DOI: 10.5152/forestist.2021.21037
Forestist 2022: 72(2): 129-136

ISTANBUL UNIVERSITY
CERRAHPAŞA

Original Article

Determining the Best Dimension of Transversal Drainage for a Forest Road Network by Employing Hydrological Models

Ramin Naghdi[1], İsmail Ghajar[1], Mehrdad Nikooy[1], Mehrab Moradi[1], Farzam Tavankar[2]

[1]Department of Forestry, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, Iran
[2]Department of Forestry, Khalkhal Branch, Islamic Azad University, Khalkhal, Iran

ABSTRACT

Several factors are involved in the destruction of forest roads, and most of them are generated as a result of rainfall runoff which directly threatens the surface of forest roads. To minimize this damage, a well-designed drainage system in accordance with the situation in the region is needed, for which the optimal number and diameter of pipes must be calculated. Mixed broadleaf high-elevation forests in northern Iran. In this study, by employing hydrological models, geographic information systems (GIS), and field survey, we divided the area to 42 sub-areas. We then considered the factors such as hydrologic soil groups, hydrology situation, curve number (CN), and time of concentration, to calculate runoff and peak flow moments. The proper diameter and the number of transversal drainage pipes were then determined. The results showed that the existing cross-drains and their diameter are not sufficient, and are therefore not suitable for the high volume of water in this area. Our findings showed that all of the pipes that have been used in this region have a 60 cm diameter, although, while considering all the relevant factors, it should be at least 80 cm. The results showed that the changing land use and deforestation are the main causes of high rate of runoff in the study areas. Improper maintenance of roads has caused widespread destruction along the road, thereby affecting all the drainage channels and blocking all connections between them.

Keywords: Drainage, forest roads, GIS, peak discharge

Introduction

Forests have some economic, social, and environmental benefits for humans. However, to achieve these benefits, the proper management of the forest road network is required. The design of the forest road network varies according to the regional structure, regional conditions, the available technology, and the aims of management (Demir et al., 2008; Gumus et al., 2007). Well-designed roads in a forest enable the best conditions for their management. Therefore, the engineers who design forest roads should consider design principles in their work (Akay et al., 2008; Zeki Bafikent & Keles, 2005). Drainage is an important factor and includes controlling surface and subsurface water for the forest roads and its neighboring areas (Öztürk, 2020). Poorly designed drainage systems deposit sediment directly into streams at road–stream crossings and shorten the life of the drainage structures and the roads (Menemencioğlu et al., 2013; Öztürk, 2010).

Road construction might have harmful environmental consequences, like forest area diminution, and the destruction of natural canals, sedimentary soil, and water (Gardner, 1997). To reduce the damage caused by runoff, well-designed drains are needed in forest roads. The location of roads and the drainage channels of forest roads, construction areas, and other areas of forestry activities are the critical factors that can affect water quality, erosion, and road maintenance costs (Öztürk, 2020). When drainage channels are improperly placed or sized, stream crossings can have destructive effects on water quality, channel stability, and aquatic habitats (Furniss et al., 1991).

One of the best tools to plan forest roads is the geographical information system (GIS). The most important advantages of GIS application in road planning are: the ability to fill a large number of layers in use, the capacity to process a large volume of data, the availability of highly accurate digital maps, easier editing, high speed, and low cost of operation. Therefore, GIS systems are increasingly used. Geomorphological mapping

Cite this article as:
Naghdi, R., Ghajar, I., Nikooy, M., Moradi, M., & Tavankar, F. (2022). Determining the best dimension of transversal drainage for a forest road network by employing hydrological models. *Forestist*, 72(2), 129-136.

Corresponding Author:
Ramin Naghdi
e-mail:
rnaghdi@guilan.ac.ir; naghdir@yahoo.com

Received:
August 7, 2021
Accepted:
October 14, 2021
Available Online Date:
November 25, 2021

using GIS was consistently reviewed and applied on a small mountain area in Sweden by Gustavsson et al. (2006, 2008) and Gustavsson and Kolstrup (2009).

