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Assessment of OSL Groundwater Monitoring Program

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Abstract

Increasing population, water demand, climate-change-induced droughts and growing strain over water resources demands better management. Groundwater is the largest distributed source of freshwater and fulfills one-third of the world's freshwater withdrawals. Therefore, countries are realizing its importance and applying measures to keep it free of pollution. Groundwater reservoirs face different risks of contamination depending upon their global location. In the northern hemisphere, deicers are widely used to keep roads and airport runways open for winter operation as well as to prevent accidents. On airports, Formate and acetate based products are used for runways while propylene glycol is used as anti-freeze on the airplane itself. De-icers are a potential source of contamination at the Oslo International Airport (OSL) which lies above the largest rain-fed aquifer of Norway. Certain regulations are applied on the management of the airport to ensure the purity of groundwater resource underneath. Airport management has developed a monitoring program to ensure the compliance. This study aims to assess the monitoring program and its strengths and weaknesses in complying with regulations regarding groundwater balance and contamination risk from deicers. Chemical and physical parameters measured over 67 monitoring wells during last 20-years is analyzed. Fluid elevation levels are used to estimate approximate water table by interpolation. Water quality of aquifer is compared with background values and drinking water standards. Retention time of a contaminant plume is estimated using a real example from the data. After above mentioned analyses, the monitoring program was found to be compatible in preventing and monitoring contamination.

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1 Introduction

During winter in the northern hemisphere, chemicals to remove snow and ice are used to ensure transportation safety. Large amounts of solids (salts) and liquids (glycols and formate) are applied to conduct deicing. These materials are collectively known as “Deicers”. Deicer is a substance that lowers the freezing point of water, contributing to the melting of ice or preventing the formation of ice over any surface. Deicers are used in three ways. The first is as a preventive measure, deicers’ application before snowfall can prevent snow accumulation. Second is as snow-melter, applied after mechanically removing the snow to melt the residual snow. The third is as ice breaker, applied to break down the build-up of ice.

During past decades, population and economic growth resulted in increasing transportation and growing demand of deicers. Use of road salt for snow melting was introduced during 1930’s and became widespread by 1960’s for highway maintenance. In some cases, where ice layer is rather thick, abrasives are used as well to provide friction on the surface of ice. Highway salt (pavement deicer) consumption for de-icing ranges from 250 to 500 kilograms of salt per kilometer per application. Many highways receive more than 50 tons of salt per mile annually (Field et al. 1974; as in Ramakrishna & Viraraghavan 2005).

In addition to pavement deicers, airports use aircraft de-icing fluids (ADFs) to keep mechanical parts of aircraft free from ice. On an average, a large aircraft takes 2000 to 4000 liters of ADFs to deice. Aircraft de-icing fluids are a mixture of different chemicals and can be sprayed on aircraft surface. Certain chemicals in ADFs including glycols and additives raise toxicity concerns in soil and water resources of the area (Switzenbaum et al. 2001). These deicers on one hand assist safe transportation but on the other hand, if not treated properly, they can also deteriorate environment.

Generally, airports are located in sub urban areas, attracting more traffic than surroundings, hence requiring more road salt than surrounding environment. This creates hotspots of potential contamination within and around the airport area. Therefore, the use of deicers at airports receives more attention. Large impervious areas on and around airports, in the form of runways, taxiways, automobile parking, roads and highways contribute more to surface runoff than infiltration of salt contaminated storm water, which endangers the quality of surface water sources, like streams and lakes. On many airports of the world deicers are released directly into the environment. However, at Gardermoen airport of Norway (OSL), use of de-icing chemicals is regulated by law, to keep surface and groundwater resources free from contamination.

1.1 Background

Our study area, the Oslo Airport, Gardermoen (OSL) is located in Northern Romerike, Ullensaker commune. In vicinity of the airport, Royal Norwegian Army base, Royal Norwegian Airforce air station, gas stations, traffic flow through busy E6 highway and agricultural activities can potentially contaminate the area. The Oslo Airport, Gardermoen (OSL) was opened in 1998, issue of pollution is given more importance at OSL than other older European airports due to the presence of the large aquifer below it and better general awareness of environment (French et al. 2010). Since that period, environmental conditions have been receiving more attention and stricter regulations for environmental protection are being introduced.

Hydrogeological research has been conducted in this area during International Hydrological Decade (1965 to 1974) and “Faneprojekt Gardermoen” (1992 to 1996) and in the EU funded SoilCAM project (2008-2012). Construction of Gardermoen Airport (OSL) in this area has induced more research on groundwater systems (Sundal 2006). The area is a combination of rural and urban environment (Figure 1.1). Oslo Airport is both the biggest and the busiest airport of Norway, the terminal building of airport covers 265,000 square meters and has a capacity to handle 12,000 passengers per hour or 32 million passengers annually, overall airport area is 13 square kilometers (Avinor.no 2017).

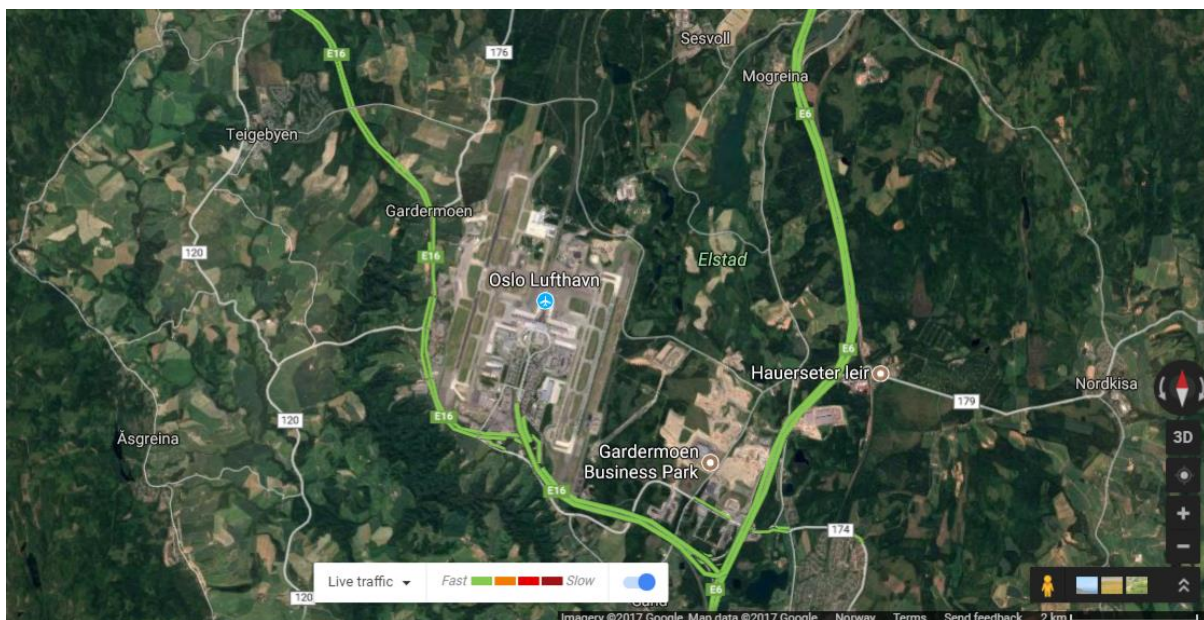


Figure 1.1 – Satellite image of the surroundings of Oslo Airport. Green lines indicate E16 and E6 highways connecting airport while passing through urban and rural areas (Google Maps).

The activities taking place at the airport, agricultural land, and highways, influence the water resources in their own way. At the airport, chemicals based on propylene glycol, and potassium formate are presently, and potassium acetate previously, used for de-icing. In winter, significant amount of normal salt and other chemicals are used to prevent ice layer formation on the highways to avoid traffic accidents. Other hazardous substances from transportation vehicles released to the environment include polycyclic aromatic hydrocarbons (PAHs), heavy metals like

lead, zinc, and copper via wearing of tires and breaks, oil leakage, and exhaust emissions. Agricultural activities like fertilizer and pesticide use, runoff from farms, and leakage through septic tanks can contaminate surface and groundwater resources. However, this study focuses on the use of deicers and their potential impact on groundwater resources in the area.

1.2 Geological setting of the area

The ice-contact Gardermoen Delta (also called the Hauerseier Delta) located around 50 km north of Oslo, was developed in a marine and mud dominated fjord basin at depths ranging between 60 to 150 meters (Sundal 2006). Pollen analysis and ¹⁴C-dating determined that the delta was deposited approximately 9,500 year ago (Tuttle et al. 1997). The Romerike area extends about 50 km in the north-south direction and contains five ice-contact deltas, which deposited within a period of 400 years due to the Scandinavian ice cap retreat after Weichselian glaciation. Paleo-shoreline and sea level investigations by Høltedahl (1924) and Sørensen (1982) (cited in Tuttle et al. 1997) concluded that this area went through a 56 meter relative sea level fall during ice-contact delta deposition due to regional uplift caused by retreating ice front.

At OSL, groundwater flows through two sub-deltas i.e. Trandum and Li delta deposits. These two sub-deltaic deposits make a complex which is known as Gardermoen Delta Complex (GDC) consisting of 79 km² area, out of which Li delta covers 58 km² (Figure 1.2). The sediments in general consists of glaciofluvial sand and gravel with underlying silty marine sediments. Main sources of sediments in glaciomarine systems like Gardermoen Delta are unsorted subglacial basal till, and material carried by meltwater flow (Tuttle 1997). Sediments in Trandum Delta (northwest) are dominated by Permian rocks of Hurdalen area whereas, Li Delta (east) predominantly consists of sediments from Precambrian and Sparagmittic (Arkosic) rocks in Gudbrandsdalen and Mjøsa region (Jørgensen et al. 1995).

Tuttle (1997) characterized the GDC by its three delta units (topset, foreset and bottomset) and classified it as a Gilbert type¹ ice-contact delta complex. The deposits are mostly coarse sand and gravel. The upper topset unit consists of coarse gravel and sand with horizontal layers indicating subaerial braided river deposition. This unit decreases in thickness with distance as the river energy declined (Tuttle 1997). Middle foreset unit is mainly comprised of sandy submarine deposits relatively finer than the topset unit, indicating river mouth and suspension fallout deposition. The grain size decreases from proximal to distal direction of the delta (Tuttle 1997). The bottomset unit is made of fine-grained sediments in horizontal layers with random lenses of coarse sediments formed by gravity-driven mass transport (Tuttle 1997). Bedrock under the bottom layer belongs to Eastern Norwegian Precambrian basement, bordering in the west with the Permian volcanic deposits of Oslo. Bedrock contains more than 95% gneisses. Most characteristic rock in this area is the grey Romerike gneiss, formed by metamorphosis 1650 to

¹ A Gilbert type delta is formed when incoming stream and the basin water has similar density (homopycnal) resulting in the simultaneous deposition of suspended and courser particles due to rapid mixing of basin and incoming water.

1600 million years ago (Oftedahl 1981 as in; Sundal 2006). The shape of bedrock forms the geometry of overlying units (Tuttle 1997).

Unlike the ice-contact submarine fans deposited south of Romerike sub-stages, the Gardermoen Delta Complex transformed into an ice contact delta. Meltwater discharge and sediment supply increased due to retreating ice sheet, while water depth in fjord decreased due to uplifting (Sørensen 1983). This caused the outwash fans to aggrade to sea level before forming the prograding and merging delta lobes building the ice-contact delta (Tuttle 1997).

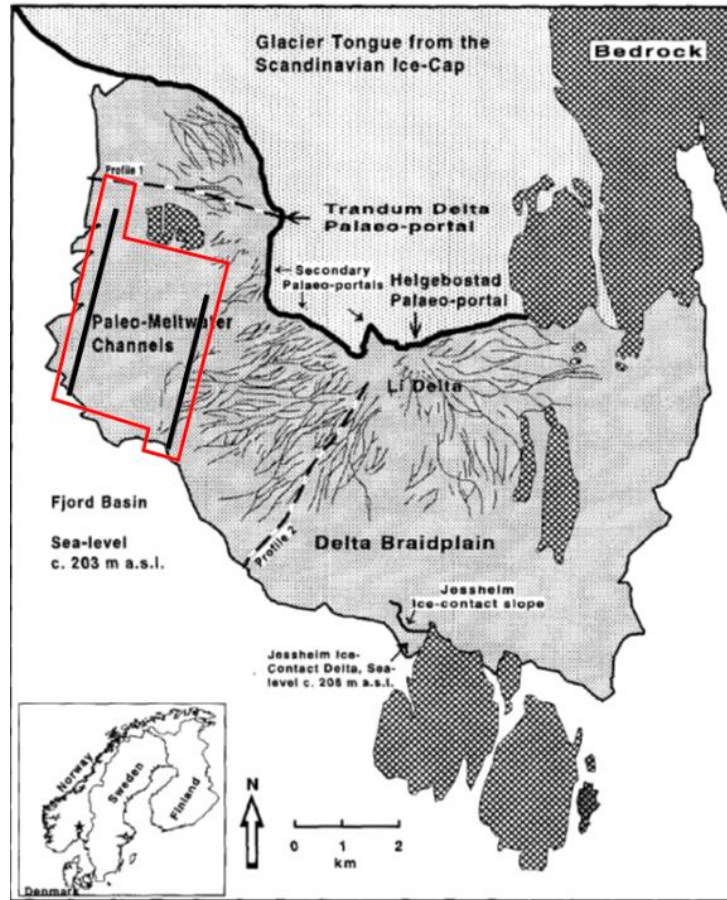


Figure 1.2 – Gardermoen Delta Complex approx. 9,500 years ago. Red borders indicate approximate location of present day Oslo Airport. Cross section of Profile 1 is in Figure 1.3 (Modified from Tuttle et al. 1997).

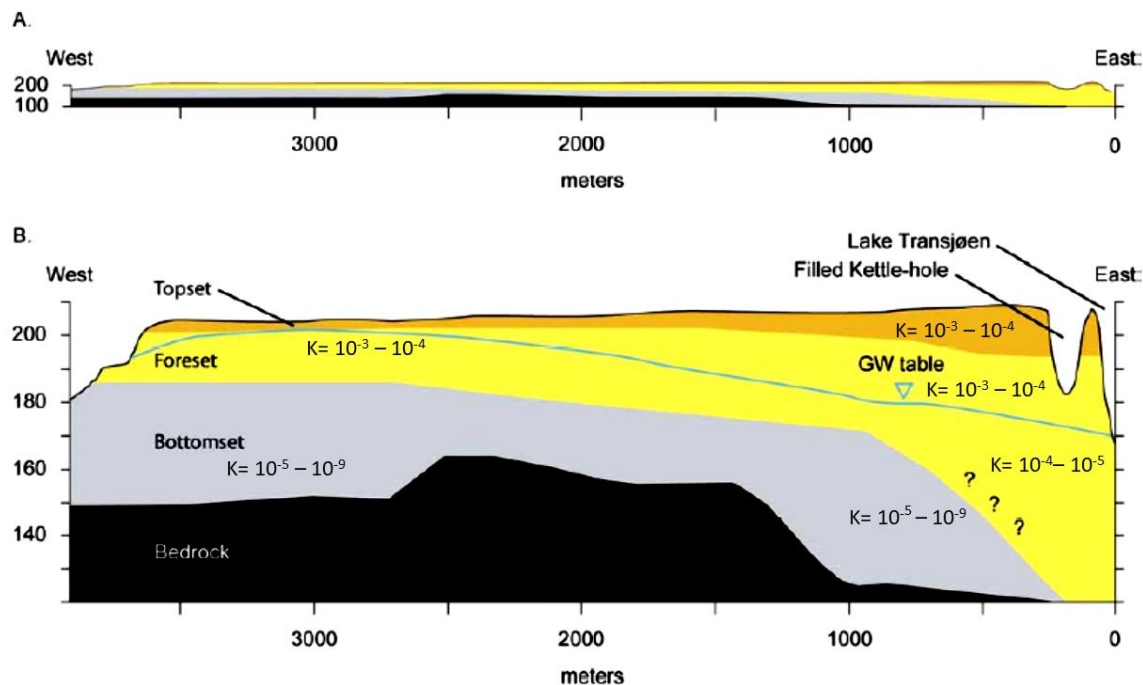


Figure 1.3 – Cross-section of Trandum delta along profile 1 in Figure 1.2, indicating the lithology and hydraulic conductivity distribution. Lower profile is vertically exaggerated by 15-times (modified after Sundal 2006).

The topset is mostly unsaturated while the middle unit corresponding to delta foreset beds is important for the Northern Romerike Aquifer which extends from the north into Gardermoen Delta Complex and covers an area of 105 km². The groundwater table ranges from 0 to 30m below the surface and fluctuates throughout the year depending upon the precipitation rate in the catchment (as cited in Sundal 2006; Østmo 1976).

1.3 Hydrogeology of the area

The Northern Romerike Aquifer covers around 105 km², including Gardermoen Delta Complex and the glaciolacustrine, glaciofluvial and silty glaciomarine sediments in its north (Tuttle 1997). Marine clays in the south and west forms no-flow boundaries. The aquifer is largely unconfined and recharged solely by precipitation. The groundwater table varies from 0 to 30 meters below surface and keeps changing throughout the year depending on the amount of precipitation, however, highest levels of groundwater are reached during snow-melting periods. The groundwater divide is semicircular in shape (Figure 1.4). Thickness of unsaturated zone increases away from the groundwater divide (Østmo 1976; as in Sundal 2006).

The drainage pattern can be divided into three sections. The area around 18 km² draining to Lake Hurdalsjøen in the north, about 32 km² to the river Leira in southwest and circa 55 km² to the Lake Hersjøen and river Risa in the northeast (Tuttle 1990; as in Sundal 2006). Lake Hersjøen and river Risa receives around 80% of the total amount of water (Jørgensen & Østmo 1990; as in Sundal 2006) through the coarse glacial contact delta deposits. Remaining water flows through the fine grain distal delta deposits in southwest, where ravines have been formed.

The position of the groundwater divide is determined by outflow distribution, higher outflow in northeast direction places the groundwater divide close to the area with least outflow i.e. southwest (Figure 1.4).

