The management of drinking water in Trondheim from 950 to 1777 as a source for attitudes towards health

"Healthy citizens are the greatest asset any country can have."

Winston S. Churchill

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Abstract

This article aims to illuminate how the management of drinking water and public health in Trondheim changed in the years from 950 to 1777, from a private to public responsibility. A systematic analysis of five excavations in Trondheim shows that during the Middle Ages only a few citizens had a well or a cistern on their property. This suggests that fetching water from above-ground sources was the regular practice. In the post-medieval period this changed, as the number of wells increased. However, the well water got polluted, and alternative water sources was too far away for the rising population. 18th century political ideas emphasized how the citizens were now the greatest resource of a state, which prompted new mentalities on how authorities now had to take care of the people. In 1777 the public authorities of Trondheim finally established a public water pipe system, ensuring clean water to its citizens.

Keywords:

Drinking water, health, medieval, early modern, Trondheim

Introduction

The access to and quality of drinking water are crucial to the health of people. Drinking water as a source of contagion has been a challenge for centuries. Its effect on public health, especially in urban areas, defined daily practices and lifestyles. Studies on public health tend to have an emphasis (in Norway) on political events from the second half of the 16th century, when public health management emerges, and these studies are mainly based on historical sources (Moseng, 2003; Schiøtz, 2017). The Middle Ages have been notoriously ignored. Consequently, there are few studies and there is a lack of archaeological sources to nuance the research.

The traditional view is that collective management of the urban environment was lacking before the 18th century, resulting in the popular notion that medieval towns were places of dirt, filth, and disease. In *Roads to Health*, Guy Geltner (2019) discusses the health infrastructure in late medieval Italian towns. He demonstrates that both the physical and legal infrastructure which aimed at taking good care of the citizens' living conditions were well developed from the 13th century onwards. This corresponds with Isla Fay's (2015), Carole Rawcliffe´s (2013), and Dolly Jørgensen's (2010) research on medieval urban health in England, pointing to the fact that late medieval local officials of English towns spent many resources and much effort in creating functioning sanitary systems and devices in the urban landscape, to ensure the common good. While these historians do not neglect archaeology, the main sources are primarily textual. In relation to his statement above, Geltner argues that the history of public health is best studied from a multi- and interdisciplinary approach and that archaeology should be an integral part of innovative research (Geltner, 2012).

In Norway, few archaeological studies are available on the water management of medieval towns. Bård Økland (1998) made a thorough study of the waste and water management of medieval Bergen, and Hege Johansen followed up with a study of medieval wells in the same town (2013). Erik Schia presented the current (1995) archaeological finds of wells and water pipes leading water into medieval Oslo, making way for comparisons of great potential.

Figure 1: Trondheim is a coastal city in central Norway, and in the Middle Ages, from 1153 to 1537, it was a metropolitan archdiocese.

By studying water supply and management in a medieval town, we can explore how people managed their surroundings which had an impact on medieval urban water quality, and, by extension, medieval urban health. Archaeology gives a unique insight into the physical installations keeping the drinking water clean or contributing to its pollution, illuminating issues rarely approached in the written records. Trondheim, a town on the outskirts of Europe in the Middle Ages (1030-1537[1]) and early modern times (1537-1800), offers a range of excavation documentation that provides valuable evidence. *Urban-like* features have existed in Trondheim since the second half of the 10th century (Sæhle, 2018), with an estimated population of about 250. The town population grew to 1500 in the 12th century, just above 2500 in the 13th century and around 3000 in the 14th century, often called the *medieval maximum*. During the 14th century, the spectacular growth stopped – Trondheim was hit hard

by climate deterioration and the Black Death. At the end of the 15th century, 1250 people lived in the city. Only in the second half of the 16th century the numbers started increasing again (Christophersen, 2020, 178), and is thought to have reached the medieval maximum again first in the mid-17th century. The population increases fast, and in 1801, there are about 9000 inhabitants in Trondheim (McLees, 2019, 127, 130). The first public water supply system in Trondheim, a piped water system, was constructed in 1777 (Christiansen, 1987, 70). As this invention is the ultimate evidence of a radical change in public health management, this study uses a long-term perceptive studying Trondheim from ca. 950–1777 to explore what changes of practice lay behind this.

Lately, a great deal of the archaeological documentation in Trondheim has been digitized, and much has recently been published in an archaeological monograph (Christophersen, 2020). No studies of water management exist for Trondheim, and new studies are needed to understand the development of water management there and place it into a broader perspective.

The overall aim of this paper is to explore how daily practices, experiences, and governance eventually led to a change in mentality from health being a private to a public responsibility. From where did the inhabitants of Trondheim in the Middle Ages and early modern period draw their drinking water? Can the physical water installations say something of their private or public nature, or reveal something of social differentiation? How can changes be explored in terms of material, competence, and meaning taken from social practice theory (Shove et al., 2012)? And is the water supply of Trondheim unique in the European or Norwegian context?

Five archaeological sites have been selected, four are in the town centre and the fifth excavation is at the Archbishop's Palace and offers access to a high-status habitation area. After a short introduction on method and social practice theory, we will focus on the results from the archaeological analysis. We will put the results into a broader context in the discussion paragraph and finally compare our results with towns in Western Europe in general, and with Bergen and Oslo in particular.

Methodological considerations

To explore the research questions, we are studying the extensive archaeological material of medieval and early modern Trondheim, with a focus on wells and cisterns. Documentation from the chosen excavations consists of drawings (plan and section drawings), daily reports, end-reports, publications of the excavations, and photographs. From these sources, data on

location, construction measures, construction differences etc. was extracted, providing information about the different water management inventions.

Historical sources and georeferenced historical maps were used together with the archaeological data to better understand location in time and space and to explore possible explanations to the research questions.

Trondheim was regularly damaged or destroyed by fires, and the devastating fire of 1681 inspired the rebuilding of the whole town. General Caspar von Cicignon from Luxembourg oversaw the great rebuilding project, and the new baroque plan[2] erased most of the medieval traits (Stang, 1981, 45-46). This great change makes it necessary to compare archaeological evidence with georeferenced historical maps from both before and after the 1681 fire. Post-Reformation archaeological constructions often have a rough dating (e.g., 1600-1800), and for a spatial analysis, it is necessary to consider the different possible physical spaces during this time span. Historical maps before and after 1681 were analysed together with the archaeological documentation to explore their possible location in the townscape.

Identifying patterns of material organization and the development of interventions in the townscape were partly done by visualization in maps (using ArcMap), and by sorting and analyzing information. The archaeological data was sorted in a Microsoft Access database, georeferenced, and presented through maps, graphs, and tables.

Social practice theory

The archaeological remains and testimonies in written sources can be considered as discarded practices, fossilized behaviour. Practices that are no longer in use. They are the physical material in a broken equation of practice, an equation consisting of the key concepts material, competence, and meaning, as suggested by Shove et. al. in their understanding of Social Practice Theory (SPT) (Shove et al., 2012, 35). By applying the key concepts, we were able to explore social practice patterns and interventions of water management in Trondheim. This enlightened how individual responsibility for water management was transferred to the public sphere and accepted as a public responsibility, leading to improved public health in the town. In our search for why certain water management practices were around, and why they are not anymore, it was helpful to use the known element (material) of the equation to explore the other two elements of the equation: meaning and competence. Suggestions of these could lie in the material, but they were not immediately clear, and needed a thorough analysis to be brought to light and interpreted.

SPT focuses on the interactions between the three elements of practice: material, competence (knowledge), and meaning (intention). Material can be the physical material, such as wood and iron, but can also be money, economy, climate, and the physical environment. Competence can be understood as "practical knowledgeability" and meaning can be explained as the peoples' intentions behind their actions and their practices. This is based on their worldview, their perception of their surroundings, their mentality (Shove et al., 2012, 23). Their intentions might not every time proceed as planned, and there can be unintended consequences. The elements are all affecting each other in the making of practices. Without them, the practice will not come to life, and if one of the elements disappears, the practice will end. When a practice ends, the elements may be discarded and forgotten, or get a new kind of life in the new practices, or lie dormant (knowledge) until its usefulness is restored somehow (Shove et al., 2012, 35).

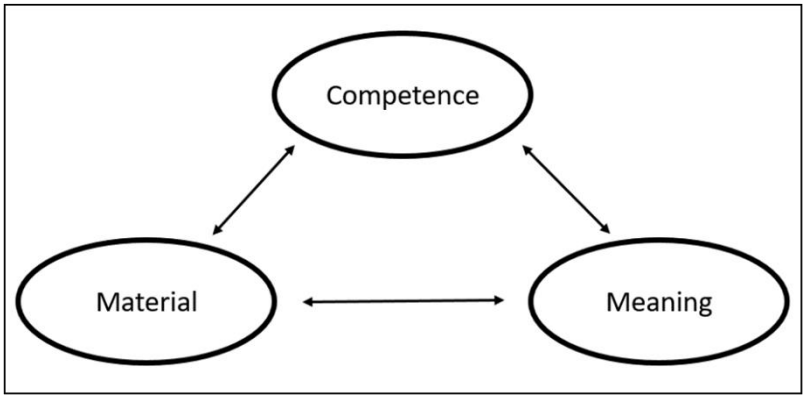

Figure 2: The elements that make practice, based on Shove et.al. (2012, 32).

The elements are dependent upon each other, and a change in one will lead to a changed or discarded practice. A typical explanation of change in the past (and it is often very plausible) is that new knowledge is introduced. For example, the threat of infected water must have been well known through an infinite mass of bad experiences in the Middle Ages. When the knowledge of miasmas was introduced (sickness connected to corrupted air or water, often evident by its bad smell) (Schiøtz, 2017, 64), possibly in the high or late middle ages (Bergqvist, 2013, 343), this would affect the management of infected water. Of course, there was a need for the right material and the meaning to be in place to get the new practice going, but it is often the new knowledge that kickstarts the process.

Archaeological and historical sources

The river Nidelva runs through Trondheim and encloses the Trondheim peninsula. It has not been thoroughly studied as a source for drinking water in different periods, but the section of the river that surrounds the town is often assumed to be undrinkable because of its proximity to saltwater (Berglund, 2007, 48). The part of it around the Nidarnes peninsula is affected by freshwater from further up the river and saltwater from the fiord. At high tide, the river will have saltwater at the bottom with freshwater on top, and at low tide it will consist mainly of freshwater, periodically with brackish zones. Freshwater weighs less than saltwater and will float on top of it (Arnekleiv et al., 2007, 111). Parts of Nidelva would have been drinkable, periodically, but the river would also have been a place for washing, production of goods, and a place to throw waste. A decree from 1313 issued by Håkon V forbade the people of Trondheim to throw waste in the river (Munch et al., 1849, 102-105; Petersen, 2018, 72), which implies that this must have been a common practice. It is reasonable to conclude, assuming the river behaved much the same then as now, that the Nidelva would have been an unreliable source of drinking water, leaving the people of Trondheim to find their supply of drinking water somewhere else.

Figure 3: This map shows the city centre of Trondheim, the river Nidelva, and the three possible drinking water streams. The palisade around the city that is shown in this map was never built, except for the western section by the main road. ©Kartverket (Pufendorf, 1658), edited by Elisabeth Forrestad Swensen.

The Pufendorf[3] map (1658), which is the oldest map of Trondheim, shows three streams close to the peninsula: Ilabekken, Singsakerbekken, and an unnamed stream. Only Ilabekken is visible above ground today. From the marketplace (today known as Torget), in the middle of the town, the distance to Ilabekken is roughly 2 km walking distance, following the road drawn on the Pufendorf map. Singsakerbekken in the south is accessible via a medieval bridge over the Nidelva and lies about 1.1 km away from the marketplace, and the north-eastern stream is about 2.1 km walking distance. The bridge still exists (Elgeseter bro) although it has been rebuilt several times, and when the water is clear you can still spot the wooden remains

of the medieval bridge close to the new one. Historically it is known that people put water in barrels or carried it in buckets from Ila, and at Bakklandet (to the east of the Nidelva) people got their water from the spring of St. Olav (Christiansen, 1987, 69-70). A newspaper from 1949 also talks of a variety of streams that ran through Trondheim in the 18th century, and we conclude that many of these would have existed in the Middle Ages as well (Todal, 1949).

Excavation name/popular name	**English translation if possible**	**Address**	**Site size (m^2)**	**Excavation ID**
Telegrafstasjonen/ Løveapoteket	The Telegraph Station/ The Lion Pharmacy excavation	Kongens gate 6	2022	1937/45, 1937/228, 1939/229, 1941/48
Brannstasjonen	The Fire Station	Søndre gate 1-3	1118	1943/45, 1945/67, 1946-47/68
Søndre gate -71	South street	Søndre gate 4/5	545	1971/1
Folkebiblioteket	The Library Site	Kjøpmannsgata 20-26	3175	1973/1
Erkebispegården	The Archbishop's Palace	Kongsgårdsgata 1B	2123	1991/1

Table 1 Names and identification of the different excavations chosen. Their popular names are often referred to in other publications. All known names and IDs are mentioned here. Site size is measured out of site outline in ArcMap.

