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AUTOMATION OF CALCULATION TOOLS FOR RIVER CHANNEL ANALYSIS AND DESIGN

Fernando Oñate-Valdivieso[1]
Santiago Quiñones
Mario Ordoñez

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A B S T R A C T

Rivers are natural channels that drain water from a specific watershed. Sometimes, the flow exceeds the capacity of the existing channel, causing it to overflow and create problems for nearby populations, damaging existing structures or flooding inhabited areas. This has caused thousands of deaths and continues to generate direct economic costs amounting to tens of billions of dollars. Therefore, it is necessary and urgent to address flooding events and develop flood management strategies to reduce adverse consequences and handle more complex types of floods. River channeling and torrent control are essential components of water resource management and natural disaster prevention. RiverChanneling is a free application developed in Visual Basic .NET within the Microsoft Visual Studio environment, designed to automate the calculation and analysis of river channel design and torrent control, and is implemented in the Virtual Hydrology Laboratory (HydroVLab). This application uses empirical and semi-empirical methods to simulate the behavior of natural channels, considering hydrological and geomorphological variables. It automates the regulated channel process, ensuring its stability, and designs the necessary horizontal and vertical control works. The intuitive interface allows for data entry and results visualization, facilitating the process of analysis, design, and decision-making.

1. INTRODUCTION

Rivers are natural channels that drain water from a given watershed. The variation in river flow depends on precipitation, infiltration, and evapotranspiration that have occurred over a given period. During times of rain, the flow increases. This increased flow, known as flood flow, often exceeds the capacity of the existing channel, causing it to overflow. This overflow can lead to problems for nearby populations, damaging infrastructure and flooding inhabited areas (Mera-Parra, 2021).

Disastrous floods caused by rapid urbanization and extreme weather events have resulted in millions of fatalities and continue to cause tens of billions of dollars in direct economic losses each year. In the context of global warming, these losses are expected to increase (Hallegatte, 2013), as the intensity of extreme precipitation events rises (Tabari, 2020) and the population exposed to water-related disasters grow (Tellman et al., 2021).

[1] Corresponding author: Fernando Oñate-Valdivieso
Email: fronate@utpl.edu.ec

It is necessary and urgent to cope with flood events, and it is essential to develop future flood management strategies to reduce adverse consequences and address more complex types of floods. Many countries have implemented a series of practices to manage stormwater and flood disasters. For example, green infrastructure, low-impact development, and best management practices have been implemented in the United States; sustainable urban drainage systems in the United Kingdom; water-sensitive urban design in Australia; low-impact urban design and development programs in New Zealand; and the concept of the "sponge city" in China (Fletcher et al., 2014; Liu et al., 2017; Wang et al., 2022).

River channelization and torrent control are essential components of water resources management and natural disaster prevention (Oñate-Valdivieso et a., 2022). River channelization and torrent control are accomplished through structural measures, which involve the construction of infrastructure designed to contain, divert, or dissipate water energy, and nonstructural measures, which focus on landscape and land use management to mitigate flood risk and control erosion (Fernandes, 2025).

This paper presents the development of a tool for the analysis and design of channelization and torrent control based on structural measures. The channel under study will be divided into sections with homogeneous slopes. The dimensions of the regulated channel will be calculated, the design of the elements for horizontal control will be carried out, the scour will be calculated, and the rectified profile of the channel with transverse works will be determined.

2. MATERIALS AND METHODS

2.1. Theoretical Basis

Regime theory for river channels studies how variations in flow and sedimentation affect river morphology and dynamics over time. This theory analyzes seasonal and annual fluctuations in water flow, sediment transport and deposition, and the configuration of the river channel, including its width, depth, and meandering patterns. It is fundamental for the design of hydraulic infrastructure, the sustainable management of water resources, and the conservation of river ecosystems, providing a framework for understanding and predicting changes in rivers due to natural and anthropogenic factors (Fernandes, 2025).

Backwater Curve: Channeling a river requires determining the water surface profile in a river section, especially in situations where the flow is under non-permanent or non-uniform conditions, such as in the presence of obstacles or changes in the riverbed. For this purpose, the method proposed by Leach (Garcia Flores & Maza Alvarez, 1997) is applied to calculate the backwater curve in a river. This involves dividing the river section into small segments and iteratively calculating the water level from downstream to upstream. Manning's formula is used to determine the flow velocity, the continuity equation ensures the conservation of flow, and the simplified Bernoulli equation relates the energy in two consecutive cross-sections, considering the energy loss due to friction.