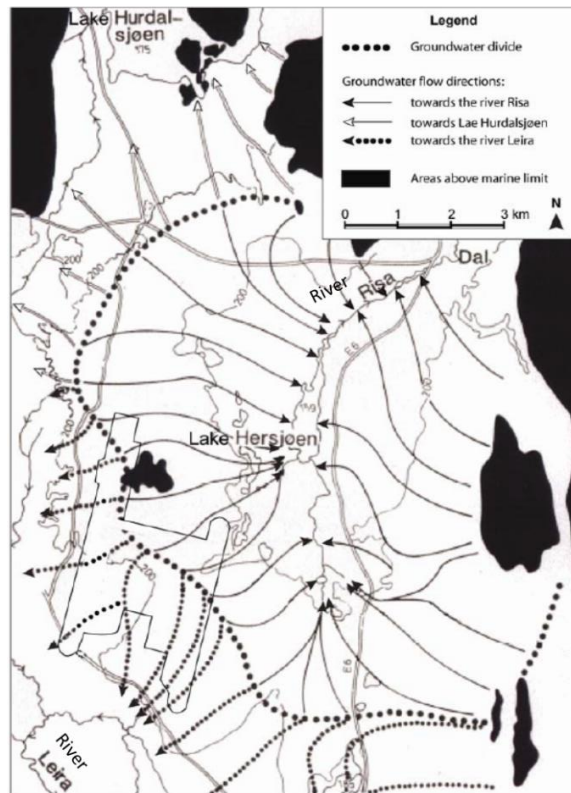


Figure 1.4 – Groundwater flow pattern before the construction of Oslo Airport. (modified after Jørgensen & Østmo 1990).

1.4 Hydro-stratigraphy

Hydro-stratigraphy of Gardermoen Delta Complex does not completely follow the lithostratigraphy. Tuttle (1997) defined four hydro-stratigraphic units based on flushed well-screen sediment and grain size analyses from sediment cores (Figure 1.5): unit (1) lies below the coarser topset unit, (2) upper foreset unit, consists of upper sandy part, whereas (3) the lower foreset unit is the silty sandy part, which becomes increasingly silt and clay rich with depth. The upper part of bottomset unit comprises of about 1-meter thick individual sand beds. Lower foreset and upper bottomset units exhibit similar hydraulic conductivity, hence combined as foreset/bottomset unit. (4) The lower bottomset unit mainly consists of silt and clay (Tuttle 1997).

The unsaturated zone generally lies in topset unit while groundwater table is normally situated in the tilted foreset layers. The saturated zone comprises the parts of (2) upper foreset, (3) lower forest/bottom set and (4) silty bottomset hydro-stratigraphic unit (Sundal 2006). As a general principal, hydraulic conductivity 'K' decreases with increasing fine-grained material and distal parts of delta are rich with fine material. Similarly, 'K' decreases in each hydro-stratigraphic

unit towards distal parts as finer sediments becomes dominated. Local depositional features like sand lenses formed by turbidites may cause changes in 'K' at a small scale.

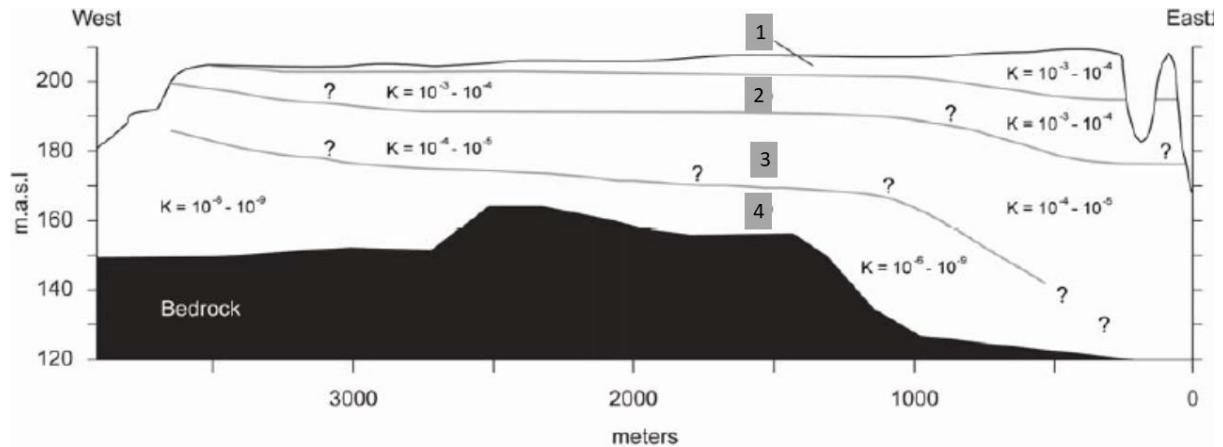


Figure 1.5 – Hydro-stratigraphic units of Trandum Delta. 'K' indicates the hydraulic conductivity (modified after Tuttle 1997)

1.5 Water budget

According to Appelo and Postma (2004), water budget equation can be represented as:

$$P = ET + Q + D + \Delta S \quad \text{Eq.1.4}$$

Where, P= precipitation, ET= evapotranspiration, Q= discharge from the catchment, D= drainage and ΔS = change in storage of aquifer.

The Gardermoen aquifer is largely unconfined and consists of coarse unconsolidated deltaic sediments having large infiltration capacity resulting in little surface runoff. The annual precipitation 'P' is around 800 mm, half of it (ca. 400 mm) is lost through evapotranspiration 'E'. Remaining half is responsible for infiltration (Jørgensen & Østmo 1990). Snow melting contributes to 60% of the aquifer recharge resulting in seasonal fluctuation of water table (Basberg et al. 1998; Kłonowski et al. 2008). Water table is lower during winter as most precipitation is in form of snow and frozen ground hinders infiltration, while discharge and drainage is continuous throughout the year. Discharge from the catchment 'Q' is approximately 490 mm/year while the amount of subsurface drainage 'D' cannot be measure but assumed negligible i.e. 0 (Jørgensen & Østmo 1990). Water table rise is delayed by approximately one month relative to autumn rainfall and infiltration. This one-month delay may indicate the retention time of water in unsaturated zone.

During the snow melting period (March to May, June), water saturation reaches around 20% and the water flow velocity in unsaturated zone reaches 20 cm/day. During summer, increased evapotranspiration lowers water saturation and decreases hydraulic conductivity in unsaturated zone up to 10 cm/day (Jørgensen & Østmo 1990). In saturated zone, groundwater velocity ranges between 10 to 20 cm/day and a mean residence time of 30 years (Jørgensen & Østmo 1990).

1.6 Minerology and Geochemistry

Silicate is the most dominant mineral class at Gardermoen, average weight proportions of silicate minerals derived from three cores at Gardermoen shown in Table 1.1. Besides some variation in mineralogy, quartz is the major silicate mineral in all samples. Non silicate minerals, calcite and pyrite which can influence groundwater chemistry are found in shale fragments. Calcite is mainly found at depth greater than 10-meter where calcite dissolution front is located (Basberg 1999; Jørgensen et al. 1991; as in Sundal 2006). Pyrite is depleted from upper saturated and unsaturated zones but found in deeper parts of Moreppen I and Moreppen II. Other accessory minerals found are imogolite, vermiculite and other oxides and oxy-hydroxides (Basberg 1999; as in Sundal 2006).

Table 1.1 – Weight proportion of silicate minerals in sediments at different locations on Trandum delta at Gardermoen (Modified from Sundal, 2006).

Location	Depth (m)	Plagioclase (w %)	Quartz (w %)	Amphibole (w %)	Mica (w %)	Chlorite (w %)	K-feldspar (w %)
Lake Hersjøen (Jørgensen <i>et al.</i> , 1991)	1 - 50	8	50	2	15	7	18
Moreppen I (Skarstad 1996)	1 - 14	31	43	1	3	3	15
Moreppen II (Dagestad, 1998)	1 - 8	18	65	1	2	6	8

Since 80% of groundwater from the aquifer drains towards northeast feeding river Risa and Lake Hersjøen. The composition of water inflow from the aquifer appears different than water composition in river Risa (Jørgensen et al. 1991; as in Sundal 2006). This suggests the main geochemical processes altering the chemistry of inflow water includes silicate weathering, calcite dissolution, pyrite oxidation, and fossil seawater.

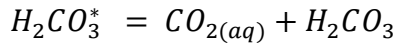
1.6.1 Silicate weathering

Silicate weathering can result in releasing cations such as Na^+ , K^+ , Ca^{2+} , Mg^{2+} , and small amounts of Al^{3+} . The most important weathering processes in the upper soil profile are transformation of muscovite to vermiculite and smectite, breakdown of chlorite and biotite (Sundal 2006).

1.6.2 Calcite dissolution

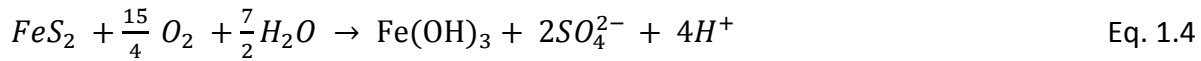
Outflow water is rich in Ca^{2+} , Mg^{2+} and HCO_3^- indicating carbonate weathering. Dissolved carbon dioxide pressure measured in field is around ten times higher than atmospheric pressure with seasonal fluctuations (Basberg 1999; as in Sundal 2006). Higher carbon dioxide pressure means higher solution in water resulting in production of carbonic acid ($H_2CO_3^-$) which release Ca^{2+} and HCO_3^- after interaction with calcite. At Moreppen, calcite depleted zone is 10-meter thick

(Jørgensen et al. 1991; as in Sundal 2006). Calcite dissolution mechanism is pH dependent described by Plummer et al. (1978) as:

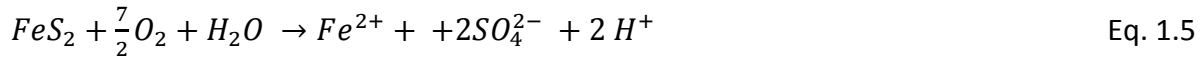


1.6.3 Pyrite Oxidation

Pyrite present in sediments acts as a source of iron and sulfate in groundwater. In river Risa, output of sulfate is higher than the input during dry and wet seasons. Weathering of pyrite can be responsible for sulfate (Jørgensen et al. 1991; as in Sundal 2006). Appelo and Postma (2004) described the overall process of pyrite oxidation as:



Initially, oxidation disulfide by O_2 takes place:



Later, Fe^{2+} oxidizes to Fe^{3+} ,



Disulfide oxidation proceeds at a lower redox potential than Fe^{2+} . Therefore, insufficient supply of electron acceptors results in a solution enriched with ions of Fe^{2+} and SO_4^{2-} after reaction Eq. 1.6. In extremely low pH, Fe^{3+} precipitates as:



The sulfate amount produced by oxidation is reduced due to adsorption of sulfate in the aquifer. In deep anoxic lake water, sulfate is reduced to sulfide (Jørgensen et al. 1991; as in Sundal 2006). In the oxygenated groundwater, dissolved ferrous ion is unstable and oxidizes to form a ferric hydroxide precipitate (Eq. 1.6 and Eq. 1.7).

1.6.4 Fossil Seawater

Jørgensen et al. (1991) found higher output of chloride than the input. It was interpreted to be the result of leaching or diffusion of old seawater from deep sediments since the distal part of the delta was deposited in marine environment. Calculations based on average seawater composition determined that discharge contained 2.61 mg/l sea salt or 0.01% fossil seawater. This low amount of seawater suggests that the transport through the sediments is slow or most of the seawater is already removed (Sundal 2006).

1.6.5 Groundwater background values

During the construction of Gardermoen airport, background values of groundwater at Gardermoen were measured (Table 1.2), parameters like calcium, iron, manganese and pH showed deviation from the indicative values (values that indicate anthropogenic effect on groundwater).

Table 1.2 – Groundwater quality at Gardermoen, background values, highlighted values are deviations from indicative values, source: Holm (2000).

Parameter	Reference values		Drinking Water Criteria	
	Median (mg/l)	Upper & Lower Quartile (25%-75%)	Indicative value (mg/l)	Max. value allowed (mg/l)
N03 (+NO2)	0.59	0.18 - 1.64	-	10
TOC	0.83	0.52 - 1.95	3	5
Fe	0.031	0.012 - 0.05	0.05	0.2
Mn	0.05	0.014 - 0.15	0.02	0.05
Na	3.2	2.5 - 4.4	20	150
K	1.3	1.0 - 1.8	10	12
Ca	27	19 - 35	15 - 25	-
Mg	2.6	1.9 - 3.3	-	20
Cl	3.2	2.1 - 4.4	25	-
S04	5.8	3.9 - 9.3	25	100
pH	7.3	6.7 - 7.7	7.5<pH<8.5	6.5<pH<8.6
Conductivity (mS/m)	182	140 – 260		

High background values of iron in the groundwater can be due to partial oxidation of pyrite or dissolution of iron containing minerals like amphibolite and pyroxenes. Pyrite and amphiboles are both part of the sediment composition of aquifer explaining high iron content than indicative values. Background calcium (Ca²⁺) values also appear higher than indicative values and are considered mainly because of carbonate weathering. Previous studies also described Gardermoen groundwater as Ca²⁺/HCO₃⁻ type. Values of pH are also deviated from indicative value, however, pH is related to calcite weathering i.e. high calcite weathering, high pH. Jørgensen et al. (1991) describes at Moreppen increasing pH and calcite weathering with increasing depth.

Risk of groundwater contamination depends upon the type of activities taking place above the surface. For example, agrochemical contamination can occur under agricultural land, hydrocarbon contamination can take place under a gas station, or petroleum storage, or in this case, deicing chemicals can threaten groundwater quality under an airport in a cold region. Deicer's contamination in low concentrations is difficult to detect in surface or groundwater because commonly used deicers are colorless and odorless (Table 2.1), therefore, require sophisticated chemical analysis. Moreover, groundwater have limited water volumes and do not

recharge as frequently as surface water sources, which makes it less likely to dilute the contaminant. Once a groundwater source is contaminated, it can take decades to recover depending upon the recharge and discharge volumes. Therefore, it is necessary to detect the source and magnitude of contamination in groundwater at the earliest for containment and mitigation. Gardermoen aquifer underneath Oslo Airport is currently not being used for drinking water purpose. However, government and environmental agency rightfully want to secure this valuable water source for future. Therefore, there are certain regulations on deicing chemicals discharge on the airport.

Using published literature and data provided by Avinor AS (OSL management), this study aims to analyze the situation of discharge permit regulations regarding water balance in the aquifer, contamination to groundwater, and restriction for long term concentration of deicing chemicals. On the basis of this analysis, the monitoring program will be evaluated on (1) strengths and weaknesses, (2) lacking or redundant chemical parameters in the program, (3) whether the frequency of monitoring parameters in groundwater is sufficient.

2 Discharge limits for Oslo Airport

The Gardermoen aquifer is the largest rain-fed unconfined aquifer in Norway due to which maintaining groundwater quality is of prime importance (French & van der Zee 2014; Wejden & Øvstedal 2006). Norwegian authorities strictly regulated the use of deicers at the Oslo Airport due to associated environmental risks. Under the Water Resource Act and Pollution Act, both Norwegian Environmental Directorate (Miljødirektoratet, 'MD') and Norwegian Water Resources and Energy Directorate (Norges vassdrag og energidirektorat 'NVE') have restricted Oslo Airport regarding the discharge of de-icing chemicals. Quality of groundwater and surface water in the area around the airport must be protected from the contaminated water from the airport.

Activities at the airport are regulated by law to not affect the erosion processes in the ravine landscape in the south-western parts. Contaminated water from the airport cannot influence kettle hole lakes and rivers in the area. The area between taxiways and runways cannot be covered by impervious membrane to prevent deicers infiltration because the official requirement is to maintain the aquifer water balance. Moreover, collecting all the runoff water with low deicer concentration will put unnecessary load on purification plant reducing its efficiency. NVE permitted the use and infiltration of deicers along runways on the condition that soil must have the capacity to degrade deicers and no traces of deicers are found in groundwater (Sjøiland 2011). However, temporary detections of 15 mg/l of PG in groundwater within airport area (Figure 2.1) are allowed (Wejden & Øvstedal 2006). Regulations from MD demand that the groundwater as a potential drinking water source must not be polluted. Oslo Airport can be fined for 2 million NOK if deicers are found in the groundwater (Sjøiland 2011).

2.1 Practices at OSL

At Oslo Airport, three de-icing platforms are used between October and April (Wejden & Øvstedal 2006) but mostly Alpha South and Bravo North are used depending upon the wind direction, indicated as AS and BN respectively in Figure 2.1. Alpha North (AN) and Bravo South (BS) are rarely used. De-icing chemicals are used over the airport in substantial amounts. Propylene glycol (PG) on the aircrafts and potassium formate (PFo) on the runways. These chemicals can be degraded in the unsaturated zone if spread out over a large area in low concentrations. Water containing high concentrations of Propylene glycol (PG) is collected and treated either (1) by infiltrating through soil with ideal hydraulic and biologic properties for degradation of dissolved chemicals or (2) by treating the wastewater at a municipal treatment plant (Sundal 2006). Around 80% of the de-icing chemical used on the aircrafts is collected and treated at OSL. Out of remaining 20%, 10% spreads diffusively next to runway during take-off and 10% leaves with the plain in the air (French & van der Zee 2014; Wejden & Øvstedal 2006).

