CHALLENGES OF GROUNDWATER MANAGEMENT IN AREAS WITH WINTER FROST AND POLLUTED SNOW COVER

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ABSTRACT

In 1998 the new main airport of Norway was opened at Gardermoen, 40 km north of Oslo. The Gardermoen aquifer is the largest rain fed unconfined aquifer in Norway. The national pollution authorities demanded from the airport that there should be no pollution of the groundwater (e.g. from de-icing chemicals and jet-fuels) and the groundwater balance should be maintained. Several studies were conducted in order to examine the general geology in the area, unsaturated and saturated flow and transport. In this article, potential pollutants caused by winter operations will be discussed. Potassium Format (KF) is used for the de-icing of runways and Propylene Glycol (PG) is the active component of the de-icing chemical used for airplanes. Field monitoring of infiltration of meltwater using electrical resistivity was employed to characterise meltwater infiltration patterns at Gardermoen in 2001 (French et al., 2002B; French and Binley, 2004) and 2006. The formation of impermeable ice cover on the ground below the melting snowcover was observed at the field site in years with ground frost, while no ice was formed in 2006 when no ground frost was present until the last month of winter. More homogeneous infiltration conditions in 2006 were also confirmed by insignificant ponding at the airport site.

Key words: snow melt, contaminants transport, de-icing chemicals, winter, frost

1. INTRODUCTION

1.1. Background

Contaminants in melt water from snow cover in the vicinity of airports and roads have received increased attention over the last decade (e.g. Nystén and Suokko, 1998; Øvstedal and Wejden, 2006). The hydrology of partially frozen systems is complicated by the fact that the soil surface may become impermeable due to ground frost and basal ice formation. The unsaturated zone may serve as a filter protecting groundwater from surface pollutants due to bio-geo-chemical processes, hence an evenly distributed infiltration process and long retention times is most ideal. According to Johnsson and Lundin (1991), Baker and Spaans (1997), Derby and Knighton (1997), French and Van der Zee (1999) and French and Binley (2004), infiltration during snowmelt often occurs as focused recharge in local depressions on the surface because of melt water redistribution on basal ice-cover. This may cause higher velocities in the unsaturated zone than during evenly distributed infiltration on the surface, hence producing less than optimal conditions for degradation. Higher levels of saturation and short retention time in the unsaturated zone will reduce the potential for microbial degradation.

1.2. Site description

The Gardermoen aquifer, 40 km north of Oslo, Norway, is the largest rain fed unconfined aquifer in Norway. The area is a glacial contact formation with sand and gravels dominating near the ground surface (Jørgensen and Østmo, 1990; Hongve, 1977). Hydraulic conductivities (K_s) are in the range 10^{-3} to 10^{-5} m/s. The annual precipitation is about 800 mm/year. Along the south and western perimeters there is a landscape protection area with active ravinating processes. In 1998 the new main airport of Norway was opened here. Large amounts of de-icing chemicals are used for removal of snow and ice every winter for airplanes (Propylene glycol, PG) and runways (Potassium Formate, KF). Pollution authorities demanded that no contaminants should enter the groundwater and the groundwater levels should be maintained. De-icing of airplanes is conducted on impermeable platforms and the run-off from these areas is collected and brought to the local waste water treatment plant. During taxing and take-off PG drips from the wings is dispersed diffusively to the green areas of the airport. There are no collection systems for KF, but membranes next to the runways ensure that chemicals do not enter the runway fundaments which are highly permeable. The unsaturated zone is used as an active bio-remediation filter in order to remove the contaminants before they reach the ground water.

The de-icing chemicals are easily degradable by bacteria and fungi which are naturally existent in the subsurface. Field experiments and modelling activities documented velocities and degradation rates in the unsaturated zone (French et al., 1999; 2001; 2002A; 2002B). An important conclusion was that that it is vital for the degradation processes that contaminants do not reach the groundwater level before the summer. During summer there is a large evapotranspiration and water is kept in the unsaturated zone at a hydrostatic pressure. Hence, it is important to know when and how these solutes infiltrate on the ground surface and their flow pattern in the ground. Retention time, degradation rates and dilution pattern will strongly influence the severity of the pollution of both groundwater and surface waters.

