Development of a New Brine Cavern Field for the Hengelo Salt Plant:

Basic Leaching Concepts and Development of the Haaksbergen Site

for:

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1 Introduction

To ensure the long-term brine supply to the salt evaporation plant in Hengelo, Akzo Nobel plans to develop a new cavern field north of the town of Haaksbergen approx. 10 km southwest of Hengelo. The new brine field is designed to produce 3 mio. t of salt per year for approx. 50 years. However, as the salt production from the Hengelo brine field will gradually decrease from 2017 onwards, the new field has to be developed to successively compensate for this difference in brine production. Consequently, cavern leaching operation is scheduled to already start in 2015 to allow for sufficient preparation time.

The Haaksbergen salt body is a bedded, slightly up-domed deposit of Z1 (Werra) Salt. The target horizon is anticipated to be up to 350 m thick in the centre of the salt body, but to thin out towards the edges of the deposit. To allow for an optimal exploitation of the resources by taking into account the varying thicknesses of the salt deposit, the current leaching and production scenario considers the development of 72 caverns of four different heights (and four different volumes) arranged in a hexagonal grid.

The subject matter of the present study are the basic leaching concepts for the 4 different cavern types and an outline of the production planning.

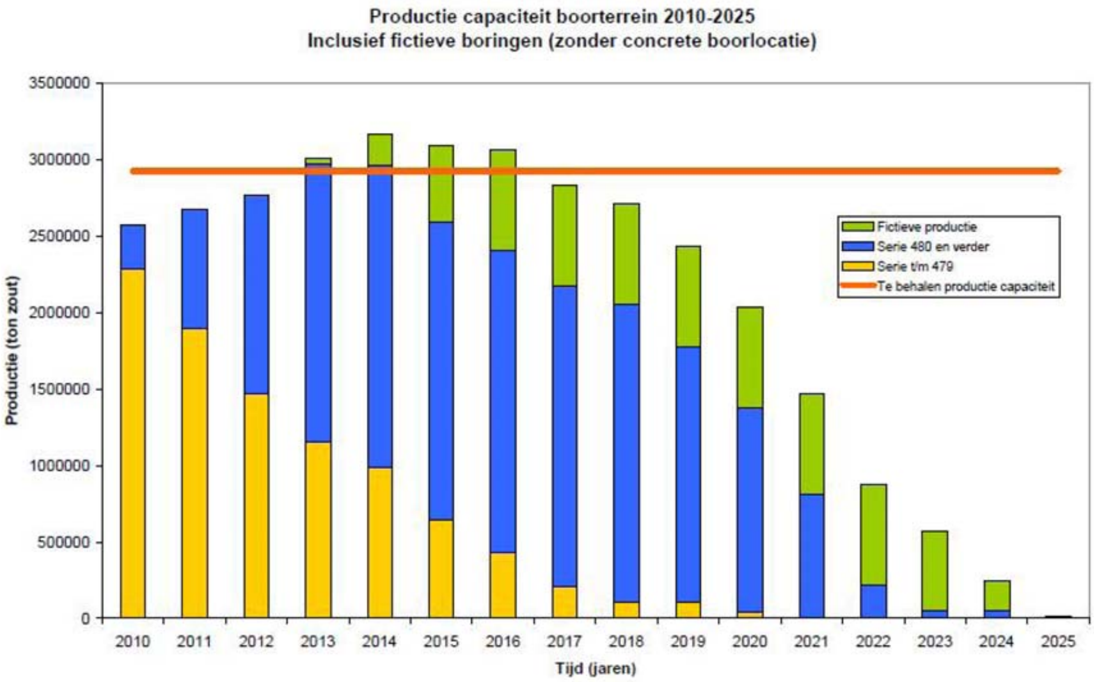


Figure 1: Brine production capacity of the Hengelo brine field (2010 – 2025)

2 Project Outline

The basic parameters for the development of the new brine field and thus, for the setup of the leaching concept, result from technical and commercial requirements of the Hengelo salt evaporation plant as well as from geological and rock-mechanical boundary conditions.

2.1 Requirements

To develop a reliable cavern field leaching strategy, several pre-conditions and requirements have to be considered. In this project, the major boundary conditions are:

- the guaranteed production of 3 M t salt per year,
- a brine flow rate of 1,200 m^3/h
- the reduction of the subsidence above the cavern field to the lowest possible magnitude and
- the production of salt for a minimum of 50 years.

2.2 Geology

In the subsurface of the Haaksbergen area, Z1 (Werra) evaporite deposits of Zechstein age occur as an elongated, roughly E-W trending salt pillow, some 6 km long and 2 km wide. Within the target area, the thickness of the Z1 Salt varies from 150 m to > 350 m while the top of the unit is found at < 550 m to 900 m depth (Enclosures 1 - 3).

The shape of the pillow as modelled on the base of seismic data [1] indicates two separate culminations where the Z1 (Werra) Salt sequence is 200 to more than 350 m thick and the top of the unit is found < 550 to 600 m below ground. However, given the sparsity of seismic data, the situation in the central part of the structure remains unclear and the two apparent highs may well be an interpretational artefact.

The Z1 Salt sequence is sandwiched between two massive anhydrite beds (Z1 Upper and Lower Anhydrite). Internally, the unit is considered to consist predominantly of rock salt (halite) with minor interbeds of anhydrite. It is assumed that the deposit has retained more or less the original horizontal bedding without complex internal structure.

The lenticular shape of the deposit with varying thicknesses of the salt sequence needs special attention in the development of the leaching concepts and field layout.

2.3 Rock-mechanics

Institut für Gebirgsmechanik GmbH (IfG), Leipzig, was contracted to perform a rock-mechanical assessment and a first dimensioning of the new salt production caverns for the Haaksbergen area [2]. As input parameters DEEP. provided a geological forecast section with average thicknesses as well as assumed average rock densities for the lithologies expected to be encountered in the target area. At this stage of the project, the rock-mechanical numerical model simplifies the salt deposit as well as the operational assumptions.

Starting point of the cavern design and prime constraint for cavern modelling is the rock-mechanical envelope, i.e. the maximum theoretical boundary that guarantees the long-term mechanical stability of the cavern void. The rock-mechanical boundary shall not be exceeded at any time during the leaching process and cavern lifetime.

The cavern is modelled in a depth range from 750 – 915 m, with an elliptical shape of the bottom part, a cylindrical section with a diameter of 135 m and a paraboloidal roof. For a 270 m thick Z1 Salt section, IfG has proposed the dimensions shown as in Figure 2. The defined rock-mechanical envelope has a volume of 1.67 M m³.

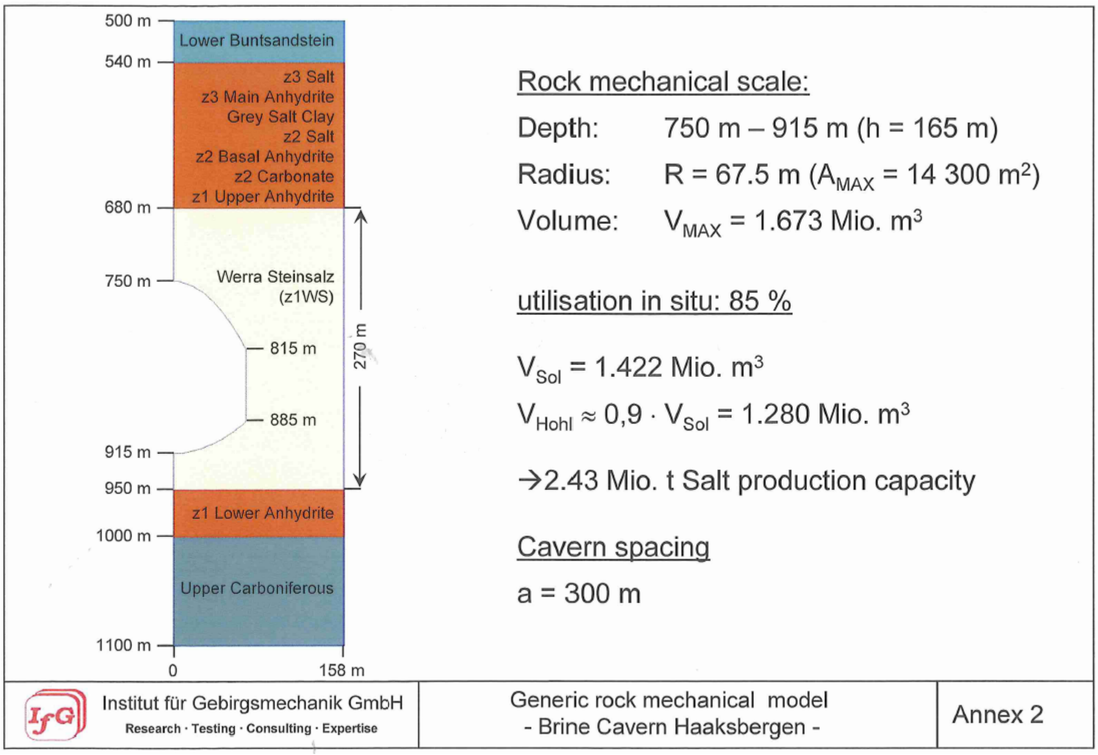


Figure 2: 'Generic rock-mechanical model – Brine Cavern Haaksbergen' (from [2]).

Based on the geometrical situation and the assumed rock salt properties, a cavern convergence rate of 0,2%/year under brine pressure and of 0,04%/year under an additional well head pressure of 50 bar were calculated. An initial estimation of the surface subsidence with brine pressure has yielded a subsidence value of 1.6 m in the central part of the field after 50 years. This assumption is regarded as the upper limit of possible subsidence rates as it considers the total cavern volume to be created all at once and held open for 50 years. More realistic scenarios that include wellhead pressure, a stepwise field development, and controlled abandonment will result in smaller values. The results of the modelling are presented in a separate report [3].

In order to mitigate the effect calculated from the first assumptions described above, it has been recommended by IfG:

- 'to limit the number of caverns that will be leached at the same time' and
- 'to minimize the stand-by operation period before cavern abandonment'.

During set up of the leaching concepts (see Chapter 4), these recommendations of the IfG were respected as important boundary conditions.

3 Conceptual Cavern Design

Following the current geological model of the Haaksbergen deposit (see Chapter 2.2, Enclosures 1-3) it is necessary to adjust the cavern design to the varying local salt thickness and thus to set up different leaching concepts.

For simplification four cavern types were defined (Table 1, Enclosure 4) at this stage of the project according to the average thickness of the Z1 Salt. These four cavern types are characterised by the same bottom and roof pillar thickness, i.e. the vertical distance to the underlying and overlying non-salt beds. In all four types, the lowest part ('sump cavern') and the cavern roof have the same height. Only the height of the cylindrical section varies from 20 to 140 m in dependence of the position in the cavern field (see Enclosures 1 - 3).

Table 1: Dimensions of cavern types 1 to 4

Type	No.	Sump height	Cylinder height	Roof height	Radius	Total cavern height
1	3	35 m	140 m	65 m	62.5	240 m
2	20	35 m	120 m	65 m	62.5	220 m
3	24	35 m	70 m	65 m	62.5	170 m
4	25	35 m	20 m	65 m	62.5	120 m

Possible measures to minimize the total surface subsidence above the cavern field are to reduce the number of caverns being open at the same time and to shorten the cavern abandonment procedure as proposed by IfG.