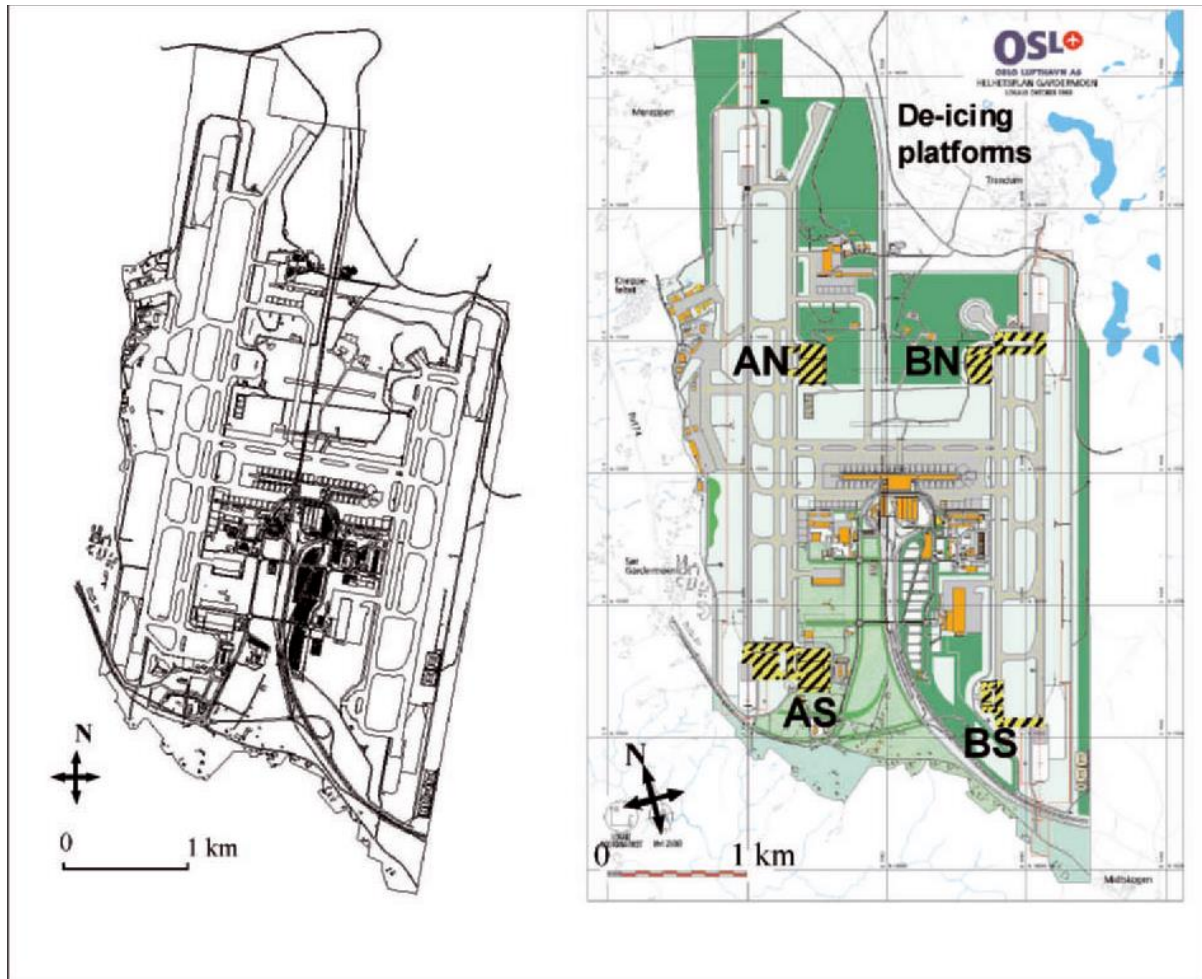


Figure 2.1 – Left: Regulated area of Oslo Airport (left), Right: de-icing platforms AS, AN, BN and BS, BS is rarely used (Wejden & Øvstedal 2006).

The spread of deicers is monitored by using snow boxes. Snow boxes are placed laterally from the runway at different distances. The boxes collect a mixture of snow thrown by jet blasts of airplanes, natural snow, and snow that is removed from the runway. The snow is melted and analysed for Propylene glycol (PG) and Potassium formate (PF) concentrations (Wejden & Øvstedal 2006). French et al. (2001) monitored the transport of de-icing chemicals in the unsaturated zone using field lysimeters. French et al. (2004) and French et al. (2002) used time-lapsed electrical resistivity measurements, which revealed a heterogeneous infiltration pattern because of ice on the ground surface. The studies indicated that if chemicals do not reach the groundwater during snowmelt, they can be completely degraded before reaching to the groundwater level. Oslo Airport routinely monitors the levels of these chemicals in groundwater around its vicinity. During winter (October to February), measurements from only selected wells are taken if snow melting take place or due to other reasons.

Oslo Airport uses the data from 70 monitoring wells to assess the potential occurrence of contaminant reaching the saturated zone. The program routines and implementation are described in internal document “Ytre Miljø – Kontroll- og Overvåkingsprogram for Grunnvann,

Vassdrag, Grytehullsjøer og Sidearealer” (appendices). According to OSL officials, the monitoring program documents are constantly evaluated and revised to meet conditions specified in the permits given by the government agencies. This program monitors inorganic compounds, along with PG, PFO, chemical oxygen demand (COD) and total organic carbon (TOC). If deicers are detected in the groundwater, the water is removed through extraction wells. Removed water is then either re-infiltrated with nutrients to accelerated biodegradation or sent to a treatment plant. The airport has its own requirement that in case of a spill, altered composition of inorganic compounds should be returned to background levels. The background levels of Manganese in Gardermoen aquifer were close to maximum concentration allowed in drinking water in Norway. Manganese (Mn) is also released during anaerobic degradation of deicing chemicals, hence, here the risk of increasing Mn concentration in groundwater was high. Therefore, a pump and treat program was used to reduce environmental effects. This program brought the TOC concentrations in groundwater to background level in March 1999. Manganese concentrations returned to background levels by May 2000 (Wejden & Øvstedal 2006).

2.2 Deicers and Environment

Common de-icing chemicals used on airplanes comprised of ethylene glycols, diethylene glycol or propylene glycol as primary component. Runway and pavement deicers consist on urea or organic salts (French et al. 2010). These chemicals spread with snow melt or runoff water around airports and roads to become potential pollutants. This threat to the environment has received increasing attention with time (Corsi et al. 2006b; French et al. 2001; French & van der Zee 2014; Hartwell et al. 1995; Mohiley et al. 2015; Switzenbaum et al. 2001; Toscano et al. 2014; Wejden & Øvstedal 2006).

Once deicers applied on the aircrafts and pavements, they start to affect the environment. Residual deicers in the soil can be consumed by plants with water, affecting plant-growth. Released chemicals can also join the streams through run-off and reach to lakes, or infiltrate into groundwater. In both cases, it alters the natural composition of water, which can lead to difficult living conditions for aquatic life, other animals and humans.

French and van der Zee (2014) illustrated the fate of contaminants in various zones of soil (Figure 2.2) through five processes.

1. The first process is how the contaminant is released in the environment. It can be a line source if surface drainage or collection of contaminants is absent around roads/runways or a point source due to leakage from a storage site or from a de-icing platform.
2. In the snow, preferential melt-out of chemicals and formation of internal structures take place.
3. At the snow-soil interface, infiltration of contaminated snowmelt into frozen, partially frozen or unfrozen soil takes place. If the soil was already frozen at the time of snowfall in the early winter, it may create an impermeable surface and restrict the infiltration affecting hydrogeological conditions, particularly boundary conditions for unsaturated flow.
4. Flow and transport in the unsaturated zone is affected by physical and biogeochemical heterogeneity of soil.
5. The contaminants if not yet stopped or degraded in overlying layers can join the groundwater.

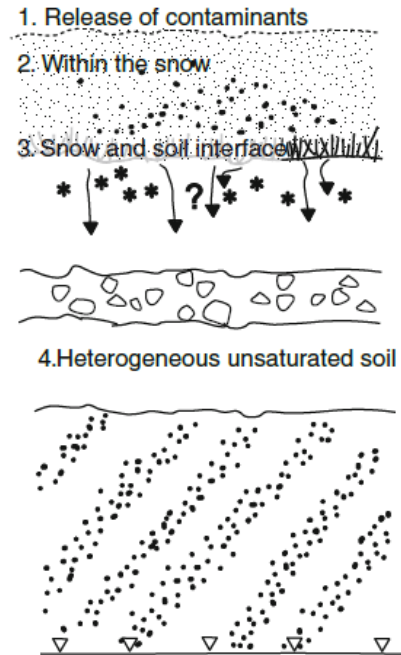


Figure 2.2 – Vertical profile of soil covered with snow prior to melting, representing the layers through which deicers will transport (French & van der Zee 2014).

After joining groundwater, high concentrations of Propylene Glycol (PG) and Potassium Formate (PFo) can create toxic conditions for aquatic organisms (Corsi et al. 2006b). Untreated dumping of deicers can damage ecosystems by creating anaerobic conditions (Hartwell et al. 1995). A study by Evans and David (1974) showed that PG can affect negatively on kidneys and nervous system of mammals. However, to enhance the effectivity of PG and PF for deicing their commercial compounds are used.

Commercial deicers contain additives to improve their effectiveness. Additives have certain properties like flame retardation, pH-adjusters, degreasers, emulsifiers, polishing and coloring agents, etc. Biodegradation of deicers is also slowed down due to the presence of additives in high concentration. These additives make deicers more toxic than the base compounds (Corsi et al. 2006b). Deicer additives are considered industrial secrets and manufacturers of deicers are not obliged to identify the environmental risk of these products. This makes it difficult for third parties to conduct a risk assessment of a chemical without properly knowing its composition. However, Oslo Airport has its own requirement to producers where additives must be identified with their toxicity to aquatic systems and associated environmental risks. Persistent de-icing additives such as sodium petroleum sulfonates and triazoles are not used at Oslo Airport (Søiland 2011).

Non-persistent deicers when adsorbed on soil particles can alter the chemical and physical properties of soil, changing the habitat conditions for living organisms. In high concentrations, deicers can degrade soil by creating an impermeable layer, reducing infiltration of water and increasing salinity (Switzenbaum et al. 2001). Deicers can mix with surface, groundwater, and change water density by chemical loading and consuming the dissolved oxygen. Contamination of pavement deicers (NaCl in most cases) in groundwater can increase sodium (Na⁺) and chloride (Cl⁻) ions, which can inflict damage on plants and animals. Drinking such water can also cause hypertension and other diseases in humans (Dunn & Schenk 1980; Fay & Shi 2012). De-icing chemicals are considered potential pollutants in the groundwater below Oslo Airport (French et al. 2001). Slower degradation rate and adverse effects on mammals make PG a higher environmental concern than PFO (section 2.3.2).

2.3 Degradation of common deicers

Major degradation of deicers takes place by microbial activity. Microbes responsible for biodegradation of deicers are much abundant in the upper part of the soil profile i.e. 10 million microbes per gram of soil in top 10 cm compared to 1 thousand per gram at 1.4 m depth (Starck 1942; as in French et al. 2001). These organisms need organic carbon for their survival, meaning the higher the organic material, the higher the microbial activity. Similarly, microorganisms are more effective at warmer temperatures than sub-zero temperature. However, deicers at the airport are used during winters and infiltrate the ground surface during ice-melting episodes when soil temperature is low and microbial activity is very limited (French et al. 2001). This allows the deeper infiltration of contaminants where microbial activity is limited even in warm temperatures, making complete biodegradation of deicers less likely. Modelling and field experiments at OSL by French et al. (2001, 2002) have shown that there is a fast vertical flow during 3 – 5 weeks of snowmelt, after this, the water in the unsaturated zone becomes stagnant during summer season because of high evapotranspiration. In summer, warmer temperature accelerates the degradation capacity of the soil. However, degradation capacity is limited by nutrient availability, degradation rates, and redox levels. This makes the natural filter system vulnerable to the total amount of deicers added to the surface and the total amount of infiltrating water (French et al. 2010).

Two factors determine the risk of contamination of the groundwater at the airport: residence time of contaminant in the unsaturated zone and rate of degradation (French et al. 2001). Contaminant's residence time depends upon the thickness of unsaturated zone, availability of infiltrating water from the surface and vertical hydraulic conductivity of the soil. Longer residence time in unsaturated zone increases the time for biodegradation of contaminants and lowers the risk of groundwater contamination. If the unsaturated zone is not thick enough to provide sufficient residence time for biodegradation of contaminants, then the risk of groundwater contamination is high. Risk of leached pollution is reduced if the meltwater does not reach to the water table before summer. Normally, annual summer precipitation and evapotranspiration are equal which can increase the residence time in the unsaturated zone at least one month. In summer, higher soil temperatures increase microbial activity resulting in higher biodegradation rates (French et al. 2001).

Generally, deicing chemicals are based either on propylene glycol or ethylene glycol (Mohiley et al. 2015), at Oslo Airport propylene glycol is used. Deicers are a mixture of at least 50% glycol and additives like corrosion inhibitors, thickening and wetting agents, and surfactants in different proportions. Glycol degradation consumes high oxygen. Toxicity of glycol-based compounds to aquatic flora and fauna is observed to be significantly higher than the toxicity of glycol alone (Mohiley et al. 2015).

Table 2.1 – Commonly used deicers at Oslo Airport (Aherns 2008).

Chemicals	Physical properties	Uses
Propylene Glycol (Kilfrost)	Viscous, Colorless, odourless liquid	Aircraft de-icing fluid, desiccant in foods, the solvent in medicine and cosmetics, in vapour form as air sterilizer for hospital and public buildings.
Potassium formate (Aviform L50)	Colorless, crystal, deliquescent	Pavement de-icing, runway de-icing
Potassium acetate (Clearway 1)	Clear odourless solution	De-icing, very low BOD (decomposing in environment quickly)

2.3.1 Pavement deicers

Generally, Potassium Acetate (KAc) and Potassium formate (PFo) based chemicals are used for pavement deicing. Currently, potassium formate based commercial deicer 'Aviform' is used at Oslo Airport. Before 2001, potassium acetate was used under the chemical name 'Clearway' when Oslo Airport was opened in 1998. After 2001, acetate was replaced by PFo, which is considered more environmental friendly due to lower biological oxygen demand than acetate, degradability at lower temperature, less leaching of trace metals from roadside and low taste level in groundwater than acetate and sodium chloride (Hellstén et al. 2005). After replacing KAc to PFo, Oslo Airport was given an expansion in discharge permit. However, it was later found out that both chemicals consume a similar amount of dissolved oxygen during degradation and have many similar chemical and physical properties (French, H. K. et al. 2000, as in ; Sjøiland 2011).

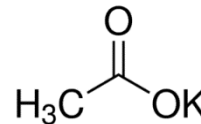


Figure 2.3 - Molecular of Potassium Acetate (moleculardimensions.com)

Potassium Formate (PFo) is used with warmed sand to prevent and clear pavement and runways from ice (Wejden & Øvstedal 2006). This chemical compound is based on Potassium acetate as the major component and its commercial form 'Aviform' is used at Oslo Airport. Potassium formate (PFo) has low toxicity and can easily degrade under aerobic conditions. Among other deicing chemicals like calcium chloride, magnesium chloride, sodium chloride, potassium acetate and

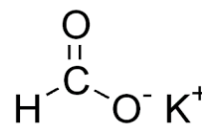


Figure 2.5 – Molecular structure of Potassium Formate (moleculardimensions.com)

calcium magnesium chloride, potassium formate is found to be the least harmful regarding groundwater quality (Hellstén et al. 2005). Both, PFO and PG are water soluble, but PFO adsorbs to soil more than PG because of its ionic nature. It dissolves in water to produce potassium and formate ions (Eq.2.1) which can take part in ion-exchange process of soil (Søiland 2011).



During the ion-exchange process, potassium (K^+) is expected to adsorb on negatively charged soil particles more than formate ($CHOO^-$), resulting in altered groundwater chemistry. However, at Oslo Airport, the background concentration of potassium is much lower (1 – 1.8 mg/l) than the recommended level (10 mg/l) in drinking water (Table 1.2). Therefore, it is thought that adsorption of K^+ by infiltration of PFO will not affect groundwater quality due to the significant difference between background and recommended values (French, H. K. et al. 2000; as cited in Søiland 2011). Formate degradation can occur at low temperature (-2°C) and requires 0.35 mg/l of oxygen for complete degradation of 1 ml/l concentration. Its low oxygen demand and degradability at low temperature makes it environment friendly deicer for runways and pavements. Formate when come in contact with water, forms formic acid (Eq. 2.2) which degrades in aerobic conditions (Eq. 2.3) to form carbon dioxide and water (Søiland 2011).



Fast degradation of PFO in unsaturated zone during snow melting periods consume oxygen potentially causing the development of anaerobic zone which in turn can slow down the degradation rate of PG. Besides oxygen consumption, commercial additives present in PG and PFO can exert adverse effects on microorganisms contributing to even slower degradation rate (Lissner et al. 2015).

2.3.2 Propylene Glycol (PG)

Propylene Glycol is used to prevent the formation of ice layers on the aircraft surface which can hinder the normal operation of mechanical parts. It is miscible in water with a boiling point of 187°C and freezing point of -60°C at 1 atm pressure (Bausmith & Neufeld 1999). At Oslo Airport, its commercial variety 'Kilfrost' is used. French et al. (2001) field experiments showed that PG does not adsorb to soil grains (no retardation) which means that theoretically, its transportation velocity is same as water front (Appelo & Postma 2004).

