© IWA Publishing 2016
273

Water Practice & Technology Vol 11 No 2
doi: 10.2166/wpt.2016.033

Flood early warning system on the Đetinja river Basin in Serbia

Aleksandar Drobnjak*, Nikola Zlatanović, Milutin Stefanović, Mileta Milojević and Milica Đapić

Department for Torrent and Erosion Control, Institute for the Development of Water Resources Jaroslav Černi', Jaroslava Černog 80, 11226 Belgrade, Serbia

* Corresponding author. E-mail: alexandar_1203@hotmail.com

Abstract

The Đetinja river basin, in Užice, western Serbia, is ungauged. Many torrential floods have occurred there over the past decades. In the city of Užice, there are no rainfall intensity gauges, and it is impossible to provide the data needed to monitor torrential floods or make a timely response, which is a precondition for successful defense from them. An early warning system for torrential floods was designed, with three key elements: measuring devices in the basin and river, a server application and a web-client application. A hydrologic study was made to assess multiple scenarios, focusing on the analysis of real data to determine alarm criteria for oncoming floods. Alarm criteria were proposed, based on analysis of previous floods and measurements. Using the direct relationship between runoff, rainfall depth and intensity, the alarm criteria are based on precipitation and river stage. There are three levels: the first level 'warning', the second 'regular flood defense', and the third 'emergency flood defense'. The earliest possible warning is of great importance, due to the nature and speed of onset of the process. The system plays a key role in active flood control and prevention, by providing the lead time to secure and strengthen the flood defense system, thereby minimizing the adverse impacts of torrential floods.

Key words: flood early warning system, flood protection, torrential floods

INTRODUCTION

The Đetinja River basin, in Užice municipality in western Serbia, is a sub-basin of the Zapadna Morava River (Figure 1). This part of Serbia is characterized by extremely hilly and mountainous terrain. Most of the Đetinja tributaries flow in from the right, making the basin asymmetric. The main tributary is the river Sušica. The basic parameters of the Đetinja basin are shown in Table 1.

The Đetinja River is a true example of an ungauged torrential watercourse where, during the first decade of the 21st century, numerous floods have caused financial loss and sometimes even human casualties. The Republic Hydro-meteorological Service of Serbia's existing observation system cannot be used to forecast floods in the basin, due to lack of measuring points or stations capable of transmitting observation data in real time, so that the competent authorities are alerted and can react to minimize the consequences.

Systems for observing rainfall intensity and runoff that are capable of recording observations and sending them automatically to a given address have already been developed in similar basins (Gavrilović *et al.* 2004). Today, they are computerized, and offer a whole new dimension to the monitoring and announcement of floods in real time. The development of communication systems has significantly improved the functionality of measuring equipment as well as the transfer of data to users. Unlike previous systems that, with the inevitable delay, transmitted data to functionally separate

Water Practice & Technology Vol 11 No 2
doi: 10.2166/wpt.2016.033

Figure 1 | Map of the Republic of Serbia with the relevant part of the Đetinja basin (red) and the Sušica sub-basin (south of the dashed yellow line).

Table 1 | Basic parameters of the Đetinja River basin

Parameter	Value	Parameter	Value
Area of considered part of basin	546.6 km^2	Mean annual rainfall	881 mm
Longest flow path	61.6 km	Mean annual temperature	8 °C
Average channel slope	0.7%	Highest recorded discharge	211 m^3/s
Maximum elevation	1,530 masl	Lowest recorded discharge	0.9 m^3/s
Mean elevation	740 masl	Mean annual discharge	5.7 m^3/s
Minimum elevation	302 masl		

centers (meteorological, hydrological, water management, etc.), modern systems can transmit data directly to all centers and their competent staff.

The system design was based on the flood early warning systems (FEWS) on the Topčiderska River in Belgrade and on the River Crnica in Paraćin (Milovanović *et al.* 2010). No hydraulic measurements were made on the River Đetinja for this study. Because of that, the methodology used was the same as that applied to ungauged basins. Maximum attention is focused on the analysis of data collected to determine early warning alarm criteria.

Hydrologic analysis is used to define the flow characteristics of the desired profile, to determine criteria for FEWS. For this study, the maximum flow discharges were calculated for flooding probabilities of 1%, 2%, 5% and 10%, correlating, respectively, with 100-, 50-, 20- and 10-year return periods. All relevant meteorological, climatological and hydrologic data for the study area were processed and analyzed.

