Norwegian University of Life Sciences

Master's Thesis 2017
30 ECTS
Faculty of Environmental Science and Technology
Department of Environmental Science

Hydrogeological Conditions at the Water Works of Elverum Kommune

Nabin Kharal
Specialization in Sustainable Water and Sanitation, Health and Development

Preface and Acknowledgement

I would like to express my sincere gratitude to the ‘Department of environmental sciences’ NMBU, for allowing me to write this thesis as a requirement for master degree in’Sustainable water and sanitation, Health and development’.

Many people deserve recognition for the help given to me during my thesis. First and foremost, I would like to thank my main supervisor, Helene K. French for tireless supervision, insightful discussions and constructive feedback on my work. Next I wish to thank my co-supervisor, Sondre Gjengedal (NTNU), for all the supervision during the field work and writing of report. I am very thankful to my friends Ania, Berit, and Ashad who helped during my field work. I also wish to thank Clara Sena, Ania , lief giving assistance during my field work.

I am thankful to my friend Sonam Shrestha who encourage me during writing of my thesis. I would like to thank to Sabnam Mahat who helped me making my final edit of my thesis report. Last not the least I am so thankful to my family who inspired me all the time to accomplish the task during the period of my study.

Ås, August 2017

Nabin Kharal

Executive Summary

Norwegian rivers and lakes can provide abundant amount of fresh water being more than 60% of these surface water sources in high ecological status. About 15 % of water consumption in Norway is using groundwater as a source. Grindalsmoen water work located in Elverum is one of the biggest water work of Norway which uses a ground water as raw source of water for municipal water supply. The water work is supplying fresh water for the population 17,000 by making pumping through 4 extraction wells. The raw water consists of iron and manganese as impurities in natural condition which are in dissolved condition. These impurities are separated from raw water through Vyredox method where air is inject to a ground water through 9- satellite wells located around the main pumping well. Glacio-fluvial and alluvial deposits are major deposits from few hundreds meter to kilometres from bank of river in both direction. This type of geological condition favours extraction of groundwater, and has possibility of high amount of groundwater recharge compared to the till deposits located at outer region of river. The objective of this study was to improve the understanding of the geological Condition and groundwater flow at Grindalmoen. Based upon these information we tried to understand the response of aquifer system during annual fluctuation on recharge and continuous pumping on water work area.

The preliminary information like Quaternary maps, annual precipitation, position of bedrock and stable water position was obtained from different sources like NVE, Granada data Base etc. The annual recharge was taken as 283.4 mm/year where 1/3 of recharge is assumed to account for autumn recharge and 2/3 of total recharge accounts for snow melt. To improve the understanding of the detailed geological condition, a field course was conducted during the summer of 2017 within collaboration between NMBU and Oslo University. During the field course, geophysical explorations, drilling and infiltration tests were conducted to understand the geological situation around Grindalmoen water work area. The task was done into two methods to understand the soil surface property and sub-surface conditions. The test like infiltration test, slug test and grain size distribution were conducted to determine the hydraulic conductivity of water work area. The average hydraulic conductivity of surface soil was found to be 0.000634 m/sec. This value represents to hydraulic conductive of fine soil particle and from grain size distribution result also we got a similar type of soil property in top surface. The geophysical investigation was performed through electrical resistivity (ERT) survey, GPR survey and seismic survey. From ERT results we obtain heterogeneous soil property with fine sand on top surface and saturated coarser soil underneath the top surface which is controlling the flow around a water work area. The GPR survey showed a clear location of ground water within 5m meters from the top surface and its flow direction was towards the river with mild gradient. The GPR survey made clear visualization of dense surface at almost 30 meter around waterworks area indicating a confining layer above a more conductive aquifer below. The seismic survey gave an indication of location of ground water table.

The numerical model was developed using a graphical user interface called Modelmuse together with the groundwater flow model Modflow-2005 to represent the geometry, including surface topography, and hydrogeological conditions of the aquifer. Information on hydraulic conductivity, recharge rate, pumping rate and positon of bedrock was introduced in the model to make the numerical model similar to real condition. The model was run for both steady state and transient state making several stress period similar to annual recharge fluctuation for 15 years. The observation was made in three different location of catchment area where were we observe clear fluctuations in head values during annual fluctuation of recharge. The pumping test was made with the same value of pumping rate i.e. 60 litres per second that Grindalmoen

water work makes and with rate of 600 litres per second to observe the drawdown in the well area. The modelling result gave the draw down head values up to 1.75m in water work area which is quite near the observed Drawdown value which was up to 2 meters during pumping at rate of 60 litres per second in Main well 4 of water work area. Further we observe that the drawdown curve did not reached to the constant head which was considered as supply of continuous water to system. But during pumping at rate of 600Litres per second drawdown was only 3.6 meter although pumping rate was 10 times higher than the normal pumping rate. The sensitive analysis was made by varying the hydraulic conductive and recharge in catchment area. The result indicates that the aquifer is more sensitive toward hydraulic conductive compared to recharge.

From the detailed study we came to know that the top surface of water work is dominated by fine sand and medium sand with lower conductivity and the subsurface consists of completely saturated coarser sand. The ground water is located at shallow depth of 5meters near water work and flow direction is almost perpendicular in norther area of water work but slowly follows in parallel direction as well move downward to water work area. The numerical modelling showed that the aquifers make change in head value in accordance with fluctuation in recharge periods. The drawdown curve made due pumping at rate of 60 litres per second doesn’t meet the constant and was similar with actual field condition. So can make assumption that there is little influence on aquifer due to drawdown of head during pumping at rate of 60 litres per second.

The entire study including modelling was done based on field study and information collected from secondary sources. Although the geophysical measurements and drillings provide useful information about the heterogeneity and hydraulic conductivity of the area, it is still limited for a very detailed understanding of the hydrogeology of the water works area. The information regarding hydraulic conductivity of soil was just determined for top soil. But to obtain much more accurate results several no of geophysical study need to be made so collect this sub-surface information. The bedrock was located up to depth 30 meter near water work and was even exposed in western part of catchment area. This steep gradient of the underlying bedrock is difficult to represent with the rectangular grid used in Modflow, alternatively a more sophisticated software using finite element or much finer grid resolution in Modlfow is required for a better representation of the real aquifer geometry.

The results obtained from this study could be used to make further investigation of the water work area. The flow pattern of ground water could be used to conduct more geophysical investigate in that area.

Table of Contents

List of figures

Chapter 1
Introduction

Norwegian rivers and lakes provide abundant amount of fresh water for different purposes, as these sources are under less pressure from human activity compared to rivers and lakes of other European nations. As a whole, more than 60 % of all rivers and lakes have good or high ecological status which could be used as good water source. But not all surface water are suitable for safe usage. Thus, ground water is used as an alternative source for water supply. Only around 10% ground water is used as fresh water source in Norway, and accounts for a mere 15 % of the water consumption. This is very low compared to many other countries in Europe as Sweden used up to 50% and Denmark uses 100% groundwater as source of raw water supply for drinking purpose and is due to the country’s abundant supply of surface water (Anon 2015).

The water work at Elverum, Grindalmoen is one of the biggest water work of Norway which uses ground water as raw source of water. The fluvial river deposits, shallow groundwater level and the river Glomma flowing near the water work area create a need to understand the morphology of catchment area, aquifer and river. Further, it represents a situation to understand whether aquifer is solely recharged through precipitation in that area or if there is any contribution by River Glomma.

1.1 Problem Formulation

Since many years Grindalmoen has been considered suitable for larger groundwater outlets. During the period from 1972 to 1982, several quaternary and hydrogeological investigations were conducted. From 1982 to 1985, the study was conducted to make Concrete plans for operating the municipal water supply because the old water supply at Sagtjerne had problems with too high contents of iron and manganese(Elverum kommune, pers. communication). All examinations and test pumping indicated that the area could be utilized for municipal water supply and the State Institute for Public Health (SIFF) has also given prior approval for the construction of a new waterworks (Knudsen 1985). On the basis of the data collected, the Grindalmoen water work came into implementation. However, the influence of river Glomma that passes near to the water work on ground water capacity was not studied sufficiently. Additional study on whether the rainfall is solely responsible for the recharge of ground water or is there any influence of the river is required to ensure safe and sustainable supply of groundwater from Elverum.

1.2 Objective

The main objective of this study was to investigate and understand the Hydrogeological conditions that is acting near the Grindalmoen water work based on both field work and numerical Modelling. The specific objective of the study area are.-

- To understand geology condition at Grindalmoen water work area.
- To identify the general flow pattern.
- To understand the response of Aquifer system during annual fluctuation and pumping in wells.

Chapter -2
Study Area

2.1 General Information

Elverum, a municipality in the Hedmark county, which is located in the eastern part of Norway, has a population of 21,030 (Statistics Norway, Collected in January 1, 2016). The municipality has operated two municipal water works among which Grindalmoen is one of the major sources of water supply for approx. 17,000 people. Grindalmoen water work is located near the biggest river of Norway, Glomma. River Glomma flows in the eastern side of this water work area. The water work has 4 production groundwater wells. Each well has a capacity to supply water at a rate of 60 litres per second (Ls^{-1}).

Figure 1 Elverum Water work Area Source: - Ngu.no

Iron and manganese are common metallic elements that occur together naturally, especially in deeper wells with little or no oxygen present. In the areas where groundwater flows through an organic rich soil and the oxygen levels are low, iron and manganese will get dissolved in the groundwater. The groundwater in this area was found to have high concentrations these dissolved iron and manganese. The removal of these dissolved iron and manganese from groundwater is generally accomplished by the oxidation and precipitation. The Vyredox was used to remove these impurities, highly oxidized zone was created around the pumping well by the injections of oxygen rich water.

The 4 wells are used to supply water for a municipality rate of 60 Ls^{-1}. The Vyredox method is carried out at each well, which is surrounded by a ring of nine satellite wells. These satellite wells are named SB1, SB2, SB3, SB4, SB5, SB6, SB7, SB8 and SB9, and can be seen in Figure

2. Water is abstracted from two satellite wells e.g. (SB1 and SB3) at a same time at the rate of 6 Ls-1 for 2 hours. This abstracted water is aerated with oxygen at its partial pressure. Then this aerated water is injected to the ground through the well located between these two wells (SB2). For next time water is abstracted from (SB4 and SB6) for two hours at the same rate, abstracted water is aerated with oxygen, and this aerated water is injected through the well locating between these two wells which is (SB5). Then this process is repeated for all other wells means every time outer two wells are abstracted and aerated water is injected through the well locating between these two. This aerated or oxygen enriched water creates the oxidized zone in aquifer which forces the iron and manganese to precipitate and purified water is pumped through the main abstraction well.

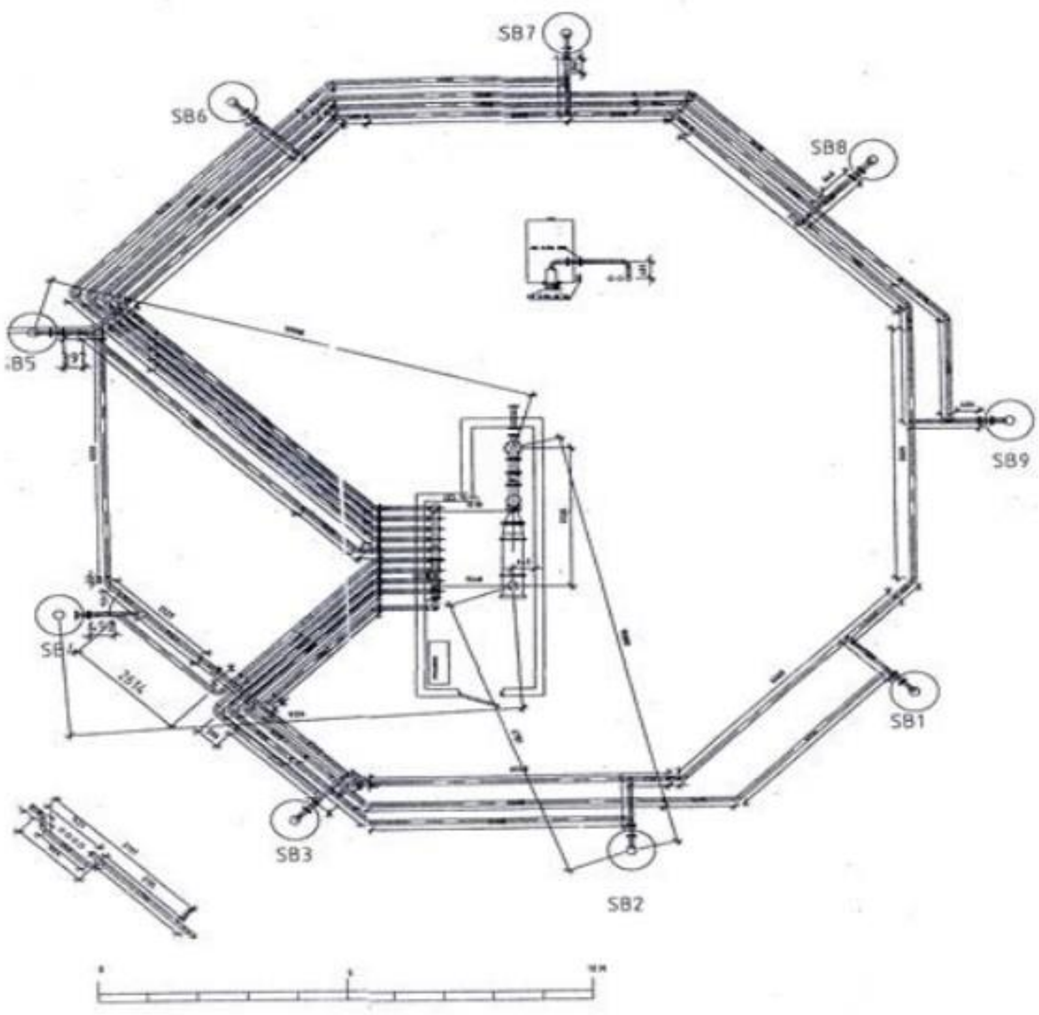


Figure 2 Well no 4 equipped with satellite wells

2.2 Geology and Quaternary Geology

Study area

At the end of ice age, the glacier were waned and extended ultimately positioning ice margins from southern Norway to northern .These glacier were formed in a U/shaped valley which gradually transformed into growing fjords in line with the receding polar ice in northwards. A significant quantities of water was dammed forming a large -ice dammed lakes due to melting of these glaciers between ice and middle Norwegian mountain range. And one of the largest ice-dammed lake was so called lower Glømsjø (Nedre Glomsjø).

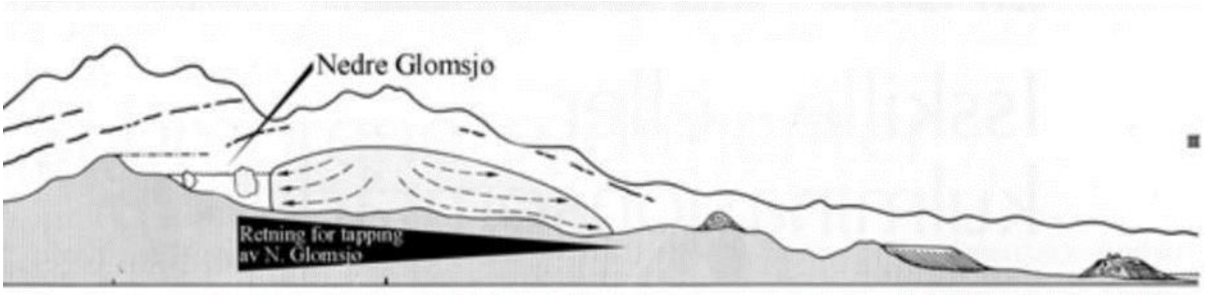


Figure 3 landforms formed due to formation of glacier in lower Glomsjø   Figure from Hansen et al. (2005)

Due to continuous melting of ice, ice cover was able to reduce pressure in the lower part. Glomsjø, a huge deluge of valley was resulted as water broke through 9200 years ago.

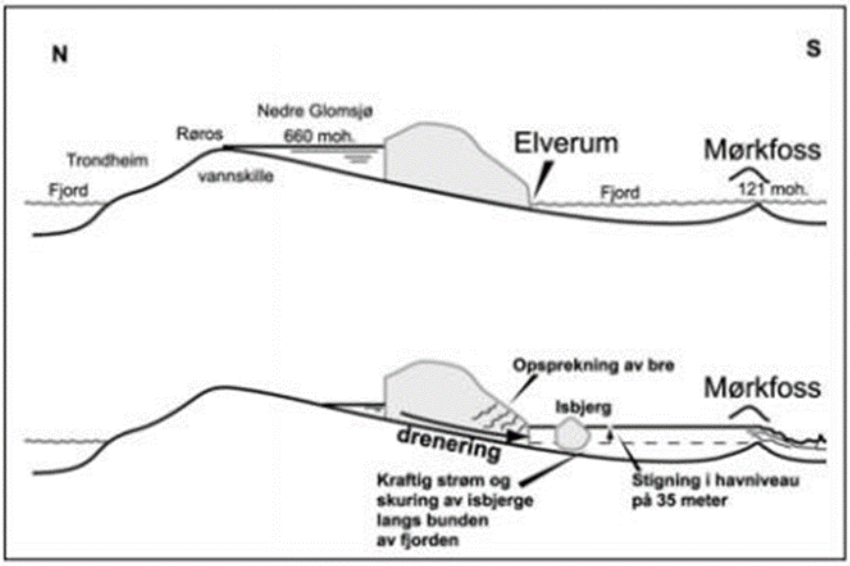


Figure 4 landform due to release of pressure due to ice melting   Figure from Hansen et al. (2005

Elverum is characterized by the soils that were deposited in connection with this drainage. Sand and gravel fractions are found to be dominating covering large area of Elverum. Specially, glacio-fluvial and alluvial deposits are major deposits where some area consists of wind deposits too (Hansen et al. 2005).

Study area

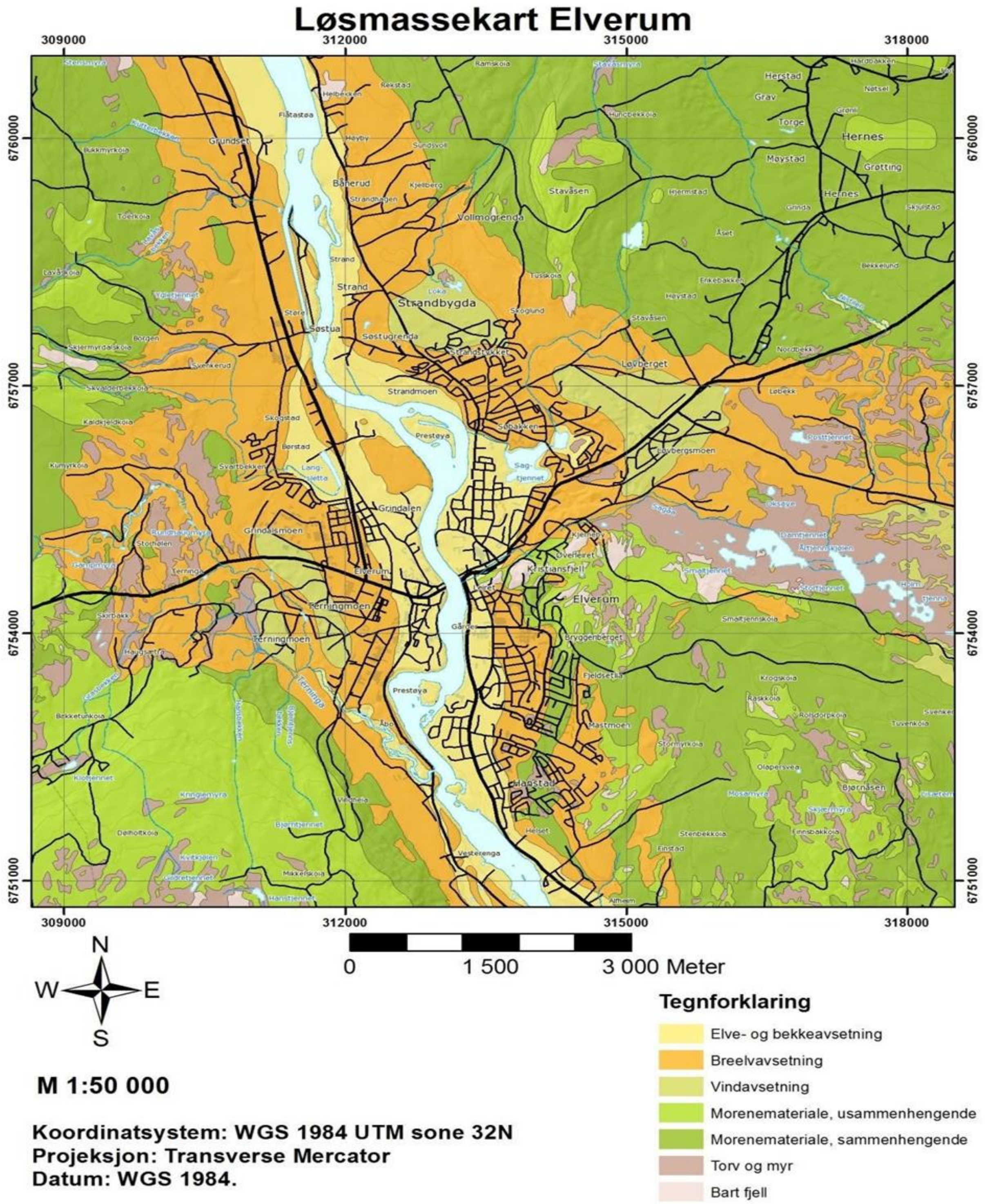


Figure 5 Soil mapping of Elverum area Source :- NVE.no

Further, in some places 30-40 meters thick glacio-deposits are found near the larger lakes and rivers (Gaut et al 1981, p.46). These can be interpreted as deposition in connection with tapping incident of lower Glomsjø. Also, some parent deposits materials was made by the glacier that came from Glomma River (Bongel 1982; Bongel 1983).

