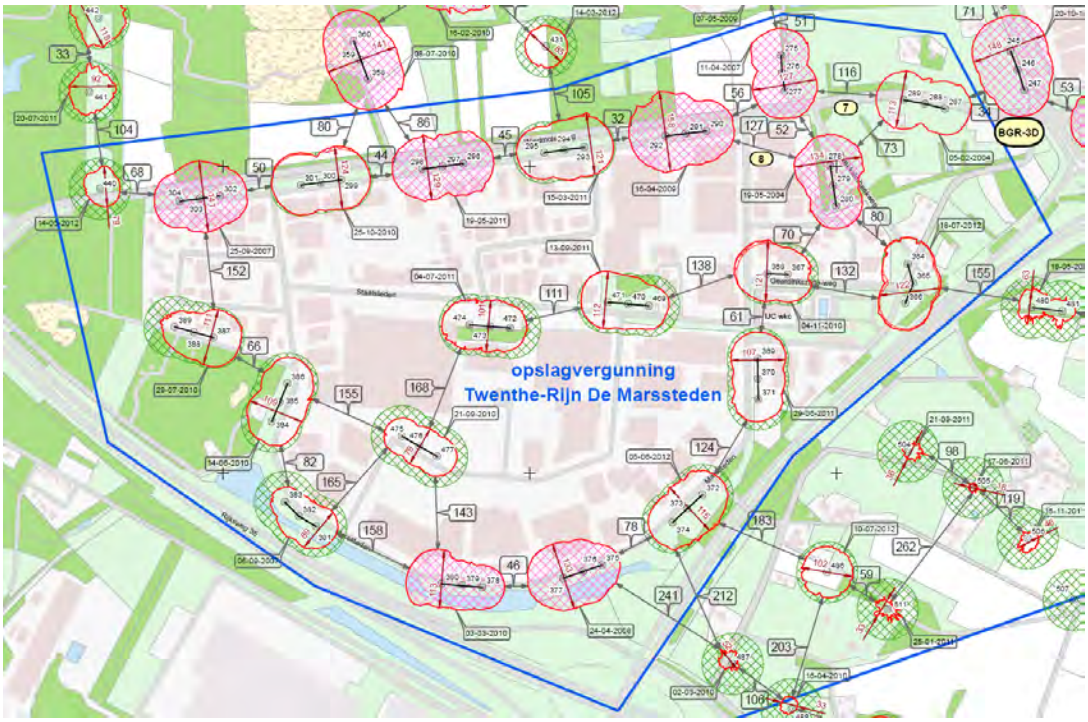
De exacte wijze waarop de monitoring van de afgesloten put uitgevoerd gaat worden zal aan SodM worden voorgelegd.

**Monitoring van de samenstelling van de annulaire vloeistof**
De packers aan de onderzijde van de annulaire ruimte van de olie- en de pekelputten zullen periodiek onderzocht moeten worden op lekdichtheid. Dit kan door aan de bovenzijde van de annulaire ruimte van de putten de daar aanwezige vloeistof (anti-corrosievloeistof) te testen op de aanwezigheid van olie. Door een vloeistof te gebruiken die zwaarder is dan gasolie, komt eventueel hierin gelekte gasolie direct bovendrijven en kan eenvoudig worden gezien of de packers lekken. Voor wat betreft de olieput wordt zo ook de lekdichtheid van de 5½”-buis in de gaten gehouden.

Het controleren van de vloeistof in de annulaire ruimte zal met een nader te bepalen frequentie gebeuren door medewerkers van AkzoNobel. Vooralsnog wordt gedacht aan een maandelijkse meetfrequentie.

De exacte wijze waarop de monitoring van de annulaire ruimten uitgevoerd gaat worden zal aan SodM worden voorgelegd.

**Behoud veilige pilaardikte**
Ten behoeve van de gesteentemechanische veiligheid is het van groot belang dat de pilaardikte (i.e. de afstand tussen de opslagcavernes en de aangrenzende cavernes) niet te klein wordt. Regels hieromtrent zijn vastgelegd in het door AkzoNobel gehanteerde zoutwinningsprotocol “Good Salt Mining Practice” (GSMP). Op dit moment wordt er uit enkele van de aangrenzende cavernes nog zout geproduceerd. Bovendien gaat er uit enkele van de opslagcavernes nog zout geproduceerd worden ten behoeve van het vlak logen van de cavernedaken. In het bijzonder bij deze activiteiten is het van groot belang dat de pilaardikte tussen de opslagcavernes en aangrenzende cavernes behouden blijft. In onderstaande figuur zijn deze pilaardiktes aangegeven.




*Figuur 4.6: kaart van de opslagvergunning met daarin de aanwezige zoutcavernes en de afstanden ertussen, die indicatief zijn voor de pilaardikte.*

Dit aspect zal met de afdeling Boorterrein van AkzoNobel Hengelo afgestemd worden. Het monitoren van de pilaardikte zal een belangrijk aandachtspunt zijn in het definitieve monitoringsprotocol.

**Sonarmetingen**
Zie: paragraaf 4.3 (onderhoudsplan)

## 4.3 Onderhoudsplan

Het onderhoudsplan wordt nader ingevuld wanneer het DO van het opslagsysteem is uitgewerkt. Enkele aspecten ervan worden hier alvast nader toegelicht.

**Inhuur van personeel (contractors)**
Zowel de voorbereidende werkzaamheden (zoals de testen), als de aanlegwerkzaamheden (zoals de milling operatie en de ombouw), als de onderhoudswerkzaamheden mogen uitsluitend worden uitgevoerd door hiervoor opgeleid en hoogwaardig gekwalificeerd personeel. De werkzaamheden dienen tevens te allen tijde onder toezicht te staan van personeel dat gekwalificeerd is om aan deze werkzaamheden leiding te geven. Indien dit personeel niet in dienst is van AkzoNobel, zal dit moeten worden ingehuurd van hiervoor geschikte contractors (DEEP, Socon, Schlumberger, Halliburton, Baker Huges, etc.).

**Sonarmetingen**
Een veelgebruikte manier om inzicht te krijgen in de vorm en inhoud van cavernes is door het uitvoeren van sonarmetingen. Deze zullen worden uitgevoerd na een volledige leging van de caverne, wat gemiddeld elke 5 à 10 jaar gedaan zal worden. In dat geval vindt de meting plaats in een volledig met pekel gevulde caverne, en is er drukevenwicht aan de boorgatafsluiters. Echter, ook wordt een sonarmeting uitgevoerd indien daar vanuit een van de andere metingen in het kader van de monitoring aanleiding voor is, bijvoorbeeld als er een duidelijke verandering van het olie-pekelspiegel niveau wordt waargenomen die ver buiten de verwachte (natuurlijke) variatie valt. In een dergelijk geval gebeurt de meting in een deels met olie gevulde caverne en moet het pekelniveau in de pekelbuis dus verlaagd worden om de druk aan de boorgatafsluiter van de olieput weg te nemen. Indien gewenst kan ook via de pekelput het sonarmeetinstrument neergelaten worden, maar omdat de pekelbuis tot diep in de caverne hangt kan dit instrument dan slechts over een klein dieptetraject metingen doen. De resultaten van de metingen worden vergeleken met de laatste sonar. Zo kunnen eventuele veranderingen in de vorm gezien worden.

Voorafgaand aan de eerste vulling zal een verder uitgewerkt onderhoudsprotocol aan SodM worden overlegd.

## 4.4 Trainingsprogramma

De volgende aspecten m.b.t. de veiligheidsmaatregelen ter voorkoming van lekkage vanuit de put naar de omgeving of ter beperking van de gevolgen van lekkage dienen minimaal tijdens het trainingsprogramma van de chauffeurs aan de orde te komen:

1. De procedure die gevolgd moet worden bij een incident waarbij olie vrij uitstroomt.
2. De procedure die gevolgd moet worden bij een automatische afsluiting van de olie toe- en afvoer.
3. De procedures m.b.t. afsluiten van het hek door chauffeurs bij het verlaten van de

laad- en loslocatie;
4. De procedures m.b.t. afsluiten van het zouthuisje bij het verlaten van de laad- en loslocatie;
5. Voorschriften m.b.t. rustig rijden nabij de olieopslaglocaties;

Voorafgaand aan de eerste vulling zal een verder uitgewerkt trainingsprogramma aan SodM worden overlegd.

## 4.5 Noodsituatie actieplan

Er zal een noodsituatie actieplan gemaakt worden waarin beschreven staat hoe te handelen in het geval van het optreden van een lekkage van olie vanuit het opslagsysteem. De volgende aspecten zullen daar minimaal deel van uitmaken:

- Lokalisering van de lekkage
- Bepaling van de omvang van de lekkage
- Reparatie van het ontstane lek
- Onttrekking van alle olie uit de caverne
- Opstelling en inwerkingtreding van het communicatieplan
- Opstelling bodemverontreinigingsrapport
- Opstelling en uitvoering grondwatersaneringsplan

Het uiteindelijke noodsituatie actieplan wordt voorafgaand aan de eerste olievulling aan SodM voorgelegd.

AkzoNobel
Tomorrow's Answers Today

# Bijlagen

AkzoNobel
Tomorrow's Answers Today

## 1. Tekstuele versie van de Bowtie “Breach of Confinement”

# Hazard Specification Sheet
## Case: Gasoil Storage Hengelo
## Hazard: Storage of Gasoil in a Salt Cavern
## Top Event: Breach of Confinement

| | |
|---|---|
| **Hazard name:** | storage of gasoil in a salt cavern |
| **Location:** | CLOVIS (Gasoil Storage Hengelo) |
| **Top event:** | breach of confinement (=leakage of gasoil) |
| **Description:** | gasoil leaks through the boundaries of the storage system |

**Threats**

**Threat**

| | | | |
|---|---|---|---|
| | **Barrier - Accountable**<br>**»Activity - Responsible** | | |
| | | **Escalation Factor** | |
| | | | **Barrier - Accountable**<br>**»Activity - Responsible** |
| • catastrophic wellhead damage due to collision with heavy traffic | | | |
| | • concrete blocks<br>Concrete blocks will be placed around the well to reduce the impact of traffic with the wellhead house | | |
| | | • reckless driving | |
| | | | • driving instructions to reduce speed<br>All drivers will be instructed to drive at reduced speed near the oil storage wellhead houses |
| • vandalism causing instantaneous catastrophic wellhead damage | | | |
| | • location outside risk area with respect to vandalism<br>The area 'De Marssteden' is not located near a city centre or near an area with many pubs, etc. | | |
| | | • close to football stadium (Grolsch Veste) | |
| | | | • extra surveillance during football matches<br>During football matches in the nearby stadium extra security surveillance will be around |
| | • security surveillance<br>The industrial area has an active security surveillance | | |
| | • security fence<br>A fence (height 2.5 m) will be placed around the wellhead house | | |
| | • wellhead house (locked)<br>The wellhead house will locked | | |
| • improperly closed valve | | | |
| | • standard working procedures<br>Closing the valves will be incorporated in the standard working procedures | | |
| | | • use of different contractors for oil transportation | |
| | | | • contractor management<br>Only highly qualified contractors will be used for work on the well head |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This systems monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | • repeated wellhead performance monitoring and actions (plan-do-check-act)<br>The wellhead status and performance is checked at a regular basis. Any irregularities will be noticed and actions will be taken upon it. | | |

| | | | |
|---|---|---|---|
| | • install backup valves<br>Backup valves will be installed, that, in case of an unforeseen improperly closed valve, will not allow oil leakage. | | |
| • malfunctioning valve | | | |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | • repeated wellhead performance monitoring and actions (plan-do-check-act)<br>The wellhead status and performance is checked at a regular basis. Any irregularities will be noticed and actions will be taken upon it. | | |
| | • install backup valves<br>Backup valves will be installed, that, in case of an unforeseen improperly closed valve, will not allow oil leakage. | | |
| • loss of wellbore integrity (Deltares_A: 5.4) | | | |
| | • well completion design (double tubing)<br>The design consists of an oil tubing within the outer casing, thus leading to two barriers between oil and cement bond. | | |
| | | • presence of brine (corrosive) | |
| | | | • annular fluid composition monitoring<br>The composition of the annular fluid of the oil well will be monitored at a regular basis. As oil floats on brine, any oil in the annulus can be easily observed at the well head, so any oil leakage from the oil tube to the annular space will be found. |
| | • USIT (Deltares_A: 5.10.1)<br>A USIT (Ultra Sonic Imager Tool) test will be used to test the quality of the cement bond at the cement/casing interface. | | |
| | • MIT (fluids) (Deltares_A: 5.10.2)<br>A fluid-MIT will be done to ensure there are no significant leaks in the well and that the mechanical components of the well function in a manner protective of the environment and human health. | | |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | • annular fluid composition monitoring<br>The composition of the annular fluid of the oil well will be monitored at a regular basis. As oil floats on brine, any oil in the annulus can be easily observed at the well head, so any oil leakage from the oil tube to the annular space will be found. | | |
| • packer failure (Deltares_A: 5.8) | | | |
| | • wellbore (casing, cementation)<br>In case of failure of the packer, the casing and cementation of the well form important barriers reducing the possibility of leakage of oil into the surroundings and the environment. | | |
| | | • presence of brine (corrosive) | |
| | | | • annular fluid composition monitoring<br>The composition of the annular fluid of the oil well will be monitored at a regular basis. As oil floats on brine, any oil in the annulus can be easily observed at the well head, so any oil leakage from the oil tube to the annular space will be found. |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | • annular fluid composition monitoring<br>The composition of the annular fluid of the oil well will be monitored at a regular basis. As oil floats on brine, any oil in the annulus can be easily observed at the well head, so any oil leakage from the oil tube to the annular space will be found. | | |
| • failure of retrievable plug, casing and cementation in the unused well (Deltares_A: 5.8) | | | |
| | • USIT (Deltares_A: 5.10.1)<br>A USIT (Ultra Sonic Imager Tool) test will be used to test the quality of the cement bond at the cement/casing interface. | | |
| | • Abandoned well brine composition measurement<br>The composition of the brine in the abandoned well will be monitored at a regular basis. As oil floats on brine, any oil in the abandoned well due to leakage along the retrievable plug, casing or cementation of the abandoned well can be easily observed at the well head. | | |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | | • non-specific monitoring system due to contact with permeable Solling Formation | |
| | | | • additional measurements to identify cause of leakage<br>As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level. |
| • loss of LCCS integrity (Deltares_A: 5.4) | | | |

| | | | |
|---|---|---|---|
| | • USIT (Deltares_A: 5.10.1)<br>A USIT (Ultra Sonic Imager Tool) test will be used to test the quality of the cement bond at the cement/casing interface. | | |
| | • reinstall well section near cavern roof (incl. LCCS)<br>The well section near the cavern roof will be milled and will be reinstalled following the milling operation, including the LCCS. | | |
| | • MIT (fluids) (Deltares_A: 5.10.2)<br>A fluid-MIT will be done to ensure there are no significant leaks in the well and that the mechanical components of the well function in a manner protective of the environment and human health. | | |
| | | • No experience with MITs in Hengelo brine field | |
| | | | • hire experienced consultants<br>Only highly qualified contractors will be used for the MIT |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | | • non-specific monitoring system due to contact with permeable Solling formation | |
| | | | • oil level measurements<br>As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level. |
| • roof collapse | | | |
| | • design: cavern selection procedure excludes potentially unstable caverns<br>During the selection procedure potentially unstable caverns were excluded from the selected caverns. | | |
| | • pressure control to keep pressures with allowable limits<br>A pressure control system will be installed. This prevents pressure to be above of below the allowable limits. | | |
| | • pressure monitoring system (deviation signals roof collapse) (Deltares_A: 5.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. As roof collapse will definitely change the observed pressures, this will be seen. | | |
| | | • non-specific monitoring system due to contact with permeable Solling Formation | |
| | | | • oil level measurements<br>As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level. |
| | • repeated sonar measurements (after every emptying of the cavern; every 5 yrs on average; at least 10 years after last measurement)<br>Sonar measurements will be done at a regular base. To keep a good eye on the development of the cavern volume, this will be done at least after every emptying of the cavern. This will be every 5 yrs on average, and will be done at least 10 years after the last measurement has taken place. | | |
| • permeation through roof (Deltares_A: 5.3) | | | |
| | • design: salt above cavern (impermeable)<br>Salt is impermeable for fluids like oil. During the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selected caverns. | | |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |
| | | • non-specific monitoring system due to contact with permeable Solling formation | |
| | | | • oil level measurements<br>As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level. |
| | • mass balance calculations based on oil in/out and brine in/out<br>A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantiy of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets). | | |
| | | • cavern volume differs from assumed volume based on most recent sonar measurement | |
| | | | • Measure oil level at several moments during first filling operation to check reliability and accuracy of sonar measurement<br>The oil level will be measured at several moments during first filling of the cavern, for example after 10,000 m3, after 25,000 m3, etc. Comparing the expected oil-brine level with the actual level gives information on the reliability and accuracy of the sonar measurements. Also it gives insight in the presence of any unknown roof pockets. |
| • permeation into the cavern walls through permeable intervals (Deltares_A: 5.1) | | | |
| | • design: cavern selection procedure excludes non-Salt A contained caverns<br>Salt is impermeable for fluids like oil. During the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selected caverns. | | |
| | • pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)<br>A pressure monitoring system will be installed. This systems monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these. | | |

        - non-specific monitoring system due to contact with permeable Solling formation
            - oil level measurements
              As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level.
    - mass balance calculations based on oil in/out and brine in/out
      A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantiy of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets).
        - cavern volume differs from assumed volume based on most recent sonar measurement
            - Measure oil level at several moments during first filling operation to check reliability and accuracy of sonar measurement
              The oil level will be measured at several moments during first filling of the cavern, for example after 10,000 m3, after 25,000 m3, etc. Comparing the expected oil-brine level with the actual level gives information on the reliability and accuracy of the sonar measurements. Also it gives insight in the presence of any unknown roof pockets.
- leakage/permeation through cracks in the cavern walls and roof (Deltares_A: 5.1)
    - design: viscoplastic behaviour of salt heals faults at cavern level
      Salt behaves viscoplastic at the given temperature and pressure at cavern level, thus sealing any faults that develop.
    - pressure control to keep pressures with allowable limits
      A pressure control system will be installed. This prevents pressure to be above of below the allowable limits.
    - pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)
      A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these.
        - non-specific monitoring system due to contact with permeable Solling formation
            - oil level measurements
              As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level.
    - mass balance calculations based on oil in/out and brine in/out
      A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantiy of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets).
        - cavern volume differs from assumed volume based on most recent sonar measurement
            - Measure oil level at several moments during first filling operation to check reliability and accuracy of sonar measurement
              The oil level will be measured at several moments during first filling of the cavern, for example after 10,000 m3, after 25,000 m3, etc. Comparing the expected oil-brine level with the actual level gives information on the reliability and accuracy of the sonar measurements. Also it gives insight in the presence of any unknown roof pockets.
- permeable faults in contact with the cavern (Deltares_A: 5.5 & 6.2)
    - design: cavern selection procedure aimed at minimizing presence of faults
      During the selection procedure caverns with known faults, that might affect the containment concept, were excluded from the selected caverns.
        - some minor faults (throw < 10 m @ Röt level)
            - viscoplastic behaviour of salt heals faults at cavern level
              Salt behaves viscoplastic at the given temperature and pressure at cavern level, thus sealing any faults that might have developed during geological history.
    - pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)
      A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these.
        - non-specific monitoring system due to contact with permeable Solling formation
            - oil level measurements
              As pressure monitoring is a very non-specific identifier for leakage, aditional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level.
    - mass balance calculations based on oil in/out and brine in/out
      A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantiy of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets).
        - cavern volume differs from assumed volume based on most recent sonar measurement
            - Measure oil level at several moments during first filling operation to check reliability and accuracy of sonar measurement
              The oil level will be measured at several moments during first filling of the cavern, for example after 10,000 m3, after 25,000 m3, etc. Comparing the expected oil-brine level with the actual level gives information on the reliability and accuracy of the sonar measurements. Also it gives insight in the presence of any unknown roof pockets.
- instantaneous loss of pillar integrity or slow pillar deformation (Deltares_A: 5.6 & 5.7)
    - design: cavern selection procedure ensuring sufficient pillar width
      During the selection procedure caverns with insufficient distance to neighbouring caverns, were excluded from the selected caverns.

        - ongoing leaching in adjacent caverns
            - leaching according to mining plan
              As long as leaching is being done according to the mining plans, the pillar width will never become too small. Cavern measurements (sonar) in caverns adjacent to oil storage caverns must be performed according to mining plans to ensure that the size stays below the maximum cavern size.
    - pressure control to keep pressures with allowable limits
      A pressure control system will be installed. This prevents pressure to be above of below the allowable limits.
    - pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)
      A pressure monitoring system will be installed. This systems monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these.
        - non-specific monitoring system due to contact with permeable Solling formation
            - oil level measurements
              As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level.
    - repeated sonar measurements (after every emptying of the cavern; every 5 yrs on average; at least 10 years after last measurement)
      Sonar measurements will be done at a regular base. To keep a good eye on the development of the cavern volume, this will be done at least after every emptying of the cavern. This will be every 5 yrs on average, and will be done at least 10 years after the last measurement has taken place.
- leakage through cavern floor (Deltares_A: 5.2)
    - design: brine layer on bottom of cavern (oil floats on brine)
      At the base of the cavern a brine layer will be present ensuring that the potentially permeable Solling formation, which is located below the cavern floor, is never in direct contact with the oil.
        - irregular shape of cavern floor (due to sump and irregular leaching)
            - brine tube opening located well above the cavern floor
              As the brine tube opening is located well above the cavern floor further lowering of the oil-brine-level is impossible as no brine can be pumped out when the oil-brine interface reaches the brine tube opening.
    - emergency shutdown system when oil enters the brine well
      In the case that oil enters the brine well during filling of the cavern with oil, the emergency shutdown prevents the further filling with oil.
    - pressure monitoring system (detection of leak) (Deltares_A: 5.10.3)
      A pressure monitoring system will be installed. This system monitors the pressure at different depths and both within the oil well and in the brine well to identify any changes of one of these.
        - non-specific monitoring system due to contact with permeable Solling formation
            - oil level measurements
              As pressure monitoring is a very non-specific identifier for leakage, additional measurements will have to be performed in case of any drastic change in pressure. The main additional measurement is measuring the oil-brine interface level.
    - mass balance calculations based on oil in/out and brine in/out
      A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantity of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets).
        - cavern volume differs from assumed volume based on most recent sonar measurement
            - Measure oil level at several moments during first filling operation to check reliability and accuracy of sonar measurement
              The oil level will be measured at several moments during first filling of the cavern, for example after 10,000 m3, after 25,000 m3, etc. Comparing the expected oil-brine level with the actual level gives information on the reliability and accuracy of the sonar measurements. Also it gives insight in the presence of any unknown roof pockets.
- oil overfill of the cavern
    - design: brine tube opening located well above the cavern floor
      As the brine tube opening is located well above the cavern floor further lowering of the oil-brine-level is impossible as no brine can be pumped out when the oil-brine interface reaches the brine tube opening.
    - emergency shutdown system when oil enters the brine well
      In the case that oil enters the brine well during filling of the cavern with oil, the emergency shutdown prevents the further filling with oil.
- overpressurization of the storage system (Deltares_A: 5.6 & 5.7)
    - Design: natural pressure release mechanism (Solling Fm.)
      Overpressurization of the system is impossible as the Solling formation probably consists of some more permeable layers.
    - pressure control to keep pressures with allowable limits
      A pressure control system will be installed. This prevents pressure to be above or below the allowable limits.
    - emergency shutdown system when oil enters the brine well
      In the case that oil enters the brine well during filling of the cavern with oil, the emergency shutdown prevents the further filling with oil.
- uncontrolled drilling activities during storage period

| | | | |
|---|---|---|---|
| | • Mining regulations<br>The different mining regulations do not allow for any deep drilling activities close to the wells. | | |
| | • Landmark (salt houses)<br>The presence of the wellhead house should signal any drilling companies that this is not a safe place for drilling. | | |
| | • security surveillance<br>The industrial area has an active security surveillance | | |
| • ground acceleration due to earthquake | | | |
| | • chance of significant magnitude earthquake in Twente is extremely low (no active tectonics; no gas and oil production)<br>In Twente, the chance of an earthquake with a significant magnitude is extremely low as there is no known active tectonics in the area and as there is no gas and oil production. | | |
| | | • New oil or gas production taking place nearby | |
| | | | • Mining regulations<br>The different mining regulations should act as an early warning system keeping oil and gas production rates that low that earthquakes with a possible effect on oil storage caverns are being prevented. |
| | • relatively safe location in the subsurface (no resonance, no free surface)<br>During an earthquake the subsurface offers a relatively safe location as there is no resonance and no free surface. | | |

**Consequences**

| **Consequence** | | | |
|---|---|---|---|
| | **Barrier - Accountable**<br>**»Activity - Responsible** | | |
| | | **Escalation Factor** | |
| | | | **Barrier - Accountable**<br>**»Activity - Responsible** |
| • injury (near wellhead) | | | |
| | • design: fast pressure decline following loss of wellhead integrity<br>When the well head integrity is lost, for example due to a truck accident, oil starts to flow out of the well due to the difference in hydrostatic pressure between the oil and the brine. After outflow of only 1.7 m3, the brine level has dropped to a level that the hydrostatic pressure of the oil equals the hydrostatic pressure of the brine, thus ending the outflow of oil. | | |
| | • emergency shutdown valve<br>When oil flows out of the well freely, the fast pressure decrease initiates the emergency shutdown valve to automatically close. | | |
| | • wellhead cellar collects entire volume that may flow out (1.7 m3)<br>The well head cellar around the well head will be enlarged to 2 m3. As the maximum volume that can flow out freely is 1.7 m3, this entire volume can be collected in this cellar. | | |
| | | • debris in cellar due to incident | |
| | | | • protective grid to cover cellar<br>A grid will be placed over the cellar, thus protecting it against getting filled with debris at any time. |
| | • obligation to wear Personal Protection Gear (PPGs) at well location<br>During filling and emptying operations or maintenance, it will be obliged to wear Personal Protection Gear. | | |
| • fire at wellhead | | | |
| | • gas oil is inflammable at atmospheric conditions<br>Gasoil is not classified as flammable but consists of hydrocarbons and can burn. Its flash point is 60 degrees Celsius. | | |
| | • design: fast pressure decline following loss of wellhead integrity<br>When the well head integrity is lost, for example due to a truck accident, oil starts to flow out of the well due to the difference in hydrostatic pressure between the oil and the brine. After outflow of only 1.7 m3, the brine level has dropped to a level that the hydrostatic pressure of the oil equals the hydrostatic pressure of the brine, thus ending the outflow of oil. | | |
| | • emergency shutdown valve<br>When oil flows out of the well freely, the fast pressure decrease initiates the emergency shutdown valve to automatically close. | | |
| | • fire extinguishers (trucks, wellhead house)<br>Fire extinguishers will be located at the trucks and at each wellhead house. | | |
| • free outflow at surface (oil spill) | | | |
| | • design: fast pressure decline following loss of wellhead integrity<br>When the well head integrity is lost, for example due to a truck accident, oil starts to flow out of the well due to the difference in hydrostatic pressure between the oil and the brine. After outflow of | | |

| | | | |
|---|---|---|---|
| | only 1.7 m3, the brine level has dropped to a level that the hydrostatic pressure of the oil equals the hydrostatic pressure of the brine, thus ending the outflow of oil. | | |
| | • emergency shutdown valve<br>When oil flows out of the well freely, the fast pressure decrease initiates the emergency shutdown valve to automatically close. | | |
| | • wellhead cellar collects entire volume that may flow out (1.7 m3)<br>The well head cellar around the well head will be enlarged to 2 m3. As the maximum volume that can flow out freely is 1.7 m3, this entire volume can be collected in this cellar. | | |
| | | • debris in cellar due to incident | |
| | | | • protective grid to cover cellar<br>A grid will be placed over the cellar, thus protecting it against getting filled with debris at any time. |
| | • oil spill remediation plan<br>An oil spill remediation plan will be made following any oil spill. Remediation will then be performed following this plan. | | |
| • instant contamination of shallow soil/groundwater (above groundwater base) | | | |
| | • repair of the leak above groundwater base<br>If the leakage occurs above the groundwater base, the leak will be repaired if possible. This can be done by lowering the brine level, so that also the oil level will be lowered. | | |
| | • shallow groundwater monitoring<br>If leakage has occurred above the groundwater level, monitoring of the groundwater quality will be done at a well selected location (downstream of the leakage location). | | |
| | • groundwater remediation plan<br>A groundwater remediation plan will be made following any oil spill. Remediation will then be performed following this plan. | | |
| | • distance to drinking water extraction points<br>The wells are located far away from any drinking water extraction locations. | | |
| | | • new groundwater extraction points (drinking water, ATES, irrigation) | |
| | | | • governmental regulations<br>Regulations with respect to new groundwater extractions should prevent new groundwater extraction locations too close to the wells. |
| • contamination of aquifers (below groundwater base) | | | |
| | • repair of the leak (depends on cause)<br>If the leakage occurs below the groundwater base, but above the cavern, the leak will be repaired if possible. This can then be done by lowering the brine level, so that also the oil level will be lowered. | | |
| | • evacuating the oil from the storage system (if no repair is possible)<br>If no repair is possible, all oil will be evacuated from the cavern. | | |
| | • multiple impermeable layers (claystone) between cavern and known aquifers<br>If leakage has occurred below the groundwater base, the presence of multiple impermeable claystone layers between the leakage depth and any used aquifers prevents contamination of these aquifers. | | |
| | • distance to water extraction points from deep aquifers (if any)<br>The wells are located far away from any locations where groundwater is extracted from deep aquifers. | | |
| | | • new groundwater extraction points (drinking water, geothermal) | |
| | | | • governmental regulations<br>Regulations with respect to new groundwater extractions should prevent new groundwater extraction locations too close to the wells. |
| • reputational damage | | | |
| | • communication plan incl. emergency response<br>To prevent any reputational damage to AkzoNobel and State Supervision of Mines, a good communication plan must be developed in case of oil leakage. | | |
| • financial loss | | | |
| | • insurance to cover financial damage<br>To prevent any financial damage to AkzoNobel a good insurance must be effective in case of oil leakage. | | |

## 2. Overzicht van barrières en het aantal voorkomens naar type

| *Barrier* | *# Times occurring* | *Barrier type* | *Description* |
|---|---|---|---|
| Abandoned well brine composition measurement | 1 | Inspection | Composition of the brine in the plugged well will be monitored at a regular basis. As oil floats on brine, any oil in the plugged well due to leakage along the retrievable plug, casing or cementation of the well can be easily monitored at the well head. |
| Additional measurements to identify cause of leakage | 1 | Procedural | As pressure monitoring is a very non-specific identifier for leakage, additional measurements must be performed in case of a significant change in pressure to find the root cause. An important measurement at cavern level is the oil-brine interface level measurement. |
| Annular fluid composition monitoring | 4 | Inspection and Maintenance | The composition of the annular fluid of the oil well will be monitored on a regular basis. As oil floats on brine, any oil in the annulus can be easily observed at the well head, so any oil leakage from the oil tube to the annular space will be detected. |
| Brine tube opening located well above the cavern floor | 1 | Design - Process concept | As the brine tube opening is located well above the cavern floor, further lowering of the oil-brine-level is impossible, because no brine can be pumped out when the oil-brine interface reaches the brine tube opening. |
| Probability of a significant magnitude earthquake in Twente is extremely low (no active tectonics; no gas and oil production) | 1 | Separation (Time or Space) | In Twente, the probability of an earthquake with a significant magnitude, either naturally occurring or induced, is extremely low as there is no known active tectonics in the area, and no gas and oil production takes place in the vicinity. |
| Communication plan incl. emergency response | 1 | Reduction in Inventory | A good communication plan incl. emergency response must be in place for when leakage occurs. |
| Concrete blocks | 1 | Guarding or Shielding | Concrete blocks will be placed around the well to reduce the impact of traffic with the wellhead house |
| Contractor management | 1 | Procedural | Only highly-qualified contractors will be used for work on the wellhead |
| Design: brine layer at the base of the cavern (oil floats on brine) | 1 | Design - Process concept | At the base of the cavern a brine layer will be present ensuring that the more permeable Solling Formation, which is located below the Salt A in which the caverns are located, is never in direct contact with the oil. |
| Design: brine tube opening located well above the cavern floor | 1 | Design - Process concept | As the brine tube opening is located well above the cavern floor, further lowering of the oil-brine-level is impossible, because no brine can be pumped out when the oil-brine interface reaches the brine tube opening. |
| Design: cavern selection procedure aimed at minimizing presence of faults | 1 | Reduction in Inventory | During the selection procedure, caverns with faults in the vicinity that have the potential to affect their integrity were excluded from the selection. |
| Design: cavern selection procedure ensuring sufficient pillar width | 1 | Reduction in Inventory | During the selection procedure, caverns with insufficient distance to neighboring caverns were excluded from the selection. |
| Design: cavern selection procedure excludes non-Salt A contained caverns | 1 | Reduction in Inventory | Salt is impermeable for fluids. During the selection procedure, caverns that developed into other salt layers than Salt A were excluded from the selection. |
| Design: cavern selection procedure excludes potentially unstable caverns | 1 | Reduction in Inventory | During the selection procedure, potentially unstable caverns were excluded from the selection. |
| Design: fast pressure decline following loss of wellhead integrity | 3 | Design - Process concept | Upon loss of wellhead integrity, e.g. due to a truck accident, oil starts to flow out of the well due to the difference in hydrostatic pressure between the oil and the brine columns. After outflow of only about1.7 $m^3$, the brine level has dropped to a level where the hydrostatic pressure of the oil and brine columns is equal, thus ending the outflow of oil. |
| Design: natural pressure release mechanism (Solling Fm.) | 1 | Design - Process concept | Overpressurization of the system is impossible as the Solling formation contains more permeable intervals. |
| Design: salt above cavern (impermeable) | 1 | Design - Process concept | Salt is impermeable for fluids. During the selection procedure, caverns that developed into other salt layers than Salt A were excluded from the selection. |
| Design: viscoplastic behavior of salt heals faults at cavern level | 1 | Design - Process concept | Salt behaves weakly viscoplastic at the temperatures and pressures at cavern depth. Faults that develop are expected to be sealing faults. |
| Distance to drinking water extraction points | 1 | Separation (Time or Space) | The wells are located far away from any drinking water extraction locations. |
| Distance to water extraction points from deep aquifers | 1 | Separation (Time or Space) | The wells are located far away from any locations where groundwater is extracted from deep aquifers. |
| Driving instructions to reduce speed | 1 | Procedural | All drivers will be instructed to drive at reduced speed near the oil storage wellhead houses |
| Emergency shutdown system when oil enters the brine tube | 3 | Design - Protection System | If oil enters the brine well during filling of the cavern with oil, the emergency shutdown system prevents further overfilling with oil. |
| Emergency shutdown valve | 3 | Design - Protection System | If oil flows out of the well freely, the fast rate of pressure decline initiates the emergency shutdown valve to automatically close. |
| Evacuating the oil from the storage system (if no repair is possible) | 1 | Reduction in Inventory | If no repair is possible, all oil will be removed from the cavern. |
| Extra surveillance during football matches | 1 | Inspection | During football matches in the nearby stadium extra security surveillance will be around |
| Fire extinguishers (trucks, wellhead house) | 1 | Control of Energy Release | Fire extinguishers will be located at the trucks and at each wellhead house. |
| Gasoil is inflammable at atmospheric conditions | 1 | Design - Process concept | Gasoil is not classified as flammable. Its flash point is 60 degrees Celsius. |
| Governmental regulations | 2 | Administrative | Regulations with respect to new groundwater extractions must prevent new groundwater extraction locations too |

| *Barrier* | *# Times occurring* | *Barrier type* | *Description* |
|---|---|---|---|
| | | | close to the oil storage wells. |
| Groundwater remediation plan | **1** | Reduction in Inventory | A groundwater remediation plan will be made directly after oil spill occurs. Remediation will be performed following this plan. |
| Hire experienced contractors | **1** | Procedural | Highly-qualified experienced contractors with a proven track record will be used for the MIT |
| Install backup valves | **2** | Design - Protection System | Backup valves will be installed that prevent oil leakage when a valve is improperly closed. |
| Insurance to cover financial damage | **1** | Reduction in Inventory | Financial damage to AkzoNobel must be covered by a good insurance, one that covers the costs for remediation and follow-up. |
| Landmark (salt houses) | **1** | Guarding or Shielding | The presence of the wellhead house signals that a salt cavern is present beneath the surface |
| Leaching according to mining plan | **1** | Procedural | As long as leaching in adjacent caverns is being done according to the mining plans, the pillar width will never become too small. Sonar measurements in caverns adjacent to oil storage caverns must be performed at intervals as specified in mining plans to ensure that the maximum cavern size is not exceeded. |
| Location outside risk area with respect to vandalism | **1** | Separation (Time or Space) | The area 'De Marssteden' is not located near a city centre or near an area with many pubs, etc. |
| Mass balance calculations based on oil in/out and brine in/out | **5** | Administrative | A good administration of in- and outflow of oil and in- and outflow of brine will provide the information for mass balance calculations. A mismatch between the quantity of oil that went into the cavern and that comes out of the cavern during a full oil recovery or at abandonment indicates that oil is trapped inside the cavern. |
| Oil level measurement inside the cavern at several moments during the first filling operation to calibrate the volume of oil trapped in pockets in the roof as estimated from the combined sonar measurements. | **5** | Administrative | The oil level inside the cavern will be measured at several moments during first filling of the cavern, e.g. after every 10,000 m3 of oil inserted. By comparing the actual level to the expected oil-brine level estimated from the combined sonar measurements the estimated volume of oil in roof pockets can be calibrated. As such, it also indicates the presence of unknown roof pockets that were not "seen" by sonar |
| Mining regulations | **2** | Administrative | The different mining regulations should act as an early warning system to keep oil and gas production rates within allowable limits to prevent occurrence of earthquakes that have the potential to destabilize the oil storage caverns. |
| MIT (fluids) (Deltares_A: 5.10.2) | **2** | Inspection | A fluid-MIT will be done to ensure there are no significant leaks in the well and that the mechanical components of the well function in a manner protective of the environment and human health. |
| Multiple impermeable layers (claystone) between cavern and known aquifers | **1** | Separation (Time or Space) | When leakage of oil in the subsurface has occurred at a deep level (i.e. at cavern level), it will take tens of thousands of years for the oil to reach an aquifer due to the presence of several thick impermeable layers between the point of leakage and the aquifers. |
| Obligation to wear Personal Protection Gear (PPGs) at well location | **1** | Procedural | During filling and emptying operations or maintenance, personnel is obligated to wear Personal Protection Gear. |
| Oil-brine interface level measurements | **8** | Reduction in Inventory | As pressure monitoring is a very non-specific identifier for leakage, additional measurements must be performed in case of a significant change in pressure to find the root cause. An important measurement at cavern level is the oil-brine interface level measurement. |
| Oil spill remediation plan | **1** | Reduction in Inventory | An oil spill remediation plan will be made when significant oil spill occurs. Remediation will be performed following this plan. |
| Pressure control to keep pressures with allowable limits | **4** | Control of Energy Release | A pressure control system will be installed. This prevents pressure to be above of below the allowable limits. |
| Pressure monitoring system (detection of leak) (Deltares_A: 5.10.3) | **12** | Design - Protection System | A pressure monitoring system will be installed. It monitors the pressure at the oil- and brine wellhead. A leak in the well will change these pressures due to a sudden change in the depth of the oil-brine-interface level |
| Pressure monitoring system (deviation signals roof collapse) (Deltares_A: 5.3) | **1** | Inspection | A pressure monitoring system will be installed. It monitors the pressure at the oil- and brine wellhead. A roof collapse will change these pressures due to a sudden change in the depth of the oil-brine-interface level |
| Protective grid to cover cellar | **2** | Guarding or Shielding | A grid will be placed over the cellar, thus protecting it against getting filled with debris at any time. |
| Reinstall well section near cavern roof (incl. LCCS) | **1** | Design - Detail Design | The well section near the cavern roof will be milled and will be reinstalled following the milling operation, including the LCCS. |
| Relatively safe location in the subsurface (no resonance, no free surface) | **1** | Design - Process concept | During an earthquake the subsurface offers a relatively safe location as there is no (resonance-enlarged) free surface movement |
| Repair of the leak (depends on cause) | **1** | Reduction in Inventory | If the leakage occurs in the well, and can be localized, attempts will be made to repair the leak. |
| Repair of the leak above the groundwater base | **1** | Reduction in Inventory | If the leakage occurs above the groundwater base, the leak will be repaired, and remediation activities will start. |
| Repeated sonar measurements (after every emptying of the cavern; every 5 yrs on average; at least 10 years after last measurement) | **2** | Inspection | Sonar measurements will be done after a full recovery of the stored oil, which is expected to be every 5 yrs on average. It will be done at least 10 years after the last measurement has taken place. |
| repeated wellhead performance monitoring and actions (plan-do-check-act) | **2** | Inspection and Maintenance | Wellhead integrity and performance is checked at a regular basis. Any irregularities will be noticed and acted upon. |
| Security fence | **1** | Guarding or Shielding | A fence (height 2.5 m) will be placed around the wellhead house |
| Security surveillance | **2** | Inspection | The industrial area has an active security surveillance |

| *Barrier* | *# Times occurring* | *Barrier type* | *Description* |
|---|---|---|---|
| Shallow groundwater monitoring | **1** | Inspection | If leakage has occurred above the hydrological base, monitoring of the groundwater quality will be done at locations downstream of the leakage location. |
| Standard working procedures | **1** | Procedural | Closing the valves will be incorporated in the standard working procedures |
| USIT (Deltares_A: 5.10.1) | **3** | Inspection | A USIT (Ultra Sonic Imager Tool) test will be used to test the quality of the cement bond at the cement/casing interface. |
| Viscoplastic behavior of salt heals faults at cavern level | **1** | Design - Process concept | Salt behaves viscoplastic at the given temperature and pressure at cavern level, thus sealing any faults that have developed during geological history. |
| Well completion design (multiple barriers) | **1** | Design - Process concept | The design consists of an oil tubing within the outer casing, thus leading to two barriers between oil and cement bond. |
| Wellbore (casing, cementation) | **1** | Separation (Time or Space) | In case of failure of the packer, the casing and cementation of the well form important barriers reducing the possibility of leakage of oil into the surroundings and the environment. |
| Wellhead cellar collects entire volume that may flow out (1.7 $m^3$) | **2** | Guarding or Shielding | The wellhead cellar around the wellhead will be 2 $m^3$. As the maximum volume that can flow out freely is 1.7 $m^3$, this entire volume can be collected in this cellar. |
| Wellhead house (locked) | **1** | Guarding or Shielding | The wellhead house will locked |

| **Storage of Gasoil in a Salt Cavern: Breach of Confinement (=Leakage of Gasoil)** | **Administrative** | **Control of Energy Release** | **Design - Detail Design** | **Design - Process concept** | **Design - Protection System** | **Guarding or Shielding** | **Inspection** | **Inspection and Maintenance** | **Operations and Maintenance** | **Procedural** | **Reduction in Inventory** | **Separation (Time or Space)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Threats:** | | | | | | | | | | | | |
| Catastrophic wellhead damage due to collision with heavy traffic | | | | | | **1** | | | | **1** | | |
| Vandalism causing instantaneous catastrophic wellhead damage | | | | | | **3** | **1** | | | | | **1** |
| Improperly closed valve | | | | | **2** | | | **1** | | **2** | | |
| Malfunctioning valve | | | | | **2** | | | **1** | | | | |
| Loss of wellbore integrity (Deltares_A: 5.4) | | | | **1** | **1** | | **2** | **2** | | | | |
| Packer failure (Deltares_A: 5.8) | | | | | **1** | | | **2** | | | | **1** |
| Failure of retrievable plug, casing and cementation in the unused well (Deltares_A: 5.8) | | | | | **1** | | **2** | | | **1** | | |
| Loss of LCCS integrity (Deltares_A: 5.4) | | | **1** | | | | **3** | | | **1** | **1** | |
| Roof collapse | | **1** | | | | | **2** | | | | **2** | |
| Permeation through roof (Deltares_A: 5.3) | **2** | | | **1** | **1** | | | | | | **1** | |
| Permeation into the cavern walls through permeable intervals (Deltares_A: 5.1) | **2** | | | | **1** | | | | | | **2** | |
| Leakage/permeation through cracks in the cavern walls and roof (Deltares_A: 5.1) | **2** | **1** | | **1** | **1** | | | | | | **1** | |
| Permeable faults in contact with the cavern (Deltares_A: 5.5 & 6.2) | **2** | | | **1** | **1** | | | | | | **2** | |
| Instantaneous loss of pillar integrity or slow pillar deformation (Deltares_A: 5.6 & 5.7) | | **1** | | | **1** | | **1** | | | **1** | **2** | |
| Leakage through cavern floor (Deltares_A: 5.2) | **2** | | | **2** | **2** | | | | | | **1** | |
| Oil overfill of the cavern | | | | **1** | **1** | | | | | | | |
| Overpressurization of the storage system (Deltares_A: 5.6 & 5.7) | | **1** | | **1** | **1** | | | | | | | |
| Uncontrolled drilling activities during storage period | **1** | | | | | **1** | **1** | | | | | |
| Ground acceleration due to earthquake | **1** | | | **1** | | | | | | | | **1** |
| **Consequences:** | | | | | | | | | | | | |
| Injury (near wellhead) | | | | **1** | **1** | **2** | | | | **1** | | |
| Fire at wellhead | | **1** | | **2** | **1** | | | | | | | |
| Free outflow at surface (oil spill) | | | | **1** | **1** | **2** | | | | | **1** | |
| Instant contamination of shallow soil/groundwater (above groundwater base) | **1** | | | | | | **1** | | | | **2** | **1** |
| Contamination of aquifers (below groundwater base) | **1** | | | | | | | | | | **2** | **2** |
| Reputational damage | | | | | | | | | | | **1** | |
| Financial loss | | | | | | | | | | | **1** | |

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## 3. Indeling van barrières naar type en gedetailleerde beschrijving

# Bijlage 3a - Administratieve barrières

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Admin_1 | Governmental regulations | Administrative | Regulations with respect to new groundwater extractions should prevent new groundwater extraction locations too close to the wells. | Groundwater extraction permits are granted by the water board or the provincial authorities. These authorities should assure that no groundwater extraction permits are granted that are too close to the oil storage caverns, at least with respect to deep groundwater extractions. For shallow groundwater extractions (i.e. phreatic groundwater) and for extractions that are not subject to the permitting procedures, no risks exists and no special distances have to be taken into account as long as no leakage of oil from te cavern occurs. If leakage occurs, groundwater extractions in the vicinity of the oil storage caverns must be abandoned or at least reconsidered. | Implementation by external parties |
| Admin_2 | Mass balance calculations based on oil in/out and brine in/out | Administrative | A good administration of in- and outflow of oil and in- and outflow of brine will provide the information for mass balance calculations. A mismatch between the quantity of oil that went into the cavern and that comes out of the cavern during a full oil recovery or at abandonment indicates that oil is trapped inside the cavern. | AkzoNobel and Argos will implement a so-called "Oil and Brine Administration". In this administration detailed figures are administered for oil flowing into and out of the cavern and for brine flowing into and out of the cavern. At any time after a full oil recovery, and after the final oil recovery, the quantity of oil that is unaccounted for confirms that oil is trapped in the cavern (roof pockets, sticking to walls) | A mass-balance administration will be incorporated in the administrative plan |
| Admin_3 | Oil level measurement inside the cavern at several moments during the first filling operation to calibrate the volume of oil trapped in pockets in the roof as estimated from the combined sonar measurements | Administrative | The oil level inside the cavern will be measured at several moments during first filling of the cavern, e.g. after every 10,000 $m^3$ of oil inserted. By comparing the actual level to the expected oil-brine level estimated from the combined sonar measurements the estimated volume of oil in roof pockets can be calibrated. As such, it also indicates the presence of unknown roof pockets that were not "seen" by sonar | Just before the first filling operation a detailed base level sonar measurement will be performed to confirm that no change has occurred in the shape and volume of the cavern. Using this sonar measurement, intermediate filling levels can be determined (e.g after 10.000 $m^3$, after 20.000 $m^3$, etc.), which can be compared with actual levels measured during the filling operation. Large differences may be an indication of additional roof pockets that were not "seen" by sonar, larger pockets than estimated from sonar, or wider caverns in general (when differences occur at all filling levels), etc. Also, it provides information on the reliability of the sonar measurements. | The results of the base level sonar measurements, performed just before first filling of the cavern, and the calibration with the oil level measurements, will be discussed in more detail with State Supervision of Mines (SodM). The technique by which the oil-brine-interface level is measured inside the cavern is decribed in the monitoring plan. |
| Admin_4 | Mining regulations | Administrative | The different mining regulations should act as an early warning system to keep oil and gas production rates within allowable limits to prevent occurrence of earthquakes that have the potential to destabilize the oil storage caverns. | At the moment no oil and gas production occurs in the immediate vicinity of the caverns. As such, earthquakes induced by oil and gas production are not expected. If oil and gas production is going to take place in Twente in the future, then the governing authorities (i.e. State Supervision of Mines and the Mininstry of Economic Affairs) must account for the presence of oil-filled caverns when granting production permits for oil and gas, i.e., by bounding the production rate to prevent induced seismicity. | Implementation by external parties |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3b - Barrières 'Control of energy release'

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Energy_1 | Fire extinguishers (trucks, wellhead house) | Control of Energy Release | Fire extinguishers will be placed at the trucks and at each well house. | Presence of fire extinguishers inside all well houses forms part of the HAZOP study, this mitigating measure will be implemented via the detailed surface design. Fire extinguishers should be checked periodically according to the specifications of the equipment itself. According to regulations for the transportation of oil products by truck, fire extinguishers are present at all trucks used for oil transportation. | Fire extinguishers will be implemented in the final wellpad layout, which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| Energy_2 | Pressure control to keep pressures within allowable limits | Control of Energy Release | A pressure control system will be installed. This prevents pressure to be above of below the allowable limits. | A pressure control system will be installed. This system will monitor the pressure at the brine wellhead and at the oil wellhead. Under static conditions, the pressure at the oil wellhead is not allowed to substantially exceed 17 bar, which is the difference in hydrostatic pressure between the oil and brine columns. When oil is being pumped into the cavern, the allowable pressure at the wellhead is the pressure generated by the oil pump (i.e. 32 bar which is necessary to pump oil into the cavern at a flowrate of 150 $m^3$/m). At oil extraction, the pressure at the brine wellhead may never significantly exceed the pressure that is build-up by the brine pump, which is 4 bar. If one of these pressure gets higher than the allowable pressure, the valves at the oil- and brine wellheads will automatically close. | Design of the pressure control system will be incorporated in the detailed engineering design which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations. Day-to-day monitoring of the system will be incorporated in the monitoring plan. |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3c - Ontwerpbarrières

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Design_1 | Design: brine layer on bottom of cavern (oil floats on brine) | Design - Process concept | At the base of the cavern a brine layer will be present ensuring that oil is never in contact with the potentially permeable Solling formation that is located below the cavern floor. | A layer of brine will allways be present at the base of the cavern. The thickness of this layer depends on the relief of the cavern floor. The oil-brine-interface-level will be placed at a level such that the top of the sump is below this level everywhere. This will be done using the base level sonar measurement, which will be performed just before the start of the oil storage operation. | This barrier will be implemented in the detailed engineering design which has to be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| Design_2 | Design: brine tube opening located well above the cavern floor | Design - Process concept | As the brine tube opening is located well above the cavern floor, further lowering of the oil-brine-level is impossible as no brine can be pumped out when the oil-brine interface reaches the brine tube opening. | The brine tube opening will be located at least one meter above the cavern floor. In this way, lowering of the oil-brine-level lower than the brine tube opening is impossible as oil will enter the brine well when this level is reached and the brine level will not be lowered any further. The depth of the brine tube opening will be determined using the base level sonar measurement, which will be performed just before the start of the oil storage operation. | This design aspect will be implemented in the final detailed engineering design which has to be approven by State supervisory of Mines (SodM) before the start of the oil storage preparations |
| Design_3 | Design: fast pressure decline following loss of wellhead integrity | Design - Process concept | Following loss of wellhead integrity, oil starts to flow out of the well due to the difference in hydrostatic pressure between the oil and the brine. After outflow of only 1.7 $m^3$, the brine level has dropped to a level where the hydrostatic pressure of the oil equals the hydrostatic pressure of the brine, thus ending the outflow of oil. | Following loss of wellhead integrity, oil starts to flow out of the well due to the difference in hydrostatic pressure between the oil and the brine. After outflow of only 1.7 $m^3$, the brine level has dropped to a level that the hydrostatic pressure of the oil equals the hydrostatic pressure of the brine, thus ending the outflow of oil. This means that a truck incident can only cause 1.7 $m^3$ of oil to flow out of the well. Calculations have indicated that the outflow of oil from the well takes place at a rate of between 3 and 6 m/sec. The period of outflow depends on the size of the hole and ranges from 2.5 minutes (entire borehole open) to 2.2 hours (for a hole with a diameter of 1 cm). | No implementation necessary. |
| Design_4 | Design: natural pressure release mechanism (Solling Fm.) | Design - Process concept | Overpressurization of the system is impossible because the top part of the Solling formation is known to contain more permeable intervals. | The Solling formation, located immediately below the Salt A layer that contains the caverns, is found to consist of sandy claystone with a permeability which is considerably higher than that of salt. As boreholes are drilled into the Solling formation, all caverns are in direct pressure connection with the Solling, although sump material will have filled the borehole and has formed a layer above the original cavern floor. As such, overpressurization of the cavern is deemed impossible. Pressure tests have proven that the maximum pressure that can be reached at cavern level is about 60 bar, which equals about 5 bar at the well head. Higher pressures are released via the permeable Solling formation, i.e. brine is then being pushed into the pores of the Solling Formation. | No implementation necessary. |
| Design_5 | Design: salt above cavern (impermeable) | Design - Process concept | Salt is impermeable for fluids like oil. During the selection procedure, caverns that developed into other salt layers than Salt A were excluded from the selection. | Salt is impermeable for fluids like oil. Permeability measurements on salt have indicated a permeability in the range of 1,00E-05 to 1,00E-02 mD, and a hydraulic conductivity of 1,00E-11 to 1,00E-08. All selected caverns are entirely situated within Salt A and during the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selection. A detailed geological description of the selected salt caverns can be found in the report titled "Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)" by Deltares (2012). | This design aspect was implemented in the cavern selection procedure. |
| Design_6 | Design: salt layer between sump and less impermeable Solling Formation | Design - Process concept | In some caverns, it may be necessary that the sump is in oil partially. In such cases, a salt layer between the lowest point of the sump (i.e. the deepest point of the cavern during its history) and the less impermeable Solling Formation must be present to prevent permeation into the Solling Formation. | In some caverns, it may be necessary that the sump is in oil partially. If so, then this is only allowed if it can be assured that a salt layer is present between the base of the sump (i.e the deepest point the cavern has ever reached) and the more permeable Solling formation. As salt is impermeable for fluids like oil this salt layer then forms a barrier preventing any permeation of oil into the Solling formation. | This design aspect will be implemented in the final cavern-specific fillling procedure which will be sent to State Supervision of Mines (SodM) before the start of the oil storage preparations |
| Design_7 | Design: viscoplastic behavior of salt heals faults at cavern level | Design - Process concept | Salt behaves viscoplasticly at the given temperature and pressure at cavern level, thus sealing any faults that develop. | At Röt salt level the few faults that have been observed in the vicinity of the caverns have small or no offset, and may be assumed to be closed due to the visoplastic behaviour of salt. | No implementation necessary. |
| Design_8 | Design: emergency shutdown system when oil enters the brine well | Design - Protection System | When oil enters the brine well during filling of the cavern, the emergency shutdown system automatically responds. | When a cavern is being overfilled with oil, i.e. when extraction of brine and influx of oil continues after having reached the allowed oil volume, the oil-brine-interface-level will at some point reach the brine tube opening. At that moment oil enters the brine tube. A pressure-controlled emergency shutdown will be implemented which will shut down automatically when oil reaches the brine wellhead. | This design aspect will be implemented in the detailed design of the brine wellhead and its connection to the brine pipe system. |
| Design_9 | Design: emergency shutdown valve | Design - Protection System | When oil flows out of the well freely, the fast pressure decrease initiates an automatic closure of the emergency shutdown valve | When oil starts to flow out of the well freely, driven by the difference in hydrostatic pressure between the oil and the brine columns, the pressue at the oil wellhead will decrease. After outflow of only 1.7 $m^3$, the brine level has dropped to a level where the hydrostatic pressures of the oil and brine columns is equal, thus ending the outflow of oil. Pressure decreases at a maximum rate of about 0.2 bar per second, when the entire borehole is open. An emergency shutdown valve will be installed that closes when a pressure decline is measured that exceeds 0.1 bar per second. | This design aspect will be implemented in the detailed engineering design which has to be approved by State supervisory of Mines (SodM) before the start of the oil storage preparations |

