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**Vladimir Petković**[1]

**Tihomir Dejanović**[2]

# ANALYSIS OF WATER FLOW THROUGH OBJECTS ON FOREST ROADS

**Abstract**: The forest roads usually lay along streams and torrents and often cross them. In these places the bridges are built and the pipe culverts are depending on conditions of basin. The dimension of clean opening of bridges or diameter and number of culverts depend on amount of a high water which can expect from basin over a flow section. The high water which can expect from basin depend on: basin shape and area, length and slope of stream or torrent, soil and the other conditions. In management unit “Prosara” on forest roads there are two pipe culverts over Pisarić and Hajduk’s stream and two bridges over stream of Eškerovac and Gašnica. Their permeability will be analyzed in this paper.

**Key words**: bridge, pipe culvert, forest road, high water, basin.

## ANALIZA PROTOKA VODE KROZ OBJEKTE NA ŠUMSKIM PUTEVIMA

**Izvod**: Šumski putevi obično se polažu pored potoka ili bujičnih korita i pri tome često prelaze preko njih. Na takvim mjestima se grade mostovi ili cijevni propusti u zavisnosti od karaktera potoka. Dimenzije svijetlog otvora mostova odnosno prečnik ili broj propusta zavisi od količine vode koja se može očekivati sa sliva iznad proticajnog profila. Maksimalna količina vode koja se može očekivati sa sliva zavisi od oblika, veličine, nagiba sliva, dužine i nagiba vodotoka, vrste podloge i drugih uslova. U Privrednoj jedinici „Prosara“ na

[1] Универзитет у Бањој Луци, Шумарски факултет

[2] Хидрометеоролошка служба РС, Хидрометеоролошка станица Градишка

šumskim putevima nalaze se dva cijevna propusta preko potoka Pisarić i Hajdučkog potoka i dva mosta preko potoka Eškerovac i Gašnica. Njihova propusnost će se analizirati u ovom radu.

**Ključne riječi**: most, cijevni propust, šumski put, maksimalni protok, sliv.

## INTRODUCTION

The forest roads permanently open forest for the rational use of its products and its space. The forest roads usually lay beside streams and across them where it is necessary. In that places there are bridges or culverts. The dimensions of these structures on forest roads should allow for crossing streams and smooth flow of high water, without compromising the body nowhere to forest road.

The bidges are structures on roads which enables crossing over obstacles such as streams or wide valleys. They are divided according to purpose on: road and rail. According to the type of materials wich are made of: wood, iron and concrete. The bridges on forest roads are built mostly of wood or reinforced concrete and they are used for bridging permanent streams. They are placed perpendicular or oblique to the streambed. Constructive elements of bridges are the main carriers, floor mats and fence. Their dimensions were calculated by statically calculation. The main carriers can be made of wooden beams of rectangular cross section, and sections of iron or reinforced concrete beams. The dimensions of main beams depend on load vehicles and the construction of bridge. On the forest roads small bridges are built, if the bridge length is less than 6 meters, dimensions of the main carrier are calculated by simple beam system, if the length is over 6 meters, dimensions are calculated by beam with overhangs or beams supported by saddles and struts system. Piles are mainly built of wood, their width ranges from 20-25 cm, heights are statically calculated and depend on load of the vehicle and the distance between main carriers. They are attached to the main beams with nails and screws. A guard rail can be made of wood or iron pipes. Width of the bridges and the curves are the same as the width of the forest roads.

The culverts are the part of forest road drainage system, precisely they are objects of underground drainage. For outlet water from drainage ditches, gutters and circular sources through the hull of road are made by tubular or flat culverts of concrete. Tubular culverts diameter is from 40-100 cm and is used for finished tubes and should be posted below road level line at least 60 cm. For flat culverts with a smaller opens should use finished plates of concrete.[7.]

## AIM OF RESEARCH

Analysis of the condition of objects above the streams and the torrents on forest roads in Management unit "Prosara" in terms of width and height opening the bridge, diameter of pipe culverts and their functionality.

