Groundwater use and policy in community water supply in Finland

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Abstract Selection between ground and surface water in community water supply has been one of the key strategic questions in Finland since the early 1900s. After some cities failed to find reliable groundwater sources, many turned to surface waters. Since the 1950s the use of groundwater and artificial recharged groundwater have continuously increased. Presently their use is promoted by the government and European water policy through technical advice and financial support. It is obvious that the share of groundwater and artificial recharged groundwater will increase in the future. This requires active public response and transparency in decision-making.

Resumé Le choix parmi l'utilisation de l'eau de surface ou de l'eau souterraine comme source d'approvisionnement en eau potable est, depuis le début des années 1900, une question stratégique en Finlande. Suite à l'échec de certaines villes à s'approvisionner en eau souterraine, plusieurs se sont tournées vers l'eau de surface. Depuis les années 1950, l'utilisation de l'eau souterraine et la recharge artificielle des aquifères est en constante croissance. Actuellement, leur utilisation est encouragée par le Gouvernement ainsi que par la politique européenne de l'eau qui fournit une expertise technique et un soutient financier. Il est évident que les proportions occupées par l'approvisionnement en eau souterraine et la recharge artificielle vont augmenter avec le temps. Ceci requiert une participation active du public ainsi que de la transparence lors du processus décisionnel.

Resumen Desde el principio de 1900 una de las preguntas estratégicas clave en Finlandia es la selección entre agua subterranea y de superficie para el suministro de agua de la comunidad. Muchas ciudades renunciaron al agua de superficie luego de haber fracesado en encontrar fuentes de agua subterránea confiables. Desde 1950 el uso de agua subterránea y de agua subterránea recargada artificialmente ha aumentado continuamente. Actualmente los políticas de agua del gobierno y de Europa promueven su uso por medio de asesoría técnica y apoyo financiero. Es obvio que la participación del agua subterránea y del agua subterránea recargada artificialmente va a aumentar en el futuro. Esto requiere una respuesta activa pública y transparencia en el proceso de toma de decisiones.

Keywords Artificial recharge · Groundwater management · Groundwater/surface-water relations · Water supply and policy · Finland

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Introduction

This paper highlights the evolution of groundwater use and policy in community water supplies in Finland over the last 100 years. It is mainly a literature survey, based partly on the book by the first author (Katko 1996, 1997), complemented by some more recent statistics and studies (Juuti and Katko 1999) and practical and policy experiences by the second and third authors (Rönkä 1983). The literature is reviewed also on the technical developments relevant to groundwater utilisation and potentially polluting activities that have influenced policies.

The objective of this paper is to describe the importance of groundwater in urban and rural water supplies in Finland, the key technical options and their development. The paper discusses the policy implications and long-term impacts of the key strategic selections made related to groundwater and its use in community water supply. The government and European water policies are discussed in terms of groundwater use in Nordic conditions. The recent high international rankings of the strongly groundwater-based public water supply in Finland, in measures

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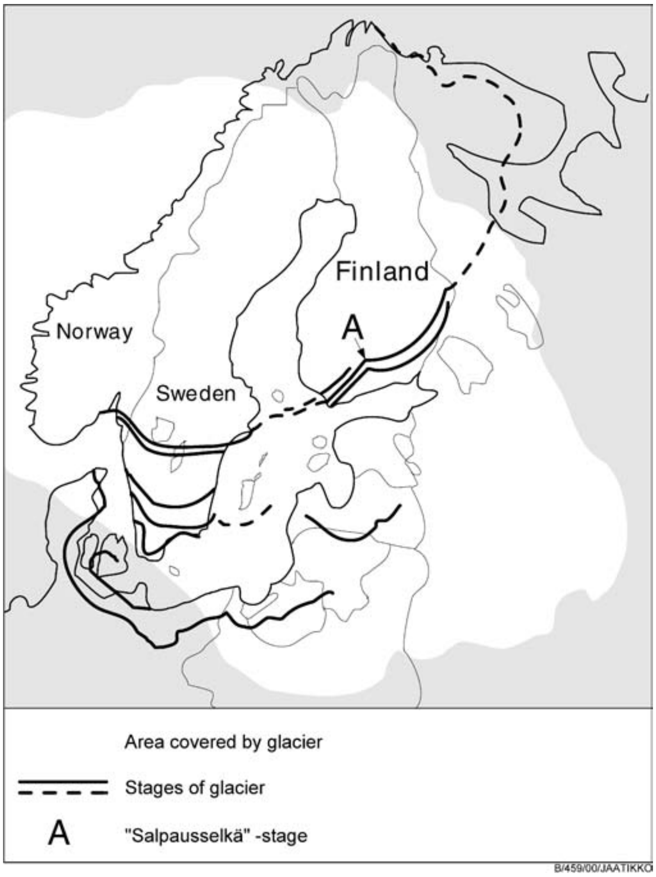

Fig. 1 Glacier over Fennoskandia during the last ice age showing the different stages and the Salpausselkä traverse ridge (Korhonen and Gardemeister 1971, modified)

such as the Water Poverty Index (Sullivan et al. 2002) and the World Water Development Report (WWAP 2003), justify an analysis of the water resources and factors that have affected the policy. The approach of this paper is a combination of hydrogeology, civil engineering and history of technology.

The geological history of Finland and the so-called Fennoscandia largely explains the distribution of water resources and has had an impact on the quality of ground and surface waters. In fact, only the first and the last pages of any international geological handbook apply to Finland: only the oldest formations of Precambrian bedrock and the youngest glacial formations are found in the country. Finland has likely been covered by continental ice sheets many times during the last 115,000 years (Donner 1995).

The last ice-sheet retreated from Finland about 9,000 to 12,000 years ago (Fig. 1). The halt of the ice retreat for approximately a 1,000 years, 11,000–10,000 B.P. lead to the formation of the Salpausselkä ice-marginal formations (e.g. Hyvärinen 1973), and that together with joining eskers host a large proportion of significant aquifers. The glacier pressed the Earth's crust downwards, which, upon melting, resulted in slow land uplift that was especially pronounced on the western coast of Finland, and the associated tilting has affected the hydrological regime (Eronen 1983).