During the ice age, the crust of this area was depressed due to isostatic pressure exerted on it. As the ice started melting, reduce in this isostatic pressure counter mended to rise in land again. As melting of ice results in increase in amount of water with rise in sea level (Reite et al 1999).

Ultimately, the rise in land cause the erosion in river basin and they began to dry down through the esker. This formed a river terrain which shows the river terrace in that area (Kalskin & Hilmo 1999, p.9).

2.3 Geographical and Topographical condition

The area around Elverum is covered with sediments from Quaternary time and later eroded and deposited again by Glomma and smaller creeks. So, area close to the river Glomma is dominated by fluvial material and adjacent to this glaciofluvial material are present from few hundreds meter to kilometres from bank of river in both direction. This can be clearly seen with change in colour from yellow to orange in map representing silt, sand and gravel deposition by running water, either in conjunction with glacier river at the end of the ice age (shown by colour orange in figure 5), or of later river activity of and around the Glomma (shown by colour yellow in figure). This type of geological condition favours for possibility of high amount of groundwater recharge compared to the till deposits located at outer region of river.

Further, the green colour which is shown on the map below is mapped as the Till (moraine) material deposited by the ice caps. Orange and yellow? Light yellow colour shows fine sand that is carried and deposited by wind (aeolian deposits). Whereas, exposed rocks is shown in light pink colour on the quaternary geological map. Areas with peat (organic matter) are shown in grey-brown colour.

The topographical condition of Elverum seems to be slightly mild grade with rolling ground surface which can be seen in figure 5. The area has maximum height of 319 m.a.s.l to lowest ground surface of 180 m.a.s.l. whereas, Grindalmoen has got a rolling topographical condition where most of the area is covered by forest. The gradient of river Glomma flowing across the river also does not have high gradient due to such topographical situation. This area is composed with fluvial deposits and glaciofluvial deposits where most of area is covered by forest vegetation. The source of raw water is taken as ground water, thus the area requires aquifer which can supply large amount of water. This area is composed with sand and gravel particles and has created a suitable environment for recharging ground water. The main source of recharge is snow melt during the winter which has precipitation value of 302.25 mm and summer precipitation 358 mm. The total recharge in the water work area is supposed to be 283.9 mm/year (NVE). The Hydrogeological map of Grindalmoen by *Gaut et al. (1981*) shows the movement of ground water from higher land fields in western part to south east towards river.

Based on Map by Gaut.et.al (1981), the gradient of river doesn't seems to be so high if we observe the counter line of groundwater meeting the river bank exactly near to the river. Also, the contour lines of groundwater in this area are far away indication a mild or small gradient as similar pattern of river bank. So, from this type of similar gradient between the river and groundwater we can assume that the groundwater flow is parallel to the river Glomma up to few hundred meters in downstream. Ultimately groundwater flow seems to be connecting river making introducing groundwater to the river in downstream

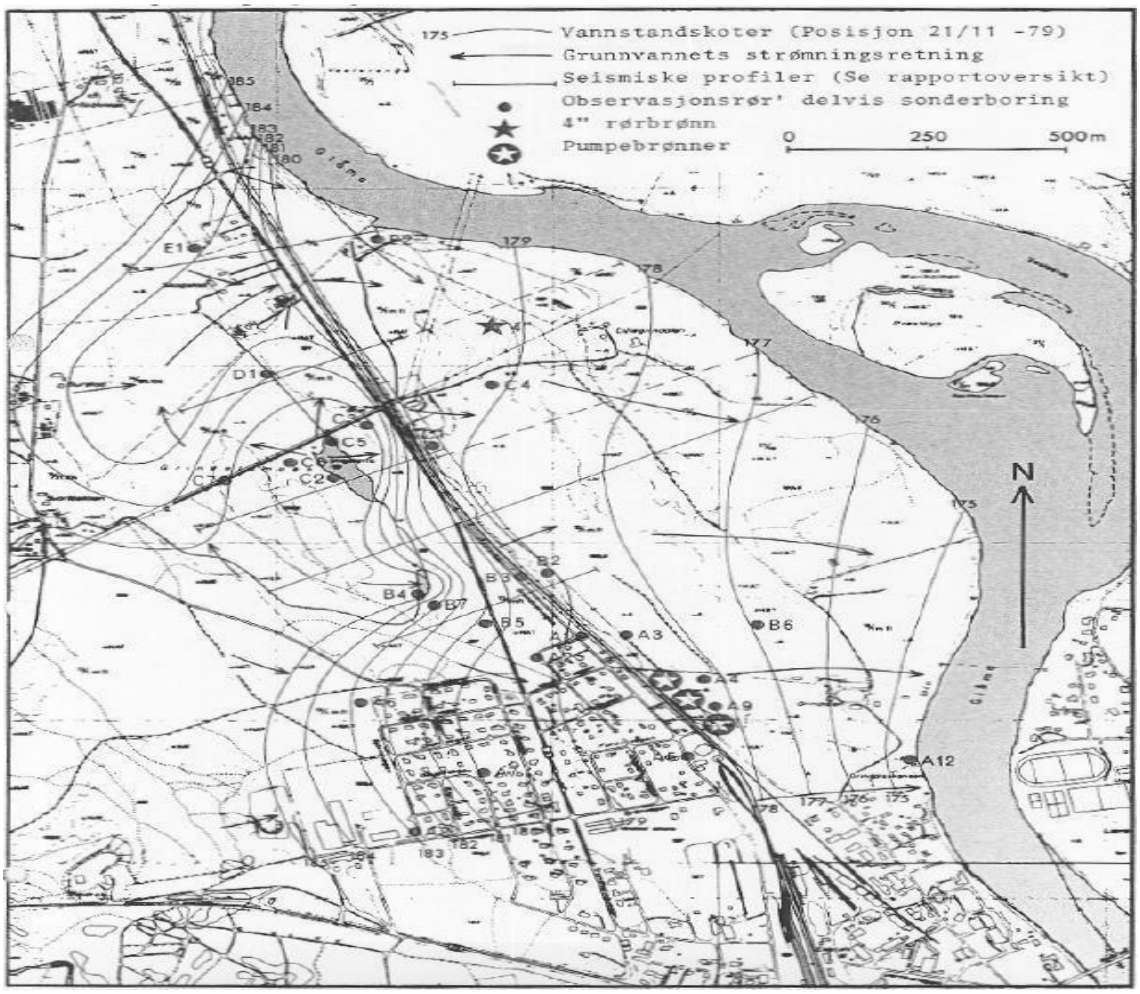


Figure 6 Hydrogeological map of Grindalmoen showing different information available in this area. Source Gaut et al. (1981)

2.4 Hydrological Scenario

This area is formed in past as result of rise in land and ultimately causing the erosion in river basin. This formed a river terrain and ultimately the river Glomma, the longest river of Norway passes from the centre of the Elverum till now. So, Elverum area is mainly found to be characterized by the river sediments. The most dominant soil type is sand and gravel fractions. These soil type possess high porosity and permeability (Bratti 2009). This type of soil deposits provides the less amount of rain water get runoff during the rain with higher amount of infiltration to ground water. This type of soil property highly dominates the hydrological condition of this area.

According to the Norwegian Metrological Department (2015), the average annual precipitation of Elverum was recorded as 670 mm per year. Since the topography of this area leans towards the river Glomma, some percent of the rainwater gets drained towards the river through surface runoff; but most of it gets infiltrated for recharging the ground water. In addition, the river flowing through this area had an average flow of 704 m^3/s and the highest flood was recorded with 3580 m^3/s and 3582 m^3/s in 1995A.D and 1967 A.D respectively (Tockner et al. 2009). To understand the possibility of direct or indirect influence on the quantity and quality of ground water source, it is very important to understand the hydrogeology of the basin. But in case of our study the influence of fluctuating river stage and extreme events such as these have not been studied.

Glomma river passes through a long distance with a large catchment area which is fed with water from several sources and agricultural fields. The groundwater body is found to be consisting of fluvial and glaciofluvial deposits with the water table gently sloping towards the river, and the ground water level of Elverum and water work is above the water level of river Glomma . Due to this reason, there is less possibility of flooding in water work area to make influence on water availability and quality in groundwater, except in case of extreme rise in water level in river Glomma. The water work has also make elevated zone that protects the water works from flooding situations in Glomma.

Figure 7 Stone marked with biggest floods in history of elverum

Chapter -3
Material and Methods

3.1 Hydrological cycle

The geological process plays a very important role to maintain quantity and quality of groundwater source. Lithification is significantly affected by presence or absence of groundwater, its chemistry and temperature.

The main system to govern this overall process of water in nature is the hydrological cycle which is vast and complex system and accounts for the storage and flow of water on the ground. Groundwater forms a part of this cycle. In order to understand how a particular groundwater system works, it is necessary to examine the other elements in the cycle. The energy from the sun, evaporation of water from surface forming clouds, precipitation, transmissivity/ percolation of water to soil reaching up to aquifers, runoff to rivers transpiration etc. are the major parts of the hydrological cycle (Brassington n.d.; Gr et al. 1999). The hydrological cycle follows a law of conservation of mass,

$$\mathbf{Input} - \mathbf{Output} = \mathbf{Storage} \qquad (1)$$

This law can be further explained as following form for any watershed,

$$\mathbf{P + GW_{IN} - (GW_{OUT} + E + R) = S} \qquad (2)$$

Where, P equals precipitation, GW equals groundwater, E equals evaporation, Q equals runoff and S equals storage of water in aquifer.

3.2 Geophysical Exploration

Geophysical technique has become one of the most sophisticated techniques to study geophysical properties of the earth crust which varies from few meter depth to earth surface to 1000's of meter. The sub-surface geophysics for groundwater investigation is usually restricted to depth less than 250m below the surface. But the application of these technique has made possibility of mapping the depth and thickness of aquifers, mapping aquitards or confining units, locating preferential fluid migration paths such as fractures and fault zones and mapping contamination to the groundwater such as that from saltwater intrusion (University of St Andrews n.d.). In this thesis three geophysical methods were used to map the geology and groundwater conditions around Elverum water works, ground penetrating radar (GPR), electrical resistivity tomography (ERT) and seismic. The surveys were done as part of the hydrogeology field course (GEO221)

3.2.1 GPR Survey

The conventional underground water survey method is regarded as "Destructive Surveying" (e.g. monitoring wells, drilling and excavation) that often consumes excessive manpower resources and yet cannot accurately establish a network of underground water levels. GPR survey is one of the best method to explore the underground geological condition in different depth with position of water level at different depth.

The GPR survey is equipped with transmitting antenna pointing towards the ground constantly transmits radar wave of 10~2500 MHz in very rapid velocity (speed of light in a vacuum environment). When a certain interface or object changes the conductivity or dielectric constant under the electromagnetic characteristic, a partial radar wave is reflected to the ground surface. The image is then displayed on the screen and, after processing, the signal can be

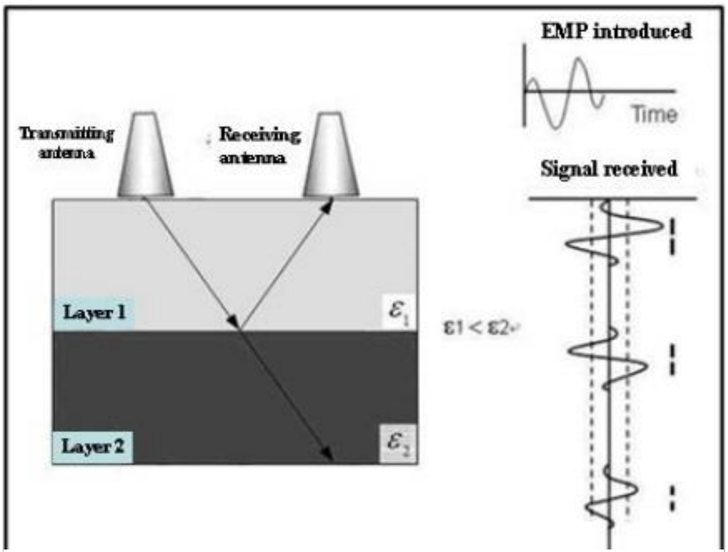


Figure 8 Principal of GPR image

plotted into a Distance-Time diagram which can be used to determine the position of abnormal underground electromagnetic waves as well as to estimate the relevant stratum interface. Ultimately, it helps to produce an image of structures and layering underground (Lin et al. 2009).

GPR penetration depth depends largely on the transmitted antenna frequency and electrical conductivity of the ground. A lower antenna frequency provides a good penetration depth, but lower resolution. Similarly, a higher frequency antenna poorer penetration depth, but a large resolution (Reynolds 2011). The GPR instrument used in this study was produced by sensors and software Inc. Canada and utilized 50 MHZ antennae spaced 1m apart.

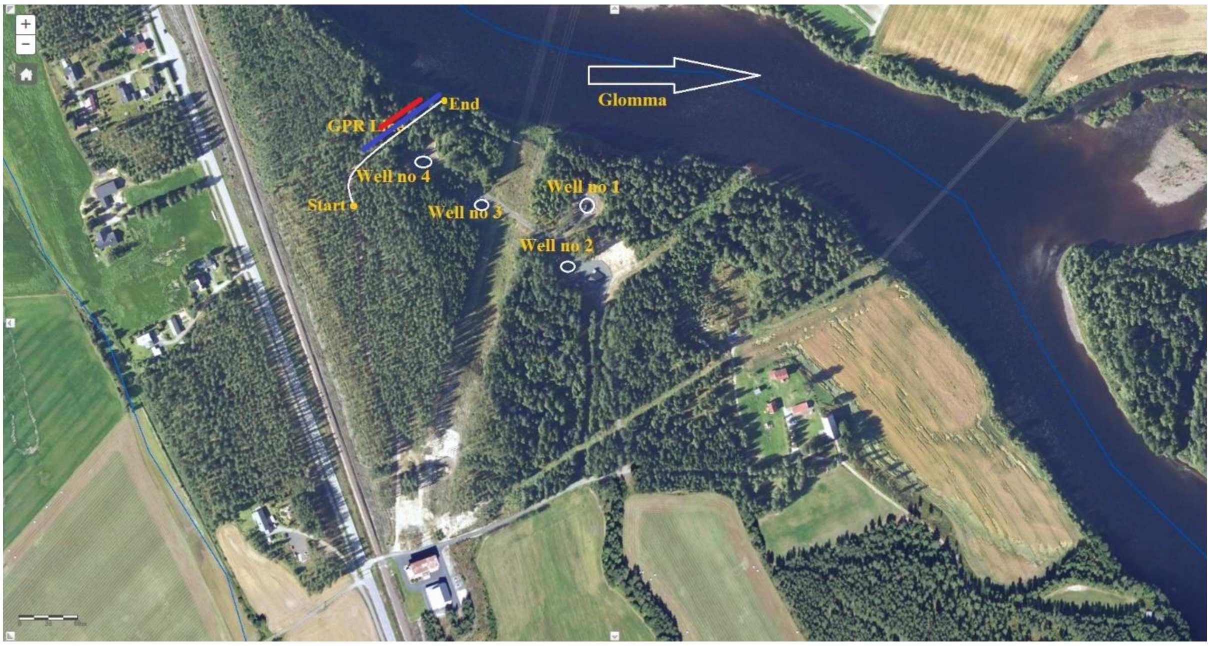


Figure 9 Overview of existing Pumping wells and GPR profile is shown by white line, ERT by Blue line and Seismic by red line in the Water work area

The interpretation of soil type would be done basically based on the peaks that is formed in formed in form of parabolic shape and different depth and response time. Computing either of dielectric constant or velocity of different soil type we use simple formula.

$$\frac{ns}{ft} = 2 * \sqrt{\sigma} \qquad (3)$$

Where,

ns = time in nano second

ft = thickness

σ= dielectric constant which varies for different soil type on different frequency level.

Figure 10 GPR field Survey with Geo 221 Team

The dielectric value of different soil type is shown in Appendix I.

3.2.2 Two Dimensional Direct Resistivity method

Resistivity measurements are based on the principle that the distribution of the electric potential in the ground around an energized electrode depends on the resistivity of the surrounding soils and rocks. The common practice in the field is to pass current into the ground between two electrodes and measuring the change in potential between two further non-energized electrodes (U.S. Environmental Protection Agency 2011) Resistivity measurements give a picture of subsoil resistivity. In order to transform this distribution into a geological picture requires knowledge of typical resistivity values for different materials.

Rocks possess their own unique electrical property in the upper part of earth's crust and primarily dependent upon the amount of water, the salinity and the distribution of water's in salt (Gressando 1999). Unsaturated and dry rocks have higher resistivity than saturated rocks. The higher the porosity of the saturated rocks, the lower its resistivity, and the higher the salinity of saturating fluids, the lower the resistivity will be. The resistivity reduces as a result of presence of clay and minerals in soil. The vertical sounding techniques are typically limited in the near surface to exploration depths less than 50m due to the spacing of the electrodes and the strength of currents required. Also at any greater depths the large electrode spacing mean that there is considerable lateral smearing of results (Haugen 2015).

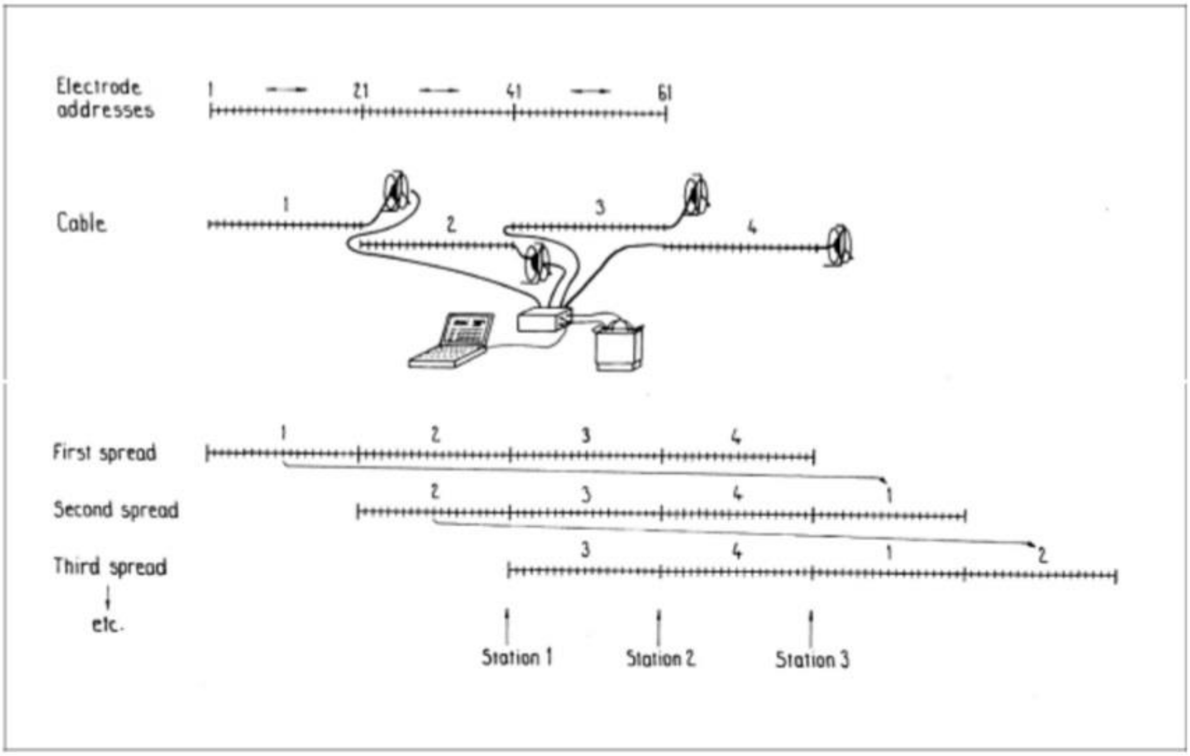


Figure 11 Illustration showing the layout of the Lund system and how the "roll along" method is performed. From Abem (2012)

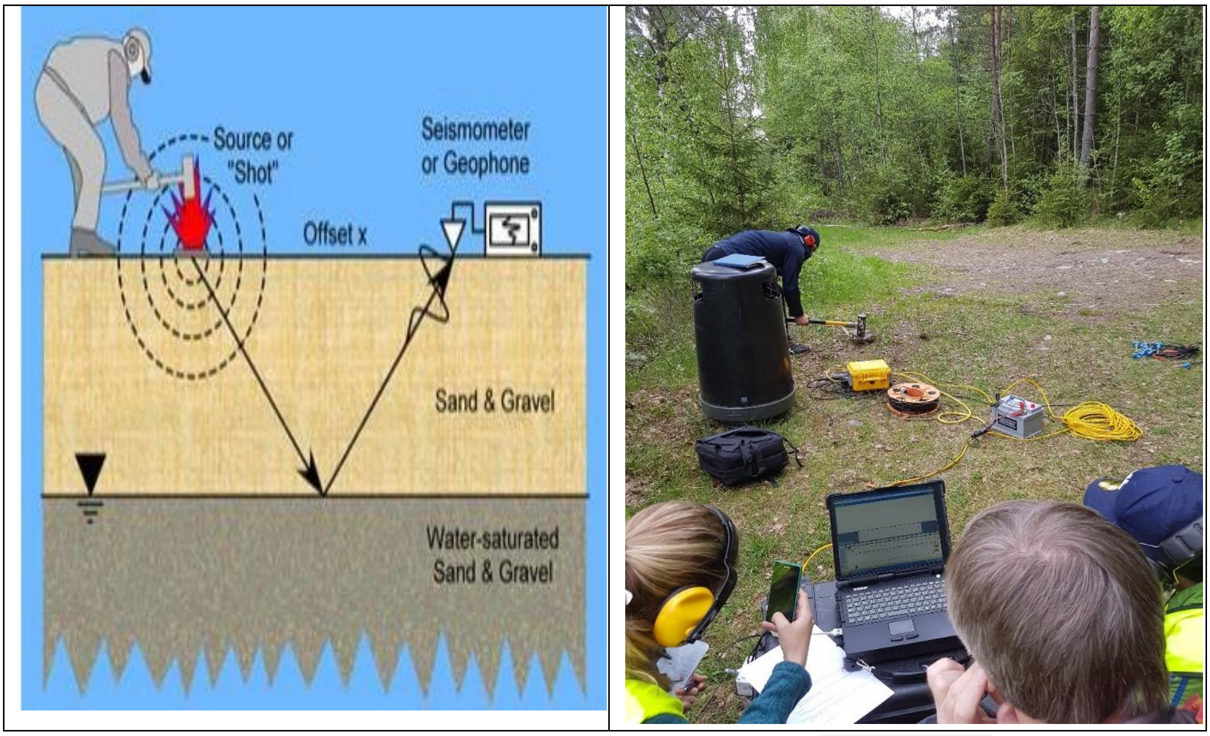
2D Resistivity test were carried were carried out in Elverum Near waterworks area during the Field course of Geology organised by Norwegian university of life sciences and Oslo university in June 2017 . one profiles was taken in this area among which was outside the water work area in northern side parallel to road reaching the river Glomma as shown in figure 9. Four pieces of cables of 25 m with 1m electrode separation was used for each measurement. The total length used was 95m with 1m electrode separation. The equipment used was a syscal pro from iris instrument and we made a use of wenner configuration to collect the apparent resistivity and used Res2Dinv to invert the data

Figure 12 ERT field Work

3.2.3 Refractive Seismic

Generally the Seismic method utilizes the propagation of waves through the earth. This propagation depends upon the elastic properties of the rocks. The size and shape of a solid body can be changed by applying force. The body tends to return to its original condition when the external forces are removed. The seismic refraction method is utilized such that the seismograph data obtained help to determine the precise depth to weathered basement and overburden thickness such that the different lithology within the subsurface so it can be easily predicted. Therefore, the first arrivals on the seismic signals derived from the seismic refraction method are plotted against shot distances to determine depth information. An extensive review of seismic refraction techniques has been given by (Haeni 1988). The review highlights the major use of refraction seismic to map the depth and geometry of bedrock surface underlying unconsolidated (drift) sediment. A further use of compressional wave seismic is demonstrated for mapping the water table as there is significant velocity increase across the water table from un- saturated to saturated material

Seismic refraction is a method to analyse the subsurface using sound waves. A straight line of several connected geophones were installed, each of them 5 m apart. Additionally, a 10 x 10 cm metal plate is placed 5 m away from the first geophone. The metal plate, as well as the line of geophones, was connected to a geode and a computer. The figure 14 shows the setup to perform a seismic test.