Another major influence on the surface subsidence is the total cavern volume. The total salt production from 72 caverns of type 1 to 4, each with 135 m diameter and an utilization factor of 0.8 of the rock-mechanical envelope is calculated to be approx. 160 M t. This would be sufficient for more than 53 years of production.

To reduce subsidence and at the same time to fulfil the requirement of 50 years of production, two additional adaptations are feasible:

- reduction of the volume of the individual cavern, or
- reduction of the number of caverns (with increased cavern spacing)

The option to construct a smaller number of caverns with a maximum diameter of 135 m was not considered any further. The rationale is that subsidence would be negatively influenced by the fact that the flow rate per cavern cannot be increased. Hence, larger caverns would have to be operated over a longer period of time, resulting in more open cavern space under brine pressure.

In respect to the reduction of the volume of the individual caverns it was calculated that a total of 72 type 1 to 4 caverns with a diameter of 125 m (s. Table 1) and an utilization factor of 0.8 are already sufficient to cover a production period of 50 years. The application of the utilization factor of 0.8 to the cross-sectional area of the cavern accounts for a safety margin that covers effects such as asymmetrical cavern development, preferred up-dip leaching, or preferential leaching of particular beds. In effect, the maximum cross-sectional area used for the leaching simulation is 9,800 m^2, which equals to a diameter of 112 m in the case of rotational symmetrical development. A rotational symmetrical cavern simulation is applied because there are no indications for expected elliptic or otherwise preferred directional development of the cavern shape.

4 Leaching Concepts

With the expected geological conditions and some empirical values regarding the properties of the salt rock, subsurface temperature etc. as input parameters, the 3D leaching simulation software *UbroAsym for Windows* was used to model the cavern development. The software tool has the capability to produce rotational symmetrical models with a vertical resolution of 500 slices. In many years of experience, the results of the simulation have always proven to be very reliable when later being compared to the actual leaching process.

For the cavern leaching simulation the type 3 cavern was used as reference as it is representative for the average cavern height throughout the field. The leaching simulation was performed for type 2, type 3 and type 4 caverns but not for type 1 as this was extrapolated by calculation from the type 2 cavern.

The basic input parameters are described below. Variables in the leaching simulation are the injection rate, leaching tubing settings and blanket level depth as well as the time allotted to each leaching step without changing these operational parameters.

The output of the leaching simulation is a conceptual leaching programme that lists the operating parameters and the sequence of actions (workovers, sonar surveys, etc.) against a realistic time frame. Moreover, the leaching model yields:

- the concentration of the brine produced,
- the dissolved and produced amount of salt,
- the net cavern volume,
- the volume of insolubles in the cavern sump and
- the 3-dimensional development of the cavern shape.

4.1 Input Parameters

4.1.1 Cavern Dimensions

The cavern dimensions as used in the leaching simulation are summarized in Table 2. Four different cavern types with different heights of the cylindrical part have been considered according to the conceptual cavern design described in Chapter 3. As already described, an additional utilization factor of 0.8 is applied to the cross-sectional area.

Table 2: Cavern dimensions as applied in the leaching simulation

roof height [m]	65
cylinder height [m]	20 / 70 / 120 / 140
sump cavern height [m]	35
max. diameter [m]	112
max. cross-sectional area [m²]	9,800

4.1.2 Formation Properties

As in the current stage of the project no site-specific data is available, some assumptions had to be made in respect to the formation properties.

Horizontal and vertical leaching velocities were chosen in accordance with the parameters known from comparable Zechstein salt deposits in northern Germany and in the Netherlands.

The percentage of insoluble component in the rock salt was estimated based on the average insoluble content in Z1 (Werra) rock salt known from a neighbouring location in Germany. A bulking factor known from many lab tests on core material from Zechstein salt was applied.

The cavern temperature used in the simulation model was adopted from other cavern projects with a comparable depth setting.

The input formation properties are summarized inTable 3.

Table 3: Formation properties as applied in the leaching simulation

leaching velocity (hor./vert.) [mm/h]	12 / 18
insolubles content [%]	10
bulking factor	1.6
salt density [kg/m³]	2155
temperature within the cavern [°C]	30

4.1.3 Operational Parameters

The leaching medium is a mixture of condensate from the Hengelo salt plant (60%) with water from the Twente canal (40%). Only a group of type 4 caverns will receive weak brine from the sump leaching process of other caverns for re-saturation (see Chapter 4.2.3). Maximum injection rates of 150 m³/h were considered for both, sump and main leaching phases.

In order to avoid high energy costs due to hydraulic friction loss within the leaching tubings, the hydraulically most efficient tubing combination is considered as leaching completion. Under the given constraints (leaching rate, depth etc.) this combination includes a 10-3/4" outer leaching tubing and a 7" inner leaching tubing.

Operational downtime assumed for workovers is 30 days, because one month is the smallest time increment that was applied in the modelling of the overall field development at this stage of the project. In reality, the time span required for workovers will be significantly lower.

Sonar measurements for volume and shape control are recommended to be performed with every 100.000 m³ of created cavern volume. From experience it is known that the number of sonar measurements can be reduced with the progress in field development as a better knowledge of the leaching behaviour of the formation is achieved.

4.2 Leaching Programme

The cavern construction process is briefly described below. Tabular leaching programmes for every cavern type are presented in Enclosures 6, 9, 13 and 15). Enclosures 7, 10, 11, 14 and 16 show the brine flow, brine concentration and development of cavern volume over time, while Enclosures 3, 8 and 12 display the development of the cavern shape as modelled by the *UbroAsym for Windows* simulation software tool.

Table 4 summarizes the number of interventions (workovers, blanket adjustments) and key production data considered for every cavern type.

4.2.1 Sump Leaching Phase

The 'sump leaching phase' is defined as the initial stage of cavern development during which the cavern delivers undersaturated brine. The leaching process in this phase is identical for all cavern types, irrespective of the final volume and height.

The sump leaching phase starts with the creation of a broad initial cavity of approx. 80 m diameter, which serves to collect the insoluble components released from the formation during further cavern development. Therefore, the inner and outer leaching tubings are set only some 10 m apart and the initial blanket level is set just above the shoe of the outer tubing.

The slope angle of the sump cavity is designed as low as possible, resulting in an almost flat bottom. Although the rock-mechanical shape considers a cone-shaped sump [2], the flat bottom also meets the criteria of mechanical stability.

Table 4: Key production data and number of interventions per cavern type

		type 1	type 2	type 3	type 4, fresh water	type 4, weak brine
sump leaching phase	no. of workovers	1	1	1	1	1
	no. of blanket steps	2	2	2	1	1
	max. leaching rate [m³/h]	150	150	150	150	150
	total time [d]	669	669	658	672	672
	average concentration [g NaCl/l]	234	234	234	220	220
	salt extracted [M t]	0.534	0.534	0.523	0.505	0.505
	no. of sonar measurements	2	2	2	2	2
main leaching phase	no. of workovers	3	3	2	2	2
	no. of blanket steps	2	2	2	3	3
	max. leaching rate [m³/h]	150	150	150	150	150
	total time [d]	2609	2250	1627	1220	2668
	average concentration [g NaCl/l]	315	315	314	313	313
	salt extracted [M t]	2.766	2.366	1.577	0.795	0.795
	no. sonar measurements	10	10	6	3	3

A first workover serves to adjust the position of the leaching tubings, which are both raised by some 10 m. After the workover the leaching mode is switched to reverse circulation (top injection).

After some 660 days of gross leaching time (including time for workover and other measures), the cavern has achieved a volume of 245,000 m and a diameter of 100 to 105 m at the end of the sump leaching phase. Up to this point in time the brine concentration has steadily increased, yielding an average concentration of approx. 220 g NaCl/l.

4.2.2 Main Leaching Phase

The 'main leaching phase' comprises the creation of the cylindrical part and the cavern roof. The main leaching phase is run with reverse circulation (top injection) throughout. Saturated brine of >312 g NaCl/l is produced during this phase.

As the height of the cylindrical part varies from 20 to 140 m (see Chapter 3), the number of interventions (blanket movement, workovers), the timing and the sequence of actions are slightly different for the four cavern types (see Enclosures 6, 9, 13 and 15). The main leaching phase for type 1 and type 2 caverns includes three workovers and two blanket steps, while for type 3 and type 4 caverns only two workovers and two (type 3) or three (type 4) blanket steps are considered (Table 4).

For all cavern types, the main leaching phase starts with a workover. Thereafter, a large amount of the total volume is created in the cylindrical part of the caverns.

Subsequent blanket steps and adjustments of leaching tubings already serve to develop the cavern roof. In order to utilize the reserves enclosed in the paraboloidal shape as defined by the rock-mechanical envelope (see Chapter 2.3), the cavern roof is leached stepwise to form a terraced cupola. While shaping the roof, considerable volume is still added to the cylindrical part.

The leaching concept considers two blanket changes at the end of the leaching process which result in a cavern roof shape that only roughly fits into the rock-mechanically ideal, domal contour. Here, potential for improvement and optimization is still given for the next phase, when more details are known, i.e. by planning for one or two more blanket steps to adjust the cavern roof to an optimum shape.

To keep the brine concentration above 312 g NaCl/l, leaching rates have to be lowered to 80 to 130 m³/h for some periods of time during the main leaching phase.

In the type 4 caverns the main leaching phase is shortest in comparison to the other types. Due to the reduced overall cavern height, the development of the cylindrical part is missing and the roof is developed immediately after completion of the sump leaching phase.

4.2.3 Fresh Water versus Weak Brine Injection

During the sump leaching phase, undersaturated brine with an average concentration of 224 g NaCl/l is produced. To guarantee a constant flow of saturated brine (>312 g NaCl/l), this weak brine needs to be re-saturated by passing it through other caverns before being delivered to the Hengelo plant. The concept of re-saturation is described in more detail in Chapter 5. It is considered that the weak brine will be re-saturated within the Haaksbergen field as soon as it has been sufficiently developed.

While the cavern volume is created relatively fast when injecting fresh water at a rate of 150 m³/h (volume increase of average 360 m³/d), the cavern lifetime is significantly increased by weak brine injection at the same rate (average volume increase of 195 m³/d). Therefore, the small-sized type 4 caverns are chosen for re-saturation. Keeping the smaller cavern volume open for a longer time span has a much lesser effect on the overall subsidence than using larger caverns with increased lifetime for re-saturation.

The leaching programme for type 4 'saturator caverns' operated with weak brine is basically the same as for those that receive fresh water. As seen in Table 4, the duration of the main leaching phase is increased by a factor of 2.2.

5 Field Development

For a maximum utilization of the Z1 Salt reserves of the Haaksbergen structure, the caverns are arranged in a roughly elliptical, strictly hexagonal grid with 300 m distance between the cavern axes and a safety pillar width of minimum 175 m (Enclosures 1 - 3). A few cavern positions have been left out because of surface infrastructure constraints, i.e. mainly in the area of the village of Sint Isidorushoeve and the northern outskirts of Haaksbergen.