The determination of the magnitudes and frequencies of discharge in sewers and in natural catchments drained by open streams with respect to the amounts and frequencies of rainfall over the area has been the subject of many papers published during the past half-century (Akay et al., 2008; Nash, 2016). A comprehensive digital geomorphological mapping tool may be useful in planning land reclamation, developing the area sustainably, and assessing risks and hazards (Condorachi, 2011). One of the best methods to employ satellite imagery and apply GIS in the calculation of runoff in precipitation, is to use hydrological models. These models can enable proper estimation in terms of spatial distribution of rainfall (Douvneck, 2000). The source curve system (SCS) method is one of the hydrological methods in this area, provided by the Soil Conservation Service of America. This method uses environmental features to calculate runoff. In the SCS method, researchers need to estimate the curve number (CN), which is calculated based on the properties of the soil, vegetation, land use, and prior soil moisture conditions. Occasionally, long-term trends in runoff are shown to differ from long-term trends in precipitation (Milliman et al., 2008). This is particularly prevalent at the catchment level, where direct human influences, such as water withdrawal for irrigation (Milliman et al., 2008; Xu et al., 2010) and land cover or land-use change (Piao et al., 2007; Sterling et al., 2013) can have significant impacts. The relationship between two variables is complicated. For example, recent research has shown that a precipitation shift from snow to rain may lead to a decrease in runoff (Berghuijs et al., 2014). This may play a role in explaining the steady evapotranspiration increases seen over the Northern Hemisphere mid-latitude (NHML) region and particularly in the North American continent.

Effective road drainage is crucial to protect the road prism from damage and to keep the road surface stable for good road quality (Menemencioğlu et al., 2013). The effective factors in determining drain path, topography, size, and dimensions of the section are the existing drainage, drainage sub-branch junction, geological conditions, stability period, the status of existing bridges, land use, and other important physical conditions. With the occurrence of rainfall, runoff from the slopes above the road on the excavation side overflows as a stream, and combining with other streams, flows into the side runnel. On the road, half of the runoff flows into the side runnels and the other half overflows on the embankment side. The combined embankment runoff enters the forest (Dabi et al., 2004). A good culvert stream-crossing or cross-drain depends on sound installation procedures, as well as proper culvert type, length, size, and location (Öztürk, 2020).

The construction and use of forest roads affects the hillslope hydrology and can be an important source of sediment delivery to streams in forested basins (Menemencioğlu et al., 2013). Gedney et al. (2006) found a detectable increase in local river flow in response to increased NHML aerosol emissions in the 1960s and 1970s. Boise and Bestoun (2008), by employing the CN method, showed that runoff from rain is very sensitive to changes in the index. Their research also showed that the CN is greatly affected by land use and soil physical properties. Zahang and Hohang (2009) used the capabilities of GIS to determine the CNs and calculate water infiltration after a rainfall, in Kansas (USA). Mishra and Rose (2010) used the relationship between SCS and the Universal Soil Loss Equation method to assess sediment production during a specific period of rainfall. Dong et al. (2012) measured road runoff and soil erosion in China. The results showed that soil bulk density had a positive effect on the rate of runoff. In the soil which had higher density, the rate of soil loss during low rainfall rose sharply, while the amount of soil loss during intense rainfall significantly decreased. The effect of slope on runoff rate was dependent on rainfall intensity. Soil erosion also showed a positive correlation with slope. Kayhan et al. (2013) investigated the effect of different vegetation types on the location and type of cross-drains of forest roads in Turkey using GIS, remote sensing, and hydrological models. They concluded that in cross-section channels with a length of 10 m, using a bridge is best; however, in case of .4 m, a large diameter pipe, and in .2 m a small diameter pipe should be used. For forest roads, different drainage structures such as pipe, culvert, ditch, bridge, and dip-drain (Öztürk, 2010) are used. Permanence of the road is feasible by designing and constructing effective road drainage systems, which allow the water to move away from the road surface as quickly as possible. Erosion control on forest roads can be achieved by preventing water from accumulating and concentrating on the road surface (Keller & Sherar, 2003; Menemencioğlu et al., 2013).

The main objective of this study was to estimate the maximum discharge streams in forest roads, determine the appropriate number and dimensions for transverse drainage along the forest road according to the longitudinal profile of the road, review the existing cross-drains along the road network in the study area, and also determine the force of passing water flow based on maximum discharge.

Material and Methods

This study was conducted in the Shafarood forests, in the western part of Guilan province, in the Hyrcanian forests in the north of Iran (Figure 1). This area is located in a valley between 48°54'5" and 49°01'27" longitude, and 37°31'51" and 37 33'16" latitude. The total area of this series is 1742 ha, of which 1155.93 ha are usable for forest operation. This series is located at an altitude of 250–1150 m above sea level.

Topographical maps of the slope, aspect, and elevation of the study area, with a scale of 1:25000 and a Digital Elevation Model (DEM) were used.