METHODOLOGY

Hydrologic analysis of the study area

Hydrologic analysis was carried out for a profile on the Đetinja where it was proposed that the measuring device be installed. Maximum water levels were estimated for the profile using a

Water Practice & Technology Vol 11 No 2
doi: 10.2166/wpt.2016.033

rainfall–runoff model. This was based on the synthetic unit hydrograph theory for determining peak runoff, as well as the SCS method for determining effective rainfall USDA (1986).

Data from the main meteorological station at Zlatibor, which is nearby, were used as input for the analysis (Institute for the Development of Water Resources 'Jaroslav Černi', 2009). Flow curves and water levels for individual profiles were used where there were appropriate measurements covering sufficiently long periods.

The calculations yielded the probable maximal flows – $P = 1$, 2, 5 and 10% – for the return periods noted above. The maximum flows calculated were used to define the FEWS criteria, as well as water levels and flow curves available.

The system design for monitoring precipitation and flows

FEWS comprises several parts:

1. *Data acquisition systems (3 measuring points).* These are rainfall and water level measuring points (Figure 2). Measuring equipment is installed in the basin and watercourse in relation to the basin's hydro-energetic potential, the potential for forecasting and the formation of floods.

Figure 2 | Measuring points in the Đetinja Basin.

2. *The server:* this runs on the TCP/IP principle. If the internet protocol crashes, backup communication with the server is via SMS. When there is an alarm message, the server sends e-mails to predefined addresses and SMS messages to predetermined phone numbers. The server application must be installed on a computer with a fixed IP address and reliable power source. The computer must have a backup power source – e.g., a generator – that runs in case of power failure on the existing network. The application server system includes GSM cards with fixed IP addresses, as well as priority on the mobile phone network when sending messages from the measuring units to the server.
3. *The web-client application:* the client application contains a graphic interface that shows the geo-positioned measuring unit locations on a map. In normal mode, the measuring units are shown in green. When one or more sends an alert, however, the color changes automatically to red on the screen, to make them easy to see. The station also sends an audio alarm, which continues until the user confirms receipt. The client application can be designed meet the priorities, and provide the analyses and reports essential to various organizations to enable them to perform their parts of the job better.

Water Practice & Technology Vol 11 No 2
doi: 10.2166/wpt.2016.033

Flood warning system software and hardware

The software was developed at the Institute for the Development of Water Resources 'Jaroslav Černi', in the Department of Torrent and Erosion Control (Gavrilović *et al.* 2004). It can be adapted to user needs, and has a clear interface with options to connect to other databases. The equipment can be programmed to give an emergency alarm under specific conditions.

The hardware must be of good quality and reliable, with fast and efficient service in the event of malfunction. It must also be of simple and flexible structure, resistant to atmospheric effects and simple to operate. The rain sensors must have a measurement accuracy of +/− 0.1 mm of rainfall and the water level sensors must be accurate to +/− 1 cm.

RESULTS

The study yielded criteria for FEWS alarms. The definitions were based on the analyses of data on rainfall and flow rates, as well as the flow curves and water levels available from the target area. These criteria are crucial to the timely announcement of a flood surge, so it is very important to define them precisely.

Criteria for flood warning alarm system

The alarm system criteria for rapid flood warning were determined from the causal analysis of data from previous events. There are three criteria, as noted above.

- Level I – a warning is given when it rains at an average intensity exceeding 20 mm/30 min;
- Level II – an alarm is given when it rains at an average intensity exceeding 30 mm/30 min;
- Level III – an alarm is given when the average intensity of the rain exceeds 40 mm/30 min and it continues raining at this rate for than an hour.

The alarm time interval of 30 minutes is used rather than 1 hour, due to the size of the basin, to enable an efficient and timely response.

Water level-based criteria (Figure 3):

- Level I – a signal is transmitted only when the water level reaches 1.6 m in the river channel at the monitoring point on the Đetinja;
- Level II – an alarm is given when the water level exceeds 1.9 m;
- Level III – an alarm is given when the water level exceeds 2.2 m.

