Hydrogeological investigation for the PEGASUS project, southern Skåne, Sweden

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Master Thesis
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Content

Cover Picture: Picture over the investigated area, taken by C. Sparrenbom from well location 1 towards well location 2 and 3

NOTE: names of villages and rivers have been excluded as a request from SLU due to their ongoing research in the area.

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Abstract: SLU (Swedish University of Agricultural Sciences) have had a project ongoing in a catchment area in southern Skåne for 20 years where they study how pesticide occurrence in surface waters correlate to the sort and amount used on the agricultural fields. A new project started by SGI (Swedish Geotechnical Institute) called PEGASUS (PEsticide occurrence in Groundwater, A Study for sustainable Use in Skåne) has begun an investigation in the same catchment to study the pesticide behavior and effects in the deeper groundwater. This paper is a geological and hydrogeological investigation of the catchment area for the PEGASUS project.

The catchment area is located in a valley that is partly formed by a river and partly by faulting. The river's course is anthropogenically modified by a culvert system draining the agricultural fields and the river emerges first in the SE part of the catchment area. The valley sediments consist of an upper and lower glaciofluvial sand divided by a silty clay layer. The surface sediments consist of a clayrich till which makes up 90 % of the surface sediments, the remaining 10 % consists of glaciofluvial sediments and postglacial sediments.

There are two groundwater divides within the investigated aquifer, one in the northern part of the catchment area and one to the west of the catchment area. The groundwater gradient follows the surface water gradient which is SE and E towards the river. The recharge from surface water to the upper aquifer is low meaning that recharge likely occurs during heavy precipitation periods. The average age of the groundwater is *c.* 40-60 years. The hydraulic conductivity was calculated based on three different methods, Hazen's method, slugtest and percolation tube test. The results varied between these methods but the general hydraulic conductivity of the upper aquifer ranges from $2*10^{-4}$ m/s, for the coarsest sediments, to $2*10^{-7}$ m/s, for the finest sediments.

Keywords: South Sweden, South Skåne, geology, hydrogeology, PEGASUS

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Hydrogeologisk undersökning för PEGASUSprojektet, södra Skåne, Sverige

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Sammanfattning: SLU (Sveriges Lantbruksuniversitet) har ett pågående projekt i ett område i södra Skåne sedan 1989 där de studerar hur bekämpningsmedel i åar korrelerar med vad som används på åkrarna. Ett nytt projekt, initierat av SGI (Statens Geotekniska Institut), kallat PEGASUS (PEsticide occurrence in Groundwater, A Study for sustainable Use in Skåne) har påbörjat en undersökning i samma område för att studera hur bekämpningsmedel uppför sig och påverkar grundvattnet. Detta arbete är en geologisk och hydrogeologisk undersökning av området åt PEGASUS-projektet.

Området ligger i en dalgång som dels är formad av en flod och dels av förkastningar. Floden har sin början i sydöstra delen av området. Dalgången är fylld med glaciala flodsediment. De glaciala flodsedimenten kan delas upp i två sedimentenheter, en övre enhet och en undre enhet. Dessa delas av ett lerlager som ligger mellan dem. De översta sedimenten består till 90 % av leriga moräner och de övriga 10 % består av glaciala flodsediment och andra senglaciala sediment.

Där finns två stycken grundvattendelare i området som skärmar av det undersökta magasinet från andra närliggande, den första grundvattendelaren ligger norr om området och den andra väster om området. Grundvattnet i det övre magasinet har en gradient och ett flöde mot ån. Från vattenbalansberäkningar kan vi konstatera att akvifären fylls på med mycket lite vatten uppifrån och att påfyllning troligen sker vid perioder av kraftigt regn. Vattnets ålder är *c.* 40-60 år. Den hydrauliska konduktiviteten beräknades med hjälp av tre olika metoder, Hazen’s metod, slug-test och perkolationsrörs-test. Resultaten varierade mellan de olika metoderna men den generella hydrauliska konduktiviteten varierar från $2*10^{-4}$ m/s, för de grövsta sedimenten, till $2*10^{-7}$ m/s, för de finaste sedimenten.

Nyckelord: Södra Sverige, Södra Skåne, geologi, hydrogeologi, PEGASUS

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1 Introduction

1.1 Background

There are numerous factors controlling pesticide leakage to groundwater, e.g. the hydrogeological properties of the sediment, pesticide properties and land use. Soils with a high sand content and a low biomass have a low pesticide degration rate and high pesticide mobility. The pesticide mobility is, apart from its chemical characteristics and the microbial activity in the soil, related to groundwater velocities, which in turn are related the grain size distribution and porosity of the sediments. Sediments with high content of gravel and sand yield a high effective porosity whereas sediments with high clay content have a low effective porosity (Axelsson 2003).

Another important factor is the thickness of the unsaturated zone (the zone between the groundwater surface and the ground surface), which control the time it takes for a pesticide to reach the groundwater zone. The groundwater level varies naturally throughout the year, affecting the thickness of the unsaturated zone (Axelsson 2003).

Kreuger (1998) has since 1989 kept a pesticide transport project running in a catchment area in southern Skåne. The project focuses on pesticide concentrations within the surface water and sediments in relation to agricultural pesticide usage. Kreuger and colleagues (Krueger 1998, Kreuger *et al.* 1999) have found a correlation between the amount of agricultural pesticide used and the concentrations found in stream water.

This work is the first part of a new project, in which we study pesticide behaviour and transport to and within the deeper groundwater of the catchment area. The project is called PEGASUS (PEsticide occurrence in Groundwater, A Study for sustainable Use in Skåne) and is governed by SGI (Swedish Geotechnical Institute) in Malmö in cooperation with Lund University. The project will last for three years and was initiated during the summer of 2009.

A number of similar studies have been carried out over the past five years in the United States (Steele *et al.* 2008) and they have shown pesticide contamination of the groundwater. In the presented investigations, the pesticides have been applied on agricultural land and contaminating the groundwater as a result of downward movement and subsurface transport. Detection of pesticides in the groundwater is a difficult task due to numerous factors e.g. the multitude of pesticides, the intensity of pesticide application, time of application in relation to major recharge events of the aquifers, frequency of precipitation and irrigation, water table depth, properties of the soils and management of the land. Transformations of pesticides have a relatively large impact on the detection rates. This is due to pesticides degradation, resulting in an undetectable parent compound. The rate of transformation has been found to be largest in the upper soil root region and decreasing with depth mostly as a result of a decrease in microbial populations (Steele *et al.* 2008).

The rates at which pesticides and their metabolites move through the soil are also related to their tendency to adsorb to soil particles and geologic materials (Steele et al 2008).

1.2 Pesticides

Pesticides are chemicals used to eliminate or remove harmful insects, vegetation, fungi and microorganisms. The pesticides used in Sweden have to be approved by the Swedish Chemicals Agency (Kemikalieinspektionen) (Axelsson 2003).

A pilot study made by Hagerberg (2007) concludes that over 40 % of wells reaching the bedrock and 50 % of wells withdrawing water from unconsolidated sediments, within high agricultural usage areas, exceed proposed minimum values (as proposed by SGU:FS:2008:2) for one or more of the following substances; chloride, sulphate, nitrate, ammonium, cadmium, mercury, arsenic, lead or pesticides. 30 % of these wells exceed the environmental goal for good groundwater quality.

A similar local investigation has been carried out by Leander and Jönsson (2003). They investigated pesticide concentrations in Alnarpsströmmen, which crosses western Skåne from around Barsebäck in the NW to Skurup in the SE . Their result showed that 65% of the upper part of the groundwater table was contaminated with pesticides. Seven out of seventeen samples contained more than one type of pesticide.

Pesticides affect the environment in numerous ways, both direct and indirect. Direct effects could be high toxicity with a direct affect on human health or water and soil ecosystems and the environment in a short time span. Indirect effects are longlasting and affect the environment or humans slowly and the effects are not visible until after a long time (Axelsson 2003).

A study made by Laino 2009 relates the increased use of pesticides in USA with the increase of Alzheimer's disease. The result points towards a relation but more investigation is needed for a concluding result.

1.3 Purpose

The purpose of this work is to give a geological and hydrogeological overview of the catchment area used by Kreuger *et al.* (1998, 1999) for a better understanding of the aquifer systems in the area, the groundwater flow direction and velocities. This is the first step in a larger investigation about sorption, degradation and movement patterns of pesticides in the aquifer system.

1.4 Aims

This work aims to:

- Describe and characterize the geology in the catchment area.
- Describe and characterize the different aquifers

in the catchment area (number of aquifers, type of aquifers and how do they interact?)

- Describe groundwater flow direction and velocities in the different aquifers
- Calculate the water balance and aquifer recharge of the catchment area;
- Participate in investigating the age of the groundwater at different depths.

2 Catchment area

2.1 Area description

The investigated area is located in southern Skåne. There is an undulating topography throughout the area with an average height of 45 m above sea level (a.s.l.). The area is dominated by agricultural activities (Svensson 1999).

The dominating quaternary deposits within the catchment area is till. The total catchment area is 9 km^2 where arable land makes up 95% of the area. The surface soil contains on average 2.5 % organic matter. Apart from the cultivated crops during the growing season, the vegetation coverage is scarce and concentrated to gardens and agricultural borders (Kreuger *et al.* 1998).

The regional climate of the area is maritime due to westerly winds and the vicinity of the Baltic Sea. The annual mean temperature of the area was 7.2^{o} C in 1961-1990 (Kreuger *et al.* 1998).

During the late 1950's, the xeisting ditches in a large part of the area were replaced with a culvert system. 40 % of the field area is drained through this culvert system and the remaining parts are drained through tile installations that follow the natural drainage routes. These systems discharge the water into a stream which can be seen in figure 1. The stream has formed a small valley in the landscape that continues downstream (Kreuger *et al.* 1998).

2.2 Geology

The oldest known bedrock in the southern part of Skåne is made up of gneiss, gneisses granites and amphibolites. Their origin is uncertain and they are only visible at two locations, Romeleåsen (a horst located to the NW of Skurup) and at Torpaklint (a small horst) (Daniel 1992).