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| Design_10 | Gasoil is inflammable at atmospheric conditions | Design - Process concept | Gasoil is not classified as inflammable. Its flash point is 60 degrees Celsius. | Atmospheric conditions in the Netherlands do not allow for gasoil to inflame spontaneously. It can burn, causing a so-called 'plasbrand', but it cannot cause an explosion. A fire might develop due to a collision of an oil truck with the wellhead or with another vehicle. | No implementation necessary. |
| Design_11 | Install backup valves | Design - Protection System | Backup valves will be installed to prevent outflow of oil in case of an improperly closed valve. | In compliance with the Mining law, two valves will be installed at each possible outlet of the wellhead. For a preliminary design of the wellhead, the reader is referred to the wellhead design in the Storage Plan. | This design aspect will be implemented in the detailed engineering design which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| Design_12 | Reinstall well section near cavern roof (incl. LCCS) | Design - Detail Design | The well section near the cavern roof will be milled and will be reinstalled following the milling operation, including the LCCS. | For all wells the cementation and casing have been or will be evaluated using an ultrasonic imaging tool (USIT). A good cementation quality at the casing shoe and in the salt section above the cavern is important to ensure the tightness of the storage system. For wells with an improper LCCS depth or with a bad cementation or casing quality in the section penetrating the cavern roof, a milling operation will take place and both the well section and the LCCS will be reinstalled. This ensures the integrity of the well at the level of the cavern roof. | This design aspect will be implemented in the detailed engineering design which has to be approven by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| Design_13 | Relatively safe location in the subsurface (no free surface waves) | Design - Process concept | During an earthquake the subsurface offers a relatively safe location as there is no (resonance-enlarged) free surface movement | Earthquake damage is most severe at the surface, where the ground accelerations are largest due to earthquake-induced surface waves and the resonance between them. At depth, ground acceleration is negligible for all but the highest magnitude earthquakes, which are not expected to occur in the Twente region. | No implementation necessary. |
| Design_14 | Viscoplastic behavior of salt heals faults at cavern level | Design - Process concept | Salt behaves viscoplastic at the given temperature and pressure at cavern level, thus sealing any faults that have developed during geological history. | At Röt salt level hardly any faults have been observed and faults that have been At Röt salt level the few faults that have been observed in the vicinity of the caverns have small or no offset, and may be assumed to be closed due to the visoplastic behaviour of salt. | No implementation necessary. |
| Design_15 | Well completion design (multiple barriers) | Design - Process concept | The design consists of an oil tubing within the outer casing, thus leading to two barriers between oil and cement bond. | Both at the oil well and at the brine well, a 5 1/2" central tube will be placed within the 7" last cemented casing, with packers at the downside of the annulus. As such, two barriers are present between the oil (or brine) in the inner tube and the cement, and three barriers are present between the oil (or brine) and the overburden rock (i.e. 5 1/2" tubing, 7" casing and cement). For a design of the wells, please see the well design in the Storage Plan. | This design aspect will be implemented in the final cavern specific layout which has to be approven by State supervisory of Mines (SodM) before the start of the oil storage preparations |
| Design_16 | Pressure monitoring system (detection of leak) (Deltares_A: 5.10.3) | Inspection | A pressure monitoring system will be installed. It monitors the pressure at the oil- and brine wellhead. A leak in the well will change these pressures due to a sudden change in the depth of the oil-brine-interface level | Pressure monitoring is implemented to detect a change in the depth of the oil-brine-interface level, which signals either leakage from the storage system or roof collapse in the cavern. The rate of pressure decline provides a good indication of the change in depth of the oil-brine-interface leve, and allows to distinguish between roof collapse and leakage. Pressures will be monitored at the oil and the brine wellheads. | A detailed description of the pressure monitoring system is included in the monitoring plan |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3d - Beschermende en afschermende barrières

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| GuardShield_1 | Concrete blocks | Guarding or Shielding | Concrete blocks will be placed around the well to reduce the impact of traffic with the wellhead house | (Heavy) traffic at the industrial area De Marssteden may damage the wellhead during a collision. To reduce the risk and minimize the potential effects of a collision, concrete blocks will be placed around the well house. | This aspect will be implemented in the wellpad layout which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| GuardShield_2 | Landmark (salt houses) | Guarding or Shielding | The presence of the wellhead house signals that a salt cavern is present beneath the surface | Deep drilling near a gasoil storage cavern must be prevented. The presence of a wellhead house has a signalling function as it indicates the presence of a salt cavern in the subsurface below the wellhead house. | This aspect will be implemented in the wellpad layout which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| GuardShield_3 | Protective grid to cover cellar | Guarding or Shielding | A grid will be placed over the cellar, thus protecting it from getting filled with debris at any time. | During a collision with the concrete blocks around the well house and the well house itself, debris might fall into the well cellar, reducing its capacity for collecting oil during loss of wellhead integrity. A grid that is placed over de well cellar prevents the well cellar from getting filled with larger particles of debris. | This aspect will be implemented in the wellpad layout which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| GuardShield_4 | Security fence | Guarding or Shielding | A fence (height 2.5 m) will be placed around the wellhead house | A security fence with a heigt of 2.5 m will be placed around the wellhead house, and the area where the mobile pump installation will be placed. The fence will be locked when no pumping activities are taking place. | This aspect will be implemented in the wellpad layout which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| GuardShield_5 | Wellhead cellar collects entire volume that may flow out (1.7 $m^3$) | Guarding or Shielding | The wellhead cellar around the wellhead will be 2 $m^3$. As the maximum volume that can flow out freely is 1.7 $m^3$, this entire volume can be collected in this cellar. | As the maximum free outflow volume of oil (due to the difference in hydrostatic pressure between the oil and brine well) is 1.7 $m^3$, the capacity of the cellar will be 2 $m^3$, such that it is able to contain the entire volume that can flow out freely, even when some smaller particles of debris have fallen into the cellar during a collision. | This aspect will be implemented in the wellpad layout which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |
| GuardShield_6 | Wellhead house (locked) | Guarding or Shielding | The wellhead house will be locked | As is already the case in the present situation, the wellhead house will be locked and only AkzoNobel personnel will have a key to unlock the wellhead house. | This aspect will be implemented in the wellpad layout which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3e - Barrières op het gebied van inspectie en onderhoud

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Inspection_1 | Abandoned well brine composition measurement | Inspection | The composition of the brine in the abandoned well will be monitored at a regular basis. As oil floats on brine, any oil in the abandoned well due to leakage along the retrievable plug of the abandoned well can be easily observed at the wellhead. | The abandoned well will be plugged temporarily with a retrievable plug. The well itself will be filled with brine or with a corrosion inhibitor. This wellhead of the abandoned well will be monitored on a regular basis and the composition of the fluid will be checked. As oil floats on brine (or on the corrosion inhibitor) any leakage of oil through the plug will be seen immediately. | Monitoring of the abandoned well composition on a regular basis is included in the monitoring plan |
| Inspection_2 | Annular fluid composition monitoring | Inspection and Maintenance | The composition of the annular fluid of the oil well will be monitored at a regular basis. As oil floats on brine or on a corrosion inhibitor, any oil in the annulus can be easily observed at the well head, so any oil leakage from the oil tube to the annular space will be detected. | The annular fluid composition will be monitored on a regular basis. In the annular space between the oil tubing and the 7" casing, either brine or a corrosion inhibitor will be inserted. If leakage occurs from the oil tube to the annulus (via the 5 1/2 " casing) or from the cavern to the annulus (via the packer) this oil will enter the annulus. As oil floats on brine (or on the corrosion inhibitor) any leakage will be detected. | Monitoring of the annular fluid composition on a regular basis is included in the monitoring plan |
| Inspection_3 | Extra surveillance during football matches | Inspection | During football matches in the nearby stadium extra security surveillance will be planned | The Grolsch Veste, the football stadium of FC Twente, is located quite close to the industrial area where gasoil storage will take place. Therefor it is deemed necessary that during football matches extra security surveillance takes place at the industrial area near the caverns. | This will be implemented by the security surveillance company of the industrial area |
| Inspection_4 | MIT (fluids) (Deltares_A: 5.10.2) | Inspection | A fluid-MIT will be done to ensure there are no significant leaks in the well and that the mechanical components of the well function in a manner protective of the environment and human health. | During the preparation of the caverns for gasoil storage, an MIT will be performed. This test (Mechanical Integrity Test), which will be done for each well individually, will be performed by pumping an exactly measured quantity of oil into the well, so that the oil-brine-interface is in the uncased neck of the well. Then, pressure is built up by pumping in brine up to 150% of the expected operating pressures if possible, or as close to it as can be achieved. After brine pumping stops, the pressure will slowly decrease. After a certain amount of time, the oil is retrieved again and the quantity is measured exactly. Any missing oil indicates (significant) leakage of oil throug the last cemented casing, the packer, or the casing. | Specifications of the MIT procedure are included in the risk management plan. Results of the MIT's will be discussed with State Supervision of Mines (SodM) once available. |
| Inspection_5 | Pressure monitoring system (deviation signals roof collapse) (Deltares_A: 5.10.3) | Inspection | A pressure monitoring system will be installed. It monitors the pressure at the oil- and brine wellhead. A roof collapse will change these pressures due to a sudden change in the depth of the oil-brine-interface level | Pressure monitoring is implemented to detect a change in the depth of the oil-brine-interface level, which signals either leakage from the storage system or roof collapse in the cavern. The rate of pressure decline provides a good indication of the change in depth of the oil-brine-interface leve, and allows to distinguish between roof collapse and leakage. Pressures will be monitored at the oil and the brine wellheads. | A detailed description of the pressure monitoring system is included in the monitoring plan |
| Inspection_6 | Repeated sonar measurements (after every emptying of the cavern; every 5 yrs on average; at least 10 years after last measurement) | Inspection | Sonar measurements will be done after a full recovery of the stored oil, which is expected to be every 5 yrs on average. It will be done at least 10 years after the last measurement has taken place. | Sonar measurements are performed to monitor the shape and volume of the cavern. Measurements will be done through the oil well (as the brine well has a tubing down to the cavern floor) and can therefore only be done when the cavern is not under pressure, i.e. when all the oil has been taken out of the cavern and before new oil is put into it. On average a full recovery of the oil from the cavern is expected to occur every 5 to 10 years on averange and at least every 10 years. Significant differences between consecutive sonar measurements, for example due to roof collapse, will be detected. | Sonar measurement will form part of the regular maintenance operations in-between emptying and filling of a cavern and will therefore be incorporated in the maintenance plan. |
| Inspection_7 | Repeated wellhead performance monitoring and actions (plan-do-check-act) | Inspection and Maintenance | Wellhead integrity and performance is checked at a regular basis. Any irregularities will be noticed and acted upon. | At a regular basis | Regular integrity and performance checks of the wellhead will be incorporated in the monitoring plan |
| Inspection_8 | Security surveillance | Inspection | The industrial area has an active security surveillance | The wellhouses above the gasoil storage caverns are located on an industrial area. The roads in this area are under constant security surveillance, especially during the evening, the night and the early morning. The surveillance will be informed about specific risks with respect to the gasoil storage. | This will be implemented by the security surveillance company responsible for security of the industrial area |
| Inspection_9 | Shallow groundwater monitoring | Inspection | If leakage has occurred above the hydrological base, monitoring of the groundwater quality will be done at locations downstream of the leakage location. | If oil leakage has occurred at a level above the hydrological base, this might have affected the quality of shallow groundwater that can be used for consumption. Groundwater monitoring will be implemented to assess the level of contamination. Groundwater monitoring wells will be placed at one ore more locations,which will be selected on the basis of the shallow groundwater flow (size and direction), the size of the leak and the depth of the leak. | This aspect will be implemented in the form of a groundwater contamination remediation plan which will be made directly after a leak above the hydrological base is detected. The making of the groundwater contamination remediation plan will be incorporated in a 'What if leakage occurs' action plan. |

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| Inspection_10 | USIT (Deltares_A: 5.10.1) | Inspection | A USIT (Ultra Sonic Imager Tool) test will be used to test the quality of the cement bond at the cement/casing interface. | Good-quality cementation at the casing shoe and in the salt section above the cavern is a basic requirement for a tight storage system.To test the quality of the cement bond at the cement-casing interface and the quality of the 7" casing itself, a USIT (Ultra Sonic Imager Tool) test will be performed for each well. For several wells this has already been done, while for some wells it still must be done. Results of the USIT tests that were already performed indicate fair to good cement bond qualities, especially in the sections directly above the cavern roof. For wells with an incorrect LCCS depth or with a bad cementation or casing quality at the lowest level, a milling operation will take place and both the well section and the LCCS will be reinstalled. | The results of the USITs will be discussed with State Supervision of Mines (SodM) |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3f - Procedurele barrières

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Procedural_1 | Contractor management | Procedural | Only highly-qualified contractors will be used for work on the wellhead | | This aspect will be incorporated in the maintenance plan. |
| Procedural_2 | Driving instructions to reduce speed | Procedural | All drivers will be instructed to drive at reduced speed near the oil storage wellhead houses | All drivers of oil trucks that load or unload oil the caverns get a special training for this type of (un)loading. Part of this training will be the instruction to drive at reduced speed near all oil wells, to reduce the chance of a unwanted collision with a well house. | This aspect will be incorporated in the training program. |
| Procedural_3 | Hire experienced consultants | Procedural | Only highly qualified contractors will be used for the MIT | | This aspect will be incorporated in the maintenance plan. |
| Procedural_4 | Leaching according to mining plan | Procedural | As long as leaching in adjacent caverns is being done according to the mining plans, the pillar width will never become too small. Sonar measurements in caverns adjacent to oil storage caverns must be performed at intervals as specified in mining plans to ensure that the maximum cavern size is not exceeded. | Maintaining the pillar width (i.e. the distance between the wall of the oil storage cavern and the nearest adjacent cavern) is an important measure in maintaining pillar integrity. The minimum distance, i.e. the maximum size of adjacent caverns is known and is incorporated in the mining plans for these adjacent caverns (Good Salt Mining Practice). As the oil storage caverns have a higher risk (as they contain oil instead of brine) monitoring the size of adjacent caverns where salt mining is still going on is of great importance. At the moment salt mining is only going on in a limited number of caverns adjacent to the oil storage caverns. For these caverns extra attention will be paid to ensure that the size of the cavern is kept within allowable limits. | This aspect will be discussed with the salt mining operation of the brine field and will be incorporated in the monitoring plan |
| Procedural_5 | Obligation to wear Personal Protection Gear (PPGs) at well location | Procedural | During filling and emptying operations or maintenance, personell is obligated to wear Personal Protection Gear. | To reduce the risk of getting injured during loading and unloading of trucks, personell is obliged to wear Personal Protection Gear during all activities. | This aspect will be incorporated in the training program. |
| Procedural_6 | Standard working procedures | Procedural | Closing the valves will be incorporated in the standard working procedures | After having loaded or unloaded at a cavern, all valves have to be closed. This will be incorporated in the standard working procedure. This aspect will form part of the trainig program for oil truck drivers. | This aspect will be incorporated in the training program. |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3g - Barrières ter vermindering van het voorkomen van bedreigingen

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| ReductionInventory_1 | Communication plan incl. emergency response | Reduction in Inventory | To prevent any reputational damage to AkzoNobel and State supervision on Mines, a good communication plan must be developed in case of oil leackage. | In case of any breach of confinement due to leakage of oil, measures must be taken to minimize reputational damage, both for AkzoNobel (being the owner of the caverns) as for State supervision of Mines (being the responsible authority). Good communication towards all stakeholders is an important measure to reduce this damage. Therefore a good communication plan must be in place for when leakage occurs. | A communication plan will be written by AkzoNobel and Argos, but this is not part of the Risk Management Plan |
| ReductionInventory_2 | Design: cavern selection procedure aimed at minimizing presence of faults | Reduction in Inventory | During the selection procedure caverns with faults that are expected to threaten the integrity of the storage system were excluded from the selected caverns. | Salt is impermeable for fluids like oil. Measurements at salt caverns have indicated a permeability of 1,00E-05 mD to 1,00E-02 mD, and a hydraulic conductivity of 1,00E-11 to 1,00E-08. In faults, permeabilities are known to be higher. Generally, the permeability of permeable faults can be considered several orders of magnitude higher than that of the surrounding host rock. The effect of movement along normal faults on salt layers is different from that of other rock types. As a result of the viscous properties of rock salt, displacement along normal faults normally does not lead to brittle deformation and permeable faults in the salt layers. In faults zones with limited displacement, the throw will be accommodated within the salt by alterations in the crystal structure. Generally, it can be stated that the porosity and permeability of salt layers do not change significantly in such fault zones. Nevertheless, during the selection process caverns with faults with significant throw were excluded from the selected caverns. The detailed geological description of the selected salt caverns can be found in the report titled "Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)" by Deltares (2012). | This aspect was implemented in the cavern selection procedure. |
| ReductionInventory_3 | Design: cavern selection procedure ensuring sufficient pillar width | Reduction in Inventory | During the selection procedure caverns with insufficient distance to neighboring caverns were excluded from the selected caverns. | Maintaining the pillar width (i.e. the distance between the wall of the oil storage cavern and the nearest adjacent cavern) is an important measure in maintaining pillar integrity. The minimum distance, i.e. the maximum size of adjacent caverns is known and is incorporated in the mining plans for these adjacent caverns (Good Salt Mining Practice). During the selection process caverns with insufficient distance to neighboring caverns were excluded from the selected caverns. The detailed geological description of the selected salt caverns can be found in the Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC), Deltares (2012). | This aspect was implemented in the cavern selection procedure. |
| ReductionInventory_4 | Design: cavern selection procedure excludes non-Salt A contained caverns | Reduction in Inventory | Salt is impermeable for fluids like oil. During the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selected caverns. | Salt is impermeable for fluids like oil. Measurements at salt caverns have indicated a permeability of 1,00E-05 to 1,00E-02, and a hydraulic conductivity of 1,00E-11 to 1,00E-08. All selected caverns are antirely located within Salt A and during the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selected caverns. The detailed geological description of the selected salt caverns can be found in the Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC), Deltares (2012). | This aspect was implemented in the cavern selection procedure. |
| ReductionInventory_5 | Design: cavern selection procedure excludes potentially unstable caverns | Reduction in Inventory | During the selection procedure potentially unstable caverns were excluded from the selected caverns. | Some caverns within the AkzoNobel Hengelo brine field are known to be potentially unstable. This means that subsidence may occur above these caverns due to upward cavern migration after roof collapse. As such, potentially unstable caverns were excluded from the selection. A detailed geological description of the selected salt caverns can be found in the report titled "Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)" by Deltares (2012). | This aspect was implemented in the cavern selection procedure. |
| ReductionInventory_6 | Evacuating the oil from the storage system (if no repair is possible) | Reduction in Inventory | If no repair is possible, all oil will be evacuated from the cavern. | When repair of a leak from the cavern or the well is not possible, evacuation of the oil from the storage system is the only possibility to minimize further leakage of oil. If the location/depth of the leak is at cavern level and known, the oil-brine-interface level will be raised such that the leak is below this level. | This aspect will be incorporated in a remediation plan that will be developed as part of a 'What if leakage occurs' action plan. |
| ReductionInventory_7 | Groundwater remediation plan | Reduction in Inventory | A groundwater remediation plan will be made when significant oil spill occurs. Remediation will be performed according to this plan. | If oil leakage has occurred at a level above the hydrological base, or when a significant oil spill has occurred, soil and groundwater remediation must take place. Remediation must be done according to a well defined remediation plan, that is made directly after the spill or leak has been detected. It will primarily based on a investigation during which the size of the pollution is determined. | This aspect will be incorporated in a remediation plan that will be developed as part of a 'What if leakage occurs' action plan. |
| ReductionInventory_8 | Insurance to cover financial damage | Reduction in Inventory | Financial damage to AkzoNobel must be covered by a good insurance, one that covers the costs for remediation and follow-up. | Financial damage, e.g. in the form of remediation costs associated with oil spill or leakage, must be properly insured by AkzoNobel. | Before the start of the oil storage operation AkzoNobel will verify that the present insurance covers any potential financial damage related to oil storage (mitigating actions, remediation activities, value irretrievable oil, etc.) |
| ReductionInventory_9 | Oil-brine interface level measurements | Reduction in Inventory | As pressure monitoring is a very non-specific identifier for leakage, additional measurements must be performed in case of a significant change in pressure to find the root cause. An important measurement at cavern level is the oil-brine interface level measurement. | In case of a pressure drop at one of the pressure gauges, measuring the oil-brine-interface level gives additional information on the root cause of the change in pressure. By combining continuous pressure monitoring with periodic oil-brine-interface level measurements, valid information can be obtained on the location and the size of the leakage, such as e.g. whether the leak is above or below the oil-brine-interface level. | The oil-brine-interface level measurement technique will be explained in the monitoring plan. |

| | | | | | |
|---|---|---|---|---|---|
| ReductionInventory_10 | Oil spill remediation plan | Reduction in Inventory | An oil spill remediation plan will be made when significant oil spill occurs. Remediation will be performed following this plan. | If oil leakage has occurred at a level above the hydrological base, or when a significant oil spill has occurred, soil and groundwater remediation must take place. Remediation must be done according to a well defined remediation plan, that is made directly after the spill or leak has been detected. It will primarily based on a investigation during which the size of the pollution is determined. | Development of a remediation plan will be incorporated in a 'What if leakage occurs' action plan. |
| ReductionInventory_11 | Repair of the leak (depends on cause) | Reduction in Inventory | If the leakage occurs in the well, and can be localized, attempts will be made to repair the leak. | After detection of a leak, and after determination of the exact location of a leak, attempts will be made to repair the leak. If the leak is in the well below the groundwater base for instance, repair may be possible. If the leak is at cavern level, the cavern will most likely be emptied and abandoned. | Development of a plan to locate and repair a leak will be incorporated in a 'What if leakage occurs' action plan. |
| ReductionInventory_12 | Repair of the leak above groundwater base | Reduction in Inventory | If the leakage occurs above the groundwater base, the leak will be repaired, and remediation activities will start. | After detection of a leak, and after determination of the exact location of a leak, attempts will be made to repair the leak. If the leak is in the well above the groundwater base for instance, repair is most likely possible. | Development of a plan to locate and repair a leak will be incorporated in a 'What if leakage occurs' action plan. |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

# Bijlage 3h - Barrières die een scheiding in tijd of plaats betreffen

| Barrier nr. | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Separation_1 | Probability of a significant magnitude earthquake in Twente is extremely low (no active tectonism; no oil and gas production) | Separation (Time or Space) | In Twente the probability of an earthquake with a significant magnitude is extremely low as there is no no known active tectonism in the area. Also, there is no gas and oil production in the vicinity of the caverns, which excludes damage due to induced seismicity. | Earthquakes cause ground accelerations which may affect the oil storage caverns. Earthquakes can have a natural cause (i.e. tectonic movement along a fault) or be induced due to oil and gas production. Induced seismicity: as the distance to areas where oil and gas production is taking place is large (over 60 kilometers) any induced seismicity will not have an impact on the stability of the oil storage caverns in Twente. Naturally occurring earthquakes: tectonic movement along faults is only known in the most southern provinces of the Netherlands, i.e. in Brabant and Limburg, and across the border in Germany ("Roer valley graben system"), at distances of 80 km or more from Twente. Furthermore, if an earthqueake occurs, this will mainly affect the earth surface and will have negligible effect on the caverns at a depth of 450 meters, because the primary cause of damage during earthquakes are the are so-called Rayleigh surface waves, which propagatel along the earth surface. | No action required |
| Separation_2 | Distance to drinking water extraction points | Separation (Time or Space) | The wells are located far away from any drinking water extraction locations. | When leakage of oil in the subsurface has occurred and groundwater has become polluted, the polluted groundwater will travel through the subsurface by groundwater flow. Depending on the permeability, porosity and differences in groundwater level, this flow has a magnitude of several meters up to approximately 100 meters per year. As the wells and caverns are located at large distances from drinking water extraction points (several kilometers) it will take tens to hundreds of years before polluted groundwater will arive at the drinking water extraction location and then only if the groundwater flow is in the right direction. | No action required |
| Separation_3 | Distance to water extraction points from deep aquifers (if any) | Separation (Time or Space) | The wells are located far away from any locations where groundwater is extracted from deep aquifers. | When leakage of oil in the subsurface has occurred and groundwater has become polluted, the polluted groundwater will travel through the subsurface due to groundwater flow. The magnitude of this flow depends on the permeability, porosity and differences in groundwater level. In deep acquifers this flow normaly has a magnitude of several meters up to tens of meters per year. As the wells and caverns are located at large distances of deep groundwater extraction points (several kilometers) it will take hundreds of years before polluted groundwater will arive at the groundwater extraction location and then only if the groundwater flow is in the right direction. | No action required |
| Separation_4 | Location outside risk area with respect to vandalism | Separation (Time or Space) | The area 'De Marssteden' is not located near a city centre or near an area with many pubs, etc. | The area 'De Marssteden' is not located near the city centre of Enschede, where many pubs and clubs are present, and there is no other area with pubs nearby. This lowers the risk of vandalism. | No action required |
| Separation_5 | Multiple impermeable layers (claystone) between cavern and known aquifers | Separation (Time or Space) | If leakage has occured below the groundwater base, then the presence of multiple impermeable claystone layers between the leakage point at depth and the aquifers prevents contamination of these aquifers for a long period of time (tens of thousands of years, if at all) | When leakage of oil in the subsurface has occurred at a deep level (i.e. at cavern level), it will take tens of thousands of years for the oil to reach an aquifer due to the presence of several thick impermeable layers between the point of leakage and the aquifers. A detailed geological description of the selected salt caverns can be found in the report titled "Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)" by Deltares (2012). | No action required |
| Separation_6 | Wellbore (casing, cementation) | Separation (Time or Space) | In case of failure of the packer, the casing and cementation of the well form important barriers reducing the probability of leakage of oil into the surrounding rock and the environment. | Both at the oil well and at the brine well, a 5 1/2" inner tube will be placed within the 7" last cemented casing, with packers at the downside of the annulus. This means that always two barriers are present between the oil in the inner tube and the cementation (i.e. the packer and 7" casing), and that even three barriers are present between the oil and the overburden rock (i.e. packer, 7" casing and cement bond). Reader is referred to the storage plan for an overview of the well design. | This design aspect will be implemented in the detailed engineering design which must be approved by State Supervision of Mines (SodM) before the start of the oil storage preparations |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'monitoring plan' |
| | See 'maintenance plan' |
| | See 'What if leakage occurs' action plan |
| | See 'training program' |

Akzo Nobel Industrial
Chemicals B.V.

# Risicobeheersplan
# *Achterblijven van Olie na Abandonnering*

AkzoNobel
Tomorrow's Answers Today

From Akzo Nobel Industrial Chemicals – Mining Technology Department
Date 09-01-2013
Subject Risicobeheersplan m.b.t. achterblijven van olie na abandonnering

## Introductie

AkzoNobel heeft, op basis van overleg met experts, input van TNO en Deltares, eigen inzicht en overleg met Staatstoezicht op de Mijnen (SodM), voor de olieopslag in zoutcavernes een zogenaamde "Bowtie" risico analyse uitgevoerd voor de twee belangrijkste gevaren:

1. Verspreiding van olie in de ondergrond als gevolg van lekkage van olie uit het opslagsysteem, i.e. vanuit de caverne of een van de boorgaten (zie Bijlage 14 bij het Opslagplan);
2. Achterblijven van een aanmerkelijke hoeveelheid olie na beëindiging van de olieopslag (zie Bijlage 15 bij het Opslagplan).

Voorliggend risicobeheersplan gaat in op het gevaar dat er na beëindiging van de olieopslag, dus na de laatste leging, een significante hoeveelheid olie in de caverne achterblijft, die zonder extra maatregelen niet meer terug te nemen is. In soortgelijke vorm is ook een risicobeheersplan bij het opslagplan bijgevoegd dat ingaat op het gevaar van lekkage van olie uit het opslagsysteem en verspreiding in de ondergrond (Bijlage 16).

De risico analyse geeft een goed overzicht van de afzonderlijke bedreigingen ("threats") en de gevolgen daarvan ("consequences"). Barrières zijn benoemd die de kans dat een bedreiging daadwerkelijk optreedt verkleinen of die de gevolgen van een eventueel toch optredend gevaar beperken. Voor sommige barrières zijn escalatiefactoren benoemd (die de functionaliteit van een barrière verminderen) waarvoor vervolgens ook weer extra barrières zijn benoemd.

De benoemde barrières zijn ingedeeld in typen en zijn verder uitgewerkt. Sommige barrières vallen buiten de invloed van AkzoNobel, andere dienen nader te worden uitgewerkt in specifieke delen van voorliggend risicobeheersplan, zoals in het monitoringsplan of in het onderhoudsplan. Daarnaast zijn er nog enkele barrières die in technisch opzicht nader moeten worden uitgewerkt, zoals de uitvoering van tests die voorafgaand aan de olieopslag worden uitgevoerd en waarvoor geldt dat het wel of niet goed doorstaan ervan een cruciale factor is alvorens olieopslag in de cavernes kan worden gestart. Deze uitwerking zal gedaan worden in overleg met SodM.

# Inhoudsopgave

# 1 Bowtie ‘Irretrievable Oil at Abandonment’

## 1.1 Inleiding

In dit hoofdstuk beschrijven we op welke manier de risico’s m.b.t. het achterblijven van een aanmerkelijke hoeveelheid olie na beëindiging van de olieopslag zijn geïnventariseerd, en welke stappen daarvoor zijn doorlopen. Het resultaat van de risico inventarisatie is weergegeven in de Bowtie “Irretrievable Oil at Abandonment” (Bijlage 15).

## 1.2 Workshop met experts

In een in december 2010 door Deltares en AkzoNobel georganiseerde workshop is door experts uit de verschillende relevante vakgebieden (geologie van Twente, mechanisch gedrag van zout, oplosmijnbouw, ondergrondse opslag, risico analyse in relatie tot stabiliteit van cavernes en gerelateerde bodemdaling, well engineering, hydrogeologie, bodem- en water kwaliteit, en vloeistofstroming in poreuze media) een eerste inventarisatie gemaakt van de risico’s m.b.t. achterblijven van olie in de caverne. Een lijst van experts is opgenomen in Appendix C van Bijlage 11 van het opslagplan. Ter voorbereiding op deze workshop werd de experts gevraagd om hun visie te geven op mogelijke gevaren en de gerelateerde risico’s in de vorm van ontwikkelscenario’s na beëindiging van de opslag en hun mogelijke effecten. Aanvullend aan deze workshop is door Deltares en TNO een literatuurstudie gedaan om de geïnventariseerde risicoscenario’s te controleren en waar nodig aan te vullen.

## 1.3 Generieke Risico Inventarisatie door Deltares/TNO

Op basis van de tijdens de workshop gemaakte inventarisatie zijn de risico’s door Deltares en TNO in de vorm van een rapport (Bijlage 11 van het opslagplan) verder technisch uitgewerkt op generiek niveau, d.w.z. op een niveau geldend voor zoutcavernes in de regio Twente. In het rapport wordt voornamelijk aandacht besteed aan de risico’s m.b.t. lekkage van olie en verspreiding in de ondergrond. Echter, de lange-termijn lekdichtheid van een zoutcaverne gevuld met olie komt ook aan bod in het kader van het risico dat er olie achterblijft in de caverne na beëindiging van de opslag. Tevens kan gesteld worden dat een groot deel van de risicoscenario’s m.b.t. lekkage van olie en verspreiding in de ondergrond ook relevant zijn op langere termijn als olie in de caverne achterblijft. De aard en kans van optreden van de oorzaken die kunnen leiden tot een lekkage worden in het rapport in detail beschreven, en de effecten worden gekwantificeerd d.m.v. een modelstudie van de verspreiding van olie in de ondergrond voor een generieke caverne in Twente. Vervolgens is voor een aantal voorname risicoscenario’s een semikwantitatieve risico analyse uitgevoerd. In de selectie van de scenario’s zijn de experts nauw betrokken, d.w.z., aan hen is gevraagd de selectie te controleren op relevantie en volledigheid, en om additionele scenario’s te beschrijven indien nodig. Op basis van de resultaten van de semikwantitatieve risico analyse is door Deltares en TNO een checklist samengesteld waarmee de geschiktheid van een caverne voor opslag van olie kan worden getoetst.

## 1.4 Caverne-Specifieke Risico Analyse door Deltares

Vervolgens is door Deltares voor 4 geselecteerde cavernes (cavernes met nummer 367, 372, 469, en 472) een caverne-specifieke risico analyse uitgevoerd op basis van alle over de cavernes beschikbare informatie over historie, status, vorm, inhoud, en lokale geologie. Hierin wordt ook nader ingegaan op de vorm van de cavernedaken, en de hoeveelheid olie die zich naar verwachting in de welvingen nestelt en die zonder specifieke mitigerende maatregelen niet terug kan worden gehaald. Tevens is voor iedere caverne een modelstudie gedaan waarin voor de voorname risicoscenario's de effecten van optreden zijn gekwantificeerd in de vorm van hoeveelheid en verspreiding van olie in de ondergrond. De rapportage waarin deze risico analyse in detail wordt beschreven is in de vorm van een bijlage (Bijlage 12) opgenomen bij het Opslagplan.

## 1.5 BowtieXP software

Op basis van alle beschikbare informatie over de risico's m.b.t. opslag van olie in zoutcavernes in Twente is vervolgens met de Bowtie XP software de Bowtie voor het achterblijven van olie in het opslagsysteem na beëindiging van de opslag opgesteld.

## 1.6 Bespreking met Staatstoezicht op de Mijnen

De conceptversie van de Bowtie is op 14 november 2012 gepresenteerd aan SodM en is gezamenlijk doorlopen. Belangrijkste conclusie was dat de concept-Bowtie een goed en gedetailleerd beeld gaf van de risico's en de barrières. Naar aanleiding van de opmerkingen van SodM is de Bowtie nog op diverse punten aangepast. Dit betrof m.n. het aanpassen van de naam van enkele hazards, en de opname van enkele additionele maatregelen. Tevens is een verdiepingsslag gemaakt door de toevoeging van 'escalatiefactoren' bij al benoemde barrières en de benoeming van extra barrières om de kans op het optreden van dergelijke escalaties te verminderen.

## 1.7 De Bowtie "Irretrievable Oil at Abandonment"

De definitieve Bowtie voor het achterblijven van olie in het opslagsysteem na beëindiging van de opslag (top event "Irretrievable Oil at Abandonment") is weergegeven in Bijlage 15 bij het Opslagplan. Een tekstuele versie is als Bijlage 1 toegevoegd bij voorliggend risicobeheersplan.

# 2 Barrières

## 2.1 Inleiding

In dit hoofdstuk geven we een overzicht van alle barrières in de Bowtie "Irretrievable Oil at Abandonment". De verschillende typen barrières die er zijn worden beschreven, de aanwezige barrières worden gerangschikt naar type, en van iedere barrière wordt een gedetailleerde beschrijving gegeven.

## 2.2 Aanwezige barrières

In totaal zijn er 13 unieke barrières benoemd. Deze komen alle minimaal één en maximaal 3 keer voor in de Bowtie voor het achterblijven van olie na beëindiging van de opslag. Bijlage 2a bij dit risicobeheersplan is een overzicht waarin wordt aangegeven hoe vaak elke barrière voorkomt en wat voor type het betreft (zie paragraaf 2.3). Bijlage 2b toont voor elke bedreiging en voor elke consequentie welk type barrières er zijn ingesteld. Indien een bedreiging veel verschillende typen barrières kent is dit een indicatie dat het risico dat deze bedreiging tot gevaar leidt op veel verschillende manieren geminimaliseerd wordt.

De belangrijkste barrières in deze Bowtie zijn de barrières die de kans dat er na beëindiging van de opslag olie achterblijft in welvingen in het dak vermindert:

***1. "Leaching of roof pockets prior to storage"***

Voor caverne 367 is op basis van sonarmetingen bepaald dat er ongeveer 13.000 $m^3$ olie in welvingen in het dak zal gaan zitten. Omdat dit een zeer grote hoeveelheid is, zal direct na de verlening van de vergunningen gestart worden met het weg logen van de welvingen, en vóórdat de boorgaten worden omgebouwd voor opslag. Dit gebeurt op dezelfde manier als waarop pekel is gewonnen uit de caverne tijdens de winning van zout (conventionele oplosmijnbouw), zij het met een aanmerkelijk dikkere oliedeken om er zeker van te zijn dat alle welvingen in het dak volledig gevuld zijn. De dikte van de oliedeken wordt vervolgens met kleine stappen verminderd, waardoor steeds de onder de oliedeken uitstekende delen van het dak zullen weglogen. De uit de welvingen vrijgekomen olie wordt uit de caverne gepompt. Uiteindelijk ontstaat zo een caverne met een vlak dak waarin nauwelijks tot geen olie achterblijft. De totale tijd die nodig is om het dak vlak te logen wordt geschat op 250 dagen. Een gedetailleerde uitwerking van de procedure van het vlak logen van het dak is door DEEP Underground Engineering gemaakt (zie Bijlage 18 bij het opslagplan).

Op dezelfde manier als hierboven beschreven voor caverne 367 zal ook voor caverne 469 direct na verlening van de vergunningen gestart worden met het vlak logen van het dak. In dit geval zal naar verwachting ongeveer 2.000 $m^3$ olie in welvingen in het dak gaan zitten. Hoewel dit naar verhouding een relatief geringe hoeveelheid is, duurt het bijna drie jaar om het dak volledig vlak te logen, en daarom wordt ook voor deze caverne direct gestart met vlak logen.

***2. "Leaching of roof pockets after last oil retrieval by Argos"***

Voor cavernes 372 en 472 is op basis van sonarmetingen bepaald dat er respectievelijk 2.000 $m^3$ en 2.400 $m^3$ olie in welvingen in het dak zal gaan zitten, en dat het respectievelijk 250 en 150 dagen duurt voordat het dak volledig vlak is geloogd en alle olie uit de welvingen is teruggewonnen. Omdat dit naar verhouding relatief geringe hoeveelheden zijn, en de tijdsduur voor terugwinning relatief kort is, zal voor deze cavernes het dak na teruglevering van de laatste opgeslagen olie aan Argos vlak worden geloogd. Om dit te kunnen doen zullen de boorgaten na de laatste teruglevering weer worden omgebouwd tot boorgaten voor reguliere pekelwinning (zie Bijlage 18 bij het opslagplan).

Drie barrières komen vaker dan één keer voor:

***1. "Mass balance calculations based on oil in/out and brine in/out"***
Deze barrière komt 3 keer voor. Een goede administratie van de hoeveelheid in- en uitgaande olie en pekel is van groot belang voor massabalans berekeningen. Een significant verschil tussen de hoeveelheid olie die de caverne is ingegaan en de hoeveelheid de er is uitgehaald tijdens een volledige leging is een sterke indicatie dat er olie in de caverne gevangen zit, of, in het ergste geval, dat er olie is weggelekt.

***2. "Additional leaching to retrieve oil from walls"***
Deze barrière komt 2 keer voor. Olie die in de loop der jaren enige millimeters in de wanden van de caverne is gedrongen of vastzit in onregelmatigheden in de wanden kan mogelijk door middel van logen (circulatie met zoet water zodat zout met daarin de olie oplost) uit de wand losgemaakt worden. Deze losgeweekte olie kan via de boorgaten worden teruggehaald.

***3. "Circulate brine through cavern to retrieve oil from wells"***
Deze barrière komt 2 keer voor. Olie die aan de wanden van de caverne plakt kan mogelijk door middel van circulatie van pekel van de wand losgemaakt worden. Deze losgeweekte olie kan via de boorgaten worden teruggehaald.

De andere barrières komen elk slechts één keer voor.

## 2.3 Typen barrières en gedetailleerde beschrijving

In totaal worden 6 typen barrières onderscheiden:

### 2.3.1 Administratieve barrières

Dit zijn barrières die op een administratieve wijze zorgen voor extra controle en daarmee voorkomen dat eventuele bedreigingen daadwerkelijk een gevaar gaan vormen. Voorbeelden zijn de Mijnbouwwet- en regelgeving en de wet- en regelgeving op het gebied van grondwateronttrekking. Deze vallen buiten de invloed van AkzoNobel. Ook het interne systeem waarmee de in- en uitgaande stromen olie en pekel geregistreerd gaan worden is een administratieve barrière. Deze administratie is van groot belang om te weten hoeveel olie er nog in de caverne aanwezig is (bijvoorbeeld na beëindiging van de opslag), maar is ook van groot belang om de correlatie te kunnen maken tussen de sonarmetingen en de olie-pekelspiegel metingen. Indien de olie-pekelspiegel zich op een andere diepte bevindt dan op basis van de sonar en het geadministreerde olievolume verwacht wordt is sprake van een ongewenste situatie die nader onderzoek vereist.

Bijlage [3a] toont de onderscheiden administratieve barrières

### 2.3.2 Ontwerpbarrières

Er zijn 2 barrières die zijn opgenomen in het ontwerp van het opslagsysteem.

Dit zijn van nature of vanuit de natuurkunde aanwezige barrières die een rol hebben gespeeld bij de selectieprocedure waarmee de uiteindelijke opslagcavernes geselecteerd zijn, en deels zijn het technische ontwerp-aspecten, die het ontstaan van een bedreiging (helpen te) voorkomen.

Bijlage [3b] toont de onderscheiden barrières die voortkomen uit het ontwerp, of daaraan gerelateerde zaken.

### 2.3.3 Barrières op het gebied van inspectie

Onder dit type valt uitsluitend de sonarinspectie die wordt uitgevoerd als er wordt geconstateerd dat niet alle olie die in de caverne is ingebracht er uit terug komt. Zie Bijlage 3c.

### 2.3.4 Barrières op het gebied van uitvoering

Bijlage [3d] toont de onderscheiden barrières op het gebied van uitvoering en onderhoud. Dit betreft die activiteiten die, anders dan het voorafgaand aan of na afloop van de olieopslag vlak logen van het cavernedak, ervoor zorgen dat niet terugneembare olie toch terug kan komen. Dit betreft dan olie die in het dak of de wanden van de caverne is gedrongen of hieraan vastgekleefd zit. Dit kan mogelijk door logen (circuleren van zoet water), waardoor het buitenste stukje cavernewand oplost, of door circuleren van pekel door de caverne.

### 2.3.5 Barrières die de kans op het optreden van een bedreiging verminderen of de effecten na optreden verminderen

In deze categorie bevinden zich die barrières die duidelijk de kans op het optreden van een bepaalde bedreiging verminderen of die de gevolgen van het optreden ervan verminderen. Hieronder valt het voorafgaand aan de olieopslag of na afloop van de olieopslag vlak logen van het caverne dak, zoals dat bij een aantal cavernes zal gebeuren (zie sectie D3 van het Opslagplan).

Bijlage [3e] toont de onderscheiden barrières die het vóórkomen van een bedreiging verminderen.

### 2.3.6 Barrières die een scheiding in plaats of tijd betreffen

In deze categorie vallen die barrières die de niet terugneembare olie nadrukkelijk in plaats of tijd scheiden van het bedreigde. Hieronder valt de afstand tussen drink- en grondwateronttrekkingen en de opslagcavernes, waardoor het achterblijven van olie een uiterst gering restrisico oplevert voor de volksgezondheid (zie Bijlage 3f).

# 3 Overzicht van nog aan te leveren en te bespreken documenten

## 3.1 Inleiding

In dit hoofdstuk wordt aangegeven op welke punten nog nadere detaillering zal plaatsvinden.

## 3.2 Nog aan te leveren en te bespreken documenten

### 3.2.1 Definitief Ontwerp boorgaten en boorgatafsluiter

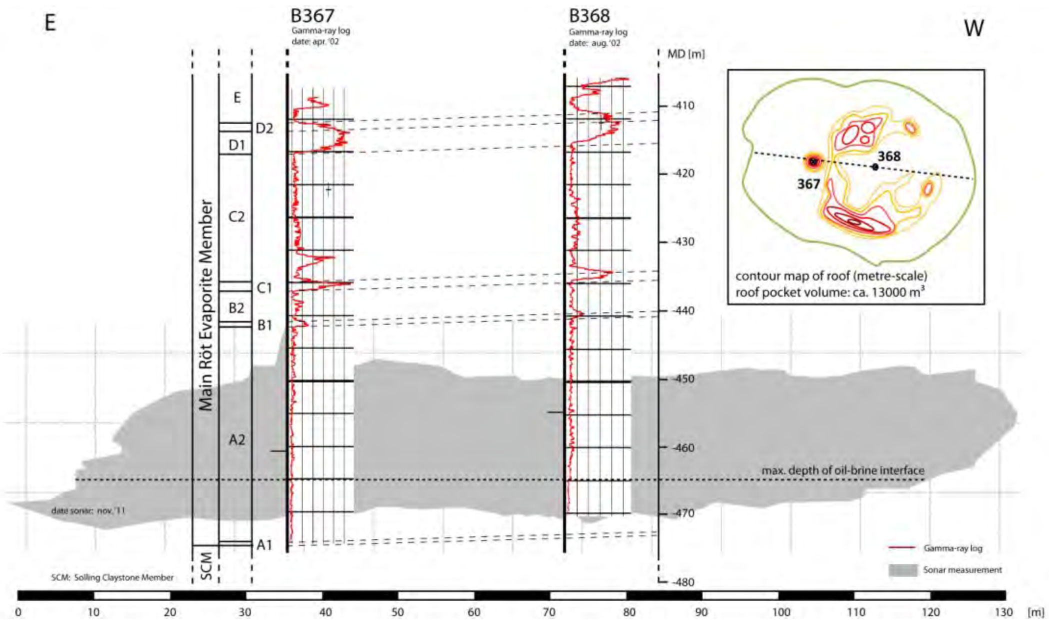
**Diepteligging olie-pekelspiegel boven de cavernevloer**

Het diepst bereikbare niveau van de olie-pekelspiegel is de onderzijde van de pekelbuis, omdat, als er wordt doorgegaan met olietoevoer, er door de pekelbuis olie naar boven komt. Op dat moment sluiten automatisch de olietoevoer en de pekelafvoer (zie hierna). De diepte van de opening van de pekelbuis is tijdens de inbouw te kiezen. Deze dient echter wel afgestemd te zijn op de cavernegeometrie. Bij de bepaling van deze diepte is rekening gehouden met de volgende aspecten:

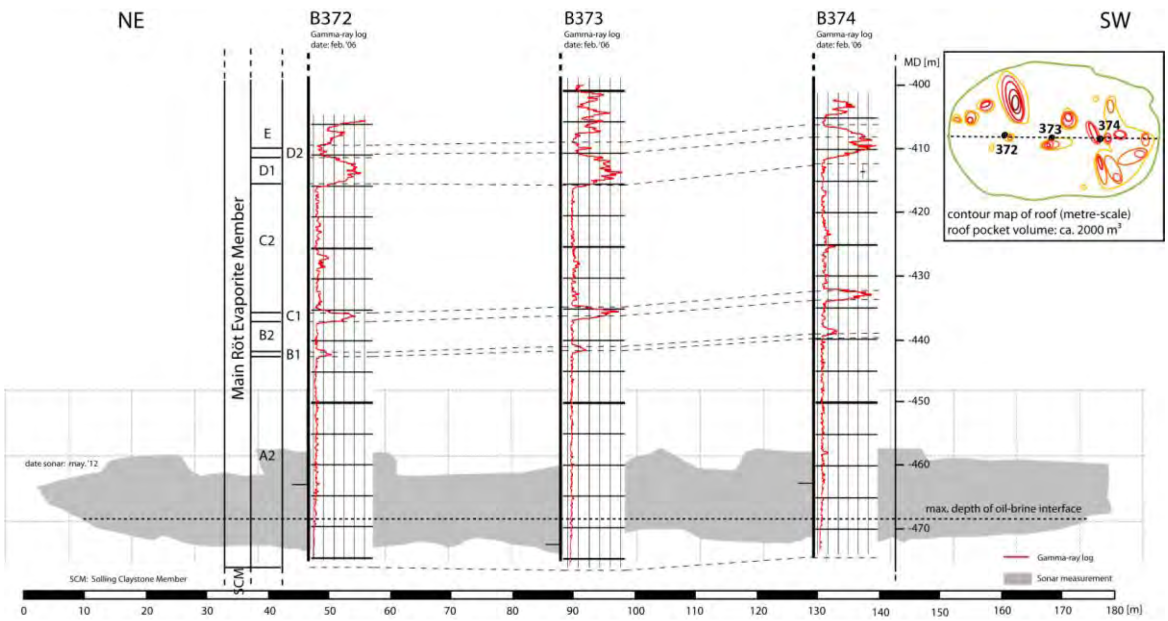
- Het volume aan olie, dus het cavernevolume boven het gekozen niveau. Dit dient tenminste 100.000 $m^3$ te zijn (contractuele verplichting);
- De diepteligging en het verloop van de cavernevloer;
- De samenstelling van de cavernevloer; bestaat deze uit ondoordringbaar zout of ligt er een doordringbare laag onoplosbaar materiaal (sump);
- De eventuele aanwezigheid van een nog intacte ondoordringbare zoutlaag tussen het diepste, ooit bereikte caverneniveau en de bovenzijde van de doordringbare Solling formatie.

De voorlopige olie-pekelspiegel niveaus zijn in de figuren 4.1, 4.2, 4.3, en 4.4 weergegeven. Alleen in het geval van caverne 472 ligt een klein deel van de cavernevloer in de olie. Uit oude sonarmetingen is echter vastgesteld dat er in dit deel van de caverne nog een dikke zoutlaag aanwezig is tussen de huidige cavernevloer en de top van de Solling formatie.

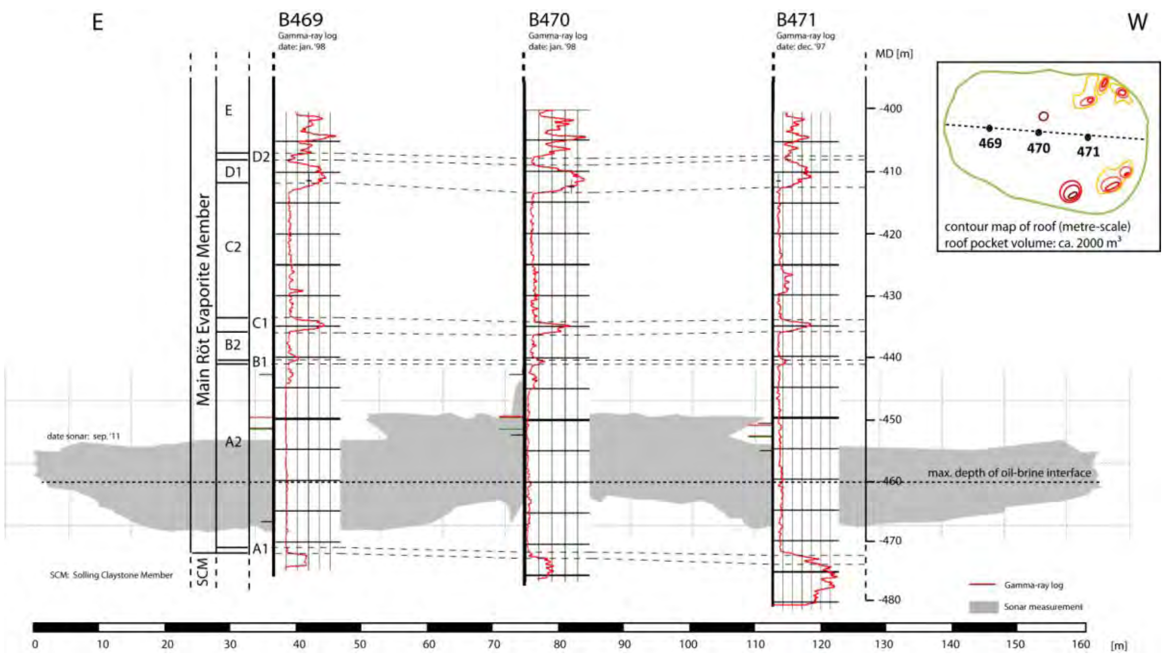
De diepteligging van de olie-pekelspiegel zal voorafgaand aan de eerste vulling van de cavernes aan SodM worden voorgelegd.



