Groundwater response to climate variability in southern Sweden

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Abstract
The changing climate if affecting the temperature and precipitation which in turn could cause changes in the groundwater recharge. In this report 61 aquifers distributed in 14 regions in southern Sweden have been analyzed and compared to precipitation data to see how local geography, geology and aquifer characteristics affect the groundwater response to climate variability. A table with aquifer properties, a map, a figure of seasonal groundwater and precipitation variability and a figure showing yearly averaged normalized values of changes in precipitation and groundwater levels between 1975-2012 for each region was used for the analysis. Results show a correlation between precipitation and groundwater levels with the best correlated ones located on the south and west coast. Some aquifers have a delay in response time which could be due to soil type and depth but due to the lack of specific soil type classification it cannot be confirmed. Aquifers with no delay in response time have a shallow depth to the aquifer. Since yearly average values were used all short term variability was lost so short time delays were not detected. Anthropogenic changes of the groundwater level have taken place at several aquifers, some changes are noticeable and others are not.

Keywords: groundwater, aquifer, groundwater recharge, groundwater response, climate change, aquifer properties, southern Sweden

GRUNDVATTENRESPONS PÅ KLIMATFÖRÄNDRINGAR I SÖDRA SVERIGE

Anna Josefin Ridl, Göteborgs Universitet, Geovetarcentrum

Sammanfattning
Klimatförändringar påverkar temperaturen och nederbörden som i sin tur kan orsaka förändringar i grundvattenpåfyllningen. I den här rapporten har 61 akviferer fördelade i 14 regioner i södra Sverige blivit analyserade och jämförda med nederbördssdata för att se hur lokal geografi, geologi och akvifer egenskaper påverkar grundvattens respons på klimatförändringar. En tabell med akvifer egenskaper, en karta, en figur med säsongsvariationer i nederbörd och grundvattennivåer och en figur som visar årliga normaliserade medelvärden av förändringar i nederbörd och grundvattennivåer mellan 1975-2012 för varje region användes för analysen. Resultatet visar en korrelation mellan nederbördén och grundvattennivåer där de med bäst korrelation ligger på syd- och västkusten. Några akviferer har en försening i respons tid vilket skulle kunna vara på grund av jordarten i kombination med djupet men på grund av bristfällig specifik jordart klassificering det kan inte fastställas. Akviferer utan försening i responsstiden har ett grunt djup till akviferen. Eftersom årliga medelvärden användes gick all korttids variabilitet förlorad och därför kunde inga korttids förseningar i responsstid upptäckas. Människoorsakade förändringar av grundvattennivåer har ägt rum vid flera akviferer, vissa förändringar går att upptäcka, andra inte.
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1. Introduction
In many parts of the world there is a great lack of drinking water but this is not the case in Sweden. The country’s geology combined with its climate creates good conditions for storing water. About half of the drinking water in Sweden comes from surface water. The other half comes from either groundwater or artificial groundwater, i.e. water from lakes and streams which has been filtrated through sand and gravel ridges. (Länsstyrelsen, 2014; SGU, 2014b; SOU, 2007)

The ongoing climate change is likely to influence the availability of groundwater. Climate change is affecting both global and local weather patterns such as precipitation and temperature. Research indicates that by the next century the groundwater levels in the south-eastern parts of Sweden could decrease markedly while in other parts of the country it is expected to increase (SMHI, 2011). A decrease in the groundwater level would not only lead to reduced water availability but could lead to saltwater intrusions along coastal areas (SMHI, 2011) – a process which would additionally be accelerated by the predicted sea level rise (NASA, 2015). A rise of the groundwater level would make more water available for use but it also enhances the risk of landslides and lessens the ability of the ground to purify the water (SMHI, 2011).

1.1. Aim
The planning of ground water wells and withdrawals in the future will benefit from knowing if and how climate change and ground water levels are connected. This study is a part of a long-term project whose purpose is to find a relationship between climate change and changes in groundwater levels in Sweden.

In this study measured data from 61 different ground water stations were analyzed and compared to precipitation data from the respective region. The goal is to analyze how local geography, geology and aquifer characteristics affect the groundwater response to climate variability in southern Sweden. Specific research questions are:

1. What is the connection between the precipitation and groundwater levels?
2. Does this connection show a general trend or can local conditions lead to significant differences? What geological and geographical aspects and aquifer characteristics may cause these differences?
3. Do similar geological conditions lead to similar behavior in the aquifers’ groundwater levels?
1.2. Background
A lot of people in the world are today suffering from water scarcity and in the future it is expected to get much worse due to the changing climate. The lack of fresh water now and in the future is an extremely important global problem which must be taken care of. (Appelo & Postma, 2010) Only 3% of the world’s water is fresh water. Of this water 30.1% is stored as groundwater, 68.7% in ice caps and glaciers and the rest as surface water (Hubbart & Medalye, 2013; Marshak, 2008; USGS, 2014). This means that more than 97% of the world’s usable freshwater resources are groundwater (Shiklomanov, 2000).

In Sweden there are a lot of good groundwater resources of good quality. (Ojala et al., 2009) In some coastal areas, especially in southeastern Sweden, the access to groundwater can sometimes be scarce. Different kinds of aquifers respond differently to groundwater recharge from precipitation. Small aquifers have a quick response time (a few hours - 2 weeks) and big variations in groundwater level while large aquifers have a long response time (1 week – several months) and a small variation in groundwater level. Other geological factors such as topographical location, aquifer type and porosity of soil type also influences the response time. A confined aquifer usually has a 1-2 weeks longer response time than an unconfined aquifer. (Ojala et al., 2009)

1.2.1. Groundwater and climate change
The changing climate is causing the seasonal weather patterns to change. More frequent and intense climate extremes such as floods and droughts will take place in the world and at high altitudes the snow starts melting earlier in the season and less snow accumulates. This causes a change in the groundwater availability for private and agricultural needs and ecological functions over the year (Taylor et al., 2012).

According to Sundén et al. (2010) an increased precipitation will cause rising groundwater levels in most parts of Sweden. In the larger aquifers the groundwater level could rise over 10 centimeters. In the southeastern part of Sweden the groundwater levels are expected to decrease due to a decrease in precipitation. As the temperature rises Sweden will experience higher groundwater levels in the beginning of the year because the snowing will be replaced by raining. Spring will come earlier which will cause the snow to melt earlier resulting in high groundwater levels earlier in the year. The period between the snowmelt and the rainy autumn months will be longer and therefor the groundwater levels may be lower during late summer and early autumn. The last couple of months of the year are not expected to change much. Some of the early snow may instead become rain and contribute to some elevated groundwater levels. (Sundén et al., 2010)
1.2.2. Groundwater regimes

Sundén et al. (2010) have divided Sweden into four groundwater regimes depending on the aquifers seasonal groundwater level variations (see figure 1). Each region has a diagram showing how the groundwater level varies throughout the year. The different zones starting from the north:

1. The main part of the groundwater recharge is due to the snowmelt in spring. The groundwater levels rise quickly and reach their maximum in the early summer and then they steadily decrease until they reach their minimum just before the next snowmelt.

