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Flash Flood Guidance Gazette

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Flash Flood Guidance (FFG) Gazette, a bi-annual newsletter bringing users of FFG products all the latest news – operational information, technical advances, case studies and education for the flash flood community.

The Central America Flash Flood Guidance System (CAFFGS) use during the passage of Hurricane Otto in Costa Rica

On 24 November 2016, Hurricane Otto made landfall over southern Nicaragua and northern Costa Rica as a category 2 hurricane. This was the first direct passage of a hurricane over Costa Rica since historical records have been kept. Prior to this, a tropical cyclone directly impacted the country in 1888 but without hurricane intensity. Figure 1 shows the satellite image at 10:15am local time (16:15 UTC) on Nov 24, along with the storm trajectory map indicating the hurricane path along the Costa Rica-Nicaragua border. At this time, the hurricane had sustained winds of 175 km/h and wind force extended up to 30km from the center of the cyclone.

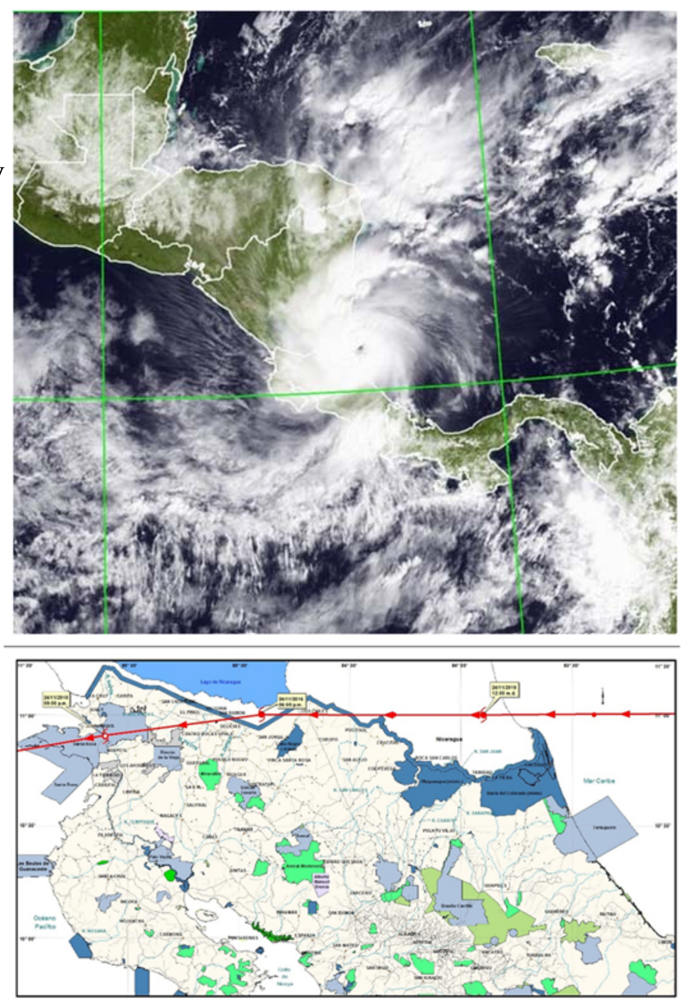

Figure 1. (a) GOES-R satellite imagery of Hurricane Otto on 16:15 UTC on 24 November 2016; and (b) storm trajectory (source: IMN).

At the Instituto Meteorológico Nacional (IMN) of Costa Rica, the Central America Flash Flood Guidance System (CAFFGS) was used as a key tool in the preparation of meteorological warnings during this extreme event and in briefings with the national emergency commission (CNE). IMN Director, Juan Carlos Fallas Sojo, presented briefings for the Emergency Operations Center using information from CAFFGS and reviewed by the operational forecast meteorologists from IMN.