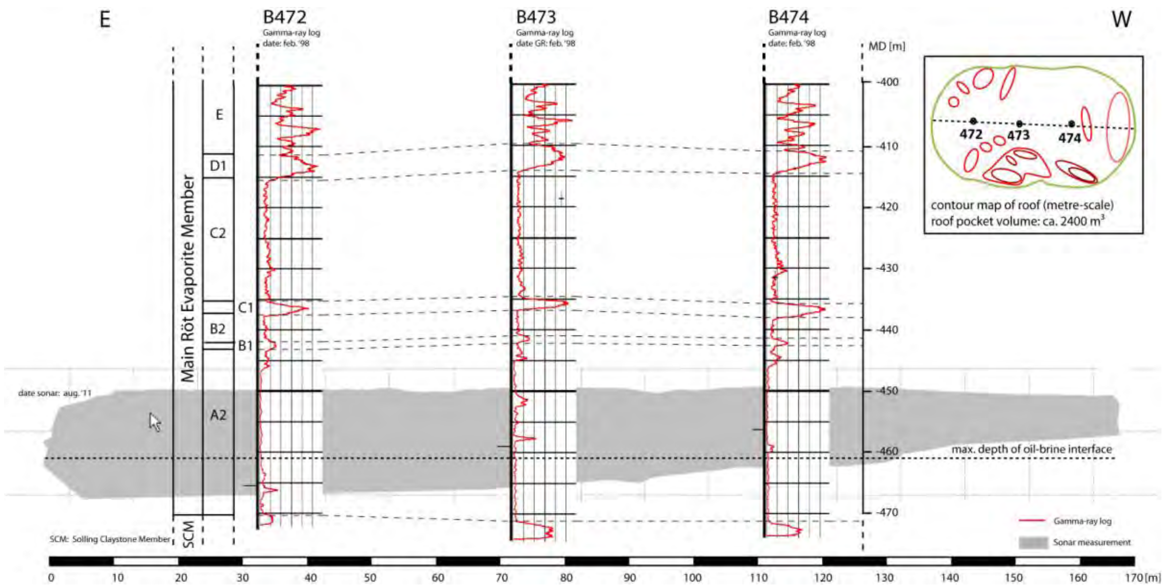

*Figuur 4.1: sonarbeeld van caverne 367 met daarin aangegeven de diepteligging van de olie-pekelspiegel.*




*Figuur 4.2: sonarbeeld van caverne 372 met daarin aangegeven de diepteligging van de olie-pekelspiegel.*




Figuur 4.3: sonarbeeld van caverne 469 met daarin aangegeven de diepteligging van de olie-pekelspiegel.




Figuur 4.4: sonarbeeld van caverne 472 met daarin aangegeven de diepteligging van de olie-pekelspiegel.

# 4 Deelplannen risicobeheersing

## 4.1 Administratief plan

**Olie-pekel-administratie**
AkzoNobel en Argos houden een olie- en pekeladministratie bij. Daarin wordt exact bijgehouden hoeveel olie er de caverne in en uit is gegaan en hoeveel pekel er de caverne in en uit is gegaan. Zo is er altijd een exact inzicht in de in de caverne aanwezige hoeveelheid olie. Dit is ook de hoeveelheid die er bij het volledig legen van de caverne weer uit moet komen. Een afwijking hiervan kan twee oorzaken hebben:

1. Olielekkage tijdens opslag;
2. Olie in onbereikbare welvingen in het caverne dak.

Voorafgaand aan de eerste vulling zal een verder uitgewerkt protocol voor de administratie aan SodM worden overlegd.

**Calibratie van geschat volume in aanwezige welvingen in het dak**
De nauwkeurige administratie van ingaande olie biedt, ten tijde van de eerste vulling, een belangrijke mogelijkheid om de laatste sonarmeting, die kort voor de eerste vulling gemaakt wordt, te toetsen, in het bijzonder op het volume aan olie dat zich nestelt in welvingen in het dak. Op basis van deze sonar kan worden bepaald op welke diepte de olie-pekelspiegel moet staan na een bepaalde hoeveelheid ingebrachte olie, bijvoorbeeld na 10.000 $m^3$, na 20.000 $m^3$, etc. Deze dieptes kunnen vergeleken worden met de daadwerkelijke diepteligging zoals bepaald m.b.v. de olie-pekelspiegel meting. De belangrijkste redenen voor afwijkingen zijn:

1. Aanwezigheid van extra welvingen in het dak die door de sonar niet worden "gezien". Dit zal al snel duidelijk worden, bij de eerste 10.000 $m^3$ olie die ingepompt wordt;
2. Een groter dan verwachte radius van de caverne (voortdurend langzamere daling van het olie-pekelspiegel niveau dan verwacht).

Op deze wijze ontstaat een goed inzicht in de betrouwbaarheid van de sonarmetingen, in de exacte caverne vorm en in de aanwezigheid van welvingen in het dak en het volume aan olie dat zich hier in nestelt.

## 4.5 Procedure beëindiging opslag

Bij beëindiging van de olieopslag dienen een aantal stappen te worden doorlopen die ertoe leiden dat:

1. Er een goed en betrouwbaar inzicht is in de hoeveelheid olie die er eventueel in de caverne is achtergebleven;
2. Er een goed en betrouwbaar inzicht is in de locatie waar de achtergebleven olie zich bevindt (i.e. in dakwelvingen, in de sump, in of tegen de wand, etc.);
3. Er een volgorde kan worden bepaald van de te nemen maatregelen om de olie

alsnog terug te kunnen krijgen. Deze maatregelen zijn, in waarschijnlijk toe te passen volgorde:

a. Uitlogen van dakwelvingen conform het (aangepaste) dakoptimalisatie uitloogproces;
b. Het circuleren van pekel door de caverne;
c. Het inpompen van zoet water en uitpompen van pekel t.b.v. het beperkt logen van de wanden voor die cavernes die nog niet de maximaal toegestane diameter hebben bereikt;

4. De gevolgen van de niet-terugneembaarheid van de olie voor eventueel bedreigde objecten wordt geminimaliseerd. Daartoe behoren onder andere:

- Opstelling en inwerkingtreding van het communicatieplan
- Opstelling bodemverontreinigingsrapport
- Opstelling van een saneringsplan, als sanering mogelijk is

De verder uitgewerkt procedure voor de beëindiging van de opslag wordt voorafgaand aan de eerste vulling aan SodM overlegd.

## Bijlagen

AkzoNobel
Tomorrow's Answers Today

## 1. Tekstuele versie van de Bowtie “Irretrievable Oil at Abandonment”

# Hazard Specification Sheet
## Case: Gasoil Storage Hengelo
## Hazard: Storage of Gasoil in a Salt Cavern
## Top Event: Gasoil is Irretrievable at Abandonment

| | |
|---|---|
| **Hazard name:** | storage of gasoil in a salt cavern |
| **Location:** | CLOVIS (Gasoil Storage Hengelo) |
| **Top event:** | gasoil is irretrievable from cavern at abandonment |

**Threats**

| Threat | | | |
|---|---|---|---|
| | **Barrier - Accountable**<br>**»Activity - Responsible** | | |
| | | **Escalation Factor** | |
| | | | **Barrier - Accountable**<br>**»Activity - Responsible** |
| • oil is trapped in pockets in roof | | | |
| | • asap leaching of roof pockets<br>After the storage plan and related oil storage permits have been granted, roof pockets will be leached, to reduce the pocket volume (i.e. the volume of potentially irretrievable oil). This will be done for Cavern 367 which has a high pocket volume of 14.000 m3. | | |
| | **• mass balance calculations based on oil in/out and brine in/out**<br>A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantity of oil that went into the cavern and that comes out of the cavern at the end signals oil trapped in roof pockets. | | |
| | | • pocket volume differs from assumed volume based on most recent sonar measurement | |
| | | | • Measure oil level during first filling operation after given filling volume (for example after 10.000 or 20.000 m3) to check reliability and accuracy of sonar measurement<br>The oil level will be measured at several moments during first filling of the cavern, for example after 10,000 m3, after 25,000 m3, etc. Comparing the expected oil-brine level with the actual level gives information on the reliability and accuracy of the sonar measurements. Also it gives insight in the presence of any unknown roof pockets. |
| | • leaching of roof pockets after last oil delivery<br>If, at the last oil delivery, not all stored oil is retrieved, roof pockets will be leached, to reduce the pocket volume and to be able to retrieve all oil from the roof pockets, This will be done for Caverns 372 and 472. | | |
| | | • leaching of roof might encounter problems (insoluble rock benches, unleachable pockets) | |
| | | | • expel oil with a gas (nitrogen, compressed air)<br>If also after leaching of the roof not all oil is retrieved, it can be considered to expel the last quantities of oil by a gas, like nitrogen or compressed air. |
| • oil is sticking to cavern walls/roof | | | |
| | • mass balance calculations based on oil in/out and brine in/out<br>A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantiy of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets). | | |
| | • circulate brine through cavern to retrieve oil from wells<br>By circulating brine through the storage cavern oil that is sticking to the wall might go into suspension. After a period of rest, the oil can be retrieved from the oil well. | | |
| | • additional leaching to retrieve oil from walls<br>By additional leaching (circulation of fresh water) oil that is sticking to the wall might go into suspension. After a period of rest, the oil can be retrieved from the oil well. | | |
| • oil has permeated into cavern walls or roof | | | |
| | • mass balance calculations based on oil in/out and brine in/out<br>A good administration of in and out flowing oil and in and out flowing brine will provide the necessary information for mass balance calculations. Any differences between the quantiy of oil that went into the cavern and that comes out of the cavern at the end signals leakage of oil (or oil trapped in roof pockets). | | |
| | • circulate brine through cavern to retrieve oil from wells<br>By circulating brine through the storage cavern oil that is sticking to the wall might go into suspension. After a period of rest, the oil can be retrieved from the oil well. | | |

| | |
|---|---|
| | • additional leaching to retrieve oil from walls<br>By additional leaching (circulation of fresh water) oil that is sticking to the wall might go into suspension. After a period of rest, the oil can be retrieved from the oil well. |

**Consequences**

| | | | |
|---|---|---|---|
| **Consequence** | | | |
| | **Barrier - Accountable**<br>**»Activity - Responsible** | | |
| | | **Escalation Factor** | |
| | | | **Barrier - Accountable**<br>**»Activity - Responsible** |
| • retarded contamination of aquifers associated with residual oil in cavern | | | |
| | • design: salt above cavern (impermeable)<br>Salt is impermeable for fluids like oil. During the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selected caverns. | | |
| | • multiple impermeable layers (claystone) between cavern and known aquifers<br>If leakage has occurred below the groundwater base, the presence of multiple impermeable claystone layers between the leakage depth and any used aquifers, prevents contamination of these aquifers. | | |
| | • distance to water extraction points from deep aquifers (if any)<br>The wells are located far away from any drinking water extraction locations. | | |
| | | • new groundwater extraction points (drinking water, geothermal) | |
| | | | • governmental regulations<br>Regulations with respect to new groundwater extractions should prevent new groundwater extraction locations too close to the wells. |
| • violation of storage permit | | | |
| • reputational damage | | | |
| | • communication plan incl. emergency response<br>To prevent any reputational damage to AkzoNobel and State Supervision of Mines, a good communication plan must be developed in case of oil leakage. | | |
| • financial loss | | | |
| | • insurance to cover financial damage<br>To prevent any financial damage to AkzoNobel a good insurance must be effective in case of a volume of oil is irretrievable. | | |

## 2. Overzicht van barrières en het aantal voorkomens naar type

| *Barrier* | *# Times occurring* | *Barrier type* | *Description* |
|---|---|---|---|
| Additional leaching to retrieve oil from walls | 2 | Operations and Maintenance | By additional leaching (circulation of fresh water) oil that is sticking to the wall may be retrievable. After a period of rest, the oil can be retrieved from the oil well. |
| Leaching of roof pockets prior to storage | 1 | Reduction in Inventory | For caverns 367 and 469 roof pocket leaching will be performed before filling the caverns with oil entirely. In this way, the majority of roof pockets will be leached away and these caverns will have developed a flat roof before start of the storage operation. |
| Circulate brine through cavern to retrieve oil sticking to walls | 2 | Operations and Maintenance | By circulating brine through the storage cavern, oil that is sticking to the wall may go into suspension. After a period of rest, the oil can be retrieved from the oil well. |
| Communication plan incl. emergency response | 1 | Administrative | To prevent any reputational damage to AkzoNobel and State supervision on Mines, a good communication plan must be developed in case of oil leakage. |
| Design: salt above cavern (impermeable) | 1 | Design - Process concept | Salt is impermeable for fluids like oil. During the selection procedure, caverns that developed into other salt layers than Salt A were excluded from the selection. |
| Distance to water extraction points from deep aquifers | 1 | Separation (Time or Space) | The wells are located far away from any water extraction locations. |
| Expel oil with a gas (nitrogen, compressed air) | 1 | Operations and Maintenance | If after leaching of the roof not all oil is retrieved, it can be considered to expel the last quantities of oil by a gas, such as e.g. nitrogen or compressed air. |
| Governmental regulations | 1 | Procedural | Regulations with respect to new groundwater extractions should prevent new groundwater extraction locations too close to the wells. |
| Insurance to cover financial damage | 1 | Administrative | Financial damage to AkzoNobel must be covered by a good insurance, one that covers the cost for additional measures to retrieve the oil, and, in worst-case, the value of the irretrievable oil |
| Leaching of roof pockets after last oil retrieval by Argos | 1 | Reduction in Inventory | If, at the last oil delivery, not all stored oil is retrieved, roof pockets will be leached to reduce the pocket volume and to be able to retrieve all oil from the roof pockets, This will be done for caverns 372 and 472. |
| Mass balance calculations based on oil in/out and brine in/out | 3 | Administrative | A good administration of in- and outflow of oil and in- and outflow of brine will provide the information for mass balance calculations. A mismatch between the quantity of oil that went into the cavern and that comes out of the cavern during a full oil recovery or at abandonment indicates that oil is trapped inside the cavern. |
| Oil level measurement inside the cavern at several moments during the first filling operation to calibrate the volume of oil trapped in pockets in the roof as estimated from the combined sonar measurements | 1 | Administrative | The oil level inside the cavern will be measured at several moments during first filling of the cavern, e.g. after every 10,000 m3 of oil inserted. By comparing the actual level to the expected oil-brine level estimated from the combined sonar measurements the estimated volume of oil in roof pockets can be calibrated. As such, it also indicates the presence of unknown roof pockets that were not "seen" by sonar |
| Multiple impermeable layers (claystone) between cavern and known aquifers | 1 | Design - Process concept | If leakage has occurred below the groundwater base, then the presence of multiple impermeable claystone layers between the leakage point at depth and the aquifers prevents contamination of these aquifers for a long period of time (tens of thousands of years, if at all) |

| **Storage of Gasoil in a Salt Cavern: Gasoil is Irretrievable from Cavern at Abandonment** | **Administrative** | **Control of Energy Release** | **Design - Detail Design** | **Design - Process concept** | **Design - Protection System** | **Guarding or Shielding** | **Inspection** | **Inspection and Maintenance** | **Operations and Maintenance** | **Procedural** | **Reduction in Inventory** | **Separation (Time or Space)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Threats*:*** | | | | | | | | | | | | |
| Oil is trapped in pockets in roof | **2** | | | | | | | | **1** | | **2** | |
| Oil is sticking to cavern walls/roof | **1** | | | | | | | | **2** | | | |
| Oil has permeated into cavern walls or roof | **1** | | | | | | | | **2** | | | |
| **Consequences:** | | | | | | | | | | | | |
| Retarded contamination of aquifers associated with residual oil in cavern | | | | **2** | | | | | | **1** | | **1** |
| Violation of storage permit | | | | | | | | | | | | |
| Reputational damage | **1** | | | | | | | | | | | |
| Financial loss | **1** | | | | | | | | | | | |

## 3. Indeling van barrières naar type en gedetailleerde beschrijving

# Bijlage 3a - Administratieve barrières

| Barrier nr, | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Admin_1 | Insurance to cover financial damage | Administrative | Financial damage to AkzoNobel must be covered by a good insurance, one that covers the cost for additional measures to retrieve the oil, and, in worst-case, the value of the irretrievable oil | Financial damage, e.g. in the form of costs for additional measures to recover the oil, and, in worst case, the value of the irretrievable oil itself, must be properly insured by AkzoNobel. | Before the start of the oil storage operation AkzoNobel will verify that the present insurance covers any potential financial damage related to oil storage (mitigating actions, remediation activities, value irretrievable oil, etc.) |
| Admin_2 | Mass balance calculations based on oil in/out and brine in/out | Administrative | A good administration of in- and outflow of oil and in- and outflow of brine will provide the information for mass balance calculations. A mismatch between the quantity of oil that went into the cavern and that comes out of the cavern during a full oil recovery or at abandonment indicates that oil is trapped inside the cavern. | AkzoNobel and Argos will implement a so-called "Oil and Brine Administration". In this administration detailed figures are administered for oil flowing into and out of the cavern and for brine flowing into and out of the cavern. At any time after a full oil recovery, and after the final oil recovery, the quantity of oil that is unaccounted for confirms that oil is trapped in the cavern (roof pockets, sticking to walls) | A mass-balance administration will be incorporated in the administrative plan |
| Admin_3 | Oil level measurement inside the cavern at several moments during the first filling operation to calibrate the volume of oil trapped in pockets in the roof as estimated from the combined sonar measurements | Administrative | The oil level inside the cavern will be measured at several moments during first filling of the cavern, e.g. after every 10,000 $m^3$ of oil inserted. By comparing the actual level to the expected oil-brine level estimated from the combined sonar measurements the estimated volume of oil in roof pockets can be calibrated. As such, it also indicates the presence of unknown roof pockets that were not "seen" by sonar | Just before the first filling operation a detailed base level sonar measurement will be performed to confirm that no change has occurred in the shape and volume of the cavern. Using this sonar measurement, intermediate filling levels can be determined (e.g after 10.000 $m^3$, after 20.000 $m^3$, etc.), which can be compared with actual levels measured during the filling operation. Large differences may be an indication of additional roof pockets that were not "seen" by sonar, larger pockets than estimated from sonar, or wider caverns in general (when differences occur at all filling levels), etc. Also, it provides information on the reliability of the sonar measurements. | The results of the base level sonar measurements, performed just before first filling of the cavern, and the calibration with the oil level measurements, will be discussed in more detail with State Supervision of Mines (SodM). The technique by which the oil-brine-interface level is measured inside the cavern is decribed in the monitoring plan. |
| Admin_4 | Governmental regulations | Administrative | Regulations with respect to new groundwater extractions should prevent new groundwater extraction locations too close to the wells. | Groundwater extraction permits are granted by the water board or the provincial authorities. These authorities should assure that no groundwater extraction permits are granted that are too close to the oil storage caverns, at least with respect to deep groundwater extractions. For shallow groundwater extractions (i.e. phreatic groundwater) and for extractions that are not subject to the permitting procedures, no risks exists and no special distances have to be taken into account as long as no leakage of oil from te cavern occurs. If leakage occurs, groundwater extractions in the vicinity of the oil storage caverns must be abandoned or at least reconsidered. | Implementation by external parties |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'Abandonment procedure' |

# Bijlage 3b - Ontwerpbarrières

| Barrier nr, | *Barrier* | *Barrier type* | *Short description* | *Extended description* | *Implementation into the risk management plan* |
|---|---|---|---|---|---|
| Design_1 | Design: salt above cavern (impermeable) | Design - Process concept | Salt is impermeable for fluids like oil. During the selection procedure, caverns that developed into other salt layers than Salt A were excluded from the selection. | Salt is impermeable for fluids like oil. Permeability measurements on salt have indicated a permeability in the range of 1,00E-05 to 1,00E-02 mD, and a hydraulic conductivity of 1,00E-11 to 1,00E-08. All selected caverns are entirely situated within Salt A and during the selection procedure caverns which developed into other salt layers than Salt A were excluded from the selection. A detailed geological description of the selected salt caverns can be found in the report titled "Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)" by Deltares (2012). | This design aspect was implemented in the cavern selection procedure. |
| Design_2 | Design: salt layer between sump and less impermeable Solling Formation | Design - Process concept | In some caverns, it may be necessary that the sump is in oil partially. In such cases, a salt layer between the lowest point of the sump (i.e. the deepest point of the cavern during its history) and the less impermeable Solling Formation must be present to prevent permeation into the Solling Formation. | In some caverns, it may be necessary that the sump is in oil partially. If so, then this is only allowed if it can be assured that a salt layer is present between the base of the sump (i.e the deepest point the cavern has ever reached) and the more permeable Solling formation. As salt is impermeable for fluids like oil this salt layer then forms a barrier preventing any permeation of oil into the Solling formation. | This design aspect will be implemented in the final cavern-specific fillling procedure which will be sent to State Supervision of Mines (SodM) before the start of the oil storage preparations |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'Abandonment procedure' |

# Bijlage 3c - Barrières op het gebied van inspectie

| Barrier nr, | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Inspection_1 | Sonar measurement to locate possible oil pockets and estimate their volumes | Inspection | If a significant amount of oil cannot be retrieved after abandonment of the oil storage cavern, new sonar measurements will be done to identify oil pockets in the cavern roof, based on which a leaching program can be developed. | A proven method to gain insight into the shape and volume of a cavern and the presence and location of roof pockets is to use sonar measurements. If a significant amount of oil cannot be retrieved at the end of the storage period, then an accurate sonar measurement will be done through all available wells obtain the most accurate estimate of pocket volume possible. Based on the results, a roof leaching plan will be made to recover the remaining oil by leaching away the pockets, | This measure will be incorporated in the Abandonment procedure |

| KEY | |
|---|---|
| | See 'Administrative plan' |
| | Will be discussed with SodM |
| | See 'Abandonment procedure' |

# Bijlage 3d - Barrières op het gebied van operatie en onderhoud

| Barrier nr, | *Barrier* | *Barrier type* | *Short description* | *Extended description* | *Implementation into the risk management plan* |
|---|---|---|---|---|---|
| Operations_1 | Additional leaching to retrieve oil from walls | Operations and Maintenance | By additional leaching (circulation of fresh water) oil that is sticking to the wall may be retrievable. After a period of rest, the oil can be retrieved from the oil well. | Additional leaching may be a good way to retrieve additional oil from a cavern after abandonment. After releaching (by circulation of fresh water) and extraction of brine, any oil that sticks to the walls of the cavern or that has permeated a few centimeters into the cavern walls can be retrieved because the salt that it is sticking to or that it has permeated into dissolves. There is no experience with leaching of cavern walls of caverns that were formery used for oil storage. This makes the success of this technique unsure. | This measure will be incorporated in the Abandonment procedure |
| Operations_2 | Circulate brine through cavern to retrieve oil from wells | Operations and Maintenance | By circulating brine through the storage cavern, oil that is sticking to the wall may go into suspension. After a period of rest, the oil can be retrieved from the oil well. | Circulating brine through a cavern may be a good way to retrieve additional oil from a cavern after abandonment. During circulation of brine, oil that sticks to the walls of the cavern might go into suspension, thus becoming retrievable. There is no experience with circulation of brine in caverns that were formery used for oil storage. This makes the success of this technique unsure. | This measure will be incorporated in the Abandonment procedure |
| Operations_3 | Expel the irretrievable oil with a gas (nitrogen, compressed air) | Operations and Maintenance | If after leaching of the roof not all oil is retrieved, it can be considered to expel the last quantities of oil by a gas, such as e.g. nitrogen or compressed air. | When a gas (like nitrogen) is pumped into the cavern, this will form a new uppermost layer in the cavern and in the roof pockets, thereby exelling the gasoil from these pockets. The gasoil can then be extracted via one of the wells. As nitrogen is a non-toxic and less polluting material, the irretrievability of this nitrogen is no problem. However, it requires a significant investment to convert the wells to be suitable for gas injection and withdrawal. | This measure will be incorporated in the Abandonment procedure |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'Abandonment procedure' |

# Bijlage 3e - Barrières ter vermindering van het optreden van bedreigingen

| Barrier nr, | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| ReductionInventory_1 | Communication plan incl. emergency response | Reduction in Inventory | To prevent any reputational damage to AkzoNobel and State supervision on Mines, a good communication plan must be developed in case of oil leakage. | In case of any breach of confinement due to leakage of oil, measures must be taken to minimize reputational damage, both for AkzoNobel (being the owner of the caverns) as for State supervision of Mines (being the responsible authority). Good communication towards all stakeholders is an important measure to reduce this damage. Therefore a good communication plan must be in place for when leakage occurs. | A communication plan will be written by AkzoNobel and Argos, but this is not part of the Risk Management Plan |
| ReductionInventory_2 | Leaching of roof pockets prior to storage | Reduction in Inventory | After the storage plan and related oil storage permits have been granted, roof pockets will be leached of caverns 367 and 469 to reduce the pocket volume (i.e. the volume of potentially irretrievable oil). | For caverns 367 and 469 roof pocket leaching will be performed before filling the caverns with oil entirely. In this way, the majority of roof pockets will be leached away and these caverns will have developed a flat roof before start of the storage operation. | The roof leaching procedure is decribed in attachment [18] to the Storage plan |
| ReductionInventory_3 | Leaching of roof pockets after last oil retrieval by Argos | Reduction in Inventory | If, at the last oil delivery, not all stored oil is retrieved, roof pockets will be leached to reduce the pocket volume and to be able to retrieve all oil from the roof pockets, This will be done for caverns 372 and 472. | From caverns 372 and 472 it is known that roof pockets are present in which gasoil will remain at abandonment. For these caverns leaching will be performed after the last oil retrieval by Argos, such that the trapped oil can be retrieved. | The roof leaching procedure is decribed in attachment [18] to the Storage plan. This measure will be incorporated in the Abandonment procedure. |

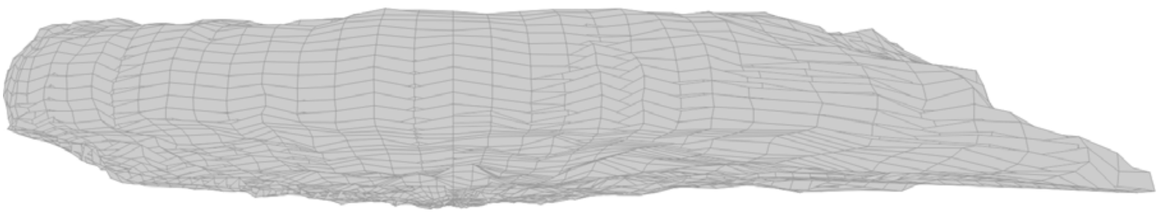
| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'abandonment procedure' |

# Bijlage 3f - Barrières die een scheiding in tijd of plaats betreffen

| Barrier nr, | Barrier | Barrier type | Short description | Extended description | Implementation into the risk management plan |
|---|---|---|---|---|---|
| Separation_1 | Distance to water extraction points from deep aquifers | Separation (Time or Space) | The wells are located far away from any water extraction locations. | When oil is found to be irretrievable from the abandoned storage cavern, there is a a risk that groundwater may become polluted in the (far) future due to loss of cavern integrity with geologic time. If this happens, then the oil-polluted groundwater will travel through the subsurface due to groundwater flow. Depending on the permeability, porosity and differences in groundwater level, this flow has a magnitude of several meters up to approximately 100 meters per year. As the wells and caverns are located at large distances of drinking water extraction points (several kilometers) it will take tens to hundreds of years before polluted groundwater will arive at the drinking water extraction location and then only if the groundwater flow is in the right direction. | No action required |
| Separation_2 | Multiple impermeable layers (claystone) between cavern and known aquifers | Separation (Time or Space) | If leakage has occurred below the groundwater base, then the presence of multiple impermeable claystone layers between the leakage point at depth and the aquifers prevents contamination of these aquifers for a long period of time (tens of thousands of years, if at all) | When leakage of oil in the subsurface has occurred at a deep level (i.e. at cavern level), it will take tens of thousands of years for the oil to reach an aquifer due to the presence of several thick impermeable layers between the point of leakage and the aquifers. A detailed geological description of the selected salt caverns can be found in the report titled "Cavern-specific risk assessment of gas oil storage in the Marssteden concession based on the Second Use Containment Concept (2U-CC)" by Deltares (2012). | No action required |

| KEY | |
|---|---|
| | See 'administrative plan' |
| | Will be discussed with SodM |
| | See 'Abandonment procedure' |

# Leaching Recommendations for conversion of Akzo salt production caverns into oil storage caverns in the Clovis project



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## Table of contents

# 1 INTRODUCTION

Akzo dedicated four former salt production caverns for conversion into oil storage caverns (project Clovis). During the leaching process for salt production the roof of the caverns developed not ideally for potential oil storage (back-pockets). It is planned to optimize the roof shape by leaching so that an optimum of oil withdrawal after oil storage operations will be achieved. This memorandum summarizes the technical aspects and working steps for leaching of the four caverns. Considerations about the retrievability of the oil from the back pockets are added.

# 2 LEACHING RECOMMENDATIONS

## 2.1 Cavern B367 - B368

The process of roof-flattening will be performed before oil storage operations.

### 2.1.1 Conditions

The existing back pockets (roughly estimated approx. 13,000 m³) shall be eliminated by filling the pockets with oil and leaching a flat roof by continuously extracting the backfloating oil from the roof pockets (see enclosures 1, 2).

### 2.1.2 Leaching Concept

- Well B368: milling the 7” LCCS approx. in 415.50 m NAP (see enclosures 1, 2)
- Well B368: static pressure testing of 7” LCCS
- Well B368: installation of two blanket monitoring systems at -425.05 m NAP and -423.50 m NAP (bottom depth)
- Well B368: set 4 ½” casing shoe to -427.00 m NAP
- Well B367: 7” production string actually at -432.52 m NAP remains unchanged
- Well B368: blanket system and completion measurement (wireline)
- Well B368: oil injection of approx. 14,000 m³ to fill the pocket volume of approx. 13,000 m³ (initial blanket filling). The blanket level should be approx. at -423.70 m NAP (lowest pocket barrier at -423.56 m NAP) (see enclosure 1)
- Well B368: oil retrieval to -421.50 m NAP (top of upper blanket monitoring system)
- Well B368: lift 4 ½” casing to -422.00 m NAP
- Well B368: withdrawal oil to set blanket level to -417.50 m NAP

- Well B368: start of leaching with a freshwater injection rate of 10 m³/h for 20 days to yield a roof diameter of about 8 m

- Well B368: daily oil withdrawal if necessary to keep the blanket level at -417.50 m NAP

- Well B368: increase of injection rate to 25 m³/h

- Well B368: blanket adjustment by periodical release of oil to keep blanket between -417.50 m NAP and -419.50 m NAP; alarm marker for the lower blanket control system is recommended due to close distance to the 4 ½" casing shoe

- Well B368: total leaching duration: 250 days (see enclosure 3)

Enclosure 3 gives an overview over the leaching parameters and concept for cavern series B367 - B368.

## 2.2 Cavern B372 – B373 – B374

The process of roof-flattening will be performed after oil storage operations.

### 2.2.1 Conditions

Due to leaching activities from January to May 2012, the roof sections close to wells B372 and B374 were elevated, forming roughly cylindrical shaped roofs with radii up to 30 m each. The existing back pockets volume was estimated roughly to approx. 2,000 m³.

Before oil storage operations the 7" LCCS have to be milled approx. in -421.50 m NAP. Subsequently pressure tests of the new 7" LCCS have to be performed.

During oil storage operations the back pockets will be completely filled with oil. Thus withdrawing oil at the end of the storage period, oil in the back pockets will not back-float from the pockets and remains primarily in the cavern roof (see enclosures 4, 5).

### 2.2.2 Leaching Concept

- Well B373: remove temporary plug

- Wells B372, B373, B374: remove/modify oil completion (well head, casings) and install leaching completion

- Well B373: set 4 ½" production string to -443.66 m NAP and install two blanket monitoring systems at -428.50 m and -434.00 m NAP (bottom depth)

- Wells B372, B374: set 4 ½" casing shoes to -430.50 m NAP and install three blanket monitoring systems at -424.00 m NAP, -428.50 m NAP and -428.55 m NAP (bottom depth) per well; alarm marker for the lower blanket control system is recommended due to close distance to the 4 ½" casing shoe (see enclosures 4, 5)

- Wells B372, B373, B374: blanket system and completion measurement (wireline)
- Wells B372, B374: set blanket level to -427.50 m NAP
- Well B372: start of leaching with an injection rate of 25 m³/h for 240 days; blanket adjustment if necessary to keep the blanket level at -427.50 m NAP
- Well B374: start of leaching with an injection rate of 25 m³/h for 220 days; blanket adjustment if necessary to keep the blanket level at -427.50 m NAP
- Wells B372, B374: set blanket level to -423.50 m NAP
- Wells B372, B374: set 4 ½" casing shoes to -426.00 m NAP
- Wells B372, B374: continue leaching with an injection rate of 10 m³/h for 10 days to yield a roof diameter of about 5 m.
- Wells B372, B374: blanket adjustment if necessary to keep the blanket level at -423.50 m NAP
- Well B372: total leaching duration: 250 days (see enclosures 6, 7)
- Well B374: total leaching duration: 230 days (see enclosures 6, 7)

Enclosure 6 gives an overview over the leaching parameters for cavern series B372 – B373 – B374, enclosure 7 shows the leaching concepts for wells B372 and B374.

## 2.3 Cavern B469 – B470 – B471

The process of roof-flattening will be performed before oil storage operations.

### 2.3.1 Conditions

To eliminate the existing pockets on the outskirts of the cavern, the elevated roof section will be filled to a level of -423.00 m NAP (450.04 m MD), requiring about 2,600 m³ of oil. Afterwards leaching from the centre well will lift the complete cavern roof to a uniform level and thereby eliminating the roughly estimated pocket volume of about 2,000 m³ (see enclosures 8, 9).

By applying the below mentioned procedure, an optimised roof for the later oil with-drawal will be shaped with only the minimum needed amount of oil. During the course of leaching the amount of blanket needs to be replenished on a regular basis due to the increase of the roof area.

### 2.3.2 Leaching Concept

- Well B471: milling the 7" LCCS approx. in -416.00 m NAP (see enclosures 8, 9)

- Well B471: static pressure testing of 7” LCCS

- Well B470: installation of three blanket monitoring systems at -420.00 m NAP, -423.50 m NAP and -423.55 m NAP (bottom depth)

- Wells B469 and B471: installation of one blanket monitoring system per well at -423.50 m NAP (bottom depth)

- Well B470: set 4 ½” casing shoe to -424.00 m NAP

- Well B471: 4 ½” production string actually at -427.98 m NAP remains unchanged

- Well B469: 4 ½” production string actually at -439.45 m NAP remains unchanged

- Wells B469, B470 and B471: blanket system and completion measurement (wireline)

- Well B470: oil injection of approx. 2,600 m³ to fill the central roof section. The blanket level should be approx. at -423.00 m NAP. The highest pocket barrier is located at -424.00 m NAP (see enclosure 8)

- Well B470: start of leaching with an injection rate of 25 m³/h for 700 days

- Well B470: blanket adjustment if necessary to keep the blanket level at -423.00 m NAP; alarm marker for the lower blanket control system is recommended due to close distance to the 4 ½” casing shoe

- Well B470: oil retrieval to -421.50 m NAP

- Well B470: lift 4 ½” casing to -422.00 m NAP (see enclosure 8)

- Well B470: oil retrieval to -417.00 m NAP (upper blanket monitoring system)

- Well B470: continue leaching with a freshwater injection rate of 25 m³/h for 20 days to yield a roof diameter of about 6 m; blanket adjustment if necessary to keep the blanket level at -417.00 m NAP; alarm marker for the lower blanket control system is recommended due to close distance to the 4 ½” casing shoe

- Well B470: set blanket level to -421.00 m NAP

- Well B470: leaching with a freshwater injection rate of 25 m³/h for 300 days

- Well B470: blanket adjustment if necessary to keep the blanket level at -421.00 m NAP; alarm marker for the lower blanket control system is recommended due to close distance to the 4 ½” casing shoe

- Well B470: total leaching duration: 1,020 days

Enclosures 10 gives an overview over the leaching parameters and the concept for cavern series B469 – B470 – B471.

## 2.4 Cavern B472 - B473 - B474

The process of roof-flattening will be performed after oil storage operations.

### 2.4.1 Conditions

During oil storage operations the back pockets will be filled completely with oil. Thus withdrawing oil at the end of the storage period, oil in the back pockets will not back-float from the pockets and remains primarily in the cavern roof. The existing back pockets were estimated roughly with a volume of approx. 2,400 m³ (see enclosures 11, 12).

### 2.4.2 Leaching Concept

- No milling required for the 7” LCCS’s in this cavern (see enclosures 11, 12)
- Well B473: remove temporary plug
- Wells B472, B473, B474: remove/modify oil completion (well head, casings) and install leaching completion
- Well B473: set 5 ½” production string to -433.00 m NAP
- Wells B472, B474: set 4 ½” casing shoes to -422.50 m NAP and install two blanket monitoring systems at -422.30 m NAP and -421.75 m NAP per well (bottom depth)
- Wells B472, B474: blanket system and completion measurement (wireline)
- Wells B472, B474: set blanket level to -420.00 m NAP (top of upper blanket monitoring system)
- Wells B472, B474: start of leaching with a freshwater injection rate of 10 m³/h for 20 days to yield a roof diameter of about 6 m
- Wells B472, B474: daily oil withdrawal if necessary to keep the blanket level at -420.00 m NAP
- Wells B472, B474: increase of injection rates to 25 m³/h
- Wells B472, B474: blanket adjustment by periodical release of oil to keep blanket between -420.00 m NAP and -421.90 m NAP; alarm marker for the lower blanket control system is recommended due to close distance to the 4 ½” casing shoe (see enclosure 11)
- Well 472: total leaching duration: 150 days
- Well 474: total leaching duration: 105 days

Enclosure 13 gives an overview over the leaching parameters. Enclosure 14 shows the concepts for cavern series B472 - B473 - B474.



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## 3 RETRIEVABILITY OF OIL FROM BACK POCKETS

The calculation of the pocket volumes was performed by using existing sonar measurement results. By doing this, the minimum amount of oil to protect the roof area from non-regular development during leaching was derived. Due to measurement inaccuracies the necessary amount of oil can differ from the calculated one. Reasons for these inaccuracies are the fragmentary interpretation of the sonar measurements (especially in the roof sections) and the decrease of the efficiency for the pocket detection at the outskirts of the cavern.

To reduce these inaccuracies using a well-positioned BCS (blanket control system) during oil injection and leaching process will help to provide a better estimation for existing and yet undetected pocket volumes. Table 1 shows the estimated pocket volume per cavern-series based on the recent sonar measurements.

**Tab. 1:** Estimated pocket volume based on sonar measurement

| Cavern-series | Estimated pocket volume |
|---|---:|
| **B367-B368** | **13,000 m³** |
| **B372-B373-B374** | **2,000 m³** |
| **B469-B470-B471** | **2,000 m³** |
| **B472-B473-B474** | **2,400 m³** |
| **Total** | **19,400 m³** |

For the estimation of the amount of non-retrievable oil following aspects have to be considered: the distance of the pockets to the injection point, the height of the pockets, undetected pocket volumes and sonar measurement inaccuracies. The estimation of the non-retrievable oil is very rough and will have to be updated continuously as soon as new data is available (e.g. sonar measurements, amount of injected blanket).

The oil retrievability depends on the roof development during leaching. This will be steered by blanket adjustments and monitoring the cavern shape by sonar measurements. Based on the sonar results, leaching concepts will be updated to reduce the amount of non-retrievable oil to a minimum.

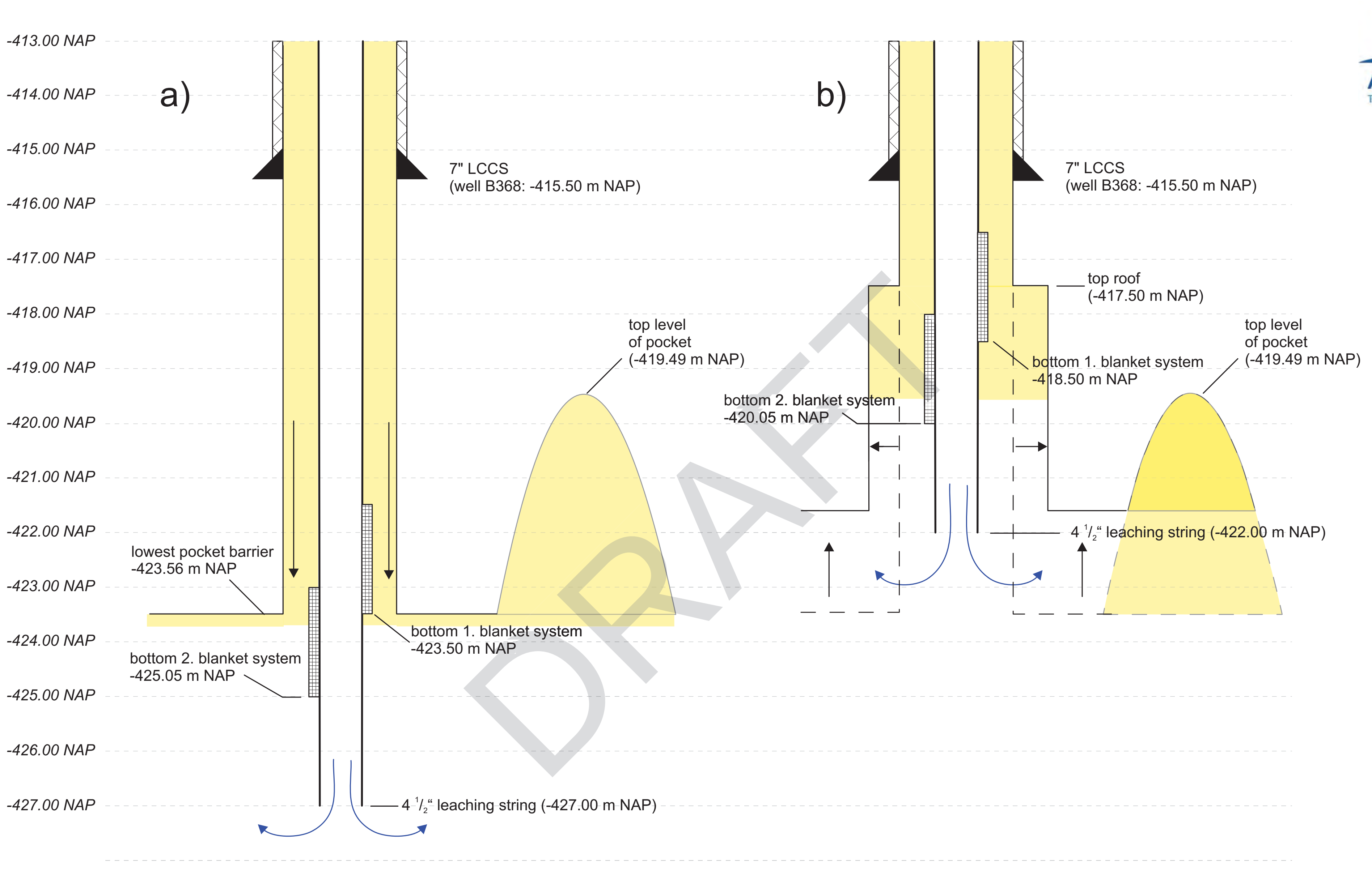
Regarding the above mentioned aspects and uncertainties even in case of an optimal leaching process of the cavern roof it has to be stated that a significant amount of oil (roughly estimated several hundred cubic metres per cavern-series, except of cavern series B367/B368 where a higher volume may be trapped) may be non-retrievable from the cavern after oil operations.

Storage caverns with salt resources available could be taken back into brine production. In such cases the gas oil not recovered could be used as blanket.

Trapped gas oil can be recovered from the roof by replacing the pocket volume with a gaseous medium. Depending on the pocket volume, a significant amount of gas (e.g. nitrogen, air) may be necessary to replace the gas oil. The design of the cavern and wells should be able to deal with gas for displacement of remaining oil.

In caverns with 3 wells, one well is planned to be plugged during the storage period. After the end of conventional gas oil withdrawal, the plugged well can be re-entered to recover gas oil concentrated in the cavern roof around this well bore.

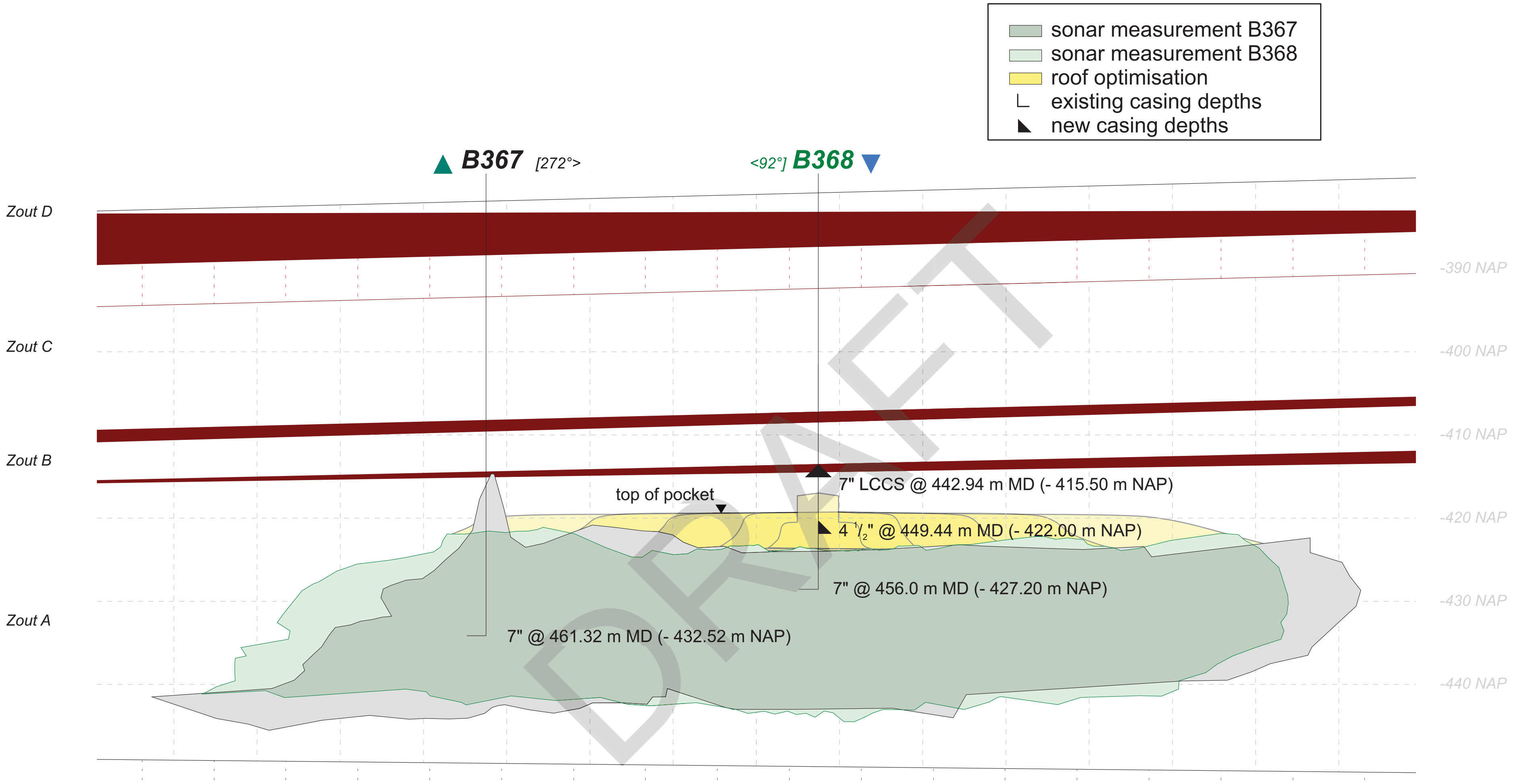
Another option for oil recovery could be the use of a submersible pump. As the cavern wells and the cavern roof would have to be under atmospheric conditions for this option, it has to be evaluated by rock mechanical expertise.








**Enclosure 1:** Oil injection and withdrawal for roof optimization for well B368




**Enclosure 2:** Cross section B367 - B368 including leaching parameters for well B368

PN 5305
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## Leaching parameter cavern series B367 - B368

| Cavern Series | Existing depth 7" casing NAP [m] | Existing depth 7" casing MD [m] | Offset | Top zoutlaag A NAP [m] | New depth 7" LCCS NAP [m] | New depth 7" LCCS MD [m] | Leaching string 4 ½" NAP [m] | Leaching string 4 ½" MD [m] | Pocket range NAP from | Pocket range NAP to | Pocket range MD from | Pocket range MD to | Max. pocket distance [m] | Leaching duration [d] | Volume increase [m³] | Salt production [t] | Pocket volume [m³] | Additional oil for initial roof coverage [m³] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | -419,49 | -423,56 | | | | | | | | |
| B367 **) | -432,52 | 461,32 | 27,51 | -415,08 | - | - | | | | | 447,00 | 451,07 | 47 | 250 | 22,000 | 46,000 | 13,000 | 1,000 |
| B368 *) | -427,20 | 456,00 | 27,44 | -414,48 | -415,50 | 442,94 | -422,00 | 449,44 | | | 446,93 | 451,00 | | | | | | |

*) injection well

**) production well

## Leaching Concept Well B368

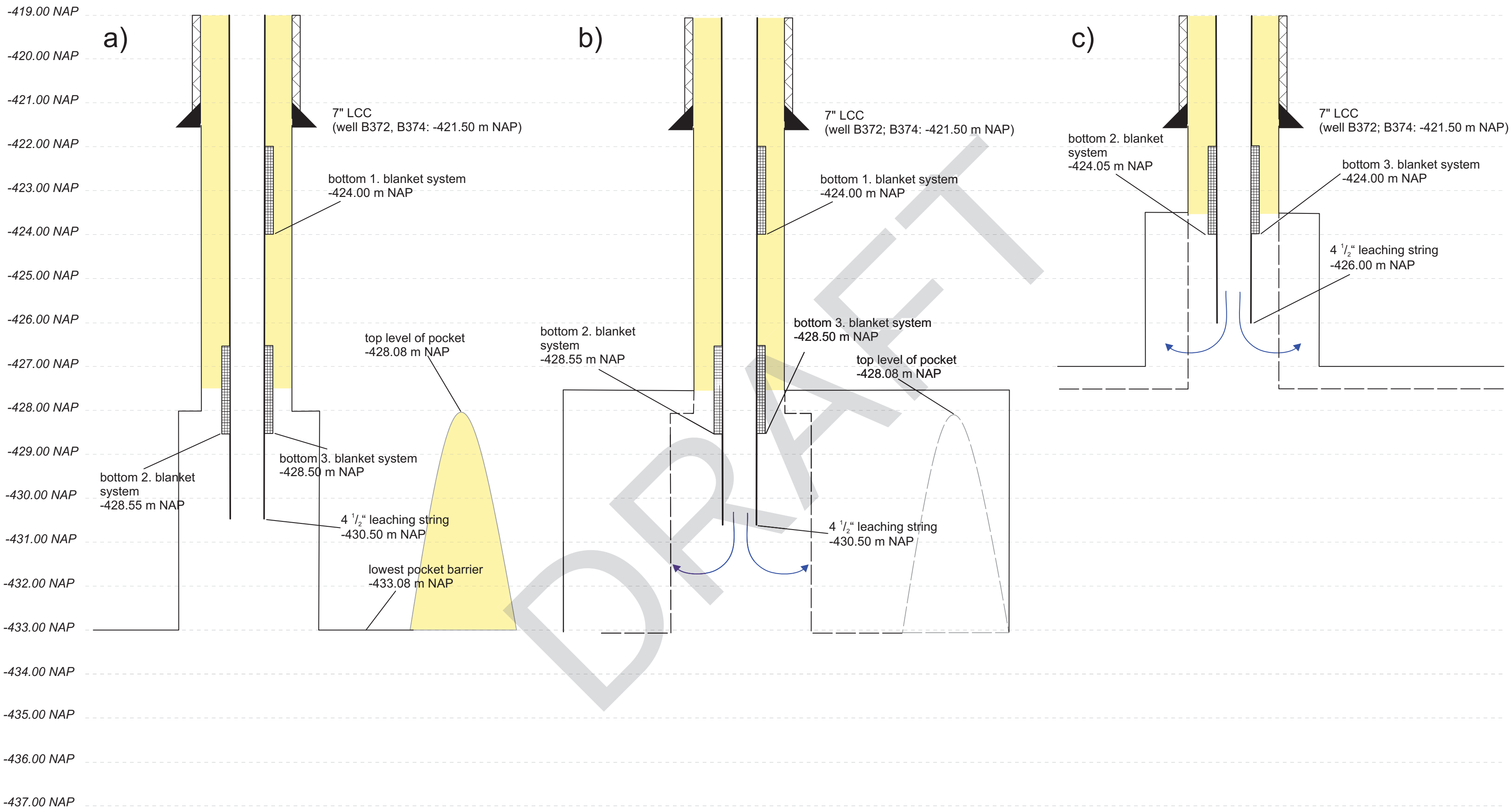
| Settings: Start [d] | Activities | Duration [d] | Inner string *) MD [m] | Inner string *) NAP [m] | Outer string MD [m] | Outer string NAP [m] | Blanket depth MD [m] | Blanket depth NAP [m] | Leaching: Duration [d] | Mode | Injection rate [m³/h] | Results: Duration total [d] | NaCl average [kg/m³] | Sump level MD [m] | Sump level NAP [m] | Volume **) [m³] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Beginn of leaching | | 461.32 | -432.52 | 449.44 | -422.00 | 444.94 | -417.50 | 20 | top | 10 | 20 | 320 | 469.74 | -442.30 | 159,500 |
| 20 | Blanket | | | | | | 446.94 | -419.50 | 230 | top | 25 | 250 | 320 | 469.44 | -442.00 | 180,000 |

*) Production string in well B367

**) Partial volumen derived from sonar measurement well B368



**Enclosure 3:** Leaching parameters and concept for cavern series B367 - B368




**Enclosure 4:** Oil injection and withdrawal for roof optimization for wells B372 and B374

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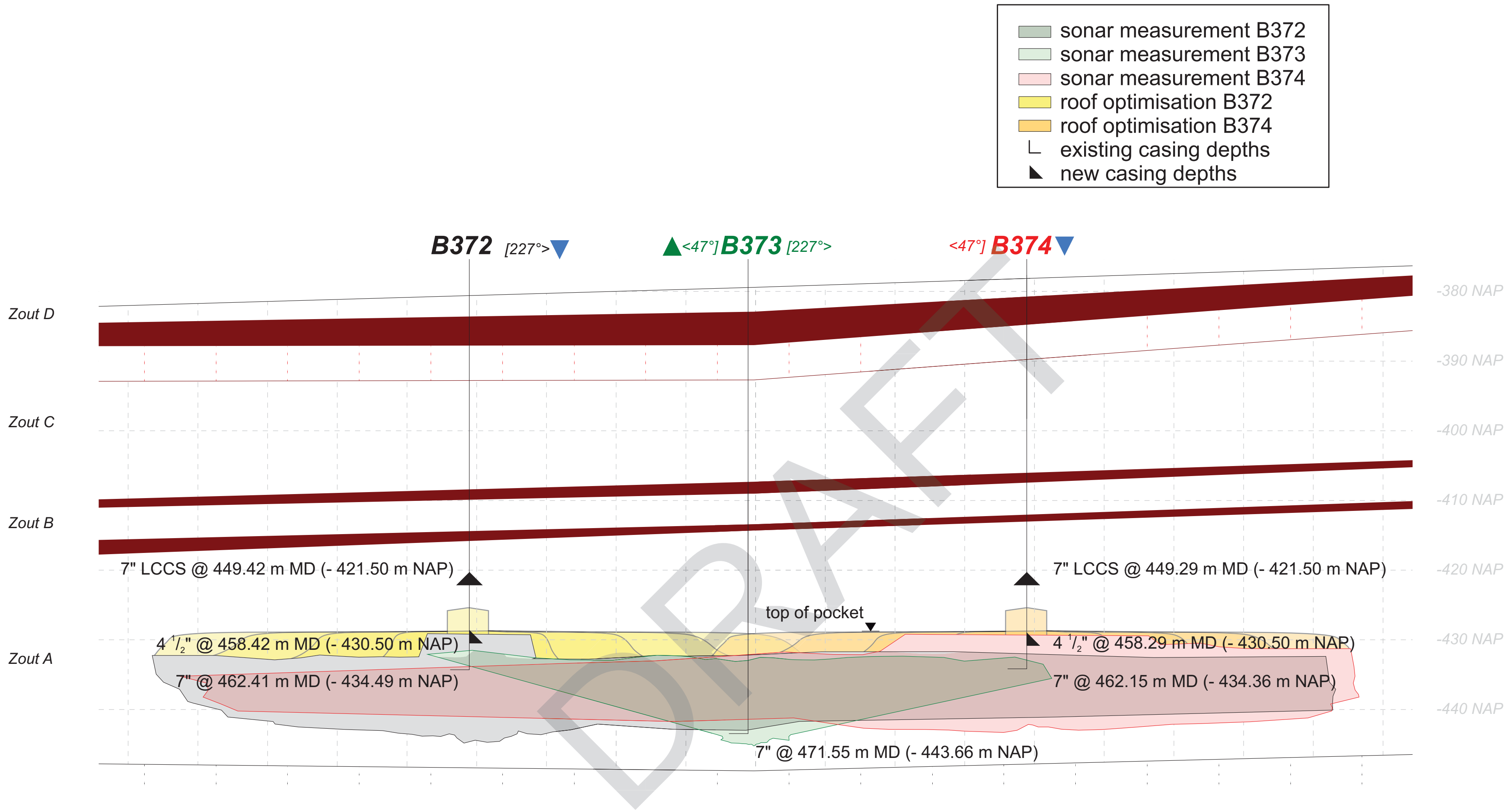


