R-09-08

Underground design Laxemar Layout D2

Layout and construction plan

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December 2009

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author. SKB may draw modified conclusions, based on additional literature sources and/or expert opinions.

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Abstract

The Swedish Nuclear Waste and Management Company (SKB) have the responsibility for the final repository of radioactive waste from Swedish nuclear power plants. SKB plans to design, construct and operate a final repository for spent nuclear fuel in a system where copper canisters, containing the spent radioactive fuel, are deposited at a depth of about 500 m in crystalline bedrock.

Controlling documents describe prerequisites for the underground facility, concerning, for example, the boundaries of the target volume, geological aspects, the construction work and the final deposition resources. The repository is found to have a gross capacity of 8,031 canisters. Geological features, such as deformation zones, have large impact on the deposition capacity as deposition is not allowed in deformation zones, or even within a respect distance of major deformation zones > 3,000 m trace length at ground surface. Additionally, the thermal conductivity in the different rock domains restricts the spacing of canister positions.

The layout of the underground facility, which includes the access ramp, shafts, rock caverns in the central area, transport tunnels, main tunnels, deposition tunnels and deposition holes, was achieved through an iterative process between layout studies, functionality studies and the prerequisites for the underground facility. The result from the generic functionality study showed that the construction strategy called "the Linear Development Method" which is based on using doors/walls to separate rockworks from deposition works in the same main tunnel is the strategy that is applicable for the Laxemar site.

The repository will be situated between 500.0 m (highest level of deposition tunnel roof) and 513.2 m (lowest level of main and transport tunnel floor), below ground surface. The deposition tunnels shall be aligned in a small angle to the major horizontal stress.

Two exhaust ventilation shafts are required to maintain satisfactory ventilation combined with door/walls to prevent polluted air from contaminating areas where deposition is performed.

Deposition of the first canister is made 6.4 year after starting excavation from central area. 39.6 years after start the last deposition tunnel is backfilled and sealed.

Close to 2,600,000 m^3 of rock will be excavated and close to 11,600,000 ton × km of transport work will be carried out.

With help from the functionality study, and with the prerequisites in mind, certain strategies for the construction plan could be pointed out, for example how to optimize the amount of deposition positions by placing transportation tunnels outside the boundaries for deposition.

Sammanfattning

Svensk kärnbränslehantering AB (SKB) ansvarar för att ett slutförvar för radioaktivt avfall från de svenska kärnkraftverken tas fram. SKB planerar att projektera, bygga och driva ett slutförvar för använt kärnbränsle i ett system där kopparkapslar, innehållande det uttjänta kärnbränslet, förvaras i kristallin berggrund på ett djup av 500 m.

Styrande dokument innehåller riktlinjer för utformningen av undermarksanläggningen. Dokumenten behandlar olika områden, till exempel gränser för området där möjligheterna för slutförvar undersöks, geologiska aspekter inom undersökningsområdet, utbyggnadsarbetet och resurserna för den slutliga deponeringen. Förvaret rymmer 8 031 deponeringshålspositioner, brutto. Geologiska förhållanden, såsom förekomst av deformationszoner, har stort inflytande på deponeringskapaciteten eftersom deponering av kapslar inte är tillåten i deformationszoner, eller ens inom ett respektavstånd från större deformationszoner med en spårlängd på markytan > 3000 m. Dessutom, bestäms avståndet mellan kapselpositionerna i olika bergdomäner av skillnad i termisk ledningsförmåga.

Layouten av undermarksanläggningen, vilken inkluderar tillfartsramper, schakt, bergrum i ett centralområde, transporttunnlar, stamhuvudtunnlar, deponeringstunnlar och deponeringshål, arbetades fram genom en iterativ process mellan studerade layouter, en funktionalitetsstudie och riktlinjerna för undermarksanläggningen. Resultaten från den generella funktionalitetsstudien visade att en utbyggnadsordning med separering av deponerings- och bergbyggnadsverksamheterna med dörrar/väggar i samma stamtunnel var den strategi som var användbar för Laxemar som plats.

Förvaret placeras på ett djup under markytan mellan 500,0 m (högsta punkt i deponeringstunnel) och 513,2 m (lägsta punkt i stam- och transporttunnlar). Deponeringstunnlarna orienteras i en liten vinkel till största huvudspänningsriktningen.

Två frånluftsschakt i kombination med ventilationsskott (dörrar/väggar) krävs för att upprätthålla en god ventilation och förhindra att förbrukad luft förorenar luft i områden där deponering pågår.

Deponering av den första kapseln görs 6,4 år efter starten från centralområdet. 39,6 år efter start har den sista kapseln deponerats och den sista deponeringstunneln återfyllts och förslutits.

Närmare 2 600 000 m^3 berg kommer vid slutförandet ha schaktats bort och 11 600 000 ton × km transportarbete ha utförts.

Med hjälp av funktionalitetsstudien och med givna förutsättningar, kunde vissa strategier för utbyggnadsordningen arbetas fram, till exempel hur optimering av antalet deponeringshålspositioner kunde ske genom att lägga vissa transporttunnlar utanför deponeringsområdet.

Contents

1 Introduction

The Swedish Nuclear Waste and Management Company (SKB) have the responsibility for the final repository of radioactive waste from Swedish nuclear power plants. Spent nuclear fuel is presently transferred successively from the Swedish nuclear power plants to a central interim storage facility for spent fuel (Clab). SKB plans to design, construct and operate a final repository for spent nuclear fuel in accordance with the KBS-3 method, which provides three protective barriers. The spent nuclear fuel is encapsulated in watertight and load-resistant copper canisters. The canisters are deposited in crystalline rock at a depth of about 500 m and enclosed by a buffer of bentonite clay to prevent inflow of water and to protect the canisters. Tunnels and rock caverns are backfilled with bentonite clay when the disposal is completed.

To carry out disposal according to the KBS-3 method a corresponding comprehensive system is required. The KBS-3 *system* covers intermediate storage facilities, encapsulation plant, canister factory and final repository. SKB plans to locate the encapsulation plant close to the interim storage Clab on the Simpevarp peninsula outside Oskarshamn. Two places are currently of interest for location of the final repository; Forsmark in Östhammar municipality and Laxemar in Oskarshamn municipality.

To enable SKB to build and operate the facilities it is required that they are subjected to licensing application in accordance with both the Swedish Environmental Code and the Nuclear Activities Act.

This report presents suggestions for location and layout of a final repository facility at Laxemar, Oskarshamn municipality.

1.1 Objectives

The main objective of the present layout work in design step D2 was to investigate and demonstrate the functionality of the underground facility /SKB 2007a/. Other objectives included are:

- Drafting a description of a facility for the selected site with a layout proposal for the surface and underground facilities of the final repository as part of the supporting documents for an application. The description shall account for constructability, technical risks, costs, environmental impact and robustness/effectiveness. The underground layout is to be based on information from the site investigation and constitute the basis for the safety evaluation.
- The layout shall demonstrate areas enabling deposition of 6,000 canisters.
- Demonstrate a possible site adaptation of the repository with respect to the overall requirements for long-term safety, functionality and robustness.
- Demonstrate the constructability and effectiveness of a step-wise extension of the underground parts of the repository.
- Ensuring separation of the two main activities, construction and operation of the repository.

The layout also provides advising material in accordance with chapter 6 of the Swedish Environmental Code concerning:

- Localization of the surface facility.
- Localization and extension of the underground facility.
- Technical description and functionality description of possible layout.

1.2 Strategy

The overall strategy with regard to the layout for the underground facility of the final repository is to optimize the number of potential deposition hole positions with respect to available facility volume, also considering geological limitations, condition of the bedrock such as rock domains, fracture domains, hydraulic domains, abundance/type of fracture/fracture zones, water conditions, thermal and mechanical conditions and financial prerequisites.

To optimize the layout the strategy has also included performance of a generic functionality study followed by presentation of a construction plan for the proposed layout at Laxemar.

1.3 Design methodology

The design methodology for design step D2 is described in chapter 5.4 in /SKB 2007a/ and is divided into five main activities:

1. An initial study based on results from the design phase D1 /chapter 6 in SKB 2007a/ with regard to new information that can influence the layout work.
2. A functionality study of the repository and its function. This main activity has been carried out as a separate item and is presented in chapter 3.1 of this report.
3. Compilation of layout alternatives, with regard to the premises noted in /SKB 2008/, that have adequate deposition capacity. Evaluate which alternative(s) that is/are the most favourable with regard to prescribed requirements and objectives.
4. Evaluation of constructability for proposed layouts from the perspective of rock reinforcement and grouting is presented in two separate reports respectively.

The achieved output from these studies will serve as input to other separately performed detailed studies for the design of drainage and ventilation systems (including fire ventilation), fire protection plans and rescue arrangements, transport systems, detailed planning of investigation and construction works, etc.

1.4 Nomenclature

This chapter provides definitions of terms that are of basic importance for the layout modelling and description of the Laxemar site. Many geological terms relate to the geometrical framework of the modelling and thus are common to all disciplines within the design work (Table 1-1).

Table 1-1. Designations and explanations.

Terms referring to the investigation site	Explanation
Candidate area	The candidate area refers to the area at the ground surface that has been recognised as suitable for a site investigation, following the feasibility study work. Its extension at depth is referred to as candidate volume.
Target area/volume	The target area refers to The Laxemar target area and the rock volume beneath that was selected during the site investigation process as potentially suitable for hosting a final repository for spent nuclear fuel /SKB 2007b/.
Terms referring to geology	**Explanation**
Deformation zone	A structure along which there is a concentration of brittle, ductile or combined brittle and ductile deformation. Those deformation zones which are possible to correlate between a surface lineament with a length > 1,000 m or have an interpreted true thickness of > 10 m, are modeled deterministically, and are thus explicitly accounted for in the 3D RVS model. The deterministically modeled deformation zones are given unique names ZSMx zone (intersecting ground surface) or KLXx-DZx (not intersecting ground surface, i.e. only found in boreholes).
Discrete fracture network (geological DFN)	A discrete fracture network model involves a description of the fracturing in the bedrock on the basis of a statistical model, which provides geometries, directions and spatial distributions for the fractures and the local minor deformation zones within defined *fracture domains*.
Fracture domain	A fracture domain is a rock volume outside deformation zones in which rock units show similar fracture frequency characteristics. Fracture domains at Laxemar are defined on the basis of the single-hole interpretation and its modifications and extensions.
Fracture zone	Fracture zone is a term used to denote a brittle deformation zone without any specification whether there has or has not been a shear sense of movement along the zone.
Rock domain	A rock domain refers to a rock volume in which rock units that show specifically similar composition, grain size, degree of bedrock homogeneity, and degree and style of ductile deformation have been combined and distinguished from each other.
Hydraulic domain	The hydraulic SDM modelling is conducted on different scales. Hydraulic domain (HRD) represents the fractured bedrock between the deformation zones.
Terms referring to the work with the underground facility and the underground facility itself	**Explanation**
Operational area	The on surface area containing all surface facilities.
Central area	Part of facility for rock caverns, tunnels, etc, for personnel, operation and maintenance.
Deposition area	Part of facility for disposal in deposition tunnels, main tunnels, transport tunnels and deposition holes.
Deposition work	Installation of buffer (bentonite), deposition of canister, backfilling and pouring (casting) of concrete plug.
Excavation work	Excavation by drilling and blasting of main-, transport- and deposition tunnels, drilling of deposition holes and preparation for deposition.
Main activities	Excavation work and deposition work.
Respect distance	Deformation zones that have a trace length at ground surface longer than 3,000 m require a respect distance of 100 m on each side of the zone. This means that deposition of canisters is not allowed within this distance.
Underground opening	Underground excavation that is required to operate the final repository.

2 Design premises and site conditions

Premises given for the design work of the layout for the repository for spent fuel are described in the steering document Underground Design Premises /D2 (UDP/D2) /SKB 2007a/ and Site Engineering Report (SER) /SKB 2008/.

The following chapter is a summary description of these premises.

2.1 Underground Design Premises/D2

The Underground Design Premises/D2 (UDP/D2) /SKB 2007a/ presents the design requirements for Design D2 and references to other steering documents. /SKB 2007a/ provides an overall description of the premises for the work and includes references to other controlling documents.

In accordance with /SKB 2007a/ the underground design shall be conducted with regard to the geological conditions as described in /SKB 2008/.

Tunnels are to be constructed at a suitable inclination to facilitate drainage. The inclination is to be 1:100 for a maximum of 500 m, after which an angle break is to be made. Accordingly, a 5 m difference in level between main- and transport tunnel bottoms of the deposition area can be anticipated, and an additional difference of 3 m at inner ends of the deposition tunnels.

/SKB 2007a/ also describes how the final repository for spent fuel is to be extended stepwise and begins with an initial 3-year period for 300 canisters. Normal operation will then commence in steps of 150–200 canisters per year until 6,000 canisters have been deposited.

Conditions in /SKB 2007a/ will not be listed here but will be referred to whenever needed later in the document.

2.1.1 Deviations from design premises

UDP/D2 includes design premises and instructions for the design of underground openings and rock construction works at the two candidate sites Laxemar and Forsmark. The design premises are based on current SKB requirements and on specially elaborated documents, based on the experiences from previous design steps and the needs and objectives of the rock engineering design in design step D2.

The following deviation from the design premises /SKB 2007a/ were made. According to the requirements given the deposition area should not intrude into major deformation zones or the respect distance to a major deformation zone. Deformation zones that have a trace length at ground surface longer than 3,000 m require a respect distance of 100 m on each side of the zone /SKB 2008/. This means that deposition of canisters is not allowed within this distance. However, in order to optimize available area for deposition, it was decided by the design coordinator to allow transport tunnels to pass within respect distances.

2.2 Site Engineering Report

The Site Engineering Report (SER) /SKB 2008/ provides a site–specific engineering geologic description of the Laxemar site. It also presents design prerequisites for long term safety issues and constructability.

The report describes the geological prerequisites of Laxemar, which for example include an introduction to rock and fracture domains, deformation zones, respect distance for zones which have a trace length greater than 3,000 m at ground surface, required distance between deposition holes due to thermal and mechanical rock conditions and direction of deposition tunnels. Consideration is also to be taken to the distance between existing investigation boreholes and tunnels, access ramp and shafts.

2.3 Input from design coordinator

Every activity in the design phase is to follow the SKB environmental programme. The purpose of the environmental programme is to ensure, from an initial stage, that the facilities and operations are adapted so that consequences with regard to health and the environment are as favourable as possible. Within the layout work, special concerns need to be taken when placing the ventilations shafts.

The possible location of the underground facility has been defined by SKB to lie within the *Laxemar target area* /SKB 2007b/. The design coordinator specifies in Figure 2-1 the proposed location of the operational area. The main access to the repository will be arranged via vertical shafts and an inclined ramp will be located in the Oxhagen area.

Based on preliminary reports and conclusions made in the initial design work, the design coordinator decided to change the interpretation of the repository restraining borders to the north and west in order to expand accessible rock volume.

Instead of having the northern border constituted by a vertical line where EW007 intersect the ground surface, the position of the border is changed to restrained by the southern safety distances of the deformation zones EW002 and EW007 at repository depth. The western border was similarly changed from the vertical continuation of where NS001 cut the surface, to the vertical continuation of the western limit of the respect distance to NS001 at repository depth /SKB 2008/.

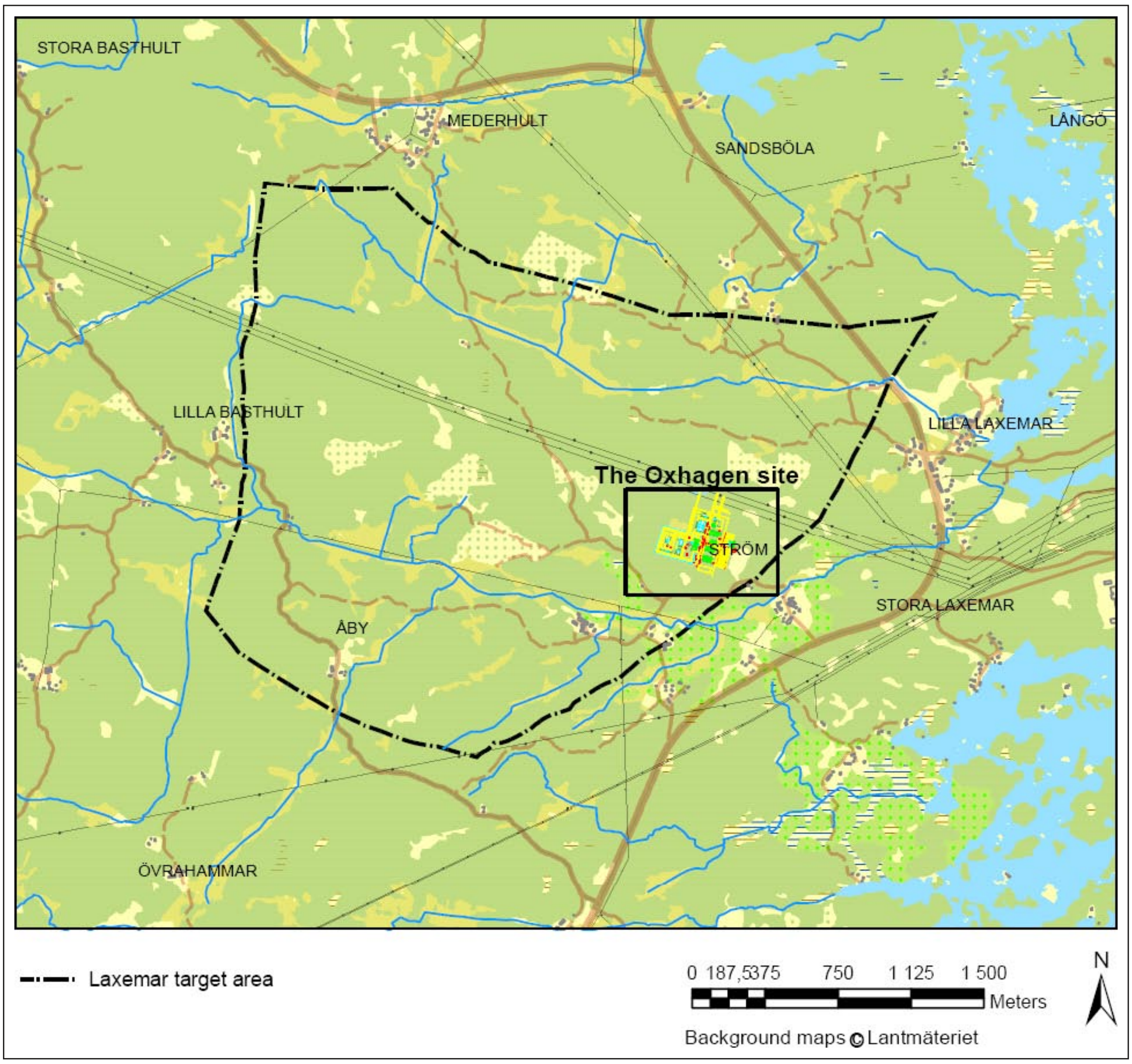


Figure 2-1. *Available underground area projected on the ground surface. The target area as defined in /SKB 2007b/ was revised by the design coordinator.*

2.4 Site specific conditions

2.4.1 Geological description

The bedrock properties and the deformation zones are major guiding conditions for the layout of the potential underground facility. The following text is an overall geological description of the target volume whereas a more thorough description is given in /SKB 2008/.

Rock domains

All rocks in the area are igneous rocks that belong to the Transscandinavian Igneous Belt (TIB). The general bedrock distribution in the target volume can be described in terms of three rock domains, RSMA01, RSMM01 and RSMD01. The northeastern part is occupied by rock domain RSMA01, which principally consists of Ävrö granite, whereas rock domain RSMD01, which is dominated by quartz monzodiotite, occupies the southern and southwestern part. The two domains are separated by a central, arc-shaped domain characterized by frequent diorite to gabbro bodies in quartz monzodiorite and particularly Ävrö granite. Mixtures of fine-grained dioritoid and Ävrö granite are locally embedded in RSMM01. All contacts towards RSMM01 dip north or northeastwards.

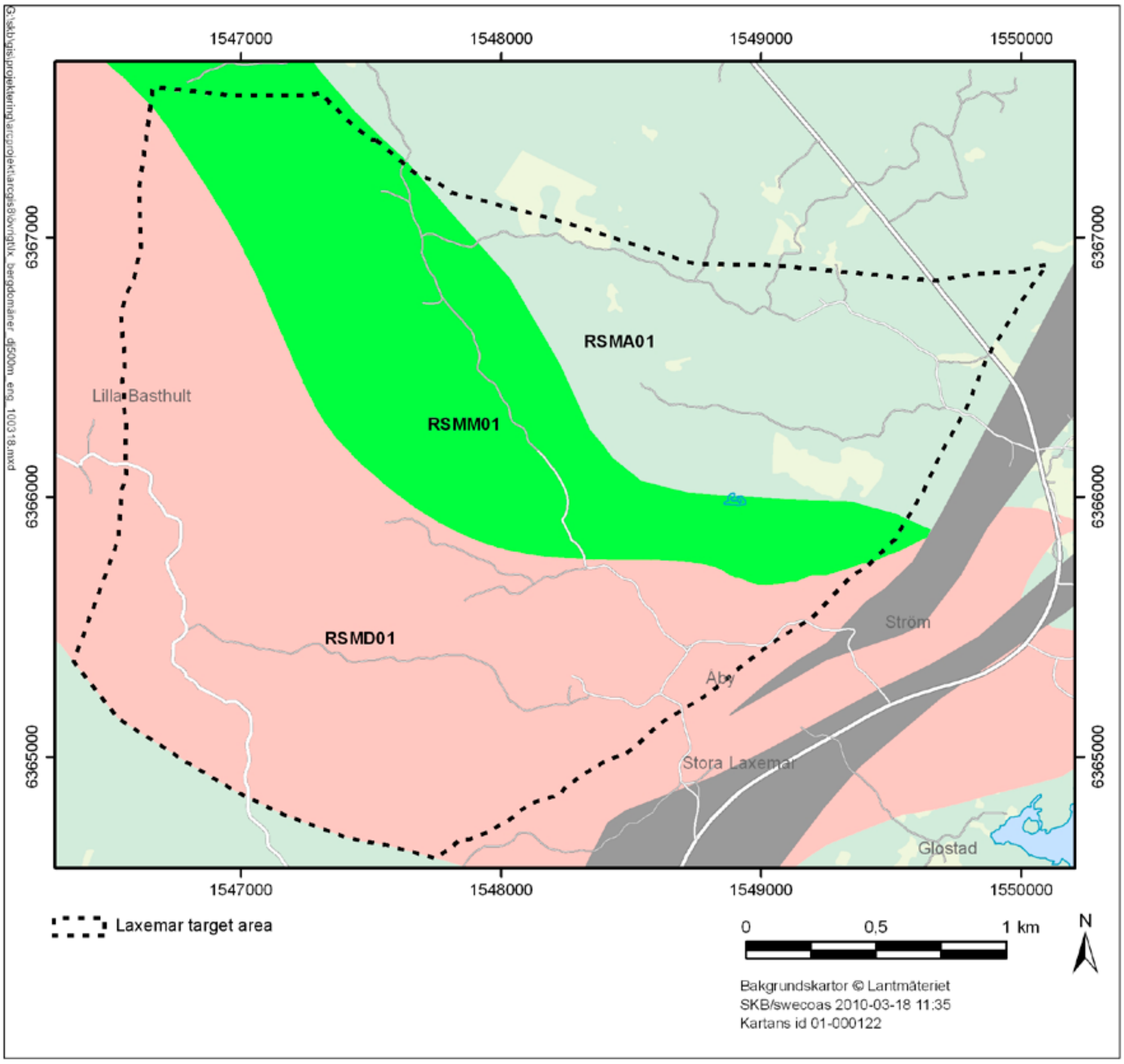


Figure 2-2. *Plane view at 500 m depth of the Laxemar rock domain model.*

Deformation zones

To the east, the target volume is delimited by a north-easterly belt of low-grade brittle-ductile deformation zones, which includes the Äspö shear zone (NE005A). Although the orientations of individual deformation zones in the volume are highly variable, there is a principal pattern of vertical to steeply dipping, north–south and east–west trending zones. Including deformation zone NE005A, seven major deformation zones of largely brittle character occur within the target volume (Figures 2-7 and 2-8). They are all inferred to have a trace length > 3,000 m at ground surface, which is large enough to require a respect distances of 100 m on each side of the zone margins /SKB 2008/. In addition, there are several, less conspicuous zones in the inferred length interval 1–3 km, which not require respect distances.

Fracture domains

Based on the fracture conditions, four separate fracture domains can be recognised in the target volume (Figure 2-3). Fracture domain FSM_C is located in the central part of the volume. It is separated from fracture domain FSM_W in the western part by NS059A, and from fracture domain FSM_NE005 in the eastern part, by NE107A. The fourth fracture domain, FSM_EW007 is situated north of FSM_C and FSM_NE005, around EW007.

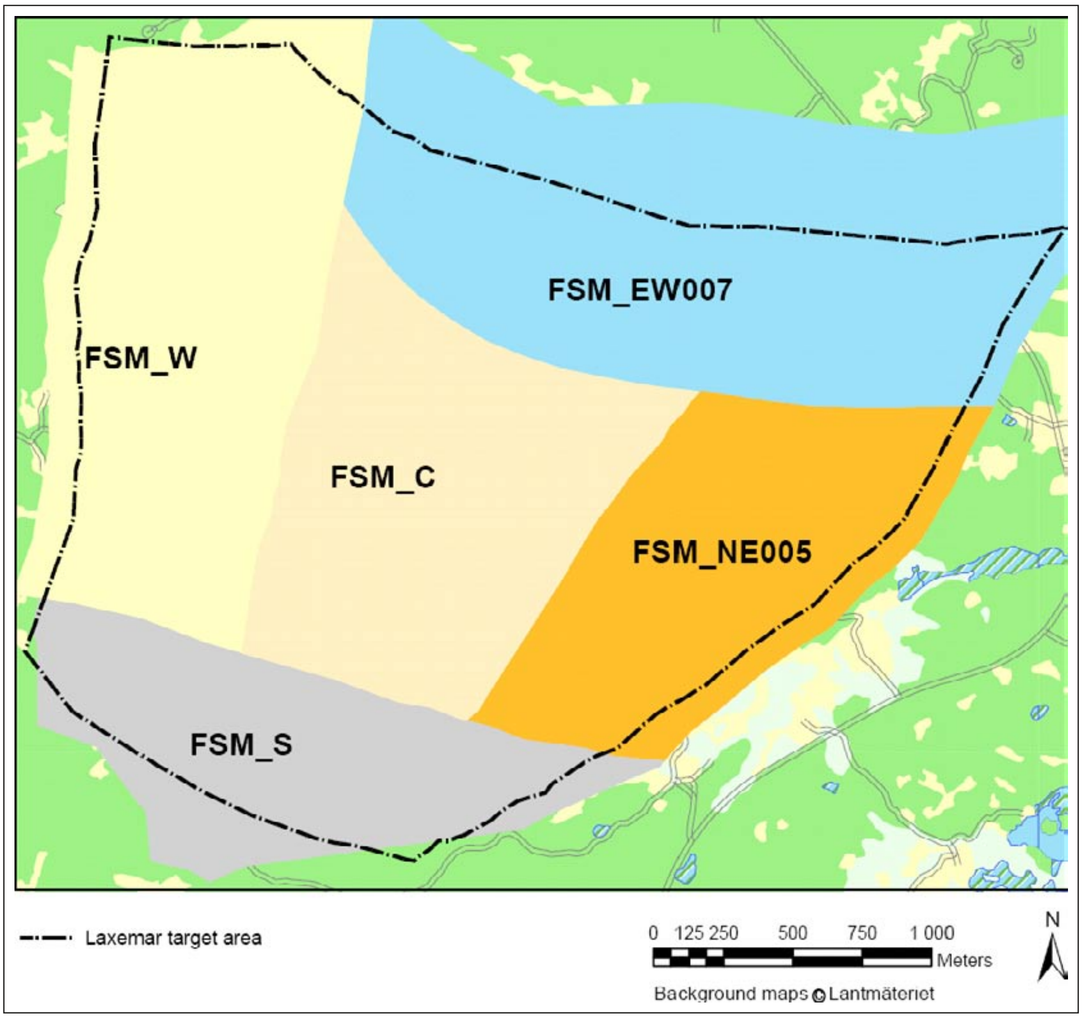


__Figure 2-3.__ Plane view at 500 m depth of the Laxemar fracture domain model. The fracture domains are used to describe volumes with similar properties in terms of fracture intensity and orientation.