A

B

Figure 13 A) Seismic surveying set up with the source (hammer on metal plate) creating sound waves and B)Field Work For Seismic Survey

By hitting the metal plate with a sledge hammer, a sound wave is created that travels in a radial direction from its source (Fig. 14). The geophones have a direct contact to the soil; they measure the arrival time of the sound wave and send this information further to the computer. The time of arrival depends on the soils properties, which lead to different sound wave velocities. These are slowest in gas (air: 343 m/s), faster in liquids (water: 1500 m/s) and fastest in solids; indicating that saturated soil will show faster velocities than dry soil (Mavko, 2005). When a ray passes through a boundary of two varied materials (assumption: sound wave velocity of material 1 > sound wave velocity of material 2 (v1>v2), it will first be directed further down into the ground (Fig.15). At the 'critical distance', however, it will be reflected back to the surface. The angle of this ray is called critical angle and will be the same for all refracted rays. In a time-distance diagram, the refracted waves will be straight lines with its slope being the inverse of the velocity of the lower layer. The time for a single wave, or ray, from the source to the receiver can be calculated with the following equation:

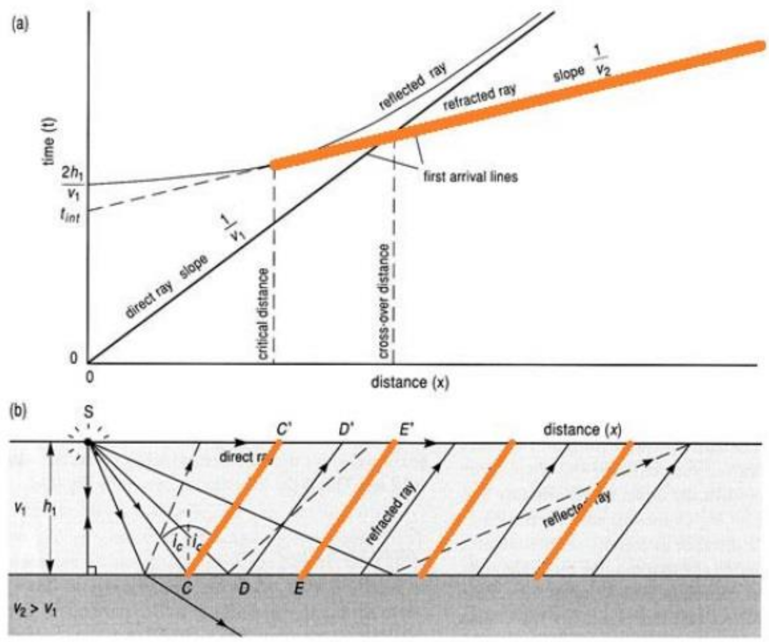


Figure 14 Basic principle of Seismic

$$t_{int} = 2h\sqrt{\frac{1}{v_1^2} - \frac{1}{v_2^2}}$$ Eqh 3.2.3

where t is the time, v1 the velocity in layer 1, v2 the velocity in layer 2, h1 the depths of layer 1 (presumption: v2 > v1). Figure 15 also shows the 'cross-over distance', the distance where refracted rays arrive at the geophones earlier than the direct ray, which had been faster up until this point.

3.3 Drilling and Exploratory wells

Sounding and drilling of Exploratory well facilitates the interpretation of the geophysical surveys, providing a reliable interpretation of soil type and position of groundwater table and make some physical and chemical test. Initially, it involves running down rods with 25 mm diameter in the unconsolidated sediments by means of impact from a manual drilling rig or a crawler rig. Each bar is either 1 or 2 m, and the tip is a 4-edged probe. At each pole shift pivoted rods around to register frictional sound between the sediments and the probe.

Materials and Methods

Different materials provide different sound, and sound can thus be used to say something about the soil type. For example, clay almost no sound, While gravel producing a characteristic cracking sound. During driving of the rods are also recorded dropping speed and, together with information on soil type, this gives an indication of powerful heat of the water-bearing and non-water bearing loads. The results are used to characterize the aquifer ability to extract a water. The rods pulled up by means of a manual or automatic jack (Riise 2015). Further, based on information gathered during sounding test, exploratory wells are drilled for the further investigation of underground soil and water property.

Sounding

First, the sounding test was performed by inserting metal rods of 1 meter segment each as shown in figure 16. The rods were penetrated to the point in aquifer considerably below the water table. The data from GPR was used to decide the depth of water table. The sound was observed and registered after each segment of 1m drilling rod by rotation. The crushing and sliding of grains against the rod give an estimate of the grain size and type of segment. The segment penetrated mainly consists of sand with different grain sizes and boulder layers. Based on the sounding, the first meter consists of sand and boulders; the segment was not possible to turn. The second meter produced a sound that indicated finer grains, followed by a coarser layer in 3- 4 and 5.5 m depth. The depth of 7 m was achieved in well at the river bank and in ridge top well the depth of penetration was 14 m. If the results of probes bores show soils with good water ability, then we will use same bores for drilling of wells. These are used to take water and lots of samples and for making study of underground hydrogeological condition


Figure 15 Sounding Test on Before Drilling Well

Drilling

Two wells were drilled on the river bank and ridge top respectively as shown figure 16.The well on the river bank was successfully installed, whereas however, the well on the ridge top was stuck in the boulder layer at the depth of 8 meters and it was difficult to remove the pipe penetrated through hole. Therefore, the penetrated segment was left as it is in the borehole.

Pipes were penetrated in the same hole used for sounding test Lower segment of pipe string consists of filter (1.35 m) and the remaining segments is ordinary pipe (1.5 m each). The drilling was stopped, when the filter was almost submerged in the aquifer. Sounding test for estimating the grain size. The metal rods are penetrated using the driller as shown in figure 18. The borehole drilled was flushed out with high pressure water pumped from the river by using water pump. The main purpose of flushing was to remove the sediments that were trapped inside the pipe drilling from filters. This allows the ground water to come inside the pipe and help to identify the actual water level and perform slug test in the same pipe. Further, we performed a pumping test for information regarding temperature, pH and electrical conductivity. These were further sent to a laboratory for analysing the physical- chemical and optionally bacteriological parameters.

Figure 16 Drilling Well Near Glomma Named R2

3.4 Estimation of Hydraulic Conductivity

3.4.1 Infiltration Test

Infiltration is an important and fundamental process in Hydrological cycle. Importance of infiltration is to maintain Groundwater level, and to reduce surface drainage. Figure 19 shows how Precipitation intensity, infiltration capacity and surface drainage are affected by each other. Soil ability to receive water is expressed as the Hydraulic conductivity. This is a measure of how fast the infiltration occurs and can be reported in the unit [cm / hour] (Hillel, 2004).

The water infiltrates in the unsaturated zone, where the water flows into the porous system. Where the soil moisturizes and the moisture face increases lengths down, the rate of infiltration will decrease. In case of infiltration, when the soil is saturated (all pores are filled with water), the infiltration rate is too referred as saturated hydraulic conductivity (conductivity) (K_{sat}), where constant infiltration rate is achieved (see Figure 19). Hydraulic conductivity depends on both the water and the soil characteristics. The infiltration capacity is affected by the soil conditions, especially on the surface. Soil moisture at the start of a precipitation where the temperature, weather conditions, texture and soil structure affect infiltration ability (Hillel, 2004). The infiltration test was performed at top soil which will be responsible for the recharge of ground water. The soil was naturally unsaturated or slightly saturated before the test was performed; it was saturated to identify the hydraulic conductivity of soil measuring the flow of water inside a certain area of soil with in specific time interval.

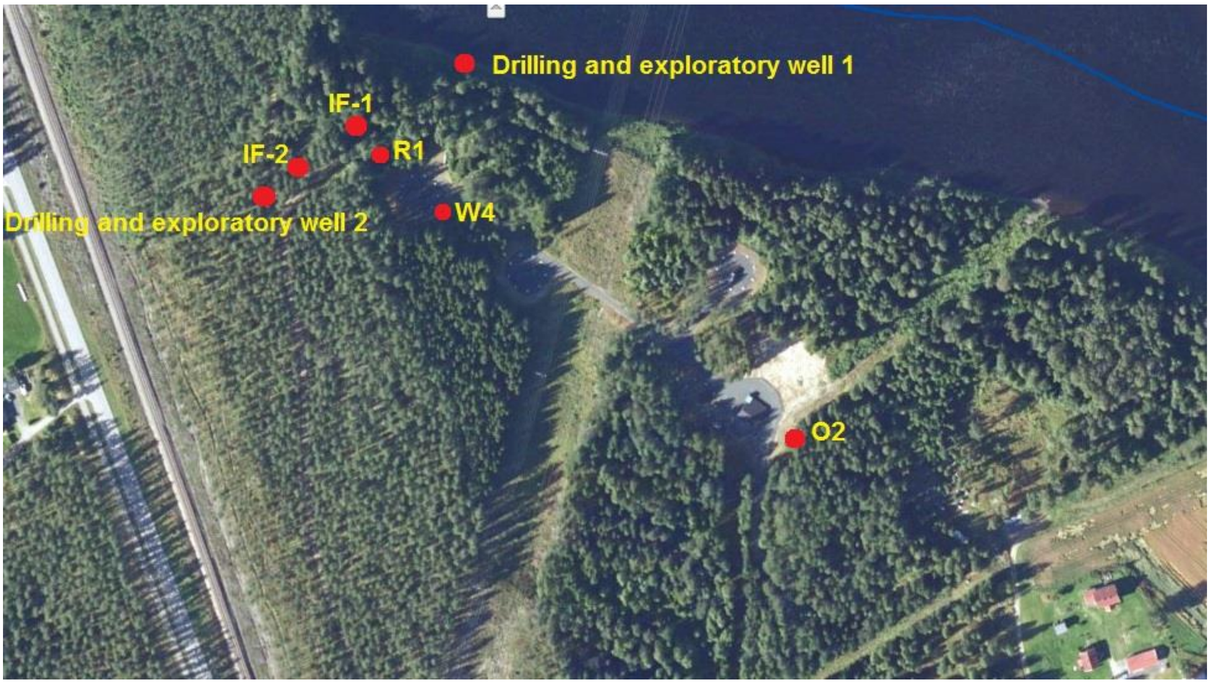


Figure 17 Location of various observation wells, drilled wells and infiltration test location

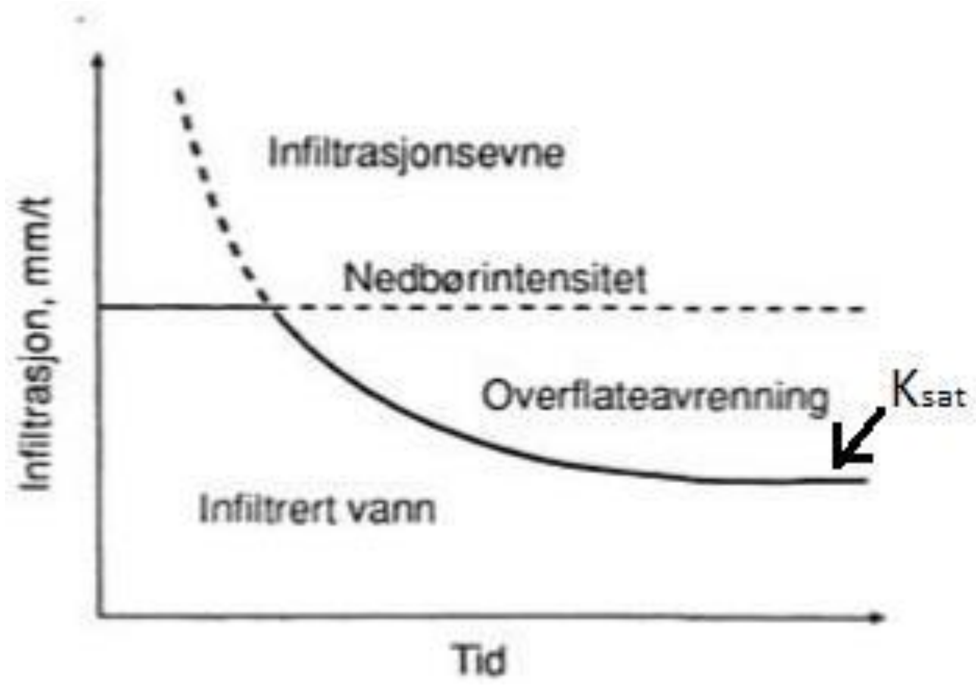


Figure 18 Infiltrating capacity as a function of time, at constant precipitation intensity (Bøyum et al., 1997)

There are several methods for conducting infiltration test to determine the hydraulic conductivity of soil. Most of the common methods are Field methods: - Modified Philip- Dunne infiltrometer, Double ring – Infiltrometer, Constant head infiltration test (Mariotte cylinder) Laboratory method: Grain size distribution

In our case, the Mariotte cylinder and Modified Philip Dunne methods have been used as field method and sieve analysis was done for grain size distribution of the soil sample in the laboratory to find hydraulic conductivity of the soil in the Grindalmoen Waterworks area

Constant head infiltration test (Mariotte cylinder)

Mariotte Cylinder Test was performed at two locations near the water work area which is supposed to represent the overall hydraulic conductivity of that area as shown in figure 17.

Procedure

- Initially a 60x60x20 cm cuboid was dug into the soil and inside this another 25x25x30 cm cuboid was dug out
- The cuboid was replaced by a sponge with the same size, which had a 20 cm cylindrical hole in the middle.
- Above this ground setup, an acrylic cylinder with two hoses was hold by tripod as in figure 20 A.
- After this setup, the sponge was filled with water until a stable water level was achieved.
- Then, the smaller hose was placed 10.5 cm below the water level, while the bigger hose reached down to the end of the cylindrical hole within the sponge. The upper cylinder was filled with water.
- When the water flows into the sponge then to the ground, an air bubble is formed due to the level difference in the pipe and the water level inside the sponge.
- The time of every air bubble formed was noted along with the corresponding reduction in the water level in the cylinder.
- The process was repeated by refilling the cylinder to obtain more precise result.

This method is used to calculate the hydraulic conductivity, based on its infiltration characteristics. Because this test is based on saturated hydraulic conductivity, the Darcy equation can be used as shown in equation (3):-

Materials and Methods

$$Q = Ksat * I * A \quad (4)$$

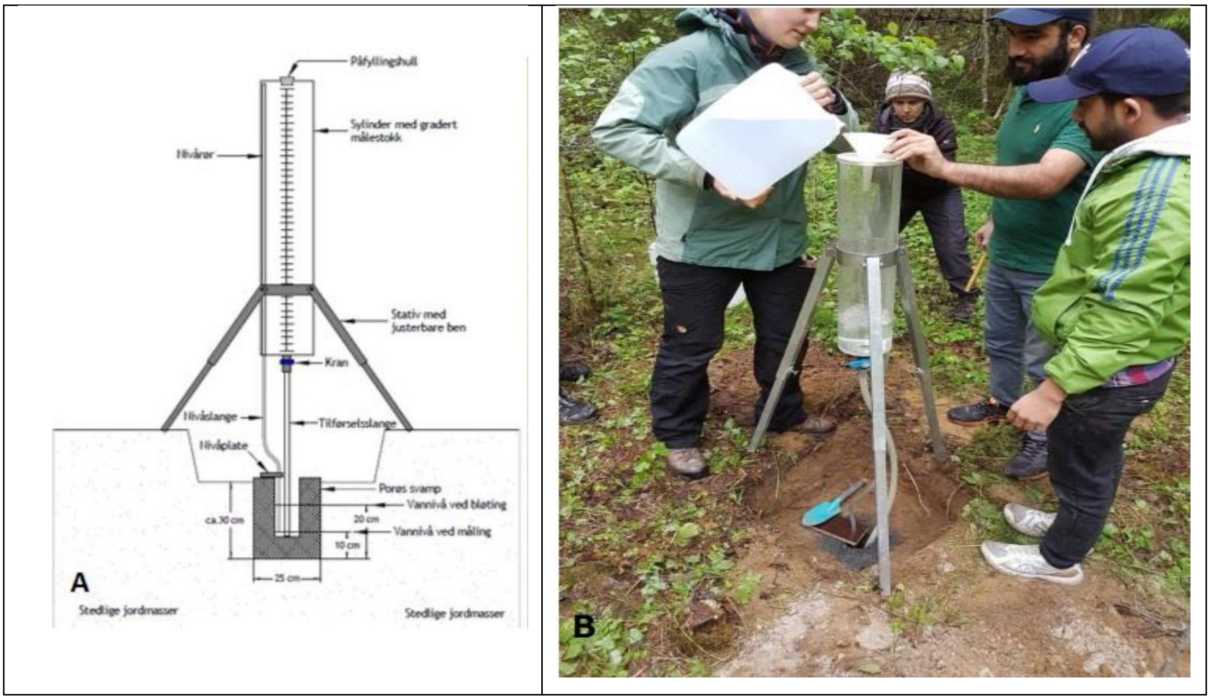


Figure 19 Mariotte-infiltrometer (A) (Bioforsk, 2009). Mariotte-infiltrometer in field (B)

Where, Q being the discharge in m^3/s, K_{sat} the hydraulic conductivity in m/s, A the area in m^2 (in this case the area of the sponge) and I (i=1) the change of hydraulic head over a distance in M/m. Further, as we know that amount of water getting inside soil equal to amount of water leaving from the cylinder as in equation 5.

$$Qout = Qin = \pi r^2 * dh \quad (5)$$

Ultimately, saturated hydraulic conductivity is computed using equation 6.

$$Ksat = \frac{\pi r^2 * dh}{(4ab + b^2)t * i} \quad (6)$$

Falling Head infiltration test: Modified Philip Dunne Method

Modified Philip – Dunne (MPD) method is the simplest and easiest method for estimating hydraulic conductivity of the soil. Although, the results are not so realistic for making decision on bigger issue but it will help to understand the property of soil to make preliminary estimate of soil conductivity. This method is also based on Darcy’s equation (1).

In this study, MPD infiltrometer (Figure 20) was used of PVC tubes with a height of approx.50 cm and inner diameter of approx. 10 cm. The same cuboidal dig pits were used to perform this test too.

Procedure

- Ground surface is prepared by removing the top surface, which will affect the soil conductivity.
- A ring is made by dipping MPD base into a surface by 5cm a with a hand sledge and the installation tool (be careful not to break the MPD cylinders).
- Try to ensure the soil around the MPD base is tight to prevent water seepage.
- The cylinder with dia. 10 cm is filled with clean water and time taken along with dropping height in cylinder column is noted. This helps to estimate the amount of water entering the soil.
- Finally, using Darcy's law equation 6 hydraulic conductivity of soil is calculated.

Figure 20 Modified Phillip -Dunne Infiltrometer in Field

3.4.2 Grain size distribution

The grain size analysis is used to categorize the soil depending on its grain size fractions. Therefore, three soil sample were taken: (1) at the newly installed piezometer next to the river, (2) at the first infiltration test location and (3) at the end of the ERT line (Fig. X). After that, all samples were dried in room temperature for 24 hours, or until dry. Finally, the dried samples (weighing between 92 and 208 g) were fractionated using a sieving tower consisting of 8 sieves, with its fraction intervals being: 16000, 8000, 4000, 2000, 1000, 500, 250, 125, 63 µm. For a broad examination of properties, the software GRADISTAT was used with specifications after Folk & Ward (1957). From having the grain size distribution in a sum curve, it is possible to read the d10 and d60 values for each sample. These values are then used to calculate the hydraulic conductivity. If the ratio of d60 and d10 is below 5, the d10 value can directly be used for further calculations. For a ration of >5, a modified method was used to estimate d10. For this, the log-log scale graph was plotted and a rectangle with the corners being (1000 µm, d10), (5000 µm, d10), (1000 µm, d60) and (5000 µm, d60) visualized. This rectangle is then fitted to the sum curve of the specific sample with the graph passing the lower left and upper right corner. The x-axis value of the lower left corner is then the new d10 value.