For optimal degradation conditions it is important that the de-icing chemicals infiltrate evenly over the area. This will ensure sufficient retention time for degradation in the unsaturated zone. Several experiments conducted at Moreppen, Gardermoen revealed a situation where chemicals percolate by gravity dominated flow during the snowmelt period which normally lasts from 3-5 weeks (French et al., 2001). After the melting period, water remains at hydrostatic pressure, because most of the precipitation during summer will evapotranspire. Autumn rains will start to move contaminants further down in the profile. Hence it is important that contaminants do not reach the groundwater level before the summer (French et al., 2001).

1.2. Objectives

Although the airport area is fairly flat there are large scale features which give rise to large spatial variation in infiltration rates, especially during snowmelt, which is when the contaminants are present in the infiltrating water. Water contents and temperatures in soils during winter and snowmelt have large impact on the infiltration properties (Baker and Spaans, 1997). The formation of an impermeable ice cover is common, and will cause meltwater to be redistributed and collected in local depressions.

The questions addressed in this paper are:

1) How has the climatic conditions prior to snowmelt influenced the accumulation of meltwater in depressions?
2) What are possible solutions? and
3) Can the infiltration pattern be monitored with the use of electrical resistivity measurements?

2. METHODS

Within the airport area the regular monitoring programme includes a large number of boreholes for monitoring groundwater levels and chemical composition of water. The top 2.5 m of the soil has also been monitored with various instruments such as lysimeters, and TDR. In order to monitor the ponding of meltwater in depressions, measuring sticks were placed in the lowest point and the water levels logged manually. Manual observations of ponding levels were started in 1999, a pump for removal of ponded water was installed before the winter season of 2001/2002 And volumes monitored through out the melting periode on a daily basis. Water samples were also collected and analysed for DOC as a bulk parameter for de-icing chemicals. Climatic data was taken from the national monitoring station at Gardermoen (The Norwegian Meteorological Institute). As snow accumulation was not measured during the early part of winter, we estimate accumulated amount of snow based on precipitation on days with minimum, mean and maximum daily temperatures are below 0°C, accordingly. As this method does not take into account the daily fluctuations in temperatures and the potential melting of snow during shorter periods, it does not represent the real accumulation of snow. As part of research projects in 2000-2002 and 2005-2008, soil temperatures were measured by Thermistor temperature sensors (Campell Scientific 107) at depths from 0.05m to 2.4 m below surface at a nearby research station, Moreppen (French et al, 1994). The snow equivalent prior to snowmelt started was measured manually and serves as a correction with respect to the estimates based on easily available meteorological data described above. During the autumn of 2005 a 48 m electrical cable was installed at 0.5 m depth 63 m east of the eastern runway at the airport. The cable was placed in a relatively flat area. The cable consists of 48 electrodes with 1m separation. The cable is used for time-lapse measurements of changes in electrical resistivity in the top 5-7 m. Data were collected on a regular basis throughout the snowmelt of 2006 with a SyscalPro (Iris instruments) using a Wenner configuration (eg. Sharma, 1997). The snowmelt took place in the period March-April.To examine changes in electrical resistivities, data collected on each date was normalised on the data set collected on March 28th, which is was prior to snowmelt. Ratios of electrical resistivity below 1 show areas of the soil profile becoming less resistive. The groundwater level in this area is about 10 m, while over a larger area it can range from 2-20 m.