## OBJECT OF RESEARCH

Objects of research are the bridges and culverts on forest roads in Management Unit "Prosara" which are located in the area, are Forest management "PODGRADCI", Forest enterprise "GRADIŠKA". The area is influenced by temperate continental climate characteristics. Annual amount of rainfall is average 959.75mm, and average temperature is 10,4 $^{o}$C. Soil is deep (>70 cm), sour, brown and illimerized on silicate rocks. The management unit is crossed by many streams or torrents of which the most important streams are: Pisarić, Gašnica, Small and Great Bistrica. Altitude of the management unit is to 350 m, and average slope of terrain is around 51%. The management unit area is 3827 ha. The forest land is covered with clean forest and with beech (Fagus silvatica) and mixed forest consists of beech and oak (Fagus silvatica and Quercus petrea). [6.] In this management unit area, the length of public roads is estimated to 4 km, length of main forest roads is 20, 9 km, and of secondary is 12 km. There are recorded two bridges over the streams Eškerovac and Gašnica in the field, and two culverts over the streams in  Hajduk and Pisarić area.

## METHOD

Based on the literature review it was determined which information is required: to determine the maximum amount of water, for calculating constructive elements of the bridge or culvert.

### *Field data*

Recording of a network of forest roads was carried out using a handheld device global positioning GARMIN GPSMAP 62nd and on that occasion were located and recorded bridges and culverts on forest roads over permanent streams. Then these points were recorded in cross sections, the measured width and height of the bridge opening or culvert pipe diameter and length of the bridge and culvert pipe. We measured height of pavement above the bottom of the stream bed and the slope of stream. The data were obtained on the basin by establishing geographic information system (GIS) of a given basin. This procedure consists of determining the boundaries of the basin, and its area, the digitization of watercourses which determines the length of the stream and its inclination to flow profile, then the slope basin and the other necessary information.

***Processing of data collected***

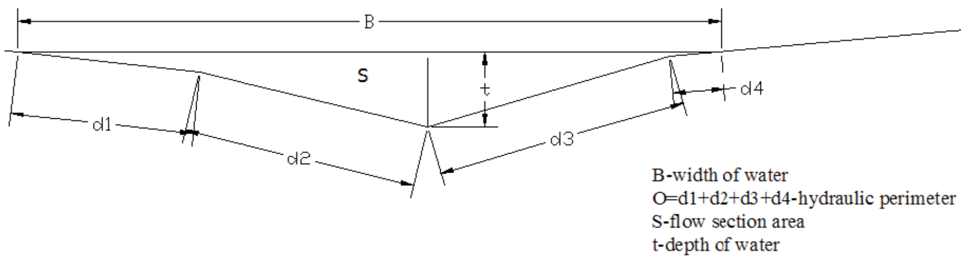
Maximum amount of water in the stream ($Q_{max}$) was calculated based on data collected using a table and field method. For determination of $Q_{10}$ was elected Pintar's method.

- Method of Pintar

$$Q_{10} = q_{10}A^k = [\mathrm{m}^3/\mathrm{s}]$$

Where: $q_{10}$-runoff coefficient for 10 years ($m^3$/s/sqkm), A-basin area sqkm, and k=0,65-0,85- coefficient which depend on shape and slope of basin, geological substrates. [10.]

The runoff coefficient represents the amount of rainfall in cubic meters which falls in per secound in an area of one square kilometer. Main disadvantage of empirical formulas is that they cannot cover all factors which affect the runoff, which indicates that the random occurrence of high water. [12.]. Application of field methods requires drawing a recorded cross section of the hull in the respective point in the scale of 1:100 and based on the assumed depth of water in the watercourse determined: surface profile flow S, hydraulic perimeter O, hydraulic radius R, the ratio of flow by Chezy C, the speed of water in the streams based on these data the maximum amount of water in the streams Qmax.




Picture 1. Flow section

- Method of Chezy

$$Q_{max} = AC\sqrt{Ri} = [\mathrm{m}^3/\mathrm{s}]$$

Where: A (sqm) - flow section area.