Once d10 is known, the following formula was used to calculate the hydraulic conductivity.

Ks=C*d10^2, with C=1/100

With Ks being the hydraulic conductivity in m/s, C=1/100, a soil specific parameter, and d10 the grain size of 10% of the sample in mm.

3.5 Numerical Ground Water Modelling

3.5.1 Definition and purpose of modelling

"A model is any device that represents an approximation of a field situation. (Anderson & Woessner, 1992). Further, 'A ground water model is a computer-based representation of the essential features of a natural hydrogeological system that uses the laws of science and mathematics'. A ground water model provides a scientific means to draw together with the available data into a numerical characterization of a ground water system . Simply modelling refers to *"replace reality, enabling measuring and experimenting in a cheap and quick way, when real experiments are impossible, too expensive, or too time-consuming"(Eppink, 1993).* Since, hydrology is a subject of great importance for people and their environment. Practical applications of hydrology are found in tasks such as water supply (both surface and ground water), wastewater treatment, irrigation, drainage, flood control, erosion and sediment Control, salinity control, pollution reduction, and flora and fauna protection.

Although several study have been made since many years in this area but few report including report by *Gaut et al. (1981)* gave some information regarding how the water movement is taking palace in that area. The study made by Gaut .et.*al.(1981)* showed position of ground water and its flow direction with in vicinity of water work . This map cannot clearly explain what is the exact catchment area which is actually recharging the ground water?. Also, which area much responsible to make recharge and from which point the ground water exactly meets river Glomma. At a present moment, Grindalmoen water work is extracting water continuously at rate of 60 Ls^{-1} to make supply water to Elverum municipality. But there is not any concrete information regarding whether the pumping of water cause intrusion of river water to the aquifer due to lowering of hydraulic head in aquifer or aquifer is independent with river to make continuous supply during pumping.

Since a *groundwater flow model* can be used to simulate hydraulic heads (and water table elevations in the case of unconfined aquifers) and groundwater flow rates within and across the boundaries of the system under consideration. Also, it can provide estimates of water balance and travel times along flow paths. Understanding the hydrogeological morphology of Grindalmoen water works factor is necessary to know controlling factor for the ground water movement in this area. Simulation of several factors as mentioned above would be done with use of numerical modelling.

To make a good model several parameters will be required along with general experience of that area regarding tentative geological formation of that area. Although we have collected some physical information like hydraulic conductivity and position of ground water taking measurement in pre-installed observation wells. But rest of information like depth of bed rock, ground water position, was fixed based on report obtained from NVE report and constant head boundary was set to fix the ground water position and define the initial flow direction. The recharge value on that area was taken based on NVE report.

.

3.5.2 Modelling of Groundwater Flow

A groundwater model is a simplified representation of a groundwater system. Groundwater models can be classified as physical or mathematical. *Mathematical model* describes the physical processes and boundaries of a groundwater system using one or more governing equations. An *analytical model* makes simplifying assumptions (e.g. Properties of the aquifer are considered to be constant in space and time) to enable an exact solution to a given problem.

A *numerical model* divides space and/or time into discrete pieces. Features of the governing equations and boundary conditions (e.g. aquifer geometry, hydrogeological properties, pumping rates or Sources of solute) can be specified as varying over space and time. This enables more complex, and potentially more realistic, representation of a groundwater system than could be achieved with an analytical model. Numerical models are usually solved by a computer and are usually more computationally demanding than analytical models.

Groundwater modelling begins with a conceptual understanding of the physical problem. The next step in modelling is translating the physical system into mathematical terms. In general, the results are the familiar groundwater flow equation and transport equations. The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\left[\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)\right]-Q=S_s\,\frac{\partial h}{\partial t} \tag{8}$$

K_{xx}, K_{yy}, K_{zz} = hydraulic conductivity along the x,y,z axes which are assumed to be parallel to the major axes of hydraulic conductivity;
h = piezometric head;
Q = volumetric flux per unit volume representing source/sink terms;

S_s = specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material.

3.5.3 Conceptualization

The conceptualisation of the aquifer is to set up as a schematised or pictorial representation of the hydrological problem we want to model. Simplification is necessary because a complete reconstruction of the hydrologic system is not feasible. As mentioned in chapter 2.3, the quaternary map, geological map and results from the field study will be used to characterise the hydrological and geological setup of the Grindalmoen waterwork area. The result from field study shows that the area near the water work consists of river and glacier deposits with fine sand on top. Coarse and non-uniformly graded soil is present underneath the top soil. The soil mapping of Elverum area obtained from NVE shows similar soil type as observed during field study.

The landscape of this area consists of steep slope in the west and also in the north with a forest. The bedrock is located at a depth of few meters (i.e upto 5m and in some places they are exposed) in northern and western part of the catchment area. This kind of topography create a shallow depth for storing water as aquifer. Further due to steep slope in western and Northern part, water will flow with higher velocity towards low-lands in eastern region of catchment area which has mild slope with higher aquifer depth. Due to such topography in western and northern part, this area will not give sufficient recharge to groundwater during melting of ice and autumn recharge as compared to low and flat lands in southern and eastern area. Top surface does not contribute much recharge due to earlier runoff during summer precipitation but due to less evapotranspiration, precipitation in the form of ice recharge. But due to shallow top soil it will get saturated early and flow in downward direction meeting creek lying on low land. The orientation of bedrock seems to be sloping towards lowlands in eastern direction which creates a higher velocity for ground water movement. Due to such geological and topographic condition the depth in water table will fluctuates comparatively more storing minimum water during some dry periods.

The lower eastern and southern part of catchment has mild and rolling ground topography which favours for good recharge in case of both summer rainfall and winter ice melting. Also, the several drilling results (Granada well databased) showed that the bed rock is located up to 30m near the river Glomma, which provides the sufficient volume to store water in aquifer. The top soil is found to be quite highly conductive with sand on top soil and further supported by coarse sand below this top surface. Due to mild slope, creek flowing across this area will also make some contribution on recharging the ground water before meeting the river Glomma. It is assumed that Bedrock forms a Non-permeable (no-flow) boundary against the overlying aquifer. The position of bedrock showed that the depth is varying creating gradual variation in bedrock position. The flowing of ground water is towards south-east direction, which is almost perpendicular to river Glomma or either might be mixing into river in some extent. This type of geological and topographical is providing good condition for making storage of higher amount of water by recharging through precipitation although it remains very near to river.

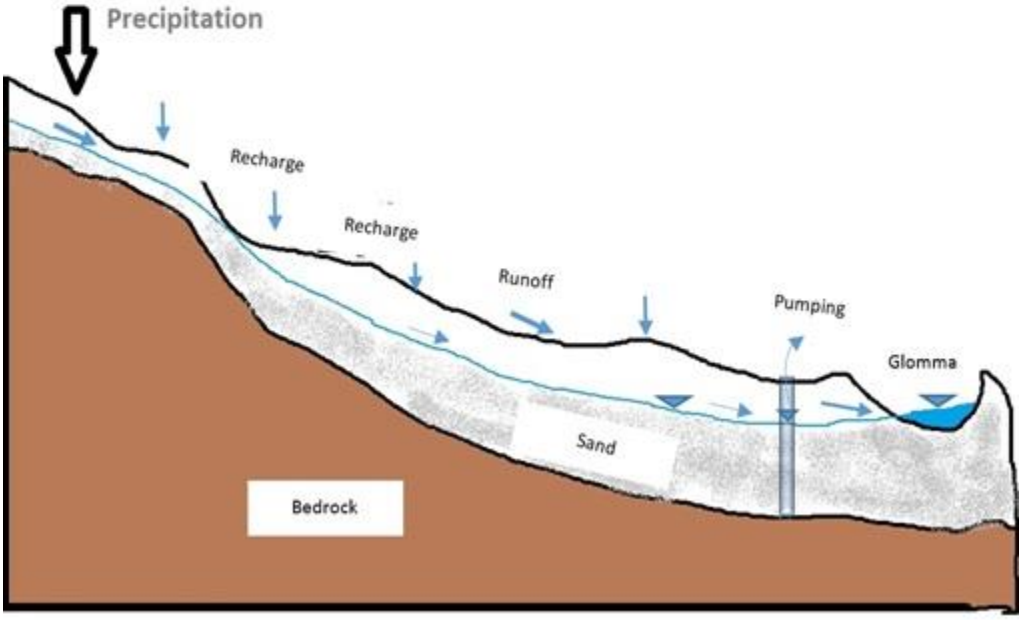


Figure 21 The schematisation of the subsoil and bedrock of the groundwater in Grindalmoen Area

3.5.4 Selection of computer Code and Definition of geometry and boundary conditions

Modflow

MODFLOW is currently (one of) the most widely used groundwater flow code in the field of Hydrogeology .MODFLOW is the name that has been given to the USGS Modular Three-Dimensional ground water Flow Model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard ground water flow model (Anon 1997).

MODFLOW is used to simulate systems for water supply, containment remediation and mine dewatering(Anon n.d.). When properly applied, MODFLOW is the recognized standard model. Within MODFLOW the groundwater system is modelled by a set of mathematical equations representing the flow phenomenon and physiographic characteristics of the groundwater system. A finite difference scheme is utilised where the applied equations incorporate the (groundwater) flow equation of Darcy and a continuity equation. MODFLOW is able to simulate saturated steady state and transient flow conditions in one, two, or three dimensions. Making decision to use MODFLOW should be taken carefully while we are going to model any system. This software favours for only saturated flow condition and while working with large topography area it would be difficult to make finite difference discretisation of system. The overall structure of the MODFLOW programme consists of a pre-processing, a processing and a post processing part (Anon 1997).

Materials and Methods

MODFLOW-2005 simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic (restricted to having the principal directions aligned with the grid axes), and the storage coefficient may be heterogeneous. Specified head and specified flux boundaries can be simulated as a head dependent flux across the model's outer boundary that allows water to be supplied to a boundary block in the modelled area at a rate proportional to the current head difference between a "source" of water outside the modelled area and the boundary block. The governing three-dimensional flow equation used by MODFLOW (McDonald and Harbaugh, 1988 and Harbaugh, et.al., 2000) combines Darcy's Law and the principle of conservation of mass via Equation (7).

Aquifer thickness and grid resolution

On the basis of catchment area the grid size was decided so that all element can be adjusted over grid properly. The grid of 332 columns and 354 rows was chosen where rows and column was chosen with uniform width of 10m X10m. Initially single and convertible layer was selected to make the model simple so that all other parameters can be easily fitted to run the model. ArcGis was used to export the real topography information that was gathered through Lidar survey of working area and also it gave realistic topography of that area, but at same time the model became so complex that we got varying topography within small area where bedrock position was with few meter from surface or either exposed to 30m in two ends of catchment area. This situation created a steep bedrock orientation with ground water table almost on surface of ground during precipitation in steep northern and western area and at lower depth as we go towards eastern section. In real topography there is a creek in catchment area but While executing the model , Creek which can act as river was not included. This made the model so complex that interconnection between each element might cause numerical instabilities in the model and problem with convergence.

Boundary and initial Condition

The model is defined in such a way that it will helps us to understand hydrological condition of water work area based on recharge, soil property and geological condition. So, layer with various thickness was defined where we introduce an initial position of water table by letting it to be equal to model surface. This layer surface was further used to execute the model where we just introduce constant head as boundary condition as specific head. To know the influences within water work area due to hydrogeological situation, flux boundary condition as well and recharge were used. To know the head value of ground water in aquifer system, constant head boundary were used as initial head. These initial value during the simulations will responses to flux boundary distributing head within an aquifer. Although river was in vicinity of water work area, river parameters were not introduced to understand the model without influence of river.

Physical conditions and time discretisation

The most important parameters of model to convert real model to numerical model are hydraulic conductivity, geometry of aquifer and capacity of aquifer to make storage of water . Based on field results and information from several past study hydraulic conductivity was taken as 6.34E-4 m/sec as average value of hydraulic conductivity obtained from infiltration test during the field course. The recharge was defined as 283.9mm/year which was based on NVE report in that area and details can found in Appendices A. To make understanding of impact on hydrology in catchment area, a model with seasonal fluctuation in recharge was introduced in this model. Here, while executing a model a we divide an annual recharge into a four different cycles so that model will represent the similar scenario as in field situation. For autumn recharge 1/3 value of Annual Recharge i.e 94 mm was used while during winter no recharge was made from November till April, melting of snow will made recharge of 189mm of recharge and there is no any recharge during the summer.

The existing pumping wells were setup with each well with 30m depth from top surface where water table was considered to be located at 5m below the ground water with pumping rate 60 Ls-1 in each well. The initial water table and bedrock position was fixed based on several boring information collected from NVE and Granada Data base which are listed in Appendix I.The model was set for two hydrological stress period with steady initial condition and transient condition with annual seasonal fluctuations for 15 year. To make the observation of impact of well during pumping, a stress period for 7 weeks with each steps for 6 hours was setup.

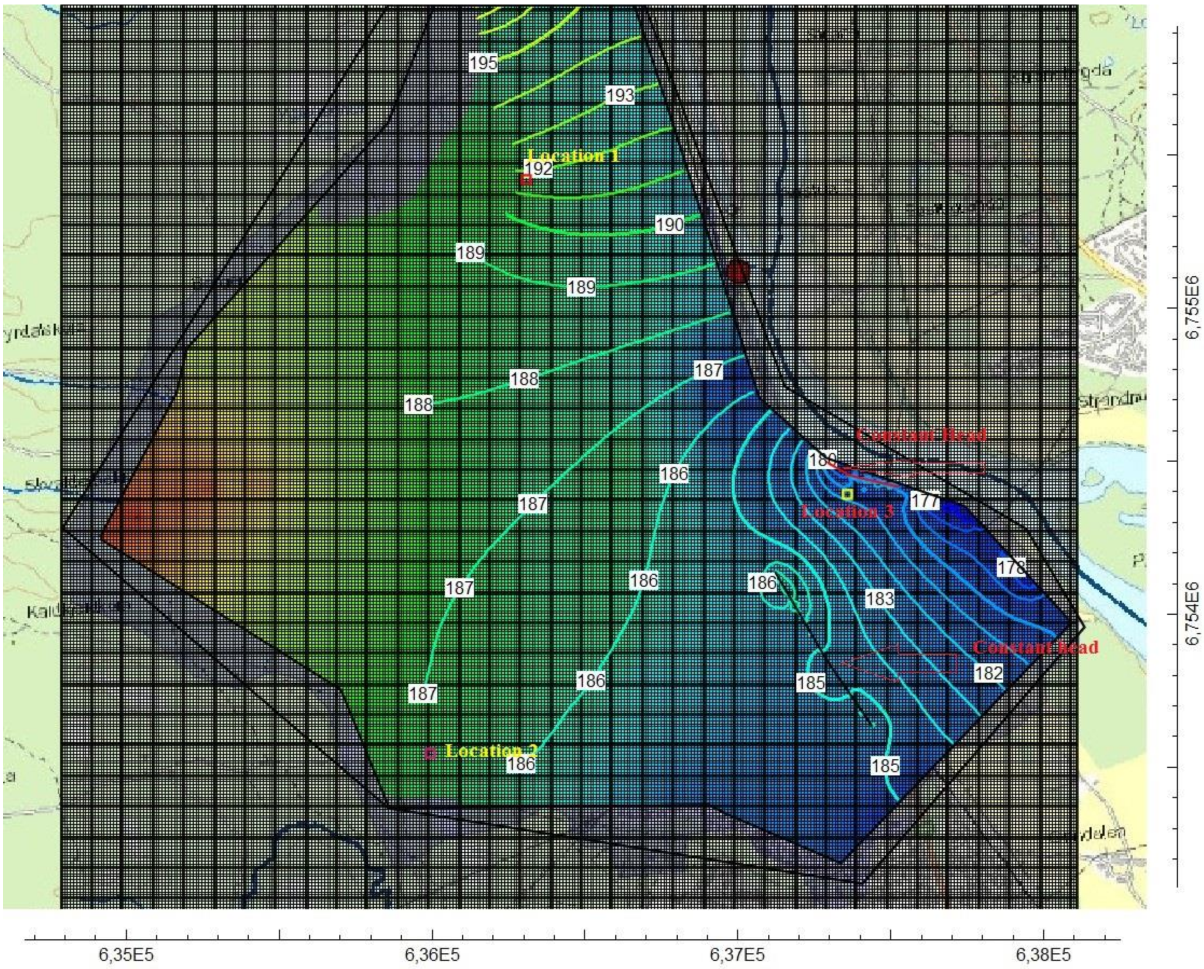


Figure 22 Overall grid of model with different obesrvation locations and constant head

Sensitivity Analysis

The sensitive analysis was done in two perspective to understand the behaviour of aquifers under variation of recharge value and conductivity of aquifer system.

Table 1 Different condition for sensitivity analysis

Hydrological condition		
Recharge	increased by 10%	decreased by 10%
Hydraulic conductivity	increased by 30%	decreased by 30%
Pumping	Constant pumping at rate of 60 Litre per second	Initial pumping with 60o Litre per sec and followed by 60 litre per second
Annual Fluctuation	*Autumn Recharge, snow melt with no recharge in summer and winter*	

The above table 1 shows the three different conditions for sensitivity analysis. The observation on head value in 3- different location shown in figure 26 was made. During the sensitivity analysis we observe change in head value as accordance with change in recharge and hydraulic conductivity.

Chapter 4
Results

4.1 Geophysical Investigation

4.1.1 GPR Survey

The result shown below is obtained based on GPR survey done in Grindalmoen water work area along a line as shown in figure 23.

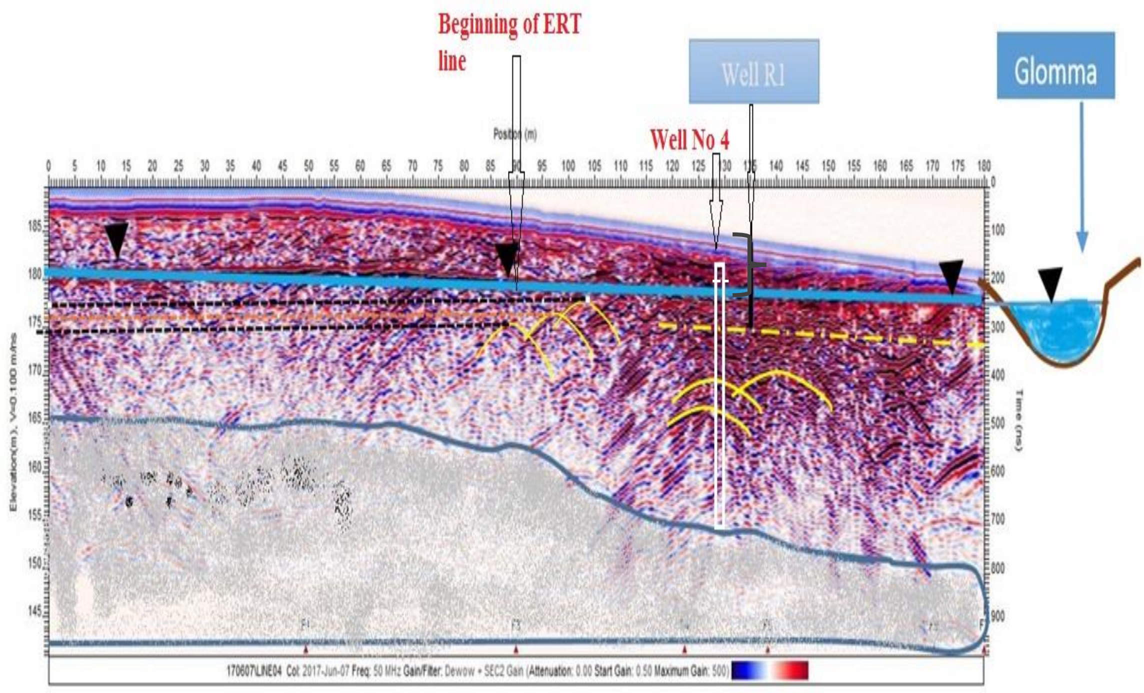


Figure 23 Results from GPR survey done along Grindalmoen Area whose survey line can be seen in pic 10

The result obtained from the GPR survey reveals the similar type of information regarding position of water table and its gradient that we were expected or assumed to obtained based on Granada data base shown in Annex I. The area can be interpreted as it is composed of thick aquifer with loose conductive top soil of almost 25 meter in left corner and with almost 30m near river Glomma as shown in figure 9. This grey area shown in figure can be interpreted as bedrock or soil below which is in completely saturated condition. The grey portion and its orientation further support that bedrock or either confined layer of compact soil is acting as aquifer and maintain water level without making influence by river in ground water storage. Also, the blue line shown in fig shows that the ground water is flowing towards river from west to east with consistent gradient and indicating the direction of ground water to make groundwater recharge and get aquifer less or completely minimum influence from river

4.1.2 ERT Survey

The above result is obtained based on survey done in Grindalmoen water work area for ERT along a line as shown in figure 24.

