The History of Hydrogeology in Norway – Part I

Av Kim Rudolph-Lund, Editor with contributions from: Bioforsk, Holymoor Consultancy, NGU, NGI, NIVA, NVE, SWECO, UMB

Kim Rudolph-Lund er fagleder Grunnvann og hydrogeologi ved NGI og IAH-Board Member.

Introduksjon og sammendrag

Dette er første del av en artikkel opprinnelig ment for en bok, "History of hydrogeology", som skulle inneholde tilsvarende artikler fra flere land. Bokprosjektet er foreløpig lagt på is. Del to av artikkelen kommer i neste nummer av VANN.

Tidlige aktiviteter rundt boring av brønner for vannforsyning til gårdsbruk og lokalsamfunn ga med tiden en forståelse av hydrogeologi som vitenskap. Denne aktiviteten ble etter hvert utvidet og institusjonalisert av myndighetene. Siden 50-tallet var NGU den dominerende drivende kraft bak utviklingen av hydrogeologi som fagfelt i Norge, ofte i samarbeid med NVE og NLH. På 70- og 80-tallet ble det gjennomført omfattende grunnvannskartlegging med tanke på vannforsyning til kommuner flere steder I landet. Kartleggingen indikerte at 25 til 30 % av Norges befolkning kunne få sin vannforsyning fra grunnvann. Dette i kontrast til 13 % som faktisk benyttet grunnvann på den tiden.

Sentre for forskning og konsulentvirksomhet innenfor hydrogeology ble etablert i denne perioden samtidig som flere utdanningsinstitusjoner utviklet utdanningstilbud innenfor faget på alle nivåer, også doktorgradsnivå. De omfattende aktivitetene i fagmiljøer som Noteby og NGI var et klart uttrykk for en økende anerkjennelse av hydrogeologi som et viktig fagområde.

Abstract

The early development of hydrogeology was one of necessity. The art of drilling wells to supply groundwater to farms and communities gradually included an understanding of the science of hydrogeology. This activity was expanded and institutionalized by national authorities. Since the 1950's, NGU was the dominant driving force behind the expansion of hydrogeology, often working with NVE and NLH. Major groundwater mapping programs were conducted during the 1970's and 1980's, supplying groundwater to large municipalities around the country. Results from studies indicated that 25 to 30 percent of Norway's popu-

lation could be supplied with groundwater, in contrast to the 13 percent which was using groundwater at the time.

Centers of hydrogeology study, research and consulting were established around the country during the 1970's and 1980's when the higher institutions of learning began offering advanced degrees in hydrogeology. Activities at the large public consulting companies, notably Noteby and NGI, represented the expanding recognition of hydrogeology as an important earth science.

The historical background for hydrogeology in Norway

A brief introduction

To understand the history of hydrogeology in Norway, a brief introduction to the country's geology, hydrology and demography is useful. Norway is situated on the western margin of the Precambrian Fennoscandian shield. The Caledonian orogenic belt runs as a backbone through the country from the southwest to the northeast. In Permian and Carboniferous times, the region around Oslo was affected by extensional rifting and volcanism. Therefore, practically all of the country is underlain by igneous, metasedimentary or metamorphic bedrock.

Only very small residues of Mesozoic and Tertiary rocks are preserved above the sea level in Norway today. However, some geologists believe that deep, subtropical weathering processes during the Mesozoic may have been responsible for the characteristic mineralogy (e.g. swelling clays) that is observed in the largest fracture zones in the crystalline bedrock of some areas of Norway. It is the mineralogy which in turn controls the hydrogeological behavior of those zones (Olesen & Rønning 2008).

During the most recent Ice Age, which ended about 10,000 years ago, the mountains were heavily eroded and the bedrock was deeply scoured by glaciers, resulting in the deep valleys and fjords which are visible today as typical features in the Norwegian landscape. Many of Norway's large, deep lakes are also a result of the glaciers, overlying local and regional structural features in the bedrock.