The Finnish aquifers reflect the hydrogeological setting characteristic of Finland and comprise glaciofluvial deposits such as eskers and ice-marginal formations. The most extensive survey of the groundwater areas was carried out in 1988–1995 (Britschgi and Gustafsson 1996). The glaciofluvial aquifers are mostly unconfined, long, narrow, only a few tens of metres thick, and are composed of sand and gravel formations. In the zone of the First Salpausselkä, the median size of aquifers in eskers deposited in shallow water and discharging to the environment is 2.4 km^2 (Hänninen et al. 1994). The median size of a type aquifer in ice-marginal formation is 3.5 km^2. The volume of groundwater storage is small, and characterised by relatively short residence time. Therefore, for larger water supply purposes groundwater resources are commonly increased by artificial recharge. Today, glaciofluvial aquifers provide close to 60% of publicly distributed community water (FEI 2002). If very small and individual systems are included, the total share of groundwater is some three quarters.

Groundwater in Finland is usually of good quality and, except for the coastal areas and for some geologically distinct areas of limited extent, it meets the requirements set for household water. In general, groundwater in Finland is acidic with a mean pH of 6.4 (Lahermo et al. 1999), a $Ca\text{-}HCO_3$ type and soft due to the granitic bedrock and the lack of carbonate sediments (Lahermo et al. 1990, 1999). Especially on the western coast, acid sulphate soil, formed during the brackish Litorina Sea period some 7,000 years ago, presents a special problem. When these layers are exposed to atmospheric oxygen, e.g. due to flood control and agricultural activities, exceptionally high sulphur loadings may occur (Weppling 1997). In these areas, groundwater wells often have quality problems.

In the western part of the country, surface waters are typically rich in humus. Watercourses are covered by ice during the winter and groundwaters are very soft compared to, for instance, Central Europe where limestone units in bedrock are more common. Especially in the coastal areas, groundwater contains high concentrations of iron and manganese, which present problems for water treatment and water supply. National (Lahermo et al. 1990) and regional geochemical surveys of groundwater quality have increased the awareness of natural, geology-derived quality defects and have helped to identify problematic areas. In the 1990s, some quality problems due to fluoride emerged that were linked to bedrock wells in the southern coastal areas, also outside the bedrock areas consisting of fluorine-bearing granites, where such problems have been met earlier. In some southern inland areas high arsenic values have been detected in similar wells (MoSAH and NBoWE 1997). As the concentrations of substances originating from soil and bedrock are typically higher in bedrock groundwater than in groundwater in superficial deposits, the geology-based areal quality problems are particularly relevant to drilled wells com-

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monly used for private water supply. Their emergence has led some representatives of national health authorities to recommend refraining from utilising drilled wells in the identified risk areas (Hiisvirta 1994). Nevertheless, in a recent international assessment by United Nations agencies, the water quality in Finland was ranked the highest among 122 countries (Esty and Cornelius 2002; WWAP 2003).

In the international Water Poverty Index (WPI), which measures a countries position relatively to others in the provision of water (Sullivan et al. 2002) and takes into account both water resources and their management, Finland was ranked the first country in the world. This ranking provides a measure of how well water is available and accessible, internationally, because Finland has a largely groundwater-based system of water supply. WPI is a measure of water-wellbeing and is a weighted additive value of five major components: resources, access, capacity, use and environmental impact. The groundwater and surface water availability, adjusted for quality and reliability, affect the score through the resource component of the index. Finland fared particularly well with respect to the components of use, capacity and environment. The environment component includes indices of water quality and water stress (pollution), among others. The weighting given to different components and the chosen indicators in general affect the ranking. The high score nevertheless infers to certain merits in the environmental and management setting in Finland.

History of Groundwater Investigations and Use

Early Wells

In the countryside, domestic water has traditionally been taken from natural springs when they occur in the vicinity. For several reasons, dwellings were often situated along bodies of water and also occasionally close to natural springs.

The oldest Finnish wells have been found in prehistoric dwelling places and under old city streets and castles. A French expedition visited the Tornio River valley in the northern part of the country, among other places, in 1736–1737. A drawing by a member of the expedition depicts a well with a counter-poise lift close to the dwellings, and a natural spring adjacent to the village (Outhier 1744).

Up to the mid-1880s, urban water supply was quite similar to that of rural areas. For instance, Helsinki had many public wells in addition to private ones. However, towards the end of the century water quality and quantity problems arose. The worldwide cholera epidemic in the 1830s increased the interest for improving the hygienic conditions in Finnish urban areas, although public water supply systems were not considered at that time. The water quality of public wells deteriorated gradually along with the population growth.

Debates on Groundwater Use

One of the key questions in establishing an urban water supply system at the turn of the 20th century was whether to use groundwater or surface water. Vyborg, in present-day Russian Karelia, was the first Finnish city to use groundwater for public supplies in 1892, followed by Turku on the south-western coast in 1902. In Helsinki, on the southern coast, the idea to use ground or spring water was already raised in 1875. The first groundwater investigations for the Helsinki area started in 1898 followed by surveys in other areas.

During the first two decades of the century, a heated public debate was conducted in the country on the availability and feasibility of using groundwater for urban areas. There were two major schools: the geological 'bird's eye view' and the theories developed by Thiem, the famous German hydrogeologist, based on particle size and water conductivity. In several cases, the estimated yields proved to be too high. After the biggest cities decided not to use groundwater, the interest towards groundwater investigations and research was almost abandoned for several decades (Gagneur 1910, 1918; Sederholm 1911; Lillja 1938; WA 1990).

The city of Tampere prepared detailed plans for using groundwater, but in 1920 the project was postponed at the last moment. Now the city is planning, together with the neighbouring municipalities, a new system that uses artificial recharge by the year 2010 (Juuti and Katko 1999). Thus, the new system may become a reality a century after the first investigations.

Historical Development of Well Construction

In 1950–1951, the Engineering Division of the National Board of Agriculture conducted a survey of rural water sources. The most common water-lifting devices at that time were the bucket and rod, the hand pump and the windlass. It was also estimated that, in 1952, Finnish women walked every day the distance from the Earth to the Moon and back fetching water (Wäre 1952). Since those days, the services have become modernised. Yet, due to long distances and sparse population, there are still some half a million people outside the service of common water supplies. Since the 1980s, the modernisation of these services has been supported by the government. At the same time, people are increasingly using their holiday houses all year round and expect the same level of service as in their permanent dwellings.