2. The snowmelt in spring causes the max groundwater level in early summer. The second peak in autumn is due to rainfall in combination with small absorption from plants.

3. The lowest groundwater levels occur during the late summer months. Precipitation is high during autumn so the groundwater levels rise but when it starts snowing during winter the levels decrease. As the snow starts melting the levels rise again and reach their max during spring.

4. In this region there is very little snowmelt as precipitation falls as rain most of the time. The lowest levels occur during autumn and steadily increase until they reach their max in spring. (Sundén et al., 2010)

When the climate changes these regimes are likely to change too. A rising temperature will cause the snow to melt earlier which will result in a shorter winter and therefore a longer recharge period. The max groundwater levels will decrease and the min levels may get even lower. An increasing temperature could cause an increasing evaporation which would then lower the groundwater levels. (Sundén et al., 2010)
1.3. Site description
This study contains observations at 61 groundwater stations which are distributed in the vicinity of 14 different cities at slightly different elevations (see figure 2). The yearly total precipitation varies between 513 mm in Böda to 975 mm in Nissafors (see table 1). The yearly average temperature is as lowest at Brattforsheden with 5°C and as highest in Vellinge with 8.4°C (see table 1). Figure 3 and 4 and table 2 shows how the normalized yearly total precipitation and normalized yearly average temperature has varied between 1975-2012 in all 14 regions. Figure 3 and 4 with actual values instead of normalized can be found in appendix 1 and 2.

Table 1. Yearly total precipitation (mm) and yearly average temperature (°C) calculated as an average for the years 1975-2012. (Based on data from: SMHI-luftwebb (2014).)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly tot prcp (mm)</td>
<td>663</td>
<td>652</td>
<td>804</td>
<td>689</td>
<td>544</td>
<td>513</td>
<td>700</td>
</tr>
<tr>
<td>Yearly avg temp (°C)</td>
<td>8.4</td>
<td>7.8</td>
<td>6.6</td>
<td>6.8</td>
<td>7.4</td>
<td>7.6</td>
<td>7.3</td>
</tr>
<tr>
<td>Yearly tot prcp (mm)</td>
<td>840</td>
<td>975</td>
<td>819</td>
<td>738</td>
<td>709</td>
<td>647</td>
<td>816</td>
</tr>
<tr>
<td>Yearly avg temp (°C)</td>
<td>7.9</td>
<td>6.5</td>
<td>6.6</td>
<td>6.4</td>
<td>6.3</td>
<td>6.9</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Figure 2. Elevation and location of the regions where all groundwater stations are located. (Based on data from: DIVA-GIS (2014).)
Figure 3. Changes in yearly total precipitation from 1975 to 2012 plotted as normalized values. Each number represents a specific region (see table 1). (Based on data from: SMHI-luftwebb (2014).)

Figure 4. Changes in yearly average temperature from 1975 to 2012 plotted as normalized values. Each number represents a specific region (see table 1). (Based on data from: SMHI-luftwebb (2014).)

Table 2. Slope of linear trendline for precipitation (figure 2) and temperature (figure 3) for each of the regions.

<table>
<thead>
<tr>
<th>Region number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>0.029</td>
<td>0.023</td>
<td>0.038</td>
<td>0.033</td>
<td>0.021</td>
<td>0.030</td>
<td>0.033</td>
<td>0.048</td>
<td>0.031</td>
<td>0.046</td>
<td>0.042</td>
<td>0.030</td>
<td>0.046</td>
<td>0.019</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.041</td>
<td>0.038</td>
<td>0.037</td>
<td>0.040</td>
<td>0.040</td>
<td>0.044</td>
<td>0.045</td>
<td>0.038</td>
<td>0.042</td>
<td>0.036</td>
<td>0.040</td>
<td>0.039</td>
<td>0.040</td>
<td>0.034</td>
</tr>
</tbody>
</table>
2. Materials and methods
All of the following calculations and figures have been created using the software MATLAB version 2014a and all maps have been created using ArcMap version 10.1.

2.1. Data
2.1.1. Collecting data
Two datasets were received from SGU (2014a), one containing detailed data for both active and inactive groundwater stations and the other dataset only contained limited data of the 81 active groundwater stations. (This data can be obtained online at SGU (2014c).) After having eliminated bad data there were 61 stations left (see section 2.1.2). All necessary data for the 81 active stations was collected into a new dataset. This contained area and station number, station name, soil type, aquifer type, topographical location, coordinates, measured groundwater level as meters above sea level (m.a.s.l.) and as meters below ground level (m.b.g.l.). All measured data had been measured manually. A new station number was given to each station (1-81). Each of the 81 stations are located close to one of 15 cities so each station was given another numbering “subarea” (1-15) depending on which city it was close to.

Monthly precipitation and temperature data for 1975-2012 was downloaded from SMHI-luftwebb (2014). Data was downloaded for the cities under the assumption that the precipitation data in each city would be representative for all groundwater stations in that region. It should not matter much if precipitation were to be acquired for each groundwater station instead, since in this report only normalized anomalies are analyzed which are spatially more uniform than raw precipitation totals. A comparison of the regions (figure 3) shows that the precipitation pattern is similar for all locations with only some small variations which justifies the previous assumption.

2.1.2. Eliminating bad data
The measured groundwater level (m.a.s.l.) from each station was plotted against time (See appendix 3). Stations considered to be of no use - with respect to the objectives of this study - were removed, i.e. stations:

- With an obvious irregularity between measurements of the groundwater level (stations 42 and 63). See figure 5.
- With an obvious offset (stations 5 and 75). See figure 6.
- With obvious changes in behavior, where human influence such as pumping from or infiltration into the aquifer is a very likely reason to its behavior (stations 32, 58, 71 and 74). See figure 7.
- With a later start-measuring date than 1st of January 1975 (stations 33, 34, 35, 39, 40, 41, 59, 60, 61, 62, 80, 81).

After eliminating these stations subarea 7 (Hemse) had no stations left and was therefore removed. This is why number 7 is missing in figures and tables and there is no area number 7 later in the result and discussion. After having eliminated these stations there are 61 left which are used in this report.
Figure 5. Stations 42 and 63 which have an obvious irregularity between measurements. (Based on data from: (SGU, 2014a).)

Figure 6. Stations 5 and 75 which have an obvious offset. (Based on data from: (SGU, 2014a).)

Figure 7. Stations 32, 68, 71 and 74 which have an obvious change in behavior where human influence is likely to be the cause. (Based on data from: (SGU, 2014a).)
2.2. Workflow

- The average groundwater level (m.a.s.l.) and (m.b.g.l.) was calculated for each station for the time period 1975-2012.

