Report
P-18-10
December 2019

Surface-water levels and groundwater levels in regolith at the Forsmark site

Monitoring programme updates prior to start of repository construction

Per-Olof Johansson

Kent Werner

SVENSK KÄRNBRÄNSLEHANTERING AB

SWEDISH NUCLEAR FUEL
AND WASTE MANAGEMENT CO

Box 3091, SE-169 03 Solna
Phone +46 8 459 84 00
skb.se

SVENSK KÄRNBRÄNSLEHANTERING

ISSN 1651-4416
SKB P-18-10
ID 1686878
December 2019

Surface-water levels and groundwater levels in regolith at the Forsmark site

Monitoring programme updates prior to start of repository construction

Per-Olof Johansson, Artesia Grundvattenkonsult AB

Kent Werner, EmpTec

Keywords: Operative programme, Surface system, Surface-water level, Groundwater level, Regolith, Update, Monitoring.

Abstract

This report describes proposed updates of the programme for monitoring of surface-water levels and groundwater levels in regolith at the Forsmark site. The report is part of preparations for an operative programme for investigations, monitoring and modelling of the surface system, which will be implemented during construction and operation of the spent nuclear fuel repository at Forsmark. In total, installation of seven surface-water level gauges and 23 groundwater-monitoring wells are proposed in the present work, as well as initiation of monitoring in three existing wells.

Three local reference areas have been identified outside the simulated hydraulic influence area of the spent nuclear fuel repository; the catchment areas of Lake Eckarfjärden, Lake Gunnarsboträsket and Lake Vambörsfjärden. Installations of three surface-water level gauges and five groundwater wells are proposed to obtain a good representation of the hydrological and hydrogeological conditions in these areas. Existing groundwater-monitoring wells were reviewed in terms of well geometries, screen depths in relation to monitored minimum and average groundwater levels, and functionality. Furthermore, wells at risk to dry up according to simulated drawdowns due to groundwater diversion from the repository were identified. With few exceptions, the status of the wells in the monitoring network is deemed as good. According to function controls, filter clogging is not yet any substantial problem. However, there may be pipe-joint leakages in some wells, and there are indications that sediments have accumulated in a large number of wells.

It is therefore recommended (i) to inspect wells using e.g. a borehole TV camera and to clear away sediments, (ii) that two wells are replaced, (iii) that well geometries are checked for wells with negative difference between minimum groundwater level and the lower level of the well screen, and (iv) that a thorough time-series screening is performed to eliminate data influenced by interference disturbances, in order to make full use of the existing data in an early warning system. Since the wells predicted to get dry all have their screens partly in bedrock, installation of new, deeper wells are not proposed at these sites.

To fill gaps in representativity (i) a groundwater-monitoring well is proposed in clayey till in a groundwater recharge area, (ii) a surface-water level gauge is proposed in a remote wetland where groundwater-level drawdown may occur according to simulations, as well as (iii) a groundwater-monitoring well in a fracture zone connected to this area. Furthermore, four supplementary groundwater-monitoring wells are proposed in areas where distinct drawdown caused by the repository is simulated and where wells are missing. The final layout of the access area is not yet settled, but several of the existing groundwater-monitoring wells are located so that they at some point in time will have to be removed and replaced, if possible. Three new wells in regolith, to be used both for groundwater-level monitoring and water sampling, are proposed already at the present stage.

As part of the permit process, SKB has proposed concepts for protective measures for six wetlands. The present monitoring is proposed to be complemented by four new groundwater-monitoring wells in till and two surface-water level gauges. TDR (time-domain reflectometry) equipment for monitoring of water content in the unsaturated zone are already installed at four locations at the Forsmark site. New groundwater-monitoring wells are proposed to be installed at two of these sites where wells are missing. A cluster of three groundwater-monitoring wells at different depths are proposed to enable studies of an area where discharge of deep groundwater has been indicated by chemical and isotopical signatures and model simulations.

The problems with dislocation of the surface-water level gauges and groundwater-monitoring wells in and below lakes and ponds, mainly due to ice lifting, are recommended to be coped with by installation of one or two supporting pipes at each location. These pipes should be connected to each gauge/well by iron bars welded to the pipes to form a triangle, in combination with annual levelling of top of casing of wells/gauges. As an alternative for monitoring of surface-water levels, a test of time-lapse cameras combined with well-anchored gauging scales is recommended.

It is argued that little essential information will be obtained from regional reference areas, considering the very extensive monitoring in the Forsmark area, both in the model-calculated influence area and in local reference areas. However, SKB is recommended to contact SGU (Swedish Geological Survey) to obtain information on plans for installations of automatic groundwater-level monitoring at existing and new sites of the National Groundwater Network.

Sammanfattning

Denna rapport föreslår uppdateringar av programmet for övervakning av ytvattennivåer och grundvattennivåer i jord i Forsmarksområdet. Rapporten är en del av förberedelserna för ett operativt program för undersökning, övervakning och modellering av ytsystemet, som kommer att vara implementerat under uppförande och drift av Kärnbränsleförvaret i Forsmark. Totalt föreslås sju nya peglar för ytvattennivåmätning och 23 nya grundvattenrör. Vidare föreslås att övervakning initieras i tre befintliga grundvattenrör.

Tre lokala referensområden har identifierats utanför Kärnbränsleförvarets simulerade hydrauliska influensområde, nämligen avrinningsområdena för sjöarna Eckarfjärden, Gunnarsboträsket och Vambörsfjärden. I syfte att erhålla representation av de hydrologiska och hydrogeologiska förhållandena i dessa områden föreslås installation av tre mätpunkter för ytvattennivå och fem mätpunkter för grundvattennnivå i jord. En genomgång har gjorts av befintliga grundvattenrör gällande rörgeometrier, intagssilarnas djup i förhållande till mätta minimi- och medelgrundvattennivåer samt rörens funktionalitet. Dessutom har rör identifierats som riskerar att bli torra, enligt de modellsimuleringar som gjorts avseende avsänkning till följd av grundvattenbortledning från förvaret. Med få undantag bedöms statusen vara god för de grundvattenrör som ingår i övervakningssystemet. Funktionskontroller indikerar inga problem av betydelse gällande igensättning av filter. Däremot finns indikationer på problem med läckage i rörskarvar i några rör och på att sediment har ackumulerats i botten på ett större antal rör. Det rekommenderas därför (i) att inspektera grundvattenrören med exempelvis borrhålskamera och att vid behov rensa dem från sediment, (ii) att två grundvattenrör ersätts, (iii) att rörgeometrier kontrolleras för rör med negativ skillnad mellan uppmätt minimi-grundvattennivå och intagssilens nederkant, och (iv) att en grundlig genomgång görs av tidsserierna för att eliminera data som är påverkade av interferensstörningar i syfte att fullt ut kunna nyttja tidsserierna i ett system för tidig varning. Eftersom de grundvattenrör som enligt gjorda simuleringar kommer att bli torra har sina intagssilar delvis i berget, föreslås inga nya, djupare rör i dessa lägen.

För att fylla luckor i övervakningssystemet föreslås (i) ett grundvattenrör i ett inströmningsområde med lerig morän, (ii) en mätpunkt för ytvattennivå i en avlägsen våtmark där modellsimuleringar indikerar att en grundvattenavsänkning kan uppstå, samt (iii) ett nytt grundvattenrör i en sprickzon som har förbindelse med detta område. Vidare föreslås också att fyra grundvattenrör installeras i områden där modellsimuleringar visar på tydliga avsänkningar på grund av förvaret, men där det saknas grundvattenrör i nuläget. Utformningen av förvarets ovanmarksdel är ännu inte slutligt bestämd, men flera av de befintliga grundvattenrören är belägna så att de i något skede kommer att behöva tas bort och om möjligt ersättas. Tre nya grundvattenrör i jord, vilka kan användas för både grundvattennivåmätningar och vattenprovtagning, föreslås redan i nuvarande skede.

I tillståndsprocessen har SKB presenterat ett koncept för skyddsåtgärder vid sex våtmarker. Den nuvarande övervakningen föreslås kompletteras med fyra nya grundvattenrör och två peglar för ytvattennivåmätning. TDR (time-domain reflectometry)-utrustning för övervakning av markvattenhalt i den omättade zonen är sedan tidigare installerad på fyra platser i Forsmark. Nya grundvattenrör föreslås installeras vid de två platser där grundvattenrör idag saknas. Ett kluster med tre grundvattenrör med intagssilarna installerade på olika djup föreslås för att möjliggöra studier av förhållandena i ett område där utströmning av djupt grundvatten indikerats genom kemi- och isotopsignaturer, och även i modellsimuleringar.

Problemet med rörelser av peglar och grundvattenrör i och under sjöar och gölar, främst orsakade av islyftning, rekommenderas att hanteras genom installation av ett eller två stödrör. Dessa rör kopplas ihop med varje grundvattenrör/pegel via stag som svetsas till stödrören i triangelform. Den föreslagna typen av installation kombineras med årliga avvägning av grundvattenrörens/peglarnas röröverkanter. Som ett alternativ för övervakning av ytvattennivå föreslås ett test med automatisk fotografering med ett bestämt tidsintervall av väl förankrade pegelskalor.

Det framförs argument för att mätningar i regionala referensområden endast har begränsat informationsvärde, med hänsyn till det mycket omfattande övervakningsprogrammet i Forsmarksområdet, både i det modellberäknade influensområdet och i lokala referensområden. Det rekommenderas dock att SKB kontaktar SGU (Sveriges geologiska undersökning) för att få information om planer för installation av automatisk grundvattennivåövervakning vid befintliga och nya mätplatser inom ramen för Grundvattennätet.

Contents

1 Introduction

The Swedish Nuclear Fuel and Water Management Company (SKB), in the process of establishing an operative programme for investigations, monitoring and modelling of the surface system to be implemented at the Forsmark site, has identified the need for further elaboration of some issues regarding monitoring of surface-water levels and groundwater levels in regolith:

1. Identification of local reference areas and proposal for a monitoring programme for surface-water levels and groundwater levels in regolith in these areas.
2. Review of the existing monitoring programme for surface-water levels and groundwater levels in regolith based on the location of the repository for spent nuclear fuel and its access area, and identification of gaps in spatial representativity. In particular, the monitoring programme should include the catchment areas of wetlands (lime-rich ponds and rich fens), for which SKB has presented concepts for protective measures as part of the licensing process.
3. Assessment of the need for additional groundwater-monitoring wells in regolith at the four locations where TDR (time domain reflectometry) equipment has been installed for monitoring of water content in the unsaturated zone.
4. Discussion regarding the need for regional reference areas for monitoring of surface-water levels and groundwater levels in regolith.
5. Identification and analysis of difficulties in long-term monitoring of surface-water levels of lakes and ponds and groundwater levels in regolith below surface waters due to ice lifting, and identification and assessment of possible alternative monitoring techniques.
6. Discussion of possible locations of additional groundwater-monitoring wells in regolith in present terrestrial discharge areas for deep groundwater, in order to increase the understanding of groundwater-discharge areas in the far-future (present sub-sea) Forsmark landscape.

The work presented in this report has been carried out in close cooperation with Emma Lindborg, Susanna Andrén, Sara Nordén (SKB) and Gunnar Rauséus (Geosigma AB), and supporting material and valuable comments have been provided by Mats Tröjbom (Mats Tröjbom Konsult AB).

All planar (X, Y) coordinates are given in the coordinate system SWEREF 99 18 00 and vertical (Z) coordinates are given in the RHB 70 elevation system.

2 Identification of local reference areas and proposed monitoring

Based on extensive hydrogeological investigations (Follin 2008, Johansson 2008) and flow-model simulations (Mårtensson and Gustafsson 2010), a generalized influence area of groundwater-table drawdown has been delineated for the construction and operation phases of the repository for spent nuclear fuel, see Figure 2-1. The generalized influence area is based on a numerical simulation using the MIKE SHE modelling tool, based on the model setup of Bosson et al. (2008). The generalized influence area of Figure 2-1 represents a hypothetical modelling case with a fully open repository and a hydraulic conductivity of the grouted zone (K_{grout}) of 10^{-7} m/s. Specifically, the generalized influence area is defined as the area with a model-calculated annual average groundwater-table drawdown of 0.1 m or larger, plus a "buffer zone" of 300 m away from the outer edge of the "drawdown areas".

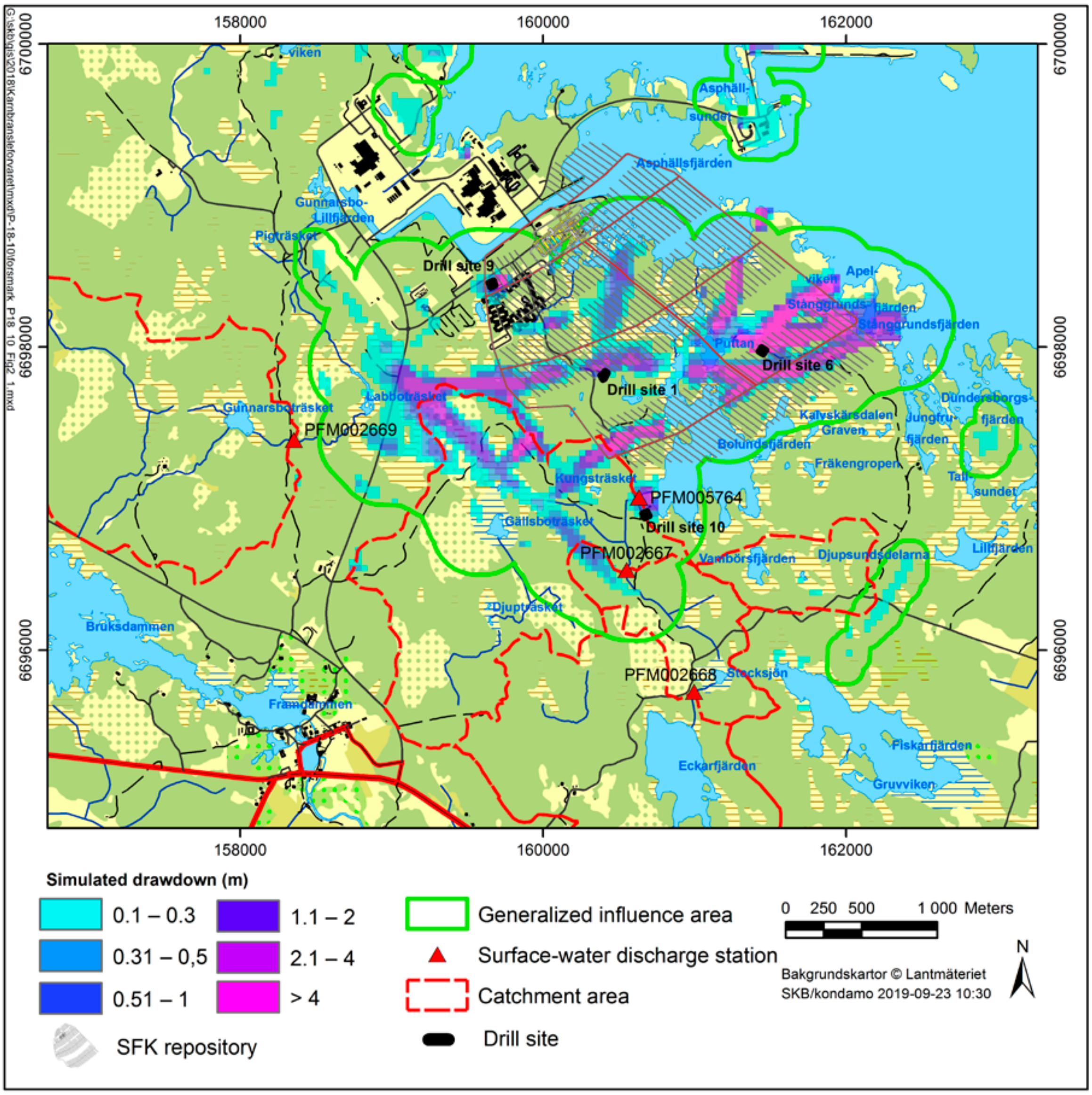

Figure 2-1. *Model-calculated drawdown of the groundwater table in regolith for a hypothetical modelling case with a fully open repository and a hydraulic conductivity of 10^{-7} m/s of the grouted zone. The map also shows the boundaries of a generalized influence area (annual average drawdown > 0.1 m) including a buffer zone of 300 m from the outer edge of drawdown areas. The catchment areas where SKB performs stream-discharge measurements are indicated in the map as well as the catchment area of Lake Vambörsfjärden.*

A “local reference area” here denotes a catchment area investigated and monitored by SKB, and a “reference-area” prerequisite is that the area will not be hydrologically affected by groundwater diversion from the spent-fuel repository. Monitoring of local reference areas, also during the “baseline stage” prior to start of repository construction, is hence of outmost importance to enable detection and quantification of hydrological impacts of construction and operation. For a long-term project, reference-area redundancy is also important, e.g. in case of unexpected hydrological impacts or land-use changes. Furthermore, sufficient monitoring in local reference areas reduces the need for regional reference areas (see Sction 3.7). According to Figure 2-1, the topographically delineated catchment areas of Lake Eckarfjärden and Lake Gunnarsboträsket (Brunberg et al. 2004) are located outside the generalized influence area (a small area of the downstream part of the Lake Eckarfjärdens catchment area is located within the “buffer zone” of the generalized influence area). Accordingly, Lake Eckarfjärden and Lake Gunnarsboträsket are proposed as local reference areas for surface-water discharge, surface-water levels and groundwater levels in regolith.