Groundwater wells have been constructed either as dug wells or tube wells. Large-diameter dug wells have normally been cast on the spot whereas smaller ones have been made using concrete rings. In the 1960s, a Finnish company developed a special type of screen for tube wells. It is made of PVC and contains plastic rings of triangular cross section. The size of the screen openings can be selected according to the geological conditions. A separate gravel pack is also often used. In the 1950s and 1960s it took about 1 week to construct an average 10-m

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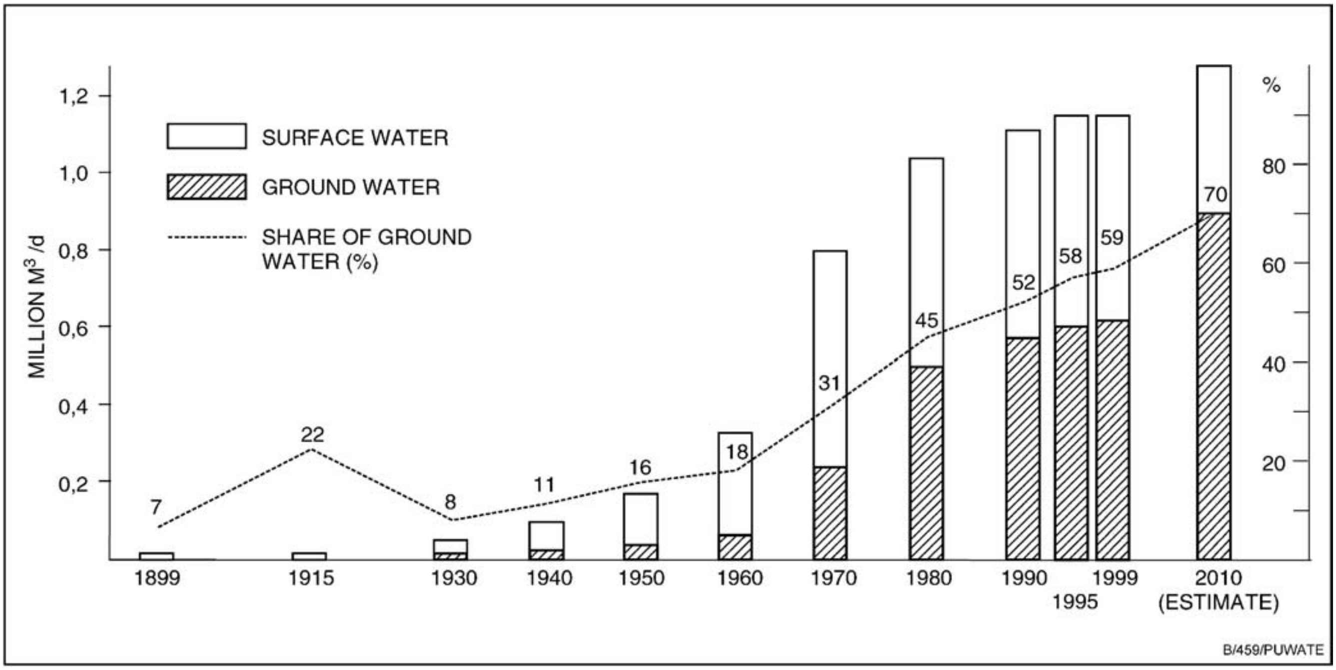

SINCE 1980 INCLUDING ARTIFICIAL RECHARGE

Fig. 2 The development of the amount of water distributed by public water works and the relative share of groundwater in Finland, 1889–2010 (Hausen 1900; Bergman 1916; Peräkylä 1967; Katko 1996; FEI 2002)

tube well. In the 1970s a 20-ton machine mounted on a lorry was developed after which it took 3 days to construct a similar well. In the 1980s, the weight and efficiency were increased and the construction time decreased to 1–2 days.

Nowadays, a typical tube well machine weighs over 30 tons and it is possible to drill a well in 1 day. With the modern machines it is possible to sink the tube on top of the esker since the water quality and quantity are at their best in the 'heart' of the formation. In addition, computer-based field measurements for yield and water quality, screen location and other constructional features have been, and are being developed for in-situ use.

After World War II, many bedrock wells have also been constructed. Some experiments involved cable-tool drilling down to 1,000 m. However, experience shows that it is hardly feasible to drill a rock well deeper than 100 m. In the 1980s and 1990s, the use of high-pressure hydraulic fracturing for increased yield also became common. By the early 1980s, some 3,000 to 4,000 rock wells had been drilled. Higher yields can be gained if fracture zones can be located (Rönkä 1983).

Urban Groundwater Use

There are three key sources for community water supply: surface water, groundwater or artificial groundwater by recharge. Especially in the coastal areas, there are only a few lakes and very often a limited amount of groundwater available. In these areas, consequently, several artificial reservoirs have been constructed for water supply purposes on the rivers or in some cases along the seashore. The share of groundwater and artificial recharge has increased continuously since the 1930s. Yet, in the early part of the century, the relative share of groundwater decreased after many cities turned to surface water sources (Fig. 2). The availability of groundwater in sufficient quantity is variable, as indicated by the distribution of significant aquifers.

There are plans to construct additional inter-municipal water supply systems using artificial recharge in the beginning of the 21st century, two of which are described later. Thus, by 2010, the share of groundwater may exceed 70%. Small systems serving less than 200 people are mostly excluded from these statistics, as well as individual systems that almost always use groundwater. All in all, about three quarters of all consumed domestic water is groundwater.

Groundwater Investigations

Various types of geological and geophysical methods have been developed and put into practice to improve groundwater investigations. Traditionally, water balance thinking has been the core concept, and flow measurements of springs and topography have been important indicators of hydrogeological conditions. Test pumpings have been carried out to estimate hydraulic parameters of aquifers and to estimate the long-term sustainability of groundwater extraction. Measuring groundwater quality in situ in test wells has become increasingly common since the early applications in the late 1970s (Mälkki 1980). Groundwater modelling has become a common

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supporting tool, especially in studying large aquifers and in testing artificial recharge.

