A groundwater vulnerability assessment of the Korgen waterworks, Lillehammer

DAVID SEGAR

David Segar, Norges geologiske undersøkelse, P.O. Box 3006-Lade, N-7002 Trondheim, Norway.

Introduction

The Korgen waterworks are today the principal water source for Lillehammer kommune and were upgraded in 1993 to provide both for the increased demand during the Winter Olympic Games in February 1994 and to provide a 'reference' waterworks to demonstrate Norwegian competance within the groundwater supply industry. The idea to develop the waterworks was initiated by Berdal Strømme and was developed during the "Groundwater in Norway" project undertaken by the Geological Survey of Norway (NGU) for the Norwegian Department of the Environment and the State Pollution Authority (SFT).

The study described here forms the final part of NGUs contribution to the project. This contribution included the collation of all existing data, the production of a digital terrain model, a groundwater flow model and a groundwater vulnerability assessment of the waterworks. This work is described in detail in Segar (1993, 1994a and 1994b). The study area is shown in Fig.1.

Objectives and methodology

The principal objective of this study was to assess the groundwater pollution risks to the Korgen waterworks through a consideration of the potential pollution sources and their effect following a hypothetical pollution event. A groundwater protection scheme was then to be proposed. It should be noted that the Korgen waterworks already has a high degree of protection from pollution through a groundwater protection zone scheme initiated in 1973. This study is intended to demonstrate an alternative approach to assessing the vulnerability to groundwater pollution of the waterworks.

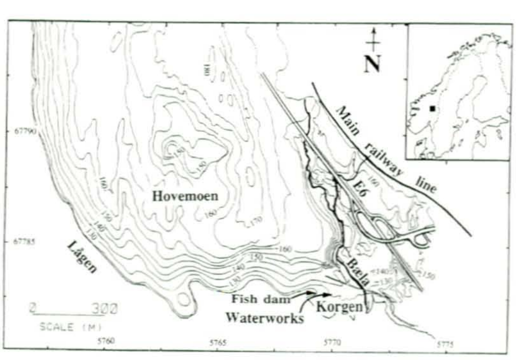

Fig. 1. Location map of the study area showing the Korgen waterworks site.

The advection-only particle tracking model MODPATH was used to evaluate the vulnerability of the Korgen waterworks to pollution. This model is capable of calculating three-dimensional pathlines and particle positions at specified times within a steady-state groundwater flow system. MODPATH was coupled to the MODFLOW 3-dimensional finite-difference groundwater flow model of the Korgen area produced earlier in the project (see Segar 1994b). Three layers were used in the MODFLOW model. The MODFLOW and MODPATH models were executed on an Intergraph 20/20 Workstation using Intergraphs ERMA interface.

Geology and hydrogeology

The superficial geology of the study area consists of a sequence of Quaternary deposits of mixed glacial and fluvio-glacial origin. Underlying much of the area is a low permeability fine-grained deposit. This deposit varies from 40-80 m thick and is designated as Layer 3 in the MODFLOW model. Overlying this deposit in the Korgen area are the Bæla fan and associated deposits. These sediments are extremely permeable and typically vary from 20-30 m in thickness. They form the main aquifer unit within the area and are grouped together as Layer 2 in the MODFLOW model.

Across much of the study area outside the Bæla fan area is a shallow high permeability layer. Under 'normal' or low groundwater level conditions, this layer is considered to be unsaturated. It may, however, become partially saturated during periods of high groundwater levels. Due to the inability of the MODFLOW version used to model the 're-wetting' of a node, this layer was necessarily excluded from the groundwater flow model. In the western part of the fan there is an upper, moderately high permeability deposit formed by a landslide on the southern side of Hovemoen. This deposit is designated as Layer 1 in the MODFLOW model.

The regional groundwater flow drains towards the Lågen in the SSW of the study area. The overall pattern is complicated, however, by the presence of the Bæla stream which acts as a groundwater sink in its upper reaches and as a source across the Bæla fan.

MODPATH was used to track particles from the wellfield to their recharge or source areas in Layers 2 and 3, i.e. to 'reverse-track' the groundwater flow from sink to source. Travel times were also calculated. Layer 1 is absent from the wellfield area and so was not considered.

The tracking of particles from the wellfield area within the aquifer (Layer 2), shown in Fig.2, indicates that the main sources of groundwater are the Lågen and the fish dam to the west and northwest. Transit times to the wellfield are short, typically being between 25-60 days. This agrees with tracer test results from Dahl et al (1971). A minor contribution comes from infiltration from the Bæla and from upward vertical flow from the underlying Layer 3. Groundwater in Layer 3 flowing towards the wellfield originates from two localised regions to the northwest and northeast. (see Fig. 2) The travel times to the wells within these layers are in excess of 1500 years.

Groundwater discharging from Layer 3 into the upper section of the Bæla may re-infiltrate across the fan. The low permeability of Layer 3, however, is likely to limit the groundwater contribution to the stream under 'normal' groundwater conditions.