The average monthly rainfall has been reported at 108.9 mm in this area. Most rainfall is reported in September and October, and the lowest rainfall in June and July. The annual mean temperature is 16.5°C, the maximum average annual temperature is 19.7°C, and the minimum of average annual temperature is 1.11°C. Thus, according to the Domarten climate model, this area is located in a very wet climate.

In terms of stratigraphy, the scope of the series has Mesozoic sediments that have been completed in the Cretaceous period. In terms of lithology, most of the area was formed from lava deposits associated with igneous rock.

According to the purposes and uses, the most common type of roads existing in this area are second-grade forest road (Figure 2). Road density in this series is 30 m/ha. Rocks fall due to excavation trenches in the slopes, blocking a part of the route. The lack of lateral channels creates shutters and holes on the road surface, especially in areas that receive less sunlight,. Filling the inlet and outlet water drainage piping, and disturbances in the upstream water drainage can lead to water movement on the road. Movements of machines in such a situation

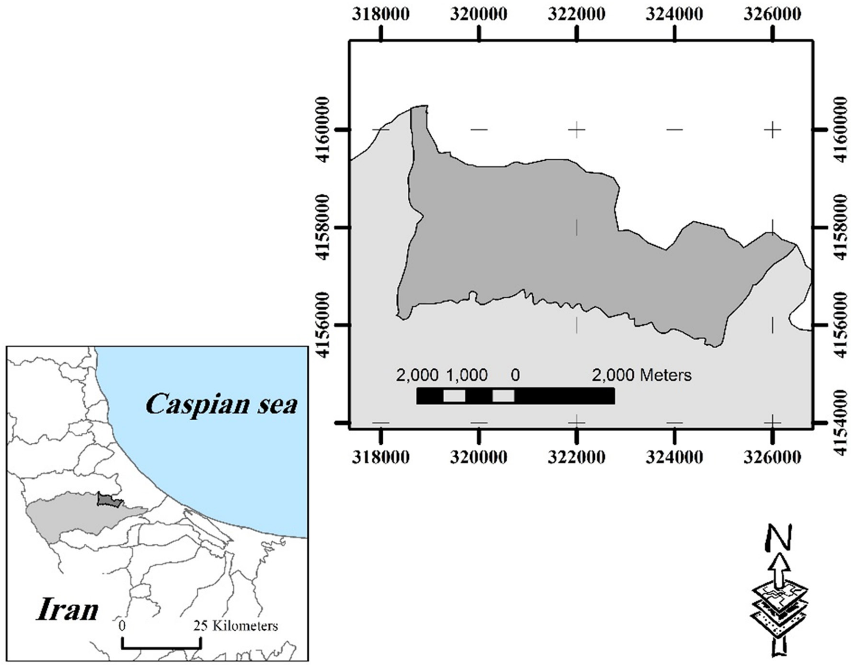

Figure 1.
Location of the Study Area in South Coast of the Caspian Sea.

create wheel prints and slots in the path. Therefore, the lack of a pavement and surface water accumulation cause progressive destruction of the road.

The choice of a hydrological analysis method depends on the type of facility being designed (conveyance, detention, or water quality) and the required performance standard. The size of the tributary area and watershed characteristics, including backwater effects, should also be considered (Diane & Sugimura , 2015). Hence, in this study, the SCS method was employed.

First, sub-basins were determined using the Arc Hydro software, providing basic data and using the field's surface flow method. The data of the DEM and the slope map were first entered into the software; then, the direction of surface flow for each pixel in this application were determined (Figure 3).

Because of the small size of the drainage area in our study and having precipitation figures to determine the maximum discharge runoff and runoff height estimation, the SCS method was employed with the following formula. *Q* is runoff height, *P* is rainfall height, *S* is the maximum ability for storage of evapotranspiration, soil infiltration, and surface storage during a 24-hour rainfall.

$$\text{Runoff estimation formula (Eq. 1)}: Q = \frac{(p - 0.2s)^2}{p + 0.8s} \quad (1)$$

In order to determine the amount of total losses (*S*), the following formula was employed. *S* is total loss in millimeters and CN is the curve number in millimeters.

$$\text{Total loss formula (Eq. 2)}: S = \frac{25\,400}{\text{CN}} - 254 \quad (2)$$

After determining the value of CN, the amount of S is determined, and the amount of runoff is also calculated based on the rainfall. The value of CN might be variable between 0 and 100. If CN = 0, no runoff comes from rainfall, but if CN = 100, all precipitation at ground level flows and runoff height will be equal to the rainfall height.