**Enclosure 5:** Cross section B372 - B373 - B374 including leaching parameters for wells B372 and B374

PN 5305
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## Leaching parameter cavern series B372 - B373 - B374

| | Existing depth 7" casing | | Offset | Top zoutlaag A | New depth 7" LCCS | | Casing shoe 4 ½" | | Pocket range | | | | Max. pocket distance | Leaching duration | Volume increase | Salt production | Pocket volume | Additional oil for initial roof coverage | Additional oil for roof coverage during leaching operation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NAP | MD | | NAP | NAP | MD | NAP | MD | NAP | | MD | | | | | | | | |
| | [m] | [m] | | [m] | [m] | [m] | [m] | [m] | from | to | from | to | [m] | [d] | [m³] | [t] | [m³] | [m³] | [m³] |
| Cavern Series | | | | | | | | | -428.08 | -433.08 | | | | | | | | | |
| B372 *) | -434.49 | 462.41 | 27.92 | -415.78 | -421.50 | 449.42 | -430.50 | 458.42 | | | 456.00 | 461.00 | 40 | 250 | 24,200 | 45,200 | | | |
| B373 **) | -443.66 | 471.55 | 27.89 | -414.31 | | | | | | | | | | | | | 2,000 | 30,000 | 1,400 |
| B374 *) | -434.36 | 462.15 | 27.79 | -413.01 | -421.50 | 449.29 | -430.50 | 458.29 | | | 455.87 | 460.87 | 45 | 230 | 22,300 | 40,300 | | | |

*) injection well

**) production well



**Enclosure 6:** Leaching parameters for cavern series B372 - B373 - B374

### Leaching Concept Well B372

| Settings | | | | | | | | | Leaching | | | Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | Activities | Duration | Inner string *) | | Outer string | | Blanket depth | | Duration | Mode | Injection rate | Duration total | NaCl average | Sump level | | Volume **) |
| [d] | | [d] | MD [m] | NAP [m] | MD [m] | NAP [m] | MD [m] | NAP [m] | [d] | | [m³/h] | [d] | [kg/m³] | MD [m] | NAP [m] | [m³] |
| 1 | Beginn of leaching | | 471,55 | -443,66 | 458,42 | -430,50 | 455,42 | -427,50 | 240 | top | 25 | 240 | 319 | 469.92 | -442.00 | 77,000 |
| 240 | Blanket | | | | 453,92 | -426,00 | 451,42 | -423,50 | 10 | top | 10 | 250 | 320 | 469.92 | -442.00 | 78,000 |

*) Production string in well B373

**) Partial volume derived from sonar measurement well B372

### Leaching Concept Well B374

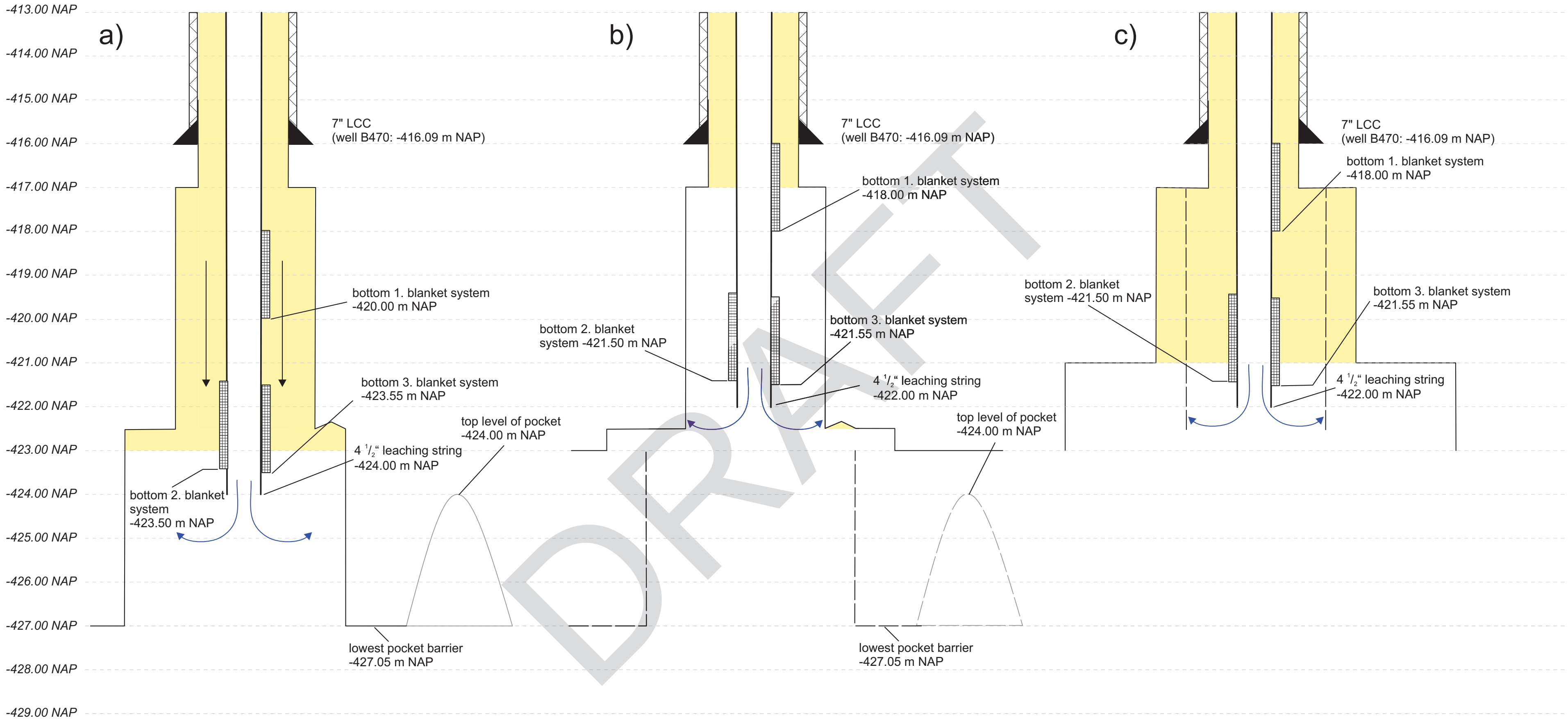
| Settings | | | | | | | | | Leaching | | | Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | Activities | Duration | Inner string *) | | Outer string | | Blanket depth | | Duration | Mode | Injection rate | Duration total | NaCl average | Sump level | | Volume **) |
| [d] | | [d] | MD [m] | NAP [m] | MD [m] | NAP [m] | MD [m] | NAP [m] | [d] | | [m³/h] | [d] | [kg/m³] | MD [m] | NAP [m] | [m³] |
| 1 | Beginn of leaching | | 471,55 | -443,66 | 458,29 | -430,50 | 455,42 | -427,50 | 220 | top | 25 | 220 | 317 | 469.02 | -441.10 | 88,000 |
| 220 | Blanket | | | | 453,79 | -426,00 | 451,42 | -423,50 | 10 | top | 10 | 230 | 314 | 468.92 | -441.00 | 89,000 |

*) Production string in well B373

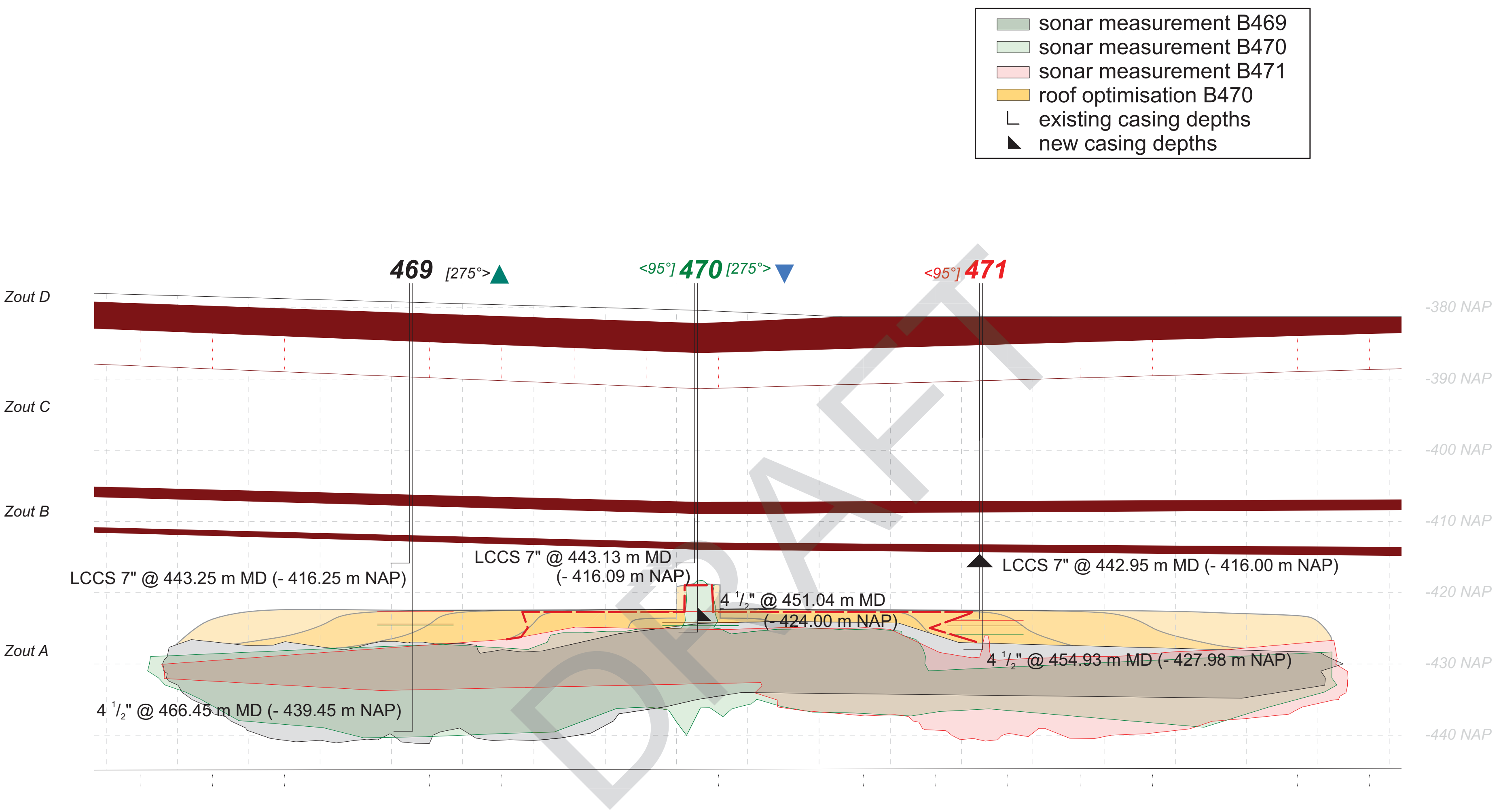
**) Partial volume derived from sonar measurement well B374



**Enclosure 7:** Leaching concepts for wells B372 and B374




**Enclosure 8:** Oil injection and withdrawal for roof optimization for well B470




**Enclosure 9:** Cross section B469 - B470 - B471 including leaching parameters for wells B469, B470 and B471

PN 5305
121214_Enclosures.des/BA

## Leaching parameter cavern series B469 - B470 - B471

| | Existing depth 7" casing | | Offset | Top zoutlaag A | New depth 7" LCCS | | Casing shoe 4 ½" | | Pocket range | | | | Max. pocket distance | Leaching duration | Volume increase | Salt production | Pocket volume | Additional oil for initial roof coverage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NAP | MD | | NAP | NAP | MD | NAP | MD | NAP | | MD | | | | | | | |
| | [m] | [m] | | [m] | [m] | [m] | [m] | [m] | from | to | from | to | [m] | [d] | [m³] | [t] | [m³] | [m³] |
| Cavern Series | | | | | | | | | -424.00 | -427.05 | | | | | | | | |
| B469 **) | -416.25 | 443.25 | 27.00 | -412.84 | - | - | -439.45 | 466.45 | | | 451.00 | 454.00 | | | | | | |
| B470 *) | -416.09 | 443.13 | 27.04 | -413.96 | - | - | -424.00 | 451.04 | | | | | 80 | 1,020 | 97,800 | 186,500 | 2,000 | 2,600 |
| B471 **) | -424.02 | 450.97 | 26.95 | -414.32 | -416.00 | 442.95 | -427.98 | 454.93 | | | 452.50 | 454.00 | | | | | | |

*) injection well

**) production well



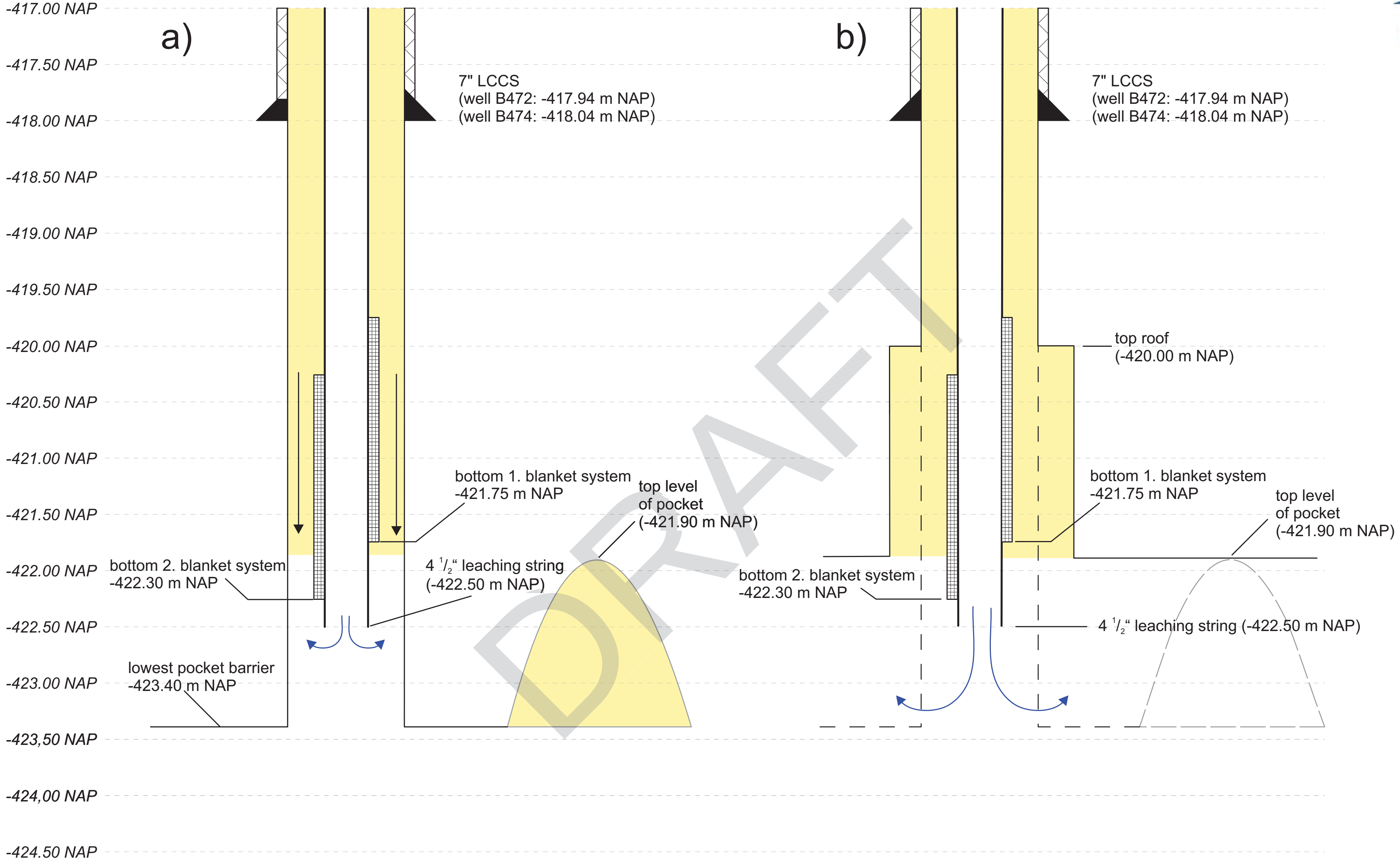
### Leaching Concept Well B470

| Settings | | | | | | | | | Leaching | | | Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | Activities | Duration | Inner string *) | | Outer string | | Blanket depth | | Duration | Mode | Injection rate | Duration total | NaCl average | Sump level | | Volume **) |
| [d] | | [d] | MD [m] | NAP [m] | MD [m] | NAP [m] | MD [m] | NAP [m] | [d] | | [m³/h] | [d] | [kg/m³] | MD [m] | NAP [m] | [m³] |
| 1 | Beginn of leaching | | 466.45 | -439.45 | 451.04 | -424.00 | 450.04 | -423.00 | 700 | top | 25 | 700 | 318 | 464.44 | -437.40 | 269,000 |
| 700 | W/O, Blanket | | | | 449.04 | -422.00 | 444.04 | -417.00 | 20 | top | 25 | 720 | 312 | 464.34 | -437.30 | 278,000 |
| 720 | Blanket | | | | | | 448.04 | -421.00 | 300 | top | 25 | 1,020 | 320 | 463.94 | -436.90 | 304,000 |

*) Production string in well B469

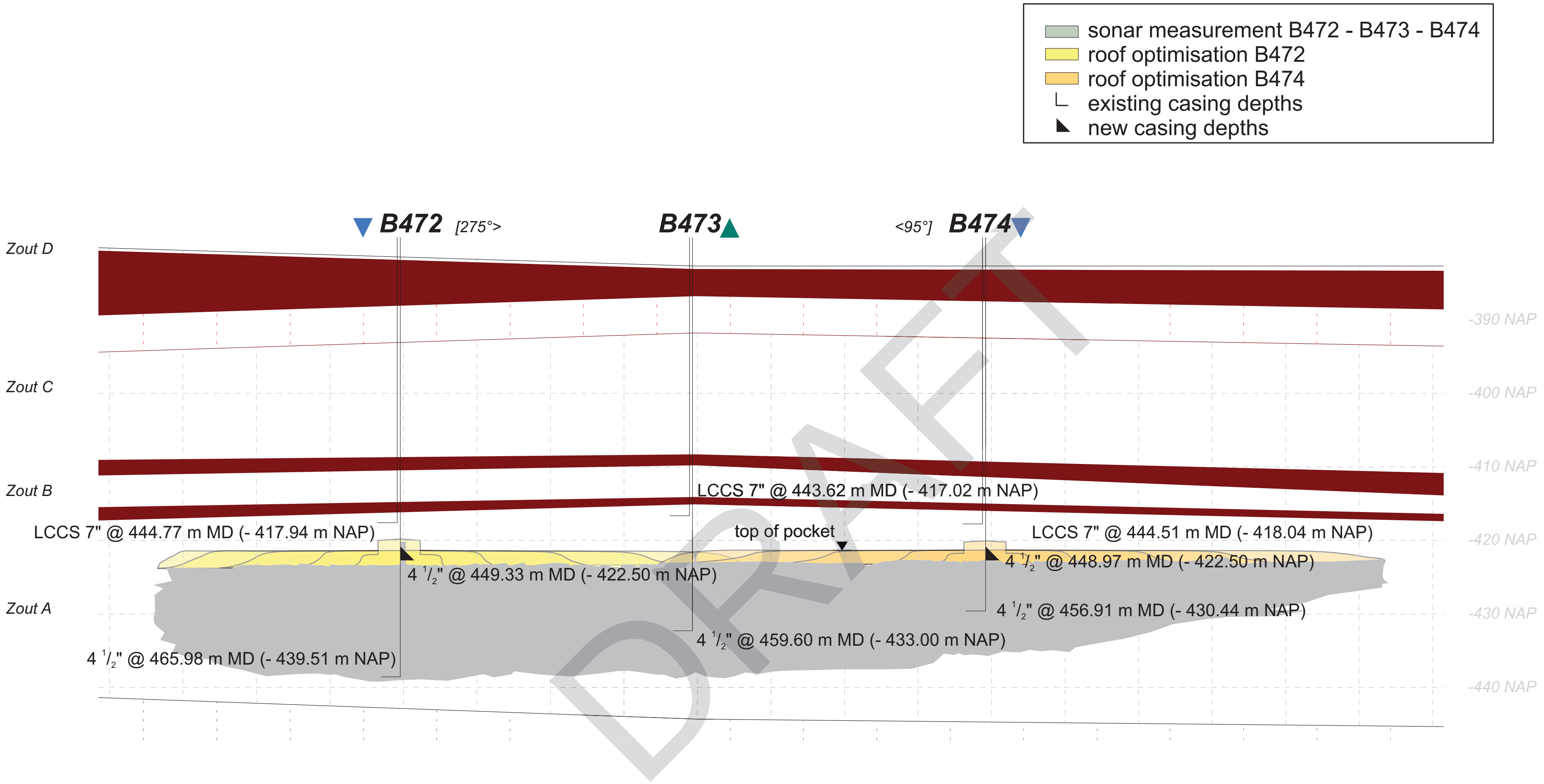
**) Partial volumen derived from sonar measurement well B470

**Enclosure 10:** Leaching parameters and concept for cavern series B469-B470-B471




**Enclosure 11:** Oil injection and withdrawal for roof optimization for wells B472 and B474

PN 5305
121214_Enclosures.des/BA




**Enclosure 12:** Cross section cavern series B472 - B473 - B474 including existing and proposed casing depths for wells B472 and B474

PN 5305
121214_Enclosures.des/BA

## Leaching parameter cavern series B472 - B473 - B474

| Cavern Series | Existing depth 7" casing NAP [m] | Existing depth 7" casing MD [m] | Offset | Top zoutlaag A NAP [m] | New depth 7" LCCS NAP [m] | New depth 7" LCCS MD [m] | Leaching string 4 ½" NAP [m] | Leaching string 4 ½" MD [m] | Pocket range NAP from | Pocket range NAP to | Pocket range MD from | Pocket range MD to | Max. pocket distance [m] | Leaching duration [d] | Volume increase [m³] | Salt production [t] | Pocket volume [m³] | Additional oil for initial roof coverage [m³] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | -421,90 | -423,40 | | | | | | | | |
| B472 *) | -417,94 | 444,77 | 26,83 | -416,16 | - | - | -422,50 | 449,33 | | | 448,73 | 450,23 | 50 | 150 | 11,500 | 26,000 | | |
| B473 **) | -417,02 | 443,62 | 26,60 | -415,08 | - | - | -433,00 | 459,60 | | | 448,50 | 450,00 | | | | | 2,400 | 1,000 |
| B474 *) | -418,04 | 444,51 | 26,47 | -415,98 | - | - | -422,50 | 448,97 | | | 448,37 | 449,87 | 50 | 105 | 8,000 | 20,000 | | |

*) injection wells

**) production well



**Enclosure 13:** Leaching parameter for cavern series B472 - B473 - B474

### Leaching Concept Well B472

| Settings | | | | | | | | | Leaching | | | Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | Activities | Duration | Inner string *) | | Outer string | | Blanket depth | | Duration | Mode | Injection rate | Duration total | NaCl average | Sump level | | Volume **) |
| [d] | | [d] | MD [m] | NAP [m ] | MD [m] | NAP [m ] | MD [m] | NAP [m ] | [d] | | [m³/h] | [d] | [kg/m³] | MD [m] | NAP [m ] | [m³] |
| 1 | Beginn of leaching | | 459,60 | -433,00 | 449,33 | -422,50 | 446,83 | -420,00 | 20 | top | 10 | 20 | 320 | 465.33 | -438.50 | 69,000 |
| 20 | Blanket | | | | | | 448,73 | -421,90 | 130 | top | 25 | 150 | 320 | 464.43 | -437.60 | 80,000 |

*) Production string in well B473

**) Partial volume derived from sonar measurement well B472

### Leaching Concept Well B474

| Settings | | | | | | | | | Leaching | | | Results | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | Activities | Duration | Inner string *) | | Outer string | | Blanket depth | | Duration | Mode | Injection rate | Duration total | NaCl average | Sump level | | Volume **) |
| [d] | | [d] | MD [m] | NAP [m ] | MD [m] | NAP [m ] | MD [m] | NAP [m ] | [d] | | [m³/h] | [d] | [kg/m³] | MD [m] | NAP [m ] | [m³] |
| 1 | Beginn of leaching | | 459,60 | -433,00 | 448,97 | -422,50 | 446,47 | -420,00 | 20 | top | 10 | 20 | 320 | 461.50 | -435.03 | 49,500 |
| 20 | Blanket | | | | | | 448,37 | -421,90 | 85 | top | 25 | 105 | 320 | 460.00 | -433.53 | 56,500 |

*) Production string in well B473

**) Partial volume derived from sonar measurement well B474



**Enclosure 14:** Leaching concepts for wells B472 and B474

# Hazard Study 2

**Sheet 1**

| **Project: Clovis** | | **Site: Hengelo** | **Plant/Section: Salt** | | | |
|---|---|---|---|---|---|---|
| Author: S. Woudstra | | | File: | | Meeting no.: | # 1 |
| Drawing Title: | | | Drawing No.: | | Meeting date: | 27-1-2011 |
| **Team Members** | **Name** | **Role** | **Name** | **Role** | Revision: | |
| | S. Woudstra | HS Leader | P. Klappe | Project manager engineering | Date: | |
| | H.J. Leusink | Operations representative | Th. Van Lotringen | Sr. Process engineer | Issue No.: | |
| | M. Pijnenborg | Project manager overall | M. Mampaey | DCM EMBA / operations | Approved for issue: | |
| | K. Wuesten | Process engineer | J. Arns | North Sea Group / operation | Signed: | |
| **Process description** | Aansluiten van de pompcontainer op de boorgatkop: druk tot 17 barg olie/ atmosferisch pekel, temperature ambient, Systeem wordt vooraf ontlucht om te zorgen voor boorgat gevuld met pekel/olie. Ter voorbereiding op het vullen met olie. | | | | | |
| **NOTE (version 1 - 2010):** | Use drop down lists for "Guidewords", "Severity", "Frequency" and "Action Status" columns.<br>Site and project data in the title box is automatically transferred from sheet 1 to other sheets.<br>Item and action numbers are generated automatically. Do not insert or delete rows or columns to preserve the automatic numbering.<br>Do not use "CUT AND PASTE" to move data from text cells. Use "COPY AND DELETE".<br>The actions are automatically transferred into the Prioritisation sheet matrices so you can see the actions for the highest risks. | | | | | |

The summary definition of the severity and frequency categories can be seen by clicking on the yellow and blue boxes here:

| | | |
|---|---|---|
| S5 | F6 | Implemented |
| S4 | F5 | Ongoing |
| S3 | F4 | Overdue |
| S2 | F3 | On hold |
| S1 | F2 | Deferred |
| Site issue | F1 | |

**INITIAL RISK - NO CONTROLS/SAFEGUARDS** — **FINAL RISK - WITH ACTIONS/SAFEGUARDS**

| Nr. | Guidewords | | Caused by | | Consequences | | Severity | Frequency | Initial Risk Ranking | Existing Safeguards | Recommendations | Ref | Severity | Frequency | Final Risk Ranking | Assigned to | Action Status | Action progress comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **External / Internal Explosion / Fire** | 1.1 | Geen oorzaak gevonden | 1.1.1 | | | | | | | | | | | | | | |
| 2 | **Uncontrolled Reaction** | 2.1 | Geen oorzaak gevonden | 2.1.1 | | | | | | | | | | | | | | |
| 3 | **Over/underpressure** | 3.1 | Onderdruk kan voorkomen door lage pekeldruk | 3.1.1 | Voor aansluiten geen probleem. Mogelijk lucht in de caverne. Gevolg is mogelijk veroudering van de olie. | | S1 | F4 | **Priority C** | | Schrijf procedure opstarten en neem op:ontluchten van de leiding. | 1 | S1 | F3 | **Priority C** | Leusink | | |
| 4 | **Over/underpressure** | 4.1 | Na eerste keer vullen staat de caverne onder druk tot 17 barg. | 4.1.1 | Vrijkomen van een kleine hoeveelheid olie. Ca 1 liter (ruimte tussen de blindflens en de afsluiter). | 4.1.1.1 | S1 | F6 | **Priority A** | Olie opvang in kelder. | Schrijf procedure opstarten en neem op: Zorg voor miliebeschermende maatregelen (bijvoorbeeld lekbak, absorbtiemiddel) | 2 | S1 | F4 | **Priority C** | Weusten | | |
| 5 | **Over/underpressure** | 5.1 | Pekelafsluiter staat open, druk is 17 + 5 barg. | 5.1.1 | Vrijkomen van een kleine hoeveelheid olie. Ca 1 liter (ruimte tussen de blindflens en de afsluiter. | 5.1.1.1 | S1 | F6 | **Priority A** | Olie opvang in kelder. | Schrijf procedure opstarten en neem op: Zorg voor miliebeschermende maatregelen (bijvoorbeeld lekbak, absorbtiemiddel) | 3 | S1 | F4 | **Priority C** | Weusten | | |
| 6 | **Over/underpressure** | 6.1 | Afsluiter van Dilution string staat open. | 6.1.1 | Extra drukopbouw bij de olieafsluiter. Maximaal 17 + 20 barg). Vrijkomen van een kleine hoeveelheid olie. Ca 1 liter (ruimte tussen de blindflens en de afsluiter. | 6.1.1.1 | S1 | F6 | **Priority A** | Olie opvang in kelder. | Schrijf procedure opstarten en neem op: Zorg voor miliebeschermende maatregelen (lekbak, oid). Monitoren van de druk. Koppel de dilution string af na gebruik. | 4 | S1 | F4 | **Priority C** | Weusten | | |
| 7 | **Exposure (Chemical)** | 7.1 | Vrijkomen van olie, gevolg is blootstelling aan operators. | 7.1.1 | Mogelijk letsel door vrijkomen onder hoge druk (spuiter of vernevelen) Contact met olie. | | S3 | F6 | **Resolve now** | | Schrijf procedure opstarten en neem op: check de druk, Voorzie de flenzen van Safe-ringen. Gebruik van PBM's. | 5 | S2 | F4 | **Priority B** | Procedure en PBM: Weusten. Saferingen: Klappe | | |
| 8 | **Leak** | 8.1 | Vrijkomen van olie | 8.1.1 | Milieu incident: bodemverontreiniging | 8.1.1.1 | S2 | F6 | **Resolve nov** | Olie opvang in kelder. | Voorzie de flenzen van Safe-ringen | 6 | S1 | F4 | **Priority C** | Klappe | | |
| 9 | **Maloperation of openings** | 9.1 | Niet werken volgens de procedure. | 9.1.1 | Mogelijk letsel door vrijkomen onder hoge druk (spuiter of vernevelen) Contact met olie. Milieu incident. | | S3 | F5 | **Resolve now** | | Maak de afsluiters voor olie en pekel locked closed. Dubbel slot op elke afsluiter. Neem het gebruik op in de procedure opstarten. | 7 | S3 | F4 | **Priority A** | Klappe | | |
| 10 | **Non-routine operations** | 10.1 | Onervarenheid operators | 10.1.1 | Mogelijk letsel door vrijkomen onder hoge druk (spuiter of vernevelen) Contact met olie. Milieu incident. | | S3 | F5 | **Resolve now** | | Instrueer operators | 8 | S3 | F4 | **Priority A** | Weusten/ Arns | | |
| 11 | **Noise** | 11.1 | Geen oorzaak gevonden | 11.1.1 | | | | | | | | | | | | | | |
| 12 | **External / Internal Explosion / Fire** | 12.1 | Statische electriciteit | 12.1.1 | Schade aan de installatie | 12.1.1.1 | S1 | F5 | **Priority B** | Aarding is voorzien. | Regel periodiek onderhoud en inspectie van de aardinstallatie en onderdelen. | 9 | S1 | F3 | **Priority C** | Groothuismink/ Arns | | |
| 13 | **External / Internal Explosion / Fire** | 13.1 | Blikseminslag | 13.1.1 | Schade aan de installatie | 13.1.1.1 | S3 | F4 | **Priority A** | Systematisch doorlussen van alle installatiedelen. De casing werkt als aarding. | Voorzie alle verbindingen van doorlussing van voldoende diameter. | 10 | S2 | F4 | **Priority B** | Klappe/ Arns | | |

# Hazard Study 2

**Sheet 2**

| **Project: Clovis** | **Site:** | **Hengelo** | **Plant/Section: Salt** | |
|---|---|---|---|---|
| Drawing Title: | | | Drawing No.: | Meeting no.: |
| **Process description** | Vullen van de caverne met olie. 35 m3 per keer.Frequentie is 3 keer per uur. Flow is 150 m3 per uur. Druk is ca 32 barg maximaal. | | | Meeting date:<br>Revision:<br>Date: |
| **NOTE:** | Use drop down lists for "Guidewords", "Severity", "Frequency" and "Action Status" columns.<br>Site and project data in the title box is automatically transferred from sheet 1 to other sheets.<br>Item and action numbers are generated automatically. Do not insert or delete rows or columns to preserve the automatic numbering.<br>Do not use "CUT AND PASTE" to move data from text cells. Use "COPY AND DELETE".<br>The actions are automatically transferred into the Prioritisation sheet matrices so you can see | | | |

The

| | | |
|---|---|---|
| S5 | F6 | Implemented |
| S4 | F5 | Ongoing |
| S3 | F4 | Overdue |
| S2 | F3 | On hold |
| S1 | F2 | Deferred |
| Site issue only | F1 | |

| | | | | | | | INITIAL RISK - NO CONTROLS/SAFEGUARDS | | | | | | FINAL RISK - WITH ACTIONS/SAFEGUARDS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nr.** | **Guidewords** | | **Caused by** | | **Consequences** | | **Severity** | **Frequency** | **Initial Risk Ranking** | **Existing Safeguards** | **Recommendations** | **Ref** | **Severity** | **Frequency** | **Final Risk Ranking** | **Assigned to** | **Action Status** | **Action progress comment** |
| 14 | **External / Internal Explosion / Fire** | 14.1 | Geen oorzaak gevonden. | 14.1.1 | | | | | | | | | | | | | | |
| 15 | **Uncontrolled Reaction** | 15.1 | Geen oorzaak gevonden. | 15.1.1 | | | | | | | | | | | | | | |
| 16 | **Over/underpressure** | 16.1 | Hoge druk: geen oorzaak gevonden. | 16.1.1 | | | | | | | | | | | | | | |
| 17 | **Over/underpressure** | 17.1 | Opstarten van de installatie geeft lage druk. | 17.1.1 | Terugstroming vanuit de caverne richting pompset. Spill van olie, milieuincident. | 17.1.1.1 | S4 | F6 | Resolve no | Electrisch gestuurde kleppen die openen bij voldoende druk. Terugslagklep. Tankwagenchauffeur | Overwogen wordt om een zogenaamde dodemansknop te installeren (chauffeur dient de knop ingedrukt te houden tijdens lossen van de tankwagen) | 11 | S4 | F2 | Priority B | Klappe/ Arns | | |
| 18 | **Over/underpressure** | 18.1 | Uitval electrische voorziening | 18.1.1 | Drukschommelingen | | S5 | F6 | Resolve now | | Ga na door middel van berekeningen wat de effecten zijn. | 12 | | | | Klappe | | |
| 19 | **Over/underpressure** | 19.1 | Tankwagen raakt leeg | 19.1.1 | Drukschommelingen | | S5 | F6 | Resolve now | | Ga na door middel van berekeningen wat de effecten zijn. | 13 | | | | Klappe | | |
| 20 | **Leak** | 20.1 | Niet goed aangesloten van de koppelingen/flenzen. | 20.1.1 | Lekkages, milieuincident. | 20.1.1.1 | S2 | F6 | Resolve no | Vloeistofdichte vloer, lekbak. | Opleiding chauffeur | 14 | S1 | F4 | Priority C | Pijnenborg/ Arns | | |
| 21 | **Maloperation of openings** | 21.1 | Afsluiter open voordat aangesloten is. | 21.1.1 | Lekkages, milieuincident. | 21.1.1.1 | S4 | F6 | Resolve no | Vloeistofdichte vloer, lekbak. | Opleiding chauffeur | 15 | S1 | F4 | Priority C | Pijnenborg/ Arns | | |
| 22 | **Maloperation of openings** | 22.1 | Wegrijden zonder af te koppelen. | 22.1.1 | Lekkages, milieuincident. Schade aan de slang. | 22.1.1.1 | S4 | F4 | Resolve no | Vloeistofdichte vloer, lekbak. | Opleiding chauffeur | 16 | S1 | F3 | Priority C | Pijnenborg/ Arns | | |
| 23 | **Noise** | 23.1 | Verpompen van de olie door pomp in het huisje. Tankauto bewegingen. | 23.1.1 | Geluidoverlast | 23.1.1.1 | S2 | F5 | Priority A | Huidige maatregelen zijn voldoende om binnen de vergunde waarden te blijven. | | | Site issue only | F5 | Priority C | | | |
| 24 | **Maloperation of openings** | 24.1 | Overvullen van de caverne met olie. | 24.1.1 | Olie in de pekelleiding richting pekelzuivering. | 24.1.1.1 | S2 | F4 | Priority B | Continue monitoring maximale olie-pekel interface. | Opnemen in caverneontwerp. | 17 | S1 | F4 | Priority C | Pijnenborg | | |

# Hazard Study 2

**Sheet 3**

AkzoNobel
Tomorrow's Answers Today

| **Project: Clovis** | **Site:** | **Hengelo** | **Plant/Section: Salt** | | |
|---|---|---|---|---|---|
| Drawing Title: | | | Drawing No.: | Meeting no.: | |
| **Process description** | Stationaire situatie. Bemonstering en inspecties op lekkages. | | | Meeting date: | |
| | | | | Revision: | |
| | | | | Date: | |
| **NOTE:** | Use drop down lists for "Guidewords", "Severity", "Frequency" and "Action Status" columns.<br>Site and project data in the title box is automatically transferred from sheet 1 to other sheets.<br>Item and action numbers are generated automatically. Do not insert or delete rows or columns to preserve the automatic numbering.<br>Do not use "CUT AND PASTE" to move data from text cells. Use "COPY AND DELETE".<br>The actions are automatically transferred into the Prioritisation sheet matrices so you can see the actions for the highest risks. | | | | |

The summary definition of the severity and frequency categories can be seen by clicking on the yellow and blue boxes here:

| | | |
|---|---|---|
| S5 | F6 | Implemented |
| S4 | F5 | Ongoing |
| S3 | F4 | Overdue |
| S2 | F3 | On hold |
| S1 | F2 | Deferred |
| Site issue only | F1 | |

**INITIAL RISK - NO CONTROLS/SAFEGUARDS** | **FINAL RISK - WITH ACTIONS/SAFEGUARDS**

| Nr. | Guidewords | | Caused by | | Consequences | | Severity | Frequency | Initial Risk Ranking | Existing Safeguards | Recommendations | Ref | Severity | Frequency | Final Risk Ranking | Assigned to | Action Status | Action progress comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | **External / Internal Explosion / Fire** | 25.1 | Geen oorzaak aanwezig | 25.1.1 | | | | | | | | | | | | | | |
| 26 | **Uncontrolled Reaction** | 26.1 | Geen oorzaak aanwezig | 26.1.1 | | | | | | | | | | | | | | |
| 27 | **Over/underpressure** | 27.1 | Drukopbouw door toestroming in de caverne. | 27.1.1 | Eventuele lekkages uit de caverne zijn niet goed waar te nemen. Mogelijk milieu incident | 27.1.1.1 | S2 | F6 | Resolve no | Olie opvang in kelder. Pekelkolom aan maaiveld dicht bij atmosferische druk houden, druk monitoren. Bij daling kolom wordt uitstroom van vloeistof vanuit de caverne opgemerkt. | Monitoren van de druk en eventueel druk af laten (pekelzijdig). Procedure schrijven: reguliere inspectie van de boorputten. | 18 | S1 | F4 | Priority C | Leusink | | |
| 28 | **Long Term Weakening** | 28.1 | Geen oorzaak aanwezig | 28.1.1 | | | | | | | | | | | | | | |
| 29 | **Burst** | 29.1 | Geen oorzaak aanwezig | 29.1.1 | | | | | | | | | | | | | | |
| 30 | **Exposure (Chemical)** | 30.1 | Monstername | 30.1.1 | Blootstelling van olie aan operators | 30.1.1.1 | S3 | F6 | Resolve no | Gebruik van de PBM's en instructies. | Ontwerp een methode/apparaat waarbij de operator vrij is van blootstellingen | 19 | | | | Pijnenborg | | |
| 31 | **Leak** | 31.1 | Lekkage langs de pakking van de afsluiter. | 31.1.1 | Spill van olie in het huisje. | 31.1.1.1 | S2 | F5 | Priority A | Olie opvang in kelder. | Controle van de huisjes / lekkages opnemen in de taken van de operator. | 20 | S1 | F4 | Priority C | Groothuismink | | |
| 32 | **Non-routine operations** | 32.1 | Inbraak | 32.1.1 | Spill van olie in het huisje. | 32.1.1.1 | S2 | F4 | Priority B | Cameratoezicht. | Schrijven en uitvoeren van een securityplan | 21 | S1 | F4 | Priority C | Pijnenborg | | |

# Hazard Study 2
**Sheet 4**

| **Project: Clovis** | **Site:** Hengelo | **Plant/Section: Salt** | |
|---|---|---|---|
| Drawing Title: | | Drawing No.: | Meeting no.: |
| **Process description** | Laden van de tankauto. | | Meeting date: |
| | | | Revision: |
| | | | Date: |

**NOTE:**
Use drop down lists for "Guidewords", "Severity", "Frequency" and "Action Status" columns.
Site and project data in the title box is automatically transferred from sheet 1 to other sheets.
Item and action numbers are generated automatically. Do not insert or delete rows or columns to preserve the automatic numbering.
Do not use "CUT AND PASTE" to move data from text cells. Use "COPY AND DELETE".
The actions are automatically transferred into the Prioritisation sheet matrices so you can see the actions for the highest risks.

The summary definition of the severity and frequency categories can be seen by clicking on the yellow and blue boxes here:

| | | |
|---|---|---|
| S5 | F6 | Implemented |
| S4 | F5 | Ongoing |
| S3 | F4 | Overdue |
| S2 | F3 | On hold |
| S1 | F2 | Deferred |
| Site issue only | F1 | |

**INITIAL RISK - NO CONTROLS/SAFEGUARDS** | **FINAL RISK - WITH ACTIONS/SAFEGUARDS**

| Nr. | Guidewords | | Caused by | | Consequences | | Severity | Frequency | Initial Risk Ranking | Existing Safeguards | Recommendations | Ref | Severity | Frequency | Final Risk Ranking | Assigned to | Action Status | Action progress comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | External / Internal Explosion / Fire | 33.1 | Geen oorzaken gevonden | 33.1.1 | | | | | | | | | | | | | | |
| 34 | Uncontrolled Reaction | 34.1 | Geen oorzaken gevonden | 34.1.1 | | | | | | | | | | | | | | |
| 35 | Over/underpressure | 35.1 | Onderdruk door dichthouden van de pekelafsluiter. | 35.1.1 | Vacuum in de pekelleiding, mogelijk schade aan de leiding. | | S2 | F4 | Priority B | | Plaats een beluchtingsklep in de pekelleiding. Ga na of de casing / systeem bestand is tegen vacuum. | 22 | S1 | F3 | Priority C | Klep: Klappe Casing: Pijnenborg | | |
| 36 | Over/underpressure | 36.1 | Instantaan stoppen van de lossing. Bijvoorbeeld door ongewenst sluiten van een klep. | 36.1.1 | Waterslag in de leiding. Schade aan de leiding. | 36.1.1.1 | S4 | F4 | Resolve no | Flowregeling behorende bij de pomp. | Aanleveren van informatie mbt de druk/flow hoeveelheid. | 23 | | | | Pijnenborg/ Arns | | |
| 37 | Over/underpressure | 37.1 | Uitval van de E-voorziening. Instantaan stoppen van de lossing. | 37.1.1 | Waterslag in de leiding. Drukpiek van 60 - 70 barg. Schade aan de leiding. | 37.1.1.1 | S4 | F4 | Resolve no | Sluitsnelheid van de klep is in te stellen door middel van een naaldventiel. | Aanleveren van informatie mbt de druk/flow hoeveelheid. | 24 | | | | Pijnenborg/ Arns | | |
| 38 | Over/underpressure | 38.1 | Te hoge olieflow in de leiding | 38.1.1 | Vacuum in de pekelleiding door beperkte toevoer van pekel. Schade aan cementlining van de pekelleiding en aan de koppelingen. Spill van pekel en economische schade door uit bedrijf zijn. | 38.1.1.1 | S3 | F4 | Priority A | Flowregeling behorende bij de pomp. | Plaats een beluchtingsklep in de pekelleiding. Denk na over een alternatief systeem (drukbewaking). Ga na of de casing / systeem bestand is tegen vacuum. | 25 | S1 | F3 | Priority C | Klep: Klappe Casing: Pijnenborg Alternatief: Klappe | | |
| 39 | Leak | 39.1 | Overvullen van een tankwagen compartiment. | 39.1.1 | Spill van olie | 39.1.1.1 | S4 | F6 | Resolve no | Overvulbeveiliging op de compartimenten. Toevoerklep wordt gesloten van het betreffende compartiment. | | | S1 | F4 | Priority C | Pijnenborg/ Arns | | |
| 40 | Exposure (Chemical) | 40.1 | Zie tabel aansluiten pompcontainer en tabel vullen caverne | 40.1.1 | | | | | | | | | | | | | | |
| 41 | Leak | 41.1 | Oliespill uit de slang na afkoppelen. | 41.1.1 | Spill van olie | 41.1.1.1 | S1 | F6 | Priority A | Opvangbak voor de olie. Olie / water afscheider aanwezig. | Plaats een compressor in de container om de slang richting tankwagen leeg te blazen. | 26 | S1 | F4 | Priority C | Pijnenborg/ Arns | | |
| 42 | Leak | 42.1 | Slang niet juist aangekoppeld. | 42.1.1 | Spill van olie | 42.1.1.1 | S2 | F6 | Resolve no | Opvangbak voor de olie. Olie / water afscheider aanwezig. | Zorg voor reserve ringen/afdichtingen in de container. | 27 | S1 | F4 | Priority C | Pijnenborg/ Arns | | |

# INITIAL PRIORITIZATION OF HEALTH, SAFETY AND ENVIRONMENTAL ISSUES

***( without safeguards/controls)***

## Consequence category

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **S5** | On site: >1 fatality;<br>Off-site: one or more fatalities or several severe injuries, major damage >2million Euros;<br>Reputation: International attention, damage to AkzoNobel stakeholders;<br>Health: Fatal exposure, or severe off-site exposure;<br>Environment: >LoC D, major offsite damage and international publicity | | | | | | **12,13,** |
| **S4** | On site: one fatality or several several injuries, significant damage <2million Euros;<br>Off-site: One severe injury;<br>Reputation: Damage to BU stakeholders, severe fine, national media attention;<br>Health: Severe exposure with life threatening effect or permanent chronic illness;<br>Environment: LoCD, off site impact generating public concern | | | | **16,23,24,** | | **11,15,,** |
| **S3** | On site: Severe injury (in-patient hospital treatment), important damage <500kEuros;<br>Off-site: Few people require hospital treatment;<br>Reputation: Damage to local stakeholders, local media attention;<br>Health: Exposure leading to occupational illness, i.e. irreversible, sensitising effects;<br>Environment:LoCC with observable impact off site | | | | **10,25,** | **7,8,** | **5,19,** |
| **S2** | On site: Reportable injury without in-patient hospital treatment, medium damage < 100kEuros;<br>Off-site: Sustained nuisance e.g. smell/dust;<br>Reputation: External complaint, affects reputation with some employees;<br>Health: Exposure > OEL;<br>Environment:LoCB escape almost certain contained on site, not readily controlled, with | | | | **17,21,22,** | **,20,** | **6,14,18,27,** |
| **S1** | On site: First aid case, small damage <20k Euros;<br>Off-site: Short duration nuisance;<br>Reputation: No damage:<br>Health: minor exposure < OEL;<br>Environment:LoCA escape readily controlled, contained on site with no off-site impacts | | | | **1,** | **9,** | **2,3,4,26,** |
| **(0) SITE ISSUE ONLY** | On site: Max. high potential incident;<br>Off-site: No issue | | | | | | |
| | **Likelihood of Occurrence** | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** |
| **Site**<br><br>**Date** | | Once in 10000 years - theoretically possible but very remote chance | Once in 1000 years - foreseeable event but remote chance of happening in plant life time, requires multiple | Rarely heard of, once in 100 years | Happens occasionally, once in 10 years | Happens sometimes, once per year | Happens regularly, > once per year |
| | For Process Hazard Review | Critical<br><br>Important | Urgent<br><br>Non critical | | | | |

## FINAL PRIORITIZATION OF HEALTH, SAFETY AND ENVIRONMENTAL ISSUES *(with safeguards/controls*

*(with safeguards/controls)*

| Consequence category | | | | | | | |
|---|---|---|---|---|---|---|---|
| **S5** | On site: >1 fatality;<br>Off-site: one or more fatalities or several severe injuries, major damage >2million Euros;<br>Reputation: International attention, damage to AkzoNobel stakeholders;<br>Health: Fatal exposure, or severe off-site exposure;<br>Environment: >LoC D, major offsite damage and international publicity | | | | | | |
| **S4** | On site: one fatality or several several injuries, significant damage <2million Euros;<br>Off-site: One severe injury;<br>Reputation: Damage to BU stakeholders, severe fine, national media attention;<br>Health: Severe exposure with life threatening effect or permanent chronic illness;<br>Environment: LoCD, off site impact generating public concern | | **11,** | | | | |
| **S3** | On site: Severe injury (in-patient hospital treatment), important damage <500kEuros;<br>Off-site: Few people require hospital treatment;<br>Reputation: Damage to local stakeholders, local media attention;<br>Health: Exposure leading to occupational illness, i.e. irreversible, sensitising effects;<br>Environment:LoCC with observable impact off site | | | | **7,8,** | | |
| **S2** | On site: Reportable injury without in-patient hospital treatment, medium damage < 100kEuros;<br>Off-site: Sustained nuisance e.g. smell/dust;<br>Reputation: External complaint, affects reputation with some employees;<br>Health: Exposure > OEL;<br>Environment:LoCB escape almost certain contained on site, not readily controlled, with | | | | **5,10,** | | |
| **S1** | On site: First aid case, small damage <20k Euros;<br>Off-site: Short duration nuisance;<br>Reputation: No damage:<br>Health: minor exposure < OEL;<br>Environment:LoCA escape readily controlled, contained on site with no off-site impacts | | | **1,9,16,22,25,** | **6,14,15,17,18,20,21,,** | | |
| **(0) SITE ISSUE ONLY** | On site: Max. high potential incident;<br>Off-site: No issue | | | | | **,** | |
| | **Likelihood of Occurrence** | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** |
| **Site**<br><br>**Date** | | Once in 10000 years - theoretically possible but very remote chance | Once in 1000 years - foreseeable event but remote chance of happening in plant life time, requires multiple | Rarely heard of, once in 100 years | Happens occasionally, once in 10 years | Happens sometimes, once per year | Happens regularly, > once per year |
| | For Process Hazard Review | Critical<br><br>Important | Urgent<br><br>Non critical | | | | |

# Hazard Study 2

**Guide Diagram - Loss of Containment (LoC)**

AkzoNobel

Tomorrow's Answers Today

| Guidewords | Caused by | |
|---|---|---|
| **1 External / Internal Explosion / Fire** | Flammable material | Flammable gas, vapour, liquid, mist, solid, metal, wood, waste material, pyrophoric material, dust. Explosive/Unstable material |
| | Oxidant | Chemical oxidant (oxygen/chlorine). Air ingress. Inadequate purging, LoC, poor housekeeping |
| | Source of ignition | Auto-ignition, Static built up (also elecrostatic ignition - human, cloth), Electrical equipment, Sparks/Welding/Friction, Pyrophorics, Lightning |
| | | |
| **2 Uncontrolled Reacti** | Reactive materials | Runaway reaction. Decomposition. Contamination. Incorrect material. No inhibitor |
| | Incorrect conditions | Excess temperature. Mixing failure. Control failure. Hot spots. Shelf life. |
| | Sequence error | Omission/repeat of step. Too much/little. Too early/late |
| | | |
| **3 Physical Over/** | | Closed valves. Vent blocked by freezing/polymerization/solidification. Vent undersized. |
| **Under- pressure** | Overpressure by | Overheating. Pressure letdown/flashing. Pump dead-head. Roll-over. Water hammer. Machine surge. Liquid into compressor. Tube rupture. Equipment failure. Service failure. External fire. Ambient changes. Thermal expansion. Overfill, frost. |
| | Under pressure by | Vacuum. Pump-out. Gravity drainage. Condensation. Gas absorption.. |
| | Ineffective relief | Relief system isolated/blocked/undersized. Relief valve failed. Wrong relieve valve fitted. |
| | | |
| **4 Long Term Weakening** | | Internal/external corrosion. Erosion. Stress corrosion. Thermal creep. Thermal cycling. Embrittlement. Vibration. Fatigue, impact (hammer) |
| | | |
| **5 Burst** | Impact/Puncture | Vehicle, road/rail/ship/forklift truck. Missile. Lifting failure. Knock-on/Domino effect. Operation/maintenance activities. Digging/Excavation. Landslide. subsidence. |
| | Mechanical failure | Rotating/Reciprocating machines. Tanker drive-away. Structural collapse. Flood-tank float. Wind loading. High or low temperature failure. Extreme natural phenomena. |
| | | |
| **6 Exposure (Chemical** | Acute/Chronic Harmful / | Toxic gasses, vapours, mists, liquids, dusts, fumes, acids, alkalis, biological, waste solids, thermal burn, electro chock, overflowing, odour release |
| | Exposure Mechanism | LOC., decontamination, mechanical handling, sampling, manipulation, ventilation failure, Biological exposure (legionella) |
| | Exposure to moving part | Guarding |
| | | |
| **7 Leak** | Equipment items | Joints. Seals. Bellows. Hoses. Filters. Sight glasses. |
| | Causes | Poor assembly. Poor welding. Wrong material. Seal wear. Frequent make/break. |
| | | |
| **8 Mal-operation of ope** | Equipment items | Vent. Drain. Sample point. Overflow. Blow down line. Relief discharge. Loading connection. |
| | Causes | Error following maintenance. Opened in error/by accident. Control failure. Spurious relief. |
| | | |
| **9 Non-routine operations** | | Start-up. Shut-down. Maintenance. Cleaning. Inspection/testing. Blockage removal. Trip defeat. Trapped pressure. Poor isolation. Waste disposal. Open manholes. 'Abnormal' operating mode, training new operators. Software integrity (computer too hot) |
| | | |
| **10 Noise** | Sources | Machinery, ejectors, flares, pressure let-down, vents, reliefs, road / rail traffic, sirens, alarms, conveyors, mechanical handling, high pressure cleaning, demolition, construction. |

