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Observations on groundwater-surface water interactions at River Vantaa, Finland

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Abstract

Purpose – The purpose of this paper is to emphasize the importance of groundwater-surface water interaction when studying, modeling and assessing climate change impacts on river water management.

Design/methodology/approach – The investigations were focused on River Vantaa and its tributaries in southern Finland. The main methods used involved aerial infrared photography, thermal profiling of river sediments, water quality measurements, isotopic composition of oxygen and hydrogen $\delta^{18}\text{O}$, $\delta^2\text{H}$ and river water temperature measurements. The authors present the first results of the field measurements targeted to identify the groundwater recharge and discharge zones within the river system.

Findings – Groundwater discharge zones were found to have a significant impact on water quality and volume in River Vantaa and its tributaries. In the drainage basin, the aerial infrared photography seemed to be a feasible and cost-effective method to identify areas of groundwater discharge across the entire river basin. Around 350 groundwater/surface water interaction sites along the 220 km river system could be identified.

Practical implications – The interaction sites identified during the season of low flow rate should be considered as potential risk areas because during flood periods groundwater quality might be at risk due to bank infiltration. This should be considered in river basin management within predicted changing climatic conditions.

Originality/value – This is the first attempt in Finland to map systematically groundwater and river water interactions. The focus of the paper is relevant, because according to the existing climate scenarios, flooding of the main rivers in Finland will be more frequent in future, increasing the probability of groundwater-surface water interaction.

Keywords Finland, Rivers, Climate change, Groundwater, Floods,
Surface water-groundwater interaction, Aerial infrared photography, River Vantaa

Paper type Technical paper



1. Introduction

Jylhä *et al.* (2004) have constructed national-scale seasonal and annual climate change scenarios for Finland during the twenty-first century. According to predictions the annual mean temperature is projected to rise by 2.5°C and the annual mean precipitation 5-40 percent by the 2050s. Lehner *et al.* (2006) have predicted the rise in flood frequencies in northeastern Europe, but according to Veijalainen *et al.* (2010) the

impacts of climate change will not be uniform within Finland. In some parts of the country, the flooding will decrease, but in central lakes and their outflow rivers as well as in some southern watersheds, predicted increase in precipitation will result in intensified floods (Veijalainen *et al.*, 2010). According to Veijalainen *et al.* (2009) heavy rains during summertime are expected to increase floods in the tributaries of River Vantaa. Summer flood in 2004 caused severe damage at the drainage basin of the River Vantaa and resulted in water quality problems at two major groundwater intake plants in Riihimäki and Hyvinkää (Suhonen and Rantakokko, 2006).

Management of water resources in Finland has traditionally focussed on either surface water or groundwater. However, surface water is commonly hydraulically connected to groundwater and vice versa (Fleckenstein *et al.*, 2010). Management of one component of the hydrologic system is only partly effective because each hydrologic component is in continuing interaction with other components; and development or contamination of one affects also the other (Winter *et al.*, 1998). Because the interaction is difficult to observe, it is usually ignored in water management considerations (Krause *et al.*, 2007). Moreover, according to Dahl *et al.* (2007) the EU Water Framework Directive outlines a new approach to water administration in which interactions between groundwater bodies, groundwater dependent terrestrial ecosystems and surface water bodies take on a central role. In northern regions there will be a challenge to manage our surface and/or groundwater resources in changing climate conditions as well as in changing water utilization situation. In Denmark Dahl *et al.* (2007) has developed a new multiscale and process oriented typology integrating interactions between groundwater, riparian areas and wetlands as well streams and rivers.

Here we present the first attempt to study systematically groundwater and stream water interactions in Finland. The research was focussed on the River Vantaa and its tributaries (220 km altogether, Figure 1). The main target of the study is to increase the knowledge about aquifer-river interaction in the study area. The research was expected to give new insights on the water management, which could be used in evaluating possible effects of climate change to river water and groundwater quality and quantity.

The scope of this research project is first, to identify the sections and branches of river systems where significant hydraulic connection between groundwater and river water exists, second, to quantify flux of groundwater into the stream and/or riverbank filtration of surface water to the aquifer through the shoreline in the areas where the aquifer is used for water supply, third, to study seasonal variations in water fluxes between surface water and groundwater and fourth, to evaluate the impacts of water exchange on water quality in the discharge/infiltration zones and especially in pumping wells of groundwater intake plants of the drainage basin area.

In this paper we show the results of the first scope and discuss their practical implications for future studies. The aim of the initial field period was to locate the groundwater recharge and discharge zones within the river system and to test suitable research methodology, which could be applied in groundwater-river water interaction studies.

2. Study site

Field studies were performed at River Vantaa and its tributaries Herajoki, Palojoki, Keravanjoki and Tuusulanjoki in July 2010 (Figure 1). The total length of the rivers studied is approximately 220 km (Table I). River Vantaa is one of the raw water reserves for the Finland's capital area (ca. one million people). In addition, within the River Vantaa drainage basin there are 25 significant aquifers used by the local

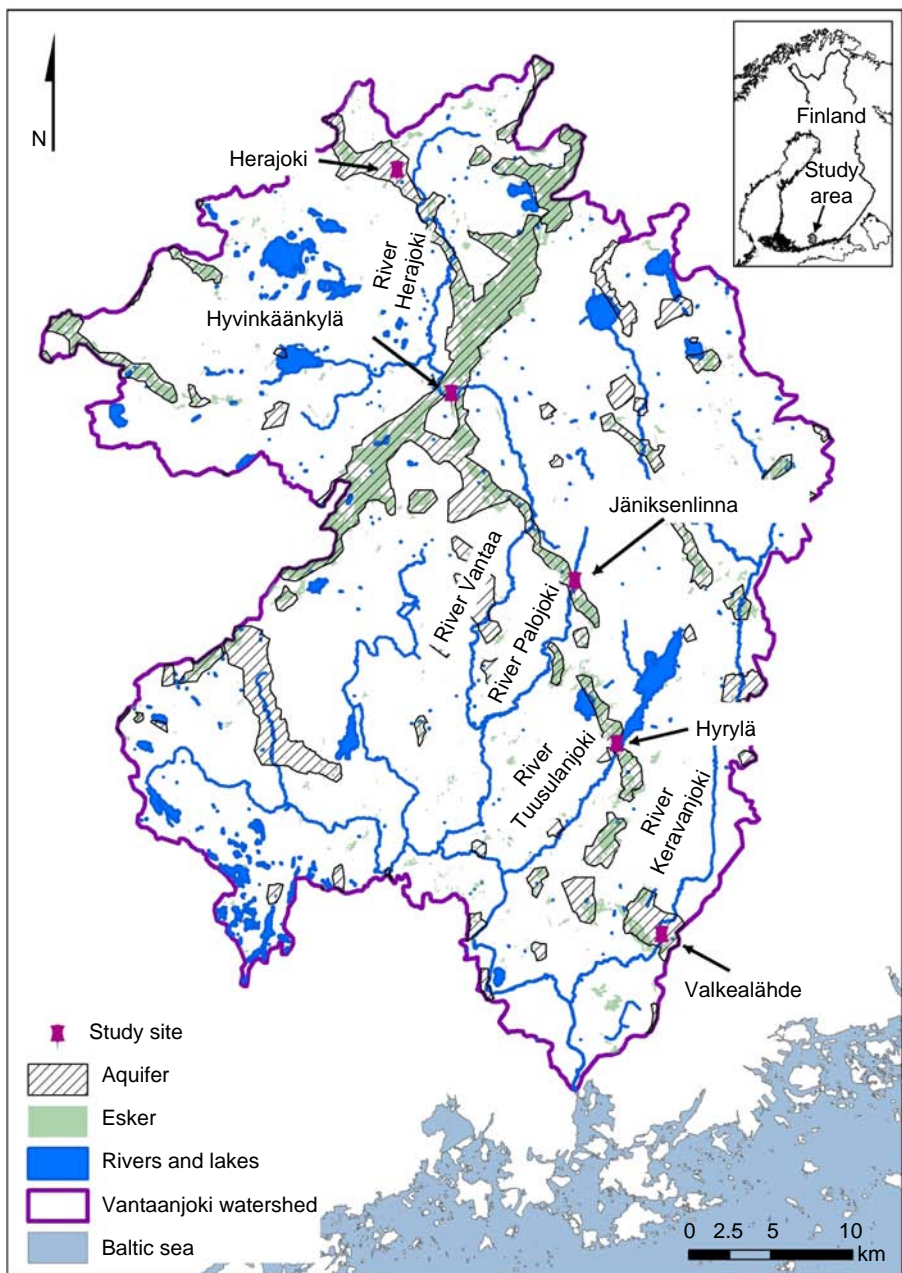


Figure 1.
River Vantaa watershed
and the aquifers connected
to the river basin

Notes: Field studies performed in 2010 at Rivers Vantaa (Hyvinkäänkylä site), Herajoki, Palojoki (Jäniksenlinna site), Keravanjoki (Valkealähde site) and Tuusulanjoki (Hyrylä site)

municipalities or water companies (Table I, Figure 1). River Vantaa and its tributaries are also widely used for recreational activities. The quality of the rivers has been monitored regularly since 1970s in order to identify the incoming load and contaminants.

The River Vantaa drainage basin is rather flat lying or smoothly undulating glacial landscape. Precambrian bedrock is covered by a continuous layer of glacial and postglacial sediments deposited during the Weichselian glacial stage and Holocene. Till makes the lowermost sediment unit (Lunkka *et al.*, 2004; Saarnisto and Salonen, 1995; Tikkanen, 1989, Table II). Aquifers are related to glaciofluvial sand and gravel deposits, i.e. eskers or ice-marginal end moraine complexes. They are normally unconfined, but also semi-confined or confined parts of the aquifers exist, because clays deposited in glaciolacustrine lakes or Baltic Sea often cover the surface of the terrain.

3. Research methods

All existing data from the national groundwater database (HERTTA database) and previous site-specific hydrogeological reports of the aquifers as well as river water monitoring results were collected and analyzed. The additional methods used in this study involved aerial infrared photography, thermal profiling of river sediments, water quality measurements (electrical conductivity, pH, main ionic concentration, isotopic composition of oxygen and hydrogen $\delta^{18}\text{O}$, $\delta^2\text{H}$), river water temperature

River	Length (km)	Width (m)	Number of aquifers
Vantaa	99	20-70	11
Herajoki	7	<5-6	1
Paalijoki	8	<5	0
Kytäjoki	8	5-25	0
Keravanjoki	65	10-60	8
Tuusulanjoki	15	<10	2
Palojoki	45	<10-25	1
Lepsämäinjoki	37	<5-20	2
Luhtajoki	46	<5-15	0
Total	330		25

Table I.
Aquifers and riverbeds
within the River Vantaa
drainage basin

River basin (total area km ²)	Bedrock terrain (%)	Glacigenic till (%)	Glaciofluvial sand and gravel (%)	Marine, lacustrine and littoral silt and clay (%)	Biogenic peat deposit (%)
Vantaa (1,680)	7.0	24.6	20.3	38.7	9.4
Keravanjoki (395)	5.0	24.8	21.1	38.2	10.9
Tuusulanjoki (128)	4.6	19.3	20.2	48.8	7.0
Palojoki (92)	2.9	30.9	18.0	44.6	3.6
Luhtajoki (155)	6.8	17.4	18.6	52.1	5.4
Lepsämäinjoki (213)	21.3	19.9	12.0	38.1	8.7

Table II.
The coverage of
geomorphological units
within River Vantaa
drainage basin
(Tikkanen, 1989)

measurements and measurements with seepage meters and mini-piezometers (Korkka-Niemi *et al.*, 2011).

Aerial infrared imagery was acquired using Thermo Vision A40 sensor, which has a 320 times 240 focal plane array with the sensitivity for 7.5-13 μm of the electromagnetic spectrum. The field of view of the camera is $24 \times 18^\circ$. Based on the FLIR systems, the temperature differences as small as 0.08°C, with an accuracy of $\pm 2^\circ$, could be measured. The camera was mounted in a pod of a side of a Raven R44 II helicopter together with Nikon D1X digital camera. All together $\sim 10,000$ images were acquired from 100 to 250 above ground surface following the river courses on July 16 and July 28. The flying height above ground between 100 and 250 meters produced ground resolution between 0.13 and 0.33 cm. Aerial infrared imagery was used to identify areas of discrete and diffuse discharge of groundwater to stream water based on the temperature contrast between surface water and groundwater (Torgersen *et al.*, 2001; Anderson, 2005).

Field measurements with multiparameter probe (YSI 600 XLM-V2-M) and multilevel sediment temperature probe (TP62_S, Umwelt Elektronik GmbH) were done at selected river sections concurrently with the aerial photography. Moreover, automatic YSI 600 sensors were installed at three water supply sites. Exceptionally arid and warm period preceded the time of the field activities resulting in the high difference between the temperature of river water (+ 20 to + 24°C) and groundwater (+ 4 to + 8°C).

4. Results and discussion

More than 350 locations with groundwater-surface water interaction along the 220 km long river system could be depicted. Based on aerial infrared photography and site-specific field measurements, groundwater-surface water interaction sites could be identified and classified into the four main categories (Figure 2):

- Category 1: a spring discharging into the river. This can be observed as cold spots next to the river or in the riverbank.
- Category 2: a ditch/creek discharging into the river. Cold groundwater originates from spring areas further from the riverbank.
- Category 3: diffuse discharge of groundwater along the shoreline.
- Category 4: diffuse discharge over a wide seepage area around a riverbed.

There were 67 visible springs and 64 notable ditches or creeks discharging groundwater into the river (Table III). There were also over 200 areas along the studied river system, where diffuse groundwater discharge either by a shoreline or over a wide area around a riverbed could be observed.

According to Winter *et al.* (1998) the withdrawal of water from a stream can deplete groundwater or conversely, pumping of groundwater can affect the stream water quality and quantity. Similarly the pollution of either surface water or groundwater body can degrade the other. As Winter *et al.* (1998) has summarized, effective water management requires a clear understanding of the linkages between groundwater and surface water bodies at any hydrologic settings. This is easy to understand when observing, e.g. River Vantaa cutting an esker formation of

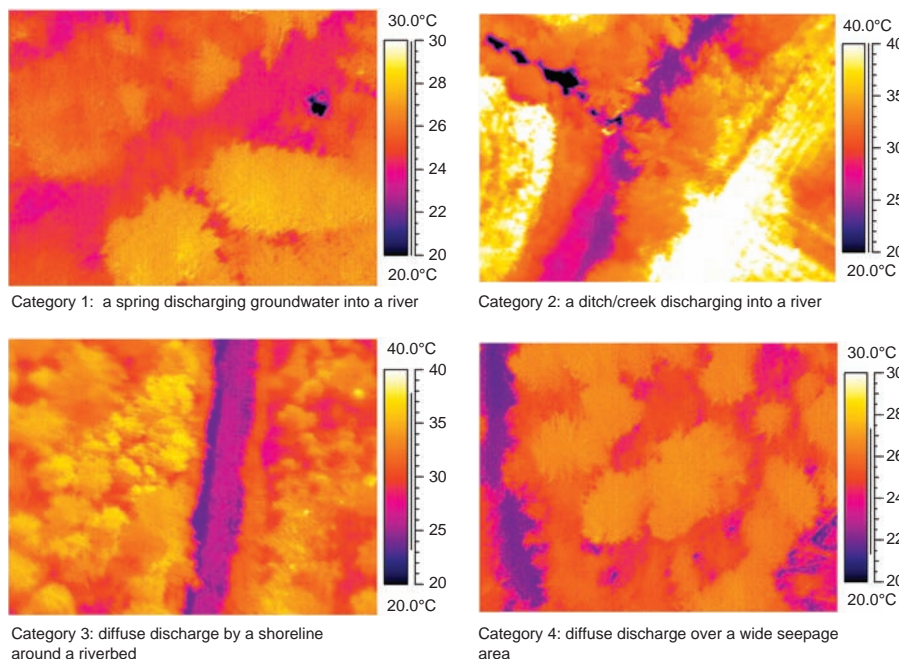


Figure 2.
Categories of discrete and
diffuse groundwater
discharge areas

River	Category 1 spring	Category 2 ditch/creek	Category 3 diffuse by shoreline	Category 4 diffuse wide seepage area
Vantaa	36	27	3	76
Herajoki	0	2	1	14
Keravanjoki	11	23	17	48
Tuusulanjoki	5	7	3	31
Palojoki	15	5	2	26
Total	67	64	26	195

Table III.
The identified discrete and
diffuse groundwater
discharge areas classified
into four categories

Hyvinkäänkylä aquifer (Figure 3). At the Hyvinkäänkylä study site, River Vantaa is 9-14 m wide, maximum depth is 2 m and the flow rate in mid-July is 0.7-0.8 m³/s (peak flow in April 2010 was 39.24 m³/s). An average river water temperature in July is 17.0-19.3°C, while during observation days in July 2010 river water temperature was 22-24°C. The temperature of groundwater in Finland is generally between +4 and +8°C. Figure 3 displays the groundwater discharge detected as low temperatures in infrared images. There is a groundwater intake plant (in the middle of the Figure 3) on the riverbank pumping 3,800 m³/d groundwater and it is possible that there is a connection between pumping wells and river water in certain hydrologic conditions.

At four study sites thermal profiling with temperature probe of water and river bottom sediments revealed zones of groundwater discharge and provided reference data for aerial photography data (Figure 4). Seepage meters and mini-piezometers (Baxter *et al.*, 2003; Korkka-Niemi *et al.*, 2009; Rautio and Korkka-Niemi, 2011) were

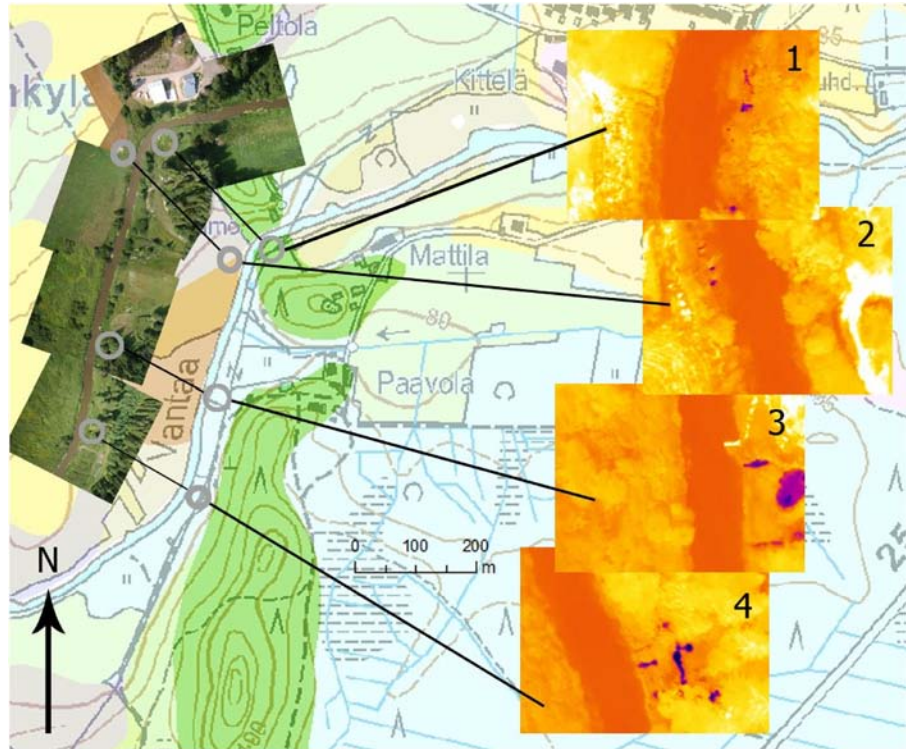


Figure 3.
River Vantaa cutting the
esker formation of the
Hyvinkäänkylä aquifer

Notes: Dark areas represent the groundwater discharge zones

used at selected locations in order to quantify the observed flux of groundwater into the stream and to take water samples. The aerial infrared photography seemed to be feasible and cost-effective method to identify areas of groundwater discharge across the entire river basin as also, e.g. Conant *et al.* (2009) has noticed earlier in Canada.

5. Future research interests

In next steps of the research we will use water quality data (O_2 , pH, EC, turbidity, suspended solids, COD_{Mn} , total phosphorus, total nitrogen, NO_3-N , NO_2-N , NH_4-N , enterococci, *E. coli* bacteria), main ionic concentrations, DOC and isotopic composition of oxygen, hydrogen and dissolved inorganic carbon ($\delta^{18}O$, δ^2H , $\delta^{13}C$) of river water, groundwater and discharging water to determine shares of surface water and groundwater within the identified mixing zones.

Quantification of groundwater flux into the river and vice versa will be observed with seepage meters and mini-piezometers and using more detailed thermal profiling of river water and the sediment. In narrow and shallow tributaries, the stream discharge will be measured directly with a flow meter.

In addition, the future target is to test and create methods to assess and estimate the effects of changing groundwater intake into the aquifer and connected surface water body (Rosenberry and LaBaugh, 2008; Poulsen *et al.*, 2011). This could be done using 3D mathematical and hydrogeochemical modelling (Stauffer *et al.*, 2008).

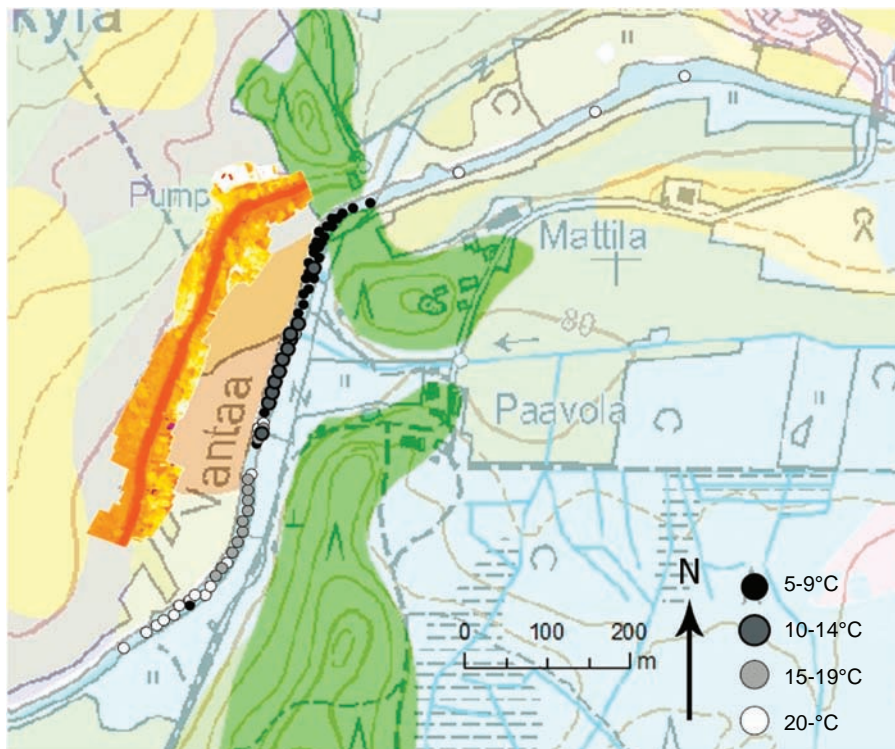


Figure 4.
Measured water
temperatures above the
riverbed sediments in
Hyvinkäänkylä study site

6. Conclusion

In the River Vantaa drainage basin, there is a need for greater understanding of the interaction of ground water and surface water with respect to the water supply, water quality and characteristics of aquatic environments in changing climatic conditions.

The aerial infrared photography was found to be feasible and cost-effective method to identify areas of groundwater discharge across the river basin. According to aerial infrared photography and site-specific measurements, around 350 groundwater-surface water interaction sites along the 220-km-long river system could be located.

Groundwater discharge zones may have more significant impact on water quality and quantity in the River Vantaa and its tributaries than has thus far been acknowledged. The interacting locations identified during the low-flow season in July 2010 should be considered as potential risk areas during flood periods (groundwater quality deterioration due to bank infiltration) and should be taken under considerations in river water basin management in changing climatic situations.

In future, water quality data, stable isotopic compositions of waters, stream flow measurements, seepage measurements, thermal profiling, additional aerial infrared photographing and mathematical and hydrogeochemical modelling will be used in order to assess the interaction between groundwater aquifers and river.

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