The bedrock in FSM_W, FSM_C and FSM_NE005 can be described as medium fractured rock. However, the intensity of different fracture sets varies among the three domains. The fracture intensity is slightly higher in FSM_EW007, with an increased frequency of fractures oriented sub-parallel to EW007.

The conductive features form an anisotropic system; near surface subhorizontal and steeply dipping features with WNW strike dominate and below 100–200 m depth the relative intensity of the subhorizontal features decreases and steeply dipping conductive features with WNW strike dominate. Taking also the decrease by depth of the intensity of the flowing features, it is realised that a large portion of the groundwater recharge is only flowing through the upper 200 m of rock before discharging. At repository depth (i.e. 450–650 m depth), the hydraulic properties are essentially the same for FSM_W and FSM_C with few high transmissive features. Fracture domain FSM_EW007, on the other hand, is much more conductive, due to a high frequency of connected transmissive fractures.

Hydraulic rock domains

Hydraulic domain (HRD) represents the fractured bedrock between the deformation zones.

/SKB 2009/ define hydraulic rock domains defined based on the spatial distribution of hydraulic properties. Statistical analyses of the hydraulic data have shown that a slight modification of the fracture domains can be used as a basis for hydraulic domain (Figure 2-4).

The following hydraulic rock domains have been defined /SKB 2008/:

- HRD_N coinciding with fracture domain FSM_N.
- HRD_EW007 coinciding with fracture domain FSM_EW_007.
- HRD_C being the combination of fracture domains FSM_C, FSM_NE and FSM_S.
- HRD_W coinciding with fracture domain FSM_W.

The upper 150 m of rock generally have quite high frequency of connected and transmissive fractures. The frequency of connected transmissive fractures as well as the average hydraulic conductivity decreases with depth and is also somewhat different in the different HRDs.

It should be noted that the difference between HRD_C and HRD_W is relatively small. The higher "average conductivity" in HRD_W is due to a few highly transmissive features. In contrast, data suggest that HRD_EW007 is much more conductive as it contains a high frequency of connected transmissive fractures.

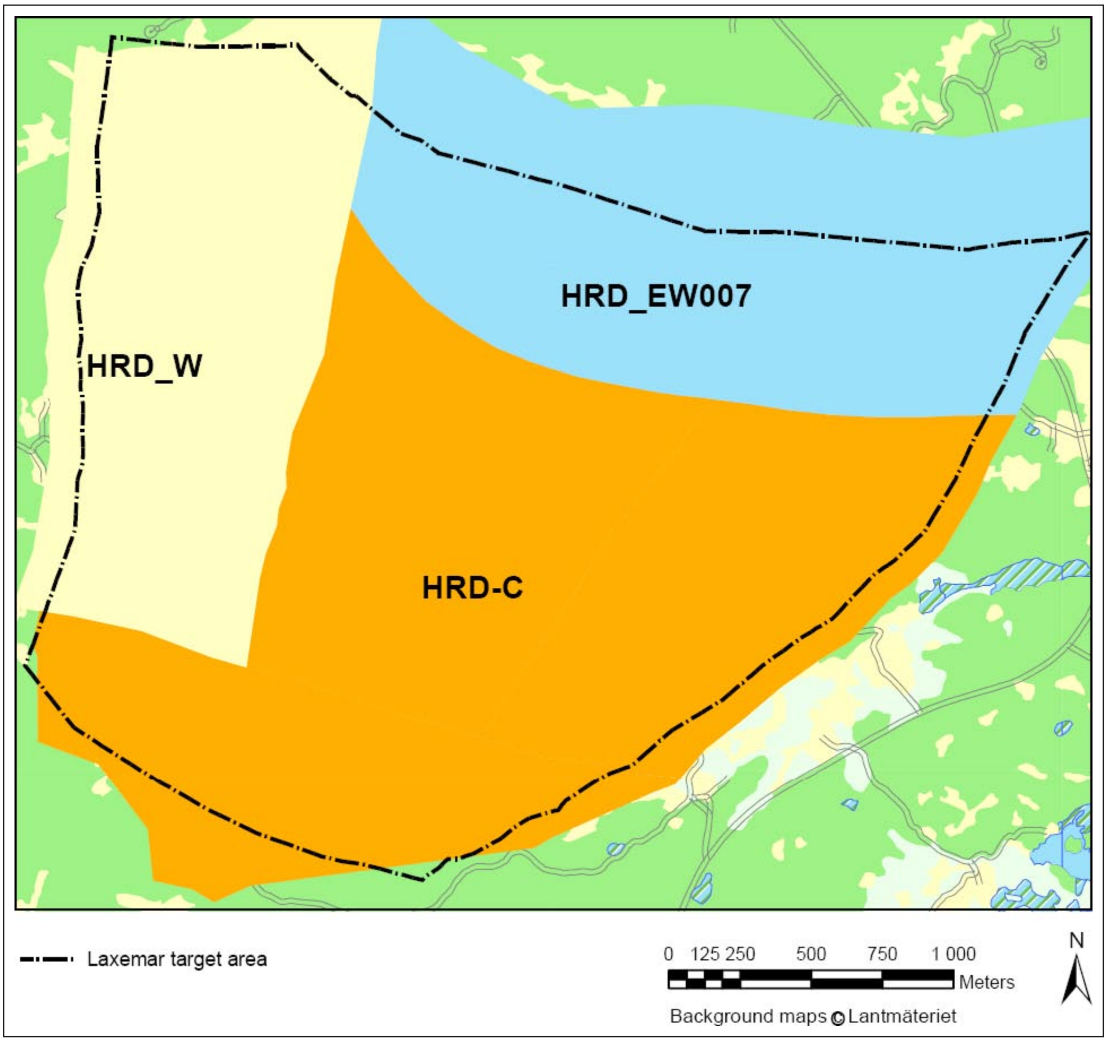


Figure 2-4. The figure shows the outline of the hydraulic rock domains. Locations projected at 500 meter below ground surface.

2.5 Key issues and site adaption

A central question for design is whether or not there is sufficient available rock volume, of sufficient quality, to accommodate the repository. Adaptation of the underground facility to the existing conditions with regard, for example, to pass through different types of fracture domains; the location of facility parts in relation to deformation zones and their respect distances; etc, has been made during the design process.

The deposition area shall be developed step-wise, and the two activities construction and operation of the final repository facility must always be separated by a physical protection allowing for no contact between the activities. The applied steps for development may time-wise run from a few years up to about 5 years /SKB 2007a/.

The operation and construction plan shall provide basis for the required deposition rate of 50, 100, 150 canisters/year for the first three years of initial operation, and after that for a capacity of 150–200 canisters/year until deposition has reached 6,000 canisters /SKB 2007a/.

The results of the design process as described in this report have included a thorough analysis of all functions of the different elements constituting the deposition area, leading to a construction plan for the whole construction sequence.

The work has been carried out in accordance with UDP guidelines and relevant adaptations are presented below.

2.5.1 Optimization of available deposition area

The layout is to a large extent controlled by the distribution of the deformation zones that cross the target area. The selected orientation of the deposition tunnels in combination with the geometry of the resulting deposition blocks controls the possible deposition tunnel layouts with limited opportunity for flexibility. The direction of the deposition tunnels should correspond with the main direction of the major horizontal stress, to minimize the risk for spalling in deposition holes.

To optimise the available deposition area, the possibility of locating transport tunnels within respect distances for major deformation zones has been considered.

Given the prerequisites as above, the studies for the deposition area commenced by a thorough analysis of all functions of the different elements constituting the deposition area, leading to the following strategy for the layout design work, given in order of priority:

- To locate the repository at a depth of 500 m /SKB 2008/.
- To align main tunnels in principal northeast/southwest, a consequence of previous requirement since main tunnels preferable also should be oriented in a large angle to the deposition tunnels. Due to the geometry of the selected deposition area and the position of the central area the selection of 4 main tunnels is the only prevailing option.
- To locate all deposition tunnels aligned with the maximum principal stress and only to allow small deviations from that direction. The most likely direction (trend) of major principle stress is stated in /SKB 2008/.
- To align the deposition tunnels parallel to the northern and southern borderlines of the deformation zones, giving higher priority to fracture domains of less hydraulic conductivity.
- To align deposition tunnels with an angle of 60°–90° relative main tunnels (Figure 2-5).

Having the strategy given above in mind during the preparation of the layout, alternative possible configurations of the main- and deposition tunnels gradually could be ruled out during the design process.

Nevertheless, depending on actual principal rock stress levels obtained during construction of the repository, small modifications and adjustments of the layout might be introduced at a later stage.

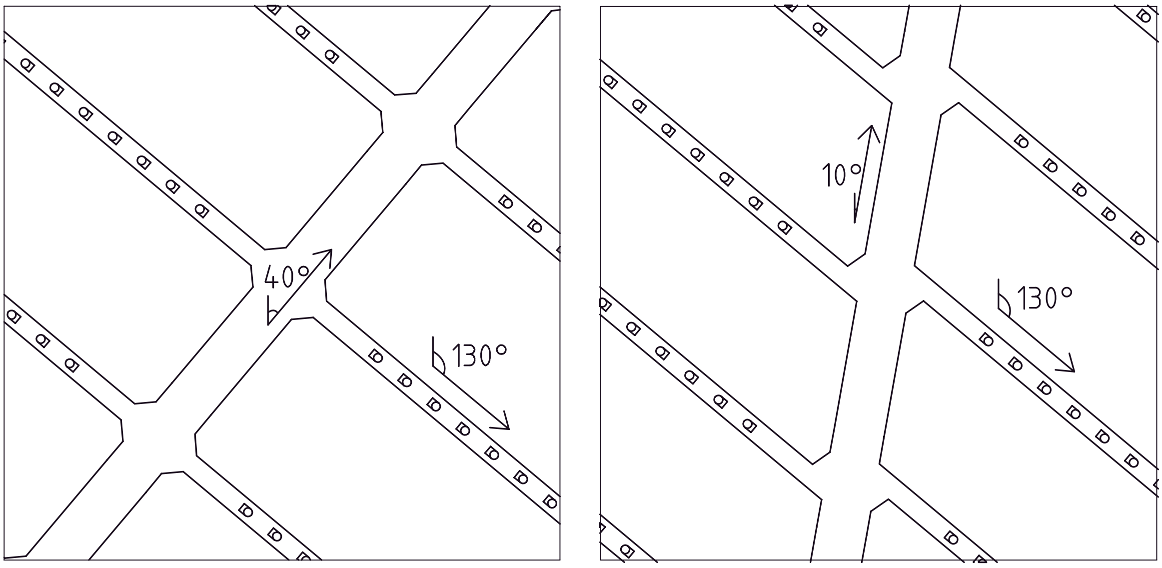


Figure 2-5. *Orientation of main and deposition tunnels.*

2.5.2 Deformation zones

Deformation zones with a trace length greater than 3,000 m require a respect distance of 100 m on each side of the zone, due to the risk of seismic activity caused by post-glacial rebound /SKB 2008/. Deformation zones with trace length less than 3,000 m do not require respect distance, but deposition is not allowed within the boundaries of these zones. Volumes that are penetrated by investigation boreholes are rejected (Figure 2-6). A minimum distance from a tunnel to an investigation borehole shall be set to one tunnel diameter /SKB 2007a/.

Deformation zones with trace length at ground surface longer than 3,000 m within the deposition area, i.e. EW002, EW007, NW042a, NS001c, NS059a, NE107a and NE005a require respect distances that preclude deposition within that distance (Figure 2-7).

Deformation zones with a length between 1,000 and 3,000 meter are shown in Figure 2-7. They do not need respect distances but will, nevertheless, affect the layout by loss of deposition positions, which also is the case with deformation zones only verified in boreholes (Figure 2-8).

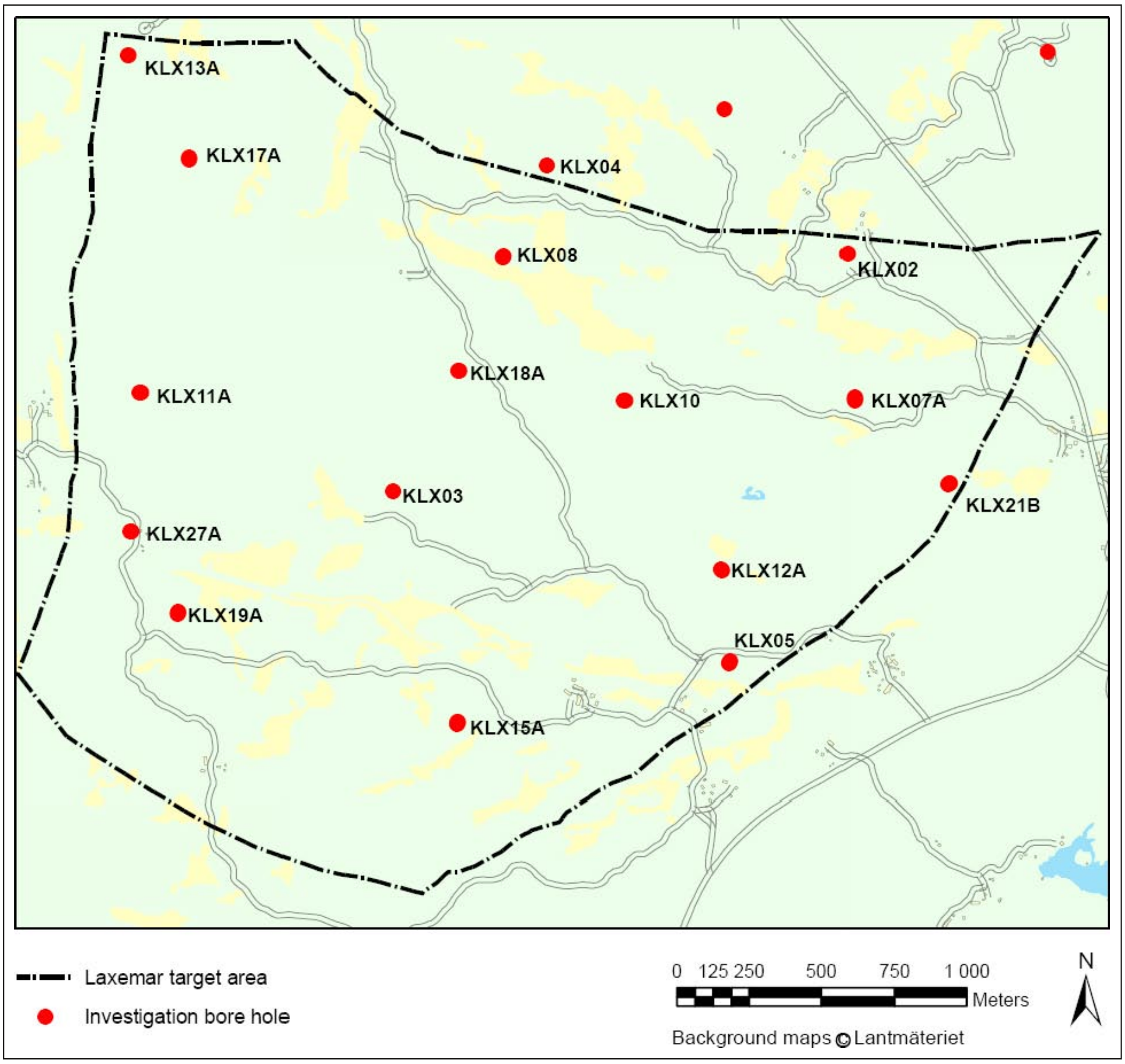


Figure 2-6. Volumes that are penetrated by investigation boreholes. Locations projected at 500 meter below ground surface.

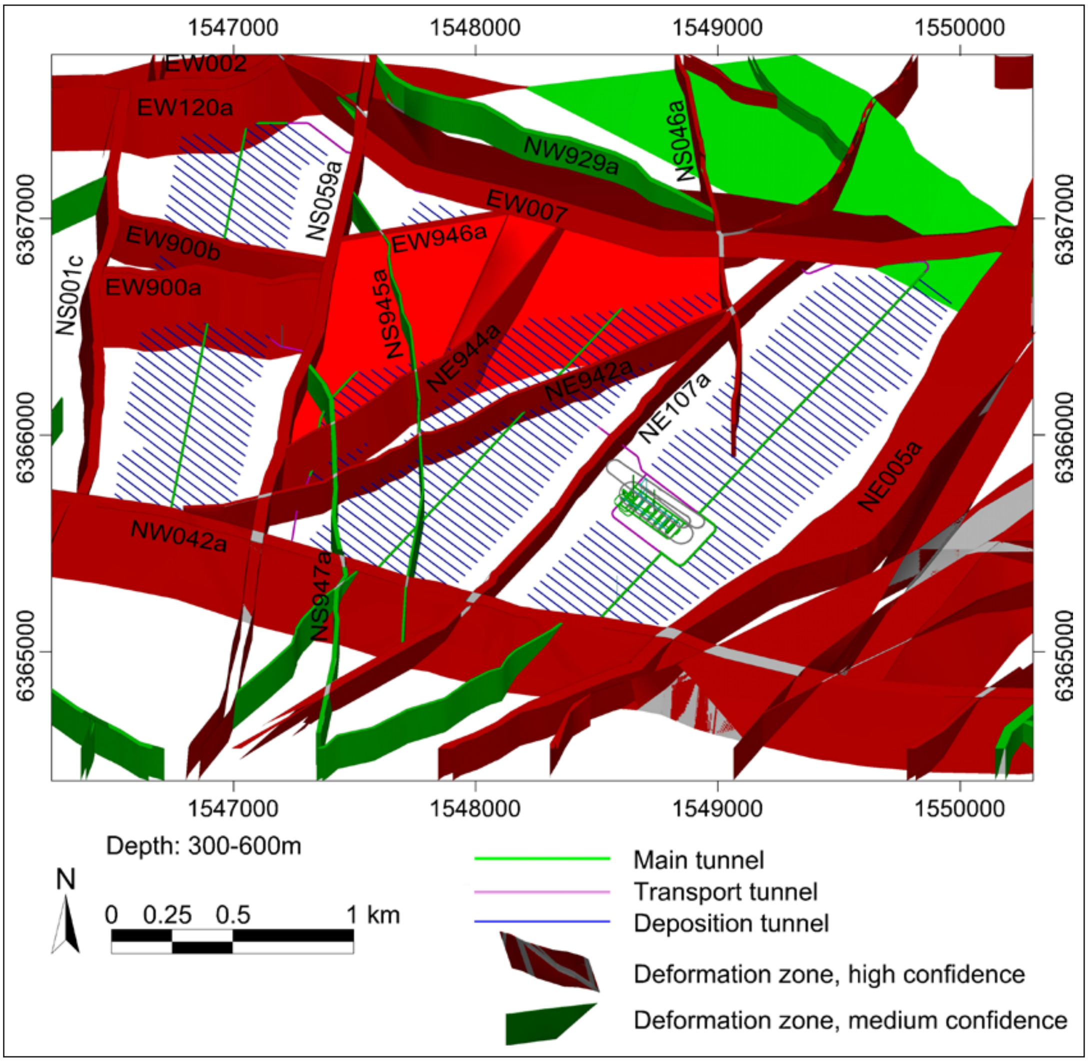


Figure 2-7. *Schematic three-dimensional view of the repository area at 300–600 m depth, showing modelled deformation zones, larger than 1,000 m, relative to the layout. Discrete deformation zones without associated surface lineaments (modelled as circular slabs and denoted KLXxx_DZxx) have been excluded for the readability.*

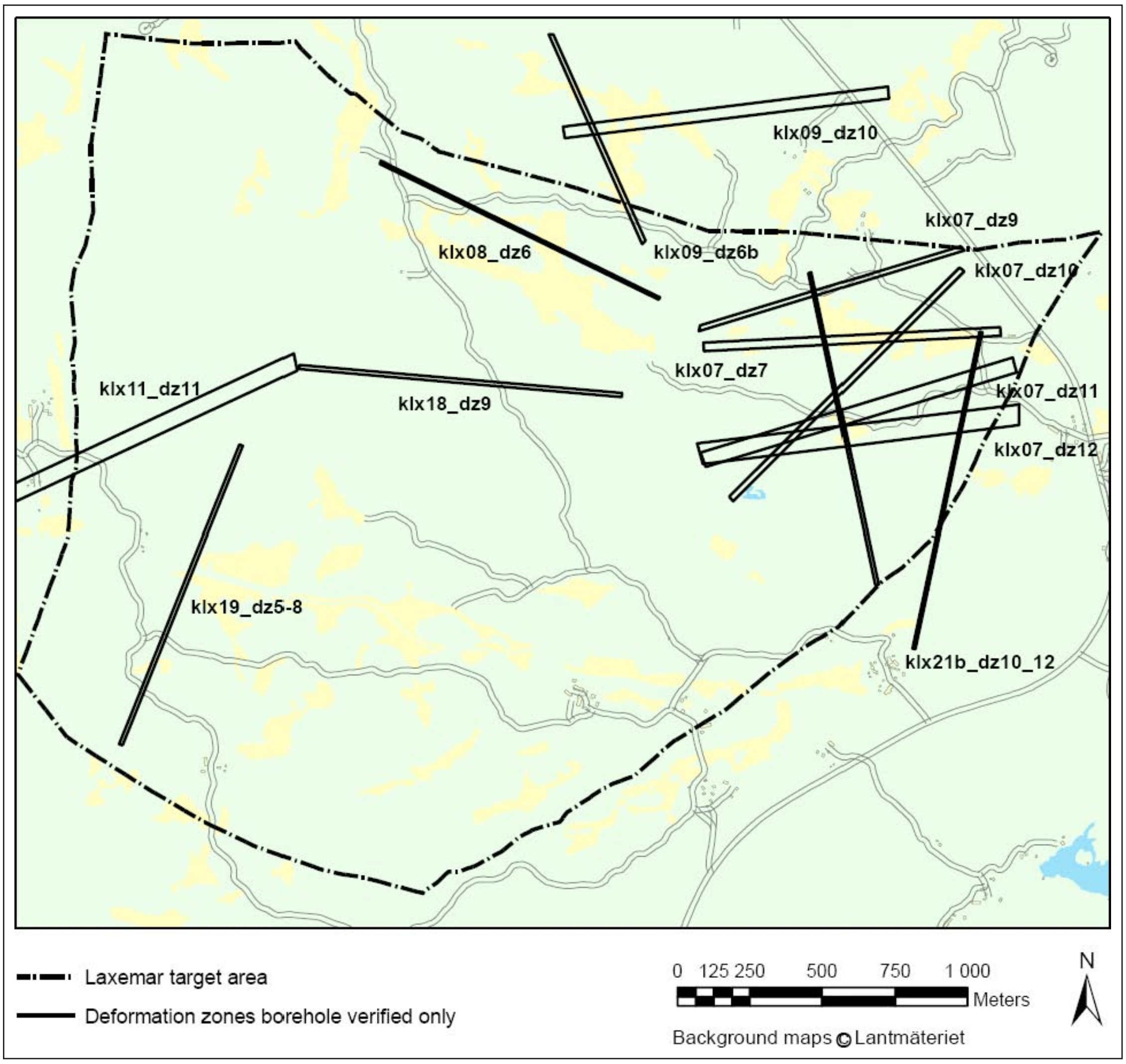


Figure 2-8. Locations of deformation zones verified in boreholes only. Locations projected at 500 meter below ground surface.

2.5.3 Repository depth

In /SKB 2006a/ it is stated that a repository should be constructed at a depth interval between 400–700 m. At this depth range there are several site specific factors related to long-term safety that have been considered when selecting the exact repository depth:

- In situ temperature.
- Fracture orientation and frequency.
- Hydrogeology considerations.
- Spalling considerations.
- Available space – site adaptation.

The depth of the repository must balance the safety requirements for the repository and the constructability of the underground excavations required for the deposition tunnels and deposition holes. The safety requirements are largely influenced by the hydrogeology of the site, i.e., frequency and occurrence of transmissive fractures as well as rock mechanics issues, i.e., stability of the deposition holes due to spalling.

According to /SKB 2008/ the repository shall be located at 500 m depth or lower. This means the roofs of the deposition tunnels is set at 500 m depth.

2.5.4 Mechanical properties

Description of the strategy and methodology with regard to rock mechanics and rock support is given by /Eriksson et al. 2009/. The only rock mechanical issue that had direct implications on the repository layout is the spalling in deposition holes. The results of /Eriksson et al. 2009/ show that the rock types with the lowest spalling strength in the area is the Ävrö granodiorite to quartz monzodiorite, which predominates both RSMA01 and RSMM01. The calculated maximum tangential stress may result in local spalling in deposition holes. This risk increases below 500 m.

The most favourable orientation of the deposition tunnels relative to the maximum horizontal principal stress is not always optimal considering the fracture pattern in the area. Rock mechanical analysis shows that wedge stability is not foreseen to cause any constructability problems. Therefore, minimizing the risk of spalling in deposition holes has been given priority before optimal orientations relative to prevalent fracture sets during the layout work.

Another rock mechanical issue is the increased fracturing that typically give block sizes in decimetre-scale in fine-grained dyke rocks of the area /see Carlsson and Christiansson 2007/. Since the occurrence of such rocks is rather evenly distributed among the rock domains in the repository volume /SKB 2008/, it had no impact on the layout work. The effect on constructability is, moreover, judged small to insignificant and can be solved by increasing the amount of reinforcement.

2.5.5 Hydraulic rock domains

Consideration must be taken to the heterogeneous hydraulic conditions amongst the fracture domains.

Using input from the design coordinator in reference to the assumed hydraulic properties of the fracture domains, an overall order of construction development (Chapter 4.1), in reference to the central area has been outlined. It is anticipated to have an order of development from the south-eastern corner of the area available, moving west along the southern part, turning north along the western border, and finally moving east to finalise the repository.

Using this order of development the major part of the hydraulic domain HRD_EW007 has the most unfavourable conditions from a hydraulic perspective and will be utilised as deposition area at the end of the repository construction time schedule.

3 Final repository layout

The results of the design process as described in this report have included a thorough analysis of all functions of the different elements constituting the deposition area, leading to an overall approach on how the repository could be developed and organised. Having this strategy in mind during the preparation of the layout, alternative possible configurations of the main- and deposition tunnels gradually could be ruled out during the design process, and no complete alternative layouts consequently had to be elaborated.

3.1 Functional studies

According to the UDP/D2 the layout work in D2 shall elaborate a conceptual plan for efficient and optimal strategy for the sequential construction of the underground facility providing a simultaneous step-wise excavation and deposition. The overall aim shall be to investigate and to demonstrate that the various construction operations do not disrupt each other at any time and do not conflict with any of the deposition activities.

A number of issues that should be taken into consideration, and the optimisation work shall in particular consider for each construction step, but not restricted to, items such as:

- Physical protection.
- Health and safety.
- Geological uncertainties.
- Strategies for investigation during the stepwise construction.
- Transport and hoisting efficiency from repository level to ground surface (actual time and transport distance per ton).
- Ventilation (number and placement of exhaust ventilation shafts).
- Environmentally economising.