Five excavation sites have been chosen for this study of medieval and post-medieval drinking water constructions, a choice based partly on the existence of wells and cisterns, the availability of documentation, and partly on location. Several of the sites show human activity already from the late Viking Age. The oldest sites (excavated before the 1950s) revealed several wells, but the results of these early excavations are challenging since the wells have not been dated. The excavations were also based on different archaeological traditions and practices. However, comments from the excavation leaders in reports, knowledge on stratigraphy and the towns development made it possible to date even some of these to a roughly medieval or post-medieval period. The older excavations do provide useful information on construction techniques and locations and serve as the basis for interesting interpretations. All excavations in the medieval town of Trondheim are rescue excavations.

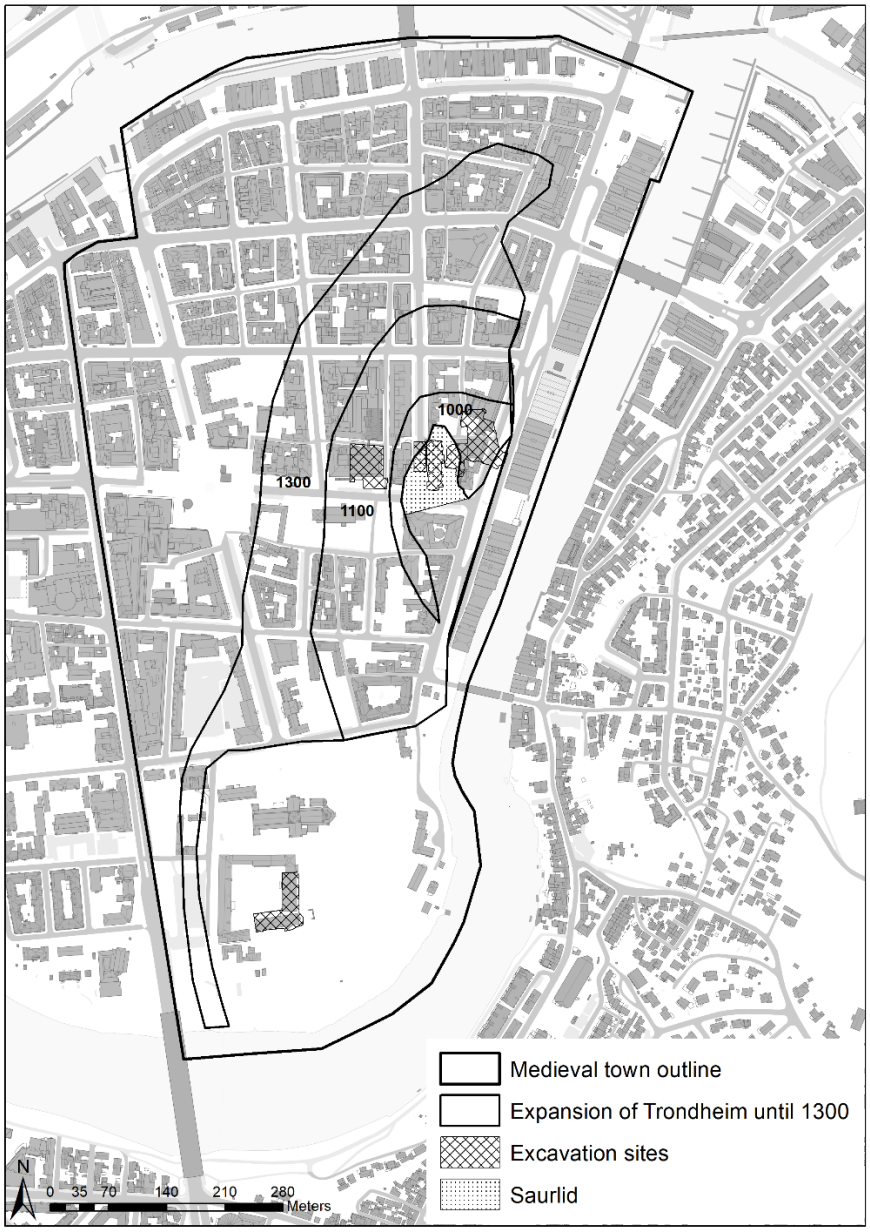

Figure 4: The map shows the expansion of the medieval town until 1300, based on Christophersen (2020, 171) and our excavations, including in the Saurlid area. (This area was before 950 partly a harbour, but post-glacial rebound dried it up. The townspeople began throwing waste into the marshy area and reclaimed it as building land (Christophersen 2020, 222–224)). The outer border shows the protected medieval town.

More recent excavations have many dated structures, but the post-medieval layers are under-represented. Archaeologists were limited by the goal to uphold the Cultural Heritage Act protecting only the finds older than 1537 (the year of the Reformation in Norway), leaving younger layers to be removed by the mechanical excavators (Lovdata, 2018). Because of this,

post-medieval shallow constructions such as cisterns and conduits are most likely under-represented in our material.

Figure 5: Presentation of the chosen excavations in Trondheim and their relevant constructions. Illustration by Elisabeth Forrestad Swensen.

The written documentation (diaries and reports) concerning the selected excavations is abundant after 1970, but before this it is limited. However, field drawings of constructions are a great source of information from the old excavations. The drawings were a collaboration between architects and excavations leaders, and thus very precise and neatly made. Photographic documentation is often of good quality, but hard to find. From the seventies there was often a dedicated photographer documenting many sites at the same time, resulting in pictures of very good quality.

Could there have been a significant number of drinking water installations not found in the archaeologically material (yet)? The whole of medieval Trondheim is not excavated, and wells could also have been located outside town centre. One piece of evidence may support this idea: a copper engraving of Trondheim made by Jacob Maschius in 1674 (see figure 6). On this engraving we have identified several possible shadoofs (well sweeps, a crane-like apparatus with a lever mechanism) behind the town buildings, just outside the town centre. Were such constructions too big to construct elsewhere? The shadoofs could point to an older tradition of establishing wells in the outskirts of the town, or the engraving could be another trait showing the increase of wells in the 17th century. On the other hand, our sites cover 8983 m^2 (see Table 1), representing more than 5% of the medieval town (Christophersen, 1992, 15), a gathering of excavations with plentiful available documentation. The excavations chosen for this paper offer a timespan, ca. 900-1800, worthy of the task, and cover different social groups. The medieval town of Trondheim was initially a place where people came to do trade and business. As they settled and created an urban environment, Trondheim became a home for all different kinds of people. The plots excavated in Kjøpmannsgata have been interpreted as a high-status area, such as a merchants' area, a place of business (Christophersen & Nordeide, 1994, 16). The name of the street, Kaupmannastretet or Kjøpmannsgata, both in the Middle Ages and today, means the merchants' street. In the 17th century, historical sources talk of the owners of these plots being mayors, landowners, officials, and the like. There are also indications that the town had a geographical divide based on professions and economy in the late Middle Ages (Christophersen & Nordeide, 1994, 16). The social status of the other sites, at least from the 17th century, seems to be much lower - they belong to an area where common people and the poor lived (Stang, 1981, 63-64). Residents of the Archbishop's Palace speak for themselves, they were even higher on the list of rich and influential than those who lived in Kjøpmannsgata. We conclude that the sites are representative of medieval and early modern Trondheim.

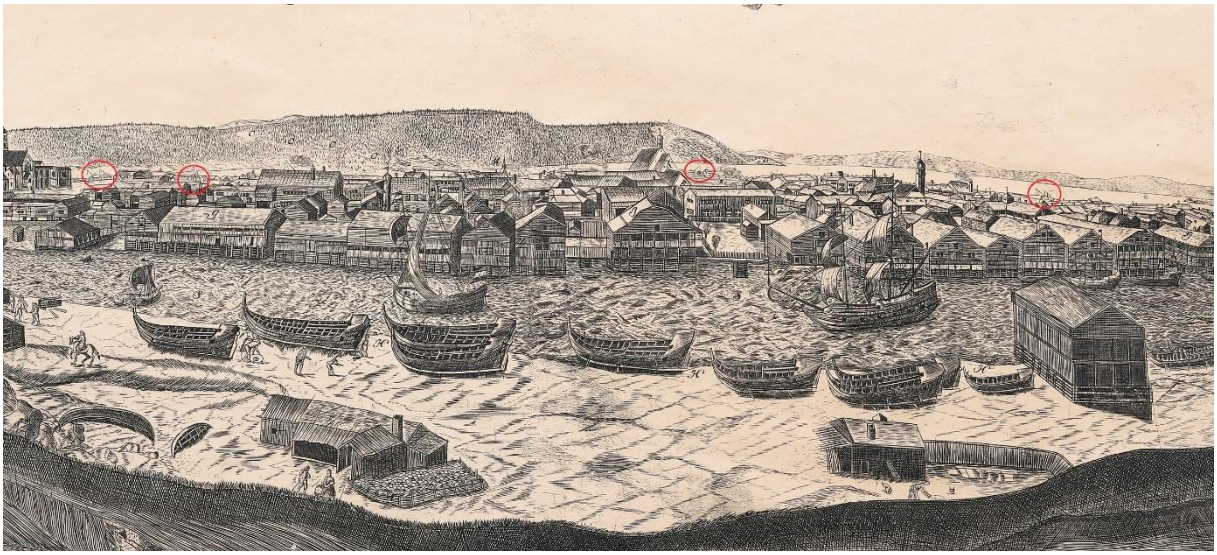

Figure 6: A scanned photocopy of the print by Jacob Maschius from 1674. Possible shadoofs are marked in red. Photo: Sverresborg Folkemuseum, edited by Elisabeth Forrestad Swensen.

Presenting the material

Wells

A well makes groundwater available for people. A pit is dug to reach this water, and sometimes a well shaft is inserted into it so the sides will not collapse. Groundwater is rainwater that has infiltrated the ground. From there it seeks to be reunited with the ocean (Frengstad & Dagestad, 2008, 137) through the path of least resistance. This means that if you dig into the groundwater level, the water will flow into the hole (Frengstad, 2021), and you have yourself a spring or the possibility of a well. Water will then either be brought to the surface by a pump, or by lowering a bucket. The typical Norwegian medieval well, in various constructions, is wood-lined, and the water was reached with buckets. There are some possible evidence of shadoofs from the early modern period, as earlier mentioned, in the map from 1674.

All uncovered wells are wood lined with the lining square to slightly rectangular shaped. They range from small (longest side 0.8-1.1 m) to large (2.5-3.5 m) (Table 2). Size may be an indication of their public or private function, as a public well could have been larger than a private one. The construction types are varied, but most are either corner-jointed, post-and-plank, or dovetail joint. Two wells were a combination of two construction types, one consisting of two different corner-joint techniques on top of each other and the other had a

combination of post and plank and corner-joint. Only four wells are medieval, 22 are post-medieval, five are undated.

Figure 7: Corner jointed (laft), post-and-plank and stave technique medieval wells side by side. Found at the Gullskoen excavation site in Bergen in 1972. © University Museum of Bergen.

Figure 8: Dovetail joint exemplified in a building from Rendalen in Norway. Photo: Per Hvamstad/Anno Musea i Nord-Østerdalen.

Many were not fully excavated for various reasons, and the depth is rarely mentioned in the archaeological documentation. The depth measured would also have been preserved depth,

not the original depth from historical ground level to the bottom, as the top parts of the wells have been disturbed by stratigraphically younger layers. Where noted, however, we find that five wells were fully excavated and documented to reach the sterile ground (the bottom of the well), and the depths range from 3.2 to 4.5 metres.

Table 2 The measures of wells and cisterns, based on the longest side, possibly indicating a public or private function.

Size	Measure (longest side), m
s (small)	0.8-1.1
m (medium)	1.1-2.5
l (large)	2.5-3.5

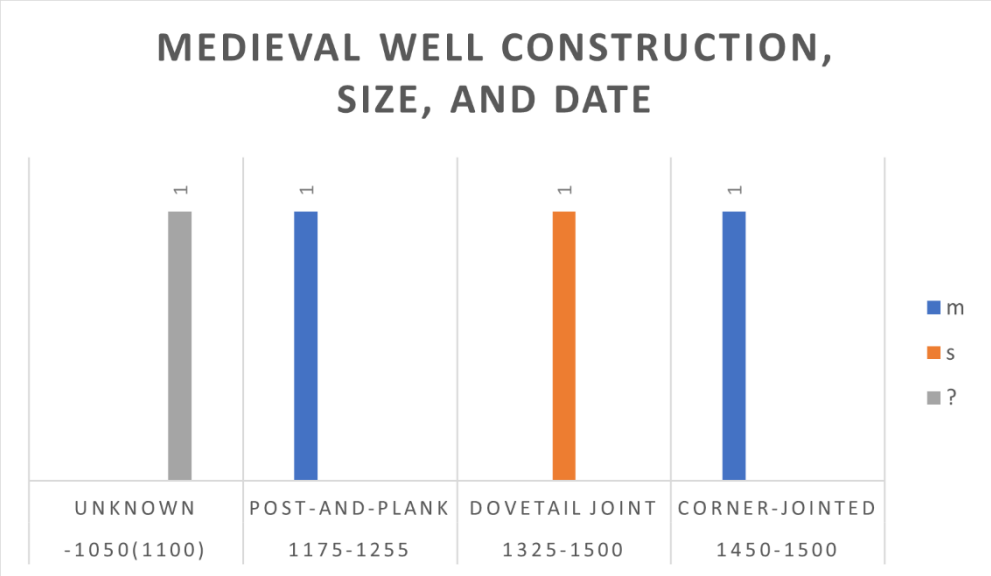

Figure 9: Size and construction of medieval wells. Illustration by Elisabeth F. Swensen.