In the current phase of the project, the proposed field layout comprises a total number of 72 caverns. Each cavern is considered to have a maximum allowable diameter of 125 m while the cavern height varies according to the 4 types defined in Chapter 3. Due to the assumed lenticular geometry of the Haaksbergen salt pillow, the largest caverns (type 1) are situated in the centre of the field while the smallest caverns (type 4) are arranged at marginal positions.

Designed as such, the Haaksbergen cavern field will provide brine at a rate of 1,200 m³/h for a period of 50 years. This figure corresponds to an annual production of 3 M tons of salt.

The minimization of overall subsidence has been considered by an optimized cavern design, i.e. by reduction of the rock-mechanically feasible diameter from 135 to 125 m. The second major measure to minimize subsidence is the development of an appropriate cavern field design and an optimal cavern leaching sequence. The current model considers the development of the field from SE to NW.

5.1 Hengelo - Haaksbergen Transition

The field development model assumes that only two pipeline legs are laid from the Haaksbergen brine field to the Hengelo plant. This means that while one leg is used for leaching water the other can be used either for undersaturated brine to the Hengelo brine field or for fully saturated brine to the salt plant.

To realize the transition between the Hengelo brine field and the new Haaksbergen field, the basic production concept includes two steps prior to independent production from Haaksbergen (Fig. 3).

Figure 3 and Enclosure 18 schematically show the chronological order of leaching and the interaction of caverns. The field development starts with three type 4 caverns that produce weak brine during the sump leaching phase for two years after start-up. This weak brine is delivered to the Hengelo field and injected into the production caverns for further saturation.

During the second step from year 3 to year 4 three new cavern wells are drilled and the undersaturated brine from the sump leaching process of these caverns is re-saturated within the Haaksbergen field. The first three caverns are at that point capable to produce saturated brine. At this stage, after two years of operations in Haaksbergen, the brine pipeline is transferred from transporting 450 m^3/h weak brine to delivering fully saturated brine, also at a rate of 450 m^3/h for two years. The remaining brine demand of the plant has still to be delivered from the Hengelo field.

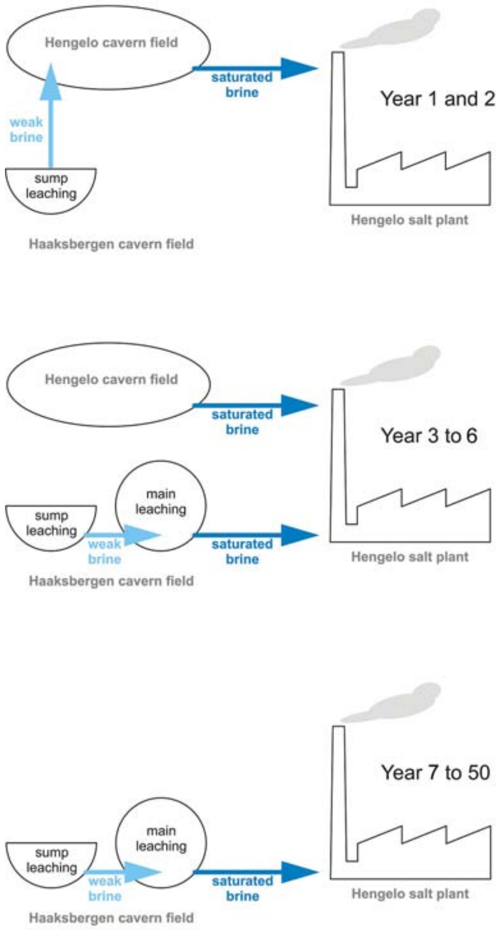


Figure 3: Operation schematic for the transition from the Hengelo to the Haaksbergen field

After year 4, three further caverns are brought into production. Again the weak brine is directed to the type 4 saturator caverns and the three caverns that had started at year 3 are now also capable to deliver fully saturated brine. The total brine flow from Haaksbergen to the salt plant is about 900 m^3/h at that time while 300 m^3/h have still to be delivered from Hengelo. In case of shutdown of one cavern due to workover or other purposes, the flow can be adjusted by increasing flow rates of either the Haaksbergen or the Hengelo caverns.

At the beginning of year 7, three more caverns have to be implemented. The weak brine from sump leaching is again directed towards the first three type 4 caverns for re-saturation. The saturated brine from these three caverns together with the saturated brine from the other six pre-developed caverns are capable to deliver 1,350 m^3/h of fully saturated brine. Thus, the total brine flow can compensate for an outage of one cavern due to e.g. workovers so that it is still possible to deliver 1,200 m^3/h of brine to the plant. The saturator caverns (type 4) are still able to saturate brine for another three to four years. Nevertheless, in year 7 planning needs to be started to develop new type 4 saturator caverns in order to substitute the first type 4 caverns.

5.2 Independent Haaksbergen Production

Based on the operational scheme developed for the transition from Hengelo to Haaksbergen the principle of cavern operation of a Haaksbergen brine field working independently becomes obvious (Enclosure 19). Almost constantly during the approximately 40 years of independent production at Haaksbergen three type 4 cavern need to be available to receive weak brine from the sump leaching phase of other caverns.

The graph in Enclosure 17 demonstrates that at average 450 m^3/h of undersaturated brine is produced and re-saturated in type 4 caverns. The diagram also shows the total flow of saturated brine over the whole time period. The average flow is slightly above the required rate of 1,200 m^3/h and therefore includes some safety margin for unexpected downtime.

The delivery of 1,200 m^3/h of saturated brine lasts for approx. 40 years. Including the periods of increasing flow at the beginning and gradually decreasing flow at the end of the whole production time and considering that the average brine flow is above 1,200 m^3/h, a brine supply for 50 years is theoretically feasible. Any adjustments to this concept will be done when more site-specific information about the total salt reserves are available after the exploration phase.

With a nominal flow of 150 m^3/h per cavern which needs to be reduced only during short periods of time as described for the individual leaching concepts in Chapter 4, a total of eight caverns are necessary. Up to two caverns should be considered as back-up for necessary flexibility and replacement during times of workovers, unforeseen operational downtime etc. and three additional caverns are required for re-saturation. Thus, a total of 13 caverns need to be in simultaneous leaching operation to secure constant brine flow from the Haaksbergen field.

The bar diagram in Enclosure 19, which is a simplification of the Excel spreadsheet used to develop the field development scenario, indicates the sequential availability of the above mentioned number of caverns. In average three additional wells will have to be drilled in two years to compensate for the abandonment of fully developed caverns.

To fulfil the requirement of minimum subsidence, the field development concept aims at the shortest possible operation time per cavern, i.e. the shortest possible time span with the cavern volume kept under brine pressure. Considering the required numbers of caverns being in parallel operation and assuming that these include caverns of all types, a total volume of roughly 6 M m^3 under brine pressure will be subject to convergence. This open volume resulting from an optimized field planning is only 4% of the volume of 150 M m^3, which has initially been taken as a basis for a first subsidence calculation.

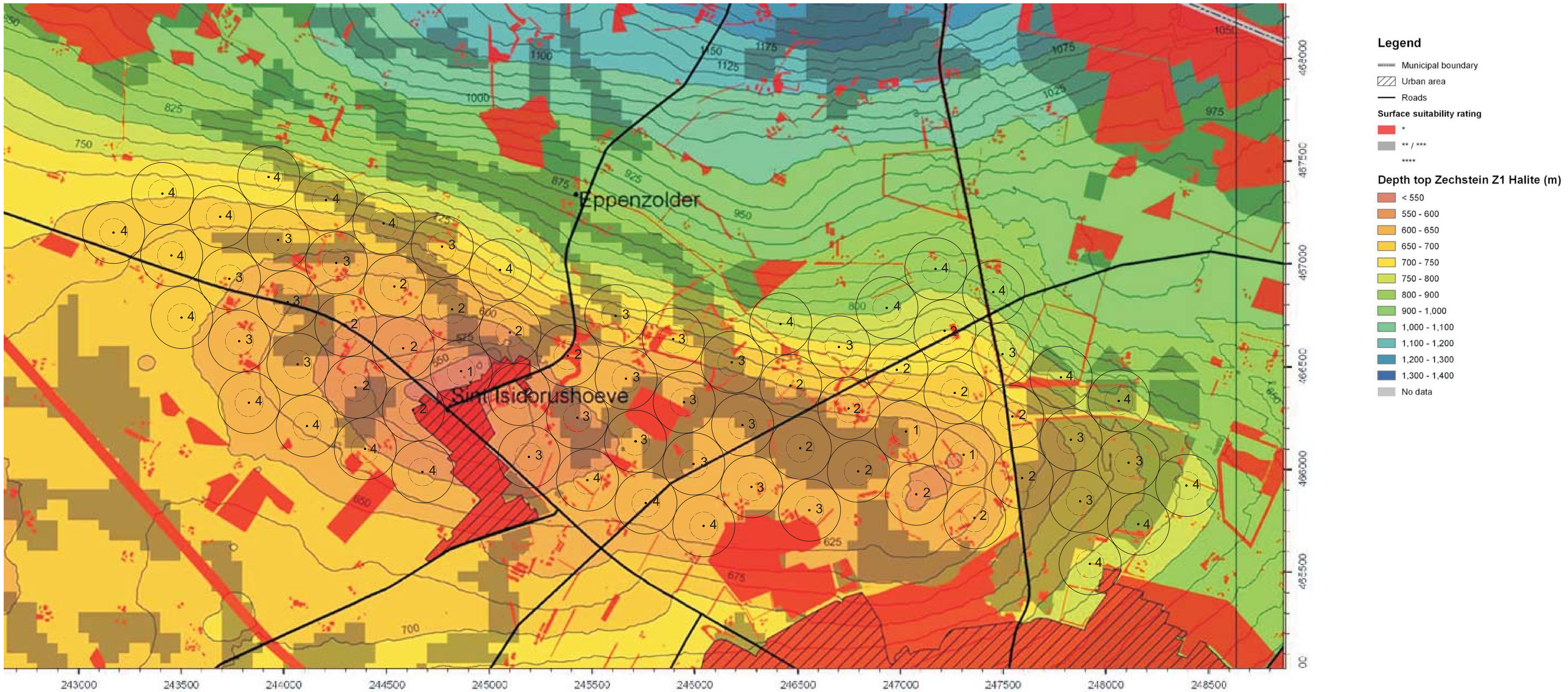
References

[1] MWH B.V. (2008): Study of the Salt Mining Possibilities in the Haaksbergen Area, the Netherlands, report, 82 pp, enclosures.

[2] IfG (2009): Rock Mechanical Investigations and Dimensioning for the new AkzoNobel NaCl-Brine Production Field Haaksbergen, report, 18pp., enclosures.

[3] KBBUT (2010): Development of a new Brine Cavern Field for the Hengelo Salt Plant: Basic subsidence Prediction, report, 15 pp., enclosures.

List of Enclosures



Enclosure 1: Haaksbergen salt pillow, iso-contour map of modelled top Z1 (Werra) Salt (from [1]) and proposed brine production cavern field layout.