- A map showing the location and elevation of all 14 regions was created (figure 2) using data from DIVA-GIS (2014). One zoomed in map for each area was created (map 2-15). These maps contain the location of the city (where the precipitation and temperature data is from), the groundwater stations and an overview of the area (based on data from SLU (2014)).

- For each station the groundwater level data (m.a.s.l.) was normalized by using equation 1.

\[
\text{Equation 1: } \frac{\text{measured value} - \text{mean of all values}}{\text{standard deviation}} = \text{normalized data}
\]

The mean normalized value for each month was calculated for the years 1987-2012 and plotted. These figures were then analyzed and divided into groups according to visual appearance (see section 2.2.1). This was done by looking at when maximum and minimum values occur.

- A group classification according to Sundén et al. (2010) was also made and is presented in section 3.15. Some aquifers could not be grouped under any of Sundén’s 4 groups and were not given any classification (n/a).

- The yearly total precipitation and the yearly average temperature were calculated for each region for 1975-2012 (table 1) and were then normalized by using equation 1. These values were plotted in figures, one for precipitation (figure 3) and one for temperature (figure 4) to see the variability between the cities.

- The yearly total precipitation and the yearly average groundwater level (m.a.s.l.) were calculated for all stations. This data was normalized by using equation 1 and then plotted in figures. One figure was created per region with all its stations represented by different colors (see figures in result section).

- Each region was analyzed separately and stations with a delay and/or a deviating pattern were discussed. A summary consisting of two maps and one table was created to give a good overview and to be able to compare different areas and analyze the different geological properties. The results are discussed and research questions answered.
2.2.1. Group classification

The following section describes each group and its characteristics and shows examples of the general pattern of its group type. At the end there is a map giving an overview of how the different groups are distributed between the cities (see figure 14).

Group A is characterized by a maximum value between May-July and a minimum value between October-February (see figure 8). Group A has 11 stations.

Group B is characterized by a maximum value between March-May and a minimum value between August-November with a “sinus curve” pattern (see figure 9). Group B has 7 stations.

Figure 8. Seasonal changes in groundwater levels for the time period 1975-2012 plotted as normalized values. The figure shows station 26 and 28 which belongs to group A. *(Based on data from: (SGU, 2014a).)*

Figure 9. Seasonal changes in groundwater levels for the time period 1975-2012 plotted as normalized values. The figure shows station 2 and 73 which belongs to group B. *(Based on data from: (SGU, 2014a).)*
Group C is characterized by a minimum value between August-September, a second minimum value between January-March and a maximum value between April-May (see figure 10). Group C has 6 stations.

Figure 10. Seasonal changes in groundwater levels for the time period 1975-2012 plotted as normalized values. The figure shows station 69 and 76 which belongs to group C. (Based on data from: SGU, 2014a.)

Group D is characterized by a minimum value between August-September and a maximum value between December-April (see figure 11). Group D has 25 stations and is therefore the largest group.

Figure 11. Seasonal changes in groundwater levels for the time period 1975-2012 plotted as normalized values. The figure shows station 17 and 52 which belongs to group C. (Based on data from: SGU, 2014a.)
Group $D_{subgroup}$ ($Ds$) is a subgroup to group $D$. They have a similar maximum and minimum pattern but are different enough not to fit into group $D$ (see figure 12). Group $Ds$ has 4 stations.

Figure 12. Seasonal changes in groundwater levels for the time period 1975-2012 plotted as normalized values. The figure shows station 38 and 43 which belongs to group $Ds$. (Based on data from: (SGU, 2014a).)

Group $S$ is characterized by a very small seasonal variance with no obvious maximum and minimum value like in group A-D (see figure 13). Group $S$ has 8 stations.

Figure 13. Seasonal changes in groundwater levels for the time period 1975-2012 plotted as normalized values. The figure shows station 7 and 68 which belongs to group $S$. (Based on data from: (SGU, 2014a).)
Figure 14. Map showing where the different cities are located and their distribution of groups. Each group is represented by a color. The colored numbers in the lower right corner of each city shows how many wells of that group is located there. (Based on figure 2)
3. Results
In the following sections the results for each region will be presented. Every section consists of a map of the city and its groundwater stations, a table with geological information for each station and a figure showing how the precipitation and groundwater levels have changed between 1975 and 2012 with a short analysis. After each region has been presented there will be a summary of the geological information and results.

3.1. 1 Vellinge
Vellinge is situated in the very southwestern corner of Sweden (see Figure 2), less than 9 km from the sea (see figure 15). The groundwater stations are located within 15 km of Vellinge. Stations 1, 2 and 4 are located on fields while station 3 is in the outskirt of a small area of buildings. The yearly total precipitation is 663 mm and the yearly average temperature is 8.4°C (see table 1).

![Map of Vellinge showing groundwater stations](image)

Figure 15. An overview of the region 1 Vellinge showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)

The groundwater stations in this region are located between 9.1 and 21.4 m.a.s.l. and the average depth to the groundwater varies between 3.7-7.8 m.b.g.l. (see table 3). All aquifers consist of boulder clay and belong to the same group classification B. Station 1 and 2 are unconfined aquifers in unconsolidated material located in a water divide area while station 3 and 4 are confined aquifers in bedrock located in a recharge area.
Table 3. Information about each groundwater station located in the vicinity of Vellinge. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Boulder clay is also known as boulder till.) (Based on data from: SGU (2014a).)

In the Vellinge area there is clear correlation between the groundwater levels and the precipitation (see figure 16). Station 1 has a slightly different trend before 1982 compared to other stations. Otherwise all stations follow the same general trend except for some temporary deviations (station 1 year 2005 & 2009, station 2 year 2003-2004 and station 4 year 2010).

![Vellinge, normalized groundwater levels and precipitation](image)

Figure 16. Vellinge: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.2. 2 Kristianstad

Kristianstad is situated in the southern part of Sweden close to the sea (see Figure 2). The groundwater stations 6-9 are located about 12 km south of Kristianstad within 0.5 km of each other (see figure 17). The groundwater stations 10 and 11 are located about 24 km northwest of Kristianstad within 0.1 km of each other. Stations 6-9 are located on fields/open surfaces and station 9 is also close to some forest. Stations 10 and 11 are located between fields and a small forest. The yearly total precipitation is 652 mm and the yearly average temperature is 7.8°C (see table 1).

Figure 17. An overview of the region 2 Kristianstad showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014)).

The groundwater stations in this region are located between 16.4-20.1 m.a.s.l. and the average depth to the groundwater varies between 0.9-4.1 m.b.g.l. (see table 4). All aquifers consist of sand and are classified into different groups. Station 10 is a confined aquifer while the others are unconfined aquifers in and station 9 is located in a water divide area while the others are located in recharge areas.

Table 4. Information about each groundwater station located in the vicinity of Kristianstad. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a)).
In the Kristianstad area there is a strong correlation between precipitation and the groundwater level (see figure 18). Between the years 1977-1987 the groundwater levels are slightly higher than the precipitation curve and towards the end they are lower. This indicates a lowering of the groundwater levels which may be due to human influences such as increased population and increased agricultural water needs.

