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Stream-crossing Approaches on Forest Roads Networks: A Critical Review on Practices in Türkiye

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Abstract

Appropriate planning and construction of the stream-crossing structures projecting is very important in forest road networks in order to use the roads throughout the planned lifetime and ensure their desired services. Crossing structures in Turkish forestry are planned according to the cross-sectional area value calculated with the Talbot formula which is the general approach to the issue. However, localized precipitation values are not used in the Talbot formula; therefore, significant damages may occur in flood flows due to structural sizing errors. The aim of this study is to suggest a strategy that can be used in Turkish forestry in planning stream-crossing structures.

Keywords: Forest roads, stream-crossing, flood flow, discharge, road drainage structures

1. Introduction

Stream-crossings are important for accessing forest resources. Forestry activities, rural communities located in/around forests and national economy depend on functioning road networks and safe stream-crossings (Levine and Valley, 2013). Stream-crossing structures should be designed in accordance with the highest flood flows that may occur in order for forest road networks to provide the expected services especially in mountainous areas. Interpretation of hydrological variabilities such as transmissibility, permeability, and water holding capacity of a drainage basin is complex issue because comparative catchment studies are affected by differences in the catchment and climate characteristics (e.g. land use, land cover, topography, geology, geomorphology, soil, rainfall).

The accurate quantification of the morphological, geomorphic, and topographic features of a watershed becomes imperative, as this will help in evaluating the hydrologic response of watersheds (Bulygina et al., 2013; Abdulkareem et al., 2018; Putty, et al. 2021). Stream flood occurs generally on unexpected heavy rains. Estimation methods should be focused on peak flows at unmeasured locations. The flood volume estimation in a stream-crossing design study is essential for the construction of sustainable drainage systems (Vesuviano et al., 2020).

It is reported that poorly designed crossings are caused to erode and clog stream banks and roads, thereby increasing flood damage. Intense precipitation may lead to the failure of undersized crossings. The predominant mechanism of failure for road-stream- crossings is the deposition of wood and sediment at the inlet initiated by small woody debris (e.g., twigs, sticks) in many forest lands (Figure 1). The crossing blockage during flood events can be eliminated through proper sizing and configuration, especially replacing small sized structures with properly designed culverts and bridges (Levine and Valley, 2013; Gillespie et al. 2014; Roy and Sahu, 2018).

It is important to consider the aquatic ecosystem, as well as the location of the structure, traffic safety, longevity, cost, design, construction area, and watershed characteristics, while crossing streams in forest areas. Improperly designed and positioned passages are known to cause destruction of stream habitat and disruption of fish migrations due to sediment deposition. Structure replacements for the reorganization of aquatic organism passages often incur re-costs. In recent studies, detrimental effects have been observed on the habitats of streams and riverbanks as well as roads, since the culverts are sized to transmit only floodwaters after a great storm on mountain roads (Aust et al., 2003; Gubernick, et al. 2003; Christiansen, et al., 2014; Olson, et al. 2017).

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Figure 1. Accumulation of branches, leaves and sediment at the entrance of the drainage structures

The cross-sectional area for road-stream-crossing structures is calculated with the Talbot formula (Chow, 1962) in Türkiye. This value is envisaged as an initial approximation value. According to this value, the size of the cross-sectional opening is decided by the experience of the planner, taking into account the runoff of recurrent peak precipitation (50 and 100 years). The planner's experience and how it will be taken into account are not defined in the official implementation document of the General Directorate of Forestry (Communique No.292). Since this is not an application directive, forest managers sometimes have a dilemma in choosing the dimension and type of stream-crossing structure. However, the General Directorate of Highways, which is another institution of Turkiye, uses some pick flow models such as the Rational formula in the calculation it uses for the same purpose. In this case, precipitation amounts are added to the flow rate calculation. If it is not correctly predicted, it will cause traffic disruption by clogging up structures, catching or disrupting the road. These disruptions are important because forest roads serve for a limited wood production times.

This study aimed to evaluate current status of the planning stream-crossing structures in Türkiye and introduce an approach to the Turkish forestry so that calculations and design of these structures can be more accurate.

2. Flood Runoff and Predicting

Precipitation is the most studied subject in the understanding of the hydrological system and is a key topic. The majority of research emphasized the importance of the spatial structure of precipitation and its representation for flood runoff generation. This might be expected due to the complex interactions between the type of event, the nature of the watershed and the spatial scale of the problem. However, although the literature on the relationship between spatial precipitation and runoff response is extensive, results have been sometimes contradictory (Segond et al., 2007).

Representation of land management still remains a compelling issue in hydrological modeling. This is because there are few or no data on how the relevant changes affect either local-scale physical properties (for example, soil-plant hydrology) or catchment-scale, and because modelling methods face fundamental challenges of methodology and data support (Bulygina et al., 2013). There are many models representing hydrological processes and estimating discharge in watershed currently available.

