ESTIMATION OF MAXIMAL ACCEPTABLE FLOWS USING GROUNDWATER-SURFACE WATER RELATIONSHIPS FOR THE KURA RIVER, AZERBAIJAN

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Abstract. Floods in the Kura River of Azerbaijan occur most often along the alluvial plain of the cachment area, where the river frequency meanders and streambed slopes are very shallow. It is illustrated that construction of dykes and leaves actually do not prevent flooding, where hydrologic connections between groundwater and surface water are high. The paper suggests an approach to define maximal acceptable flows (MAF) in the lower part in order to predict floods and regulate outlets from the upper reservoirs. MAF computations before high-water season allows for further regulation of outlets further downstream in order to prevent flooding and enable to forecast floods. While the study focuses on the specific region, the overall approach suggested is generic and may be applied for elsewhere.

Key words: flooding, high water, channel capacity, riverbed siltation, maximum acceptable flow

Introduction

The Kura River is the largest international river of the South Caucasus. The origins of the Kura can be found in east Turkey, and flows across the Ardakhan plateau, through Georgia and enters Azerbaijan. In Azerbaijan, the Kura crosses the Kura-Araks plain, where it joins with the Araks and finally flows out into the Caspian Sea. The Kura River plays a vital role in both local and regional economies and has been used to generate energy production, irrigation and water supply in Azerbaijan and Georgia (Figure 1).

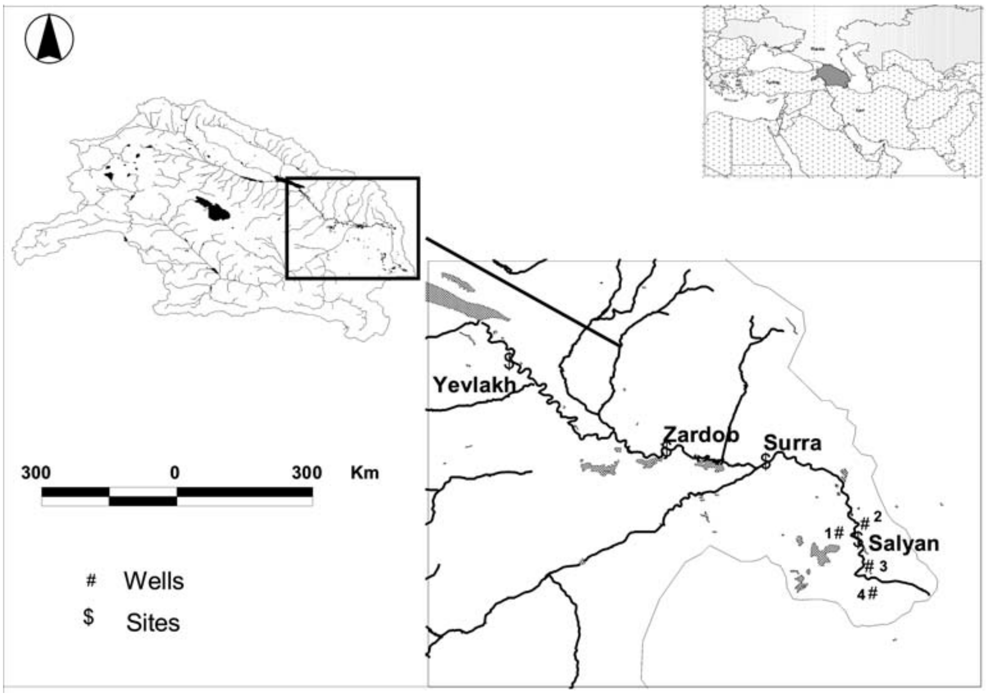

Figure 1. A map of the Kura river basin and the area of interest showing the sites and experimental wells referred to in the paper

Consistently high flows caused by intensive rains, creates flooding conditions near the mouth of the Kura. As a result, agricultural lands of the Kura-Araks lowlands are flooded and colossal economic and social damage is caused to municipalities a located near the banks. Flow regulation has historically been considered the most effective method for flood prevention, although large flood events began to occur even in the highly regulated reaches in recent years. Also, while most of the Kura River's flood events have usually occurred during high flow periods, flooding events have been more recently observed even during low flow water periods. Floods in the Kura River occur most often along the alluvial plain of the watershed, where the river frequency meanders and streambed slopes are very shallow. This recent change in the river's flood frequency and magnitude has increased the threat to floodplain residences and the productivity of floodplain agricultural activities. Larger flood events have the potential to cause colossal economic and social damage to municipalities located near the banks of the river by not only flooding the surface of the floodplain, but also by raising local groundwater levels that affect the normal function of households both at the banks and the territories located far from the river.

Estimation of maximal acceptable flows for the mouth of the Kura river.

Some authors consider that flooding occurs when the volume of water passing through a channel per unit time exceeds the volume of the channel reach, or the channel capacity (Andrew 1992). However, this general definition assumes the surface channel's streambed is composed of impervious material, inhibiting any hydrologic connection between the surface channel and the nearby alluvial aquifer. This "hydrologic connection" can also be considered streambed leakage (seepage), a type of groundwater-surface water interaction that occurs when the hydraulic head of the surface channel is greater than the hydraulic head of the nearby alluvial aquifer. If there are such interactions between the surface channel and groundwater, a flow event that falls under normal high water levels can lead to the rise in groundwater levels, causing "groundwater flooding" which are able to disrupt the normal economic functioning of buildings and households along of coastal areas. This can occur in low-lying areas along the floodplain, where the water table is driven upward by stream discharge and intersects the land surface. Because of the potential for economic damage to be incurred without the need for the Kura River to physically spill over its surface channel banks, it is prudent to use the term "maximal acceptable flow", rather than "channel capacity". As defined by Alexeevskiy and *et. all* (2000), the maximal acceptable flow discharge (MAF) is a threshold discharge value, with any flows below the MAF do not cause any danger to households and other establishments. The MAF may also be defined as a maximum amount of water flowing through a cross-section in the given unit of time that does not cause danger to floodplain facilities and households during this flow (Abbasov, 2007). Water discharges that exceed the MAF can be defined as undesirable discharges. "Undesirable discharges" have been typically considered flow events that produce surface flooding and have the potential to damage bridges, agricultural lands and other facilities situated on or near banks and floodplains. However, considering the effects of non-flood events on nearby groundwater levels, an "undesirable discharge" may occur even though the flow may not have spilled over its stream banks. An example of an undesirable discharge event that did not result in surface flooding occurred in the Kura basin in 2005, when groundwater levels rose enough to disrupt agricultural productivity at irrigated fields along the bank, even though the channel itself did not overflow. This situation occurred after the construction of several dykes on the Kura River that are aimed at eliminating surface channel flooding. Because these dykes are higher than the natural riverbanks, they cause the ground water level to rise and damage floodplain facilities even though no surface channel flooding occurred. As a result of this, undesirable flow discharges in the Kura River are observed long before flooding occurs. This example illustrates how groundwater-surface water interactions between the surface channel and the alluvial aquifer can cause the water table to rise above the ground surface in some fluvial systems. For this situation, the channel's MAF is always less than the channel capacity. Excessive in-stream sedimentation in the lower regions of the Kura River basin can cause not only a diminution in the overall channel capacity but also an increase in surface water elevation, which can drive water through the streambed and into the nearby aquifer. Both of these can affect the MAF values for the river reach. This has been observed in the river Kura during last years, with active sedimentation in the streambed caused by intensive deforestation in the cachment area.

The MAF can be estimated by simply multiplying velocity of flow by maximum area of cross section:

$$Q_{MAF} = V\omega_{max} \tag{1}$$

Where, Q_{MAF} is maximal acceptable flow, V velocity of flow in the riverbed, ω_{max} is maximum area of cross-section that does not create undesirable flow discharges.