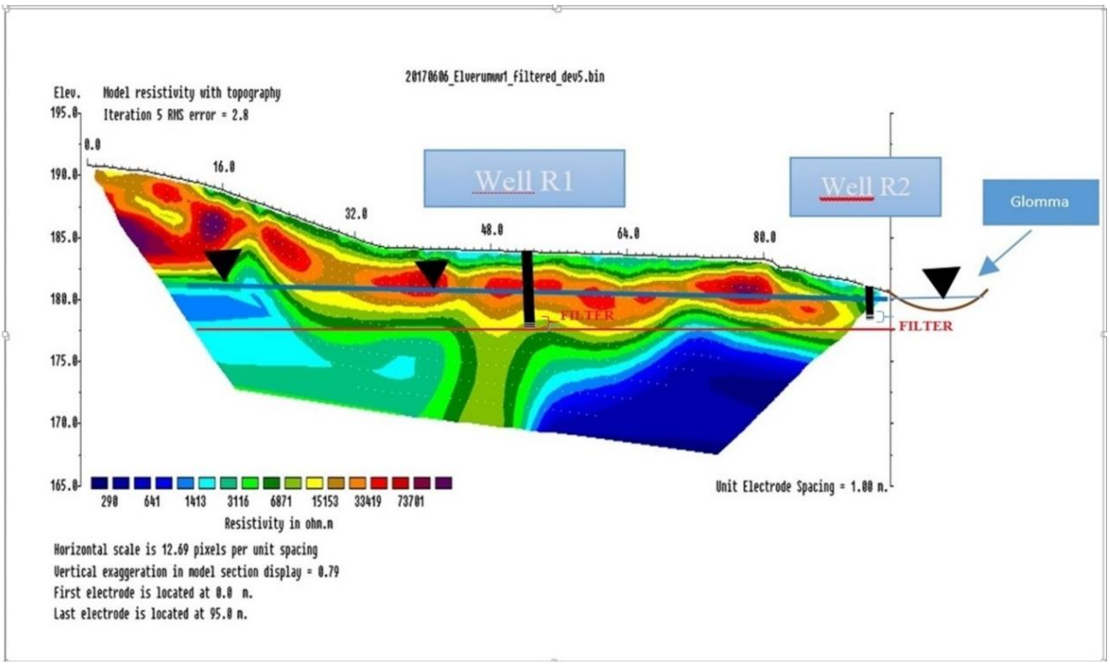


Figure 24 Results from ERT survey done along Grindalmoen Area whose survey line can be seen in pic 10

The ERT profile results shows the various resistivity value along a perpendicular direction to river Glomma from east to west. The top soil surface is found to be with lower resistivity up to few meter at lower edge while at upper left edge has soil with high resistivity indicated by red and dark colour which is extended up to almost 8 meter and constantly decreasing towards river having thickness up to almost 5 meter. Below this layer the soil seems to be less resistive indicating possibility of ground water and further below with less resistive soil type similar to clay material with higher conductive value.

4.1.3 Seismic Survey

The results from seismic survey along the line shown in figure 25 using an array of Geophones are shown in figure 10.

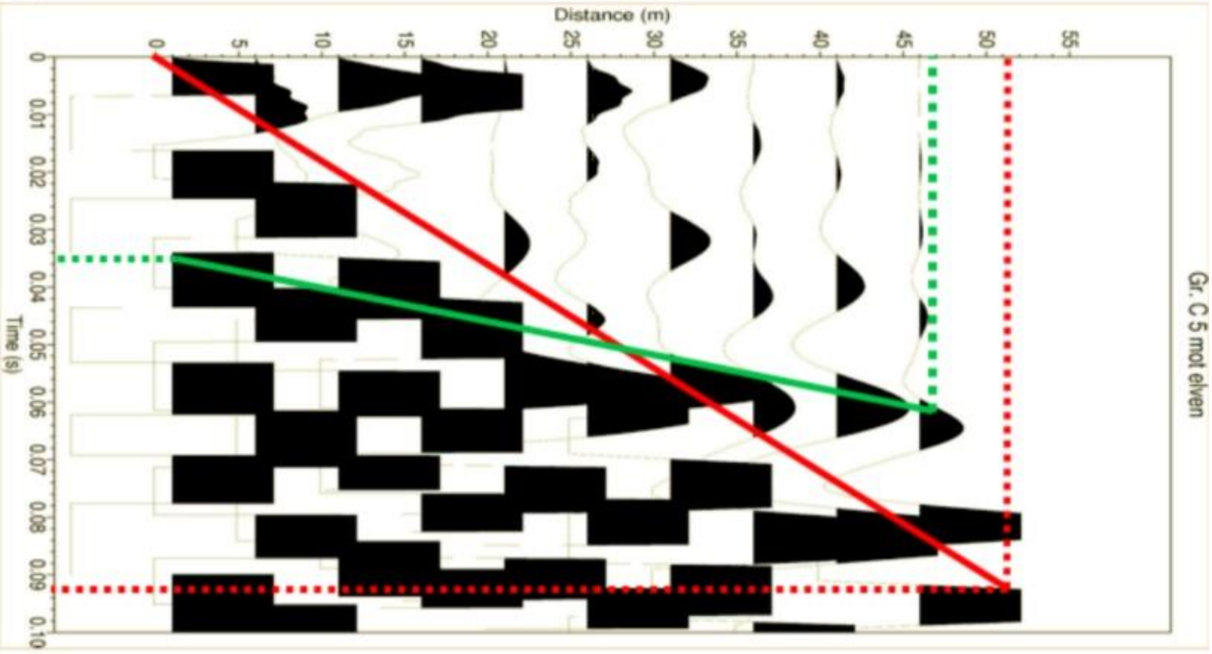


Figure 25 seismic results with geophones plotted in x-axis and arrival time in y-axis. the solid red line indicates direct wave and solid green line is first refracted waves arrived at receiver.

The velocity calculated for head wave in the first layer was found 565 m/sec and velocity for refracted wave was 2350 m/sec in second layer. Using the equation we were able to obtain the depth of water table at 10m from top surface.

4.2 Drilling and Exploratory Well

The results from Sound Boring and Exploratory wells performed at two different location are presented in figure 17. The position of these two wells are selected in such way that that can be used to interpret over the results gathered from geophysical test in that area.

Results

Location: - Drilling well No 1

Table 2 Soil Property in different depth obtained during sounding and drilling exploratory wells

Depth(m)	Soil Type	Remarks
0-1.5	Fine sand	Easy to drill both sounding rod and well with soft metallic sound
1.5-3.0	Fine sand with some coarse material	Easy to drill both sounding rod and well with soft metallic crushed sound
3.0-4.5	Medium sand with some coarse material	Feel like compacted and crushed metallic sound, difficulty during both sounding and making exploratory well
4.5-6.0	Coarse sand with indication of Gravels	Metallic sound 0f gravel and hard to drill and make exploratory well
6.0-6.1	Poorly sorted coarse sand with gravels	Hard to drill with metallic sound cannot go further drilling

Mechanical hammering was done to make sound drilling before making exploratory wells .it was quite easy to conduct at top surface at both the location. But due to heterogeneous and compact soil condition at lower depth, we were able to make drilling up to 6.1 m at well near to river and 9.5m at western part of water work named as location 2 for drilling in as figure 17. The location 2 was inside the forest were we found a shallow fine sand layer at top and below it was medium to coarse sand and gravel layer where drilling was possible up to 9.5 meter but exploratory well cannot be drilled more than 4.5 m below the ground surface .

Location: - Drilling Well No 2

Table 3 Soil Property in different depth obtained during sounding and drilling exploratory wells

Depth(m)	Soil Type	Remarks
0-1.5	Fine sand	Easy to drill both sounding rod and well with soft metallic sound
1.5-3.0	Medium sand	metallic sound during sounding and difficult make drilling of exploratory wells
3.0-4.5	coarse sand with gravel	Crushed metallic sound of sand and gravel during sounding and cannot go further down to make exploratory drilling due to compact soil

4.5-6.0	coarse sand and gravels	Crushed metallic sound of sand and gravel during sounding and cannot go further down to make exploratory drilling due to compact soil
6.0- 7.5	Coarse sand and Gravel	Crushed metallic sound of sand and gravel during sounding and cannot go further down to make exploratory drilling due to compact soil
7.5- 9.5	Coarse sand and gravel	Crushed metallic sound of sand and gravel during sounding and cannot go further down to make exploratory drilling due to compact soil

4.3 Hydraulic conductivity

The hydraulic conductivity of soil was determined based on direct field measurement as infiltration test, in lab by making grain size distribution and through slug test performed existing observation wells and new drilled wells. The location where several methodology were used are shown in figure 17.

4.3.1 Infiltration test

The results of infiltration test performed at different location using MPD and mariotte are shown in Table 4. The details of calculation are shown in appendix II. The location 1 was within the line of ERT survey and at end of seismic survey which will help to compare with findings from geophysical methods and help interpret the results. The location 2 was just after the end of ERT profile in flat surface. These results help to interpret how easily the aquifer will get recharge during raining and snow melting.

Table 4 Hydraulic conductivity based on infiltration test

S.n	**Location**	**Hydraulic Conductivity(m/s)**	
		Mariotte	**MPD**
1	Infiltration location 1	2.42E-05	
2	Infiltration location 1	2.48E-05	2.70E-05
3	Infiltration location 2	3.36E-04	
4	Infiltration location 2	1.49E-03	1.93E-03

The two sets of test were performed for mariotte test and one set for MPD test in both of the locations. The results from mariotte test and MPD are almost similar with very low conductivity in range of 10^-5 m/sec in location 1. Whereas location 2 possess quite high conductivity within range of 10^-4 to10^-3 when performed through different methodology. Although, up on our field visual inspection duration test the top soil which is responsible for infiltration in location 2 was medium sand compared to fine sand in location 1 with very low conductivity.

4.3.2 Slug Test

The result of slug tests performed at different location (Fig.17) are shown in table 5. The slug test represents the hydraulic conductivity of soil at greater depths. This helps to interpret the sub surface geological conditions.

Table 5 hydraulic conductivity based on slug test and details of different wells

Well no.	Depth to GW(m)	Dia. of pipe(m)	Dia. of Filter(m)	Length of filter(m)	Initial Deth ho (m)	Final depth, H (m)	T0	Hydraulic conductivity (m/sec)
1	1.04	.035	.035	1.35	.27	.93	824	2.59E-7
O1	7.22	.045	.045	1.35	5.48	7.17	232	1.44E-5
R1	6.92	.045	.045	1.35	5.01	6.25	2672	8.72E-7
W4	4.83	.035	.035	1.35	0.2	1.4	14577	1.46E-8

4.3.3 Grain size Distribution

The results for the grain size analysis shows different type of sediments for the three locations as shown in table 6. The Sample 1, from next to the river, is fine sand, sample 2, from the infiltration location 2, is coarse silt, and sample 3, from the end of the ERT line, is coarse sand. The detailed of the calculation is shown in appendix II.

Table 6 Grain Size distribution, soil type and Hydraulic conductivity at different location Based on Grain Size Distribution

Sample location	Soil type	Mean size (µm)(Geometric)	Sorting	D60/D10	K(m/s)
Location -1 (river)	Fine sand	130.9	Poorly sorted	6.7	4.9E-5
Location – 2 (Infiltration location 1)	Very coarse silt	56.3	Poorly sorted	10.4	1.60E-5
Location -3 (End of ERt)	Coarse sand	568.8	Moderately sorted	2.5	7.3E-4

4.4 Numerical Ground Water Modelling

The ground water Numerical model was executed under several situation to understand the aquifer system in the catchment of Grindalmoen water work area. The figure 26 represents a situation where we force the water table to be similar to the groundwater map *by Gaut.et.al (1981)* , by including a number of constant heads in the catchment area . The figure 27 shows a vertical section (west-east) giving the depth of bedrock and ground water position.

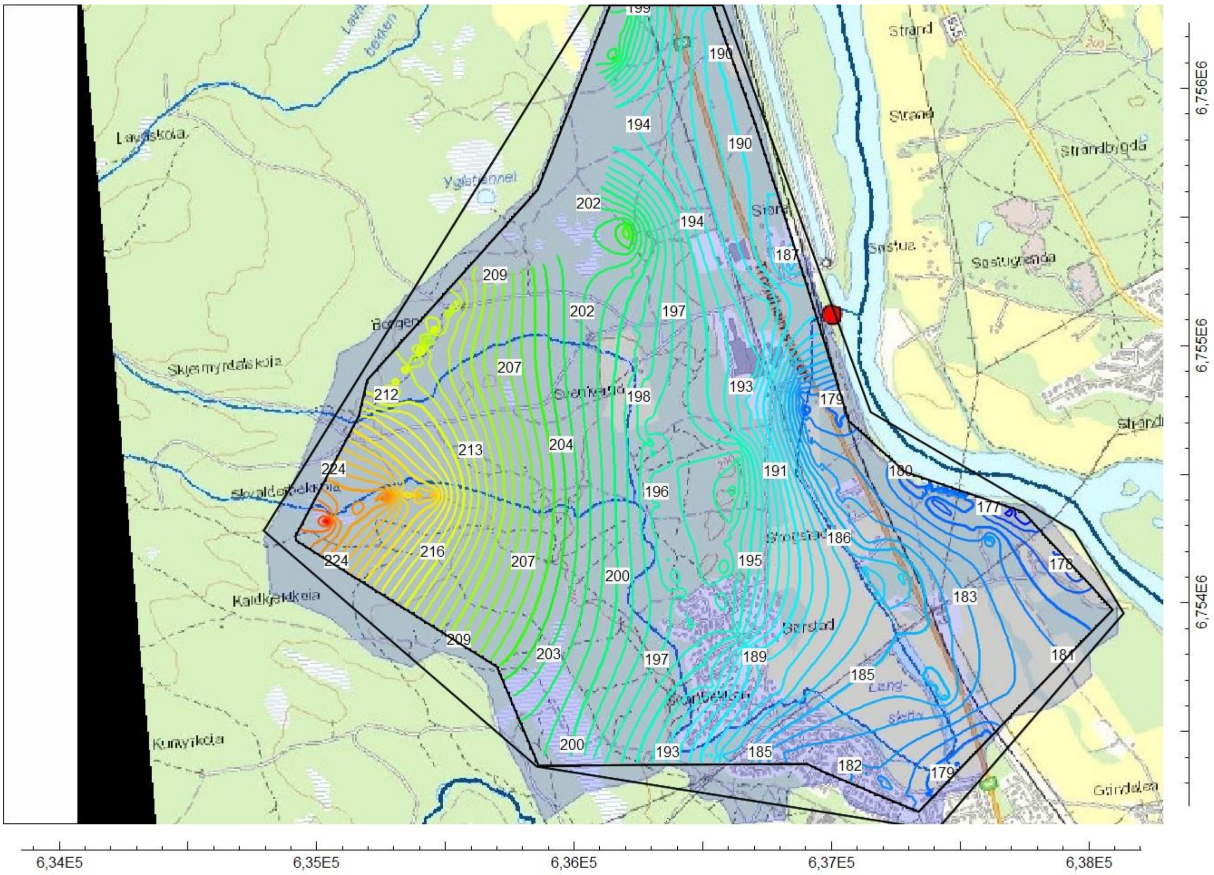


Figure 26 Groundwater position represented by contour lines in Grindalmoen area based on Numerical modelling

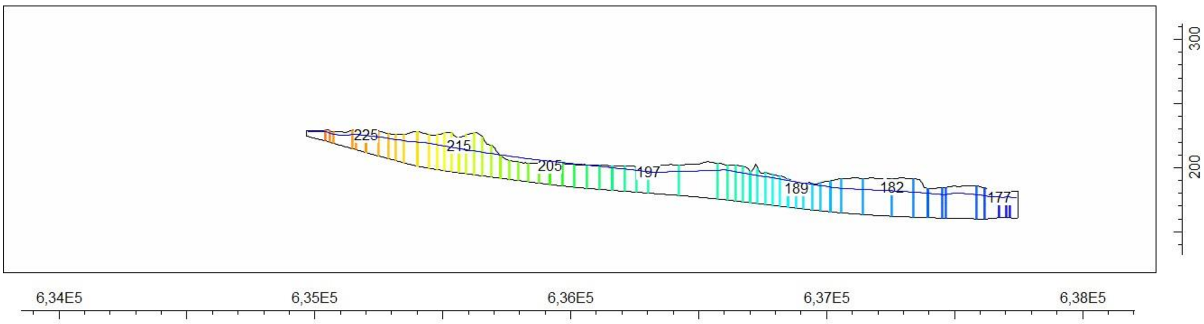


Figure 27 Cross section at water work area showing bedrock orientation and ground water position and its flow direction.

Results

The above figures were made based on stable ground water position on several places which were obtained from GRANADA Data base. This stable Ground water position was used as constant head to construct these contour lines over the catchment area.

Although a model giving a ground water table similar to that suggested by Gaut (1981) the constant head locations defined in the model will add unrealistic quantities of water continuously into a system and is not saticefactory for realistic studies of the aquifer responses to changes to recharge, Ks values etc.. Hence, a model with more realistic boundary conditions was made with constant head just in two location which will be used to study the area under several condition, even though this produced a groundwater map less similar to the one by Gaut (1981).

Condition I: - Reference model Under steady state condition.

The reference model was setup to understand the aquifer under steady state where we run a model with normal annual recharge of 283 mm/year and mean hydraulic conductivity of 0.000634 m/sec. Figure 28 shows head values at within an aquifer system .

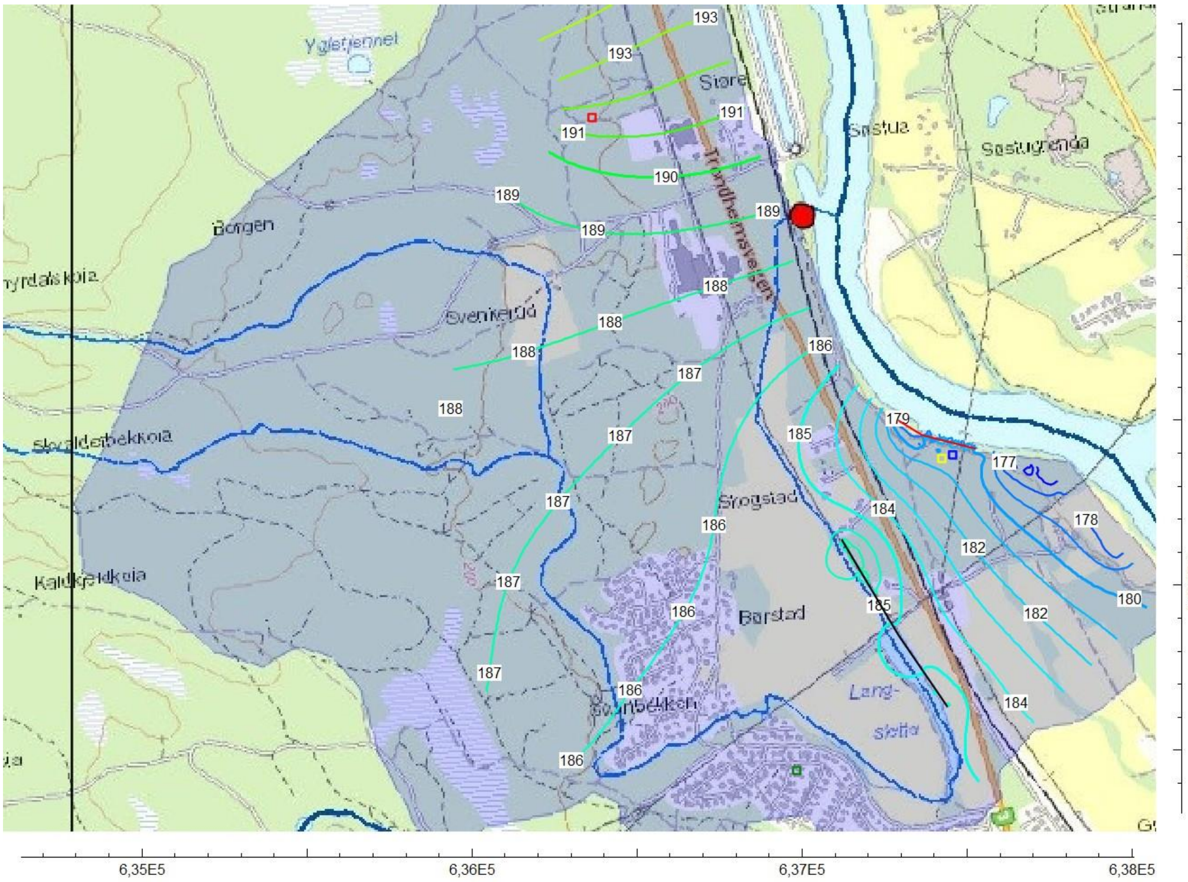


Figure 28 Head values of Ground water under steady state reference conditions.

Condition II: - Model Under annual cycle effect with recharge in form of precipitation and snowfall

Figure 29 shows a head value of numerical model under annual cycle which will represent the real recharge scenario in catchment system. The figure also shows locations of well-observations of simulated head values. This annual fluctuation of recharge is also showing similar response with cyclic fluctuation on head values at different observation points shown in figure 29. This model secnario was also used to simulate the influence of the pumping well. Two pumping rates were defined; a constant pumping rate of 60 Ls-1 and consequently with 600 Ls-1 in two different cycles. The well was located at same location of well no 4 in Grindalmoen water work area.

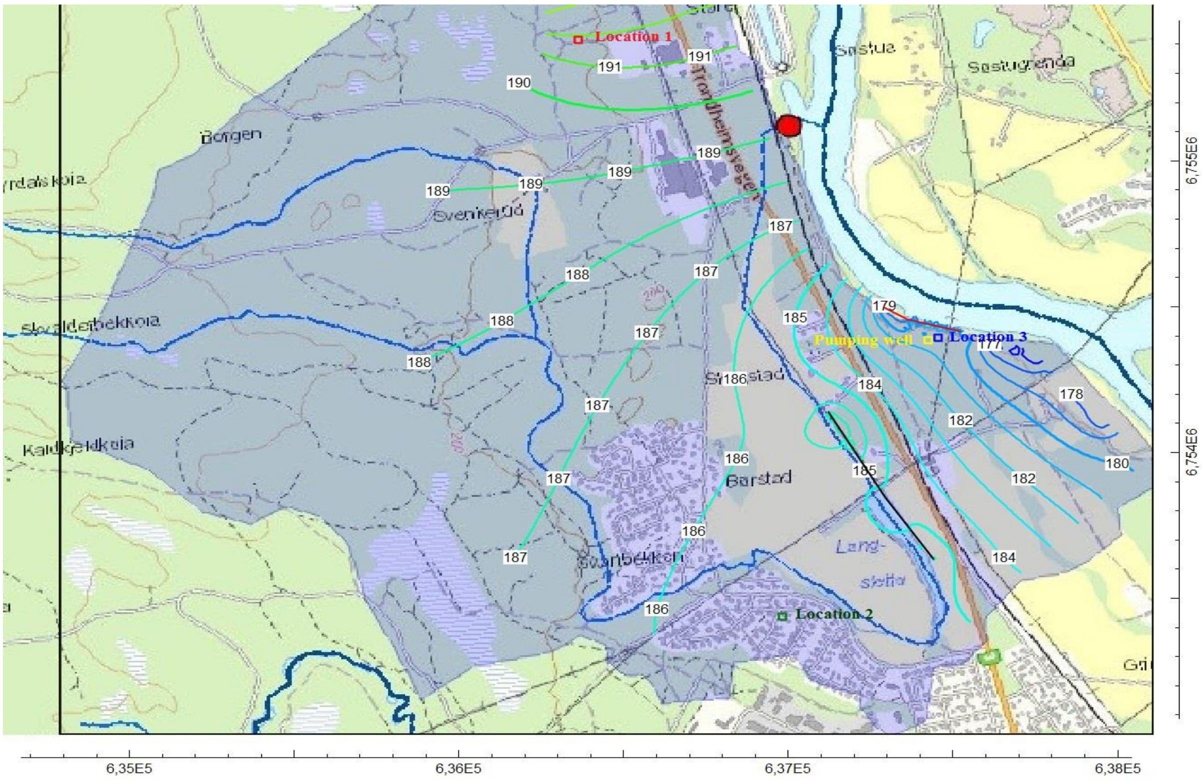


Figure 29 Overview of head values under annual fluctuation and indication of several observation point with in a cathcment area.