To determine calculation of the amount of high water in the profile we first should determine:

- The hydraulic radius

$$R = \frac{S}{O} = [m]$$

Where: S flow section area, O (m) hydraulic perimeter

- Chezy's coefficient of flow

$$C = \frac{1}{n} = R^{1/6}$$

Where is: n-Manning coefficient of roughness, R-hydraulic radius

Manning roughness coefficient (n) depends on conditions of basin, stream bed and objects over stream or torrent. Manning roughness coefficient (n) for irregular stream is possible to estimate based on equation.

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

Where: $n_b$=0.045-basic value Manning's coefficient for flat and smooth natural stream bed, $n_1$=0,02-correction factor depend on surface irregularities, $n_2$=0,005-correction depend on changing flow surface, $n_3$=0,004-correction factor depend on barriers in the stream bed, $n_4$=0,1-correction factor depend on vegetation, and m=1-coefficient meandering.

$$n = 0.174$$

To this Manning coefficient was added Manning coefficient for concrete which is 0,013.

Was adopted n=0,187. [9.]

- Speed of water in flow section

$$v = C\sqrt{Ri} = [m/s]$$

i-slope of stream in absolutle units. [3.]

Maximum the amount of high water can be calculated by terreain's method which can differentiate from maximum of the amount of high water and can be calculated by method of four coefficient for 5-10%. [8.]

- Froude's Number

A Froude's number is undimensional number, the ratio of intertial forces to gravitational forces, and defined as:

$$F_r = \frac{V}{\sqrt{g(A/B)}}$$

Where: $F_r$-Froude's number, V-velocity of flow (m/s), g-gravity ($m/s^2$), A-cross sectional area of flow ($m^2$), B-width of flow at surface (m). This equation is valid for irregular channel, stream section. Froude's number indicates the state of flow. Critical flow occurs when $F_r$=1. When $F_r$ is greater than 1, the flow is supercritical, and when it is less than 1 the flow is subcritical. When $F_r$ is close to 1 (>0.99 but <1.1) the flow state is unstable and waves appear on the water surface. Design is recommended to achieve a Froude's number less than 0.9 (subcritical flow).[1.] Then compare the maximum amount of water obtained with method of Pintar and Chezy's method and the difference between them indicates whether the object is correctly sized to accept the amount of water that can be expected from a given basin.

## RESEARCH RESULTS

### *Recorded objects in "Prosara" Management Unit*

In the PJ "Prosara" were filmed four facilities on forest roads over permanent streams. From the four buildings there are two bridges over the stream Eškerovac and Gašnica, and two pipe culverts across the Hajduk`s stream and Pisarić.

*CP1*

CP2

Picture 2. CP1 pipe tube over the stream Pisarić, CP2 pipe tubes at  Hajduk`s stream

*M1*

*M2*

Pictures 3. bridge over Eškerovac M1, M2 bridge over Gašnica

Table 1. The dimensions and possibilities of flow through the pipe culverts

| | d m | L m | A $m^2$ | B (m) | O m | R | i m/m | n | C | v m/s | $F_r$ | $Q_{max}$ $m^3/s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CP1 | 1,0 | 8,0 | 0,79 | 6,1 | 3,14 | 0,25 | 0,06 | 0,187 | 4,24 | 0,52 | 0,46 | 0,41 |
| CP2 | 0,8 | 6,4 | 1 | 7,2 | 10.05 | 0,1 | 0,06 | 0,187 | 3,64 | 0,28 | 0,24 | 0,28 |

Table  2. The dimensions and possibilities for flow waters under the bridges

| | b m | H m | A $m^2$ | B (m) | O m | R | i m/m | n | C | v m/s | $F_r$ | $Q_{max}$ $m^3/s$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M1 | 3,85 | 0,9 | 2,68 | 11,2 | 4,91 | 0,55 | 0,05 | 0,187 | 4,84 | 0,8 | 0,52 | 2,1 |
| M2 | 3,25 | 1,65 | 4,38 | 9,2 | 5,57 | 0,79 | 0,046 | 0,187 | 5,14 | 0,98 | 0,45 | 4,3 |

Pipe culverts (CP2) through Hajduk`s stream are consisted of two concrete pipes with diameter 0.8 m, of which only one in operation. Pipe culvert (CP1) consists of one pipe diameter of 1 m which is serving the entire profile, but in the bed of the stream are piled stones and debris from trees and bushes, in a one word the stream bed is weedy. The bridge over the stream Eškerovac M1 has coastal pillars of concrete.