Dimensions of the Regulated Channel: Three methodologies can be applied (Garcia Flores & Maza Alvarez, 1997): a.) Altunin's method: The width and height of the section are determined based on the design flow rate and channel slope b.) Maza and Cruickshank Method: Considers three equations (one for flow resistance, another for sediment transport, and a third for bank resistance) to obtain the width, depth, and slope of a stable channel. c.) Blench Method: The dimensions of the regulated channel are determined based on the depth of the section, the viscosity of the water-sediment mixture and gravitational acceleration, the concentration of suspended material in the bottom layer (ppm), and the mean velocity of the flow.

Scour: The scour determined by applying the equations proposed by Lischtvan & Lebediev (1959) that is a function of diameter of particles composing the bed, the mean depth of the section before erosion and the effective surface width.

Weirs: The correction of the longitudinal slope of the channel is carried out using bottom thresholds located transversely to the channel axis which are sized according to the water depth over the spillway, a discharge coefficient, a contraction coefficient, and an emergence coefficient.

2.2. Computational Solution

RiverChanneling is a free application developed in Visual Basic .NET (Microsoft, 2024) within the Microsoft Visual Studio environment (Visual Studio, 2024), designed to automate the calculation and analysis of river channel design and torrent control. It is implemented in the Virtual Hydrology Laboratory (HydroVLab) (Oñate-Valdivieso et al., 2022b). This application uses empirical and semi-empirical methods to simulate the behavior of natural channels, considering hydrological and geomorphological variables. It automates the calculation of design flow rate, sediment transport, channel stability, and channelization structures. The intuitive interface allows for data input and visualization of results, facilitating the analysis and design process. The software includes validation procedures to ensure the accuracy and reliability of results. Methodologies used include Leach method for backwater curve calculation, as well as sediment transport methods such as Lischtvan-Lebediev, and channel stability models by Altunin, Maza – Cruickshank and Blench. It utilizes .NET Framework 2.0, enabling the creation of applications with Active Server Pages (ASP) and the development of web services in a robust component-based architecture. The advantages of the software include improved accuracy in hydraulic structure design, significant time savings, and detailed visualization of results.

2.3. Implementation

The implementation process of the application for river channelization analysis and design is organized into several operational modules (see Figure 1).

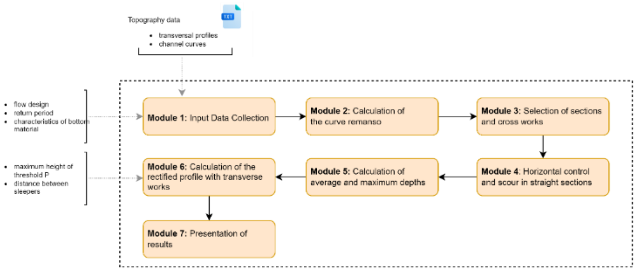

Figure 1. Operation Phase of RiverChanneling

Next, these modules are described in detail.

Module 1: Input Data Collection: The first module focuses on gathering necessary data for analysis. In this initial phase, the user selects the riverbed material and enters the discharge (Q) and characteristics of the bed material into the application. These input data are crucial as they enable calculations necessary for channel modeling. Additionally, .txt files containing cross-sectional profiles and channel curve locations are inputted. Input data includes design discharge, estimated through specific methods, and characteristics of the bed material, which vary depending on whether the material is granular, sandy, or cohesive. These data allow for a detailed analysis of channel stability and are essential for subsequent phases of the application.

Module 2: Backwater Curve Calculation: Once the necessary data are entered, the backwater curve is calculated using the Leach method. This calculation is essential for determining water elevation at different sections of the channel under uniform flow conditions. The backwater curve provides key information on how flow energy is distributed along the channel, essential for designing hydraulic structures that ensure river stability. This module ensures calculations consider all relevant variables, including discharge and bed material characteristics, to provide an accurate representation of flow conditions.