Results

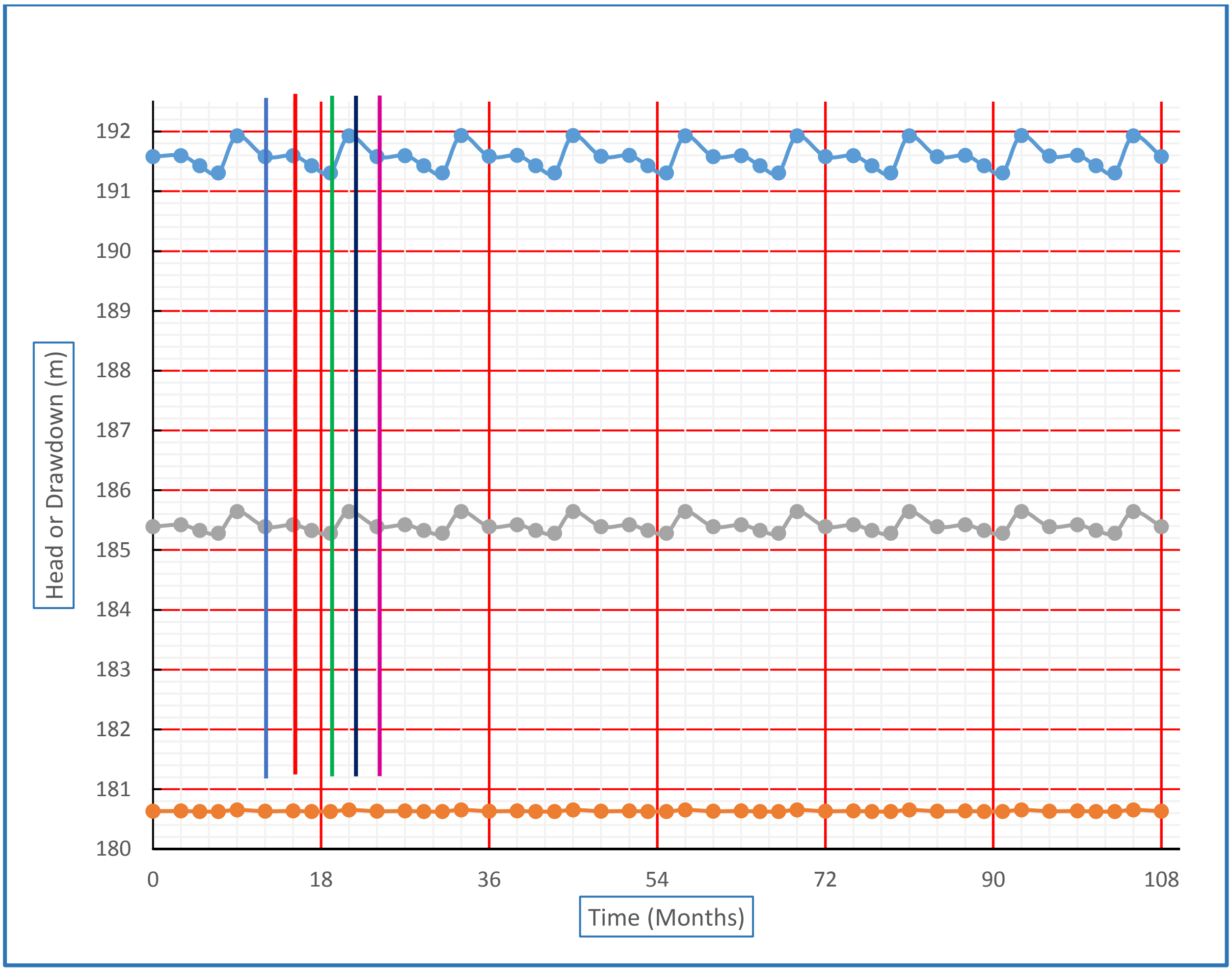


Figure 30 Seasonal fluctuations of Ground water in 3 different places with head values in blue ,grey and orange represents location1,2and 3 as shown in figure 24. The region between blue and red vertical lines indicate summer recharge, region between red and blue indicates winter with no recharge, region between green line and dark blue indicates winter recharge and region Between dark blue and pink indicate summer with no recharge

Case A:- Pumping at constant rate of 60 Ls-1 .

The figure 31 shows fluctuation of head values of ground water during Pumping at the rate of 60 Ls-1 and figure 32shows Drawdown in head value in well location during pumping.

Results

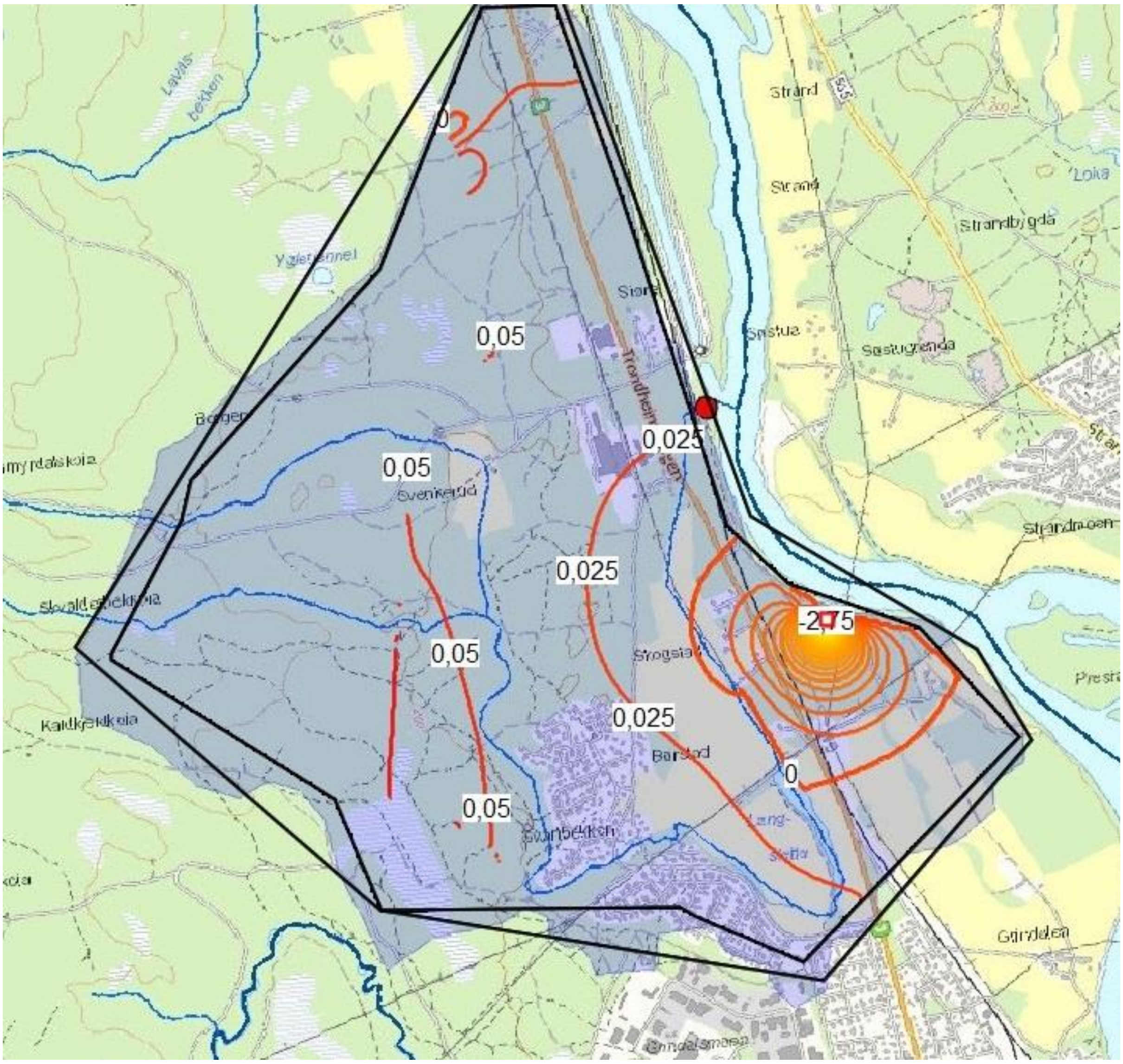


Figure 31 Draw down curve during Pumping Test made in water work Area

Results

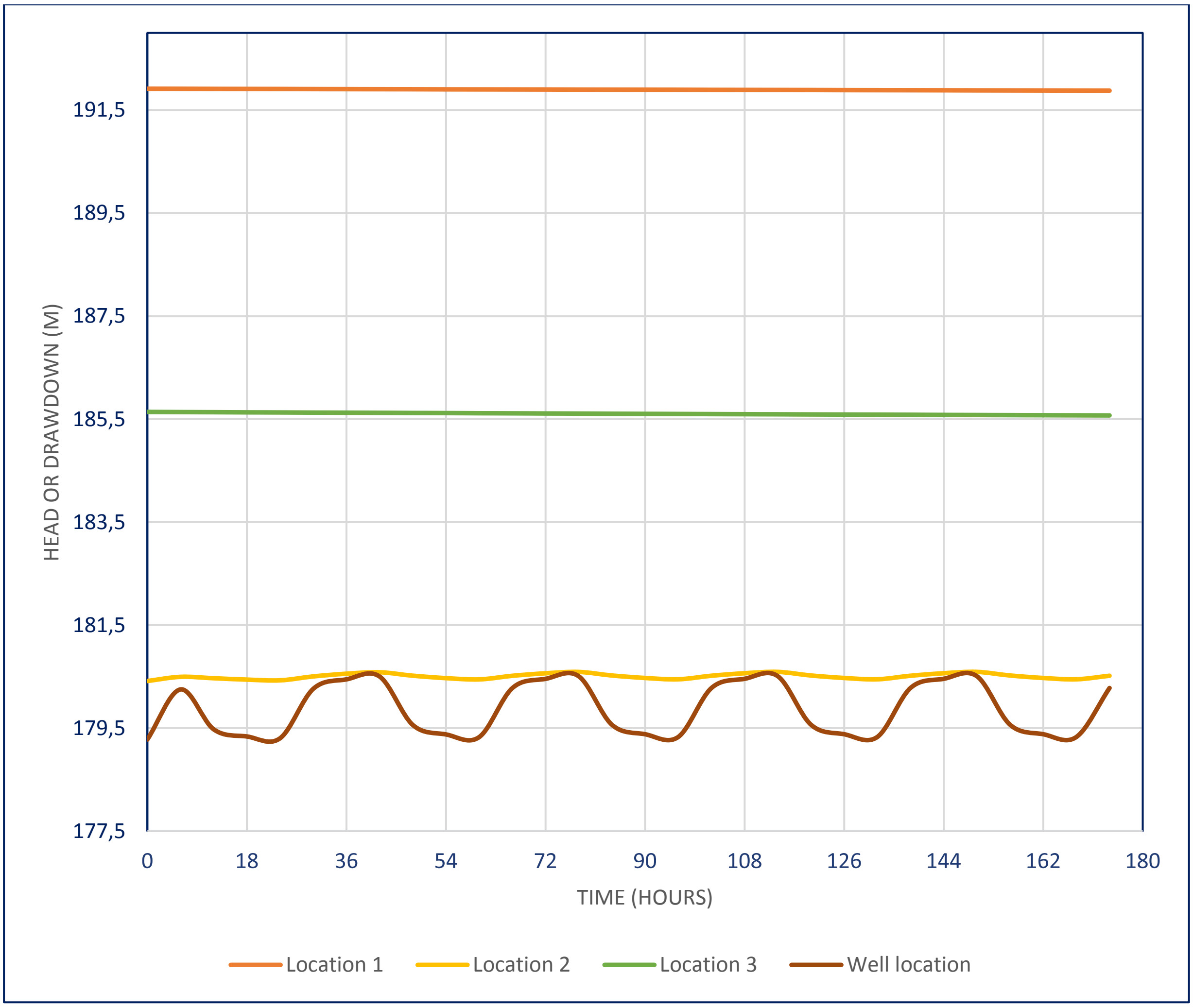


Figure 32 Head values at well and in 3-Different Locations during Pumping at 60 Ls-1 for 1 week

Case A: - Pumping at rate of 60 Ls-1 and 600 Ls-1

The figure 33 shows shows the drawdown of ground water during extensive pumping at rate of 600 Ls-1 and constant pumping at rate of 60 Ls-1.

Results

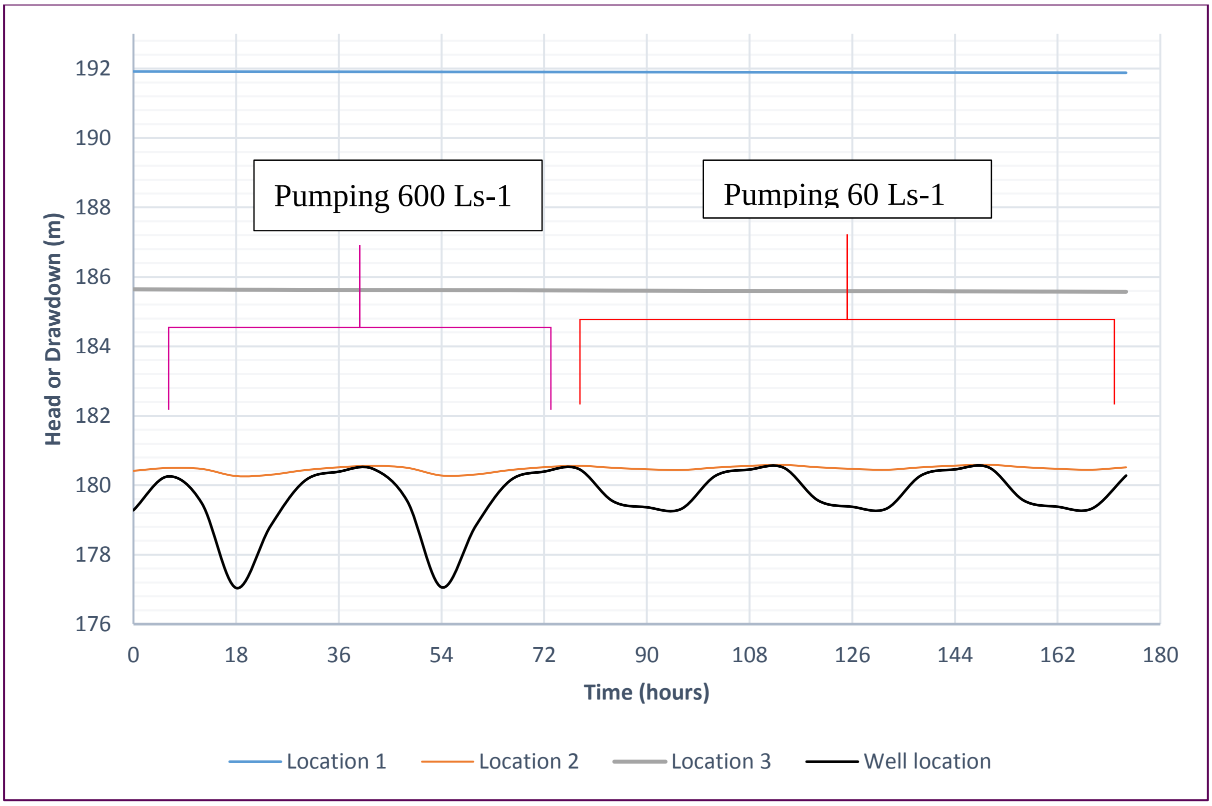


Figure 33 Head values at well and in 3-Different Locations during Pumping at 600 Ls-1 at initial condition followed by constant pumping of 60 Ls-1

Sensitivity Analysis

.

Case I: - Variation in recharge by +10% and – 10%

The numerical model was executed by increasing recharge by 10% from its mean annual recharge and by decreasing by 10% from mean annual recharge under the steady conditions. The figure 34 and 35 shows change in head value in overall aquifer system respectively and figure 36 shows the details of change in head values of ground water at 3 different locations during variation of recharge.

Results

Figure 34 Head values 10% decrease in recharge

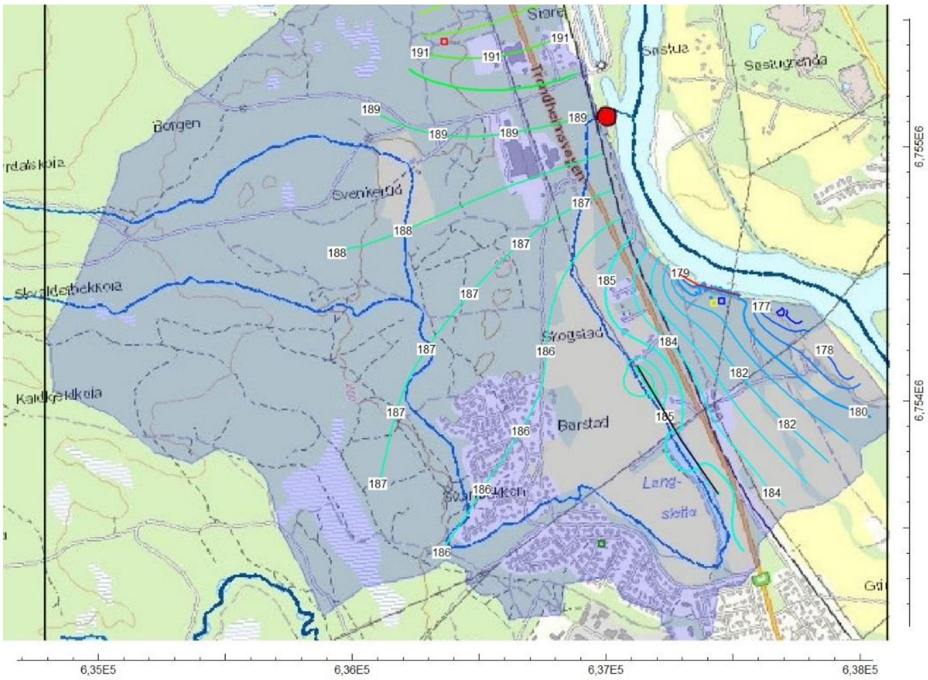


Figure 35 Head values due to 10% increase in Recharge

Results

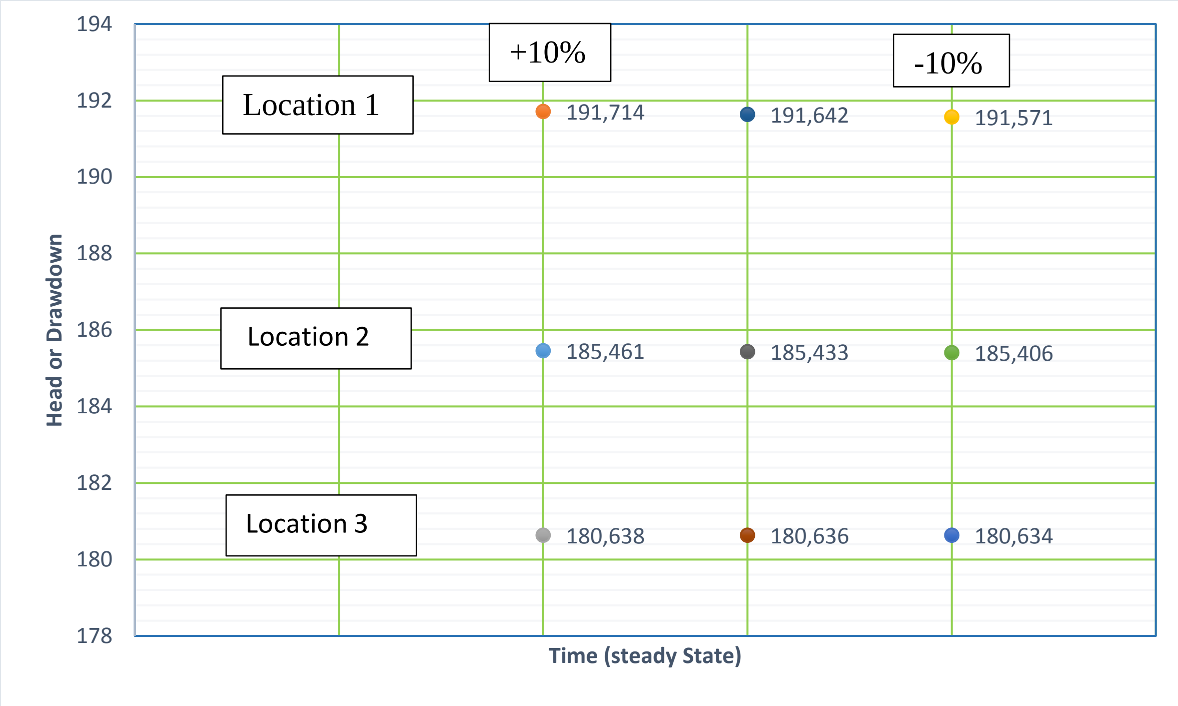


Figure 36 6 Head in 3-observation location due to change in Recharge Value

Case II: - Variation in Hydraulic Conductivity by +30% and – 30%

The numerical model was executed by increasing conductivity 30% from its mean hydraulic conductivity and by decreasing 30% from its mean Hydraulic Conductivity under the steady state conditions. The figure 37 and 38 shows change in head value in overall aquifer system respectively and figure 39 shows the details of change in head values of ground water at 3 different locations during variation of Hydraulic conductivity.