The glaciers also left behind drift deposits of variable types and thickness': upland areas are mainly overlain by thin deposits of till and peat, and lower-lying areas and valley bottoms are dominated by glaciofluvial gravel, sand and alluvial sediments. Due to post-glacial uplift, which was the result of isostatic rebound, previously submerged areas along the coast and the fjords are today covered by marine silts and clays.

There has always been relatively easy access to surface water resources in Norway. Annual precipitation ranges from 250 mm in the inland rain-shadow behind the mountains to almost 4000 mm locally along the Atlantic coast. Norwegian surface waters have therefore received the main focus within water resources management, resulting in comparatively less interest in obtaining new knowledge and developing new technology related to groundwater resources. However, in the occasional cases when surface water quality is an issue, the inherent advantages of using groundwater come to light.

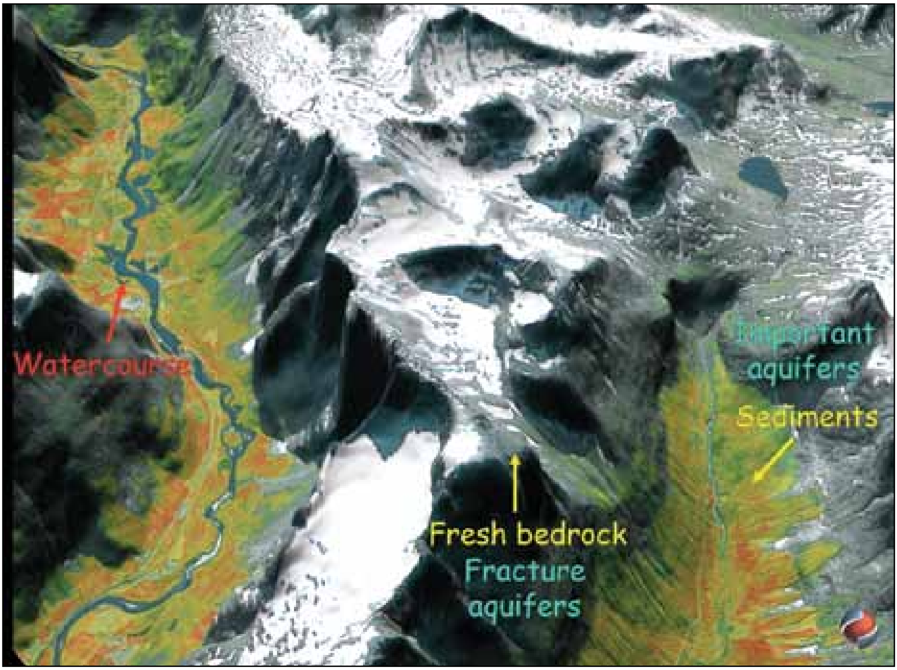

Figure 1. Groundwater sources in Norway.

When people first settled in Norway after the Ice Age, they lived by hunting and fishing, before gradually starting to keep livestock and cultivate the land. The first farms came into existence from about 500 B.C. Arable land was sparse in rural areas and farms were widely spread in the countryside. Traditionally, each farm had their private water supply from a brook, spring or shallow dug well. Towns and cities were usually fed by water from a lake or a river.

Peoples, myths and legends

Historically, Norway has been inhabited by several groups of peoples. The Sami (or Lapps) are usually considered to be the oldest indigenous people of Scandinavia and northern Russia, speaking a language of the Finno-Ugric group. The Northmen (also called Norsemen or Vikings), on the other hand, represent a northern Germanic branch of the Indo-European linguistic/cultural group that probably ultimately had its origins in the Near East or Central Asia. For many families, daily life was a struggle. It was a constant challenge combating the harsh northern climate while trying to provide enough food, water and shelter.