Overlying the bedrock is a limestone formation, which was formed during middle Cretaceous to the late Tertiary period. These sediments contain unconsolidated sandstone with a varying content of limestone and chalk. The limestone can in some parts reach a thickness of up to 1000 meters, preserved thanks to the Tornquist fault zone going through the area. The Tornquist zone has a direction of NW-SE and had its highest intensity during the Jurassic and Cretaceous periods (Daniel 1992). The area NE of the fault zone consists of older sedimentary bedrock whereas the SW consist of younger sedimentary bedrock. Due to the faulting of the area the limestone has an undulating upper boundary which is also visible through the undulation in the landscape. SW of Romeleåsen the Cretaceous limestone is overlain by Tertiary Dan limestone (Daniel 1992).

The limestone in the catchment area has an upper boundary at depths that ranges from 10 to 80 meters, the depth of the lower boundary is unknown (SGU).

Two till types are present in the catchment area, the dominating one is coarse clayey till (fig. 1). Coarse clayey till has a clay content of 15 – 25 %. The second till type is clayey sandy silty till (fig. 1) with a clay content of 5 – 15 % making it very similar to the coarse clayey till. Both till types have a low content of gravel and boulders. Limestone can be found in the till in areas where the upper limestone boundary is located close to the surface. Intermoraine sediments in the area are located at a general depth of 10 – 20 meters. The thickness of the intermoraine sediments can reach up to 35 meters in the south and thins out towards the north. (Daniel 1992).

Glaciofluvial sediments are few in the area and are mostly concentrated to low relief areas (fig. 1). The composition is the same as for the intermoraine sediments (Daniel 1992).

Glaciolacustrine sediments are also few within the area and are concentrated to the W of the catchment area in the N-S directed valley (Daniel 1992, 1988) (fig. 1). The composition of sediments varies between clayey silt and sand (Daniel 1992, 1988).

Postglacial sediments are few within the catchment and are located in the same area as the glaciofluvial and ice lake sediments (Daniel 1992, 1988) (fig. 1).

2.3 Hydrogeology

The limestone in SW Skåne has undergone major faulting. This has resulted in a valley known as Alnarpsdalen. The valley has been filled with coarse sediments forming a high conductivity aquifer. The aquifer is divided into two main parts, one aquifer to the NW and one aquifer to the SE (Fig. 2). The groundwater divide is located between Svedala and Skurup. The groundwater divide has a NE-SW direction. Parts of SE aquifer pass through the north region of the investigated catchment area. The sediments are composed of a gravel and sand mixture with a thickness of over 50 meters (Gustavsson *et al.* 2005).

The limestone directly under this aquifer has a lower conductivity compared to the limestone located to the NE and SW. The upper parts of the limestone to the NE and SW consist of chalk and are highly cracked resulting in a high conductivity (Gustavsson *et al.* 2005).

Overlying the Alnarpsdal sediment aquifer is glaciofluvial sediments composed of sand and gravel. These sediments constitute the upper aquifer in Fig 2. The glaciofluvial sediments are overlain by coarse

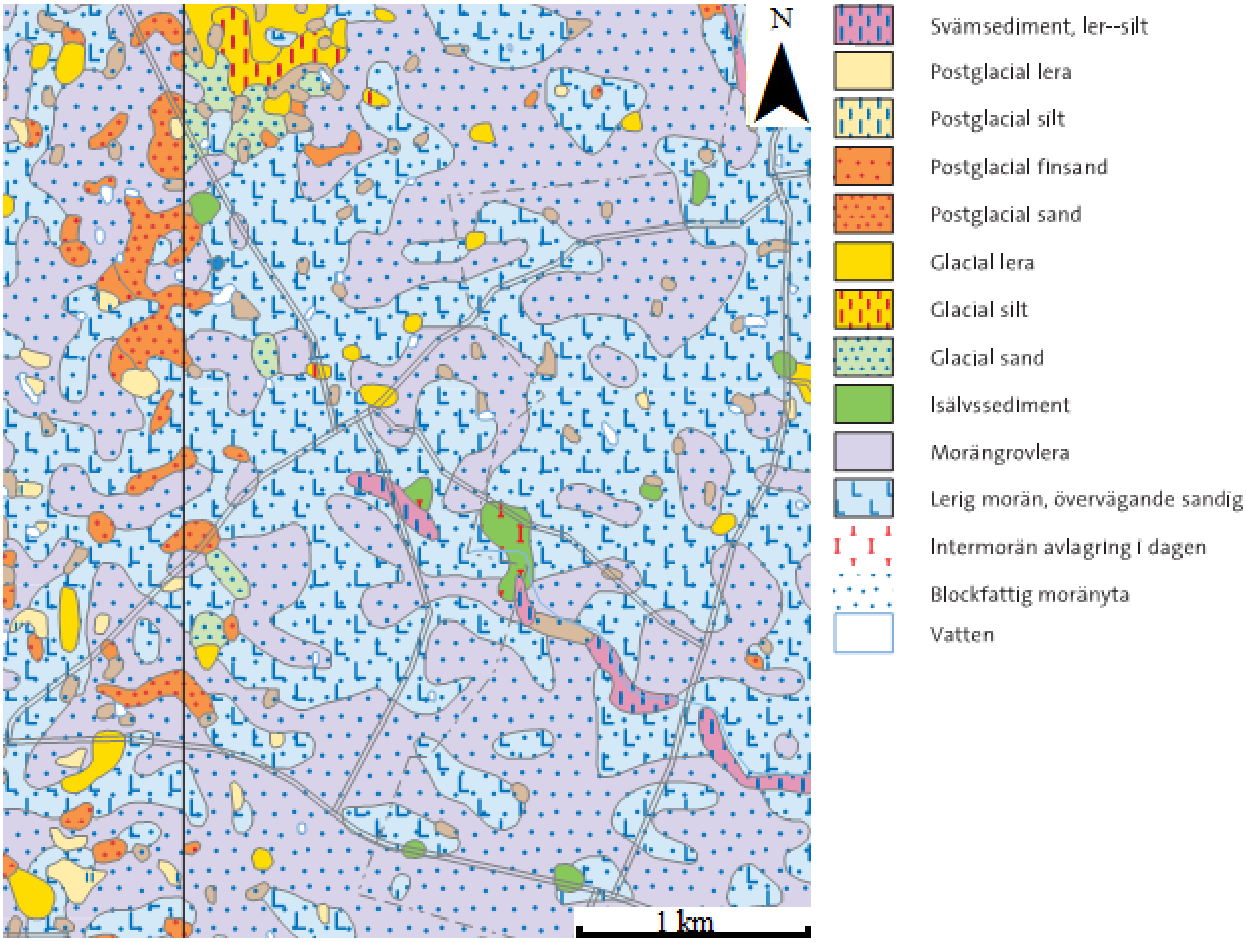

Figure 1. Quartenary map over the investigated area. Copyright of the background map from the National Land Survey of Sweden, grant I2010/0047.

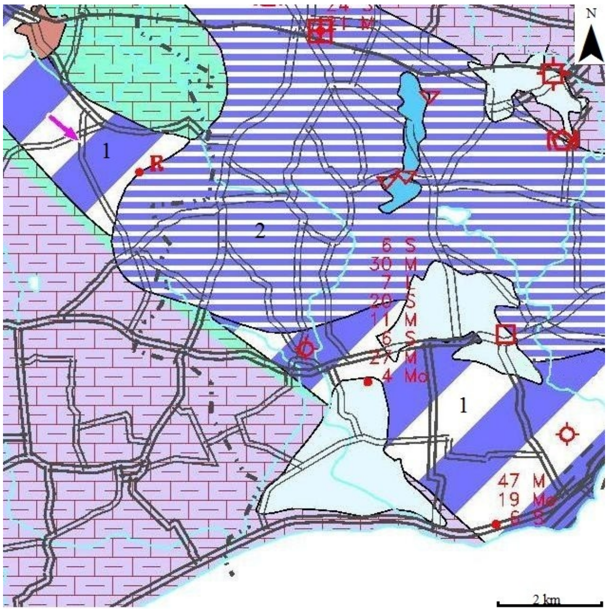

Figure 2. Map of the regional hydrogeology SW of Skurup. 1 is the SE aquifer and 2 is the upper investigated aquifer (Map taken from Gustavsson 1999).

clayey till and clayey sandy silty till constituting a confining layer to the aquifer (Gustavsson *et al.* 2005).

3 Methods

The methods used in this study are; mapping of existing wells, measurements of groundwater level in the already existing wells, sediment sampling during drilling and well establishment, grain size analysis (sieving and hydrometer analyses), Hazen's method, Hvorslevs slugtest, Bouwer and Rice slugtest, percolation tube test, water sample collection and water balance calculation.

3.1 Mapping of existing wells

The first thing that was performed in the area was a mapping of the existing wells. This was done to get an overview of the groundwater level, to construct a hydraulic gradient map over the area, and to generalize the groundwater flow direction. Each well location was measured with a GPS and the water level was measured using a flat tape water level meter. All wells in the area were not accessible due to gravel or concrete cover or lack of approval to enter the estates. The wells used are shown in Fig 3, and the measured groundwater level and well location can be seen in appendix A. Geological data received from the Swedish well archive (SGU) was studied to get an overview of the geology of the catchment area. The purpose of this was to create two profiles through the catchment