Results

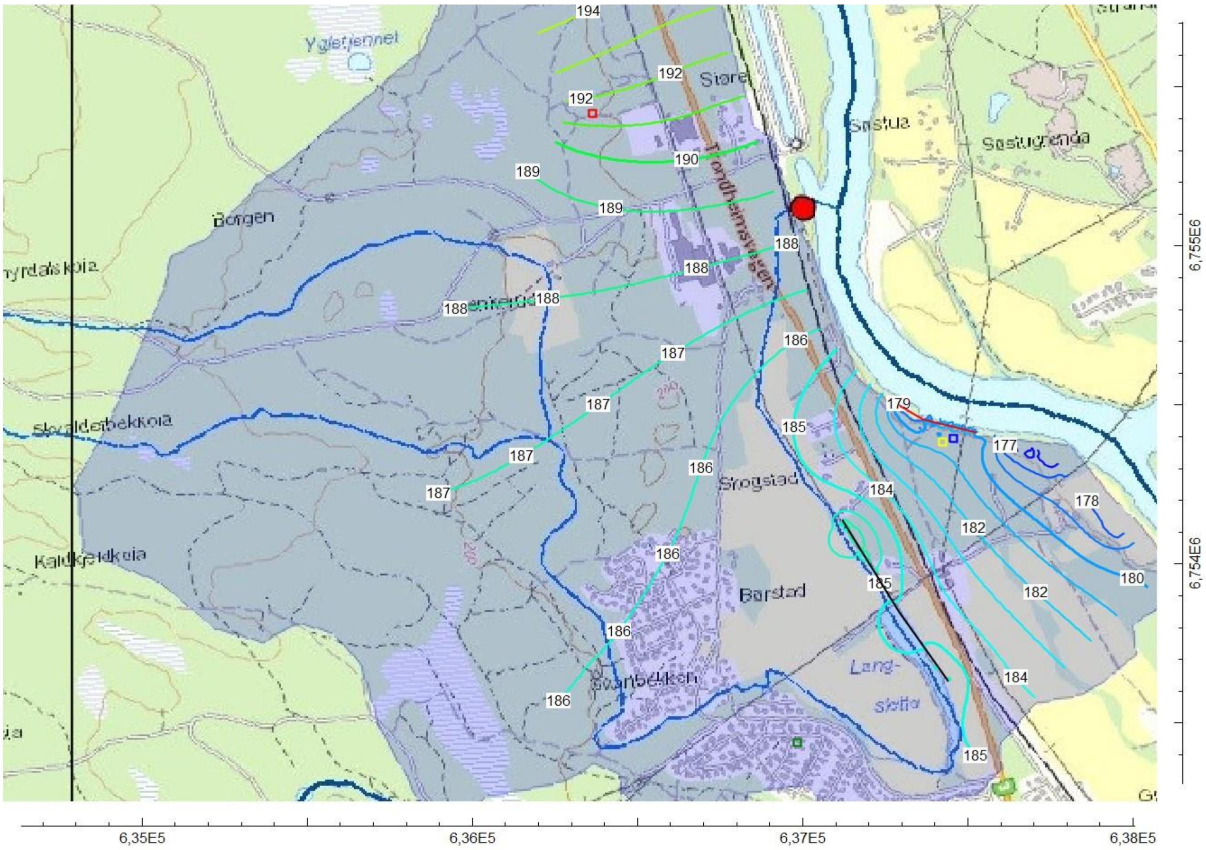


Figure 37 Head value due to increase in hydraulic Conductivity By 30%

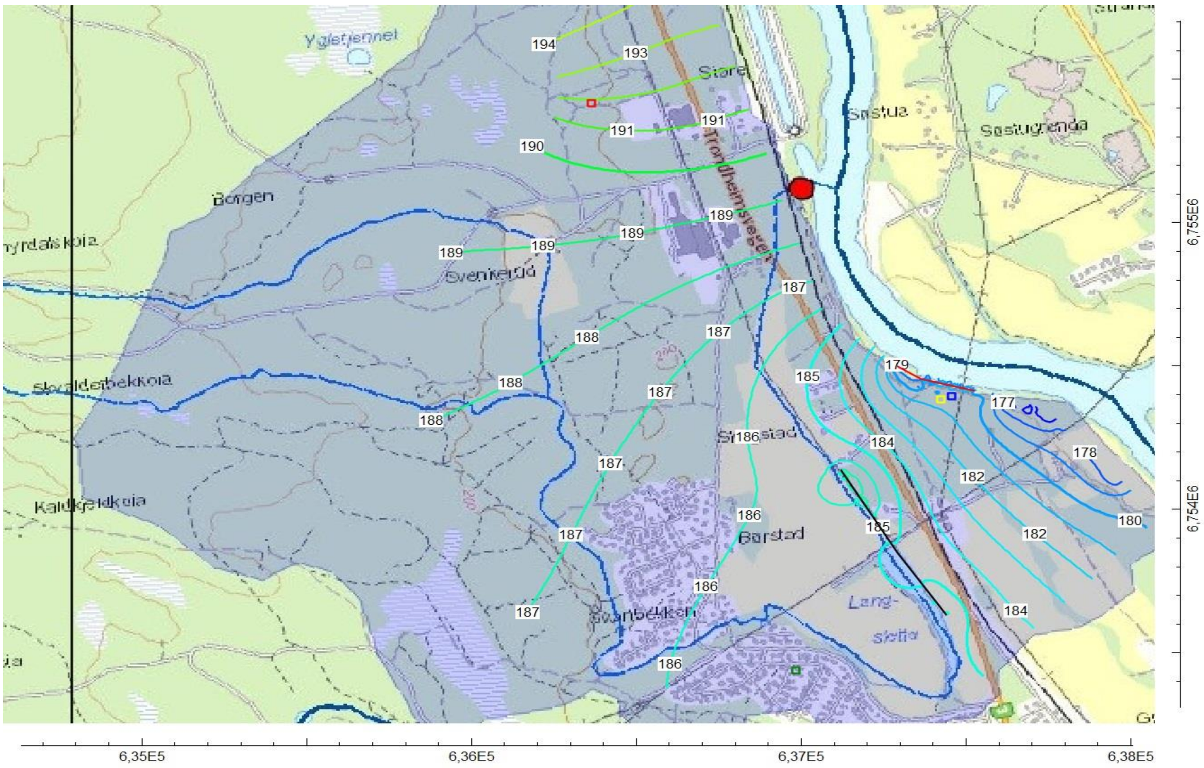


Figure 38 head values during decrease of hydraulic conductivity by 30%

Results

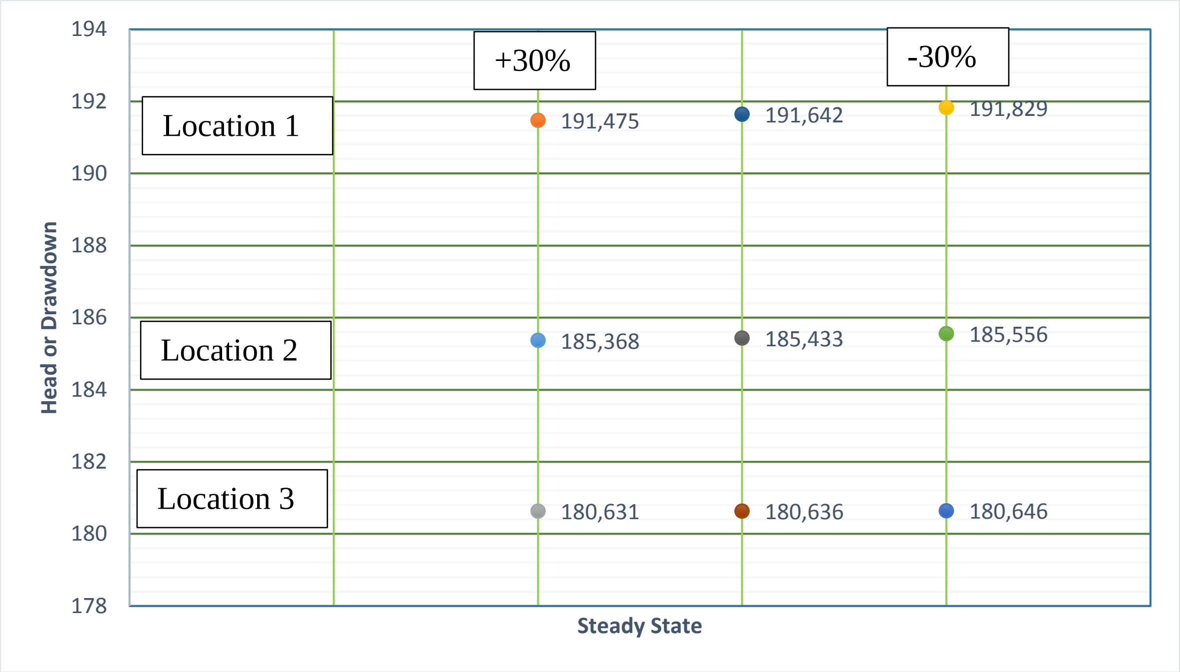


Figure 397 Head values in 3- Different observation Points due to change in Hydraulic conductivity

Chapter-5
Discussion

5.1 Hydrogeological interpretation based on Geophysical Study

In this section, we try to interpret the hydrogeological condition of Grindalmoen area. Here we will try to make clear visualization of how the ground water and river is interacting and heterogeneity within soil of different layer of Grindalmoen waterworks area based on information gathered from geophysical results presented in chapter 4.

The GPR results shows the similar type of dry soil at top surface up to 7m in depth beginning with giving a straight wave forms with higher velocity at top surface but thickness of top dry soil decreases as we goes left towards river, shown by blue dash line in figure 23. The consistent line passing above hyperbolic curve with decreasing velocity indicates the water table.The gradient of water table is towards river with mild steep in beginning and decreases when it reaches near to river either making flow into river or flowing parallel to the river. The piezo metric head at well R1 is above river water level indicating hydraulic head is more at this point and minimum chance to have intrusion of river water into a ground water except during high flooding condition. Since the frequency was just 50 MHz so it cannot gives clear picture up to greater depth but it is showing curve with different Relative Dielectric Permittivity (RDPs) indicating different soil type. Just beneath the water table the Hyperbolic curve represents to lower RDP's value with wet sand but if we go further down curve with Higher RDPs value indicating wet sandy soils. The curve at greater depth are distorted and wave are absorbed which might be due to shale material or presence of bed rock shown with in brown shaded part. The well no 4 shown in figure 23 is projection made for pumping well located 10m far south from well R1. The depth of this well is located 30m below the ground surface. When we made this well projected in the GPR profile its bottom just hit the distorted wave of GPR results. So, we can make preliminary interpretation that this distorted wave is indicating either of bedrock or compacted shale material acting as confined layer. To make further Justification of this bottom layer we need to perform other more GPR survey in water work area.

When we make observation results from ERT survey in figure 24, the top surface possess quite less resistive soil compared to stable continuous soil with higher resistivity just beneath top surface. The soil represented between dash lines indicates the highly resistive sandy soil which can be considered as layer controlling the movement or recharge of water into a aquifers. The blue continuous line projected from GPR results passes in between the highly resistive soil layer. So, the indication of high resistivity can be assumed as presence of completely saturated non-uniformly distributed coarser sand. The presence of such highly resistive saturated layer can be verified by sounding test that was performed at location near to end and beginning points of ERT survey lines. But everything above and below this dash line can be considered as viable sand to make easy movement of water. As we just move below the bottom dash line we are hindering into a water table and soil with less resistance. The water table seems to be passing vicinity to boundary layer with very high and less resistance.This type of flow pattern is unique property of water to follow such boundary to make its flow.

If we observe the top soil layer just beneath the slope and near to well R1, it possess soil with higher resistance and don't allow easily to make infiltration which was identified during field infiltration test. The continuous Stable soil with almost 10m- 5m thickness following the line from left top of section and up to river. Although we were not able to extract the geophysical information at bottom of river but this regular stable soil of high resistance might also exist which is acting as strong boundary to control flow in between the river and aquifer.

The seismic survey performed along the ERT line shows just the position of groundwater. Due to lack of more information in result we were not able to make interpretation of Asbjørn in that area.

5.2 Estimation of Hydraulic conductivity

As described in chapter 4.3, infiltration test and slug test were used to determine the hydraulic conductivity of soil at top surface of water work area. Understanding of top soil property is so important to estimate the amount of water that will get recharge into the aquifer system. Although these methods are both field methodology to determine the hydraulic conductivity but due to several other factors such as test location, procedure and accuracy of theses methodology, there is some variation in results. The result obtained from infiltration test that was performed on to location IF1 with two method mariotte and MPD was almost same within range of 10^-5 m/sec. But values of hydraulic conductivity obtained for location IF2 had difference in value range of 10^-1. Since the test performed over location IF2 possess coarser sand with higher conductivity where water percolates so fast as compared to fine sand in locationIF1. Due to such field situation, it was very difficult to make test efficient where water percolates so fast and taking measurement of the flow rate precisely was so challenging task. In overall, the field test gave the value which represents the similar value for hydraulic conductive of top soil in the study area.

The main objective of performing slug test was to understand the underlying soil type and its capacity to make flow within aquifer system. As presented in chapter 4.3.2, 4 several location was selected to make slug test which includes one new well that was drilled during field course. The result obtained from this test gave very low conductivity which were in range of 10^-5m/sec to 10^-8 and these value are almost half the value compared to hydraulic conductivity of top soil. The reason behind this might be lack of proper information regarding position and size of filters over existing wells. Further, the observations wells were located near to the water work area where they made a continuous pumping to make supply of water to the municipality. As mentioned in chapter 2.1, Vyredox method is being used to make precipitation of iron and manganese. So, during the slug test we observe the very black water during pumping of observation well W4 and O1 which were near to main pumping well. Due to these precipitated matter, the pores of soil matter in shallow depth were clogged or decreased the flow velocity. The process of addition of water into a soil to make slug test was so slow indicating very low conductive .In such field condition, we need to make drilling of new wells in that area which would be less effected from these supply wells to make better understanding of underlying soil property.

The results from the grain size distribution were very close to infiltration test which further increases the accuracy of results. The top soil was used to determine conductivity from grain size distribution method from two same location. i.e IF1 and end of ERT test. These results from infiltration and grain size distribution were much more near value. The mean of these value were used as hydraulic conductivity for making overall study of Numerical modelling.

5.3 Numerical ground water Modelling

The overall study of Hydrogeological condition was made with the development of numerical model of Grindalmoen water work area. The information regarding Hydraulic conductivity taken from field measurement and several other information like depth to bed rock and ground water position were collected from Granada data base. The numerical model with head values of groundwater at several locations with bedrock orientation and water level in aquifer was developed as shown figure 21. The figure 26 and 27 clearly shows that the thickness of aquifer with shallow top soil in western part of catchment compared to much thicker in eastern part.

During the modelling, catchment area for ground water recharge for water work area was selected based on surface flow direction which will not completely represent the actual ground water recharge area. The information regarding bedrock depth was from Granada data base with well information, where we found that the bed rock depth was so shallow that it was exposed in some of the places which was even shallower than what we were able to simulate due to the discretisation method in Modflow. On the basis of location of bedrock we created an initial numerical model with varying bed rock orientation in a smaller distances. This made a model so complex that it couldn’t run properly as it made difficult to make a calculation in between each element of the grid. So, the bedrock was also further simplified doing interpolation of bedrock position at greater distance. In real scenario, the area is composed with multiple layer with varying soil property in each layer. But due to complexity of model, single layer was used to indicate the overall Numerical model.

If we make comparison to the information used in map by *Graut.et al*, we have introduced much more information regarding bed rock position and stable water position in catchment area near water work but make our model much more realistic. But as we described in earlier chapter we introduced more no of constant head to make our model much more realistic with the map by *Gaut.et.al (1981)*. But in real field condition recharge will be acting as boundary condition in northern and western part of aquifer whereas possibility of flux boundary parallel to the river in subsurface near to water work area. Thus, obtained head value and flow direction of ground water might not be realistic in real scenario due to in sufficient information and the true fact that ground water map is not static over time period . This might be due to several reasons like less recharge into a soil compared to field situation, less depth to water table aquifer due shallow bedrock position in western part. Further, the recharge assumed to done over the inclined topography in model which will be lesser as compared to recharge that would occurred in real field which will be more.

Condition I: - Reference Model under steady state condition.

The model with overall head value of ground water was made with the use of several no of constant head in the model. But due to large no of constant head in the model, the constant head will add maximum amount of water into aquifer system and observation on variation of the hydrogeological information cannot be obtained properly. So, just two constant head i.e near to the river Glomma and one near to creek was introduced in the model which will represent the similar hydrogeological condition and would show variation in head value in different observation points that we have selected in map.

The result shown in figure 30 gives similar head value with in water work area as we had included the constant head near water work where river is acting as constant head. So, the influence on hydrological information won't be affect in larger extent in this area as compared to area farther to constant head. This model was further used to make sensitive analysis in the Grindalmoen area. We have used a constant annual recharge and same value of hydraulic conductivity in the numerical model with steady state. So, we can easily observe and compare the hydrological information during the sensitive analysis where we make changes in recharge rate and conductivity of aquifer.

Condition II: - Model under annual cycle effect with recharge in from of Precipitation and Snow fall.

The figure 30 shows the similar nature in fluctuation in head value in three different location. The is slight increase in head value during the autumn recharge but as soon as winter starts there is no any recharge so water level starts to get reduce during these months. As soon as snow starts to melt the head value starts to increase and ultimately decreases until end of summer. This is an indication of clear annual fluctuation in head value at observation location 1&2 as compared to location 3 with respect to annual fluctuations of recharge. As we have defined the observation point very far from the constant head and change in recharge in aquifer system will directly affect as compared to other points located near to the constant head. Since, constant head will add maximum amount of water into the system and does not allow to make fluctuation in head value near those areas.

Pumping at constant rate of 60 Ls^{-1} and at rate of 600 Ls^{-1} followed by 60 Ls^{-1}

To make observation of impact of pumping in head values and draw down in that region, we made a pumping with same rate and by increasing pumping rate by 10 times that actual for 1 week. Although, Grindalmoen water work possess 4- pumping well but we made pumping through 1 well to make simplicity of the model. To make clear observation of impact of pumping the pump was run with each cycle of 36 hours, where continuous pumping was done for 18hours and no pumping for next 18 hours. Ultimately, we obtained a similar cycle in change in head value as we make change in pumping rate.

The result presented in figure 32 and figure 33 shows there is drawdown of head in well up to 1.75 meter during the pumping at rate of 60 Ls^{-1} and up to 3.6 m. The drawdown curve during the pumping in Grindalmoen area with same pumping rate shows the similar nature of drawdown in case of pumping of 60 Ls^{-1} as shown in figure 40.

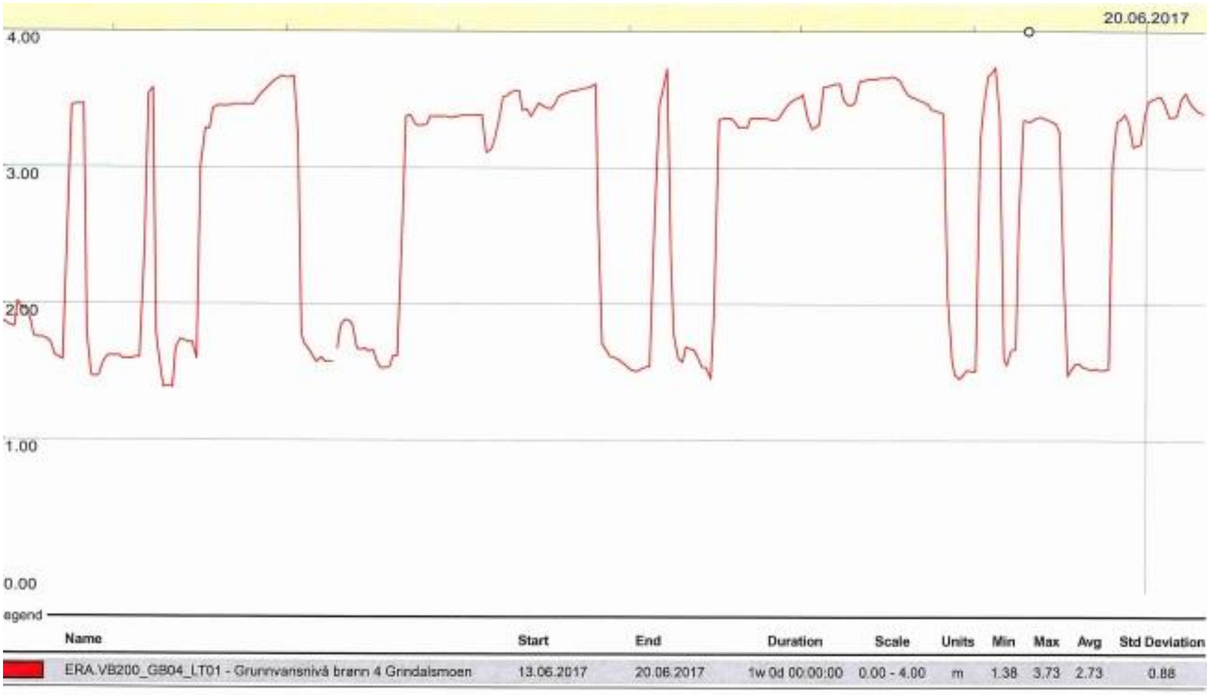


Figure 40 Drawdown during Pumping in well No4 In Grindalmoen water work area. source:- Geir Engen, Elverum Kommune

But if we observe the drawdown value for 6oo Ls^{-1} its only increase by double although we increase the pumping by 10 time. This type of condition resulted due to being constant head being near to the well which will make addition of maximum amount of water to the system. So, to make the better understanding we need to include the change in head value that occurs in river so that we could determine the degree of impact in aquifer during the extensive pumping in well.