Seismic sounding was first used in soil investigations by the road authorities in the 1950s. In groundwater investigations in Finland, the use of the method began in 1960s (by consulting company Maa ja vesi Oy, personal communication Mälkki 2003). The first extensive (artificial) groundwater investigation and inventory of groundwater resources with a so-called deep investigation technique, the basis of which was a wide seismic survey, was reported in 1972 in Säkylä. Later on, refraction seismic sounding has been one of the main surveying methods for groundwater deposits in Finnish conditions. In the 1980s, a modified seismic sounding method involving a hammer was put into use, particularly for small systems serving dispersed rural areas.

Electrical resistivity sounding was already used by energy companies in 1930 and later by the State Railways. In groundwater investigations of a larger scale, this method was used by Finnish companies in a development cooperation project in East Africa in the 1970s, and later on it has been applied also in Finland.

In the 1970s, a method was developed for measuring the direction and velocity of groundwater flow in situ. It was shown that flow velocity in the central part of eskers was almost 100 times higher than earlier believed (Mälkki 1979). One of the key ideas was to measure and also utilise groundwaters from the central part of eskers. Mälkki (1980) concluded that, because of topographical reasons, large aquifers, like most parts of the Salpausselkä ridges, had not been exploited. The development of 'deep' investigation, referring to techniques reaching groundwater level below 8 m, the approximate depth above which preliminary test pumping with simple arrangements was possible, provided means to investigate radial eskers that form the most important aquifers in Finland. The advocated method for 'deep' groundwater (Mälkki 1980) included geological and hydrogeological mapping, seismic sounding, installation of monitoring wells jointly with soil sampling, measurements of groundwater flow velocity, hydraulic conductivity and water quality, and test pumping from a test well. The described procedure was utilised in the investigation made in the Muurame commune (Wihuri and Salmi 1978). It should be mentioned that several of the geophysical survey methods are now being used to investigate contaminated soil and groundwater to help remediation activities.

During the 1980s, ground-penetrating radar became one of the most important geophysical methods in mapping glacial deposits (Hänninen 1991). These formations are the main hosts of aquifers, and the adoption of the method into groundwater investigations has been a major step. The geophysical surveying techniques provide valuable information, particularly in mapping bedrock surface topography and complex underground geological structures. The utilisation of aerogeophysics in the preliminary stage of investigations, as reviewed by Mattsson (2001), has also resulted in important progress.

A limited number of large-scale investigations for water supply on bedrock aquifers have been conducted in the last 10 years, particularly by the Geological Survey of Finland (e.g. Breilin et al. 2003). These have involved aerogeophysics for fracture zone interpretation, as well as seismic, conductivity and resistance soundings. The cost is still a potential constraint to extensive use of geophysical methods of investigation.

Artificial Recharge

The production of artificial recharge had been already experimented with in Scotland in the 1810s. In Essen, Germany, a plant based on the same principle started operating in the 1890s. Similar ideas were already suggested in Finland in the 1870s. The first experiment with artificial groundwater infiltration took place 1912–1914, but the method was not taken into use due to insufficient purification of humic river water in soil (Hatva 1996). The first Finnish plant using artificial recharge started operating in Vaasa in 1929. There were also some other plants utilising groundwater recharge before World War II. Yet, the actual development of artificial recharge started in Finland in the 1960s. Several visits were made to Sweden, and various types of research was carried out in the field (Rönkä et al. 1978). By 1992, there were in total 20 water-supply works utilising artificial recharge. The majority were constructed in the 1970s (Kivimäki 1992). In 2002, there were 25 operating water works (Kivimäki, personal communication 2003). In 1995, some 9% of public water supplies used basin recharge and another 9% used bank filtration. The latter is often combined with additional treatment (Kivimäki 1995). The current estimate of artificial groundwater's proportion is 13–15% (Kivimäki, personal communication 2003).

In practice, many water works utilise groundwater to the maximum rate allowed, the rest being supplied from surface water. In spite of the cold winter, this method works well. Sprinkling irrigation as a method of infiltration can potentially cause frost damage to trees and vegetation (Tavase Oy 2003). There are currently two sizeable artificial recharge plants going through the approval process of their Environmental Impact Assessment (EIA; TRW 2001; Tavase Oy 2003). In the case of the plant that is to supply potable water with the planned capacity of 70,000 m^3/day in Tampere and the neighbouring communities, harmful impacts are estimated to be limited to potential changes in the quality of water in private wells in the area. The development is considered to improve the supply of high-quality water and remove the taste and odour defects related to the use of surface water. Verification of the groundwater flow model has turned out to be a key issue for assessing environmental impacts. Concern and interest in the impacts are reflected by the large number of responses received in the public hearings (CFREC 2003).

The project of infiltrating water from Kokemäenjoki River into Virttaankangas esker to supply ca. 285,000 inhabitants in Turku and the neighbouring cities is in the

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permitting process. The exceptional scale of this project nationally, designed to meet the needs of 110,000 m^3/day on average, is reflected in the comprehensive EIA. With regard to the long-term operation, possible impacts from soil ending up in the esker, the development of humus in the infiltration zone and the microbial risks posed by the raw water are particularly relevant (HREC 2001). It seems that artificially recharged groundwater continues to be a favoured water supply solution in Finland. Arguments for favouring groundwater or artificial groundwater instead of surface water include its better quality requirements for potable water, less chemical treatment required and better protection against pollution (Hatva 1996).

Since the 1990s, some recharge plants that use surface irrigation have been constructed. Their applicability depends on local conditions. In Hämeenlinna, it has proved feasible to change and alternate the recharge area after every half a year to mitigate the risk of clogging (Manninen, personal communication 2001). Research on the effects of surface irrigation on water quality is on-going (Helmisaari et al. 1998). In one case, surface irrigation was abandoned and infiltration wells were constructed inside the esker.

The results of a recent joint research project, on infiltration techniques, soil processes and water quality in artificial recharge, lead by the Finnish Forest Research Institute, indicates that the reduction of organic matter to a considerable extent only takes place in the groundwater zone, at an increased rate with prolonged infiltration time. The method of infiltration did not noticeably influence the removal of organic matter. Microorganism growth observed in several artificial groundwater samples demonstrates certain microbiological instabilities (Lindroos et al. 2002). Pre-treatment such as rapid filtration can be used to overcome the problem of clogging of the soil caused by solid substances such as clay.

In 1996–1998, FEI participated in an EU Research project called “Artificial recharge of groundwater” headed by the Water Quality Institute (VKI) in Denmark. As part of the EU project, an international symposium on artificial recharge was held by FEI, Helsinki, in cooperation with the other Nordic countries (Kivimäki and Suokko 1996). The Finnish research focused on organic matter and cyanobacterial hepatotoxins in bank filtration. In two bank filtration plants, the highest molecular weights of organic matter were removed at the beginning of infiltration, whereas the lowest molecular weight fractions were predominant at the end of infiltration. Later, during the underground passage, no remarkable decrease in assimilatable organic carbon (AOC) content occurred, whereas the content of total organic carbon (TOC) still decreased. Results indicated that in saturated reducing conditions only minor microbial degradation will occur (Kivimäki et al. 1998). Lahti et al. (1998) found that the anaerobic conditions, which are common in bank filtration, probably hinder degradation of microcystins.

Temperature was identified as probably the most important factor affecting the fluorine concentration of artificially recharged groundwater during a monitoring period of 8 years in Utti, the First Salpausselkä. The elevated fluorine in groundwater is due to the characteristics of the dominant granitic rock type in the area. The temperature of the flow field in the area of the plants has been observed to be rising (Eskola et al. 2002). The recommended concentration limit of 1.5 mg/l of fluorine set by the health authorities has led to the use of methods such as partial treatment or dilution of groundwater with low-fluorine water. At Utti, a treatment plant using reverse osmosis, has been built to reduce the content of dissolved fluorine.

Groundwater Quality Problems

With the rights given by the Finnish Act of Extracted Land Resources from 1997, sand and gravel extraction versus groundwater use presents a difficult conflict. In addition to hosting aquifers, eskers are commonly important sources of sorted high-quality aggregate. The extraction of gravel and rock aggregates disturbs landscape and increases the pollution risk of groundwater. For any large-scale soil extraction a permit is needed as a prerequisite, as well as requirements for rehabilitation after the extraction to ensure protection of groundwater and to minimise the impacts to the environment in general. One of the challenges is the old gravel extraction areas where the activity took place prior to the current legal obligations and that should be rehabilitated. In construction activities, crushed rock material is nowadays increasingly used. In addition, the use of excess soil from construction and leftover bedrock material from dimension stone production is encouraged. During late 1990s and early 2000s, joint regional projects have been carried out by the Environment Administration, GTK and the extraction industry to adjust for groundwater protection and aggregate production. These projects, which already cover the majority of the provinces (personal communication Britschgi 2003), provide relevant information on the distribution of the geological formations, their aggregate resources and their suitability for water supply. The resulting proposals are based on the spirit of the Act, but they are not legally enforceable (Britschgi 2002). The proposals nevertheless help to guide the allocation of aggregate extraction to formations that are not vital to the community water supply.

In the late 1980s, it was noticed that the use of salt for de-icing on the main roads increases the salt content of groundwaters in certain areas. A high chlorine content, depending on the other chemical properties of water, potentially enhances corrosion of pipes and water tanks. Due to the generally low pH and softness of groundwater in Finland, occurrence of chlorine, even at concentrations below the recommended limit values (national limit 100 mg/l, aim set by EU 25 mg/l), increases corrosiveness (Nystén and Hänninen 1997). At a waterworks in south-eastern Finland, salt has had to be removed from groundwater and in another case in central Finland, the

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location of the supply well had to be moved due to an elevated chlorine concentration (Nystén, personal communication).

A mapping of risk in groundwater areas caused by de-icing was carried out jointly by the Environment Administration and the Road Administration in 1993. There are roads with some level of de-icing in 44% of all the classified groundwater areas. In 21% of the groundwater areas classified as important or suitable for water supply, roads exist that are being de-iced (Gustafsson and Oinonen 1998). Quality monitoring was recommended to be continued in the groundwater areas with roads under de-icing, and more detailed investigations, including the level of chloride concentration, should be carried out in identified areas of high risk. In the mid-1990s, experiments with less or no saltation were carried out in a few regions (Gustafsson and Nystén 2000). The deteriorating impacts of de-icing salt on the quality of groundwater have led to studies and testing of alternative de-icing chemicals (Hellstén and Nystén 2003). Yet, at least to some extent, the use of salt seems to be necessary for de-icing purposes to guarantee traffic safety.

In its current environmental policy, the Road Administration mitigates the harmful impacts both through decreasing the amount of salt applied and through building protective constructions. Since the 1990s, protective constructions consisting of various types of bentonite and synthetic geomembranes have been applied to slopes along the main roads in major groundwater protection areas, with variable success. During the period 1997–2000, the Road Administration invested approximately 5.1 MEUR in groundwater protection annually and projected it to increase to 6.7–8.4 MEUR in 2001–2005 (Road Administration 2001).

Limitations have been set on de-icing in important aquifers that are in the zone of the First Salpausselkä ice-marginal deposit. This, together with major eskers, commonly coincide with main roads due to the sound construction foundation that these coarse-grained formations make in a terrain prone to freeze-and-thaw. As the average chloride concentrations from the late 1990s are lower than those observed in 1980s and after (Gustafsson 2001), it seems that the increased awareness and the measures taken have had an impact on a national scale. In the First Salpausselkä area, however, the decreased salting volumes and protective constructions on average do not seem to have had an impact on the chloride concentrations (Gustafsson and Nystén 2000).

Groundwater has, in some cases, become contaminated due to industrial and related activities. In the late 1980s, a larger case was first noticed when chlorophenols were detected in a municipal water supply. These contaminated sites have now been investigated and various types of remediation technologies that suit the Finnish four distinct seasons are being developed. The development of special technology for bioremediation and treatment of chlorophenols in boreal conditions is going on and in situ bioremediation seems to offer the most cost-efficient technology (Puhakka and Melin 1998). Due to the relatively small aquifer areas, contamination is normally limited only to small areas. However, purification of aquifers may take several decades.

European Directives

As a Member State of the European Union (EU), the framework Directive for the water policy (WFD) of the EU (60/2000) (CEC 2000), entered into force in 2000, sets the framework and objectives for water protection in Finland. The characteristics of groundwater are reflected in further detail in the 'daughter' directive for groundwater. A major objective is to reach a good quantitative and chemical status of groundwater within 15 years from the entry into force of the Directive. To better meet the European requirements of the WFD, a joint groundwater monitoring network of the environment administration and GTK (Geological Survey of Finland) has been developed. According to WFD, water bodies that provide more than 100 m^3/day will be monitored.

