Groundwater Option in Raw Water Source Selection and Related Policy Changes in Finland

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Abstract

Since the late 1800s, the source selection – surface water or groundwater – for urban water supply has faced several policy changes in Finland. First, groundwater was favored. In 1920, driven by cost and reliability issues, one major city turned to surface water which was a sourcing determination for the country. After WWII, groundwater gradually gained preference motivated by reliability, including managed aquifer recharge since 1970. Instead of identified policy decisions, this shift was based on accumulated strategy. Since the 1980s security issues have favored groundwater while environmental concerns manifest themselves controversially. As a sub-study, treated lake water and groundwater were tasted by 167 persons of whom 86% preferred the latter. An additional expert survey (n=14) showed several benefits for groundwater. Combining these findings, groundwater has several advantages over surface water for Finnish urban water. Yet, for the futures, we need to keep both water sources in as good condition as possible.

Keywords

water services, managed aquifer recharge, contentious projects, groundwater protection, policy changes

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Introduction

For community water supply, the focus of our paper, we can either use groundwater, artificial recharge (managed aquifer recharge, MAR), surface water, or conjunctive use of both sources. In countries where the same water sources are used for a variety of purposes, the competition between the uses and their priorities is more intense. However, our earlier research showed that while the volumes of water used for other purposes, such as irrigation in many countries, may be more significant, the first priority of water use is commonly community water supply, as also determined by legislation in many countries (Katko & Rajala, 2005; International Law Association, 2004).

The aim of this paper is to explore and understand the policy changes on raw water source selection for community water supplies and particularly on the aspects related to groundwater. This is explored in the context of Finland while also reflecting wider views and development of groundwater use in other countries.

In Finland, the policy on raw water source selection has changed several times over the last 150 years: from groundwater to surface water, again to groundwater and more recently favoring groundwater and MAR. This has been verified through several case studies on Finnish water utilities, such as Tampere (Katko & Juuti, 2007, p. 24).

Globally, groundwater use is estimated to be 43 percent of the total consumptive irrigation water use. Various problems from elsewhere in the world are reported related to large volumes of groundwater abstracted for agriculture. The countries with the most extensive groundwater irrigation are India, China and the USA (Siebert et al., 2010). However, approximately 25% of global groundwater use is assessed as unsustainable and groundwater use is estimated to be growing at 5% per annum by Zheng, Ross, Villholth & Dillon (2021, 16-18). In Finland, groundwater is used for irrigation only occasionally in summertime, while it is mainly used for community water supply for drinking water.

In a wider context, Varady et al. (2013) noted in their global literature review that "in reviewing the literature and assessing prevailing notions on how groundwater is being governed across the globe, we have sensed a very palpable rise in the recognition of the centrality of governance. It is difficult not to notice how far we have come since the days when water management was left solely to engineers and technocrats."

The relative share of groundwater and surface water use for urban areas varies largely depending on the country and regions and the occurrence of ground and surface waters. For instance, of the Nordic countries Denmark only uses groundwater for drinking, industry and agriculture purposes (Jørgensen, Villholth, & Refsgaard, 2017), while Finland combines groundwater and artificial recharge (also called managed aquifer recharge) 65 percent for communities (Rintala J., personal communication, September 21, 2020). Sweden uses surface water (60%) and combines groundwater and artificial recharge (40%) for communities (Statistiska centralbyrån, 2017), and Norway exclusively draws surface water. Other countries with high groundwater share include Italy, Lithuania, and Slovakia. (IWA 2012, cited by Jørgensen et al., 2017) Globally groundwater is an essential resource that provides the largest store of freshwater, apart from the ice caps. Current groundwater abstraction represents 26 percent of total freshwater withdrawal globally, to supply almost half of all drinking water. For drinking water supply, one advantage of groundwater is that it is naturally protected from many contaminants. (World Water Quality Alliance, 2021)

The natural yield of groundwater can be increased by MAR. In Europe, Sprenger et al. (2017) identified 224 MAR systems in 23 countries including Finland, France, Germany, Hungary, the Netherlands, Poland, Slovakia, and Switzerland. MAR also has future potential for reuse and storage of water resources using nature-based systems. Through their global MAR inventory, Dillon et al. (2019) observed that MAR, together with demand management, is an increasingly important water management strategy, and for protecting and improving water quality. Some specific water quality challenges can be highlighted, though. Geological and climatic factors as well as the governance structure can also be inferred to have influenced the application of MAR.

In Finland and Sweden MAR is mainly used for water treatment (Kolehmainen, 2008), whereas in the United States, Australia and many European countries MAR is used for storage of ”surplus” surface water supplies in groundwater aquifers. (Balke & Zhu, 2008; Barnett, Howles, Martin, & Serges, 2000; Fort, 2013). Integrated planning of surface water and groundwater resources through the River Basin Management Plans provides for coordination in the use of these resources at a larger scale.

In several countries such as Finland groundwater is typically a major source in rural areas. In addition to quantity, the question of water quality and its protection, both surface water and groundwater, is of high importance while selecting raw water sources for community purposes.

The choice of water sources depends on hydrological and hydrogeological, geographical, ecological and climatic conditions. For instance, the grand-old-man of water services, the late professor Dan Okun (1917–2007) identified five key principles for sustainable water services, the fifth concerning raw water selection. He stated as follows: “In the case of domestic water, priority must be given to clean over polluted water abstraction sites…” The highest quality water should be reserved for domestic consumption – such as groundwater.” (Okun, 1977, pp. 4–7)

The apparent advantage of surface water for community use is its visibility and easy access. In Finland by the 1960s and 1970s surface water had often become polluted by community wastewaters, and particularly by forest industry. Thereafter, thanks to proper legislation and control, efficient water pollution control and wastewater treatment have dramatically improved surface water quality in just two decades (Katko, 2016, pp. 106–107). Finnish surface waters contain natural organic matter (humus, discharging from forest and marshland areas) and they are exceptionally soft due to low-calcium bedrock. Therefore, to meet domestic water quality requirements, surface water requires more complicated, often chemical treatment.

The source water selection is a complex matter, and even though groundwater is not – for hydrogeological reasons – an option available for all cities, limited volumes of groundwater are commonly available throughout the country in Finland. Various economic and non-economic considerations are relevant for the water supply solution as demonstrated, e.g. by the criteria selected by Amorocho-Daza, Cabrales, Santos & Saldarriaga (2019), including operational time, infrastructure setup, operational risk, and socio-environmental considerations. Such multi-criteria decision analysis may be applied to evaluate the available options systematically.

Conjunctive water management allows the combined use of surface water and groundwater and other non-conventional sources (UNESCO-IHP Groundwater Portal, n.d.). In Geneva, for instance, household water is supplied partly from groundwater, partly from Lake Geneva; the groundwater component replenished also by recharge from the Arve River (de los Cobos, 2002). Groundwater supplying Berlin is bank filtrate from percolated stormwater and surface water, benefitting from natural cleaning while passing through soil. (Anonymous n.d.)

For community water supply, one of the available options needs to be selected – surface water, groundwater or artificial recharge – or a combination of these options. Due to limitations of groundwater quantity, larger cities may often rely on surface water as e.g. in Sweden and partly in Finland. Path dependences related to earlier decisions may also affect the development.

On the basis of this introduction, the major research questions of this paper are as follows: first, what are the reasons for policy changes of raw water source in various phases, and second, what are the policy implications of different water supply sources for the futures. For these we use the experience and developments observed in Finland.

The paper is structured as follows: after the introduction we will first explain the methods. Thereafter, we briefly introduce water resources and community sources in Finland and describe the trends in groundwater and surface water use for communities, including the most recent policy debate. This is followed by exploration of two regional and contentious groundwater systems, and a case study on tasting surface water and groundwater as well as a survey on the pros and cons of groundwater and surface water. In the discussion, we explore the major issues and concerns for the foci in raw water source over time and discuss policy implications for the futures. Finally conclusions are drawn.

Methods

This review-type paper has four major parts. First, we conducted a literature review on the criteria for the use of groundwater and surface water in Finland for human settlements from the late 1800s until 2020, as well as changes in related policies. Second, two recent contentious MAR projects were analyzed based on a doctoral dissertation. (Kurki, 2016) They both have faced remarkable resistance. It took 40 years to implement the first case in the Turku region on the south-western coast. The second project, located in Tampere region, had its first general plan prepared in 1993 (SKOY, 1993), the regional wholesale company was established in 2002 but is still in planning stage. In the first case discourse analysis was used based on newspaper articles (approx. 400), supplemented by expert interviews (n=9). The second case applied conflict analysis, including stakeholder interviews (n=28), one workshop, and supplementary

Figure 1. Major areas with known and possible acid sulphate soils in Finland and the location of the cities related to the paper (Weppling et al., 1999).

newspaper articles and official documents. Additional reflections on other cases were also made.

Third, a tasting test of groundwater and surface water for drinking purposes in Tampere region is briefly explained. Unidentified groundwater and surface water samples were tasted by 167 persons during an open-door networking event in September 2013. After tasting, each individual was asked whether they perceived any taste differences between the two waters. If yes, they were asked: ”Which of the two samples was better?” The preference of each person was recorded. (Luonsi, 2014)

Fourth, a short survey on the pros and cons of surface water and groundwater for community use was conducted. First issues were identified by the authors and presented and compiled in a table: for surface water six pros and five cons, for groundwater nine pros and seven cons. These were sent to be ranked by 14 experts, including the authors. The four angles are finally discussed by the authors, assessing major drivers and issues over time as well as quickness versus persistence of policy changes.

Water resources and community sources in Finland

Finland has a unique geological history with the oldest formations of Precambrian bedrock and the youngest glacial formations, both having a fundamental impact on water conditions in the country, especially on the western coast. According to Donner (1995), continental ice sheets covered Finland on several occasions during the last 115,000 years. The sand and gravel deposits built up during the ice age are classified as glaciofluvial deposits, mainly eskers and ice-marginal formations. Therefore, in any international textbook on geological history only the first few pages and the last ones are valid for Finnish conditions.

Yet, on coastal regions acid sulphate soil, formed during the brackish Litorina Sea period some 7,000 years ago, creates a special quality problem. When such layers get in contact with atmospheric oxygen, e.g., due to flood control or cultivation, high sulphur loadings may occur. (Weppling, 1997; Österholm & Åström, 2004) Such loadings especially occur on the western coast (Figure 1). In specific areas, due to the composition of the bedrock, elevated concentrations of e.g., fluoride, arsenic, and radon may affect the use of groundwater notably, from drilled wells, for households (Lahermo et al., 2002)

In rural areas water supply has always relied on wells and springs, whereas in urban areas the well water gradually became inadequate and contaminated (Juuti, 2001). Therefore, higher yield sources such as rivers, lakes and more systematic exploration and use of groundwater aquifers have become prevailing for settlements. The biggest cities in Finland mainly rely on surface water for their water supply. The beverage industry that requires high-quality water mainly prefers groundwater or water resulting from MAR.

In international comparisons, Finnish groundwater formations are quite small: the average size being only 1–2 km^2 and the thickness of the sand and gravel layers around 10 m (Groundwater in Finland, n.d.). The scattered distribution of groundwater formations limits their effective utilization, but at the same time prevents large-scale pollution.

The earlier definition of almost 6,000 groundwater areas in Finland was based on their significance for water supply. Thanks to the delineations, the classification and the underlying information, the locations of gravel and sand formations are suitable for centralized water supply. After the legislative amendments in 2016, the boundaries of all groundwater areas are classified for classes 1, 2 and E. Class 1 refers to important areas for community water supply, class 2 to other areas suitable for water supplies, and class E to those areas on which protected areas are directly dependent on. (Britschgi, Rintala, & Puharinen, 2018)

In the Finnish conditions, groundwater has at least three advantages over surface water. It is often of better quality, its temperature is more stable, and it is better protected from immediate surface contamination. Groundwater use can, however, be limited by excess iron and manganese, particularly in the coastal regions, as well as by excess fluoride in weathered bedrock areas in a few locations.

Evolution of groundwater and surface water use for communities

First focus on groundwater

In 1892 Vyborg, today part of Russian Karelia, was the first Finnish city to use groundwater for public supplies. This was followed by Turku on the south-western coast in 1902, and the inland trio of Lahti, Jyväskylä, and Hämeenlinna in 1910.

In Helsinki, the capital of the country since 1812, the idea of using groundwater or spring water was raised as early as in 1875, one year before the start of the first urban water and wastewater system in the country. The first groundwater investigations by Helsinki were started in 1898 followed by surveys in other areas. (Lillja, 1938, pp. 38–73)

In those days the Finnish expertise on water management and groundwater was very limited. Therefore, the cities on the coast, particularly, had direct expert contacts with Sweden and Germany. Finland had been a part of Sweden for 700 years until 1809. Till the early 1900s Swedish was also the predominant administrative language, which also helped in establishing contacts and even applying Swedish legislation to Finnish conditions.

Through these early expert networks in the late 1800s and early 1900s, the well-known German hydrogeologists A. and G. Thiem and E. Printz were involved in developing groundwater use in several Finnish cities. The major contributing Swedish expert in this field was J.R. Richert. For Vaasa, on the western coast, he suggested an artificial recharge plant based on the one put into service in 1902 in Gothenburg, Sweden. (Juuti & Katko, 2006, pp. 506–508) Yet, in Vaasa the aquifer proved to be inadequate for any large-scale infiltration.

In the early 20th century, a heated public debate was conducted in Finland on the use of groundwater or surface water in urban areas. With groundwater, there were two major schools of thought: the geological "bird's eye view" (Sederholm, 1911) and Thiem's approach based on particle size and water conductivity (Gagneur, 1910; Gagneur, 1918). The arguments were very strong and personal while the debate was about the reliability of groundwater assessment methods and especially on the yield.

Shift to surface waters around 1920

In the 1910s, groundwater investigations were made in several places in Tampere, 160 km north of Helsinki. After the dramatic typhus epidemics of 1915–16 (Katko & Juuti, 2007, pp. 21–22), the worst water epidemics in Finland's history due to polluted surface water, the use of groundwater was considered and debated. Extensive groundwater inventories were made. Yet, since the experts could not agree on the reliability of groundwater yields, and were afraid of the costs, the city of Tampere changed their previous policy of favoring groundwater and decided on surface water use in 1920 (Juuti & Katko, 2006, p. 24)

One argument was that the services of the Swedish Richert would likely be too expensive and, therefore, he was not even contacted. (Juuti & Katko, 1998, pp. 103–107) Had artificial recharge, experimented only in Vaasa on the western coast, been applied in inland areas, the development path could have been different. In any case, other cities soon started to follow the policy change made in Tampere and thus the interest in groundwater investigations slowed down for several decades.

After WWII, a special type of upflow clarification treatment plant was sold to many cities, even to those that had groundwater resources available. Later many of these plants were, on the other hand, converted to flotation treatment that required much less space than conventional methods. Yet, after WWII the policy started to change slowly, and cities like Tampere gradually started to use groundwater in the 1950s. In 2020 it accounted for about 30% of total water use. (Juuti & Katko, 1998, pp. 101–107)

In a book on inventions, Solitander (1937, p. 164) assessed the pros and cons of groundwater and surface water for community use. He noted that ”…naturally it is more difficult to assess water quantities located underground than visible water bodies. The quality and purity of groundwater suitable for many purposes tend to favor its use whenever possible and also if surface water of reasonable cost is not available close enough”.

In a handbook on water supply and sanitation, Leskelä (1953) noted that community water supply should be based on groundwater and that it is beneficial to convey good quality groundwater from reasonable distances. In 1955 Finnish urban centers had 38 utilities using groundwater (Erkola, 1958, p. 30). However, more serious efforts on using groundwater were not made until the 1960s[1].

Policy promoting groundwater use since 1960s

In the 1960s, the Finnish Government started to promote groundwater use. Several senior governmental experts recall that the idea was discussed in many long-term plans. Awareness of groundwater started to increase, leading to regional groundwater investigations and planning of groundwater use. (Mälkki, 1980) From the 1960s until 1974 it was commonly believed that cities as well as their per capita use will grow continuously, and therefore only surface waters will meet the demand (Niemelä, 1961, 13). Since 1974 the per capita use started to decline and, in many cases, also the total use. (Katko, Juhola, & Kallioinen, 1998) This decline likely favored the use of groundwater.

After the establishment of National Water Administration in 1970, the use of groundwater in community water supply became practically a paradigm. This can be seen in several multipurpose plans for watercourses completed in the late 1970s and early 1980s. Besides, cities using surface water were instructed to supply at least 50 liters (13 US gallons) of groundwater per person per day, bearing in mind crisis supplies. (e.g., Vesihallitus, 1981)

During the International Drinking Water Supply and Sanitation Decade (IDWSSD) 1981–1990, the use of groundwater was also favored. (Saviranta & Katko, 1990;

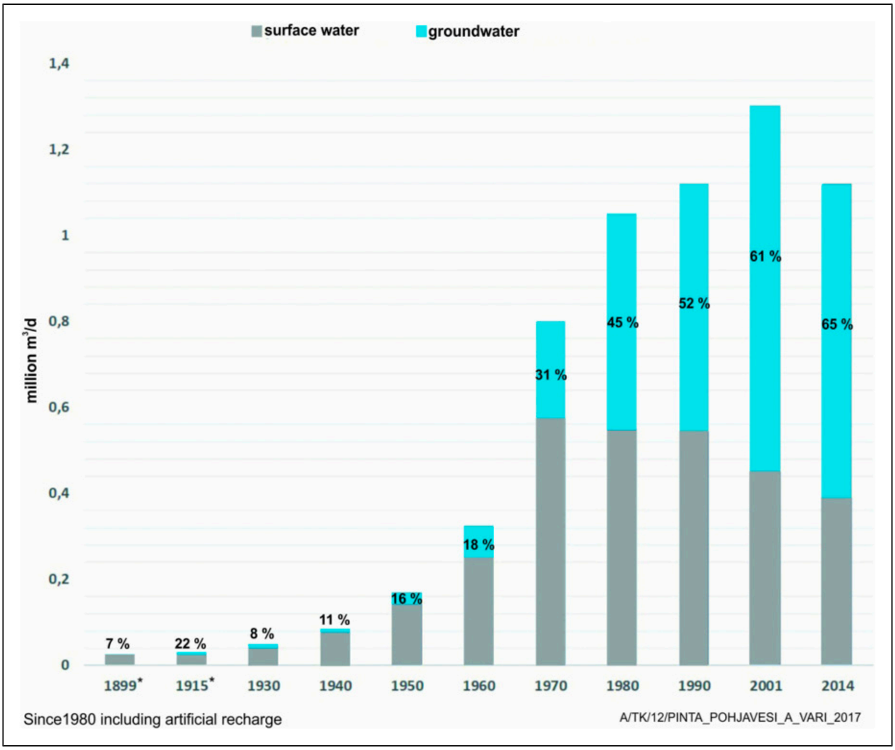

Figure 2. Use of raw water for community water supplies and the changes in relative shares of surface water and groundwater use in Finland, 1899–2014. (Bergman, 1916; Hausen, 1900; Erkola, 1958, 30; Peräkylä, 1967; SYKE, 1995; J. Rintala, Personal communication, September 21, 2020).

Saviranta & Vikman, 1990) The 1986 Chernobyl nuclear power plant disaster in Ukraine and its fallout heavily impacted Finland and promoted the use of groundwater as well. However, a reference to any specific policy decision favoring the groundwater paradigm and policy from the 1960s–1980s could not be identified[2].

Figure 2 summarizes the relative changes of surface water and groundwater use (including artificial recharge) for community water supplies from 1899 until 2014. The share of groundwater has continuously increased since 1940. In the early part of the 20th century, the relative share of groundwater decreased after many cities turned to surface water sources. In 1970 the share of groundwater use was 31%, and by 1980 it was 45%. The shares of groundwater and surface water uses were equal in 1984 (Isomäki et al., 2007, p. 11) From 2014 until 2020 the estimated share of groundwater and artificial recharge has remained at 65% for community raw water source. (J. Rintala, personal communication, September 21, 2020)

In the early 1970s the first classification of the most important groundwater areas for community water supply was prepared. The 1987 amendments to the Water Act emphasized groundwater protection. The Water Administration of that time promoted groundwater use through planning, investigations, financial assistance and by employing groundwater experts throughout the administration. (L. Saviranta, personal communication, February 3, 2012). Protection measures taken with regard to salt used for road maintenance and deicing purposes in wintertime, particularly for traffic safety reasons, can be mentioned as one example. Since the 1980s, approximately 300 km of groundwater protections in areas of high importance for community water supply have been made along the main roads. Recently the Finnish Transport Infrastructure Agency has renewed the guidelines for reaching more efficient protection. (Grekula, 2021)

By the 1990s, the national information and knowledge base on groundwater resources to support policymaking had become well consolidated and accessible. Currently, the groundwater database (POVET) carries information on approx. 6,000 classified groundwater areas and their management according to the Water Framework Directive (WFD), as well as information on 80 national monitoring stations. Qualitative and quantitative data on the state of groundwater areas is collected in the database as well as survey results on risk factors and land use. The database also includes information on observation tubes, wells and springs located in the classified groundwater areas. (SYKE, n.d.)

Outside of Finland, the debate between groundwater and surface water use has also occurred, e.g., in development cooperation projects supported by the Finnish Government, such as the one in Sri Lanka in 1980–87. An international evaluation team and media in Finland favored the use of groundwater, although these resources were estimated to be inadequate to meet the needs of a growing population. (J. Hukka, personal communication, March 8, 2012)

Most current debate: regional contentious groundwater systems

For two decades or so, the preference of groundwater over surface water for community water supply in Finland has become less rigorous. This is likely due to a few groundwater pollution cases and the relatively dry years of 2002–03 (Vienonen, Rintala, Orvomaa, Santala, & Maunula, 2012, pp. 23–43), among others, that reduced groundwater availability/supplies.

In Finland community water supply has increasingly relied on natural groundwater and artificially recharged groundwater as raw water source. Several MAR projects have proceeded considerably well in co-creation between the involved parties, whereas some cases have faced considerable resistance among the public or some of the stakeholders.

The first modern MAR systems in Finland were constructed in the 1970s. A study by the Water and Environment Administration (Kivimäki, 1995) included 28 actual bank infiltration facilities where more than 30% of the abstracted groundwater originated from bank infiltration, but beyond these, potential for enhancement of yield by bank infiltration was identified at various waterworks. By 2012 there were altogether 25

MAR plants in Finland producing supplies to 16% of the country's total drinking water (Kurki, Lipponen, & Katko, 2013). These systems mostly use basin recharge, but also sprinkling infiltration, well injection, and a few use bank filtration (Katko, 2016, 62–65; Jylhä-Ollila, Laine-Kaulio, Niinikoski-Fusswinkel, Leveinen, & Koivusalo, 2020). It is often difficult to assess the actual magnitude of filtration, not least due to the fact that over time, especially as a function of the raw water quality, the permeability may change.

The major advantages of MAR systems include a planned overall system, good and homogeneous quality, nearly stable temperature, and non-use of chemicals. Disadvantages may cover the risk of raw water pollution, possible problems due to blue-green algae occurring in the surface water source during warm seasons, impacts on the recharging environment, and potential economic and social contradictions because of competing interests. (Isomäki et al., 2007, 53; Kurki, 2016) The possibility to shut down raw water pumping temporarily in case of raw water pollution without stopping water supply is considered as an advantage of certain types of MAR systems.

According to Kurki (2016), success or failure in MAR cooperation is largely related to management cultures and ways in which various interests are taken into account, from the very beginning throughout the project cycle. Here we refer to two conflictual case studies in Finland: one in the Turku region and the other in the Tampere region.

In the first case, the project started in 1972 with the original aim of drawing surface water from a long distance to Turku (Figure 1) and its neighboring municipalities. That time Turku drew its raw water from the local river, the quality of which had become very low due to pollution and natural discharge within the region. After negotiations in the early 1970s, several of the neighboring municipalities decided to join the project. However, after the elections a new local government of Turku, the central city, voted down the project in 1993, and thus replanning started. (Kurki, 2016, pp. 30–32)

In the late 1980s, the MAR option came on the agenda. In spite of some resistance, the project was finally implemented by drawing raw water from the river Kokemäenjoki further to the north, and after preliminary treatment pumping it to a MAR system 30 km southwards. Thereafter water is pumped 70 km further towards southwest to the supply area. The Turku region MAR project is the largest in Finland, currently supplying approximately 65,000 m^3 per day. Although it took 40 years to implement the project, the delay allowed more time to use and develop modern hydrogeological surveys with 3d modelling etc. within the MAR area (Artimo, Saraperä, & Ylander, 2008). These studies showed higher yields than was originally assumed. From that point of view the delay was beneficial. (Katko 2016; p. 65) Zheng et al. (2021, 22) note that "The system is extensively monitored and managed to ensure compliance with environmental and health regulations." In this case a critical value was produced through thorough hydrogeological and hydrochemical investigations (Zheng et al., 2021, p. 71).

In the second case, after conducting groundwater investigations, two neighboring municipalities persuaded the region's largest city, Tampere, the central city of Tampere to join the project. A supra-municipal wholesale company was formed for the MAR project in 2002. However, the same year, people in a third municipality started to oppose the project where an infiltration area was planned within its boundaries, as that municipality did not see the project as necessary. Besides, according to several sources, negotiation tactics by the city of Tampere failed by giving an overpowering impression of itself. Later one of the initiating municipalities had a new surface water treatment plant constructed and decided that it wants to sell its share in the joint MAR company. The project has faced several appeals to all possible levels of courts, while the process continues, with some kind of MAR scheme still possible in the future.

The findings of the two cases indicate that conventional management approaches, relying on expert-based instrumental rationality, were inadequate. Kurki (2016) points out that legitimacy for groundwater projects should be gained through joint knowledge production and interaction in creating options for collaboration. The emerging paradigm, called for by Kurki (2016), emphasizes more collaborative approaches for natural resources management and urban planning. Such issues should be taken more seriously also in education and research, if the aim is to promote MAR systems with their huge potential. The cases also imply that it is important to consider collaborative tactics and strategic thinking by which potential constraints can be avoided or alleviated.

Using groundwater or MAR can also be connected to the auxiliary water source required for larger cities since 2006 (Council of State, 2006, p. 73), as in the case of Oulu (Figure 1) in Northern Finland where the major water source is the local river. When the Supreme Court did not grant permit for drawing the suggested amount of 32,000 m^3/d, options for water sources were explored by a multi-criteria analysis. However, it proved difficult to restore trust in a situation where all the stakeholders were not adequately heard in the very beginning. (Rantala, Karjalainen, & Rossi, 2014) In 2015, the city decided that the primary source will be the river, augmented by groundwater. The project continues with permit request of one third of the original, but its future is still unknown (Lähdemäki J., personal communication, April 5, 2021).

Interestingly, there have also been cases in Finland where hardly any resistance has existed and the local community has largely supported and even promoted MAR systems. Such cases have been identified in Hämeenlinna (Figure 1) where both basin and sprinkling infiltration have been used in a protected area next to the city. Another case is noted in Jyväskylä (Figure 1) where, in the 1990s, the promoters seemingly used proper tactics in first negotiating with landowners on the grounds on which MAR could be implemented (Katko, 2016, p. 65) A survey on the experiences by water utilities indicated that when pumping rates increase, potential resistance will also increase (Wallin, Salmi, Rossi, Karjalainen, & Rantala, 2016). Further studies on the reasons behind such successes would be worthwhile. According to Jylhä-Ollila (2022), contentious groundwater and MAR projects have reached a lot of visibility in the media, while more successful projects are hardly heard about. Such a recent case is in Nurmijärvi, 30 km north of Helsinki. The required permits were applied for and granted in less than one year and the whole project likely takes four years only before it can be used. (Öhberg, 2022)

Case study on tasting surface and groundwater

One key argument in favor of using groundwater is its assumed better taste. This has often been used in Finland, and especially in the case of the planned supra-municipal MAR system in the Tampere region. To explore this, a simplified tasting test was organized in a situation where the participants most likely used to drink both groundwater and surface water in their everyday life. Therefore, their earlier experiences most likely did not clearly favor either of the options. During the overall 3-hour tasting session the temperature of the water in the containers changed from 5 ($\pm$ 1) °C to 10 ($\pm$ 1) °C. This temperature range resembles that of the tap water served in Finland. (Luonsi, 2014)

The two waters A and B were kept unidentified to the participants. The surface water, tapped for sample A, was taken from a lake 20 km west of Tampere, the major raw water source of the city. The treatment of lake water contains carbon dioxide, lime and ferric sulphate additions, water/air dispersion for flotation, sand and activated carbon filtration as well as chlorine dioxide and/or chlorine additions and UV radiation.

The groundwater sample B was a mixture supplied from different groundwater intakes 25–60 km from the main delivery area in Sastamala, some 60 km southwest of Tampere. Their treatment included only alkalization with soda/lye/lime addition and disinfection with UV radiation. Disinfection for the delivery network was made by chlorine.

Only five out of 167 persons perceived that there was no taste difference between these waters. Surface water received 19 preferences (12%) and groundwater as many as 143 (88%). Water networks connected to the taps used for sampling were of different age: 5–7 years in the groundwater case and approximately 20–25 years in the surface water. For assessing potential reasons for the taste differences, water quality data was collected from the water works close to the time of the sampling for the tasting test. Higher organic matter indicated by Total Organic Carbon in surface water is likely connected with worse taste. Similar potential in the treated surface water is seen through higher conductivity and hardness values. Unfortunately, proper simultaneous analyses on residual chlorine were not available.

In conducting the tasting test, there were some practical limitations and drawbacks such as the inadequate privacy of the tasters, and the order of tasting with water sample B first. In an ideal tasting environment, no other eating or drinking is allowed, either. Arranging such conditions in relation to a public event was in practice not possible. This was known in advance, and preference was given to a high number of testers. In spite of its obvious and unavoidable drawbacks, the results, however, clearly favored better taste of groundwater over surface water, and thus the test can be here considered justified.

Pros and cons of surface water and groundwater

For supplementing the three angles on the selection of surface water and groundwater as community water source, the pros and cons as seen by 14 Finnish experts are shown in Table 1. Groundwater was generally considered as having better quality, being less costly and easier to treat, and having stable temperature and better taste. Yet, it is a limited resource, more difficult to clean if polluted, and faces occasional quality problems.

Surface water was deemed easily accessible, often with adequate quantity, and improved quality thanks to water pollution control. Its cons included changes in water quality, more costly treatment, and generally lower quality. Some of the identified issues were noted both in pros and cons. In principle, groundwater is better protected by the hosting or overlaying geological formations and therefore less vulnerable to surface

Table 1. Pros and cons of surface water and groundwater for community raw water source. For surface water six pros and five cons, and for groundwater nine pros and seven cons were first identified. These were ranked by 14 experts (1 for the most important, highest number for the least important)

Source	Pros (scale 1 to 6 for SW; 1 to 9 for GW)	Cons (scale 1 to 5 for SW; 1 to 7 for GW)
Surface water	* easy to access 1.9	* changes in water quality 2.2
	* adequate quantity often available 2.6	* more costly and difficult to treat 2.3
	* due to efficient water pollution control quality has improved remarkably 3.0	* generally lower quality due to humus and acidity 2.4
	* treatment methods have developed 3.7	* large variation in temperature 3.1
	* can be seen if polluted 4.7	* not visible in wintertime 5.0
	* visible for most of the year 5.1	
Groundwater	* generally better quality except for coastal areas 2.8	* limited resource 2.3
	* generally less costly and easier to treat 3.1	* more difficult to clean if polluted 2.9
	* more stable temperature 4.1	* occasional quality problems (fluoride, iron, manganese, radon) 3.4
	* better taste 4.6	* more difficult to assess yield 3.6
	* possibility to increase yield by MAR 4.6	* sometimes exploration may be expensive 5.1
	* source for crisis situations 5.2	* landowners may think they own the resource 5.2
	* safer against nuclear fallout 6.5	* mostly not visible 5.6
	* normally no overexploitation due to permit system and control 6.6	
	* modern exploration techniques have proved useful 7.5	

pollution. On the other hand, groundwater may be more exposed to leaks from networks or septic tanks underground which are harder to detect.

Discussion

The first research question on the reasons for policy changes in various phases are not that straight-forward. Conflicts between various schools of thought appeared in the early 1900s related to the assessment methods of groundwater yield. Since there were diverse views of estimating safe yield, the surface water option seemed easier and more practical in the 1920s considering the methods available that time.

The strong policy that favored the use of groundwater for community water supplies started to emerge in the 1960s and was likely at its strongest in the 1980s. Instead of being based on a single policy decision, it was rather an accumulated development path where the improved knowledge on groundwater areas and their potential likely played a role, among other factors.

In Finnish conditions, particularly beyond the most extensive esker systems and ice-marginal systems, groundwater-bearing formations are typically mosaic, fairly small, and commonly discontinuous due to complex internal structures and heterogeneity. Therefore, exploration of groundwater conditions and further safe yield may not be that easy even with the most current methods, pumping tests and major undertakings.

More recently, different views of the safe yield and in particular environment impacts of groundwater and MAR projects seem to exist. Some of these at least partly resemble the debate a century ago. In any case, in current regional contentious groundwater or MAR projects some hydrogeological experts have joined ranks with both the supporters and opponents on a voluntary basis or through expertise services.

Regarding the views of the public, one likely common view is the perception that landowners and even municipalities would own the groundwater in their area. In Finland, groundwater is not owned by anybody, but its use is to be decided by public authorities and the court system, based on legislation. Besides, in Finland the landowner is entitled to use groundwater max 100 m^3/day for his own use, provided that it does not negatively impact the neighbors or the environment (Water Act 587/2011–2:15, 3). If abstraction from the groundwater formation exceeds 250 m^3/day, it is subject to obtaining permission (Water Act 587/2011–3:3, 3). If infiltration of water into ground for the purposes of MAR is involved, a permit is always required.

This perception of landowners is understandable since the country has a strong and long tradition of private ownership of land and forest. Even today most of the forests are owned by private people. On the other hand, it is no wonder that common people may be confused with the use of groundwater and MAR systems, if and when even the experts seem not to share similar views among themselves.

Municipalities, from their part, are currently in charge of granting permits to extract sand and gravel that may conflict with potential groundwater use. The environmental impacts of MAR using any of the available techniques cannot fully be avoided, either. However, the negative environmental impacts of sand and gravel mining are certainly larger and of different magnitude, and everlasting. Thus, we must wonder why these problems have hardly raised any resistance. Perhaps sand and gravel mining are still seen as a positive factor in promoting municipal economic life.

Our case of tasting samples of groundwater and surface water in a public event strongly favored the better taste of groundwater in spite of the limitations and partial drawbacks for this study. Although these tests are not qualitatively adequate alone, they, however, help in making up a holistic view on the topic. Our rapid survey on the pros and cons of groundwater and surface water for community use in Finnish conditions favored groundwater over surface water sources as well.

With the current emphasis on water safety and security in Finland and worldwide (Ministry of Agriculture and Forestry, Ministry of Economic Affairs and Employment, Ministry of the Environment, Ministry for Foreign Affairs & Ministry of Social Affairs and Health, 2018), and likely the increasing expectations on better services by the citizens, the groundwater option is likely to maintain its position as strong as it currently is or even stronger in the future.

In community raw water selection, a few issues may be recognized as change drivers from the late 1800s to 2020. In 1920, the change in favor of surface water was mainly driven by *cost and reliability* issues. After WWII, certain *technology* factors still favored surface water while *reliability* started to promote groundwater use. Since the late 1980s, *security* issues have also been emphasized in favor of groundwater. Interestingly, *environmental* concerns are still seen as controversial, since in large groundwater and artificial recharge projects the opponents are pointing out the negative impacts while largely ignoring the conservation potential of groundwater use versus gravel mining.

Political scientists may point out that in small countries such as Finland we tend to act fast in the changes in the operational environment should the conditions so require (Briguglio, Byron, Moncada, & Veenendaal, 2020). However, in raw water source selection and priorities sudden changes are far less likely. Therefore, over the last 100 years, in spite of changes in focus, continuity seems to have been a major principle. In the future, both surface water and groundwater sources and their conjunctive use are to be secured.

Policy implications

As for the policy implications for the future in Finland, the major aim will continue to be, as per the WFD, to keep both groundwater and surface water sources in as good state as possible. Due to active pollution control since the 1960s, especially the point-source organic and phosphorous loadings are largely in good order. Yet, loadings from non-point sources such as forest and farmland are far more difficult to manage and control. The use of MAR is expected to increase as there are not enough groundwater areas in the proximity of many cities where sufficient natural groundwater could be supplied from (Britschgi et al., 2018).

A good long-term case of active groundwater protection comes from the Tuusula Region Water Utility (currently called Keski-Uudenmaan Vesi in Finnish), 30 km north of Helsinki. Established in 1967, the utility has actively protected their groundwater areas. It has bought land in groundwater areas with earlier polluting activities and then reconditioned them as well as old gravel mining areas. Their struggle, almost 40 years long, of protecting groundwater areas was awarded in 2000 by regional environmental authorities. This federation of four municipal authorities was largely established to create social pressure for protecting the main groundwaters within the region. Besides, as early as the late 1960s, the utility adopted a proactive public relations and communications strategy whereby they had contacts to major regional and national media of that time. (Katko, 2007, pp. 162–167) Interestingly, such reputation management proactively seems to be absent in the two cases of contentious MAR projects of this paper, although they might not be directly comparable.

Ensuring a high potential for use, effective protection of groundwater benefit from forward-looking urban and land use planning. Among the means are coordinating plans to reconcile different activities that depend on the resources hosted by eskers and ice-marginal formations: gravel, construction foundations, recreational areas and groundwater. While MAR infiltration areas may be located very far from the users (as in the case of Turku), observing groundwater protection zones gets more challenging within and in the proximity of settlements.

Historically, industrial or residential areas or roads, possibly posing risks of pollution, may have inconveniently ended up on top of groundwater bodies. De-icing of roads in wintertime has been a source of pollution in some areas, and while the protection measures adopted since the 1990s have proved to be at least partly inadequate, preventing pollution is more cost-effective than trying to purify the polluted groundwater. More recently emerged potential of groundwater relates to cooling or heating which can provide benefits for infrastructure, further indicating value of co-ordinated development.

The advantages of conjunctive use include improved security and resilience where both surface water and groundwater sources are available. Nevertheless, holistic assessments of the strengths of each water source and integrated planning are still relatively rare. Through path dependence the larger Finnish cities are bound by the water supply decisions they made in the past based on the information and projections available at the time. For example, the Finnish capital city area is supplied with surface water conveyed through a rock tunnel from 120 km away (Lipponen, 2006); motivations at the time of the planning in the 1960s included quality problems related to near-by sources and expectations of significant water use increase.

For developing and expanding cities, the benefits of diversifying their water sources should be evaluated, and planning backup water intakes can be a concrete solution occasion to that end. Major cities should have at least two water intakes or intake areas. If conditions allow, one of them should preferably be groundwater.

Although Finland has abundant water resources, it is not immune to climate change and its impacts on water services. Vienonen et al. (2012, p. 86) found out that substantial effects are expected due to more frequent extreme weather events such as prolonged droughts, storms, heavy rainfall, and floods. For raw water selection, adaptation measures include positioning intake wells in groundwater bodies with favorable water yields and outside of flood risk areas. Veijalainen et al. (2019) simulated the severe drought of 1939–1942 and found out that severe drought would significantly reduce water supply and hydropower production. Thus, water utilities should have extra capacity or alternatives in their intake systems.

In large-scale future groundwater and MAR projects better understanding of the socio-economic conditions, major players and their wishes are needed. Otherwise, extensive delays can be faced. In any case, it is very obvious that both surface and groundwater sources are needed. As Abell et al. (2017) note, healthy source watersheds are vital natural infrastructure for nearly all cities around the world. Besides, along with expected urban growth, cities will need to play an active role in protecting their water sources on which people and nature depend. Regarding the futures, all significant groundwater resources for community use have not yet been found or investigated. These include sand and gravel deposits that lie in deformation zones below those formed during the last ice age (Skyttä et al., 2015). This would favor additional use of groundwater when located at a reasonable distance from users.

One development is the concept of multilocality, since 860,000 people in Finland work outside their home municipality and 2.4 million regularly spend time in the country's 512,000 second homes (Finnsson, 2021). The COVID-19 pandemic has reinforced the role of second homes and, related to water, the importance of rural water supplies and on-site systems where groundwater is a dominant source.

The World Water Development Report 2022 (United Nations, 2022) reminds that groundwater offers multiple services which may include; (i) provisioning services allowing groundwater to be withdrawn for human water uses (ii) regulatory services based on the buffer capacity of aquifers; (iii) supporting services on which groundwater-dependent ecosystems and other environmental features rely; (iv) and cultural services linked to leisure activities, tradition, religion or spiritual values. The report also reminds that groundwater accounts for approximately 99 percent of all liquid freshwater on Earth and thereby it has a huge potential for use, bearing in mind its sustainable and resilient use. Taking stock of the situation across the world, the UN WWDR highlights various distinguishing characteristics and benefits of groundwater as a water source. Among others, users can access the resource directly and in a decentralized way.

Another very recent episode, the war in Ukraine that started in late February 2022, is a reminder that the risk of nuclear fallout still exists and the use of groundwater should therefore be preferred or it should at least be available just in case it is needed in such crisis situations.

Conclusions

Based on our study the following conclusions on the selection between surface and groundwater for urban raw water source in Finland are drawn:

(i) There has been a long and continuous debate and remarkable changes over the emphasis on the selection of surface water and groundwater for community raw water source, and it seems to continue.
(ii) Since the 1960s, Finland's central government has supported groundwater exploration and mapping of groundwater areas and thereby promoted groundwater use.
(iii) Strong policy favoring groundwater use for community purposes particularly from the 1960s–1980s was based on accumulated strategy instead of specific policy decisions.
(iv) With the limitations described, the tasting test by 167 persons people indicated the clear preference (86%) of groundwater over surface water.
(v) Pros and cons of groundwater and surface water uses seem to favor groundwater although surface water also plays a role and has its advantages.
(vi) In spite of path dependent determination and some changes in focus over time, considerable continuity seems to be a major principle.
(vii) Since large groundwater and MAR projects in Finland may still create opposition among the public, we propose using more collaborative approaches and involving all major stakeholders in the early phases of master planning for such projects. Such joint knowledge production and interaction could potentially reduce the confrontations.

For the futures, it is important to keep the quality of both surface water and groundwater sources as good as possible, since both will be needed for community use especially in the growth centers. Challenges include the general trend in the climate change with increased extreme conditions including rainfall patterns, its distribution and intensity, as well as surface runoff.

Whatever the raw water sources, it is always important to protect them for various types of community uses and citizen needs. It is also vital that the cities 1) make sure their water sources have adequate capacity for their future needs, projected based on sound assessments, 2) take into account groundwater protection in land use planning and reconcile it with other needs in the development of built environment, and 3) optimize the use of water sources utilizing the potential for conjunctive use. Such forecasting policies should be taken into account also in education and research.

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Notes

1. over 3,000 people became sick, over 300 died
2. approximately a dozen requests to experts of that time by the corresponding author

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