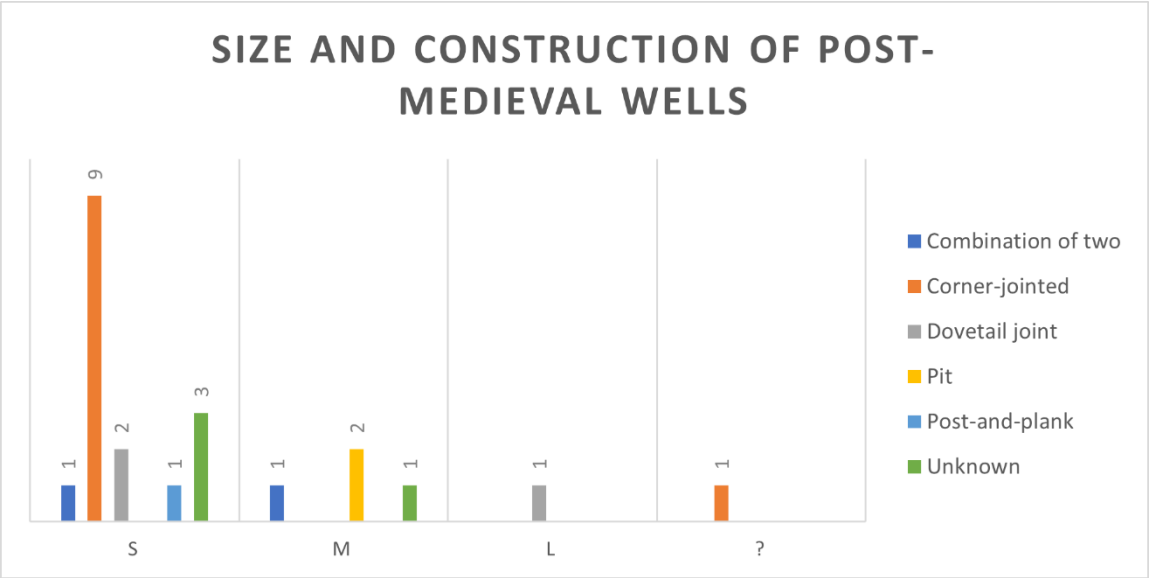

Figure 10: Size and construction of post-mediveal wells. Illustration by Elisabeth F. Swensen.

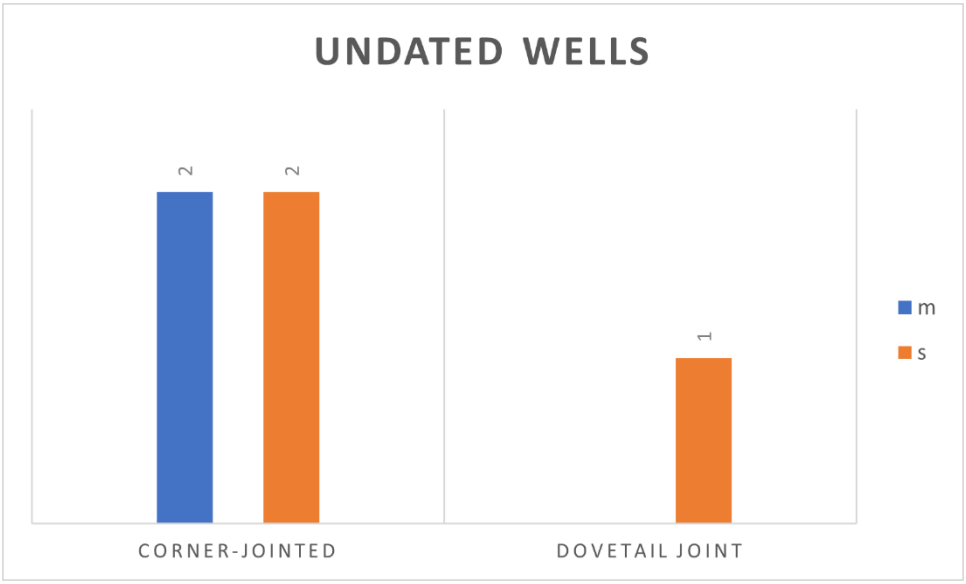

Figure 11: Size and construction of undated wells. Illustration by Elisabeth F. Swensen.

Locations are important because it may indicate private or public functions. It can also suggest wether the construction relates to a possible contagiuos environment, such as waste pits and latrines. Private location is defined by private property, for example in a cellar or far back on the property. A possible public function is defined by location in an area avaliable for more people, as in a street, or close to a street on private property. Undated wells are hard to locate in relation to other constructions as we do not know which they are contemporary with.

Table 3 Location of wells indicating public or private function, and their relation to contagious environments

Date	Private location	Public location	Uncertain location	Close to waste pit or latrine	Later used as waste pit
Medieval	2	1	1		
Post-Medieval	6	2	14	2	3
Undated			5		

Cisterns

A cistern is generally understood as a container to store water in. This could be rainwater (from a roof), water brought there by a channel from a water source of some kind, or perhaps also water brought in buckets. What distinguishes a cistern from a well is that the cistern will often have a (wood) bottom, and/or an intake for water. Surrounding water is not supposed to enter the container, only the intake (or the roof) provides water.

All seven uncovered cisterns in the data set have a square or circular wood lining. They range from 0.8 m to 3.5 m, longest side measured. Their construction techniques include the corner joint, the post-and-plank, a barrel-lined pit, and a barrel-lined pit with a corner jointed wooden case (figure 13). Only two of the cisterns found, the ones from Kongsgårdsgata 1b, are named cisterns (because of their feeder channels) in the reports, and both are from the early 16th century. All the others are older and four are found at Kjøpmannsgata 20-26, and one at Kongens gate 6. These are argued to be cisterns because of their location and construction, and the possibilities of water coming from somewhere else than the ground (Christophersen & Nordeide, 1994, 152).

Figure 12: Cistern 119 at the top with its feeder channel (conduit 118) at the Archbishop's Palace. © NTNU Museum of Science.

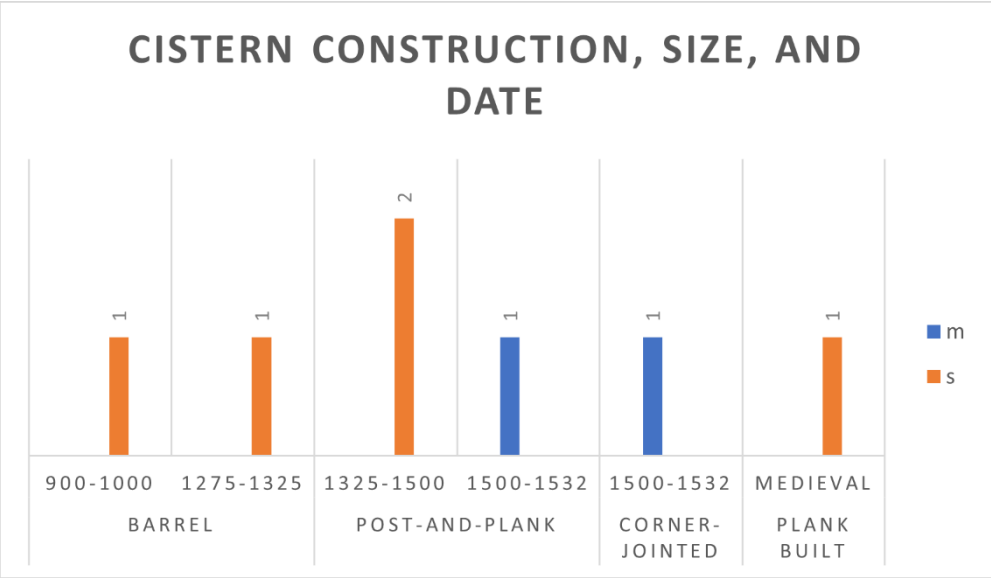

Figure 13: Cistern construction, date, and size. Illustration by Elisabeth F. Swensen.

Five of the cisterns are interpreted as private because of their location on private property. Even though on private property, two cisterns were placed a bit differently, possibly serving not only one private household, but perhaps several people in the neighborhood (on the border between properties, and close to a road).

It is important to remember that cisterns collecting rainwater from rooftops could have been above-ground features, resulting in very few (or no) archaeological remains. Finds or remains of barrels are unreliable indicators of the presence of cisterns since a barrel could have had many other functions.

Conduits

By conduit, it is here referred to a certain kind of construction of hollowed out logs cut in two lengthwise. They were *not* on top of each other to look like a pipe but were laid on the ground hollowed side up or down, several overlapping each other at the ends, forming long conduits. They were sometimes insulated with birch bark, and/or covered with planks. Similar conduits have been found in medieval Oslo, where some are interpreted as drainage/sewage pipes (Haavik & Hegdal, 2020, 66-67)). As the one conduit at Kongsgårdsgata was a feeder channel for a cistern, and this looks very much like the Oslo pipes, we have chosen to keep the mind open for possible other functions than drainage. Several undated conduit features were found at Søndre gate 1-3 but were interpreted by us (after considering the notes by Digre, the project leader at the site, often referring to them as pipes) as remains of the 1777 system, which construction is not being analysed in this paper.

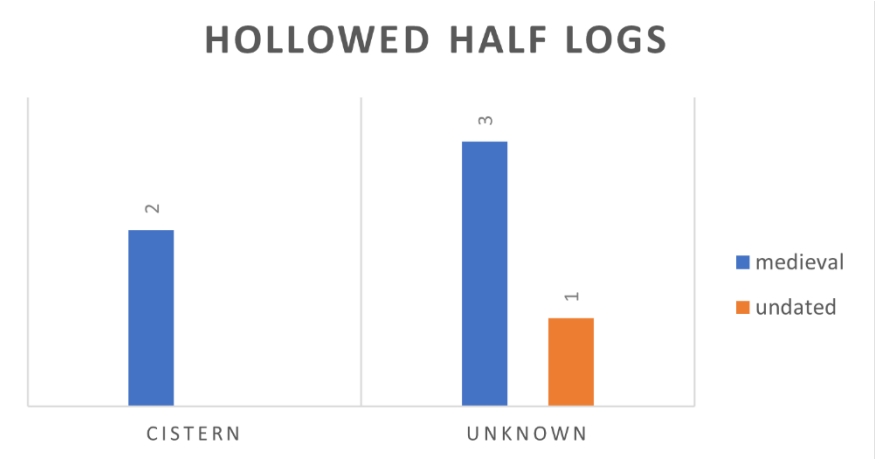

Figure 14: Hollowed half logs and their connections to other constructions. Illustration by Elisabeth F. Swensen.

Table 4 Conduits and their dates

Excavation	Feature number	Dating
Kjøpmannsgata 20-26	340	1225-1275
Kjøpmannsgata 20-26	457	1325-1500
Søndre gate 1-3	41	undated
Søndre gate 1-3	43	medieval
Søndre gate 1-3	47	medieval
Kongsgårdsgata 1B	118	1498

Discussing medieval water management (950-1500)

Throughout Norwegian history people have settled close to water – this, we dare to say, is true of most countries. Those settling in Trondheim in its early years as a small town came from the surrounding farmlands, with practices and traditions from their former homes which were close to freshwater sources. Trondheim is also close to freshwater sources, making it possible to continue such practices.

The dangers of water in the Middle Ages

Infected water was a common source for contagious diseases in Nordic and Continental towns during the Middle Ages and early modern times as well (Rosen, 1993, 102-103), and recent DNA, historical, and palaeopathological studies confirm this (Gilbert, 2021; Robb et al., 2021). When people fell sick they acted according to their competence, intentions, and material surroundings.

Robb (2021) estimated, from a study of health and welfare in medieval Cambridge (project "After the Plague"), that infectious diseases were most likely the most common cause of death in the Middle Ages. Poor sanitation and water quality would have contributed to this. At the same time, water-borne diseases are difficult to track in many scientific disciplines, such as osteology and historical sources (Robb et al., 2021, 104). Today we know that conditions of potable water and sanitation are some of the greatest sources of infectious diseases (WHO, 2021), and it was probably so in the Middle Ages as well.

This is exemplified by the results of the DNA research done on an individual from medieval Trondheim. Salmonella (in this case; salmonella entrica serovar Parathyphi C) is a disease resulting in paratyphoid fever, which can lead to death. An infection was found in the DNA of a woman, 19–24 years old, buried in Trondheim in the 13th century (Zhou et al., 2018, 2421). Recently, there have been found five[4] more possibilities of the same salmonella example in Trondheim (Gilbert, 2021). This type of salmonella spreads "through sewage contamination of food or water" (CDC, 2020).

To understand how people could be affected by contaminated water, we must understand how the water exists in a dynamic relation with humans and the environment. It is usually when the rainwater hits the ground that the greatest chance of contamination occurs. The filtration in the ground and the water's slow movement in low temperatures kills pathogenic microorganisms (at least some) and makes for hygienically safe water. However, there are still possibilities for contamination, especially from human practices. Fertilizer on fields close to the filtration areas of wells and leaks from latrines and waste pits are dangerous. The area around the wells should be protected, and the surface water should not be able to enter the wells (Frengstad & Dagestad, 2008, 140-141). A town or city provides problematic well-locations, with dense populations of people (and often animals) in close contact with waste, food, and water.