**External / Internal**
**Explosion / Fire**
**Uncontrolled Reaction**
**Over/Under pressure**

**Long term**
**weakening**
**Burst**
**Exposure (Chemical)**
**Leak**
**Mal-operation of opening**
**No routine operation**
**Noise**

# Hazard Study 2

## PHR Consequence Guide Diagram

| Consequences | Prompts | | | | Mitigation measures |
|---|---|---|---|---|---|
| Fire/Explosion | Material | | | Explosion hazard: Vapour, Flashing liquid, Dust. Fire hazard: Liquid, solid, packaging, pyrophoric, metals | Layout , Spacing |
| | | Ignition | | Mechanical: Friction, tools, hot missiles Thermal: Hot spot, sparks, smoking, welding Chemical: Pyrophoric, thermite Electrical: Switchgear, motor, static, lightning | Inventory Reduction , Eliminate sources of ignition Rapid fire detection , Equipment Fire Protection Fire fighting facilities |
| | | | Instant ignition | Pool Fire, Jet Fire | Emergency procedures |
| | | | Delayed ignition | Flash Fire, Vapour cloud explosion, Dust explosion, BLEVE/Fireball | Dispersion aids (sprays) Control Room design Off-site emergency plan |
| Toxic release | Acute | | | Toxic vapour/liquid/dust/smoke. Corrosive acids & alkalis. Nitrogen asphyxiant. Ionising radiation. Short term exposure limits | Leak contamination , Emergency isolation, Gas detectors, Radiation detectors, Toxic refuges, Emergency procedures |
| | | Chronic | | Carcinogens. Dermatitis. Heavy metals. Asbestos. Pathogens. Narcotics. Ionising radiation. Occupational Exposure Limits | Off-site emergency plans Personal monitors Health surveillance |
| Guidewords/Cause by Release of Pollution | Atmospheric | | | Acid )HCL, NH3, NOx, SOx), Global warming potential (CH4, CO2, VOCs), Ozone depletion ( CFCs, CCL4), Photochemical Ozone Creation ( Ethylene, VOCs) | Regular Operating Patrols, Inventory Checks, Leak containment, Gas leak detectors |
| | | Release to Water | | Drains. Spillage. Run-off. Bunds. Firewater. Lubricants. Foams. Reactions. Laboratory Waste. Tank cleaning. Wash-down. | Analyzers in drain/outfalls Emergency isolations Emergency procedure |

# Hazard Study 2

## Guidance for Consequence Categories - Safety, Health and Reputation

AkzoNobel
Tomorrow's Answers Today

| | ACUTE INJURY INCIDENTS<br>-on-site effects- | ACUTE INJURY INCIDENT<br>- off-site effects- | CHRONIC HEALTH HAZARD OR PHYSICAL CONDITION<br>-on-site effects- |
|---|---|---|---|
| **SEVERITY 5 EVENT<br>EXTREMELY SERIOUS CONSEQUENCES** | Several fatalities on site | One or more off-site fatalities, or several severe injuries off-site. | Fatal Exposure: Exposure to an active agent which causes death, and or several severe external exposures |
| **SEVERITY 4 EVENT<br>MAJOR CONSEQUENCES** | Fatality (F); One fatality, or several severe injuries on site | One severe injury off-site | Severe Exposure: Exposure to an active agent with life threatening effect or permanent chronic illness |
| **SEVERITY 3 EVENT<br>SEVERE CONSEQUENCES** | Severe Injury (SI); On-site injury to employees, contractors or members of the general public which leads to in-patient hospital treatment. (Directive 13.4) | Few people require hospital treatment | Exposure to active agent leading to Occupational illness (St. 3; definition 3.2.3.5) |
| **SEVERITY 2 EVENT<br>SERIOUS CONSEQUENCES** | Reportable injury (RI); Medical treatment Injury, Restricted Work Injury, or Lost Time Injury not requiring in-patient hospital treatment. | People affected - short term minor | Exposure: Exposure to an active agent above occupational effect level |
| **SEVERITY 1 EVENT<br>SIGNIFICANT CONSEQUENCES** | First aid treatment injury (FA) (St. 3: definition 3.2.3.4) | Nuisance offsite - see Environmental | Minor Exposure: Exposure to an active agent (St. 3: definition 3.2.3.5) well below occupational effect level |

# Hazard Study 2

## Guidance for Consequence Categories - Environmental Incidents

AkzoNobel
Tomorrow's Answers Today

Hazards are linked to the Loss of Containment (LoC) categories from our KPIs (HSE&S St. 3: definition 3.3.1.30)

| | DEFINITION FROM GUIDANCE NOTES 14.13 | AIRBORNE INCIDENT - ON-SITE EFFECTS | AIRBORNE INCIDENT - OFF-SITE EFFECTS | LIQUID DISCHARGE INCIDENT |
|---|---|---|---|---|
| **CATEGORY 5 EVENT EXTREMELY SERIOUS CONSEQUENCES** | S5: >LoCD catastrophic escape with major off site damage and international media attention (like Seveso or Bhopal accidents) | Lose employee confidence - withdraw from site. | Release of large quantity of highly toxic material. Repeated serious incidents affecting offsite areas. Operation forced to close. | Very serious contamination of ground and water sources. Long-term loss of aquatic life. Repeated category 4 event. |
| **CATEGORY 4 EVENT MAJOR CONSEQUENCES** | S4: LoCD significant escape which has to be reported to the authorities; with off-site impact and that gives rise to public concern and media attention. | Major concern on-site:<br>- fires, explosions,<br>- site evacuation.<br>Repeated emergencies. | Gas or smoke discharge, large offsite evacuation. Release of carcinogen leading to long term concern. Major damage to wildlife. Serious complaints, MPs | Major loss of very harmful or toxic liquid. 5-10 mile distinct effect. High Court prosecution and large fine. "Major Accident" (D or E definition, CIMAH Guidance Note. June 1991) |
| **CATEGORY 3 EVENT SEVERE CONSEQUENCES** | S3: LoCC escape that is observable or has impact off-site and can give rise to public concern and media attention; | Cause concern on-site:<br>- flames, shock wave,<br>- serious toxic release,<br>- offices engulfed in smoke. | Fire and smoke affecting offsite areas. Explosion shock wave. Large dust/soot fall-out. Numerous complaints. | Large loss of listed substance. Disturbing visible evidence - foam, colour, oil slick - up to 1 mile from release point. Fish killed. Prosecution. |
| **CATEGORY 2 EVENT SERIOUS CONSEQUENCES** | S2: LoCB escape almost certain contained on site, not readily controlled, with no observable impact off-site | Severe nuisance:<br>- high intensity noise,<br>- smoke, dust,<br>- offensive smell.<br>Toxic emergencies. | Sustained nuisance -<br>noise, unpleasant and persistent smell, dust/soot fall-out, including flaring or venting. Public complaints likely | Significant amount of listed substance lost. More than Consent Limit. Definite visible evidence. Low fish-kill potential. Complaints likely.<br>Possible prosecution. |
| **CATEGORY 1 EVENT SIGNIFICANT CONSEQUENCES** | S1: LoCA escape readily controlled, contained on site with no off-site impacts | Nuisance on-site:<br>- sustained noise,<br>- dust on cars.<br>Sustained discharge:<br>Ozone-depleting gases | Short duration nuisance -<br>unusual noises -<br>smoke, offensive smell -<br>flaring or venting leading to the above<br>Complaints unlikely. | Spillage mostly contained. Small amount lost to river. Possible visible effect. Within or slightly outside Consent Limits. Complaints unlikely. |

# Hazard Study 2

## Guidance for Consequence Categories - Reputation, Asset Damage and Security Incidents

AkzoNobel
Tomorrow's Answers Today

Asset damage hazards are linked to costs of replacement. As the local currency can differ from the Euro a familiar object is given with an equivalent price.

| | REPUTATION | TYPICAL ACTION BY | SECURITY | ASSET DAMAGE |
|---|---|---|---|---|
| **SEVERITY 5 EVENT EXTREMELY SERIOUS CONSEQUENCES** | Damage to AkzoNobel stakeholders, International media attention | Prohibition | Impact with international media attention harming AkzoNobel's reputation, terrorist attack resulting in significant off-site effects as described in other categories. | > 2 million€: major damage equivalent to the loss of a plant < 500 k€: important damage equivalent to a detached family house |
| **SEVERITY 4 EVENT MAJOR CONSEQUENCES** | Damage (including financial and quality of life) to BU stakeholders. National media attention | Severe Fine | Impact on company strategic objectives or kidnap/extortion, fatal assault | < 2 million€: significant damage equivalent to a small storage building |
| **SEVERITY 3 EVENT SEVERE CONSEQUENCES** | Damage (including financial and quality of life) to local stakeholders (such as local suppliers or neighbors). Local media attention | Prosecution | Sabotage with off site consequences and media attention, bomb threat | < 500 k€: important damage equivalent to a detached family house |
| **SEVERITY 2 EVENT SERIOUS CONSEQUENCES** | External complaint, affects company reputation for some employees | Warning | Burglary, fraud or theft with significant financial impact including business interruption, non-fatal assault, robbery involving injury, sabotage with on-site effects only. | < 100 k€: medium damage equivalent to small flat or apartment |
| **SEVERITY 1 EVENT SIGNIFICANT CONSEQUENCES** | No damage to company reputation | None | Trespass, stalking, personal threats with no follow-up, burglary, robbery or petty theft with minor financial impact only (no injuries) | < 20 k€: small damage equivalent to an average family car |

**Gestandaardiseerde aanvraag "Instemming meetplan in geval van zoutwinning"**
*conform artikel 41, lid 1, Mijnbouwwet ( Mbw) junctis artikelen 30 en 33, Mijnbouwbesluit (Mbb)*
*Deze aanvraag wordt in drievoud ingediend bij: De Minister van Economische Zaken*
*t.a.v. de heer J. van Herk*
*Postbus 24037, 2490 AA Den Haag*

| Artikel | Onderwerp | Beschrijving |
|---|---|---|
| Mbw 41 lid 1 | Meetplan:<br>Winningsvergunningen Twenthe-Rijn, Uitbreiding Twenthe-Rijn en Twenthe-Rijn Helmerzijde | Meetplan voor de zoutvoorkomens:<br>Rötzout |
| | A) Algemene gegevens | |
| | A1.1) Naam aanvrager | Akzo Nobel Salt B.V. |
| | A1.2) Adres | Stationsstraat 77, 3811 MH Amersfoort |
| | A1.3 ) Contactpersoon | W.A. Paar |
| | A1.4) E-mail | wim.paar@akzonobel.com |
| | A1.5) Fax | 074 244 3401 |
| | A1.6) Aanvrager | Is houder van de vergunning |
| | A2) Winningvergunning gebied | Twenthe-Rijn, Uitbreiding Twenthe-Rijn en Twenthe-Rijn Helmerzijde |

| | |
|---|---|
| | B) Bodemdalingsmetingen<br>*Deze informatie zal jaarlijks (tot 5 jaar na einde winning) worden geactualiseerd.* |
| Mbb 30, lid 7a<br>Mbb 30, lid 7c | B1) Beschrijving van tijdstip(pen) van meting en te gebruiken meetmethoden.<br>De nulmetingen zijn uitgevoerd in 1937 voor de voorkomens in het Rötzout |

| Jaar eerstvolgende meting: | Interval: | Laatste jaar van meting: | Meetmethode: |
|---|---|---|---|
| 2012 najaar | jaarlijks<br>5-jaarlijks | 2055/2060/2061 [1] | 2de orde optische waterpassing<br>GPS |

[1] Metingen worden beëindigd 30 jaar na einde van de winning (looptijd geldige winningsplannen) of zoveel eerder als uit de metingen blijkt, dat de bodemdaling door zoutwinning niet verder toeneemt

| | |
|---|---|
| Mbw 30, lid 7b | B2) Beschrijving van plaatsen waar gemeten wordt:<br>Rapport Meetplan Twenthe-Rijn 2012, revisie 00 van 20 oktober 2011 van Ingenieursbureau Oranjewoud met bijbehorende kaart |

| | |
|---|---|
| | C) Bodemtrillingsmetingen<br>*Deze informatie zal jaarlijks (tot 5 jaar na einde winning) worden geactualiseerd* |
| Mbb 30, lid 7a<br>Mbb 30, lid 7c | C1)Beschrijving van tijdstip(pen) van meting en te gebruiken meetmethoden<br>De seismische monitoring geschiedt door middel van de al in het land aanwezige seismometers die door het KNMI beheerd en uitgelezen worden. De detectiegrens van trillingen met het bestaande instrumentarium ter plekke van onderhavige winning is voldoende nauwkeurig om eventueel schadeveroorzakende bevingen te lokaliseren. |
| Mbb 30, lid 7b | C2) Beschrijving van de plaatsen waar gemeten wordt:<br>Het KNMI rapport "Seismic hazard due to small shallow induced earthquakes" (WR2004-01) bevat in Appendix 3, Figuur 2, een kaart met de locaties en detectiecapaciteit van de betrokken seismische waarnemingsstations; zie bijlage. |

| | |
|---|---|
| | D) Holruimtemetingen<br>*Deze informatie zal jaarlijks (tot 5 jaar na einde winning) worden geactualiseerd.* |
| Mbb 33, lid 1 | D1) Beschrijving van tijdstip(pen) van meting per holruimte en te gebruiken meetmethode. |

| Holruimte (boring nr.): | Jaar eerst-volgende meting: | Interval: | Laatste jaar van meting[2]: | Meetmethode: |
|---|---|---|---|---|
| Zie werkplan<br>2012 - 2016 | Zie werkplan<br>2012 - 2016 | Zie werkplan<br>2012 - 2016 | Zie werkplan<br>2012 - 2016 | Sonar |

[2] Metingen worden beëindigd 30 jaar na einde van de winning of zoveel eerder als uit de metingen blijkt, dat de holruimte niet wezenlijk meer van vorm verandert.

| | |
|---|---|
| *Ondertekening Naam:* E. Schasfoort<br>*Functie:* Sitemanager Akzo Nobel Salt Hengelo | *Datum*: 10 november 2011<br>*Plaats*: Hengelo |

| | |
|---|---|
| *Bijlagen:* | Rapport Meetplan Twenthe-Rijn 2012, revisie 00 van 20 oktober 2011 van Ingenieursbureau Oranjewoud<br>Kaart met locaties en detectiecapaciteit van de betrokken seismische waarnemingstations |

oranjewoud
Member of Antea Group

# Rapport:
Meetplan Twenthe-Rijn 2012

projectnr. 243657
revisie 00
20 oktober 2011

## Opdrachtgever
AkzoNobel Industrial Chemicals B.V.
Postbus 25
7550 GC Hengelo (O)

AkzoNobel
Tomorrow's Answers Today

| datum vrijgave | beschrijving revisie 00 | goedkeuring | vrijgave |
|---|---|---|---|
| 20-10-2011 | definitief | P. Meinders | P.Vos |

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## Distributielijst

- Staatstoezicht op de Mijnen — R. van Lieshout (3 x)
- Plantmanager Hengelo — E. Schasfoort
- Boor-, en Pekelwinningsbedrijf — J. Withag
- Mining Technology Department — W.A. Paar (2 x)

## Revisie historie

| Revisienummer | Wijziging |
|---|---|
| 00 | definitief |

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# Inhoud

blz.

# 1 Inleiding

In de omgeving van Hengelo wordt door AkzoNobel Industrial Chemicals B.V. (hierna: AkzoNobel) zout gewonnen uit de diepere ondergrond. Conform de mijnbouwwet (artikel 31, mijnbouwbesluit 2002) is AkzoNobel verplicht bodemdalingmetingen uit te voeren. Boven nieuwe cavernes dient een nulmeting plaats te vinden en bij in bedrijf zijnde en reeds uit bedrijf genomen cavernes dienen regelmatige herhalingsmetingen te worden uitgevoerd.

Doordat sinds 2006 geen vlakdekkende waterpassing over het gehele gebied van de boringen meer wordt uitgevoerd, wordt volgens Staatstoezicht op de Mijnen (hierna: SodM) niet voldaan aan hetgeen in de Mijnbouwwet staat omschreven. Daarom is het noodzakelijk om voor de winningsvergunning Twenthe-Rijn een nieuw meetplan op te stellen waarin een programma voor deformatiemetingen wordt beschreven om eventuele bodemdaling door zoutwinning te meten.

## 1.1 Achtergrond

AkzoNobel heeft tot en met 2005 halfjaarlijks nauwkeurigheidswaterpassingen uitgevoerd in de winningsvergunning Twenthe-Rijn ter controle op verticale deformaties ten gevolge van de zoutwinning. In het kader van haar 'Beleid voor bodemdaling boorterrein Hengelo' van 28 maart 2007 heeft AkzoNobel een aantal boringseries met kans op het veroorzaken van significante bodemdaling aan het maaiveld toegankelijk gemaakt om deze cavernes met sonarmetingen te kunnen monitoren. Zolang niet alle in aanmerking komende cavernes toegankelijk gemaakt zijn, wordt jaarlijks een beperkte waterpassing uitgevoerd boven deze cavernes.

## 1.2 Uitbreiding

Naast het opnieuw opzetten van een meetnet voor de gebieden waar in het verleden waterpasmetingen werden uitgevoerd is het noodzakelijk om in het nieuwe boorveld Usseler Es Noord en Zuid een meetnet in te richten voor het uitvoeren van een nulmeting. Deze uitbreiding van het meetnet sluit bij het reeds bestaande meetnet aan.

Tevens wordt voor het gebied Usseler Es Noord en Zuid een GPS signaleringsmeting als alternatief voor de herhalingsmeting opgezet. Dit wordt beschreven in paragraaf 7 van dit meetplan.

Tenslotte wordt voor het gebied De Marssteden, waar de opslag van gasolie in bestaande cavernes is voorzien, eveneens een nulmeting ingericht. Daarbij wordt van bestaande peilmerken gebruik gemaakt.

## 1.3 Doel

In dit rapport wordt het meetplan beschreven voor het uitvoeren van een vlakdekkende nauwkeurigheidswaterpassing in winningsvergunning Twenthe-Rijn en opslagvergunning Twenthe-Rijn De Marssteden. Daarnaast zijn voor de gebieden: Usseler Es Noord en Zuid nieuwe meetrajecten bepaald welke als nulmeting worden uitgevoerd.

## 1.4 Verantwoordelijkheid

AkzoNobel is verantwoordelijk voor de uit te voeren werkzaamheden en de rapportage over de resultaten. Dit betekent dat AkzoNobel in dit kader als aanspreekpunt van SodM fungeert.

oranjewoud
Member of Antea Group

# 2 Gebied

## 2.1 Te monitoren gebied

De zoutwinning in de omgeving van Hengelo vindt sinds medio jaren 30 van de 20ste eeuw plaats. Sinds begin jaren 40 worden er in het winningsgebied deformatiemetingen uitgevoerd. Het bestaande meetnet bestrijkt een gebied ten zuiden van Hengelo, tussen het Twentekanaal en Rijksweg A35. De uitbreiding van het meetnet bevindt zich deels ten noorden (Usseler Es Noord) en deels zuiden (Usseler Es Zuid) van Rijksweg A35.
Het gebied De Marssteden bevindt zich in het zuidoosten van het boorterrein, ten noorden van de Rijksweg A35 en ten westen van de Westerval.

## 2.2 Bodemdaling

Voor het bestaande boorterrein (Oude bodemdalingsgebied TC/Boortorenweg, Ring rond oude bodemdalingsgebied, Twekkelo, De Marssteden en Infillboringen) is geen samengestelde dalingsprognose opgesteld. In dit gebied zijn bij de boringen peilmerken geplaatst om eventuele zakkingen te detecteren. De gemeten zakkingen variëren over een periode van meer dan 70 jaar van “niet meetbaar” (enkele millimeters) tot “enkele meters” (in de zakkingsgebieden).

Voor de winning in Usseler Es Noord en Zuid is een bodemdalingprognose opgesteld. De verwachte bodemdaling zal ≤ 50 mm / 100 jaar in het diepste deel van de bodemdalingskom bedragen (zie rapport 'Usseleres Zuid Subsidence Modeling Results, Topical Report RSI-2171 van RESPEC Consulting & Services d.d. november 2010).

# 3 Verkenning van andere oorzaken bodemdaling

In het kader van het meetplan wordt de bodemdaling door delfstofwinning door de mijnbouwmaatschappij gemonitoord. Deze monitoring is erop gericht om de bodemdaling door diepe oorzaken te meten en daarbij andere oorzaken van bodemdaling in het gebied uit te sluiten. In deze paragraaf worden de andere oorzaken benoemd.

## 3.1 Grondwateronttrekkingen

Via de provincie Overijssel zijn de gegevens van grootschalige waterwinning in de nabijheid van de boorlocaties van AkzoNobel opgevraagd. Volgens deze gegevens vindt er op een afstand van ca. 3 kilometer aan de Noord oostkant van de boorlocaties, grootschalige waterontrekking plaats. Gezien de relatief grote aftand en het ontbreken van zettingsgevoelige gronden heeft deze waterontrekking geen invloed op een eventuele (meetbare) maaivelddaling. Deze waterwingebieden zijn weergegeven op tekening P55.91.47/972 (zie bijlage 5).

## 3.2 Kleinschalige wateronttrekkingen

Binnen het gebied vind op een aantal locaties kleinschalige waterontrekking plaats voor o.a. industrie en landbouw. Door deze onttrekkingen op kleine schaal zijn geen zettingen in de ondergrond te verwachten.

## 3.3 Andere delfstoffenwinning

Binnen het gebied vindt momenteel geen andere delfstoffenwinning plaats.

## 3.4 Autonome bodemdaling

Autonome bodemdaling in gebieden waar bodemdaling door delfstofwinning kan optreden is voornamelijk aan de orde bij gronden waar in de ondiepe ondergrond veenlagen voorkomen. Concreet zijn dit de veengronden (volgens de classificatie van Stiboka). Binnen het gebied waar bodemdaling door zoutwinning door AkzoNobel kan optreden komen alleen zandgronden voor. Naar verwachting zal er dus nagenoeg geen autonome bodemdaling optreden. De pleictocene toplaag is aangegeven in tekening P55.91.47/973 (zie bijlage 4).

# 4 Historie

## 4.1 Meetnet

In het boorterrein Hengelo worden al sinds het begin van de zoutwinning deformatiemetingen verricht. In de loop der jaren is het beleid voor het uitvoeren van deze metingen enkele malen gewijzigd.

### *4.1.1 Periode tot en met 2005*

In deze periode vonden twee metingen per jaar plaats. In het voorjaar werd een deel van het buitengebied en het fabrieksterrein gemeten. In het najaar werd het gehele meetnet gemeten. In 2001 zijn boringen (meetpunten) verdeeld in verschillende klassen (zie 'Eindrapport Deformatiemetingen concessiegebied Twenthe-Rijn van 18 oktober 2001). Aan de hand van deze klassenindeling is de meetfrequentie per meetpunt bepaald. Daarnaast zijn in 2001 een groot aantal nieuwe meetpunten geplaatst. Het meetnet was verdeeld in een primair deel, dat als het basisnet werd beschouwd, en uit een secundair deel, dat een verdichting van het primaire net was. Het primaire deel werd in heen en teruggang gemeten, het secundaire deel werd enkel gemeten.
Vanaf 2006 zijn er geen vlakdekkende metingen meer uitgevoerd.

### *4.1.2 Periode 2007 – heden*

In deze periode zijn een groot aantal boringen geopend met als doel deze risicocavernes met sonarmetingen te controleren.
Er vindt een beperkte waterpassing plaats waarbij cavernes, die niet voor sonarmeting toegankelijk zijn, gemeten worden. Met het uitvoeren van het programma voor het toegankelijk maken van cavernes voor sonarmetingen, verviel de noodzaak voor een nauwkeurigheidswaterpassing over de peilmerken nabij deze boringen. Hetzelfde gold voor de boringserie 167 nadat deze boring met kalkslurry gevuld was.
Op dit moment wordt jaarlijks nog boven een zestal cavernes gemeten. Verder wordt het bodemdalingsgebied ‘Omgeving Locatiekantoor / Technology Center’ gemeten[1].

### *4.1.3 Aansluiting*

In het verleden zijn er meerdere aansluitpunten gebruikt om het meetnet aan te sluiten op het NAP-net. In 2005 is een onderzoek uitgevoerd naar de aansluitingen van het meetnet ( ‘Herziening aansluiting deformatienet 2005’, 29 juni 2005). In dit onderzoek zijn de volgende punten naar voren gekomen welke als aansluitpunt(en) gebruikt kunnen worden: 34F298 (7501), 34F516 (7802), 34F325 en 34E185. Deze aansluitpunten liggen buiten de invloedsfeer van de zoutwinning en zijn verdeeld over de richtingen noord, oost, zuid en west van het meetnet.

Vanaf 2008 is besloten om het meetnet op twee peilmerken (34E185 en 34F516) aan te sluiten in verband met het kleiner worden van het meetnet. De trajecten van het meetnet kwamen op dusdanig grote afstand van de peilmerken 34F325 en 34F298 te liggen dat besloten is deze twee aansluitpunten niet meer in de meting op te nemen.

[1] Het meten in dit bodemdalingsgebied wordt bemoeilijkt door het feit dat het gebied grootschalig geherstructureerd wordt. In het kader hiervan is een groot deel van de peilmerken verdwenen.

| **Meting** | **Aansluitpunten** | | | |
|---|---|---|---|---|
| 2004 voorjaarsmeting | 6109 | 7531 | 34F516 | |
| 2004 najaarsmeting | 34F267 | 6109 | | |
| 2005 voorjaarsmeting | 6109 | 7531 | 34F516 | |
| 2005 najaarsmeting | 34E185 | 34F516 | 34F298 | 34F325 |
| 2006 voorjaarsmeting | 6109 | 7531 | 34F516 | |
| 2007 voorjaarsmeting | 34E185 | 34F516 | 34F298 | 34F325 |
| 2008 najaarsmeting | 34E185 | 34F516 | | |
| 2009 voorjaarsmeting | 34E185 | 34F516 | | |
| 2010 najaarsmeting | 34E185 | 34F516 | | |

# 5 Meetplan 2012

## 5.1 Bestaande meetnet

Zoals aangegeven bestond het meetnet uit de periode voor 2006 uit trajecten over meetpunten welke bij alle boringen zijn aangebracht. Gezien de uitkomsten van analyses m.b.t. deformaties van deze peilmerken lijkt het niet noodzakelijk om alle peilmerken van het meetnet uit 2005 wederom te meten. Er is voor gekozen om de trajecten uit het primaire net grotendeels te handhaven. In de bestaande trajecten is een onderlinge peilmerkafstand aangehouden van ca. 500 meter en een kringoppervlak van ca. 2 – 4km$^2$.

## 5.2 Uitbreiding meetnet

In de gebieden Usseler Es Noord en Zuid en De Marssteden wordt het huidige meetnet uitgebreid in verband met nieuwe boringen en de voorziene opslag van gasolie. Voor de winning in Usseler Es Noord en Zuid is een bodemdaling voorspeld van van maximaal 50 mm in 100 jaar (zie rapport 'Usseleres Zuid Subsidence Modeling Results, Topical Report RSI-2171 van RESPEC Consulting & Services, d.d. november 2010). Als invloedgebied voor het gebied Usseler Es Noord en Zuid is de als figuur 2.2 van bovengenoemd rapport opgenomen prognose na 100 jaar genomen.

Voor het gebied De Marssteden is de te verwachte bodemdalingskom bepaald door middel van de regel waarin een 'grenshoek' van 45 graden gehanteerd wordt. Hieronder wordt de hoek verstaan die de verbindingslijn tussen het diepste punt van de zoutcaverne met de nul-centimetercontour (=maaiveld) maakt.

De invloedsferen van beide activiteiten zijn weergegeven in tekening P55.91.47/970 (bijlage 3). Het meetnet voor dit gedeelte strekt zich uit tot ca. 750 meter buiten de theoretische invloedsfeer voor bodemdaling. In deze uitbreiding van het meetnet is een onderlinge peilmerkafstand aangehouden van ca. 500 meter in het centrum tot ca. 800 meter in de buitenste kringen en een kringoppervlak van ca. 2 – 4 km$^2$.

## 5.3 Peilmerken

In het bestaande meetnet zijn voornamelijk peilmerken opgenomen die bestaan uit een peilmerkbout die verankerd is in een ingegraven betonnen paal met een lengte van 1,5 meter of peilmerken die geplaatst zijn in stabiele objecten.

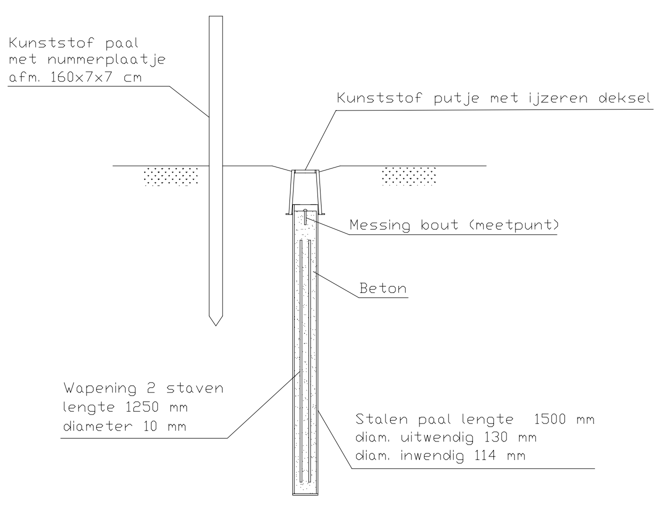


fig. 1 peilmerk in betonpaal

In de nieuwe trajecten wordt daar waar mogelijk gebruik gemaakt van RD-NAP peilmerken. Ten behoeve van de selectie van peilmerken voor de monitoring van bodembeweging is historische informatie van de in het gebied aanwezige peilmerken opgevraagd bij de Rijkswaterstaat Data-ICT-Dienst (RWS-DID).
Aan de hand van deze gegevens is de geodetische stabiliteit van de peilmerken geïnventariseerd. Hierbij is van de publicabele peilmerken het hoogteverschil tussen de meest recente hoogte en de oudste hoogte vertaald in een deformatiesnelheid in eenheden van mm/jaar (zie bijlage 2). Voor het meetnet zijn vervolgens de bestaande peilmerken geselecteerd die een deformatiesnelheid hebben van minder dan 2 mm/jaar.

Tevens is bij de Rijkswaterstaat Data-ICT-Dienst (RWS-DID) navraag gedaan over de aanwezigheid van diep gefundeerde ondergrondse peilmerken binnen of in de nabijheid van het te monitoren gebied. Deze peilmerken blijken op twee plaatsen nabij het meetnet te zitten; om die reden worden ze in het meetnet opgenomen.

In trajecten met onvoldoende RD-NAP peilmerken worden extra peilmerken geplaatst in objecten (gebouwen) die voorafgaand aan plaatsing gecontroleerd worden op stabiliteit door middel van een visuele bouwkundige inspectie. Daar waar geen objecten aanwezig zijn om een peilmerk te plaatsen worden schroefankers geplaatst. Het betreft verzinkte schroefankers die verankerd worden in de Pleictocene zandlaag (figuur 2 en 3).

figuur 2: schroefanker

figuur 3: schroefanker afgewerkt met putje

## 5.4 Verkenningsberekening

Om het ontworpen meetnet te toetsen conform de eisen als vastgelegd in de productspecificaties van RWS-DID is een verkenningsberekening uitgevoerd. Uit deze berekening blijkt dat het netontwerp voldoet aan de gestelde voorwaarden. De uitkomsten van deze berekening zijn weergegeven in bijlage 1.

## 5.5 Aansluiting

Om de meting aan te sluiten aan het NAP-net moeten één of meerdere stabiele peilmerken bepaald worden welke buiten de invloedsfeer van zoutwinning liggen. Met de huidige uitbreiding van het meetnet worden naast de peilmerken 34E185 en 34F516 die zijn gebruikt als aansluitpunt in de jaren 2008 t/m 2010 ook de peilmerken 34F298 en 34F325 weer opgenomen in het meetnet. Deze vier punten zijn in een onderzoek in 2005 als meest gunstige aansluitpunten bepaald (zie 'Herziening aansluiting deformatienet 2005, 29 juni 2005).

In de nieuwe meetopzet worden de potentiële aansluitpunten benoemd als referentiepunt. Vanwege de uitbreiding van het meetnet aan de zuidoost zijde is hier ondergronds peilmerk A03522 als referentiepunt toegevoegd. Aan de noordzijde van het meetnet, nabij oude aansluitpunt 34F516 zit het ondergronds merk A06031. Dit ondergronds merk wordt in de meting meegenomen als referentiepunt. Deze beide ondergrondse peilmerken zijn meetpunten van de $1^e$ orde en worden als zeer stabiele punten gezien. Deze meetpunten zijn verankerd in de Pleictocene zandlaag en vertonen geen zetting door autonome daling.

Over het algemeen wordt tegenwoordig gekozen om een meetnet aan te sluiten aan één NAP peilmerk. Dit wordt gedaan om eventuele 'verwringing' te voorkomen als gevolg van aansluitverschillen bij het aansluiten op meerdere peilmerken. Omdat deze "verwringing" bij het bestaande meetnet nauwelijks optrad zijn tot nog toe de metingen op meerdere punten aangesloten.

Voor aansluiting van het huidige net zijn verschillende opties mogelijk:
- aansluiten op één stabiel peilmerk buiten de invloedsfeer
- aansluiten op de twee ondergrondse peilmerken (A03522 en A06031)
- aansluiten op meerder stabiele peilmerken buiten de invloedsfeer, bijvoorbeeld op de vier in 2005 als meest gunstig bepaalde peilmerken

Met de laatste mogelijkheid zou de keuze die in het verleden gemaakt is bevestigd worden. Wij stellen echter voor om na een eerste vereffening de resultaten te analyseren en, bij gebleken geschiktheid, beide ondergrondse peilmerken in de toekomst als aansluitpunt te gaan gebruiken. Het gebruik van deze ondergrondse peilmerken heeft als voordeel dat de punten als zeer stabiel worden aangemerkt, goed beschermd zijn tegen verstoringen en een 'lange levensduur' hebben.

# 6 Meetprocedure

## 6.1 Bestaande meetnet

Voor dit deel wordt een herhalingsmeting uitgevoerd van het deformatienet.

## 6.2 Uitbreiding meetnet (Usseler Es Noord en Usseler Es zuid)

Voor dit deel wordt een nulmeting uitgevoerd van het deformatienet.

De herhalingsmeting en nulmeting (nauwkeurigheidswaterpassingen) worden uitgevoerd conform de procedure die met ingang van 18 augustus 2005 is vastgesteld door Staatstoezicht op de Mijnen en de afdeling NAP van de Data-ICT-Dienst van Rijkswaterstaat (RWS-DID). De uitvoering van de secundaire waterpassing moet voldoen aan de 'Productspecificaties Beheer NAP' versie 1.1 dd. januari 2008.

De herhalingsfrequentie van de nauwkeurigheidswaterpassing is nog niet bepaald en zal deels afhangen van de resultaten van de GPS monitoring (zie Par. 7).

## 6.3 Presentatie

De resultaten van de nauwkeurigheidswaterpassingen van zowel het bestaande meetnet als de uitbreiding van het net, worden in één rapport (Meetregister) gepresenteerd.

# 7 GPS signaleringsmeting

## 7.1 Doel

Door het uitvoeren van een secundaire waterpassing van het meetnet voor aanvang van de zoutwinning wordt de zogenaamde nul-situatie vastgelegd. Door de meting over een aantal jaren te herhalen is het mogelijk om de vorm van de bodemdalingskom en de hoeveelheid daling te detecteren. De eerstvolgende herhalingsmeting is vastgesteld na een periode van 5 jaar, dus in 2017. Om eventuele zettingen binnen deze periode van 5 jaar te kunnen signaleren is gekozen om een meetopzet te maken voor het uitvoeren van een GNSS(GPS) meting (hierna genoemd GPS meting). Op deze wijze is het mogelijk om binnen de periode van de herhalingsmeting zettingen in het centrum van de dalingskom te monitoren, zonder dat het gehele meetnet gemeten hoeft te worden.

## 7.2 Configuratie meetnet GPS meting

De boorvelden Usseler Es Noord en Zuid liggen op korte onderlinge afstand van elkaar. Beide boorvelden vormen één geheel en hebben één gezamenlijk geprognosticeerde bodemdalingskom. Om de bodemdaling in het centrum van de kom met GPS metingen te monitoren is in dit gebied een stabiel peilmerk noodzakelijk wat de beweging van de diepere ondergrond volgt. Hiervoor wordt in het centrum van de kom een ondergronds peilmerk van de hoogste stabiliteit geplaatst. Bij dit ondergrondse peilmerk worden op korte afstand tevens twee schroefankers of meetbouten geplaatst. Het ondergrondse merk en de meetbouten / schroefankers worden tijdens de secundaire waterpassing (nulmeting) gemeten en in het meetnet opgenomen.

Buiten de invloedsfeer, aan de rand van het meetnet zitten twee ondergrondse peilmerken (A06031 en A03522). Deze ondergrondse peilmerken worden eveneens tijdens de secundaire waterpassing (nulmeting) gemeten en in het meetnet opgenomen.

De exacte locatie van het te plaatsen ondergrondse merk in het centrum van de dalingskom moet nog nader bepaald worden.

## 7.3 GPS signaleringsmeting

Bij de nulmeting worden met GPS de hoogten van de ondergrondse merken gemeten. Er wordt nabij ieder ondergronds meetmerk een gekalibreerde (choke ring) antenne met een GPS ontvanger opgesteld, vervolgens wordt er 5 dagen gemeten. De na te streven meetnauwkeurigheid bedraagt 1-2mm in de standaardafwijking. De hoogten van de GPS antennes worden in een multistationoplossing bepaald waarbij gebruik wordt gemaakt van bestaande verder weg gelegen permanente GPS referentiestations. Direct na de installatie van een antenne wordt het hoogteverschil tussen het antenne referentiepunt en het nabijgelegen ondergronds merk gemeten via een secundaire nauwkeurigheids-waterpassing. Ook de omringende schroefankers en/of hoogtebouten worden bij deze waterpassing in hoogte gemeten. Om voldoende betrouwbaarheid te garanderen wordt deze waterpassing 3 maal uitgevoerd. Dit gebeurt de eerste keer bij het opstarten van de GPS meting, tweede keer na 2 á 3 dagen en de derde keer bij beëindiging van de GPS meting. De na te streven meetnauwkeurigheid van een enkele meting is 0.2-0.4 mm.

## 7.4 Constructie

De GPS meetpalen bestaan uit een GNSS hoge nauwkeurigheid choke-ring antenne, bijvoorbeeld de Leica Ar25 of Ar10. Een choke-ring antenne heeft de eigenschap multi-path effecten zeer goed te reduceren. De meetpaal bestaat uit een circa 3 meter lange RVS mast (Er is gekozen voor RVS omdat dit minder uitzet bij temperatuursveranderingen), een GNSS antenne en een GNSS ontvanger in een waterdichte behuizing en een stroomvoorziening. De stroomvoorziening van de antenne en ontvanger kan zowel via tractie accu als via netstroom plaatsvinden. De choke-ring GNSS antenne wordt bevestigd door middel van schroefdraad aan een massieve vaste bus aan de bovenzijde van de antenne. Het ARP van de antenne wordt voor de XY positie gevormd door het middelpunt van de schroefdraad en voor de hoogte is de onderkant van de antenne maatgevend.

Om de antenne te beschermen tegen weersinvloeden wordt over de antenne een kunststof kap (Dome) geplaatst. De meetpaal wordt geplaatst op een in de bodem geslagen mastpen en wordt vervolgens vertikaal opgericht door de top van de mast te schoren aan drie schoorpalen door middel van stalen tuidraden.

## 7.5 Conclusie

Door deze GPS meting periodiek te herhalen wordt het tijdsverloop van de bodemdaling in het centrale gebied bewaakt: de GPS metingen hebben een signaleringsfunctie. Indien het resultaat van een GPS herhalingsmeting a) significant afwijkt van de resultaten ten tijde van de voorgaande vlakdekkende waterpassing (d.w.z. meer dan 3 maal de standaardafwijking van de meetprecisie) *en* b) een bodemdaling impliceert die groter is dan de in het winningsplan opgenomen prognose (zoals uit de prognose met tijdlijn blijkt), kan besloten worden om een vlakdekkende waterpassing uit te voeren.

# Bijlage 1: Verkenningsberekening

243657 Meetplan Twenthe-Rijn 2012

MOVE3 Versie 4.0.4

Verkenning en Vereffening van Geodetische Netwerken

www.MOVE3.nl



AKZO Hengelo 2012-verk ber

25-10-2011 17:42:11

1D vrij netwerk -- Projectie : RD -- Ellipsoide : Bessel 1841

PROJECT
R:\00005000\00008773\Geo-info\08773_Waterpassing 2011-voorbereiding\Verkenningsberekening\AKZO TWENTHE 2012_verk ber.prj

| STATIONS | |
|---|---|
| Aantal (gedeeltelijk) bekende stations | 1 |
| Aantal onbekende stations | 181 |
| Totaal | 182 |

| WAARNEMINGEN | |
|---|---|
| Hoogteverschillen | 426 |
| Bekende coordinaten | 1 |
| Totaal | 427 |
| ONBEKENDEN | |
| Coordinaten | 182 |
| Totaal | 182 |
| | |
| Aantal voorwaarden | 245 |

VEREFFENING

| TOETSING | |
|---|---|
| Alfa (meer dimensionaal) | 0.5420 |
| Alfa 0 (een dimensionaal) | 0.0010 |
| Beta | 0.80 |
| Kritieke waarde W-toets | 3.29 |
| Kritieke waarde T-toets (3 dimensionaal) | 4.24 |
| Kritieke waarde T-toets (2 dimensionaal) | 5.91 |
| Kritieke waarde F-toets | 0.99 |

F-toets

| PROJECTIE EN ELLIPSOIDE CONSTANTEN | |
|---|---|
| Projectie | RD |
| Lengte oorsprong/centrale meridiaan | 5 23 15.50000 O |
| Breedte oorsprong | 52 09 22.17800 N |
| Projectie schaalfactor | 0.999907900 |
| Translatie Oost | 155000.0000 m |
| Translatie Noord | 463000.0000 m |
| Ellipsoide | Bessel 1841 |
| Halve lange as | 6377397.1550 m |
| Inverse afplatting | 299.152812800 |

INVOER BENADERDE TERRESTRISCHE COORDINATEN

| Station | X Oost (m) | Y Noord (m) | Hoogte (m) | Id.Sa XY (m) | Id.Sa h (m) |
|---|---|---|---|---|---|
| 0000n61 | 253041.2660 | 473434.4700 | 0.0000 | 0.0000 | 0.0000 |
| 034F0397 | 255150.0000 | 466200.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0216 | 255540.0000 | 471100.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0000n60 | 251904.8766 | 468898.7737 | 0.0000 | 0.0000 | 0.0000 |

| | | | | | |
|---|---|---|---|---|---|
| 0000n59 | 252050.3201 | 468483.9021 | 0.0000 | 0.0000 | 0.0000 |
| 0000n58 | 252716.7375 | 468318.1918 | 0.0000 | 0.0000 | 0.0000 |
| 0000n57 | 253397.4608 | 467456.2602 | 0.0000 | 0.0000 | 0.0000 |
| 0000n56 | 253734.8421 | 467121.2633 | 0.0000 | 0.0000 | 0.0000 |
| 0000n55 | 254048.3802 | 466951.9766 | 0.0000 | 0.0000 | 0.0000 |
| 0000n54 | 254669.4955 | 467419.3033 | 0.0000 | 0.0000 | 0.0000 |
| 0000n53 | 254790.4178 | 466978.1375 | 0.0000 | 0.0000 | 0.0000 |
| 0000n52 | 255020.5047 | 466652.6778 | 0.0000 | 0.0000 | 0.0000 |
| 0000n51 | 255449.8902 | 466899.0806 | 0.0000 | 0.0000 | 0.0000 |
| 034F0508 | 256840.0000 | 467980.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0501 | 256830.0000 | 468540.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0499 | 257010.0000 | 468690.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0481 | 256620.0000 | 469170.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0473 | 256780.0000 | 468920.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0359 | 252950.0000 | 467840.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0249 | 256450.0000 | 469910.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0233 | 251640.0000 | 469180.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0226 | 251900.0000 | 469390.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0185 | 256230.0000 | 467410.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0174 | 256330.0000 | 469840.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0165 | 255900.0000 | 467100.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0164 | 255750.0000 | 466970.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0159 | 256290.0000 | 467030.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0062 | 256680.0000 | 470060.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0038 | 253380.0000 | 468220.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0000n50 | 256549.5367 | 470384.1731 | 0.0000 | 0.0000 | 0.0000 |
| 0000n49 | 256461.4594 | 470802.7581 | 0.0000 | 0.0000 | 0.0000 |
| 0000n48 | 256200.7158 | 470922.2292 | 0.0000 | 0.0000 | 0.0000 |
| 0000n47 | 255860.4957 | 471007.3597 | 0.0000 | 0.0000 | 0.0000 |
| 0000n46 | 255916.9997 | 471323.4766 | 0.0000 | 0.0000 | 0.0000 |
| 0000n45 | 255428.3166 | 471764.8185 | 0.0000 | 0.0000 | 0.0000 |
| 0000n44 | 254869.3853 | 472190.8891 | 0.0000 | 0.0000 | 0.0000 |
| 7510 | 252742.0000 | 470810.0000 | 0.0000 | 0.0000 | 0.0000 |
| 106450 | 251872.6472 | 473559.9320 | 0.0000 | 0.0000 | 0.0000 |
| 108150 | 251805.2640 | 472930.3080 | 0.0000 | 0.0000 | 0.0000 |
| 106750 | 251809.4080 | 473286.0280 | 0.0000 | 0.0000 | 0.0000 |
| 107450 | 252203.0000 | 473191.0000 | 0.0000 | 0.0000 | 0.0000 |
| 107250 | 252196.0000 | 473331.0000 | 0.0000 | 0.0000 | 0.0000 |
| 111050 | 251493.6160 | 472210.0680 | 0.0000 | 0.0000 | 0.0000 |
| 119150 | 250035.7197 | 471924.8703 | 0.0000 | 0.0000 | 0.0000 |
| 0000n43 | 254873.8777 | 473186.8860 | 0.0000 | 0.0000 | 0.0000 |
| 0000n42 | 254478.4388 | 472639.8668 | 0.0000 | 0.0000 | 0.0000 |
| 0000n41 | 253983.6327 | 473261.5710 | 0.0000 | 0.0000 | 0.0000 |
| 0000n40 | 254506.0008 | 473545.8007 | 0.0000 | 0.0000 | 0.0000 |
| 0000n39 | 253158.2993 | 470236.0432 | 0.0000 | 0.0000 | 0.0000 |
| 0000n38 | 253174.9354 | 470512.2471 | 0.0000 | 0.0000 | 0.0000 |
| 0000n37 | 252913.8428 | 470535.1308 | 0.0000 | 0.0000 | 0.0000 |
| 0000n36 | 252522.3743 | 470561.2888 | 0.0000 | 0.0000 | 0.0000 |
| 0000n35 | 252633.7459 | 470087.2664 | 0.0000 | 0.0000 | 0.0000 |
| 034F0310 | 252050.0000 | 470220.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0000n34 | 252000.2939 | 469829.4990 | 0.0000 | 0.0000 | 0.0000 |
| 0000n33 | 252623.3522 | 469489.6329 | 0.0000 | 0.0000 | 0.0000 |
| 0000n32 | 252209.3791 | 469446.6670 | 0.0000 | 0.0000 | 0.0000 |
| 0000n31 | 252996.4474 | 469535.3175 | 0.0000 | 0.0000 | 0.0000 |
| 0000n30 | 254464.9171 | 468186.1816 | 0.0000 | 0.0000 | 0.0000 |
| 0000n29 | 254576.9174 | 468671.4336 | 0.0000 | 0.0000 | 0.0000 |
| 0000n28 | 254322.3784 | 468699.7157 | 0.0000 | 0.0000 | 0.0000 |
| 0000n27 | 254301.4656 | 469218.1552 | 0.0000 | 0.0000 | 0.0000 |
| 0000n26 | 253871.0687 | 469120.0901 | 0.0000 | 0.0000 | 0.0000 |
| 0000n25 | 255736.2377 | 468191.7532 | 0.0000 | 0.0000 | 0.0000 |
| 215150 | 251600.7751 | 472200.4164 | 0.0000 | 0.0000 | 0.0000 |
| 201351 | 252295.7867 | 472516.2370 | 0.0000 | 0.0000 | 0.0000 |
| 7576 | 249490.0000 | 473038.0000 | 0.0000 | 0.0000 | 0.0000 |
| 7542 | 252810.3722 | 473482.2600 | 0.0000 | 0.0000 | 0.0000 |
| 7536 | 251733.6890 | 472652.6610 | 0.0000 | 0.0000 | 0.0000 |
| 7532 | 253409.1200 | 470142.3000 | 0.0000 | 0.0000 | 0.0000 |
| 7528 | 250749.8900 | 472161.4500 | 0.0000 | 0.0000 | 0.0000 |

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|---|---|---|---|---|---|
| 7520 | 254663.0000 | 471041.0000 | 0.0000 | 0.0000 | 0.0000 |
| 7519 | 254119.0000 | 471671.0000 | 0.0000 | 0.0000 | 0.0000 |
| 7515 | 249807.0000 | 473491.0000 | 0.0000 | 0.0000 | 0.0000 |
| 7514 | 249168.0000 | 473602.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0298 | 251702.0000 | 470441.0000 | 0.0000 | 0.0000 | 0.0000 |
| 7014 | 250712.4050 | 472824.8620 | 0.0000 | 0.0000 | 0.0000 |
| 64 | 250533.0000 | 471080.0000 | 0.0000 | 0.0000 | 0.0000 |
| 6105 | 250314.0000 | 473405.0000 | 0.0000 | 0.0000 | 0.0000 |
| 5706 | 250715.8438 | 473968.7000 | 0.0000 | 0.0000 | 0.0000 |
| 3912 | 251130.0000 | 473940.0000 | 0.0000 | 0.0000 | 0.0000 |
| 034F0516 | 251978.1300 | 473917.5300 | 0.0000 | 0.0000 | 0.0000 |
| 034F0345 | 254050.0000 | 472220.0000 | 0.0000 | 0.0000 | 0.0000 |
| 34E0273 | 248952.7659 | 473128.8040 | 0.0000 | 0.0000 | 0.0000 |
| 34E0185 | 248780.0526 | 472471.5588 | 0.0000 | 0.0000 | 0.0000 |
| 3239 | 251463.2000 | 473909.3600 | 0.0000 | 0.0000 | 0.0000 |
| 142601 | 253295.2500 | 473032.8200 | 0.0000 | 0.0000 | 0.0000 |
| 142001 | 253604.4000 | 472380.3800 | 0.0000 | 0.0000 | 0.0000 |
| 141701 | 253483.4000 | 472606.6000 | 0.0000 | 0.0000 | 0.0000 |
| 138701 | 252380.8400 | 470464.7800 | 0.0000 | 0.0000 | 0.0000 |
| 137901 | 252867.0800 | 469979.9500 | 0.0000 | 0.0000 | 0.0000 |
| 136801 | 253464.0800 | 470590.1200 | 0.0000 | 0.0000 | 0.0000 |
| 136001 | 252655.3000 | 471045.1800 | 0.0000 | 0.0000 | 0.0000 |
| 135601 | 250314.1200 | 471456.3500 | 0.0000 | 0.0000 | 0.0000 |
| 135001 | 250831.1600 | 470692.2200 | 0.0000 | 0.0000 | 0.0000 |
| 134850 | 251153.2340 | 470614.5880 | 0.0000 | 0.0000 | 0.0000 |
| 134501 | 251405.7800 | 470652.4300 | 0.0000 | 0.0000 | 0.0000 |
| 132401 | 251915.3700 | 470688.6100 | 0.0000 | 0.0000 | 0.0000 |
| 132101 | 251770.9800 | 470848.9800 | 0.0000 | 0.0000 | 0.0000 |
| 131901 | 251802.3800 | 471149.9300 | 0.0000 | 0.0000 | 0.0000 |
| 130001 | 252591.4500 | 470768.4800 | 0.0000 | 0.0000 | 0.0000 |
| 129401 | 253067.2200 | 470832.1400 | 0.0000 | 0.0000 | 0.0000 |
| 128701 | 253811.5400 | 470912.2100 | 0.0000 | 0.0000 | 0.0000 |
| 127901 | 253593.1700 | 470761.7000 | 0.0000 | 0.0000 | 0.0000 |
| 127501 | 253491.0700 | 471017.3200 | 0.0000 | 0.0000 | 0.0000 |
| 124101 | 253765.2400 | 471379.3400 | 0.0000 | 0.0000 | 0.0000 |
| 123501 | 253157.4500 | 471740.7100 | 0.0000 | 0.0000 | 0.0000 |
| 123001 | 252695.4700 | 471921.6100 | 0.0000 | 0.0000 | 0.0000 |
| 122350 | 251769.0180 | 471938.1990 | 0.0000 | 0.0000 | 0.0000 |
| 121601 | 252464.7100 | 472252.8000 | 0.0000 | 0.0000 | 0.0000 |
| 120550 | 252139.2620 | 472989.9230 | 0.0000 | 0.0000 | 0.0000 |
| 119450 | 250138.5370 | 471705.3340 | 0.0000 | 0.0000 | 0.0000 |
| 119250 | 249875.2890 | 473019.9590 | 0.0000 | 0.0000 | 0.0000 |
| 118850 | 250325.2010 | 471685.5580 | 0.0000 | 0.0000 | 0.0000 |
| 118450 | 250570.4030 | 471553.0840 | 0.0000 | 0.0000 | 0.0000 |
| 117750 | 250281.3040 | 471953.4270 | 0.0000 | 0.0000 | 0.0000 |
| 115350 | 249442.6440 | 472452.9860 | 0.0000 | 0.0000 | 0.0000 |
| 113250 | 250316.9840 | 472792.8540 | 0.0000 | 0.0000 | 0.0000 |
| 112450 | 250900.0000 | 471900.0000 | 0.0000 | 0.0000 | 0.0000 |
| 110150 | 250731.9820 | 472510.4690 | 0.0000 | 0.0000 | 0.0000 |
| 109550 | 250426.8560 | 473134.0260 | 0.0000 | 0.0000 | 0.0000 |
| 108450 | 251949.4880 | 472575.8890 | 0.0000 | 0.0000 | 0.0000 |
| 107851 | 251616.1975 | 472388.7588 | 0.0000 | 0.0000 | 0.0000 |
| 107251 | 252160.9920 | 473387.4540 | 0.0000 | 0.0000 | 0.0000 |
| 107150 | 252424.8710 | 473600.9000 | 0.0000 | 0.0000 | 0.0000 |
| 104601 | 251506.8210 | 473563.2600 | 0.0000 | 0.0000 | 0.0000 |
| 104002 | 250502.8700 | 473348.9700 | 0.0000 | 0.0000 | 0.0000 |
| 103751 | 250615.8440 | 473964.7940 | 0.0000 | 0.0000 | 0.0000 |
| 0000n24 | 254313.2020 | 469569.5654 | 0.0000 | 0.0000 | 0.0000 |
| 0000n23 | 254382.6722 | 469972.2552 | 0.0000 | 0.0000 | 0.0000 |
| 0000n22 | 254601.7655 | 469551.9489 | 0.0000 | 0.0000 | 0.0000 |
| 0000n21 | 254818.6377 | 469884.0391 | 0.0000 | 0.0000 | 0.0000 |
| 0000n20 | 255107.0620 | 470106.5714 | 0.0000 | 0.0000 | 0.0000 |
| 0000n19 | 254591.8952 | 470410.7337 | 0.0000 | 0.0000 | 0.0000 |
| 0000n18 | 254851.3945 | 470570.4676 | 0.0000 | 0.0000 | 0.0000 |
| 034F0217 | 255010.0000 | 470790.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0000n17 | 255370.9897 | 471252.8813 | 0.0000 | 0.0000 | 0.0000 |
| 126801 | 253151.6200 | 471287.8300 | 0.0000 | 0.0000 | 0.0000 |