Station 7 seems to be slightly less responsive to the precipitation changes, the groundwater level do not follow all the minimum and maximum values of the precipitation very closely. One reason to this behavior could be the group classification S. Group S is characterized by almost no seasonal variation in the groundwater level. This could be because the aquifer is connected to a large body of water such as a river or a lake, so whenever the precipitation increases or decreases the aquifer will not be as directly affected by that.

For some years a delay can be seen in the response where the maximum/minimum value of the precipitation shows one year later in the groundwater level. This can be seen year 1975-1976, 1978-1979, 1981-1982, 2004-2005, 2005-2006, 2009-2010 and 2010-2011. This delay is not consistent throughout the entire time series. Fine sand could cause a delay in the response time but the depth to the aquifers is not deep and also the delay is not consistent.

![Figure 18. Kristianstad: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)](image-url)
3.3. 3 Liatorp

Liatorp is situated in the southern middle part of Sweden (see Figure 2). All groundwater stations in this region are located in the forest within 2 km of one another (see figure 19). All stations are quite close to wetland areas and station 16 is close to a small field. The yearly total precipitation is 804 mm and the yearly average temperature is 6.6°C (see table 1).

Figure 19. An overview of the region 3 Liatorp showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. *(Based on data from: SLU (2014)).*

The groundwater stations in this region are located between 149.1-154.9 m.a.s.l. and the average depth to the groundwater varies between 0.7-2.8 m.b.g.l. (see table 5). All are unconfined aquifers which are located in recharge areas. Aquifers 14, 16 and 18 consist of moraine while the others consist of sand. All stations belong to the same group classification D.

Table 5. Information about each groundwater station located in the vicinity of Liatorp. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.).*(Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Area No. 3</th>
<th>Liatorp</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Topographical location</th>
<th>Aquifer type</th>
<th>Aquifer type</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>D</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>149,1</td>
<td>2,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>D</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>149,1</td>
<td>2,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>150,2</td>
<td>1,2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>D</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>151,7</td>
<td>1,8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>152,6</td>
<td>2,0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>D</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>154,9</td>
<td>0,7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>150,7</td>
<td>0,9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>D</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>152,0</td>
<td>2,1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the Liatorp area a correlation between precipitation and groundwater changes can be found (see figure 20). During the time period between 1996-2003 all groundwater levels are lower than the precipitation curve and after the peak at 2007 all stations have a higher groundwater level than precipitation except for stations 17 and 19. This change is too sudden and extreme to be a natural change. It is likely due to human influences such as infiltration into the aquifer. Station 17 has a decreasing trend that deviates from all the other stations. It is likely due to human influence such as pumping.

Figure 20. Liatorp: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.4. 4 Emmaboda

Emmaboda is situated in the southeastern part of Sweden (see Figure 2). The three groundwater stations are located in the forest within 1.5 km of one another (see figure 21). They are all close to fields, other open surfaces and some smaller wetlands. The yearly total precipitation is 689 mm and the yearly average temperature is 6.8°C (see table 1).

The groundwater stations in this region are located between 117-120.1 m.a.s.l. and the average depth to the groundwater varies between 0.6-1.2 m.b.g.l. (see table 6). All of the aquifers are unconfined and consist of moraine. Station 20 and 21 are located in recharge areas while station 22 is located in a discharge area. All three stations belong to the same group classification D.

Table 6. Information about each groundwater station located in the vicinity of Emmaboda. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l). (Based on data from: SGU (2014a).)
In the Emmaboda area all three stations have a pattern that resembles the precipitation curve but they are not quite the same. Station 22 seems to have a slightly different behavior with very high groundwater levels before year 1988 and a sharp decline with very low levels after 1998. The sharp decline in groundwater level in combination with an increase in precipitation seems like a very unnatural behavior and is likely caused by human influence. After year 1988 there are no big changes in the groundwater level even if the precipitation fluctuates a lot which is strange. It is possible that a geographical change has taken place or that people has started pumping in water. Road work or other construction work may have affected the water supply to the aquifers. It is possible that the water recharging aquifer 22 was redirected to the other two aquifers either unintentionally or intentionally. Another possibility is that water is being infiltrated into aquifer 20 and 21 while water is being pumped from aquifer 22 around year 1998.

Figure 22. Emmaboda: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.5. Kalmar
Kalmar is situated in the southeastern part of Sweden right on the water (see Figure 2). The groundwater stations are located within 14 km of one another (see figure 23). They are all located in the forest close to fields and station 23 is also close to buildings. The yearly total precipitation is 544 mm and the yearly average temperature is 7.4°C (see table 1).

Figure 23. An overview of the region 5 Kalmar showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)

The groundwater stations in this region are located between 12-57.2 m.a.s.l. and the average depth to the groundwater varies between 4.2-12.2 m.b.g.l. (see table 7). All of the aquifers consist of gravel. Station 23 belongs to group classification S while the others belong to A. Other data was not available for this location.

Table 7. Information about each groundwater station located in the vicinity of Kalmar. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Area No. 5</th>
<th>Kalmar</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>23</td>
<td>S</td>
<td>Gravel</td>
<td>No data</td>
<td>No data</td>
<td>12.0</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24</td>
<td>A</td>
<td>Gravel</td>
<td>No data</td>
<td>No data</td>
<td>28.8</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25</td>
<td>A</td>
<td>Gravel</td>
<td>No data</td>
<td>No data</td>
<td>57.2</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26</td>
<td>A</td>
<td>Gravel</td>
<td>No data</td>
<td>No data</td>
<td>46.7</td>
<td>NaN</td>
</tr>
</tbody>
</table>
The groundwater levels in Kalmar correspond quite well with the precipitation curve with some minor deviations (see figure 24). Station 23 deviates from the other stations which have a very similar pattern. They do not respond well to minor changes in precipitation and the response to minimum precipitation is slightly delayed. For example the min precipitation year 1982, 1989, 1997, 2003, 2008 and 2011 can be seen in the groundwater levels usually about one year later. This is not visible with the max values except for year 2010. This behavior could be because of the aquifers’ soil type. Water can quite easily flow through gravel which explains the quick response to increases in precipitation.

Station 23 is similar to the others but has a more smooth curve where all the peaks and dips in precipitation does not show in the groundwater response. Station 23 also has a longer delay time between the precipitation and the groundwater. This station belongs to group S while the others belong to group A which is a likely cause to this behavior. It has almost no seasonal variation which may be because it is connected to a river or lake which constantly supplies the aquifer with water all year round. Small changes in precipitation would not show since that would not cause a difference on such a large body of water. Station 23 is located next to buildings which may also influence its pattern if people are drawing water from the aquifer or building. Since geological data is missing it is hard to do a complete and correct analysis for this area.