Of particular interest, the HydroEstimator (GHE) product of the CAFFGS provided hourly precipitation estimates over in the region in places where there is a lack of real-time, hydrometeorological observation stations. The daily total precipitation from GHE complemented the data from IMN raingauge network in production of isohyetal maps during this period.

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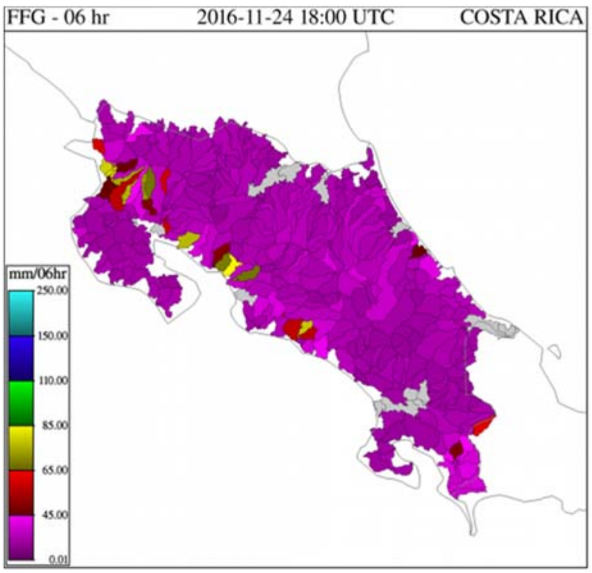
CAFFGS use during the passage of Hurricane Otto in Costa Rica

The Flood Flood Guidance (FFG) product was used with rainfall forecasts produced the numerical weather prediction model WRF which is run at IMN of Costa Rica with 2km resolution to make evaluation of ‘at-risk’ communities. Figure 2 presents examples of the FFG product on 2016-11-24 at 18 UTC (approximately the time of landfall) and the IMN-WRF model 6-hour precipitation forecast ending on 2016-11-25 at 00 UTC. The CAFFG System indicated low FFG values (< 45mm/6-hr) throughout most of the country, and precipitation forecasts exceeding 75mm/6-hr near the center of the storm. This information was used to generate a list called “Populations with Flood Risk”. This list was updated hourly during the hurricane passage and provided to CNE for response protocols and potential evacuation of impacted places.



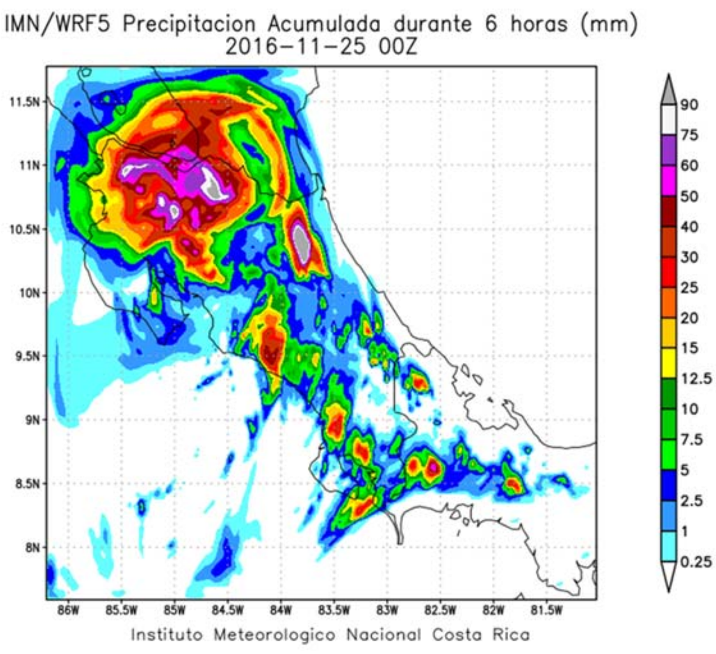


Figure 2. CAFFGS flash flood guidance product and IMN-WRF forecast precipitation at approximately the beginning of landfall of Hurricane Otto.