0 1 km

scale 1 : 15,000

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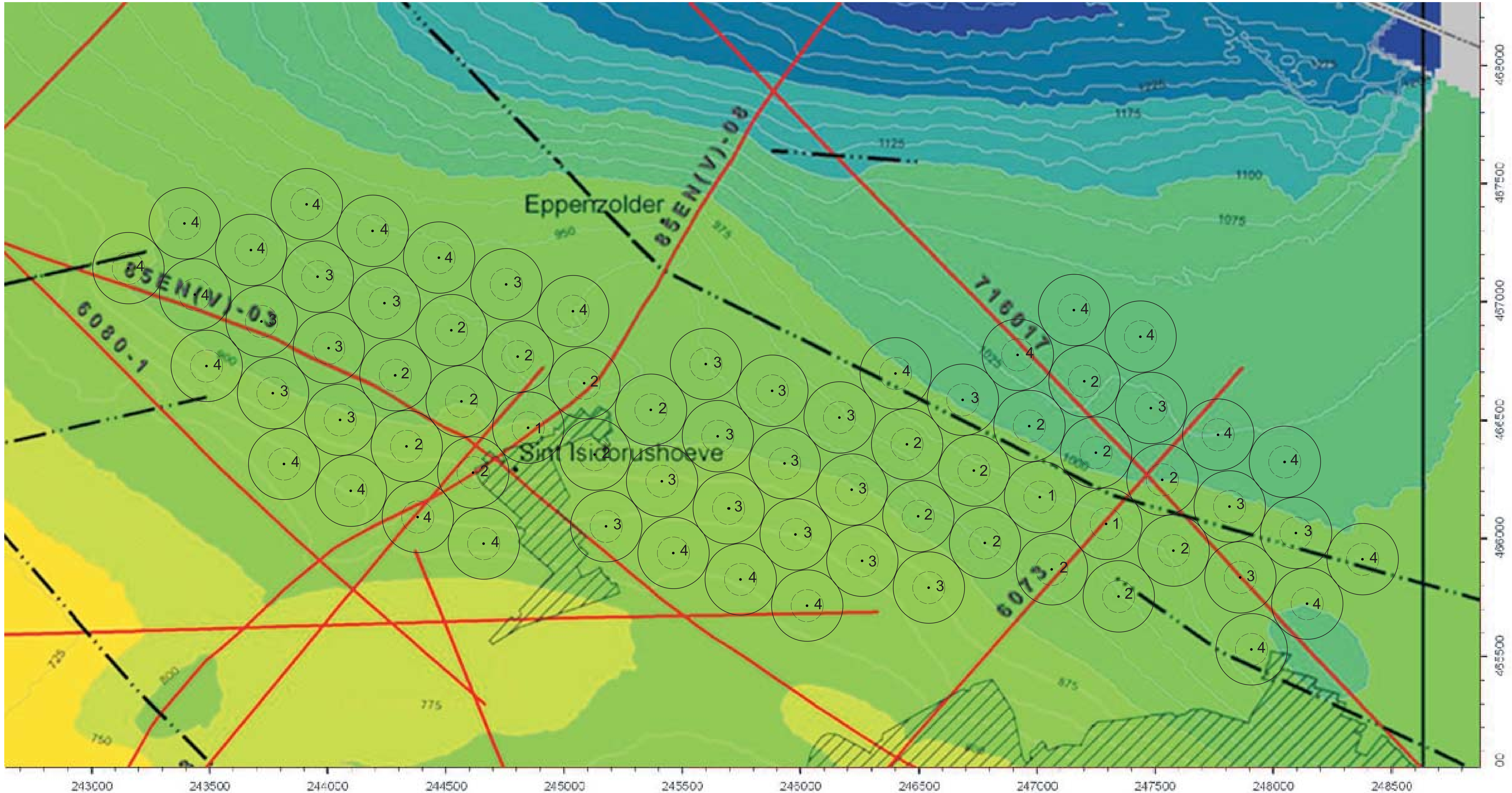

AkzoNobel

Legend

- Municipal boundary
- Urban area
- Seismic lines
- Fault lines

Depth base Zechstein Z1 Halite (m)

- < 550
- 550 - 600
- 600 - 650
- 650 - 700
- 700 - 750
- 750 - 800
- 800 - 900
- 900 - 1,000
- 1,000 - 1,100
- 1,100 - 1,200
- 1,200 - 1,300
- 1,300 - 1,400
- No data

Enclosure 2: Haaksbergen salt pillow, iso-contour map of modelled base Z1 (Werra) Salt (from [1]) and proposed brine production cavern field layout.

0 1 km

scale 1 : 15,000

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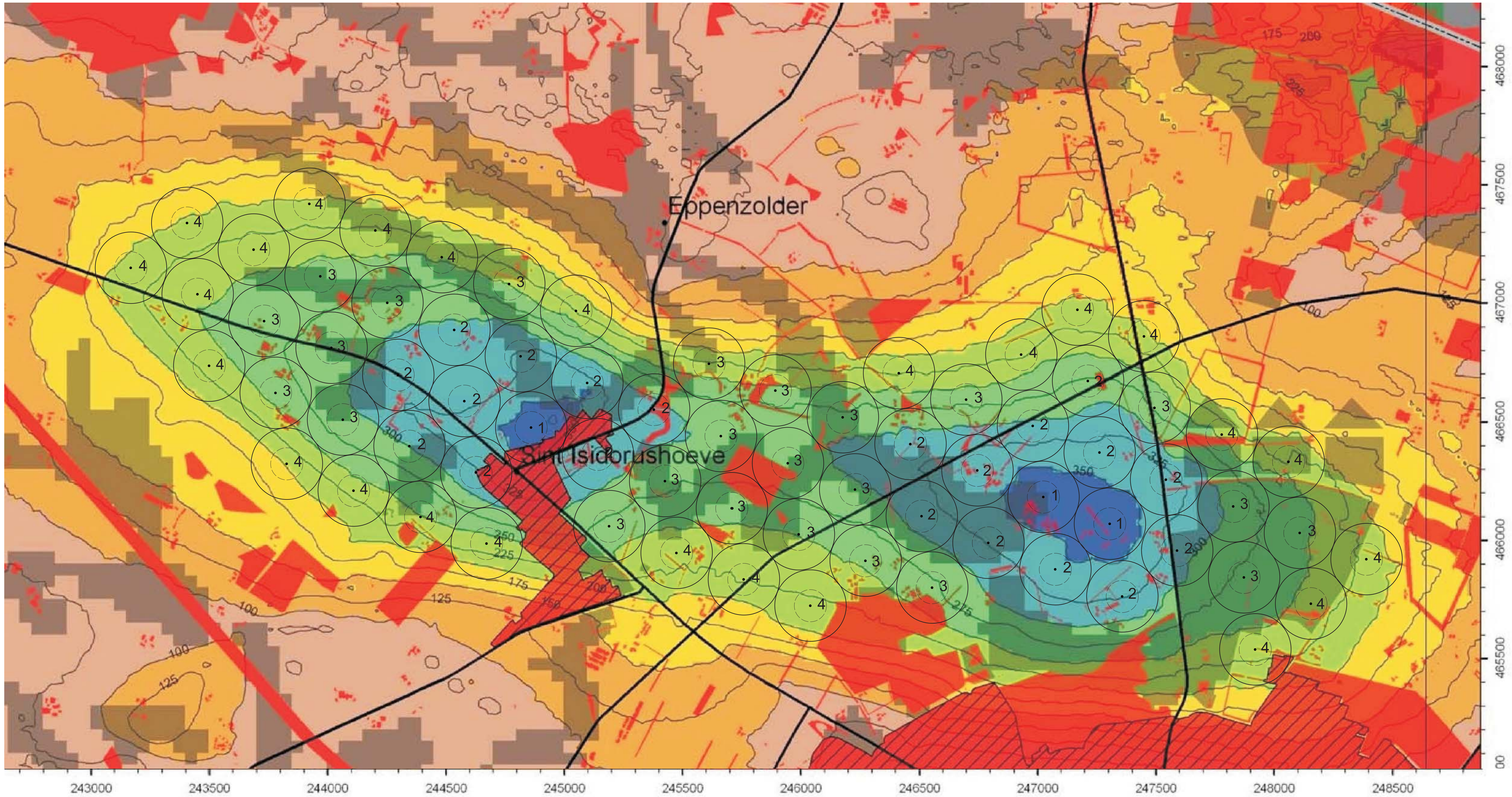

Enclosure 3: Haaksbergen salt pillow, iso-contour map of modelled thickness Z1 (Werra) Salt (from [1]) and proposed brine production cavern field layout.

0 1 km
scale 1 : 15,000

Legend

- Municipal boundary
- Urban area
- Roads

Surface suitability rating

- *
- ** / ***
- ****

Thickness of Zechstein Z1 Halite (m)

- < 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- 300 - 350
- > 350
- No data