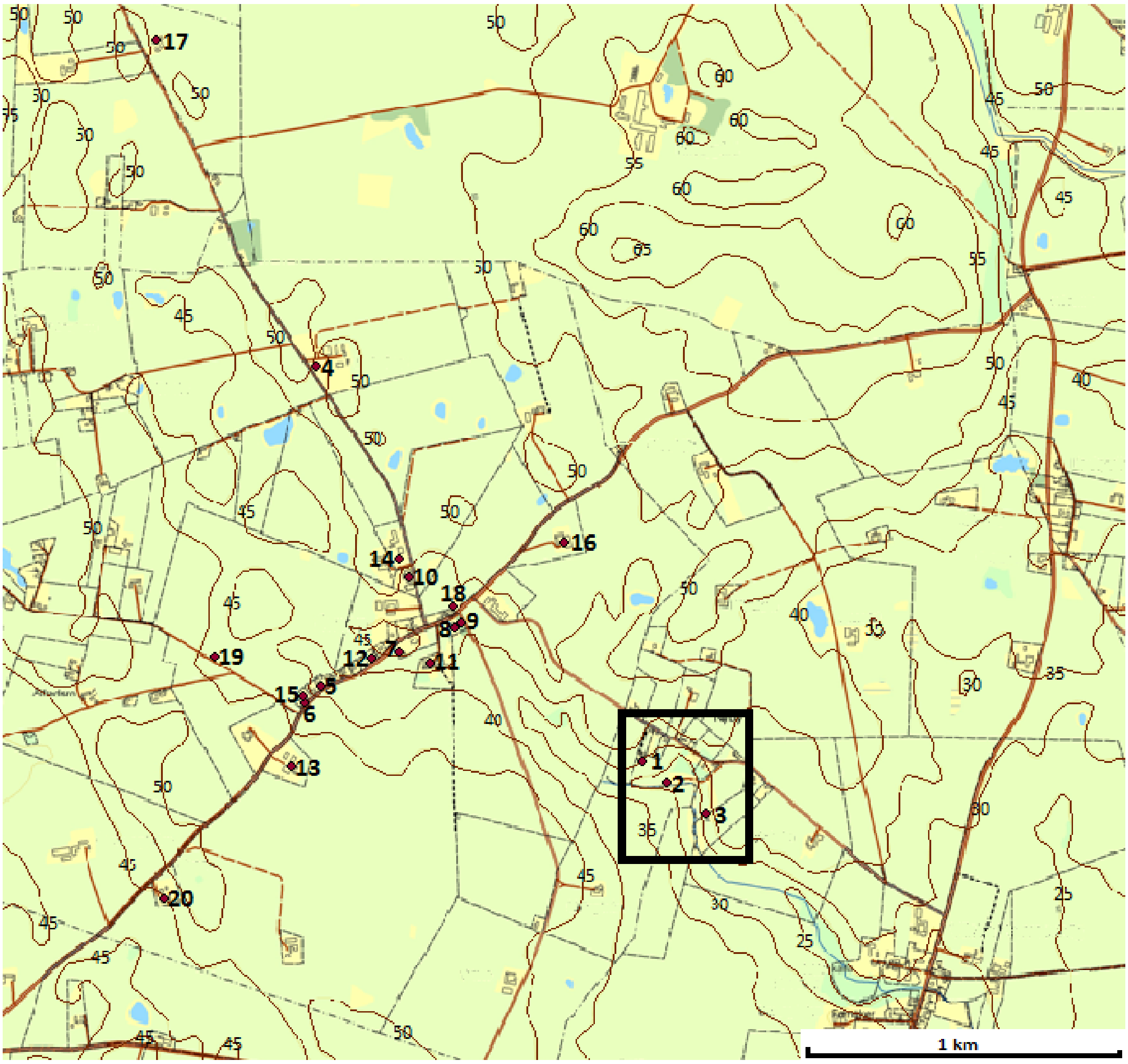

Figure 3. A map showing the location of the wells used for the hydraulic gradient map, wells 1 – 3 are the newly drilled wells within the PEGASUS project and wells 4 – 20 are the already existing wells. Copyright of the background map from the National Land Survey of Sweden, grant I2010/0047.

area to complement the profile made from the drilled wells described under 3.2. The location for these profiles can be seen in Fig 4.

3.2 Well drilling

As a more thorough research, six (2") monitoring wells and one larger (158,3 mm Ø) well were drilled in close connection to a surface watersampling station used for environmental monitoring.

The larger well was drilled at site 3 shown in Fig 4 with a DTH – down the hole drilling with ring bit, ("robit casing system"). The monitoring wells were driven down with a pneumatic hammer and had a closed point.

A total of seven wells were drilled to different depths at three different locations shown in Fig 3. At location 1 are three monitoring wells located, with depths of 35 m, 18 m and 10,5 m, at location 2 are two monitoring wells located with a depth of *c.* 27 m, and 7 m and at location 3 is the larger well located with a depth of 22 m and one monitoring well with a depth of 5.5 m.

During the drilling, samples were collected every meter for the deeper monitoring wells and every ½ m for the large well and the shallower monitoring wells. The samples were placed in pre-marked plastic bags and transported to the coldroom (4°C) for storage and then analysed in the laboratory.

3.3 Grain size analysis

3.3.1 Sieve analysis

The samples collected from the drilling were dried in an oven at 105 °C for 24 hours. Once dried the samples were divided for sieving and hydrometer analysis. The sample size is based on the grain size, 200 g for

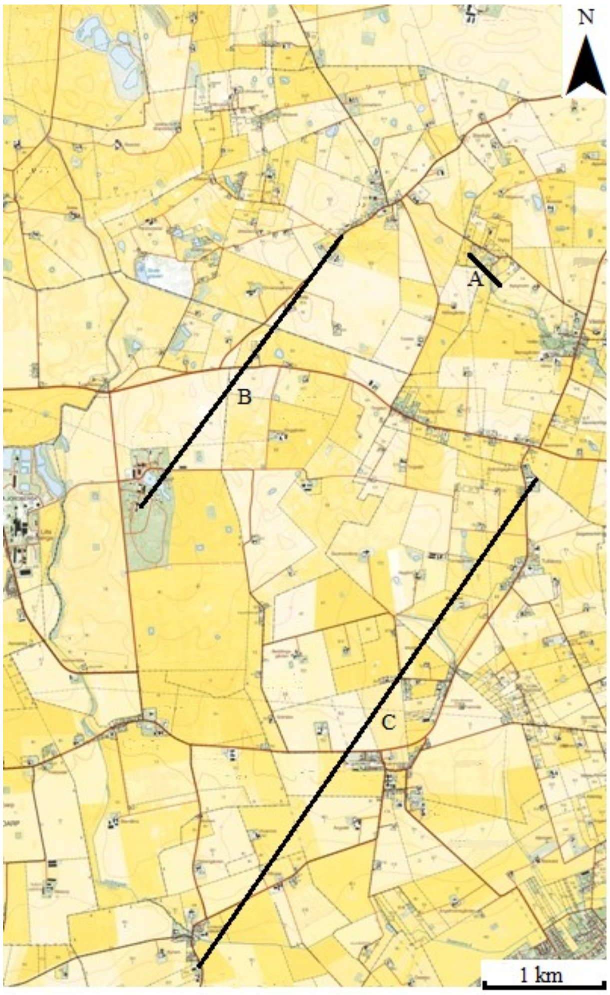

Figure. 4. The location for the 3 profiles over the local area, Copyright of the background map from the National Land Survey of Sweden, grant I2010/0047.

finer sediments and 500 g for coarser sediments. A 200 g sample was used for each sieving analyses due to the fact that all samples analysed, mainly contain fine sediments. Each sample was then washed through a 0,0063 mm mesh sieve to remove the finest grains and oven dried again at 105 °C for 24 hours. Once dried, the samples were weighted again, to measure the amount of sediments <0,0063 mm. The coarser part of the sample was then put in a sieving column, which was placed in a sieve shaker for 15 minutes. The amount of sediments for each fraction was weighted. The results were put in the excel file KORNSTOR.xls to calculate the percentage variation for further analyses, the result can be seen in appendix B.

3.3.2 Hydrometer

Hydrometer analysis was conducted on samples that, from a visual inspection, had a content of >10 % grains smaller than 0,0063 mm. The sample size ranged from 25 – 100 g depending on the content of grains smaller than 0,0063 mm. The amount of 100 g was used for all samples, except those from the deeper part of drill site 3, for which 25 g were used. The samples were mixed with 100 ml sodium phosphate ($Na_4P_2O_7$) and 300 ml distilled water in a 1000 ml cylinder. The cylinder was sealed with para-film and placed in a rotating cradle for 15 minutes. Distilled water was then added up to the 990 ml mark and the content was mixed with an agitator for 1 minute. Distilled water was used to wash off any sediment on the agitator and to fill the cylinder to the 1000 ml mark. A hydrometer was placed in the cylinder and measurements were taken after 30 seconds, 1, 2, 5, 10, 20, 50, 100, 200, 400 minutes and 24 hours from the start. The procedure was restarted after 24 hours until the results coincided with the previous results. The results were then put in the excel file KORNSTOR.xls to calculate the percentage variation for use in Hazen’s method. The result can be seen in appendix B.

3.4 Hazen’s method

The grain size results from the sieving were used to calculate the hydraulic conductivity from “Hazen’s equation”. The equation is only usable on samples with an effective grain size between 0,1 – 3 mm (Fetter 2001).

From the grain size analysis the hydraulic conductivity was calculated through Equation 1 (Hazen in Koenig *et al.* 1911). The unit for Equation 1 is in feet per day which will be recalculated into metres per second.

Equation 1

$$V = 8200 d^2 s$$

Where

V = water velocity (feet/day)

d^2 = the effective grain size and

s = the hydraulic gradient

3.5 Slugtest

Hvorslev’s slugtest (Fetter 2001) is a hydraulic conductivity test carried out in the field.

One to two litres of distilled water with added sodium chloride (NaCl) were poured into the well. A flat tape water level meter was used to measure the change in the water table until the water level had fallen to at least 37 % of the original level. Measurements were taken in even intervals. The intervals used varied between the wells due to different hydraulic conductivities. The measurements were then added to Excel to calculate the time it took for the water to fall to 37 % of the original water level. Hvorslev’s equation, Equation 2 (Fetter 2001), was used for all the wells except for the shallow well at well location 1. Because the filter did not completely penetrate the groundwater surface at the time of the test. Bouwer and Rice slugtest, Equation 3 (Fetter 2001), had to be used for that particular well.