![Kalmar, normalized groundwater levels and precipitation](image)

Figure 24. Kalmar: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.6.  Böda

Böda is situated on an island (Öland) in the southeastern part of Sweden (see Figure 2). Stations 27, 29-31 are located within 0.5 km of one another and station 28 is about 1 km away from the other stations (see figure 25). All stations are located in the forest, close to an open surface and about 3.5 km away from the sea. The yearly total precipitation is 513 mm and the yearly average temperature is 7.6°C (see table 1).

The groundwater stations in this region are located between 9.8-11.4 m.a.s.l. and the average depth to the groundwater varies between 5.5-8.3 m.b.g.l. (see table 8). All of the aquifers are unconfined, belong to the group classification A and consist of sand. Station 28 is located in a recharge area while the others are located in water divide areas.

Table 8. Information about each groundwater station located in the vicinity of Böda. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Area No. 6</th>
<th>Böda</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Böda</td>
<td></td>
<td>27</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>11.4</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>9.8</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>11.4</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>11.4</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in bedrock, unconfined aquifer</td>
<td>Water divide</td>
<td>11.4</td>
<td>6.6</td>
</tr>
</tbody>
</table>
In the Böda area all groundwater stations have almost exactly the same pattern. A correlation between the groundwater changes and precipitation can be found but with about a one year delay in the groundwater response. This delay difficult to explain on the basis of the available information. Soil type (sand), aquifer type (unconfined) and depth to the groundwater (shallow) speak against geological origin of the delay. The delay could have anthropogenic influence.

Figure 26. Böda: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.7. 8 Isums

Isums is situated on an island (Gotland) in the southeastern part of Sweden (see Figure 2). The only station is located in an area with fields in the vicinity of forest (see figure 27). The yearly total precipitation is 700 mm and the yearly average temperature is 7.3°C (see table 1).

![Figure 27. An overview of the region 8 Isums showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)](image)

The groundwater station in this region is located at 33.2 m.a.s.l. (see table 9). Station 36 is a confined aquifer which belongs to the group classification D. The recharge area consists of boulder clay and the aquifer is located in a water divide area.

<table>
<thead>
<tr>
<th>Area No. 8</th>
<th>Isums</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>36</td>
<td>D</td>
<td>Boulder clay</td>
<td>Pipe in bedrock, confined aquifer</td>
<td>Water divide</td>
<td>33.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Table 9. Information about each groundwater station located in the vicinity of Isums. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Boulder clay is also known as boulder till.) (Based on data from: SGU (2014a).)
In the Isums area the groundwater level seems to correspond quite well with the precipitation curve up until year 1986 (see figure 28). After that the groundwater level flattens out and does not respond well to the changes in precipitation. This change in behaviour does not seem natural and is likely due to human influence. On Gotland where this aquifer is located there are very few groundwater aquifer of significance. It is likely that people are infiltrating water into this aquifer on a regular basis or they have redirected a water flow from a lake or river so it is constantly supplying the aquifer with water and it is therefore not as influenced by the precipitation any more.

![Isums, normalized groundwater levels and precipitation](image)

Figure 28. Isums: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. *(Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)*
3.8. 9 Varberg

Varberg is situated in the southwestern part of Sweden right on the water (see Figure 2). The two stations are located within 3 km of one another and about 10 km away from Varberg (see figure 29). Both stations are located in an area with forest and fields, both pretty close to an area with some buildings. The yearly total precipitation is 840 mm and the yearly average temperature is 7.9°C (see table 1).

![Figure 29. An overview of the region 9 Varberg showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)](image)

The groundwater stations in this region are located between 26-34.6 m.a.s.l. and the average depth to the groundwater is 0.5 m.b.g.l. (see table 10). Both are confined aquifers that are located in discharge areas. Station 37 consists of gravel and belongs to group classification D while station 38 consists of sand and belongs to group classification Ds.

Table 10. Information about each groundwater station located in the vicinity of Varberg. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Varberg</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>D</td>
<td>Gravel</td>
<td>Pipe in consolidated material, confined aquifer</td>
<td>Discharge area</td>
<td>26.0</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Ds</td>
<td>Sand</td>
<td>Pipe in consolidated material, confined aquifer</td>
<td>Discharge area</td>
<td>34.6</td>
<td>NaN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The groundwater levels in Varberg correspond well with the precipitation curve with some minor deviations (see figure 30). Station 37 responds well to changes and is close to the precipitation. Station 38 does not respond as well to minor changes. The recharge area of station 37 consists of gravel which will easily let water flow through and the recharge area of station 38 consists of sand for which it takes water longer to flow through. The surface area of the recharge area also matters. A small recharge area will be more easily affected by changes in precipitation than a large area. Station 37 belongs to group D while station 38 belongs to group Ds which has a smaller seasonal variation. That could be explained if station 38 has a large recharge area.

![Figure 30. Varberg: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)](image-url)

Figure 30. Varberg: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.9. 10 Nissafors

Nissafors is situated in the southern middle part of Sweden (see Figure 2). Stations 46-48 are located about 0.5 km northeast of Nissafors within 60 m of one another (see Figure 31). Stations 43-45 are located about 1.5 km southwest of Nissafors within 0.8 km of one another. Stations 46-48 are located in between forest, fields and open surfaces while stations 43-45 are located in the forest pretty close to some water. The yearly total precipitation is 975 mm and the yearly average temperature is 6.5°C (see table 1).

![Figure 31](image)

Figure 31. An overview of the region 10 Nissafors showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. *(Based on data from: SLU (2014)).*

The groundwater stations in this region are located between 157-183.2 m.a.s.l. and the average depth to the groundwater varies between 0.3-10.4 m.b.g.l. (see table 11). Station 43-45 are unconfined aquifers that consist of sand and all belong to the group classification Ds. Station 43 is located in a water divide area while stations 44 and 45 are located in recharge areas. Stations 46-48 are confined aquifers that consist of moraine. They all belong to the group classification D and are located in an intermediate area.

<table>
<thead>
<tr>
<th>Area No. 10 Nissafors</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>Ds</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>157.0</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Ds</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>163.2</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Ds</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>163.0</td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, confined aquifer</td>
<td>Intermediate area</td>
<td>181.1</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in bedrock, confined aquifer</td>
<td>Intermediate area</td>
<td>182.5</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, confined aquifer</td>
<td>Intermediate area</td>
<td>183.2</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

*The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). *(Based on data from: SGU (2014a)).*
In the Nissafors area the groundwater level at all stations corresponds well with the precipitation curve (see figure 32). A delay in response of about a year can be seen only a few times but it is not consistent. Station 47 has one minimum value that deviates from all the other stations but otherwise follows the same pattern. This sudden change in groundwater level is most likely due to human influence such as pumping out extra water or sudden temporary water loss due to drilling and/or construction work.

Stations 46-48 have the lowest min values the years 1976, 1996 and 2003 while stations 43-45 have the highest max values the years 2000 and 2007 and the lowest min value year 1979-1980 and 1991. The changes are not big and the rest of the time the stations’ trends are very similar. The groups of stations are located about 2 km from each other and all geological aspects are different between the two groups. The maximum and minimum differences are likely due to the stations’ differing geographical locations and their local surroundings.