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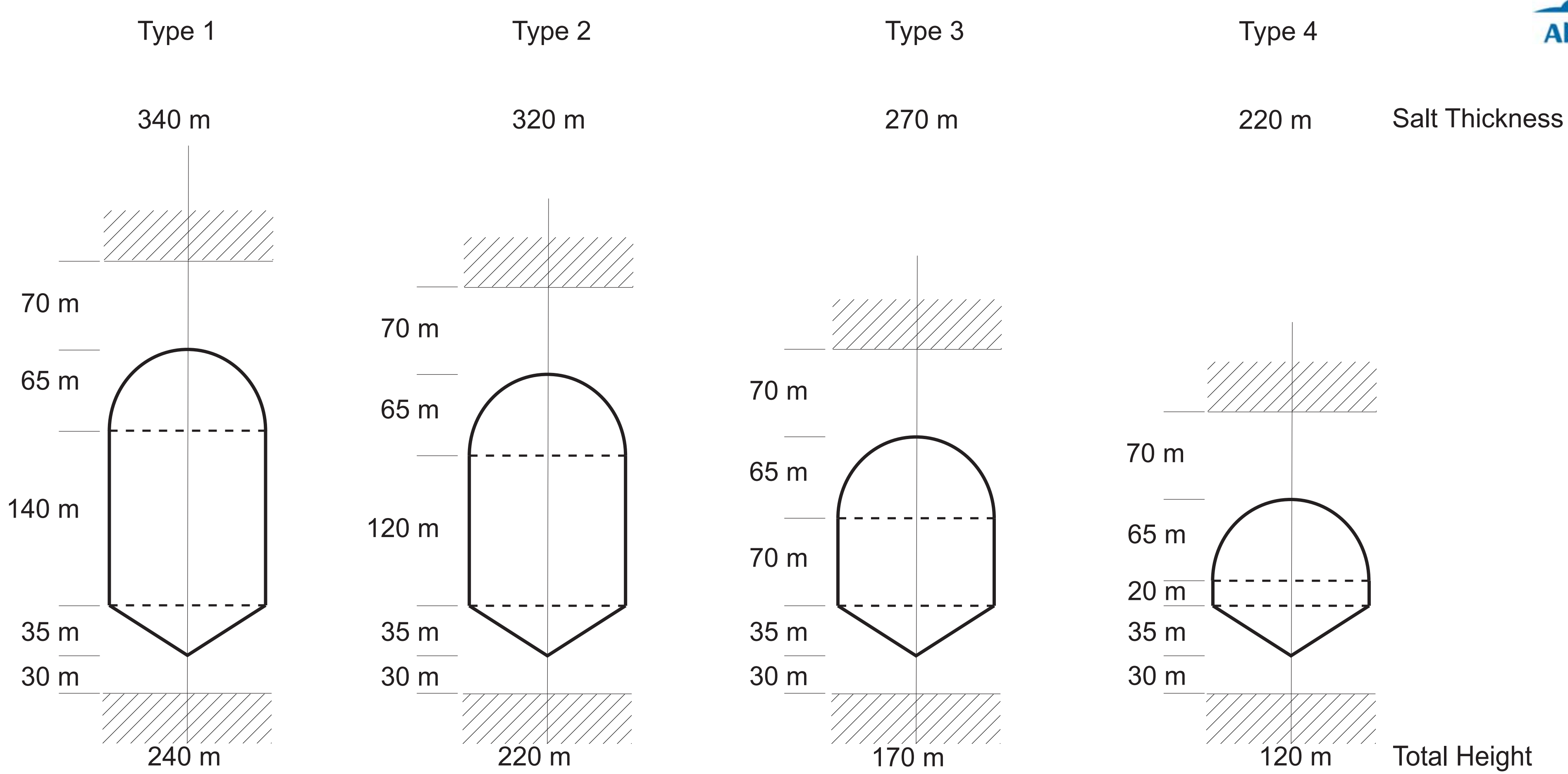
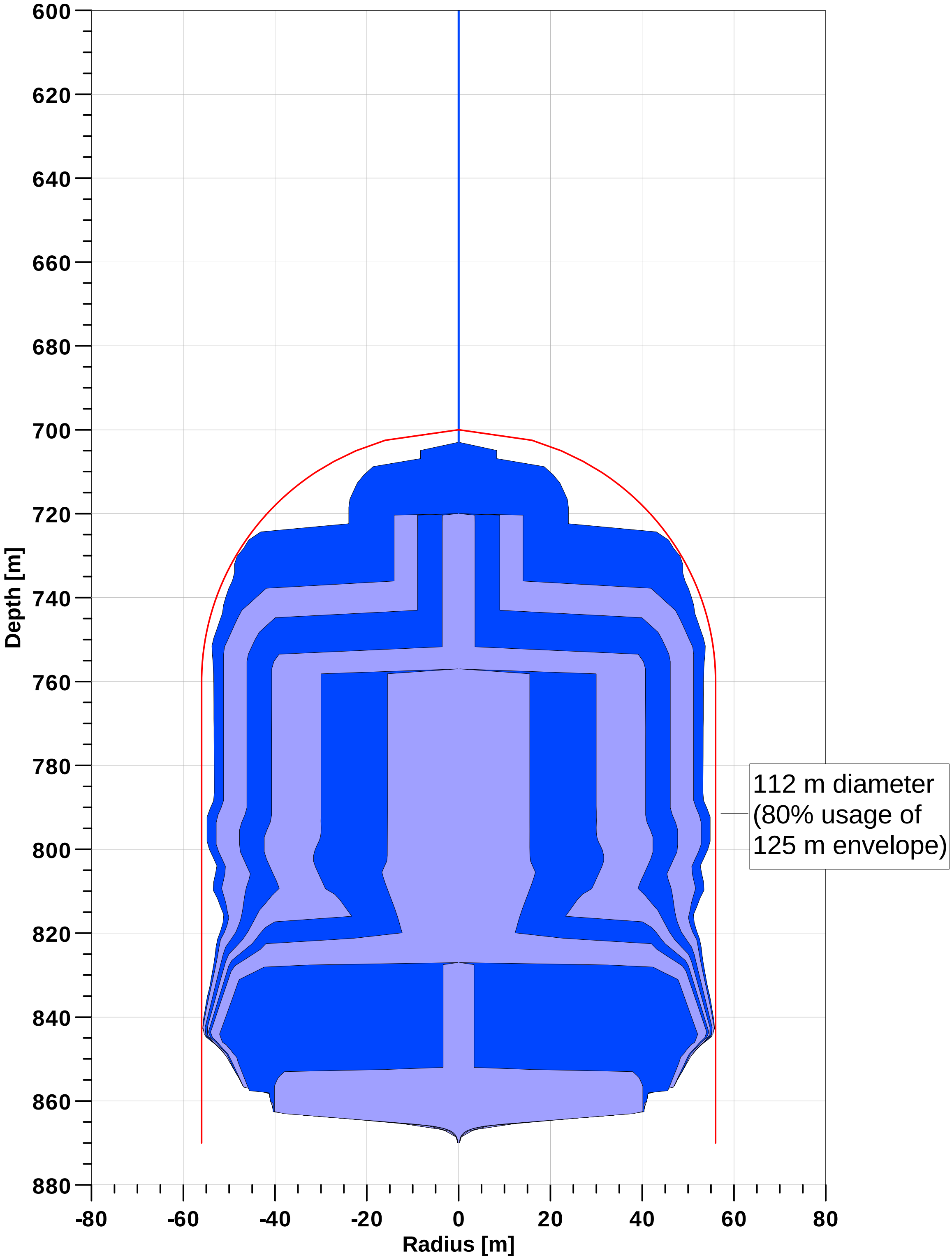


Enclosure 4: Dimensions of type 1 to type 4 caverns.



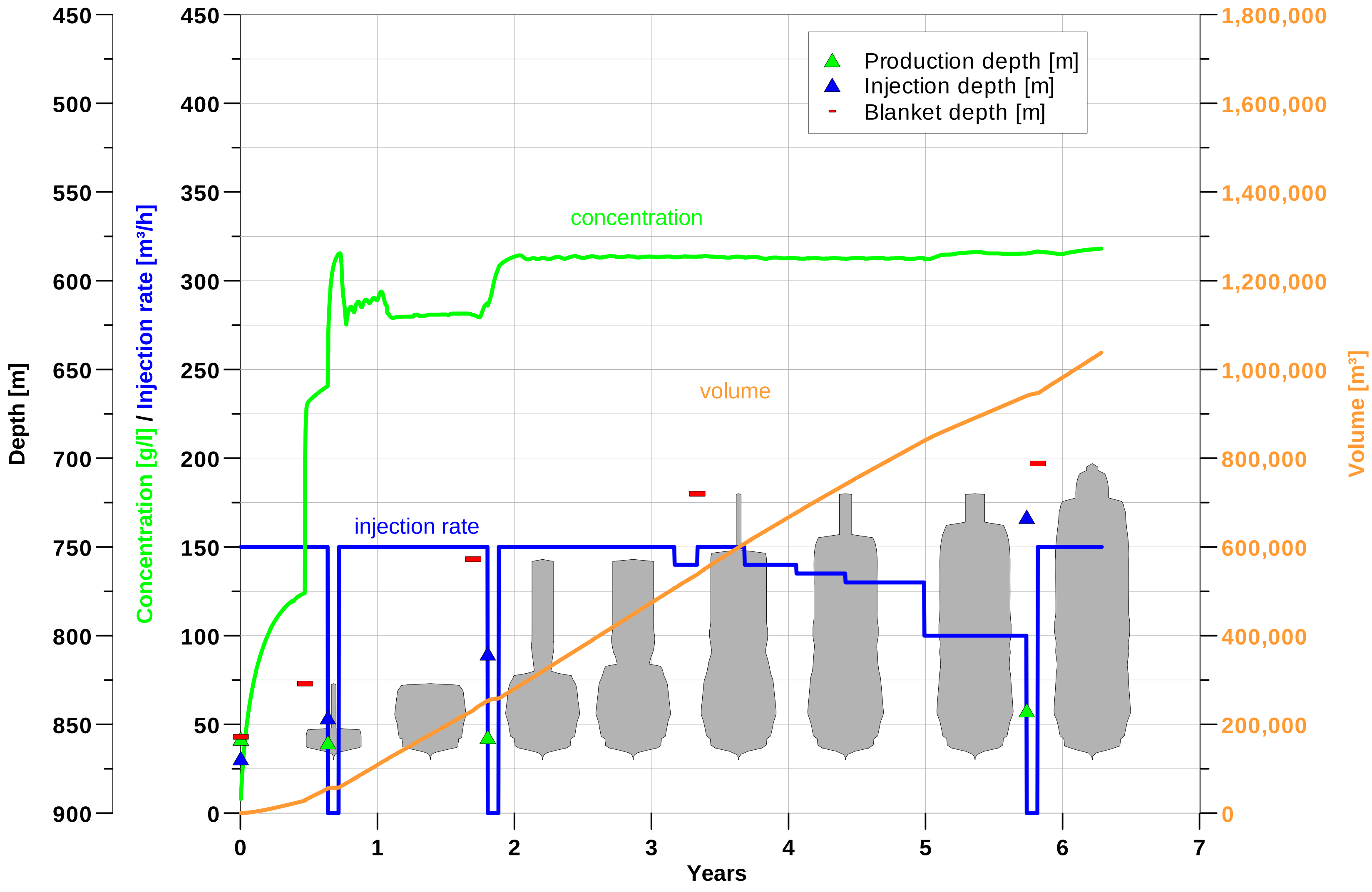
Encl. 5: Type 3, cavern shape development, 70 m cylindrical height (reference cavern).