Equation 2

$$K = \frac{r^2 \ln\left(\frac{L_e}{R}\right)}{2L_e t_{37}}$$

Where
K = hydraulic conductivity (m/s)
r = radius of the well casing (m)
R = radius of the well screen (m)
L_e = the length of the well screen (m)
T_{37} = time it takes for the water to fall to 37 % of the initial change (s)

Equation 3

$$K = \frac{r_c^2 \ln\left(\frac{R_e}{R}\right)}{2L_e} \frac{1}{t} \ln\left(\frac{H_0}{H_t}\right)$$

Where
K = hydraulic conductivity (m/s)
r_c = the radius for the well casing (m)
R = the radius for the gravel envelope (m)
R_e = effective radial distance over which head is dissipated (m)
L_e = the length of the screen or open section of the well through which water can enter (m)
H_0 = drawdown at time t = 0 (m)
H_1 = drawdown at time t = t (m)
t = is the time since H = H_0 (s)

3.6 Percolation tube test

The percolation tube test is a lab test to calculate the hydraulic conductivity using sampled sediments. A plastic tube with a plug containing a small hose was used. The plastic tube was filled up with 5 cm of sediments. The sediments were stamped with a wooden shaft to get it as dense as possible to reflect natural packing as good as possible. The sediments in the tube were soaked and then the tube was filled with water. The time it took for the water level to fall from 30 cm (h_0) above the sediments to 20 cm (h_1) above the sediments was measured These values were then implemented in Equation 4 (pers. com. Charlotte Sparrenbom 2009-10-17).

Equation 4

$$K = \frac{l}{t} \ln\left(\frac{h_0}{h_1}\right)$$

Where
K = hydraulic conductivity (m/s)
l = length of the sample (m)
t = time for the water to fall from h_0 to h_1 (s)
h_0 = initial water level, 30 cm above the sediment surface (m)
h_1 = target water level, 20 cm above the sediment surface (m)

3.7 The CFC-Method

It is important to know what age the groundwater has because different pesticides has been used throughout the years. Most of the pesticides used in the 1940-1970 has been removed from the market due to health issues. If the groundwater age is known it narrows down the possible pesticides that may be present in the water samples. The CFC-method can date water with an age younger than *c.* 60 years. The method focuses on the concentration of CFC-gases in the groundwater.

CFC-gases (ChloroFluoroCarbon compounds) are used in spraybottles, as coolants and as isolation in some pipe types. Different forms of CFC-gases has been used throughout the years since 1940. The different CFC-gas variants can be used to date groundwater since it follows the precipitated water through the ground to the groundwater (Hinsby *et al.* 1997).

When the concentration of man made CFC gases in the atmosphere rises it will also rise in the precipitation water. Since aquifers are recharged from precipitated water the anomalies will also be seen in the groundwater. As much as 77 % of the world's production of CFC's contain CFC – 11 and CFC – 12. The remaining 23 % are composed of CFC – 113, CFC – 114 and CFC – 115. CFC – 11 and CFC – 12 can be used to date water younger than 50 – 55 years under good circumstances. CFC – 113 can be used to date water younger than 30 years (Hinsby *et al.* 1997).

Special equipments are used to take groundwater samples for CFC-gas analysis. This because the concentration of CFC in the water sample will be altered instantly if it gets in contact with the atmosphere. There are a number of different methods that can be used in the field to avoid atmospheric contact (Hinsby *et al.* 1997).

3.8 Water balance

To know the amount of water infiltrating to the aquifers it is needed to calculate the water distribution within the catchment area. This is calculated with a water balance equation. The water balance is based on the following factors (Jönsson 2000).

1. Added water amount:
   - precipitation (N)
   - surface water recharge (Q_{yt})
   - groundwater recharge (Q_{gt})

2. Removed water amount:
   - evapotranspiration (A_{ET})
   - surface water discharge (Q_{ya})

groundwater discharge (Q_{ga})

3. Changes in the groundwater aquifer (ΔM)

The surface water recharge and discharge can be added to form a net surface water term (Q_y) ($Q_y = Q_{yt} + Q_{ya}$). The same can be done for the groundwater recharge and discharge, forming a net groundwater recharge or discharge (Q_g) ($Q_g = Q_{gt} + Q_{ga}$). This can be combined to form Equation 5.

Equation 5

$$N = A_{ET} + Q_y + Q_g + \Delta M$$

Where
N = precipitation
A_{ET} = evapotranspiration
Q_y = net surface water
Q_g = net groundwater
ΔM = changes in the groundwater aquifer

4 Results

4.1 Geology

4.1.1 Geological profiles from the catchment area

Profile A shown in Fig 5 (see Fig 4 for location) is a profile over the newly drilled and investigated area and is based on the grain size analysis from the three deeper wells at well location 1, 2 and 3. There are two main units that can be distinguished in the profile. The lowest consists of silty clay. The origin of this layer is unknown but could be either of marine or lacustrine origin. The second main unit is a glaciofluvial sediment that can be divided into three subunits. The lowermost subunit consists of silty medium sand fining upwards. The intermediate subunit consists of silty gravelly medium to coarse sand, also with a fining upwards throughout the unit. The upper subunit consists of silty sand, which is also fining upwards. The intermediate and lower subunit forms the upper aquifer. There is also a general change in grain size towards the NW, with finer sediments towards the NW and coarser towards the SE.

Profile B shown in Fig 6, is located to the west

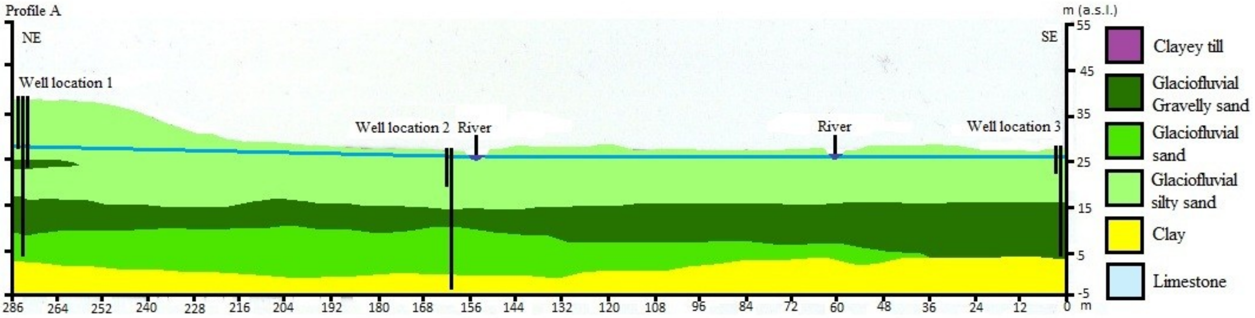

Figure. 5. Profile A. Showing the geology based on the drilled wells at the 3 well locations. The lower unit consits of a claeyey silt overlain by glaciofluvial sediments. The blue line represent the groundwater level.

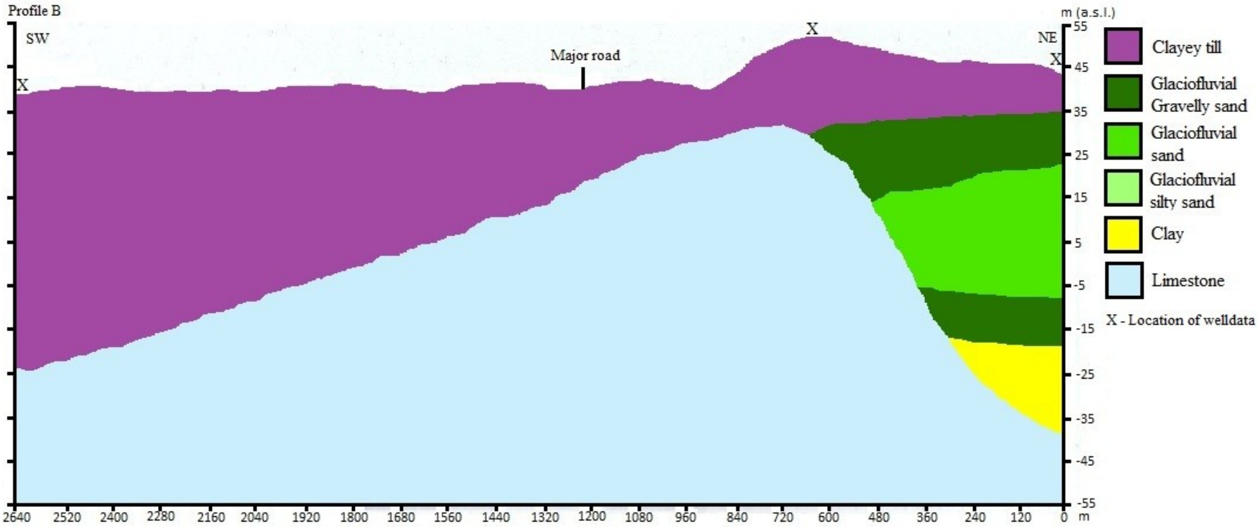

Figure 6. Profile B. Showing the geaology W of the drillsites, The glaciofluvialsediments to the NE are connected with those in profile A.

of profile A. The profile is constructed from geological descriptions taken from the SGU well archive and the topography is based on the soil map by Daniel (1988). The area can be divided into two main areas. A SW area containing a thick clayey till layer on top of limestone. The second area is located to the NE and can be divided into three main units. A lower clay unit, an intermediate glaciofluvial sediment and an upper clayey till unit. The glaciofluvial sediments can be further divided into three subunits. A lower gravel unit, intermediate sand unit and an upper gravel unit.

Profile C shown in Fig 7 is located south to the SW of profile A and consists of two units. An upper clayey till and a lower limestone. The profile is constructed from geological descriptions taken from the SGU well archive and the topography is based on the soil map by Daniel (1988). This profile is situated outside the valley filled with glaciofluvial deposits. The glaciofluvial sediments found in profile A and B are likely to be connected i one larger unit.

4.1.2 Grain size analysis

The result from the grain size analysis varies between the three sites, due to the two different drilling techniques. The hammered metal pipes at drill sites 1, 2 and the shallow well at drill site 3 have filter holes with 8 mm diameter, limiting the amount of coarser fractions brought up by this technique compared to the DTH drilling technique.

Results from drill site 1 (see figure 3 for location)
The sediment column can be divided into 3 units, one from 0 – 21 m, one from 21 – 30 m and one from 30 – 35 m below ground surface (b.g.s.) (fig. 5).

The uppermost unit (0 – 21 m b.g.s.) at drill site 1 constitute a silty fine sand with a sand content of *c.* 50 %, a silt content of 35 – 50 % and a clay content of up to 15 %. A thin subunit at 13 – 14 m b.g.s. has generally coarser sediments and a minor gravel content (5 %). The second unit at 21 – 30 m b.g.s. contain coarse sand with a minor silt content (<2 %) and a small content of gravel (up to 5 %). The third unit at 30 – 35 m b.g.s. contain medium sand with a minor silt content (<2 %).