In the early days of Trondheim, it must have been easy to access clean groundwater. It would have been much cleaner than in the late Middle Ages, both because of the deep medieval cultural layers, and the population density in the late medieval period. Decomposed organic materials would be of a chemical composition (with e.g., sulphur and methane) not favourable for the human body. The groundwater could be contaminated by this if it were in direct contact with it, in channels between the layers. Hege Johansen (2013) found in her study of medieval wells in Bergen that many wells drew water from cultural layers. Her interpretation was that these wells were not used for drinking water, but for washing, firefighting, and industry (Johansen, 2013, 20). In Trondheim, this could have been a problem for well 445 dated 1325-1500, but this was one of the few documented wells to go into the sterile subsoil, avoiding the contamination problem.

A denser population[5] in the high Middle Ages would have contributed to bad water quality. None of the four medieval wells in Trondheim was placed near latrines or waste pits, but wastewater could have been a problem, also for streams in the town. Contaminated food and water, and the sickness they brought, affected daily medieval life. This being of frequent occurrence, people must have known what made them sick.

There is a good example found in Trondheim which illuminates the knowledge people had concerning the polluted drinking water. This example might be considered medieval biological warfare, as people knew that certain factors would make the water toxic and dangerous. In the 12th century, civil war raged between the Birkebeinere and the Baglere on who should be the king of Norway. In the contemporary saga of Sverre, a dead Birkebeiner was thrown into the well at Sverresborg, King Sverre's castle close to Trondheim. This man was later found archaeologically and dated to the 12th century, with household waste, latrine waste and stones thrown on top, to fully ensure the well's uselessness (Petersén, 2017, 11-12). They could have used just stones, but by using a dead man and latrine waste, they deliberately poisoned the water. However, the castle was rebuilt in the 13th century (Folkemuseum, undated) without restoring this well, which means that there must have been other sources of drinking water nearby. There is probably more to this story than has been told here, but this does not alter the fact that the well was deliberately destroyed.

This knowledge of pollution is likely achieved through a series of experiences involving water. But later in the Middle Ages this experience-based knowledge got a stronger connection to continental miasma philosophy. Seeping into Trondheim, the Galenic principles (humoral teachings) won wide acceptance, as they did elsewhere in Northern Europe. But

these ideas spread slowly. Johanna Bergqvist (2013) has studied the development of the arts of healing in Sweden and Northern Europe through the Middle Ages and the Renaissance. One of her main conclusions is that humoral teaching was not a part of the common medieval society in the early Middle Ages and that this way of understanding disease does not appear to have been widely practised until the high- or late Middle Ages (Bergqvist, 2013, 343). Increasing awareness of, for example, how the climate and water would affect health and sickness must have come to exist parallel with Christian medicine practiced in the hospitals (Schiøtz, 2017, 30-35). Until the 19th century, the ideas of miasmas and how sickness could spread were leading strategies for preventing and fighting epidemics (Schiøtz, 2017, 235). We can only assume that the practices around water management were increasingly founded on those ideas.

Another problem could arise in the use of wells in lowlands close to saltwater. Johansen suggested that such wells could be contaminated by saltwater. While she found it unlikely in the case of Bergen because of its topography, she did find evidence for this in many other coastal towns (Johansen, 2013, 68-69). Another factor worth noting is that excessive use of freshwater in those towns could also cause saltwater infiltration, and Bergen could have suffered from this too. High pressure from the infiltrating rainwater would make it difficult for saltwater to infiltrate from a river or a fiord. But if the use of freshwater were greater than the infiltration, the pores which were usually filled with freshwater might have filled with salt water, and thus contaminated the well. When the infiltration of freshwater increased, the saltwater would again be pressed away (Skjeseth, 1957, 62-64). As the wells of medieval Trondheim were so few, saltwater infiltration would most likely not have been a problem, but, as we shall see later, it might have become one in the 17th century.

Tradition may hold a strong hand over practice, and the knowledge, meaning or material would have to undergo a massive transformation to rock such a boat. We must not forget that God played a role in this too. He was responsible for the medieval peoples' health, and their sickness. Strong beliefs would have added to an idea that if you got sick you deserved it, or it was a test, and if you were worthy, you would get out of it alive (Christophersen, 2020, 339). This belief must have been challenged by the Black Death in 1349.

Wells, cisterns, and conduits

The tradition of digging wells is old, and in Norway we find wells from as early as the Bronze age (Wenn & Gaut, 2013, 31). Four wells in Trondheim have been dated to the 10th to 16th

century, and they show evidence of very old construction techniques. One of the wells was of unknown technique, but the others were constructed using post-and-plank, dovetail joints and corner joints. Corner-jointed constructions were representative of Trondheim from the 10th century, and 96 % of the medieval buildings at Kjøpmannsgata 20-26 were constructed as such (Christophersen, 2020, 211-212). Post-and-plank constructions are found in Nordic countries both in the Viking Age and Middle Ages, and in some places even in modern times (Hauglid, 1980, 20). Dovetail joint constructions can be traced from 3000 BC to the 21st century (Edwards, 2012, 2-6). None of the techniques used in the medieval wells of Trondheim seem to be try-outs of new ideas, but rather manifestations of solid building traditions.

All the seven cisterns found at the chosen excavations were medieval. In Kjøpmannsgata two were barrels dug into the ground, and the rest were of post-and-plank construction, some with feeder channels. As with the wells, we can see varied construction techniques. They are not deep and building a cistern must have involved a smaller investment than the building of a well. Many cisterns may also have existed as constructions (barrels) above the ground and provided water through seasonal variations of water supply. Cisterns may have been easy-to-build installations to collect and store water close to the settlement without going through the whole operation of digging a well.

Conduits, half hollowed logs, however, were probably a hard-earned investment. The pipes of 1777 and their technology was something different, hollowed out tree trunks, but the conduits of medieval Trondheim might have been their predecessors. The very use of covered half-logs was something entirely different than open channels/drainage/waterways. There is a different intention reflected in the material remains. Some interpret such conduits as sewage pipes, as in the case of one example in Oslo (Haavik & Hegdal, 2020, 67), but in the Trondheim context three out of six conduits lead to or from a cistern or a well, and these were certainly water conduits. However, the other three might have had different functions, as their connecting cistern or well has not been found.

Whatever the function, these half-log conduits were probably individual solutions before a collective solution was proposed. They are proof of knowledge of such systems, but individual citizens did not have the means necessary, or the initiative, to make this a solution for the whole of Trondheim. Perhaps both wells and cisterns (and their conduit systems) started as attempts to provide clean water close to home, but they were not numerous enough

to provide drinking water to the population at any given time in the Middle Ages. People had to use the above-ground water sources for their daily needs.

Concerning firefighting and beer

It is said in the Town Law of King Magnus Lagabøte (King Magnus the Lawmender) in 1276 that anyone who does not have a well should have a barrel of water in case of fire. All must work together and even use peoples' drinking water to fight a fire (Robberstad & Taranger, 1923, 32-33). This shows that people usually had drinking water close to their homes, but the few sources found archaeologically cannot count for most people. Perhaps this point to barrels of water above ground?

The importance of water as a thirst quencher is underlined by many (Grøn, 1984, 160; Lunden, 1980, 108; Myhre & Øye, 2002, 216). It is well known how beer was a part of the medieval diet in Europe, and it is usually said that this was because it was healthier than water since the brewing process sterilized the drink, and because of its ingredients, it would also be more nutritious (Nelson, 2011, 78). The brewers would probably prefer clean, not polluted, water because of the taste. However, the fermentation process would sterilize the water, making polluted water into something drinkable (Unger, 2004, 5, 167).

Figure 15: Bowl for beer drinking, found at Kjøpmannsgata, dated 1050-1100 (N38082 – collections online). Photo: Ole-Aleksander Ulvik. © NTNU Museum of Science. (Ulvik, 2020).

This could have been the reason for the Gulating law in western Norway demanding that well-off people had to brew beer (Robberstad & Lien, 1981, 9, 19-20), and if so, it would make a considerable political move to improve the health of the people. Even though water was not the most popular drink, Max Nelson (2011) claims that it was known how to sterilize water. There is documentary evidence that Hildegard of Bingen (1098-1179) knew that boiling water would purify it, and that she insisted that others, too, should do this. Since bacteriology was still unknown, this was probably experienced-based knowledge. One might ask why people would turn to beer as a healthy drink, when it was much easier just to boil water to get it cleansed? Beer was more nutritious, but Nelson argues that water was the most available and basic beverage, and it was drunk if nothing else was available or affordable (Nelson, 2011, 73-78).

Water from wells and cisterns could have been used for the brewing of beer, as it was closer the produce buildings than the streams, and just as, if not better, quality of water. Our few examples could indicate locations of a local, specialized, beer industry. Or that could have been one of the functions. It is necessary to open the mind for a variety of explanation of wells in medieval towns where such constructions are the exception rather than the rule. There must have been good reasons to invest in such constructions when others chose not to.

Private or public

Firstly, the terms private and public refer to our modern conceptions of the words. Private as an individual intervention, and public as governed by a public authority. Something in between this can be identified as a neighbourhood initiative, shared, but not managed by a public authority. A law would be something regulated by public authority, and thus a way for the public to manage the physical environment.

In Trondheim none of the medieval constructions can be seen as public, in the modern sense of the word. Those that were not strictly private could have had more of a neighbourhood function, serving more than just one household. This arrangement is known from medieval Bergen (Johansen, 2013, 60-61). The possible difference between a semi-public and private construction is the location, surrounding pavement, and size of the well. A location near or in a public space, surrounding pavement for frequent use, deep enough to penetrate the sterile ground, and a large size, and especially a combination of several of these might indicate a more public function.

Well 329 in Kjøpmannsgata from 1175-1225 is likely the result of a private intervention for private needs, as it is confined to private property, and it is of medium size (1,4 m). It is also a possibility that it was shared with the neighbouring property. However, well 445 (also located on private property at the same excavation site) from 1325-1500 was surrounded by wooden pavement, went into the sterile ground, and was constructed using the dovetail joint technique. It was located at the front of the property (6 m from the main road, unlike 329 which is located far back on the property). It was, however, only 1 metre in width (square). The pavement could have been an entirely practical solution to cope with possibly wet surroundings, or a way of keeping the surroundings clean to prevent contamination of the water. A frontal location could have a connection with specialized use on this specific property, or to make it available for a larger group of people.

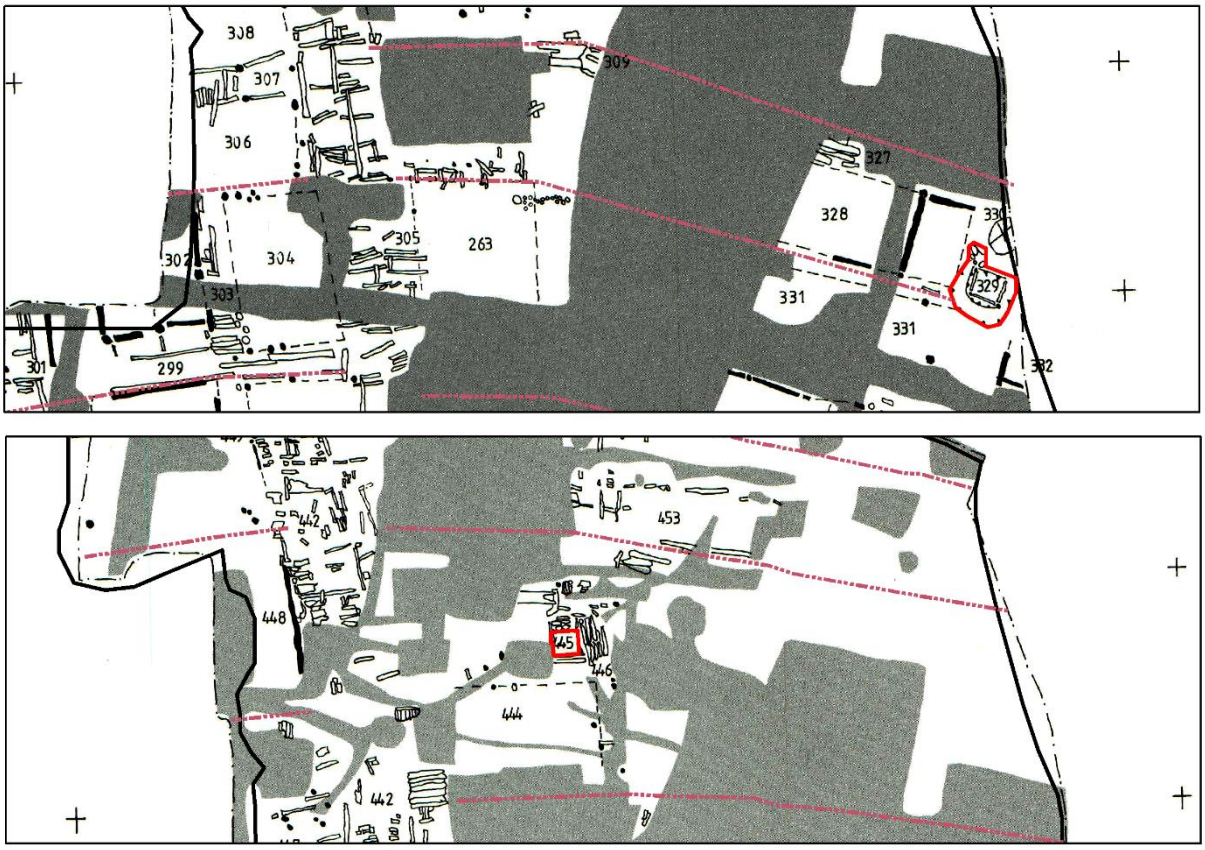

Figure 16: The two medieval wells in Kjøpmannsgata and their location in relation to other constructions. Base maps are from the published reports, as are the red dotted lines which represent possible property borders (Nordeide & Christophersen, 1988). Illustration by Elisabeth F. Swensen.

