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Regulation of river water regime by detention dams

Abstract: The Russian Far East, the North Caucasus and the foothills of the Sayan Mountains are regions of the Russian Federation characterised by a high risk of rainfall floods occurrence. Mountain rivers collect the rainfall runoff on hillsides, which creates a high risk of flooding in urban lands located in floodplain areas. Topographic and hydrological factor analysis and statistical information on the precipitation data enable the identification of the most vulnerable zones where destructive floods are expected. Analysis of the impact of hill slopes on the formation of floods makes it possible to introduce the most effective and environmentally-friendly methods and resources for flood prevention. In order to reduce the negative effects of floods, measures are taken to reduce the flood surge by controlling the inflow to the flood plain. The easiest and most efficient flood run-off control system are self-regulating dams equipped with filters or culverts that allow the creation of temporary detention reservoirs.The use of local materials for the construction of dams (stones, sandbags, brushwood) allows for an efficient and environmentally-friendly system.

Keywords: rainfall flood, regulation, flood control reservoirs, temporary filled reservoirs, dams, "dry" water reservoir, detention reservoir, flood wave elevation, flood-control system.

1. Introduction and methods

The rainfall flood is the most natural hazard affecting the Russian Far East, the North Caucasus, the foothills of the Sayan Mountains and most of the Amur river basin.

Floods in highland parts of these regions are usually caused by rainfall. The most important factor affecting the rainfall flood is the contact of cold air masses from the land with warm and humid air from the sea (UXL Encyclopedia…, 2008), which results in a heavy rainfall in the highest parts of the mountains. Urban lands located in floodplain areas are affected by heavy floods, resulting from rainfall runoff on the hillsides.The outflow formed on the mountain slopes is characterised by a large amount of load due to high velocity.

The velocity can be determined by Chezy's formula and depends on the roughness coefficient and the slopes. The velocity decreases in a flood plain, because of the low values of longitudinal slopes (Kanto Region Flood Handbook, 2003). However, the valley bottom transformed into an urban area, cleared of brushwood and forest has a lower value of the roughness coefficient and the flood flow velocity increases several times (Flood Hazard Mapping, 2005).

Water flow velocity expressed by Chezy's formula:

$$V = C\sqrt{R \cdot I},$$

where:
C – Chezy coefficient dependent on the roughness coefficient;
R – hydraulic radius;
I – slope

Flow value depends on:

$$Q = V \cdot \omega,$$

where:
V –water course velocity;
ω – cross-section area

The height and impact force of the flood wave depend on:

- the type of the direct surface flow (basin's mean slopes, roughness and tortuosity of the riverbed, forest cover and others);
- intensity of rain;
- total catchment area (Shakhin and Kolosov, 2012);
- channel inflows;
- occurrence of lateral tributaries where areas (urban centres, built-up areas, cultivated land) exposed to flash floods are situated (Flood Hazard Mapping, 2005).

Topographical and hydrological factor analysis and statistical information on the depth of precipitation enable the identification of the most vulnerable zones where destructive floods are expected.

The occurrence of historical rainfall floods in the Amur River catchment, Primorskiy Territory – the river flows from the Sikhote-Alin-mountain range), the North Caucasus rivers (Fig. 1), the upper reaches of the Yenisey River catchment, the Altay region, the city of Barnaul on the Abakan River (the river flows from the Sayan Mountains) confirm the influence of natural factors (slopes, roughness coefficient etc.) and human impact (mentioned before) on the flood hazards.

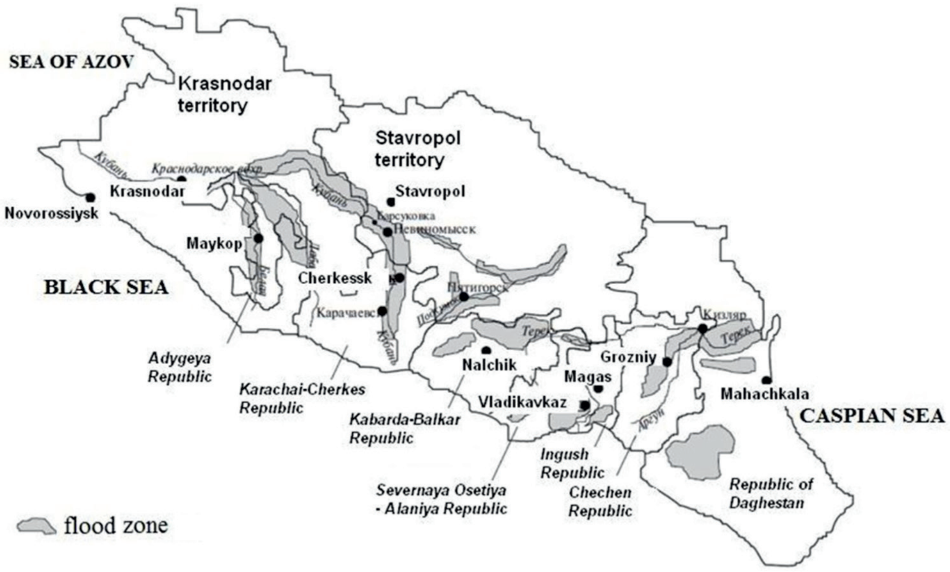

Figure 1. Areas in the south of the Russian Federation affected by the summer 2002 flood (Vorobyev et al., 2003)

In the case of the tragic flood in Krymsk, which killed 170 people in 2012, it can be observed that the maximum intensity of rain that generated the destructive flood on 6–7 July 2012 lasted only 5 hours (Fig. 2).

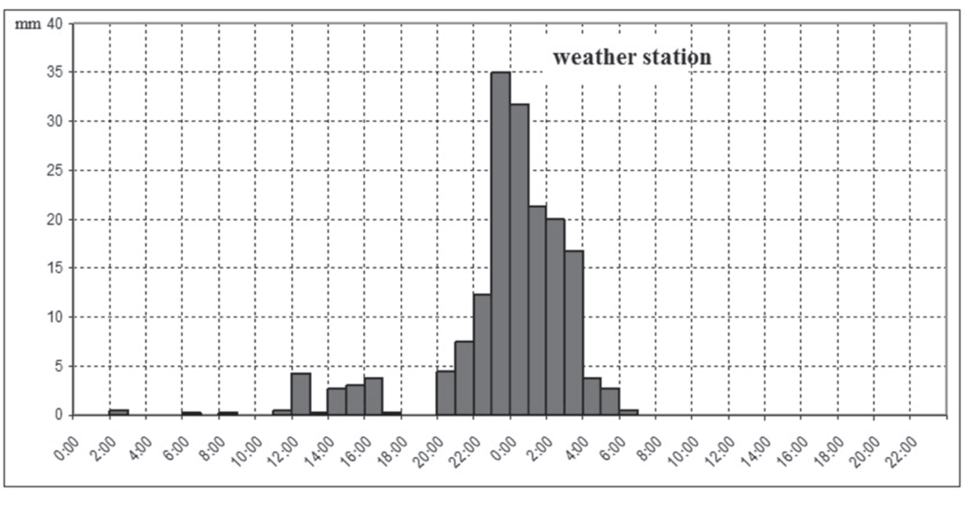

Figure 2. Intensity of rain in the Adagum River basin from 10 a.m. on 6 July till 03 a.m. on 7 July

2. Results

The analysis of the hills' impact on the formation of floods makes it possible to introduce the most effective and environmentally-friendly methods and resources for flood prevention.

The authors designed a system of small detention reservoirs (dry reservoirs) built in a river basin in order to collect water during rainfall floods, whose fail-safety is ensured by several dams. If one of the dams fails, the remaining ones will temporarily delay the flood wave. The proposed radial flood-control system is designed to reduce the peak of a high flood wave that is formed in a mountain river, characterised by a large area of hills in the catchment. The proposed system allows for delaying the water outflow and lowering the flood wave by controlling the rate of water outflow within the flood plain. The system involves a complex of dams located on tributaries (small unnavigable rivers, intermittent rivers, brooks and ravines).

Figure 3 shows an example of the complex of detention reservoirs on the Adagum river. These small reservoirs collect water temporarily during the period of high discharges (spring or summer flood). In the period of low outflow reservoirs stay dry, and the water is filtered through the dam and flows to the lower section of the river. The location of reservoirs was projected in relation to geomorphological characteristics of the basins (including riverbed roughness, the length of tributaries, slopes, flow velocity, channel lag).