All the units have a fining upwards structure.

Results from drill site 2 (see figure 3 for location)
The sediment column can be divided into 3 units, one from 0 – 11 m, one from 11 – 15 m and one from 15 – 27 m b.g.s. (fig .6).

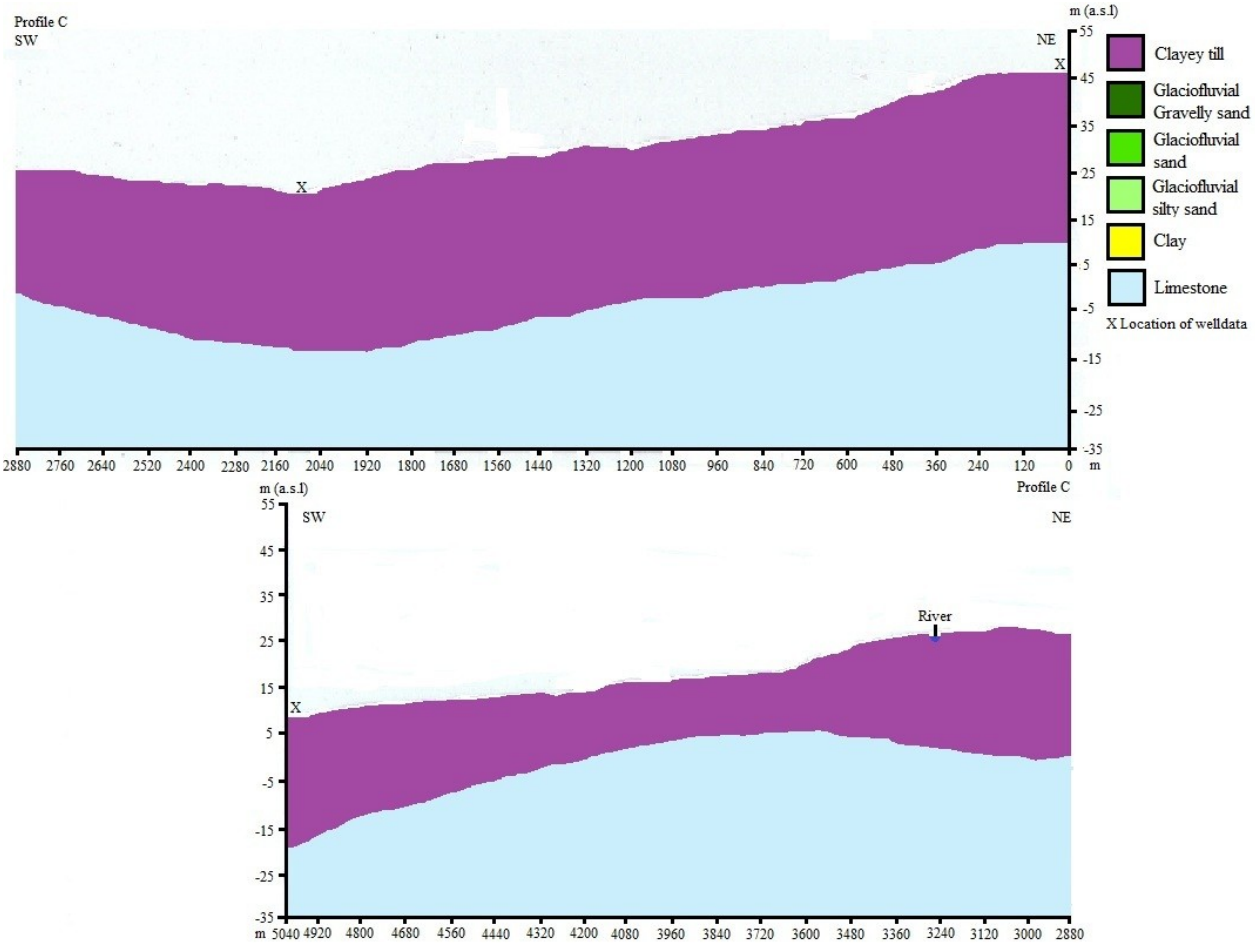

Figure 7. Profile C, note that it has been divided to fit on the page. Showing the geology S of the drillsites which consists of limestone and till.

The uppermost unit at 0 – 11 m b.g.s. contains up to 95% fine sand with little to no silt (0 – 5 %) and gravel (0 – 5 %). The second unit at 11 – 15 m b.g.s, contains 92 – 95% coarser sand and a higher gravel content (5 – 8 %). The third unit at 15 – 27 m b.g.s, contains 80 – 100 % coarser sand with a silt content of 0 – 20 % and a minor gravel content (0 – 3 %).

All the units here also have a fining upwards structure.

Results from drill site 3 (see figure 3 for location)
The sediment column can be divided into 3 units, one from 0 – 12 m, one from 12 – 22.5 m and one from 22.5 – 35 m b.g.s. (fig. 7).

The upper unit at 0 – 12 m b.g.s contains a fine sand/silt mixture (80 – 100 % fine sand and 0 – 20 % silt). There are a few minor layers within the upper unit that contain somewhat coarse sediment. The second unit at 12 – 22.5 m b.g.s. varies between 50 – 80 % sand content with 20 – 50 % gravel content. The third unit at 22.5 – 35 m b.g.s, contains a silty clay composition with a high content of silt (up to 70 %) and clay (up to 30 %).

All the units here also have a fining upwards structure.

The particles roundness vary and a dominating type cannot be established. Details from the results of the grain size analyses can be viewed further in appendix B.

4.2 Hydrogeology

4.2.1 Aquifers

From the geologic description above, it can be concluded that there is one upper aquifer in the glaciofluvial deposits and theoretically a lower aquifer. The upper aquifer located in the glaciofluvial deposits can be seen in profile A and B in Fig 5 and 6 respectively. The aquifer is thicker in profile B compared to profile A. The aquifer can be seen as semi confined as it is confined in parts by a low permeable clayey till layer, but unconfined where the glaciofluvial sediments reach the ground surface. The lower aquifer is should be located below the clay layer in profile A. This has not been confirmed since the drill was not able to penetrate all the way through the clay layer.

Since the clay layer was not penetrated, we focus our further analyses on the upper aquifer.

4.2.2 Conductivity

Table 1. Hydraulic conductivity results from the Hazen’s method, the slug-tests and percolation tube tests at well location 1

Depth m b.g.s.	**Hydraulic Conductivity (m/s)**		
	Hazen’s	**Slug-test**	**Percolation tube**
10-10,5		$1,4*10^{-8}$	
16-17	$7,3*10^{-7}$		
18-19	$1,3*10^{-7}$		$3,9*10^{-5}$
21-22	$1,0*10^{-6}$		
25-26	$1,2*10^{-7}$		
28-29	$2,4*10^{-8}$		
29-30	$1,2*10^{-7}$		
34-35	$1,5*10^{-7}$	$2,0*10^{-7}$	$2,3*10^{-4}$

Table. 2. Hydraulic conductivity results from the Hazen’s method, the slug-tests and percolation tube tests at well location 2

Depth m b.g.s.	**Hydraulic Conductivity (m/s)**		
	Hazen’s	**Slug-test**	**Percolation tube**
3-4	$0,5*10^{-8}$		
7-7,5		$5,8*10^{-6}$	$3,1*10^{-5}$
11-12	$3,0*10^{-8}$		
21-22	$3,6*10^{-8}$		
27-28	$8,9*10^{-8}$		
unknown		$4,9*10^{-6}$	

4.2.2.1 Well location 1

The hydraulic conductivity results from the Hazen's method indicate a variation with depth, which can be seen in table 1. The zone with the highest hydraulic conductivity, at about 1,0*10^{-6} m/s, is located between 21 – 22 m. It most likely reflect the hydraulic conductivity for sediment just above and below this level. The lowest hydraulic conductivity of about 2,4*10^{-8} m/s, can be found at 28 – 29 m b.g.s. This is most likely just a minor zone since the value just above and below are considerably higher. The Hazen's method was not relevant for the near surface sediments due to the small grain size.

The hydraulic conductivity results from the slug-test are similar to the results from the hydraulic conductivity calculations from the Hazen's method shown in table 1. Slug-tests were carried out on the shallow and the deep monitoring wells. Due to sediment blockage by leakage into the intermediate monitoring well, a slug-test was not carried out in this well. The hydraulic conductivity calculated from the slug-test results for the deeper monitoring well was 2,0*10^{-7} m/s and for the shallow well 6,0*10^{-6} m/s.

The percolation tube test generally yielded higher hydraulic conductivity values of 10^{2} to 10^{3} higher compared to the general values of other two methods. This is shown in table 1. The percolation tube test was carried out on sediments from the deep and intermediate monitoring wells from drill site 1 and resulted in K values of 2,3*10^{-4} m/s and 3,9*10^{-5} m/s respectively. A percolation tube test was not possible for the shallower sediments due to lack of sample for that specific level.

4.2.2.2 Well location 2

The hydraulic conductivity results from the Hazen's method indicate minor variations throughout the sedimentary column at well location 2. This is shown in table 2. The hydraulic conductivity varies between 0,5*10^{-8} m/s and 9,0*10^{-8} m/s. A higher variation might be plausible, but hasn't been shown due to the lack of samples for analysis.

The hydraulic conductivity results from the slug-test were 10^{2} to 10^{3} higher compared to those

Table. 3. Hydraulic conductivity results from the Hazen's method, the slug-tests and percolation tube tests at well 3.

Depth m b.g.s.	**Hydraulic Conductivity (m/s)**		
	Hazen's	**Slug-test**	**Percolation tube**
5-5,5		1,1*10^{-5}	
6,5-7	2,5*10^{-8}		
7-7,5	4,2*10^{-8}		
8-8,5	6,2*10^{-8}		
9,5-10	9,9*10^{-8}		
10-10,5	3,6*10^{-8}		
12-12,5	3,0*10^{-8}		
12,5-13	5,6*10^{-8}		
14-14,5	9,9*10^{-8}		
14,5-15	3,9*10^{-7}		
15,5-16	4,2*10^{-8}		
16,5-17	8,0*10^{-7}		
17,5-18	9,9*10^{-8}		
18,5-19	1,3*10^{-7}		
19,5-20	1,6*10^{-7}		
20-20,5	1,1*10^{-7}	1,5*10^{-4}	
20,5-21	6,3*10^{-8}	1,5*10^{-4}	9,7*10^{-5}
21-21,5	8,9*10^{-8}	1,5*10^{-4}	
22-22,5	9,4*10^{-8}		

calculated via the Hazen's method, which can be seen in table 2. The hydraulic conductivity for the shallow monitoring well was 5,8*10^{-6} m/s. The hydraulic conductivity for the deeper monitoring well could be inaccurate since the well might be deformed and the depth is unknown. This is discussed further in the chapter 5 discussion section.