Leaching concept type 3 cavern

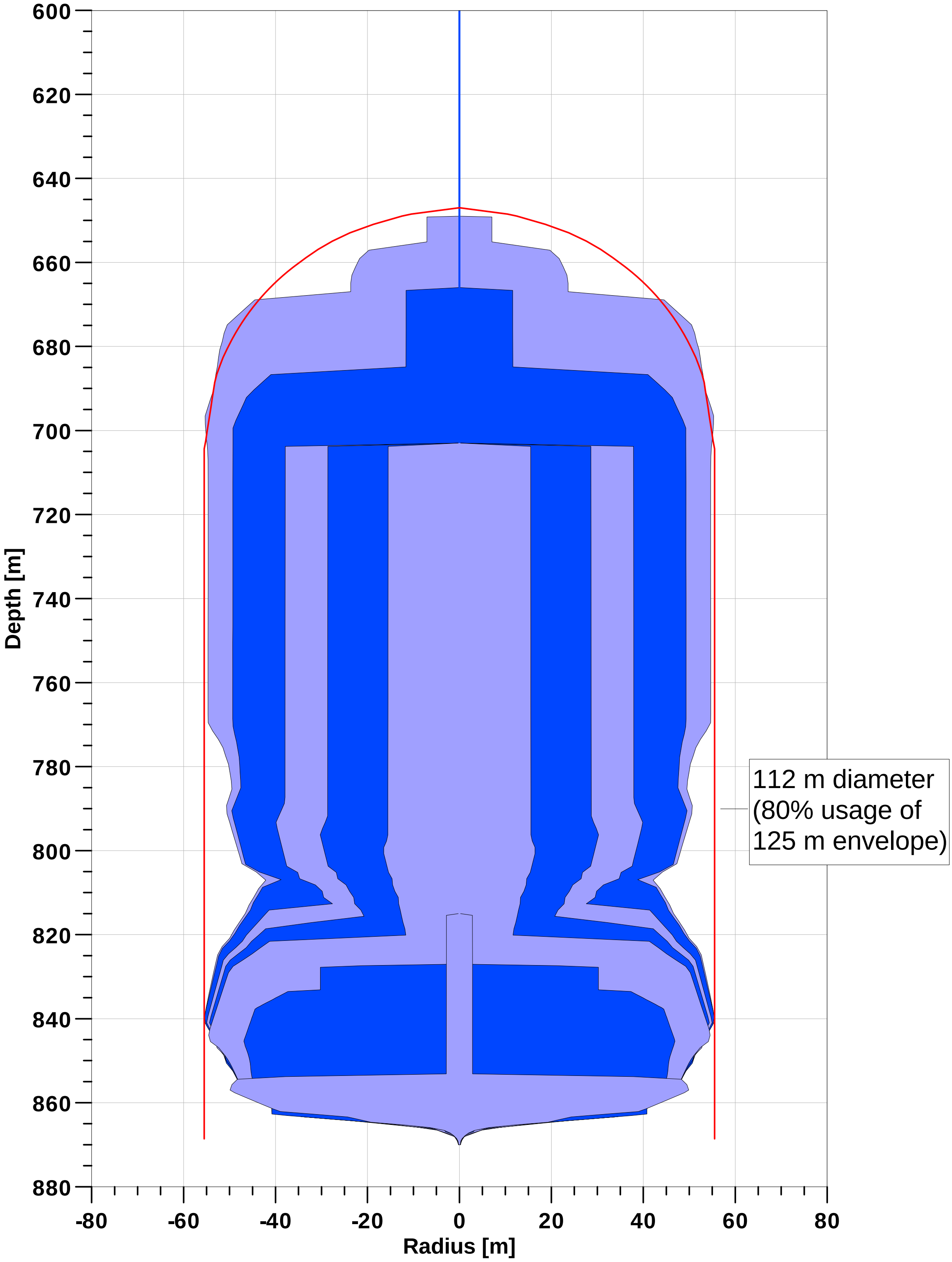
Period	Settings					Leaching				Results			
Start	Activities	Duration [d]	Inner String [m]	Outer String [m]	Blanket depth [m]	Duration [d]	Mode	Injection Rate [m³/h]	End	Duration total [d]	NaCl average [kg/m³]	Sump level [m]	Volume chem. [m³]
1			869	858	857	170	bottom	150	170	170	96	865	28.000
170	Blanket				827	61	bottom	150	61	231	234	864	55.000
231	W/O, sonar	30	860	846		358	top	150	388	619	284	859	231.000
619	Blanket				757	39	top	150	39	658	282	858	253.000
658	W/O, sonar	30	856	810		466	top	150	496	1154	313	851	507.000
1154						61	top	140	61	1215	313	851	538.000
1215	Blanket				720	125	top	150	125	1340	313	849	608.000
1340						137	top	140	137	1477	313	847	677.000
1477						130	top	135	130	1607	313	846	741.000
1607						208	top	130	208	1815	313	844	840.000
1815						270	top	100	270	2085	315	842	941.000
2085	W/O, sonar	30	842	733	703	170	top	150	200	2285	317	840	1.038.000

Encl. 6: Type 3, leaching concept with freshwater injection (tabular).

DEEP.
Underground Engineering



Encl. 7: Type 3, leaching concept with freshwater injection (graphical).

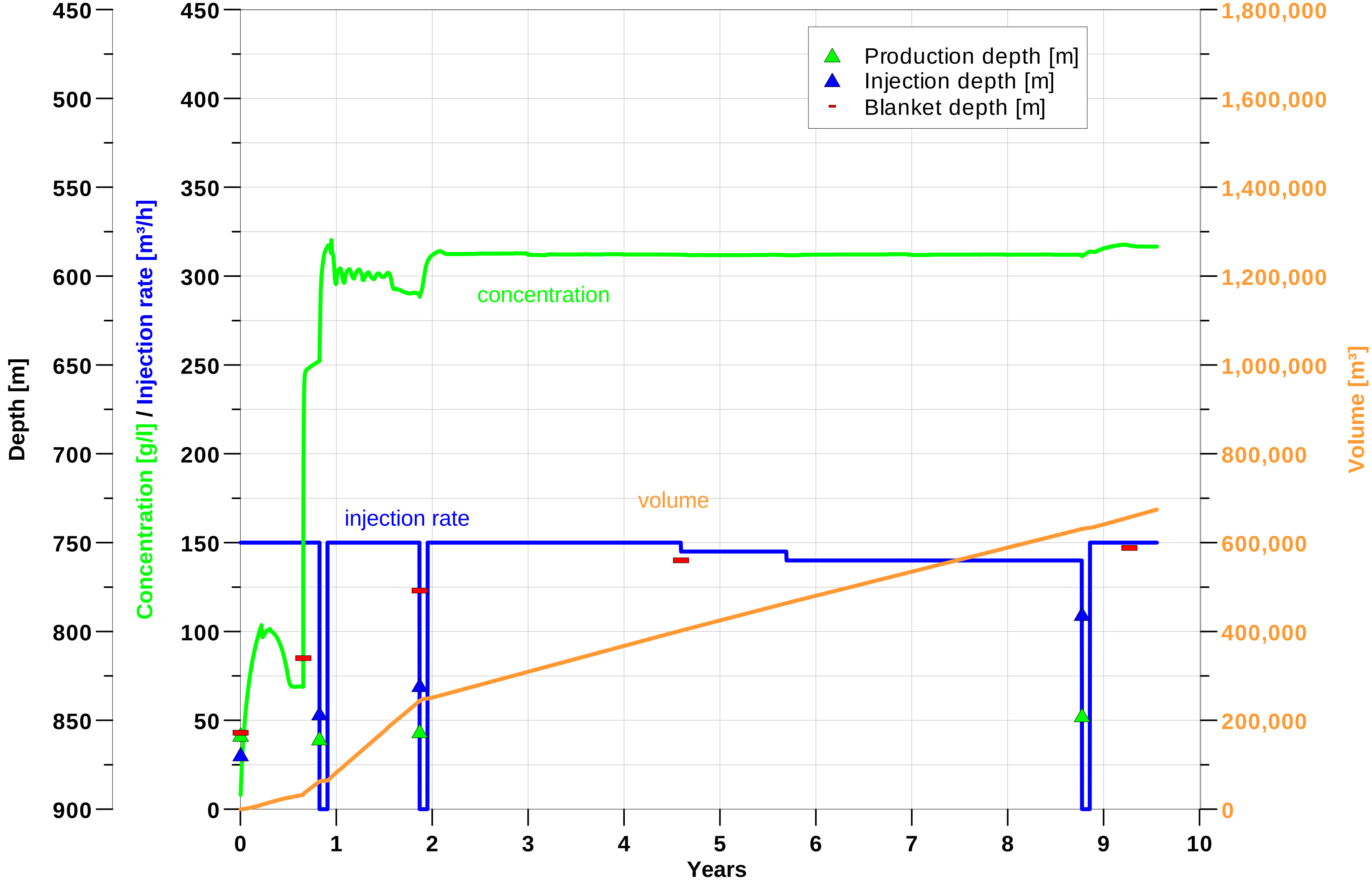


Encl. 8: Type 2, cavern shape development, 120 m cylindrical height.

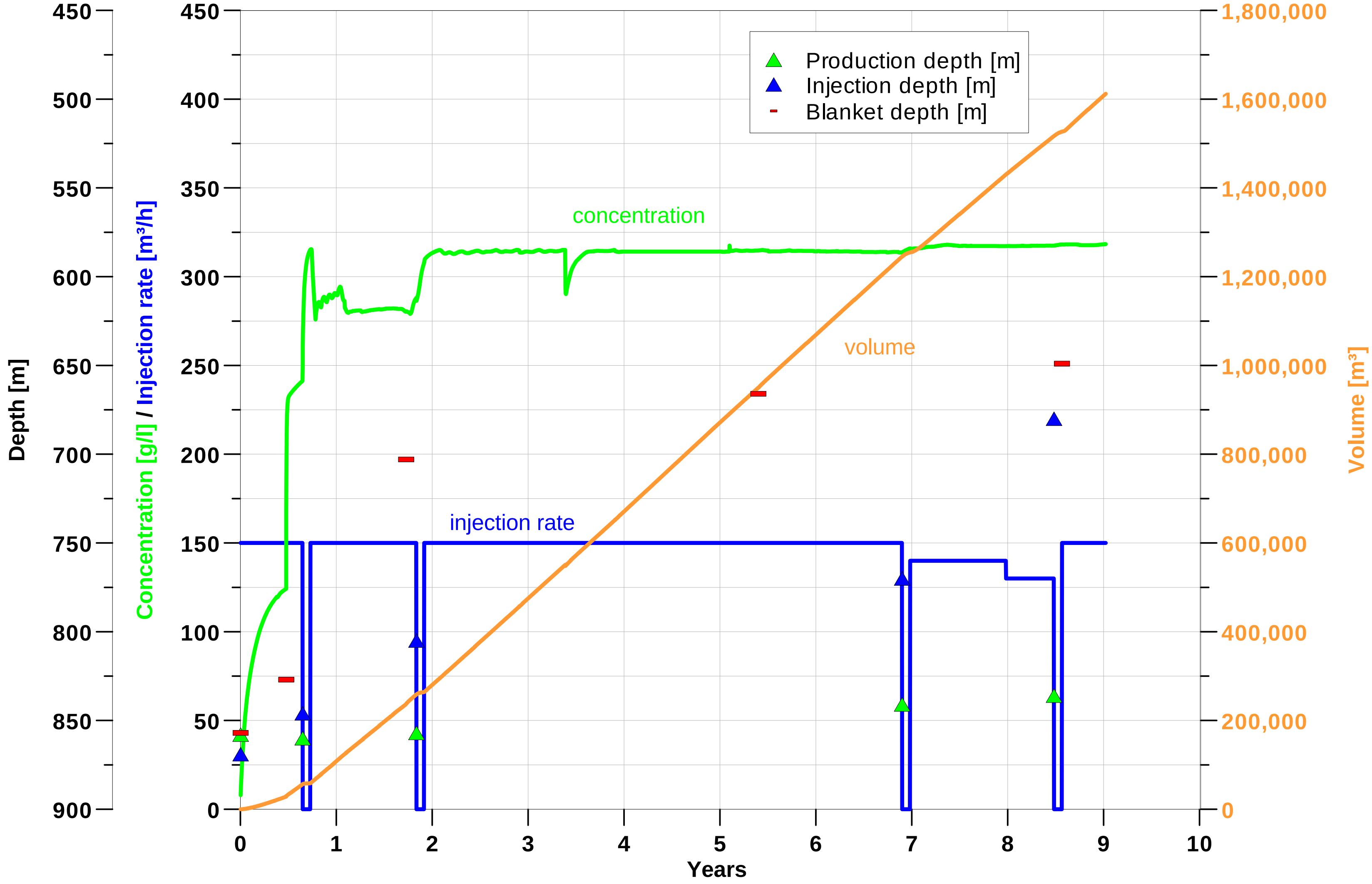
Leaching concept type 2 cavern

Period	Settings					Leaching				Results			
Start	Activities	Duration [d]	Inner String [m]	Outer String [m]	Blanket depth [m]	Duration [d]	Mode	Injection Rate [m³/h]	End	Duration total [d]	NaCl average [kg/m³]	Sump level [m]	Volume chem. [m³]
1			869	858	857	172	bottom	150	172	172	109	865	29.000
172	Blanket				827	62	bottom	150	62	234	234	864	56.000
234	W/O, sonar	30	860	846		366	top	150	396	630	285	859	236.000
630	Blanket				703	39	top	150	39	669	282	858	259.000
669	W/O, sonar	30	856	805		900	top	150	930	1599	313	846	750.000
1599	Blanket				666	540	top	150	540	2139	314	840	1.047.000
2139	W/O, sonar	30	839	770		180	top	140	210	2349	317	838	1.141.000
2349						180	top	140	180	2529	317	836	1.233.000
2529						180	top	130	180	2709	317	834	1.320.000
2709	W/O, sonar	30	834	680	649	180	top	150	210	2919	318	832	1.426.000