The catchment area of Lake Vambörsfjärden is located between two separate parts of the generalized influence area, except for a very small part in the east (Figure 2-1). In contrast to the Lake Eckarfjärden and Lake Gunnarsboträsket catchment areas, the Vambörsfjärden catchment area contains wetlands classified to have high nature-conservation values; one classified to be of national interest and three to be of regional interest (Hamrén and Collinder 2010). Based on the location in relation to the generalized influence area and the wetland nature-conservation values, the catchment area of Lake Vambörsfjärden is proposed as an additional local reference area for surface-water levels and groundwater levels in regolith.

The existing monitoring programme for surface-water discharge and level and groundwater level in regolith in the catchment areas of Lake Eckarfjärden and Lake Gunnarsboträsket is shown in Table 2-1. In the catchment area of Lake Eckarfjärden stream discharge, surface-water level and groundwater level are presently monitored, whereas at present only stream discharge is monitored in the Lake Gunnarsboträsket catchment area.

Table 2-1. Present monitoring programme in the catchment areas of Lake Eckarfjärden and Lake Gunnarsboträsket.

Catchment area	Surface discharge	Monitoring period	Surface-water level	Monitoring period	Groundwater level	Monitoring level
Eckarfjärden	PFM002668	2004-12-08 –	SFM0041	2003-04-29 – 2011-02-28	SFM0014	2003-04-29 –
			SFM000127	2011-03-03 –	SFM0015	2003-04-29 – 2010-11-26
					SFM0016	2003-04-29 – 2006-03-26
					SFM0017	2003-04-29 – 2008-09-18
					SFM0018	2003-04-29 – 2006-02-12
					SFM000126	2011-03-04 –
Gunnarsboträsket	PFM002669	2004-12-08 –				

The locations of existing monitoring points for surface-water level and groundwater level in regolith in the catchment area of Lake Eckarfjärden are shown in Figure 2-2.

The correlation between groundwater levels in monitoring wells in the catchment area of Lake Eckarfjärden is presented in Table 2-2. As can be seen in the table, correlation coefficients are generally high.

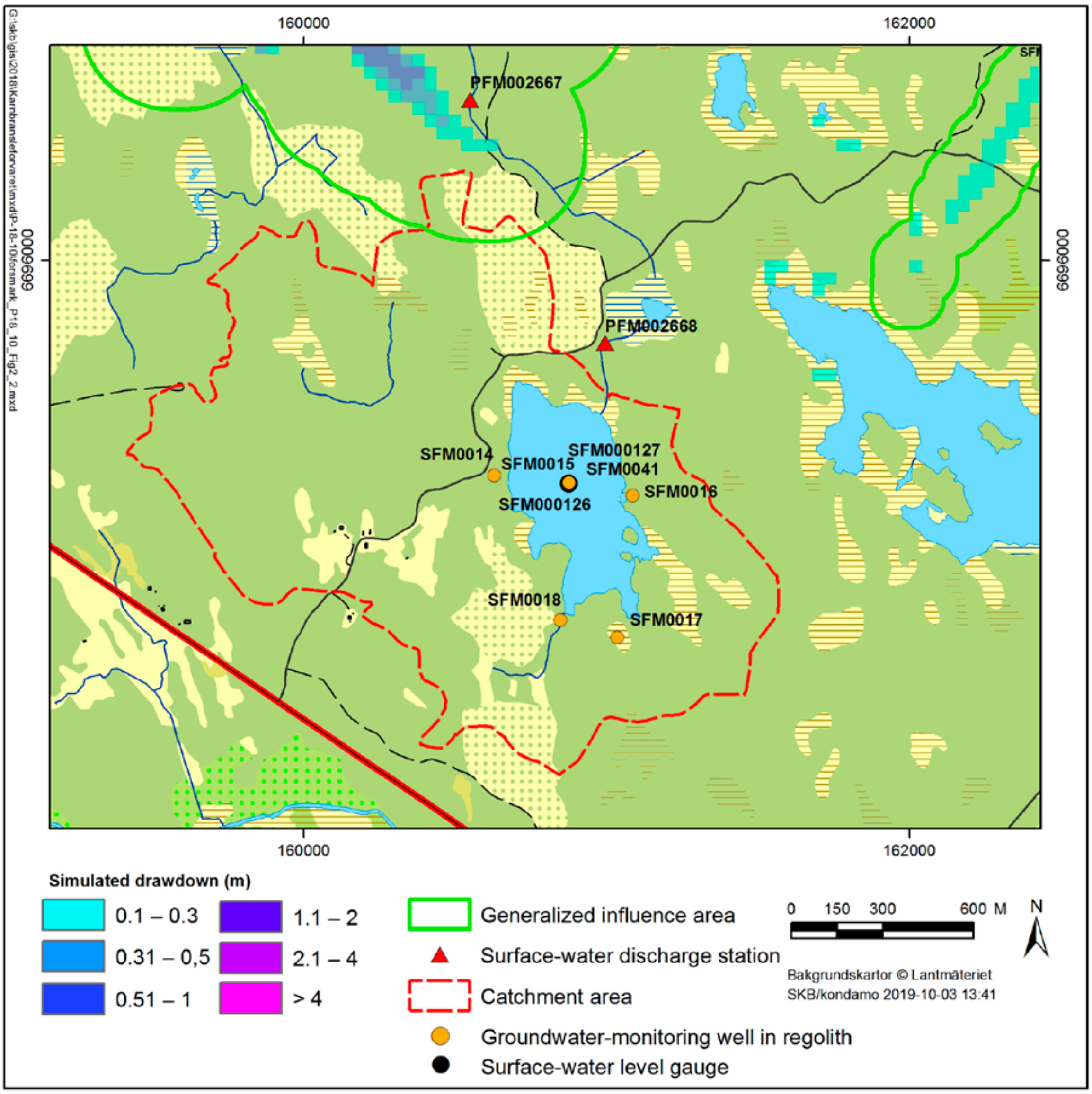

Figure 2-2. *Locations of existing monitoring points for surface-water level, stream discharge and groundwater level in regolith in the catchment area of Lake Eckarfjärden. Note that SFM0015 and -41 have been replaced with SFM000126 and -127 since 2011.*

Table 2-2. Correlation coefficients (r) for groundwater levels in existing monitoring wells in the catchment area of Lake Eckarfjärden (daily same-day average) for available time periods.

	SFM0014	SFM0015/000126	SFM0016	SFM0017
SFM0015/000126	0.83			
SFM0016	0.95	0.88		
SFM0017	0.82	0.88	0.93	
SFM0018	0.94	0.85	0.95	0.94

The existing monitoring programme for the catchment area of Lake Eckarfjärden is considered to be adequate for the purpose of the operative programme, provided that the groundwater-level monitoring of well SFM0017, in which monitoring was terminated in September 2008, is resumed. This resumption would include a monitoring point in till below a wetland in the programme. Based on available data, SFM0017 is also the groundwater-monitoring well installed on land showing somewhat lower correlation with well SFM0014 (with ongoing monitoring). It is recommended to perform a function control and an updated determination of the level of top of casing of SFM0017 in connection to resumption of monitoring.

Regarding the surface-water level gauge in Lake Eckarfjärden (SFM0041/SFM000127) and the groundwater-monitoring well installed below the lake (SFM0015/SFM000126), they have as most other gauges and wells below lakes and ponds been dislocated vertically. When the gauge (SFM000127) and well (SFM000126), respectively, were reinstalled, an extra supporting pipe was also installed and all three pipes were connected by iron flat bars welded to the pipes. Since 2011 the top of casing of the gauge and the well have been successively raised by in total 0.07 m. Compared to prior installations without such supporting pipes, this implied increased stability and uniform vertical dislocation of the wells. The problem of vertical dislocations of installations in lakes and ponds, as well as possible solutions to this problem, are further discussed in Section 3.8.

For the catchment area of Lake Gunnarsboträsket, the only ongoing monitoring is at a stream-discharge gauging station located c 320 m downstream of the lake, see Figure 2-3. To obtain a monitoring programme equivalent to the one of the Lake Eckarfjärden catchment area, the following additional monitoring points are proposed:

- Surface-water level monitoring in the lake.
- Groundwater-level monitoring in till below the lake.
- Groundwater-level monitoring in till below a wetland.
- Groundwater-level monitoring in till in a groundwater-recharge area.

Preliminary proposed locations of these new monitoring points are shown in Figure 2-3 and preliminary coordinates are given in Table 2-3.

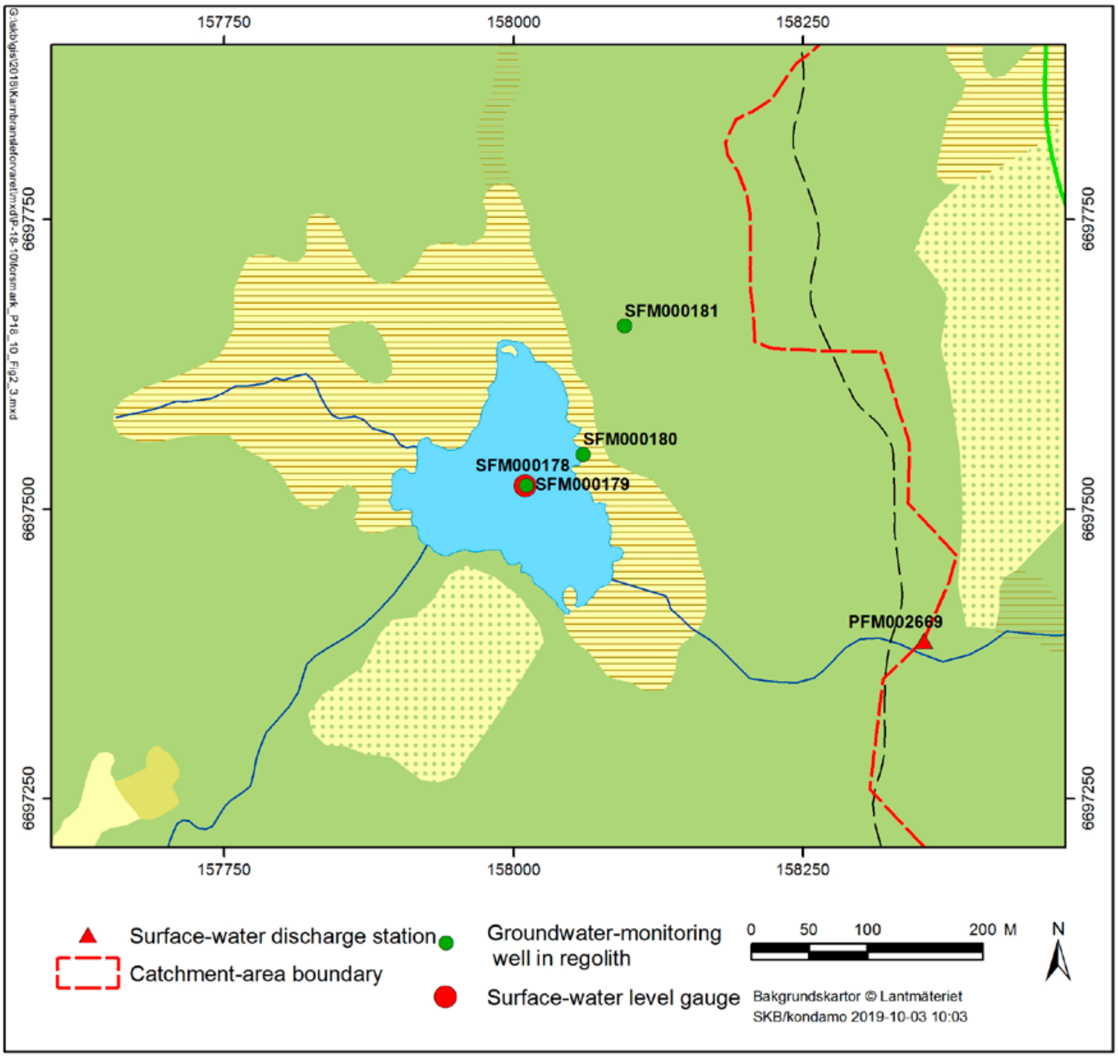

Figure 2-3. *Locations of proposed new monitoring points for surface-water level and groundwater level in regolith in the catchment area of Lake Gunnarsboträsket.*

Table 2-3. Preliminary coordinates for the proposed new monitoring points in the catchment area of Lake Gunnarsboträsket (SWEREF 99 18 00).

Surface-water level	N	E	Groundwater level	N	E
SFM000178	6697520	158010	SFM000179	6697520	158011
			SFM000180	6697547	158060
			SFM000181	6697658	158096

In the catchment area of Lake Vambörsfjärden, the current monitoring comprises four groundwater-monitoring wells; SFM0009 and SFM0020 installed in till, and SFM00161 and SFM000162 with their well screens installed in organic soil (see Figure 2-4). It is suggested that the ongoing monitoring programme in this catchment area is supplemented by two groundwater-monitoring wells in till below organic soil in the immediate vicinity of the existing wells, which have their well screens installed in organic soil. Furthermore, installation of surface-water level gauges is proposed in Lake Vambörs-fjärden and in a nameless pond at Djupsundsdelarna. Proposed preliminary locations of these new monitoring points are shown in Figure 2-4, and preliminary coordinates of the proposed monitoring points are given in Table 2-4.

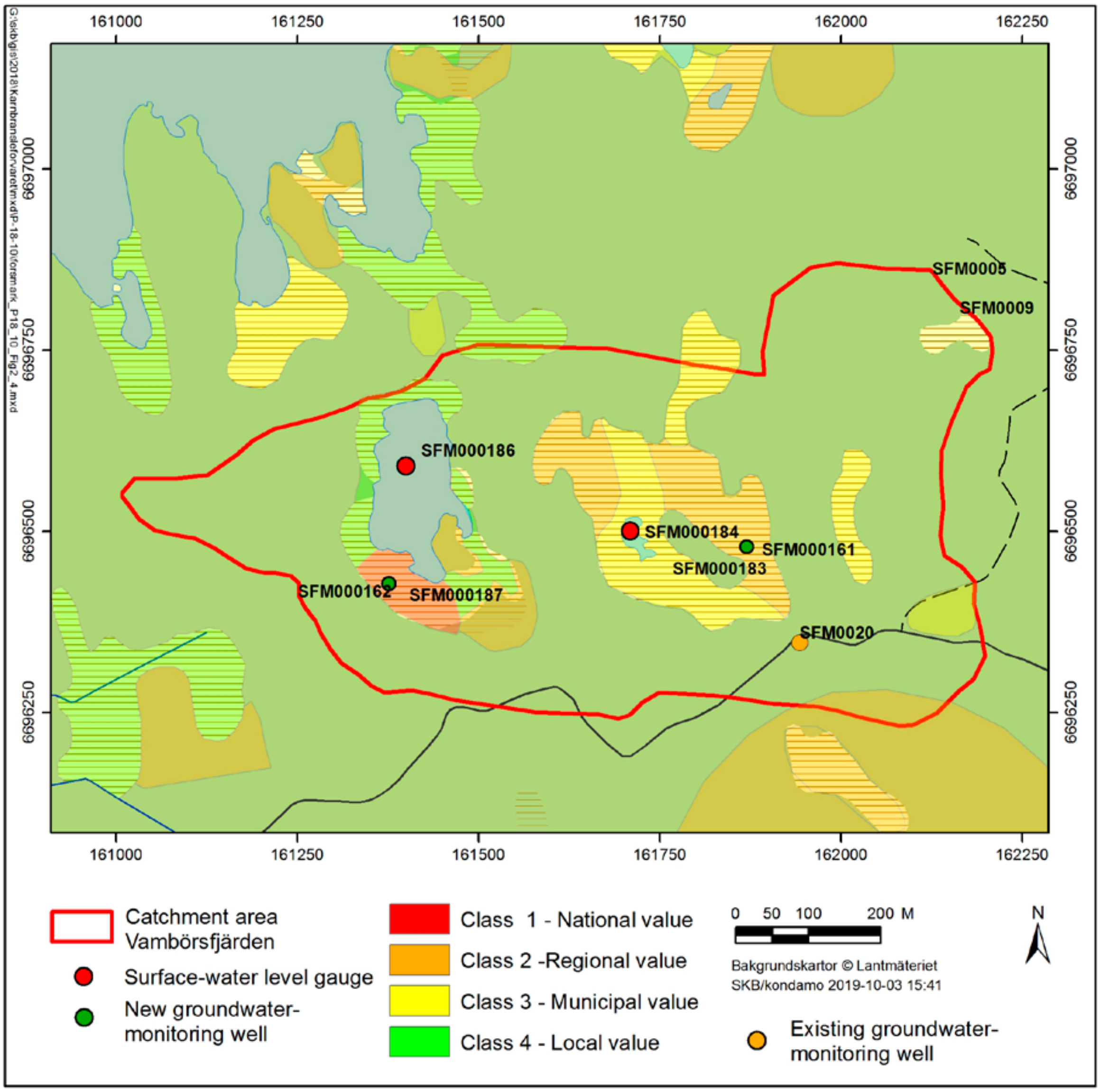

Figure 2-4. *Locations of existing groundwater-monitoring wells in regolith and preliminary locations of proposed new surface-water level gauges and groundwater-monitoring wells in regolith in the catchment area of Lake Vambörsfjärden.*

Table 2-4. Preliminary coordinates of the proposed new monitoring points in the catchment area of Lake Vambörsfjärden (SWEREF 99 18 00).

Surface-water level	N	E	Groundwater level	N	E
SFM000184	6696500	161710	SFM000183	6696478	161870
SFM000186	6696590	161410	SFM000187	6696428	161376

3 Review of the present monitoring programme for surface-water levels and groundwater levels in regolith

In addition to the need of complementing the monitoring programme in the proposed local reference areas, a review of the present monitoring programme has been done in view of the following:

- Construction works in the access area, implying that some monitoring points will be removed and therefore may need to be replaced.
- Wells that periodically are dry or for which groundwater levels periodically are below lower screen levels, implying that well replacements with wells with deeper well screens should be considered.
- Model-calculated groundwater-table drawdown (Mårtensson and Gustafsson 2010) due to groundwater diversion during construction and operation of the repository, as drawdown implies that some existing wells may get dry. Moreover, the review also considers the need to install wells in areas with substantial model-calculated drawdowns, which would be desirable to monitor also for flow-modelling purposes.
- Need for additional monitoring points in the catchment areas of the six wetlands, for which SKB has presented concepts for protective measures as part of the licensing process.
- Need for additional monitoring points to fill gaps in representation of hydrogeological environments and spatial gaps for conceptual understanding of the Forsmark site.

3.1 The access area

The final layout of the access area is not yet settled, but several of the existing groundwater-monitoring wells in regolith are located in areas where surface construction works will take place. This means that they at some point in time will have to be removed. Furthermore, the subsurface construction of the access ramp and shafts in the access area will most probably imply that some existing groundwater-monitoring wells will dry up.

In Werner et al. (2017) an assessment was made to what extent monitoring points existing at that point in time within and in the vicinity of the access area would be possible to use for long-term monitoring, and which points that ultimately have to be abandoned. In Table 3-1, the then existing groundwater-monitoring wells assumed by Werner et al. (2017) to be possible to use in a long-term perspective are shown, together with comments based on the latest available access area layout and evaluation of time series from the monitoring points.

Table 3-1. Monitoring points existing in the access area and its vicinity at the time of evaluation, assumed to be possible to use for long-term monitoring (Werner et al. 2017). Comments to the list are added based on the latest available layout of the access area and time-series data from the points. GWL = groundwater level (coordinates in SWEREF 99 18 00). Note that wells SFM000163, -167 and -168 were installed subsequent to the Werner et al. (2017) assessment.

Monitoring point	N	E	Comments
SFM0049	6698326.64	159547.61	
SFM0077	6698214.62	159700.27	
SFM0078	6697995.32	159768.54	GWL periodically below upper screen level
SFM0079	6697988.74	159571.21	
SFM000119	6698274.65	159589.72	Surface water level, Lake Tjärnpussen
SFM000139	6698088.04	159525.70	
SFM000145	6698709.17	160242.13	Gw level periodically < 0.5 m above lower screen level, located in a planned building
SFM000153	6698422.33	160030.74	Gw level periodically < 0.5 m above lower screen level
SFM000154	6698770.88	160101.88	The well is dry
PFM0100038	6699605.64	161618.45	Sea water level

The access area boundary (Gontier and Tunbrant 2019) and the latest available preliminary access area layout (design drawing v.2) are shown in Figure 3-1 together with the presently existing monitoring points and the model-calculated groundwater-table drawdown (fully open repository, $K_{grout} = 10^{-7}$ m/s). Figure 3-1 also includes a proposal for the locations of three new wells in regolith at the present stage. These wells are meant as substitutes for some wells assumed to be directly affected by the construction works and have been located in directions where wells are missing within and in the immediate vicinity of the access area. These wells could also be used for groundwater sampling for analyses of chemical impacts on groundwater quality from the construction works, for example nitrogen leakage from deposited excavated rock. Preliminary coordinates for the proposed new groundwater-monitoring wells are given in Table 3-2.

Table 3-2. Proposed new groundwater-monitoring wells in regolith close to the access area (SWEREF 99 18 00).

Monitoring well id.	N	E
SFM000182	6698215	160005
SFM000188	6698375	160166
SFM000190	6698495	159635

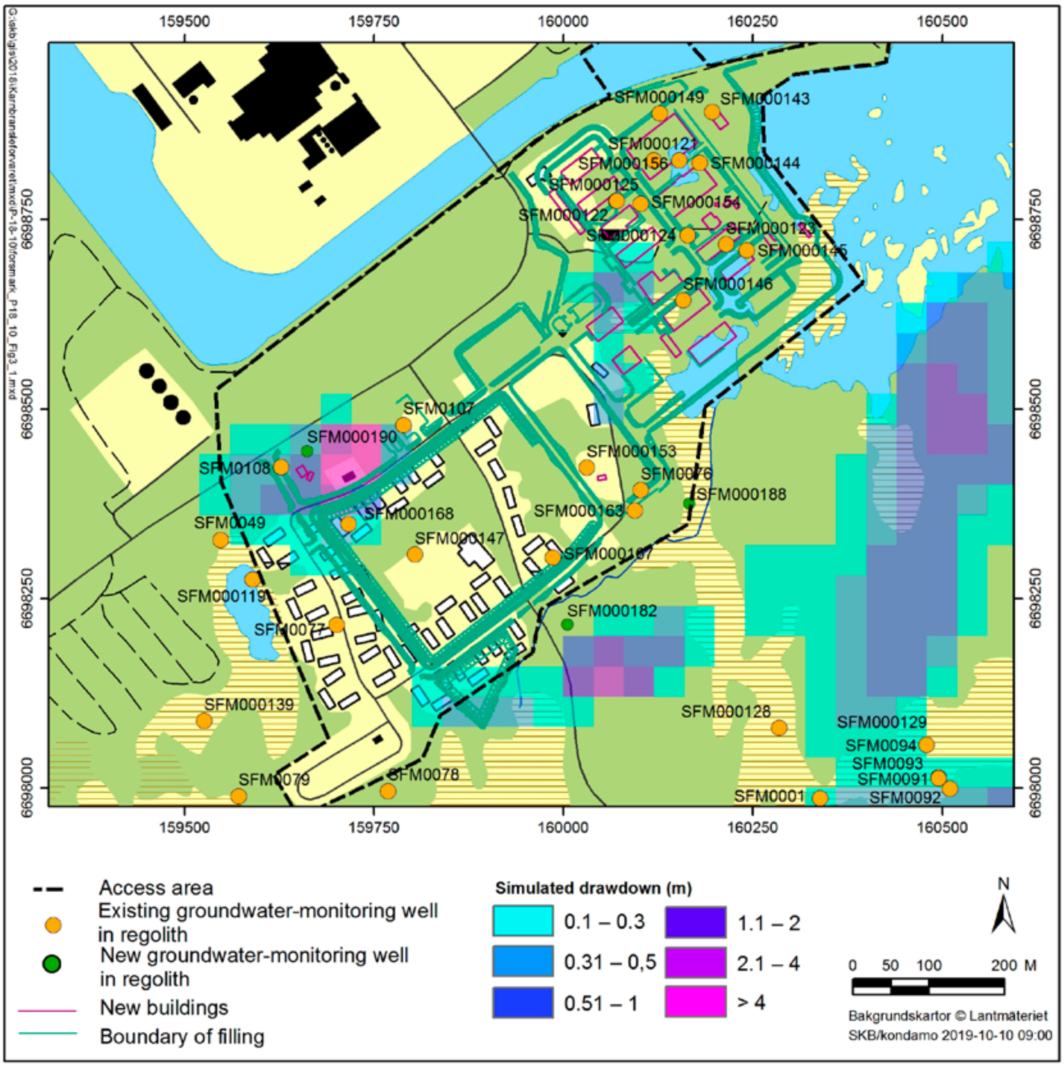

Figure 3-1. *Preliminary layout of the access area, location of presently existing groundwater-monitoring wells in regolith, model-calculated groundwater-table drawdown for a fully open repository and* $K_{grout} = 10^{-7}$ *m/s, and proposed new groundwater-monitoring wells in regolith. Note that wells SFM000163, -167 and -168 were installed subsequent to the Werner et al. (2017) assessment.*

Table 3-1 lists wells at that time (2016) assumed to be suitable for long-term monitoring. Three wells have been installed subsequent to 2016 (SFM000163, -167 and -168, see Figure 3-1), and three additional wells are proposed here (Table 3-2). The following strategy is proposed for groundwater-monitoring wells in regolith that will be directly affected by the construction works:

- Monitoring continues as today until the final access area layout is decided including a time schedule for the different stages of the construction works.
- Based on the latest layout at that time and the time schedule for the construction works, an evaluation is made of when the wells will be affected and if minor layout adjustments, as extensions of wells above ground could enable continued monitoring. Monitoring in directly affected wells is suggested to be successively concluded.
- At a later stage, when most construction works are completed, an assessment is made of the possibility and feasibility to replace the abandoned wells with new wells within the access area.

3.2 Characteristics and performance of existing groundwater-monitoring wells in regolith

Geometrical characteristics of existing groundwater-monitoring wells in regolith (cf. Figure 3-2) are given in Table A1-1 in Appendix 1, whereas minimum and average groundwater levels (GWL) in relation to lower screen levels (Seclow) are presented in Table A1-2 in Appendix 1. Depending on the minimum and average GWL distance above Seclow, the wells are in the two first columns of Table A1-2 classified in a common relative scale from red to green, where red indicates dry or close to getting dry. Moreover, the third column of Table A1-2 presents model-calculated groundwater-table drawdown in a separate relative scale at the location of each well, where red and green indicate a large and a small drawdown, respectively. Specifically, based on the model setup and modelling methodology presented in Mårtensson and Gustafsson (2010), the table shows model-calculated maximum groundwater-table drawdowns for a modelling case with only the access ramp, vertical shafts, the central area and the first repository-tunnel loop open, and with a hydraulic conductivity of the grouted zone (K_{grout}) of 10^{-8} m/s (cf. Chapter 2). It was considered feasible to use this modelling case, instead of the case with a fully open repository and $K_{grout} = 10^{-7}$ m/s used elsewhere in this report, since the main objective here is to identify existing wells at risk to get dry during the first phase of the construction and operation of the repository and a realistic level of grouting. In Table A1-2 results are only shown for well locations with an average drawdown of more than 0.1 m.

According to Table A1-2, the minimum daily average groundwater level after data screening is below Seclow in seven wells (SFM0010, SFM0068–70, SFM0078 and SFM0105–106). Most wells have sumps (closed pipes below the well screen, see Figure 3-2), which are supposed to act as within-well sediment traps. The sumps imply that groundwater levels below Seclow can be registered, e.g. if the sump leaks. Moreover, the minimum screened groundwater level is < 0.5 m above Seclow in another 13 wells (SFM0021, SFM0036, SFM0058, SFM0067, SFM0076, SFM000104, SFM000134-135, SFM000138, SFM000143, SFM000145-146 and SFM000153). Furthermore, for 13 of the wells (SFM0010, SFM0068–69, SFM0076, SFM0105, SFM000134–135, SFM000138, SFM000143, SFM000145-146, SFM000153 and SFM000162) the average groundwater level is < 1 m above Seclow. Note that groundwater levels are only measured manually in wells SFM0068–70, characterized by both low minimum groundwater levels and large differences between minimum and average groundwater levels.

The maximum simulated drawdown at the locations of monitored wells in regolith, for the selected model case, is 1.39 m in SFM0021 and SFM0068. Both these wells are situated close together immediately south of Drill site 6, see Figure 2-1 for location of the drill site). Model-calculated drawdowns are > 1 m in eight wells and between 0.5 and 1 m in another 16 wells. 16 of these in total 24 wells are located along the WSW-ENE fracture zone from Drill site 1, passing Lake Puttan to Drill site 6 and another six located in the vicinity of Drill site 10, immediately southwest of Lake Bolundsfjärden, see Figure 2-1 for the location of the drill sites. The two remaining wells, SFM000108 and SFM000168 are situated close to Drill site 9 within the access area.

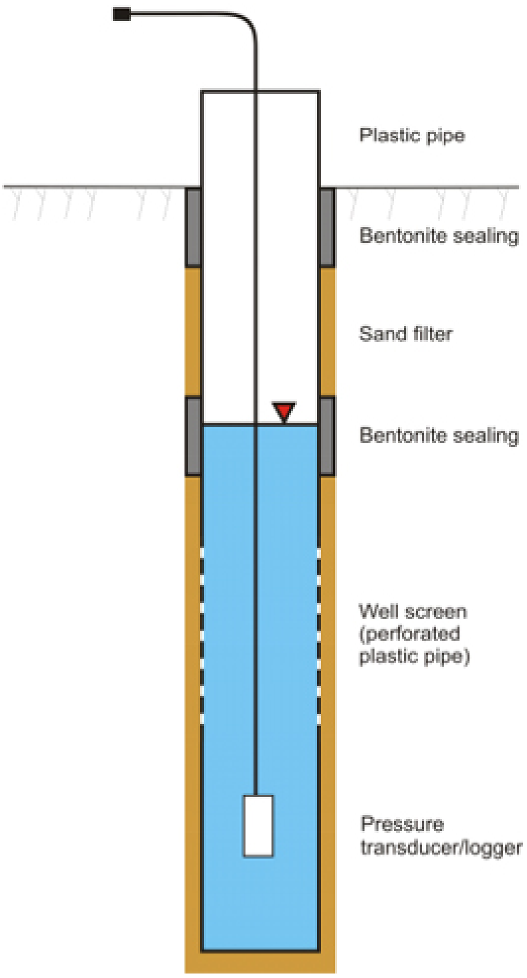

Figure 3-2. *Cross-section view illustrating features of groundwater-monitoring wells installed in Forsmark (Wass 2019). Note that the pressure transducer typically is located in the sump, below the lower level of the well screen. Also note that surface-water level gauges has the same features, except that the well screen is situated in the surface-water mass and not in the regolith.*

According to model calculations, five additional wells (with monitoring data) will have minimum groundwater levels below Seclow: SFM0021, SFM0034, SFM0068, SFM0069 and SFM000143. In SFM0068 the average groundwater level will also be below Seclow. The two wells SFM0021 and SFM0068 are, as mentioned above, situated close together, and SFM0021 has its screen partly in bedrock, see Table 3-3. This means that it cannot be replaced by a deeper well in regolith at the same location. SFM0034 is situated at the stream between Lake Bolundsfjärden and Lake Norra Bassängen and close to well SFM0033, which has its screen partly in bedrock, see Table 3-3. As for SFM0021/SFM0068, drilling a deeper well in regolith at the same place is not possible. SFM0069 is located at Drill site 10 close to SFM0032 and SFM0033. SFM0033, with ongoing monitoring, has its screen partly in bedrock and will according to model calculations not get dry and can therefore be used to monitor drawdown. The well SFM000143 is located in the access area and is according to the present access-area layout one of the wells that will be directly affected by construction works. This well will therefore not be possible to use in the future.

The conclusions above are based on screened groundwater-level data, meaning that data disturbed by e.g. known pumping or groundwater sampling in each well are removed. However, data affected by neither interference disturbances from outside of the well itself nor unknown within-well disturbances are not removed. Accordingly, especially minimum groundwater levels may not be representative for truly undisturbed conditions. To make full use of minimum and average groundwater levels as a "warning system" for groundwater-level impact due to e.g. construction and operation of the repository, as well as measures of the risk for the wells to get dry, the following is recommended before any replacements of existing wells are proposed:

- Well geometries should be checked for wells with negative differences between minimum groundwater level and Seclow, which can easily be done in the field (screen levels need to be checked using a borehole TV camera).
- A thorough time-series screening should be performed to eliminate data that are influenced by e.g. interference disturbances using all available activity logs.
- Large drawdowns are predicted in the vicinity of Drill site 6 and several wells are at risk to get dry. However, the well SFM0090, which is situated c 80 m north of the drill site, has a Seclow at c −4 m and will be able to use also with a substantial drawdown. This well has not yet been monitored and monitoring is therefore recommended to be initiated.
- Review of locations of wells with minimum groundwater levels below or slightly above Seclow, and/or average groundwater levels below upper screen levels, in relation to predicted groundwater-table drawdown areas.

During the period 2015–2018, SKB has performed function controls of a large number of groundwater-monitoring wells. Specifically, so called slug (single hole) tests were performed to investigate potential filter clogging or pipe leakages. Moreover, well-depth soundings were done to investigate if sediments have accumulated at the bottom of wells over time (e.g. Hagelius and Orbe 2018, Werner 2018a, b). The findings from these function controls can be summarised as follows:

- The function controls do not indicate that filter clogging yet is any substantial problem.
- Unexpectedly fast slug-test responses indicate that there may be pipe-joint leakages in wells SFM0032, -0049, -0077, -000144 and -000146.
- Escaping air bubbles have been observed in connection to slug tests in well SFM000112 (installed below the bottom of a pond), which is also an indication of potential pipe-joint leakage. It is therefore recommended to inspect the status of these wells using e.g. a borehole TV camera.
- The well-depth soundings indicate that there is a need to clear away sediments that have accumulated in a large number of wells (SFM0004, -0005, -0008, -0010, -0011–14, -0023, -0028, -0032, -0034, -0036, -0058, -0062, -0067–69, -0076, -0078, -0084–86, -0088–89, -0091, -0095–96, -0099, -0101, -000110, -000112, -000114, -000116, -000118, -000125–126, -000132–133, -000135, and -000138). According to the depth soundings, the sediment depth varies from a few centimetres (e.g. SFM000114 and -116) to several decimetres (e.g. SFM0012 and -13). However, it should be noted that the depth soundings are subject to some degree of uncertainty, as the sounding line may get stuck on e.g. pipe joints.
- According to Table A1-2, the model-calculated annual average drawdown is > 0.1 m for a number of wells in which groundwater-level monitoring should be initiated or resumed (SFM0002, -0031–32, -0035, -0050–51, -0068–69 (currently, manual groundwater-level measurements are performed in these wells), -0075, -0086, -0089–90, and -0108).
- The model-calculated annual average drawdown is > 0.1 m for some wells with ongoing monitoring (SFM0003, -0021, -0030, -0033–34, -0084, -0087, -0104, -000118, -000143, and -000168). It is recommended to perform function controls of all these wells, in order to detect potential filter clogging and/or sediment-accumulation issues.
- Apart from the wells mentioned above, it is also recommended to perform function controls of wells SFM0005, -0006, -00010, -0017 (located in the Lake Eckarfjärden catchment area, see Chapter 2), -0036, -0059–60, -0062, -0070–71, -0073, -0074, -0076, -0080, -0091, -0094–95, -0103, -0105–106, -0109, -000121, and -000123–125. Of these wells, there are no previous slug tests in SFM0059–60, -0074, -0076, -0090, -0094, -0105, -0109, -000121, and -000123–125.
- In connection to SKB's field inspections, it has been observed that the well lid is stuck due to rust on wells SFM0074, -0090, -0097, -0100, and -0102–103; it is recommended to remove and replace these well lids.
- According to visual inspections, there are inclinations (c 5–10°) of wells SFM0095, -000118 and -000167, which need to be accounted for in quality controls based on manual groundwater-level measurements.
- It is recommended to produce installation reports containing borehole logs and well drawings for a number of wells (SFM0057–58, -0109, -000132–135, -000144-147, -000149, -000153–154, -000160–163, -000167–168 and SFR000001–3).

3.3 New wells located based on model-calculated drawdown

Four new groundwater-monitoring wells in regolith and one new surface-water level gauge are proposed at locations with a distinct model-calculated groundwater-table drawdown, for the case with a fully open repository and a hydraulic conductivity of the grouted zone of 10^{-7} m/s, specifically at locations where wells and gauges today are missing. These monitoring points can also be used as a check of the predictive capability of the flow model. The locations of the proposed monitoring points are shown in Figure 3-3 and preliminary coordinates are listed in Table 3-3.

Table 3-3. Preliminary coordinates for proposed additional monitoring points in areas with distinct model-calculated groundwater-table drawdown (fully open repository and $K_{grout} = 10^{-7}$ m/s).

Surface water level	N	E	Groundwater level	N	E
SFM000172	6697950	161115	SFM000173	6697951	161116
			SFM000174	6697948	161860
			SFM000193	6697430	160487
			SFM000195	6697300	159575

At the proposed locations of wells SFM000173, SFM000174, SFM000193 and SFM000195, for the model case described above, the annual average drawdown is > 0.1 m and model-calculated maximum drawdowns are 0.42, 4.67, 4.07 and 1.45 m, respectively.

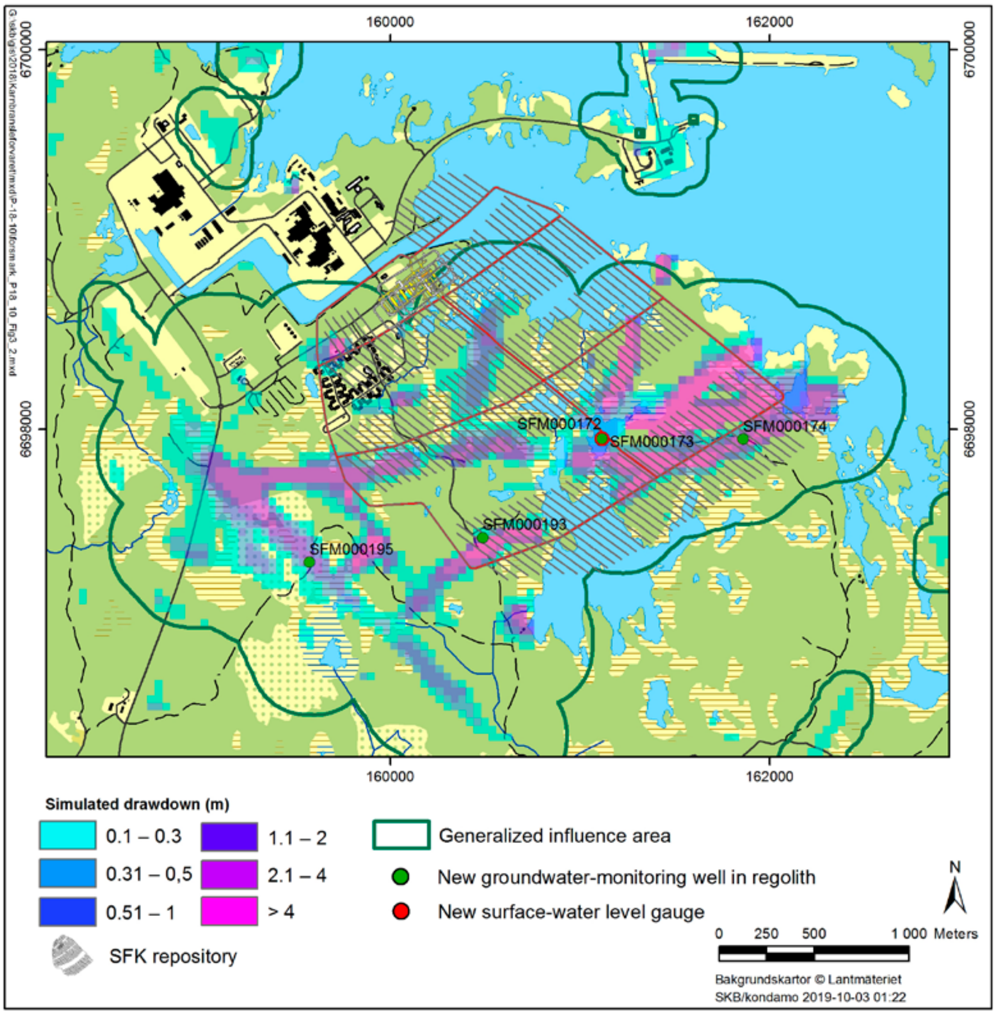

Figure 3-3. *Proposed additional monitoring points in areas with distinct model-calculated groundwater-table drawdown (fully open repository and a hydraulic conductivity of the grouted zone of 10^{-7} m/s) and where monitoring points are missing today.*

3.4 New monitoring points in catchment areas of wetlands with proposed concepts for protective measures

As part of the licensing process of the spent-fuel repository, SKB has proposed concepts for protective measures for six wetlands, classified as having national interest. These wetlands have id numbers 7, 14, 15 (Norra Labbofjärden), 16, 18 (Kungsträsket), and 23 in ecological inventories (Hamrén and Collinder 2010). See Figure 3-3 for the location of wetlands and Hamrén and Collinder (2010) for object descriptions.

The existing and proposed new monitoring points in the catchment areas of these wetlands are shown in Figure 3-4 and listed in Table 3-4. Specifically, the present monitoring is proposed to be supplemented by four new groundwater-monitoring wells in till (three wells on land and one well below the pond of wetland 23). Furthermore, a surface-water level gauge is proposed to be installed in the pond of wetland 23. With these additional monitoring points included, all wetlands will have monitoring of surface-water level, groundwater level in till below ponds and in till on land within the respective catchment areas. Groundwater level in peat/gyttja are monitored in two of the wetlands and soil-water content in one of them.

There have been problems with vertical displacement of the surface-water level gauge in the pond of wetland 16 caused by ice lifting. A test with a possible alternative monitoring technique with a well-anchored water-level gauging scale combined with a time-lapse camera is proposed (PFM008099 in Figure 3-4). The principle of this monitoring technique is that a time-lapse camera, which is directed towards the gauging scale, takes images of the water-level reading on the scale at regular intervals. The problems with vertical displacements of surface-water level gauges and groundwater-monitoring wells in lakes and ponds, and alternative solutions, are discussed in Section 3.8.

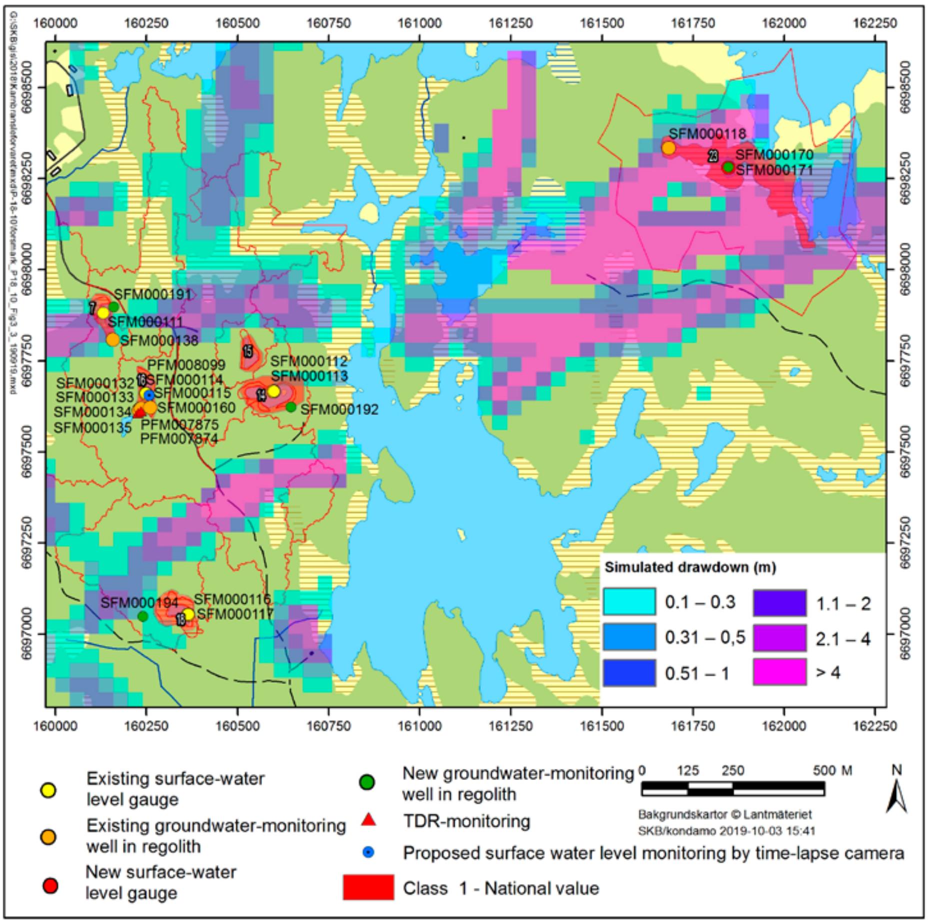

Figure 3-4. Wetlands of national nature conservation value for which SKB has proposed concepts for protective measures as part of the permit process. The map shows locations of existing and proposed locations for new monitoring points for surface-water levels, groundwater levels in regolith, as well as locations of TDR equipment installed for soil-water content monitoring.

Table 3-4. Existing and proposed new monitoring points in wetlands for which SKB has proposed concepts for protective measures (locations are shown in Figure 3-4).

Wetland object	Surface water level	Monitoring period	Groundwater level (till)	Monitoring period	Groundwater level (peat)	Monitoring period	Soil water content	Monitoring period
7	SFM000111	2009-04-28 –	SFM000110	2009-04-28 –	SFM000138	2015-06-03 –		
			SFM000191	to be installed				
14–15	SFM000113	2009-04-28 –	SFM000112	2016-10-12 –				
			SFM000192	to be installed				
16	SFM000115	2009-04-28 –	SFM000114	2009-04-28 –	SFM000140	2014-07-03–2015-12-09	PFM007874	2017-06-19 –
	SFM000137*	2014-05-20 –	SFM000132	2012-10-25–2014-02-04, 2018-03-29 –	SFM000160	2016-04-15	PFM007875	2017-06-19 –
	PFM008099	to be installed	SFM000133	2012-10-25–2014-02-04, 2018-03-29 –				
			SFM000134	2012-10-25–2014-02-04, 2018-03-29 –				
			SFM000135	2012-10-25–2014-02-04, 2018-03-29 –				
18	SFM000117		SFM000116	2009-04-30 –				
			SFM000194	to be installed				
23	SFM000170	to be installed	SFM000118	2009-05-06 –				
			SFM000171	to be installed				

* Not in the pond of object 16 but in a nearby separate constructed pond.

3.5 New monitoring points to fill gaps in representativity

Groundwater-monitoring wells in groundwater-recharge areas in clayey till are missing in the present monitoring programme. It is therefore proposed to install a new well (SFM000177) to improve the hydrogeological understanding of this hydrogeological setting at the location shown in Figure 3-5.

According to model calculations for the case of a fully open repository and $K_{grout} = 10^{-7}$ m/s, there may be groundwater-table drawdown in a remote area close to the Baltic with two objects of high nature conservation values (id 121 and id 122 in SKB's ecological inventories (see Hamrén and Collinder 2010). These two objects consist of a lime-rich coniferous forest (object id 121) of national interest and two sedge fens having regional interest (object id 122). Both these objects are considered to be sensitive to groundwater-table drawdown (Hamrén and Collinder 2010). It would have been desirable to install groundwater-monitoring wells and surface-water level gauges in these objects. However, the terrain and the remote distance imply that the objects are very difficult to reach by a drilling rig. There are no roads nearby, the terrain is boulder rich, and several wetlands have to be passed. Furthermore, the forest is full of fallen big trees. A trespass by a drilling rig to make these installations is not considered feasible, not from an economical point of view and not due to the risk of damaging other nature-conservation values.

Provided a positive outcome of the test of the technique in wetland 16 (see Section 3.4), it is proposed that a remote-controlled time-lapse camera (PFM008098), combined with a well-anchored water level scale, is installed for observation of the water level in one of the two ponds of object id 122 (only handheld equipment is needed for the installation), see Figure 3-5. The model-calculated groundwater-table drawdown in this area is connected to a fracture zone in SSW-NNE direction, see Figure 3-5. As a substitute for a groundwater-monitoring well in the area itself, a groundwater-monitoring well (SFM000175) is proposed to be installed in the same facture zone but further to the SSW, see Figure 3-5.

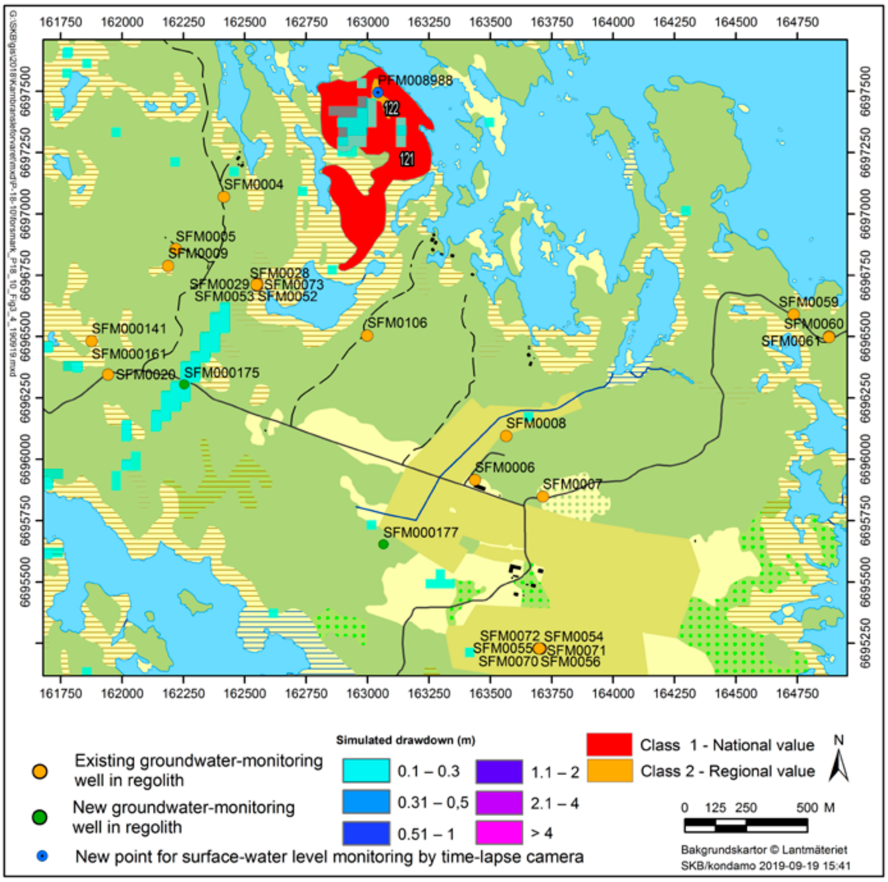

Figure 3-5. *Proposed new groundwater-monitoring well in clayey till (SFM000177) and in the SSW-NNE fracture zone (SFM000175), connecting the remote area of objects 121 and 122 of high nature conservation values where a time-lapse camera (PFM008988) is proposed to be installed for surface-water level observations.*

Preliminary coordinates for the proposed new monitoring points are given in Table 3-5.

Table 3-5. Coordinates for proposed new monitoring points to fill gaps in representativity (SWEREF 99 18 00).

Surface water level	N	E	Groundwater level	N	E
PFM008098	6697495	163041	SFM000175	6696305	162253
			SFM000177	6695654	163064

3.6 New groundwater-monitoring wells at existing TDR installations

TDR (time-domain reflectometry) equipment for monitoring of water content in the unsaturated zone has been installed at four locations classified as (i) a wetland, (ii) a coniferous forest, (iii) a herb-rich coniferous forest, and (iv) an open grassland (Hamrén and Collinder 2010), see Figure 3-6. Two sets of TDR-monitoring probes have been installed at each location. Groundwater levels in regolith are already monitored in the immediate vicinity of the TDR installations in the wetland and the coniferous forest object. To be able to study soil water–groundwater interactions also in the two location in herb-rich coniferous forest and in open grassland, two additional groundwater-monitoring wells are proposed at the locations shown in Figure 3-6. Coordinates for the TDR installations, existing groundwater-monitoring wells in their immediate vicinity, and preliminary coordinates for the proposed new wells are listed Table 3-7.

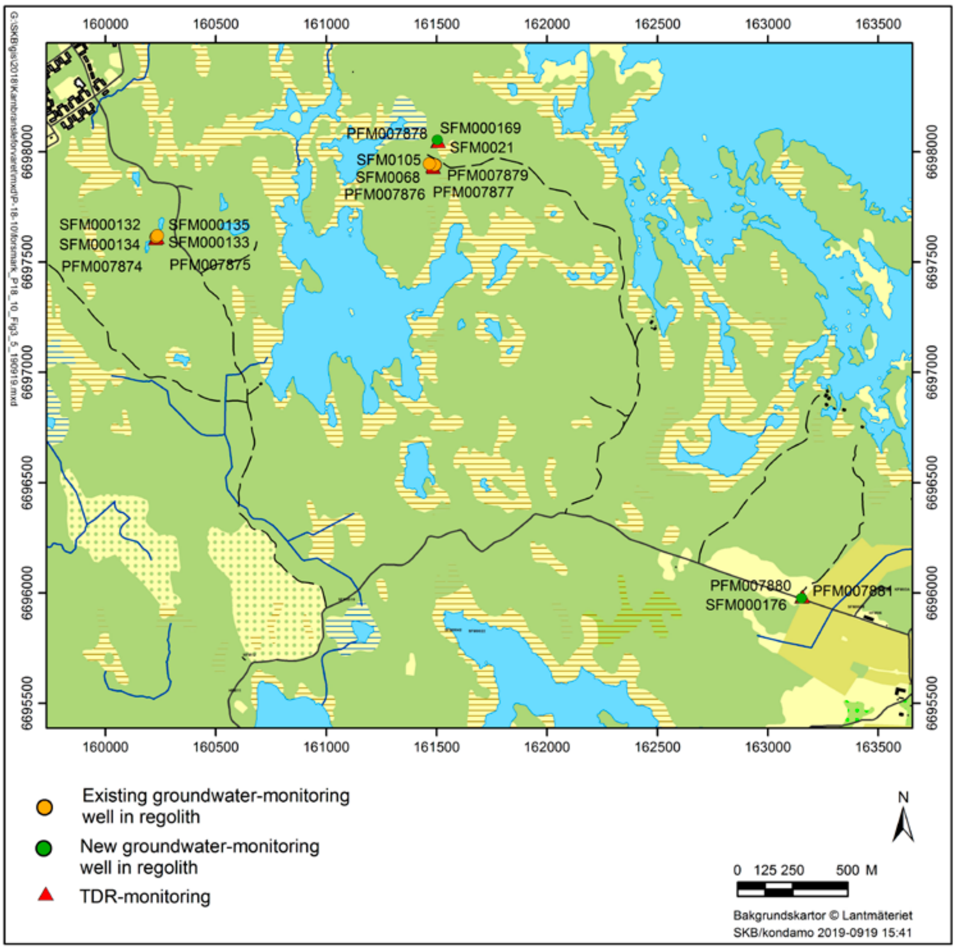

__Figure 3-6.__ TDR installations for soil-water content monitoring and existing and proposed groundwater-monitoring wells in regolith in their immediate vicinity.

Table 3-6. TDR-installations and existing and proposed groundwater-monitoring wells in regolith in their immediate vicinity.

TDR	X	Y	Monitoring period	Gw well	X	Y	Monitoring period
Wetland							
PFM007874	6697608	160227	2017-06-19 –	SFM000132	6697614	160229	2012-10-25–2014-02-04, 2018-03-29
PFM007875	6697612	160235	2017-06-19 –	SFM000133	6697619	160235	2012-10-25–2014-02-04, 2018-03-29
				SFM000134	6697613	160230	2012-10-25–2014-02-04, 2018-03-29
				SFM000135	6697620	160235	2012-10-25–2014-02-04, 2018-03-29
Coniferous forest							
PFM007876	6697929	161486	2017-06-19 –	SFM0021	6697940	161495	2003-04-30 –
PFM007877	6697935	161483	2017-06-19 –	SFM0068	6697940	161492	2006-05-03 –
				SFM0105	6697945	161467	2006-06-19 –
Herb-rich coniferous forest							
PFM007878	6698048	161505	2017-06-21 –	SFM000169	6698053	161503	to be installed
PFM007879	6698047	161508	2017-06-21 –				
Open land							
PFM007880	6695983	163153	2017-07-04 –	SFM000176	6695976	163152	to be installed
PFM007881	6695986	153157	2017-07-04 –				

3.7 Monitoring in regional reference areas

The need for monitoring of stream discharge, surface-water levels and groundwater levels in regolith in regional reference areas, as a supplement to the proposed monitoring in local reference areas (Chapter 2), has been a subject of discussion. The main argument for monitoring in regional reference areas is the hypothetical scenario that local reference areas are hydraulically affected by groundwater diversion during construction and operation of the repository, in spite of model calculations showing them to remain unaffected. However, there are several arguments in favour of the view that little additional essential information will be obtained from monitoring in regional reference areas:

- The identification of local reference areas (Chapter 2) includes redundancy, and the proposed monitoring programme in these areas is deemed sufficient to reduce the need for regional reference areas.
- Up to 15 years long time series are available in a large number of monitoring points in the Forsmark area, both inside the delineated influence area as well as in the three proposed local reference areas. Furthermore, according to the present report the existing monitoring programme will be complemented by 30 additional monitoring points, including seven surface-water level gauges and 23 groundwater-monitoring wells inside and outside of the influence area.
- Statistical methods can be used to detect also small deviations from "undisturbed conditions" in the existing time series. SKB is currently developing and testing procedures to detect influences on groundwater levels by means of statistical methods.
- A water-flow model (MIKE SHE) has been carefully calibrated and can quite accurately simulate "undisturbed conditions" as well as the influence of performed hydraulic tests. The model is planned to be run online during construction and operation of the repository. By continuously comparing simulated and monitored groundwater levels, deviations due to the construction can be detected at an early stage.
- The representativeness of a newly established regional reference area can always be questioned, due to differences in terms of meteorological conditions, topography, geology and vegetation. There are no running stream-discharge monitoring programmes in small catchment areas, surface-water levels in lakes and ponds or groundwater levels in regolith in the vicinity of the Forsmark area considered to be representative for the Forsmark area. This means that new regional reference areas have to be identified and equipped for monitoring. The representativeness then has to be verified from correlations with time series from the Forsmark area.

Based on the arguments above it is not considered feasible to establish new regional reference areas for surface hydrology and near-surface hydrogeology. However, if specific regional reference objects are identified for e.g. ecological monitoring of wetlands, it may be feasible to complement this monitoring with measurements of surface-water levels and groundwater levels.

Groundwater levels are considered as the most sensitive indicator of influence from the construction and operation of the repository. Therefore, a specific study was performed on the correlation between groundwater levels in regolith in the Forsmark area and groundwater levels in the two closest monitoring sites in the National Groundwater Network of the Swedish Geological Survey (SGU) with measurements in till, Tierp located c 30 km to the west of Forsmark and Vaxholm c 100 km south of Forsmark. The Tierp monitoring site includes one well in a confined till aquifer. The monitoring started in autumn 2010 and the well is automatically monitored every four hours. At the Vaxholm monitoring site 12 wells in till are still actively monitored. The monitoring in most of these wells started in 1968 (1975 in one well) and they are manually monitored twice per month. All wells, except one, are placed in confined aquifers. Three wells are placed in areas classified as recharge areas, two in discharge areas, and 7 in areas classified as "intermediate".

Figure 3-7 shows a co-plot of monthly average groundwater levels for wells at the Vaxholm site demonstrating high month-by-month correlations (correlation coefficient, $r > 0.70$) with the monthly site average groundwater level at Forsmark. The latter takes into account "land wells" (i.e. not wells installed below surface waters) and data days with monitoring in more than 30 wells.

Figure 3-8 shows a co-plot of daily average groundwater levels for the well at the Tierp site and daily site average groundwater level at Forsmark. Note that Tierp time-series data are only available as groundwater-level depths below the ground surface, and there is no information on ground-surface elevation at the well location. This is handled by setting an arbitrary ground-surface elevation (5 m) in order to produce the groundwater-level time series of Figure 3-8.

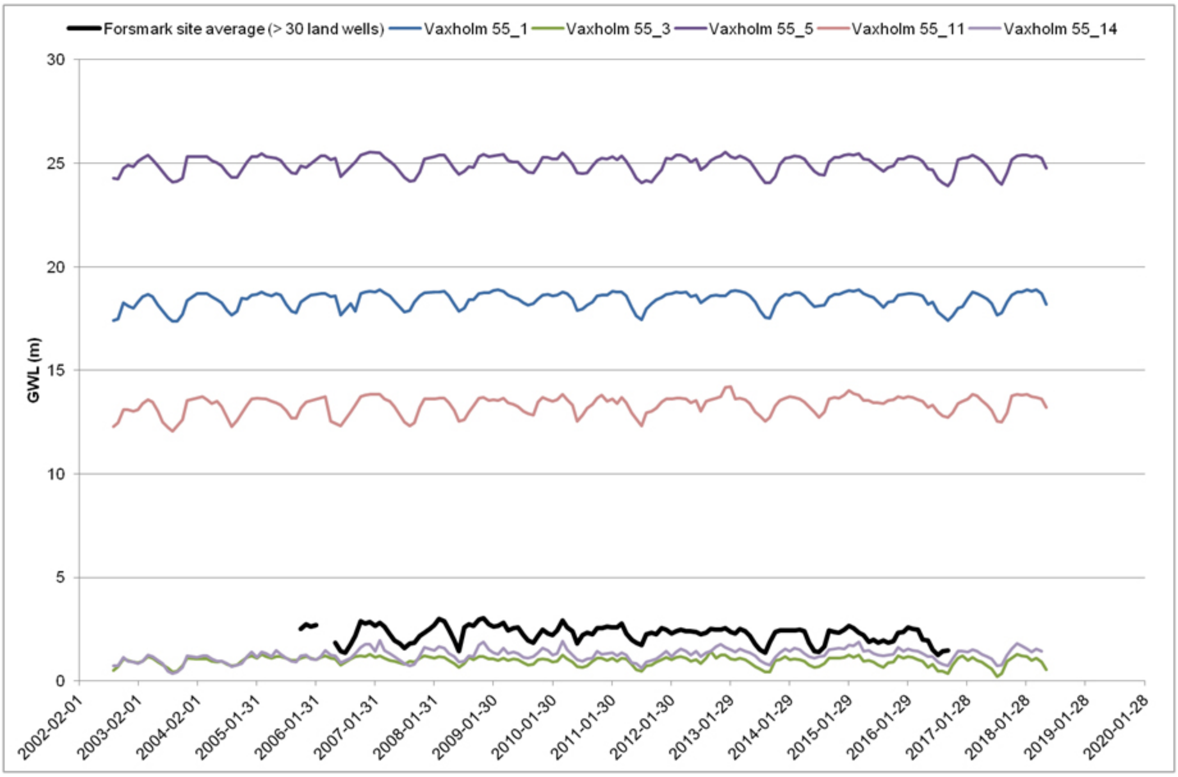

Figure 3-7. *Co-plot of monthly average groundwater levels in wells at the Vaxholm site demonstrating high month-to-month correlations (r > 0.70) to the monthly Forsmark site average.*

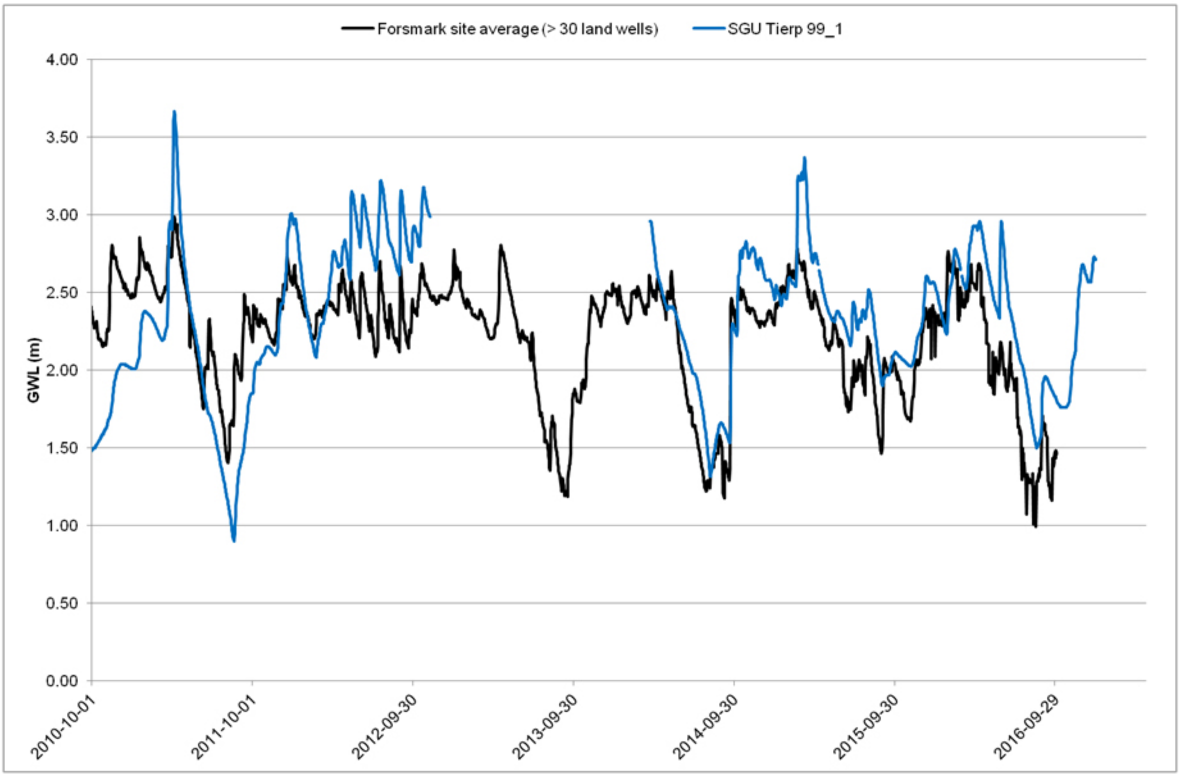

Figure 3-8. *Co-plot of daily average groundwater level in the well at the Tierp site (SGU Tierp 99_1) and the daily Forsmark site average.*

The day-by-day inter-well correlation coefficient across the Vaxholm site is r = 0.25–0.91. The month-by-month correlation coefficient between individual Vaxholm wells and the monthly Forsmark site average is r = 0.50–0.78 (Figure 3-7). Moreover, the month-by-month correlation coefficient between the Vaxholm (12 wells) and Forsmark (> 30 wells) site averages is r = 0.89, whereas r = 0.65 between the Tierp well and the Forsmark site average on a day-by-day basis (Figure 3-7). This exemplifying analysis shows that it should be possible to identify wells in the National Groundwater Network of SGU demonstrating relatively high correlations with individual groundwater-monitoring wells at Forsmark, at least on monthly or seasonal time scales.

The possibilities to analyse correlations on shorter time scales (e.g. daily basis) are limited due to mainly sparse, manual groundwater-level measurements in the SGU network. It is therefore recommended that SKB contacts SGU to obtain information on plans for further well installations and automatic (denser in time) groundwater-level monitoring at relevant monitoring sites. Furthermore, it is recommended that annual hydrological-hydrogeological data evaluations in the operative programme for the surface system include groundwater-level data from relevant SGU sites, primarily aiming to compare “extremes” and potential long-term trends at the Forsmark site in relation to other locations.

3.8 Alternatives for monitoring in lakes and ponds to avoid disturbances by ice movements

From the onset of monitoring, there have been problems with vertical dislocations of surface-water level gauges and groundwater-monitoring wells in and below lakes and ponds. The displacements are most likely caused by winter-time ice movements on lakes and ponds, causing lifting of wells and gauges (Berglund and Lindborg 2017). The problems have until now been handled by recurrent (annual) surveying of elevations of top of casings by high accuracy GPS or levelling. These determinations have revealed quite large vertical displacements, for some wells in the order of 0.3 m since installations.

There are several possible solutions to this instability problem:

a) Installation and anchoring of wells and gauges in bedrock.

b) Installation of pressure sensors on stable devices at the bottom of lakes and ponds, below the depth reached by ice.

c) Non-contact level sensors, e.g. based on radar technology.

d) Well-anchored water-level gauging scales combined with time-lapse cameras.

Alternatives a) and b) have the advantage of enabling measurements throughout the year, and the installations can also be located to areas with maximum water depths (i.e. lowest bathymetries) to minimize data gaps during dry periods. The main disadvantage of a) is that a heavy drilling rig is needed, which means that a quite thick ice cover is needed to ensure safe working conditions during installation. Problems with alternative b) include difficulties of a stable installation in soft bottom strata and difficulties to validate automatic registrations by manual measurements. Alternatives c) and d) can only be used during ice- and snow-free periods and for d) some stable feature, like exposed bedrock or a large boulder, is needed for anchoring of the gauging scale.

Considering the advantages and disadvantages of these solution alternatives, it is recommended to use the method tested in Lake Eckarfjärden. i.e. installation of one or two extra supporting pipes connected to the monitoring gauge or well by iron bars welded to the pipes to form a triangle (see example in Figure 3-9). Supporting pipes is a variant of alternative d) above and improves horizontal and vertical stabilities, and, in the case of e.g. two connected wells, a uniform vertical dislocation of the wells in case of ice lifting. The recommended solution enables measurements throughout the year and validation by manual measurements by levelling from the top of casing. However, annual top of casing surveying after ice break-up will be necessary to obtain reliable water-level data. To facilitate the elevation measurements at some sites, surveyor´s benchmarks can be installed on land as close as possible to the wells to enable levelling by a single setup.

Moreover, as a test, a time-lapse camera combined with a well-anchored water-level gauging scale (e.g. Schoener 2018) is recommended for supplementary surface-water level monitoring in the pond of wetland object 16, where results can be compared with those of the existing surface-water level gauge (see Figure 3-4 and Table 3-4 in Section 3.4). For an illustration of the monitoring principle, see Figure 3-10. If the outcome of this test is positive, a remote-controlled time-lapse camera combined with a well-anchored gauging scale is recommended also for the surface-water level monitoring of nature object 122, due to the difficulties to reach the object by a drilling rig (see Section 3.5).

Figure 3-9. *Example of anchoring by means of mutually supporting pipes connected by iron bars (wells SFM0091–93; Werner et al. 2006).*

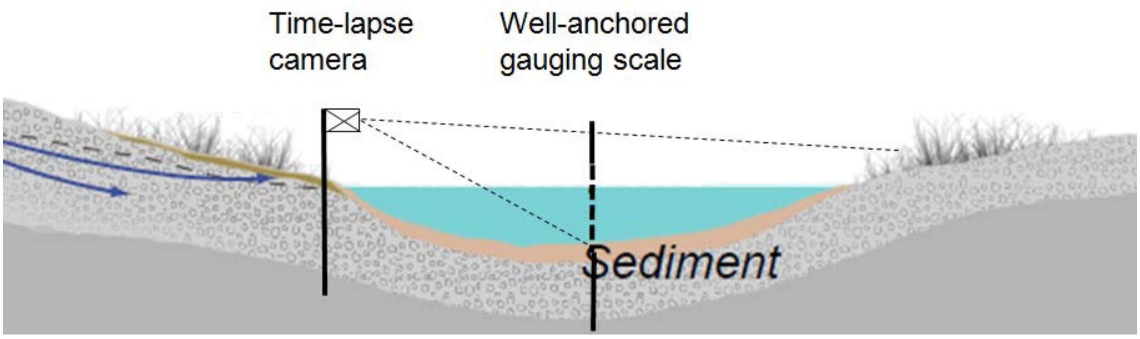

Figure 3-10. *Sketch illustrating the principle of surface-water level monitoring using a well-anchored gauging scale (cf. Figure 3-9) and a time-lapse camera.*

3.9 Monitoring of possible discharge areas for deep groundwater

SKB wants to obtain an increased understanding of far-future discharge areas for deep groundwater. As part of this, studies of present discharge areas of deep groundwater, including installation of groundwater-monitoring wells in regolith and shallow bedrock at different depths at the same location, are proposed. The wells are supposed to be used both for monitoring of vertical groundwater flow gradients and for groundwater sampling.

New so called particle-tracking simulations were performed based on the model setup and modelling methodology described in Bosson et al. (2010). In the modelling, two particles per cell were released at 400 m depth below ground surface and simulations were run for a time period of 1 000 years. The particles finally reaching the regolith are shown in Figure 3-11. Clusters of particles are found at Lake Fiskarfjärden, but also between Lake Stocksjön and Lake Bolundsfjärden. The locations of the particles at the shoreline of the Baltic Sea should be interpreted with caution, as they could be due to model boundary effects, and they are also most probably quite influenced by the present sea shoreline.

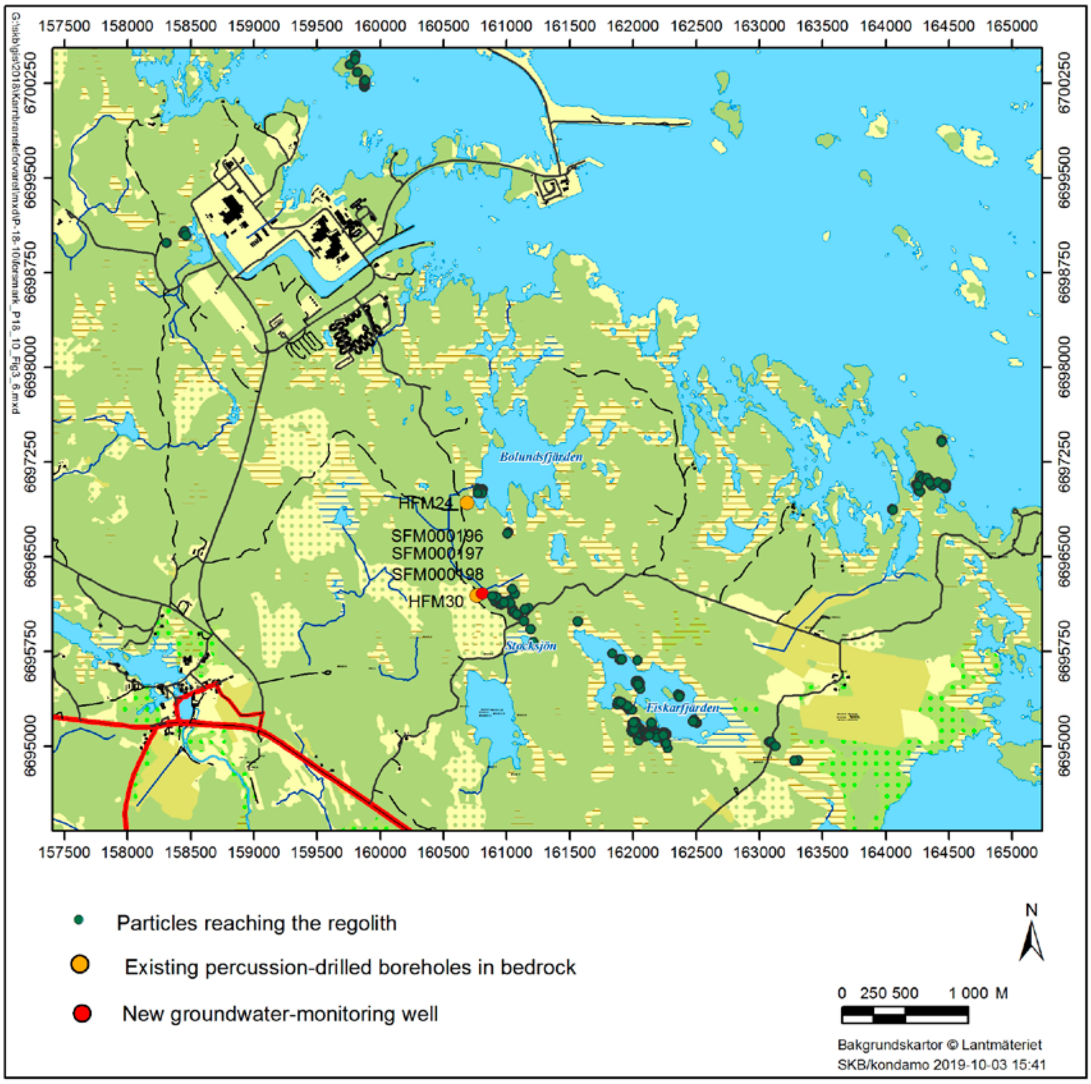

__Figure 3-11.__ Locations of particles reaching the regolith in particle tracking simulations with the present shoreline but without SFR (1 000 years of simulation, 2 particles/cell released at 400 m depth). The map also shows proposed locations of monitoring-well clusters in regolith and shallow bedrock, as well as the existing percussion-drilled boreholes HFM24 and HFM30.

Along with the model simulations, the chemical and isotopical signatures of waters from percussion-drilled boreholes were used to identify potential present discharge areas for deep groundwater. HFM30, situated at the particle cluster north of Lake Stocksjön, is the existing borehole showing the most pronounced deep-water influence with a quite saline water. In contrast, HFM24 at the cluster at Lake Bolundsfjärden has a diluted water with a weak marine signature (Mats Tröjbom, oral communication).

Based on the model simulations and chemical signatures in the percussion-drilled boreholes, it is proposed to install a cluster of three groundwater-monitoring wells east of HFM30, see Figure 3-9. Preliminary coordinates and proposed well-screen depths are shown in Table 3-7.

Table 3-7. Preliminary coordinates (SWEREF 99 18 00) and well-screen depths of proposed groundwater-monitoring wells in a probable discharge area for deep groundwater, immediately east of the existing percussion-drilled borehole HFM30 (see Figure 3-11).

Monitoring point	N	E	Screen depth
SFM000196	6696206	160807	In shallow bedrock, 2–4 m below bedrock surface
SFM000197	6696206	160807	In till, just above bedrock surface
SFM000198	6696206	160807	In till, just below estimated min. groundwater level

4 Summary

Locations of all proposed new surface-water level gauges (7, including two time-lapse cameras) and new groundwater-monitoring wells (23) are shown in Figure 4-1, whereas preliminary coordinates are listed in Table 4-1.

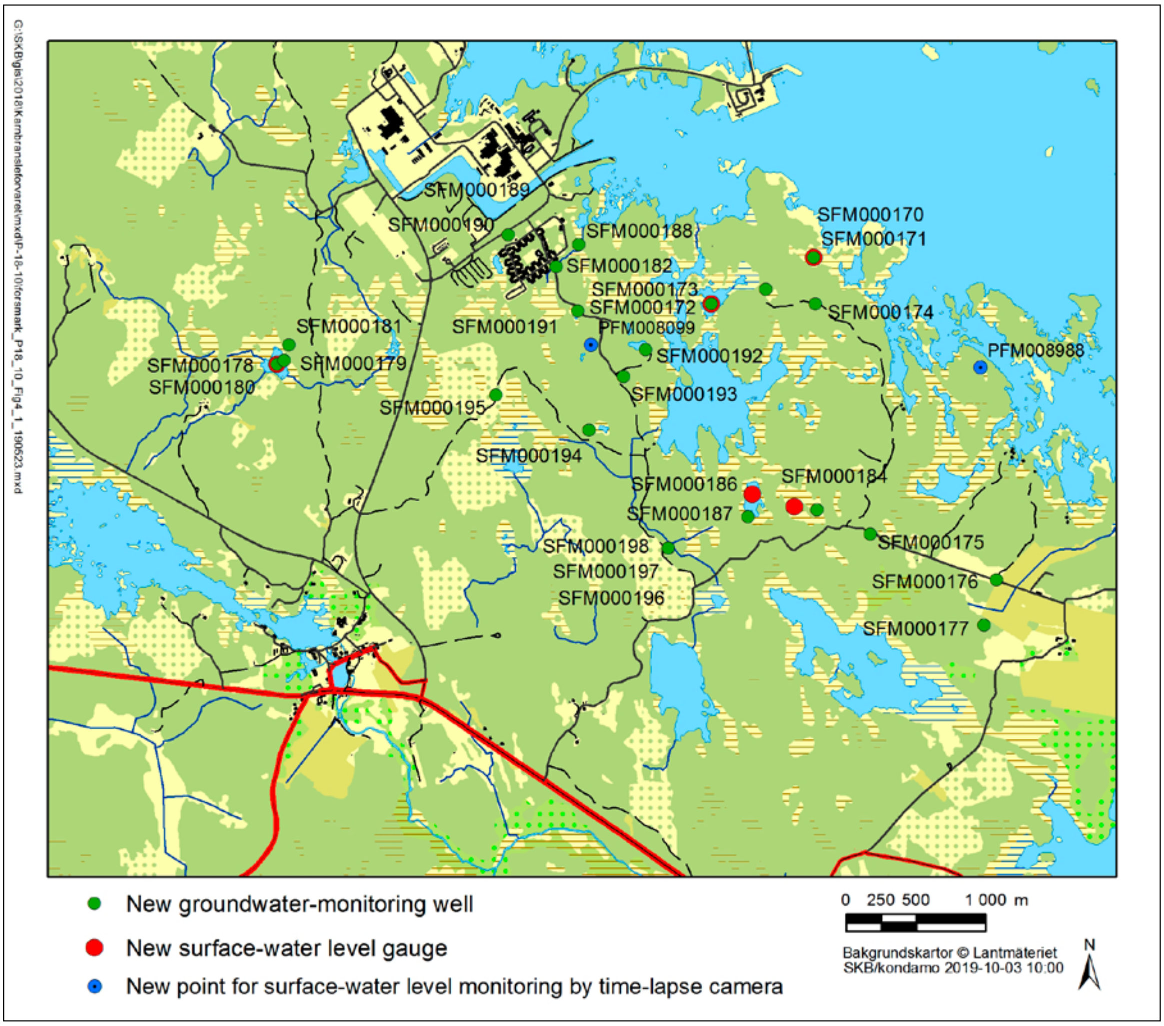

Figure 4-1. Locations of all proposed new surface-water level gauges (including two time-lapse cameras) and groundwater-monitoring wells.

Table 4-1. Proposed new surface-water gauges and groundwater-monitoring wells. Note that coordinates (SWEREF 99 18 00) are preliminary (cf. Figure 4-1).

ID	N	E	Groundwater (GW) Surface water (SW)	Comments
SFM000169	6698053	161503	GW	In till, HDPE-pipe 50/63 mm
SFM000170	6698280	161847	SW	Wetland pond, steel pipe 51.3/60.3 mm
SFM000171	6698281	161848	GW	Below wetland pond in till, steel pipe 51.3/60.3 mm
SFM000172	6697950	161115	SW	Lake, steel pipe 51.3/60.3 mm
SFM000173	6697951	161116	GW	Below lake in till, steel pipe 51.3/60.3 mm
SFM000174	6697948	161860	GW	In till, HDPE-pipe 50/63 mm
SFM000175	6696305	162253	GW	In till, HDPE-pipe 50/63 mm
SFM000176	6695976	163152	GW	In till, HDPE-pipe 50/63 mm
SFM000177	6695654	163064	GW	In till, HDPE-pipe 50/63 mm
SFM000178	6697520	158010	SW	Lake, steel pipe 51.3/60.3 mm
SFM000179	6697547	158011	GW	Below lake in till, steel pipe 51.3/60.3 mm
SFM000180	6697658	158060	GW	In till below wetland, HDPE-pipe 50/60 mm
SFM000181	6698215	158096	GW	In till, HDPE-pipe 50/63 mm
SFM000182	6696478	160005	GW	In till, HDPE-pipe 50/63 mm
SFM000183	6696500	161870	GW	In till below wetland, HDPE-pipe 50/60 mm
SFM000184	6696590	161710	SW	Lake, steel pipe 51.3/60.3 mm
SFM000186	6696428	161410	SW	Lake, steel pipe 51.3/60.3 mm
SFM000187	6698375	161376	GW	In till below wetland, HDPE-pipe 50/60 mm
SFM000188	6698495	160166	GW	In till, HDPE-pipe 50/63 mm
SFM000190	6697898	159635	GW	In till, HDPE-pipe 50/63 mm
SFM000191	6697623	160160	GW	In till, HDPE-pipe 50/63 mm
SFM000192	6697430	160646	GW	In till, HDPE-pipe 50/63 mm
SFM000193	6697048	160487	GW	In till, HDPE-pipe 50/63 mm
SFM000194	6697300	160240	GW	In till, HDPE-pipe 50/63 mm
SFM000195	6696206	159575	GW	In till, HDPE-pipe 50/63 mm
SFM000196	6696206	160807	GW	In bedrock, HDPE-pipe 50/63 mm
SFM000197	6696206	160807	GW	In till, HDPE-pipe 50/63 mm
SFM000198	6698053	160807	GW	In till, HDPE-pipe 50/63 mm
PFM008098	6697495	163041	SW	Wetland pond, time-lapse camera
PFM008099	6697655	160258	SW	Wetland pond, time-lapse camera

In addition to monitoring at the new installations, monitoring is also proposed in three groundwater wells not monitored at present: SFM0017, SFM0020 and SFM0090. Prior to start of the construction of the repository, it is recommended that groundwater-monitoring wells considered to be most important for the monitoring are equipped with GSM equipment to allow continuous data gathering and transfer. It is emphasized that the monitoring recommended in this report should be resumed or initiated as soon as possible, in order to obtain sufficient monitoring-data periods also during the “baseline stage” prior to start of repository construction.

5 Performed installations during 2019

Nearly all of the proposed new surface water gauges and groundwater monitoring wells have been installed during 2019, and they are presented in Figure 5-1 and Table 5-1 below. Time-lapse cameras are yet to be installed due to regulations, but they will be tested during the end of 2019 and permanently installed during 2020. Coordinates and elevation data for each installation should always be extracted from the SKB Sicada database. For information about conditions during drilling and type of regolith along the boreholes the reader is referred to installation protocol (Strömhag 2019).

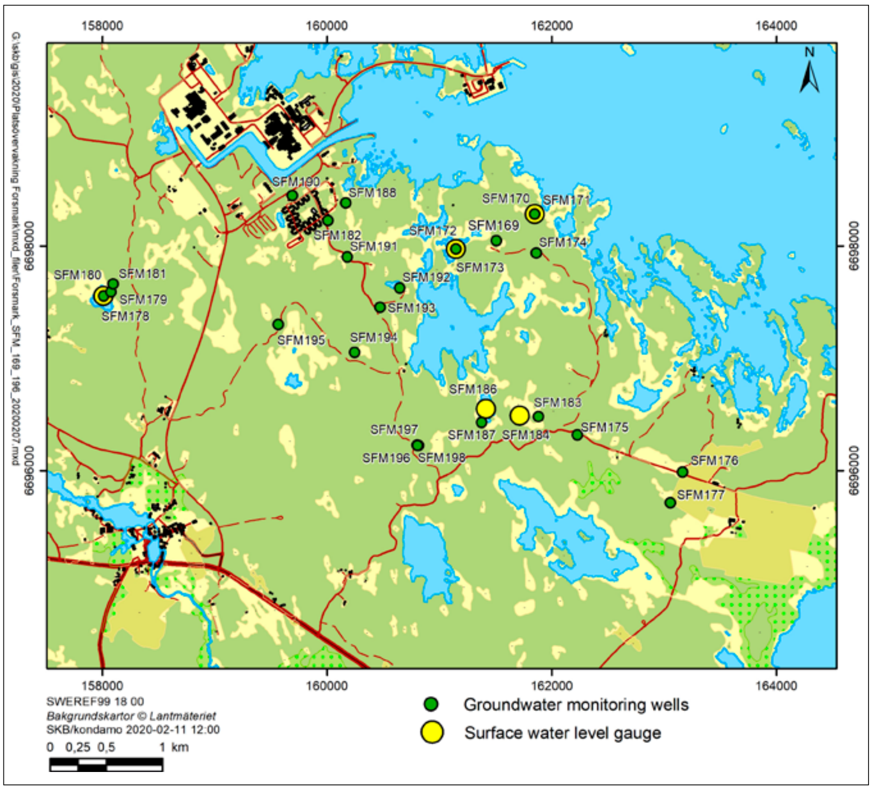

Figure 5-1. *Installed surface water level gauges and groundwater monitoring wells 2019.*

Figure 5-2. *Example of installations with support rods, example from Puttan (SFM000172–173).*

Table 5-1. Installed new surface-water gauges and groundwater-monitoring wells. Coordinates (SWEREF 99 18 00, RH2000).

ID code	N	E	Z TOC (m a.s.l.)	Z ground (m a.s.l.)	Screen SECup [m a.s.l.]	Screen SEClow [m a.s.l.]
SFM000169	6698044.377	161506.477	2.326	1.726	0.326	−0.674
SFM000170	6698281.062	161847.159	1.631	0.7	0.631	−0.369
SFM000171	6698281.133	161848.153	1.744	0.7	−0.756	−1.756
SFM000172	6697970.807	161146.247	1.823	0.7	0.823	−0.167
SFM000173	6697970.019	161145.482	1.876	0.700	−2.124	−3.124
SFM000174	6697935.952	161862.602	3.567	2.987	2.567	1.567
SFM000175	6696315.806	162226.804	4.331	3	0.331	−0.669
SFM000176	6695987.413	163163.282	5.28	4.7	0.28	−0.72
SFM000177	6695713.393	163054.585	4.821	3.8	0.821	−0.179
SFM000178	6697552.628	158010.743	6.933	6.1	5.933	4.933
SFM000179	6697552.494	158011.860	6.886	6.2	2.886	1.886
SFM000180	6697589.292	158078.427	6.954	6.3	2.954	1.954
SFM000181	6697660.349	158098.390	9.562	8.200	6.562	5.562
SFM000182	6698225.220	160009.508	2.658	1.700	−0.342	−1.342
SFM000183	6696481.168	161880.076	2.495	1.5	−2.605	−3.605
SFM000184	6696488.316	161713.564	2.381	1.4	1.381	0.381
SFM000186	6696548.330	161413.060	1.956	1	1.27	0.27
SFM000187	6696428.880	161376.137	2.142	1	0.142	−0.858
SFM000188	6698379.641	160167.733	2.291	1.000	0.291	−0.709
SFM000190	6698445.35	159691.78	5.625	4.6	0.625	−0.375
SFM000191	6697900.443	160180.128	4.487	3.397	−2.713	−3.713
SFM000192	6697624.657	160647.634	3.441	2.411	−3.559	−4.559
SFM000193	6697452.732	160471.641	6.049	4.999	2.949	1.949
SFM000194	6697051.764	160244.691	4.298	3.398	2.298	1.298
SFM000195	6697298.637	159565.596	3.775	2.800	−1.225	−2.225
SFM000196	6696224.623	160813.498	3.253	2	−5.747	−6.747
SFM000197	6696226.860	160803.115	2.699	2.1	−3.301	−4.301
SFM000198	6696222.973	160805.120	3.159	2.1	−1.841	−2.841
				Water surface		

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.com/publications.
SKBdoc documents will be submitted upon request to document@skb.se.

Berglund S, Lindborg R (eds), 2017. Monitoring Forsmark – evaluation and recommendations for programme update. SKB TR-15-01, Svensk Kärnbränslehantering AB.

Bosson E, Sassner M, Sabel U, Gustafsson L-G, 2010. Modelling of present and future hydrology and solute transport at Forsmark. SR-Site Biosphere. SKB R-10-02, Svensk Kärnbränslehantering AB.

Brunberg A-K, Carlsson T, Blomqvist P, Brydsten L, Strömgren M, 2004. Forsmark site investigation. Identification of catchments, lake-related drainage parameters and lake habitats. SKB P-04-25, Svensk Kärnbränslehantering AB.

Follin S, 2008. Bedrock hydrogeology Forsmark. Site descriptive modelling, SDM-Site Forsmark. SKB R-08-95, Svensk Kärnbränslehantering AB.

Gontier M, Tunbrant S, 2019. Komplettering om avgränsning av Kärnbränsleförvarets verksamhetsområden. SKBdoc 1684602 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Hagelius M, Orbe R, 2018. Slugtester i grundvattenrör sommaren 2017. SKBdoc 1617129 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Hamrén U, Collinder P, 2010. Vattenverksamhet i Forsmark. Ekologisk fältinventering och naturvärdesklassificering samt beskrivning av skogsproduktionsmark. SKB R-10-16, Svensk Kärnbränslehantering AB. (In Swedish, with abstract in English.)

Johansson P-O, 2008. Description of surface hydrology and near-surface hydrogeology at Forsmark. Site descriptive modelling, SDM-Site Forsmark. SKB R-08-08, Svensk Kärnbränslehantering AB.

Mårtensson E, Gustafsson L-G, 2010. Hydrological and hydrogeological effects of an open repository in Forsmark. Final MIKE SHE simulations for the Environmental Impact Assessment. SKB R-10-18, Svensk Kärnbränslehantering AB.

Schoener G, 2018. Time-lapse photography: Low-Cost, low-tech alternative for monitoring flow depth. Journal of Hydrologic Engineering 23. doi:10.1061/(ASCE)HE.1943-5584.0001616

Strömhag M, 2019. Installation GV-rör. Sweco Civil AB. SKBdoc 1877396, ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Wass E, 2019. Monitoring Forsmark. Hydro monitoring program report for October 2017 – September 2018. SKBdoc 1864943 ver 1.0, Svensk Kärnbränslehantering AB.

Werner K, 2018a. Data compilation and analysis for the description of the access area of the planned spent fuel repository in Forsmark – meteorology, hydrology and near-surface hydrogeology. SKB P-17-19, Svensk Kärnbränslehantering AB.

Werner K, 2018b. Bilaga till PM – slugtester i grundvattenrör sommaren 2017. Utvärdering av slugtester sommaren 2017. SKBdoc 1617130 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Werner K, Lundholm L, Johansson P-O, 2006. Forsmark site investigation. Supplementary drilling and soil sampling, and installation of groundwater monitoring wells, pumping wells and Svensk Kärnbränslehantering AB.T filter tips. SKB P-06-89, Svensk Kärnbränslehantering AB.

Werner K, Rydén G, Berg C, Nilsson A-C, 2017. Program för monitering av ytsystem i Söderviken – nuläge och strategi för fortsatt utveckling. SKBdoc 1560387 ver 1.0, Svensk Kärnbränslehantering AB. (In Swedish.)

Appendix 1

Tables

Table A1-1 presents geometrical characteristics of existing groundwater-monitoring wells in regolith, whereas minimum and average groundwater levels (GWL) in relation to lower screen levels (Seclow) are presented in Table A1-2.