A percolation tube test was only possible to conduct on sediments from the shallow well since the depth of the well screen of the deeper well is unknown. The hydraulic conductivity for the monitoring well was 10^2 higher than general values for Hazen's methods.

4.2.2.3 Well location 3

The hydraulic conductivity results from the Hazen's method indicate a general increase of the K value with depth. This is shown in table 3. There is a slight decrease in hydraulic conductivity between 20,5 – 22,5 m b.g.s. The hydraulic conductivity ranges from 1,1*10^{-7} m/s to 9,0*10^{-8} m/s.

The results from the slug-tests yielded lower hydraulic conductivity values compared to the Hazen's method results. The shallow monitoring well have a hydraulic conductivity of 1,1*10^{-5} m/s where as the deeper had a higher value of 1,5*10^{-4} m/s.

Percolation tube test was done for the deeper well. Lack of samples did not make it possible to do any tests for the shallow well. The hydraulic conductivity result for the deeper well was 10^2 higher than general value for the other two methods.

4.2.3 Hydraulic gradient and groundwater divides

The hydraulic gradients show that the groundwater flow follows the topography of the valley in a east to south-easterly direction as shown in Fig 8. The gradient follows the river towards the SE. The gradient increases towards the river source (where the culvert system outflows into the open). This could be the steep topography in the landscape.

There are two groundwater divides located in or close to the catchment area. The first one is located to the west of the catchment area and it seems to be related to the limestone forming the western side of lower aquifer valley (see Fig 5). The second groundwater divide is located in the north of the area (see Fig 5) and the exact placement is not well known yet due to lack of well data in the northern part of the area. It could be located further north or further south. The current location is entirely based on topography.

4.2.4 Water age results

The results from the water samples collected indicate an age of 40 – 60 years (see Fig 9). Since the water was collected close to the river it is likely that it is an outflow area (which is indicated by the age as well as the hydraulic gradient map and the location in the landscape) or the ages could reflect an age mix of wa-

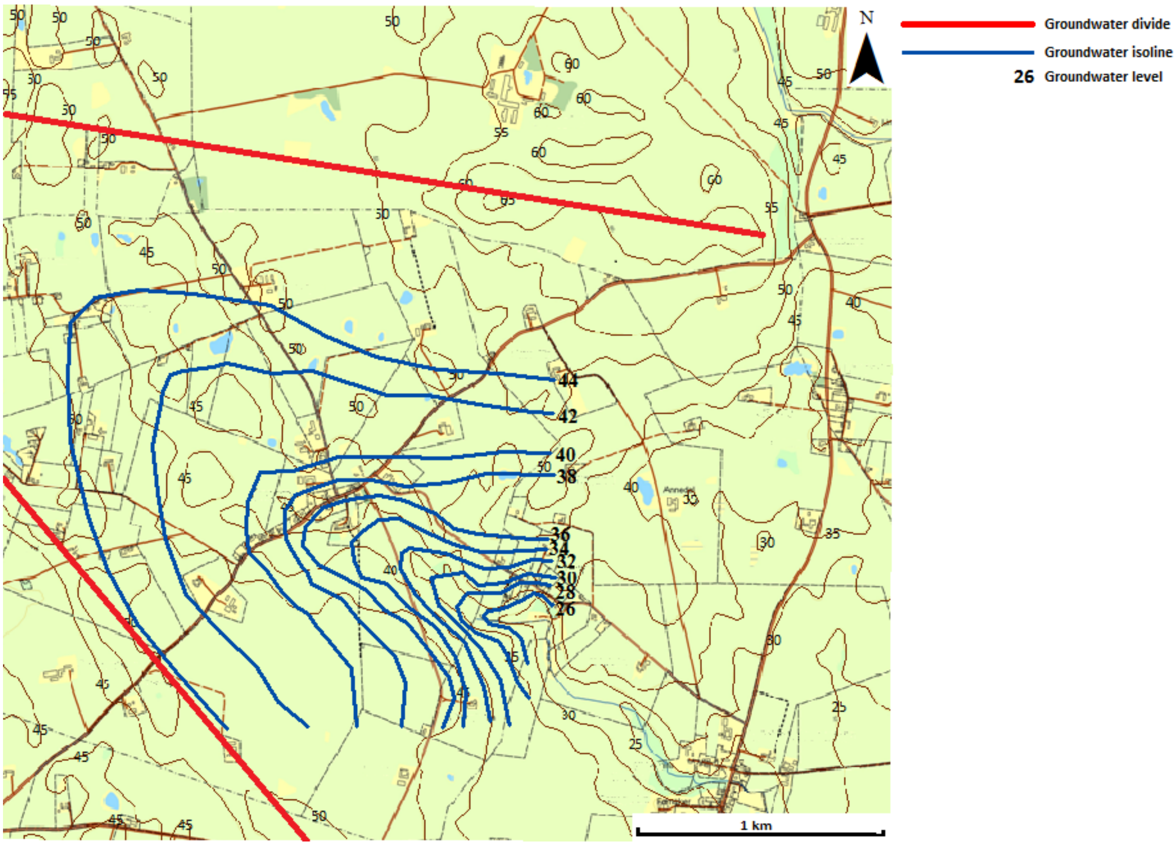

Figure 8. The hydraulic gradient over the catchment area and roughly the location of groundwater divides. Copyright of the background map from the National Land Survey of Sweden, grant I2010/0047.

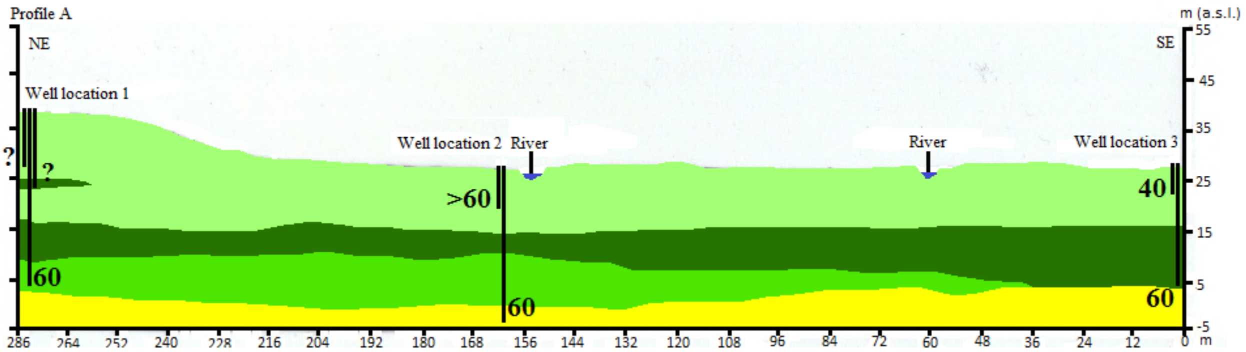

Figure 9. The result from the CFC age analysis for each well.

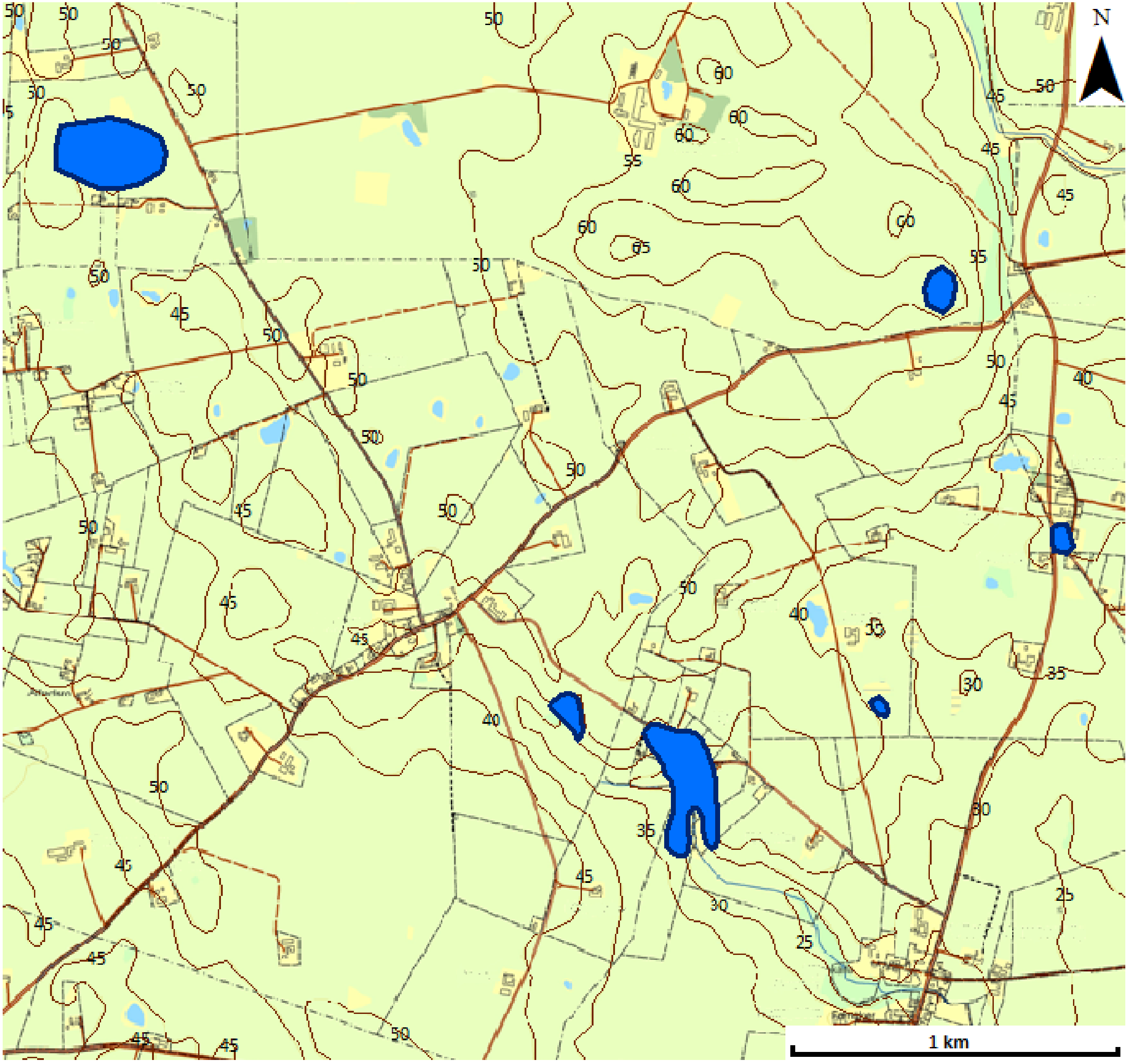

Figure 10. High permeability areas where a higher degree of recharge is likely to occur to the upper aquifer. Copyright of the background map from the National Land Survey of Sweden, grant I2010/0047.

ter with different ages.