When considering cisterns, the situation seems similar to that of the wells. Most are placed at the back of the plots, and their location close to a house (collecting runoff rainwater from the

roof) may indicate a possible private nature. Cistern 37, however, dated 900-1025, lived a relatively long life with its sturdy construction of a barrel in the bottom and a corner-jointed case on top. This cistern was only 1 metre in width as well, though. It was at the front of a property and could have served both owners, travellers, and neighbours with water.

The conduits at Søndre gate 1-3 are presumably pre-1777 because of their registered "level below present level", and Digre's comment upon them as medieval (Digre, 1943), but one is of unknown date. Conduit 43 seems to run under the pavement, along the middle of it. The streets were divided in ownership, and part of a street was at times owned by the nearest household; the streets were both a public space and private property (Christophersen, 2017, 64-69). This might indicate a public function, but it could also have been a private solution beneficial to only a few.

All constructions at Kongsgårdsgata 1b must be interpreted as private interventions. The place is physically closed off outside the town centre, and its status would most likely not have allowed other people to use it.

In sum, only three examples of drinking water management constructions can be connected to a function outside the private. Likely, they were not entirely public, in our sense of the word, but open to more than just the private household, such as a neighbourhood, or to passing travellers. It can easily be imagined that cistern 37 was a sales trick to tempt thirsty people towards the sales booth. Taking a sip of clean, refreshing water whilst you inspect a fine antler comb, or buying beer produced with water from the well at the same property.

Social differences and a comparison with the archbishop's palace

Why can we not find more wells, cisterns, or conduits at the selected sites, or more evenly disturbed constructions? Was it a show of social inequality, where only those rich and clever enough had access to these luxuries? Direct access to clean water would be reflected in the better health of the users, adding to the social gap between people. Robb shares his reflections on these issues: how social inequality and poverty would cause health inequality (Robb et al., 2021, 109). This must have been visible in Trondheim as well, as the density of clean water interventions was great at the Archbishop's Palace. Two of the sites' four medieval wells and two out of seven cisterns were found here. The technology does not appear to be significantly different from that of the town's, there is just more of it in one place. It seems that the clean water supply was adequate for the people living there, most likely resulting in better health.

However, they were not the first to implement these kinds of constructions, as similar wells, cisterns, and half-log pipes were found in older layers at Kjøpmannsgata and Søndre gate 1-3.

Table 5 Comparison of the medieval structures at the Archbishop's Palace and the other four sites.

	Archbishop's Palace	**The four other sites**
Wells	2	2
Cisterns	2	4
Conduits	1	6

Notice that as far as half-log pipes go, the two examples found in Kjøpmannsgata precede the one found at the Archbishop's Palace. The latter is documented as technically more advanced, because of its insulation, but the basic technology is 200 years older in the city centre. Also, at Søndre gate 1-3, an area presumably with a less fortunate population than Kjøpmannsgata, and less privileged than those living at the archbishop's palace, three such conduits have been found with a probable medieval dating. Generally, water management constructions here were plentiful, especially concerning drainage and conduits (Swensen, in prep-a), indicating this as an area with high needs of keeping the water clean and keeping dirty water away.

It does not seem like the people of Kjøpmannsgata had access to any cleaner water or better technology than others. Their implied superiority is not reflected in the technological realisation of drinking water management practices. It appears that most people here must have gotten their water from above-ground sources, as most of the people of Trondheim had to, except perhaps the archbishop and his people.

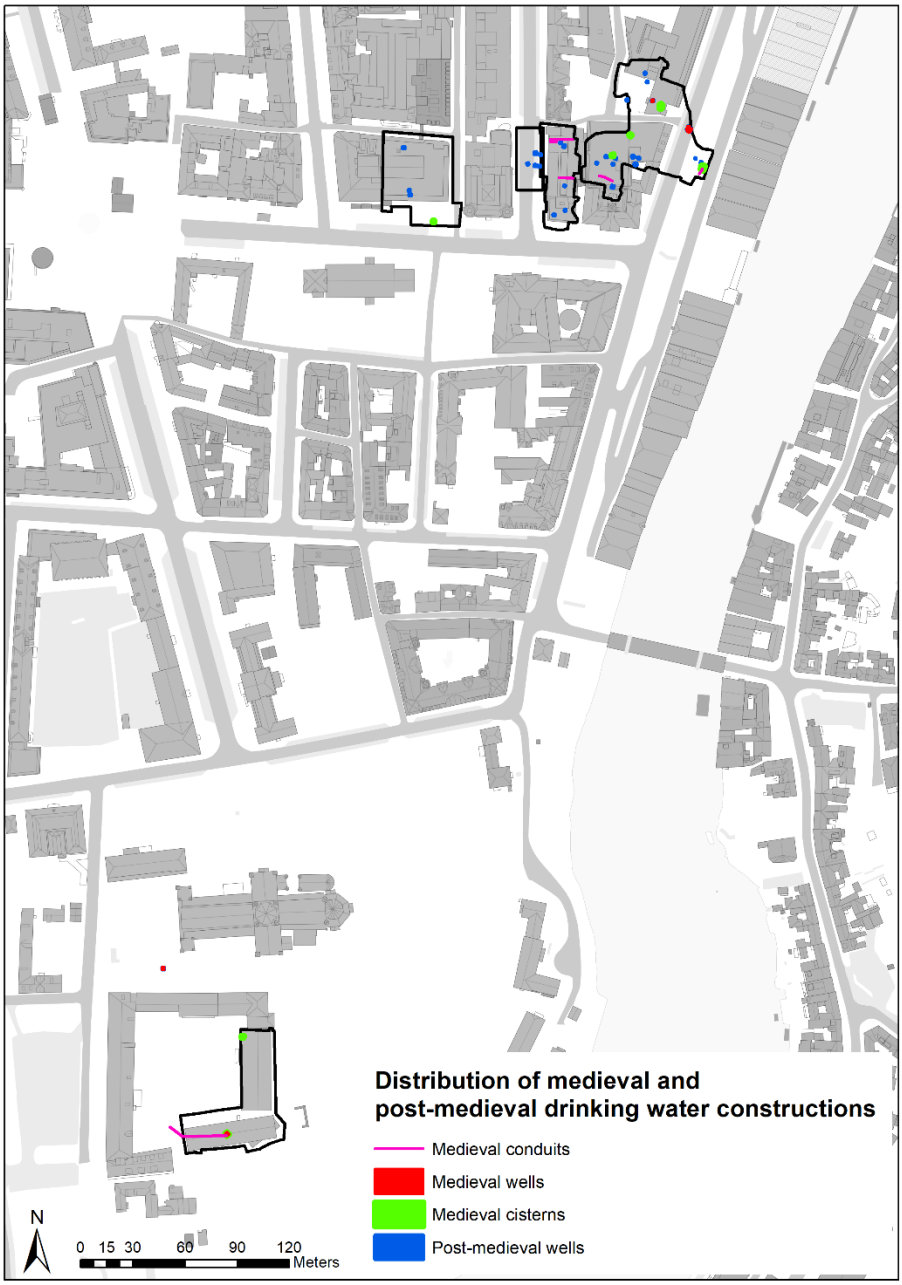

Figure 17: Distribution of medieval and post-medieval drinking water constructions in Trondheim. Illustration by Elisabeth F. Swensen.

Discussing post-medieval water management (1500-1800)

The dangers of water in the post-Middle Ages

Post-Reformation Trondheim was built upon layers and layers of medieval buildings, churches, waste, streets, and the practices of life familiar to those living there. The dangers of drinking water in the post-medieval era came from the more extensive use of wells, their location, and the growing urban population. With changes in practices and a changing

physical environment with a fast-increasing population new challenges arose. The build-up of cultural layers had slowed to a halt in the second half of the 14th century (Christophersen, 2020, 351), but many places in the town were on top of 2-6-metre-thick cultural layers. This would probably affect the now more intensive well building. If water did move through such layers, it was likely to have been contaminated. Eight of the recorded wells in this paper are documented as sunk in sterile ground. Digging into sterile ground indicates a knowledge of how far you had to dig to reach good-quality water. On the other hand, the bad permeability of cultural layers could be an argument that this was not so much an issue.

From the argument on saltwater infiltration explained earlier, it follows that a heavy use of wells would enhance the possibility of exhausting the freshwater resource, and of it being replaced by saltwater. Diocesan clerk Christian Reitzer identified this problem in 1724, claiming that brackish water from wells was not uncommon (Lund, 1925, 250-251). This indicates that the number of wells at this time was large and that they were used with such frequency that they exhausted the freshwater in the ground.

The dangers of drinking water could also come from a lack of knowledge. We have noted above that medieval people knew how a well could be affected by waste or dead things being thrown into it. But did they know that the water from the sky was the same water that would turn up in the well? If it was generally believed that rainwater and groundwater were two different things, this might have added to the contamination of groundwater. It might explain how five of the post-Reformation wells (and none of the medieval ones) were located within 4 m of a waste pit. The dangers would be great, as the rainwater could be contaminated before entering the ground, and contamination could be one of the reasons many of the wells end their lives as waste pits.

Any surviving top construction of the wells could have revealed something of measures being taken to avoid contamination. One well has remaining features that can indicate the measures taken to secure the well water. The undated well from Søndre gate 1-3 was of dovetail joint construction and was documented having the remains of a well-house (typically made to shelter the well from contamination or prevent people and animals from falling into it), and a staircase of four steps down to the well. A similar well with a well-house was found at the Søndre gate 7-11 excavation, dated to the late 16th century (Sæhle et al., 2021, 321, 325-326).

Figure 18: Undated well from Søndre gate 1-3, excavated in 1943. Visible remains of stairs going down to the well of dovetail joint construction. © NTNU Museum of Science.

The well at Søndre gate 1-3 was excavated in 1943, and the report stated that there were still 2 m of water in the well. The stairs were supposedly made because the well could have been about 1 m below the courtyard (Digre, 1943, 5), which indicates a long period of use. It must have been a solid well with good quality water if such measures were taken to preserve its purpose, and it would also indicate some knowledge of contamination.

Wells, cisterns, and conduits

When going post-Reformation, a great change is seen. After four wells through almost 600 years (none seem to be used at the same time), 22 wells show up during the next 200 years[6]. Combined with the excavation of wells from one new and one unfinished report, this number increases to 26, and these excavations had no medieval wells (Sæhle, 2021; Sæhle et al., 2021). At the medieval maximum around 1300, about 3000 people lived in Trondheim, with one well dated to that period. A presumed population of 9000 in 1801 would indicate three wells, but the material shows up to 26. This rise is significant, and if we look at the numbers, the rise in population does not explain the rise in wells.

No cisterns were found in the post-medieval period, and no conduits either. This is likely because of the limitations of the Cultural Heritage Act, as these installations are not protected because of their age, and by not being as substantial as the wells they would probably have been removed by the mechanical excavator. However, Nordeide mentions that the Archbishop's Palace's conduit was leading fresh, clean water when they found it during the excavation in the 1990s (Nordeide, 2003, 171). The conduits around town could have been operational for a long time, with no need for making new ones. It is not until 1777 that a piped system is the solution for the whole town. There must have been accumulated experiences that pipes would lead better water than wells in this town. Those experiences appear to be building up in the Middle Ages.

