Landform Analysis, Vol. 5: 66–70 (2007)

Floods in High Arctic valley systems and their geomorphologic effects (examples from Billefjorden, Central Spitsbergen)

Grzegorz Rachlewicz[*]

Institute of Paleogeography and Geoecology, Adam Mickiewicz University, Poznań, Poland

Introduction

The supply of European rivers is mainly an effect of water delivered from rainfall and the melting of snow cover. These phenomena are strongly diversified seasonally and regionally determining not only the outflow regime, but also natural and economic relations in river valleys (Knapp 1979). In polar and high-mountains glaciated areas the main volume of water, reaching 80% of the total, is transferred during the short melting season from ablating ice covers (Singh, Singh 2001). These regions are characterized by limited possibilities of water storage in the ground because of thin sedimentary covers and permafrost occurrence, temporarily unfreezing to the depth of 1 m below the surface or more. These areas are also under strong and distinct influence of the global warming and hydrological changes (Nelson 2003). Main media of water storage in glaciated basins in different time scales are snow and ice covers (Jansson et al. 2003). Water is released from them with different intensity during the short period of summer positive temperatures. Even some slight environmental changes may have the influence on abrupt release of considerable amounts of water. It is deciding about short-term rhythm and seasonality of processes run in glaciated catchments, triggering significant floods, rebuilding valley floors, not stabilized with plant covers. The aims of the present paper are to describe types of floods in glaciated catchments of the High Arctic with some examples of their geomorphologic effects.

Study area

Billefjorden, the NE branch of Isfjorden system in the central part of Spitsbergen (Fig. 1) is ending in the North with a comparatively shallow bay – Petuniabukta (bukta = *norw.* bay). The shallowness of the bay is a consequence of its lateral position to the main stream of ice during the Pleistocene, shaping the fjord bottom from the East (Karczewski 1995). Only some smaller ice tongues, flowing from the Lomonosov Plateau and valley glaciers, founded its outlet there. Such a setting created also conditions to develop, in the inner part, a large accumulation plane with overlapping glacio-fluvial and tidal influences (Borówka 1989). Contemporary glaciation around the Petuniabukta is reduced to the inner valley parts in the phase of continuous retreat from the position of the maximum of Little Ice Age advance (600–100 BP) marked with distinct frontal moraines (Rachlewicz et al. 2007.). The valleys, affected by strong slope and mass movement processes, in conditions of continuous permafrost occurrence and weak plant cover, they are the background for the operation of proglacial outflow, magnified by the decay of seasonal and perennial snow covers. The whole catchment of Petuniabukta has an area of 162.133 km^2, about 36% of which is covered with glaciers. The largest glaciers (breen = *norw.* glacier) are Ebbabreen (25 km^2), Hörbyebreen (20 km^2) and Ragnarbreen (7 km^2).

The climate of the central part of Spitsbergen is of quasi-continental type. Precipitation slightly exceeds