The structural elements of the bridge, the girders and piles are made of wood, the bridge railing is missing. The bed of the stream is overgrown by trees and bushes, and the bottom is covered with small stones. The bottom bed of Gašnica is also covered with stones, the banks are grassy, and above the right bank there are woods. The bridge M2 was previously made of concrete, and after damage concrete elements were replaced by wooden, the bridge also lacks the fence. Maximum amount of water (Qmax) indicates that the amount of water which is given by object may fail to flow profile characteristics. From tables 1 and 2 we can see that Froude's number is less than 0.99, and flow is subcritical. It means that flow of stream won't cause erosion of stream bed.

***The amount of water that can be expected from the basins***

The use of a GIS observed area obtains basic data on the stream basins over which forest roads are crossing, which will be used to calculate the maximum amount of water in the stream to the given flow profile according to the characteristics of the basin. These data are shown in the table 3.

Table 3. The maximum amount of water from the basins determined method of Pintar

| The basin | A sqkm | L km | i m/m | I% | $q_{10}$ m3/sqkm/s | k | $Q_{10\,m}{}^3/s$ |
|---|---|---|---|---|---|---|---|
| Stream of Hajduk (CP2) | 0,78 | 1,434 | 0,06 | 32 | 0,7 | 0,75 | 0,58 |
| Eškerovac stream (M1) | 0,93 | 1,686 | 0,05 | 35,5 | 0,7 | 0,75 | 0,66 |
| Pisarić stream(CP1) | 0,7 | 1,137 | 0,06 | 29,5 | 0,7 | 0,75 | 0,54 |
| Gašnica stream(M2) | 4,04 | 3,499 | 0,046 | 29,5 | 0,7 | 0,75 | 1,99 |

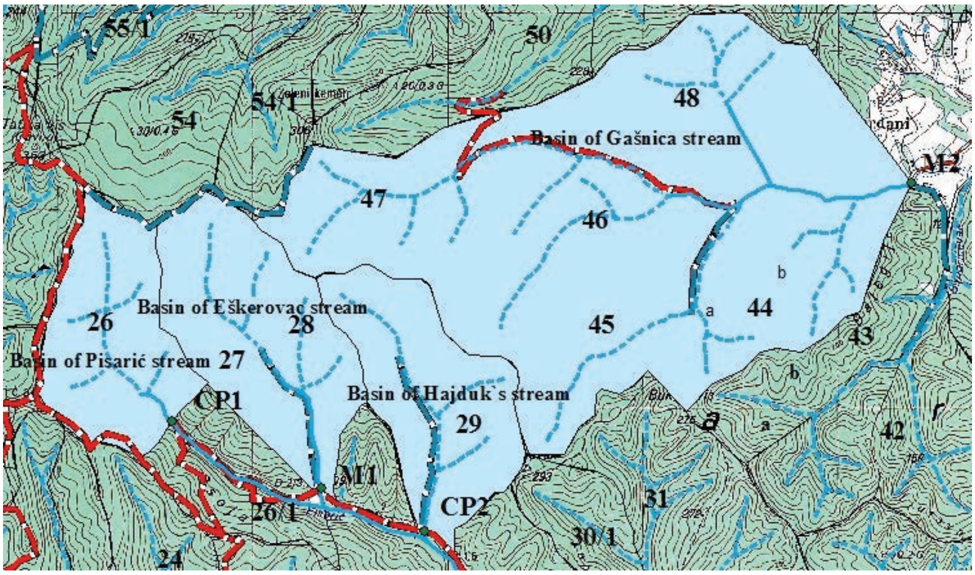
I – slope of basin %.

A runoff coefficient $q_{10}$ for 10 years was calculated based on annual rainfall of meteorological station Gradiška (Table 4). It is 0,63 $m^3$/sq km/s, because the object of research is 15 km far from Gradiška and 150 m higher than meteorological station was adopted 0,7 $m^3$/sq km/s.