To make sense of their natural surroundings, the ancestors of the Northmen turned to their mythology. Lightning was explained as originating from the mighty god Thor's thunder-hammer called Mjølner. In Norse mythology groundwater springs were essential for life. The roots of the Norse "tree of life" Yggdrasil", it was said, reached down to three subterranean wells – the Hvergelmer spring (the source of all rivers), Mimur's spring (a source of wisdom and creativity) and Urd's spring (the southernmost well, with warm waters). As in many other parts of the world, springs were given religious significance and their waters were believed to have healing powers. In Norse mythology, many springs were dedicated to Thor, also recognized as the god of rain and the protector of peasants, farmland and fertility.

When the Viking King Olav ("the Saint") forced Christianity upon his subjects in the early part of the 11th Century, as a smart trick the springs of Thor were converted to Saint Olav's springs, while maintaining their alleged healing powers. Today these springs can still be found in several places, including at the Nidaros Cathedral in Trondheim where King Olav is buried.

The Link between Hygiene and Health

The latter part of the 19th Century is recognized throughout Europe as the time when the link began to be made between hygienic living conditions, drinking water quality, sanitation and health. In around 1854, John Snow (1813-1858) connected occurrences of cholera to drinking water supplies in London. By 1882, this awareness had permeated into Norwegian literature, with Henrik Ibsen's play "En Folkefiende" (*An Enemy of the People*). In the play, the hero (or anti-hero, depending on your viewpoint), Dr. Stockmann, discovers that the springs feeding the town's tourist baths have become contaminated with industrial waste from a local tannery, stating at on point: *"All this filth up in Mølledalen – all of it, stinking to high heaven – it's contaminating the pipes leading to the well-house, and same poisonous muck is seeping out on the beach, too ...!"* Dr. Stockman became an environmental activist, antagonizing local businessmen, politicians and the press, and finally reaped the community's retribution.

The modern Nordic influence

The modern years of hydrogeology in Norway were dominated by the first water well drillers. Well drilling in Europe was a common occurrence in the middle of the 19th century. By 1890, when Norway was still part of a political Union with Sweden, the Swedish Diamond Bedrock Drilling Company AB drilled most of the wells in Norway, Sweden and Finland. Much of the early work in Norway was inspired by the work of Swedish geologists who drilled exploration wells in bedrock along the coasts of Sweden and Finland in the 1890's as a part of ore exploration near Arkø, Sweden.

In early exploration drilling, it was natural to encounter groundwater at various depths, all shallow by today's standards. One well drilled in granite/gneiss to the depth of 35 meters gave 450 liters per hour of clear, potable water. It was reported that none of the other wells were drilled deeper than 30 m, but all gave good results. Based on these data, it was concluded that it was not necessary to drill deeper than 30 meters because it was at this depth the water amassed which had infiltrated through the fractured bedrock. Everywhere in Sweden and Finland where drilling occurred at the time, water was encountered at a constant depth, slightly over 30 meters, with a production capacity of between 200 and 2000 liters per hour. In retrospect, the fractures encountered at these depths were probably relatively open horizontal "stress release" fractures near the surface.

Influenced by the Swedish geologists, the Norwegian Geological Survey of Norway (NGU) began drilling water wells for a number of fishing communities in northern Norway. All of the wells were drilled to between 30 and 45 meters and gave good results, with the exception of one well outside of Henningsvær that produced saltwater. Around this time it was recognized that water-bearing fractures could be found deeper than the 30 m assumed by the Swedes to be the lower limit for productive wells. These fractures were observed in mountainous terrain and folded bedrock (Helland, 1898).

Helland's background as a geologist led him to begin performing measurements at the turn of the twentieth century to find out how much water could be produced from a number of Norwegian rock type masses. His results showed that in Norway granite yielded 4-9 liters per m^3, Kolsås sandstone yielded 30 liters per m^3, Grip/Vardø sandstone yielded 10-21 liters per m^3, Dønna gneiss yielded 15 liters per m^3, Tonsåsen syenite yielded 23 liter per m^3, and Stamsund syenitt yielded 4.4 liter per m^3. Helland also looked to Sweden where he found that Bokedal gneiss produced 1.4 liters per m^3. These determinations should probably be interpreted as estimates of specific yield of between 0.1 to 3%. This was the first study in Norway which correlated rock types and groundwater resources.