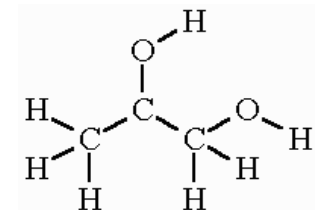
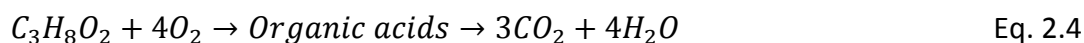


Figure 2.7 – Molecular structure of Propylene Glycol (moleculardimensions.com)

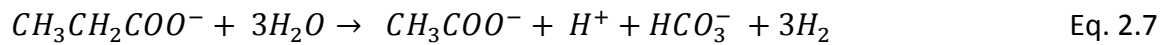
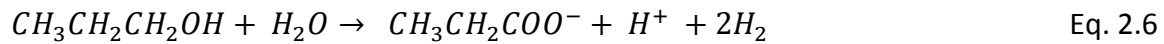
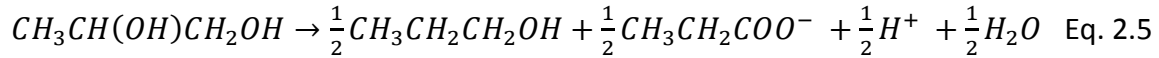
Biodegradation of PG is quite oxygen demanding, therefore, it consumes oxygen in unsaturated zone faster than the gas exchange from the surface which can create the anaerobic condition. Degradation of PG is faster in aerobic conditions than in anaerobic conditions, hence, existing anaerobic conditions can cause reduction of iron and manganese (Fernandez et al. 2014). However, PG is completely degradable under aerobic conditions through organic acids like lactic and pyruvic acid. These acids are also degraded in aerobic conditions (Søiland 2011)



Complete degradation of PG (1ml/l) requires 1.68 mg/l of oxygen. Degradation of PG depends upon the availability of electron acceptors such as oxygen, nitrate, manganese, iron (Schotanus et al. 2014). During heavy contamination episodes (by snowmelt or precipitation) oxygen in unsaturated zone may deplete leaving microbes to use other electron acceptors in order to biodegrade contaminants. This may decrease manganese and iron in the soil and eventually reduce the degradation potential. To avoid this scenario and enhance the biodegradation, nitrate is applied which can be used as electron acceptor (Schotanus et al. 2014; Toscano et al. 2014). High concentrations of iron are found in the groundwater at Oslo Airport suggesting that degradation of deicers might have caused anaerobic conditions in the groundwater (Søiland 2011).

Degradation of PG under anaerobic conditions can form intermediate products like propanol, acetate, mercaptane, and methane. Mercaptane is a toxic gas (smells like rotten onions), hence, an environmental concern (Søiland 2011). In the absence of oxygen and other electron acceptors, microbes may use carbon dioxide in a methanogenic process and release methane, a highly flammable gas (Wejden & Øvstedal 2006). Such a process can endanger hundreds of lives if occur under an airport.

In anaerobic conditions, PG initially breaks into equimolar amount of propionate and 1-propanol (Eq. 2.5), latter is converted to propionate as well (Eq. 2.6). Propionate further degrades into acetate (Eq. 2.7), methane (Eq. 2.8) and carbon dioxide (Jaesche et al. 2006).



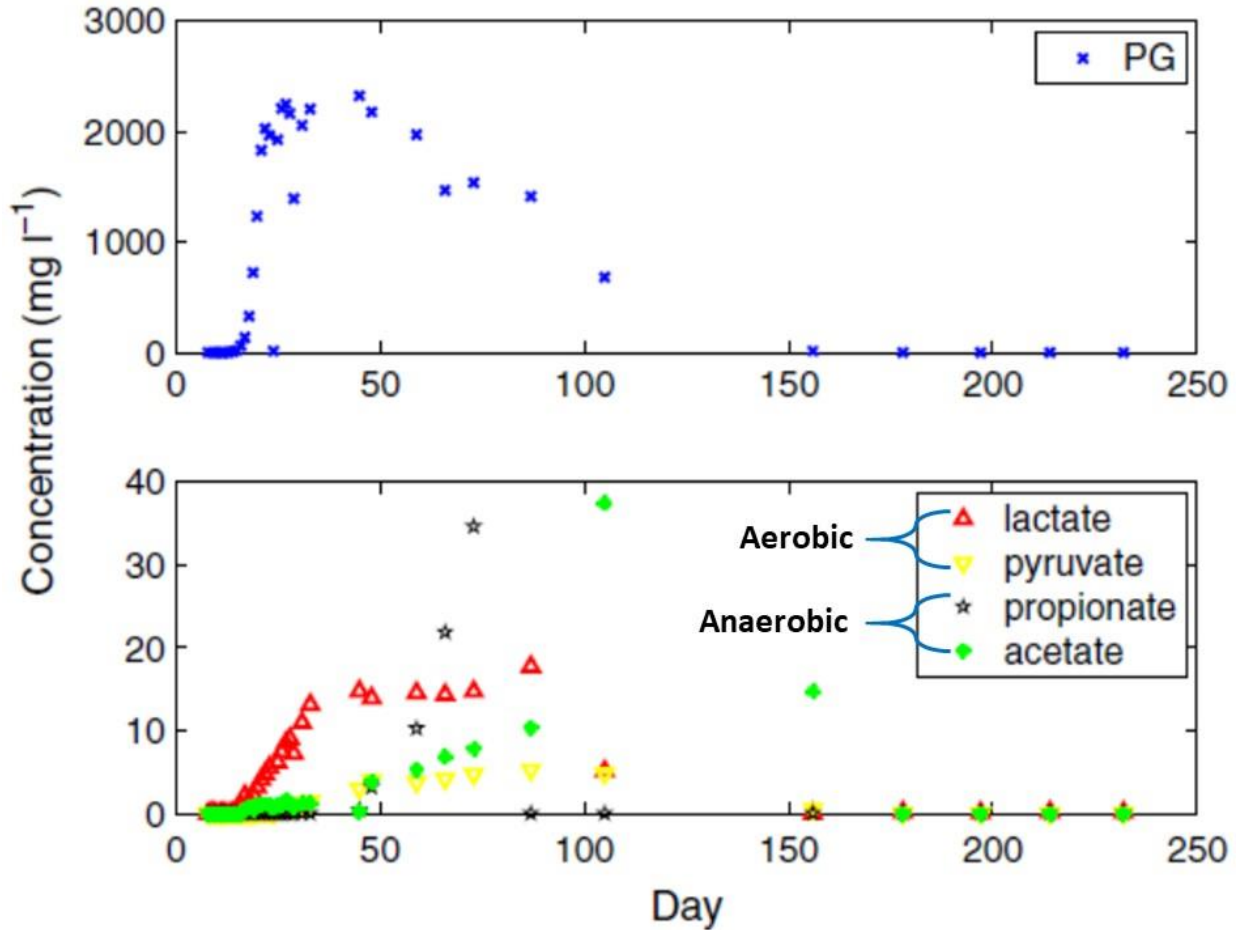


Figure 2.8 – Degradation products of PG. Lactate and pyruvate are produced in aerobic conditions while propionate and acetate are formed in anaerobic conditions (modified after Schotanus et al. 2014).

The half-life (time taken to degrade half of the original concentration) of PFO and PG is 2.6 to 61 days and 2.6 to 54 days, respectively. This variation in half-life is due to the temperature and availability of nutrients. However, after 128 days, concentrations of PFO and PG are found to be 0.04 and 8%, respectively. Slower degradation, higher chemical oxygen demand (COD) (Søiland 2011) and adverse effects on mammals (Corsi et al. 2006a) make PG a higher environmental concern than PFO.

3 Materials and Method

Avinor AS provided monitoring well data of 67 wells, comprising of the concentrations of various parameters including, fluid elevation in the well, heavy metals, organic/inorganic components, deicers, etc., since the airport begun operations in 1998 to 2017. Provided data was in the form of Microsoft Excel workbooks. Weather data such as temperature and snow depth were obtained from www.eklima.no. The data was then analyzed to map areas highly affected by deicing chemicals using statistical and geostatistical computer programs including Microsoft Excel and QGIS.

Strengths and weaknesses of the monitoring program are analyzed based on amount and frequency of data collected regarding aquifer water balance, groundwater quality and risks associated to high concentration of deicers. To check water balance, average of fluid elevations measured in the well were interpolated by inverse distance method and water table map was generated. Difference of fluid elevations of oldest and latest value from each well was interpolated by the same method to create a surface indicating change in fluid elevation levels.

Groundwater chemistry was analyzed by plotting important chemical parameters like calcium, potassium, magnesium chlorite and sulfate values measured in background, after the opening of airport, most recent measurements and drinking water criteria in a piper plot. This indicated the natural chemistry of water and changes with time due to operation of OSL, and comparing it with drinking water criteria provided extent of possible contamination. Concentrations deicing chemicals were plotted in a time series to expose long-duration high concentrations. Identified high concentration measurements were further studied to understand their distribution in time and space.

3.1 Data handling and organization

Data organization was a challenge because excel workbooks contained more than 530 thousand cells of relevant data which included well name, date of measurement, chemical parameter, concentration, measured unit, detection limit, and remarks. All these cells were distributed in more than 60 excel spread sheets in a format incompatible to most of the modern statistical programs. It is to be admitted that organizing this data would have been easier for a person familiar with programming skills, however, this was not the case. Therefore, it took significantly long time to organize presentable data charts.

Another issue was that different chemical parameters were measured on different dates for different wells. Depending upon the risk of high concentration, certain chemical parameters were more frequently measured in some wells, and less frequently measured in other wells. For example, Oxygen concentrations were not measured before 2001 but acetate and other parameters were measured, making it difficult to correlate aerobic and anaerobic conditions prior and post replacement of acetate with formate. Most likely this was to run the monitoring program efficiently and economically. However, generating a continuous picture from the data would have been easier if the measurement interval in all the wells was uniform.

In beginning of this study, simple-kriging interpolation was applied on the concentration of PG and PFO using SGeMS software. The basic requirements of kriging were not met because the data was not normally distributed resulting in unrealistic sill, range and nugget values for semi-variogram. In the absence of a quality semi-variogram, kriging cannot provide reasonable results. Therefore, other interpolation methods namely, nearest neighbor and triangulation were used.

3.2 Groundwater characterization

Data was classified to indicate situation of water quality, water balance in the aquifer, and concentration of deicers in the groundwater. Water quality was characterized based on chemistry of background values, average water chemistry in year 2000 and latest water chemistry (year 2017). As bicarbonate (HCO_3^-) values were not available in data, they were calculated through charge balance method. Concentration of cations and anions were converted from mg/l to meq/l, sum of anions and sum of cations were compared, and missing anions were compensated for bicarbonate. These values were plotted on the piper diagram along with drinking water standard values to compare the water quality. Total 67 wells were divided in two groups, one with data available since 1990 (background data set) and other drilled after the construction of airport and contain data series since 1998 (Monitoring well data set). The former group comprised 10 wells located on outskirts of the OSL boundary and remaining 57 were within the OSL boundary and has data available from 1998 (Figure 3.1). Comparing both data sets revealed the extent of changes within and outside OSL boundaries.

3.3 Spatial and temporal analysis

Changes in precipitation and land use can disturb recharge of aquifer resulting in altered water table. Therefore, fluid elevation values from each well were used to generate water table interpolation maps to observe any changes in water balance of the aquifer. Difference of fluid elevation levels from 1998 and 2017 were compared to see water table changes since the opening of airport.

Location of monitoring wells and deicing platforms is presented in Figure 3.1. Snow mechanically removed from the runways is left along the outer edges of the runways (blue arrows in Figure 3.1), this snow may contain the deicing chemical PG dropped from the airplanes while taking off as well as PFO used to prevent ice layer formation on the runway. In this area, PG and PFO can potentially infiltrate to the subsurface along with water from the snow melt. Concentrations of deicers were plotted along the measurement dates and on the map as well using MS Excel and QGIS programs, to delineate temporal and spatial distribution of high concentration. Concentration along measurement dates provided the duration of high concentration pulse. Plotting the accumulative and maximum concentrations on the map indicated the loading of deicer on a particular location.

3.4 Calculation of retention time

One instance of high PG concentration in a well was used to estimate a realistic retention time based on real concentration an observation well downstream from the runway. A well with several measurement points was selected after an initial screening of all the wells. Retention time was calculated by using Darcy's Law:

$$q = iK \quad \text{Eq.3.1}$$

Where, q = Darcy flow, i = hydraulic gradient and K = hydraulic conductivity.

$$v = \frac{q}{n_e} \quad \text{Eq.3.2}$$

Where, v = velocity, q = Darcy flow and n_e = effective porosity

$$v = \frac{x}{t} \quad \text{Eq.3.3}$$

Where, v = velocity, x = distance and t = time. The results from this calculation can be used to explain the situation of PG concentration on other sites at Gardermoen.

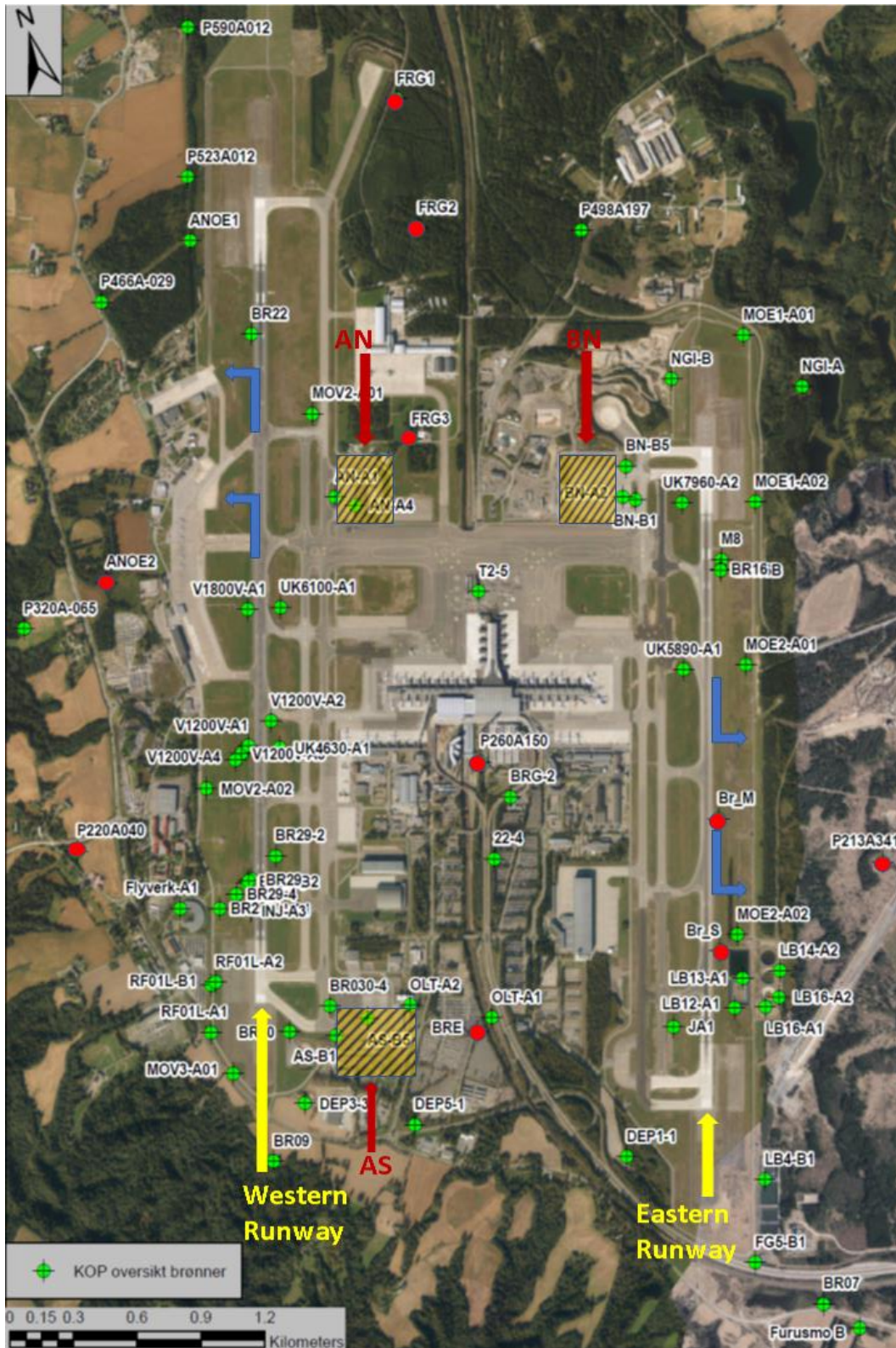


Figure 3.1 – Overview of the Airport with well names, locations and deicing platforms. Blue arrows indicate the direction in which snow is removed from the runways, green dots are monitoring wells and red-dots are wells called background data set in this thesis.

4 Results and discussion

In this chapter, results from the available data will be analysed to assess the compatibility of monitoring program with discharge permit regulations. Monitoring program will be assessed for three major regulations:

1. Water balance of the underlying aquifer should not be altered.
2. Preventing groundwater pollution.
3. Long-term high concentrations of de-icing chemicals must be avoided.

4.1 Water Balance

Main recharge of the aquifer takes place during snow melting period. Evapotranspiration during long days of summer causes fluctuation in water table. If vertical differences in total head are ignored, the water table gives the elevation of the saturated part of the aquifer system. The water table can be used to delineate groundwater flow lines. Groundwater always flows from a point of high to lower total head. Construction of impervious layers like asphalt runways over airport can change in infiltration pattern and disturb the water balance in the aquifer resulting in altered water table.

One of the official regulations applied for Oslo airport operation is to maintain the water balance of the aquifer. To analyze the water balance situation, average water table depth from available data of all wells on the airport is interpolated by inverse distance nearest neighbor method, using SAGA module in QGIS software (Figure 4.1: Left). The lowest average water table is recorded in northeastern part of the airport. Around 80% outflow of aquifer takes place in northeastern direction and provides water to lake Hersjøen and river Risa (section 1.3). Southwestern part of the aquifer accounts for remaining 20% outflow to the ravines. Therefore, relatively low average water table values interpolated in northeast are consistent with literature. To see the changes in water table since 1998, when the airport began operation, a difference of water table values between 2017 and 1998 is presented (Figure 4.1: Right). Negative values indicate drop in water table while positive indicates rise in water table. The largest drop in water table is under 5 meters in only two wells, JA1 and P260A150. Close to these wells, train tunnels are passing under the airport and a pumping system is in place to keep the water table below the tunnels without disturbing the aquifer water balance which may cause this deviation in water table. Remaining wells indicate changes within 2-meter which is more or less equivalent to seasonal variation of water table.

This analysis suggests that since the beginning of airport, water balance in aquifer has not changed to a limit that can affect water table, fulfilling one requirement of the discharge permit (section 2). Continuous documentation of fluid depth and fluid elevation is a strength of the monitoring program regarding aquifer water balance. However adding one or two more wells in the southeastern part of the airport can provide better data for water table.