3. RESULTS

3.1. Air and soil temperature and ponding

The autumn of 2000 had higher precipitation than the normal, which meant high water saturation levels in the soil prior to the winter season. The air temperatures started sinking below 0°C in mid December, while the snow in the area did not start to accumulate before late December when the air temperature was about -20°C (Fig. 1A). The soil temperatures measured during the corresponding time period shows that the top 10 cm of the soil quickly freezes during this initial cold period (Fig. 2 A). In contrast to the climatic situation in 2000/2001, the autumn of 2005 had normal precipitation levels and air temperatures below 0°C occurred at about the same time as snow started to accumulate (Fig. 1B), the corresponding soil temperatures are above 0°C until the final few weeks of snowmelt (Fig.2B). During the snowmelt of 2001, an accumulation of meltwater in one of the large depressions at the airport was about 1 m, which based on the topography in the area is an equivalent of 3500 m^3, of meltwater. During the snowmelt of 2006 there was no accumulation of meltwater in the same depression area, indicating a more homogeneous infiltration pattern than in 2001.

3.2. Infiltration observed as changes in electrical resistivity

Time-lapse changes of electrical resistivity measured during the snowmelt of 2001, published by French and Binley (2004), were highly variable with clear zones of high and low infiltration. The infiltration became more homogeneous towards the last part of the melting period. During the snowmelt of 2006 time-lapse changes in electrical resistivity predominantly showed a horizontal pattern indicating a fairly uniform infiltration pattern throughout this period (Fig. 3). This hypothesis is supported by the lack of ponding in the area during this melting season.

3.3 Concentration of de-icing chemicals in meltwater ponds

Concentrations of organic carbon (from de-icing chemicals) in the meltwater directly from snow and ice have been measured up to 10000 mg DOC l^{-1}. The maximum concentration measured in the meltwater ponds at the airport is 253 mg DOC l^{-1}, hence a dilution with clean meltwater. Based on total mass balance estimates, most of the de-icing chemicals infiltrate along the runway, even during situations with large meltwater redistribution. This would indicate that the preferential out-melt of de-icing chemicals at the beginning of the snowmelt, ensures local infiltration of most of the chemicals.

4. DISCUSSION AND CONCLUSIONS

The climatic conditions during the two winter seasons 2000/2001 and 2005/2006, represent two contrasting situations, one with significant soil frost and one with insignificant soil frost. The presence of snow in late autumn/early winter when air temperatures drop below 0°C has a clear impact on the development of soil temperatures. Snowmelt in the presence of frozen ground causes meltwater redistribution and focussed infiltration, i.e. weather conditions prior to snowfall is crucial for the hydrological processes occurring during snowmelt in this area. Time-lapse measurements of electrical reisistivity provide a useful method for observing infiltration patterns in soil and provides data for model calibration and verification. In the future a model to

4.1 Management aspects

Based on the experimental data and observations of ponding and contaminant concentration in meltwater at the airport, the following measures can be taken:

1. Water in depressions can be pumped to a storage volume and be irrigated to green areas during the summer period. This does however require large storage volumes. At Oslo airport much of the water is transported to the local wastewater treatment plant. This should be done in order to avoid focussed infiltration and low retention times in the unsaturated zone where degradation of pollutants take place. Summer irrigation will increase degradation rates due to higher temperatures and increase the retention time in the unsaturated zone.
2. Soil temperature should be measured along the runway as an early warning system for predicting snowmelt hydrological patterns and risk of ponding.

Oslo airport has already introduced both these measures. Pumping of ponded meltwater started in 2002/2002 and soil temperatures are being measured along one of the runways. This information is important for the management of runoff at the airport today. It means that they can take appropriate measures with respect to the handling of surface water along the green areas of the airport at an earlier time.

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Figure captions

Figure 1. Air temperature and accumulated precipitation as snow, based on precipitation falling on a day with maximum, mean or minimum air temperature <0°C versus time A) 2000/2001 B) 2005/2006.

Figure 2. Soil temperatures measured at different soil depths throughout the winter seasons of A) 2000/2001 and B) 2005/2006.

Figure 3. Changes in electrical resistivity in a vertical soil profile at Oslo airport a function of days from beginning of snowmelt in 2006. Darkness of grey indicates relative changes in electrical resistivity which in this case can be explained by infiltrating water.