The Swedish Diamond Bedrock Drilling Company AB, represented by Backe and Bonnevie in the Norwegian capital Kristiania (renamed Oslo in 1925), had a monopoly on the drilling market until 1920 and remained active in Norway until the late 1950's. In their 1916 brochure written after twenty years of well drilling in Sweden and Norway, the company stated, *"The wells we drill in bedrock have a 90% chance of giving more than 100 liters/hour. Only 2% of all bedrock wells have been considered dry wells!"* (This is effectively the "non-parametric statistical" approach favored by recent Scandinavian hydrogeologists working in hard-rock terrain, and the yield associated with the 90% success rate is remarkably consistent with today's estimates (Banks et al. 2005)). The company advised to drill to 60 meters. *"If the well is dry, the drilling rig should be moved 30 m to the side and you will most certainly find water"*, it was stated. At the time a new saying began to emerge in the water well drilling business: *"The amount of water produced from bedrock wells can be roughly estimated, but not precisely calculated."*

Concerning the occurrence of groundwater in sediments, one geologist wrote in the early 1920's that he doubted there were any places in Norway with enough gravel and sand accumulations similar to Finland and Sweden that would produce enough water for whole cities (Rekstad, 1922). The conclusion was based upon observations from the first large groundwater extracting operation in Åbo, Finland in 1916. This operation yielded 32 liters per second. This observation must be seen in the light of that period's assumption that groundwater was recharged from precipitation: an awareness of the possibilities that induced infiltration from surface water could offer did not dawn until the 1950's.

By 1940, sentiments about finding groundwater in sediments had changed. It was reported by NGU that in the Norwegian countryside where the bedrock was covered by sediment, "it was possible to find water for small enterprises – a small farm or a little settlement – even though Norwegian geology offers little ground water". The most common types of wells were those dug in saturated sand/gravel or so-called "flåbrønner" designed to store water within less permeable material. These wells collected mostly surface water and precipitation which fell directly in the well; groundwater comprised only a small portion of the well water due to the surrounding less permeable material. The construction of deep wells with the help of cement rings or stones was an advanced engineering feat not without danger. In Kvam, a 37 m deep stone well with a pumping chamber was constructed to supply water to a soapstone mill! This piece of well drilling history has regrettably been destroyed.

Norwegian expertise takes over

The first Norwegian firm which started with well drilling was the Norwegian Diamond Drilling Company (NDDC) around 1912. This firm had earlier drilled after minerals for the Norwegian Government until the Government bought their own diamond-drilling machine and began their own drilling program. NDDC used a German produced Urbanik drilling rig which required two men for taking 4 inch continuous cores. (Interestingly enough, it was an American who trained Norwegians in the use of the Urbanik.) This method drilled from 1.5 to 3 m per day, removing 100 mm cores ranging from 1 to 1.3 m.

After the German invasion on April 9, 1940, Norway was under military occupation and civil rule of a German commissioner in collaboration with a pro-German puppet government. In these war years, NDDC was forced to begin drilling wells for the German invaders. The forced enlistment of the NDDC drilling rig by the Germans was possible because of a complicated personal situation in the family of the rig's owner. The owner's daughter was married to an Englishman who was able to maintain his freedom only as long as the rig drilled wells for the Germans! The owner, however, probably did not lose too much sleep over unsuccessful water wells. This difficult situation continued until the occupation ended May 8, 1945 after the capitulation of German forces in Europe.