---

[*] e-mail: grzera@amu.edu.pl

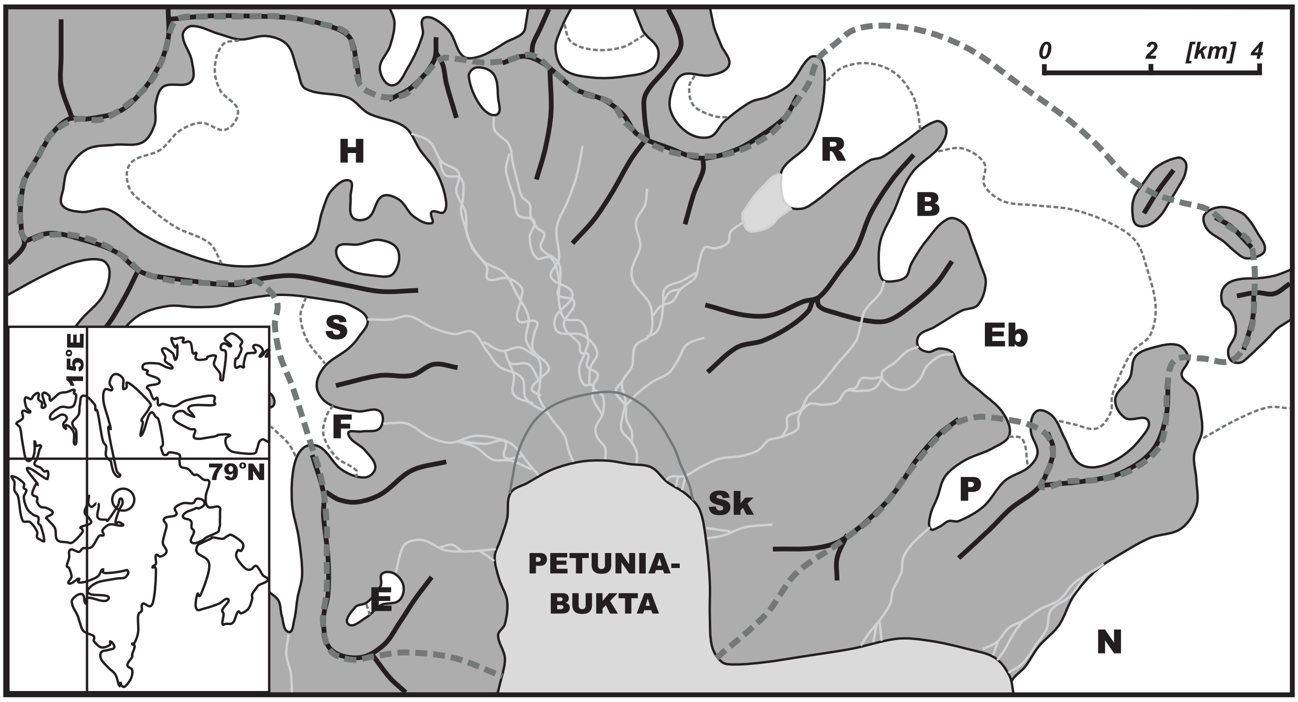

Fig. 1. Location of the study area
Black lines – main mountain crests; bold dashed lines – Petuniabukta watershed; thin dashed line – equilibrium line altitude (about 500 m a.s.l.); E – Elsabreen; F – Ferdinandbreen; S – Svenbreen; H – Hörbyebreen; R – Ragnarbreen; B – Bertrambreen; Eb – Ebbabreen; P – Pollockbreen; N – Nordenskjöldbreen; Sk – Skottehytta

200 mmy^{-1} and average summer month (June-August) temperatures are about 5°C, rarely reaching more than 10°C (Rachlewicz 2003a). Meteorological conditions were monitored at the shoreline in the base Skottehytta and by several automatic stations along valleys and on glaciers Ebba and Hörbye. The outflow is mainly of glacial origin, appearing periodically during positive temperatures occurrence and partly continued in autumn and winter in the case of larger, polithermal glaciers, in front of which icing fields are present (Bukowska-Jania, Szafraniec 2005). Episodic streams appear also on slopes, in cuts and gullies, alimented with melting snow cover and rainfalls. Problems of outflow and floods of the surveyed area and its neighbourhood, was earlier fragmentary studied by Gokhman, Khodakov (1986), Kostrzewski et al. (1989) and Rachlewicz (2003b, 2004).

Floods in glaciated valleys – examples and effects

Floods in glaciated valleys are generated through water stored in ice and snow covers in liquid or solid state. Main factors triggering flood waves are meteorological conditions in the form of rainfalls or bringing snow and ice to melt. Other features of glaciers and their surroundings like geology, endogenic activity, relief, availability of sediments, thermal state of ice etc. could not be neglected. These phenomena are a subject of studies of many specialists, also practical like planning of water supply, hydro-technical devices management or prediction of catastrophic events (Hock 2005).

Main criteria of identification of various types of floods, also with participation of melting ice masses, are their seasonality linked to the supply of water from various levels of its storage. Four types of floods generated in glaciated valleys were distinguished:

- snow-melt floods in spring,
- summer ice-ablation floods,
- summer rainfall generated floods,
- föhn-like floods.

Apart of this a separate group of short flooding waves is represented through singular outbursts of water, incurred according to the opening of englacial channels chopped with ice and snow or the draining of supraglacial or terminal lakes. On Spitsbergen such events are known for example as the single outflow of 1.0×10^6 m^3 from Tillberg ice-plateau during winter (Liestøl 1977) or the subglacial lake drainage from Kongsvegen of about 40×10^6 m^3 of water (Hagen 1987). However the most spectacular phenomena are connected with endogenic activity. Enormous jökullhlaups known recently from Island, was observed in 1995, when the lake Grimsvotn from the Vatna ice-cap released at once 1.9×10^9 m^3 (Björnsson 1998). For comparison, the total yearly outflow from the Ebba glacier is estimated to about 58×10^6 m^3 (Rachlewicz, unpubl.).

Fig. 2. Alluvial cone built during a single flood event 2003-07-06 at the outcome of small non-glaciated catchment in Ragnar glacier valley

Atmospheric conditions of the summer season (usually between June 20th and September 5th) in the Northern part of Billefjorden, generating the above mentioned four types of floods are observed with various frequency from year to year. During their occurrence the discharge of water is rising from the seasonal average of about 10 $m^3 s^{-1}$ to even more than 22 $m^3 s^{-1}$ (Rachlewicz 2003c). According to the thermal gradient measured in longitudinal profiles of valleys from 0 to 500 m a.s.l. (equilibrium line altitude [ELA] for this region, after Hagen et al. 1993) is equal to 0.6°C 100 m^{-1} (Rachlewicz 2004, Górska-Zabielska et al. 2007). The first threshold activating snow melt on slopes and glaciers is the rise and remaining of temperature above 5°C, at the level of the sea. Nivation processes reveal unequal distribution and certain amount of water is stored in the snow and firn covers. Thus intensive floods are observed in lower located small catchments on valleys slopes (Fig. 2). These processes are the most actively transforming the relief of these systems (Rachlewicz et al. in prep.).

Highest water stages are connected with the rise of air temperature above 15°C and the average daily temperature above 10°C. During the four observation seasons such situations occurrence varied from 2 to 7 days. Characteristic reaction of glacifluvial outflow is shown on Fig. 3.

Rainfall induced floods are rare for this part of Spitsbergen. It is an effect of low total precipitation and the intensity usually not exceeding 2.0 mm h^{-1}. Besides that rainfalls are associated with flushes of cold and wet air masses, transforming at the level of 200–300 m a.s.l. into snowfalls, giving weaker effects of immediate outflow. If either rainfall floods generate big changes on the glaciers and in valleys (concentration of the outflow from large surfaces, thermal effect etc.) its participation in the total outflow is small, reaching at least 4% (Rachlewicz 2003b). Time of the reaction of rivers to big intensity rainfall is very fast (Fig. 4), with its cumulating in lower parts due to tributary supply of sheet-wash and concentrated outflow. As quick is the return to the average, ablation controlled, state.

The location of the study area is favouring occurrence of föhn phenomena. The nature of föhn-like weather conditions is the flush of warm air masses over large areas, including highly situated glacier surfaces. The orographic obstacle forcing rapid air flow is the watershed between Wijdefjorden (on the North) and Billefjorden, exceeding 1000 m a.s.l.