4.2.5 Water balance calculations

For precipitation data a measuring station located *c.* 20 km NE of the catchment area was used. The station is governed by SMHI (Sweden's Metrological and Hydrological Institute) and the yearly average precipitation for the last 30 years (Adielsson 2009) can be seen in appendix C. A precipitation of 762 mm/year is used as a value for the N-term, which is the average for the 2002 – 2008 period.

The evapotranspiration (A_{ET}) is not measured in the catchment area or in any of the surrounding areas. Eriksson 1980 calculated the average precipitation, runoff and evapotranspiration for Sweden to 550 mm/year for the area from Ystad to Trelleborg. This value has been used as a rough estimate in the water balance.

The runoff (Q_y) is measured by SLU (SLU) in agricultural years (July – June). The measurements has been ongoing since 1992 and the results can be seen in appendix C. For the 1992 – 2009 period, 230 mm/year is the average runoff and has been used in the calculations

ΔM is assumed to be 0 mm/year as it could be set to even out over a 30-year period.

The net groundwater (Q_g) recharge for the catchment area is then calculated to;

$$762 - 550 - 230 = -18$$

This result shows that the aquifer could have a negative recharge of 18 mm/year from the surface. The negative recharge could be a result of the different data sets for a surface runoff average calculated for a 20 year period whereas the precipitation record is an average for a six year period only. The evapotranspiration figures used are also very general and might be wrong. There is also possibility that the upper aquifer is recharged from the lower aquifer through leakage.

4.2.6 Areas of recharge

The upper aquifer is recharged mainly where the high permeable glaciofluvial sediments reach the ground surface. These areas are shown in Fig 10. The two northern recharge areas could either be recharging the upper aquifer within the catchment area or a northern unknown aquifer. This depends on where the northern groundwater divide is located. The southernmost area of recharge is located in the area of the newly drilled wells.

4.3 Concluding results

The upper aquifer contains four different hydraulic conductivity units which can be seen in Fig 11. The lower silty clay unit has the lowest hydraulic conductivity value of less than $2*10^{-7}$ m/s. The glaciofluvial silty sand layer has a hydraulic conductivity that ranges from $2*10^{-7}$ to $6*10^{-6}$. The glaciofluvial sand layer has a hydraulic conductivity that ranges from $6*10^{-6}$ to $2*10^{-4}$. The highest hydraulic conductivity can be found in glaciofluvial gravelly sand layer which has a K value of more than $2*10^{-4}$.

The hydraulic conductivity varies throughout the sedimentary column. This can be seen in the varying purple coloured columns in Fig 11. The differences are shown for each well location. This shows the heterogeneity of the units with varying hydraulic conductivities for different parts or regions within each unit. The purple columns are based on the results from the Hazen's method.

5. Discussion

5.1 Groundwater level and well uncertainties

The depths of some of the investigated wells are unknown, as it for practical reasons, was not possible to measure the depth in the field. This results in the possibility that some of the well screens might not be located in the aquifer of interast and therefore represent a groundwater pressure head in the lower aquifer.

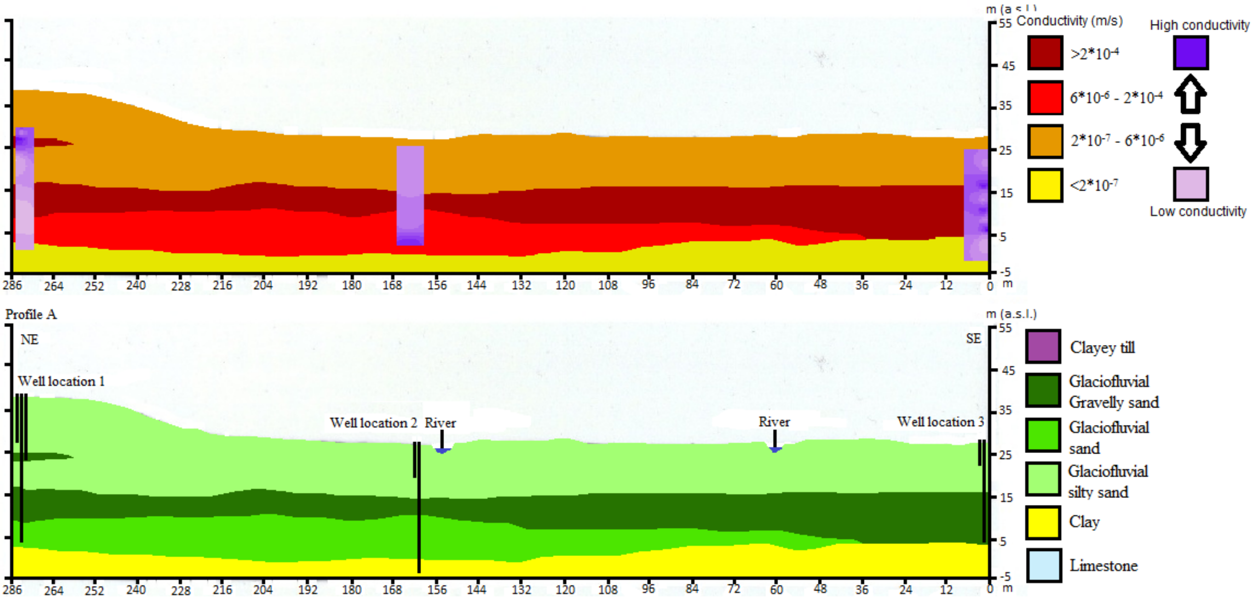

Figure 11. Generalised hydraulic conductivity value for the different layers based on the slug-test results and the variation in hydraulic conductivity for each drill site based on the Hazen method results are shown in profile A. The lower picture is the same as in figure 5, showing the geology for the 3 drill sites.

The samples collected from the monitoring wells are not completely "true samples" since the sediments are "filtered" through the screen holes during establishment. The size of the holes are 8 mm and this results in sieving off grains with a diameter lower than 8 mm.

The deeper well at well location 2 seems to have become bent at *c.* 26 m depth during drilling. This results in an uncertain depth of the well screen. That particular well is therefore hard to draw any specific conclusions concerning hydrogeological details.

Due to the silt content of the layers at the depth of the well screen, inflow of sediments has occurred in the intermediate well at well location 1. These fine sediments will affect hydrogeological studies on that particular well as the invading sediments at the well bottom disturb the inflow to the well.

To hinder sediment inflow from blocking the monitoring wells, an inner wellpipe was established. Howevere, it showed impossible to place an inner well pipe in both the deep monitoring wells at well location 1 and 2 because of the bending that had occurred during drilling.

5.2 Geology

Since the size of the holes in the well screens in the monitoring wells are just 8 mm as previously mentioned, the collected samples from those wells are incomplete. The lack of grains with a diameter greater than 8 mm increases the error of sediment classification and alters the grain size analysis results.

The composition similarities between the upper finegrained glaciofluvial sediments and the clayrich till makes it very hard to distinguish between the two. This means that either parts of the area mapped as clayrich till might be finegrained glaciofluvial sediments and areas mapped as glaciofluvial sediments might actually be clayrich till. This is of particular interest for profile A where the upper finer glaciofluvial sediments might be clayrich till.

5.3 Aquifers

During our investigation, only one aquifer was found. Literature and hydrogeological maps indicate a second aquifer below the upper aquifer of our investigation. As the clay layer was not penetrated during our drilling campaign, it is hard to confirm the existence of a lower aquifer in the sediments within the catchment area.

5.4 Hydrogeological properties

The hydraulic conductivity results from Hazen's method range from $1*10^{-6}$ to $1*10^{-10\ m/s}$. The results from the slugtest range from $1*10^{-4}$ to $1*10^{-8}$ m/s. The percolations tube test range from $2*10^{-4}$ to $1*10^{-6}$ m/s. The Hazen's method gave a generally lower value for well location 2 and 3 compared to well location 1. The cause for this might be the inaccurate samples from well location 1 and 2 compared to well location 3 where there was no "filtering" of the sediments. Another cause might be that the sediments are slightly finer towards the west compared to the east resulting in a higher hydraulic conductivity for well location 3. There might also be errors during the sieving and hydrometer analysis. As samples were divided they might not reflect the natural sediments exactly and some grains might have been stuck in the meshes during the sieving altering the result slightly.

Carrying out the slug-test on the DTH well was troublesome since it took 30 seconds for the water to return to the original groundwater level. Doing enough and accurate measurements during that short time period was difficult, this could be caused by a larger well (4 m) casing compared to the monitoring wells (0,5 and 1 m). Performing the slug-test on the intermediate monitoring well at well location 1 did not work since the well was clogged with sediments in the bottom. No slug-test was carried out in the deep monitoring well at well location 2 since the screen depth was unknown. The monitoring well at well location 1 has been filled with 1 – 2 metres of sediments below the inner well pipes, resulting in the infiltration occurring from the bottom instead of from the sides through the inner well screen.