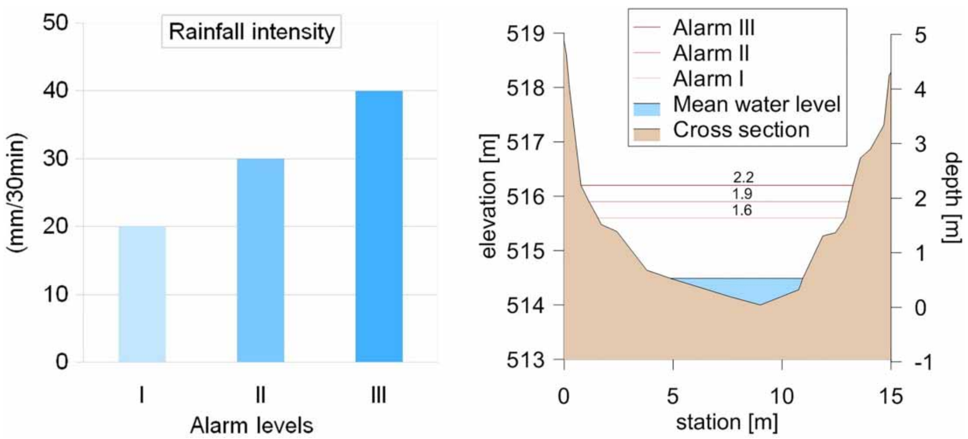

Figure 3 | Alarm criteria for rainfall intensity and water level at the stage monitoring point on the River Đetinja.

doi: 10.2166/wpt.2016.033

DISCUSSION

High intensity rainfall causes surface runoff, which can become a substantial flow. Because of this and as noted, three alarm level criteria – I, II and III – have been defined for two stations in the basin. The criteria relating to the Đetinja profile were defined on the basis of detailed hydrologic analysis and the potential hazards arising from the water level for the downstream areas of Užice.

FEWS was designed on the model of existing systems on the Crnica River, near Paraćin, and the Topčiderska River in Belgrade. These systems have proved to be very reliable and effective, especially that on the Topčiderska, which has been in operation for many years.

The main results of the study are the criteria on which almost the entire system depends, so, three criteria levels are defined:

- a warning to be ready (level I),
- engagement of regular flood defense (level II),
- emergency flood protection (level III), i.e., the need to react with all available manpower and equipment to mitigate potential flood consequences downstream of the monitoring point.

It is important that the water level monitoring profile of the River Đetinja is checked and maintained regularly. Every serious flood leaves large amounts of sediment on the river bed. The alarm criteria were defined on the basis of water levels relating to a specific river channel profile. It is necessary, after every flood, to clean the channel bottom so that the criteria specified remain relevant.

CONCLUSION

The Đetinja River is characterized by torrential flow, requiring fast warning flood defense systems that differ from the classic form. Long-term and detailed analysis of the data available indicated that torrential floods on the Đetinja are formed and reach their peak approximately two hours after heavy rain.

The specifics of the Đetinja basin mean that detailed hydrologic analytical data are needed to determine FEWS criteria. Experience gained on the Topčiderska River indicates that it is necessary to have at least two rain gauges and one river stage/water level monitoring device.

When the alarm for emergency flood defense is given, the competent services have 2 to 3 hours lead time before the critical water level is achieved at the flood zone in Užice city center. That is long enough for citizens to be warned to remove or protect property susceptible to flooding, organize additional flood defense and, if necessary, organize and execute the evacuation of vulnerable zones.

The system plays a key role in active flood control and prevention, by providing the lead time to secure and strengthen the passive flood defense system, thereby minimizing the adverse impacts of torrential floods.

ACKNOWLEDGEMENTS

The research presented in this paper is funded by Serbia's Ministry of Education and Science as part of a project 'Assessment of Climate Change Impact on Water Resources in Serbia' (TR-37005) for the period 2011–2015.

REFERENCES

Gavrilović, Z., Stefanović, M. & Milojević, M. 2004 'Application of methodology for the real-time torrent flood forecasting'. In: *10th Congress Interpraevent 2004 – The defence of populated territories from flooding, debris flows, avalanches and slope movements*, Trento, Italy.

Water Practice & Technology Vol 11 No 2
doi: 10.2166/wpt.2016.033

Institute for the Development of Water Resources 'Jaroslav Černi' 2009 'Water Resources Assessment of Serbia', Belgrade, Serbian.

Milovanović, I., Stefanović, M. & Gavrilović, Z. 2010 'Torrent Flood Monitoring in Real Time on Topčiderska River'. In: *Proceedings of the YUINFO-10 Conference on Computer Sciences and Information Technologies*, Serbian.

U.S. Department of Agriculture (USDA) 1986 'Urban Hydrology for Small Watersheds. Soil Conservation Service, Engineering Division. Technical Release 55 (TR-55)', Washington, DC, USA.