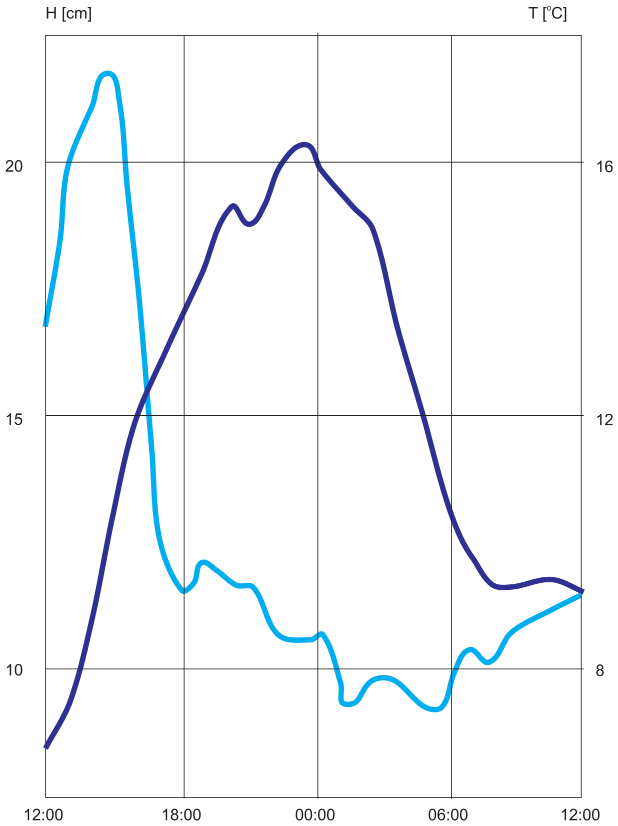

Fig. 3. A plot of daily course of Ebbaelva water level at the catchment closing point (black) and air temperature from Skottehytta (gray) from 2003–07–28/29, showing an additional peak of the flooding wave from Bertram Glacier

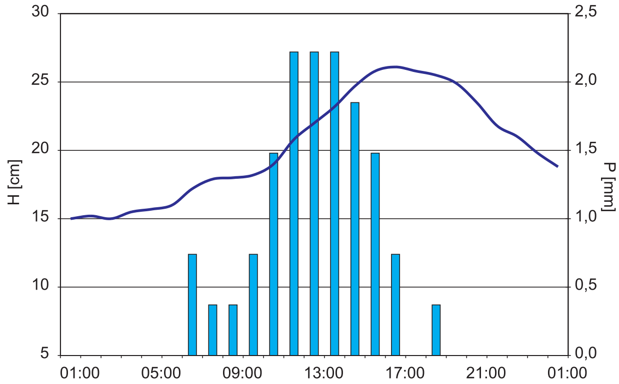

Fig. 4. Hydrogram of the flooding wave on Ebba river the 2003–08–11, on the background of hourly sum of precipitation in Skottehytta

Fig. 5. Sandy-gravel deposition of flood facies above the actual river channel in front of Hörbye glacier. Measuring rule is 1 m long

These events are disturbing thermal stratification before air masses re-cool over upper parts of glaciers. Föhn phenomena are usually followed by intensive rainfalls magnifying flood events.

Upper stages of water in river channels lead to intensive mobilization of the material stored on glaciers, beneath their covers and on their forefields: in marginal (morainic) and outwash zones. At glacier edges, where subglacial channels often operate in conditions of increased hydraulic pressure, sets of boulder layers are observed. Gravely and sandy material is transported along the whole valleys length and deposited up to 0.5 m above the average water level (Fig. 5). The intensity of glacifluvial processes transporting big amount of sediments in traction and suspension is reconstructing the layout of flat-bed braided channels. In terms of the lack of vegetation, there is also observed a lateral supply of fine material, washed out to the foot of valley slopes, where extreme floods are trimming lower parts of alluvial fans.

Conclusion

Floods and their effects are also dependent on actual state of the environment, i.e. freezing of the ground, snow cover occurrence and coverage by ice (also icing). Big dynamics of outflow increases possibility of sediments transportation and in consequence enlarge area and grain-size of deposited covers. Particularly in this parts of valley floors, where braided channels are common, their arrangement undergo distinct changes. In the gorge segments processes of lateral and bed erosion are dominating. A variety and frequency of floods is deciding about remodelling of the landscape architecture at the bottom of post-glacial valleys. It is one of the most active zones of transformations of paraglacial environment, treated as areas of fresh glacial retreat, with an unstable relief configuration and predominance of sediment transit processes (Ballantyne 2001).

Acknowledgment

Field works were performed during years 2001–2003 and in 2005 in the frame of Polish Science Ministry grants 6PO4E04121 and PBZ-KBN-108/PO4/2004.

Literature

Ballantyne, C.K., 2001. Paraglacial geomorphology. Quat. Sci. Rev., 21: 1935–2017.

Björnsson, H., 1998. Hydrological characteristics of the drainage system beneath a surging glacier. Nature 395(6704): 771–774

Borówka, M., 1989. The development and relief of the Petuniabukta tidal flat, central Spitsbergen. Polish Polar Res., 10(3): 379–384.