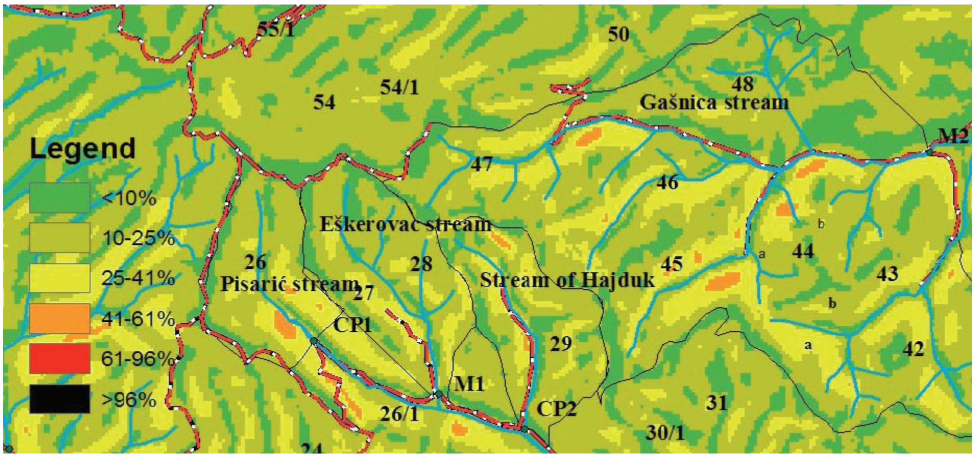
Table 4: Rainfall for 10 years [4.]

| year | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| q (mm/$m^2$) | 988,5 | 877,6 | 580,3 | 871,6 | 742,3 | 647,1 | 685,2 | 545,4 | 592,8 | 1016,2 |
| days | 141 | 175 | 109 | 146 | 138 | 118 | 128 | 120 | 138 | 152 |

From table 3 we can conclude that these are very small basins and short streams, which consist of one long vein and several short vessels that are more seasonal mainly. Considering the character of the basin, length, relief, forest cover, and permeability of the substrate in the table shows the amount of water that can expect from the surface of the basin.




Picture 4. The map of basin’s streams or torrents




Picture 5. The map of slope in the basins

The slope map shows that the slope basins range is from 10 to 61%, due to the forest cover watersheds, geology and soil conditions we can say that land is not prone to erosion. However, in valleys of streams Hajduk and Eškerovac built forest roads in some places have a high slope excavation what is causing their skating or fallout materials from them. On the tractor terrain tracks comes to the soil erosion, which appeares in drains and on the forest roads, at higher humidity tractors make deep rut and create conditions for channeling rainfall water and at the same time compacted soil.

The differences in the amounts of water are certain with method of Chezy and Pintar`s method and are shown in the table below:

Table 5. The differences in the amounts of water

| | CP1 | CP2 | M1 | M2 |
|---|---|---|---|---|
| $Q_{max}$ | 0,41 | 0,28 | 2,1 | 4,3 |
| $Q_{10}$ | 0,54 | 0,58 | 0,66 | 1,99 |
| Diffrence | - 0,13 | -0,30 | 1,44 | 2,31 |

From this table we can see that the bridges across the streams Eškerovac (M1) and Gašnica (M2) can culvert amount of water for 10 years than which can arrive with a basin of these streams. The pipe tubes on the streams of Hajduk (CP2) and Pisarić (CP1) can not culvert amount of water for 10 years. And it is necessary to increase the capacity of these facilities in order to prevent the occurrence of high slowed water, which can cause overflow of water over a forest road and so impede traffic.

## DISCUSSION AND CONCLUSIONS

In the field there were perceived pipe tubes over Pisarić (CP1) and Hajduk streams (CP2), and the bridges over Eškerovac (M1) and Gašnica streams (M2). The pipe culverts are built of concrete and their diameter range is from 0,8 to 1 m, and the bridges are built of wood, except for coastal pillars which are built of concrete.