To be able to study the complexity of the process of building the repository parallel to the deposition and backfilling, location based scheduling have been used to model and simulate the work process.

Line of Balance (LoB) is a graphical location based scheduling method that considers location explicitly as a dimension. Construction activities are defined regarding time frame, as well as resources such as equipment, materials and labour required performing the work. Using this methodology when studying the working process eliminates bottlenecks and, in this case, facilitates the process of having the deposition separated from the excavation work.

In a LoB-graph the production rate of an activity is the slope of a production line and is expressed in terms of units per time (Figure 3-1). Once the number of crews and the expected rate of output have been computed for each activity, the LoB-graph can be plotted. The number of units to be produced is plotted against time. The information needed is start, stop and where the activities are going to be carried out.

The basic outlines for the process involved in the construction of the repository as well as depositing canisters and backfilling was given by /SKB 2007a/. The outlines include the different processes, and provides estimated times for each process.

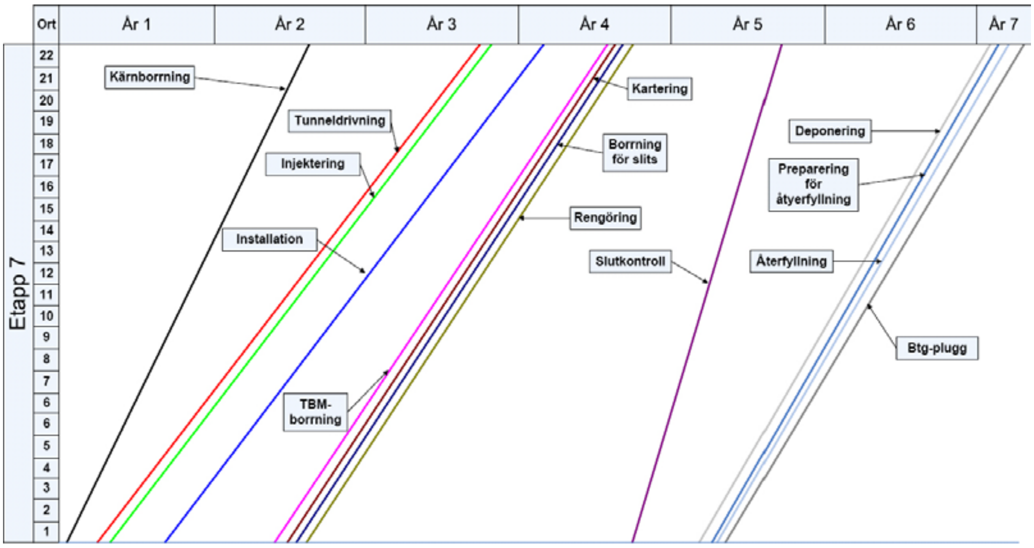


Figure 3-1. The graphical presentation of a LoB schedule. The figure shows important principles of the Line of Balance (LoB) method. In the LoB-graph each activity is represented by an inclining line. The X-axis represents time and the Y-axis represents the place where the activity is to take place.

Data concerning excavation work is given in Table 3-1. All data refers to a reference deposition tunnel, which is a 300 m long tunnel containing 36 canister positions /SKB 2008/.

The LoB-analysis was initiated by defining the activities of the first excavation step using the specifications according to Table 3-1 and 3-2 above. Using the resulting LoB-graph (Figure 3-1), optimisation of critical resources has been performed in order to obtain maximum performance within the scheduling process.

The optimisation has primarily been performed for the critical resources together with the relation between activities. Relation of activities constitutes in which order activities are being performed and how to avoid different activities being executed in the same location at the same time.

An important finding during the optimisation was that deposition never becomes critical to the operation.

3.1.1 Outline of construction steps

The design of the deposition area is controlled by the surface available for deposition together with the requirement in reference to the direction of the deposition tunnels /SKB 2008/. Another controlling requirement is that tunnel crossings between main- and deposition tunnels need to be functional.

In order to meet the demands on keeping canister transports and rock transports separated and at all times maintaining two separate escape routes, additional transport tunnels have to be deployed to the basic layout. These transport tunnels are not later to be used as deposition tunnels.

The resulting layout of main and transport tunnels are shown in Figure 3-2.

The size of each construction step have been optimized dependant on the following parameters:

- Establish deposition as early as possible – minimize size.
- Minimize the number of side changes – maximize size.
- To have the number of deposition positions as equal as possible between each construction step.

The first construction step will according to /SKB 2008/ contain 300 deposition positions. The time for conducting this initial deposition will be 3 years.

Table 3-1. Data concerning excavation works.

Activity and sub activities	Time per reference tunnel (weeks)	Critical resource
Core drilling • Core drilling for deposition tunnels. Detailed investigation of location and approval.	3.5	**Core drilling rig**
Excavating of deposition tunnel • Probing holes and grouting (3 weeks) • Gallery drilling • Charging • Blasting and ventilation • Mucking • Scaling and rock support	36	**Drilling rig** One rig provides for driving of three tunnels
Preparation of floor level • Drilling of benches. • Blasting of benches • Mucking		
Location survey, deposition holes • Cleansing • Installations • Location survey for deposition holes • Core drilling and display	16	**Installation team** 2 teams
TBM TBM • TBM-boring Cutting of wedge repository hole	36	**TBM** One TBM provides for one tunnel, 4–5 TBM in total
TBM supplementary work • Geological mapping of the deposition holes and covering with protection caps • Contour boring for concrete sealing • Scaling and cleaning of tunnel roof and tunnel walls	7	**Survey team**
Contour drilling for concrete sealing • Drilling	2	**Drill rig**
Finalizing work in deposition tunnel • Cleaning of deposition tunnel • Scaling • Shielding deposition tunnel	8	**Cleaning team**

Table 3-2. Data concerning deposition works.

Activity and subactivities	Time per reference tunnel (weeks)	Critical resource
Deposition • Final inspection of the deposition holes and overhaul of installations • Installation of bentonite blocks • Deposition	12	Deposition never becomes critical to the operation
Backfilling • Preparations for backfilling • Backfilling • Installation of filter and installation of concrete plug	20	**Backfilling machine** One machine provides for one tunnel

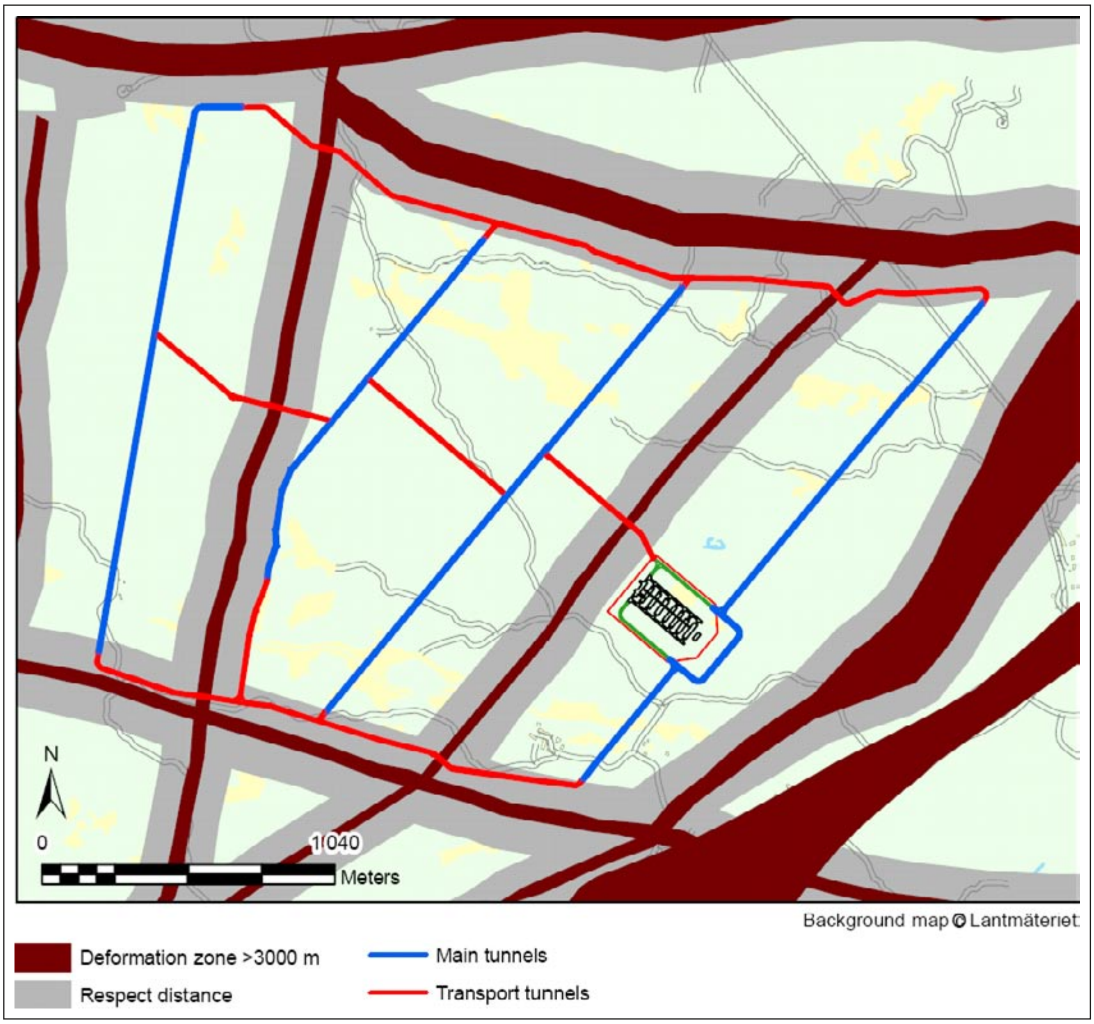


Figure 3-2. Layout of main and transport tunnels.

3.1.2 Separation by side change

The construction strategy *Separation by side change* is well described in previous SKB reports /SKB 2006/. The construction strategy simply requires the excavation and deposition activities to alternate sides as a deposition panel is excavated and filled. This requires that these two activities be tightly controlled to maintain production efficiency.

The functional studies that have been carried out for Laxemar show that there are two main disadvantages with the side-change strategy:

1. there must be at least three main tunnels available for side-change at a time, and
2. the reduction in construction efficiency as the rock excavation changes from one side to the other. When the last canister has been deposited before the side-change all backfill works (belonging to the deposition works) in that deposition tunnel remains, which will need approximately 24 weeks to complete. If the deposition of canisters immediately continues at the other side, this would requires the excavation work to stop for a minimum of 24 weeks at both sides, since deposition work would be ongoing on both sides.

Even though the layout consists of four main tunnels, only two main tunnels are available when the deposition of the first canister takes place. Hence this constrain means that the separation by side-change method cannot be effectively used in Laxemar.

With the main objective to handle the negative consequences of side changes the construction strategy of the Linear Development Method, which includes separation by doors/walls, was developed (see 3.1.3).

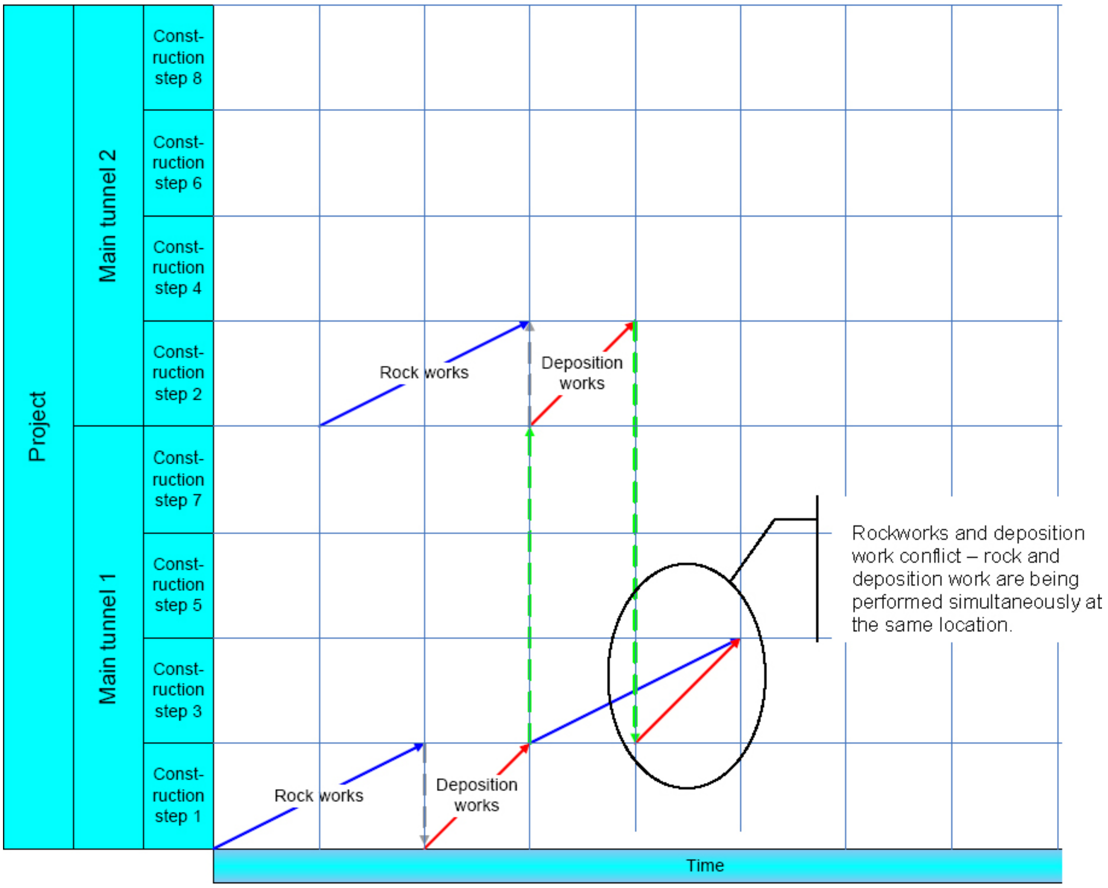


Figure 3-3. *The figure shows a conceptual outline in a LoB-graph of the relationship between rockwork and deposition work when conducting side-change. As shown, two main tunnels are not sufficient to keep rock and deposition work apart. To avoid interruption in the deposition work, rock works will need to be distributed in two main tunnels and deposition work need to be carried out in a third main tunnel.*

3.1.3 Linear Development Method

The basic idea of the construction strategy Linear Development Method which includes separation of tunnel segments by doors/walls, is that rock works and deposition works are driven forward after one another without any side-change. Accordingly, the construction steps will lie after one another in a single main tunnel.

The principle of construction is that deposition tunnels are constructed simultaneously as deposition takes place in already prepared deposition tunnels in the same main tunnel. To separate these two activities a barrier (wall/door) has to be constructed (Figure 3-4).

The construction of deposition tunnels in an area continues until deposition of canisters begins. A separating door/wall is installed in the main tunnel at the end of the extension phase. The door/wall is installed so that two tunnel widths are located separately from other tunnels to create the necessary safety distance of 80 m to blasting work in the next extension phase /SKB 2008/.

The construction then continues forward in the main tunnel beyond the buffer tunnels, while deposition begins in the preceding phase. When the first round of deposition is completed a new door/wall is installed so that the four latest constructed tunnels compose a buffer during the next phase. The construction continues beyond the buffer, at the same time as deposition begins at the area where construction has just been finished.

Backfilling work now begins in the fully deposited phase. These procedures allow the rockwork, deposition and backfilling to advance along the main tunnel without any pauses for side-change or other interruptions. Neither is there any interruption when changing to another main tunnel.

The distribution of the previously described construction steps have been revised since the construction steps will be lying after one another (Figure 3-5).

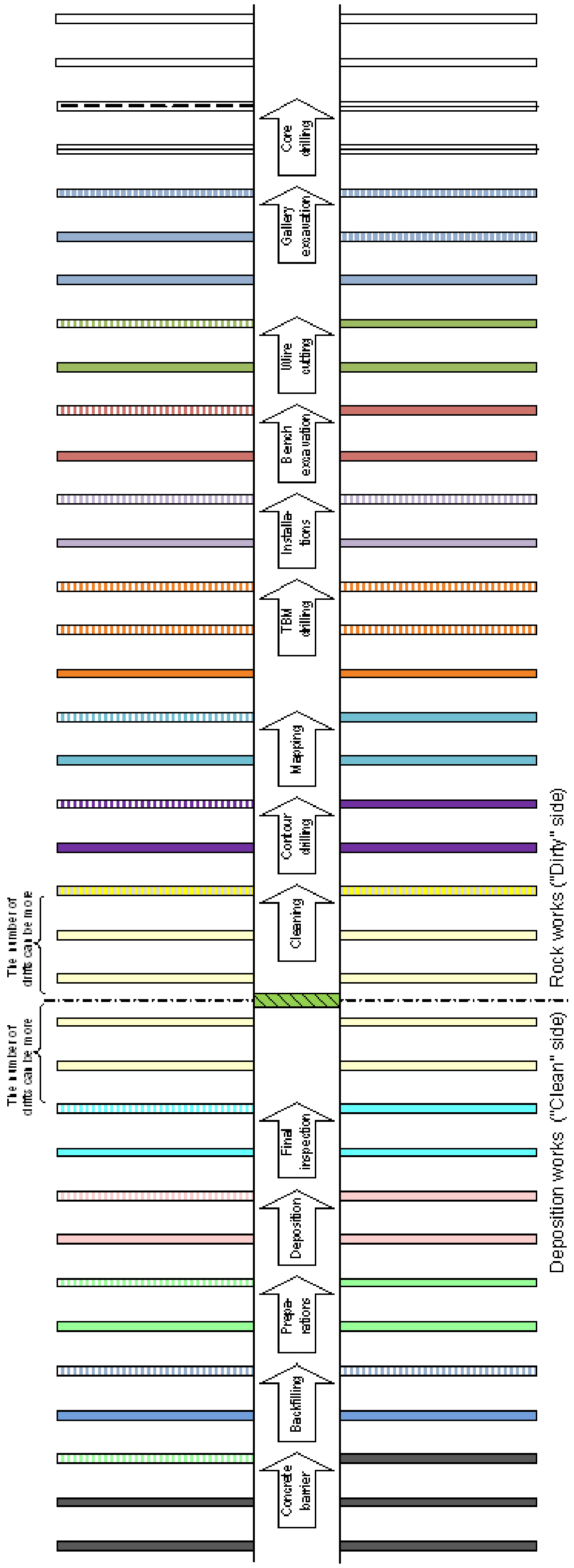


***Figure 3-4.** The linear development construction method as proposed for the Laxemar site.*

***Figure 3-5.** Outline of construction steps using the linear development construction method.*

3.1.4 Transport work

With the objective to reduce the transport work, the shortest transport route for rock materials, without interfering with canister transports and airflow, has been chosen at all times.

Since no feasible layout, from a functional point of view, has been prepared for the side-change alternative, the estimated transport work for this alternative has not been calculated.

In Table 3-3 excavated rock volumes, length of all tunnels and the total transport work is presented for the linear development method.

3.1.5 Health and safety

An overall risk assessment has been made according to AFS 2003:2 /Arbetsmiljöverket 2003/. The risk assessment is presented in Table 3-4.

Table 3-3. Transport work.

Part of final repository	Transport tunnels (m^3)	Main tunnels (m^3)	Deposition tunnels (m^3)	Total volume (m^3)	Length of transport tunnel (m)	Length of main tunnel (m)	Transport work (ton × km)
Leg 1	30,240	45,360		75,600	756	756	138,883
Leg 2		75,120		75,120	0	1,252	162,259
Leg 3	22,000			22,000	550	0	16,335
Leg 4	11,560			11,560	289	0	51,703
Leg 5	26,000			26,000	650	0	86,697
Leg 6	16,000	79,680		95,680	400	1,328	702,808
Leg 7 + 9		64,980		64,980	0	1,083	428,264
Leg 8	28,840			28,840	721	0	132,376
Leg 10		43,140		43,140	0	719	223,580
Leg 11	44,000	54,060		98,060	1,100	901	718,809
Leg 12		48,720		48,720	0	812	125,756
Leg 13	51,660	77,490		129,150	1,292	1,292	912,683
Leg 14	Will not be excavated				700	0	0
Leg 15		26,100		26,100		460	42,282
Construction step 1			76,095	76,095			108,481
Construction step 2			71,820	71,820			102,387
Construction step 3			79,800	79,800			338,272
Construction step 4			68,400	68,400			241,931
Construction step 5			79,800	79,800			226,233
Construction step 6			102,600	102,600			202,225
Construction step 7			105,754	105,754			739,823
Construction step 8			85,500	85,500			540,420
Construction step 9			79,800	79,800			564,721
Construction step 10			91,200	91,200			719,267
Construction step 11			85,500	85,500			561,196
Construction step 12			124,545	124,545			1,197,799
Construction step 13			78,090	78,090			442,612
Construction step 14			89,794	89,794			421,792
Construction step 15			102,600	102,600			91,417
Construction step 16			125,400	125,400			247,163
Construction step 17			132,240	132,240			424,887
Construction step 18			119,700	119,700			374,577
Construction step 19			125,400	125,400			254,951
Summa	**230,300**	**514,650**	**1,824,038**	**2,568,988**	**6,458**	**8,603**	**11,542,587**

Table 3-4. Risk assessment according to AFS 2003:2.

AFS 2003:2	Source of risk	What may happen?	Preventive/damage reducing activity	Estimation of probability and consequence, in relation to work environment
General §2	Relates to Investigation and risk assessment in reference to geology and rock mechanics	Insufficient knowledge in reference to rock behaviour may cause rock mass to collapse and water to flood.	Make sure of having sufficient knowledge by complementary studies.	Probability is low Consequence is high
General §3–§8	Relates to working methods, equipment, knowledge, communication, protective gear, light, warning signs and traffic rules	Work related injuries	Education and complementary studies	Probability is medium Consequence is medium/high
Traffic § 9	Speed and type of vehicles, visibility conditions, presence of pedestrians and heavy machinery	Traffic accidents: between heavy vehicles, heavy vehicles and trucks and personnel.	Traffic signs and speed control. Separation of vehicles and pedestrians.	Probability is medium Consequences medium to high
Ventilation §10	Incorrect design, documentation, dimension, alarm function	Incorrect ventilation, accidents,	Conduct separate studies on ventilation issues.	Probability is low Consequence is small/medium
Remote controlling §11–§13	Incorrect maintenance, methods for investigation at malfunction	Accidents	Cannot be handled at present stage.	Probability is low/medium Consequence is medium/high
Vehicles §14–§19	Smoke, gases, fuel	Air pollution, accidents	Sufficient ventilation and using vehicles equipped with exhaust gas filter systems.	Probability is medium/high Consequence is medium/high
Transport roads §20	Incorrect standard, pour protective activities	Traffic accidents resulting in damaged equipments and personnel injuries	Maintaining high standard on transport roads	Probability is low/medium Consequence is medium/high
Radon §21–§22	Insufficient ventilation, methods for detection, incorrect detection limits	Incorrect detection, increased risk for cancer	Continuous radon control	Probability is low Consequence is high
Evacuation, rescue, fire protection §23–§28	Inadequate action plans, Inadequate fire fighting resources, incorrect indication of alarm, inadequate marked out escape routes, Inadequate rescue chambers	Risk for suffocation, fire-related accidents	Regularity in checking and updating action plans regarding fire-fighting, alarms and rescue chambers	Probability is low Consequence is high
Rock drilling §29–§34	Spread of dust, inadequate action plans, noise, oil mist in the air	Ill health, work related injuries, accidents	Submitted to separate studies	Probability is medium/high Consequence is high
Handling of boulders and mechanical demolishing §35	Incorrect investigation, remaining blast agent	Work related injuries	A strict control of areas where explosives have been used	Probability is low/medium Consequence is high
Handling of rock §36	Incorrect investigations, remaining blast agent	Work related injuries, accidents	A strict control of areas where explosives have been used	Probability is low Consequence is variable
Rock inspection, scaling, rock reinforcements and maintenance of rock chamber §37–§40	Incorrect investigations	Work related injuries, accidents	Rules specifically addressed to the issue in question. Only certified personal to do rock inspection, scaling and rock reinforcement	Probability is low Consequence is medium/high
Elevators §41	Incorrect installation, inspection and control	Work related injuries, accidents	Only certified personal to do inspection and control. Clear rules on how to operate elevators	Probability is low Consequence is high
Pregnant and breast feeding employees §42	Ill health	Ill health	Risk assessment on work environment	Probability is low Consequence is high

3.2 Layout strategies

The underground facility comprises underground openings required to accommodate the sub-surface equipment and installations needed for the construction, operation and maintenance of the final repository facility. The underground openings consist of repository access, central area and deposition area.

The layout work describes configuration of different parts of the facility, encompassing i.e. ramp and shafts, central area and deposition area.

Site specific strategies have been compiled for the different parts of the facility, accounting for the overall objectives and purposes of the work based on /SKB 2007a/ and /SKB 2008/. The facilities and operation are also adapted to avoid unfavourable environmental consequences.

The main layout strategies have been as follows to:

- Optimise efficient utilisation of available deposition area.
- Optimise the layout based on lithology and deformation zones.
- Optimise the layout plan due to stress.
- Optimise the ventilation.
- Optimise the water drainage.

Initially, the requirements on separation of main activities was studied according to /SKB 2007a/. However, this construction strategy has some disadvantages, which has been described earlier (see 3.1.2). With the objective to handle these disadvantages and also to increase flexibility for the future step-by-step development of the repository, the linear development method, which includes separation of main activities by doors/walls in the main tunnels, has been introduced.

The overall applied strategy with regard to layout for the underground facility of the final repository is to optimise the number of deposition hole positions taking into account the available rock volume, the geographical limitations, condition of the bedrock such as rock domains, fracture frequency/fracture zones and hydrulic conditions.

3.2.1 Uncertainties

The current uncertainties are caused by uncertainties in determine spatial outline and geological properties of the rock mass. In addition to these, the large range in the proportion of loss concerning deposition positions, according to /SKB 2008/, is a significant uncertainty in the potential of the chosen location of the final repository in Laxemar.

Uncertainty in spatial outline

The boundaries of different rock and fracture domains are not clear-cut limits; they consist as a rule of gradual transitions. Similarly, the location and boundaries of deformation zones are difficult to determine unequivocally. Determining the boundary between the rock domains is important as they may have different thermal characteristics which in turn influence the distance between deposition holes.

Determining the boundary between rock domains is important because they have different rock mechanic and hydrogeological characteristics that influence construction methods and building capacity.

More detailed information on the location of major deformation zones requiring respect distances may affect the final layout.

3.3 Layout of surface facilities, ramp, shaft and central area

3.3.1 Ramp

The function of the ramp is to provide transport route for vehicle traffic between the surface operation area and the underground central area. The transports during the operation of the facility comprise casks with canisters, construction and installation material, machinery, etc. In addition, the ramp functions as secondary escape route from the underground area as well as secondary route for the Rescue service. Elevator normally does the transport of personnel.

The position of the ramp depends on the surface facility and the central area. Since the design coordinator gave the starting point of the ramp, no optimising has been performed regarding connection to topography or rock surface.

The connection of ramp to the central area has been optimised in order to as far as possible resemble the layout of the reference design (Figure 3-6).

The surface facility comprises various civil structures and buildings above ground, which are required for the operation, support and supervision of the final repository facility. The location and positioning of the surface facility in relation to the underground facility are essentially determined by the location of the four shafts (skip shaft, elevator shaft and ventilation shafts), together with a safety distance in relation to the high voltage power lines north of the facilities (Figure 3-7). To a lesser extent, the location of the surface facility is also restrained by the ramp.