In Finland, a groundwater area is considered suitable for water supply (class II) when the area is able to provide good-quality groundwater of about 250 m^3/day. Respectively, class I include those groundwater areas that are in use or will be in use within the coming 20 to 30 years, including those reserved for potential crisis services. Class III covers those that will need further investigations for potential water supply. (Britschgi et al. 1993).

Community quality standards for groundwater to date at the Directive level exist only for nitrates. All Finnish groundwaters have a nitrate-content under the national requirement of 25 mg/l, whereas, recently, the European Union raised its requirement to 50 mg/l. In a compilation by the European Environment Agency (EEA 2000), in all the 425 groundwater sampling points in Finland, the nitrate concentration was below 25 mg/l, indicating a markedly less affected quality compared to the rest of Europe with the exclusion of Iceland, Norway, Sweden and Latvia. This obviously reflects the higher level of nitrogen in groundwaters particularly in the European continent. In any case, the objective of the European Union is that, except for a few cases involving severe contamination, all groundwater bodies will be brought to a good state in terms of quality and quantity. Criticism has been presented that the WFD will not improve groundwater protection and might even lead to weakening of existing standards. This is due to reasons such as the broad definition of the 'good' groundwater status in terms of quality, which can include virtually all groundwaters except those that are severely polluted (Kallis and Butler 2001).

Discussion and Policy Implications

The water protection targets for 2005 set by the Finnish Council of State (MoE 1998) point out that the quality and quantity of groundwater must be maintained at least

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at the present level and improved in locations where the quality has been degraded by human activities. Extraction of soil, particularly sand and gravel, is to be directed as much as possible to such soil formations that are not important or otherwise valuable for community water supply. Aggregate supply and comparable activities should be carried out without posing a risk to the water resources and hence should be allocated to areas that are not important for communal water supply. Adequate groundwater protection and rehabilitation measures should be required. Increased awareness of pollution risks to groundwater due to research and international development have led to the development of legislation, environmental impact assessment of potentially polluting activities in the permitting process and policies of the actors, recognising protection of groundwater resources as an issue.

The selection of water sources, using either ground or surface water, for community water supply has been one of the strategic water sector issues in Finland since the turn of the 20th century. The importance of groundwater for the community water supply has increased and will increase, especially through artificial recharge. The more stable quality and temperature compared with surface water, less substantial treatment requirement and better protection against contamination are among the reasons why groundwater has been favoured. These experiences show the path dependence of such key strategic selections: how certain decisions, in this case the selection of water source, have influenced the sector for several decades or possibly have hindered other alternatives (Melosi 2000). It also highlights the particular long-term nature of the water services.

Since the 1960s, the role of artificial recharge and groundwater use has increased. This is linked with the increase of intermunicipal cooperation of water utilities: groundwater of better quality is drawn from further distances instead of surface water closer by. This policy is promoted by the Central Government and Environmental Administration through financial support of the mains as well as groundwater inventories. Partly, in this connection, support is also channelled to systems in dispersed rural areas. It is increasingly important to protect groundwater resources and to hinder pollution and to remediate possibly contaminated aquifers.

The fact of whether the ongoing large-scale artificial recharge projects manage to deliver the expectations and win the acceptance of all stakeholders seems likely to impact the popularity of future groundwater schemes. The active response in public hearings indicates concern and interest and this should be taken into account in the planning process by informing the public, by allowing participation and by advocating transparency in the decision making.

The importance of integrated water resources and river-basin management is emphasised in the recent EU water framework directive (WFD). However, for groundwater issues, another directive is needed. Whatever the form, it is very important that the natural conditions and the different geological background, in various parts of Europe, should be seriously taken into account. Local standards are defined according to the standard process provided in the WFD (Kallis and Butler 2001). The goal of water resources management, stated in the current Natural Resources Strategy of Finland (MAF 1999), includes the maintenance of quantitative and chemical status of groundwater and "appropriate management" of groundwater areas of special importance, with a general reference to ethical responsibility and sustainable development. In addition to Integrated Water Resources Management, there should also be discussion about "integrated aquifer management".

Conclusions

In Finland, a northern country with glaciofluvial formations, the role of groundwater as a source of community water supply has increased continuously since the 1950s and will probably do so in the future, especially in the form of artificial recharge. The current utilisation and importance of groundwater is a reflection of both the geological and hydrological setting and the policy decisions made. The development of groundwater investigation techniques, geophysical among others, has allowed the structure and water-conducting properties in deep core parts of large esker aquifers and complex ice-marginal formations to be evaluated for water supply. Hence, the utilisation potential of groundwater-bearing formations has expanded in Finland.

Geochemical mapping has increased awareness about areas with natural risks of poor quality groundwater and has resulted in subsequent recommendations on groundwater utilisation. According to Finland's current Natural Resource Strategy (MAF 1999), the availability of high-quality water services is secured by promoting the utilisation of groundwater resources, in addition to building auxiliary water supplies and combining networks.

Since the early 20th century, the selection between surface and groundwater for community water supplies has been one of the key strategic long-term questions and will remain so in the future. Due to the special geological background of Finland, in European and global perspectives, it is highly important to take into account the local natural conditions in water management. It is also very important to safeguard groundwater quality for future needs through protection and remediation, as necessary.

The increased awareness of the threats that activities such as de-icing and aggregate extraction pose to the quality of groundwater has led to the application of protection measures and changes in the policies of managing these activities with the added perspective of water supply. Urbanisation puts pressure on groundwater resources in the sparsely populated country.

As for the on-going and future large-scale artificial recharge projects, active public response and transparency in decision-making need to be assured.