Figure 32. Nissafors: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.10. 11 Herrljunga
Herrljunga is situated in the mid-southwest part of Sweden (see Figure 2). The stations are located about 6 km from Herrljunga within 0.75 km of each other (see Figure 33). Stations 49 and 50 are located in an area with fields and some nearby forest. Station 51 is located in the forest with some nearby fields and it is close to an area of wetlands. The yearly total precipitation is 819 mm and the yearly average temperature is 6.6°C (see table 1).

Figure 33. An overview of the region 11 Herrljunga showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)

The groundwater stations in this region are located between 144.8-146.8 m.a.s.l. and the average depth to the groundwater varies between 1.7-3.6 m.b.g.l. (see table 12). All aquifers are unconfined and belong to the group classification D. Stations 49 and 50 consist of moraine and are located in recharge areas while station 51 consists of gravel and is located in an intermediate area.

Table 12. Information about each groundwater station located in the vicinity of Herrljunga. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Area No. 11 Herrljunga</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>49</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>146.8</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>145.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>D</td>
<td>Gravel</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Intermediate area</td>
<td>144.8</td>
<td>1.7</td>
</tr>
</tbody>
</table>
In the Herrljunga area there is a correlation between the groundwater level and the changes in precipitation (see figure 34). The curves do not match very well but it is clear that they follow the same pattern. Station 49 is a little different from the other two stations, it does not respond to all changes in precipitation. No geological or geographical aspect can be found to explain this behavior.

Figure 34. Herrljunga: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.11. Tiveden

Tiveden is situated in the mid-southern part of Sweden between two large lakes (see Figure 2). Stations 52, 54 and 56 are located within 2 km of Tiveden in the forest (see Figure 35). Stations 53 and 57 are located in the forest very close to each other about 7 km away from Tiveden. These stations are less than 0.5 km away from a lake. Station 55 is located in the forest on the border to a wetland area about 8.5 km away from Tiveden. It is less than 1 km away from a lake and less than 0.5 km away from a larger wetland area. The yearly total precipitation is 738 mm and the yearly average temperature is 6.4°C (see table 1).

Figure 35. An overview of the region Tiveden showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)

The groundwater stations in this area are located between 121.3-143.9 m.a.s.l. and the average depth to the groundwater varies between 0.5-1.7 m.b.g.l. (see table 13). Stations 52-56 are unconfined aquifers. Station 54 consists of sand while all the others consist of moraine. Stations 52, 54, 55 and 57 belong to the group classification D and the others belong to group C. Stations 52 and 54 are located in recharge areas, stations 53 and 55 are located in water divide areas, station 56 is located in a discharge area and station 57 is located in an intermediate area.
Table 13. Information about each groundwater station located in the vicinity of Tiveden. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>121,3</td>
<td>0,8</td>
</tr>
<tr>
<td>53</td>
<td>C</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>125,0</td>
<td>1,7</td>
</tr>
<tr>
<td>54</td>
<td>D</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>123,3</td>
<td>1,3</td>
</tr>
<tr>
<td>55</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>143,9</td>
<td>1,2</td>
</tr>
<tr>
<td>56</td>
<td>C</td>
<td>Moraine</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Discharge area</td>
<td>130,7</td>
<td>0,6</td>
</tr>
<tr>
<td>57</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in bedrock, confined aquifer</td>
<td>Intermediate area</td>
<td>125,5</td>
<td>0,5</td>
</tr>
</tbody>
</table>

The groundwater levels in Tiveden follow the precipitation curve well with a few deviations (see figure 36). No single station stands out from the others which mean that the differences in geological aspects do not have any visible effect. The groundwater trends are higher than the precipitation in most of the first half of the time series but lower in the second half. This behavior is strange considering that all stations are located so close to wetlands and lakes. There is a possibility of human influence.

Figure 36. Tiveden: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.12.  13 Hallsberg

Hallsberg is situated in the mid-southern part of Sweden (see Figure 2). Stations 64 and 65 are located about 3 km southwest of Hallsberg in an area with forest, fields and some open surface (see Figure 37). The other stations are located in the forest about 6 km southwest of Hallsberg. Station 67 is located on the border to a wetland area, station 68 is close to an open surface area and some small wetland areas and station 69 is located less than 0.3 km from a lake. The yearly total precipitation is 709 mm and the yearly average temperature is 6.3°C (see table 1).

![Figure 37. An overview of the region 13 Hallsberg showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014)).](image)

The groundwater stations in this area are located between 65.8-129 m.a.s.l. and the average depth to the groundwater varies between 1.2-9.1 m.b.g.l. (see table 14). All stations are unconfined aquifers that consist of sand. Stations 64-66 belong to the group classification A, stations 67 and 68 belong to group S and station 69 belongs to group C. Stations 64 and 65 are located in an intermediate area, stations 66-68 are located in recharge areas and station 69 is located in a water divide area.
Table 14. Information about each groundwater station located in the vicinity of Hallsberg. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Intermediate area</td>
<td>65.8</td>
<td>9.1</td>
</tr>
<tr>
<td>65</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Intermediate area</td>
<td>66.0</td>
<td>7.8</td>
</tr>
<tr>
<td>66</td>
<td>A</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>119.0</td>
<td>7.5</td>
</tr>
<tr>
<td>67</td>
<td>S</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>117.8</td>
<td>8.8</td>
</tr>
<tr>
<td>68</td>
<td>S</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Recharge area</td>
<td>113.1</td>
<td>7.0</td>
</tr>
<tr>
<td>69</td>
<td>C</td>
<td>Sand</td>
<td>Pipe in consolidated material, unconfined aquifer</td>
<td>Water divide</td>
<td>129.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

In the Hallsberg area there is a correlation between the groundwater levels and the precipitation with a reoccurring delay time in response of about 1-2 years for all stations except for number 69 (see figure 38). This delay time is likely caused by the combination of the aquifers’ soil type sand and their depth which is 7 m.b.g.l. or more. The difference in group type does not seem to have any visible influence.

Station 69 has two min values that are much lower than the rest which could be caused by construction work. It has a shorter delay time in the response and has a slightly different pattern compared to other stations. The shorter delay time is likely caused by its shallower depth of 1.2 m.b.g.l. and the slightly different trend could be the cause of the difference in topographical location and group type.

Figure 38. Hallsberg: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.13. 14 Kolmården

Kolmården is situated in the mid-southeastern part of Sweden (see Figure 2). The stations are located about 13 km east of Kolmården in an area with fields and forest (see Figure 39). There are a few small wetland areas less than 1.25 km away from the stations and the water is about 2.5 km away. The yearly total precipitation is 647 mm and the yearly average temperature is 6.9°C (see table 1).