Discussion

Sensitivity Analysis

The results from the sensitive analysis for recharge showed that with increase or decrease in recharge value have similar pattern in change in head value for different location was obtained. While we made increase in recharge by 10% the head value at location 1 was increased by 0.072 and decrease by same value when we decrease recharge by 10% from initial head value. The similar way of change in head value was obtained for two other points. The fluctuation of head value in location 1was comparatively more than that of other two location 2 and 3. The existence of situation was due to distances of these points from constant head.

In case of hydraulic conductivity, sensitivity of aquifer towards increase and decrease in conductivity of aquifer by 30% was simulated. The results showed that when we increase conductivity the head values in all three locations was decreases and vice versa. Upon increase in conductivity was decreased by 0.167m where as increased by .187m upon increase in conductivity value. Similarly, in location 2 during increase in conductivity head value decreased by 0.065 but on decreasing conductivity by same percentage head value increase was almost double with value 0.123m from reference head value for that location. This type of behaviour of aquifer is relevant because when we make increment in hydraulic conductivity then flow rate will increases in specific places with lowering the head value at certain time of measurement.

The two analysis showed that aquifer system is comparatively more sensitive for the hydraulic conductivity as compared to recharge. The change for hydraulic conductive was made by 30% and for recharge was by 10 % but increase or decrease in head value was more in case of hydraulic conductive. During analysis we have considered that within all aquifer system we have same hydraulic conductive. But tin real situation we have soil with different hydraulic conductivity at different layer with finer soil at top surface and coarser at bottom surface. When make small change in hydraulic it becomes more sensitivity towards increase or decrease in head value of different locations compared to change in recharge value which might not exist in real scenario.

Chapter 6
Conclusion and Recommendation

6.1 Geophysical investigation

The geophysical investigation helped us to understand the geophysical condition near the water work area. We were able to picturize area with heterogeneous soil property near the water work area from ERT survey and GPR survey but seismic survey could give much more information except position of water table in that specific area. GPR survey helped to identify the clear position and flow direction of ground water along with some bedrock or confined layer shown 23. Whereas, ERT results indicates the heterogeneity within different layer of soil lower resistive material at top surface where recharge will occur and highly resistive layer in between two less resistive layer which might be completely saturated soil layer controlling the flow of water within the aquifer system.

Just in small scale the study was made which is not so sufficient to make better mapping of geophysical situation of that area. So, several surveys need to be performed to make precise and proper understand of Hydrogeological condition of that area.

6.2 Drilling and Exploratory Well

During the field study, we were able to make drilling for 2 wells but just one exploratory well was installed due to lack of time and difficulties during making exploratory well. But some preliminary results were obtained which helps us to know that fine-grained soil is underlying above the coarser depth representing fluvial and glacio-fluvial deposit was made in the past times during formation of those landforms.

To make a better understanding of the physical condition of the sub-surface of Grindalmoen water work area, we need to conduct sufficient no exploratory wells .This task need to be done by making use of better drilling equipment because we experienced much coarser material with some boulder fraction in the greater depth during sounding test .

6.3 Hydraulic Conductivity

The results from the infiltration test gave more realist value which represent the soil condition of Grindalmoen area at the top surface. For the material like fine sand, the Mariotte cylinder and Modified-Philip-Dunne test show very good correlations. For coarser material, however, the MPD test seems more suitable when it comes to comparable values as well as practicality of handling during fieldwork. Although, the hydraulic conductivity of soil indicates the top soil but average of these values from two test were used as hydraulic conductivity of aquifer during modelling of aquifer.

Slug test performed over observation well didn't gave good results due to lack of details of filter dimensions of existing wells and precipitation of iron and manganese. Therefore, hydraulic conductivity value from slug test were not used in the Numerical model. Due to lack of time and powerful pump to make flushing of these well we were not able to collect the good data for slug test. More powerful pump and few more extra drilling of observation wells is required to obtain precise results from slug test.

Although, the grain size distribution gave some results but we didn't make it use as it represents solely top soil as compared to results obtained from Infiltration test. As we can clearly visualize from sounding test that the underneath soil is coarser compared to top soil. Big drilling need to be done to obtain soil sample from underneath surface so that we could determine the actual hydraulic conductivity of different layer surface based on grain size distribution.

6.4 Numerical Modelling

The results from the numerical modelling clearly showed the response head toward fluctuation in recharge through out the stress period. This indicate that due to some limitation we were able to make model that will represent to our real topography.

The model executed under pumping with annual fluctuation clear showed a similar that of draw that occurs during pumping made at rate of 60 litres per second. In case of pumping at rate of 600 litre per second the drawdown was limited to 3.6m although it was 10 times more than normal pumping rate. This is due to constant head near to well which adds sufficient of water to the system. So, to make influence of extensive pumping we need to introduce a river with in a model were river water level change in every seasons.

The sensitive analysis showed that the aquifer is much sensitive toward hydraulic conductivity compared to recharge. Since we have made single layer in model with single hydraulic conductivity which is not so realistic. So, we need to make the use of much sophisticated software to include multiple layer.

References

Anon, 2015. Freshwater | Miljøstatus. *the Norwegian Environment Agency*. Available at: http://www.environment.no/topics/freshwater/ [Accessed November 21, 2016].

Anon, Learning Groundwater Modeling using Visual MODFLOW | Waterloo Hydrogeologic. *waterloo hydrogeologic*. Available at: https://www.waterloohydrogeologic.com/resources/visual-modflow-flex-resources/introduction-groundwater-modeling-with-visual-modflow/ [Accessed June 29, 2017].

Anon, 1997. *Simulation Capabilities of MODFLOW*, Available at: https://pubs.usgs.gov/fs/FS-121-97/fs-121-97.pdf [Accessed June 20, 2017].

Brassington, R., *Field hydrogeology*,

Gr, Z.Z. et al., 1999. ECOMAG: Regional model of hydrological ECOMAG: Regional model of hydrological. Available at: https://folk.uio.no/kolbjoen/nygen/ECOMAG-REPORT.pdf [Accessed May 2, 2017].

Gressando, Y. of I., 1999. *Application of geophysical techniques for groundwater investigation in lake Naivasha area, Kenya.*, Netherland.

Haeni, F.P., 1988. *APPLICATION OF SEISMIC-REFRACTION TECHNIQUES TO HYDROLOGIC STUDIES*, WASHINGTON: UNITED STATES GOVERNMENT PRINTING OFFICE,. Available at: https://pubs.usgs.gov/twri/twri2d2/pdf/twri_2-d2.pdf [Accessed December 3, 2016].

Hansen, L. et al., 2005. *Grunnvann og grunnvarme fra dype dalfyllinger langs Glåma*, Trondheim. Available at: http://www.ngu.no/upload/Publikasjoner/Rapporter/2002/2002_082.pdf [Accessed January 4, 2017].

Haugen, T., 2015. *Kartlegging av dybde til fjell i Elverum sentrum og geologisk beskrivelse til videre bruk i*, Trondheim.

Knudsen, C.-H., 1985. *Grunnvannforsyning Grindalen Landtidspr;*, Drammen. [Accessed june 22, 2017]

Lin, M.-C. et al., 2009. A Study on the Technologies for Detecting Underground Water Level and Processing Image. *International Journal of Applied Science and Engineering Int. J. Appl. Sci. Eng*, 7(1), pp.61–68. Available at: https://www.cyut.edu.tw/~ijase/2009/7(1)/6_016009.pdf [Accessed May 22, 2017].

The Norwegain water resources and energy Directorate. available at http.:/www.nve.no (accessed date july 20,2017)

Reite, A.J., Sveian, H. & Erichsen, E., 1999. *Trondheim fra istid til nåtid*, Trondheim. Available at: http://www.ngu.no/upload/Publikasjoner/Grasteinen/Graasteinen05_Trondheim.pdf [Accessed January 4, 2017].

Reynolds, J.M., 2011. *An Introduction to Applied and Environmental Geophysics* 2nd ed., Wiley-Blackwell. Available at: https://download.e-bookshelf.de/download/0000/5825/84/L-G-0000582584-0002360744.pdf.

Riise, M.H., 2015. Praktisk guide for grunnvarmeanlegg basert på oppumpet grunnvann.

Tockner, K., Uehlinger, U. & Robinson, C.T., 2009. *Rivers of Europe*, Academic Press. Available at: https://books.google.no/books?id=GDmX5XKkQCcC&pg=PT600&lpg=PT600&dq=average+flow++of+river+glomma+in+Elverum &source=bl&ots=CRZeM2tUXW&sig=8-2e34GA16eMc4uaj4hIMcyv1Rw&hl=en&sa=X&ved=0ahUKEwjr4djM25DUAhUC1i

wKHc0zCtsQ6AEINTAC#v=onepage&q=average flow [Accessed May 23, 2017].

U.S. Environmental Protection Agency, 2011. Resistivity Methods. Available at: https://archive.epa.gov/esd/archive-geophysics/web/html/resistivity_methods.html [Accessed May 22, 2017].

University of St Andrews, Applied Geophysics for Groundwater Studies. Available at: https://www.st-andrews.ac.uk/~crb/web/GWATER1.pdf [Accessed January 3, 2017].

Other Refrences from Text book

Anderson, M.P. & Woessner, W.W. 1992. *Applied groundwater modelling . Simulation of flow and*

advective transport. Academy Press, Inc., San Diego. 381 p.

Harbaugh, A. W., E. R. Banta, M. C. Hill, and M. G. McDonald. MODFLOW-2000, *The U.S. Geological Survey Modular Ground-Water Model - User Guide to Modularization Concepts and the Ground-Water Flow Process*, USGS Open-File Report 00-92.

Reston, Virginia: U.S. Geological Survey, 2000

Eppink, L.A.A.J. 1993. *Processes and models in erosion and soil and water conservation. Water*

erosion models: an overview. Lecture notes. Wageningen.

Hillel, D. (2004). *Introduction to environmental soil physics, 494 pp*: Elsevier Academic Press, Amsterdam, San Diego

Lokes, M. (1999). *Electrical imaging surveys for environmental and engineering studies – a practical guide to 2-D and 3-D surveys.* Retrieved from http://www.abem.se/files/res/2dnotes.pdf

Resistivity Methods. (2011). Retrieved from U.S Environmental protection agency: http://www.epa.gov/esd/cmb/GeophysicsWebsite/pages/reference/methods/Surface_Geophysical_

Appendix I

Table1:- Typical Dielectric value for different soil type

TABLE 1. TYPICAL RELATIVE DIELECTRIC CONSTANTS FOR SELECTED MATERIALS

MATERIAL	ε_r
Air	1
Pure Water	81
Seawater	81
Freshwater ice	4
Seawater ice	6
Snow (firm)	1.4
Sand (dry)	5
Sand (saturated)	30
Clay (saturated)	10
Granite (dry)	5
Granite (wet)	7
Limestone (dry)	7
Limestone (wet)	8
Shale (wet)	7
Sandstone (wet)	6
Soil - sandy dry	2-4
sandy wet	20-25
loamy dry	2-6
loamy wet	15-20
clay dry	2-6
clay wet	10-20
Permafrost	6-13
Strong concrete - dry	5-9
soaked 20 hrs	10-15
Cracked concrete - dry	4-5
soaked 20 hrs	13-20
Asphalt	12-16

source: https://www.google.tl/patents/WO1994029744A1?cl=en

Table 2:- Precipitation, runoff and recharge rate information of Elverum area

Rapport - genererte feltparametere

Parameternavn	Generert verdi	Editert verdi
ObjectId	21 780	21 780
Vassdragsnummer	002.H62	002.H62
Klimaregion	Ost	Ost
Region	Ost	Ost
Areal (km²)	5,96	5,96
Avrenning (mm/år)	283,75	283,75
Minimum høyde (m)	180	180
Maksimum høyde (m)	319	319
Sjø (%)	0,34	0,34
Bre (%)	0	0
Skog (%)	81,21	81,21
Dyrket mark (%)	8,56	8,56
Myr (%)	2,35	2,35
Snaufjell (%)	0	0
Urban (%)	6,21	6,21
Effektiv sjø (%)	0,34	0,34
Sommertemperatur (Mai - September) (°C)	11,65	11,65
Vintertemperatur (Oktober-April) (°C)	-3,94	-3,94
Sommernedbør (Mai-September) (mm)	358	358
Vinternedbør (Oktober-April) (mm)	302,25	302,25
Temperatur Juli (°C)	14,28	14,28

Dyrket mark (%)	8,56	8,56
Myr (%)	2,35	2,35
Snaufjell (%)	0	0
Urban (%)	6,21	6,21
Effektiv sjø (%)	0,34	0,34
Sommertemperatur (Mai - September) (˚C)	11,65	11,65
Vintertemperatur (Oktober-April) (˚C)	-3,94	-3,94
Sommernedbør (Mai-September) (mm)	358	358
Vinternedbør (Oktober-April) (mm)	302,25	302,25
Temperatur Juli (˚C)	14,28	14,28
Temperatur August (˚C)	13,48	13,48
Årstemperatur (˚C)	2,56	2,56
Årsnedbør (mm)	660,25	660,25
Feltlengde (km)	3,81	3,81
Elvelengde (km)	7,56	7,56
Elvegradient (m/km)	12,14	12,14
Elvegradient (10-85) (m/km)	5,47	5,47
Delta Hmax (m)	91,83	91,83
Vassdrag	GLOMMAVASSDRAGET	GLOMMAVASSDRAGET
Kommune	Elverum	Elverum
Fylke	Hedmark	Hedmark

Tilbake Fortsett

Source:- http://nevina.nve.no/ Retrived date 12/05/2017

Table 3.- Well information from Granada database

GRUNNVANNSDATABASEN

Løsmassebrønn nr. 55424

LOKALISERING	
Fylke	: Hedmark
Kommune	: Elverum (0427)
Gårdsnummer	:
Bruksnummer	:
UTM sone	: 32 V
ØV-koordinater	: 637534.00
NS-koordinater	: 6754365.00
Kartblad (1:50 000)	: Elverum (2016-4)
Stedfestningsmetode	: GPS etter mai 2000
Stedfestningsnøyaktighet	: 1000 cm

BRØNNPARAMETERE	
Totalt dyp av brønn	: 31.00 m
Dyp til fjell	:
Vannføring (før trykking / sprengning)	:
Stabil vannstand (etter boring målt fra overflaten)	:
Boredato	: 11.05.2009
Brukstype	: Vannforsyning
Bruk	: Vannverk
Vannverk	:
Borediameter	:
Forings- / brønnrørmateriale	: Stål
Forings- / brønnrørlengde	: 31.00
Boring	: Loddrett

BRØNNLAG (LØSMASSEBRØNN)

Dyp fra overflaten (meter)

FRA	TIL	SLAMFARGE	LØSMASSETYPE	ANDRE OPPLYSNINGER
0.00	5.00		Sand og stein	
5.00	11.00		Sand	
11.00	19.00		Grus	
19.00	31.00		Sand	

MÅLINGER

Ingen

ANNEN INFORMASJON	
Borefirma	: Nordenfjeldske brønn- og spesialboringer a.s
Borerens navn	: K. U. Jensen.
Borestedsadresse	: Grindalsmoen Vannverk, Elverum.

KOMMENTAR

Ingen

KONSULENTER / RAPPORTER / REFERANSER

Ingen

SPRENGNING / TRYKKING

Ingen

GRUNNVANNSDATABASEN

Fjellbrønn nr. 51721

LOKALISERING	
Fylke	: Hedmark
Kommune	: Elverum (0427)
Gårdsnummer	:
Bruksnummer	:
UTM sone	: 32 V
ØV-koordinater	: 636638.00
NS-koordinater	: 6753920.00
Kartblad (1:50 000)	: Elverum (2016-4)
Stedfestningsmetode	: GPS etter mai 2000
Stedfestningsnøyaktighet	: 1000 cm

BRØNNPARAMETERE	
Totalt dyp av brønn	: 140.00 m
Dyp til fjell	: 15.00 m
Vannføring (før trykking / sprengning)	: 7000.00 l/time
Stabil vannstand (etter boring målt fra overflaten)	: 6.00 m
Boredato	: 11.12.2007
Brukstype	: Energi
Bruk	: Enkelthusholdning
Vannverk	:
Borediameter	:
Forings- / brønnrørmateriale	: Stål
Forings- / brønnrørlengde	: 18.00
Boring	: Loddrett

BRØNNLAG (FJELLBRØNN)

Dyp fra overflaten (meter)

FRA	TIL	EVT. VANNINNSLAG	SLAMFARGE	BERGART	ANDRE OPPLYSNINGER
29.00	30.00	50-500 l/t			Løsere.
83.00	85.00	50-500 l/t			Løsere.
128.00	130.00	>1000 l/t			Løsere.

MÅLINGER

Ingen

ANNEN INFORMASJON	
Borefirma	: Konningrud Brønnboring AS
Borerens navn	: Dag Konningrud
Borestedsadresse	: Djupmyrv. 18 2406 Elverum

KOMMENTAR

Montert kollektor 12.12.2007, fylt med sprit. Levert 25l. ferdig.

KONSULENTER / RAPPORTER / REFERANSER

Ingen

SPRENGNING / TRYKKING

Ingen

GRUNNVANNSDATABASEN

Sonderboring nr. 18398

LOKALISERING	
Fylke	: Hedmark
Kommune	: Elverum (0427)
Gårdsnummer	:
Bruksnummer	:
UTM sone	: 32 V
ØV-koordinater	: 637353.00
NS-koordinater	: 6753761.00
Kartblad (1:50 000)	: Elverum (2016-4)
Stedfestningsmetode	: "Norgesglasset" (mellomstor tomt)
Stedfestningsnøyaktighet	: 5000 cm

BRØNNPARAMETERE	
Totalt dyp av brønn	: 30.00 m
Dyp til fjell	: 30.00 m
Vannføring (før trykking / sprengning)	:
Stabil vannstand (etter boring målt fra overflaten)	: 3.50 m
Boredato	: 01.01.1979
Brukstype	: Undersøkelse / Sonderboring
Bruk	: Ukjent
Vannverk	:
Borediameter	:
Forings- / brønnrørmateriale	:
Forings- / brønnrørlengde	:
Boring	:

BRØNNLAG (LØSMASSEBRØNN)

Dyp fra overflaten (meter)

FRA	TIL	SLAMFARGE	LØSMASSETYPE	ANDRE OPPLYSNINGER
0.00	17.00		Finsand	Vekslende lagring
17.00	30.00			Finstoff med noe stein
30.00	30.00		Fjell	

MÅLINGER

Ingen

ANNEN INFORMASJON	
Borefirma	: Ukjent
Borerens navn	:
Borestedsadresse	:

KOMMENTAR

Ingen

KONSULENTER / RAPPORTER / REFERANSER

KONSULENT	RAPPORTNR	TITTEL	ÅR
Norges geologiske undersøkelse	50417	Elverum. Vannressurskart "Grunnvann i løsavsetninger"; Elverum; 20164; 1:50 000; Trykt i sort/hvitt; Kart og beskrivelse i egen perm	1981

SPRENGNING / TRYKKING

Ingen

GRUNNVANNSDATABASEN

Fjellbrønn nr. 46503

LOKALISERING	
Fylke	: Hedmark
Kommune	: Elverum (0427)
Gårdsnummer	:
Bruksnummer	:
UTM sone	: 32 V
ØV-koordinater	: 637076.00
NS-koordinater	: 6753346.00
Kartblad (1:50 000)	: Elverum (2016-4)
Stedfestningsmetode	: GPS etter mai 2000
Stedfestningsnøyaktighet	: 1000 cm

BRØNNPARAMETERE	
Totalt dyp av brønn	: 150.00 m
Dyp til fjell	: 5.00 m
Vannføring (før trykking / sprengning)	: 1800.00 l/time
Stabil vannstand (etter boring målt fra overflaten)	:
Boredato	: 20.06.2007
Brukstype	: Energi
Bruk	: Enkelthusholdning
Vannverk	:
Borediameter	: 137 mm
Forings- / brønnrørmateriale	: Stål
Forings- / brønnrørlengde	: 6.00
Boring	: Loddrett

BRØNNLAG (FJELLBRØNN)

Dyp fra overflaten (meter)

FRA	TIL	EVT. VANNINNSLAG	SLAMFARGE	BERGART	ANDRE OPPLYSNINGER
0.00	5.00	<50 l/t			Steinblokk. Løsmasse: Grus
5.00	150.00	>1000 l/t			

MÅLINGER

Ingen

ANNEN INFORMASJON	
Borefirma	: Nordenfjeldske brønn- og spesialboringer a.s
Borerens navn	: B.Olsson
Borestedsadresse	: Ilderveien 11 2406 Elverum

KOMMENTAR

Ingen

KONSULENTER / RAPPORTER / REFERANSER

Ingen

SPRENGNING / TRYKKING

Ingen

Source: http:/Granada/ngu Retrieved at20/06/2017

Appendix II

Sample Identity :	Lcation 01 - River			Location 02 - Infiltration			Sample 03 - End of ERT		
Analyst :									
Date:									
Initial Sample Weight :	170.43			92.73			208.44		
Aperture	Class Weight	Class Weight	accumulative	Class Weight	Class Weight	accumulative	Class Weight	Class Weight	accumulative
(microns)	Retained (g)	Retained (%)	(%)	Retained (g)	Retained (%)	(%)	Retained (g)	Retained (%)	(%)
16000	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
8000	0	0.00	0.00	0	0.00	0.00	2.4	1.24	1.24
4000	0	0.00	0.00	0	0.00	0.00	2.02	1.04	2.28
2000	0.31	0.18	0.18	0.2	0.22	0.22	4.92	2.53	4.81
1000	0.44	0.26	0.44	0.28	0.30	0.52	18.93	9.75	14.56
500	0.62	0.36	0.81	0.54	0.58	1.10	94.7	48.76	63.32
250	21.22	12.47	13.28	2.69	2.91	4.02	58.6	30.18	93.50
125	78.32	46.03	59.30	16.85	18.25	22.27	11.06	5.70	99.19
63	44.06	25.89	85.20	39.6	42.90	65.17	0.94	0.48	99.68
0	25.19	14.80	100.00	32.15	34.83	100.00	0.63	0.32	100.00

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway