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The hydrochemistry of glacial Ebba River (Petunia Bay, Central Spitsbergen): Groundwater influence on surface water chemistry

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SUMMARY

The article presents the investigation of surface water chemistry changes of the glacial Ebba River (Central Spitsbergen) during three melting seasons of 2008, 2009 and 2010. The twice daily water chemistry analyses allow recognition of the surface water chemistry differentiation. The surface water chemistry changes are related to the river discharge and changes in the influence of different water balance components during each melting season. One of the most important process that influence river water component concentration increase is groundwater inflow from active layer occurring on the valley area. The significance of this process is the most important at the end of the melting season when temperatures below 0 °C occur on glaciers (resulting in a slowdown of melting of ice and snow and a smaller recharge of the river by the water from the glaciers) while the flow of groundwater is still active, causing a relatively higher contribution of groundwater to the total river discharge. The findings presented in this paper show that groundwater contribution to the total polar river water balance is more important than previously thought and its recognition allow a better understanding of the hydrological processes occurring in a polar environment.

1. Introduction

In the arctic regions the investigation of stream water origin is crucial for understanding interaction between aquatic and torrential ecosystems. The main source of water in glacial rivers in the High Arctic is the melting of ice from glaciers (Hagen and Lefauconnier, 1995; Hodkins et al., 2009; Rachlewicz, 2009; Sobota, 2014). Relatively large numbers of studies concern the investigation of the water balance of glaciers (Hagen et al., 2003). Relatively little attention has been paid to the hydrological functioning of a proglacial catchment and on the interaction and contribution of different drainage components that influence the outflow of water from the catchment (Haldorsen and Heim, 1999; Killingveit et al., 2003; Hodkins et al., 2009). Outflow of water from the catchment is related to long-term and inter-seasonal fluctuations of different discharge components (Dragon and Marciniak, 2010). Investigations of the groundwater systems on Svalbard show the unique character of these systems (Haldorsen et al., 2009). The accessible studies indicate that on Svalbard relatively little attention has been paid to water flow within the active layer (Killingveit et al., 2003; Cooper et al., 2011). However, as it has been demonstrated in previous studies groundwater can have a large contribution in the total water balance of an arctic catchment (Marciniak et al., 2014).

The chemistry of surface water in a proglacial zone of glacial catchments in most cases is used to assess chemical erosion rates (e.g., Kostrzewski et al., 1989; Stutter and Billett, 2003; Szpikowski et al., 2014). Some studies characterize surface water chemistry in the context of the influence of the glacial melt water (Stutter and Billett, 2003). Some studies analyze surface water chemistry in context of permafrost influence (Frey et al., 2007; Frey and McClelland, 2009; Keller et al., 2010). However, information characterizing water occurring in the seasonally refreezing active layer of the glacial catchments on Svalbard is relatively sparse (Cooper et al., 2002; Hodson et al., 2002; Dragon and Marciniak, 2010).

The present study was performed in the area of the Ebba River catchment (Central Spitsbergen). The research was performed as a complement to previous studies. During the last few decades, the

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region has been the subject of both geomorphologic and glaciological research (Karczewski, 1990; Kłysz, 1985; Choiński, 1989; Kostrzewski et al., 1989; Stankowski et al., 1989; Gibas et al., 2005; Rachlewicz et al., 2007; Rachlewicz and Szczuciński, 2008; Zwolinski et al., 2008; Rachlewicz, 2009a, 2009b; Szczucinska, 2011; Prach and Rachlewicz, 2012; Szpikowski et al., 2014). The occurrence of groundwater in the Ebba Valley was recognized by Marciniak et al. (2007). The hydrogeological parameters that describe the active layer have been calculated based on direct field measurements and then with the support of hydrochemical data, the conceptual model of water circulation within the catchment was formulated (Dragon and Marciniak, 2010). The recharge of the Ebba glacial river was investigated by Marciniak et al. (2014). These investigations document periodically large contribution of groundwater to the total river water balance.

In light of previous investigations of water balance in the Ebba glacial river catchment (Marciniak et al., 2014), the aim of the current study is documentation of the groundwater contribution (recharge of the glacial river by subsurface flow within the active layer) in the total water balance of this glacial river. For this purpose new methodology was applied. The chemical data (interpretation of surface water chemistry changes during three melting seasons (years 2008, 2009 and 2010-twice daily chemical measurement of surface water components) was used for confirm earlier calculations of water balance and verify influence of each water balance component.

2. The study area

The catchment that was investigated is located in the central part of Spitsbergen, the northern part of Billefjorden. The study area covered the glacial valley of the Ebba River. The Ebba River flows along a valley 2 km wide and 4 km long (Fig. 1). The valley is surrounded by Lovehovden (610 m a.s.l.), Hultbeget (719 m a.s.l.) and Pukkelkammen (760 m a.s.l.) mountain ridges from the north and Wordiekammen Massif (805 m a.s.l.) from the south. The eastern part of the valley is covered by the Bertram and the Ebba Glaciers. The Ebba Glacier is the polythermal type and has been retreating during last 100 years, what is manifested by the negative mass balance of the glacier and the retreat of its ice front (Rachlewicz et al., 2007; Prach and Rachlewicz, 2012). The Ebba River is situated in the central part of the Ebba valley. The river flows from the Ebba glacier on the east to the Petunia Bay on the west. The ground elevation of the valley area ranges from near 0 m a.s.l. at the sea coast and 25 m a.s.l. in the central part of the valley, close to the glacier front at approximately 150 m a.s.l. in the upper parts of the alluvial fans in the surrounding mountain ridges. The boundary of the catchment was assigned using morphological criteria. The catchment area is approximately 53 km^2, and approximately 27.4 km^2 is covered by glaciers.

The climate of the region is controlled by the warm West Spitsbergen Current and is modified by the morphology and the altitude configuration (Bednorz and Kolendowicz, 2010). The thermal conditions depend on the polar day, which is 133 days within the study area. The melting season when the air temperature rises above 0 °C usually starts in June and lasts until September. The melting season is the period of active groundwater and surface water flow.

Dislocations along the Billefjorden tectonic fault zone determine the geological structure of the region studied (Dallmann et al., 2004). The faults, mainly with longitudinal orientation, cause a variety of rock types to crop out in the study area. The mountain massif in part of the valley surrounding the glacier is comprised of crystalline Precambrian basement. This area is predominantly underlain by metamorphic rocks (amphibolites, granite gneisses and gneisses). The middle part of the region is formed by carboniferous rocks (mainly gypsum, anhydrite and dolomite). Sandstone, dolomite and limestone dominate the area near the sea coast.

The Ebba Valley area is covered primarily by slope deposits composed of rocks originating from the surrounding mountain massifs. In the central part of the valley, close to the sea, marine shore deposits are found. The part of the valley close to the Ebba River is covered by fluvial and glacifluvial deposits (Szczuciński and Rachlewicz, 2007).

The valley area covered by slope deposition thaws seasonally and forms a shallow active layer, which enables the flow of subsurface water (Shur et al., 2005; Gooseff et al., 2013; Quinton and Baltzer, 2013). According to previous investigation (Dragon and Marciniak, 2010; Marciniak et al., 2014) it is known that the flow of water begins when the temperature rises above 0 °C (usually in early June). During the melting season, the thickness of the active layer increases systematically. The maximum active layer thickness varies between 0.3 and 1.6 m (Gibas et al., 2005) and usually occurs at the end of the summer season (Rachlewicz and Szczuciński, 2008). During the study period, the maximum thickness of the active layer varied between 0.47 and 1.0 m (Marciniak et al., 2014). The groundwater occurring in the active layer is recharged by direct precipitation infiltration on the valley area and by streams flowing from the mountain massifs (Fig. 2). These streams, in some cases, disappear in the upper parts of the slopes and formulate subsurface flows. At the end of summer, usually in September, when the temperature drops below 0 °C, the sediments freezes up and water stays locked up until the next summer season.

According to the Ebba River water balance calculations (Marciniak et al., 2014), the main component of the river recharge (calculated as the average from whole melting seasons) is the flow of water from the glaciers (75.9–81.5% of total river runoff). The recharge resulting from surface tributaries and overland flow is between 3.7% and 39.8% of the total water. The recharge occurring from groundwater was estimated average between 2% and 3.8%, but this recharge component was the most changeable during the melting season and varied between 1% at the beginning of summer season to even 27% at end of melting season (Table 3).

3. Materials and methods

The monitoring gauging station was located 200 m above the estuary of the Ebba River to Petunia Bay (Fig. 2). This location enables measurement of total river runoff and allows the influence of the tides on the water level position in the river to be avoided. Regular recording of the water level was performed twice a day (at 8 AM and 8 PM LT, the time that correspond to maximum and minimum of daily water level fluctuations) with an accuracy of 1 cm. The temperature of the water and the air was measured every 15 min with the use of automatic recording (Diver and BaroDiver, Schlumberger Houston, USA). The discharge of the Ebba River was measured at the cross profile of the channel with use of a Seba-Hydrometrie electromagnetic water flow meter. The measurements were performed in 5-day intervals (29 measurement series for the 3-year period).

Based on the measurements performed, the rating curve was calculated. The rating curve enabled calculation of the discharge curve (as a function of water level fluctuations) for each measuring season.

Water samples from the Ebba River were taken twice every 24 h: at 8 AM and 8 PM LT. The specific conductance of the water was measured directly in the field using computer device CX-741 (Elmetron, Poland). The water samples were filtered through a 0.45 μm membrane. After sampling, water was stored at a cold