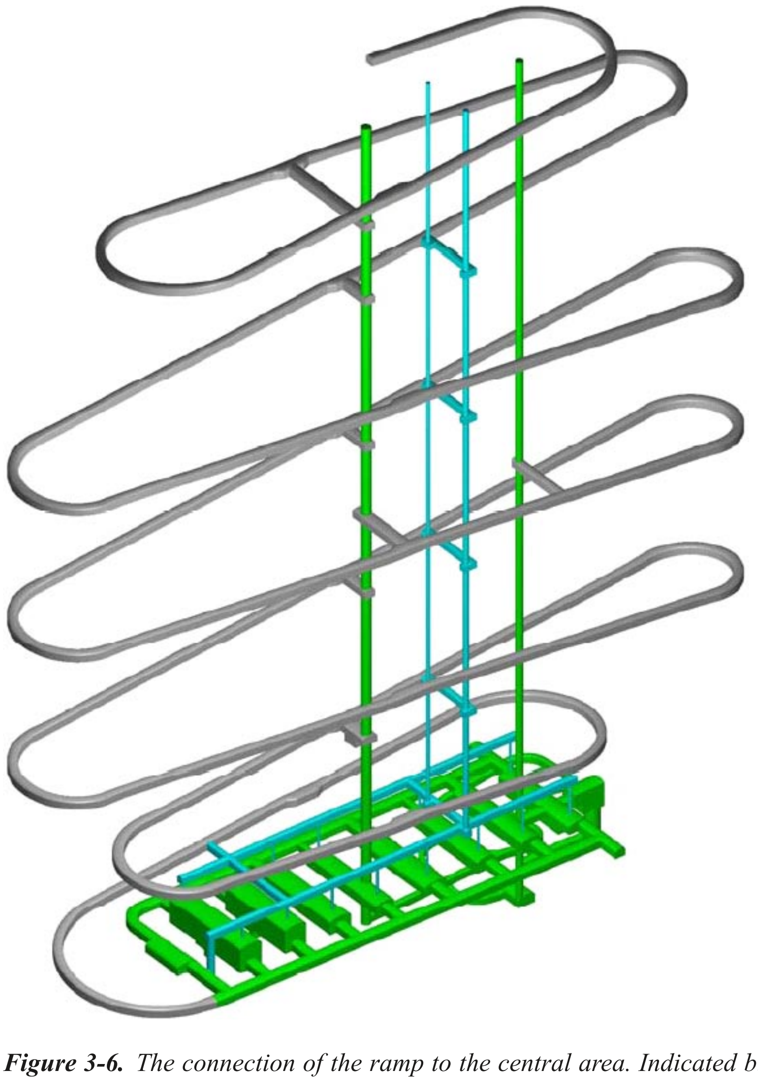


Figure 3-6. *The connection of the ramp to the central area. Indicated blue shafts are part of the ventilation system.*

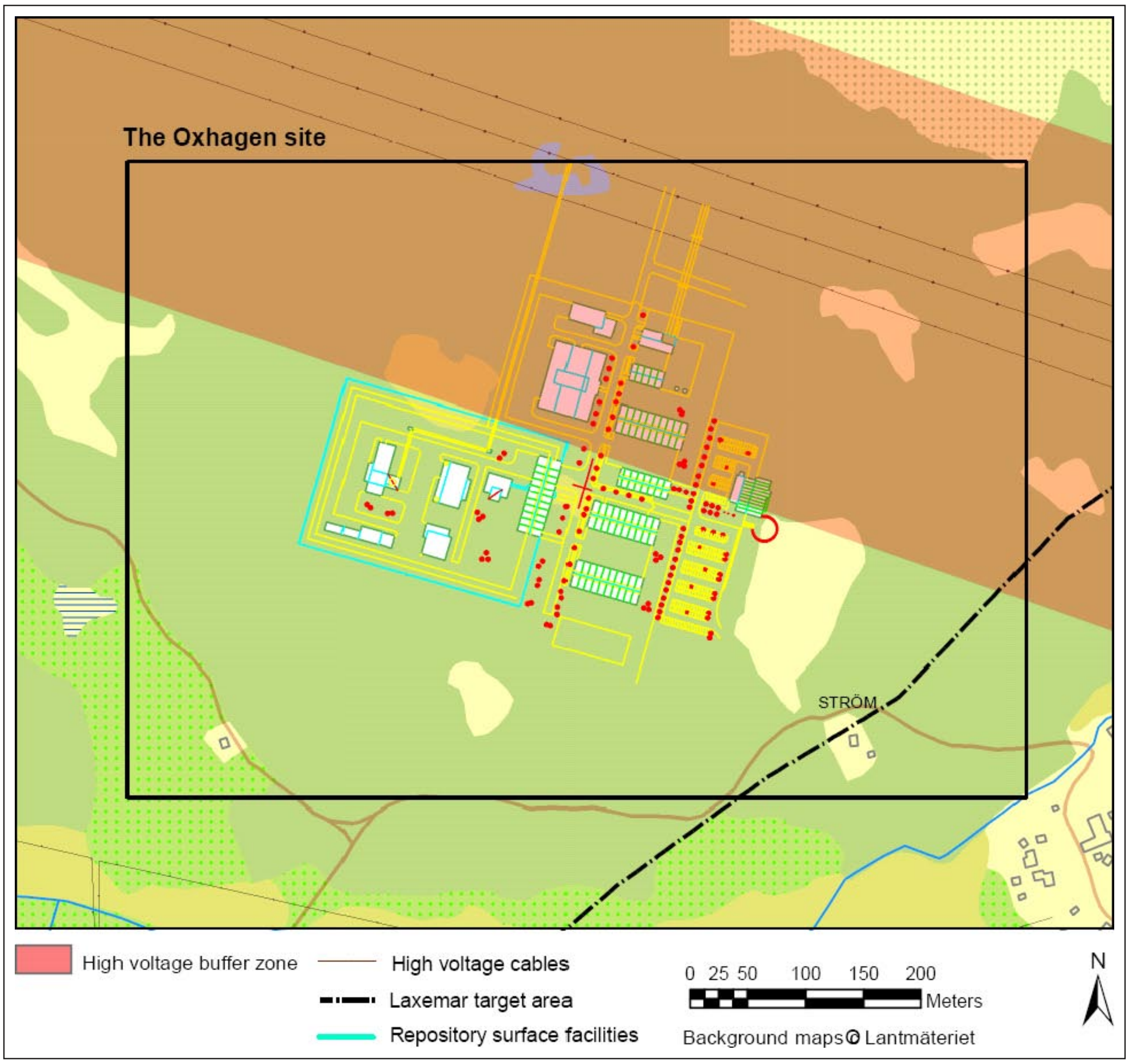


Figure 3-7. *The operational area as projected on ground surface. A buffer zone (in red) has been projected in relation to the high voltage power lines north of the area. The buffer zone is 200 meters wide, which have been guiding the localization of buildings where staff permanently resides.*

3.4 Layout of ventilation shafts

The deposition area must have a sufficient number of ventilation shafts to ensure a favourable and safe working environment and to enable ventilation at the deposition level. Results from functional studies have specified positions for two ventilation shafts within the deposition area (Figure 3-8).

The positions of the ventilation shafts are chosen from a best ventilation point of view. This means that the airflow has been taken in high consideration in which order the construction steps are developed. The positions of the ventilation shafts are also chosen in respect of transportation routes for the excavated rock, and the transportation routes for the canisters to be deposited, in order to minimize the number of doors/walls to be built.

Thus, the way polluted air is flowing is never to cross any transportation routes of the canisters or enter a construction step where deposition work is carried out after the air is polluted in areas where rock works are carried out.

Figure 3-8. *Positioning of the ventilation shafts.*

3.5 Layout of deposition area

The layout comprises the following main features (Figure 3-9 and Figure 3-10):

- Four main tunnels, allowing optimal utilisation of the available area at 500 m depth. With a maximum length for deposition tunnels of ≤300 m, four main tunnels will be required in order to cover the available target area with deposition tunnels.
- The configuration of the deposition tunnels will maximise the number of positions, and still no or only small problems with spalling in deposition holes is expected to occur.

The deposition area consists in total of 104,149 m of tunnels, of which slightly more than 8% is in modelled deformation zones.

Of the transportation tunnels are slightly more than 80% located within deformation zones or respect distances to major zones.

The total distance transport tunnels within the major zones NE107A and NS059A amounts to 256 m and within respect distances to such zones 5,015 m.

The major deformation zones or their respect distances do not intersect with other facility parts of the deposition area.

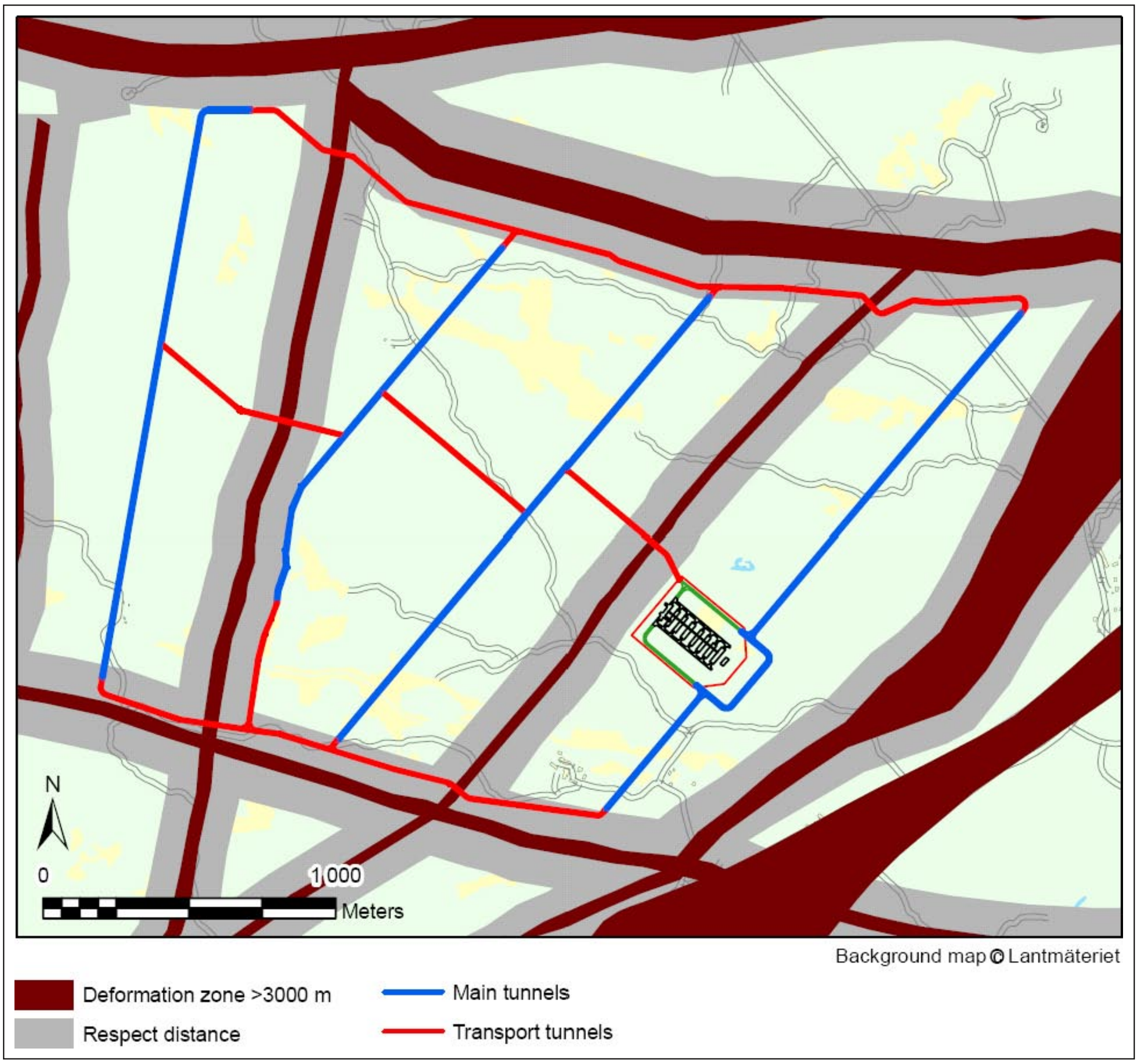


Figure 3-9. *The proposed outline of main and transport tunnels for the Laxemar site.*

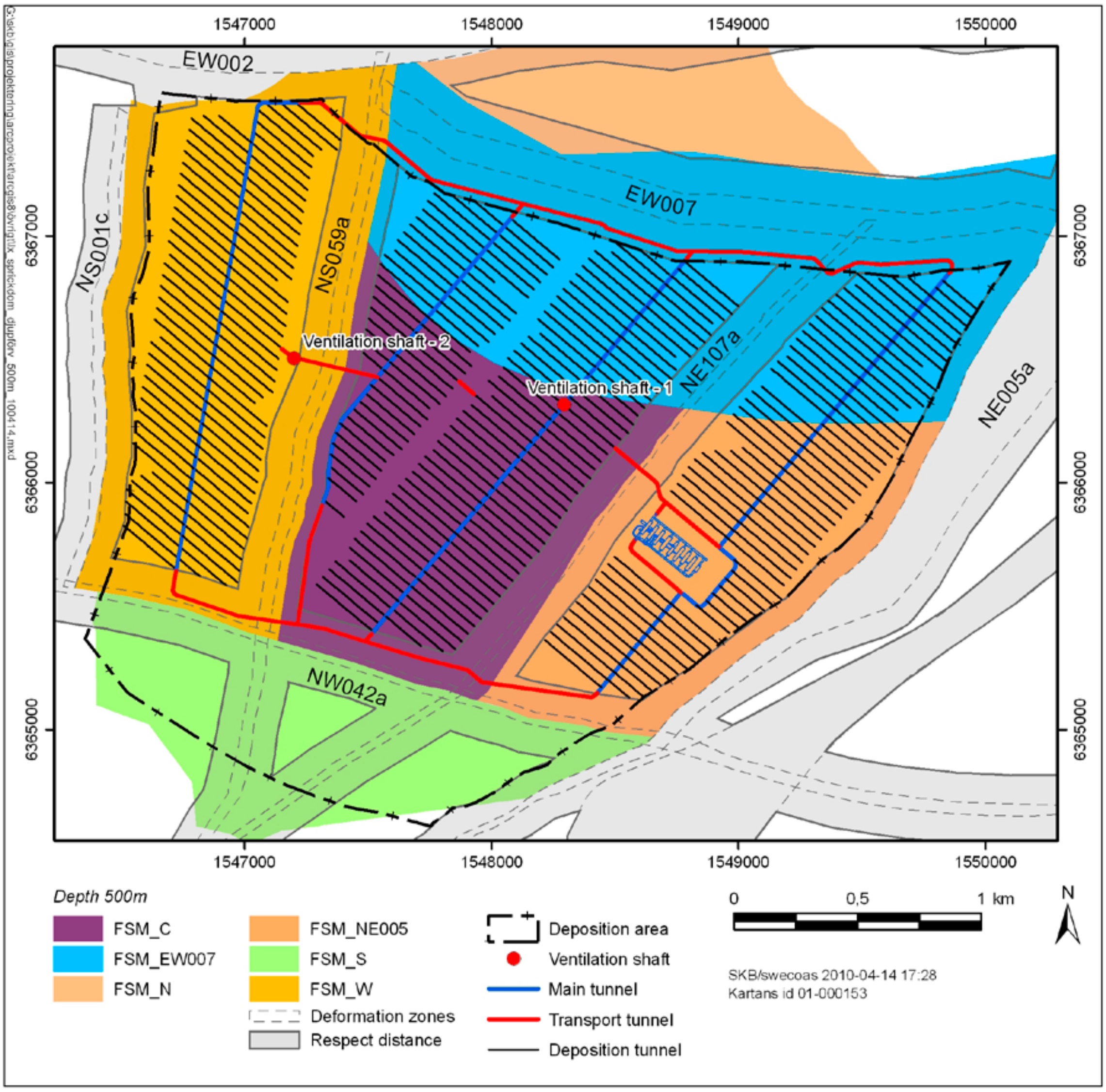


***Figure 3-10.** The complete proposed layout for the Laxemar site, including the deposition tunnels.*

A total of nine modelled deformation zones in the length interval 1–3 km, and eleven zones defined in single boreholes and modelled as discs with a standard radius of 564 m are involved in the deposition area. Three of these zones (EW946A, KLX07_DZ10 and KLX11_DZ11) are gently dipping with dips less than 30°. About 2% (in relation to length) of the deposition tunnels and 2% of the main tunnels are located within these gently dipping zones.

For presentation purposes, a schematic system has been developed to visualize the number of deposition hole positions, according to the proposed layout (Figure 3-11).

The layout has also been sub-sectioned based on rock-, fracture- and hydraulic domains in accordance with Figure 3-12, Figure 3-13 and Figure 3-14 below.

The total number (bulk capacity) of deposition hole positions may be appreciated in Figure 3-15 below.

The number of deposition hole positions per rock domain is shown in Figure 3-16.

The number of deposition hole positions per fracture domain is shown in Figure 3-17.

The number of deposition hole positions per hydraulic domain is shown in Figure 3-18.

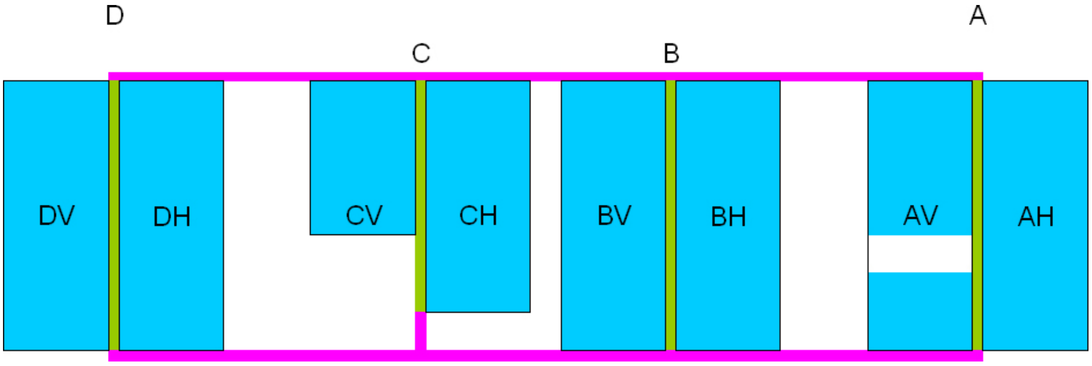


Figure 3-11. The figure shows a schematic presentation of the layout. The four main tunnels are abbreviated A, B, C and D. Accordingly, the deposition area has been divided into sub areas A, B, C and D, delineated by the configuration of the major deformation zones. The sub areas have been further divided into a left and right side of main the tunnel, hence the V and H.

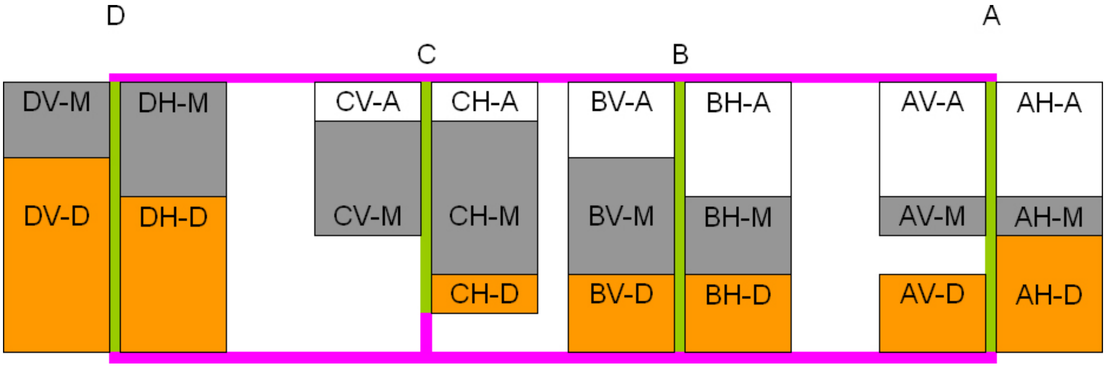


***Figure 3-12.** Splitting of the layout based on rock domains. Sub division in accordance with Figure 3-11, with the addition of abbreviations for rock domains (A, D and M).*

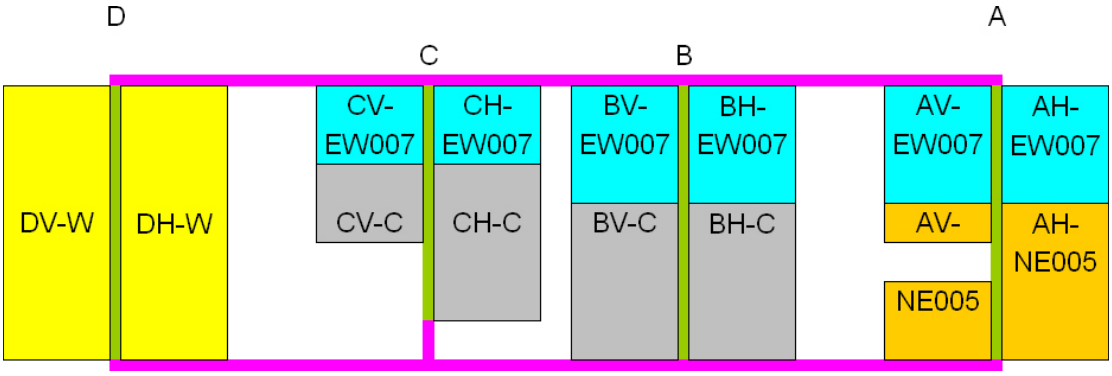


***Figure 3-13.** Splitting of the layout based on fracture domains. Sub division in accordance with Figure 3-11, with the addition of abbreviations for fracture domains (EW007, NE005, C and W).*

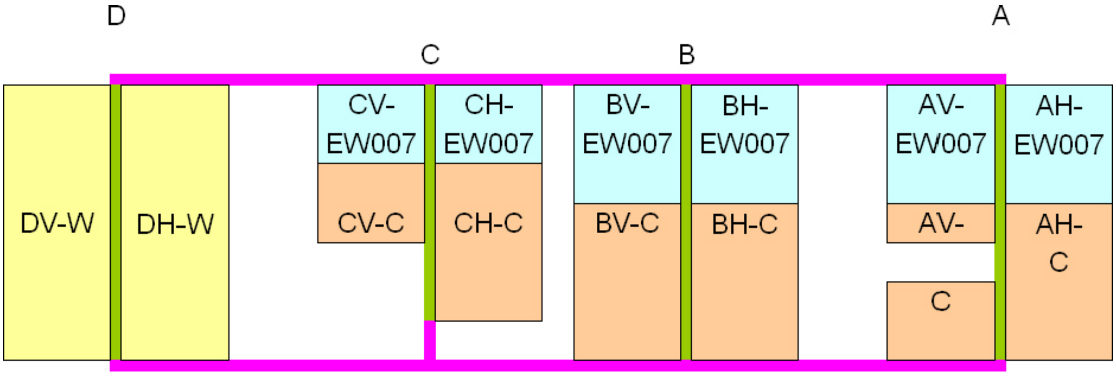


Figure 3-14. *Splitting of the layout based on hydraulic rock domains. Sub division in accordance with Figure 3-11, with the addition of abbreviations for hydraulic domains (EW007, C and W).*

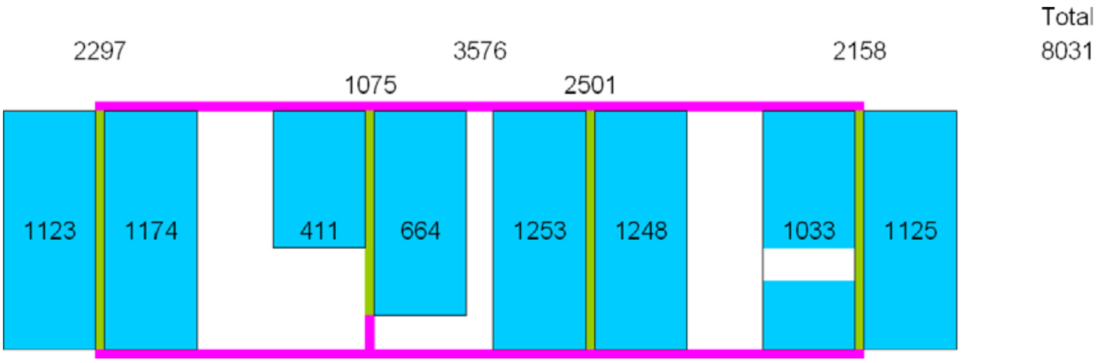


Figure 3-15. *Figure shows the number of deposition hole positions in total, and by sub area. Sub division in accordance with Figure 3-11.*

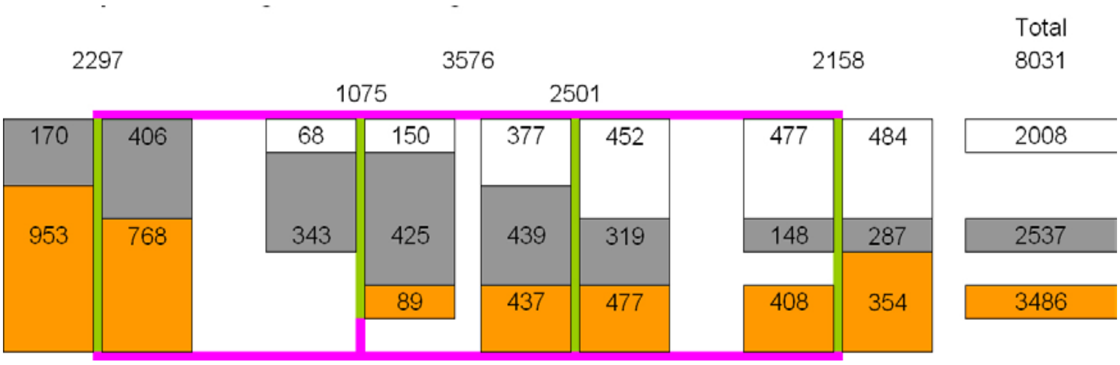


Figure 3-16. *Figure shows the number of deposition hole positions by rock domain. Sub division in accordance with Figure 3-12.*

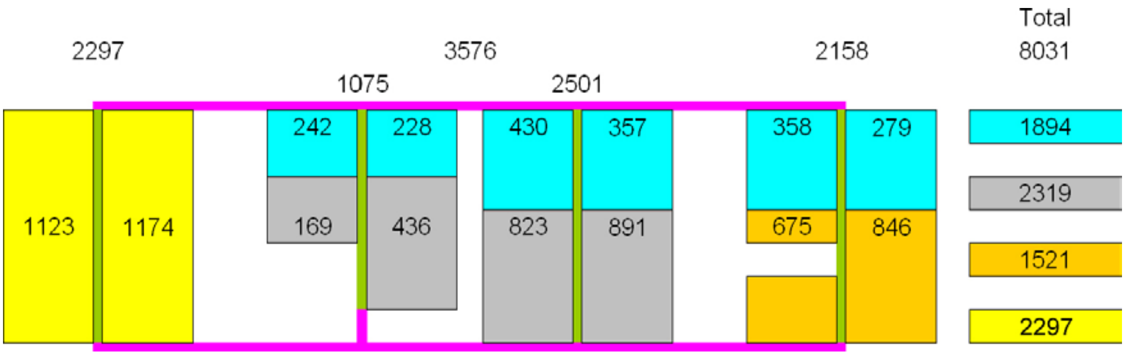


Figure 3-17. *Figure shows the number of deposition hole positions by fracture domain. Sub division in accordance with Figure 3-13.*

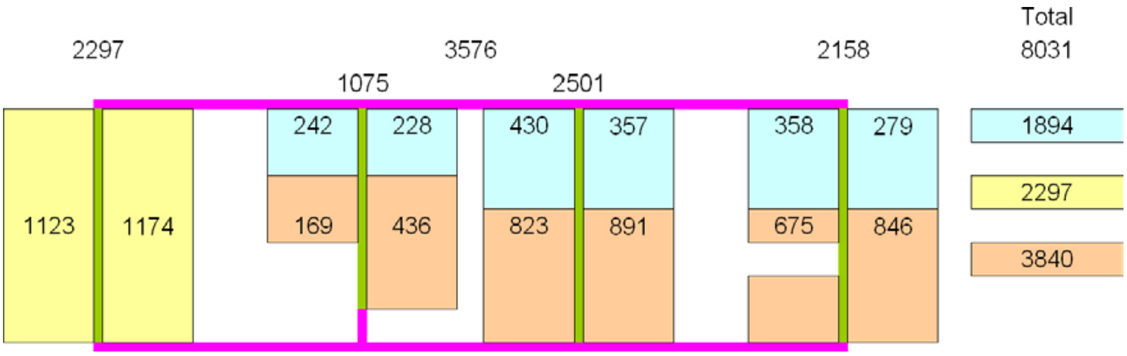


Figure 3-18. *Figure shows the number of deposition hole positions by hydraulic domain. Sub division in accordance with Figure 3-14.*

3.5.1 Drainage system

Drainage of the deposition area is arranged by means of a gravity system, where all tunnels are inclined 1:100 towards local pumping pits located in the main-/transport tunnel system (Figure 3-15). Local pumping pits are in general arranged at a distance of 1 km from each other, allowing the maximum height difference in the repository being limited to approximately 5 m.