To accurately define a MAF value for a location along a river, the hydraulic connection between the riverbed and the level of groundwater in surrounding areas needs to be carefully explored. In other words, the channel stage at which groundwater levels are altered enough to cause floodplain damage must be observed before that event's discharge value can be identified. For studying surface water-ground water connections on the Salyan site area data taken from 4 experimental wells were used (Figure 1). Depth of the each well is about 8 meters and they are located on several distances from the Salyan site. Measurements were taken every 4 days during high water season, since the end of the April until the beginning of May, in 2004. Figure 2 illustrates the relationship between underground water tables and water level at Salyan site in 2004 using data from the experimental well 1. Similar relationships have been established for all 4 wells. The R^2 for such relationships ranges from 0.92 to 0.92. Such relationships can be used to estimate $_{max}$ for any area and to be used to forecast underground flooding using hydrologic forecasts.

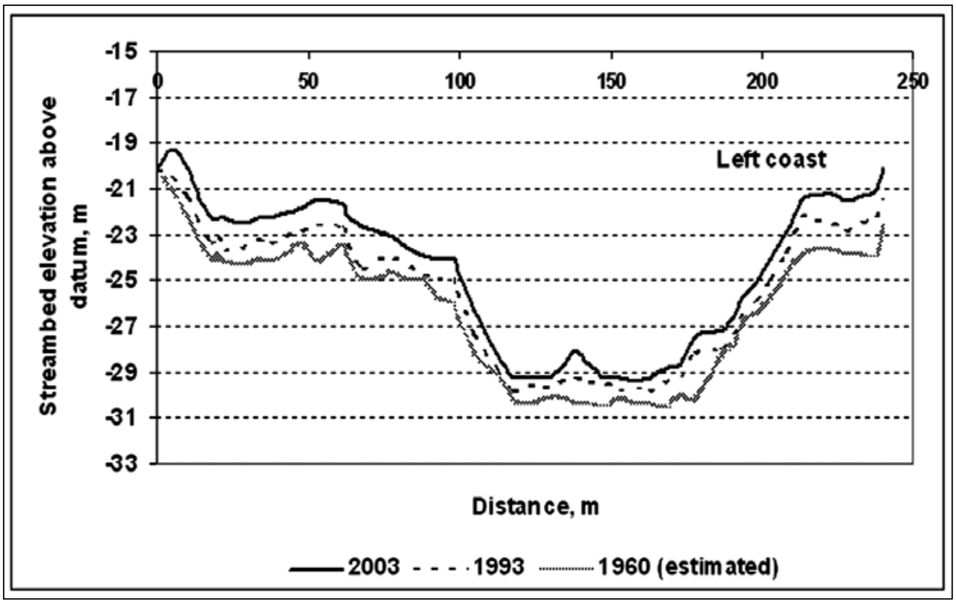

Figure 2. A relationship of groundwater table with water level at Salyan site, 2004

This relationship shows that when the water level in the riverbed is up to – 22 m BC (Baltic system), the level of underground waters does not disturb the usual functioning of residential facilities. However, above that level, the water level intersects land surfaces and floods agricultural lands, even though surface channel flooding is not observed. This is considered the threshold water surface elevation, which can then be used to compute the MAF for that location using relationship between water discharge and cross section. Figure 3 illustrates the channel cross-section, surveyed on April 15, 2004, and a Q=f (ω) curve for the Kura river at Salyan (a site on in the Kura) for several flow events that occurred in 2004. As seen in from the figure, the area of maximum cross-section area for a surface water elevation of -22 BC was computed to be approximately 998 m^2. This curve reflects the relationship between cross-sectional area and discharge flows. This site's MAF may be computed for maximum capacity based on this curve. It was defined that flows no larger than 1100 m^3/s could be conveyed through the maximum cross sectional area of 998 m^2. In other words, it was defined that at the MAF for the Salyan was 1050 m^3/sec in 2004 and any flows exceeding 1050 m^3/sec. can be considered "undesirable discharge" events (Figure 3). Riverbed elevation in the river, observed during the last half century has resulted in changing of MAF values as well. According to estimations, MAF value of the riverbed in 15.04.2004 was approximately 1050 m^3/s. Nevertheless, the same value for the cross section of 1993, shown on the figure 4 has made 1300 m^3/s. Consequently, despite of construction of leaves and dykes in the river coasts MAF value has decreased.