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|---|---|---|---|---|---|---|
| 123801 | 253369.8300 | 471620.7500 | 0.0000 | 0.0000 | 0.0000 | |
| 7809 | 254626.8117 | 472775.8384 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0325 | 254880.8656 | 473397.2930 | 0.0000 | 0.0000 | 0.0000 | |
| 7810 | 254249.6307 | 473194.3296 | 0.0000 | 0.0000 | 0.0000 | |
| 7811 | 253586.1202 | 473376.8105 | 0.0000 | 0.0000 | 0.0000 | |
| 000A3522 | 256208.9500 | 468077.2000 | 0.0000 | 0.0000 | 0.0000 | |
| 000A6031 | 251916.2900 | 474019.1500 | 0.0000* | 0.0000 | 0.0000 | bekend |
| 034F0478 | 254480.0000 | 469340.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n16 | 254429.2867 | 467709.9715 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0400 | 254730.0000 | 467630.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n15 | 253522.2824 | 468438.1570 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n14 | 255066.6078 | 467940.7639 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n13 | 254124.4036 | 469103.7459 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0393 | 254950.0000 | 468740.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0040 | 254410.0000 | 468480.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n12 | 254295.3151 | 468927.4175 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n11 | 255297.9219 | 468937.8972 | 0.0000 | 0.0000 | 0.0000 | |
| 0000n10 | 253984.6880 | 470576.3357 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n9 | 253512.2985 | 469673.2634 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n8 | 254178.9270 | 467900.8818 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n7 | 255507.9245 | 468032.5310 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n6 | 255698.5329 | 468586.0425 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n5 | 255646.2277 | 469615.8442 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n4 | 255945.1788 | 469688.7053 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n3 | 255285.1891 | 469594.0673 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n2 | 252382.1945 | 471642.7369 | 0.0000 | 0.0000 | 0.0000 | |
| 00000n1 | 254621.4575 | 471627.6578 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0061 | 254820.0000 | 470200.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 267 | 253283.0000 | 472877.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 138601 | 252525.7100 | 470375.1600 | 0.0000 | 0.0000 | 0.0000 | |
| 128301 | 254310.4480 | 470927.5840 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0480 | 255600.0000 | 469220.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0476 | 253200.0000 | 469670.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0387 | 254060.0000 | 469580.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0386 | 254020.0000 | 470190.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0385 | 253520.0000 | 470090.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0347 | 254470.0000 | 470470.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0329 | 253970.0000 | 470870.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0312 | 253630.0000 | 469400.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0219 | 255610.0000 | 469970.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0184 | 253680.0000 | 468770.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0183 | 253780.0000 | 468330.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0054 | 255740.0000 | 469050.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0050 | 254760.0000 | 469540.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0048 | 253810.0000 | 469200.0000 | 0.0000 | 0.0000 | 0.0000 | |
| 034F0047 | 253210.0000 | 469460.0000 | 0.0000 | 0.0000 | 0.0000 | |

INVOER STANDAARDAFWIJKINGEN VAN BEKENDE STATIONS

| Station | Sa X Oost (m) | Sa Y Noord (m) | Sa Hoogte (m) | |
|---|---|---|---|---|
| 000A6031 | | | 0.0000* | bekend |

INVOER WAARNEMINGEN

| | Station | Richtpunt | St ih (m) | Rp ih (m) | Aflezing | Sa |
|---|---|---|---|---|---|---|
| DH | 034F0508 | 000A3522 | | | 0.00000 | 0.00113 m |
| DH | 000A3522 | 0000n25 | | | 0.00000 | 0.00098 m |
| DH | 034F0385 | 034F0386 | | | 0.00000 | 0.00101 m |
| DH | 00000n5 | 00000n4 | | | 0.00000 | 0.00078 m |
| DH | 00000n4 | 034F0174 | | | 0.00000 | 0.00091 m |
| DH | 034F0174 | 034F0249 | | | 0.00000 | 0.00053 m |
| DH | 034F0249 | 034F0062 | | | 0.00000 | 0.00074 m |
| DH | 000A6031 | 3239 | | | 0.00000 | 0.00096 m |
| DH | 3239 | 3912 | | | 0.00000 | 0.00082 m |
| DH | 7510 | 130001 | | | 0.00000 | 0.00056 m |
| DH | 130001 | 0000n36 | | | 0.00000 | 0.00066 m |
| DH | 138601 | 138701 | | | 0.00000 | 0.00058 m |
| DH | 138701 | 132401 | | | 0.00000 | 0.00101 m |

| | | | | | |
|---|---|---|---|---|---|
| DH | 132401 | 132101 | 0.00000 | 0.00066 | m |
| DH | 034F0062 | 034F0481 | 0.00000 | 0.00133 | m |
| DH | 034F0481 | 034F0473 | 0.00000 | 0.00077 | m |
| DH | 034F0473 | 034F0499 | 0.00000 | 0.00080 | m |
| DH | 034F0499 | 034F0501 | 0.00000 | 0.00068 | m |
| DH | 034F0501 | 034F0508 | 0.00000 | 0.00106 | m |
| DH | 0000n32 | 0000n33 | 0.00000 | 0.00091 | m |
| DH | 0000n33 | 0000n31 | 0.00000 | 0.00086 | m |
| DH | 034F0359 | 0000n58 | 0.00000 | 0.00103 | m |
| DH | 0000n58 | 0000n59 | 0.00000 | 0.00117 | m |
| DH | 0000n59 | 0000n60 | 0.00000 | 0.00093 | m |
| DH | 0000n60 | 034F0233 | 0.00000 | 0.00088 | m |
| DH | 034F0233 | 034F0226 | 0.00000 | 0.00082 | m |
| DH | 034F0226 | 0000n32 | 0.00000 | 0.00079 | m |
| DH | 034F0359 | 034F0038 | 0.00000 | 0.00107 | m |
| DH | 034F0038 | 0000n15 | 0.00000 | 0.00072 | m |
| DH | 0000n54 | 0000n55 | 0.00000 | 0.00124 | m |
| DH | 0000n55 | 0000n56 | 0.00000 | 0.00084 | m |
| DH | 0000n56 | 0000n57 | 0.00000 | 0.00097 | m |
| DH | 0000n57 | 034F0359 | 0.00000 | 0.00108 | m |
| DH | 0000n54 | 0000n16 | 0.00000 | 0.00087 | m |
| DH | 0000n16 | 00000n8 | 0.00000 | 0.00079 | m |
| DH | 034F0508 | 034F0185 | 0.00000 | 0.00129 | m |
| DH | 034F0185 | 034F0159 | 0.00000 | 0.00087 | m |
| DH | 034F0159 | 034F0165 | 0.00000 | 0.00089 | m |
| DH | 034F0165 | 034F0164 | 0.00000 | 0.00063 | m |
| DH | 034F0164 | 0000n51 | 0.00000 | 0.00078 | m |
| DH | 0000n51 | 034F0397 | 0.00000 | 0.00123 | m |
| DH | 034F0397 | 0000n52 | 0.00000 | 0.00097 | m |
| DH | 0000n52 | 0000n53 | 0.00000 | 0.00089 | m |
| DH | 0000n53 | 0000n54 | 0.00000 | 0.00095 | m |
| DH | 034F0062 | 0000n50 | 0.00000 | 0.00083 | m |
| DH | 0000n50 | 0000n49 | 0.00000 | 0.00092 | m |
| DH | 0000n49 | 0000n48 | 0.00000 | 0.00076 | m |
| DH | 0000n48 | 0000n47 | 0.00000 | 0.00084 | m |
| DH | 0000n47 | 034F0216 | 0.00000 | 0.00081 | m |
| DH | 0000n15 | 034F0184 | 0.00000 | 0.00085 | m |
| DH | 034F0184 | 034F0048 | 0.00000 | 0.00095 | m |
| DH | 00000n8 | 034F0183 | 0.00000 | 0.00108 | m |
| DH | 034F0183 | 0000n15 | 0.00000 | 0.00075 | m |
| DH | 034F0480 | 0000n25 | 0.00000 | 0.00144 | m |
| DH | 0000n42 | 0000n44 | 0.00000 | 0.00109 | m |
| DH | 0000n44 | 0000n45 | 0.00000 | 0.00118 | m |
| DH | 0000n45 | 0000n46 | 0.00000 | 0.00114 | m |
| DH | 0000n46 | 0000n47 | 0.00000 | 0.00080 | m |
| DH | 0000n42 | 034F0345 | 0.00000 | 0.00109 | m |
| DH | 0000n12 | 0000n28 | 0.00000 | 0.00068 | m |
| DH | 0000n28 | 034F0040 | 0.00000 | 0.00069 | m |
| DH | 7519 | 034F0345 | 0.00000 | 0.00105 | m |
| DH | 034F0329 | 128301 | 0.00000 | 0.00083 | m |
| DH | 128301 | 7520 | 0.00000 | 0.00086 | m |
| DH | 7510 | 129401 | 0.00000 | 0.00081 | m |
| DH | 0000n36 | 138601 | 0.00000 | 0.00061 | m |
| DH | 7519 | 124101 | 0.00000 | 0.00095 | m |
| DH | 124101 | 123801 | 0.00000 | 0.00096 | m |
| DH | 7536 | 108450 | 0.00000 | 0.00067 | m |
| DH | 108450 | 201351 | 0.00000 | 0.00084 | m |
| DH | 106450 | 107251 | 0.00000 | 0.00082 | m |
| DH | 132101 | 131901 | 0.00000 | 0.00078 | m |
| DH | 131901 | 122350 | 0.00000 | 0.00125 | m |
| DH | 122350 | 215150 | 0.00000 | 0.00079 | m |
| DH | 215150 | 107851 | 0.00000 | 0.00061 | m |
| DH | 107851 | 7536 | 0.00000 | 0.00076 | m |
| DH | 132101 | 034F0298 | 0.00000 | 0.00091 | m |
| DH | 7536 | 108150 | 0.00000 | 0.00076 | m |
| DH | 108150 | 106750 | 0.00000 | 0.00084 | m |
| DH | 106750 | 106450 | 0.00000 | 0.00075 | m |

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|---|---|---|---|---|---|
| DH | 0000n61 | 7811 | 0.00000 | 0.00104 | m |
| DH | 7811 | 0000n41 | 0.00000 | 0.00091 | m |
| DH | 0000n41 | 7810 | 0.00000 | 0.00074 | m |
| DH | 7810 | 0000n40 | 0.00000 | 0.00093 | m |
| DH | 0000n40 | 034F0325 | 0.00000 | 0.00090 | m |
| DH | 034F0325 | 0000n43 | 0.00000 | 0.00065 | m |
| DH | 0000n43 | 7809 | 0.00000 | 0.00098 | m |
| DH | 7809 | 0000n42 | 0.00000 | 0.00063 | m |
| DH | 034F0216 | 0000n17 | 0.00000 | 0.00067 | m |
| DH | 0000n17 | 7520 | 0.00000 | 0.00121 | m |
| DH | 0000n20 | 0000n21 | 0.00000 | 0.00085 | m |
| DH | 0000n21 | 0000n22 | 0.00000 | 0.00089 | m |
| DH | 034F0050 | 0000n22 | 0.00000 | 0.00056 | m |
| DH | 0000n19 | 034F0061 | 0.00000 | 0.00079 | m |
| DH | 034F0061 | 0000n20 | 0.00000 | 0.00077 | m |
| DH | 0000n19 | 0000n18 | 0.00000 | 0.00078 | m |
| DH | 0000n18 | 034F0217 | 0.00000 | 0.00073 | m |
| DH | 034F0217 | 034F0216 | 0.00000 | 0.00110 | m |
| DH | 034F0329 | 034F0347 | 0.00000 | 0.00113 | m |
| DH | 034F0347 | 0000n19 | 0.00000 | 0.00052 | m |
| DH | 0000n23 | 0000n19 | 0.00000 | 0.00098 | m |
| DH | 034F0386 | 0000n23 | 0.00000 | 0.00092 | m |
| DH | 0000n23 | 0000n24 | 0.00000 | 0.00090 | m |
| DH | 034F0040 | 0000n30 | 0.00000 | 0.00077 | m |
| DH | 0000n30 | 00000n8 | 0.00000 | 0.00090 | m |
| DH | 034F0048 | 034F0312 | 0.00000 | 0.00073 | m |
| DH | 034F0312 | 034F0047 | 0.00000 | 0.00092 | m |
| DH | 034F0047 | 0000n31 | 0.00000 | 0.00067 | m |
| DH | 034F0298 | 034F0310 | 0.00000 | 0.00091 | m |
| DH | 034F0310 | 0000n34 | 0.00000 | 0.00088 | m |
| DH | 0000n34 | 0000n32 | 0.00000 | 0.00093 | m |
| DH | 0000n35 | 138601 | 0.00000 | 0.00078 | m |
| DH | 0000n37 | 0000n38 | 0.00000 | 0.00072 | m |
| DH | 0000n36 | 0000n37 | 0.00000 | 0.00088 | m |
| DH | 0000n35 | 0000n39 | 0.00000 | 0.00104 | m |
| DH | 0000n39 | 0000n38 | 0.00000 | 0.00074 | m |
| DH | 129401 | 0000n37 | 0.00000 | 0.00082 | m |
| DH | 3912 | 104601 | 0.00000 | 0.00103 | m |
| DH | 104601 | 106450 | 0.00000 | 0.00085 | m |
| DH | 7542 | 107150 | 0.00000 | 0.00090 | m |
| DH | 107150 | 034F0516 | 0.00000 | 0.00104 | m |
| DH | 034F0516 | 000A6031 | 0.00000 | 0.00049 | m |
| DH | 7542 | 0000n61 | 0.00000 | 0.00068 | m |
| DH | 0000n61 | 142601 | 0.00000 | 0.00097 | m |
| DH | 142601 | 267 | 0.00000 | 0.00056 | m |
| DH | 267 | 141701 | 0.00000 | 0.00082 | m |
| DH | 141701 | 142001 | 0.00000 | 0.00071 | m |
| DH | 142001 | 034F0345 | 0.00000 | 0.00097 | m |
| DH | 107251 | 7542 | 0.00000 | 0.00114 | m |
| DH | 104002 | 103751 | 0.00000 | 0.00112 | m |
| DH | 103751 | 5706 | 0.00000 | 0.00045 | m |
| DH | 5706 | 3912 | 0.00000 | 0.00091 | m |
| DH | 109550 | 104002 | 0.00000 | 0.00067 | m |
| DH | 34E0273 | 7514 | 0.00000 | 0.00102 | m |
| DH | 7514 | 7515 | 0.00000 | 0.00114 | m |
| DH | 7515 | 6105 | 0.00000 | 0.00101 | m |
| DH | 6105 | 104002 | 0.00000 | 0.00063 | m |
| DH | 34E0273 | 7576 | 0.00000 | 0.00104 | m |
| DH | 7576 | 119250 | 0.00000 | 0.00088 | m |
| DH | 119250 | 113250 | 0.00000 | 0.00099 | m |
| DH | 113250 | 109550 | 0.00000 | 0.00084 | m |
| DH | 201351 | 120550 | 0.00000 | 0.00100 | m |
| DH | 120550 | 107450 | 0.00000 | 0.00065 | m |
| DH | 107450 | 107250 | 0.00000 | 0.00053 | m |
| DH | 107250 | 107251 | 0.00000 | 0.00036 | m |
| DH | 215150 | 111050 | 0.00000 | 0.00046 | m |
| DH | 111050 | 112450 | 0.00000 | 0.00115 | m |

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|---|---|---|---|---|---|
| DH | 112450 | 7528 | 0.00000 | 0.00077 | m |
| DH | 7528 | 110150 | 0.00000 | 0.00083 | m |
| DH | 110150 | 7014 | 0.00000 | 0.00079 | m |
| DH | 7014 | 109550 | 0.00000 | 0.00091 | m |
| DH | 123001 | 121601 | 0.00000 | 0.00090 | m |
| DH | 121601 | 201351 | 0.00000 | 0.00079 | m |
| DH | 118850 | 118450 | 0.00000 | 0.00074 | m |
| DH | 118450 | 7528 | 0.00000 | 0.00112 | m |
| DH | 118850 | 119450 | 0.00000 | 0.00061 | m |
| DH | 119450 | 119150 | 0.00000 | 0.00069 | m |
| DH | 119150 | 117750 | 0.00000 | 0.00070 | m |
| DH | 117750 | 115350 | 0.00000 | 0.00139 | m |
| DH | 115350 | 34E0185 | 0.00000 | 0.00115 | m |
| DH | 34E0185 | 34E0273 | 0.00000 | 0.00116 | m |
| DH | 123801 | 123501 | 0.00000 | 0.00070 | m |
| DH | 123501 | 123001 | 0.00000 | 0.00099 | m |
| DH | 136001 | 126801 | 0.00000 | 0.00105 | m |
| DH | 126801 | 123801 | 0.00000 | 0.00089 | m |
| DH | 136001 | 00000n2 | 0.00000 | 0.00114 | m |
| DH | 00000n3 | 00000n5 | 0.00000 | 0.00085 | m |
| DH | 00000n5 | 00000n3 | 0.00000 | 0.00085 | m |
| DH | 00000n2 | 123001 | 0.00000 | 0.00091 | m |
| DH | 127501 | 127901 | 0.00000 | 0.00074 | m |
| DH | 127901 | 136801 | 0.00000 | 0.00065 | m |
| DH | 7520 | 00000n1 | 0.00000 | 0.00108 | m |
| DH | 00000n1 | 7519 | 0.00000 | 0.00100 | m |
| DH | 0000n20 | 034F0219 | 0.00000 | 0.00102 | m |
| DH | 034F0219 | 00000n5 | 0.00000 | 0.00084 | m |
| DH | 034F0329 | 128701 | 0.00000 | 0.00057 | m |
| DH | 128701 | 127501 | 0.00000 | 0.00082 | m |
| DH | 034F0298 | 134501 | 0.00000 | 0.00085 | m |
| DH | 134501 | 134850 | 0.00000 | 0.00071 | m |
| DH | 134850 | 135001 | 0.00000 | 0.00081 | m |
| DH | 135001 | 64 | 0.00000 | 0.00099 | m |
| DH | 64 | 135601 | 0.00000 | 0.00093 | m |
| DH | 135601 | 118850 | 0.00000 | 0.00068 | m |
| DH | 129401 | 127501 | 0.00000 | 0.00096 | m |
| DH | 7510 | 136001 | 0.00000 | 0.00071 | m |
| DH | 0000n38 | 136801 | 0.00000 | 0.00077 | m |
| DH | 7532 | 137901 | 0.00000 | 0.00106 | m |
| DH | 137901 | 0000n35 | 0.00000 | 0.00071 | m |
| DH | 7532 | 136801 | 0.00000 | 0.00095 | m |
| DH | 034F0386 | 0000n10 | 0.00000 | 0.00088 | m |
| DH | 0000n10 | 034F0329 | 0.00000 | 0.00076 | m |
| DH | 034F0385 | 7532 | 0.00000 | 0.00049 | m |
| DH | 00000n3 | 034F0480 | 0.00000 | 0.00099 | m |
| DH | 00000n3 | 034F0050 | 0.00000 | 0.00102 | m |
| DH | 0000n24 | 034F0387 | 0.00000 | 0.00071 | m |
| DH | 034F0387 | 00000n9 | 0.00000 | 0.00105 | m |
| DH | 00000n9 | 034F0385 | 0.00000 | 0.00091 | m |
| DH | 0000n31 | 034F0476 | 0.00000 | 0.00070 | m |
| DH | 034F0476 | 7532 | 0.00000 | 0.00101 | m |
| DH | 034F0048 | 0000n26 | 0.00000 | 0.00045 | m |
| DH | 0000n26 | 0000n13 | 0.00000 | 0.00071 | m |
| DH | 0000n13 | 0000n12 | 0.00000 | 0.00070 | m |
| DH | 0000n25 | 00000n7 | 0.00000 | 0.00074 | m |
| DH | 00000n7 | 0000n14 | 0.00000 | 0.00095 | m |
| DH | 0000n14 | 034F0400 | 0.00000 | 0.00095 | m |
| DH | 034F0400 | 0000n54 | 0.00000 | 0.00066 | m |
| DH | 0000n12 | 0000n27 | 0.00000 | 0.00076 | m |
| DH | 0000n27 | 034F0478 | 0.00000 | 0.00066 | m |
| DH | 034F0478 | 034F0050 | 0.00000 | 0.00083 | m |
| DH | 034F0040 | 0000n29 | 0.00000 | 0.00071 | m |
| DH | 0000n29 | 034F0393 | 0.00000 | 0.00087 | m |
| DH | 034F0393 | 0000n11 | 0.00000 | 0.00089 | m |
| DH | 0000n11 | 034F0480 | 0.00000 | 0.00091 | m |
| DH | 000A3522 | 034F0508 | 0.00000 | 0.00113 | m |

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|---|---|---|---|---|---|
| DH | 0000n25 | 000A3522 | 0.00000 | 0.00098 | m |
| DH | 034F0386 | 034F0385 | 0.00000 | 0.00101 | m |
| DH | 00000n4 | 00000n5 | 0.00000 | 0.00078 | m |
| DH | 034F0174 | 00000n4 | 0.00000 | 0.00091 | m |
| DH | 034F0249 | 034F0174 | 0.00000 | 0.00053 | m |
| DH | 034F0062 | 034F0249 | 0.00000 | 0.00074 | m |
| DH | 3239 | 000A6031 | 0.00000 | 0.00096 | m |
| DH | 3912 | 3239 | 0.00000 | 0.00082 | m |
| DH | 130001 | 7510 | 0.00000 | 0.00056 | m |
| DH | 0000n36 | 130001 | 0.00000 | 0.00066 | m |
| DH | 138701 | 138601 | 0.00000 | 0.00058 | m |
| DH | 132401 | 138701 | 0.00000 | 0.00101 | m |
| DH | 132101 | 132401 | 0.00000 | 0.00066 | m |
| DH | 034F0481 | 034F0062 | 0.00000 | 0.00133 | m |
| DH | 034F0473 | 034F0481 | 0.00000 | 0.00077 | m |
| DH | 034F0499 | 034F0473 | 0.00000 | 0.00080 | m |
| DH | 034F0501 | 034F0499 | 0.00000 | 0.00068 | m |
| DH | 034F0508 | 034F0501 | 0.00000 | 0.00106 | m |
| DH | 0000n33 | 0000n32 | 0.00000 | 0.00091 | m |
| DH | 0000n31 | 0000n33 | 0.00000 | 0.00086 | m |
| DH | 0000n58 | 034F0359 | 0.00000 | 0.00103 | m |
| DH | 0000n59 | 0000n58 | 0.00000 | 0.00117 | m |
| DH | 0000n60 | 0000n59 | 0.00000 | 0.00093 | m |
| DH | 034F0233 | 0000n60 | 0.00000 | 0.00088 | m |
| DH | 034F0226 | 034F0233 | 0.00000 | 0.00082 | m |
| DH | 0000n32 | 034F0226 | 0.00000 | 0.00079 | m |
| DH | 034F0038 | 034F0359 | 0.00000 | 0.00107 | m |
| DH | 0000n15 | 034F0038 | 0.00000 | 0.00072 | m |
| DH | 0000n55 | 0000n54 | 0.00000 | 0.00124 | m |
| DH | 0000n56 | 0000n55 | 0.00000 | 0.00084 | m |
| DH | 0000n57 | 0000n56 | 0.00000 | 0.00097 | m |
| DH | 034F0359 | 0000n57 | 0.00000 | 0.00108 | m |
| DH | 0000n16 | 0000n54 | 0.00000 | 0.00087 | m |
| DH | 00000n8 | 0000n16 | 0.00000 | 0.00079 | m |
| DH | 034F0185 | 034F0508 | 0.00000 | 0.00129 | m |
| DH | 034F0159 | 034F0185 | 0.00000 | 0.00087 | m |
| DH | 034F0165 | 034F0159 | 0.00000 | 0.00089 | m |
| DH | 034F0164 | 034F0165 | 0.00000 | 0.00063 | m |
| DH | 0000n51 | 034F0164 | 0.00000 | 0.00078 | m |
| DH | 034F0397 | 0000n51 | 0.00000 | 0.00123 | m |
| DH | 0000n52 | 034F0397 | 0.00000 | 0.00097 | m |
| DH | 0000n53 | 0000n52 | 0.00000 | 0.00089 | m |
| DH | 0000n54 | 0000n53 | 0.00000 | 0.00095 | m |
| DH | 0000n50 | 034F0062 | 0.00000 | 0.00083 | m |
| DH | 0000n49 | 0000n50 | 0.00000 | 0.00092 | m |
| DH | 0000n48 | 0000n49 | 0.00000 | 0.00076 | m |
| DH | 0000n47 | 0000n48 | 0.00000 | 0.00084 | m |
| DH | 034F0216 | 0000n47 | 0.00000 | 0.00081 | m |
| DH | 034F0184 | 0000n15 | 0.00000 | 0.00085 | m |
| DH | 034F0048 | 034F0184 | 0.00000 | 0.00095 | m |
| DH | 034F0183 | 00000n8 | 0.00000 | 0.00108 | m |
| DH | 0000n15 | 034F0183 | 0.00000 | 0.00075 | m |
| DH | 0000n25 | 034F0480 | 0.00000 | 0.00144 | m |
| DH | 0000n44 | 0000n42 | 0.00000 | 0.00109 | m |
| DH | 0000n45 | 0000n44 | 0.00000 | 0.00118 | m |
| DH | 0000n46 | 0000n45 | 0.00000 | 0.00114 | m |
| DH | 0000n47 | 0000n46 | 0.00000 | 0.00080 | m |
| DH | 034F0345 | 0000n42 | 0.00000 | 0.00109 | m |
| DH | 0000n28 | 0000n12 | 0.00000 | 0.00068 | m |
| DH | 034F0040 | 0000n28 | 0.00000 | 0.00069 | m |
| DH | 034F0345 | 7519 | 0.00000 | 0.00105 | m |
| DH | 128301 | 034F0329 | 0.00000 | 0.00083 | m |
| DH | 7520 | 128301 | 0.00000 | 0.00086 | m |
| DH | 129401 | 7510 | 0.00000 | 0.00081 | m |
| DH | 138601 | 0000n36 | 0.00000 | 0.00061 | m |
| DH | 124101 | 7519 | 0.00000 | 0.00095 | m |
| DH | 123801 | 124101 | 0.00000 | 0.00096 | m |

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|---|---|---|---|---|---|
| DH | 108450 | 7536 | 0.00000 | 0.00067 | m |
| DH | 201351 | 108450 | 0.00000 | 0.00084 | m |
| DH | 107251 | 106450 | 0.00000 | 0.00082 | m |
| DH | 131901 | 132101 | 0.00000 | 0.00078 | m |
| DH | 122350 | 131901 | 0.00000 | 0.00125 | m |
| DH | 215150 | 122350 | 0.00000 | 0.00079 | m |
| DH | 107851 | 215150 | 0.00000 | 0.00061 | m |
| DH | 7536 | 107851 | 0.00000 | 0.00076 | m |
| DH | 034F0298 | 132101 | 0.00000 | 0.00091 | m |
| DH | 108150 | 7536 | 0.00000 | 0.00076 | m |
| DH | 106750 | 108150 | 0.00000 | 0.00084 | m |
| DH | 106450 | 106750 | 0.00000 | 0.00075 | m |
| DH | 7811 | 0000n61 | 0.00000 | 0.00104 | m |
| DH | 0000n41 | 7811 | 0.00000 | 0.00091 | m |
| DH | 7810 | 0000n41 | 0.00000 | 0.00074 | m |
| DH | 0000n40 | 7810 | 0.00000 | 0.00093 | m |
| DH | 034F0325 | 0000n40 | 0.00000 | 0.00090 | m |
| DH | 0000n43 | 034F0325 | 0.00000 | 0.00065 | m |
| DH | 7809 | 0000n43 | 0.00000 | 0.00098 | m |
| DH | 0000n42 | 7809 | 0.00000 | 0.00063 | m |
| DH | 0000n17 | 034F0216 | 0.00000 | 0.00067 | m |
| DH | 7520 | 0000n17 | 0.00000 | 0.00121 | m |
| DH | 0000n21 | 0000n20 | 0.00000 | 0.00085 | m |
| DH | 0000n22 | 0000n21 | 0.00000 | 0.00089 | m |
| DH | 0000n22 | 034F0050 | 0.00000 | 0.00056 | m |
| DH | 034F0061 | 0000n19 | 0.00000 | 0.00079 | m |
| DH | 0000n20 | 034F0061 | 0.00000 | 0.00077 | m |
| DH | 0000n18 | 0000n19 | 0.00000 | 0.00078 | m |
| DH | 034F0217 | 0000n18 | 0.00000 | 0.00073 | m |
| DH | 034F0216 | 034F0217 | 0.00000 | 0.00110 | m |
| DH | 034F0347 | 034F0329 | 0.00000 | 0.00113 | m |
| DH | 0000n19 | 034F0347 | 0.00000 | 0.00052 | m |
| DH | 0000n19 | 0000n23 | 0.00000 | 0.00098 | m |
| DH | 0000n23 | 034F0386 | 0.00000 | 0.00092 | m |
| DH | 0000n22 | 0000n24 | 0.00000 | 0.00076 | m |
| DH | 0000n24 | 0000n22 | 0.00000 | 0.00076 | m |
| DH | 0000n24 | 0000n23 | 0.00000 | 0.00090 | m |
| DH | 0000n30 | 034F0040 | 0.00000 | 0.00077 | m |
| DH | 00000n8 | 0000n30 | 0.00000 | 0.00090 | m |
| DH | 034F0312 | 034F0048 | 0.00000 | 0.00073 | m |
| DH | 034F0047 | 034F0312 | 0.00000 | 0.00092 | m |
| DH | 0000n31 | 034F0047 | 0.00000 | 0.00067 | m |
| DH | 034F0310 | 034F0298 | 0.00000 | 0.00091 | m |
| DH | 0000n34 | 034F0310 | 0.00000 | 0.00088 | m |
| DH | 0000n32 | 0000n34 | 0.00000 | 0.00093 | m |
| DH | 138601 | 0000n35 | 0.00000 | 0.00078 | m |
| DH | 0000n38 | 0000n37 | 0.00000 | 0.00072 | m |
| DH | 0000n37 | 0000n36 | 0.00000 | 0.00088 | m |
| DH | 0000n39 | 0000n35 | 0.00000 | 0.00104 | m |
| DH | 0000n38 | 0000n39 | 0.00000 | 0.00074 | m |
| DH | 0000n37 | 129401 | 0.00000 | 0.00082 | m |
| DH | 104601 | 3912 | 0.00000 | 0.00103 | m |
| DH | 106450 | 104601 | 0.00000 | 0.00085 | m |
| DH | 107150 | 7542 | 0.00000 | 0.00090 | m |
| DH | 034F0516 | 107150 | 0.00000 | 0.00104 | m |
| DH | 000A6031 | 034F0516 | 0.00000 | 0.00049 | m |
| DH | 0000n61 | 7542 | 0.00000 | 0.00068 | m |
| DH | 142601 | 0000n61 | 0.00000 | 0.00097 | m |
| DH | 267 | 142601 | 0.00000 | 0.00056 | m |
| DH | 141701 | 267 | 0.00000 | 0.00082 | m |
| DH | 142001 | 141701 | 0.00000 | 0.00071 | m |
| DH | 034F0345 | 142001 | 0.00000 | 0.00097 | m |
| DH | 7542 | 107251 | 0.00000 | 0.00114 | m |
| DH | 103751 | 104002 | 0.00000 | 0.00112 | m |
| DH | 5706 | 103751 | 0.00000 | 0.00045 | m |
| DH | 3912 | 5706 | 0.00000 | 0.00091 | m |
| DH | 104002 | 109550 | 0.00000 | 0.00067 | m |

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|---|---|---|---|---|---|
| DH | 7514 | 34E0273 | 0.00000 | 0.00102 | m |
| DH | 7515 | 7514 | 0.00000 | 0.00114 | m |
| DH | 6105 | 7515 | 0.00000 | 0.00101 | m |
| DH | 104002 | 6105 | 0.00000 | 0.00063 | m |
| DH | 7576 | 34E0273 | 0.00000 | 0.00104 | m |
| DH | 119250 | 7576 | 0.00000 | 0.00088 | m |
| DH | 113250 | 119250 | 0.00000 | 0.00099 | m |
| DH | 109550 | 113250 | 0.00000 | 0.00084 | m |
| DH | 120550 | 201351 | 0.00000 | 0.00100 | m |
| DH | 107450 | 120550 | 0.00000 | 0.00065 | m |
| DH | 107250 | 107450 | 0.00000 | 0.00053 | m |
| DH | 107251 | 107250 | 0.00000 | 0.00036 | m |
| DH | 111050 | 215150 | 0.00000 | 0.00046 | m |
| DH | 112450 | 111050 | 0.00000 | 0.00115 | m |
| DH | 7528 | 112450 | 0.00000 | 0.00077 | m |
| DH | 110150 | 7528 | 0.00000 | 0.00083 | m |
| DH | 7014 | 110150 | 0.00000 | 0.00079 | m |
| DH | 109550 | 7014 | 0.00000 | 0.00091 | m |
| DH | 121601 | 123001 | 0.00000 | 0.00090 | m |
| DH | 201351 | 121601 | 0.00000 | 0.00079 | m |
| DH | 118450 | 118850 | 0.00000 | 0.00074 | m |
| DH | 7528 | 118450 | 0.00000 | 0.00112 | m |
| DH | 119450 | 118850 | 0.00000 | 0.00061 | m |
| DH | 119150 | 119450 | 0.00000 | 0.00069 | m |
| DH | 117750 | 119150 | 0.00000 | 0.00070 | m |
| DH | 115350 | 117750 | 0.00000 | 0.00139 | m |
| DH | 34E0185 | 115350 | 0.00000 | 0.00115 | m |
| DH | 34E0273 | 34E0185 | 0.00000 | 0.00116 | m |
| DH | 123501 | 123801 | 0.00000 | 0.00070 | m |
| DH | 123001 | 123501 | 0.00000 | 0.00099 | m |
| DH | 126801 | 136001 | 0.00000 | 0.00105 | m |
| DH | 123801 | 126801 | 0.00000 | 0.00089 | m |
| DH | 00000n2 | 136001 | 0.00000 | 0.00114 | m |
| DH | 123001 | 00000n2 | 0.00000 | 0.00091 | m |
| DH | 127901 | 127501 | 0.00000 | 0.00074 | m |
| DH | 136801 | 127901 | 0.00000 | 0.00065 | m |
| DH | 00000n1 | 7520 | 0.00000 | 0.00108 | m |
| DH | 7519 | 00000n1 | 0.00000 | 0.00100 | m |
| DH | 034F0219 | 0000n20 | 0.00000 | 0.00102 | m |
| DH | 00000n5 | 034F0219 | 0.00000 | 0.00084 | m |
| DH | 128701 | 034F0329 | 0.00000 | 0.00057 | m |
| DH | 127501 | 128701 | 0.00000 | 0.00082 | m |
| DH | 134501 | 034F0298 | 0.00000 | 0.00085 | m |
| DH | 134850 | 134501 | 0.00000 | 0.00071 | m |
| DH | 135001 | 134850 | 0.00000 | 0.00081 | m |
| DH | 64 | 135001 | 0.00000 | 0.00099 | m |
| DH | 135601 | 64 | 0.00000 | 0.00093 | m |
| DH | 118850 | 135601 | 0.00000 | 0.00068 | m |
| DH | 127501 | 129401 | 0.00000 | 0.00096 | m |
| DH | 136001 | 7510 | 0.00000 | 0.00071 | m |
| DH | 136801 | 0000n38 | 0.00000 | 0.00077 | m |
| DH | 137901 | 7532 | 0.00000 | 0.00106 | m |
| DH | 0000n35 | 137901 | 0.00000 | 0.00071 | m |
| DH | 136801 | 7532 | 0.00000 | 0.00095 | m |
| DH | 0000n10 | 034F0386 | 0.00000 | 0.00088 | m |
| DH | 034F0329 | 0000n10 | 0.00000 | 0.00076 | m |
| DH | 7532 | 034F0385 | 0.00000 | 0.00049 | m |
| DH | 034F0480 | 00000n3 | 0.00000 | 0.00099 | m |
| DH | 034F0050 | 00000n3 | 0.00000 | 0.00102 | m |
| DH | 034F0387 | 0000n24 | 0.00000 | 0.00071 | m |
| DH | 00000n9 | 034F0387 | 0.00000 | 0.00105 | m |
| DH | 034F0385 | 00000n9 | 0.00000 | 0.00091 | m |
| DH | 034F0476 | 0000n31 | 0.00000 | 0.00070 | m |
| DH | 7532 | 034F0476 | 0.00000 | 0.00101 | m |
| DH | 0000n26 | 034F0048 | 0.00000 | 0.00045 | m |
| DH | 0000n13 | 0000n26 | 0.00000 | 0.00071 | m |
| DH | 0000n12 | 0000n13 | 0.00000 | 0.00070 | m |

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|---|---|---|---|---|
| DH | 00000n7 | 0000n25 | 0.00000 | 0.00074 m |
| DH | 0000n14 | 00000n7 | 0.00000 | 0.00095 m |
| DH | 034F0400 | 0000n14 | 0.00000 | 0.00095 m |
| DH | 0000n54 | 034F0400 | 0.00000 | 0.00066 m |
| DH | 0000n27 | 0000n12 | 0.00000 | 0.00076 m |
| DH | 034F0478 | 0000n27 | 0.00000 | 0.00066 m |
| DH | 034F0050 | 034F0478 | 0.00000 | 0.00083 m |
| DH | 0000n29 | 034F0040 | 0.00000 | 0.00071 m |
| DH | 034F0393 | 0000n29 | 0.00000 | 0.00087 m |
| DH | 0000n11 | 034F0393 | 0.00000 | 0.00089 m |
| DH | 034F0480 | 0000n11 | 0.00000 | 0.00091 m |

VERDE COORDINATEN (vrij netwerk)

| Station | | Coordinaat | Corr (m) | Sa (m) |
|---|---|---|---|---|
| 0000n61 | Hoogte | 0.0000 | | 0.0010 |
| 034F0397 | Hoogte | 0.0000 | | 0.0018 |
| 034F0216 | Hoogte | 0.0000 | | 0.0014 |
| 0000n60 | Hoogte | 0.0000 | | 0.0016 |
| 0000n59 | Hoogte | 0.0000 | | 0.0016 |
| 0000n58 | Hoogte | 0.0000 | | 0.0016 |
| 0000n57 | Hoogte | 0.0000 | | 0.0017 |
| 0000n56 | Hoogte | 0.0000 | | 0.0017 |
| 0000n55 | Hoogte | 0.0000 | | 0.0017 |
| 0000n54 | Hoogte | 0.0000 | | 0.0016 |
| 0000n53 | Hoogte | 0.0000 | | 0.0017 |
| 0000n52 | Hoogte | 0.0000 | | 0.0017 |
| 0000n51 | Hoogte | 0.0000 | | 0.0018 |
| 034F0508 | Hoogte | 0.0000 | | 0.0017 |
| 034F0501 | Hoogte | 0.0000 | | 0.0017 |
| 034F0499 | Hoogte | 0.0000 | | 0.0017 |
| 034F0481 | Hoogte | 0.0000 | | 0.0016 |
| 034F0473 | Hoogte | 0.0000 | | 0.0017 |
| 034F0359 | Hoogte | 0.0000 | | 0.0016 |
| 034F0249 | Hoogte | 0.0000 | | 0.0015 |
| 034F0233 | Hoogte | 0.0000 | | 0.0015 |
| 034F0226 | Hoogte | 0.0000 | | 0.0015 |
| 034F0185 | Hoogte | 0.0000 | | 0.0018 |
| 034F0174 | Hoogte | 0.0000 | | 0.0015 |
| 034F0165 | Hoogte | 0.0000 | | 0.0018 |
| 034F0164 | Hoogte | 0.0000 | | 0.0018 |
| 034F0159 | Hoogte | 0.0000 | | 0.0018 |
| 034F0062 | Hoogte | 0.0000 | | 0.0015 |
| 034F0038 | Hoogte | 0.0000 | | 0.0016 |
| 0000n50 | Hoogte | 0.0000 | | 0.0015 |
| 0000n49 | Hoogte | 0.0000 | | 0.0015 |
| 0000n48 | Hoogte | 0.0000 | | 0.0014 |
| 0000n47 | Hoogte | 0.0000 | | 0.0014 |
| 0000n46 | Hoogte | 0.0000 | | 0.0014 |
| 0000n45 | Hoogte | 0.0000 | | 0.0014 |
| 0000n44 | Hoogte | 0.0000 | | 0.0014 |
| 7510 | Hoogte | 0.0000 | | 0.0012 |
| 106450 | Hoogte | 0.0000 | | 0.0009 |
| 108150 | Hoogte | 0.0000 | | 0.0011 |
| 106750 | Hoogte | 0.0000 | | 0.0010 |
| 107450 | Hoogte | 0.0000 | | 0.0010 |
| 107250 | Hoogte | 0.0000 | | 0.0010 |
| 111050 | Hoogte | 0.0000 | | 0.0012 |
| 119150 | Hoogte | 0.0000 | | 0.0014 |
| 0000n43 | Hoogte | 0.0000 | | 0.0013 |
| 0000n42 | Hoogte | 0.0000 | | 0.0013 |
| 0000n41 | Hoogte | 0.0000 | | 0.0012 |
| 0000n40 | Hoogte | 0.0000 | | 0.0013 |
| 0000n39 | Hoogte | 0.0000 | | 0.0013 |
| 0000n38 | Hoogte | 0.0000 | | 0.0013 |
| 0000n37 | Hoogte | 0.0000 | | 0.0013 |
| 0000n36 | Hoogte | 0.0000 | | 0.0013 |
| 0000n35 | Hoogte | 0.0000 | | 0.0013 |

| | | |
|---|---|---|
| 034F0310 Hoogte | 0.0000 | 0.0014 |
| 0000n34 Hoogte | 0.0000 | 0.0014 |
| 0000n33 Hoogte | 0.0000 | 0.0014 |
| 0000n32 Hoogte | 0.0000 | 0.0014 |
| 0000n31 Hoogte | 0.0000 | 0.0014 |
| 0000n30 Hoogte | 0.0000 | 0.0015 |
| 0000n29 Hoogte | 0.0000 | 0.0015 |
| 0000n28 Hoogte | 0.0000 | 0.0015 |
| 0000n27 Hoogte | 0.0000 | 0.0015 |
| 0000n26 Hoogte | 0.0000 | 0.0015 |
| 0000n25 Hoogte | 0.0000 | 0.0016 |
| 215150 Hoogte | 0.0000 | 0.0011 |
| 201351 Hoogte | 0.0000 | 0.0011 |
| 7576 Hoogte | 0.0000 | 0.0014 |
| 7542 Hoogte | 0.0000 | 0.0008 |
| 7536 Hoogte | 0.0000 | 0.0011 |
| 7532 Hoogte | 0.0000 | 0.0013 |
| 7528 Hoogte | 0.0000 | 0.0012 |
| 7520 Hoogte | 0.0000 | 0.0013 |
| 7519 Hoogte | 0.0000 | 0.0012 |
| 7515 Hoogte | 0.0000 | 0.0013 |
| 7514 Hoogte | 0.0000 | 0.0014 |
| 034F0298 Hoogte | 0.0000 | 0.0013 |
| 7014 Hoogte | 0.0000 | 0.0012 |
| 64 Hoogte | 0.0000 | 0.0014 |
| 6105 Hoogte | 0.0000 | 0.0012 |
| 5706 Hoogte | 0.0000 | 0.0010 |
| 3912 Hoogte | 0.0000 | 0.0008 |
| 034F0516 Hoogte | 0.0000 | 0.0003 |
| 034F0345 Hoogte | 0.0000 | 0.0012 |
| 34E0273 Hoogte | 0.0000 | 0.0014 |
| 34E0185 Hoogte | 0.0000 | 0.0015 |
| 3239 Hoogte | 0.0000 | 0.0006 |
| 142601 Hoogte | 0.0000 | 0.0011 |
| 142001 Hoogte | 0.0000 | 0.0012 |
| 141701 Hoogte | 0.0000 | 0.0012 |
| 138701 Hoogte | 0.0000 | 0.0013 |
| 137901 Hoogte | 0.0000 | 0.0013 |
| 136801 Hoogte | 0.0000 | 0.0013 |
| 136001 Hoogte | 0.0000 | 0.0012 |
| 135601 Hoogte | 0.0000 | 0.0013 |
| 135001 Hoogte | 0.0000 | 0.0014 |
| 134850 Hoogte | 0.0000 | 0.0014 |
| 134501 Hoogte | 0.0000 | 0.0013 |
| 132401 Hoogte | 0.0000 | 0.0013 |
| 132101 Hoogte | 0.0000 | 0.0012 |
| 131901 Hoogte | 0.0000 | 0.0013 |
| 130001 Hoogte | 0.0000 | 0.0013 |
| 129401 Hoogte | 0.0000 | 0.0013 |
| 128701 Hoogte | 0.0000 | 0.0013 |
| 127901 Hoogte | 0.0000 | 0.0013 |
| 127501 Hoogte | 0.0000 | 0.0013 |
| 124101 Hoogte | 0.0000 | 0.0013 |
| 123501 Hoogte | 0.0000 | 0.0012 |
| 123001 Hoogte | 0.0000 | 0.0012 |
| 122350 Hoogte | 0.0000 | 0.0012 |
| 121601 Hoogte | 0.0000 | 0.0011 |
| 120550 Hoogte | 0.0000 | 0.0010 |
| 119450 Hoogte | 0.0000 | 0.0014 |
| 119250 Hoogte | 0.0000 | 0.0014 |
| 118850 Hoogte | 0.0000 | 0.0013 |
| 118450 Hoogte | 0.0000 | 0.0013 |
| 117750 Hoogte | 0.0000 | 0.0014 |
| 115350 Hoogte | 0.0000 | 0.0015 |
| 113250 Hoogte | 0.0000 | 0.0013 |
| 112450 Hoogte | 0.0000 | 0.0012 |
| 110150 Hoogte | 0.0000 | 0.0012 |

| | | | |
|---|---|---|---|
| 109550 | Hoogte | 0.0000 | 0.0012 |
| 108450 | Hoogte | 0.0000 | 0.0011 |
| 107851 | Hoogte | 0.0000 | 0.0011 |
| 107251 | Hoogte | 0.0000 | 0.0009 |
| 107150 | Hoogte | 0.0000 | 0.0007 |
| 104601 | Hoogte | 0.0000 | 0.0009 |
| 104002 | Hoogte | 0.0000 | 0.0011 |
| 103751 | Hoogte | 0.0000 | 0.0010 |
| 0000n24 | Hoogte | 0.0000 | 0.0014 |
| 0000n23 | Hoogte | 0.0000 | 0.0013 |
| 0000n22 | Hoogte | 0.0000 | 0.0014 |
| 0000n21 | Hoogte | 0.0000 | 0.0014 |
| 0000n20 | Hoogte | 0.0000 | 0.0014 |
| 0000n19 | Hoogte | 0.0000 | 0.0013 |
| 0000n18 | Hoogte | 0.0000 | 0.0014 |
| 034F0217 | Hoogte | 0.0000 | 0.0014 |
| 0000n17 | Hoogte | 0.0000 | 0.0014 |
| 126801 | Hoogte | 0.0000 | 0.0013 |
| 123801 | Hoogte | 0.0000 | 0.0012 |
| 7809 | Hoogte | 0.0000 | 0.0013 |
| 034F0325 | Hoogte | 0.0000 | 0.0013 |
| 7810 | Hoogte | 0.0000 | 0.0013 |
| 7811 | Hoogte | 0.0000 | 0.0012 |
| 000A3522 | Hoogte | 0.0000 | 0.0016 |
| 000A6031 | Hoogte | 0.0000* | 0.0000 |
| 034F0478 | Hoogte | 0.0000 | 0.0014 |
| 0000n16 | Hoogte | 0.0000 | 0.0016 |
| 034F0400 | Hoogte | 0.0000 | 0.0016 |
| 0000n15 | Hoogte | 0.0000 | 0.0015 |
| 0000n14 | Hoogte | 0.0000 | 0.0016 |
| 0000n13 | Hoogte | 0.0000 | 0.0015 |
| 034F0393 | Hoogte | 0.0000 | 0.0016 |
| 034F0040 | Hoogte | 0.0000 | 0.0015 |
| 0000n12 | Hoogte | 0.0000 | 0.0015 |
| 0000n11 | Hoogte | 0.0000 | 0.0015 |
| 0000n10 | Hoogte | 0.0000 | 0.0013 |
| 00000n9 | Hoogte | 0.0000 | 0.0014 |
| 00000n8 | Hoogte | 0.0000 | 0.0015 |
| 00000n7 | Hoogte | 0.0000 | 0.0016 |
| 00000n5 | Hoogte | 0.0000 | 0.0014 |
| 00000n4 | Hoogte | 0.0000 | 0.0015 |
| 00000n3 | Hoogte | 0.0000 | 0.0014 |
| 00000n2 | Hoogte | 0.0000 | 0.0013 |
| 00000n1 | Hoogte | 0.0000 | 0.0013 |
| 034F0061 | Hoogte | 0.0000 | 0.0014 |
| 267 | Hoogte | 0.0000 | 0.0011 |
| 138601 | Hoogte | 0.0000 | 0.0013 |
| 128301 | Hoogte | 0.0000 | 0.0013 |
| 034F0480 | Hoogte | 0.0000 | 0.0015 |
| 034F0476 | Hoogte | 0.0000 | 0.0014 |
| 034F0387 | Hoogte | 0.0000 | 0.0014 |
| 034F0386 | Hoogte | 0.0000 | 0.0013 |
| 034F0385 | Hoogte | 0.0000 | 0.0013 |
| 034F0347 | Hoogte | 0.0000 | 0.0013 |
| 034F0329 | Hoogte | 0.0000 | 0.0013 |
| 034F0312 | Hoogte | 0.0000 | 0.0015 |
| 034F0219 | Hoogte | 0.0000 | 0.0015 |
| 034F0184 | Hoogte | 0.0000 | 0.0015 |
| 034F0183 | Hoogte | 0.0000 | 0.0015 |
| 034F0050 | Hoogte | 0.0000 | 0.0014 |
| 034F0048 | Hoogte | 0.0000 | 0.0015 |
| 034F0047 | Hoogte | 0.0000 | 0.0014 |

ABSOLUTE STANDAARD ELLIPSEN

| Station | A (m) | B (m) | A/B | Phi (gon) | Sa Hgt (m) |
|---|---|---|---|---|---|