Because of the hurricane movement across its trajectory, vigilance for regions and rivers impacted varied throughout the data. During the night of the 24th, two rivers flowed over their banks: Zapote River in the province of Alajuela, and Blanco River in the province of Guanacaste. The CAFFG System had identified these river basins as having high flash flood threat.

Once the hurricane had passed, the Average Soil Moisture (ASM) product was a decisive factor in decision making regarding areas to maintain a higher level of risk-alert for the civilian population. Areas which showed continued high degree of soil saturation were identified and the emergency brigade continued a high level of vigilance in these regions during the following days.

In conclusion, the CAFFGS was a key tool in the monitoring of Hurricane Otto during its passage through Costa Rica, providing data on hourly precipitation and areas at risk of flash flooding. Such information was reported to the National Emergency Commission with hourly updates. Combination of the CAFFGS products with geographically referenced information allowed for the identification and monitoring of specific cities with high flash flood potential. As a note, the network of IMN meteorological stations which are automatically ingest into the CAFFGS increased from 14 to 56 in 2015. This have been a valuable improvement for flash flood and weather system monitoring within Costa Rica.

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ESTABLISHMENT OF A FLASH FLOOD GUIDANCE SYSTEM FOR SOUTH AMERICA

The Regional Association III (South America) Working Group on Hydrology and Water Resources (RAIII WGHWR) at its last meeting in Asuncion, Paraguay, from 5 – 9 October 2015, had discussed progress to date on the demonstration in pseudo real time Flash Flood Guidance System (FFGS) for the Zarumilla River basin. The Zarumilla River is a trans-boundary basin of importance to the countries of Ecuador and Peru. The meeting had also been informed of the potential to hold a meeting to discuss lessons learned on the application of the FFGS to the Zarumilla River basin and to further explore the possible implementation of the System within South America. The RAIII WGHWR decided to hold the meeting in Peru, in the second half of 2016. Based on this decision, the WMO Secretariat organized this Initial Planning Meeting on establishing a FFGS for South America, which was held at the kind invitation of the National Meteorological and Hydrological Service of Peru (SENAMHI) in Lima, Peru, from 16 – 18 August 2016. The Initial Planning Meeting was held at SENAMHI headquarters allowing participants the opportunity of visiting the meteorological and hydrological offices of SENAMHI to observe first-hand its forecast operations and interact with those responsible for the functioning of its forecasting facilities.

The Initial Planning Meeting was attended by representatives of National Meteorological and Hydrological Services (NMHSs) from Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela. Unfortunately, representatives from French Guyana (France) were unable to participate in the meeting. Other participants included representatives from World Meteorological Organization (WMO), US National Weather Service (US NWS) and the Hydrologic Research Center (HRC).

Experts from each country provided in-depth presentations on the current situation of their National Services related to hydrometeorological forecasting capabilities, practices and development plans. The presentations revealed the similarities and differences that exist among the countries regarding their capabilities to deliver weather and flood forecasting and early warnings, especially for those pertaining to flash floods. Countries do not presently have dedicated systems including the use of hydrological modelling to specifically address the provision of flash flood forecasts and warnings.

There was a lively discussion on several aspects pertaining to the development and implementation of the FFGS in South America. These covered different aspects including how many regions might there be within the continent of South America, which countries might be associated with each regional project, the potential interest of countries to be a Regional Centre for one or more regional projects, and the characteristics of the system that would be needed for each individual regional project. On this latter point, use of radar data for improving the resolution and accuracy of quantitative precipitation estimates was discussed, as was the importance of having the projects focus on where people lived, that is large urban centres. Riverine flooding and landslide susceptibility, captured by new FFGS functionality under development, were also cited as being of importance in regional application development.