By establishing a GIS in the observed area obtained four very small basins whose area is from 0,7 to 4 sq km, the length of the main watercourses range is from 1 to 3.5 km. The small basins have a surface to 400 sq km [12.].

The maximum amount of water for last 10 years that can be expected from the basin to reach flows profiles, ranges from 0,5 to 2 $m^3$/s.

The objects over the streams can fail amount of water from 0,3 to 4,3 $m^3$/s.

The stream beds are stable according to Froude’s number.

The velocity of flow of these streams ranges from 0,3 to 1 m/s. In Russia, small streams in the hilly conditions have velocity from 1,5 to 2,5 m/s [12.]. According to Road drainage manual erosive velocity for gravel stream bed ranges from 0,6 to 3 m/s [1.].

To prevent damage to objects and forest roads of the high water it is necessary to:

- For pipe culvert CP1 should be build another pipe diameter of 1,0 m, which could increase the flow from 0,41 $m^3$ / s to 0,82 $m^3$ / s, and from the basin of Pisarić stream can be expected 0,54 $m^3$ / s,
- For point CP2 should be cleaned a pipe culvert of two existing ones,
- For same point should be built one more pipe diameter of 0,8 m to increase the flow capacity,
- Maintenance of stream beds by establishing protection zones around streams or torrents,
- Maintenance of existing pipe culverts and structural elements of bridges,
- During the planning and construction of such facilities to take care of size of them to adjust amount of high water which can be expected from the basin or in a specific period of time,
- During the planning and designing forest roads to make sure that they are not build near streams or torrents , because their protection and to prevention of flooding during times of high waters, and to avoid the appearance of high cut slopes which may cause the appearance of their slipping or landslides. In this

way will be prevented the occurrence of sediment in the stream and protect the road from flooding.

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Vladimir Petković
Tihomir Dejanović

# ANALIZA PROTOKA VODE KROZ OBJEKTE NA ŠUMSKIM PUTEVIMA

*Rezime*

*Istraživanjima je utvrđeno da se na šumskim putevima u području Privredne jedinice "Prosara" nalaze dva cijevna propusta preko potoka Pisarić (CP1) i Hajdučkog potoka (CP2) i dva mosta preko potoka Eškerovac (M1) i Gašnica (M2). Na tim mjestima su snimljeni poprečni profili, izmjerene dimenzije svijetlih otvora mostova i cijevnih propusta. Uspostavljenjem GIS-a slivova datih potoka dobijeni su podaci o površinama, nagibima slivova, dužinama i nagibima vodotoka. Pomoću podataka o količinama padavina u proteklih 10 godina (2001-2010) iz meteorološke stanice Gradiška izračunat je odtočni koeficijent* $q_{10}$*. Prikupljeni i izračunati podaci će poslužiti za izračunavanje maksimalne količine vode koja se može očekivati sa slivova metodom Pintara i maksimalne količine vode koju mogu da propuste dati objekti metodom Chezy s obzirom na njihove dimenzije. Rezultati pokazuju da se ovdje radi o izrazito malim slivovima 0,7 – 4 km*$^2$*, dužina potoka iznosi 1-3,5 km, količina vode koja se može očekivati u period od 10 godina kreće se 0,5-2 m*$^3$*/s. Količina vode koju mogu da propuste objekti na šumskim putevima iznosi 0,3-4,3 m*$^3$*/s. Stanje korita je stabilno prema vrijednostima Frodovog broja, a i prema brzinama koje se kreću od 0,3-1 m/s. Kako bi se omogućilo nesmetano funkcionisanje objekata i sprečavanje šteta na šumskim putevima potrebno je: povećati propusnost cijevnih propusta CP1 i CP2 kako bi mogli da prihvate očekivanu visoku vodu sa slivova, održavati date objekte, uspostaviti zaštitne zona oko korita potoka kako bi se spriječilo nagomilavanje različitih materijala u njima, prilikom planiranja i gradnje dimenzije objekata prilagoditi količini visokih voda i na kraju šumske puteve graditi izvan zone zaštite vodotoka.*