Table A1-1. Geometrical data on existing groundwater monitoring wells in regolith. GSE = ground-surface elevation, RSE = rock-surface elevation ("–" means that the rock surface was not reached during drilling), Secup = upper screen level, Seclow = lower screen level, Secmid = mid-level of screen (elevation system RHB 70).

Well id	GSE	RSE	Secup	Seclow	Secmid
SFM0001	0.96	−3.85	−2.85	−3.85	−3.35
SFM0002	1.62	−3.19	−2.19	−3.19	−2.69
SFM0003	1.46	−8.75	−7.05	−9.05	−8.05
SFM0004	3.53	−1.58	−0.88	−1.88	−1.38
SFM0005	6.00	3.90	4.60	3.60	4.10
SFM0006	5.78	2.38	3.08	2.08	2.58
SFM0007	6.59	1.09	1.89	0.89	1.39
SFM0008	3.36	−2.15	−1.38	−2.38	−1.88
SFM0009	4.34	1.84	2.64	1.64	2.14
SFM0010	13.24	-	12.54	11.54	12.04
SFM0011	2.01	-	−0.86	−1.86	−1.36
SFM0012	1.23	−3.47	−2.40	−3.40	−2.90
SFM0013	1.29	−3.50	−2.50	−3.50	−3.00
SFM0014	5.60	3.60	4.62	3.62	4.12
SFM0015	2.58	-	−0.69	−1.69	−1.19
SFM0016	5.22	−1.99	−1.32	−2.32	−1.82
SFM0017	5.65	1.65	2.69	1.69	2.19
SFM0018	5.78	1.28	2.18	1.18	1.68
SFM0019	3.68	−1.13	0.28	−0.73	−0.23
SFM0020	1.67	−1.54	−0.76	−1.76	−1.26
SFM0021	1.43	−0.48	−0.04	−1.04	−0.54
SFM0022	0.09	−3.43	−3.53	−4.03	−3.78
SFM0023	−1.94	−4.25	−3.17	−4.17	−3.67
SFM0024	−0.83	−2.74	0.47	−2.75	−1.14
SFM0025	−0.95	-	−5.21	−6.21	−5.71
SFM0026	0.70	−15.31	−14.42	−15.42	−14.92
SFM0027	0.91	−6.10	−5.26	−6.26	−5.76
SFM0028	0.22	−6.89	−5.94	−6.94	−6.44
SFM0029	0.21	−6.89	−5.92	−6.92	−6.42
SFM0030	1.67	−1.94	−1.22	−2.22	−1.72
SFM0031	1.74	−1.86	−0.87	−1.87	−1.37
SFM0032	0.57	−2.33	−1.37	−2.37	−1.87

Table A1-1, continued.

Well id	GSE	RSE	Secup	Seclow	Secmid
SFM0033	0.54	−2.07	−1.31	−2.31	−1.81
SFM0034	0.67	−1.34	−0.43	−1.43	−0.93
SFM0035	0.66	−1.64	−0.51	−1.51	−1.01
SFM0036	0.62	−1.19	−0.49	−1.49	−0.99
SFM0037	0.60	−1.40	−0.50	−1.50	−1.00
SFM0049	2.93	−0.88	0.03	−0.98	−0.48
SFM0057	4.27	0.47	1.37	0.27	0.82
SFM0058	3.20	−0.31	0.70	−0.30	0.20
SFM0059	4.04	−1.27	−0.35	−1.35	−0.85
SFM0060	4.26	−2.74	−1.69	−2.69	−2.19
SFM0061	4.33	−2.18	−0.62	−2.67	−1.65
SFM0062	−0.17	-	−1.93	−2.33	−2.13
SFM0063	−0.17	-	−1.92	−2.42	−2.17
SFM0065	−0.38	-	−3.48	−3.88	−3.68
SFM0067	2.11	-	1.64	0.64	1.14
SFM0068	1.61	−0.23	1.27	0.27	0.77
SFM0069	1.87	-	1.50	0.50	1.00
SFM0070	3.26	-	2.04	1.04	1.54
SFM0071	3.29	-	−1.40	−2.40	−1.90
SFM0072	3.27	−6.13	−4.81	−5.81	−5.31
SFM0073	0.23	-	−2.87	−3.87	−3.37
SFM0074	0.52	−1.48	−1.18	−3.88	−2.53
SFM0075	3.27	−6.13	−3.88	−4.88	−4.38
SFM0076	3.36	0.99	2.26	1.26	1.76
SFM0077	4.75	−1.86	−0.98	−1.98	−1.49
SFM0078	4.84	1.04	1.74	0.74	1.24
SFM0079	3.60	−1.21	−0.51	−1.51	−1.01
SFM0080	3.59	−3.62	−4.27	−5.27	−4.77
SFM0081	−1.24	-	−3.56	−3.96	−3.76
SFM0082	0.44	-	−1.29	−1.33	−1.31
SFM0084	0.33	-	−2.47	−2.87	−2.67
SFM0085	0.67	-	−1.55	−1.59	−1.57
SFM0087	0.31	-	−0.70	−0.90	−0.80
SFM0088	0.72	-	−0.12	−0.16	−0.14
SFM0090	1.01	−2.89	−1.43	−3.93	−2.68
SFM0091	0.41	-	−0.49	−0.89	−0.69
SFM0092	0.63	-	−0.36	−0.40	−0.38
SFM0094	0.57	−2.14	−0.88	−3.38	−2.13
SFM0095	11.10	6.10	7.10	6.10	6.60
SFM0096	11.00	-	8.42	8.38	8.40
SFM0099	11.07	-	9.34	9.30	9.32

Table A1-1, continued.

Well id	GSE	RSE	Secup	Seclow	Secmid
SFM0101	11.01	-	9.82	9.78	9.80
SFM0103	11.04	6.04	6.90	4.40	5.65
SFM0104	2.95	−3.66	−0.46	−1.46	−0.96
SFM0105	2.92	0.82	1.62	0.62	1.12
SFM0106	4.30	0.60	1.70	0.70	1.20
SFM0107	2.50	−2.71	−1.86	−2.86	−2.36
SFM0108	3.41	−1.49	−0.79	−1.79	−1.29
SFM0109	7.41	2.37	4.06	3.01	3.53
SFM000110	0.99	-	−0.19	−0.69	−0.44
SFM000112	1.29	-	0.31	−0.20	0.05
SFM000114	2.17	-	0.85	0.35	0.60
SFM000116	1.85	-	0.13	−0.38	−0.13
SFM000118	0.59	-	−0.06	−0.56	−0.31
SFM000121	1.26	-	−3.32	−3.82	−3.57
SFM000122	2.45	-	−4.16	−4.66	−4.41
SFM000123	0.73	-	−1.51	−2.01	−1.76
SFM000124	1.33	-	−0.82	−1.32	−1.07
SFM000125	2.64	-	−0.47	−0.97	−0.72
SFM000126	2.87	-	−0.32	−0.92	−0.62
SFM000132	2.93	-	1.81	0.91	1.36
SFM000133	2.55	-	1.47	0.57	1.02
SFM000134	2.88	-	2.80	1.90	2.35
SFM000135	2.53	-	2.42	1.52	1.97
SFM000138	1.40	-	1.56	0.56	1.06
SFM000139	2.88	-	1.68	0.68	1.18
SFM000140	2.34	-	2.40	1.40	1.90
SFM000141	1.16	-	1.24	0.24	0.74
SFM000142	0.99	-	1.39	0.39	0.89
SFM000143	0.77	-	0.27	−0.74	−0.24
SFM000144	0.96	-	−0.54	−1.54	−1.04
SFM000145	0.47	-	0.47	−0.54	−0.04
SFM000146	2.21	-	0.21	−0.79	−0.29
SFM000147	2.18	-	0.78	−0.23	0.28
SFM000149	0.49	-	0.03	−0.97	−0.47
SFM000153	3.37	-	1.97	0.97	1.47
SFM000154	3.43	-	2.03	1.03	1.53
SFM000160	2.48	0.56	1.56	0.56	1.06
SFM000161	1.30	−0.13	0.88	−0.13	0.38
SFM000162	1.05	0.18	1.18	0.18	0.68
SFM000163	2.36	−0.51	0.61	−0.39	0.11

Table A1-1, continued.

Well id	GSE	RSE	Secup	Seclow	Secmid
SFM000167	1.61	−2.82	−2.01	−3.01	−2.51
SFM000168	4.46	-	1.45	0.45	0.95
SFR000001	2.19	-	−3.54	−4.24	−3.89
SFR000002	2.52	-	−3.09	−3.79	−3.44
SFR000003	3.54	-	−3.48	−4.18	−3.83
SFR000004	3.71	-			
SFR000005	1.29	-			

Table A1-2. Differences (m) between groundwater level (GWL) and Seclow, calculated from minimum (Min.) and average (Av.) daily average groundwater levels. "Screened" means that data affected by e.g. water pumping or groundwater sampling are removed from the dataset (a single number means that there is no difference between screened and unscreened data). Max. drawdown is the maximum MIKE SHE-calculated drawdown, shown for well locations with an annual average drawdown of more than 0.1 m.

Well id	Data period	Notes	DIFF (GWL – Seclow) (m)		Max. drawdown (m)
			Min. GWL (unscreened/screened)	Av. GWL (unscreened/screened)	
SFM0001	2002-09-20–2016-08-09		1.70/2.67	4.37/4.38	
SFM0002	2002-09-20–2006-05-03	Terminated	3.35	4.42	0.80
SFM0003	2002-09-20–2016-10-19		8.26	10.31	0.80
SFM0004	2003-02-12–2016-10-12		2.25/2.42	4.85	
SFM0005	2003-02-12–2016-09-11		0.67	1.29	
SFM0006	2003-12-10–2016-04-06		0.66	2.57	
SFM0007		The well is dry			
SFM0008	2003-08-21–2016-10-11		1.88	2.91	
SFM0009	2003-04-30–2006-01-12	Terminated	1.57	2.33	
SFM0010	2003-05-14–2016-12-31		−0.12	0.99	
SFM0011	2003-04-29–2016-12-31		2.92	3.80	
SFM0012	2003-05-09–2016-08-11		3.21/4.90	5.21	
SFM0013	2003-04-29–2016-12-31		3.55	4.76/4.77	
SFM0014	2003-04-29–2016-10-11		1.08	1.74	
SFM0016	2003-04-29–2006-03-26	Terminated	7.26	7.55	
SFM0017	2003-04-29–2008-09-18	Terminated	3.14	3.75	
SFM0018	2003-04-29–2006-02-12	Terminated	3.73	4.10	
SFM0019	2003-04-30–2006-10-11		2.36	3.86	
SFM0020	2003-04-30–2006-05-03	Terminated	2.52	3.16	
SFM0021	2003-04-30–2016-09-30		0.21	2.04	1.39
SFM0022	2004-09-16–2016-12-02		4.24	4.59	
SFM0023	2003-05-16–2016-10-18		2.22/4.01	4.47/4.55	
SFM0026	2003-08-18–2016-10-11		14.55	16.23	
SFM0027	2004-10-14–2016-01-21	Manual gw. level meas.	5.35	6.99	
SFM0028	2003-04-30–2016-09-26		5.93	7.19	
SFM0029		No monitoring data			
SFM0030	2003-04-29–2016-01-19		0.80	3.46	0.63
SFM0031		No monitoring data			0.63
SFM0032		No monitoring data			1.29
SFM0033	2003-05-23–2016-10-06		1.68	2.81	1.29
SFM0034	2003-04-30–2016-10-03		1.12	1.93	1.28
SFM0035		No monitoring data			1.28
SFM0036	2003-04-30–2016-12-31		0.34	1.90	

Well id	Data period	Notes	DIFF (GWL – Seclow) (m)		Max. drawdown (m)
			Min. GWL (unscreened/screened)	**Av. GWL (unscreened/screened)**	
SFM0037		No monitoring data			
SFM0049	2003-05-13–2016-06-20		1.12/2.41	3.26	
SFM0050		No monitoring data			0.52
SFM0051		No monitoring data			0.52
SFM0052		No monitoring data			
SFM0053		No monitoring data			
SFM0054		No monitoring data			
SFM0056		No monitoring data			
SFM0057	2003-12-12–2016-09-30		1.34	3.16	
SFM0058	2004-05-27–2016-10-12		0.30	1.91	
SFM0059	2004-12-16–2006-05-01	Terminated	1.22	1.42	
SFM0060		No monitoring data			
SFM0061	2004-02-16–2016-12-21		2.31	2.68	
SFM0062	2004-06-05–2016-06-06		2.06	2.77	
SFM0063		No monitoring data			
SFM0067	2006-05-04–2016-01-20	Manual gw. level meas.	0.47	1.20	
SFM0068	2006-05-03–2016-03-01	Manual gw. level meas.	−0.29	0.81	1.39
SFM0069	2006-05-04–2016-01-20	Manual gw. level meas.	−0.25	0.87	0.63
SFM0070	2006-05-03–2016-03-01	Manual gw. level meas.	−0.51	1.13	
SFM0071	2006-05-03–2016-03-01	Manual gw. level meas.	0.84	4.25	
SFM0072	2006-05-03–2016-03-01	Manual gw. level meas.	4.55	7.31	
SFM0073	2006-05-03–2015-07-14	Manual gw. level meas.	2.80	4.10	
SFM0074		No monitoring data			1.29
SFM0075	2006-05-03–2016-03-01	Manual gw. level meas.	3.70	6.79	
SFM0076	2005-01-10–2005-02-02	Terminated	0.05	0.27	
SFM0077	2005-10-18–2016-10-03		0.82/4.28	4.74	
SFM0078	2005-10-18–2016-10-11		−0.30	2.86	
SFM0079	2005-10-18–2016-10-19		2.08/3.44	4.33	
SFM0080	2006-10-02–2016-10-12		4.40	6.79	
SFM0083		No monitoring data			
SFM0084	2006-06-19–2016-09-28		2.94	3.51	0.50
SFM0085	2006-10-10–2009-01-12	Pore pressure, terminated			0.50
SFM0086		No monitoring data			0.50
SFM0087	2006-06-20–2016-09-27		1.10	1.47	0.50
SFM0088	2006-10-10–2009-01-12	Pore pressure, terminated			0.50
SFM0089		No monitoring data			0.50
SFM0090		No monitoring data			1.18

Table A1-2, continued.

Well id	Data period	Notes	DIFF (GWL – Seclow) (m)		Max. drawdown (m)
			Min. GWL (unscreened/screened)	Av. GWL (unscreened/screened)	
SFM0091	2006-06-09–2016-10-03		0.48/0.91	1.41	
SFM0092	2006-10-10–2009-01-08				
SFM0093		No monitoring data			
SFM0094		No monitoring data			
SFM0095	2006-05-29–2016-12-31	Leans slightly	2.17/3.73	4.63/4.64	
SFM0096	2006-10-10–2009-01-07	Pore pressure, terminated			
SFM0097		No monitoring data			
SFM0099	2006-10-10–2009-01-07	Pore pressure, terminated			
SFM0100		No monitoring data			
SFM0101	2006-10-10–2009-01-07	Pore pressure, terminated			
SFM0102		No monitoring data			
SFM0103		No monitoring data			
SFM0104	2006-06-19–2016-09-30		0.56	2.68	0.24
SFM0105	2006-06-19–2016-10-12		−0.26	0.60	
SFM0106	2006-06-19–2016-0616		−0.53/−0.24	2.48/2.49	
SFM0107	2006-06-20–2016-10-19		2.55	3.98	
SFM0108		No monitoring data			0.64
SFM0109		No monitoring data			
SFM000110	2009-04-28–2016-10-19	Slightly bent	1.76	2.10	
SFM000112	2009-04-28–2016-10-12		1.52	1.97	
SFM000114	2009-04-28–2016-10-13		1.58/1.63	2.03	
SFM000116	2009-04-30–2016-10-12		2.00	2.71	
SFM000118	2009-05-06–2016-08-03	Leans slightly	0.92	1.34	0.76
SFM000121	2011-05-12–2016-11-02		3.43	4.26	
SFM000122	2011-05-12–2016-12-31		4.12	5.73	
SFM000123	2011-05-12–2016-12-31		1.69	2.10	

Arkitektkopia AB, Bromma, 2020

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

skb.se