From the local pumping pits the drainage water is pumped up and on to the next section of the deposition area, and by gravity subsequently led further on until it reaches next pumping pit or the central area. At the central area temporary storage basins for removal of sediments and oil fragments is arranged, and from these basins the water is pumped up to the surface water treatment plant.

The water handling system will be designed to withstand a power cut of minimum 24 hours from the central area electrical system. In case of emergency as a major fire, explosion, etc, jeopardizing the power supply for longer periods, an additional storage capacity for drainage water may also be arranged by an automatic overflow system leading surplus drainage water to the bottom of the skip shaft.

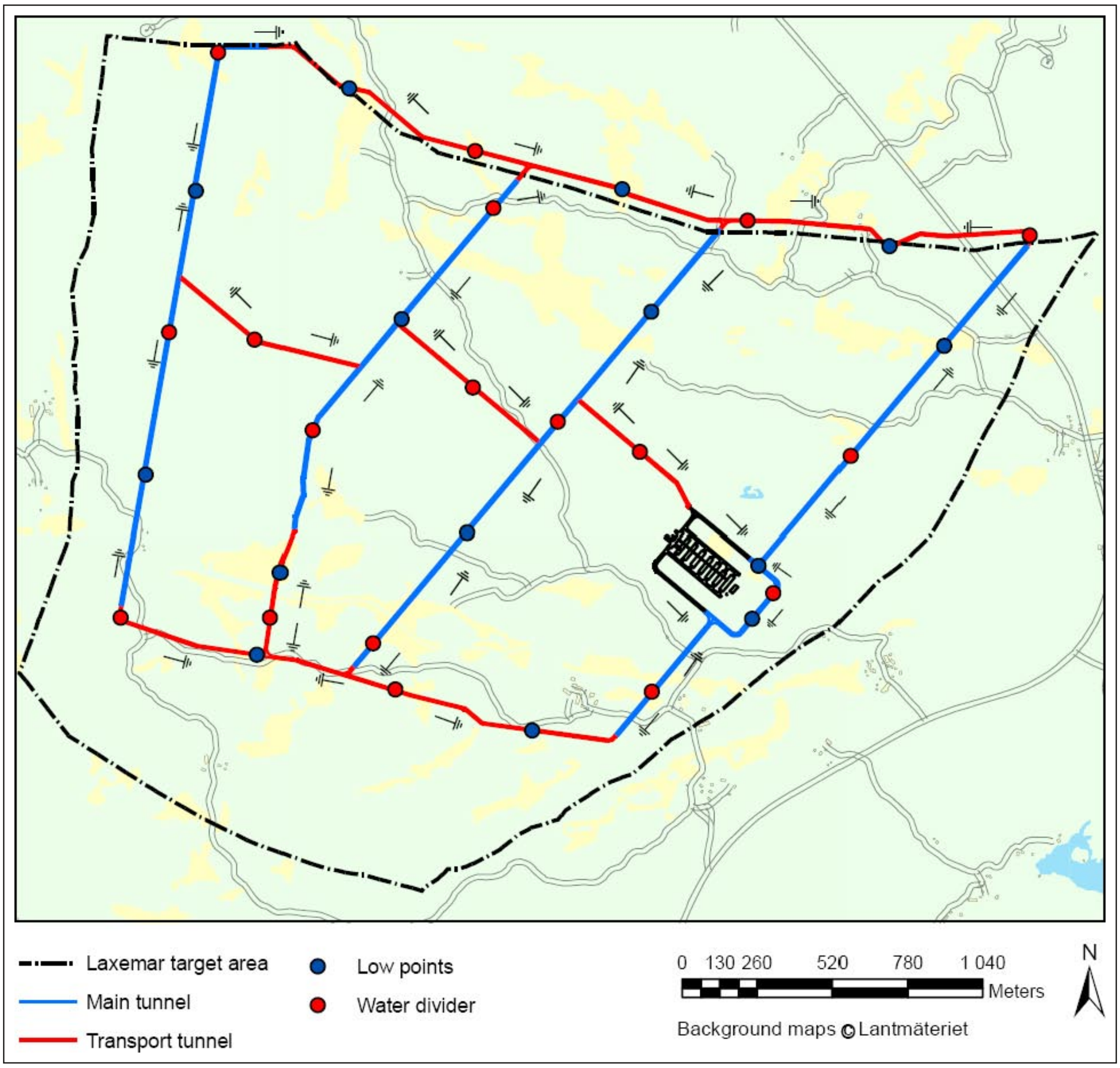


Figure 3-19. *Figure shows the drainage system plan for the deposition area. The water will run from higher points (water divider) to the lower point where it will be pumped away.*

3.6 Estimated excavated volumes

In order to measure and calculate the excavated rock volumes for main and transport tunnels, all tunnels have been sub sectioned into manageable constructions steps, in the following called *legs*. The sub sectioning may be studied in Figure 3-20.

Estimates of excavation volumes are presented in Table 3-5. The values represent undisturbed theoretical rock volumes based on the proposed 3D layout.

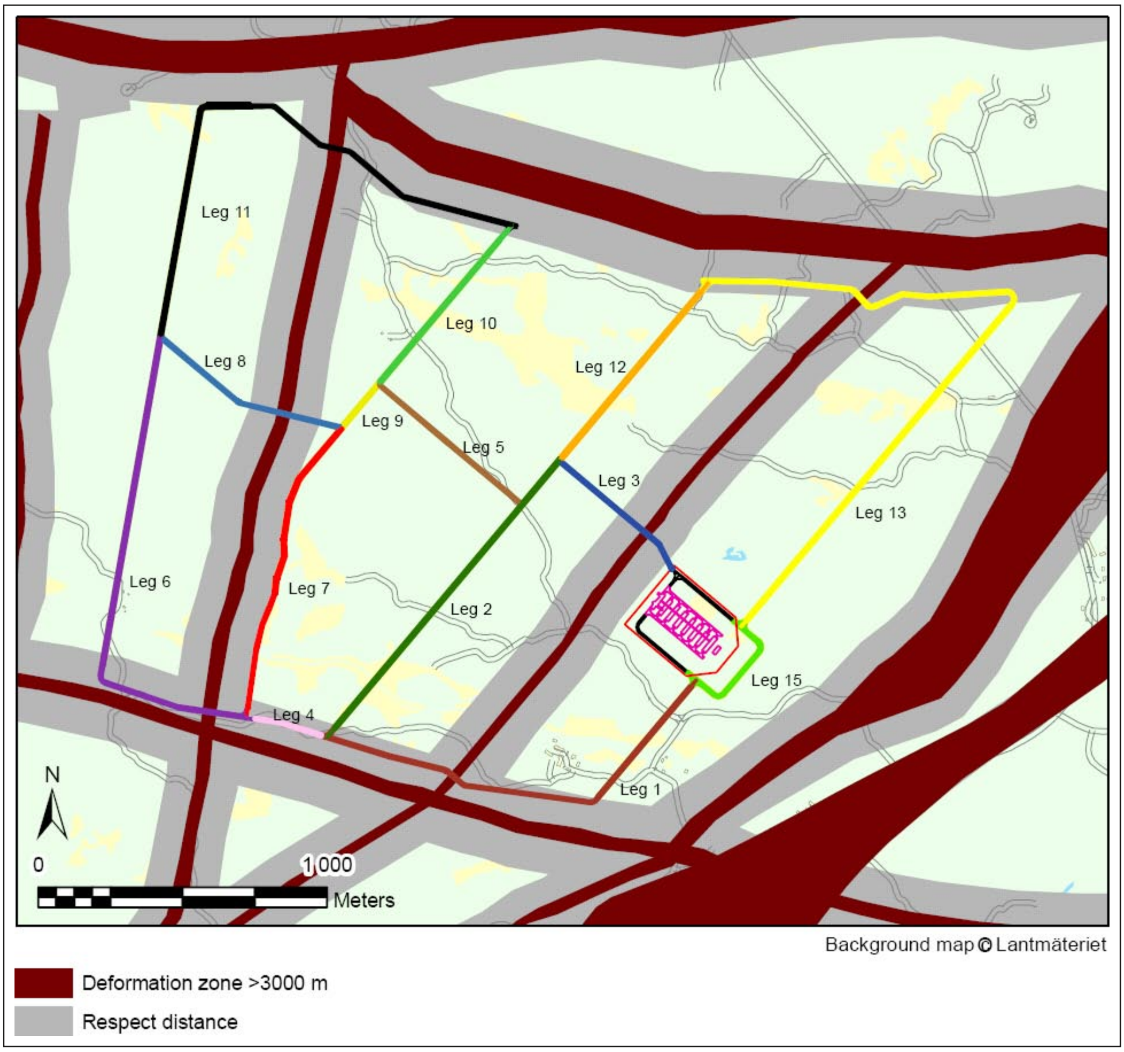


Figure 3-20. *Main and transport tunnels sub-sectioned into legs.*

Table 3-5. Excavated rock volumes in the deposition area.

Part of final repository	Transport tunnels (m^3)	Main tunnels (m^3)	Deposition tunnels (m^3)	Total volume (m^3)	Length of transport tunnel (m)	Length of main tunnel (m)
Leg 1	30,240	45,360		75,600	756	756
Leg 2		75,120		75,120	0	1,252
Leg 3	22,000			22,000	550	0
Leg 4	11,560			11,560	289	0
Leg 5	26,000			26,000	650	0
Leg 6	16,000	79,680		95,680	400	1,328
Leg 7 + 9		64,980		64,980	0	1,083
Leg 8	28,840			28,840	721	0
Leg 10		43,140		43,140	0	719
Leg 11	44,000	54,060		98,060	1,100	901
Leg 12		48,720		48,720	0	812
Leg 13	51,660	77,490		129,150	1,292	1,292
Leg 14 (will not be excavated)					700	0
Leg 15		26,100		26,100		460
Construction step 1			76,095	76,095		
Construction step 2			71,820	71,820		
Construction step 3			79,800	79,800		
Construction step 4			68,400	68,400		
Construction step 5			79,800	79,800		
Construction step 6			102,600	102,600		
Construction step 7			105,754	105,754		
Construction step 8			85,500	85,500		
Construction step 9			79,800	79,800		
Construction step 10			91,200	91,200		
Construction step 11			85,500	85,500		
Construction step 12			124,545	124,545		
Construction step 13			78,090	78,090		
Construction step 14			89,794	89,794		
Construction step 15			102,600	102,600		
Construction step 16			125,400	125,400		
Construction step 17			132,240	132,240		
Construction step 18			119,700	119,700		
Construction step 19			125,400	125,400		
Sum	**230,300**	**514,650**	**1,824,038**	**2,568,988**	**6,458**	**8,603**

4 Proposed construction plan for the repository area

4.1 Construction plan

The following construction plan precludes the needed initial construction of the access ramp, shafts and central area. The order of development for the construction steps is discussed in Chapter 2.5.3.

All tunnels have been divided into excavation legs in accordance with Figure 3-20.

PERIOD: year 0–9.8

Excavation and deposition works in construction steps 1–4.

The excavation sequence begins with leg 1–3 and leg 15 (Figure 4-1). Excavation work starts from the Central area, with investigation tunnels and thus defines the year zero of excavation work of the transport and main tunnels. These tunnels will subsequently be enlarged to form the main tunnels and will be finalized after 7.4 years.

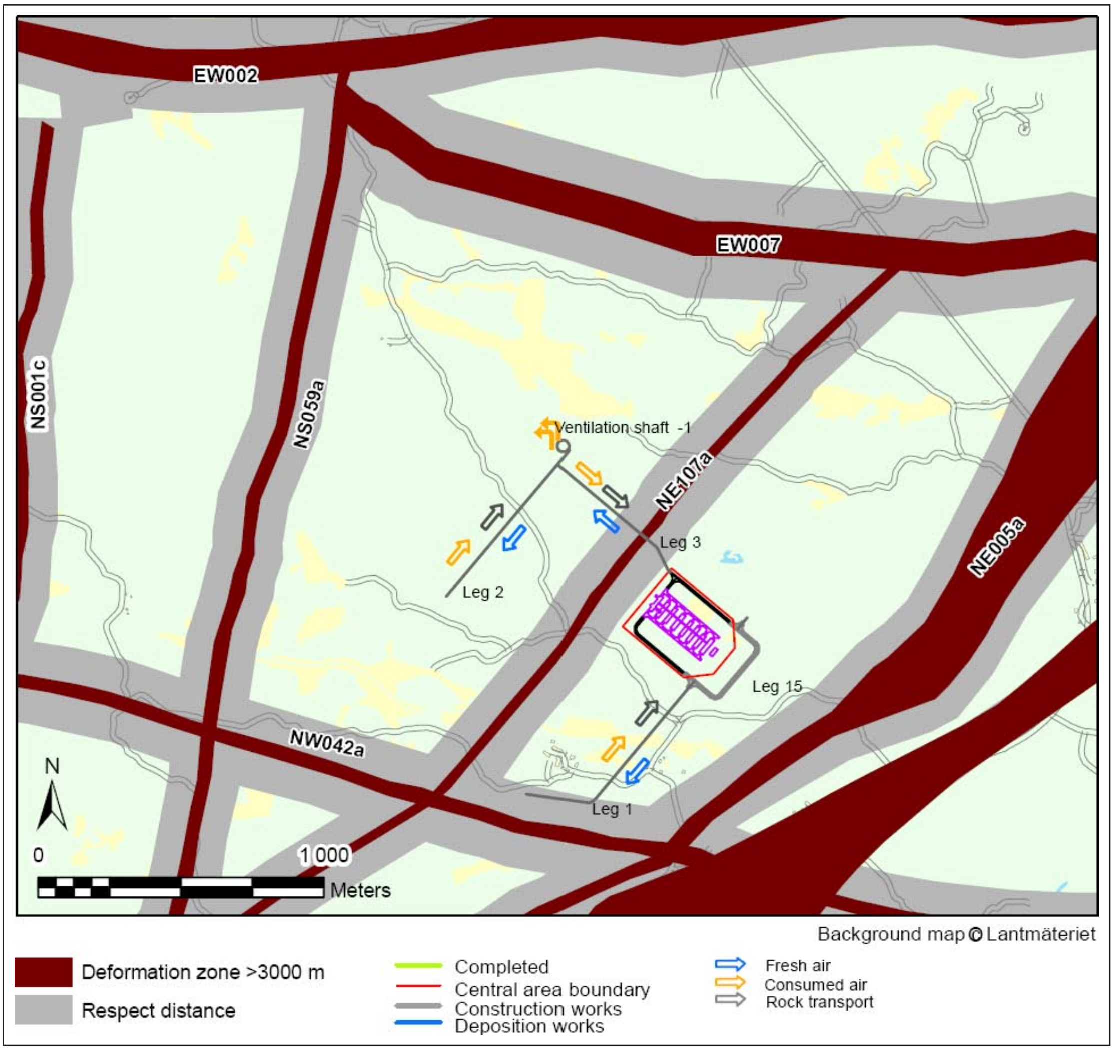


Figure 4-1. Development of leg 1–3, leg 15 and the first ventilation shaft.

A first exhaust ventilation shaft, located remotely from the central area, is drilled and raise-bored followed by excavation of a series of deposition tunnels. The drilling of the ventilation shaft starts at the same time as the first excavation work begins and will be finalized after approximately 3 years.

Excavation in the 1st construction step will commence year 4.3 and will be finalized in year 6.5 (Figure 4-2).

The excavation volumes of leg 1–3, leg 15 and construction step-1 will amount to approximately 275,000 m^3.

Excavation in the 2nd construction step will commence year 5.9 (Figure 4-3).

The excavation volumes of construction step-2 will amount to approximately 76,000 m^3.

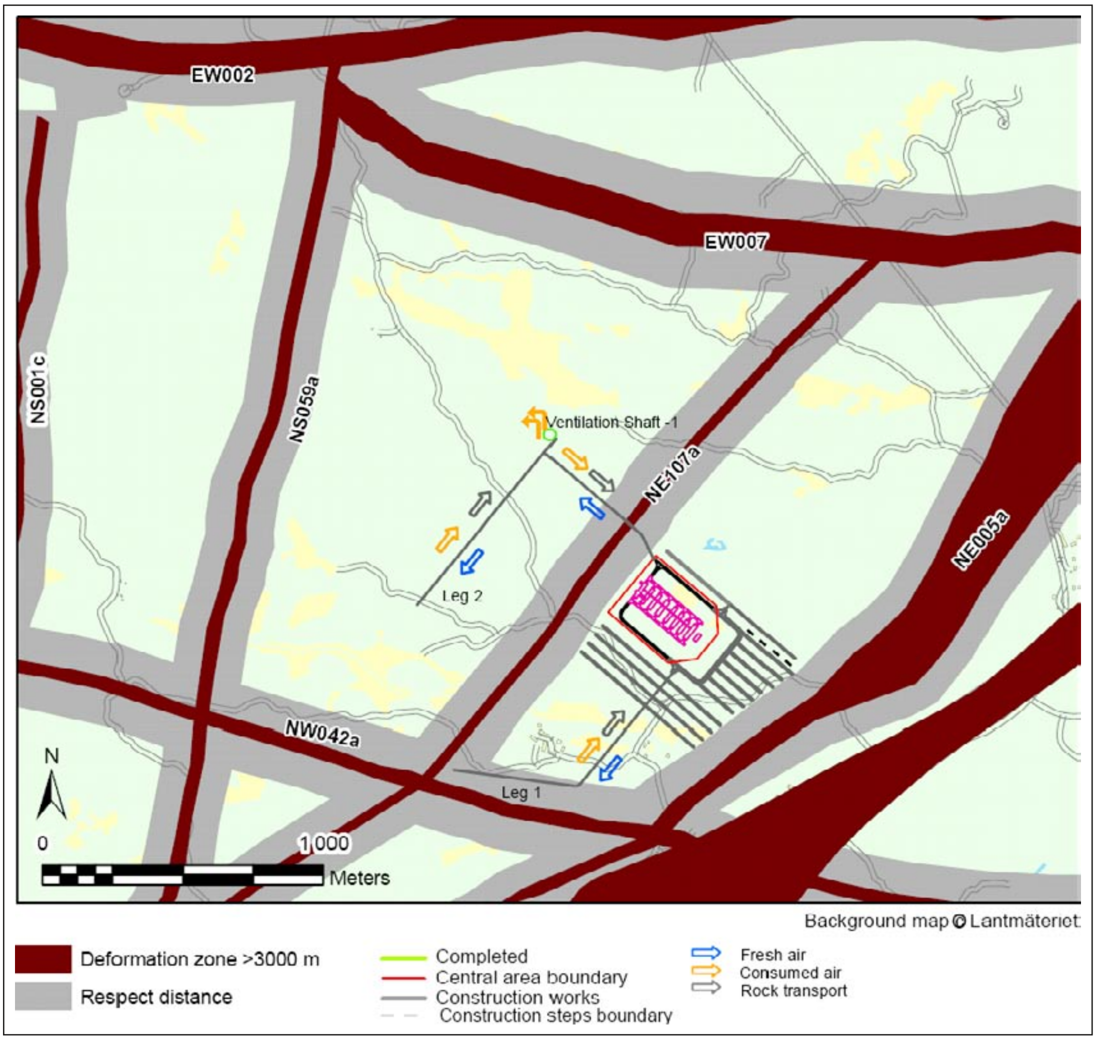


Figure 4-2. *Development of deposition tunnels in 1st construction step.*

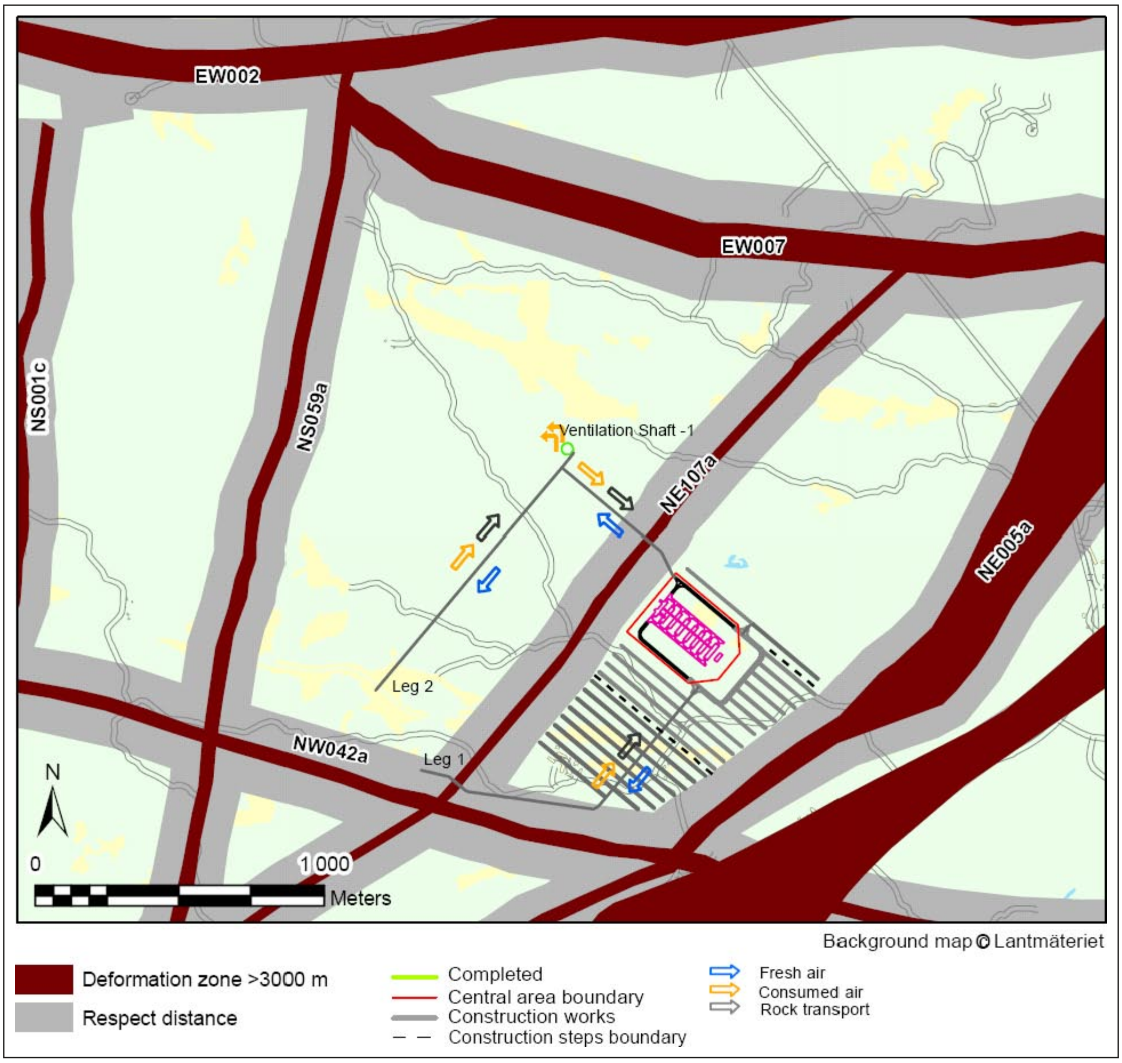


Figure 4-3. *Development of deposition tunnels in the 1st and 2nd construction step.*

Deposition works in the first construction step will commence year 6.4 and finalizes year 9.8 and during this time 300 canisters have been deposited (Figure 4-4).

Excavation of leg 1, 2, 3 and 15 are finalized year 7.4.

Excavation of construction step-3 will commence in year 7.0 and in construction step-4 in year 8.7.

Excavation of leg 4 and 5 will commence in year 7.4 (Figure 4-4).

Excavation in construction steps 2 and 3 will be finalized in year 9.2 and year 10.8 respectively.

The excavation volumes of leg 4 and 5 and construction steps 3 and 4 will amount to approximately 186,000 m^3.

The length of leg 1–3 and leg 15 are to be viewed as graphical representations of the average work that is done in that segment at that specific time. The tunnels are excavated in two steps where the first step is excavation of the tunnel as a survey tunnel and in the second face back ripped to its full area (Figure 4-1).

This means when the excavation of the deposition tunnels commences in construction step-1 the consumed air can be ventilated through leg 1, 2 and 3 and finally through the first ventilation shaft, without contaminating the central area with polluted air (Figure 4-3).