Bukowska-Jania, E., Szafraniec, J., 2005. Distribution and morphometric characteristics of icing fields in Svalbard. Polar Res., 24(1–2): 41–53.

Gokhman, V.V., Khodakov, V.G., 1986. Hydrological investigations in the Mimer River basin, Svalbard, in 1983. Polar Geogr. Geol., 10(4): 309–316.

Górska-Zabielska, M., Ewertowski, M., Kasprzak, L., Szczucińska, A., Rachlewicz, G., 2007. Przebieg elementów meteorologicznych na lodowcu Ebba w miesiącach letnich 2005 roku. Wyprawy WNGiG na Spitsbergen, Ms.14 pp.

Hagen, J.O., 1987. Glacier surge at Usherbreen, Svalbard. Polar Res. 5(2): 239–252.

Hagen, J.O., Liestøl, O., Roland, E., Jørgensen, T., 1993. Glacier atlas of Svalbard and Jan Mayen, Norsk Polarinstitutt Meddelelser, 129: 141 pp.

Hock, R., 2005. Glacier melt: a review of processes and their modelling. Progr. Phys. Geogr. 29 (3): 362–391.

Jansson, P., Hock, R., Schneider, T., 2003. The concept of glacier storage – a review. J. Hydrol., 282: 116–129.

Karczewski, A., 1995. Contemporary glaciation of the Petuniabukta area against the background of late-Vistulian and Holocene deglaciation (western Olav V Land, Spitsbergen), Quaestiones Geographicae, Special Issue, 4: 133–138.

Knapp, B.J., 1979. Elements of geographical hydrology. George Allen & Unwin, 85 pp.

Kostrzewski, A., Kapuściński, J., Klimczak, R., Kaniecki, A., Stach, A., Zwoliński, Zb., 1989. The dynamics and rate of denudation of glaciated and non-glaciated catchments, central Spitsbergen. Pol. Polar Res., 10(3): 317–367.

Liestøl, O., 1977. Stetvatnet, a glacier dammed lake in the Kongsfjorden area, Spitsbergen. Norsk Polarinstitutt Årbok 1975: 31–35.

Nelson, F.E., 2003. (Un)frozen in time. Science, 299: 1673–1675.

Rachlewicz, G. [ed.], 2004. Obieg materii w lądowo-morskim geoekosystemie arktycznym na przykładzie Billefjorden, Spitsbergen Środkowy. Raport grantu KBN 6PO4E 041 21, Inst. Paleogeografii i Geoekologii UAM, Ms. 250 pp.

Rachlewicz, G., 2003a. Warunki meteorologiczne w Zatoce Petunia (Spitsbergen Środkowy), w sezonach letnich 2000-2001. Probl. Klim. Pol., 13: 127–138.

Rachlewicz, G., 2003b. Uwarunkowania środowiskowe obiegu wody w systemie lodowca Hörbye (środkowy Spitsbergen). In: Funkcjonowanie Geoekosystemów Zlewni Rzecznych, tom III, A. Kostrzewski, J. Szpikowski [eds.], Bogucki Wyd. Nauk.: 351–365.

Rachlewicz, G., 2003c. Transport osadów w systemie dolinnym Ebba (Spitsbergen Środkowy podczas ponadprzeciętnych stanów pogodowych. Mat. IV Symp. Geneza, litologia i stratygrafia utworów czwartorzędowych, Poznań: 71–72.

Rachlewicz, G., Burzyk, M., Samołyk, M., Szczucińska, A.M., Szczuciński, W., in prep. Denudation rates in small non-glaciated high arctic basins in Central Spitsbergen. Inst. Paleogeografii i Geoekologii UAM, Ms. 15 pp.

Rachlewicz, G., Ewertowski, M., Szczuciński, W., 2007. Post „Little Ice Age" retreat rates of glaciers in central Spitsbergen, Svalbard. Inst. Paleogeografii i Geoekologii UAM, Ms. 35 pp.

Singh, P., Singh, V.P., 2001. Snow and Glacier Hydrology. Kluwer Academic Publishers, Dordrecht, 742 pp.