Hydraulic conductivity results from the percolation tube-tests are all generally higher than the results from the other methods hydraulic conductivity and this is due to it being almost impossible to achieve the same degree of sediment packing in a tube as it is in situ.

The most reliable value is derived from the slugtest since this was carried out in situ giving the most natural circumstances for the test compared to the other two. For the rest of the sedimentary column, that lack slug-test values, the results from the Hazen's method can be used instead.

The hydraulic gradient is based on measurements in mostly already existing wells. There is a higher concentration of wells around the village compared to the agricultural area around. This results in gradient values being more accurate around the central parts in the map compared to the outer areas. The isolines have also been handdrawn with an interpolation as reference to make them more in line with the topography. Errors may occur here both based on human factors and machine ignorance. The largest error is the uncertain measurements of height values and uncertainties of filter depths in the already existing wells.

The placement for the N groundwater divide is completely based on the topography since it has not been possible to get the exact location due to lack of wells in the northern part of the area.

The water balance resulted in a low to strangely negative groundwater recharge. To get a more reasonable water balance, a longer period is needed to even out the extremes better. The evapotranspiration values used are 30 years old and could be different if the measurements were made more recently since the climate is changing. However, it can be concluded that the groundwater recharge is rather small in the catchment area. There is also a possibility of groundwater recharge through leakage from the lower aquifer.

Areas of recharge are based on the geological map. The accuracy of these can be debated, but it is the best available at the moment. The areas marked on the map in figure 10 are locations of glaciofluvial deposits in the surface where the water can easily infiltrate down to the aquifer. There could be other areas of recharge and in particular areas containing younger sand sediments overlying glaciofluvial sediments. The geological map is in the 1:50000 scale and does not include smaller areas of highly permeable material that might be of importance to infiltration.

The water used for the age determination could be a mix of water with different ages, which means that the result is an average age for the water.

5.5 Pesticides

The results from the water age measurements yielded a general age of 60 years. The pesticides that could be present in the water are probably the ones used 60±20 years ago. The pesticides reach the surface water near the stream were the groundwater has its outflow area.

6 Conclusions

- The catchment area consists of two coarse grained sediment units, the upper glaciofluvial sediments and the lower aquifer. These are divided by a silty clay layer. The upper glaciofluvial sediments are generally overlain by a clay-rich till.
- The upper aquifer consists of 2 high conductivity layers, a gravelly sand layer with a hydraulic conductivity greater than $>2*10^{-4}$ m/s and a sand layer with a hydraulic conductivity that ranges from $2*10^{-4}$ m/s to $6*10^{-6}$ m/s.
- There are two low conductivity layers above and below the upper aquifer. The upper one consists of silty fine sand and has a hydraulic conductivity that ranges from $6*10^{-6}$ m/s to $2*10^{-7}$ m/s . The lower clayey silt has a hydraulic conductivity of less than $2*10^{-7}$ m/s.
- The different methods used for hydraulic conductivity calculations varied. The most reliable are the slug-tests and Hazen's method. The least reliable is the percolation tube test.
- The general hydraulic gradient in the area is towards the river with a groundwater movement towards the E-SE.
- The groundwater recharge is low in the catchment area and probably occurs during heavy precipitation events.
- The age of the groundwater is uncertain but an average age around Profile A is *c.* 40-60 years based on CFC analysis.

7 Recommendations for future work

- The inventory of already existing wells should be extended further north to pinpoint the northern groundwater divide. It should also be extended to the NW to locate the groundwater divide in that particular direction.
- Perform a drilling to penetrate the lower clay unit to confirm the existence of the lower aquifer sediments would be beneficial to the project.
- Drilling a fourth well closer to the northern groundwater divide for additional groundwater samples to try and get a better understanding and constrain on the recharge and age of the groundwater in the upper aquifer.

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Appendix A, Well information

ID	Groundwater level a.s.l (m)	Well location a.s.l (m)
1	26,6	37
2	25,5	26
3	25	26
4	46,8	51
5	35,9	40
6	39,9	43
7	43	45
8	42,3	44
9	42,6	44
10	42	44
11	42,2	45
12	42,1	45
13	42,7	45
14	41,8	46
15	41,1	43
16	44	48
17	46,5	50
18	42,2	44
19	43,8	47
20	33,5	45

Appendix B, Sieving and hydrometer analysis results

Sieving and hydrometer analysis results for drill site 1.

Depth (m)	Clay (%)	Silt (%)	Clay and silt (%)	Sand (%)	Gravel (%)
1 - 2	7,74	35,35	43,09	N/A	N/A
2 – 3	7,16	35,84	43	N/A	N/A
4 – 5	7,71	37,46	45,17	N/A	N/A
10 – 11	5,1	40,93	46,03	N/A	N/A
13 – 14	2,87	40,62	43,49	53,50	3,01
14 – 15	1,34	8,81	8,94	91,03	0,03
16 – 17	N/A	N/A	2,52	97,12	0,36
18 – 19	0	3,34	3,34	96,48	0,18
19 – 20	0	3,92	3,92	96,04	0,04
21 – 22	N/A	N/A	0,81	96,99	2,20
25 – 26	N/A	N/A	1,49	97,50	1,01
28 – 29	N/A	N/A	1,16	96,38	2,46
29 – 30	N/A	N/A	0,18	96,10	3,72
30 – 31	N/A	N/A	1,41	98,22	0,37
34 – 35	N/A	N/A	1,44	98,12	0,44

Sieving and hydrometer analysis results for drill site 2.

Depth (m)	Clay (%)	Silt (%)	Clay and silt (%)	Sand (%)	Gravel (%)
3 – 4	0,06	5,94	6	82,49	11,52
4 – 5	N/A	N/A	6,63	91,96	1,41
6 – 7	N/A	N/A	4,62	95,27	0,11
8 – 9	N/A	N/A	4,36	94,96	0,68
10 – 11	N/A	N/A	8,80	91,13	0,7
11 – 12	N/A	N/A	1,96	91,20	6,83
12 – 13	0	9,26	9,26	88,36	2,37
14 – 15	N/A	N/A	8,70	90,31	0,99
19 – 20	N/A	N/A	4,36	95,63	0,01
21 – 22	N/A	N/A	2,64	97,15	0,22
23 – 24	2,93	8,70	9	N/A	N/A
27 – 28	N/A	N/A	1,30	96,56	2,14
34 – 35	N/A	N/A	7,76	92,24	0,11

Appendix B, Sieving and hydrometer analysis results

Sieving and hydrometer analysis results for drill site 3.

Depth (m)	Clay (%)	Silt (%)	Clay and silt (%)	Sand (%)	Gravel (%)
3 – 3,5	0,20	9,60	9,80	86,36	3,84
3,5 – 4	0,19	9,23	9,42	88,85	1,74
4 – 4,5	0,07	12,79	12,86	85,85	1,25
5 – 5,5	0,20	13,37	13,57	80,93	5,50
5,5 – 6	0	8,16	8,16	91,56	0,26
6,5 – 7	0	3,72	3,72	96,03	0,25
7 – 7,5	N/A	N/A	2,58	97,35	0,07
8 – 8,5	0	2,32	2,32	97,29	0,40
8,5 – 9	0,04	4,33	4,37	95,25	0,38
9,5 – 10	N/A	N/A	1,46	98,33	0,21
10 – 10,5	0	1,77	1,77	97,90	0,33
10,5 – 11	N/A	N/A	15,13	84,85	0,01
12 – 12,5	N/A	N/A	1,47	94,91	3,63
12,5 – 13	N/A	N/A	3,57	86,78	9,65
13 – 13,5	N/A	N/A	15,92	83,92	0,15
14 – 14,5	N/A	N/A	0,47	87,70	11,83
14,5 – 15	N/A	N/A	0,57	36,11	63,32
15,5 – 16	0	3,68	3,68	95,27	1,05
16,5 – 17	N/A	N/A	2,80	87,54	9,66
17,5 – 18	0,01	1,69	1,70	92,31	5,99
18,5 – 19	N/A	N/A	1,67	95,71	2,61
19,5 – 20	N/A	N/A	1,08	90,37	8,56
20 – 20,5	N/A	N/A	1,19	96,77	2,04
20,5 – 20	0	3,79	3,79	94,15	2,06
21 – 21,5	N/A	N/A	1,50	91,52	6,98
21,5 – 22	0	24,23	24,23	69,60	6,17
22 – 22,5	0,23	1,81	2,04	74,08	23,88
23 – 23,5	22,19	45,31	67,5	N/A	N/A
24 – 24,5	27,10	47,21	74	N/A	N/A

Appendix C, Precipitation and runoff

Precipitation, Adielsson, S., Graaf, S., Andersson, M., & Kreuger, J., 2009: Resultat från miljöövervakningen av bekämpningsmedel (växtskyddsmedel). Långtidsöversikt 2002-2008. Årssammanställning 2008.

Month	**30 year average precipitation (mm/month)**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
January	57	97	52	97	55	31	140	84
February	36	117	16	36	71	57	92	29
Mars	43	33	12	53	55	49	51	77
April	38	43	46	26	6	51	17	45
May	40	57	40	28	40	69	58	35
June	54	86	76	89	42	39	139	23
July	64	61	83	102	47	22	195	32
August	59	20	38	94	65	232	127	146
September	65	20	37	50	10	40	68	42
October	65	134	67	81	61	66	32	115
November	76	78	66	70	57	96	38	40
December	66	30	60	73	79	92	67	39
Annual	662	776	595	800	587	843	1025	707

Runoff, Swedish University of Agricultural Sciences (SLU). 2010. The national database at the Department of Soil and Environment, May 2010.

Agrohydrogeological year	**Runoff (mm)**	**Month (2008-2009)**	**Runoff (mm)**
92/93	209,7	January	0,366832
93/94	314,1	February	0,812917
94/95	334,1	Mars	0,301349
95/96	70,8	April	8,551183
96/97	94,3	May	28,74545
97/98	184,5	June	44,19465
98/99	348,6	July	22,96642
99/00	255,7	August	25,60182
00/01	164,7	September	30,03462
01/02	298,9	October	7,514907
02/03	92,8	November	3,569203
03/04	130,8	December	3,133103
04/05	293,0		
05/06	133,8		
06/07	446,2		
07/08	356,6		
08/09	175,8		

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