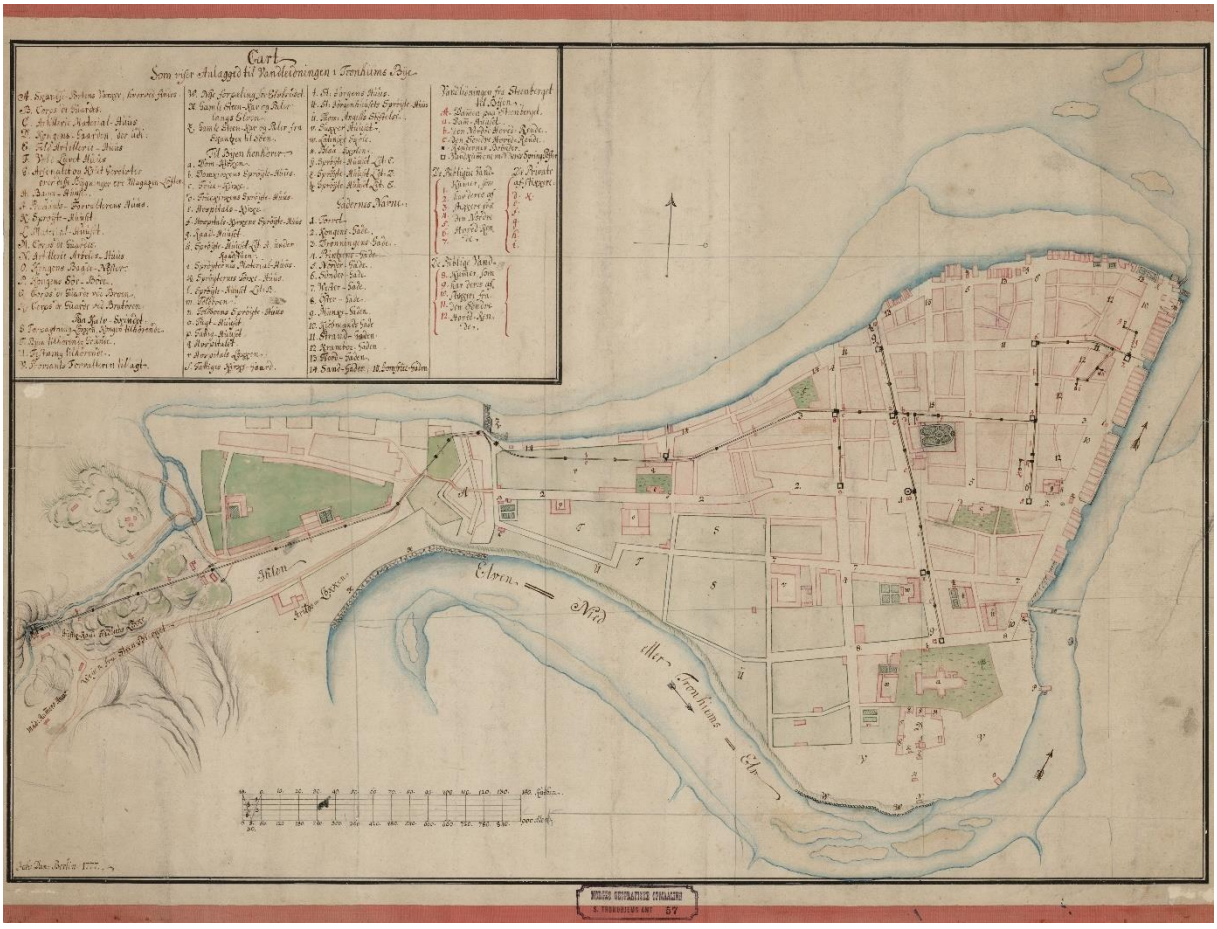

Figure 19: The original 1777 water pipes (black lines) and water pumps (black squares) in Trondheim, both public and private branches, by Johan Daniel Berlin. ©Kartverket.no (Berlin, 1777).

As the medieval practice was mainly to get water from above-ground sources, the rise of the number of wells may correlate with other changes in Trondheim. The people were not familiar with the extensive use of wells in urban areas; they had yet to experience both the

advantages and disadvantages of that. Trondheim in the 17th century experienced population growth due to immigration both from the surrounding districts and from foreign places. Immigrants, and especially merchants from Flensburg (in the Duchy of Schleswig, in union with the Danish kingdom at the time) were central in the development of the town. In this period, Trondheim was often referred to as "the city of Flensburg" (Supphellen, 1997, 20). Many immigrants from the continent had different practices and traditions concerning drinking water. It is likely that outsider influence, outsider tradition, entered Trondheim and resulted in a change of practices.

The introduction of wells in the town coincided with a time that was not favourable for the establishment of wells. A growing population resulted in a growing number of buildings, and additional pavements would reduce the permeability of the ground. Reduced permeability meant less rainwater entering the ground, with equal less groundwater. This happened roughly simultaneously with the construction of more wells, thus exhausting the freshwater resources, and enabling the infiltration of saltwater. Large waste pits and an increasing number of latrines posed a large threat of contamination of the wells. A dense population and heavy use of wells probably lead to many infected water sources, eventually pushing the need for a piped system with cleaner water.

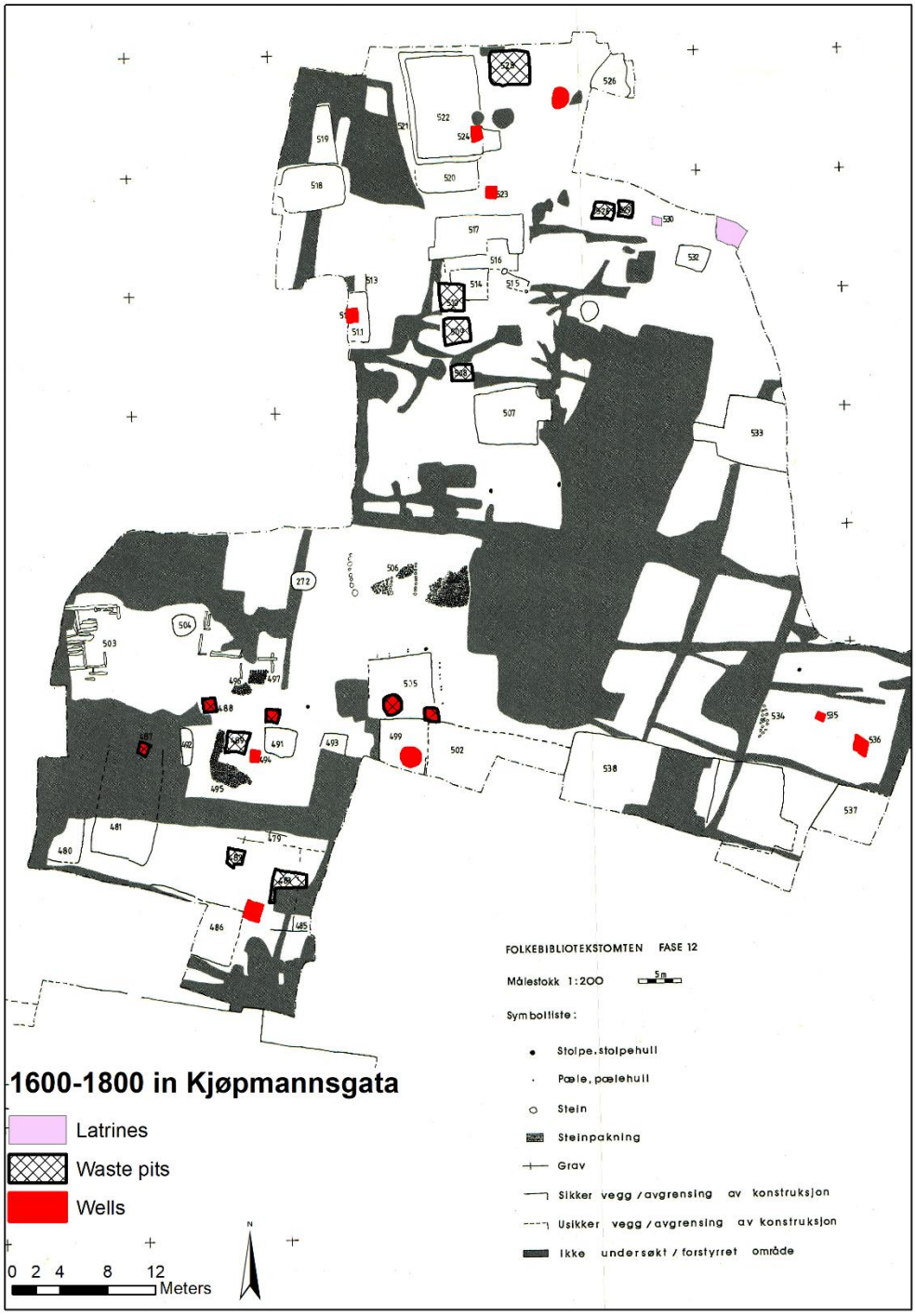

Figure 20: The location of post-medieval wells, latrines, and waste pits at Kjøpmannsgata 20-26. Many of the wells were later reused as waste pits, perhaps because the water was no longer usable, or the freshwater source exhausted and the well empty. Illustration by Elisabeth Forrestad Swensen, based on maps from the excavation report. © NTNU Museum of Science.

Concerning fire fighting

It is not certain that the post-Reformation wells were made for supplying drinking water, or at least for that purpose only. Historical sources talk of a Mr Wesing (1684-1759), director of fire prevention in Trondheim, and that he during his period in office oversaw the construction of many fire-wells (Christiansen, 1987, 68). A few of the constructions that have been dated as post-medieval might be among these (because of their possible location in public areas) – that is, wells whose main function seems to have been fire prevention, not necessarily the supply of drinking water. Even so, the water could still be drunk. Whilst the owners earlier (at least from 1276) were obligated to keep water on their property, the public authorities now started ensuring the availability of water across the town. The establishment of these new wells might have added to the possible saltwater pollution of the other wells.

Figure 21: Fire pump dated 1749 from its inscription, from the same county as Trondheim, namely Trøndelag. ©Rørosmuseet.

When Wesing died, Johan Daniel Berlin succeeded him as fire chief, and he expanded the equipment of fire pumps and their storage buildings. Berlin was later appointed water inspector, and when he oversaw the work of the new piped system in 1777, he made sure that

the public water pumps were placed near these storage buildings (Christiansen, 1987, 68-70). Practices of fire prevention and giving access to drinking water seemed to go hand in hand at that time.

Private or public post-medieval

Both private and possibly public wells from 1600-1800 have been found. We can identify six private wells in cellars and possibly a few public ones as well. In Göttingen, Germany, a change is seen when public wells are built in the streets in the 15th century. According to Arndt, this is when the authorities took more responsibility for the water supply (Arndt, 2020, 220). Using georeferencing we can explore if similar trends can be found in medieval Trondheim.

Table 6 Summary of suggested private and public water facilities in Trondheim

	Medieval (7 cisterns, 4 wells, 5 conduits)	**Post-medieval (22 wells)**	**Undated (5 wells, 1 conduits)**
Private water facilities	10	6	
Public water facilities	3	2	
Unknown	3	14	6

Since most of the post-Reformation wells can only be dated very imprecisely – sometime in between 1600 and 1800 – we cannot know if they were established before or after the rebuilding in 1681. As this rebuilding resulted in an almost total change of street layouts, it is difficult to decide the public or private location of these wells. By using the georeferenced structures and placing them on top of two different post-Reformation maps, one from 1658 and one post-1681, we can identify some possible locations in different "real" time surroundings. Those outside the main road, at any time, and placed on private property are most likely of a private nature. There were five wells located on private property in 1681 and later, but in connection with the map from 1658 they would have been close to, or in, a road. Their private or public function remains unknown, as we do not know their exact date.

Figure 22: Georeferenced post-medieval wells and the 1658 map of Trondheim. Some wells are located on private property, and some are in, or close to the street. As the dating is approximate and the map even more so it is difficult to decide the wells' private or public function. ©Kartverket (Pufendorf, 1658). Illustration by Elisabeth Forrestad Swensen.

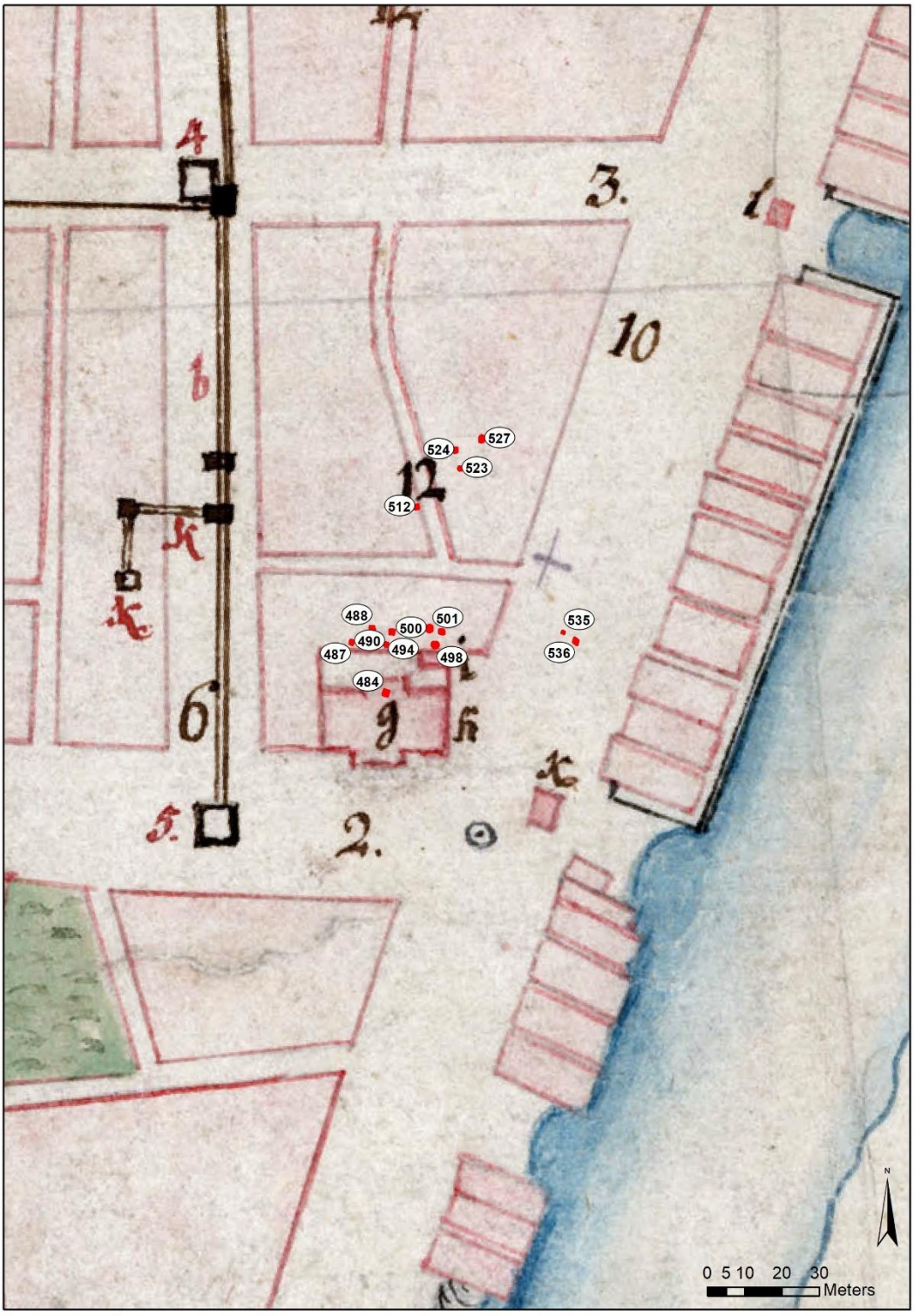

Figure 23: Georeferenced post-medieval wells and the 1777 map of the new piped system (original in figure 19). Some wells are located on private property, and some are in, or close to the street. ©Kartverket.no (Berlin, 1777). Illustration by Elisabeth Forrestad Swensen.

Well 494 at Kjøpmannsgata 20-26, however, was located by a stone-paved yard. In the 1658 map, this well was also close to, or in the road, and the paved area close to it might suggest an area used by many people. Post-1681 it would have been some distance from any road, and the stone-paved area could have been a private luxury. It could also have been a more neighbourhood-friendly well, instead of a strictly public one. Wells 535 and 536, however, lied close to, or in a road in both maps, and both were sunk into sterile ground. Georeferencing of the wells and the 1777 piped system suggests that these were not a part of this system, and thus probably older. Well 535 had a dovetail joint construction and was a massive 3.1 x 3.4 m in size! Well 536 lied close by, only 1 x 1 m in size, and had a combination of post-and-plank and corner-jointed construction. The corner-jointed construction was an older well, and it had been reused and improved with a post-and-plank construction on top. These traits point to a considerable amount of investment in the building of the wells and to their use over a longer period. Their location in, or close to the road strengthens the case for seeing these as public wells, as suggested by Arndt for Göttingen.

The answer: a public water pipe system

The 17th century in Norway was a time when the economy was thriving. There was a growing political idea that for the state to become more powerful it needed to enhance its resources (become rich), and humans were increasingly seen as a resource. For the people to be a good resource, they had to stay alive and healthy. The authorities needed to make sure of this, to enhance the power of the state through the health of its people by strategically implementing measures ensuring good health (Moseng, 2003, 110-114, 118-119). In Norway the gathering of knowledge (in the second half of the 18th century) on local natural and cultural conditions was extensive. A part of this illuminated the health situation and provided the background for further political action (Moseng, 2003, 126-127). This new knowledge gave the state new incentives, new meaning, to change ongoing practices around the country.

In 1723, the new diocesan clerk Christian Reitzer came to Trondheim from Copenhagen, the capital of the kingdom Denmark-Norway[7]. He came with the ideals of a powerful centra to discover that Trondheim was a periphery, and very much on the periphery when it came to heeding the laws and demands of Denmark. He wanted to improve the town's standards. In a letter from 1724, Reitzer urged the wealthy people of Trondheim to donate money to construct a piped water system from Ilabekken. He argued that it is bad economy to use a horse and carriage every so often to get water, and that servants might be tempted to use the bars along the way, leading to all sorts of bad behaviour. There was also a call to do the right

thing, as he pointed out that the poor suffered from not having a horse and were left to use the brackish water from the wells. In addition, he argued that there is not enough water to put out fires in the town and that Trondheim, like almost all other towns in Norway and Denmark, should have access to water "for the town's beauty, contentment, salvation, and health" (translation by corresponding author Swensen) (Lund, 1925, 250-251). He appealed to the economy, charity, health, and the basic standards of Nordic towns to try to convince people that the piped system was necessary. Reitzer started to collect the money needed, but unfortunately was sent back to Copenhagen, and the project was not realized until 50 years later (Supphellen, 1997, 229-230). To be realized, the project needed money and the personal drive and initiative of someone in authority.

Figure 24: Munkegata in Trondheim, 1800. Painting by Johan F.L. Dreier. Photo by Gunnar Houen. One of the water pumps from 1777 is seen in the foreground. © Trondheim Byarkiv.

The money issue was solved about 50 years later. Thomas Angell, the foremost among the town's elite, died in 1767 and bequeathed most of his earthly remains to the poor of Trondheim (Supphellen, 1997, 340). Some of the money was set aside for investment, and in 1776 it was decided that this money could be used for other needs in Trondheim. Finally, the idea of an intake dam with conduits into the town could be realized, the project now proposed

by general von Krogh and N.F. Krogh (local elites with ancestry in Lübeck (Bratberg, 2009). The work started in 1776 and was finished the following year, with Daniel Berlin as the dedicated water inspector. An intake dam of timber and stone was built at Ilabekken, with hollowed logs connected with wrought iron carrying water to the town centre. People could pay to get their own branch to their private property or collect water at one of the 12 public water pumps (well-like constructions). Steinar Supphellen argued that this would have improved fire safety and the health of the people of Trondheim (Bonsaksen & Michelsen, 1987, 70; Supphellen, 1997, 345-346).

Comparing drinking water practices

We have seen that Trondheim was not without private, and perhaps also public, water facilities in its earliest days, but that these facilities did not supply the general population with clean water. Why? Norway has a topography rich with freshwater sources. Lakes, tarns, streams, rivers, and springs are visible and accessible almost anywhere you turn. The groundwater, however, is a hidden resource and it requires specific knowledge and technology to access it. Frengstad and Dagestad argue that this has led to groundwater not being thought of as an accessible source of potable water in Norway (Frengstad & Dagestad, 2008, 136). This may be the explanation why wells were not in great use in Trondheim in the Middle Ages.

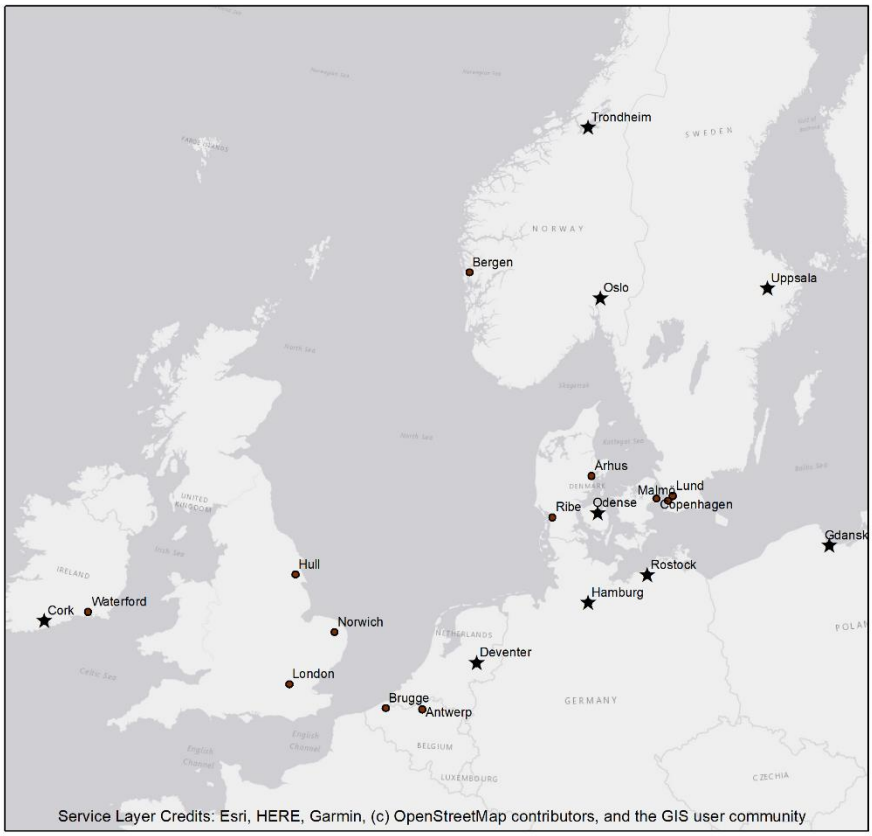

Figure 25: Geographical distribution of the towns mentioned in the comparison. Towns marked with a circle had early wells, towns marked with a star did not. Illustration by Elisabeth Forrestad Swensen.

Wells as a second thought

The situation is similar in Oslo, and perhaps the same explanation can be valid there as well. From the excavation of 60 properties, only eight wells from the period 1025-1624 were found. Three of these were constructed in the early 11th century and were wattle constructed. From the 13th century, there is evidence of corner-jointed constructions (Schia, 1995, 170-171).

Similar trends are seen in many towns and cities in Hanseatic Europe, shown in the collection "Lübecker Kolloquium zur Stadtarchäologie im Hanseraum IV, Die Infrastruktur" (Dunckel et al., 2004). This work collects archaeological finds of medieval infrastructure from many Hanseatic towns in north-western Europe. Here we can read about European medieval towns for which there is little or no evidence of early wells.

Cork has many streams, and wells and cisterns are constructed in later medieval times (Hurley, 2004, 19). Gdansk has little evidence of well-use between the 10-13th century (Paner, 2004, 323). Deventer lacks evidence of wells from the 9-10th century, but they are very

numerous from the 12th century; the same is true for cisterns (Spitzers, 2004, 123-124) In Hamburg, wells are extremely rare in all of the medieval period, and the reason is said to be the high water table (Busch, 2004, 170). This would have made groundwater accessible, and the use of wells logical. On the other hand, it might have given rise to numerous springs around town, making wells redundant. In Rostock, it was a long way down to the water table, 11-15 m, which is seen as the reason for there not being many medieval wells – however, many pop up, at least from the 16th century, on numerous plots, especially those owned by brewers (Mulsow, 2004, 234). From 1170-1300 there is no archaeological evidence of wells in Uppsala, perhaps because the river Fyris ran through the town. From 1300-1700 there is a variety of wells, and public wells are known from the 17th century (Anund, 2004, 438).

The lack of wells in early periods is mostly explained by the availability of fresh water from natural sources above ground in or close to the town. Changing practices towards using and constructing more wells are generally explained by a growing population, by pollution of the water supply, or by seeing such development as part of urbanization processes.

Kirstine Haase studied Odense in the Middle Ages. She also finds no evidence of wells in the earliest 200 years of the town's existence (from the 10th century). One explanation for this, she suggests, could be that there are wells of this age, but that they lie outside the excavated areas, while another could be that there was no need for wells at this time because the rivers supplied enough water for the population. The change, which involved the construction of at least 58 wells, has a possible explanation in the church's extensive ownership of land and its building activity on these plots, leading to restricted access to the water. Another explanation is a general increase in the demand for water (Haase, 2019, 198-199, 204).

Haase explores the introduction of wells in Odense through social practice theory. Both competence and materiality were in place in Odense from the beginning, as similar wells are known from contemporary rural areas and in prehistory, and the tradition can be followed into the Middle Ages (Haase, 2019, 215). We may say the same of Trondheim, as a well dated to the Iron Age is known in the location of the later Archbishop's Palace (McLees, 2003, 16), and especially since some wells are even evident in the medieval town. This shows that people knew how to make a well (it was not something unique to the Middle Ages or to towns and cities), and occasionally there was a need to use a well instead of gathering water from streams. The meaning, the intention, the mentality, is the essential point in the discussion of why wells were made and used, and why not. Haase explains the why by referring to "notions of self-sufficiency, functionality, tradition and practical solutions to a basic need" (Haase,

2019, 216). These are logical explanations and may very well be true for Odense and many other towns. It is a possibility that the intensive use of wells for drinking water is a tradition from those towns with a flat topography or little freshwater resources above ground, a tradition brought into Trondheim by newcomers, just as the early inhabitants of Trondheim brought with them from rural areas their tradition of using the water from above-ground sources.

This migration of ideas and traditions could explain the phenomenon of a sudden change in many towns from a policy of no wells to a policy of rapid well construction. The key factor was not the need to meet existing or emerging challenges, but the power of tradition, the power of a well-established practice.

But why, then, are there some examples of wells in medieval Trondheim? Why not rely totally upon above-ground sources outside of the town? As medieval tradition would have you fetch your drinking water from streams, it is a possibility that the medieval wells were not used for drinking water, or at least that it served multiple functions. Could we perhaps interpret these as specialized installations for specific needs? Those at the Archbishop's Palace were surrounded by different kinds of production houses, and the wells could have been for the water needs of the archbishop himself and those around him. The two wells at Kjøpmannsgata could perhaps have been situated on properties concerned with the brewing of beer or other kinds of production requiring clean (or easily accessible) water, such as drinking water for animals. Or it could simply be there as a luxury made by a person with another background or tradition – someone not from the rural areas near Trondheim.

Wells as the starting point

In Bergen, however, there is a different practice, which might not fit into the hypothesis of Frengstad and Dagestad. Bergen was a great city in the Middle Ages, and one of the largest in Scandinavia. It was a town with plenty of streams and rivers close by, but Johansen writes that there are some uncertainties as to whether these were reliable and plentiful enough to support the inhabitants of Bergen with potable water. That is her explanation on why many wells existed there in medieval times. From her chosen excavations there are 54 wells, of which only 12 are from the period 1476-1702. All the others are dated to ca. 1120-1475. The most numerous constructions are post-and-plank and barrel wells. These are interpreted as partly public, since each plot in Bergen were the home of many families and individuals (Johansen, 2013, 1, 40-60). However, there is no proof that wells were established by any

public authority, and they were probably neighbourhood wells, as we interpret it, not public wells.

On the continent, we find similar traditions in some medieval towns, as presented in Dunckel et al (2004). Waterford started early with both wells and cisterns (Hurley, 2004, 24-25). Hull has two rivers close by, but also a high water table argued to be a reason for early wells (Evans, 2004, 56). Ribe had wells being prominent as early as the 8th century (Kieffer-Olsen, 2004, 547). In London, there is archaeological evidence of wells from the 10th century onwards. There were also water carriers selling water taken from the river Thames or the early 13th century conduits (Sloane, 2004, 91). Antwerp had wells from the 9th century (Veeckman, 2004, 97). Lund had a large number of wells in 1000-1200, where they were found in every plot excavated (Carelli, 2004, 455). Copenhagen is an exception as it had very little natural running water (opposite to most other medieval towns), which meant there was a more compelling reason for the many medieval wells there. In 1679 there were registered 616 wells, of which 188 did not generate water any longer (Jensen, 2004, 533-534). Aarhus had wells from 900, even though the early town was situated close to rivers and streams (Skov, 2004, 551). In Malmö, wells are interpreted as the main water supply until large earthworks affected the groundwater, and a piped solution was constructed in the 16th century, consisting of drilled logs of pine (Reisnert, 2004, 466-467).

The variations in construction techniques are great, and no one town favours only one type of well technology. Most of the towns have natural water sources close by, but the pollution of these, a growing population, or the groundwater table not being deep down, are among the circumstances that made the early sinking of wells a sensible practice. In Aarhus, animal husbandry is explained as one of the reasons for the many wells. Skov also studied the water supply, finding that the streams could be muddy due to heavy rainfalls, and the quality of the river water could be too varied (Skov, 2004, 551), similar to the argument we have made for Nidelva.

Norwich had a bit of both traditions, with several streams, cockeys, which provided water to the town and were regulated by law so that all could benefit. In addition, public and private wells and cisterns were present from the town's beginning, and the well-makers of the town could construct wells 45 m deep already in the 11th century (still exists in Norwich Castle Keep) (Ayers, 2004, 31-33).

Some towns were like Trondheim, starting with few or no wells, and some were like Bergen, and started with a great number of wells. Almost all towns had streams or rivers nearby, but they did not rely on these in the same way. Topography was both similar and different from town to town and did not seem to be the primary factor determining which practice was followed. The well constructions did not seem to have any strong common model of technological development to follow, almost all kinds of wells were apparent at all times, with variations between towns.

The reason for this variation may be the routinized practices of the first people settling the town, primarily locals from the rural areas. Their traditions would have been highly influential for the way the town was structured in the beginning, before slowly becoming urbanized and getting an urban identity. As most wells in medieval times were of a private character, they seem to reflect different traditional identities, different practices. Later changes might have been the result of a growing urban identity through the lived life where many kinds of people settled and interacted in a small area.

Introduction of piped systems

Even the introduction of piped water systems varied greatly from town to town. Trondheim was neither early nor late in this regard. By the end of the 16th century, there was an increased use of wooden pipes to supply wells with water in Oslo. In the 17th century, the inhabitants of Oslo got a public waterwork going (Schia, 1995, 170-171). On the continent, the introduction of piped drinking water supply in towns varied from the 13th to 19th century. The constructions were variations of wooden and metal pipes, with a few made of lead, which must have caused problems with lead poisoning.

Figure 26: Iron ring for connecting two hollowed wooden logs in the 1777 piped system in Trondheim (N25042, collections online). Photo: Ole-Aleksander Ulvik. © NTNU Museum of Science.

The earliest of the towns in the comparisons are London and Brugge, both displaying a piped water supply as early as the 13th century. In 1236 London had lead pipes leading to a lead tank pumping water to public constructions above ground (Sloane, 2004, 89-90). Brugge had a system of leaden tubes running underground supplying public wells at least as early as the 13th century (De Witte, 2004, 107).

At the other end of the scale, there are those introducing pipes for drinking water in the 19th century. Deventer is said to have introduced these because of new knowledge on cholera and bad water quality. In 1893 the town got a water tower with high-pressure waterworks, with hundreds of piped connections to households (Spitzers, 2004, 124). In Antwerp, a system of metal water pipes was established in 1881, but open canals are known to have functioned as drinking water supply from the 15th century (Veeckman, 2004, 99). Aarhus got a public water supply in 1872. A few pipes of hollowed-out tree trunks are known from the 17th-18th century, but these were mainly used for drains (Skov, 2004, 551, 558).

The other towns vary within these limits, but the majority acquire a public water pipe system during the 17th century. This timing might coincide with the growing idea of the people as a

resource for the state, and that these people needed to stay healthy. Both today, the Middle Ages, and in the early modern era, there is a consensus that clean drinking water is essential to the maintenance of good public health. Leading water through pipes would protect the clean water and distribute it to all citizens.

Conclusion

People did get sick from infected water in the Middle Ages in Trondheim. This is shown by the aDnA results, and indicated by the law against polluting the Nidelva, and perhaps by the law controlling the brewing of beer, and more generally demonstrated by Robb et.al 2021 (see earlier mentions of their work). It is also apparent in the example of the Birkebeiner in the well at Sverresborg in the 12th century.

The wells, and other installations for the supply of drinking water in medieval Trondheim, however, are few. From the five excavations analysed, four wells are dated to the Middle Ages, in addition to seven cisterns, and at least three out of six conduits can be connected to a well or cistern. The cisterns were most likely connecting rainwater from either springs or rooftops, providing water when seasonal variations would cause the other water sources to be unstable. Medieval wells were probably connected to activities beyond the supply of drinking water (or in addition to this) and could have been specialized for a specific property's needs. They do not seem to be especially predisposed to pollution, as the constructions were located at a safe distance from latrines and waste pits, and the wells were not numerous enough to exhaust the freshwater in the ground. Different well-technologies had long traditions both in the town and in the surrounding rural areas but were not initially chosen to provide the citizens with water. Evidence suggests that the rivers, streams, springs, and other natural, above-ground freshwater sources were the go-to for potable water in medieval Trondheim.

Infectious diseases in the Middle Ages most likely came from the pollution of the above-ground sources most people used, for example by insufficient storage of water, or the throwing of waste in the water supply. Waste pits and latrines might have polluted the streams in the town, and poor hygiene when handling water, food and waste could have played a large role in creating a hazardous environment (Swensen, in prep-b). We would assume that the gradual development of a town, of Trondheim, initiated the need for a gradual change of the management of drinking water. Their practices started as mostly private initiatives, solutions for specific needs, although some of them were the product of a more neighbourhood-friendly approach where the wells could have been shared by many people. A growing population

meant a growing need for drinking water, and for water to use in activities like washing, production (e.g., of beer) and fire safety. This growing population would also initiate increased pollution of the water sources. Somehow the town experienced a rise in population (950-1300, a presumed maximum of 3000 inhabitants[8] in 1300) followed by a fall (1300-1500 AD, around 1250 citizens in the late 15th century) without any marked changes in water supply practices. There does not seem to have been any immediate changes in practice or the management of water connected to the aftermath of the Black Death in Trondheim in 1349. Significant changes cannot be found until another rise in the population during the period 1500-1700, reaching the medieval maximum once again. A modern presumed need is not reflected in the material. However, 1349 might have brought on a change of mentality: God, it appeared, could not help deserving people from succumbing to the plague. They had to do something for themselves.

In Bergen and many other towns in Europe, the situation was different. Very early in their development they used wells extensively, even though freshwater sources above ground were readily available. In Trondheim, along with certain other towns, an extensive use of wells did not commence until several hundred years after the town's founding. However, towns with very different water supply practices did have a similar topography and a similar depth down to the groundwater level. The decision to rely on other water sources than wells seems to originate elsewhere, for example in the rural traditions those moving into and inhabiting the towns at the beginning brought with them.

A great change took place in the 17th century, and a bit earlier in some of the other towns, with numerous wells being constructed. In Trondheim, post-medieval cisterns and conduits have not been found (except from some pipes and constructions connected to the 1777 piped system), but this most likely is due to the archaeological practices concerned with the Cultural Heritage Act. The post-medieval wells were of the same construction as before, revealing there was no change in materials or competence, but rather in the meaning (intention). In the period 1600-1800, there was an increasing awareness of fire safety. A few wells were possibly set in a public space, and these might have been among the fire-wells that were made at that time. Still, many wells were of a private character, located in cellars or at private properties. The change in practice might relate to increased immigration from the continent, where most towns at this point used wells extensively. There was a growing need to get water closer to the homes of the citizens. It is also quite likely that a growing population

overburdened the existing sources, polluting town water sources, or exhausting sources too dependent on seasonal variations.

The greater use of wells put increasing pressure on the groundwater, making it possible for saltwater to contaminate it. In contrast to the few medieval wells, post-medieval wells were now occasionally placed close to waste pits, and wastewater could also have contributed to polluting the well water. This experimenting with wells solved neither the problems of fire safety nor the need for clean water, and there would have been an increased number of bad experiences with well water. In the 17th and 18th centuries there was an increasing awareness of the people as an asset to the state, and public health got into the political agenda. When Reitzer arrived in 1723, he soon realized that Trondheim needed a piped water system to ensure clean water for its inhabitants, and this was the first problem to solve to improve public health. Knowledge of piped water technology existed, but the medieval conduits were not hollowed logs, as the 1777 pipelines were. That technology seems to not have been a part of the practice until late, perhaps because they did not know how to hollow a log, or to fit logs together with iron? This transition from hollowed half-logs to hollowed logs appears to be a new technique.

But even though Reitzer insisted on a piped system in 1724, it was not possible to follow through his project. The reasons why this piped system was constructed in 1777 and not earlier were economic, social, and cultural. Whilst the knowledge of well making (competence) was present, money (material) and meaning (political will) were not. Because of this combination, no money was set aside for such a project earlier. In 1776 however, money was available from a great benefactor, and with some locals pushing for the piped solution, Berlin saw it through in 1777.

The practices of medieval Trondheim built up competence and knowledge on how to provide clean water (conduits and above-ground sources) and in the beginning their solutions were sufficient. Even when the population and contamination situations were presenting acute new challenges, people held strongly onto their rural traditions. To change their practices, they needed new mentalities to replace their old ones, and it had to be the right time and place for it.

The archaeological material has given insight into how the drinking water situation was in the Middle Ages. Traditions and practices were challenged by newcomers, and wells gained importance after the Reformation. However, the experiences of the extensive use of wells in

the town, and the growing political focus on people as an asset to the state, gave rise to a demand for a piped system in Trondheim. Water management became a public responsibility, after almost 700 years in the private sector.

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Endnotes

[1] There is an ongoing discussion of when the Middle Ages began and when it ended in Norway, and we hope that this article can contribute to the understanding of material cultural and its dynamics and continuity beyond 1030 and 1537.

[2] This new town plan is still the face of Trondheim today.

[3] Pufendorfs Carl X Gustavs Historie. Deleniatio Urbis Nidro Fiævuglo, Dronheem. in Norvegia á Danis d.28 septem. obsefæ et 11. Deesemb. deditione capa An. 1658.

[4] Stenøien commented that one incident of salmonella in the limited material studied indicates that this was most likely a common disease in the Middle Ages (Stenøien, 2021). Six incidents could indicate that this was a daily nuisance for most people, and probably a common cause of death.

[5] The population was, however, declining in the late Middle Ages and this could have resulted in less contamination of waterways.

[6] It is important to remember that 5 wells remain undated. All the undated wells were located at Søndre gate 1-3 and in Kongens gate 6, and do most likely represent the same variations in time as found elsewhere. The general idea of a rise in the number of wells in the post-medieval period remains valid.

[7] Norway and Denmark had a common king from 1380 and Norway became politically subordinate to Denmark in 1537. The result was a typical early modern European composite state with Denmark as the centre of the state. Denmark held this position until 1814 (the end of the union), but Norwegians gradually filled more of the administrative posts in Norway (Moseng et al., 2003).

[8] Population number estimates based on archaeological finds (Christophersen 2020, 178).