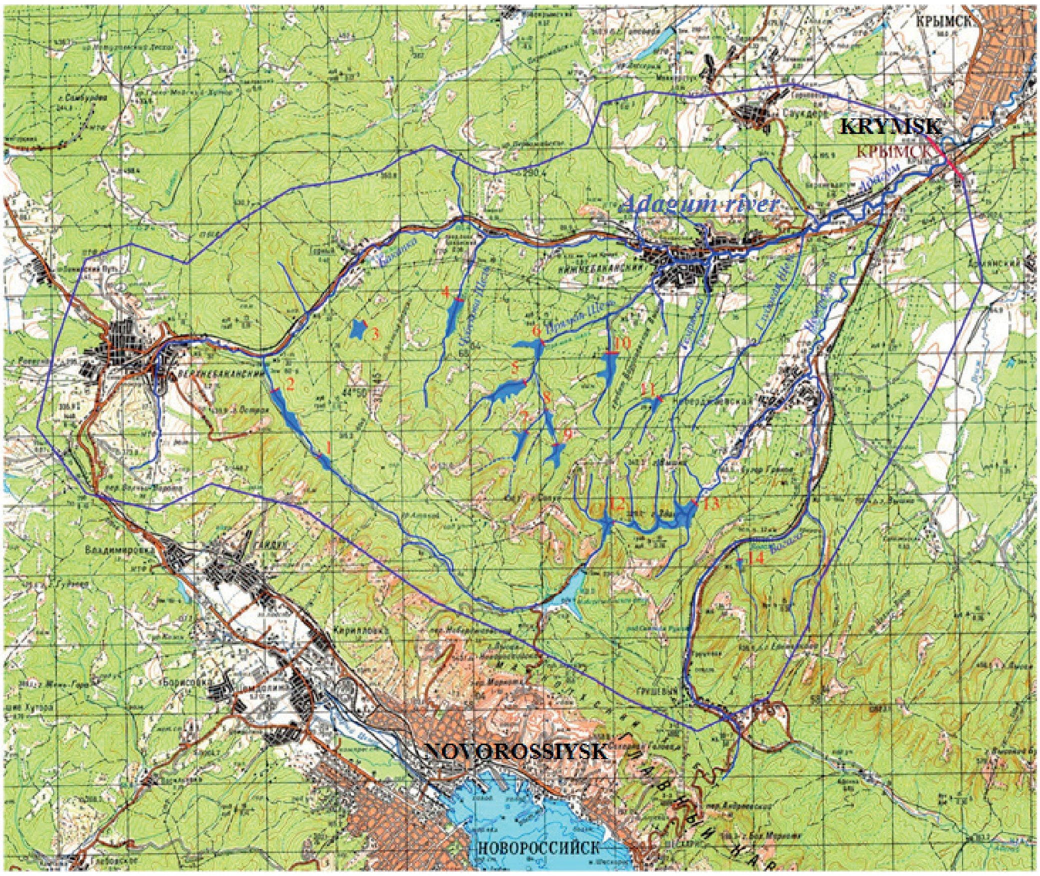

Figure 3. Location of the complex of temporary detention reservoirs (1-14) in the Adagum catchment (Kolosov and Selezneva, 2014)

In order to facilitate the implementation of the presented flood-prevention solution, the easiest and most efficient solution is to build self-regulating filter dams or dams equipped with a culvert spillway, which create temporary water storage reservoirs.

It is possible to locate the dams on tributaries of a flooding river by a radial or cascade scheme. The use of local materials for the construction of dams (stones, sandbags, brushwood) allows for an efficient and environmentally-friendly system.

The hydrological effects of using this solution are presented in Figure 4.

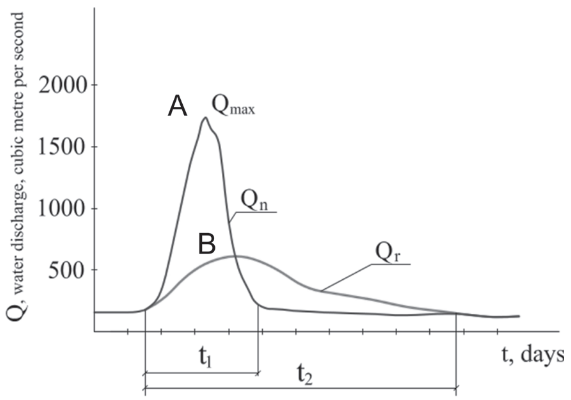

Figure 4. River outflow before (A) and after (B) using temporary detention reservoirs

The system of streamflow regulation through "dry" temporary detention reservoirs requires refilling of a reservoir during floods and gradual storage of the outflow (by spillways, rock filter or culvert spillways).

The following constructions are used as flood-control dams (Kolosov and Selezneva, 2014) (Fig. 5):

– rock filter dams;
– earth dams with a bottom culvert spillway;
– gabion dams;
– directed-explosion dams;
– fascine dams;
– sandbag dams with spillways in a forming layer
– earth dams with a siphon spillway.

Brushwood-and-stone dams and sandbag dams can be built in zones with no access roads.

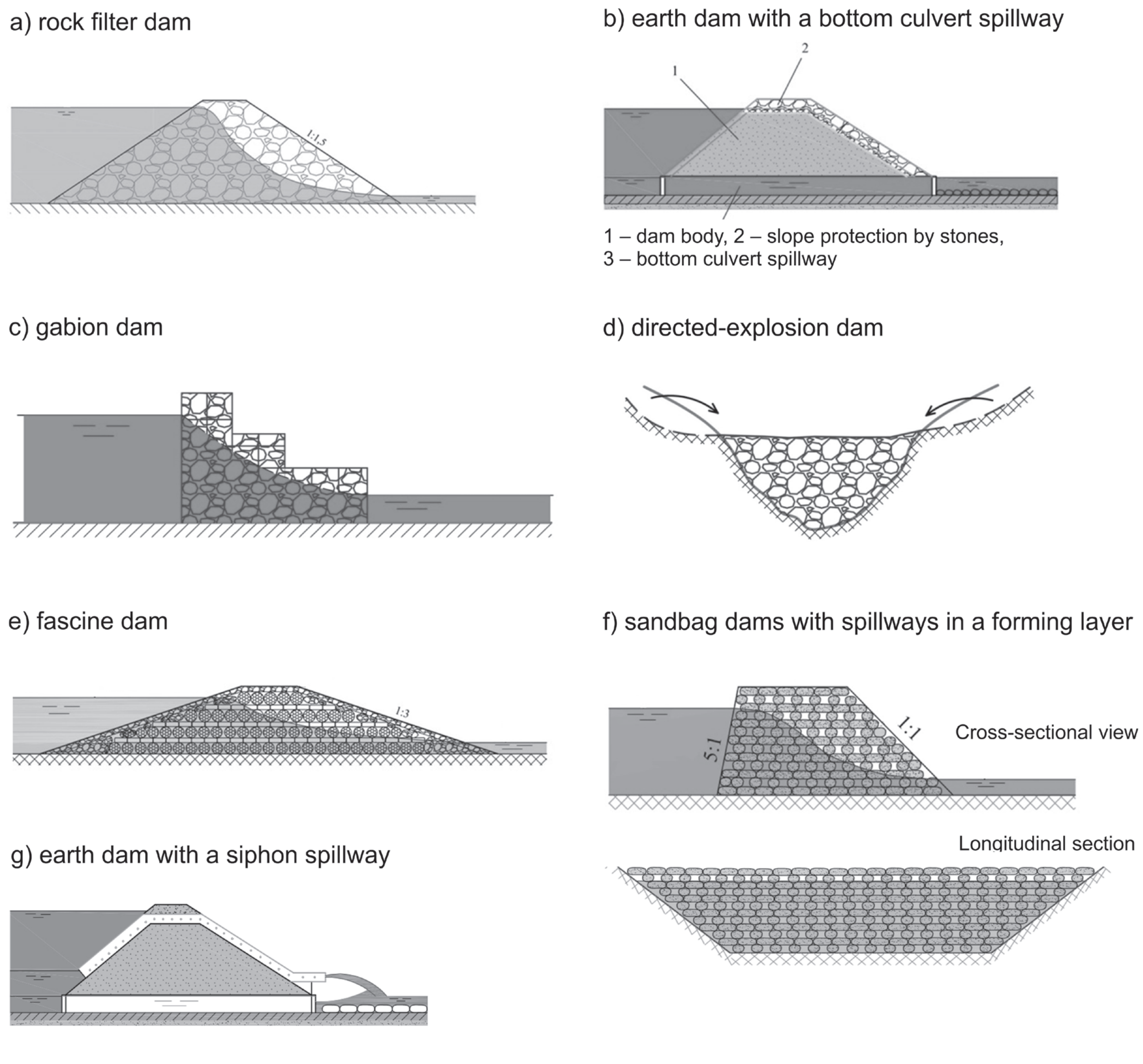

Figure 5. Types of dams designed to collect water in retention reservoirs

A filter sandbag dam will filtrate the discharge like rockfill as a result of sandbags stacked in longitudinal and transverse layers forming culverts. Such a dam is ecologically sustainable and may be built by local population at sites threatened by flood where it is not possible to deliver other materials due to the lack of access roads (when sandbag's weight is up to 50 kg).

The authors' invention of flood-control dams built of sandbags has been patented (Kolosov et al., 2015).

3. Conclusion

1. The analysis of the flood formation process showed that the flood wave elevation and shape depend on the total area and geomorphological features of a river basin.
2. An effective and valid engineering decision was made regarding the flood prevention based on the construction of reservoirs for water storage in tributaries and resulting in the reduction of high flood waves in the main river.
3. The presented flood protection system does not interfere with environmental conditions, because of temporary water detention.

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