After determining the height of surface runoff caused by heavy rainfall, the flood's peak flow can be achieved with the use of different hydrograph dimensionless methods. In our study, the following equation, expressed in metric units, was used. Where Q_{max} is maximum discharge rate in cubic meters per second, and 2.083 is an index suitable for common areas in terms of slope, which should be increased by 20% in steep mountainous areas and decreased by 30% in flat areas. *Q* is the runoff height, calculated in centimeters, *A* is the basin area in square kilometers, and tp is time of start of the rising limb of the hydrograph to reach its peak point in hours, it is half-time of rainfall.

$$\text{Flood peak formula (Eq. 3)}: Q_{\text{max}} = \frac{2.083AQ}{\text{tp}} 3 \quad (3)$$

Focus time is the time it takes water reach from the farthest areas to the exit point of the basin. Its value is directly related to the main channel length, slope, and hydraulic conditions of the flow path, such as the roughness coefficient and the hydraulic radius. Many relationships have been presented to calculate the focus time. In this research, we employed the relationship that was presented by Krpych. In this formula, T_c is focus time in minutes, *L* is the largest watercourse in area in meter units, and *S* is slope of watercourse in meter/meter. It could be mentioned that this relationship was used frequently for small areas until now.

$$\text{Focus time formula (Eq. 4)}: Tc = 0/0195 L^{0/77} S^{-0/385} \quad (4)$$

Next, time to peak was calculated. This is the time from the start time of peak shoots of hydrograph to the time of peak discharge, and its unit of measurement is hours.

$$\text{Time to peak (Eq. 5)}: tc\ 0/6+ = \sqrt{tc}\ tp \qquad (5)$$

The hydrograph shows discharge changes in terms of time, and the height of a 24-hour precipitation was then determined.

The volume of discharge in each sub-basin area is essential in calculating discharge amount. Therefore, in the CN formula for calculating the maximum discharge, it is necessary to calculate the area of each of the following areas. The area of the sub-basins is obtained by drawing the polygon of each sub-basin in the Arc GIS software, and calculating the area of each sub-basin. The mean hydrological measurements in hydrologic soil groups were compared by ANOVA and Duncan's tests.

One of the most important factors in determining the size of pipes is discharge or periodic runoff. The return period is the number of years between two similar floods or rainfall. The return period should be equal to the time period for use of the facilities. For the forest roads, this period is considered to be 25 years. Rural roads and commuting by villagers are important factors in this selection. Otherwise, a ten-year return period will be sufficient (Fardad, 1982).

The most important factor in order to determine the diameter of the pipes is that it should pass the calculated discharge rate for a given return period without risk of water-level rise above a specified height, flooding, silt, and water passes on the road surface.

Taking into account the consistency of water flow, divided by the diameter of the pipes and calculating the area of discharge in cubic feet per second, the pipe diameter in inches can be achieved; by multiplying the resulting number by 2.54, the result is expressed in centimeters.

Results

The area of the basin has an important role in determining the rate of runoff discharge. In a smaller area, the empirical relationship is useful as an argument for the CN method. In British Columbia, Toland and Band (2004) used the CN method based on rainfall data to determine the peak flow discharge, in order to design pipe networks and culverts under the road, due to lack of data.

The results of using the SCS model to estimate the maximum discharge of flood with a return period of 25 years are provided in Table 1. Since the coefficient CN has a major role in increasing floods, according to results (Table 1) the highest CN values are in the areas that have the greatest flood discharge.

According to the hydrographic characteristics of the sub-basins, the most important factor affecting the peak runoff discharge rate is hydrologic soil groups. In the sub-basins number 0, 1, 2, 4, 5, 7, 8, 9, 11, 13, 14, 15, 18, 21, 22, 24, 25, 27, 28, 29, 30, 35, and 41, the hydrologic soil group is A. Due to this, the runoff CN and height are low, and as a result, the instantaneous runoff discharge is also low. For example, in sub-basins in which instantaneous runoff discharge is low, fewer drains are suggested. As an illustration, in sub-basins number 1 and 2, having just one drain, the second drain was suggested. On the other hand, in the sub-basins with more instantaneous runoff discharge, more drains are suggested. For example, in sub-basins number 18 and 24, each having four drains, we suggested that they need four and three drains respectively.

In sub-basins number 3, 6, 12, 17, 19, 20, 23, 31, 36, 37, and 40, the hydrologic soil group is B. The CN, runoff height, and instantaneous discharge are average. As an illustration, in the sub-basin number 6, there are two drainage channels, and we proposed that three drains should be added; and in sub-basin number 12, which has no drainage channels, we suggested that four drains are necessary.