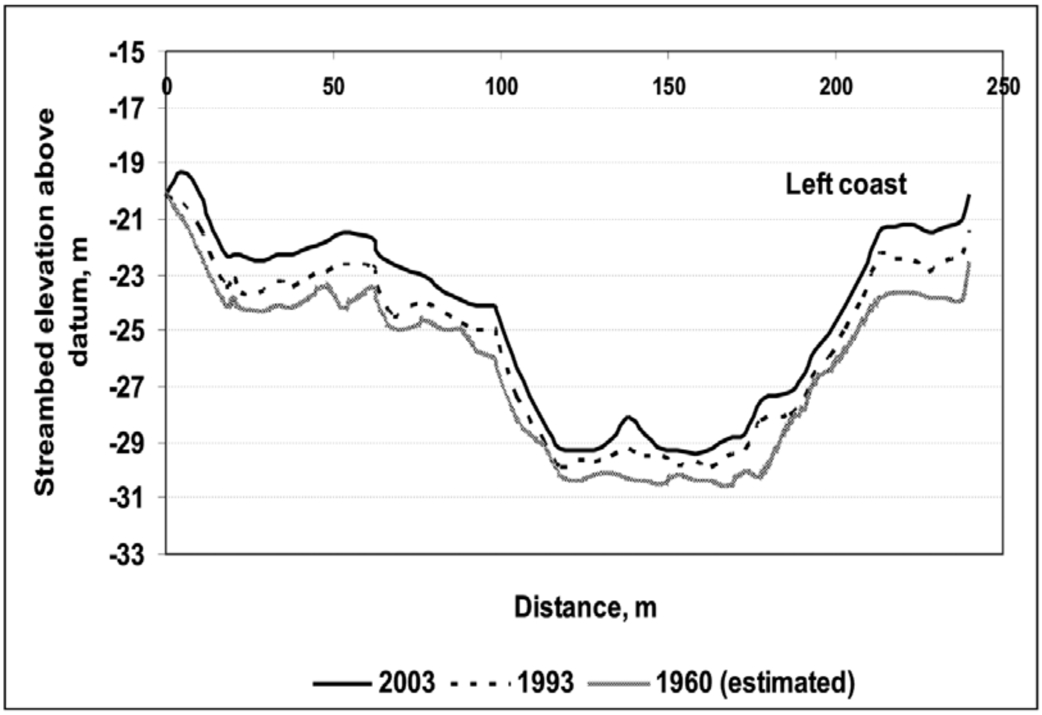

Figure 3. Rising of the riverbed at Salyan over the period 1960-2003

In dry climates where channel levels are consistently low, there is no need to estimate the MAF for the entire water year. In rivers with intensive in-stream sedimentation, MAF value may change very rapidly. For such rivers, it may be necessary to compute a new MAF at the beginning of every high-water season. MAF computations before high-water season allows for further regulation of outlets further downstream in order to prevent flooding and enable to predict floods, including underground ones.

For any site in the river, a MAF value can be determined using the following steps:

- Construct a cross-sectional profile of the surface channel
- Determine the maximum area of the cross-section determined based on this profile (If there is a hydrologic connection between ground and surface waters, the relationships like (1) should be used).
- Determine the maximum discharge rate for a given maximum cross-sectional area