Memory of the German occupation lingers long in Norwegian consciousness, but it is likely that German scientists and engineers introduced a number of highly innovative techniques during the wartime period. Indeed, one of the earliest applications of Leo Casagrande's large-scale electro-osmotic soil dewatering and stabilization was carried out during the construction of the massive U-boat base (The *Dora* Complex in Nyhavna) in Trondheim, using 40 V and 20-30 A per well (Rasmussen & Haigler 1953).

After World War II, there was disagreement in NDDC from 1945 to 1946 about whether they should continue with the Urbanik or switch to cable-tool-percussion. As a result, an employee formed the new company O. Jansen Machine and Well Drilling. By 1950 a number of new drilling firms had also established themselves in Norway. Diamond drilling equipment, which until that time was the dominant drilling technique, was replaced by cable-tool-percussion methods. This new method could drill up to 6 m per day. These machines dominated the Norwegian market for water well drilling during the 1950's and 1960's, drilling faster than the older machines and requiring only one man to do the drilling.

Drilling with cable-tool-percussion was performed using a chisel and drilling rod. The rod weighed 300-400 kg and was lifted up and released 30 to 60 times per minute, dependant upon the adjustable lifting distance. The crushed material was removed from the borehole with a dart valve bailer. There was no difference in the techniques used in drilling in loose sediments contra bedrock. Drilled wells at this time were test pumped for 48 hours.

Figure 2. Cable-tool-percussion drilling.

Drilling with cable-tool-percussion was, however, very difficult and physically demanding work. Especially when drilling in bedrock the chisel needed to often be repaired. With its 10 m high drilling tower and heavy rod, dangerous situations sometimes did occur. Occasionally, the drilling rig even tipped over; in some rare cases, workers were injured or killed.

The hydraulic top hammer was used by a number of well drillers, before it was replaced by drilling rigs using pneumatic down-the-hole (DTH) hammers in the early 70's. The hydraulic top hammer wells were notoriously crooked and seldom drilled deeper than 60 m. The DTH drilling rigs could drill to greater depths than previously possible. The drilling capacity with these new rigs resulted in a ten-fold increase in drilling and started a new revolution within the well drilling industry.

By the middle of the 1970's the ODEX drilling machine was introduced into the Norwegian market. ODEX equipment enabled the drilling and casing of deep holes simultaneously in all types of formation, even those with large boulders. The method is based on a pilot bit and eccentric reamer, which together drill a hole slightly larger than the external diameter of the casing tube. This enables the casing tube to follow the drill bit down the hole.

The first compressed air machines were foreign made, but in 1976 the first Norwegian product NEMEK (Nestetog-mekaniske) from Vinje in Telemark was introduced. This machine has since dominated the Norwegian market. The NEMEK machines had their own diesel engines, but much of the equipment still needed to be connected to an air compressor.

New developments improved the capabilities of the well drillers. Directional drilling gave the driller the ability to rotate from vertical to horizontal wells. To increase the water production in a well, controlled explosion, an old and accepted method, was also used. This method was replaced over the years by hydraulic fracturing which involved injecting water, at extremely high pressure, through a packer. Eventually, the water pressure becomes so great that it exceeds in-situ gravitational and tectonic stresses, and the tensile strength of the rock, and it literally "cracks" the rock, producing a new fracture (or, at the very least, opening up an existing fracture). Hopefully, the new fracture will connect into a wider, water-bearing, fracture network, enhancing the yield of the well.

With the increasing demands on well drilling, there was also a movement to establish a certification of well drilling during the 1980's. This led to a voluntary certification of well drillers with the intention of maintaining a certain standard for rendered services. The movement was coordinated by a Well Drilling Committee (WDC), a subcommittee of the Water Resources Committee in Norway at the time. The WDC had numerous representatives: one (the leader) came from the Norwegian Institute of Public Health, one from the Norwegian Municipal Alliance, one from Ramnes Municipality, and one from the Ministry of the Environment. Apart from the raising of standards for well drilling, WDC's work also contributed to the consolidation of well drillers in Norway.

Next: The new science of hydrogeology