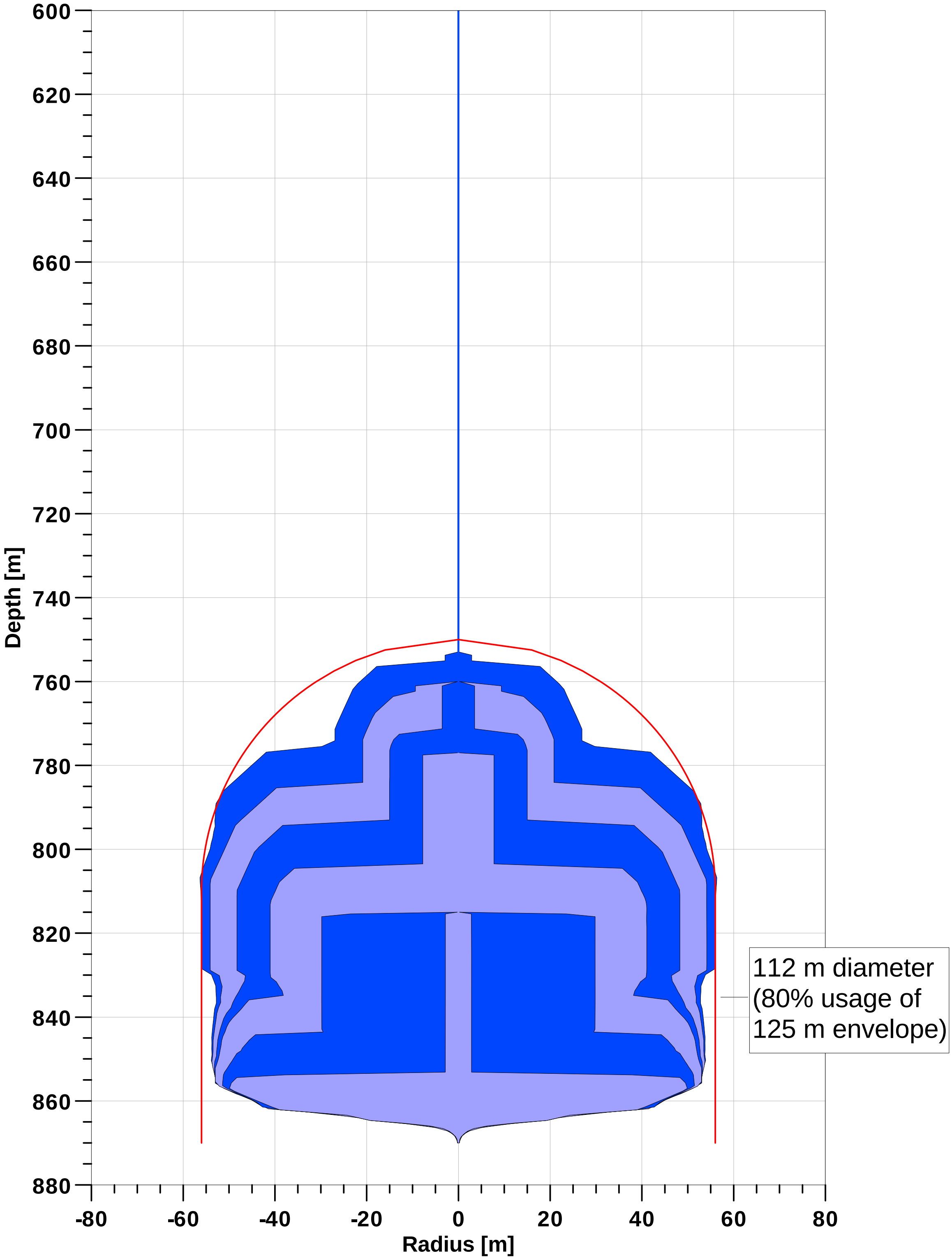
Encl. 9: Type 2, leaching concept with freshwater injection (tabular).



Encl. 10: Type 2, leaching concept with freshwater injection (graphical).



Encl. 11: Type 1, leaching concept with freshwater injection (graphical).

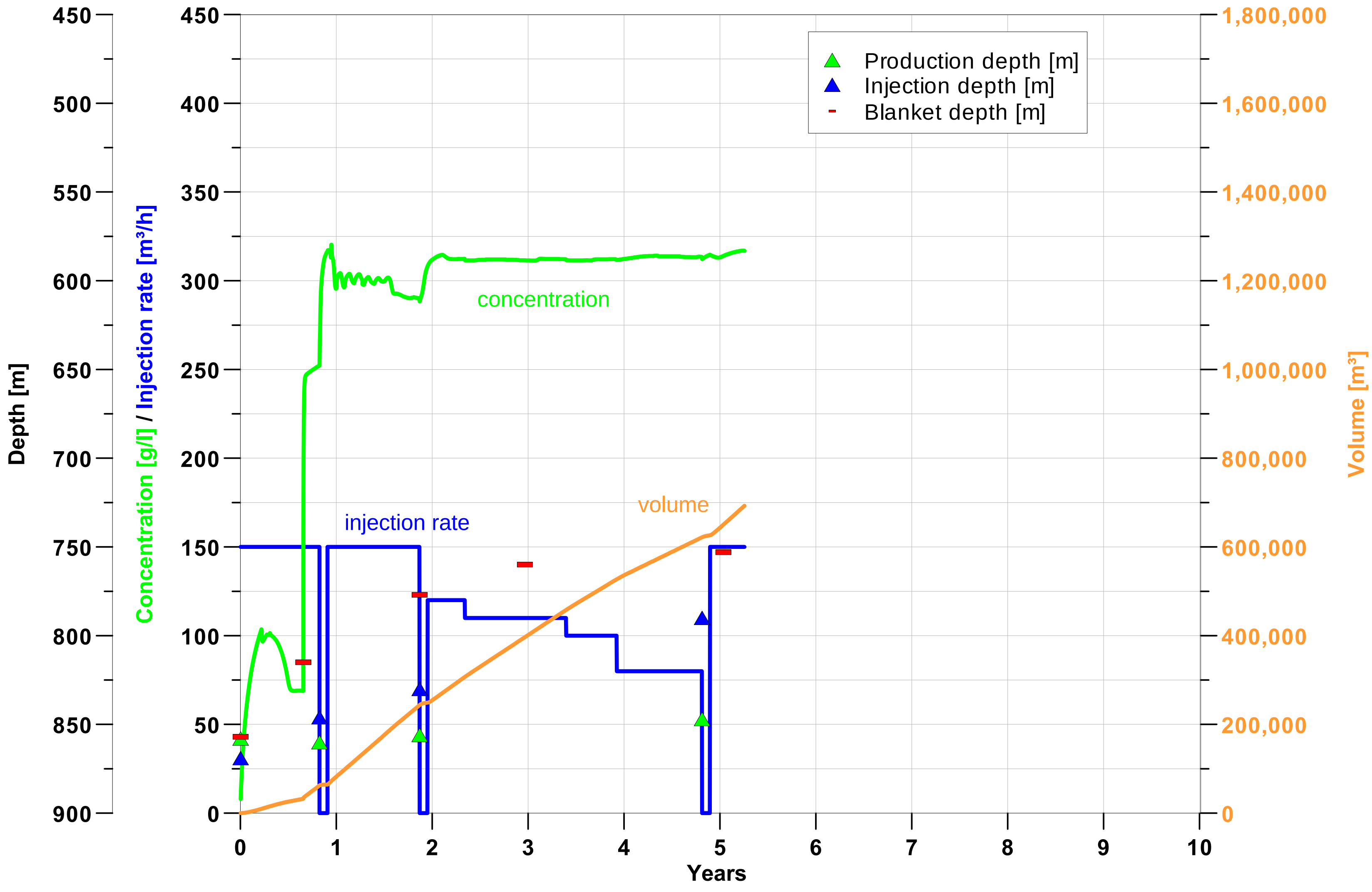


Encl. 12: Type 4, cavern shape development, 20 m cylindrical height.

Leaching concept type 4 cavern (fresh water injection)

Period	Settings					Leaching				Results			
Start	Activities	Duration [d]	Inner String [m]	Outer String [m]	Blanket depth [m]	Duration [d]	Mode	Injection Rate [m³/h]	End	Duration total [d]	NaCl average [kg/m³]	Sump level [m]	Volume chem. [m³]
1			869	858	857	235	bottom	150	235	235	91	864	32.000
235	Blanket				815	61	bottom	150	61	296	246	863	62.000
296	W/O, sonar	30	860	846		346	top	150	346	672	299	859	243.000
672	W/O, sonar	30	856	830	777	140	top	120	140	842	313	857	307.000
842						225	top	110	225	1067	312	855	396.000
1067	Blanket				760	155	top	110	155	1222	312	854	458.000
1222						190	top	100	190	1412	312	853	527.000
1412						320	top	80	320	1732	313	851	622.000
1732	W/O, sonar	30	847	790		50	top	150	50	1812	314	850	650.000
1812	Blanket				753	80	top	150	80	1892	316	849	693.000

Encl. 13: Type 4, leaching concept with freshwater injection (tabular).