The meeting decided that the best way to capture the outcomes of the discussion was through its conclusions and recommendations. It was anticipated that these could then be further discussed and agreed upon at the Ibero-American meeting of Directors of National Meteorological and Hydrological Services (NMHSs) that is to take place 23 – 25 November 2016 in Antigua, Guatemala. Some of the main conclusions and recommendations included that it was of interest to the region to implement the Flash Flood Guidance System (FFGS) in South America in order to reduce the loss of human life and economic damages. In addition, after being informed of the objectives of the WMO Severe Weather Forecasting Demonstration Project (SWFDP), the meeting considered that it was equally important to implement it concurrently with the FFGS, including the co-location of the regional centers, where possible. For the FFGS, in view of the extent and diversity of meteorological and hydrological phenomena and geophysical characteristics of the region, the meeting concluded that the continent of South America could be divided into four sub-regional applications of the Flash Flood Guidance System.

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Enhancements to Capabilities Of FFG Systems

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RIVERINE ROUTING
In collaboration with National Meteorological and Hydrological Agencies, the Hydrologic Research Center begun implementation of riverine routing components in regional flash flood guidance systems (FFGSs). The implementation involves the use of diffusive routing methods for river systems involving a very wide range of channel slopes. The enhancement involves extending the lead time of the numerical weather predictions ingested into the regional FFGSs out to 3 days or so, and the development of predicted hydrographs for selected river systems and for certain points on the river. These selections are done by the country that embeds the modelled river system. At present, the riverine routing implementation is in process for two River Systems in Turkey.

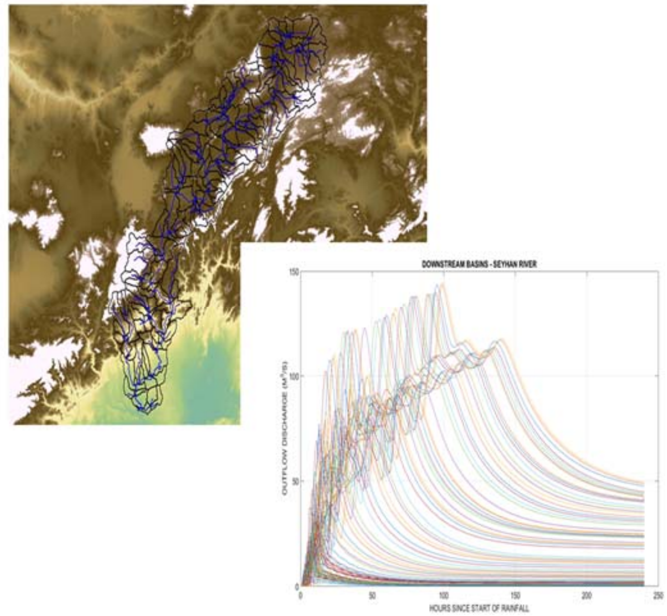

Figure 1. Basin for riverine routing demonstration (Seyhan River in southern Turkey) and example output of stream hydrographs (for each subcatchment shown).

LANDSLIDE PREDICTION
In collaboration with National Meteorological and Hydrological Services and Disaster Management Agencies in Central America, the Hydrologic Research Center is in the process of enhancing the Central America Flash Flood Guidance (CAFFG) system to incorporate capability for assessing the potential for landslide occurrence in operations. The methodology has a first step that uses historical data of landslide occurrence (location and time) to determine susceptibility maps describing the likelihood of land slide occurrence with high resolution. In addition, thresholds of precipitation and soil water are determined below which there has not been historical flash flood occurrence. A second step uses the CAFFG real-time precipitation and soil water estimates to identify the basins for which these values are greater than the thresholds specified in the first step. For these basins the susceptibility maps are then used to further identify the specific regions within these basins that have the highest climatological likelihood for landslide occurrence. The landslide enhancement of the CAFFG is designed to allow adjustments by operational forecasters for more reliable real-time warnings. It is implemented in a generic form to allow implementation to other FFGSs.