RELATIEVE STANDAARD ELLIPSEN

| Station | Station | A (m) | B (m) | A/B | Psi (gon) | Sa Hgt (m) |
|---|---|---|---|---|---|---|
| 034F0508 | 000A3522 | | | | | 0.0007 |
| 000A3522 | 0000n25 | | | | | 0.0006 |
| 034F0385 | 034F0386 | | | | | 0.0006 |
| 00000n5 | 00000n4 | | | | | 0.0005 |
| 00000n4 | 034F0174 | | | | | 0.0006 |
| 034F0174 | 034F0249 | | | | | 0.0004 |
| 034F0249 | 034F0062 | | | | | 0.0005 |
| 000A6031 | 3239 | | | | | 0.0006 |
| 3239 | 3912 | | | | | 0.0005 |
| 7510 | 130001 | | | | | 0.0004 |
| 130001 | 0000n36 | | | | | 0.0004 |
| 138601 | 138701 | | | | | 0.0004 |
| 138701 | 132401 | | | | | 0.0006 |
| 132401 | 132101 | | | | | 0.0004 |
| 034F0062 | 034F0481 | | | | | 0.0009 |
| 034F0481 | 034F0473 | | | | | 0.0005 |
| 034F0473 | 034F0499 | | | | | 0.0005 |
| 034F0499 | 034F0501 | | | | | 0.0005 |
| 034F0501 | 034F0508 | | | | | 0.0007 |
| 0000n32 | 0000n33 | | | | | 0.0006 |
| 0000n33 | 0000n31 | | | | | 0.0006 |
| 034F0359 | 0000n58 | | | | | 0.0007 |
| 0000n58 | 0000n59 | | | | | 0.0008 |
| 0000n59 | 0000n60 | | | | | 0.0006 |
| 0000n60 | 034F0233 | | | | | 0.0006 |
| 034F0233 | 034F0226 | | | | | 0.0006 |
| 034F0226 | 0000n32 | | | | | 0.0005 |
| 034F0359 | 034F0038 | | | | | 0.0007 |
| 034F0038 | 0000n15 | | | | | 0.0005 |
| 0000n54 | 0000n55 | | | | | 0.0008 |
| 0000n55 | 0000n56 | | | | | 0.0006 |
| 0000n56 | 0000n57 | | | | | 0.0006 |
| 0000n57 | 034F0359 | | | | | 0.0007 |
| 0000n54 | 0000n16 | | | | | 0.0006 |
| 0000n16 | 00000n8 | | | | | 0.0005 |
| 034F0508 | 034F0185 | | | | | 0.0008 |
| 034F0185 | 034F0159 | | | | | 0.0006 |
| 034F0159 | 034F0165 | | | | | 0.0006 |
| 034F0165 | 034F0164 | | | | | 0.0004 |
| 034F0164 | 0000n51 | | | | | 0.0005 |
| 0000n51 | 034F0397 | | | | | 0.0008 |
| 034F0397 | 0000n52 | | | | | 0.0007 |
| 0000n52 | 0000n53 | | | | | 0.0006 |
| 0000n53 | 0000n54 | | | | | 0.0006 |
| 034F0062 | 0000n50 | | | | | 0.0006 |
| 0000n50 | 0000n49 | | | | | 0.0006 |
| 0000n49 | 0000n48 | | | | | 0.0005 |
| 0000n48 | 0000n47 | | | | | 0.0006 |
| 0000n47 | 034F0216 | | | | | 0.0005 |
| 0000n15 | 034F0184 | | | | | 0.0006 |
| 034F0184 | 034F0048 | | | | | 0.0006 |
| 00000n8 | 034F0183 | | | | | 0.0007 |
| 034F0183 | 0000n15 | | | | | 0.0005 |
| 034F0480 | 0000n25 | | | | | 0.0008 |
| 0000n42 | 0000n44 | | | | | 0.0007 |
| 0000n44 | 0000n45 | | | | | 0.0008 |
| 0000n45 | 0000n46 | | | | | 0.0007 |
| 0000n46 | 0000n47 | | | | | 0.0005 |
| 0000n42 | 034F0345 | | | | | 0.0007 |
| 0000n12 | 0000n28 | | | | | 0.0004 |
| 0000n28 | 034F0040 | | | | | 0.0005 |
| 7519 | 034F0345 | | | | | 0.0007 |
| 034F0329 | 128301 | | | | | 0.0005 |
| 128301 | 7520 | | | | | 0.0005 |
| 7510 | 129401 | | | | | 0.0005 |
| 0000n36 | 138601 | | | | | 0.0004 |

| | | |
|---|---|---|
| 7519 | 124101 | 0.0006 |
| 124101 | 123801 | 0.0006 |
| 7536 | 108450 | 0.0004 |
| 108450 | 201351 | 0.0005 |
| 106450 | 107251 | 0.0005 |
| 132101 | 131901 | 0.0005 |
| 131901 | 122350 | 0.0008 |
| 122350 | 215150 | 0.0005 |
| 215150 | 107851 | 0.0004 |
| 107851 | 7536 | 0.0005 |
| 132101 | 034F0298 | 0.0006 |
| 7536 | 108150 | 0.0005 |
| 108150 | 106750 | 0.0005 |
| 106750 | 106450 | 0.0005 |
| 0000n61 | 7811 | 0.0007 |
| 7811 | 0000n41 | 0.0006 |
| 0000n41 | 7810 | 0.0005 |
| 7810 | 0000n40 | 0.0006 |
| 0000n40 | 034F0325 | 0.0006 |
| 034F0325 | 0000n43 | 0.0004 |
| 0000n43 | 7809 | 0.0007 |
| 7809 | 0000n42 | 0.0004 |
| 034F0216 | 0000n17 | 0.0005 |
| 0000n17 | 7520 | 0.0007 |
| 0000n20 | 0000n21 | 0.0005 |
| 0000n21 | 0000n22 | 0.0005 |
| 034F0050 | 0000n22 | 0.0004 |
| 0000n19 | 034F0061 | 0.0005 |
| 034F0061 | 0000n20 | 0.0005 |
| 0000n19 | 0000n18 | 0.0005 |
| 0000n18 | 034F0217 | 0.0005 |
| 034F0217 | 034F0216 | 0.0007 |
| 034F0329 | 034F0347 | 0.0006 |
| 034F0347 | 0000n19 | 0.0004 |
| 0000n23 | 0000n19 | 0.0005 |
| 034F0386 | 0000n23 | 0.0005 |
| 0000n23 | 0000n24 | 0.0005 |
| 034F0040 | 0000n30 | 0.0005 |
| 0000n30 | 00000n8 | 0.0006 |
| 034F0048 | 034F0312 | 0.0005 |
| 034F0312 | 034F0047 | 0.0006 |
| 034F0047 | 0000n31 | 0.0005 |
| 034F0298 | 034F0310 | 0.0006 |
| 034F0310 | 0000n34 | 0.0006 |
| 0000n34 | 0000n32 | 0.0006 |
| 0000n35 | 138601 | 0.0005 |
| 0000n37 | 0000n38 | 0.0004 |
| 0000n36 | 0000n37 | 0.0005 |
| 0000n35 | 0000n39 | 0.0006 |
| 0000n39 | 0000n38 | 0.0005 |
| 129401 | 0000n37 | 0.0005 |
| 3912 | 104601 | 0.0006 |
| 104601 | 106450 | 0.0006 |
| 7542 | 107150 | 0.0006 |
| 107150 | 034F0516 | 0.0007 |
| 034F0516 | 000A6031 | 0.0003 |
| 7542 | 0000n61 | 0.0005 |
| 0000n61 | 142601 | 0.0006 |
| 142601 | 267 | 0.0004 |
| 267 | 141701 | 0.0005 |
| 141701 | 142001 | 0.0005 |
| 142001 | 034F0345 | 0.0006 |
| 107251 | 7542 | 0.0007 |
| 104002 | 103751 | 0.0007 |
| 103751 | 5706 | 0.0003 |
| 5706 | 3912 | 0.0006 |
| 109550 | 104002 | 0.0005 |

| | | |
|---|---|---|
| 34E0273 | 7514 | 0.0007 |
| 7514 | 7515 | 0.0007 |
| 7515 | 6105 | 0.0007 |
| 6105 | 104002 | 0.0004 |
| 34E0273 | 7576 | 0.0007 |
| 7576 | 119250 | 0.0006 |
| 119250 | 113250 | 0.0006 |
| 113250 | 109550 | 0.0006 |
| 201351 | 120550 | 0.0006 |
| 120550 | 107450 | 0.0004 |
| 107450 | 107250 | 0.0004 |
| 107250 | 107251 | 0.0003 |
| 215150 | 111050 | 0.0003 |
| 111050 | 112450 | 0.0007 |
| 112450 | 7528 | 0.0005 |
| 7528 | 110150 | 0.0006 |
| 110150 | 7014 | 0.0005 |
| 7014 | 109550 | 0.0006 |
| 123001 | 121601 | 0.0006 |
| 121601 | 201351 | 0.0005 |
| 118850 | 118450 | 0.0005 |
| 118450 | 7528 | 0.0007 |
| 118850 | 119450 | 0.0004 |
| 119450 | 119150 | 0.0005 |
| 119150 | 117750 | 0.0005 |
| 117750 | 115350 | 0.0009 |
| 115350 | 34E0185 | 0.0008 |
| 34E0185 | 34E0273 | 0.0008 |
| 123801 | 123501 | 0.0005 |
| 123501 | 123001 | 0.0006 |
| 136001 | 126801 | 0.0006 |
| 126801 | 123801 | 0.0006 |
| 136001 | 00000n2 | 0.0007 |
| 00000n3 | 00000n5 | 0.0005 |
| 00000n2 | 123001 | 0.0006 |
| 127501 | 127901 | 0.0005 |
| 127901 | 136801 | 0.0004 |
| 7520 | 00000n1 | 0.0007 |
| 00000n1 | 7519 | 0.0006 |
| 0000n20 | 034F0219 | 0.0006 |
| 034F0219 | 00000n5 | 0.0005 |
| 034F0329 | 128701 | 0.0004 |
| 128701 | 127501 | 0.0005 |
| 034F0298 | 134501 | 0.0006 |
| 134501 | 134850 | 0.0005 |
| 134850 | 135001 | 0.0006 |
| 135001 | 64 | 0.0007 |
| 64 | 135601 | 0.0006 |
| 135601 | 118850 | 0.0005 |
| 129401 | 127501 | 0.0005 |
| 7510 | 136001 | 0.0005 |
| 0000n38 | 136801 | 0.0005 |
| 7532 | 137901 | 0.0006 |
| 137901 | 0000n35 | 0.0005 |
| 7532 | 136801 | 0.0005 |
| 034F0386 | 0000n10 | 0.0005 |
| 0000n10 | 034F0329 | 0.0005 |
| 034F0385 | 7532 | 0.0003 |
| 00000n3 | 034F0480 | 0.0006 |
| 00000n3 | 034F0050 | 0.0006 |
| 0000n24 | 034F0387 | 0.0005 |
| 034F0387 | 00000n9 | 0.0006 |
| 00000n9 | 034F0385 | 0.0006 |
| 0000n31 | 034F0476 | 0.0005 |
| 034F0476 | 7532 | 0.0006 |
| 034F0048 | 0000n26 | 0.0003 |
| 0000n26 | 0000n13 | 0.0005 |

| | | |
|---|---|---|
| 0000n13 | 0000n12 | 0.0005 |
| 0000n25 | 00000n7 | 0.0005 |
| 00000n7 | 0000n14 | 0.0006 |
| 0000n14 | 034F0400 | 0.0006 |
| 034F0400 | 0000n54 | 0.0005 |
| 0000n12 | 0000n27 | 0.0005 |
| 0000n27 | 034F0478 | 0.0004 |
| 034F0478 | 034F0050 | 0.0005 |
| 034F0040 | 0000n29 | 0.0005 |
| 0000n29 | 034F0393 | 0.0006 |
| 034F0393 | 0000n11 | 0.0006 |
| 0000n11 | 034F0480 | 0.0006 |
| 0000n22 | 0000n24 | 0.0005 |

VEREFFENDE WAARNEMINGEN

| | Station | Richtpunt | Vereff wn | Corr | Sa |
|---|---|---|---|---|---|
| DH | 034F0508 | 000A3522 | | | 0.00072 m |
| DH | 000A3522 | 0000n25 | | | 0.00065 m |
| DH | 034F0385 | 034F0386 | | | 0.00056 m |
| DH | 00000n5 | 00000n4 | | | 0.00052 m |
| DH | 00000n4 | 034F0174 | | | 0.00060 m |
| DH | 034F0174 | 034F0249 | | | 0.00036 m |
| DH | 034F0249 | 034F0062 | | | 0.00050 m |
| DH | 000A6031 | 3239 | | | 0.00063 m |
| DH | 3239 | 3912 | | | 0.00055 m |
| DH | 7510 | 130001 | | | 0.00036 m |
| DH | 130001 | 0000n36 | | | 0.00042 m |
| DH | 138601 | 138701 | | | 0.00040 m |
| DH | 138701 | 132401 | | | 0.00064 m |
| DH | 132401 | 132101 | | | 0.00044 m |
| DH | 034F0062 | 034F0481 | | | 0.00085 m |
| DH | 034F0481 | 034F0473 | | | 0.00053 m |
| DH | 034F0473 | 034F0499 | | | 0.00055 m |
| DH | 034F0499 | 034F0501 | | | 0.00047 m |
| DH | 034F0501 | 034F0508 | | | 0.00070 m |
| DH | 0000n32 | 0000n33 | | | 0.00059 m |
| DH | 0000n33 | 0000n31 | | | 0.00057 m |
| DH | 034F0359 | 0000n58 | | | 0.00069 m |
| DH | 0000n58 | 0000n59 | | | 0.00076 m |
| DH | 0000n59 | 0000n60 | | | 0.00063 m |
| DH | 0000n60 | 034F0233 | | | 0.00059 m |
| DH | 034F0233 | 034F0226 | | | 0.00056 m |
| DH | 034F0226 | 0000n32 | | | 0.00054 m |
| DH | 034F0359 | 034F0038 | | | 0.00068 m |
| DH | 034F0038 | 0000n15 | | | 0.00049 m |
| DH | 0000n54 | 0000n55 | | | 0.00078 m |
| DH | 0000n55 | 0000n56 | | | 0.00057 m |
| DH | 0000n56 | 0000n57 | | | 0.00064 m |
| DH | 0000n57 | 034F0359 | | | 0.00070 m |
| DH | 0000n54 | 0000n16 | | | 0.00056 m |
| DH | 0000n16 | 00000n8 | | | 0.00052 m |
| DH | 034F0508 | 034F0185 | | | 0.00084 m |
| DH | 034F0185 | 034F0159 | | | 0.00060 m |
| DH | 034F0159 | 034F0165 | | | 0.00061 m |
| DH | 034F0165 | 034F0164 | | | 0.00044 m |
| DH | 034F0164 | 0000n51 | | | 0.00054 m |
| DH | 0000n51 | 034F0397 | | | 0.00081 m |
| DH | 034F0397 | 0000n52 | | | 0.00066 m |
| DH | 0000n52 | 0000n53 | | | 0.00061 m |
| DH | 0000n53 | 0000n54 | | | 0.00065 m |
| DH | 034F0062 | 0000n50 | | | 0.00056 m |
| DH | 0000n50 | 0000n49 | | | 0.00061 m |
| DH | 0000n49 | 0000n48 | | | 0.00051 m |
| DH | 0000n48 | 0000n47 | | | 0.00056 m |
| DH | 0000n47 | 034F0216 | | | 0.00054 m |
| DH | 0000n15 | 034F0184 | | | 0.00056 m |
| DH | 034F0184 | 034F0048 | | | 0.00060 m |

| | | | |
|---|---|---|---|
| DH | 00000n8 | 034F0183 | 0.00066 m |
| DH | 034F0183 | 0000n15 | 0.00049 m |
| DH | 034F0480 | 0000n25 | 0.00082 m |
| DH | 0000n42 | 0000n44 | 0.00072 m |
| DH | 0000n44 | 0000n45 | 0.00077 m |
| DH | 0000n45 | 0000n46 | 0.00075 m |
| DH | 0000n46 | 0000n47 | 0.00054 m |
| DH | 0000n42 | 034F0345 | 0.00069 m |
| DH | 0000n12 | 0000n28 | 0.00045 m |
| DH | 0000n28 | 034F0040 | 0.00045 m |
| DH | 7519 | 034F0345 | 0.00067 m |
| DH | 034F0329 | 128301 | 0.00053 m |
| DH | 128301 | 7520 | 0.00055 m |
| DH | 7510 | 129401 | 0.00047 m |
| DH | 0000n36 | 138601 | 0.00039 m |
| DH | 7519 | 124101 | 0.00062 m |
| DH | 124101 | 123801 | 0.00062 m |
| DH | 7536 | 108450 | 0.00045 m |
| DH | 108450 | 201351 | 0.00053 m |
| DH | 106450 | 107251 | 0.00052 m |
| DH | 132101 | 131901 | 0.00052 m |
| DH | 131901 | 122350 | 0.00077 m |
| DH | 122350 | 215150 | 0.00053 m |
| DH | 215150 | 107851 | 0.00042 m |
| DH | 107851 | 7536 | 0.00051 m |
| DH | 132101 | 034F0298 | 0.00059 m |
| DH | 7536 | 108150 | 0.00050 m |
| DH | 108150 | 106750 | 0.00054 m |
| DH | 106750 | 106450 | 0.00049 m |
| DH | 0000n61 | 7811 | 0.00069 m |
| DH | 7811 | 0000n41 | 0.00061 m |
| DH | 0000n41 | 7810 | 0.00051 m |
| DH | 7810 | 0000n40 | 0.00062 m |
| DH | 0000n40 | 034F0325 | 0.00060 m |
| DH | 034F0325 | 0000n43 | 0.00045 m |
| DH | 0000n43 | 7809 | 0.00065 m |
| DH | 7809 | 0000n42 | 0.00044 m |
| DH | 034F0216 | 0000n17 | 0.00045 m |
| DH | 0000n17 | 7520 | 0.00071 m |
| DH | 0000n20 | 0000n21 | 0.00053 m |
| DH | 0000n21 | 0000n22 | 0.00054 m |
| DH | 034F0050 | 0000n22 | 0.00038 m |
| DH | 0000n19 | 034F0061 | 0.00050 m |
| DH | 034F0061 | 0000n20 | 0.00050 m |
| DH | 0000n19 | 0000n18 | 0.00051 m |
| DH | 0000n18 | 034F0217 | 0.00049 m |
| DH | 034F0217 | 034F0216 | 0.00067 m |
| DH | 034F0329 | 034F0347 | 0.00061 m |
| DH | 034F0347 | 0000n19 | 0.00035 m |
| DH | 0000n23 | 0000n19 | 0.00055 m |
| DH | 034F0386 | 0000n23 | 0.00053 m |
| DH | 0000n23 | 0000n24 | 0.00053 m |
| DH | 034F0040 | 0000n30 | 0.00051 m |
| DH | 0000n30 | 00000n8 | 0.00057 m |
| DH | 034F0048 | 034F0312 | 0.00049 m |
| DH | 034F0312 | 034F0047 | 0.00059 m |
| DH | 034F0047 | 0000n31 | 0.00045 m |
| DH | 034F0298 | 034F0310 | 0.00060 m |
| DH | 034F0310 | 0000n34 | 0.00059 m |
| DH | 0000n34 | 0000n32 | 0.00062 m |
| DH | 0000n35 | 138601 | 0.00048 m |
| DH | 0000n37 | 0000n38 | 0.00044 m |
| DH | 0000n36 | 0000n37 | 0.00048 m |
| DH | 0000n35 | 0000n39 | 0.00058 m |
| DH | 0000n39 | 0000n38 | 0.00047 m |
| DH | 129401 | 0000n37 | 0.00046 m |
| DH | 3912 | 104601 | 0.00065 m |

| | | | |
|---|---|---|---|
| DH | 104601 | 106450 | 0.00056 m |
| DH | 7542 | 107150 | 0.00059 m |
| DH | 107150 | 034F0516 | 0.00067 m |
| DH | 034F0516 | 000A6031 | 0.00034 m |
| DH | 7542 | 0000n61 | 0.00047 m |
| DH | 0000n61 | 142601 | 0.00064 m |
| DH | 142601 | 267 | 0.00038 m |
| DH | 267 | 141701 | 0.00055 m |
| DH | 141701 | 142001 | 0.00049 m |
| DH | 142001 | 034F0345 | 0.00064 m |
| DH | 107251 | 7542 | 0.00069 m |
| DH | 104002 | 103751 | 0.00073 m |
| DH | 103751 | 5706 | 0.00031 m |
| DH | 5706 | 3912 | 0.00061 m |
| DH | 109550 | 104002 | 0.00045 m |
| DH | 34E0273 | 7514 | 0.00066 m |
| DH | 7514 | 7515 | 0.00072 m |
| DH | 7515 | 6105 | 0.00066 m |
| DH | 6105 | 104002 | 0.00043 m |
| DH | 34E0273 | 7576 | 0.00067 m |
| DH | 7576 | 119250 | 0.00058 m |
| DH | 119250 | 113250 | 0.00065 m |
| DH | 113250 | 109550 | 0.00056 m |
| DH | 201351 | 120550 | 0.00061 m |
| DH | 120550 | 107450 | 0.00043 m |
| DH | 107450 | 107250 | 0.00036 m |
| DH | 107250 | 107251 | 0.00025 m |
| DH | 215150 | 111050 | 0.00032 m |
| DH | 111050 | 112450 | 0.00073 m |
| DH | 112450 | 7528 | 0.00052 m |
| DH | 7528 | 110150 | 0.00056 m |
| DH | 110150 | 7014 | 0.00053 m |
| DH | 7014 | 109550 | 0.00060 m |
| DH | 123001 | 121601 | 0.00059 m |
| DH | 121601 | 201351 | 0.00053 m |
| DH | 118850 | 118450 | 0.00050 m |
| DH | 118450 | 7528 | 0.00071 m |
| DH | 118850 | 119450 | 0.00042 m |
| DH | 119450 | 119150 | 0.00048 m |
| DH | 119150 | 117750 | 0.00048 m |
| DH | 117750 | 115350 | 0.00089 m |
| DH | 115350 | 34E0185 | 0.00076 m |
| DH | 34E0185 | 34E0273 | 0.00077 m |
| DH | 123801 | 123501 | 0.00046 m |
| DH | 123501 | 123001 | 0.00061 m |
| DH | 136001 | 126801 | 0.00063 m |
| DH | 126801 | 123801 | 0.00056 m |
| DH | 136001 | 00000n2 | 0.00067 m |
| DH | 00000n3 | 00000n5 | 0.00053 m |
| DH | 00000n5 | 00000n3 | 0.00053 m |
| DH | 00000n2 | 123001 | 0.00058 m |
| DH | 127501 | 127901 | 0.00046 m |
| DH | 127901 | 136801 | 0.00042 m |
| DH | 7520 | 00000n1 | 0.00068 m |
| DH | 00000n1 | 7519 | 0.00064 m |
| DH | 0000n20 | 034F0219 | 0.00062 m |
| DH | 034F0219 | 00000n5 | 0.00054 m |
| DH | 034F0329 | 128701 | 0.00038 m |
| DH | 128701 | 127501 | 0.00051 m |
| DH | 034F0298 | 134501 | 0.00058 m |
| DH | 134501 | 134850 | 0.00049 m |
| DH | 134850 | 135001 | 0.00055 m |
| DH | 135001 | 64 | 0.00066 m |
| DH | 64 | 135601 | 0.00063 m |
| DH | 135601 | 118850 | 0.00047 m |
| DH | 129401 | 127501 | 0.00054 m |
| DH | 7510 | 136001 | 0.00047 m |

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|---|---|---|---|
| DH | 0000n38 | 136801 | 0.00046 m |
| DH | 7532 | 137901 | 0.00060 m |
| DH | 137901 | 0000n35 | 0.00046 m |
| DH | 7532 | 136801 | 0.00053 m |
| DH | 034F0386 | 0000n10 | 0.00053 m |
| DH | 0000n10 | 034F0329 | 0.00048 m |
| DH | 034F0385 | 7532 | 0.00033 m |
| DH | 00000n3 | 034F0480 | 0.00062 m |
| DH | 00000n3 | 034F0050 | 0.00059 m |
| DH | 0000n24 | 034F0387 | 0.00047 m |
| DH | 034F0387 | 00000n9 | 0.00063 m |
| DH | 00000n9 | 034F0385 | 0.00057 m |
| DH | 0000n31 | 034F0476 | 0.00047 m |
| DH | 034F0476 | 7532 | 0.00063 m |
| DH | 034F0048 | 0000n26 | 0.00031 m |
| DH | 0000n26 | 0000n13 | 0.00047 m |
| DH | 0000n13 | 0000n12 | 0.00046 m |
| DH | 0000n25 | 00000n7 | 0.00050 m |
| DH | 00000n7 | 0000n14 | 0.00062 m |
| DH | 0000n14 | 034F0400 | 0.00062 m |
| DH | 034F0400 | 0000n54 | 0.00045 m |
| DH | 0000n12 | 0000n27 | 0.00050 m |
| DH | 0000n27 | 034F0478 | 0.00044 m |
| DH | 034F0478 | 034F0050 | 0.00054 m |
| DH | 034F0040 | 0000n29 | 0.00048 m |
| DH | 0000n29 | 034F0393 | 0.00057 m |
| DH | 034F0393 | 0000n11 | 0.00058 m |
| DH | 0000n11 | 034F0480 | 0.00059 m |
| DH | 000A3522 | 034F0508 | 0.00072 m |
| DH | 0000n25 | 000A3522 | 0.00065 m |
| DH | 034F0386 | 034F0385 | 0.00056 m |
| DH | 00000n4 | 00000n5 | 0.00052 m |
| DH | 034F0174 | 00000n4 | 0.00060 m |
| DH | 034F0249 | 034F0174 | 0.00036 m |
| DH | 034F0062 | 034F0249 | 0.00050 m |
| DH | 3239 | 000A6031 | 0.00063 m |
| DH | 3912 | 3239 | 0.00055 m |
| DH | 130001 | 7510 | 0.00036 m |
| DH | 0000n36 | 130001 | 0.00042 m |
| DH | 138701 | 138601 | 0.00040 m |
| DH | 132401 | 138701 | 0.00064 m |
| DH | 132101 | 132401 | 0.00044 m |
| DH | 034F0481 | 034F0062 | 0.00085 m |
| DH | 034F0473 | 034F0481 | 0.00053 m |
| DH | 034F0499 | 034F0473 | 0.00055 m |
| DH | 034F0501 | 034F0499 | 0.00047 m |
| DH | 034F0508 | 034F0501 | 0.00070 m |
| DH | 0000n33 | 0000n32 | 0.00059 m |
| DH | 0000n31 | 0000n33 | 0.00057 m |
| DH | 0000n58 | 034F0359 | 0.00069 m |
| DH | 0000n59 | 0000n58 | 0.00076 m |
| DH | 0000n60 | 0000n59 | 0.00063 m |
| DH | 034F0233 | 0000n60 | 0.00059 m |
| DH | 034F0226 | 034F0233 | 0.00056 m |
| DH | 0000n32 | 034F0226 | 0.00054 m |
| DH | 034F0038 | 034F0359 | 0.00068 m |
| DH | 0000n15 | 034F0038 | 0.00049 m |
| DH | 0000n55 | 0000n54 | 0.00078 m |
| DH | 0000n56 | 0000n55 | 0.00057 m |
| DH | 0000n57 | 0000n56 | 0.00064 m |
| DH | 034F0359 | 0000n57 | 0.00070 m |
| DH | 0000n16 | 0000n54 | 0.00056 m |
| DH | 00000n8 | 0000n16 | 0.00052 m |
| DH | 034F0185 | 034F0508 | 0.00084 m |
| DH | 034F0159 | 034F0185 | 0.00060 m |
| DH | 034F0165 | 034F0159 | 0.00061 m |
| DH | 034F0164 | 034F0165 | 0.00044 m |

| | | | |
|---|---|---|---|
| DH | 0000n51 | 034F0164 | 0.00054 m |
| DH | 034F0397 | 0000n51 | 0.00081 m |
| DH | 0000n52 | 034F0397 | 0.00066 m |
| DH | 0000n53 | 0000n52 | 0.00061 m |
| DH | 0000n54 | 0000n53 | 0.00065 m |
| DH | 0000n50 | 034F0062 | 0.00056 m |
| DH | 0000n49 | 0000n50 | 0.00061 m |
| DH | 0000n48 | 0000n49 | 0.00051 m |
| DH | 0000n47 | 0000n48 | 0.00056 m |
| DH | 034F0216 | 0000n47 | 0.00054 m |
| DH | 034F0184 | 0000n15 | 0.00056 m |
| DH | 034F0048 | 034F0184 | 0.00060 m |
| DH | 034F0183 | 00000n8 | 0.00066 m |
| DH | 0000n15 | 034F0183 | 0.00049 m |
| DH | 0000n25 | 034F0480 | 0.00082 m |
| DH | 0000n44 | 0000n42 | 0.00072 m |
| DH | 0000n45 | 0000n44 | 0.00077 m |
| DH | 0000n46 | 0000n45 | 0.00075 m |
| DH | 0000n47 | 0000n46 | 0.00054 m |
| DH | 034F0345 | 0000n42 | 0.00069 m |
| DH | 0000n28 | 0000n12 | 0.00045 m |
| DH | 034F0040 | 0000n28 | 0.00045 m |
| DH | 034F0345 | 7519 | 0.00067 m |
| DH | 128301 | 034F0329 | 0.00053 m |
| DH | 7520 | 128301 | 0.00055 m |
| DH | 129401 | 7510 | 0.00047 m |
| DH | 138601 | 0000n36 | 0.00039 m |
| DH | 124101 | 7519 | 0.00062 m |
| DH | 123801 | 124101 | 0.00062 m |
| DH | 108450 | 7536 | 0.00045 m |
| DH | 201351 | 108450 | 0.00053 m |
| DH | 107251 | 106450 | 0.00052 m |
| DH | 131901 | 132101 | 0.00052 m |
| DH | 122350 | 131901 | 0.00077 m |
| DH | 215150 | 122350 | 0.00053 m |
| DH | 107851 | 215150 | 0.00042 m |
| DH | 7536 | 107851 | 0.00051 m |
| DH | 034F0298 | 132101 | 0.00059 m |
| DH | 108150 | 7536 | 0.00050 m |
| DH | 106750 | 108150 | 0.00054 m |
| DH | 106450 | 106750 | 0.00049 m |
| DH | 7811 | 0000n61 | 0.00069 m |
| DH | 0000n41 | 7811 | 0.00061 m |
| DH | 7810 | 0000n41 | 0.00051 m |
| DH | 0000n40 | 7810 | 0.00062 m |
| DH | 034F0325 | 0000n40 | 0.00060 m |
| DH | 0000n43 | 034F0325 | 0.00045 m |
| DH | 7809 | 0000n43 | 0.00065 m |
| DH | 0000n42 | 7809 | 0.00044 m |
| DH | 0000n17 | 034F0216 | 0.00045 m |
| DH | 7520 | 0000n17 | 0.00071 m |
| DH | 0000n21 | 0000n20 | 0.00053 m |
| DH | 0000n22 | 0000n21 | 0.00054 m |
| DH | 0000n22 | 034F0050 | 0.00038 m |
| DH | 034F0061 | 0000n19 | 0.00050 m |
| DH | 0000n20 | 034F0061 | 0.00050 m |
| DH | 0000n18 | 0000n19 | 0.00051 m |
| DH | 034F0217 | 0000n18 | 0.00049 m |
| DH | 034F0216 | 034F0217 | 0.00067 m |
| DH | 034F0347 | 034F0329 | 0.00061 m |
| DH | 0000n19 | 034F0347 | 0.00035 m |
| DH | 0000n19 | 0000n23 | 0.00055 m |
| DH | 0000n23 | 034F0386 | 0.00053 m |
| DH | 0000n22 | 0000n24 | 0.00048 m |
| DH | 0000n24 | 0000n22 | 0.00048 m |
| DH | 0000n24 | 0000n23 | 0.00053 m |
| DH | 0000n30 | 034F0040 | 0.00051 m |

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|---|---|---|---|
| DH | 00000n8 | 0000n30 | 0.00057 m |
| DH | 034F0312 | 034F0048 | 0.00049 m |
| DH | 034F0047 | 034F0312 | 0.00059 m |
| DH | 0000n31 | 034F0047 | 0.00045 m |
| DH | 034F0310 | 034F0298 | 0.00060 m |
| DH | 0000n34 | 034F0310 | 0.00059 m |
| DH | 0000n32 | 0000n34 | 0.00062 m |
| DH | 138601 | 0000n35 | 0.00048 m |
| DH | 0000n38 | 0000n37 | 0.00044 m |
| DH | 0000n37 | 0000n36 | 0.00048 m |
| DH | 0000n39 | 0000n35 | 0.00058 m |
| DH | 0000n38 | 0000n39 | 0.00047 m |
| DH | 0000n37 | 129401 | 0.00046 m |
| DH | 104601 | 3912 | 0.00065 m |
| DH | 106450 | 104601 | 0.00056 m |
| DH | 107150 | 7542 | 0.00059 m |
| DH | 034F0516 | 107150 | 0.00067 m |
| DH | 000A6031 | 034F0516 | 0.00034 m |
| DH | 0000n61 | 7542 | 0.00047 m |
| DH | 142601 | 0000n61 | 0.00064 m |
| DH | 267 | 142601 | 0.00038 m |
| DH | 141701 | 267 | 0.00055 m |
| DH | 142001 | 141701 | 0.00049 m |
| DH | 034F0345 | 142001 | 0.00064 m |
| DH | 7542 | 107251 | 0.00069 m |
| DH | 103751 | 104002 | 0.00073 m |
| DH | 5706 | 103751 | 0.00031 m |
| DH | 3912 | 5706 | 0.00061 m |
| DH | 104002 | 109550 | 0.00045 m |
| DH | 7514 | 34E0273 | 0.00066 m |
| DH | 7515 | 7514 | 0.00072 m |
| DH | 6105 | 7515 | 0.00066 m |
| DH | 104002 | 6105 | 0.00043 m |
| DH | 7576 | 34E0273 | 0.00067 m |
| DH | 119250 | 7576 | 0.00058 m |
| DH | 113250 | 119250 | 0.00065 m |
| DH | 109550 | 113250 | 0.00056 m |
| DH | 120550 | 201351 | 0.00061 m |
| DH | 107450 | 120550 | 0.00043 m |
| DH | 107250 | 107450 | 0.00036 m |
| DH | 107251 | 107250 | 0.00025 m |
| DH | 111050 | 215150 | 0.00032 m |
| DH | 112450 | 111050 | 0.00073 m |
| DH | 7528 | 112450 | 0.00052 m |
| DH | 110150 | 7528 | 0.00056 m |
| DH | 7014 | 110150 | 0.00053 m |
| DH | 109550 | 7014 | 0.00060 m |
| DH | 121601 | 123001 | 0.00059 m |
| DH | 201351 | 121601 | 0.00053 m |
| DH | 118450 | 118850 | 0.00050 m |
| DH | 7528 | 118450 | 0.00071 m |
| DH | 119450 | 118850 | 0.00042 m |
| DH | 119150 | 119450 | 0.00048 m |
| DH | 117750 | 119150 | 0.00048 m |
| DH | 115350 | 117750 | 0.00089 m |
| DH | 34E0185 | 115350 | 0.00076 m |
| DH | 34E0273 | 34E0185 | 0.00077 m |
| DH | 123501 | 123801 | 0.00046 m |
| DH | 123001 | 123501 | 0.00061 m |
| DH | 126801 | 136001 | 0.00063 m |
| DH | 123801 | 126801 | 0.00056 m |
| DH | 00000n2 | 136001 | 0.00067 m |
| DH | 123001 | 00000n2 | 0.00058 m |
| DH | 127901 | 127501 | 0.00046 m |
| DH | 136801 | 127901 | 0.00042 m |
| DH | 00000n1 | 7520 | 0.00068 m |
| DH | 7519 | 00000n1 | 0.00064 m |

| | | | |
|---|---|---|---|
| DH | 034F0219 | 0000n20 | 0.00062 m |
| DH | 00000n5 | 034F0219 | 0.00054 m |
| DH | 128701 | 034F0329 | 0.00038 m |
| DH | 127501 | 128701 | 0.00051 m |
| DH | 134501 | 034F0298 | 0.00058 m |
| DH | 134850 | 134501 | 0.00049 m |
| DH | 135001 | 134850 | 0.00055 m |
| DH | 64 | 135001 | 0.00066 m |
| DH | 135601 | 64 | 0.00063 m |
| DH | 118850 | 135601 | 0.00047 m |
| DH | 127501 | 129401 | 0.00054 m |
| DH | 136001 | 7510 | 0.00047 m |
| DH | 136801 | 0000n38 | 0.00046 m |
| DH | 137901 | 7532 | 0.00060 m |
| DH | 0000n35 | 137901 | 0.00046 m |
| DH | 136801 | 7532 | 0.00053 m |
| DH | 0000n10 | 034F0386 | 0.00053 m |
| DH | 034F0329 | 0000n10 | 0.00048 m |
| DH | 7532 | 034F0385 | 0.00033 m |
| DH | 034F0480 | 00000n3 | 0.00062 m |
| DH | 034F0050 | 00000n3 | 0.00059 m |
| DH | 034F0387 | 0000n24 | 0.00047 m |
| DH | 00000n9 | 034F0387 | 0.00063 m |
| DH | 034F0385 | 00000n9 | 0.00057 m |
| DH | 034F0476 | 0000n31 | 0.00047 m |
| DH | 7532 | 034F0476 | 0.00063 m |
| DH | 0000n26 | 034F0048 | 0.00031 m |
| DH | 0000n13 | 0000n26 | 0.00047 m |
| DH | 0000n12 | 0000n13 | 0.00046 m |
| DH | 00000n7 | 0000n25 | 0.00050 m |
| DH | 0000n14 | 00000n7 | 0.00062 m |
| DH | 034F0400 | 0000n14 | 0.00062 m |
| DH | 0000n54 | 034F0400 | 0.00045 m |
| DH | 0000n27 | 0000n12 | 0.00050 m |
| DH | 034F0478 | 0000n27 | 0.00044 m |
| DH | 034F0050 | 034F0478 | 0.00054 m |
| DH | 0000n29 | 034F0040 | 0.00048 m |
| DH | 034F0393 | 0000n29 | 0.00057 m |
| DH | 0000n11 | 034F0393 | 0.00058 m |
| DH | 034F0480 | 0000n11 | 0.00059 m |

TOETSING VAN WAARNEMINGEN

| | Station | Richtpunt | MDB | MDBn | Red | BNR |
|---|---|---|---|---|---|---|
| DH | 034F0508 | 000A3522 | 0.00608 m | 5.4 | 59 | 3.5 |
| DH | 000A3522 | 0000n25 | 0.00540 m | 5.5 | 57 | 3.6 |
| DH | 034F0385 | 034F0386 | 0.00502 m | 5.0 | 69 | 2.8 |
| DH | 00000n5 | 00000n4 | 0.00436 m | 5.6 | 55 | 3.7 |
| DH | 00000n4 | 034F0174 | 0.00497 m | 5.5 | 57 | 3.6 |
| DH | 034F0174 | 034F0249 | 0.00300 m | 5.7 | 52 | 3.9 |
| DH | 034F0249 | 034F0062 | 0.00414 m | 5.6 | 54 | 3.8 |
| DH | 000A6031 | 3239 | 0.00526 m | 5.5 | 57 | 3.6 |
| DH | 3239 | 3912 | 0.00454 m | 5.6 | 55 | 3.7 |
| DH | 7510 | 130001 | 0.00304 m | 5.5 | 57 | 3.6 |
| DH | 130001 | 0000n36 | 0.00351 m | 5.3 | 60 | 3.4 |
| DH | 138601 | 138701 | 0.00330 m | 5.7 | 53 | 3.9 |
| DH | 138701 | 132401 | 0.00542 m | 5.3 | 60 | 3.4 |
| DH | 132401 | 132101 | 0.00368 m | 5.6 | 54 | 3.8 |
| DH | 034F0062 | 034F0481 | 0.00716 m | 5.4 | 59 | 3.4 |
| DH | 034F0481 | 034F0473 | 0.00436 m | 5.7 | 53 | 3.9 |
| DH | 034F0473 | 034F0499 | 0.00455 m | 5.7 | 53 | 3.9 |
| DH | 034F0499 | 034F0501 | 0.00390 m | 5.7 | 52 | 3.9 |
| DH | 034F0501 | 034F0508 | 0.00584 m | 5.5 | 56 | 3.7 |
| DH | 0000n32 | 0000n33 | 0.00496 m | 5.4 | 57 | 3.6 |
| DH | 0000n33 | 0000n31 | 0.00474 m | 5.5 | 57 | 3.6 |
| DH | 034F0359 | 0000n58 | 0.00570 m | 5.5 | 56 | 3.7 |
| DH | 0000n58 | 0000n59 | 0.00639 m | 5.5 | 57 | 3.6 |
| DH | 0000n59 | 0000n60 | 0.00523 m | 5.6 | 55 | 3.8 |

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|---|---|---|---|---|---|---|
| DH | 0000n60 | 034F0233 | 0.00493 m | 5.6 | 54 | 3.8 |
| DH | 034F0233 | 034F0226 | 0.00461 m | 5.6 | 53 | 3.9 |
| DH | 034F0226 | 0000n32 | 0.00448 m | 5.7 | 53 | 3.9 |
| DH | 034F0359 | 034F0038 | 0.00570 m | 5.3 | 60 | 3.4 |
| DH | 034F0038 | 0000n15 | 0.00403 m | 5.6 | 54 | 3.8 |
| DH | 0000n54 | 0000n55 | 0.00662 m | 5.3 | 60 | 3.4 |
| DH | 0000n55 | 0000n56 | 0.00470 m | 5.6 | 55 | 3.8 |
| DH | 0000n56 | 0000n57 | 0.00536 m | 5.5 | 56 | 3.6 |
| DH | 0000n57 | 034F0359 | 0.00589 m | 5.4 | 58 | 3.5 |
| DH | 0000n54 | 0000n16 | 0.00471 m | 5.4 | 58 | 3.5 |
| DH | 0000n16 | 00000n8 | 0.00435 m | 5.5 | 56 | 3.6 |
| DH | 034F0508 | 034F0185 | 0.00704 m | 5.5 | 57 | 3.6 |
| DH | 034F0185 | 034F0159 | 0.00495 m | 5.7 | 53 | 3.9 |
| DH | 034F0159 | 034F0165 | 0.00502 m | 5.7 | 53 | 3.9 |
| DH | 034F0165 | 034F0164 | 0.00361 m | 5.7 | 52 | 4.0 |
| DH | 034F0164 | 0000n51 | 0.00446 m | 5.7 | 53 | 3.9 |
| DH | 0000n51 | 034F0397 | 0.00676 m | 5.5 | 57 | 3.6 |
| DH | 034F0397 | 0000n52 | 0.00544 m | 5.6 | 54 | 3.8 |
| DH | 0000n52 | 0000n53 | 0.00503 m | 5.7 | 53 | 3.9 |
| DH | 0000n53 | 0000n54 | 0.00536 m | 5.6 | 54 | 3.8 |
| DH | 034F0062 | 0000n50 | 0.00466 m | 5.6 | 55 | 3.8 |
| DH | 0000n50 | 0000n49 | 0.00510 m | 5.5 | 56 | 3.7 |
| DH | 0000n49 | 0000n48 | 0.00425 m | 5.6 | 54 | 3.8 |
| DH | 0000n48 | 0000n47 | 0.00466 m | 5.6 | 55 | 3.8 |
| DH | 0000n47 | 034F0216 | 0.00448 m | 5.5 | 56 | 3.6 |
| DH | 0000n15 | 034F0184 | 0.00465 m | 5.4 | 58 | 3.5 |
| DH | 034F0184 | 034F0048 | 0.00506 m | 5.4 | 60 | 3.4 |
| DH | 00000n8 | 034F0183 | 0.00562 m | 5.2 | 63 | 3.2 |
| DH | 034F0183 | 0000n15 | 0.00411 m | 5.5 | 56 | 3.6 |
| DH | 034F0480 | 0000n25 | 0.00725 m | 5.0 | 67 | 2.9 |
| DH | 0000n42 | 0000n44 | 0.00597 m | 5.5 | 57 | 3.6 |
| DH | 0000n44 | 0000n45 | 0.00642 m | 5.4 | 58 | 3.5 |
| DH | 0000n45 | 0000n46 | 0.00624 m | 5.5 | 57 | 3.6 |
| DH | 0000n46 | 0000n47 | 0.00451 m | 5.6 | 54 | 3.8 |
| DH | 0000n42 | 034F0345 | 0.00580 m | 5.3 | 61 | 3.3 |
| DH | 0000n12 | 0000n28 | 0.00372 m | 5.5 | 56 | 3.7 |
| DH | 0000n28 | 034F0040 | 0.00378 m | 5.5 | 56 | 3.6 |
| DH | 7519 | 034F0345 | 0.00562 m | 5.4 | 60 | 3.4 |
| DH | 034F0329 | 128301 | 0.00448 m | 5.4 | 58 | 3.5 |
| DH | 128301 | 7520 | 0.00462 m | 5.4 | 59 | 3.4 |
| DH | 7510 | 129401 | 0.00412 m | 5.1 | 65 | 3.0 |
| DH | 0000n36 | 138601 | 0.00330 m | 5.4 | 58 | 3.5 |
| DH | 7519 | 124101 | 0.00517 m | 5.4 | 58 | 3.5 |
| DH | 124101 | 123801 | 0.00520 m | 5.4 | 58 | 3.5 |
| DH | 7536 | 108450 | 0.00373 m | 5.5 | 56 | 3.7 |
| DH | 108450 | 201351 | 0.00449 m | 5.4 | 59 | 3.4 |
| DH | 106450 | 107251 | 0.00436 m | 5.3 | 60 | 3.4 |
| DH | 132101 | 131901 | 0.00433 m | 5.6 | 55 | 3.8 |
| DH | 131901 | 122350 | 0.00655 m | 5.2 | 62 | 3.2 |
| DH | 122350 | 215150 | 0.00439 m | 5.6 | 55 | 3.7 |
| DH | 215150 | 107851 | 0.00346 m | 5.6 | 54 | 3.9 |
| DH | 107851 | 7536 | 0.00421 m | 5.6 | 55 | 3.7 |
| DH | 132101 | 034F0298 | 0.00492 m | 5.4 | 58 | 3.5 |
| DH | 7536 | 108150 | 0.00414 m | 5.5 | 57 | 3.6 |
| DH | 108150 | 106750 | 0.00454 m | 5.4 | 59 | 3.5 |
| DH | 106750 | 106450 | 0.00410 m | 5.5 | 57 | 3.6 |
| DH | 0000n61 | 7811 | 0.00576 m | 5.5 | 56 | 3.7 |
| DH | 7811 | 0000n41 | 0.00507 m | 5.6 | 55 | 3.8 |
| DH | 0000n41 | 7810 | 0.00419 m | 5.7 | 53 | 3.9 |
| DH | 7810 | 0000n40 | 0.00519 m | 5.6 | 55 | 3.7 |
| DH | 0000n40 | 034F0325 | 0.00501 m | 5.6 | 55 | 3.8 |
| DH | 034F0325 | 0000n43 | 0.00369 m | 5.7 | 52 | 3.9 |
| DH | 0000n43 | 7809 | 0.00542 m | 5.6 | 55 | 3.7 |
| DH | 7809 | 0000n42 | 0.00362 m | 5.7 | 52 | 3.9 |
| DH | 034F0216 | 0000n17 | 0.00376 m | 5.6 | 55 | 3.8 |
| DH | 0000n17 | 7520 | 0.00618 m | 5.1 | 66 | 3.0 |
| DH | 0000n20 | 0000n21 | 0.00448 m | 5.3 | 62 | 3.3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DH | 0000n21 | 0000n22 | 0.00464 m | 5.2 | 63 | 3.2 |
| DH | 034F0050 | 0000n22 | 0.00312 m | 5.6 | 55 | 3.7 |
| DH | 0000n19 | 034F0061 | 0.00423 m | 5.4 | 59 | 3.5 |
| DH | 034F0061 | 0000n20 | 0.00418 m | 5.4 | 59 | 3.5 |
| DH | 0000n19 | 0000n18 | 0.00428 m | 5.5 | 56 | 3.6 |
| DH | 0000n18 | 034F0217 | 0.00406 m | 5.5 | 56 | 3.7 |
| DH | 034F0217 | 034F0216 | 0.00576 m | 5.2 | 63 | 3.2 |
| DH | 034F0329 | 034F0347 | 0.00553 m | 4.9 | 71 | 2.6 |
| DH | 034F0347 | 0000n19 | 0.00291 m | 5.6 | 54 | 3.8 |
| DH | 0000n23 | 0000n19 | 0.00489 m | 5.0 | 69 | 2.8 |
| DH | 034F0386 | 0000n23 | 0.00465 m | 5.1 | 66 | 2.9 |
| DH | 0000n23 | 0000n24 | 0.00460 m | 5.1 | 66 | 3.0 |
| DH | 034F0040 | 0000n30 | 0.00423 m | 5.5 | 57 | 3.6 |
| DH | 0000n30 | 00000n8 | 0.00481 m | 5.4 | 59 | 3.4 |
| DH | 034F0048 | 034F0312 | 0.00407 m | 5.6 | 55 | 3.7 |
| DH | 034F0312 | 034F0047 | 0.00498 m | 5.4 | 58 | 3.5 |
| DH | 034F0047 | 0000n31 | 0.00376 m | 5.6 | 54 | 3.8 |
| DH | 034F0298 | 034F0310 | 0.00502 m | 5.5 | 56 | 3.7 |
| DH | 034F0310 | 0000n34 | 0.00491 m | 5.6 | 55 | 3.7 |
| DH | 0000n34 | 0000n32 | 0.00515 m | 5.5 | 56 | 3.7 |
| DH | 0000n35 | 138601 | 0.00410 m | 5.2 | 62 | 3.2 |
| DH | 0000n37 | 0000n38 | 0.00376 m | 5.2 | 63 | 3.2 |
| DH | 0000n36 | 0000n37 | 0.00433 m | 4.9 | 71 | 2.6 |
| DH | 0000n35 | 0000n39 | 0.00517 m | 5.0 | 69 | 2.8 |
| DH | 0000n39 | 0000n38 | 0.00397 m | 5.3 | 60 | 3.4 |
| DH | 129401 | 0000n37 | 0.00408 m | 5.0 | 68 | 2.8 |
| DH | 3912 | 104601 | 0.00548 m | 5.3 | 60 | 3.4 |
| DH | 104601 | 106450 | 0.00466 m | 5.5 | 57 | 3.6 |
| DH | 7542 | 107150 | 0.00494 m | 5.5 | 56 | 3.7 |
| DH | 107150 | 034F0516 | 0.00565 m | 5.4 | 58 | 3.5 |
| DH | 034F0516 | 000A6031 | 0.00279 m | 5.7 | 52 | 4.0 |
| DH | 7542 | 0000n61 | 0.00388 m | 5.7 | 53 | 3.9 |
| DH | 0000n61 | 142601 | 0.00531 m | 5.5 | 57 | 3.6 |
| DH | 142601 | 267 | 0.00318 m | 5.7 | 52 | 3.9 |
| DH | 267 | 141701 | 0.00456 m | 5.6 | 55 | 3.7 |
| DH | 141701 | 142001 | 0.00402 m | 5.6 | 54 | 3.8 |
| DH | 142001 | 034F0345 | 0.00531 m | 5.5 | 57 | 3.6 |
| DH | 107251 | 7542 | 0.00590 m | 5.2 | 64 | 3.1 |
| DH | 104002 | 103751 | 0.00609 m | 5.5 | 57 | 3.6 |
| DH | 103751 | 5706 | 0.00258 m | 5.8 | 51 | 4.0 |
| DH | 5706 | 3912 | 0.00507 m | 5.6 | 55 | 3.7 |
| DH | 109550 | 104002 | 0.00375 m | 5.6 | 55 | 3.7 |
| DH | 34E0273 | 7514 | 0.00553 m | 5.4 | 58 | 3.5 |
| DH | 7514 | 7515 | 0.00607 m | 5.3 | 60 | 3.4 |
| DH | 7515 | 6105 | 0.00550 m | 5.4 | 58 | 3.5 |
| DH | 6105 | 104002 | 0.00355 m | 5.7 | 53 | 3.9 |
| DH | 34E0273 | 7576 | 0.00563 m | 5.4 | 58 | 3.5 |
| DH | 7576 | 119250 | 0.00484 m | 5.5 | 56 | 3.7 |
| DH | 119250 | 113250 | 0.00541 m | 5.4 | 58 | 3.5 |
| DH | 113250 | 109550 | 0.00468 m | 5.5 | 56 | 3.7 |
| DH | 201351 | 120550 | 0.00523 m | 5.3 | 62 | 3.2 |
| DH | 120550 | 107450 | 0.00361 m | 5.6 | 55 | 3.7 |
| DH | 107450 | 107250 | 0.00299 m | 5.7 | 53 | 3.9 |
| DH | 107250 | 107251 | 0.00209 m | 5.8 | 52 | 4.0 |
| DH | 215150 | 111050 | 0.00266 m | 5.7 | 52 | 4.0 |
| DH | 111050 | 112450 | 0.00614 m | 5.3 | 60 | 3.4 |
| DH | 112450 | 7528 | 0.00433 m | 5.6 | 55 | 3.8 |
| DH | 7528 | 110150 | 0.00463 m | 5.6 | 55 | 3.7 |
| DH | 110150 | 7014 | 0.00442 m | 5.6 | 55 | 3.8 |
| DH | 7014 | 109550 | 0.00503 m | 5.5 | 56 | 3.6 |
| DH | 123001 | 121601 | 0.00491 m | 5.5 | 57 | 3.6 |
| DH | 121601 | 201351 | 0.00439 m | 5.6 | 55 | 3.7 |
| DH | 118850 | 118450 | 0.00418 m | 5.6 | 54 | 3.8 |
| DH | 118450 | 7528 | 0.00600 m | 5.3 | 60 | 3.4 |
| DH | 118850 | 119450 | 0.00351 m | 5.7 | 52 | 4.0 |
| DH | 119450 | 119150 | 0.00397 m | 5.7 | 52 | 3.9 |
| DH | 119150 | 117750 | 0.00401 m | 5.7 | 52 | 3.9 |