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References

Bergman GK (1916) Den kemiska beskaffenheten af vattnet vid centrala vattenverk och vid grundvattentag i Finland (Chemical quality of water in urban waterworks and water intakes in Finland) (in Swedish). Öfvertryck av Finska kemistsamfundets meddelanden, jubileumsnummer

Breilin O, Tikkanen J, Kesola R, Leveinen J, Mursu J (2003) Groundwater from crystalline bedrock in municipal of Leppävirta in southeast Finland. In: Krasny J, Hrkal Z, Bruthans J (eds) 2003 Proceedings of the International Conference on Groundwater in Fractured Rocks. 15–19 Sept 2003, Prague, Extended Abstracts. IHP-VI, Series on Groundwater 7:31–32

Britschgi R (2002) Adjusting of groundwater protection and aggregate production. In: Kuula-Väisänen P, Uusinoka R (eds) Proceedings of Aggregate 2001: Environment and Economy, 6–8 August 2001, Helsinki, pp 377–380

Britschgi R, Gustafsson J (eds) (1996) Suomen luokitellut pohjavesialueet (The classified groundwater areas in Finland) (in Finnish). Suomen ympäristö 55, FEI

Britschgi R, Hatva T, Suomela T (1993) Pohjavesialueiden kartoitus- ja luokitusohjeet (Guidelines for the mapping and classification of groundwater areas) (in Finnish). National Board of Waters and the Environment, B 7

CEC (Commission of the European Communities) (2000) Directive of the European Parliament and of the Council establishing a framework for Community action in the field of water policy: joint text approved by the Conciliation Committee 1997/0067(COD) C5-0347/00

CFREC (Central Finland Regional Environment Centre) (2003) Lausunto ympäristövaikutusten arviointiselostuksesta: Vehoniemen-Isokankaan tekopohjavesihanke (Statement on the Environmental Impact Assessment Report of Vehoniemi-Isokangas artificial groundwater project) (in Finnish). http://www.ymparisto.fi/poltavo/yva/arkisto/ksu/6/lausselo.htm

Donner J (1995) The Quaternary history of Scandinavia. World and Regional Geology 7, Cambridge University Press

EEA (European Environment Agency) (2000) Sustainable use of Europe's water?: state, prospects and issues. Environmental assessment series 7, Copenhagen

Eronen M (1983) Late Weichselian and Holocene shore displacement in Finland. In: Smith DE, Dawson AG (eds) Shorelines and Isostacy. Institute of British Geographers, Special Publication 16, Academic Press, London, pp 183–207

Eskola T, Hyyppä J, Isakow M, Kyntäjä T, Myry J, Mälkki E, Vuorinen A (2002) Fluorine investigations and studies at the artificial groundwater plants in Utti, the First Salpausselkä 1992–2001. Kouvolan Vesi, Kymenlaakson Vesi Oy

Esty DC, Cornelius PK (eds) (2002) Environmental performance measurement: global report 2001–2002. Oxford University Press, New York

FEI (Finnish Environment Institute) (2002) Statistics on community water supply and sanitation

Gagneur B (1910) Om grundvattenförhållanden (Of groundwater conditions) (in Swedish). Teknikern 20:377–383

Gagneur B (1918) Muutama sana Kuopion ja Kajaanin vesijohdoista (A few words on Kuopio and Kajaani water pipelines) (in Finnish). Teknillinen Aikakauslehti 8:1:21–22

Gustafsson J (2001) Tiesuolauksen riskikartoitus pohjavesialueilla (Risk Mapping of the road deicing on the groundwater areas) (in Finnish). In: Salonen V-P, Korkka-Niemi K (eds), pp 207–212

Gustafsson J, Nystén T (2000) Trends of chloride concentration in groundwater and results of risk assessment of road salting in Finland. In: Bjerg P, Engesgaard P, Krom T (eds) Groundwater, Proceedings of International Conference on Groundwater Research, 6–8 June 2000, Copenhagen, Denmark. A.A. Balkema, Rotterdam, The Netherlands, pp 249–251

Gustafsson J, Oinonen T (1998) The risk assessment of road salting and water quality monitoring. In: Deicing and dustbinding—risk to aquifers. Proceedings of an International Symposium, 14–16 Oct 1998, Helsinki, Finland, NHP Report 43, Helsinki

Hänninen P (1991) Maatutkaluotaus maaperägeologisissa tutkimuksissa. Geological survey of Finland. Report of investigation 103 [English summary: Ground penetrating radar in Quaternary geological studies]

Hänninen T, Kivimäki A, Liponkoski M, Niemi A (1994) Tiesuolauksen vaikutus tärkeillä pohjavesialueilla (Effects of deicing within important groundwater areas) (in Finnish). Internal publication of the Road Administration 70/1994

Hatva T (1996) Artificial groundwater recharge in Finland. In: Kivimäki A-L, Suokko T (eds), pp 3–12

Hausen C (1900) Statistisk tabell öfver vattenledningarna i Finland (Statistics on water works in Finland) (in Swedish). Teknikern 10:197

Hellstén P, Nystén T (2003) Migration of alternative de-icers in unsaturated zone of aquifers: in vitro study. In: Proceedings of the 1st International Conference on Urban Drainage, Hellstén, pp 47–54

Helmisaari H-S, Kitunen V, Lindroos A-J, Lumme I, Monni S, Nöjd P, Paavolainen L, Pesonen E, Salemaa M, Smolander A (1998) Sprinkling infiltration in Finland: effects on forest soil, percolation water and vegetation. In: Peters JH (ed) pp 243–248

Hiisvirta L (1994) Arseeni talousvedessä ja siihen liittyvät terveysriskit (Arsenic in domestic water and related health risks) (in Finnish). Ympäristö ja Terveys-Lehti 6/94:32–34

HREC (Häme Regional Environment Centre) (2001) Statement re: artificial groundwater project, environmental impact assessment report http://www.turunseudunvesi.fi/Pdf/regenv.pdf

Hyvärinen H (1973) The deglaciation history of eastern Fennoscandia—recent data from Finland. Boreas 2:85–102

Juuti P, Katko T (1999) From pollution to pure water bodies — Tampere city water works 1835–1998. Water Int 24:204–210

Kallis G, Butler D (2001) The new EU water framework directive: measures and implications. Water Policy 3(3):125–142

Katko T (1996) Vettä! — Suomen vesihuollon kehitys kaupungeissa ja maaseudulla (Water! — evolution of urban and rural water supply and sanitation in Finland) (in Finnish). FIWA, Helsinki

Katko T (1997) Water! — evolution of water supply and sanitation in Finland from the mid-1800s to 2000. FIWA, Helsinki

Kivimäki A-L (1992) Tekopohjavesilaitokset Suomessa (The artificial groundwater recharge plants in Finland) (in Finnish, abstract in English). National Board of Waters and the Environment, A 98