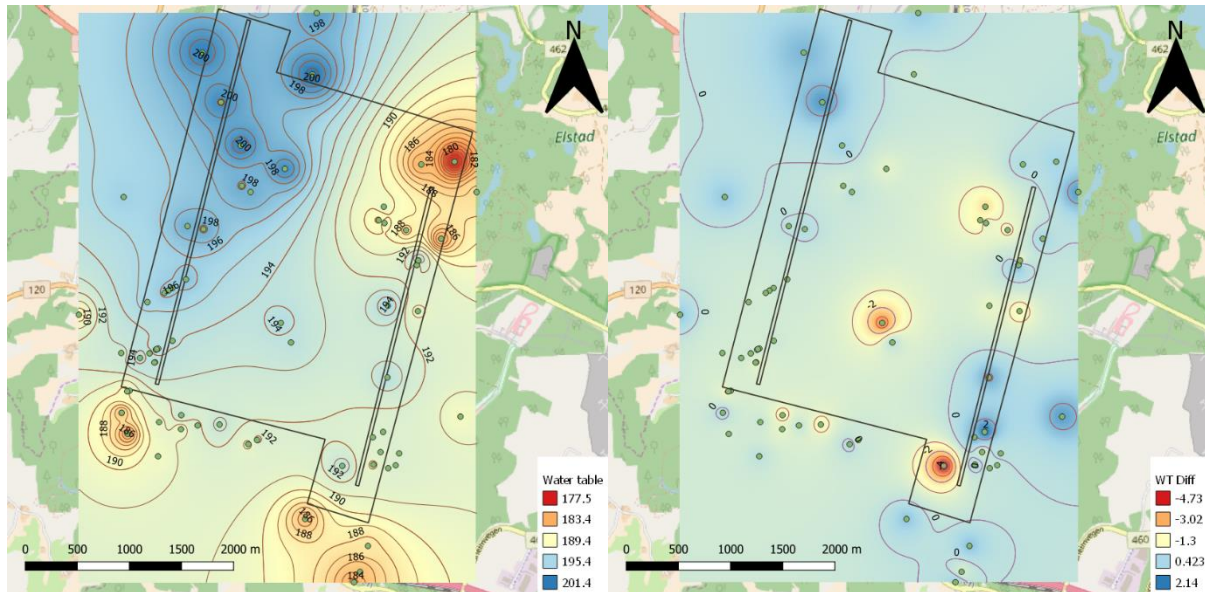


Figure 4.1 – Left: Average groundwater table; Right: Difference between water table values from 2017 and 1998.

4.2 Groundwater characterization

In discharge permit to Oslo airport management, Miljødirektoratet (MD) demands that groundwater as a potential drinking water source must not be polluted. Therefore, background, past, and present chemistry of groundwater was compared with drinking water standard values (Table 4.1). Bulk chemical composition of water with background values, maximum allowed drinking water standard values, average values of chemical parameters measured in 2000 (past average), and average chemical composition of 2017 (present average) from all available wells were plotted in the Piper diagram (Figure 4.2).

In lower left and upper part of the Piper plot, background, past average and present average measurements indicate calcium levels higher than recommended values. In the lower right part of the figure, groundwater is closest to drinking water standards and does not show variation from the background values. The symbols position in lower right and left triangle indicate groundwater chemistry dominated by calcium and bicarbonate similar to previous studies by Sundal (2006) and Jørgensen et al. (1991). Piper plot indicates that past average and present average values have not changed significantly from background values. This shows that groundwater chemistry is not affected to a considerable level as restricted by the discharge permit. However, water quality at a particular time in a well can vary due to the risk of deicers contamination.

Table 4.1 – Water chemistry Background reference, drinking water criteria, calculated average from all available wells since 1998, and average of all available wells in September 2017.

Parameter	Background Reference values	Human influence	Drinking water standard	Average since 1998	Recent September 2017
	Median (mg/l)	Indicative value (mg/l)	Max. value allowed (mg/l)	(mg/l)	(mg/l)
N03 (+NO2)	0.59	0	10	1.28	0.86
TOC	0.83	3	5	7.73	2.41
Fe	0.031	0.05	0.2	2.04	2.01
Mn	0.05	0.02	0.05	1.25	0.68
Na	3.2	20	150	6	13.20
K	1.3	10	12	12	19.25
Ca	27	15 - 25	-	57	58.69
Mg	2.6	-	20	5	5.54
Cl	3.2	25	-	5	10.60
S04	5.8	25	100	17	9.84
PH	7.3	7.5<pH<8.5	6.5<pH<8.6		
Conductivity (uS/cm)	182				

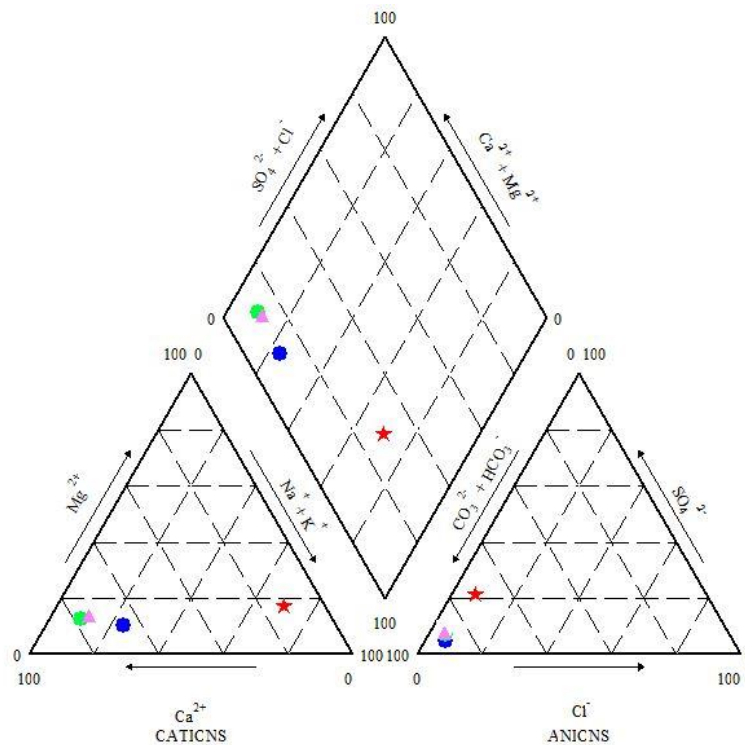


Figure 4.2 – Piper diagram indicating drinking water standards (red star), background values (green circle), past average (from year 2000, pink triangle) and present average (year 2017) (blue circle).

Two sets of wells i.e. wells with data set since 1990, consisting of 10 wells located at the outskirts of OSL (background data set) and the monitoring wells in OSL boundaries, with data after 1998 (monitoring wells data set) shows variation in some chemical parameters. At Gardermoen, high concentration of potassium was not expected. In the beginning of the airport when potassium acetate was being replaced by potassium formate, it was thought that potassium ion does not pose threat to groundwater because it adsorbs on the soil surface, and groundwater potassium content was 1.3 mg/l, already 8.7 mg/l less than indicative value (Table 4.1). However, potassium concentration is increasing gradually since 1998 (Figure 4.3). The background data set (Figure 4.3) does not show any increase in potassium concentration validating that it is taking place within OSL boundaries. Since potassium formate is continuously used in large quantities inside OSL boundaries, it is the only cause of increasing K^+ concentration.

Iron (Fe), calcium (Ca) and sulfates (SO_4) are also showing the similar trend. The pattern of Fe concentration is similar in background and monitoring well data sets but concentration levels are much higher. Biodegradation of deicing chemicals under limited or no oxygen can increase Fe and manganese (Mn) ions in groundwater. Mn levels are also higher in monitoring well data set than in background dataset (Figure 4.3). Deicing chemicals, PG, PFO and acetate are low in background data set as expected, indicating very limited or no contaminant transport to outer areas from OSL. Zinc (Zn), copper (Cu), magnesium (Mg) and lead (Pb) levels remained same or showed in both data sets while chloride concentration were higher in background dataset (Figure 4.4) than in monitoring data set. The shape of sodium concentration is remarkably similar to chloride concentration plot in background data set. Most likely because road salt is used as a deicer outside the OSL. Therefore, in monitoring dataset, both sodium and chloride concentration are much lower than in background data set (Figure 4.4).

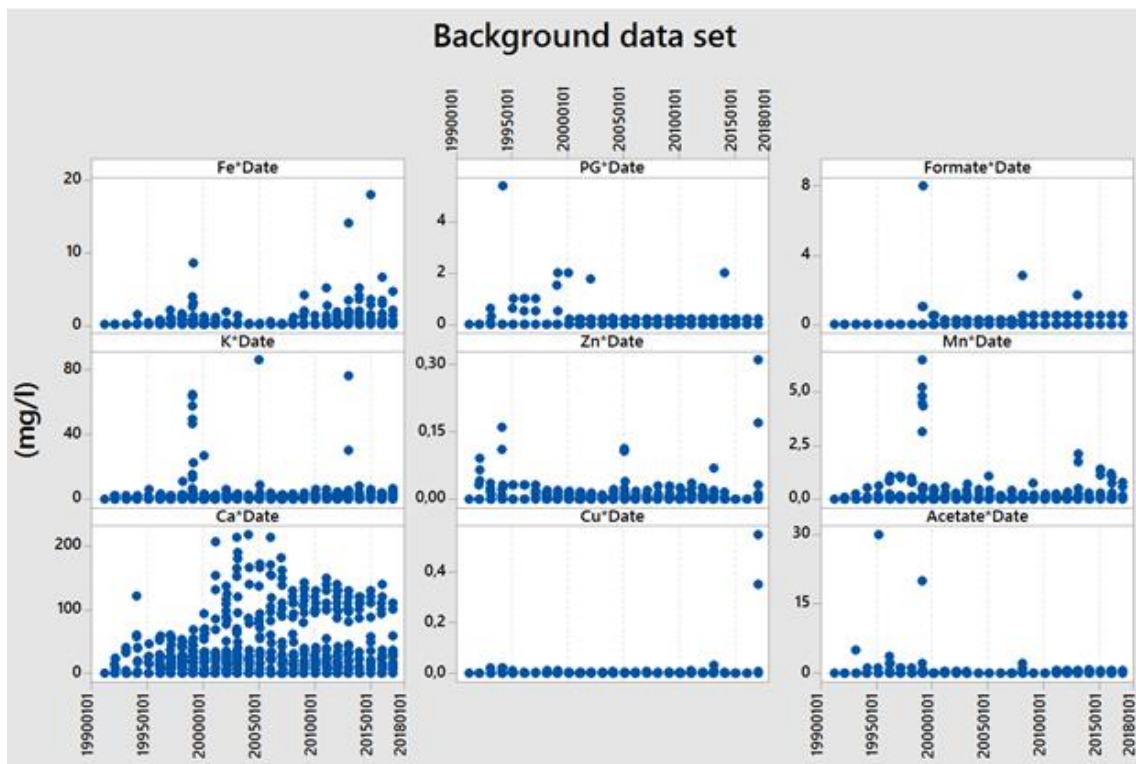
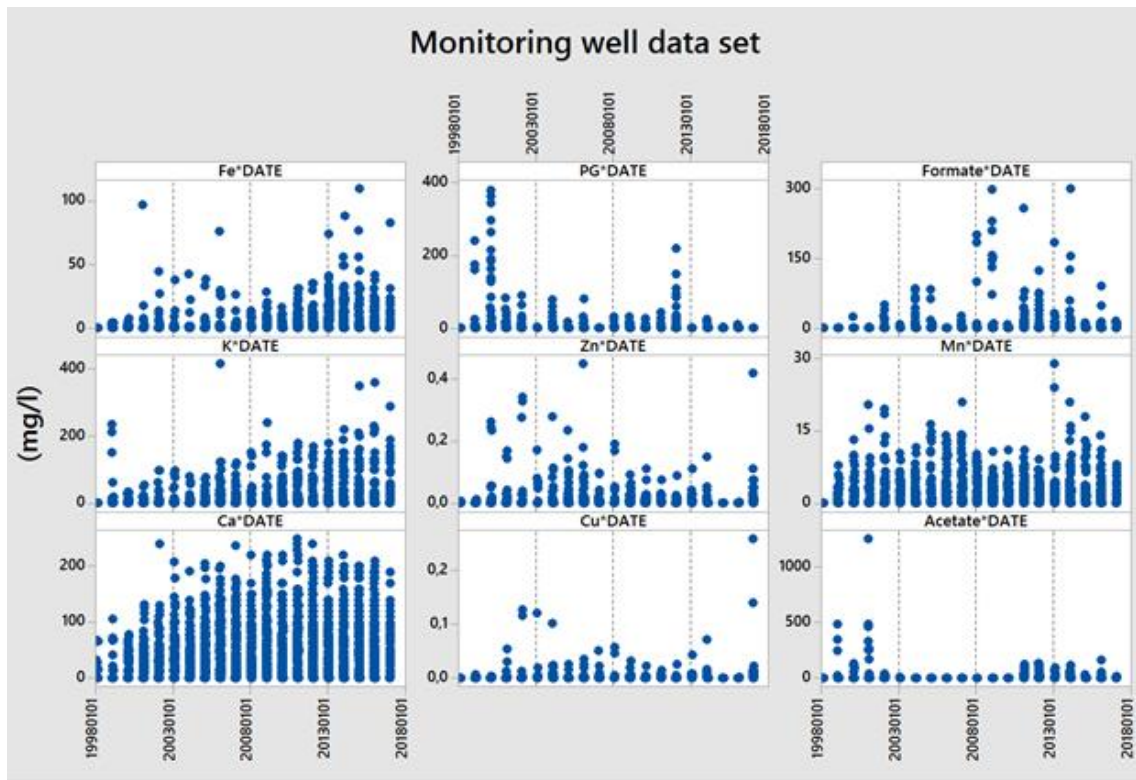


Figure 4.3 – Concentration of various chemical parameters in two wells data sets. Monitoring well show high values than background data set in most parameters.

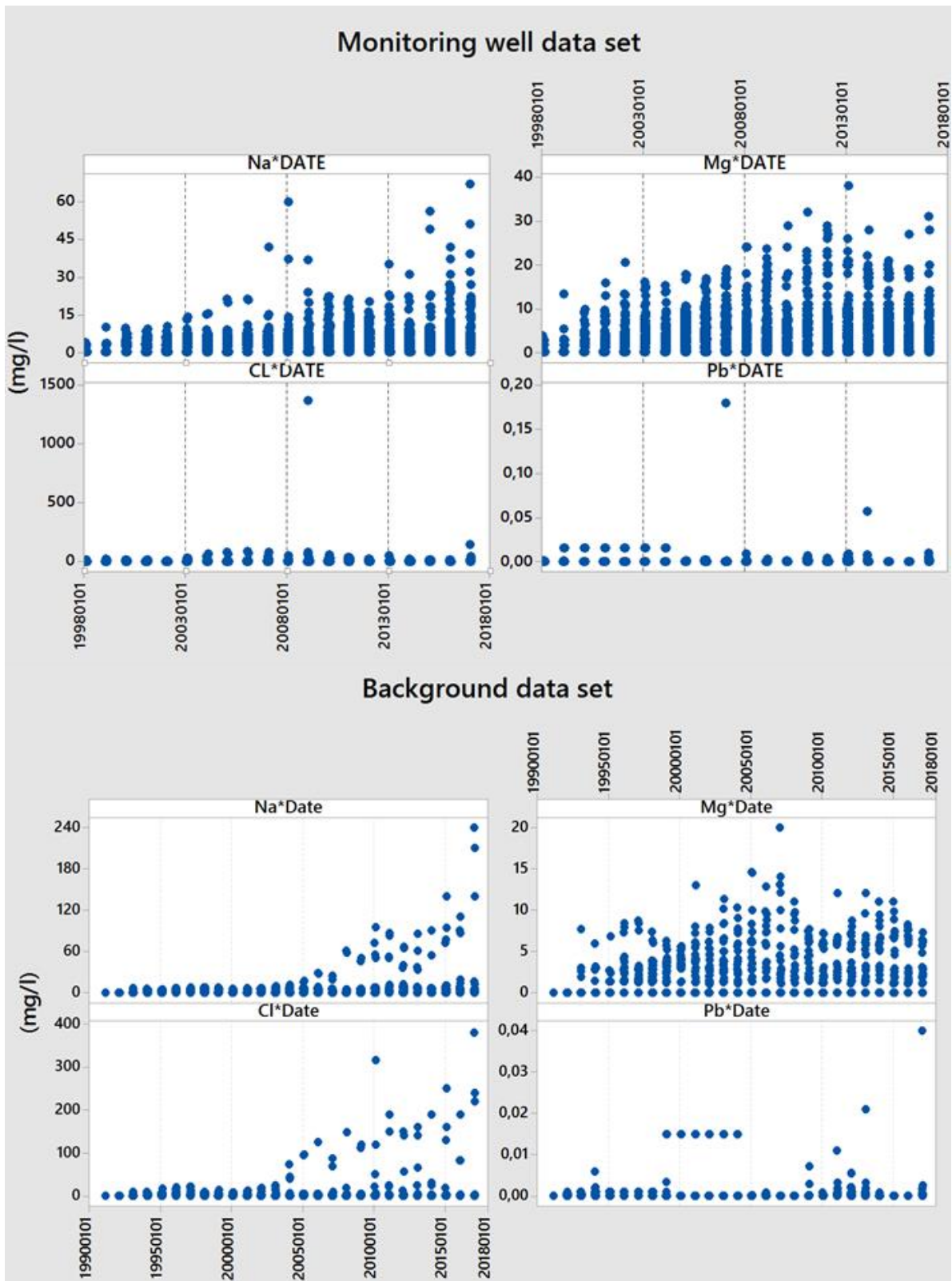


Figure 4.4 – Concentrations of groundwater chemical parameters from the wells since the beginning of airport.