Module 3: Section Selection and Transverse Works: In this phase, river sections are selected, and the characteristics of necessary transverse works are defined. The application allows users to choose between different design methods, including Altunin, Maza Cruickshank, and Blench methods, to determine dimensions and locations of works. Depending on the bed material, the appropriate method is selected: Altunin for granular material, Maza and Cruickshank for sandy material, and Blench for cohesive material. This module also includes defining specific characteristics of transverse works, ensuring they are optimally designed to manage water flow and maintain channel stability.

Module 4: Horizontal Control and Scour in Straight Sections: Horizontal control of the channel is performed to verify the stability of transverse works. In straight sections, scour is evaluated to ensure there is no excessive erosion compromising channel integrity. This module includes checking horizontal stability of the channel and transverse works, as well as evaluating scour depth in straight sections, for both non-cohesive and cohesive materials. These calculations ensure the proposed design is effective not only in theory but also in practice under real flow conditions.

Module 5: Calculation of Mean and Maximum Depths: The application calculates mean and maximum depths of the channel using methodologies selected in the previous module. This calculation ensures channel dimensions are adequate to handle water flow without causing erosion or sedimentation problems. Calculation of mean and maximum depths provides a detailed insight into how the channel will behave under different flow conditions, allowing adjustments in design to optimize stability and hydraulic efficiency of the channel. This module ensures all critical parameters are considered and calculated accurately.

Module 6: Calculation of Rectified Profile with Transverse Works: In this module, the rectified profile of the channel is calculated, incorporating designed transverse works. The rectified profile provides a detailed view of how the channel will be adjusted to meet established design criteria. This calculation includes integrating transverse works into the channel profile and adjusting channel dimensions to ensure stability. The rectified profile is essential for visualizing how changes in the channel will be implemented and ensuring these changes effectively manage water flow and prevent erosion and sedimentation problems.

Module 7: Results Presentation: A presentation of results is generated, including all curves, profiles, and calculations performed. These results allow the user to assess the effectiveness of the proposed design and make necessary adjustments. Results presentation includes generating detailed reports and visualizing data through graphs and tables that clearly and comprehensively display relevant information. This module ensures analysis results are accessible and useful to users, facilitating informed decision-making on channel design and management.

2.4. Validation

The RiverChanneling's results were validated by comparison with those obtained through a manually assisted process using spreadsheets and CAD tools. Three case studies were conducted in the Puliche ravine located in the Vilcabamba parish, Loja canton, Loja province (4° 15' 54" S, 79° 13' 18" W). The first case selected a section with a total of 8 horizontal curves, allowing for comparison of results for alluvial channels and the design of a bottom threshold and weir. The second case focused on an upstream section of the same water ravine, which has a sandy channel. The third case used topographic data from the second example, comparing results for a cohesive material channel.

3. RESULTS

The RiverChanneling application developed for river channeling analysis and design is available at www.hydrovlab.utpl.edu.ec. Initially, the user selects and loads necessary data, starting with flood discharge and return period. Next, the type of channel bed material is specified, which can be granular, sandy, or cohesive. Depending on the material type, specific variables are entered: for granular material, particle size distribution and density data; for sandy material, particle size distribution, density, and cohesion data; and for cohesive material, cohesion, friction angle, and shear strength data are entered. Additionally, .txt files containing cross-sectional profiles and channel curves are loaded, as shown in Figure 2.

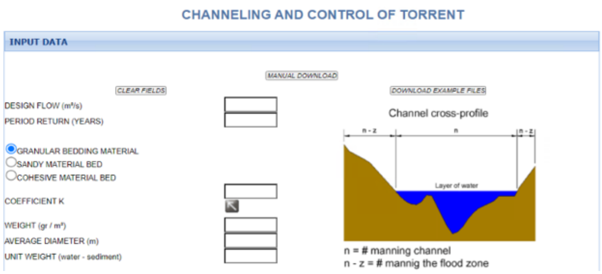

Figure 2. Input of model parameters

Once the data is entered, the application allows for the calculation of the natural terrain's longitudinal profile and backwater curve using the Leach method (Figure 3). Upon obtaining the calculations of the backwater curve, the streambed abscissas are uploaded into the application. The application allows drawing the cross-sectional profile by selecting the required abscissa (Figure 3).