Figure 39. An overview of the region 14 Kolmården showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)

The groundwater stations in this area are located between 50.3–57.6 m.a.s.l. and the average depth to the groundwater varies between 0.6–3.4 m.b.g.l. (see table 15). All aquifers consist of moraine and are located in intermediate areas. Station 70 is a confined aquifer and the other two are unconfined aquifers. Stations 70 and 72 belong to the group classification C and station 73 belongs to group B.

Table 15. Information about each groundwater station located in the vicinity of Kolmården. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)
In the Kolmården area a correlation between groundwater levels and the precipitation can be found even though the groundwater levels deviates a lot from the precipitation curve (see figure 40). All stations seem to follow the same pattern except for around year 1990 when station 70 has an extremely low minimum value and after 2001 when station 72 and 73 have lower groundwater levels. These sudden extreme decreases in the groundwater level could be a natural response to previous decrease in precipitation. Since the stations otherwise seem to respond in the same way these decreases are more likely due to human influences such as pumping or construction work. The difference in group and aquifer type does not seem to have any visible influence.

Figure 40. Kolmården: changes in precipitation (prec) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.14. **15 Brattforsheden**

Brattforsheden is situated in the mid-southern Sweden north of the big lake Vänern (see Figure 2). Station 78 is located in the forest right next to a wetland with less than 0.3 km from a lake and about 1 km away from Brattforsheden (see Figure 41). The other stations are located in the forest with some nearby open surface areas less than 0.65 km from Brattforsheden. The yearly total precipitation is 816 mm and the yearly average temperature is 5.0°C (see table 1).

![Figure 41. An overview of the region 15 Brattforsheden showing the location of the groundwater stations. The green symbol shows from where the precipitation and temperature data was extracted. (Based on data from: SLU (2014).)](image)

The groundwater stations in this area are located between 155.3-165.1 m.a.s.l. and the average depth to the groundwater varies between 1.5-7.6 m.b.g.l. (see table 16). All are unconfined aquifers located in recharge areas and consist of sand. Station 76 belongs to the group classification C while the others belong to group S.

**Table 16. Information about each groundwater station located in the vicinity of Brattforsheden. *The yearly average groundwater level calculated for the period 1975 to 2012 as meters above sea level (m.a.s.l.) and meters below ground level (m.b.g.l.). (Based on data from: SGU (2014a).)***

<table>
<thead>
<tr>
<th>Area No. 15 Brattforsheden</th>
<th>Station No.</th>
<th>Group type</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.a.s.l.*</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
</table>
| 76                          | C           | Sand       | Pipe in consolidated material, unconfined aquifer | Recharge area | 163.2 | 1.5
| 77                          | S           | Sand       | Pipe in consolidated material, unconfined aquifer | Recharge area | 161.2 | 6.4
| 78                          | S           | Sand       | Pipe in consolidated material, unconfined aquifer | Recharge area | 165.1 | 3.3
| 79                          | S           | Sand       | Pipe in consolidated material, unconfined aquifer | Recharge area | 155.3 | 7.6
In the Brattforsheden area a correlation between the groundwater levels and the precipitation can be seen even though the groundwater levels do not follow the precipitation curve so closely (see figure 42). Stations 77-79 sometimes have a one year delay time in the response which could be caused by the soil type sand in combination with their depth. Station 76 has a slightly different pattern compared to the other stations and it does not have a delay in the response time. This may be because the station belongs to group C while the other stations belong to group S which has almost no seasonal variation possibly due to being connected to a large body of water.

Figure 42. Brattforsheden: changes in precipitation (prcp) and groundwater levels from 1975 to 2012 plotted as normalized values. Each number represents a specific groundwater station for this area. (Based on data from: SMHI-luftwebb (2014) and SGU (2014a).)
3.15. Summary of all regions
For this section two maps and one table were created to summarize all the data about the regions. The first map (figure 43) shows the group distribution according to this report (lower right corner) and according to Sundén et al. (upper right corner). The second map (figure 44) shows the soil type distribution. The table shows the geological properties for all regions including correlation between groundwater levels and precipitation, response time and less responsive aquifers (see table 17).

Figure 43. An overview of the distribution of group classification according to this report and to Sundén et al. (2010).
(Based on data from: (SGU, 2014a), (DIVA-GIS, 2014) and (Sundén et al., 2010).)
Lower right corner
Sand: 31 stations
Moraine: 19 stations
Gravel: 6 stations
Boulder clay: 5 stations

Figure 44. An overview of the soil type distribution. (Based on data from (SGU, 2014a) and (DIVA-GIS, 2014).)
### Table 17. An overview of geological properties. (Boulder clay is also known as boulder till.) *(Based on data from: SGU, 2014a) and analysis from results.)*

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Group type</th>
<th>acc. To Sundén et al.</th>
<th>Soil type</th>
<th>Aquifer type</th>
<th>Topographical location</th>
<th>Average m.b.g.l.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vellinge</td>
<td>D</td>
<td>B</td>
<td>Boulder clay</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Water divide</td>
<td>3.9</td>
</tr>
<tr>
<td>2. Kristianstad</td>
<td>D</td>
<td>B</td>
<td>Boulder clay</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Water divide</td>
<td>3.7</td>
</tr>
<tr>
<td>3. Liatorp</td>
<td>D</td>
<td>D</td>
<td>Gravel</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Water divide</td>
<td>4.3</td>
</tr>
<tr>
<td>4. Emmaboda</td>
<td>D</td>
<td>A</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>1.6</td>
</tr>
<tr>
<td>10. Nissafors</td>
<td>D</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>1.1</td>
</tr>
<tr>
<td>11. Herrljunga</td>
<td>D</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>0.9</td>
</tr>
<tr>
<td>12. Tiveden</td>
<td>D</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>0.9</td>
</tr>
<tr>
<td>13. Hallsberg</td>
<td>D</td>
<td>A</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>0.9</td>
</tr>
<tr>
<td>14. Kolmården</td>
<td>D</td>
<td>A</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>0.9</td>
</tr>
<tr>
<td>15. Brattforsheden</td>
<td>D</td>
<td>D</td>
<td>Moraine</td>
<td>Pipe in soil, unconfined aquifer</td>
<td>Recharge area</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**Possible human influence**
- **Correlation**
- **Response**
- **Groundwater trend**
  - **Short term**
    - Very good
    - No delay
    - Clearly increasing
  - **Long term**
    - Good
    - Sometimes delay
    - Clearly decreasing
  - **(1975-2012)**

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4. Discussion
Each of the geological properties from table 17 will be analyzed and discussed to see if any patterns can be found. Figures 43 and 44 are also used for this part.

4.1. Correlation
The aquifers with best correlation between precipitation and groundwater level can mainly be found the southernmost part of Sweden in region 1 and 2. There is also one on the west coast in region 9. The ones with good correlation are spread out in regions 1, 3, 5, 9, 10, 11 and 12. The aquifers with some correlation are also spread out in regions 3, 4, 5, 6, 8, 11, 13, 14 and 15. No common variable can be found to explain the difference in correlation between the precipitation and groundwater levels.