4.3 Deicer use with temperature

To deal with date and measurement issues, most of the data was organized on a monthly and annual basis. Monthly mean temperature was plotted against monthly mean snow depth to observe any trends. However, snow depth measurements were not available from Gardermoen weather station after 2009 therefore, snow depth measurements were used from Ukkestad weather station located within 3-km south of Gardermoen. Until 2009, snow depth measurements from both Gardermoen and Ukkestad appear similar with around 80% correlation (Figure 4.5). High snow depth values coincide with Low mean temperature values of corresponding months, possibly due to the reason that low temperatures favored snow accumulation (Figure 4.6).

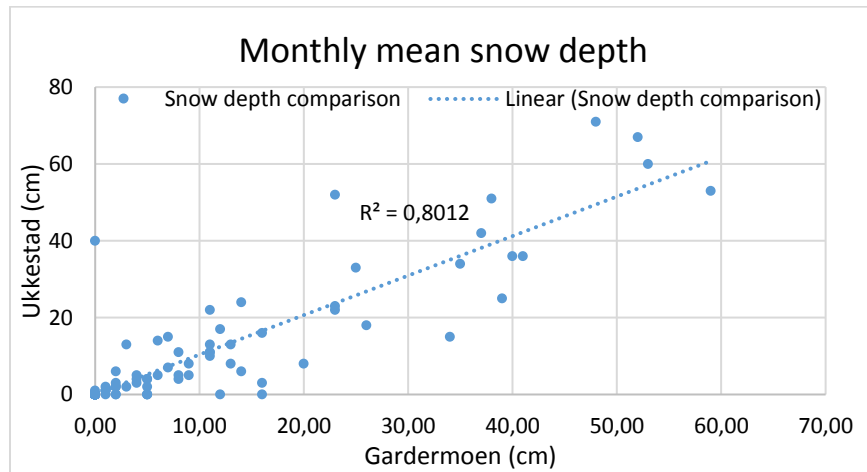


Figure 4.5 – Scatterplot of monthly mean snow depth values from Gardermoen and Ukkestad weather stations. Correlation is around 80%.

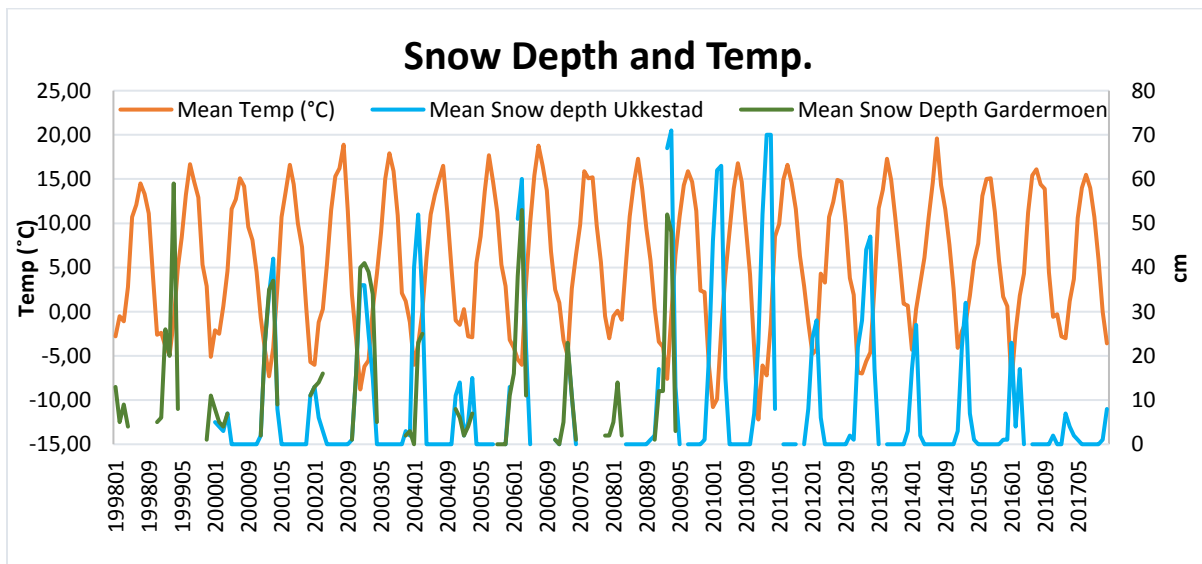


Figure 4.6 – Snow depth and mean temperature at Gardermoen airport (source: www.eklima.no).

At Gardermoen, normally snow accumulation continues from October to February-March. High amount of snow, heavily loaded with deicing chemicals can infiltrate to groundwater during snow melting months (Figure 4.7), similar situations are observed in coming sections.

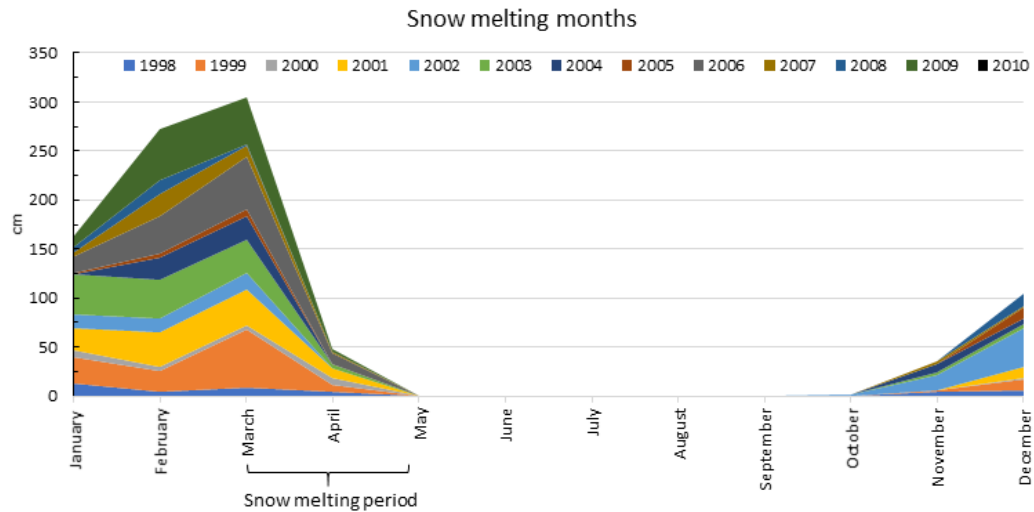


Figure 4.7 – Snow accumulating and snow melting months.

4.4 Acetate

At OSL, Potassium Acetate was used as a deicer on paved surfaces until 2001, afterwards it was replaced by Potassium Formate (PFO) because of its environmental benefits (section 2.3.1). Highest acetate concentrations were found in two wells close to deicing platform Bravo Nord (BN) (Figure 4.10: Left). In M8, concentration curve begins in February 1999 with 490 mg/l which depletes in March 1999, lasting for only 20 days (Figure 4.13). Acetate concentration in well BN-B1 increased gradually from September 1999, but after September 2000, it increased steadily and reached 1260 mg/l in January 2001. This stable and steady increase for more than 4 months in concentration, points towards a continuous source of acetate. Officials from OSL verified that in the beginning of airport deicer consumption was high and deicing platform did not have elevated shoulders to prevent runoff to the side areas. After January 2001, reduction began, and concentration returned to normal detection levels in July 2001 taking 120 days in the process (Figure 4.13). After this period, wells BN-B1 and M8 have not shown any significant increase in acetate concentration until present.

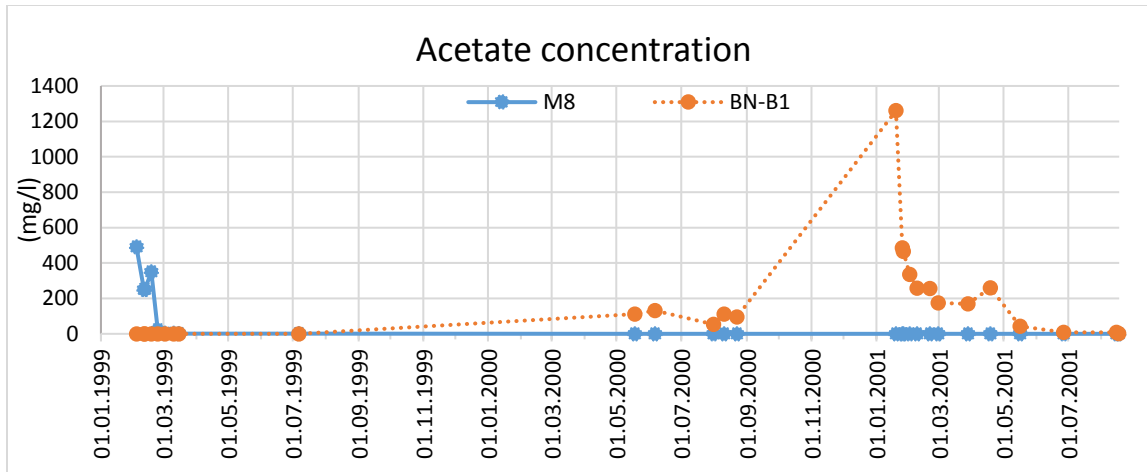


Figure 4.8 – Acetate concentration level at wells BN-B1 and M8.

Possibility of contaminant plume transport between both well was considered but dismissed on two reasons. First, earlier concentration in M8 was much lower than measured in BN-B1, which is opposite to normal trend, where plume concentration decreases with time due to dilution and degradation processes. Second, the hydraulic conductivity at M8 is much slow for this short period transport (Figure 4.9). Other wells on western runway also indicate acetate concentrations higher than 100 mg/l in year 2012 and 2016. The accumulated acetate measurements since the opening of airport is also highest in wells BN-B1, M8, BR29, BR29-B2, and BR29-3 indicating a risk of acetate contamination (Figure 4.10: Right).

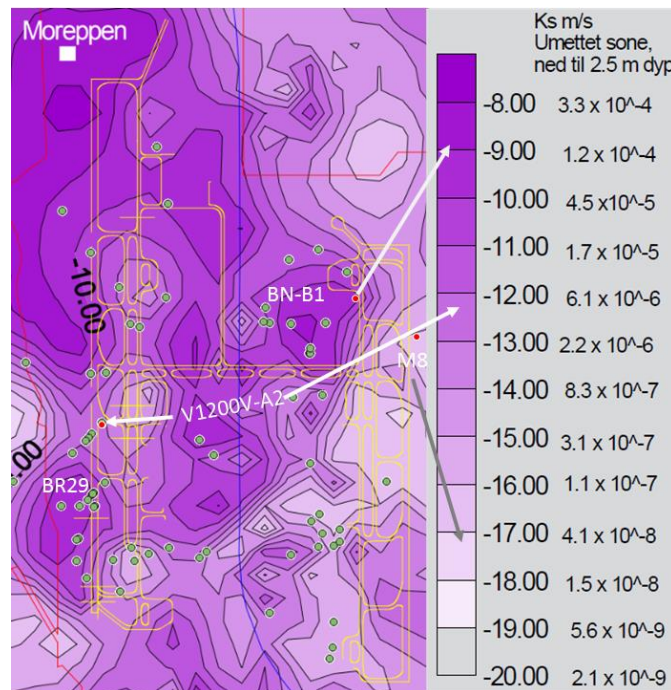


Figure 4.9 – Hydraulic conductivity distribution in upper 2.5m of unsaturated zone over OSL, (modified from French, Helen K. et al. (2000)).

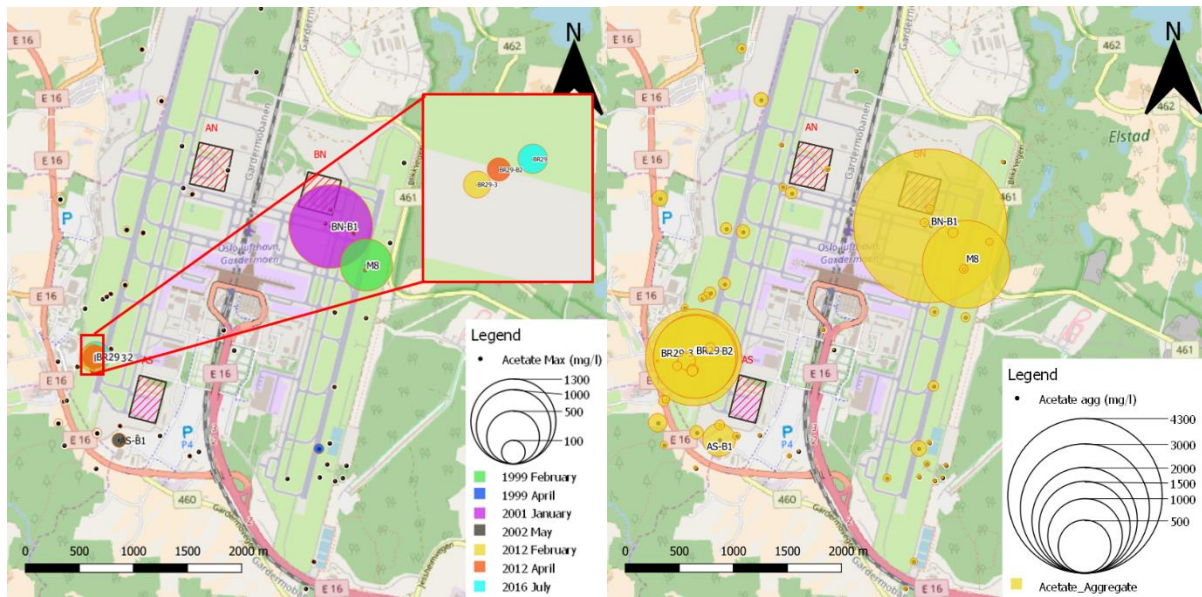


Figure 4.10 – Left: Highest measured values (>30 mg/l) of acetate in a year; Right: Accumulative of all the measurements taken at each well since the opening of airport. Deicing platforms are indicated by black squares filled with red strips.

11-years after the replacement of acetate, high acetate concentrations were measured only on the west side of western runway. Wells BR29-3, BR29-B2 and BR29 indicated high concentrations 133, 102, 161 mg/l, respectively, during February and April 2012, and July 2016. Average maximum concentration in other wells on the eastern side, between 2001-2017 was less than 4 mg/l with a few exceptions where concentrations went over 20 mg/l for a short time. Measured acetate concentration is most likely degradational product of PG (section 2.3.2, Eq. 2.7). , as these wells are located close to deicing platform Alpha South (AS), within 24 meters distance to each other (Figure 4.10: Left). Higher acetate concentrations are detected during the periods of oxygen depletion (Figure 4.11) a strong signal of anaerobic degradation of PG

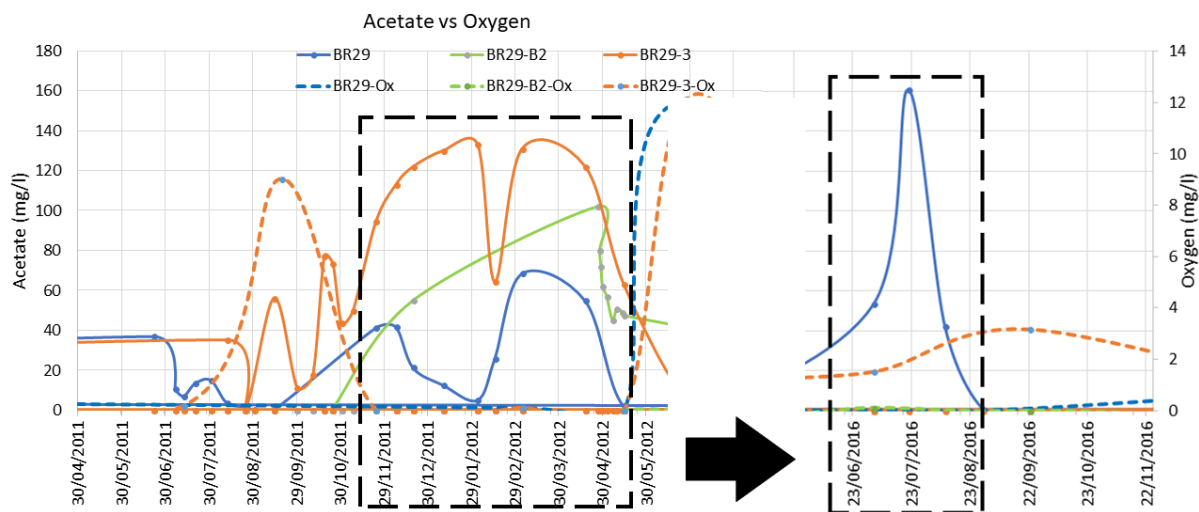


Figure 4.11 – Oxygen concentration (dotted lines) in wells is depleted when acetate concentration is high (solid lines). Black rectangles mark the periods of high acetate and low oxygen concentration.

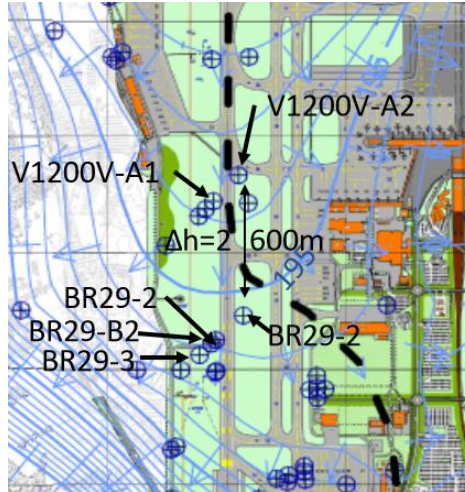


Figure 4.12 – Location of monitoring wells on western runway, blue lines indicate groundwater contours.

From the shape of the acetate concentration curves between September 2011 and May 2012 (Figure 4.11), it is apparent that peak concentrations lasted for extended periods possibly due to low temperatures and limited microbial activity. In BR29-3 there are two episodes of acetate high concentration. The second episode begun in mid-February 2012 and reached a peak in mid of March and eventually finished in July bringing the values back to the detection limit (i.e. 0.5 mg/l). It appears that it took 147 days to reduce 131 mg/l of deicer, but we assume a period of 125 days, because acetate measurements have interval of 1 to 2 months at this location and might miss out the point in time when concentration lowered back to detection limit level. Therefore, arrows are added on reduction curves for the proposed time when concentration returned to the detection limit (Figure 4.13). In BR29-B2 this episode lasted between December 2011 and November 2012 (318 days). Peak concentration of 102 mg/l took 230 days to lower back to detection limit.