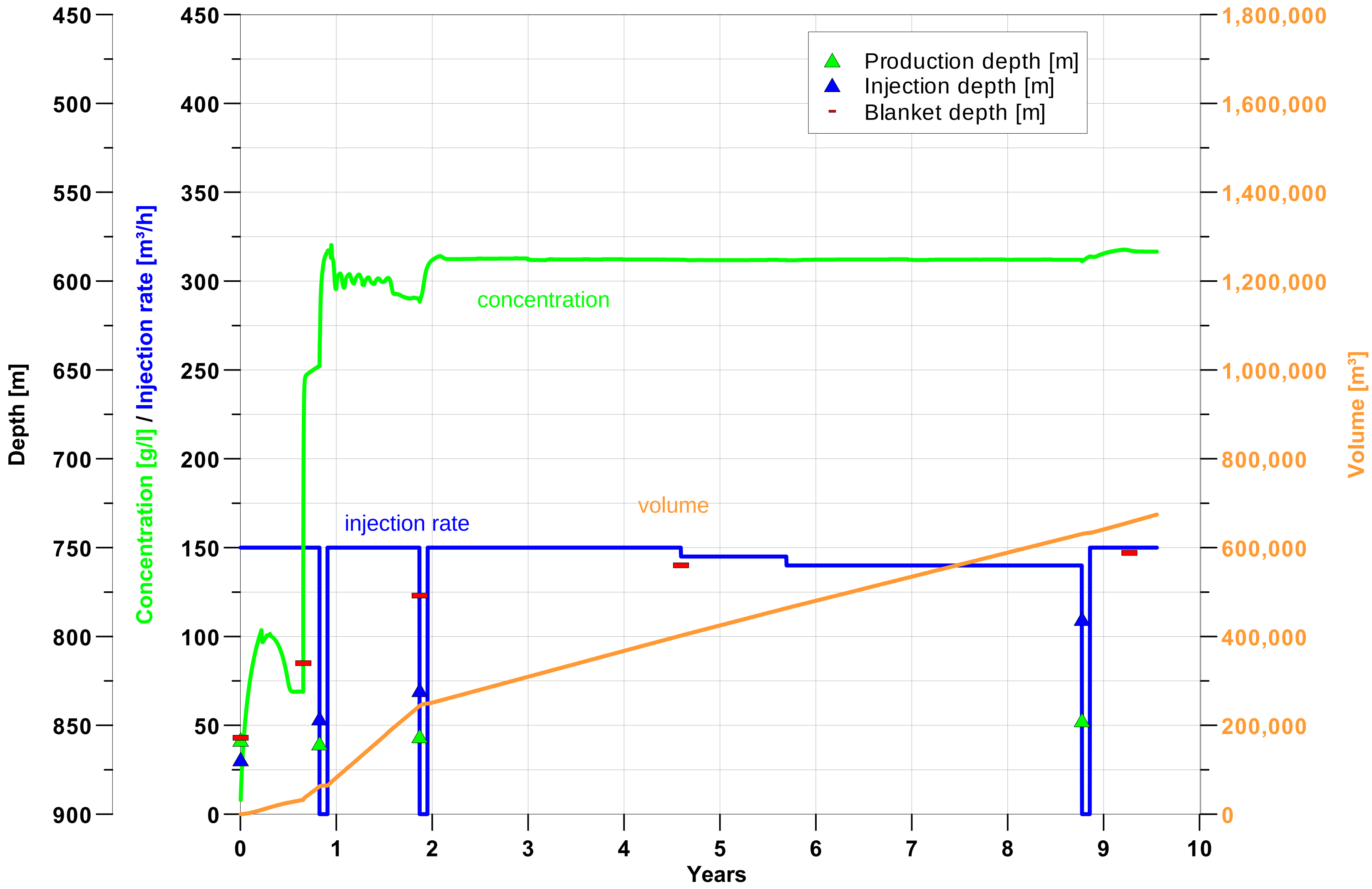


Encl. 14: Type 4, leaching concept with freshwater injection (graphical).

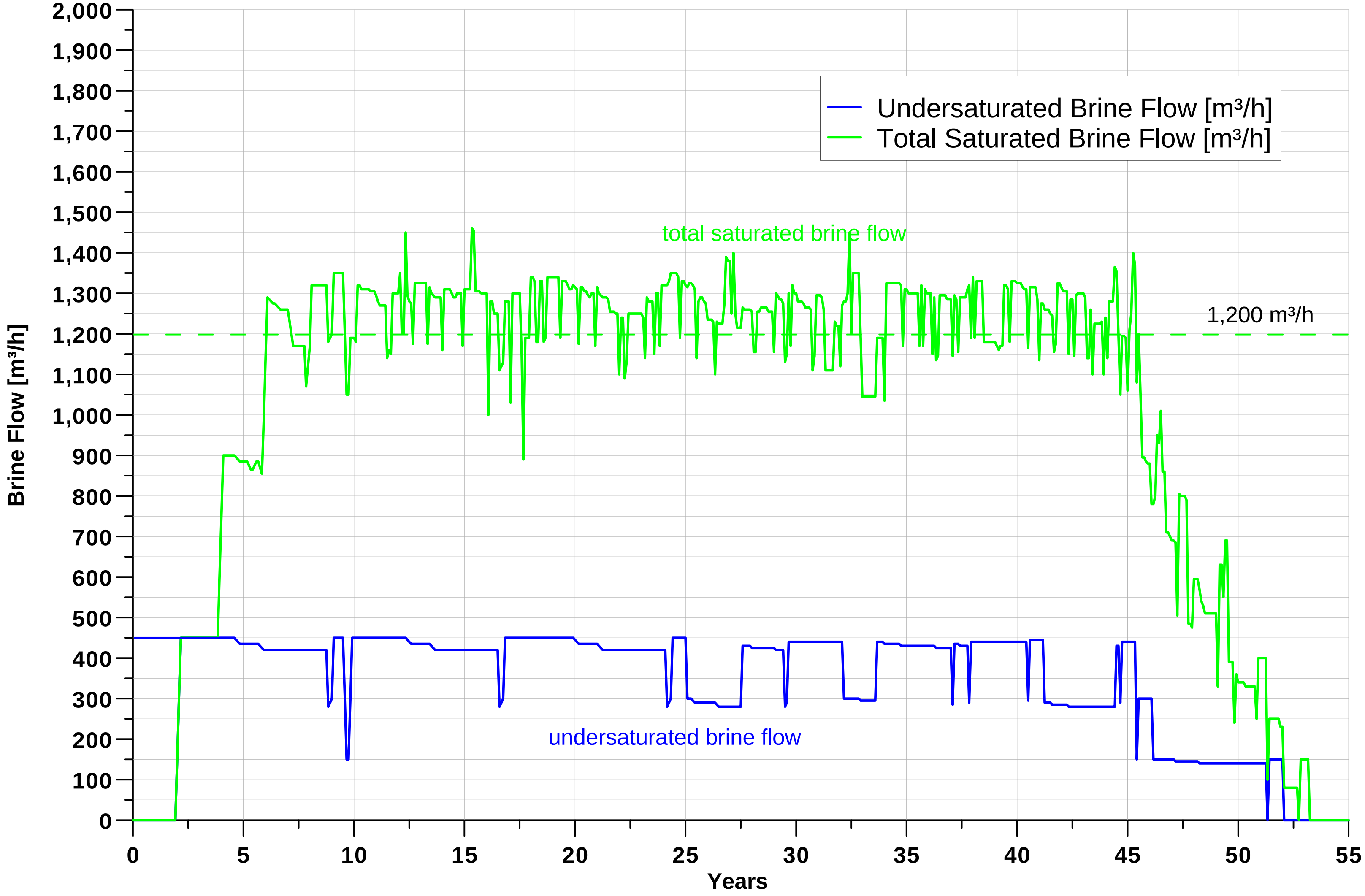
Leaching concept type 4 cavern (weak brine injection)

Period	Settings					Leaching				Results			
Start	Activities	Duration [d]	Inner String [m]	Outer String [m]	Blanket depth [m]	Duration [d]	Mode	Injection Rate [m³/h]	End	Duration total [d]	NaCl average [kg/m³]	Sump level [m]	Volume chem. [m³]
1			869	858	857	235	bottom	150	235	235	91	864	32.000
235	Blanket				815	61	bottom	150	61	296	246	863	62.000
296	W/O, sonar	30	860	846		346	top	150	346	672	299	859	243.000
672	W/O, sonar	30	856	830	777	951	top	150	951	1653	313	855	402.000
1653	Blanket				760	396	top	145	396	2049	312	854	464.000
2049						1.109	top	140	1109	3158	312	851	633.000
3158	W/O, sonar	30	847	790		148	top	150	148	3336	316	850	657.000
3336	Blanket				753	104	top	150	104	3440	317	850	675.000

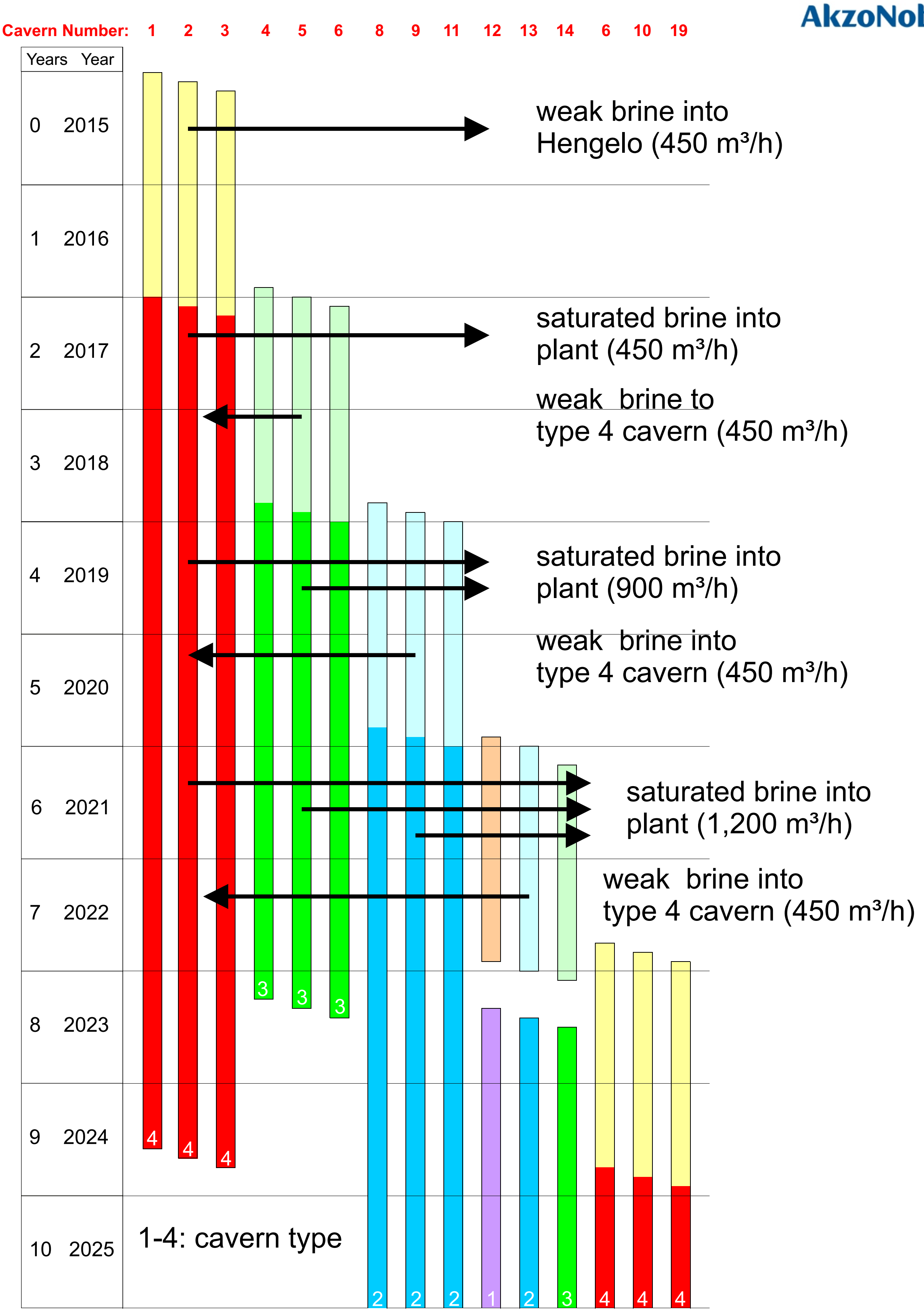
Encl. 15: Type 4, leaching concept with weak brine (220 g/l NaCl) injection (tabular).



Encl. 16: Type 4, leaching concept with weak brine (220 g/l NaCl) injection (graphical).



Encl. 17: Saturated brine flow and weak brine injection into type 4 caverns, cavern field Haaksbergen.



Enclosure 18: Detailed view of the production outline during Hengelo - Haaksbergen transition until full production capacity of 1,200 m³/h

Enclosure 19: Haaksbergen field development

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