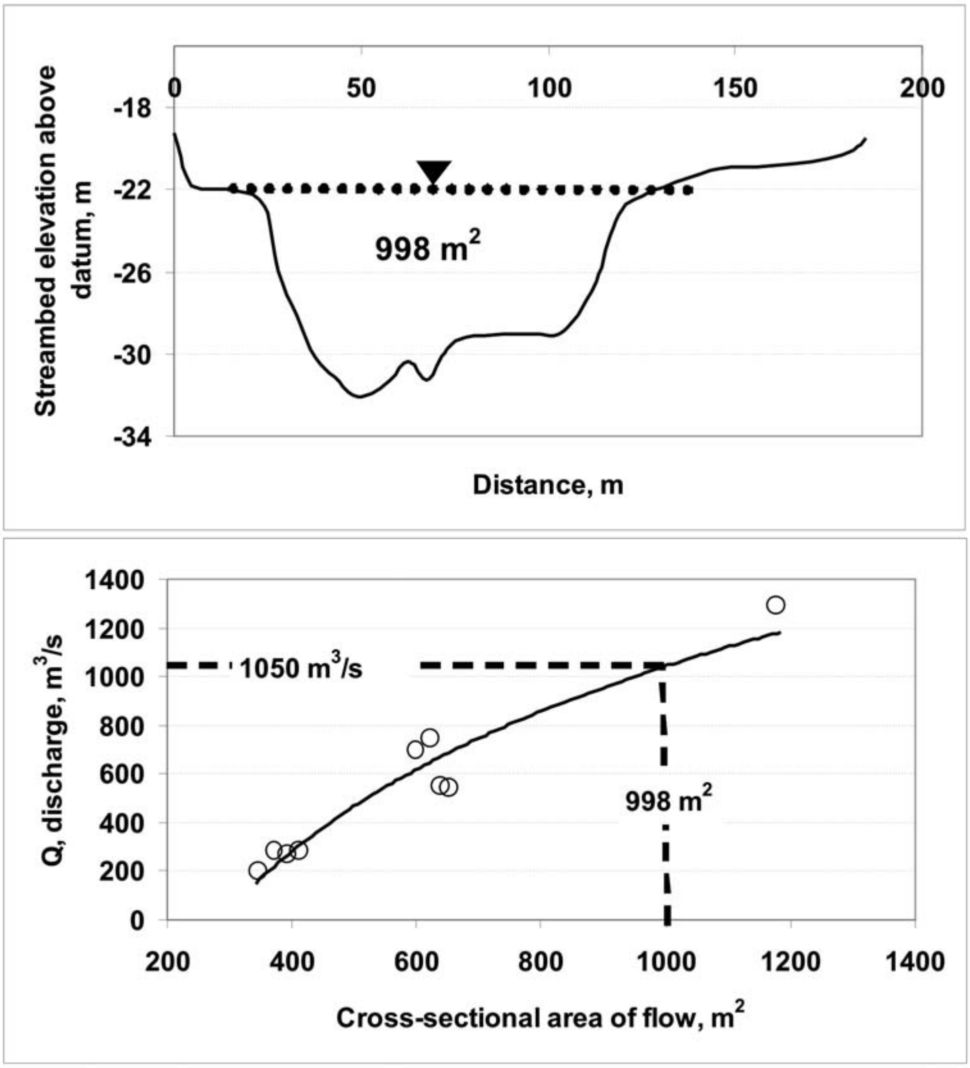

Figure 4. Cross section of the Kura river (top) and a Q=f() curve at Salyan on 15.04.2004.

CONCLUSIONS

Simple solutions have been proposed for estimation of MAF in mouth part of the Kura through regression relationships of underground water table with the surface water level. MAF referred in the paper as a maximum amount of water flowing through a cross-section in the given unit of time that does not cause danger to floodplain facilities and households during this flow. It has been illustrated that construction of dykes cannot increase MAF for rivers such as Kura, since there are high interactions between the surface channel and groundwater, a flow event that falls under normal high water levels can lead to the rise in groundwater levels, causing “groundwater flooding”. MAF computations before high-water season allows for further regulation of outlets further downstream in order to prevent flooding. Moreover estimating them enables to predict forecast floods, including underground ones

REFERENCES

1. Abbasov R.K. (2007) Hydrology of floods (A case study on Kura river). Journal of Geography. 14. 121-131.

2. Alexeevskiy N.I., Estigneev V.M., Khramenkov S.B., Khristoforov S.B. (2000) A General approach to assessment and achievement of ecohydrological safety for water reservoirs. Publications of Moscow State University, ser. 5, ¹ 1, Geography. 49-61

3. Andrew D. A. (1992). Water Resources Planning. Rowman and Liftlefild Publishers. pp. 392