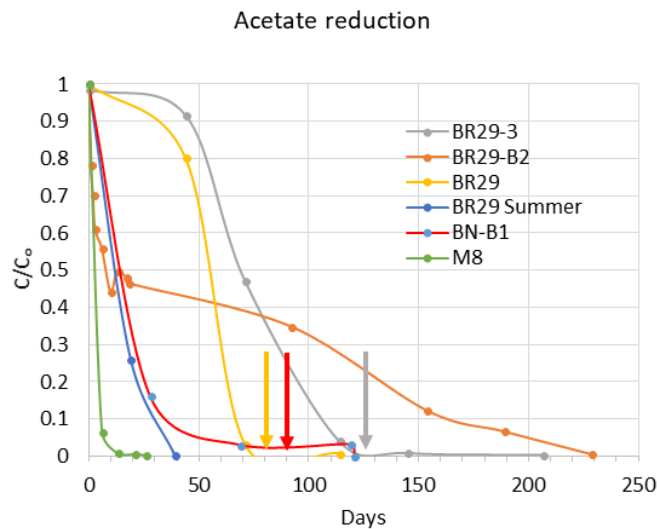


Figure 4.13 – Reduction of Acetate with time after observed maximum concentration. Arrows represent proposed time when concentration lowered to detection levels.

Well BR29 concentration curve is similar in shape to BR29-3 with almost half of its concentration. However, peak concentration reached in March 2012 to 68 mg/l and came to detection level by the end of June, lasting for 70 days (Figure 4.13). In July 2016, 161 mg/l was measured in the same well, but it lowered to detection levels in only 39 days. This rapid reduction was potentially caused by warm temperatures during July and August which contributes to intensive microbial activity. Previous acetate episodes in 2012 were less in concentration but lasted much longer potentially because they initiated during winter periods. Microorganisms are not very active during winter and snow melting periods. Therefore, degradation of deicers took longer.

4.5 Potassium Formate

Potassium formate (Pfo) is used as pavement deicer upon runways and taxiways. Concentrations higher than 20 mg/l are plotted, most of them are around the western runway which is more frequently used during winter season and (Figure 4.14: Left) and mechanically removed snow from the runways I also left on the same side of runway (blue arrows in Figure 3.1). Same wells have received high accumulated Pfo concentrations since 2001 (Figure 4.14: Right). Wells UK6100-A1, BR22 and BR29 have shown some high concentrations of formate in the past as well. However, formate does not seem to be a major risk to groundwater contamination as it reached to a maximum 300 mg/l only twice in past (Figure 4.15). Moreover, this peak concentration came to detection limit level (0.5 mg/l) within 2 months in almost all the wells except UK6100-A1, where it prolonged to 85 days. In this well, addition of formate is visible during reduction in concertation, possibly be due to the snow melting period (Figure 4.16).



Figure 4.14 – Left: Maximum values of Pfo measured; Right: Accumulative of all the measurements taken at each monitoring well since year 2001.

Formate concentration and reduction

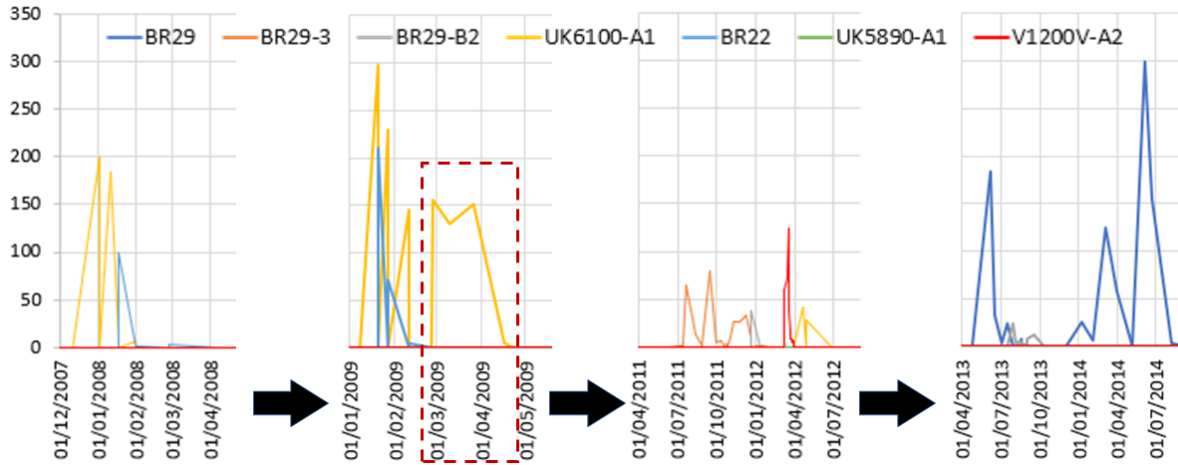


Figure 4.15 – History of formate concentration (mg/l) in affected wells. Red rectangle indicates addition of formate during March and April 2009.

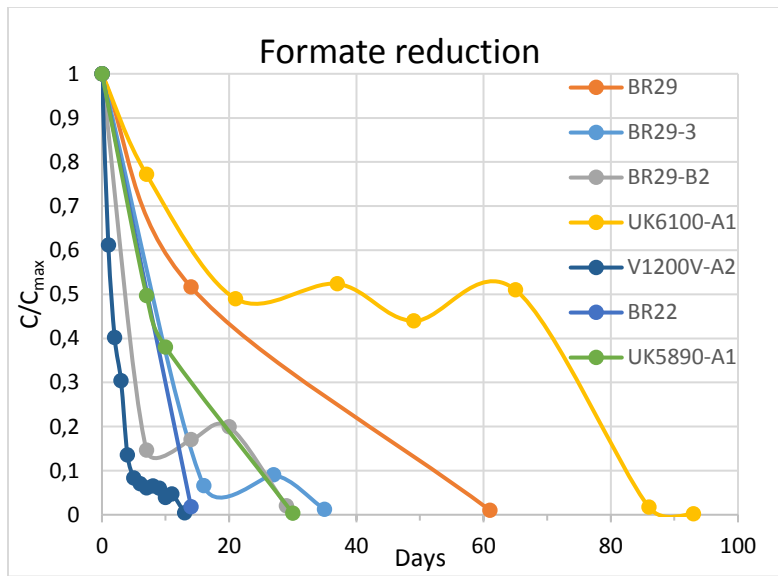


Figure 4.16 – Degradation duration of various concentrations of formate.

4.6 Propylene Glycol

Propylene glycol concentrations appear to be spread around the airport, but mostly close to the deicing platforms AS and BN. In Figure 4.17 maximum concentrations of PG measured at each well are plotted to highlight PG effected locations, concentrations less than 50 mg/l were ignored. Wells BN-B1 and M8 have shown high concentrations of acetate, formate and PG between 1999 and 2001, possibly due to intensive deicing operations at platform BN and runoff from the platform (section 4.4). Both wells are oldest in operation and monitoring program another reason for their highest cumulative values of deicing chemicals (Figure 4.17). High

concentrations of PG were measured in wells soon after the temperature started rising above zero °C, i.e. snow melting season (Figure 4.18).

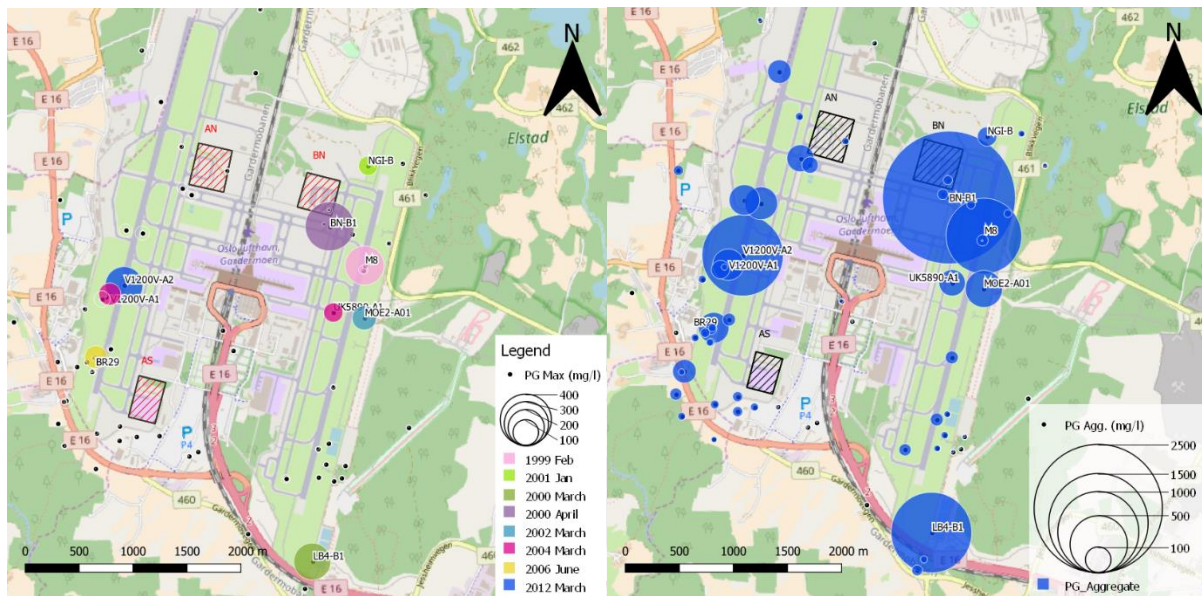


Figure 4.17 – Left: Maximum values measured at each location, values less than 50 mg/l were ignored; Right: Aggregate of all the measurements taken at each monitoring well since year 2001.

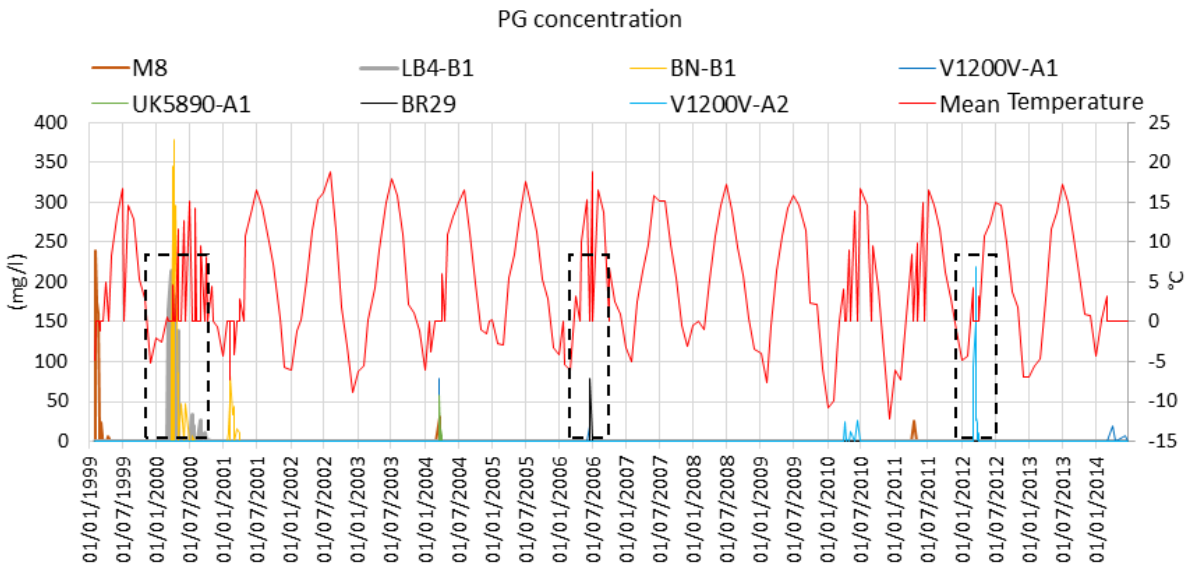


Figure 4.18 – Historical concentrations of PG at OSL and mean monthly temperature. Black rectangles indicate the period of increasing temperatures and rising PG concentrations.

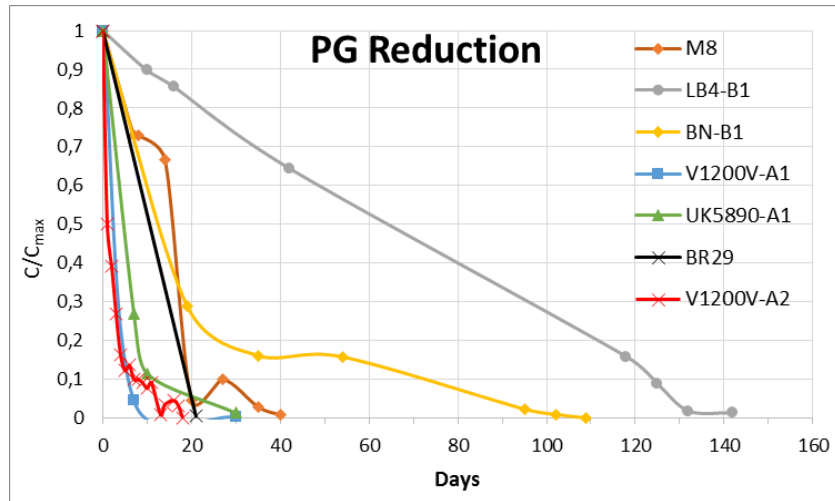


Figure 4.19 – Reduction of PG with time.

Reduction of PG for wells M8, V1200V-A1, UK2980-A1, BR29 and V1200-A2 took place within 30 days. In well V1200V-A1, 79 mg/l of PG concentration came to detection level within 20 days (Figure 4.19). In well M8, 240 mg/l concentration came back to detection level in 40 days. Well LB4-B1 is located in the south of eastern runway beside PG water storage ponds (Figure 4.17), in March 2000, 214 mg/l of PG was measured here which took more than 4 months (130 days) to reduce. In BN-B1, 297 was measured during April 2000, taking more than 100 days to lower back to detection levels. This long duration in reduction could be due to the slow continuous leakage of PG or limited microbial activity.

4.6.1 Calculating retention time

Monitoring well V1200V-A2 was measured almost daily after the detection of 220 mg/l PG in March 2012, however, it was not measured for almost 9 months before the detection of this concentration (Figure 4.20). Absence of measurements before the peak concentration make it difficult to estimate retention time and plume generation time. Therefore, another curve is assumed by adding an imaginary measurement of 0 mg/l. This imaginary measurement is placed 13-days before the peak concentration was reached since the peak concentration also took 13-days to completely reduce. This made the pulse a normal distribution curve (Figure 4.21 b).

We assume the pulse of PG was generated at western runway, at least 10-meters away from well V1200V-A2, where water table is 5-meter below the surface (Figure 4.21 a). The reason for this infiltration can be preferential from runway after the snow melt. Because PG does not adsorb to soil particles, retardation factor was not included in calculation. Fluid depth and Time taken by the pulse to reach the maximum concentration can be calculated by using hydraulic conductivity 'K' from the literature. In unsaturated zone K is assumed 2.2×10^{-6} (Figure 4.9) and 10^{-4} in saturated zone (Tuttle 1997). However, due to lack of real data to calculate unsaturated hydraulic gradient, three values were tried by using the following calculation. The most reasonable values are in column 'C' of Table 4.2.

Retention time in unsaturated zone :

Hydraulic conductivity = $K_{\text{unsat}} = 2.2 \times 10^{-6}$ or 0.19 m/day

Water table depth = $x = 5$ meters

Effective porosity = $n_e = 0.2$

Hydraulic gradient = $i_{\text{unsat}} = 0.02$ (taking the most reasonable value from Table 4.2)

Retention time = $t = ?$

Specific discharge according to Darcy's Law,

$q = iK = 0.02 \times 0.19 = 0.0038$ m/day

$$\text{Velocity} = \frac{q}{n_e} = \frac{0.0038}{0.2} = 0.019 \text{ m/day}$$

$\text{Retention time} = t_{\text{unsat}} = \frac{x}{v} = \frac{5}{0.019} = 263 \text{ days}$

Retention time in saturated zone = t_{sat}

$K_{\text{sat}} = 10^{-4}$ m/s or 8.64 m/day

Hydraulic gradient = $i = \frac{\Delta h}{x} = \frac{2}{600} = 0.003$ (calculated from Figure 4.12)

$x = 10$ meters

$q = iK = 0.003 \times 8.64 = 0.0259$ m/day

$$\text{Velocity} = \frac{q}{n_e} = \frac{0.0259}{0.2} = 0.129 \text{ m/day}$$

$t_{\text{sat}} = \frac{x}{v} = \frac{10}{0.129} = 77.5 \text{ days}$

Total retention time in this location is approximately **263 days** or more than 8 months. According to assumed scenario, plume reached to the well on 3rd March 2012, subtracting the total retention time estimated plume generation day is **28 March 2011** (Figure 4.21 a). Assuming constant K_{unsat} , after 263 days (t_{unsat}) it reached water table around **16 December 2011**, from where, after 77 days (t_{unsat}) it reached the well on **3 March 2012**. This estimate seems realistic as the plume was generated in snow melting period, high concentrations of other deicers also were detected during this period. However, it reached to water table in December when soil on the surface is frozen. Plume at this time was already under the surface and enough moisture content can drain it to water table. Since, the subsurface is not completely homogenous and hydraulic conductivity values are estimates, local heterogeneities and uncertainties can influence the plume transport.

Table 4.2 – Three unsaturated hydraulic gradients were tried to get most reasonable values from real measurements.