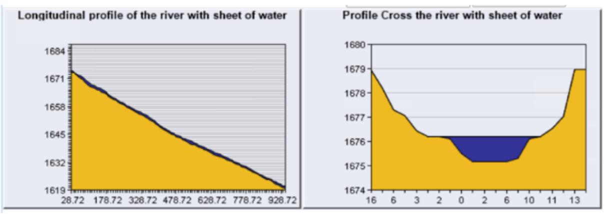

Figure 3. Longitudinal and transversal profile

Once the backwater curve has been calculated, it is necessary to decide how to divide the channel for calculation purposes, based on similar slopes. The application shows the longitudinal profile of the channel, and the abscissae corresponding to the divisions must be entered. These abscissae should match those entered in the profile text file, separated by commas. Additionally, you need to input a distance for placing the bottom sills (traverse) and specify the maximum height of the bottom sill (Figure 4). If the rectification height exceeds the maximum sleeper height, a weir with the required height will be installed.

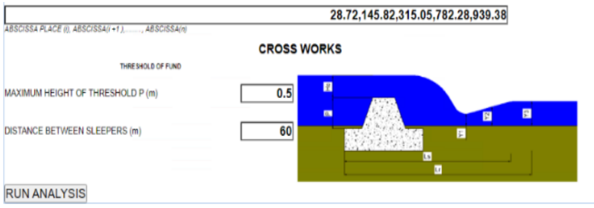

Figure 4. Data for the placement of weir

Once the analysis has been conducted, the application provides a detailed visualization of the rectified channel profile. Figure 5 illustrates these results, displaying the rectified profile featuring weirs. These graphs depict three key profiles: the rectified profile indicating potential locations, types, and elevations of the transverse works (green line), the profile of the natural channel (brown line), and the water sheet profile (blue line).

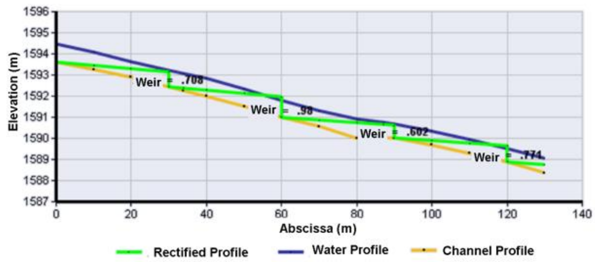

Figure 5. Rectified Profile with Weirs

The results of RiverChanneling were validated through direct comparison with calculations performed manually using spreadsheets and CAD tools. The application's results in the three analyzed cases showed a perfect match with the manually calculated values, demonstrating the accuracy of the processes and calculations performed, despite the differences among the three cases. This confirms that the application adapts well to different contexts, delivering excellent results in channels composed of alluvial, sandy, and cohesive materials.

4. CONCLUSIONS

The RiverChanneling application developed in Visual Basic .NET offers a precise and flexible tool for the analysis and design of hydraulic structures in river channels. By allowing detailed input of data such as flood discharge, return period, and bed material characteristics (granular, sandy, or cohesive), the application facilitates customized analysis according to project specifics. This ensures that the results obtained are representative of real channel conditions, thereby enhancing the effectiveness and efficiency of proposed interventions.

One of the application's key strengths is its ability to integrate detailed topographical data through .txt files containing cross-sectional profiles and channel curves. This integration enables accurate calculation of the backwater curve and rectified channel profile, considering potential locations and characteristics of transverse works. Visualizing the longitudinal channel profile and dividing it into segments based on slope similarity contributes to better planning and design of structures necessary for channel stability.

The application not only facilitates calculation and visualization of results but also allows for easy interpretation and export. Output data, including characteristics of the rectified channel and necessary transverse works, are presented clearly in result tables and graphs. Moreover, the option to download these results in .txt format and export them to Excel spreadsheets for detailed analysis provides a powerful tool for engineers and designers, enabling informed decision-making based on precise data.

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Fernando Oñate-Valdivieso
Universidad Técnica Particular de Loja, Loja,
Ecuador
fronate@utpl.edu.ec
ORCID 0000-0002-2400-0510

Santiago Quiñones
Universidad Técnica Particular de Loja, Loja,
Ecuador
lsquinones@utpl.edu.ec
ORCID 0000-0001-5894-9882

Mario Ordoñez
Universidad Técnica Particular de Loja, Loja,
Ecuador
mgordg@gmail.com