While physics-based precipitation flow models can represent small-scale processes and scale them up to arbitrary sizes, in practice such models have limited capacity to reliably predict watershed-scale land management impacts due to a lack of relevant information. In a study conducted by Bulygina et al. (2013), four models were examined: physically-based model; Base Flow Index (BFI) (hydrological system behavior in relation to the watershed); CFMP land management (estimates the daily maximum change in watershed scale), and regression-based regionalization FRMD approach parameters.

Kalantari et al. (2014), have been used the physically-based hydrological model of MIKE SHE coupled with the hydraulic model MIKE 11 (DHI Software, 2008) because it is able to simulate the whole hydrological cycle including geographically distributed land-use changes. MIKE SHE is a distributed, dynamic, deterministic, and physically-based model which describes the main hydrological processes in the land phase of the hydrological cycle (DHI Software, 2008). In their study, the following parameters were used: (i) evapotranspiration, including canopy interception according to Kristensen and Jensen (1975); (ii) overland flow, which is calculated with a 2D finite difference diffusive wave approximation of the Saint-Venant equations; (iii) channel flow; (iv) unsaturated water flow, which is described as a vertical soil profile model; and (v) saturated (groundwater) flow.

A method called Indicator of Intense Pluvial Runoff was introduced that used open-access data to produce a comprehensive mapping of areas susceptible to generating, transferring, and accumulating surface runoff (Lagadec et al., 2016). This process can be used in a large range of watersheds with data at various resolutions while keeping in mind that the usability of the maps must be tested.

3. Stream Cross Section Calculation and Structure Design

The most preferred design methods, such as the rational method and other empirical assumptions, use precipitation data as the relevant flow data are usually limited (Tolland et al.,1998). Many factors including vegetation, soil type in the area, topography and microtopography of the hillside across the road, the hydrology of the area including rainfall discharges of streams, time of runoff concentration, length, and gradient of streams are important in estimating runoff (Nasiri and Askari, 2020).

Many researches have been conducted for more efficient planning of forest road-stream-crossing structures such as: using RoadEng software to optimize forest road routes, using Distributed Hydrology Soil Vegetation Model (DHSVM) to determine impact, analysis of forest road network in watershed hydrology, calculating the sediment distribution and finding the best culvert installation method (Nasiri and Askari, 2020).

The stream-crossing structure construction in small forests watershed can be performed in four steps: (i) planning and selecting the location of structure installation, (ii) conveying surface runoff by a culvert in its natural route (iii) preparation of foundations, and (iv) installing the structure. ForCulverts as an extension package of ArcView software that use the rational method used to estimate for peak discharges, has been developed to locate culverts regarding the road gradient and hydrology (Nasiri and Askari, 2020).

Nasiri and Askari (2020) presented a methodology to offer the best location for the culverts to improve the drainage systems of forest roads by evaluating the area at the point of hydrological flow and assessing (on a small and large scale) the location of existent culverts (Figure 2). In a study conducted by Harris et al. (2008), it was stated that the culverts built for wood production in forested water basins northwestern California in the last decades were inadequate as a result of the accumulation of wood and log pieces and sediment occurring at peak flows.

Federal Highway Administration (FHWA) of Spain have been published the procedures for the hydraulic design of drainage culverts (1985, 2005) (Conesa-García, and García-Lorenzo 2013). The HY-8 program of the FHWA software package and the HEC-RAS program for water surface profiles of the Army Corps of Engineers in the USA are two basic programs for the analysis of culvert flows. There are many important culvert design studies that have been conducted previously (Charbeneau et al., 2006; Haderlie and Tullis, 2008; Sezen et al., 2008; Tullis and Robinson, 2008; Tullis et al., 2008; Singley and Hotchkiss, 2010; Chen et al., 2010; Azamathulla and Ghani, 2011; Ahmed and Alarabi, 2011; Sicking et al., 2011). These studies contain specific instructions about the hydraulic design procedures (Conesa-García, and García-Lorenzo 2013).

In recent years, stream simulation is becoming an increasing common culvert design method in many locations around the World (Barnard et al., 2015). Roy and Sahu (2018) developed active flow channel model where width, average and maximum depth, width-to-depth ratio, cross-sectional area, flow power, Froude number and flow rate parameters were used to describe the hydraulic geometry.

Talbot formula, which is widely known and one of the oldest approaches, has been taken into account in many academic studies on hydraulic structures of forest roads in Türkiye. Rational formula has been also used in some previous studies (Bayoğlu and Hasdemir, 1991; Çalışkan, 2007; Öztürk and Hasdemir, 2021). In fact, the Rational formula is the improved version of the Talbot formula, considering the precipitation factor in the model.