	A	B	C
Hydraulic gradient = i_{unsat}	1	0,01	0,02
vertical	0,0000022	0,0000022	0,0000022
Horizontal	0,0001	0,0001	0,0001
t_{unsat}	5	526	263
t_{sat}	77	77	77
Total t	82	603	340
Date of origin	11.12.2011	08.07.2010	28.03.2011
Date to reach water table	16.12.2011	16.12.2011	16.12.2011
Date to reach well	03.03.2012	03.03.2012	03.03.2012

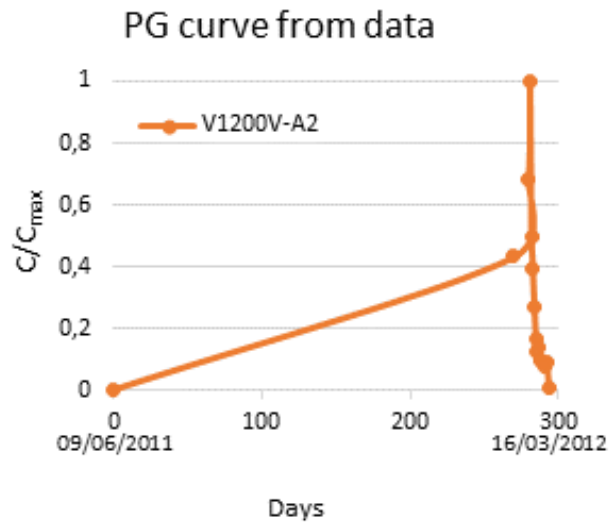


Figure 4.20 – PG concentration curve from available data.

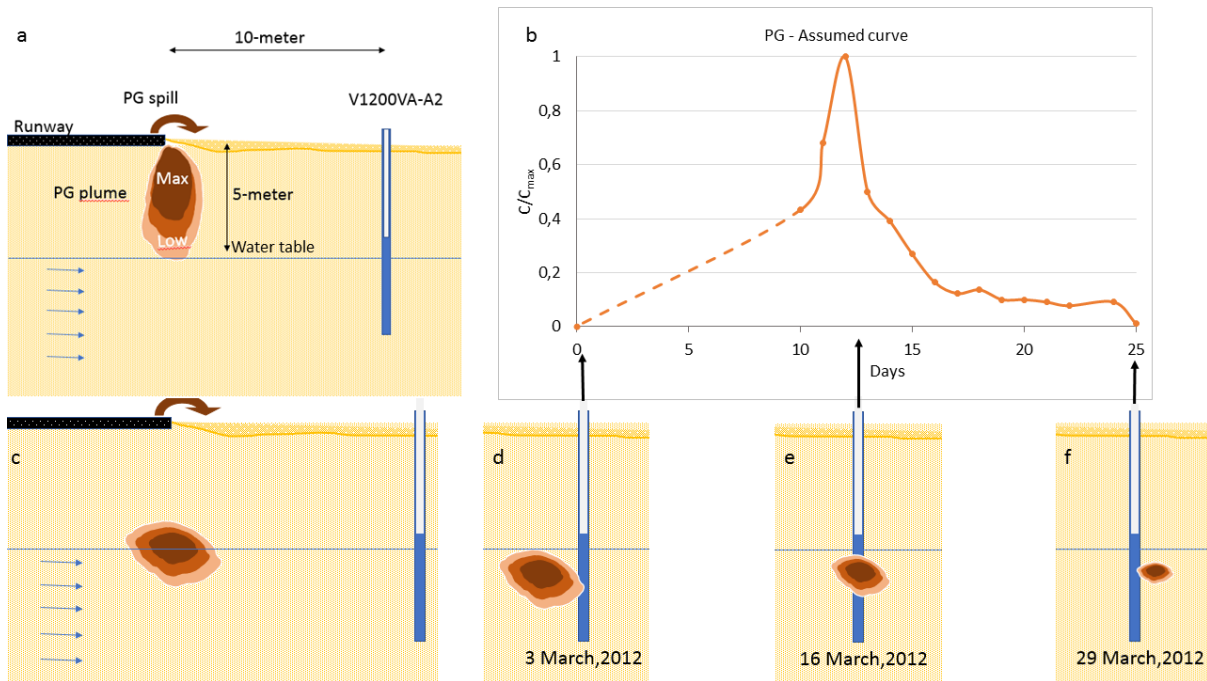


Figure 4.21 – Stages of plume generation and reduction. (a) Hypothetical scenario of PG infiltration; (b) Assumed normal concentration curve, dashed line indicate imaginary measurement (c) Plume reached to water table (d) on the way to the well, plume shape changed and size reduced due to degradation and dilution; (e) After 13-days, central part of plume with highest concentration reached to the well; (f) plume reduced in size and concentration after further 13-days.

5 Conclusions

1. The aim of this study was to assess the strengths and weaknesses of OSL groundwater monitoring program and its compatibility with discharge permit regulations. The analysis of chemical and physical parameters suggests that monitoring program is comprehensively designed to follow the guidelines of discharge permit with little room for improvement.
2. The study found no significant change in water balance of the aquifer in compliance to the discharge permit. Water table fluctuated for between 2-meter since 1998 to present, indicating very little or no effect at aquifer water balance. Fluid elevation and fluid depth are important parameters, but including the length and depth of well screens can make the estimation of vertical hydraulic gradient and water table more reliable. However, it is suggested to maintain a water table map annually or bi-annually to monitor the changes in groundwater flow pattern.
3. Groundwater chemistry is dominated by calcium and bicarbonate in accordance with previous studies. Groundwater contamination was not found as a serious issue but potassium, iron and manganese concentration has been increasing significantly since the opening of the airport. Constant use of potassium formate is increasing K^+ concentration in groundwater. Background data set is a good indicator of variations within and outside the borders of OSL. Some metallic parameters zinc, copper, lead and Magnesium did not show considerable variation in both data sets, therefore, their measurement frequency can be assigned to other more important parameters.
4. Potassium formate is not considered a threat to groundwater due to quick reduction before reaching to high concentrations. Acetate was identified as the anaerobic degradation product of Propylene glycol. Limited number of measurements during winter season were associated with high concentrations found in snow melting periods. Large amount of credible data retrieved through monitoring program can be used to develop interactive hydrogeological and geochemical models. Such a model in this study estimated the retention time, which can be used for other contamination events.

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7 Appendices

1 BESKRIVELSE

Kontroll- og overvåkingsprogrammet (KOP) beskriver omfanget av overvåking ved normale driftssituasjoner for OSL, Område Flyside og Avd. Vann- og avløpshåndtering ved seksjon Vann og grunn. Programet har som hensikt å sikre at Oslo Lufthavn dokumenterer oppfyllelsen av de krav som er spesifisert i utslipptillatelsen gitt av Miljødirektoratet og NVEs konsesjon i forhold til vannbalanse og avdekke avvik slik at nødvendige tiltak kan iverksettes. Uønskede hendelser med brudd på vilkår eller potensiell fare for brudd på vilkår, håndteres uavhengig av KOP.

Programmet omfatter overvåking av følgende:

- Grunnvann (vannkvalitet og vannbalanse) innenfor og utenfor flyplassområdet
- Belastning av avisingskjemikalier på sidearealene
- Utslipp fra kulverter til vassdrag (vannkvalitet, vannmengde og vanntemperatur)
- Vassdrag (vannkvalitet, vannmengde og vanntemperatur)
- Grytehullsjøer

2 GJENNOMFØRING

Nr	Steg
1	<p>Grunnvannskvalitet</p> <p>Overvåkingen av grunnvannet utføres gjennom prøvetaking for å dokumentere at akseptverdiene for grunnvannskvaliteten ikke overskrides, samt å påvise eventuelle endringer i forhold til referansesituasjonen. Overvåkingen knyttes opp mot driften av flyplassen og spesielle anlegg som utgjør potensiell fare for forurensning av grunnvannet.</p> <p>Det er arbeidsbeskrivelser for prøvetaking («Ytre miljø – Gjennomføring av Kontroll- og overvåkingsprogram (KOP)»).</p> <p>«Ytre miljø - Liste for Kontroll- og overvåkingsprogram (KOP) - grunnvann og forurensede lokaliteter» viser prøvetakingsprogrammet for grunnvannskvalitet og grunnvannsbilanse. Prøvetakingen må tilpasses spesielle situasjoner og smelteperioder, slik at prøvene tas på det tidspunkt der man kan forvente høyest fare for spredning av avisingskjemikalier til umettet sone og grunnvannet. Som en del av selve programmet skal en prøvetakingsrunde gjennomføres i løpet av selve vårsmeltingen, og en prøvetakingsrunde cirka en måned etter at smelteperioden er over. Tidspunkt for prøvetaking vil derfor variere med sesongene.</p> <p>For noen brønner er enkelte prøvetakingsrunder angitt med "(X)" i «Ytre miljø - Liste for Kontroll- og overvåkingsprogram (KOP) - grunnvann og forurensede lokaliteter.» Dette innebærer at prøvetaking av den aktuelle brønnen kun gjennomføres dersom:</p> <ol style="list-style-type: none"> 1) ekstra smelteperioder forekommer før vårsmeltingen, eller 2) ansvarshavende for gjennomføringen av KOP finner prøvetaking nødvendig av andre årsaker. <p>Dersom det forekommer flere smelteperioder i løpet av vintersesongen skal det i aktuelle områder tas prøver av grunnvannet dersom det anses nødvendig.</p>

	<p>Dette kan innebære flere prøvetakinger enn det som er angitt i «Ytre miljø - Liste for Kontroll- og overvåkingsprogram (KOP) - grunnvann og forurensede lokaliteter.»</p> <p>Resultatene vurderes mot akseptgrensene gitt i Miljødirektoratet sin utslippstillatelse (Miljødirektoratet), tidligere resultater fra samme målepunkt og mot den generelle grunnvannskvaliteten (OSLAS-AN-RA-0035).</p> <p><u>Overvåking i spesielle situasjoner:</u> Ved mistanke om eller påvisninger av avvik opp mot akseptgrensene i utslippstillatelsen vil en mer omfattende overvåking bli iverksatt. Overvåkningen omfang i forhold til prøvepunkter, område, prøveantall og analyseparametere må vurderes i hver enkelt situasjon. Videre overvåking og prøvetaking og eventuell utvidelse av undersøkelsesområdepunkter vurderes fortløpende.</p>
2	<p>Grunnvannsbalanse Overvåkningen av grunnvannet utføres for å dokumentere at kravene til grunnvannsbalanse blir ivaretatt, og blir beskrevet i arbeidsbeskrivelse for prøvetaking («Ytre miljø – Gjennomføring av Kontroll- og overvåkingsprogram (KOP)»).</p>
3	<p>Tilstandskontroll forurensningslokaliteter Under utbygging av Gardermoen ble det avdekket flere forurensningslokaliteter fra tidligere aktiviteter. I tillegg er noen lokaliteter kommet til etter åpning av flyplassen. Ved alle lokalitetene er det gjennomført undersøkelser og tiltak. Supplerende overvåking har blitt utført rutinemessig der dette har vært ansett som nødvendig. Overvåkningen vurderes fortløpende og vil bli avsluttet dersom man ikke påviser gjenværende forurensninger og grunnvannskvaliteten er tilbake til referansesituasjon.</p> <p>Programmet for overvåking av forurensningslokaliteter er gitt i «Ytre miljø – Liste for Kontroll- og overvåkingsprogram (KOP) – Grunnvann og forurensede lokaliteter.» Prøvetakingsintervall er gitt i listen, og varierer for de ulike lokalitetene. Omfanget (antall brønner som det tas prøver av) vurderes for hver lokalitet, men et minimum antall brønner er bestemt for hver lokalitet og oppgitt i listen. For de lokaliteter hvor det pågår aktive tiltak gjennomføres overvåking etter behov.</p> <p>Prøvetakingen skal utføres ved å ta representative grunnvannsprøver iht Arbeidsbeskrivelse for prøvetaking («Ytre miljø – Gjennomføring av Kontroll- og overvåkingsprogram (KOP)»). Prøvetakings- og analyseprogram vurderes avhengig av kilden ved hver enkelt lokalitet.</p>
4	<p>Kulverter og vassdrag Det gjennomføres prøvetaking av vann i kulverter og vassdrag for dokumentasjon av vannkvalitet. I tillegg måles vannføring automatisk på alle stasjoner, samt vanntemperatur og oksygen på målestasjonen i Sogna. Selve programmet er vist i «Ytre miljø – Overvåking av kulverter, vassdrag og grytehullsjøer.»</p> <p><u>Vannkvalitet knyttet til vinterdrift</u></p> <p>I avisningssesongen hvor det kan forekomme transport av avisingskemikalier til Sogna, tas det døgnblandprøver med automatiske vannprøvetakere («Ytre miljø – Gjennomføring av Kontroll- og overvåkingsprogram (KOP)») i utløpene til de tre overvannskulvertene; Søndre kulvert, Midtre kulvert og Nordre kulvert.</p>

	<p>Vannføringen måles automatisk. Det analyseres blandprøver fra alle døgn hvor det skjer avrenning slik at døgnmiddel, ukemiddel og totalt for sesongen kan bestemmes.</p> <p>I Sogna tas det også døgnblandprøve med automatisk vannprøvetaker. Det analyseres blandprøver fra alle døgn i vintersesongen hvor det skjer avrenning til kulvertene fra flyplassområdet. Vannføring, oppløst oksygen og vanntemperatur måles automatisk.</p> <p><u>Vanntemperatur knyttet til utslipp av temperert vann</u></p> <p>I sommersesongen hvor det periodevis forekommer utslipp av temperert vann til Midtre kulvert, måles vanntemperaturen både i Midtre kulvert og i Sogna. Målingene gjøres automatisk med temperaturmålere med innebyggede loggere. Plassering av sondene er vist i «Ytre miljø - Overvåking av kulverter, vassdrag og grytehullsjøer.»</p>
5	<p>Vannkvalitet i grytehullsjøene</p> <p>Overvåking av fysiske og kjemiske parametere i grytehullsjøene Danielsetertjern og Aurtjern er en videreføring av referanseundersøkelsene som ble gjennomført før åpning av flyplassen, samt overvåking som ble utført i anleggsfasen.</p> <p>Grytehullsjøenes lokalisering, prøvetakingsintervall og analyseprogram er vist «Ytre miljø - Overvåking av kulverter, vassdrag og grytehullsjøer.»</p>
6	<p>Belastning sidearealene</p> <p>I avisings sesongen er det plassert ut snøkasser for prøvetaking av snø med avisingskjemikalier på faste steder ved rullebanene. Snakassene tas regelmessig inn og byttes med nye slik at det står kasser utplassert gjennom hele sesongen. Både vannmengde og konsentrasjoner av avisingskjemikalier måles slik at akkumulert belastning på målestedene kan bestemmes.</p> <p>Plassering av snøkasser og måle- og analyseparametere er vist i «Ytre miljø - Gjennomføring av Kontroll- og overvåkingsprogram (KOP).»</p>
7	<p>Rapportering</p> <p>Status rapporteres ukentlig til seksjonsleder Vann og grunn og avdelingssjef Vann- og avløpshåndtering. Det rapporteres årlig status inkludert alle avvik på utslippstillatelsen til Miljødirektoratet innen 1. mars via AltInn.</p> <p>Avvik fra gjeldene utslippstillatelser varsles og rapporteres i henhold til «Ytre miljø - Håndtering av avvik og uønskede hendelser.»</p> <p>Generell grunnvannskvalitet rapporteres mot akseptgrenser gitt i utslippstillatelse, samt mot grunnvannets opprinnelige kvalitet, der innsamlede data vil sammenlignes med historiske data og referansesituasjonen. Dette er definert i rapport "Grunnvannskvalitet på Gardermoen" (OSLAS-AN-RA-0035) basert på tidligere miljøovervåkingsprogram. Generell grunnvannskvalitet vil også bli sammenlignet mot gjeldene drikkevannskriterier.</p> <p>Grunnvannsnivåer rapporteres mot historiske data.</p> <p>Vannkvalitet i vassdrag og grytehullsjøer rapporteres mot historiske data og Miljødirektoratet veileder TA-1468. I tillegg beregnes sesong døgnmiddel iht parametere gitt i utslippstillatelse fra Miljødirektoratet.</p>

3 REGISTRERINGER

Ingen

4 GRENSESNIFF OG REFERANSER TIL ANDRE PROSESSER OG DOKUMENTER

4.1 Referanser

Nr	Referanse	Forklaring
1	Miljødirektoratet (tidl SFT) – 18.12.08	Tillatelse til virksomhet etter forurensningsloven for Avinor AS avd. Oslo Lufthavn Gardermoen. Endret utslippstillatelse gitt av Miljødirektoratet 22.08.16.
2	NVE – 23.01.97	OSL AS – Driftsfasen – Utslipp av vann til Sogna og Leira
3	TA-1468 (97:04)	Klassifisering av miljøkvalitet i ferskvann. Veileder fra Miljødirektoratet.
4	OSLAS-AN-RA-0035	Grunnvannskvalitet på Gardermoen. Vurdering av vannkvalitet fra miljøovervåkingsprogram. VBB-Viak.
5		Ytre miljø - Liste for kontroll- og overvåkingsprogram (KOP) - Grunnvann og forurensede lokaliteter
6		Ytre miljø - Overvåking av kulverter, vassdrag og grytehullsjøer
7		Ytre miljø - Gjennomføring av Kontroll- og overvåkingsprogram (KOP)

4.2 Grensesnitt

Nr	Referanse	Forklaring
8	OSLAS-BL-SH-0001	Airside Safety Manual
9		Ytre miljø – Beredskapsplan for Oslo Lufthavn Gardermoen – Administrativ del
10		Ytre miljø – Beredskapsplan for Oslo Lufthavn Gardermoen – Operativ del
11	OSLAS-BP-PR-0034	Prosedyre for kjemikaliespredning på ferdselsområdet
12	OSLAS-AW-PR-0003	Prosedyre for håndtering av overvann med avisningskjemikalier
13	OSLAS-AW-PR-0004	Prosedyre for håndtering av rent overvann og dreisvann
14	OSLAS-AW-PR-0002	Prosedyre for håndtering av overvann forurenset med hydrokarboner
15		Ytre miljø - Håndtering av avvik og uønskede hendelser
16	OSLAS-AS-PR-0026	Sikkerhetsbestemmelser ved opphold og arbeid ved avløpsanlegg og i kummer.

5 VEDLEGG

Ingen.