URBAN FLASH FLOOD WARNING
Urban flooding is a high impact hazard. Flash flood guidance systems (FFGSs) provide the basis for real-time data integration and operational forecasting for several countries around the world, and offer the opportunity for extensions that address urban flood prediction. Efforts are underway to develop operational urban flash flood warning systems in Istanbul, Turkey and Jakarta, Indonesia in conjunction with the regional FFGSs implemented. The development of the urban flash flood warning systems is supported by a consortium of country agencies that include National Meteorological and Hydrological Services and city agencies for disaster management and flood control. High resolution delineations of surface drainage basins (down to 1 km^2) and storm sewer surface and subsurface networks provided by the urban agencies provide the basis for the development of parametric databases that support the prediction of flows at various locations in the urban network. Forcing from high resolution radar data is used to generate surface and subsurface flows through the urban drainage network.

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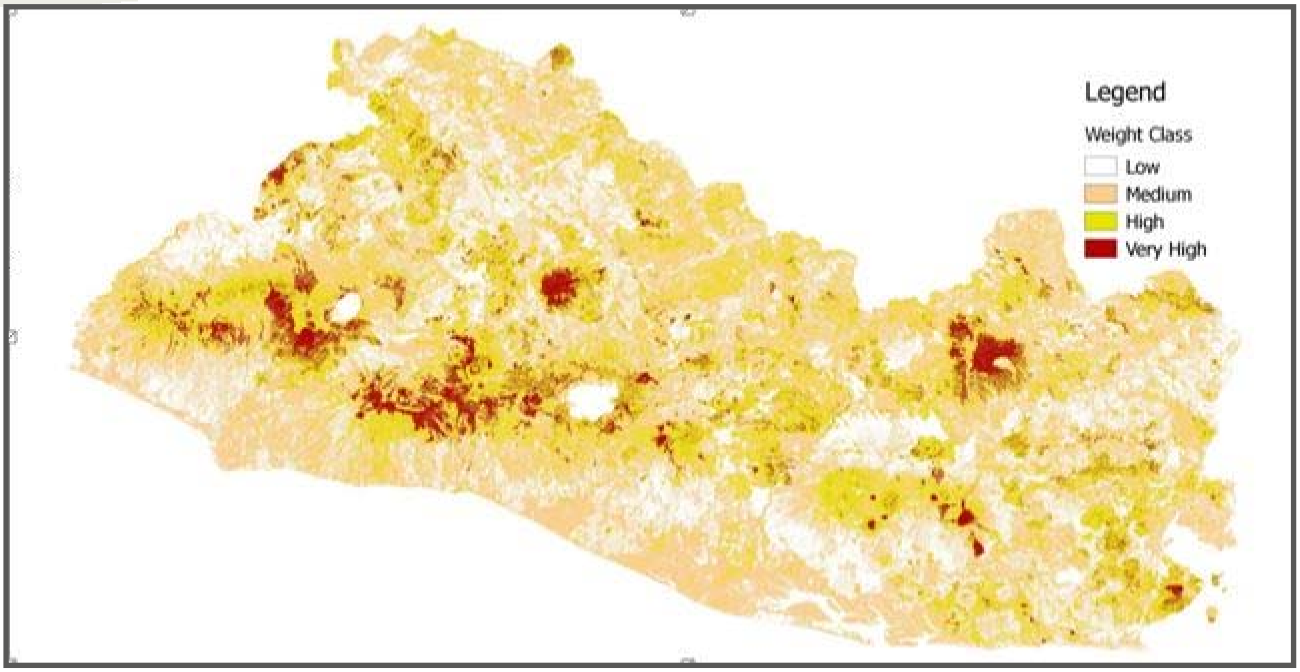

Figure 2. Landslide susceptibility map for the country of El Salvador based on historical data of rain-induced landslide occurrence time and location. Of interest is to identify with high resolution the terrain that has low, medium, high and very high likelihood of producing landslides under heavy rainfall and high soil water saturation.