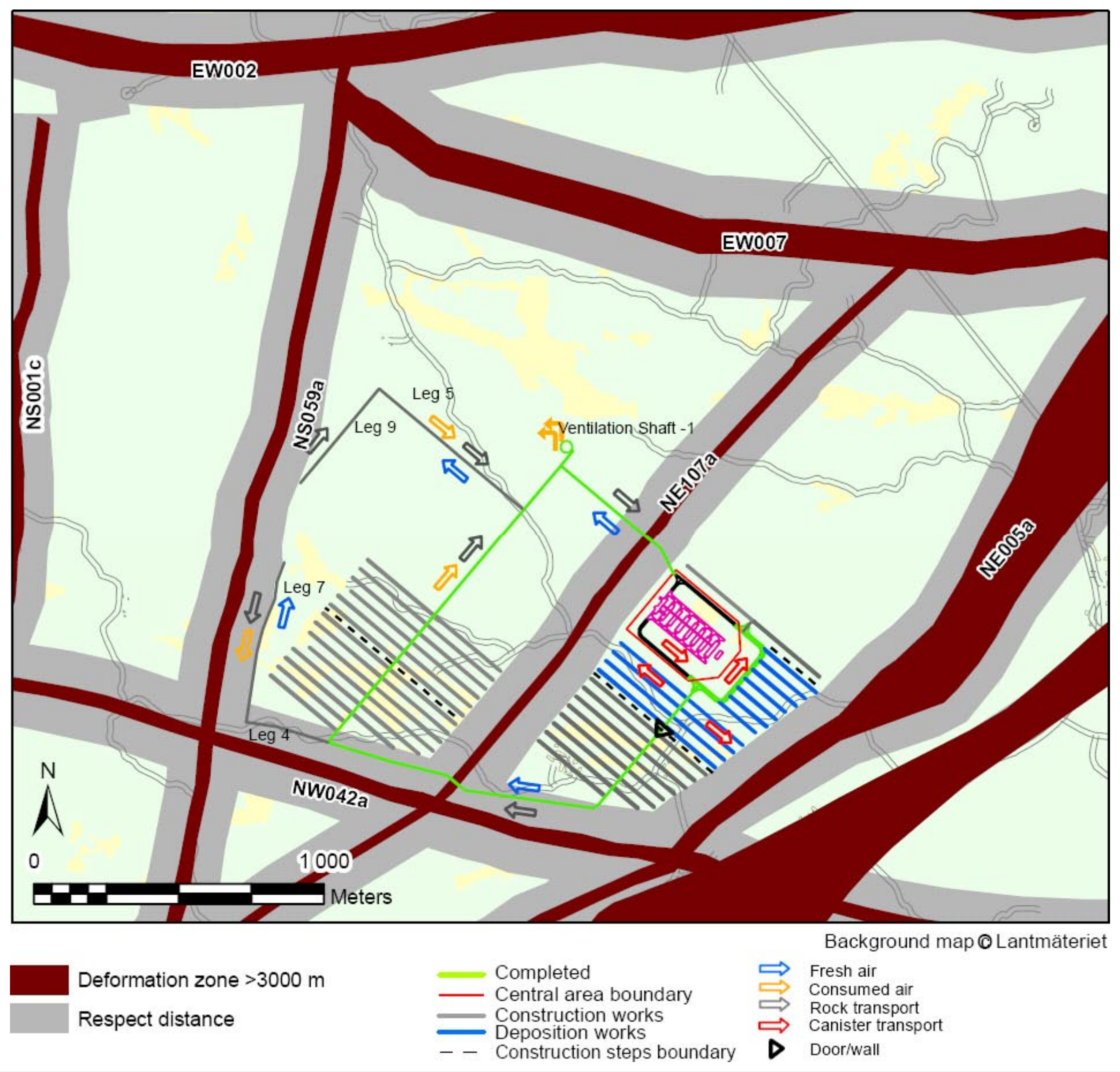


Figure 4-4. *Deposition works in construction step 1 and excavation work in construction step 2–4.*

A separating door/wall with a built in 'no return draught valve' will be constructed between construction step 1 and 2 to prevent air from entering areas where deposition works are carried out. The built in 'no return draught valve' will prevent air from flowing back into construction step 1 from construction step 2. This design will apply through out the entire expansion of the repository.

The air will be transported from the central area southwards to construction step-1 and 2. Consumed air will be ventilated to ventilation shaft passing construction step-3 and 4 (Figure 4-4).

PERIOD: year 9.8–11.4

Deposition work in construction step 2.

Deposition works in the 1st construction step will be finalized in year 8.9 concurrent with the 2nd construction step deposition to commence.

Excavation of leg 7 and 9 are finalized year 10.5.

Excavation volumes in leg 7 and in leg 9 amounts to approximately 65,000 m^3.

Deposition works will be finalized year 11.3 for construction step-2.

A separating door/wall will be constructed south of construction step 2. The air will be transported from the central area southwards to construction step-1 and 2 and northwards through 3 and 4. Consumed air will be ventilated to ventilation shaft through leg 2. Air will also flow through leg 4, 7 and 5 back to ventilation shaft-1.

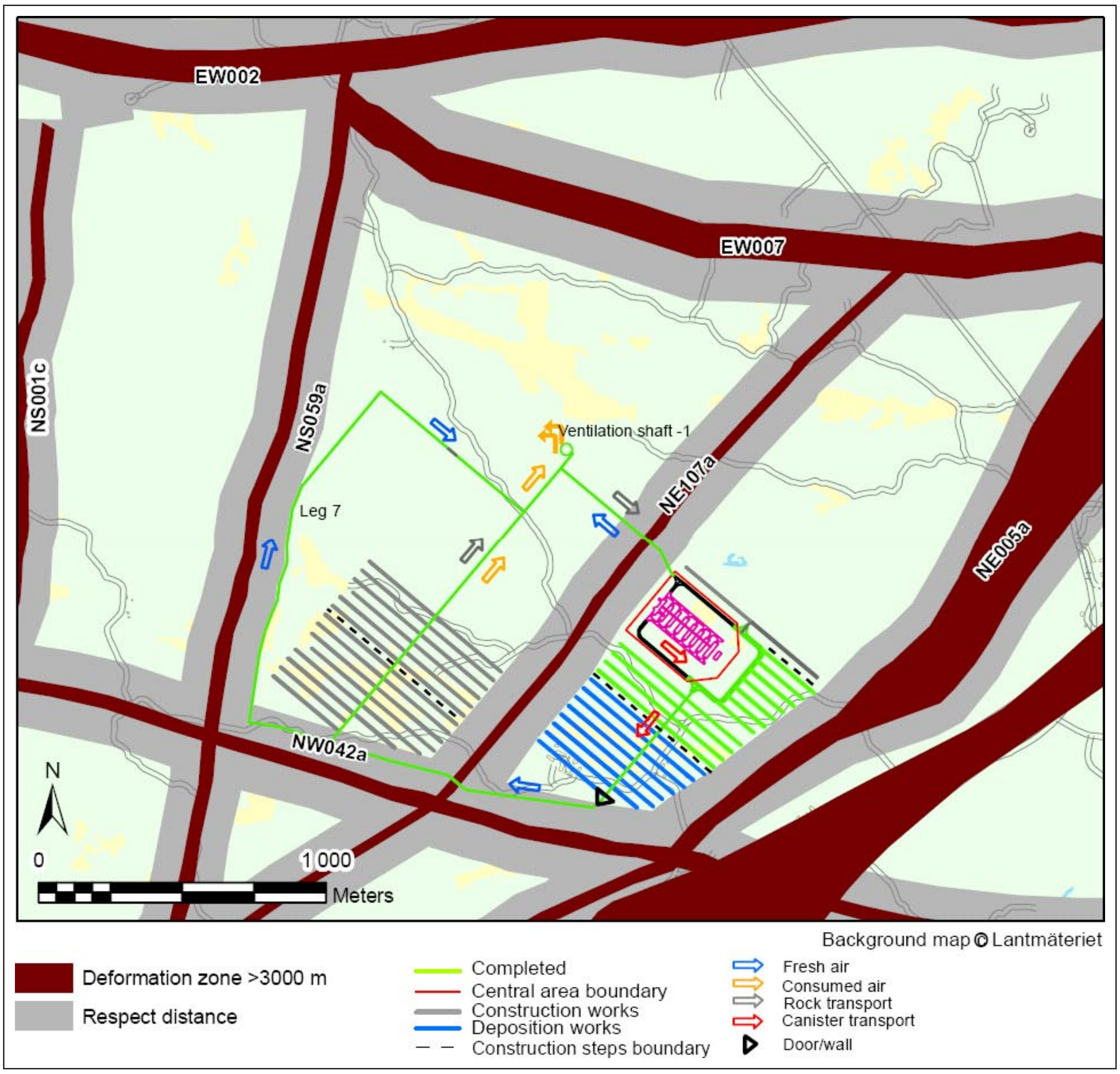


Figure 4-5. Excavation of leg 4, 5, 7 and 9. Excavation of deposition tunnels in construction step-3 and 4. Deposition works in construction step-2.

PERIOD: year 11.4–13.3

Excavation and deposition works in construction steps 5 and 6 / deposition works in construction step 3 and 4.

Deposition works will commence year 11.4 in construction step-3 and year 12.6 in construction step-4.

Excavation in construction step-5 will commence in year 10.1 and excavation in construction step-6 will commence year 12.9 (Figure 4-6).

Drilling of ventilation shaft-2 will commence year 11,3 and finalized in year 13.1.

Excavation volumes in construction step 5 and 6 amounts to approximately 182,000 m^3.

First a separating door/wall will be constructed between construction step-3 and 4 and then between construction step-4 and 5.

Airflow will be as in the previous step.

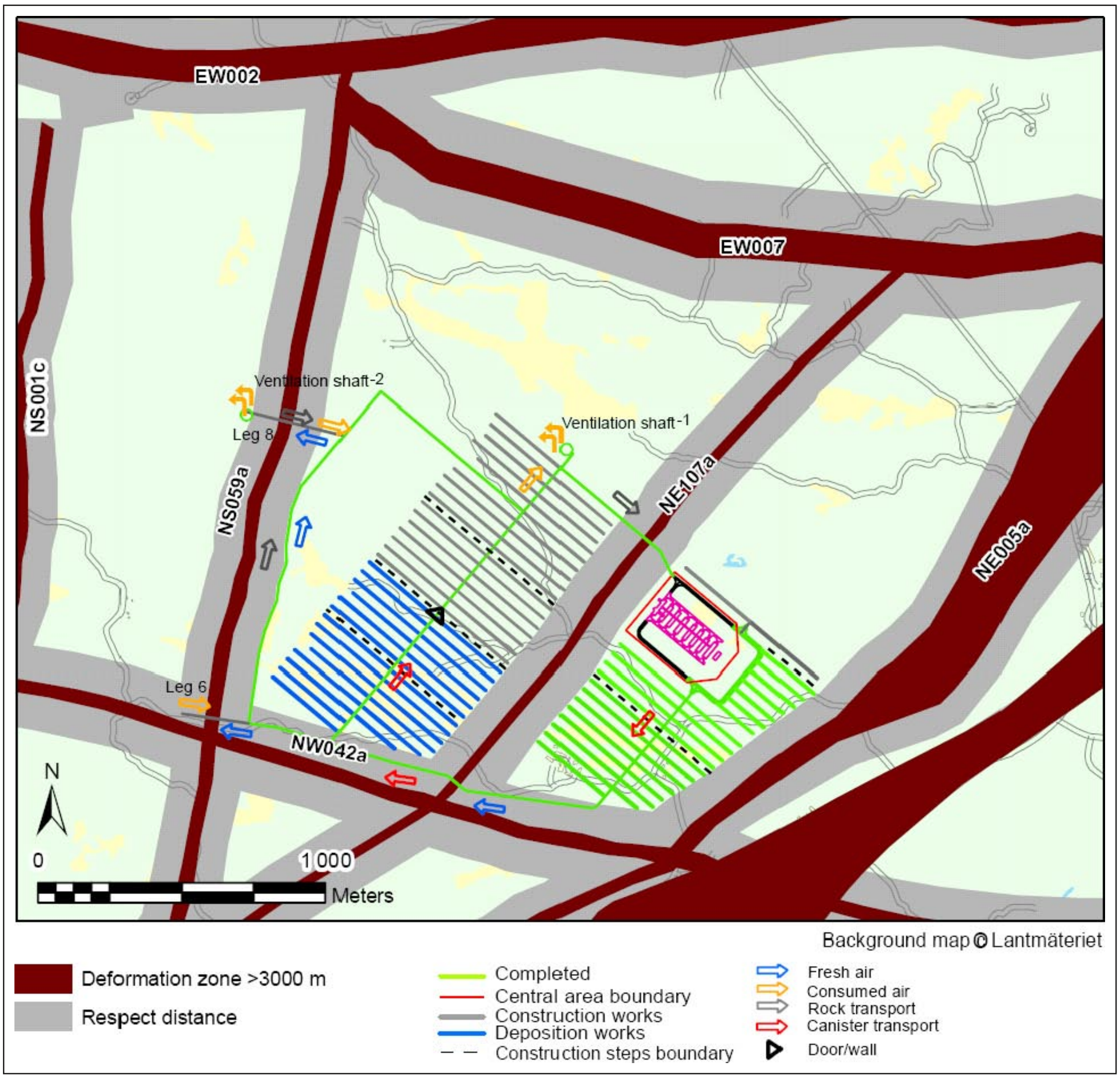


Figure 4-6. *Deposition works in construction steps 3 and 4 and excavation works in construction steps 5 and 6.*

PERIOD: year 13.3–15.3

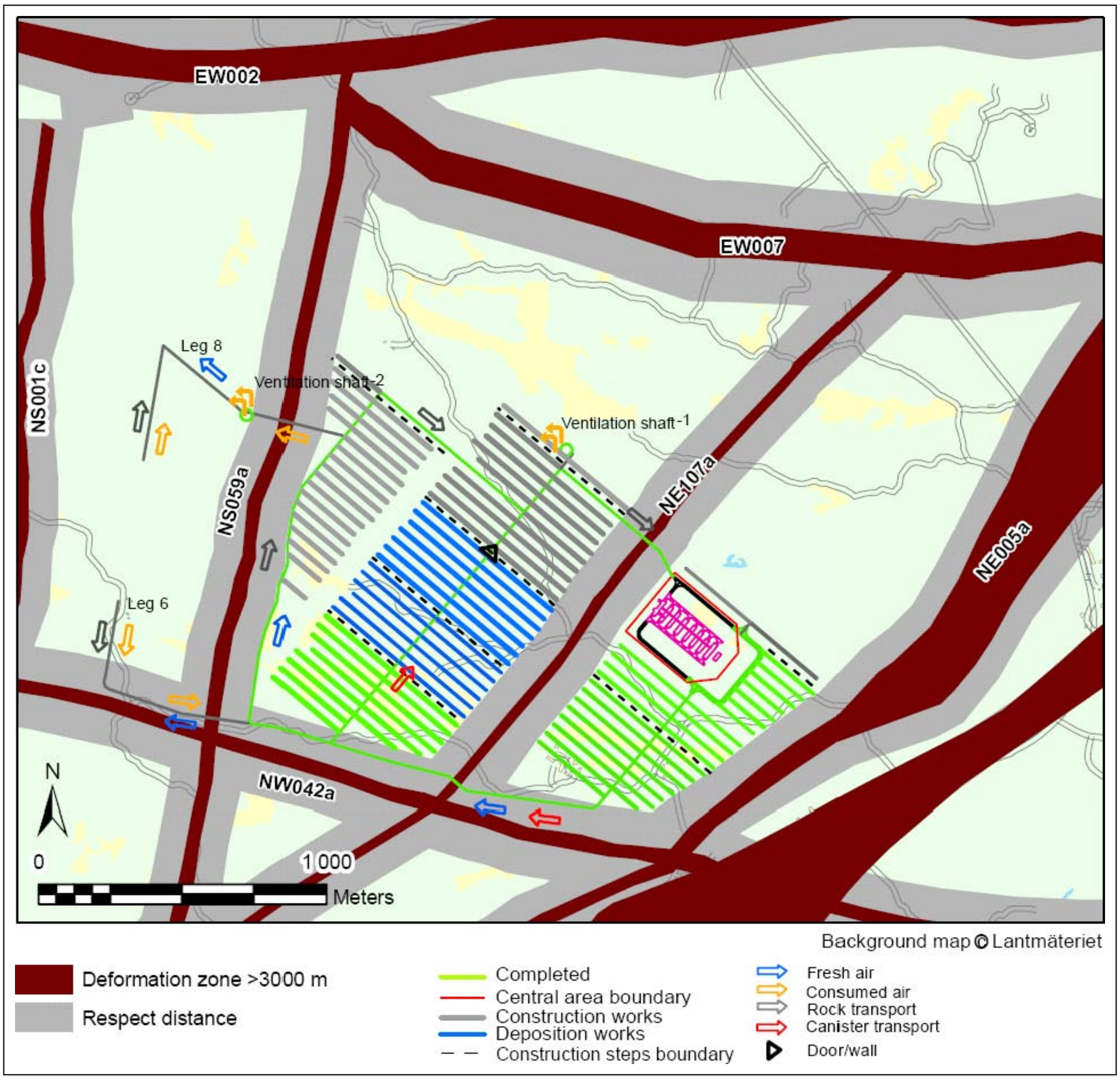
Excavation works of leg 6 and 8 / Excavation work in construction steps 6 and 7 and deposition works in 4 and 5.

Deposition works will continue in construction step 4 and commence year 14.8 in construction step 5.

Excavation continues in leg 6 and 8 and raise boring of ventilation shaft-2 will be finalized.

Excavation volumes in leg 6 and 8 and in construction step 7 amounts to approximately 230,000 m^3.

A separating door/wall will be constructed between construction step-5 and 6. Air will at this point also flow from south in leg 7 through construction step 7 and back to the ventilation shaft-1 by leg 5.



Background map © Lantmäteriet

Figure 4-7. *Excavation of leg 6 and 8 and in construction steps 6 and 7 and deposition works in 4 and 5.*

PERIOD: year 15.3–17.3

Excavation in leg 6 and 8 and in construction steps 7 and 8 and deposition works in construction step 5 and 6.

Deposition works will continue in construction step 5 and commence year 15.9 in construction step 6.

Excavation of leg 6 and 8 will be finalized year 15.5.

Excavation in construction step 8 will commence year 16.4.

Excavation volumes in construction step 8 amounts to approximately 86,000 m^3.

A separating door/wall will be constructed between construction step 6 and 7. Air will at this point also flow from south in leg 2 through construction step 3 to 6 and back to ventilation shaft-1.

Air will also flow westwards in leg 5 and northwards in leg 7 through construction step 7 and then into leg 8 and into the ventilation shaft-2.

At this point air will also flow from south to north in leg 6 through construction step 8 to ventilation shaft-2.

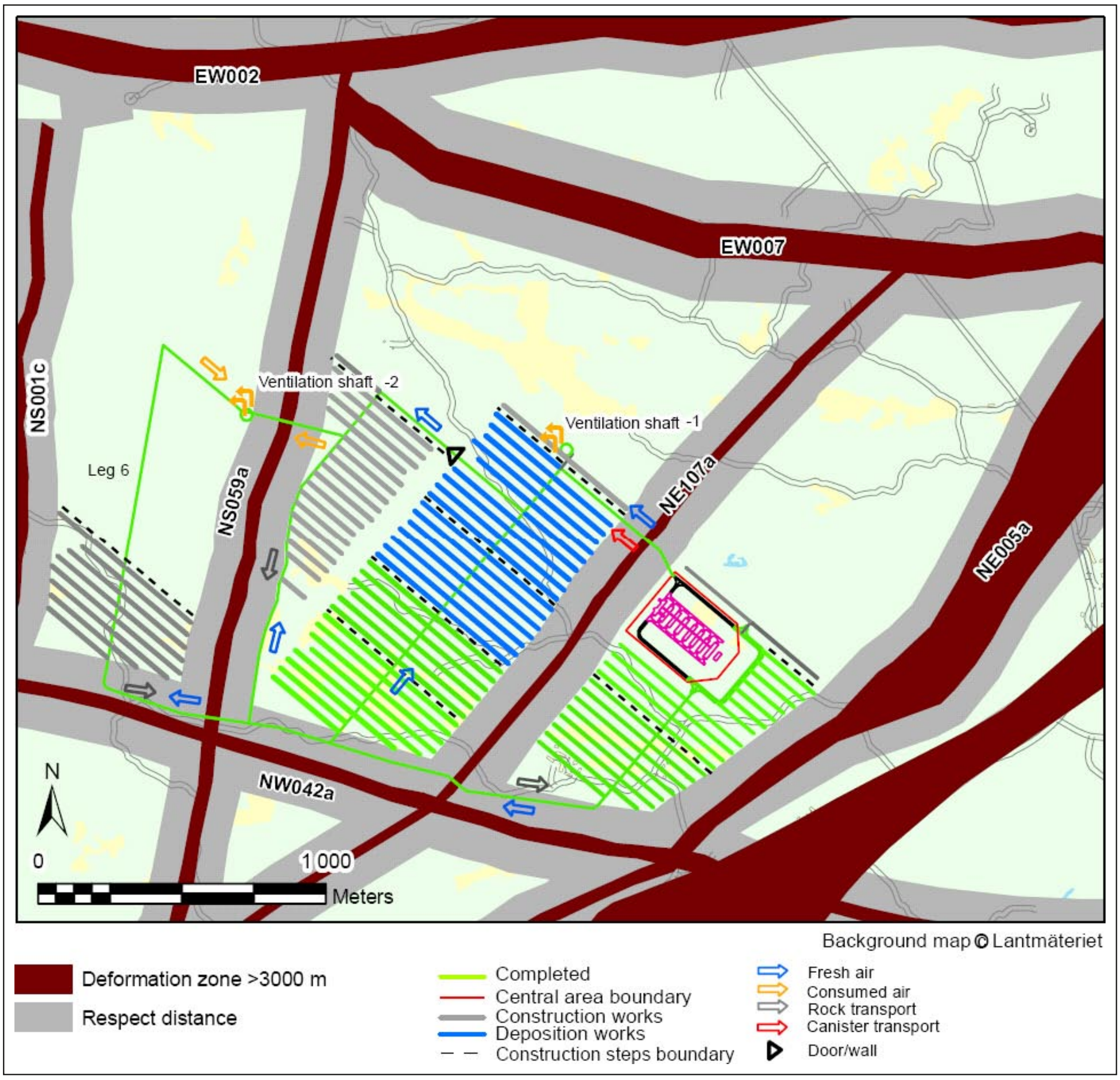


***Figure 4-8.** Excavation in leg 6 and 8 and in construction steps 7 and 8 and deposition works in construction step 5 and 6.*

PERIOD: year 17.3–19.3

Excavation in construction step 8 and 9 / deposition works in construction step 6 and 7.

Deposition works will commence year 17.6 in construction step 7.

Excavation of construction step 9 commence year 17.9.

Excavation volumes in construction step 9 amounts to approximately 80,000 m^3.

Separating doors/walls will be constructed in the west end of construction step 7 and in the south end of leg 7.

Air will at this point also flow from south in leg 2 through construction step 3 to 6 and back to ventilation shaft-1.

Air will also flow northwards in leg 7 through construction step 7 and then into leg 5 and into the ventilation shaft-1.

Air will also flow from south to north in leg 6 through construction steps 8 and 9 and out through ventilation shaft-2.

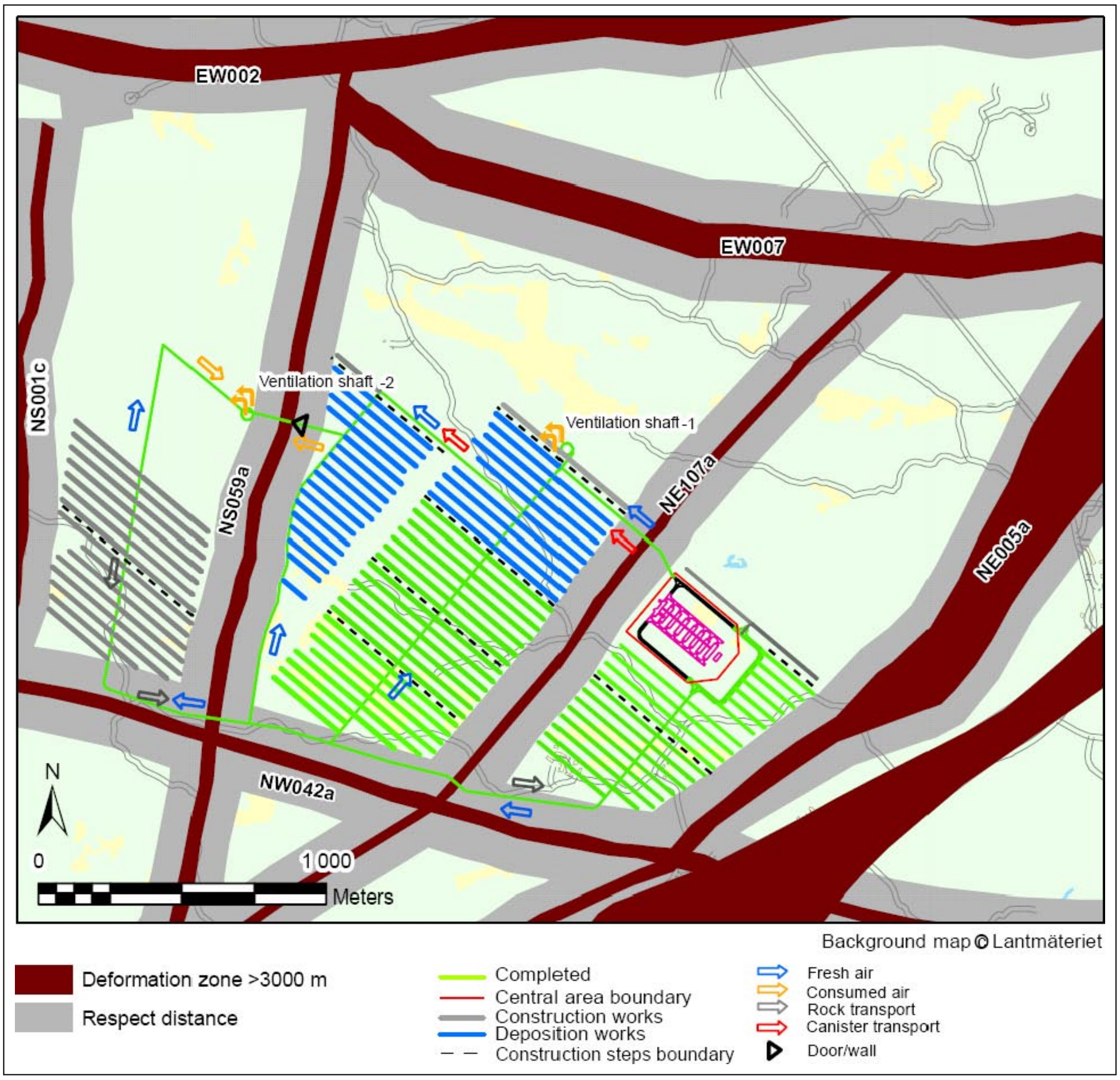


***Figure 4-9.** Excavation in construction step 8 and 9 and deposition works in construction step 6 and 7.*

PERIOD: year 19.3–21.3

Excavation in leg 10 and 11 and in construction steps 9 and 10 and deposition works in construction steps 7 and 8.

Deposition works will commence in construction step 8 year 18.9 and deposition works will be finalized in construction step 7 year 19.3.

Excavation of leg 10 and 11 will start year 19.8 and excavation in construction step 10 will commence year 19.6.

Excavation volumes in construction step 10 amounts to approximately 91,000 m^3.

A separating door/wall will be constructed between of construction steps 8 and 9. To make sure that no consumed air pollutes construction step 7 the door/wall west of construction step 7 can be redeployed.

Air will at this point also flow from south in leg 2 through construction step 3 to 6 and back to ventilation shaft-1.

Air will also flow northwards in leg 7 through construction step 7 and then into leg 5 and into the ventilation shaft-1.

Air also flows from south to north in leg 6 through construction steps 8 and 9 and out through ventilation shaft-2.