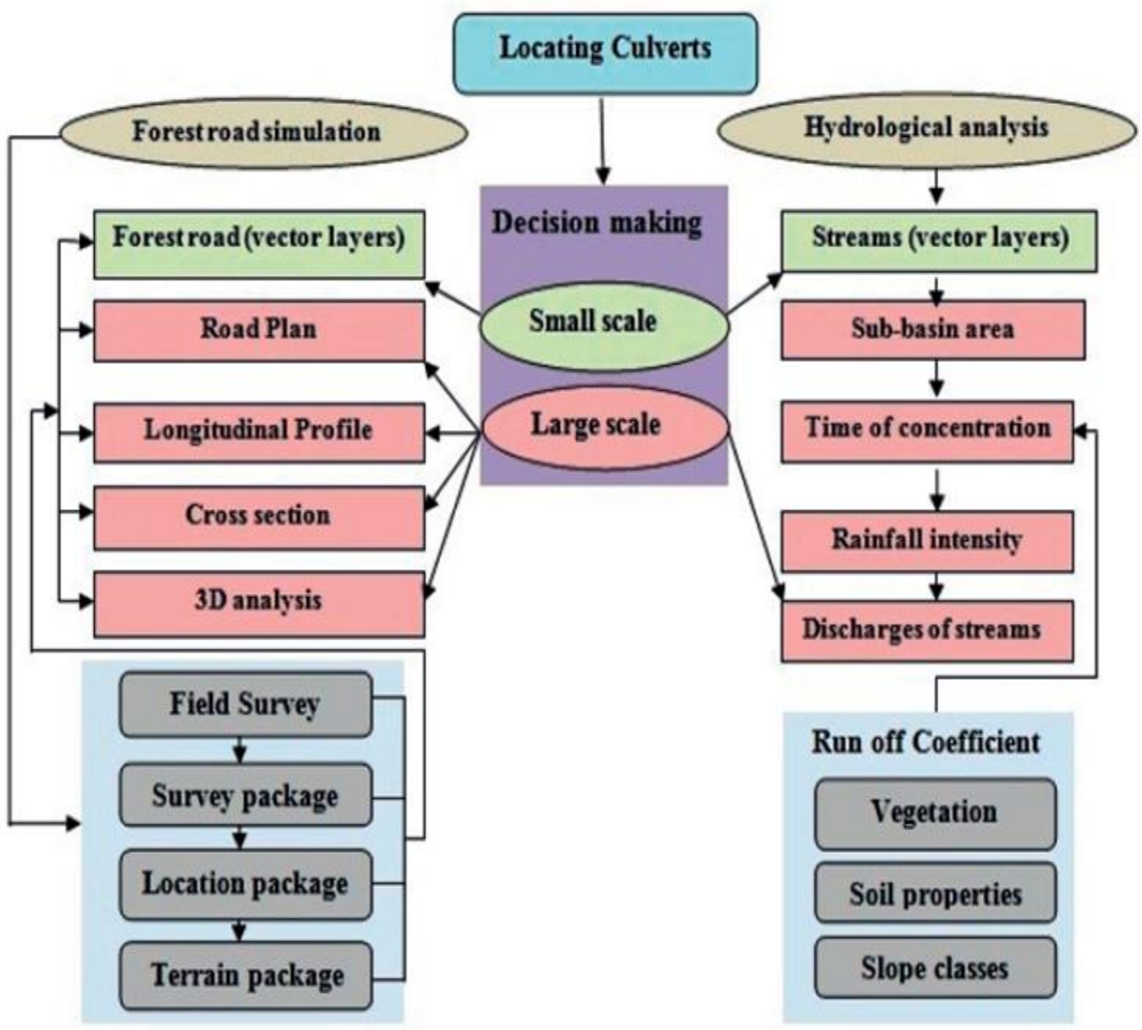

Figure 2. Culvert locating process (Nasiri and Askari, 2020)

NetHydro is a Netcad software module that defines water catchment areas and drainage networks of these areas. It can perform precipitation analysis according to all distribution types, calculate peak flow rates according to unit hydrographs and flood risk areas in flow branches by calculating flood flow rates according to different years (NetHydro, 2021). NetHydro offers basin modeling and flood flow calculation using a digital terrain model, and accordingly engineering cross-section calculation. NetHydro can check the suitability of the culvert dimensions which are determined by the calculation of the flood flow rates according to the downstream points that cut the road crossings, according to the flow depth, flow velocity, critical slope, and air margin parameters by geographical information systems analysis and remote sensing data (NetHydro, 2021).

By using NetHydro, watershed and flow branches can be generated in the structure of geographic information systems, and parameter inputs such as flood flow, the area size of each basin, the center of gravity, length of each flow branch, harmonic slope values, etc. can be calculated automatically. It can determine the most suitable precipitation distribution type by automatically performing precipitation analyzes that provide the locations and at least 15 years of the measurement information of all precipitation stations established in Türkiye by the Meteorology Affairs General Directorate with the Smirnov-Kolmogorov test. According to NetHydro Mockus, Snyder, Rational, Synthetic, and DSI synthetic methods, unit hydrograph can perform peak flow calculations and reports the results by creating a graph of the desired hydrograph (Toptaş and Gökçeoğlu, 2015).

4. Conclusion

It should determine the project discharge rates that will affect the stream-crossing in the system before starting the planning and design of the hydraulic structures in the road systems. The most important step of the studies to determine the flow rate is the hydrological analysis. The most important purpose in the hydrological analysis to be made is to calculate the flow rate that will result from the total flow and to calculate the amount of discharge that the drainage structure must control or cross. Today, many software has been developed by global and domestic companies for project discharge and stream-crossing structure design. It is considered important that forestry sector stakeholders use these technologies in road design and construction works.

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