Use of Channel Cross-Section Data in Parameterization of FFG Systems: Examples from Croatia and Slovenia

(As we all know) Within the Global Flash Flood Guidance Program, Flash Flood Guidance (FFG) is defined as the amount of precipitation of a given duration and falling over a given watershed at a given time that will cause the discharge in the stream channel at the outlet of that watershed to reach a level of minor flooding, usually defined by the bankfull discharge level. The definition provides us with a physical understanding of FFG which operational forecasters may readily use with observed or forecasted precipitation in assessing flash flood potential. Underlying this definition are several fundamental concepts including the bankfull level. The purpose of this short article is to review this concept and discuss the use of local channel survey data towards the parameterization of a FFG System.

FFG defines the initiation of flooding or flood potential by the bankfull discharge level. The bankfull level is the height of water in the stream where flow transitions from the main channel to its floodplain. During the development and parameterization phase of a FFG System project, a fundamental parameter called threshold runoff is estimated for each watershed. Similar to FFG, threshold runoff is defined as the amount of *effective rainfall* of a given duration and falling over a given watershed which will produce this bankfull level in the stream channel at the watershed outlet. *Effective* rainfall is that portion of the precipitation which goes directly to producing stream channel runoff. Thus threshold runoff represents the portion of precipitation that fills the channel capacity to the level of the bankfull discharge.

Estimation of this level and thus the bankfull discharge at a location may be derived from surveys of the stream channel cross-sectional geometry and hydraulic principles that relate the cross-sectional area with discharge. Stream channel surveys (Fig. 1) may be costly, time- and personnel-intensive, and effectively impossible to achieve for every watershed outlet of interest within a regional FFG System. Therefore, if available, limited channel survey are used to develop regional relationships between channel cross-sectional geometry parameters and watershed characteristics within larger watersheds or hydrogeomorphological and climatologically similar regions. The basis for such regional relationships comes from association of the bankfull discharge with concepts of effective sediment discharge and channel-forming discharge from the field of geomorphology. Typically, derivation of regional relationships involves the estimation of channel top width and either mean depth or hydraulic depth at the bankfull level from local channel surveys, and then relating these local cross-section parameters to the catchment area (most common) and possibly stream length or slope from many locations.

Recently, such regional analysis was performed using data from Croatia and Slovenia as part of the South Eastern Europe Flash Flood Guidance (SEEFFG) System. For Slovenia, LIDAR surveys were conducted by the Slovenian Environment Agency (ARSO), channel cross-sections extracted, and the subsequent regional analysis was performed by hydrologists of ARSO. Output of this analysis was provided to HRC for review and incorporation into parameterization of the SEEFFG System for their country. For Croatia, details from physical channel surveys were provided to HRC by the Croatian Meteorological and Hydrological Service (DHMZ). The channel cross-sections

Figure 1. Hydrologists conducting a stream survey.

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were plotted, bankfull level and cross-sectional parameters estimated, and regional analysis performed at HRC. In Slovenia, data from a total of 108 cross-sections were used in the analysis. In Croatia, data from a total of 214 locations were provided, from which 105 cross-sections were extracted and used for analysis. For threshold runoff estimation, it is important that the cross-sectional parameters are derived from streams with the following characteristics: (a) natural, un-improved channel sections, (b) covering streams with drainage area characteristics relevant for FFG applications (i.e., cumulative drainage area < 2000km^2), and (c) free from or limited impact of upstream stream flow regulation. Fig. 2 presents an example of a channel cross-section from the survey data from Croatia (the vertical exaggeration of this figure is about 10:1). The bankfull level is best identified in the field using geomorphological evidence including changes in bank slope, stream bed material size, and stream bank vegetation. In absence of field information, the bankfull level is identified by changes in the channel side slope. In the example cross-section, two levels are identified by the red horizontal lines (at elevations of 299.1 m and 300.1 m). The cross-sectional parameters of bankfull top width (B) and bankfull hydraulic depth (D) are given at each level in units of meters. In some streams, multiple "terraces" may exist in the transition from main channel and the flood plain; the lowest terrace is usually identified as the bankfull level.