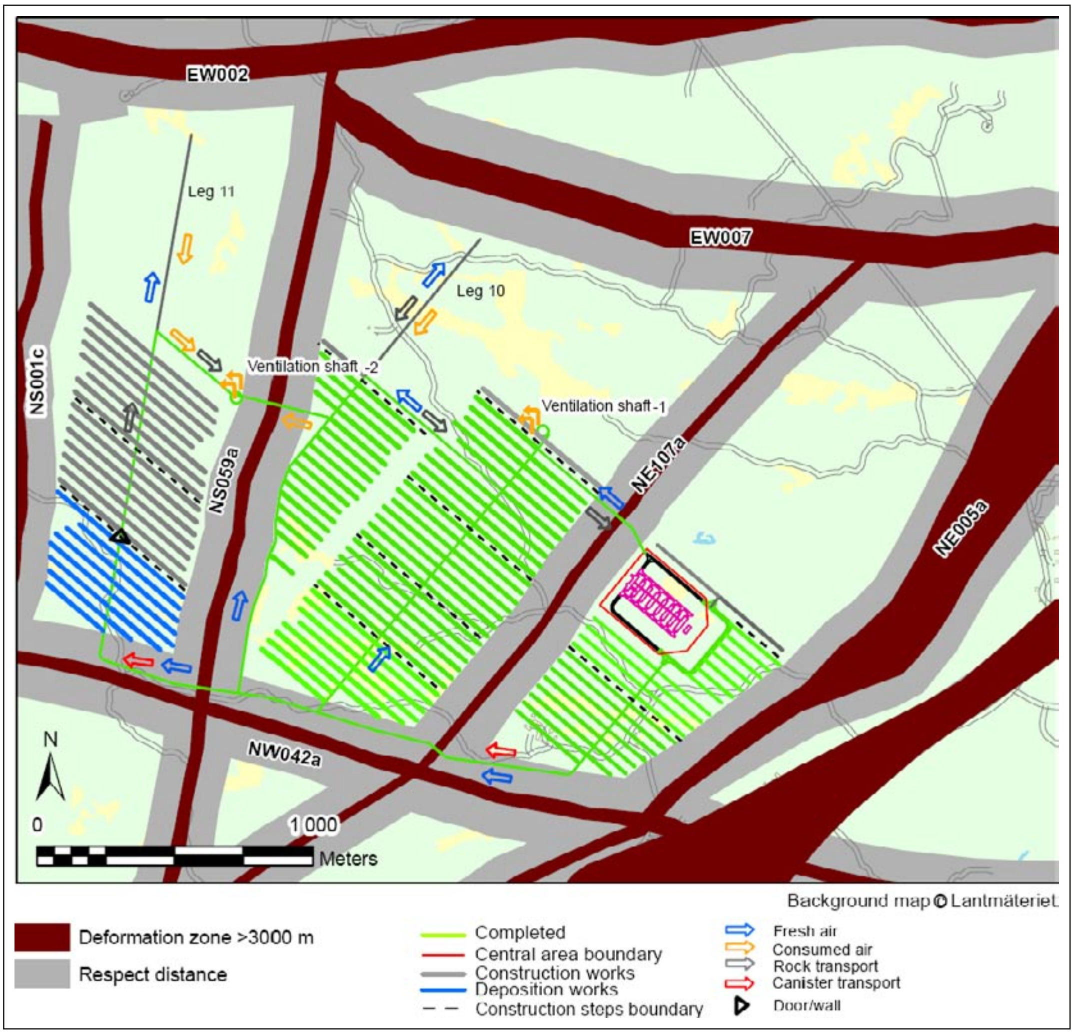


Figure 4-10. Excavation in leg 10 and 11 and in construction steps 9 and 10 and deposition works in construction step 8.

PERIOD: year 21.3–23.3

Excavation in leg 10 and 11 / Excavation work in construction steps 11 and 12 / Deposition works in construction step 9 and 10.

Deposition works will commence in construction step 9 in year 20.8 and in construction step 10 in year 22.3.

Excavation in construction steps 11 and 12 will commence year 21.6 and year 23.3.

Excavation in leg 10 and 12 will continue and be finalized year 23.3.

Excavation volumes in construction steps 11, 12 and in leg 10 and 11 amounts to approximately 351,000 m^3.

A separating door/wall will be constructed between of construction steps 9 and 10 and 10 and 11.

Air will at this time flow from south to north in leg 2, 7, 6 and 11 and south through leg 10 and then into ventilation shaft-2.

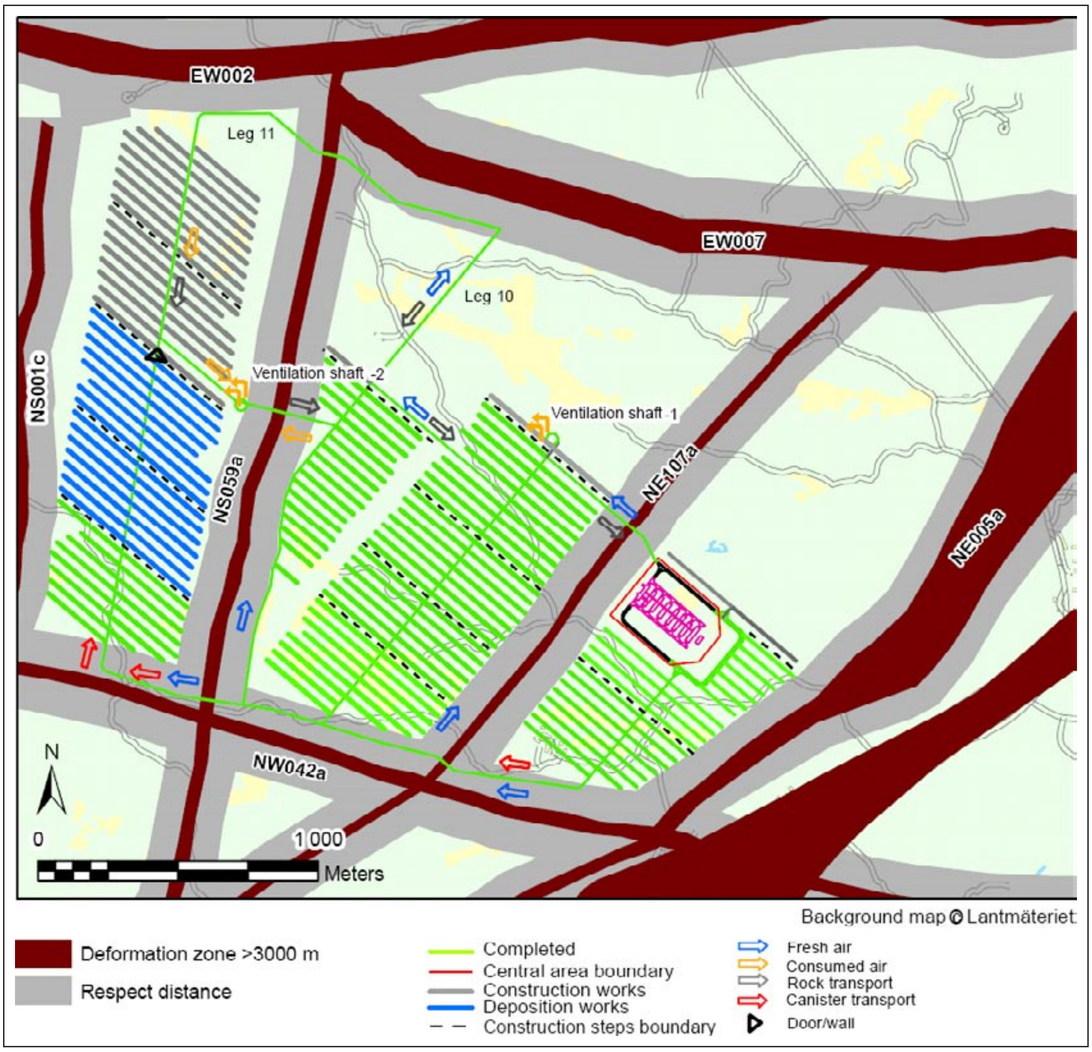


Figure 4-11. Excavation in leg 10 and 11 and excavation work in construction steps 11 and 12 and deposition works in construction step 9 and 10.

PERIOD: year 23.3–25.3

Excavation work in leg 12 and 13 and in construction step 13 / deposition works in construction step 11.

Deposition works will continue in construction step 10 and commence in construction step 11 in year 24.0.

Excavation in construction step 13 will commence year 24.9.

Excavation of leg 12 and 13 will commence in year 23.6.

Excavation volumes in construction step 13 amounts to approximately 78,000 m^3.

A separating door/wall will be constructed between of construction steps 11 and 12 and east of construction step 11.

Air will at this time flow from south to north in leg 2, 7, 6 and 11 and south through leg 10 and then into ventilation shaft-2.

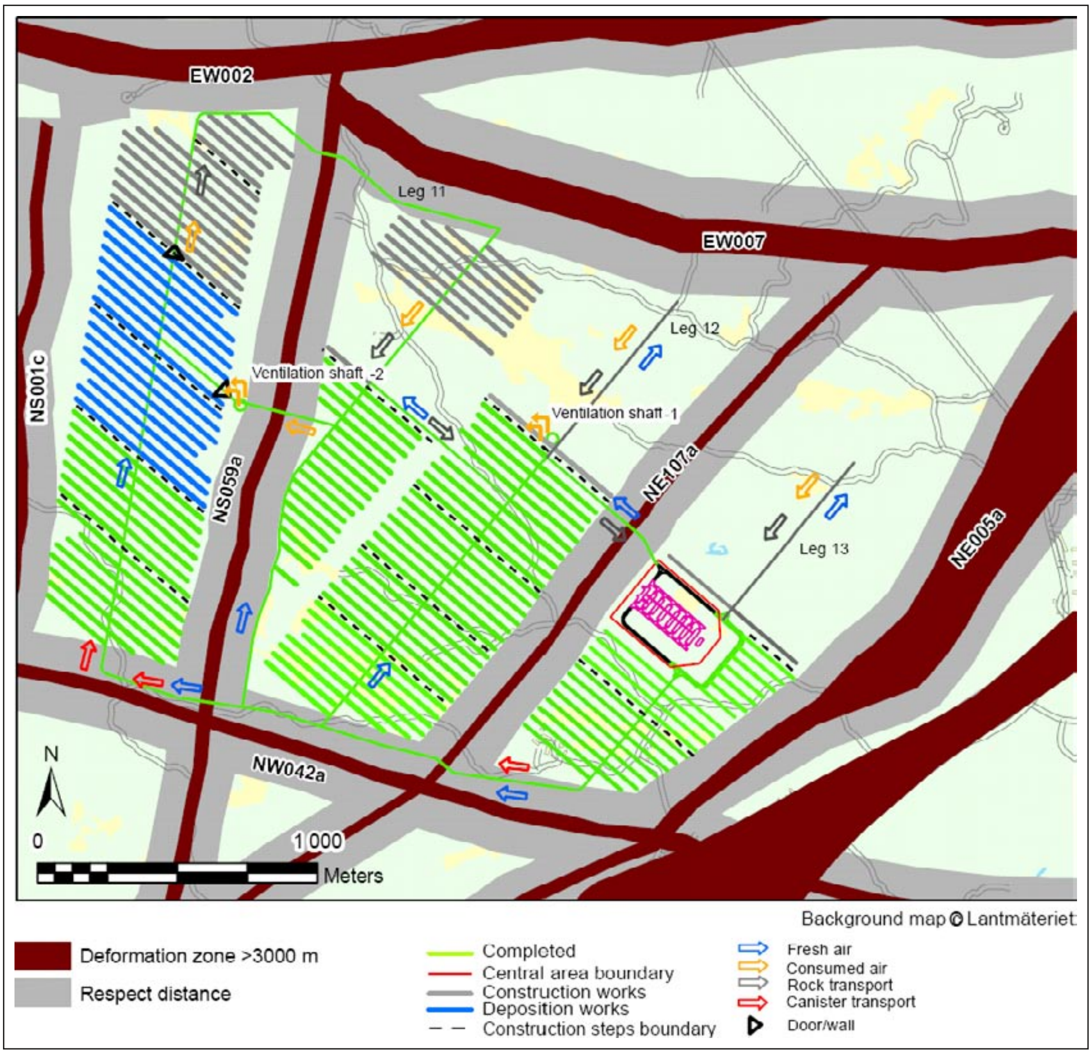


Figure 4-12. Excavation in leg 12 and 13 and in construction step 13 and deposition works in construction step 11.

PERIOD: year 25.3–27.3

Excavation work in leg 12 and 13 and in construction step 14 / deposition works in construction step 12.

Deposition works will commence in construction step 12 year 26.0.

Excavation in construction step 14 will commence year 27 and excavation of leg 12 and 13 will continue.

A separating door/wall will be constructed north of construction step 12.

Excavation volumes in construction step 14 amounts to approximately 90,000 m^3.

A separating door/wall will be constructed between of construction steps 12 and 13.

Air will at this time flow from south to north in leg 2, 7, 6 and 11 and south through leg 10 and then into ventilation shaft-2.

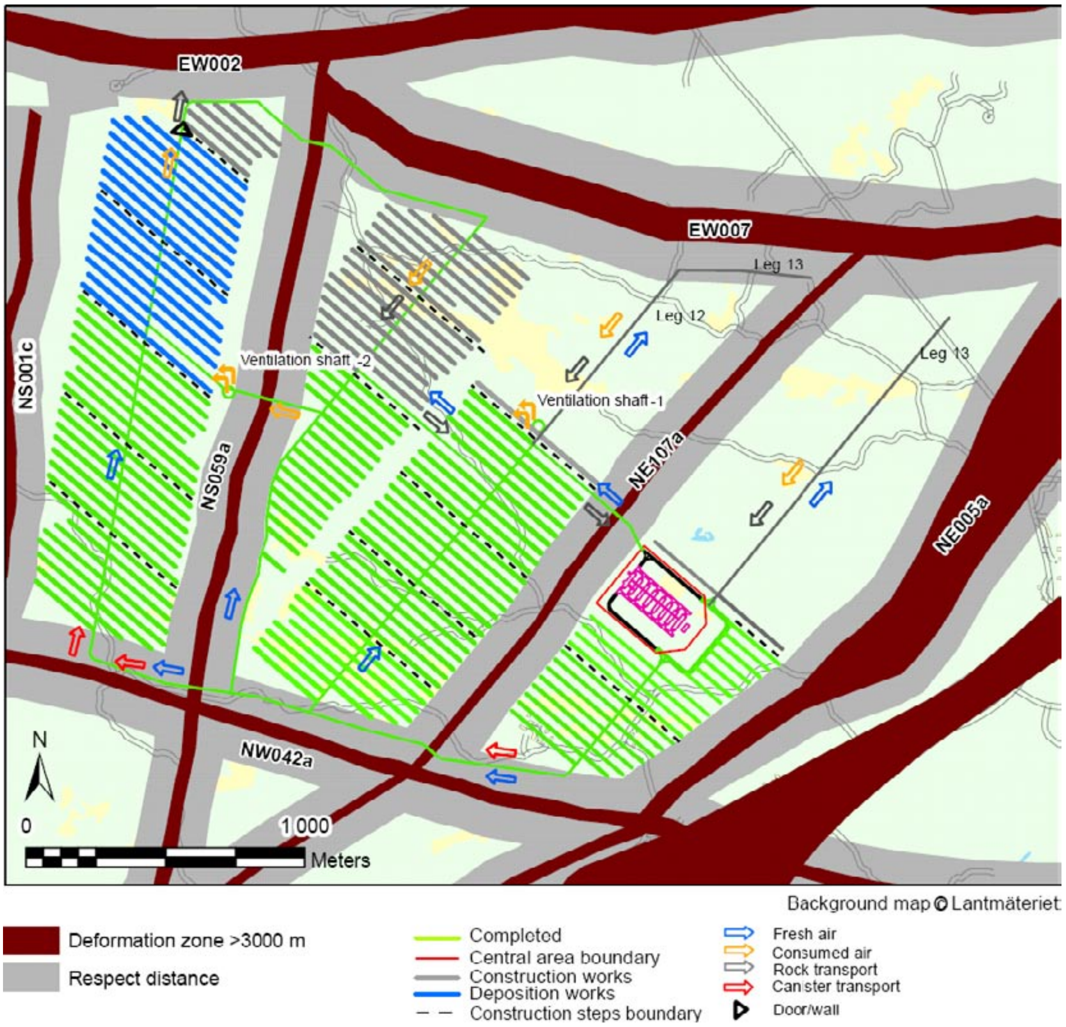


Figure 4-13. Excavation in leg 12 and 13 and in construction step 14 and deposition works in construction step 12.

PERIOD: year 27.3–29.3

Excavation work in construction steps 14 and 15 / deposition works in construction steps 12 and 13.

Deposition works will commence in construction step 13 in year 27.8. Excavation in construction step 15 will commence year 28.5. Excavation in leg 12 and 13 will be finalized year 28.2.

Excavation volumes in leg 12 and 13 and in construction step 15 amounts to approximately 280,000 m^3.

A separating door/wall will be constructed between of construction steps 13 and 14.

Air will at this time flow from south to north in leg 2, 7, 6 and 11 and south through leg 10 and then into ventilation shaft-2.

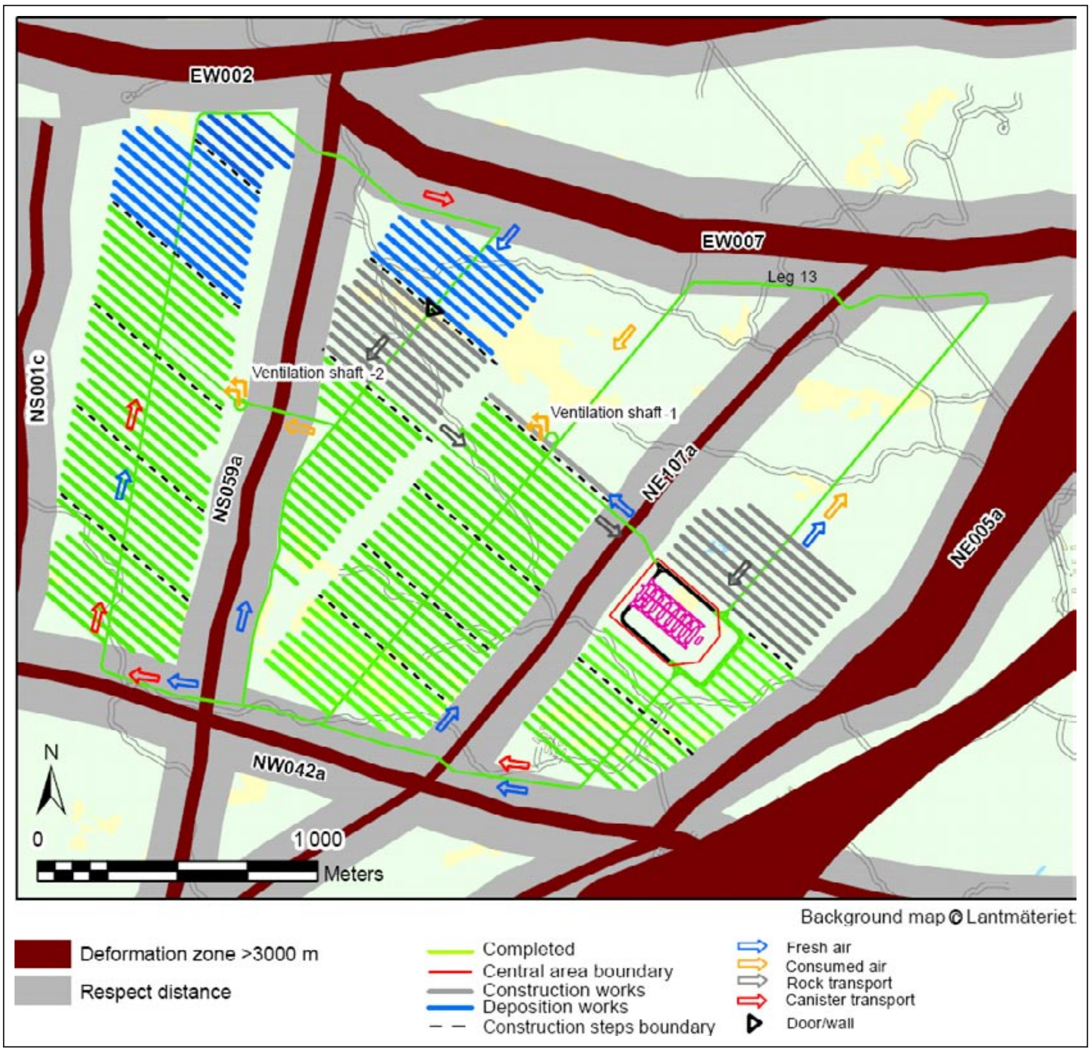


Figure 4-14. Excavation in construction steps 14 and 15 and deposition works in construction steps 12 and 13.

PERIOD: year 29.3–31.3

Excavation works in construction steps 15 and 16 / deposition works in construction steps 13 and 14.

Deposition works will be finalized in construction step 13 in year 29.6 and commence in construction step 14 in year 29.5.

Excavation in construction step 15 will continue and commence in construction step 16 year 32.8.

Excavation volumes in construction step 16 amounts to approximately 125,000 m^3.

The separating door/wall west of construction step 6 is redeployed.

Air will at this time flow from south to north in leg 2 to ventilation shaft 1. Air will also flow from south to north in leg 7, 6 and 11 and south through leg 10 and then into ventilation shaft 2.

In leg 13 the air will flow from south to north into leg 12, where it will go south to ventilation shaft-1.

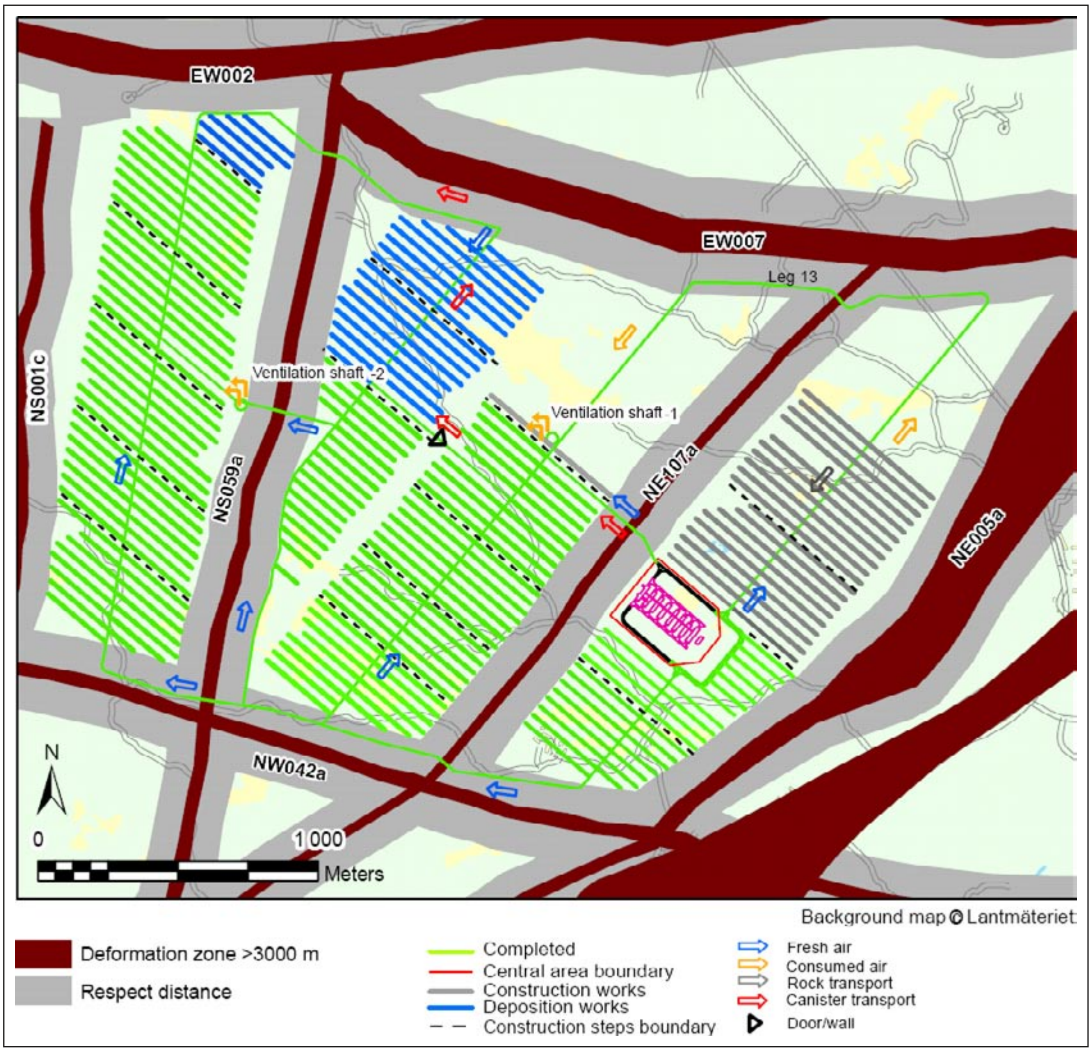


Figure 4-15. *Excavation in construction steps 15 and 16 and deposition works in construction steps 13 and 14.*

PERIOD: year 31.3–33.3

Excavation works in construction steps 17 and 18 / deposition works in construction steps 15 and 16.

Deposition works will be finalized in construction steps 13 and 14 in year 29.5 and 31.3 respectively.

Deposition works will commence in construction steps 15 and 16 in year 30.9 and 32.7 respectively.

Excavation in construction steps 17 and 18 will commence in year 31.5 and 32.9 respectively.

Excavation volumes in construction step 17 amounts to approximately 103,000 m^3.

A separating door/wall will first be constructed between construction step 15 and 16 and then between construction step 16 and 17.

Air will at this time flow from south to north in leg 2 to ventilation shaft 1. Air will also flow from south to north in leg 7, 6 and 11 and south through leg 10 and then into ventilation shaft 2.

In leg 13 the air will flow from south to north to leg 12 where it will go south to ventilation shaft 1.

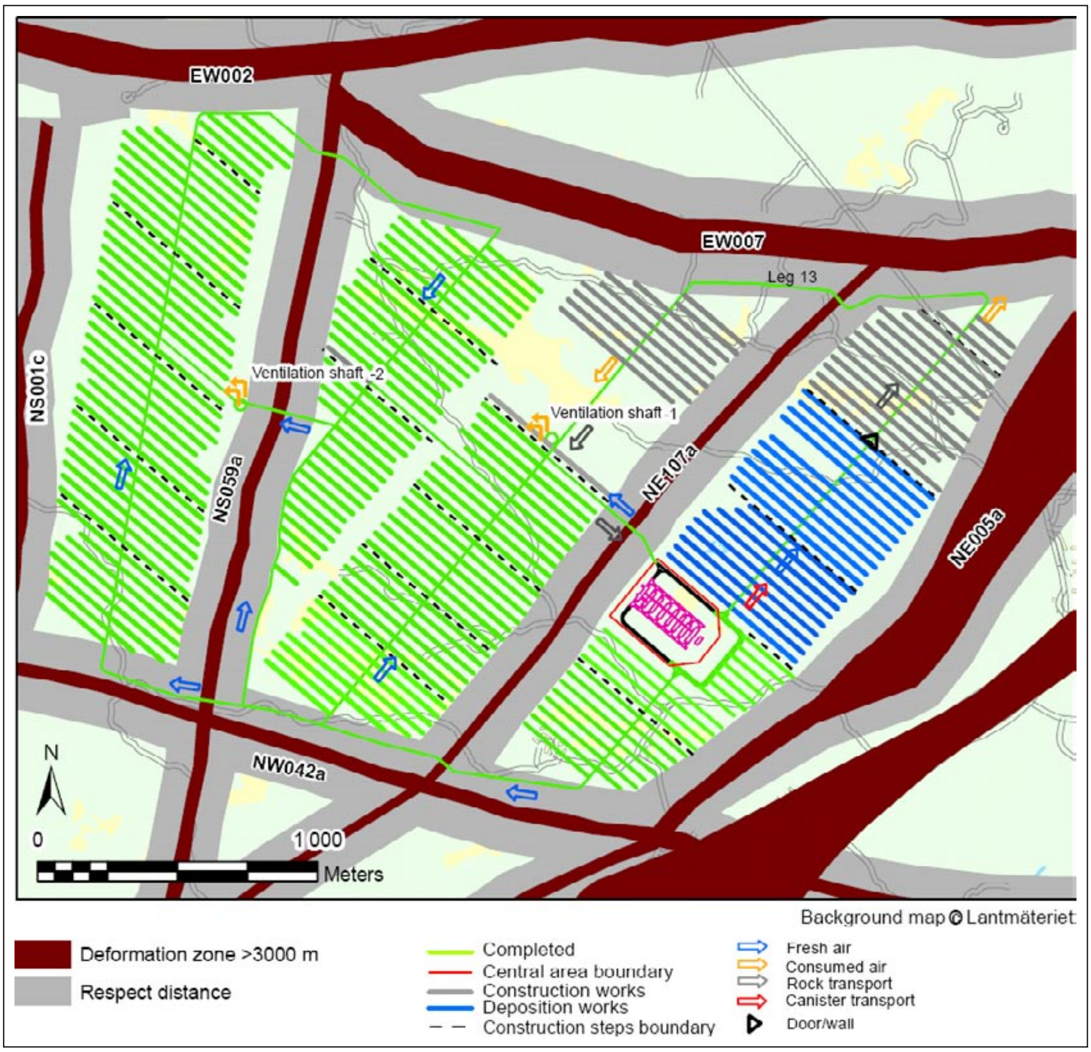


__Figure 4-16.__ Excavation in construction steps 17 and 18 and deposition works in construction steps 15 and 16.

PERIOD: year 33.3–35.3

Excavation in construction steps 18 and 19 / deposition works in construction steps 16 and 17.