Kivimäki A-L (1995) Rantaimeytys tekopohjaveden muodos-tamismenetelmänä (Bank filtration as an artificial recharge method) (in Finnish). National Board of Waters and the Environment, Report no. 573

Kivimäki A-L, Suokko T (eds) (1996) Artificial recharge of groundwater. Proceedings of an International Symposium, 3–5 June, Helsinki, Finland, NHP Report no 38

Kivimäki A-L, Lahti K, Hatva T, Tuominen SM, Miettinen IT (1998) Removal of organic matter during bank filtration. In: Peters et al. (eds), pp 107–112

Korhonen K-H, Gardemeister R (1971) Maalajien kaivuluokitus (Classification of soils) (in Finnish). Technical Research Centre of Finland, Geotechnical Laboratory, Report no 1

Lahermo P, Ilmasti M, Juntunen R, Taka M (1990) The geochemical atlas of Finland, part 1: the hydrogeochemical mapping of Finnish groundwater. Geological Survey of Finland, Espoo

Lahermo P, Tarvainen T, Hatakka T, Backman B, Juntunen R, Kortelainen N, Lakomaa T, Nikkarinen M, Vesterbacka P, Väisänen U, Suomela P (1999) Tuhat kaivoa — Suomen kaivovesien fysikaalis-kemiallinen laatu vuonna 1999 (in Finnish, English summary: One thousand wells—the physical-chemical

 DOI 10.1007/s10040-004-0351-3

quality of Finnish well waters in 1999). Geological Survey of Finland, Report of Investigation 155, Espoo
Lahti K, Vaitomaa J, Kivimäki A-L, Sivonen K (1998) Fate of cyanobacterial hepatotoxins in artificial recharge of groundwater and in bank filtration. In: Peters et al. (eds), pp 211–216
Lillja JLW (1938) Helsingin kaupungin vesijohtolaitos 1876–1936 (Helsinki city water works 1876–1936) (in Finnish)
Lindroos A-J, Kitunen V, Derome J, Helmisaari H-S (2002) Changes in dissolved organic carbon during artificial recharge of groundwater in a forested esker in Southern Finland. Water Res 36:4951–4958
MAF (1999) Natural Resources Strategy. http://www.mmm.fi/luonnonvarat_vesivarat_maanmittaus/vesivarat/vesivaratehtavat/vesiva. Ministry of Agriculture and Forestry
Mälkki E (1979) Ground-water flow velocity as an indicator of the permeability and internal structure of eskers. Water Research Institute, Report no 32. PhD Thesis, University of Turku, Finland
Mälkki E (1980) The deep investigation technique in practical ground-water survey. Vannet Norden 3:7–22
Mattsson A (2001) Geofysiikan menetelmistä pohjavesialueen rakenteen tutkimuksissa (About geophysical methods in the structural studies of groundwater areas) (in Finnish). In: Salonen V, Korkka-Niemi K (eds), pp 47–53
Melosi M (2000) The sanitary city. Urban infrastructure in America from colonial times to the present. Johns Hopkins University Press
MoE (Ministry of the Environment) (1998) Water protection targets to 2005 (In Finnish, Abstract in English). The Finnish environment 226, FEI
MoSAH (Ministry of Social Affairs and Health), NboWE (National Board of Waters and the Environment) (1997) Nationwide rural well water survey (in Finnish, abstract in English). Report A 146
Nystén T, Hänninen T (1997) Tiesuolan pohjavesihaittojen vaikutuksista ja torjuntakeinoista (English summary: Effects of road salting on groundwater and guidelines for preventive action). Suomen ympäristö 57, FEI
Outhier R (1744) Journal d ‘un voyage au Nord
Peräkylä O (1967) Vesihuollon viimeaikaisesta kehityksestä (Of recent development of water supply and sanitation) (in Finnish). Vesitalous 8:1:20–24
Puhakka J, Melin E (1998) Chlorophenol-contaminated groundwater bioremediation at low temperatures. In: Meyers RA (ed) Encyclopedia of environmental analysis and remediation, pp 1111–1120
Road Administration (2001) Tiehallinnon ympäristöpolitiikka ja–ohjelma 2001–2005. (The environmental policy and programme of the Road Administration) (in Finnish). Road Administration, Helsinki
Rönkä E (1983) Drilled wells and groundwater in the Precambrian crystalline bedrock of Finland. Water Research Institute, Report 52. PhD Thesis, University of Turku, Finland
Rönkä E, Hatva T, Iihola H (1978) Tekopohjaveden muodostaminen (English summary: Artificial recharge), YVY-34, Helsinki
Sederholm J (1911) Ännu en gång grundvattnet i Finland (Once again of groundwater in Finland) (in Swedish). Teknikern 21(711):27–28
Sullivan CA, Meigh JR, Fediw TS (2002) Derivation and testing of the Water Poverty Index, phase 1; final report. Center for Ecology and Hydrology, Wallingford, UK
Tavase Oy (2003) Vehoniemen-Isokankaan harjualueen tekopohjavesilaitos: ympäristövaikutusten arviointiselostus. (Environmental impact assessment report): http://www.tampere.fi/vesi/ajankohtaista/tavase/kappale8.pdf
TRW (Turku Region Water Ltd) (2001) Turku region artificial groundwater project, environmental impact assessment, summary. http://www.turunseudunvesi.fi/Pdf/TRW_EIA%20Summary.pdf
WA (Water Association, Finland) (1990) Pohjavesitutkimuksen kehittämisohjelma (Development programme of groundwater) (in Finnish)
Wäre M (1952) Maaseudun vesihuolto (Rural water supply and sanitation) (in Finnish). Mitä-missä-milloin, kansalaisen vuosikirja 1953
Weppling K (1997) On the assessment of feasible liming strategies for acid sulphate waters in Finland. Dissertationes Geographicae Universitatis Tartuensis 5
Wihuri H, Salmi M (1978) Uusi tapa tutkia pohjavettä—Muuramen pohjavesitutkimus. Vesitalous 19:6:20–27 (in Finnish, English abstract: A new ground-water study method — a case history of the Muurame investigation)
WWAP (2003) Water for people water for life. United Nations World Water Development Report, UNESCO-WWAP

DOI 10.1007/s10040-004-0351-3