Anthropogenic influences such as extreme sudden or long term changes of the groundwater level due to construction, artificial infiltration, pumping and altering of surface water flows will likely affect the level of correlation between the precipitation and groundwater levels.

4.2. Response time
The aquifers displaying no delay in response time are located in regions 1, 3, 4, 8, 9, 11, 12, 13, 14 and 15. The one common variable that could be found was that all aquifers except for one (31) have a depth of 4.3 m.b.g.l. or lower. The water can reach the aquifer quickly and not cause a delay in the response.

The ones with some inconsistent delay are in regions 2, 5, 10 and 15. No variable can be found to explain this kind of behavior. Region 2 has likely been long term influenced by humans (overuse/pumping) which may have caused the inconsistent delay. It is possible that some of the other regions have unnoticed anthropogenic influences. This could be the reason behind the delay at some aquifers.

The aquifers with a continuous delay can only be found in regions 6 and 13. In these two regions all aquifers are unconfined and consist of sand. 8 of the aquifers belong to group classification A (group 4 according to Sundén) and 2 to group S (n/a according to Sundén). If the sand is fine sand in combination with the depth of between 5.5-9.1 m.b.g.l. it is a possible explanation to the delay in response. In region 10 there are 3 aquifers and in region 15 there are 2 aquifers which are also deeper than 5.5 m.b.g.l. and consist of sand. These have an inconsistent delay in response time. Why these do not have a consistent delay time could be because they consist of a coarser type of sand which will allow water to infiltrate faster.

By using yearly averaged values all the short term variability is lost. An aquifers response time can vary from a few hours to several months (Ojala et al., 2009) which cannot be detected when using yearly averages. An improvement to this analysis would be to use monthly averages instead and possibly also daily averages for a shorter time period.
4.3. Group type
Group C is only found in the northern part of southern Sweden in regions 12, 13, 14 and 15 (see figure 43). Each of these regions has aquifers that belong to other groups. All other groups are spread out. No common variables could be found within the groups to explain their similar seasonal variations. In these figures a 25 year monthly average (1987-2012) was used to show the seasonal pattern of each aquifer. In order to get a more up to date seasonal pattern a shorter time period could be used for example year 2002-2012 (10 years). By doing that the groups would likely have look different.

All group A and B aquifers were classified as group 4 according to Sundén et al. (2010) while all group C and D aquifers were classified as group 3. The ones belonging to group S and one Ds had a too small seasonal variation to be able to classify according to Sundén’s groups. The other Ds were classified as group 3. There is no other common geological aspect (than seasonal pattern) that can explain the group distribution between the aquifers.

4.4. Soil type
The soil type distribution do not show any particular pattern (see figure 44). Aquifers with a specific soil type do not necessarily display a similar behavior. A more specific soil type classification (course sand-medium sand-fine sand-very fine sand) would have been very interesting, especially in the discussion about response time.

4.5. Aquifer type
Neither of the aquifer types correlates to any distinct behavior. According to Ojala et al. (2009) an unconfined aquifer has a 1-2 weeks longer response time to groundwater recharge but this cannot be seen since yearly averaged values are used.

4.6. Topographical location
All aquifers located in a discharge area have a very shallow depth (0.5-0.6 m.b.g.l.) except for one for which there is no data. This could be a correlation but more data points are needed to draw a conclusion. No correlations can be found between aquifers in other topographical locations and geological properties.

4.7. Depth to aquifer (m.b.g.l.)
A deep depth down to the aquifer in combination with a fine grain soil type like very fine sand or clay was expected to show a delay in response. Considering that the grain size is unknown this could not be detected. The opposite, a coarse grain type like gravel in combination with a shallow depth would be expected to show no delay in response time but this is not true for region 5. However it is possible that aquifers have been influenced by humans.

4.8. Anthropogenic effects
Considering that the precipitation is increasing for each region between 1975-2012 it would seem logic that so would the groundwater levels. 17 aquifers show a clearly decreasing trend and 13 show neither an increasing or decreasing trend. 22 of these 30 correlate with a detectable possible human influence. The other 8 are likely also being or have been influenced by some kind of human activity which has altered their groundwater level.
The correlation between precipitation and groundwater levels are based on one year averages. Anthropogenic changes such as road work, increased population, increased agriculture, infiltration of surface water into an aquifer and temporary or long time overuse (pumping) of a groundwater aquifer will result in sudden and/or long term unnatural changes in groundwater level. Sudden changes are usually easily spotted but smaller changes may not even be noticeable. Whatever precautions are being used to ensure natural results there is always going to be some anthropogenic influence. The population is increasing which means the water usage is increasing. People are building new roads and buildings which alters the surface flow of water which in turn can affect the groundwater recharge.

4.9. Interesting future work

- Choose two time periods, for example 1980-1994 and 1998-2012 and plot groundwater levels and precipitation for these periods. How has the seasonal variation changed?

- Monthly/weekly/daily analysis of groundwater levels and precipitation to see delays in response which cannot be spotted when using yearly averages.

- A more detailed analysis of trendlines for the groundwater, compare groundwater and precipitation slopes of linear trendlines.
5. Conclusion

Specific research questions raised in the introduction of this report will be answered and a short summary of other important information will be given.

1. What is the connection between the precipitation and groundwater levels?
- Precipitation infiltrates into aquifers and the groundwater level generally increases with an increased precipitation and decreases with a decreased precipitation.

2. Does this connection show a general trend or can local conditions lead to significant differences? What geological and geographical aspects and aquifer characteristics may cause these differences?
- The degree of correlation between changes in precipitation and groundwater level varies between the different aquifers but they do always correlate to some degree. The aquifers with best correlation are located on the south and west coast. Some aquifers have a delay in groundwater response time. All aquifers with a continuous delay consist of sand and have a depth of 5.5-9.1 m.b.g.l. If the grain size of the sand is fine this could in combination with the depth explain the delay but grain size information is not available so this cannot be confirmed. 31 out of 32 of the aquifers with no delay in response time have a shallow depth of 4.3 m.b.g.l. or lower. No other connections could be made between differences in behavior and geological or geographical properties.

3. Do similar geological conditions lead to similar behavior in the aquifers’ groundwater levels?
- With available information it was not possible to find that similar geological conditions correlate to similar changes in groundwater levels.

Since yearly averaged values were used all short term variability was lost and the delay time in the groundwater response could not be fully analyzed. A more specific soil type classification would have made it clearer whether or not the soil type has a significant effect on the groundwater response time. Anthropogenic changes, both intentional and unintentional, takes place all the time and can easily affect surface water flows and infiltration into aquifers. Some are easily spotted and can be taken into account when analyzing results but others are not so there is a margin of error.
6. Acknowledgements
I would like to thank my advisors Roland Barthel and David Rayner for their great support and encouragement throughout the whole process of finishing this thesis. I am also grateful to Hans Linderholm for being my examiner.

7. References