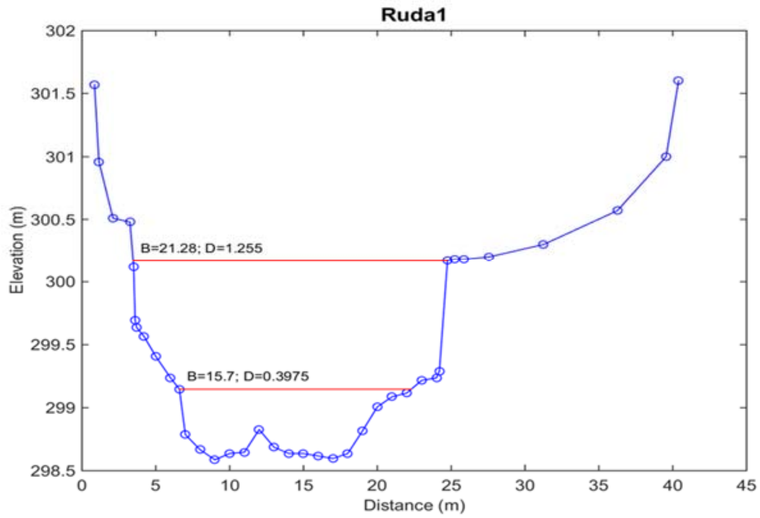

Figure 2. Example plot of a channel cross-section from a local survey for the Ruda River in Croatia.

After estimation of the cross-sectional parameters, regional relationships in the form of $B=cA^a$ and $D=bA^e$ are determined. Fig. 3 presents the plot of the natural-log transformed variables (lnB and lnD versus lnA) for all data in Croatia, along with the derived regional relationships. In the form above, these relationships are: $B=1.786A^{0.4099}$ and $D=0.213A^{0.3365}$. For both Slovenia and Croatia, the datasets were divided into river basin or hydroclimatic sub-regions, such as coastal basins, highlands, or Sava River basin (see example in Fig. 4). It is these sub-regional relationships were used in the development of threshold runoff estimates for the countries.

Figure 3. Development of regional regression relationships for bankfull channel width (B, in blue) and hydraulic depth (D, in orange) for all survey data from Croatia.

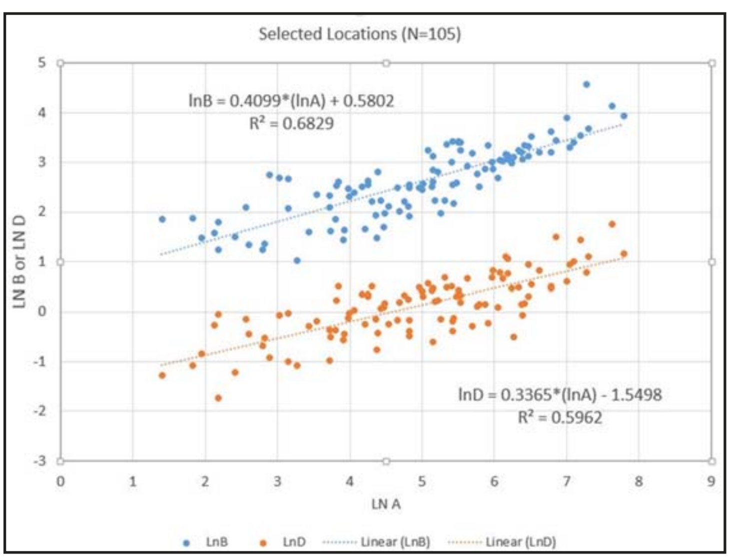

Figure 4. Comparison of Slovenian (SLO) and Croatian (HRV) cross-section estimates for the coastal Adriatic sub-region.