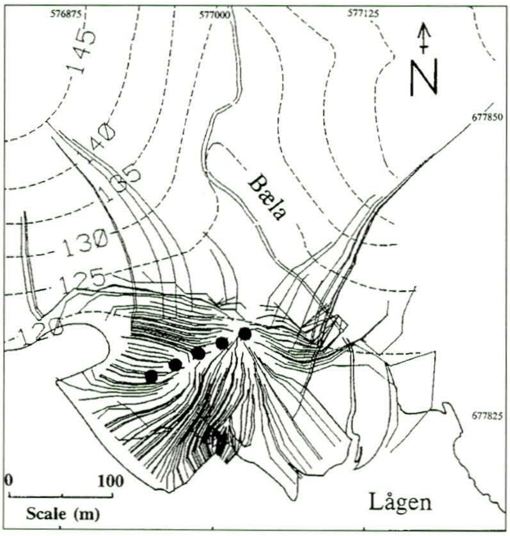

Fig. 2. Pathlines for the Bæla fan aquifer (Layer 2) generated by the reverse-tracking of particles from the Korgen wellfield area to source. Abstraction boreholes are marked with black dots. Dashed lines show modelled groundwater head distribution (metres above sea level).

Potential pollution sources

Five potential pollution sources were identified: i) the Lågen and the fish dam; ii) the Bæla stream; iii) a road traffic accident on the E6; iv) a railway accident on the Oslo-Trondheim line northeast of the wellfield and v) the gravel quarry in the Hovemoen area.

The Lågen and the fish dam are the biggest potential pollution sources. It is clear from Figure 2 that the Korgen wellfield is vulnerable to pollution occurring in either. The short transit times mean that bacteriological as well as chemical pollution is a potential problem. However, a corollary of this is that should a pollution event occur, rapid flushing of the aquifer would be possible. It should be noted that the fish dam has been filled in since the completion of this project and thus no longer represents a pollution threat.

The Bæla stream is capable of transporting pollutants originating within the entire surface water catchment area. Upstream, the Bæla acts as a groundwater sink. However, across the Korgen fan it acts as a source and it is along this stretch of the stream that a pollution threat is posed. During flood conditions, significant infiltration may occur should the Bæla stream overflow. However, dilution of any pollutants under these conditions would be considerable and would significantly reduce the pollution threat. Furthermore, the short groundwater transit times from the Bæla to the wellfield would enable rapid flushing of the pollutants following a pollution event.

An accident on the E6 road or a railway accident would both result in a pollution plume entering Layer 3 north or northeast of the wellfield. The MODPATH simulations show that such a plume would probably take over 1500 years to reach the wellfield. Furthermore, only pollution occurring in a restricted area would reach the wells as pollution elsewhere would flow to the Lågen. However, an increase in the groundwater level may result in rapid shallow groundwater flow in the upper coarse-grained layer. Much of this shallow flow would probably be intercepted by the Bæla stream and so the greatest pollution threat is likely to come from re-infiltration of groundwater as the stream crosses the Bæla fan.

As the gravel quarry in the Hovemoen area lies on the other side of a groundwater flow divide from the wellfield, it is unlikely that a pollution event in the quarry area could directly influence the groundwater quality at Korgen.

Protection zones proposal

Three groundwater protection zones are suggested, designated Zones I to III. These zones, shown in Fig.3, assume the land-use restrictions in the existing protection scheme. The full extent of Zone III is not shown as it extends beyond the area covered by the digital terrain model. It is, however, identical to the Zone III currently in use.

Zone I is based on the 60 day travel time to the wellfield recommended by the Norwegian State Institute for Public Health (SIFF). This is based on the life expectancy of commonly occurring bacteria and is intended to protect the wellfield from bacteriological pollution. It is clear that a complete protection is not possible because of the short transit times from the Lågen to the wellfield. A sub-zone, Zone Ia, includes the immediate vicinity of the wellfield. Zone II is designated as the groundwater recharge area supplying the Bæla fan area, including the Korgen waterworks. Zone III represents the surface water catchment area. It includes the Hovemoen area as there is some uncertainty concerning the geology and hydrogeology of this area.

It should be emphasised that the Lågen itself is well protected from pollution, particularly following a series of clean-up projects on the Mjøsa completed during the 1980's. No significant pollution event has occurred at the waterworks since this time. This project emphasises the vulnerability of the Korgen waterworks in the unlikely event of pollution entering the Lågen.

The protection zones proposed are similar to those already in existence and to a large extent support the work completed to date. The most significant difference is that the Zone I proposed here, representing the most vulnerable part of the aquifer, is larger than the existing Zone I. The current work has also highlighted the vulnerability of the Korgen waterworks to pollution in the Lågen and the fish dam. The potential importance of the infiltration of polluted water from the Bæla stream into the aquifer has also been demonstrated.

Acknowledgements

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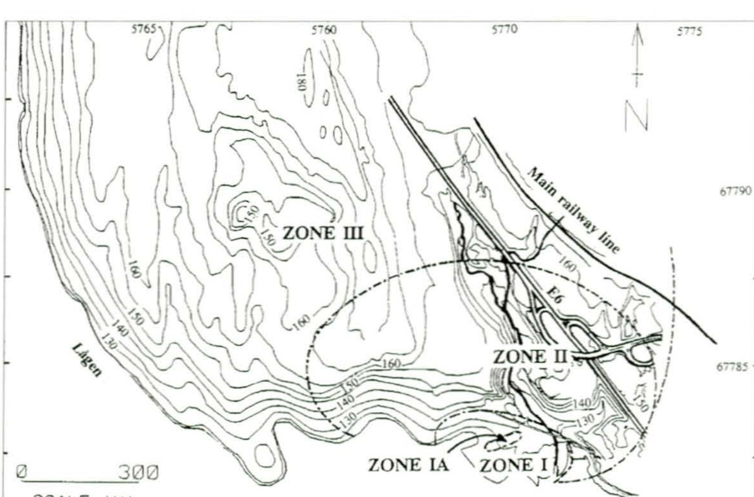

Fig. 3. Suggested groundwater protection zones for the Korgen wellfield.