Deposition works in will be finalized in construction step 15 in year 32.6 and deposition works will commence in construction step 17 in year 34.2.

Excavation work in construction step 19 will commence in year 34.6.

Excavation volumes in construction step 18 amounts to approximately 120,000 m^3.

A separating door/wall will be constructed between construction step 17 and 18.

Air will flow as in the previous step.

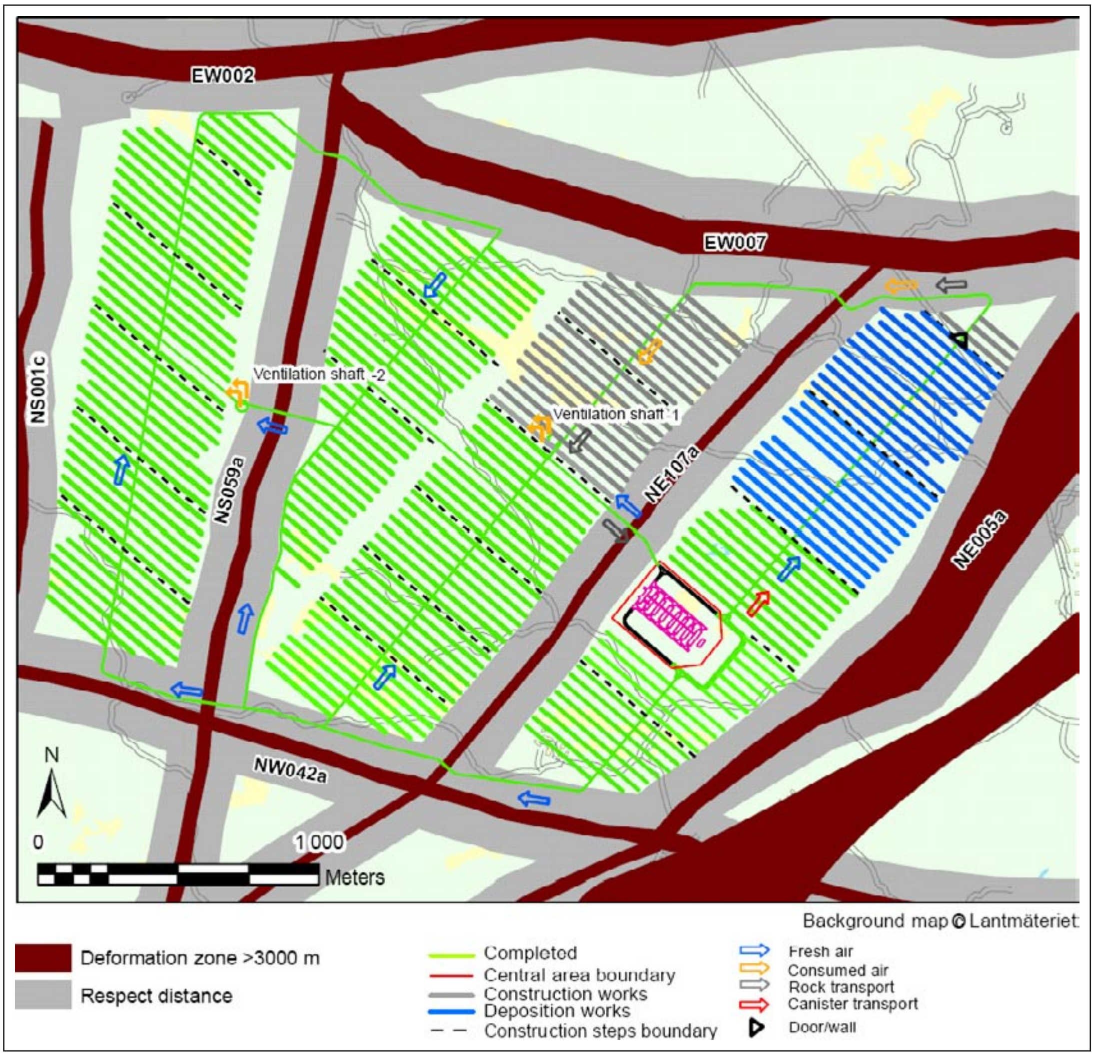


Figure 4-17. Excavation in construction steps 18 and 19 and deposition works in construction steps 16 and 17.

PERIOD: year 35.3–37.3

Excavation works in construction step 19 / deposition works in construction steps 17 and 18.

Deposition works will be finalized in the sixteenth construction step year 34.6, continue in the seventeenth construction step and commence in the eighteenth construction step year 35.9.

Excavation in the nineteenth construction step will continue.

Excavation volumes in construction step 19 amounts to approximately 125,000 m^3.

A separating door/wall will be constructed between construction step 18 and 19.

Air will flow as in the previous step.

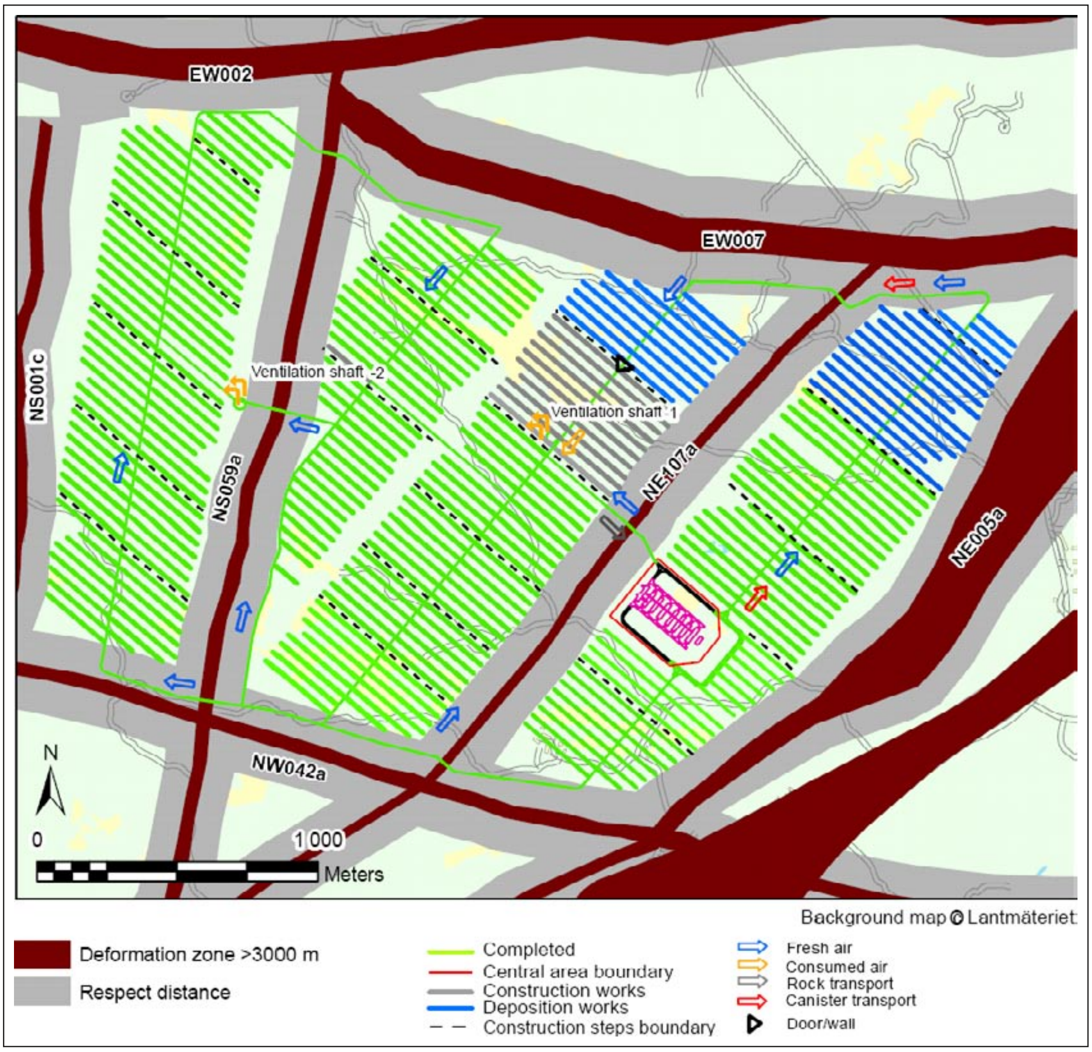


Figure 4-18. Excavation in construction step 19 and deposition works in construction steps 17 and 18.

PERIOD: year 37.3–39.3

Deposition works in construction steps 18 and 19.

Deposition works will be finalized in construction step 17 year 36, continue in construction step 18 and commence in the construction step 19 year 37.5.

Air will flow as in the previous step.

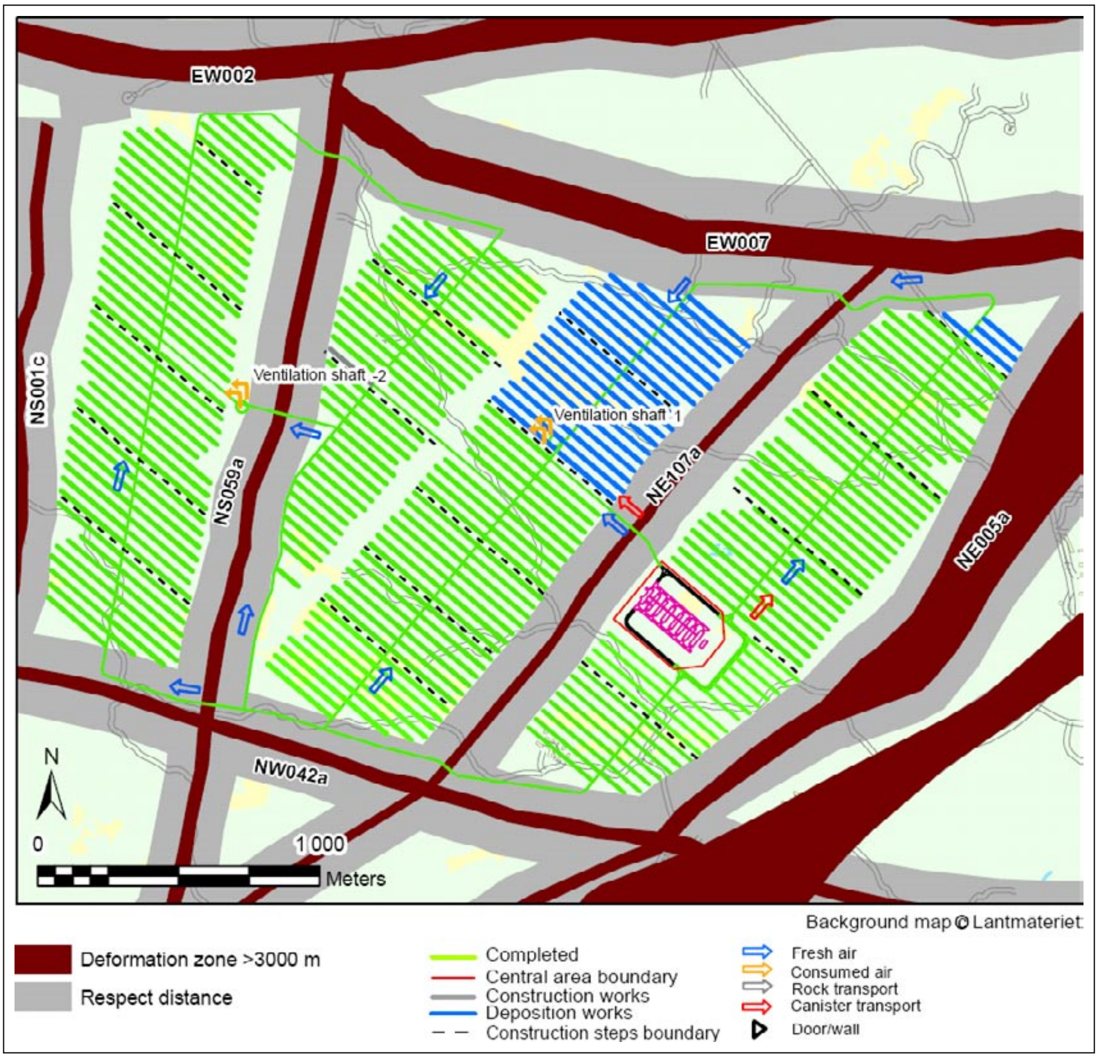


Figure 4-19. Deposition works in construction steps 18 and 19.

PERIOD: year 39.3–39.6

Deposition works finalizes in construction step 19.

Deposition works finalizes in construction step 19 year 39.6.

Air will flow as in the previous step.

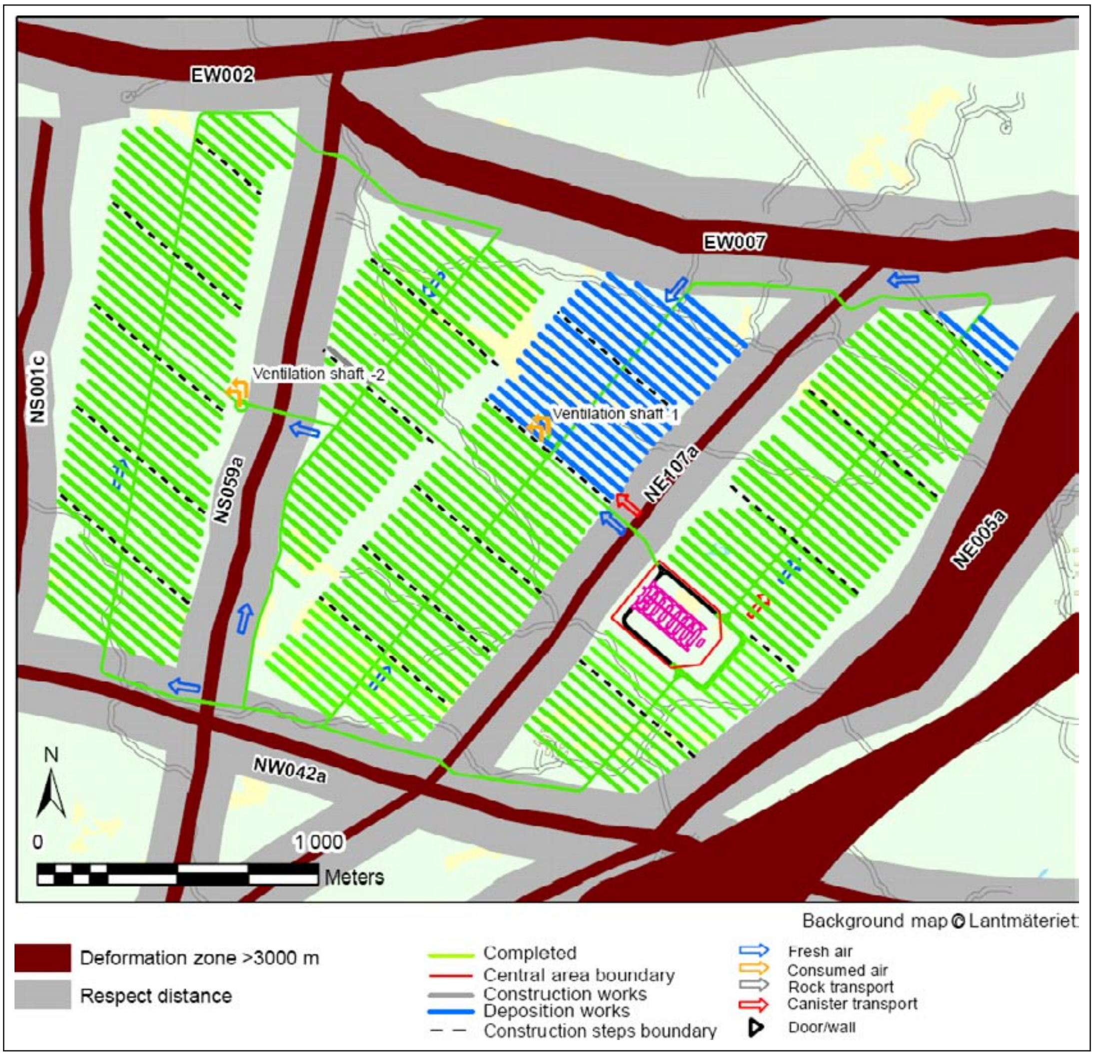


***Figure 4-20.** Deposition works finalizes in construction step 19.*

4.2 Resources

The number of resources needed to develop the repository varies over time for the different activities. Below are shown the most resource demanding activities and how the resources for each activity vary over time.

The resources needed for each activity is optimized through a LoB-analysis of the development of the final repository. Data used as input for the LoB-analysis originates from /SKB 2008/ and can be found in Table 3-1 in Chapter 3.1.

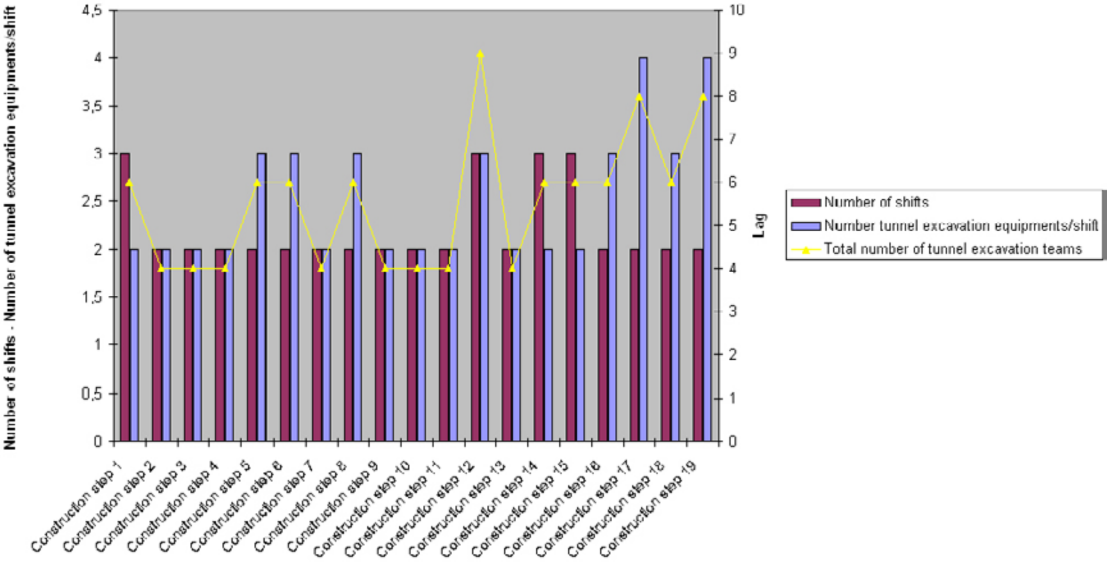


Figure 4-21. *Resources needed for tunnel excavation.*

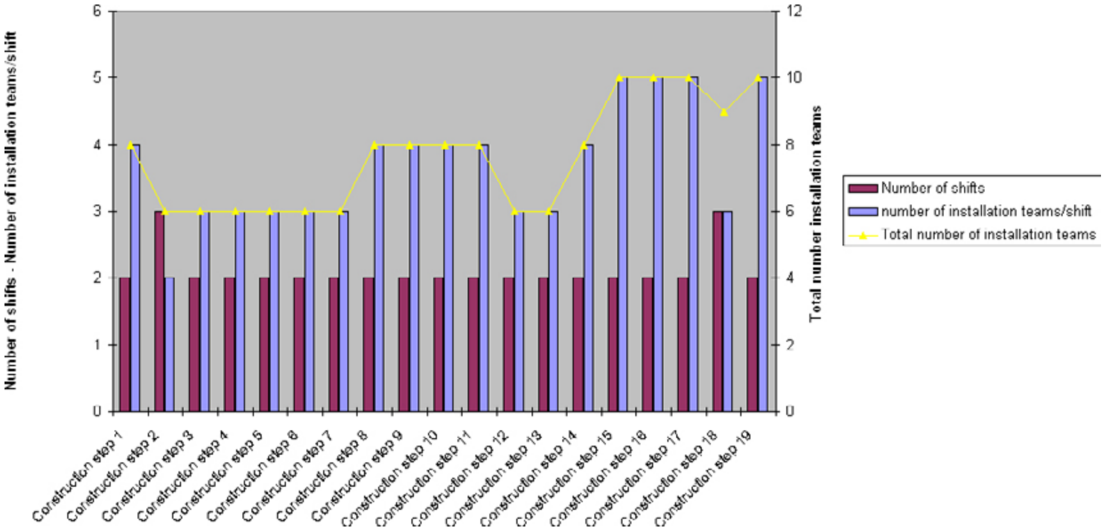


Figure 4-22. *Resources needed for installation.*

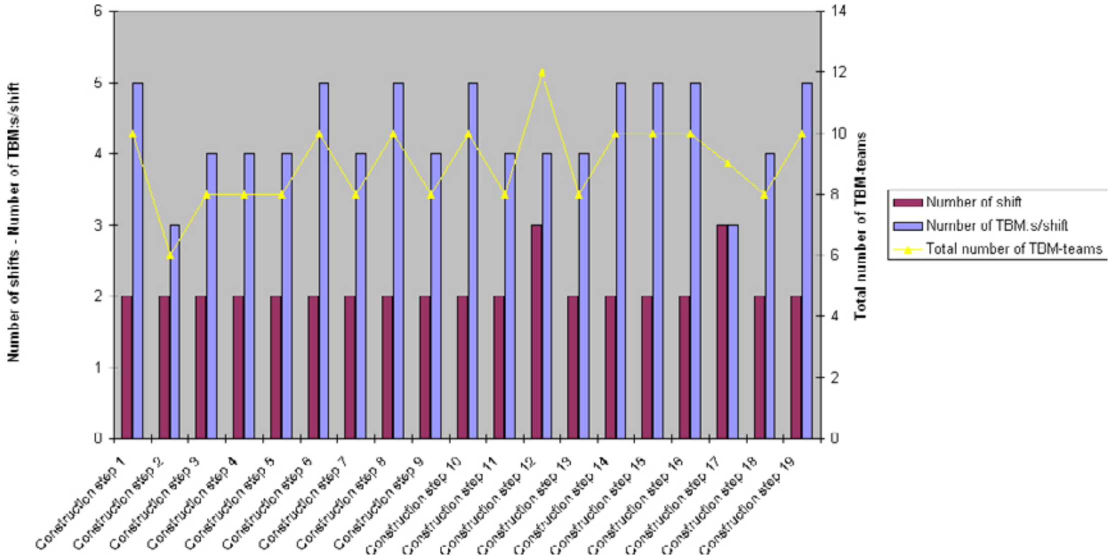


Figure 4-23. *Number of resources needed for TBM boring.*

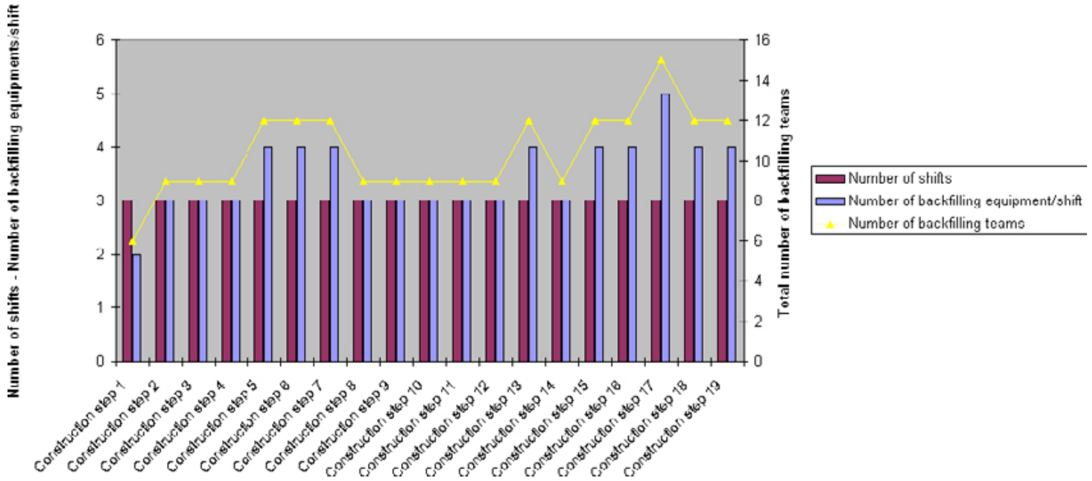


Figure 4-24. *Number of resources needed for backfilling.*

4.3 Summary of proposed construction plan for the repository area

Analysis made during the functional study of the final repository can be summarised in the following points

- Development of the final repository is possible
  - with the proposed layout using the Linear Development Method
  - using 19 construction steps
- The bulk capacity for the complete repository is estimated to 8,031 canisters.
- Repository will be situated between 500.0 m (highest level of deposition tunnel roof) and 513.2 m (lowest level of main and transport tunnel floor), below ground surface.
- Two exhaust ventilation shaft is required,
  - to maintain a satisfactory ventilation
  - combined with door/walls to prevent polluted air from contaminating areas where deposition is performed
- Deposition of the first canister is made 6.4 year after starting excavation from central area.
- 39.6 years after start
  - the last deposition tunnel is backfilled and sealed
  - Close to 2,600,000 m^3 of rock has been excavated and close to 11,600,000 ton × km of transport work has been performed
  - remains to seal the final repository

5 Conclusion

The main goal of the D2 design is to confirm that site dimensions are large enough to accommodate the required size for a final repository.

The repository will be situated between 500.0 m (highest level of deposition tunnel roof) and 513.2 m (lowest level of main and transport tunnel floor), below ground surface.

The D2 design layout at level –500 m and with deposition tunnels aligned with the principal horizontal stress is found to have a gross capacity of 8,031 deposition hole positions.

Two exhaust ventilation shafts are required to maintain satisfactory ventilation combined with door/walls to prevent polluted air from contaminating areas where deposition is performed.

Deposition of the first canister is made 6.4 year after starting excavation from central area. 39.6 years after start the last deposition tunnel is backfilled and sealed.

Close to 2,600,000 m^3 of rock will at completion have been excavated and close to 11,600,000 ton × km of transport work has been performed.

The layout of the underground facility, which includes the access ramp, shafts, rock caverns in a central area, transport tunnels, main tunnels, deposition tunnels and deposition holes, was achieved through an iterative process between a layout studies, a functionality study and the prerequisites for the underground facility. The result from the generic functionality study showed that a construction strategy based on using separating doors/walls is to prefer rather than a side-change construction strategy, which was the idea prior to the functionality study.

With help from functionality study, and with the prerequisites in mind, certain strategies for the construction plan could be pointed out, for example how to optimize the amount of deposition positions by placing transportation tunnels outside the boundaries for deposition.

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