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|---|---|---|---|---|---|---|
| DH | 117750 | 115350 | 0.00749 m | 5.4 | 59 | 3.4 |
| DH | 115350 | 34E0185 | 0.00633 m | 5.5 | 56 | 3.6 |
| DH | 34E0185 | 34E0273 | 0.00640 m | 5.5 | 56 | 3.6 |
| DH | 123801 | 123501 | 0.00385 m | 5.5 | 56 | 3.7 |
| DH | 123501 | 123001 | 0.00520 m | 5.2 | 62 | 3.2 |
| DH | 136001 | 126801 | 0.00543 m | 5.2 | 64 | 3.1 |
| DH | 126801 | 123801 | 0.00475 m | 5.3 | 60 | 3.4 |
| DH | 136001 | 00000n2 | 0.00584 m | 5.1 | 65 | 3.0 |
| DH | 00000n3 | 00000n5 | 0.00451 m | 5.3 | 60 | 3.3 |
| DH | 00000n5 | 00000n3 | 0.00451 m | 5.3 | 60 | 3.3 |
| DH | 00000n2 | 123001 | 0.00488 m | 5.3 | 60 | 3.4 |
| DH | 127501 | 127901 | 0.00390 m | 5.3 | 62 | 3.3 |
| DH | 127901 | 136801 | 0.00352 m | 5.4 | 59 | 3.4 |
| DH | 7520 | 00000n1 | 0.00575 m | 5.3 | 60 | 3.3 |
| DH | 00000n1 | 7519 | 0.00539 m | 5.4 | 59 | 3.5 |
| DH | 0000n20 | 034F0219 | 0.00530 m | 5.2 | 63 | 3.2 |
| DH | 034F0219 | 00000n5 | 0.00453 m | 5.4 | 59 | 3.4 |
| DH | 034F0329 | 128701 | 0.00318 m | 5.6 | 55 | 3.7 |
| DH | 128701 | 127501 | 0.00435 m | 5.3 | 61 | 3.3 |
| DH | 034F0298 | 134501 | 0.00479 m | 5.6 | 54 | 3.8 |
| DH | 134501 | 134850 | 0.00405 m | 5.7 | 53 | 3.9 |
| DH | 134850 | 135001 | 0.00458 m | 5.6 | 54 | 3.8 |
| DH | 135001 | 64 | 0.00548 m | 5.6 | 55 | 3.7 |
| DH | 64 | 135601 | 0.00520 m | 5.6 | 55 | 3.8 |
| DH | 135601 | 118850 | 0.00385 m | 5.7 | 52 | 3.9 |
| DH | 129401 | 127501 | 0.00481 m | 5.0 | 68 | 2.8 |
| DH | 7510 | 136001 | 0.00393 m | 5.6 | 55 | 3.7 |
| DH | 0000n38 | 136801 | 0.00399 m | 5.2 | 64 | 3.1 |
| DH | 7532 | 137901 | 0.00533 m | 5.0 | 68 | 2.9 |
| DH | 137901 | 0000n35 | 0.00388 m | 5.4 | 58 | 3.5 |
| DH | 7532 | 136801 | 0.00473 m | 5.0 | 68 | 2.8 |
| DH | 034F0386 | 0000n10 | 0.00455 m | 5.2 | 64 | 3.1 |
| DH | 0000n10 | 034F0329 | 0.00407 m | 5.3 | 60 | 3.4 |
| DH | 034F0385 | 7532 | 0.00277 m | 5.6 | 54 | 3.8 |
| DH | 00000n3 | 034F0480 | 0.00523 m | 5.3 | 61 | 3.3 |
| DH | 00000n3 | 034F0050 | 0.00517 m | 5.0 | 67 | 2.9 |
| DH | 0000n24 | 034F0387 | 0.00390 m | 5.5 | 56 | 3.6 |
| DH | 034F0387 | 00000n9 | 0.00542 m | 5.2 | 64 | 3.1 |
| DH | 00000n9 | 034F0385 | 0.00483 m | 5.3 | 61 | 3.3 |
| DH | 0000n31 | 034F0476 | 0.00387 m | 5.6 | 55 | 3.7 |
| DH | 034F0476 | 7532 | 0.00535 m | 5.3 | 61 | 3.3 |
| DH | 034F0048 | 0000n26 | 0.00255 m | 5.7 | 53 | 3.9 |
| DH | 0000n26 | 0000n13 | 0.00391 m | 5.5 | 56 | 3.6 |
| DH | 0000n13 | 0000n12 | 0.00385 m | 5.5 | 56 | 3.7 |
| DH | 0000n25 | 00000n7 | 0.00417 m | 5.6 | 54 | 3.8 |
| DH | 00000n7 | 0000n14 | 0.00517 m | 5.5 | 57 | 3.6 |
| DH | 0000n14 | 034F0400 | 0.00521 m | 5.5 | 57 | 3.6 |
| DH | 034F0400 | 0000n54 | 0.00373 m | 5.6 | 54 | 3.9 |
| DH | 0000n12 | 0000n27 | 0.00417 m | 5.5 | 57 | 3.6 |
| DH | 0000n27 | 034F0478 | 0.00365 m | 5.6 | 55 | 3.7 |
| DH | 034F0478 | 034F0050 | 0.00448 m | 5.4 | 58 | 3.5 |
| DH | 034F0040 | 0000n29 | 0.00397 m | 5.6 | 55 | 3.8 |
| DH | 0000n29 | 034F0393 | 0.00475 m | 5.5 | 57 | 3.6 |
| DH | 034F0393 | 0000n11 | 0.00486 m | 5.5 | 57 | 3.6 |
| DH | 0000n11 | 034F0480 | 0.00493 m | 5.4 | 58 | 3.5 |
| DH | 000A3522 | 034F0508 | 0.00608 m | 5.4 | 59 | 3.5 |
| DH | 0000n25 | 000A3522 | 0.00540 m | 5.5 | 57 | 3.6 |
| DH | 034F0386 | 034F0385 | 0.00502 m | 5.0 | 69 | 2.8 |
| DH | 00000n4 | 00000n5 | 0.00436 m | 5.6 | 55 | 3.7 |
| DH | 034F0174 | 00000n4 | 0.00497 m | 5.5 | 57 | 3.6 |
| DH | 034F0249 | 034F0174 | 0.00300 m | 5.7 | 52 | 3.9 |
| DH | 034F0062 | 034F0249 | 0.00414 m | 5.6 | 54 | 3.8 |
| DH | 3239 | 000A6031 | 0.00526 m | 5.5 | 57 | 3.6 |
| DH | 3912 | 3239 | 0.00454 m | 5.6 | 55 | 3.7 |
| DH | 130001 | 7510 | 0.00304 m | 5.5 | 57 | 3.6 |
| DH | 0000n36 | 130001 | 0.00351 m | 5.3 | 60 | 3.4 |
| DH | 138701 | 138601 | 0.00330 m | 5.7 | 53 | 3.9 |

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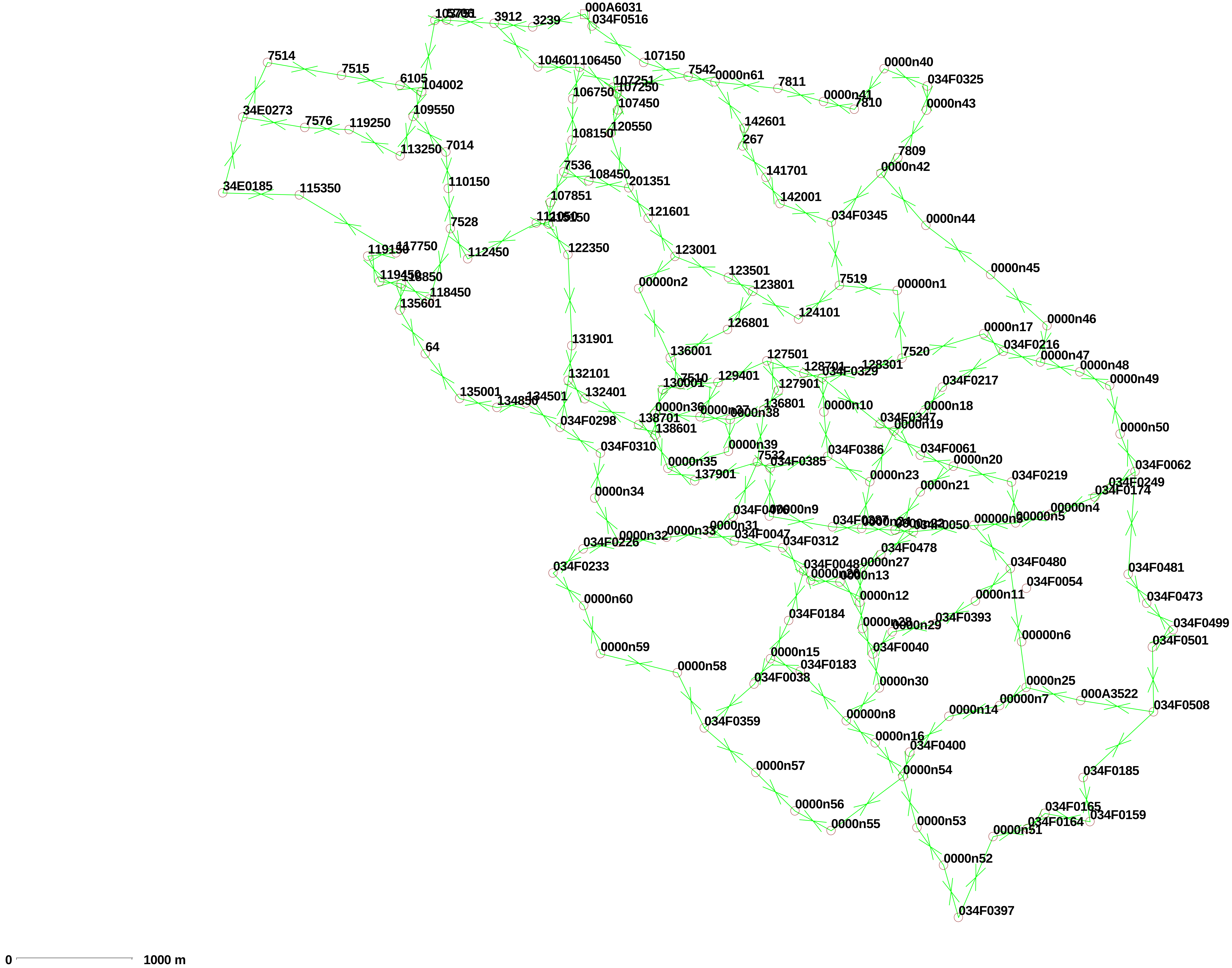
|---|---|---|---|---|---|---|
| DH | 132401 | 138701 | 0.00542 m | 5.3 | 60 | 3.4 |
| DH | 132101 | 132401 | 0.00368 m | 5.6 | 54 | 3.8 |
| DH | 034F0481 | 034F0062 | 0.00716 m | 5.4 | 59 | 3.4 |
| DH | 034F0473 | 034F0481 | 0.00436 m | 5.7 | 53 | 3.9 |
| DH | 034F0499 | 034F0473 | 0.00455 m | 5.7 | 53 | 3.9 |
| DH | 034F0501 | 034F0499 | 0.00390 m | 5.7 | 52 | 3.9 |
| DH | 034F0508 | 034F0501 | 0.00584 m | 5.5 | 56 | 3.7 |
| DH | 0000n33 | 0000n32 | 0.00496 m | 5.4 | 57 | 3.6 |
| DH | 0000n31 | 0000n33 | 0.00474 m | 5.5 | 57 | 3.6 |
| DH | 0000n58 | 034F0359 | 0.00570 m | 5.5 | 56 | 3.7 |
| DH | 0000n59 | 0000n58 | 0.00639 m | 5.5 | 57 | 3.6 |
| DH | 0000n60 | 0000n59 | 0.00523 m | 5.6 | 55 | 3.8 |
| DH | 034F0233 | 0000n60 | 0.00493 m | 5.6 | 54 | 3.8 |
| DH | 034F0226 | 034F0233 | 0.00461 m | 5.6 | 53 | 3.9 |
| DH | 0000n32 | 034F0226 | 0.00448 m | 5.7 | 53 | 3.9 |
| DH | 034F0038 | 034F0359 | 0.00570 m | 5.3 | 60 | 3.4 |
| DH | 0000n15 | 034F0038 | 0.00403 m | 5.6 | 54 | 3.8 |
| DH | 0000n55 | 0000n54 | 0.00662 m | 5.3 | 60 | 3.4 |
| DH | 0000n56 | 0000n55 | 0.00470 m | 5.6 | 55 | 3.8 |
| DH | 0000n57 | 0000n56 | 0.00536 m | 5.5 | 56 | 3.6 |
| DH | 034F0359 | 0000n57 | 0.00589 m | 5.4 | 58 | 3.5 |
| DH | 0000n16 | 0000n54 | 0.00471 m | 5.4 | 58 | 3.5 |
| DH | 00000n8 | 0000n16 | 0.00435 m | 5.5 | 56 | 3.6 |
| DH | 034F0185 | 034F0508 | 0.00704 m | 5.5 | 57 | 3.6 |
| DH | 034F0159 | 034F0185 | 0.00495 m | 5.7 | 53 | 3.9 |
| DH | 034F0165 | 034F0159 | 0.00502 m | 5.7 | 53 | 3.9 |
| DH | 034F0164 | 034F0165 | 0.00361 m | 5.7 | 52 | 4.0 |
| DH | 0000n51 | 034F0164 | 0.00446 m | 5.7 | 53 | 3.9 |
| DH | 034F0397 | 0000n51 | 0.00676 m | 5.5 | 57 | 3.6 |
| DH | 0000n52 | 034F0397 | 0.00544 m | 5.6 | 54 | 3.8 |
| DH | 0000n53 | 0000n52 | 0.00503 m | 5.7 | 53 | 3.9 |
| DH | 0000n54 | 0000n53 | 0.00536 m | 5.6 | 54 | 3.8 |
| DH | 0000n50 | 034F0062 | 0.00466 m | 5.6 | 55 | 3.8 |
| DH | 0000n49 | 0000n50 | 0.00510 m | 5.5 | 56 | 3.7 |
| DH | 0000n48 | 0000n49 | 0.00425 m | 5.6 | 54 | 3.8 |
| DH | 0000n47 | 0000n48 | 0.00466 m | 5.6 | 55 | 3.8 |
| DH | 034F0216 | 0000n47 | 0.00448 m | 5.5 | 56 | 3.6 |
| DH | 034F0184 | 0000n15 | 0.00465 m | 5.4 | 58 | 3.5 |
| DH | 034F0048 | 034F0184 | 0.00506 m | 5.4 | 60 | 3.4 |
| DH | 034F0183 | 00000n8 | 0.00562 m | 5.2 | 63 | 3.2 |
| DH | 0000n15 | 034F0183 | 0.00411 m | 5.5 | 56 | 3.6 |
| DH | 0000n25 | 034F0480 | 0.00725 m | 5.0 | 67 | 2.9 |
| DH | 0000n44 | 0000n42 | 0.00597 m | 5.5 | 57 | 3.6 |
| DH | 0000n45 | 0000n44 | 0.00642 m | 5.4 | 58 | 3.5 |
| DH | 0000n46 | 0000n45 | 0.00624 m | 5.5 | 57 | 3.6 |
| DH | 0000n47 | 0000n46 | 0.00451 m | 5.6 | 54 | 3.8 |
| DH | 034F0345 | 0000n42 | 0.00580 m | 5.3 | 61 | 3.3 |
| DH | 0000n28 | 0000n12 | 0.00372 m | 5.5 | 56 | 3.7 |
| DH | 034F0040 | 0000n28 | 0.00378 m | 5.5 | 56 | 3.6 |
| DH | 034F0345 | 7519 | 0.00562 m | 5.4 | 60 | 3.4 |
| DH | 128301 | 034F0329 | 0.00448 m | 5.4 | 58 | 3.5 |
| DH | 7520 | 128301 | 0.00462 m | 5.4 | 59 | 3.4 |
| DH | 129401 | 7510 | 0.00412 m | 5.1 | 65 | 3.0 |
| DH | 138601 | 0000n36 | 0.00330 m | 5.4 | 58 | 3.5 |
| DH | 124101 | 7519 | 0.00517 m | 5.4 | 58 | 3.5 |
| DH | 123801 | 124101 | 0.00520 m | 5.4 | 58 | 3.5 |
| DH | 108450 | 7536 | 0.00373 m | 5.5 | 56 | 3.7 |
| DH | 201351 | 108450 | 0.00449 m | 5.4 | 59 | 3.4 |
| DH | 107251 | 106450 | 0.00436 m | 5.3 | 60 | 3.4 |
| DH | 131901 | 132101 | 0.00433 m | 5.6 | 55 | 3.8 |
| DH | 122350 | 131901 | 0.00655 m | 5.2 | 62 | 3.2 |
| DH | 215150 | 122350 | 0.00439 m | 5.6 | 55 | 3.7 |
| DH | 107851 | 215150 | 0.00346 m | 5.6 | 54 | 3.9 |
| DH | 7536 | 107851 | 0.00421 m | 5.6 | 55 | 3.7 |
| DH | 034F0298 | 132101 | 0.00492 m | 5.4 | 58 | 3.5 |
| DH | 108150 | 7536 | 0.00414 m | 5.5 | 57 | 3.6 |
| DH | 106750 | 108150 | 0.00454 m | 5.4 | 59 | 3.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| DH | 106450 | 106750 | 0.00410 m | 5.5 | 57 | 3.6 |
| DH | 7811 | 0000n61 | 0.00576 m | 5.5 | 56 | 3.7 |
| DH | 0000n41 | 7811 | 0.00507 m | 5.6 | 55 | 3.8 |
| DH | 7810 | 0000n41 | 0.00419 m | 5.7 | 53 | 3.9 |
| DH | 0000n40 | 7810 | 0.00519 m | 5.6 | 55 | 3.7 |
| DH | 034F0325 | 0000n40 | 0.00501 m | 5.6 | 55 | 3.8 |
| DH | 0000n43 | 034F0325 | 0.00369 m | 5.7 | 52 | 3.9 |
| DH | 7809 | 0000n43 | 0.00542 m | 5.6 | 55 | 3.7 |
| DH | 0000n42 | 7809 | 0.00362 m | 5.7 | 52 | 3.9 |
| DH | 0000n17 | 034F0216 | 0.00376 m | 5.6 | 55 | 3.8 |
| DH | 7520 | 0000n17 | 0.00618 m | 5.1 | 66 | 3.0 |
| DH | 0000n21 | 0000n20 | 0.00448 m | 5.3 | 62 | 3.3 |
| DH | 0000n22 | 0000n21 | 0.00464 m | 5.2 | 63 | 3.2 |
| DH | 0000n22 | 034F0050 | 0.00312 m | 5.6 | 55 | 3.7 |
| DH | 034F0061 | 0000n19 | 0.00423 m | 5.4 | 59 | 3.5 |
| DH | 0000n20 | 034F0061 | 0.00418 m | 5.4 | 59 | 3.5 |
| DH | 0000n18 | 0000n19 | 0.00428 m | 5.5 | 56 | 3.6 |
| DH | 034F0217 | 0000n18 | 0.00406 m | 5.5 | 56 | 3.7 |
| DH | 034F0216 | 034F0217 | 0.00576 m | 5.2 | 63 | 3.2 |
| DH | 034F0347 | 034F0329 | 0.00553 m | 4.9 | 71 | 2.6 |
| DH | 0000n19 | 034F0347 | 0.00291 m | 5.6 | 54 | 3.8 |
| DH | 0000n19 | 0000n23 | 0.00489 m | 5.0 | 69 | 2.8 |
| DH | 0000n23 | 034F0386 | 0.00465 m | 5.1 | 66 | 2.9 |
| DH | 0000n22 | 0000n24 | 0.00406 m | 5.4 | 59 | 3.4 |
| DH | 0000n24 | 0000n22 | 0.00406 m | 5.4 | 59 | 3.4 |
| DH | 0000n24 | 0000n23 | 0.00460 m | 5.1 | 66 | 3.0 |
| DH | 0000n30 | 034F0040 | 0.00423 m | 5.5 | 57 | 3.6 |
| DH | 00000n8 | 0000n30 | 0.00481 m | 5.4 | 59 | 3.4 |
| DH | 034F0312 | 034F0048 | 0.00407 m | 5.6 | 55 | 3.7 |
| DH | 034F0047 | 034F0312 | 0.00498 m | 5.4 | 58 | 3.5 |
| DH | 0000n31 | 034F0047 | 0.00376 m | 5.6 | 54 | 3.8 |
| DH | 034F0310 | 034F0298 | 0.00502 m | 5.5 | 56 | 3.7 |
| DH | 0000n34 | 034F0310 | 0.00491 m | 5.6 | 55 | 3.7 |
| DH | 0000n32 | 0000n34 | 0.00515 m | 5.5 | 56 | 3.7 |
| DH | 138601 | 0000n35 | 0.00410 m | 5.2 | 62 | 3.2 |
| DH | 0000n38 | 0000n37 | 0.00376 m | 5.2 | 63 | 3.2 |
| DH | 0000n37 | 0000n36 | 0.00433 m | 4.9 | 71 | 2.6 |
| DH | 0000n39 | 0000n35 | 0.00517 m | 5.0 | 69 | 2.8 |
| DH | 0000n38 | 0000n39 | 0.00397 m | 5.3 | 60 | 3.4 |
| DH | 0000n37 | 129401 | 0.00408 m | 5.0 | 68 | 2.8 |
| DH | 104601 | 3912 | 0.00548 m | 5.3 | 60 | 3.4 |
| DH | 106450 | 104601 | 0.00466 m | 5.5 | 57 | 3.6 |
| DH | 107150 | 7542 | 0.00494 m | 5.5 | 56 | 3.7 |
| DH | 034F0516 | 107150 | 0.00565 m | 5.4 | 58 | 3.5 |
| DH | 000A6031 | 034F0516 | 0.00279 m | 5.7 | 52 | 4.0 |
| DH | 0000n61 | 7542 | 0.00388 m | 5.7 | 53 | 3.9 |
| DH | 142601 | 0000n61 | 0.00531 m | 5.5 | 57 | 3.6 |
| DH | 267 | 142601 | 0.00318 m | 5.7 | 52 | 3.9 |
| DH | 141701 | 267 | 0.00456 m | 5.6 | 55 | 3.7 |
| DH | 142001 | 141701 | 0.00402 m | 5.6 | 54 | 3.8 |
| DH | 034F0345 | 142001 | 0.00531 m | 5.5 | 57 | 3.6 |
| DH | 7542 | 107251 | 0.00590 m | 5.2 | 64 | 3.1 |
| DH | 103751 | 104002 | 0.00609 m | 5.5 | 57 | 3.6 |
| DH | 5706 | 103751 | 0.00258 m | 5.8 | 51 | 4.0 |
| DH | 3912 | 5706 | 0.00507 m | 5.6 | 55 | 3.7 |
| DH | 104002 | 109550 | 0.00375 m | 5.6 | 55 | 3.7 |
| DH | 7514 | 34E0273 | 0.00553 m | 5.4 | 58 | 3.5 |
| DH | 7515 | 7514 | 0.00607 m | 5.3 | 60 | 3.4 |
| DH | 6105 | 7515 | 0.00550 m | 5.4 | 58 | 3.5 |
| DH | 104002 | 6105 | 0.00355 m | 5.7 | 53 | 3.9 |
| DH | 7576 | 34E0273 | 0.00563 m | 5.4 | 58 | 3.5 |
| DH | 119250 | 7576 | 0.00484 m | 5.5 | 56 | 3.7 |
| DH | 113250 | 119250 | 0.00541 m | 5.4 | 58 | 3.5 |
| DH | 109550 | 113250 | 0.00468 m | 5.5 | 56 | 3.7 |
| DH | 120550 | 201351 | 0.00523 m | 5.3 | 62 | 3.2 |
| DH | 107450 | 120550 | 0.00361 m | 5.6 | 55 | 3.7 |
| DH | 107250 | 107450 | 0.00299 m | 5.7 | 53 | 3.9 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DH | 107251 | 107250 | 0.00209 | m | 5.8 | 52 | 4.0 |
| DH | 111050 | 215150 | 0.00266 | m | 5.7 | 52 | 4.0 |
| DH | 112450 | 111050 | 0.00614 | m | 5.3 | 60 | 3.4 |
| DH | 7528 | 112450 | 0.00433 | m | 5.6 | 55 | 3.8 |
| DH | 110150 | 7528 | 0.00463 | m | 5.6 | 55 | 3.7 |
| DH | 7014 | 110150 | 0.00442 | m | 5.6 | 55 | 3.8 |
| DH | 109550 | 7014 | 0.00503 | m | 5.5 | 56 | 3.6 |
| DH | 121601 | 123001 | 0.00491 | m | 5.5 | 57 | 3.6 |
| DH | 201351 | 121601 | 0.00439 | m | 5.6 | 55 | 3.7 |
| DH | 118450 | 118850 | 0.00418 | m | 5.6 | 54 | 3.8 |
| DH | 7528 | 118450 | 0.00600 | m | 5.3 | 60 | 3.4 |
| DH | 119450 | 118850 | 0.00351 | m | 5.7 | 52 | 4.0 |
| DH | 119150 | 119450 | 0.00397 | m | 5.7 | 52 | 3.9 |
| DH | 117750 | 119150 | 0.00401 | m | 5.7 | 52 | 3.9 |
| DH | 115350 | 117750 | 0.00749 | m | 5.4 | 59 | 3.4 |
| DH | 34E0185 | 115350 | 0.00633 | m | 5.5 | 56 | 3.6 |
| DH | 34E0273 | 34E0185 | 0.00640 | m | 5.5 | 56 | 3.6 |
| DH | 123501 | 123801 | 0.00385 | m | 5.5 | 56 | 3.7 |
| DH | 123001 | 123501 | 0.00520 | m | 5.2 | 62 | 3.2 |
| DH | 126801 | 136001 | 0.00543 | m | 5.2 | 64 | 3.1 |
| DH | 123801 | 126801 | 0.00475 | m | 5.3 | 60 | 3.4 |
| DH | 00000n2 | 136001 | 0.00584 | m | 5.1 | 65 | 3.0 |
| DH | 123001 | 00000n2 | 0.00488 | m | 5.3 | 60 | 3.4 |
| DH | 127901 | 127501 | 0.00390 | m | 5.3 | 62 | 3.3 |
| DH | 136801 | 127901 | 0.00352 | m | 5.4 | 59 | 3.4 |
| DH | 00000n1 | 7520 | 0.00575 | m | 5.3 | 60 | 3.3 |
| DH | 7519 | 00000n1 | 0.00539 | m | 5.4 | 59 | 3.5 |
| DH | 034F0219 | 0000n20 | 0.00530 | m | 5.2 | 63 | 3.2 |
| DH | 00000n5 | 034F0219 | 0.00453 | m | 5.4 | 59 | 3.4 |
| DH | 128701 | 034F0329 | 0.00318 | m | 5.6 | 55 | 3.7 |
| DH | 127501 | 128701 | 0.00435 | m | 5.3 | 61 | 3.3 |
| DH | 134501 | 034F0298 | 0.00479 | m | 5.6 | 54 | 3.8 |
| DH | 134850 | 134501 | 0.00405 | m | 5.7 | 53 | 3.9 |
| DH | 135001 | 134850 | 0.00458 | m | 5.6 | 54 | 3.8 |
| DH | 64 | 135001 | 0.00548 | m | 5.6 | 55 | 3.7 |
| DH | 135601 | 64 | 0.00520 | m | 5.6 | 55 | 3.8 |
| DH | 118850 | 135601 | 0.00385 | m | 5.7 | 52 | 3.9 |
| DH | 127501 | 129401 | 0.00481 | m | 5.0 | 68 | 2.8 |
| DH | 136001 | 7510 | 0.00393 | m | 5.6 | 55 | 3.7 |
| DH | 136801 | 0000n38 | 0.00399 | m | 5.2 | 64 | 3.1 |
| DH | 137901 | 7532 | 0.00533 | m | 5.0 | 68 | 2.9 |
| DH | 0000n35 | 137901 | 0.00388 | m | 5.4 | 58 | 3.5 |
| DH | 136801 | 7532 | 0.00473 | m | 5.0 | 68 | 2.8 |
| DH | 0000n10 | 034F0386 | 0.00455 | m | 5.2 | 64 | 3.1 |
| DH | 034F0329 | 0000n10 | 0.00407 | m | 5.3 | 60 | 3.4 |
| DH | 7532 | 034F0385 | 0.00277 | m | 5.6 | 54 | 3.8 |
| DH | 034F0480 | 00000n3 | 0.00523 | m | 5.3 | 61 | 3.3 |
| DH | 034F0050 | 00000n3 | 0.00517 | m | 5.0 | 67 | 2.9 |
| DH | 034F0387 | 0000n24 | 0.00390 | m | 5.5 | 56 | 3.6 |
| DH | 00000n9 | 034F0387 | 0.00542 | m | 5.2 | 64 | 3.1 |
| DH | 034F0385 | 00000n9 | 0.00483 | m | 5.3 | 61 | 3.3 |
| DH | 034F0476 | 0000n31 | 0.00387 | m | 5.6 | 55 | 3.7 |
| DH | 7532 | 034F0476 | 0.00535 | m | 5.3 | 61 | 3.3 |
| DH | 0000n26 | 034F0048 | 0.00255 | m | 5.7 | 53 | 3.9 |
| DH | 0000n13 | 0000n26 | 0.00391 | m | 5.5 | 56 | 3.6 |
| DH | 0000n12 | 0000n13 | 0.00385 | m | 5.5 | 56 | 3.7 |
| DH | 00000n7 | 0000n25 | 0.00417 | m | 5.6 | 54 | 3.8 |
| DH | 0000n14 | 00000n7 | 0.00517 | m | 5.5 | 57 | 3.6 |
| DH | 034F0400 | 0000n14 | 0.00521 | m | 5.5 | 57 | 3.6 |
| DH | 0000n54 | 034F0400 | 0.00373 | m | 5.6 | 54 | 3.9 |
| DH | 0000n27 | 0000n12 | 0.00417 | m | 5.5 | 57 | 3.6 |
| DH | 034F0478 | 0000n27 | 0.00365 | m | 5.6 | 55 | 3.7 |
| DH | 034F0050 | 034F0478 | 0.00448 | m | 5.4 | 58 | 3.5 |
| DH | 0000n29 | 034F0040 | 0.00397 | m | 5.6 | 55 | 3.8 |
| DH | 034F0393 | 0000n29 | 0.00475 | m | 5.5 | 57 | 3.6 |
| DH | 0000n11 | 034F0393 | 0.00486 | m | 5.5 | 57 | 3.6 |
| DH | 034F0480 | 0000n11 | 0.00493 | m | 5.4 | 58 | 3.5 |

**AKZO Hengelo 2012-verk ber**



# Bijlage 2: Geodetische stabiliteit RD-NAP Peilmerken

| RD NAP peilmerk | Stabiliteit (mm/jaar) |
|---|---|
| 034F0003 | 1,14 |
| 034F0004 | 1,17 |
| 034F0006 | 0,19 |
| 034F0009 | 1,18 |
| 034F0010 | 0,25 |
| 034F0012 | 0,19 |
| 034F0013 | 1,36 |
| 034F0014 | 1,53 |
| 034F0018 | 1,22 |
| 034F0021 | 0,13 |
| 034F0022 | 1,27 |
| 034F0026 | 1,27 |
| 034F0030 | 0,16 |
| 034F0038 | 1,55 |
| 034F0040 | 0,67 |
| 034F0041 | 0,93 |
| 034F0046 | 0,84 |
| 034F0047 | 0,82 |
| 034F0048 | 0,57 |
| 034F0049 | 0,53 |
| 034F0050 | 0,84 |
| 034F0054 | 0,92 |
| 034F0061 | 0,79 |
| 034F0062 | 1,90 |
| 034F0063 | 2,28 |
| 034F0064 | 1,04 |
| 034F0066 | 0,21 |
| 034F0071 | 3,00 |
| 034F0072 | 1,75 |
| 034F0073 | 0,86 |
| 034F0088 | 0,81 |
| 034F0095 | 0,10 |
| 034F0096 | 0,47 |
| 034F0098 | 0,91 |
| 034F0099 | 0,77 |
| 034F0101 | 0,86 |
| 034F0103 | 1,01 |
| 034F0108 | 0,98 |
| 034F0111 | 0,46 |
| 034F0113 | 0,58 |
| 034F0114 | 0,74 |
| 034F0118 | 1,80 |
| 034F0119 | 0,78 |
| 034F0120 | 1,63 |
| 034F0121 | 0,73 |
| 034F0122 | 0,71 |
| 034F0124 | 4,34 |
| 034F0127 | 1,46 |
| 034F0132 | 0,73 |
| 034F0134 | 2,52 |
| 034F0135 | 4,90 |
| 034F0137 | 1,11 |
| 034F0140 | 0,79 |
| 034F0141 | 11,79 |
| 034F0144 | 3,50 |
| 034F0147 | 0,69 |
| 034F0148 | 1,15 |
| 034F0149 | 1,03 |
| 034F0150 | 0,83 |
| 034F0151 | 1,87 |
| 034F0153 | 0,64 |
| 034F0155 | 0,59 |
| 034F0156 | 0,50 |

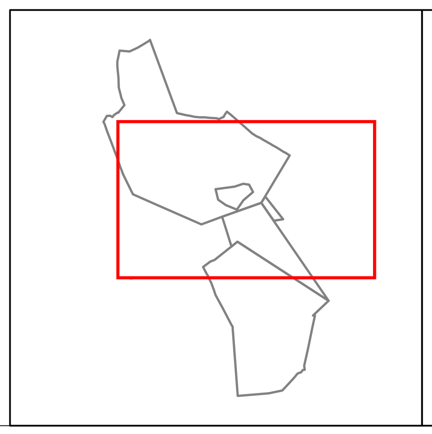
| RD NAP peilmerk | Stabiliteit (mm/jaar) |
|---|---|
| 034F0157 | 0,26 |
| 034F0158 | 0,29 |
| 034F0159 | 0,27 |
| 034F0160 | 1,25 |
| 034F0161 | 0,94 |
| 034F0162 | 2,33 |
| 034F0164 | 1,21 |
| 034F0165 | 1,02 |
| 034F0169 | 0,78 |
| 034F0173 | 2,55 |
| 034F0174 | 1,58 |
| 034F0177 | 1,15 |
| 034F0178 | 0,61 |
| 034F0179 | 0,39 |
| 034F0181 | 2,61 |
| 034F0183 | 1,01 |
| 034F0184 | 0,54 |
| 034F0185 | 0,45 |
| 034F0186 | 3,95 |
| 034F0187 | 2,26 |
| 034F0188 | 1,24 |
| 034F0189 | 0,53 |
| 034F0192 | 2,63 |
| 034F0193 | 1,33 |
| 034F0216 | 1,65 |
| 034F0217 | 1,31 |
| 034F0218 | 1,66 |
| 034F0219 | 1,60 |
| 034F0220 | 2,23 |
| 034F0221 | 0,72 |
| 034F0222 | 0,53 |
| 034F0223 | 0,63 |
| 034F0224 | 0,82 |
| 034F0225 | 1,16 |
| 034F0226 | 1,25 |
| 034F0227 | 1,20 |
| 034F0228 | 0,67 |
| 034F0230 | 1,09 |
| 034F0231 | 0,89 |
| 034F0233 | 0,76 |
| 034F0236 | 1,11 |
| 034F0237 | 2,47 |
| 034F0239 | 2,93 |
| 034F0242 | 8,40 |
| 034F0244 | 2,88 |
| 034F0248 | 1,56 |
| 034F0249 | 2,25 |
| 034F0251 | 0,92 |
| 034F0252 | 0,60 |
| 034F0253 | 0,48 |
| 034F0255 | 0,66 |
| 034F0256 | 1,96 |
| 034F0257 | 2,36 |
| 034F0259 | 1,25 |
| 034F0260 | 1,05 |
| 034F0263 | 1,35 |
| 034F0264 | 0,36 |
| 034F0265 | 0,76 |
| 034F0266 | 0,42 |
| 034F0267 | 0,73 |
| 034F0270 | 0,27 |
| 034F0271 | 0,21 |
| 034F0272 | 0,42 |

| RD NAP peilmerk | Stabiliteit (mm/jaar) |
|---|---|
| 034F0274 | 0,56 |
| 034F0275 | 0,47 |
| 034F0276 | 0,25 |
| 034F0277 | 0,35 |
| 034F0278 | 0,35 |
| 034F0279 | 1,16 |
| 034F0285 | 1,23 |
| 034F0286 | 0,25 |
| 034F0289 | 0,34 |
| 034F0290 | 0,54 |
| 034F0291 | 0,75 |
| 034F0292 | 1,28 |
| 034F0294 | 0,24 |
| 034F0296 | 1,40 |
| 034F0298 | 0,87 |
| 034F0301 | 0,82 |
| 034F0302 | 1,05 |
| 034F0304 | 1,72 |
| 034F0305 | 1,05 |
| 034F0306 | 1,58 |
| 034F0307 | 0,75 |
| 034F0310 | 0,38 |
| 034F0311 | 0,22 |
| 034F0312 | 0,30 |
| 034F0313 | 0,83 |
| 034F0316 | 1,41 |
| 034F0317 | 0,13 |
| 034F0320 | 0,45 |
| 034F0321 | 1,68 |
| 034F0322 | 0,95 |
| 034F0324 | 0,45 |
| 034F0325 | 0,45 |
| 034F0326 | 0,37 |
| 034F0327 | 0,71 |
| 034F0332 | 1,34 |
| 034F0333 | 1,07 |
| 034F0334 | 0,77 |
| 034F0336 | 0,59 |
| 034F0337 | 0,66 |
| 034F0339 | 0,98 |
| 034F0340 | 0,55 |
| 034F0343 | 1,35 |
| 034F0345 | 0,70 |
| 034F0348 | 1,14 |
| 034F0349 | 1,31 |
| 034F0350 | 1,06 |
| 034F0351 | 8,41 |
| 034F0352 | 0,03 |
| 034F0353 | 0,01 |
| 034F0355 | 0,40 |
| 034F0356 | 1,03 |
| 034F0358 | 1,02 |
| 034F0359 | 1,16 |
| 034F0365 | 2,14 |
| 034F0370 | 0,47 |
| 034F0372 | 1,16 |
| 034F0373 | 1,08 |
| 034F0374 | 1,16 |
| 034F0375 | 0,43 |
| 034F0378 | 0,75 |
| 034F0381 | 0,12 |
| 034F0387 | 1,05 |
| 034F0388 | 4,07 |

| RD NAP peilmerk | Stabiliteit (mm/jaar) |
|---|---|
| 034F0393 | 0,07 |
| 034F0394 | 0,44 |
| 034F0395 | 0,06 |
| 034F0397 | 0,57 |
| 034F0398 | 0,61 |
| 034F0400 | 1,22 |
| 034F0413 | 1,05 |
| 034F0417 | 0,44 |
| 034F0418 | 0,73 |
| 034F0419 | 0,61 |
| 034F0420 | 1,13 |
| 034F0421 | 1,60 |
| 034F0423 | 3,10 |
| 034F0424 | 0,69 |
| 034F0425 | 0,13 |
| 034F0426 | 0,41 |
| 034F0428 | 2,14 |
| 034F0429 | 0,96 |
| 034F0431 | 1,19 |
| 034F0432 | 1,19 |
| 034F0433 | 1,36 |
| 034F0434 | 1,25 |
| 034F0435 | 2,60 |
| 034F0436 | 0,90 |
| 034F0437 | 0,32 |
| 034F0438 | 1,70 |
| 034F0439 | 1,65 |
| 034F0440 | 1,12 |
| 034F0442 | 0,25 |
| 034F0444 | 0,28 |
| 034F0447 | 0,14 |
| 034F0448 | 0,58 |
| 034F0449 | 0,45 |
| 034F0450 | 2,11 |
| 034F0453 | 2,55 |
| 034F0455 | 3,75 |
| 034F0456 | 1,85 |
| 034F0457 | 2,64 |
| 034F0458 | 2,90 |
| 034F0459 | 2,99 |
| 034F0460 | 2,74 |
| 034F0461 | 2,80 |
| 034F0462 | 1,80 |
| 034F0463 | 2,34 |
| 034F0465 | 1,05 |
| 034F0466 | 0,76 |
| 034F0471 | 2,26 |
| 034F0472 | 1,34 |
| 034F0473 | 1,35 |
| 034F0475 | 0,57 |
| 034F0485 | 3,12 |
| | |

Peilmerken die slechts 1 x zijn gemeten zijn niet opgenomen in deze lijst

# Bijlage 3: P55.91.47/970 Meetplan 2012

**Legenda**

**Meetpunten**

- Bestaande peilmerken
- Nieuwe peilmerken
- (Potentieel) referentie peilmerk
- Kringnummer
- Trajecten
- Buitentrajecten
- Boring gesloten
- Boring open
- Te openen cavernes (+nr.)
- Invloedsfeer
- Vergunningsgebieden
- Gemeentegrens

0 125 250 500 m

| NR | DATUM | WIJZIGING | GET. |
|---|---|---|---|
| 0 | 24-10-2011 | - | JS |

OPDRACHTGEVER
Akzo Nobel Industrial Chemicals B.V.

PROJECTOMSCHRIJVING
Deformatienet Twenthe Rijn

KAARTTITEL
Meetplan 2012

STATUS
Definitief

GIS SPECIALIST
J. Schoonhoven

SCHAAL
1:12,000

PROJECTLEIDER
P. Meinders

FORMAAT
A0

BLAD IN BLADEN
1 IN 1

KAARTNUMMER
P55.91.47/970

WIJZ.NR
0


ORANJEWOUD HEERENVEEN
TOLHUISWEG 57
8443 DV HEERENVEEN

POSTBUS 24
8440 AA
TEL. 0513-634567

HEERENVEEN
ALMERE
OOSTERHOUT
CAPELLE A/D IJSSEL
DEVENTER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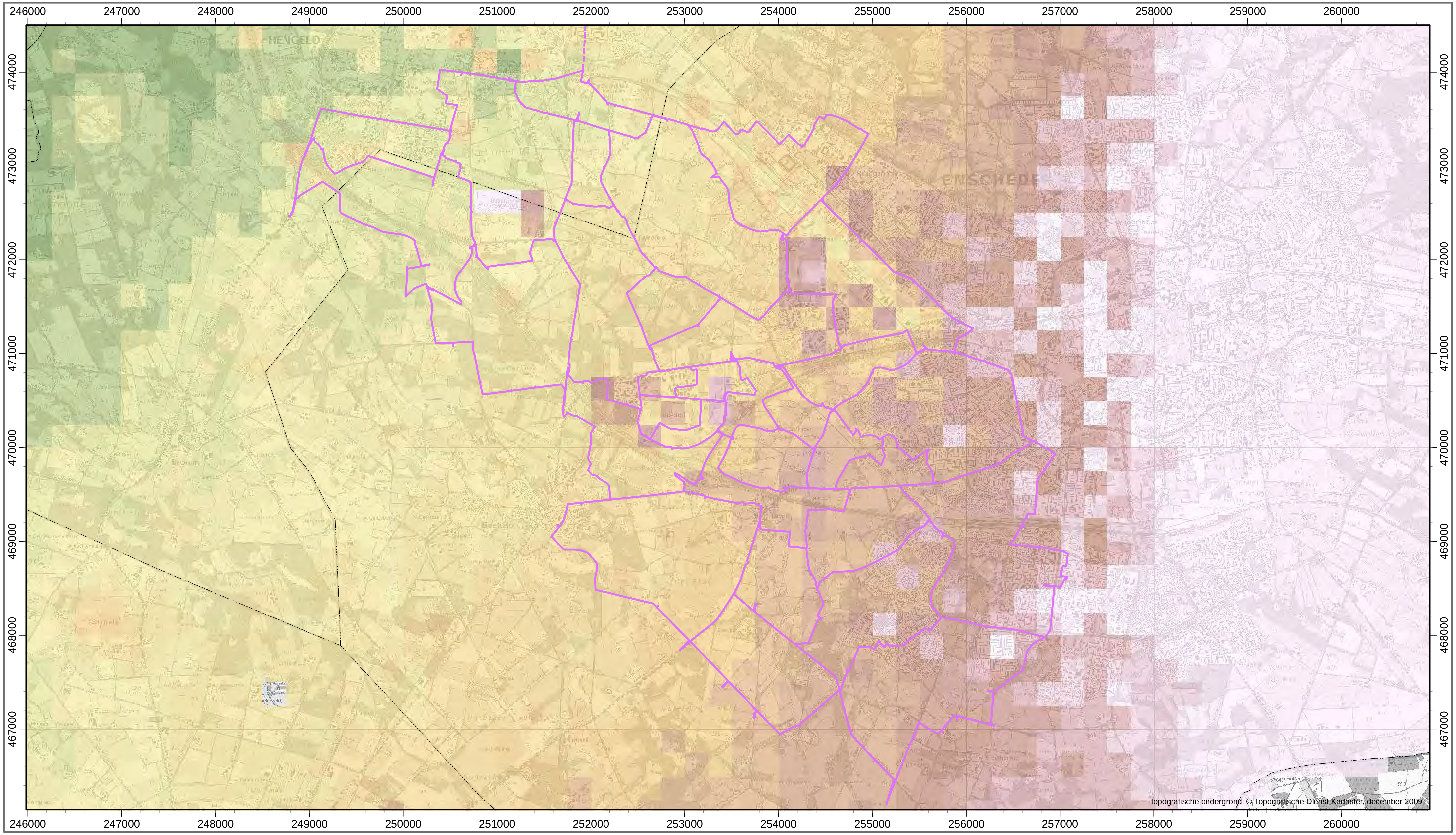
# Bijlage 4: P55.91.47/973 Pleictocene toplaag




| 0 | 24-10-2011 | - | JS |
|---|---|---|---|
| NR | DATUM | WIJZIGING | GET. |

**Legenda**

**Top Pleistoceen in meters, NAP**

- < 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26
- 26 - 28
- 28 - 30
- 30 - 32
- 32 - 34
- 34 - 36
- 36 - 38
- 38 - 40
- > 40
- Gemeentegrens
- Trajecten
- Buitentrajecten

0 0.35 0.7 1.4 km

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OPDRACHTGEVER
Akzo Nobel Industrial Chemicals B.V.

PROJECTOMSCHRIJVING
Deformatienet Twenthe Rijn

KAARTTITEL
Pleistoceen

STATUS
Definitief

GIS SPECIALIST
J. Schoonhoven

SCHAAL
1:40,000

PROJECTLEIDER
P. Meinders

FORMAAT
A3

BLAD IN BLADEN
1 IN 1

KAARTNUMMER
P55.91.47/973

WIJZ.NR
0

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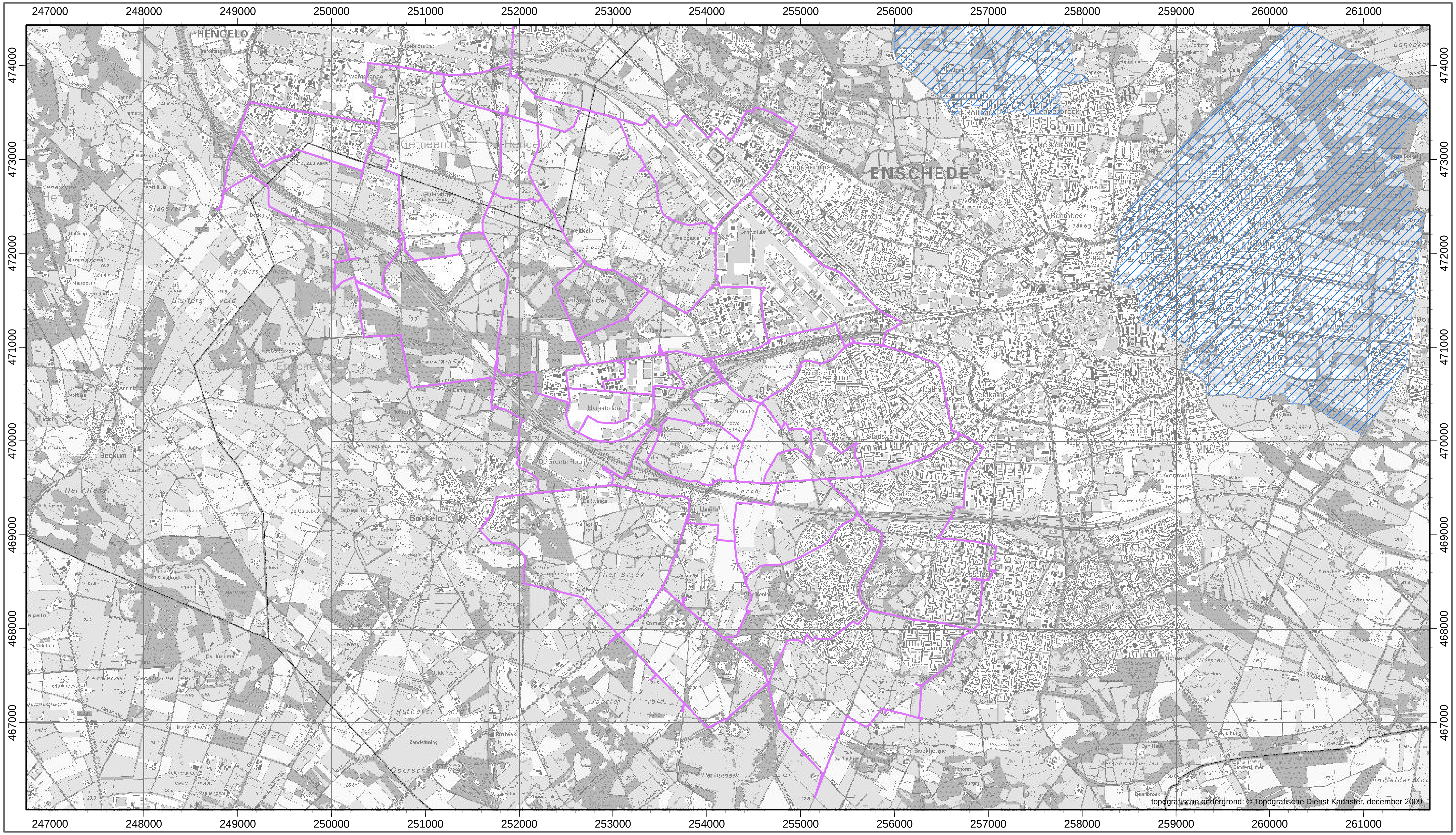
oranjewoud
Member of Antea Group

# Bijlage 5: 55.91.47/972 Grondwaterontrekkingen




## Legenda

- Waterwingebieden
- Gemeentegrens
- Trajecten
- Buitentrajecten

0 0.35 0.7 1.4 km

| NR | DATUM | WIJZIGING | GET. |
|---|---|---|---|
| 0 | 24-10-2011 | - | JS |

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PROJECTOMSCHRIJVING
Deformatienet Twenthe Rijn

BLAD IN BLADEN
1 IN 1

KAARTTITEL
Waterontrekkingsgebieden

KAARTNUMMER
P55.91.47/972

WIJZ.NR
0

STATUS
Definitief

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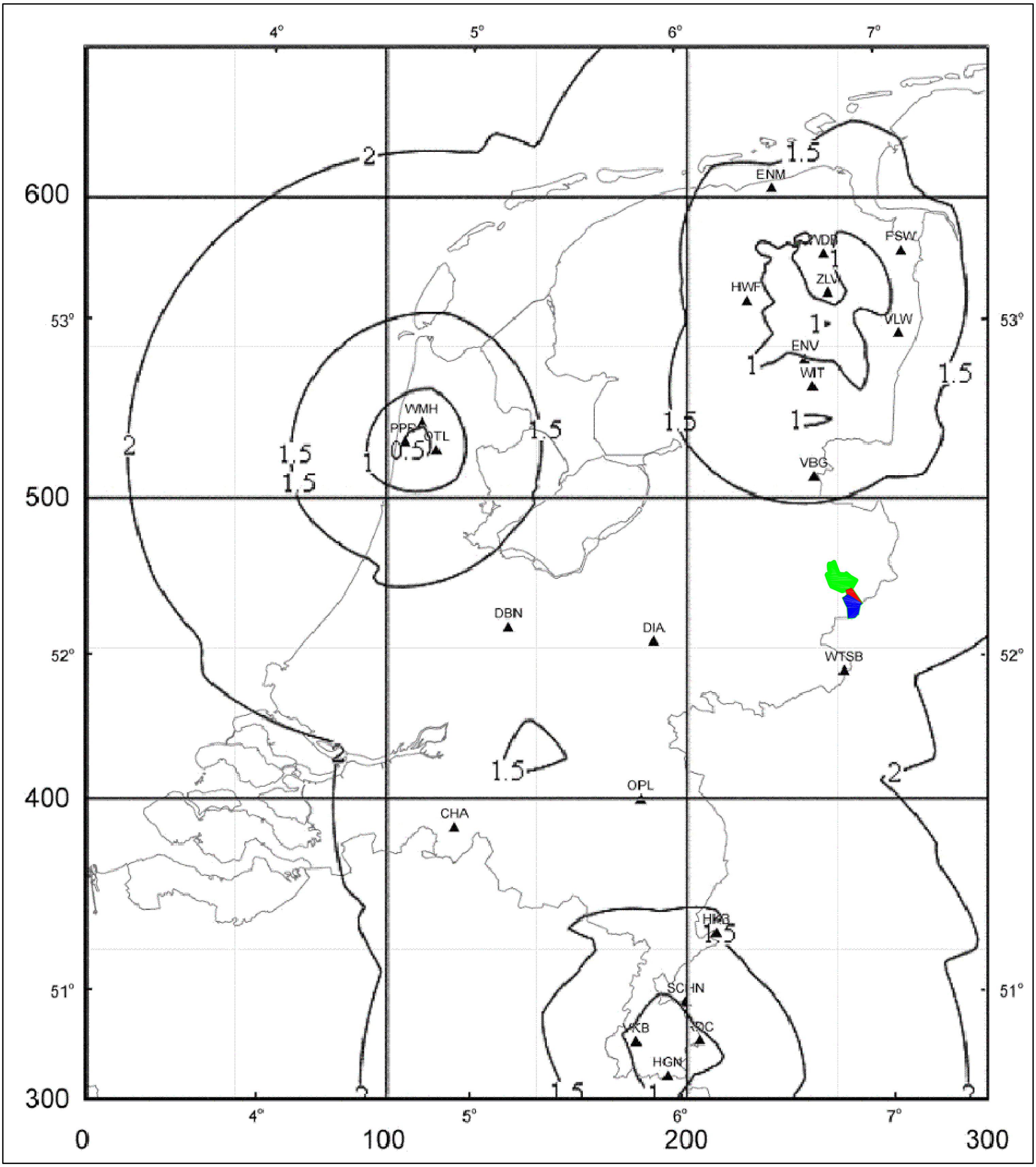
Bijlage bij het meetplan van de Winningsvergunning Twenthe-Rijn, Twenthe-Rijn Uitbreiding en Buurse




Kaart met de locaties en detectiecapaciteit van de betrokken seismische waarnemingstations

Winningsvergunninggebied Twenthe-Rijn
Winningsvergunninggebied Twenthe-Rijn Uitbreiding
Winningsvergunninggebied Buurse

Staatstoezicht op de Mijnen
*Ministerie van Economische Zaken, Landbouw en Innovatie*

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05/02/2012

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**Behandeld door**
mevr. S. Eijssens Ligtermoet

T 070 379 8433

**Ons kenmerk**
12005387

**Uw kenmerk**
-

**Bijlage(n)**

Datum 13 januari 2012
Betreft Meetplan Winningsvergunningen Twenthe-Rijn, Uitbreiding Twenthe-Rijn en Twenthe-Rijn Helmerzijde

Geachte mevrouw / heer,

Op 9 november 2011 heb ik het meetplan Winningsvergunningen Twenthe-Rijn, Uitbreiding Twenthe-Rijn en Twenthe-Rijn Helmerzijde van het voorkomen Rötzout als bedoeld in artikel 30, eerste lid van het Mijnbouwbesluit, ontvangen.

Het meetplan is ingediend op basis van artikel 30 van paragraaf 4.1 van het Mijnbouwbesluit.

De aanvraag is getoetst op de volledigheid en de juistheid van de voorgeschreven informatie op basis van artikel 30 van het Mijnbouwbesluit.
Vervolgens is de aanvraag beoordeeld op de geschiktheid om de in het winningsplan voorspelde bodemdaling te kunnen verifiëren.
Daarnaast is de aanvraag beoordeeld op de geschiktheid om de ontwikkeling van de verdeling van zoutonttrekking te kunnen volgen en toetsen.

Hierbij is het meetplan onder meer getoetst op:
- de tijdstippen waarop de metingen worden verricht (de meetfrequentie),
- de plaatsen waar gemeten wordt (de geografische dichtheid),
- de meetmethode (methodiek, precisie en nauwkeurigheid).

Uit uw gestandaardiseerde aanvraag kan worden afgeleid dat de 2$^e$ orde optische waterpassing jaarlijks en de GPS-metingen 5-jaarlijks worden uitgevoerd.
Ik ga er van uit, dat de bedoeling is, dat de GPS-meting jaarlijks en de 2$^e$ orde optische waterpassing 5-jaarlijks zal worden uitgevoerd.
Indien het resultaat van de GPS-meting meer dan 3 keer de standaardafwijking van de meetprecisie (GPS) bedraagt *en* een bodemdaling impliceert die groter is dan de in het winningplan opgenomen prognose (prognose met tijdlijn), kan SodM verzoeken om een vlakdekkende waterpassing.
Ik verzoek u aan mij te bevestigen dat de uitleg van bovenstaande correct is.

De conclusie is, dat, met in achtneming van bovenstaande uitleg, het meetplan zodanig ingericht, dat men -met in achtneming van de beperkingen door de aanwezige topografie en infrastructuur- de omvang en de vorm van de bodemdalingschotel uit de metingen kan afleiden.

Met vriendelijke groet,

R. van de Lint
*plv. Inspecteur-generaal der Mijnen*