Table 1.
Results of Hydrological Measurements (Mean ± SD) in Hydrologic Soil Groups

	Hydrologic Soil Group			
Hydrographic Information	A	B	C	D
Rainfall in 24 hours (mm)	57	57	57	57
Area (km^2)	0.83 ± 0.06^{c}	0.84 ± 0.05^{c}	0.99 ± 0.05^{a}	0.87 ± 0.05^{b}
Focus time (minute)	0.35 ± 0.05^{c}	0.37 ± 0.04^{bc}	0.40 ± 0.05^{a}	0.38 ± 0.04^{ab}
Peak time (hours)	0.87 ± 0.08^{a}	0.75 ± 0.06^{b}	0.86 ± 0.07^{a}	0.85 ± 0.06^{a}
Runoff height (mm)	2.49 ± 0.08^{c}	3.40 ± 0.08^{c}	13.89 ± 1.05^{b}	25.27 ± 1.93^{a}
Total loss (mm)	451.56 ± 23.40	165.48 ± 10.25	83.09 ± 9.27	44.02 ± 5.12
Path slope (m)	20.61 ± 1.26^{ab}	19.00 ± 1.08^{b}	22.45 ± 1.11^{a}	22.25 ± 3.70^{a}
Channel length (m)	190.04 ± 16.43^{c}	200.7 ± 13.41^{b}	235.42 ± 11.86^{a}	224.25 ± 10.73^{b}
Curve number (CN)	38.48 ± 4.53^{d}	61.24 ± 5.83^{c}	75.40 ± 6.28^{b}	85.25 ± 7.09^{a}
Peak discharge (m^3/s)	5.72 ± 0.41^{d}	7.6 ± 0.52^{c}	31.29 ± 5.10^{b}	54.01 ± 3.61^{a}

Note: Different letters after means indicate significant differences by Duncan's test at $\alpha = .05$. Hydrologic soil groups classification:
A = Low runoff potential: Soils having high infiltration rates, even when thoroughly wetted, and consisting chiefly of deep, well-to-excessively drained sands or gravels. These soils have a high rate of water transmission
B = Moderately low runoff potential: Soils having moderate infiltration rates when thoroughly wetted, and consisting chiefly of moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C = Moderately high runoff potential: Soils having slow infiltration rates when thoroughly wetted, and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.
D = High runoff potential: Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay later at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.
Source: TR-55 (NRCS 1986), Exhibit A-1. Revisions made from SCS, Soil Interpretation Record, Form No. 5, September 1988.

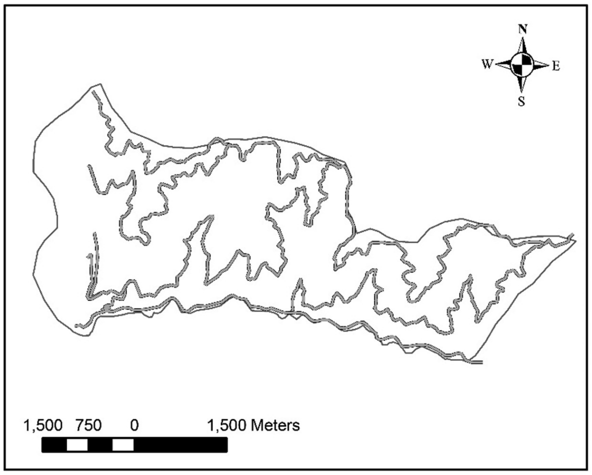

Figure 2.
Map of Road Network in the Study Area.

In sub-basins number 10, 16, 17, 38, and 39, the hydrologic soil group is C. The CN, runoff height, and instantaneous discharge in the following areas is high. Sub-basin number 16 does not have any drainage, and we suggested that it needs at least five drains, In sub-basin number 39, there are two drains, and we proposed that two more drains should be added.

In sub-basins number 26, 32, 33, and 34, the hydrologic soil group is C. The CN, runoff height, and instantaneous discharge are high. In sub-basin number 32, there are three drains, and three more drains were also recommended. In sub-basin number 33, there is no drain, but three drains were recommended. When sizing the bridge and culverts, in addition to the highest level of the stream in that calculated period, the margin of safety between the lowest part of the superstructure and the highest water level should not be less than 1.5 m in bridges and culverts where there are streams that bring trees and large logs, 1 m where streams do not bring trees and logs, and .5 m in the other culverts (Öztürk & İnan, 2010).

Discussion

The hydrological situation in the study area is mainly poor, thereby causing an increase in CN, runoff, and discharge. The less the distance between drain pipes, the smaller their diameters can be. The results showed that parts of the forest which have medium and high sensitivity to erosion have longer drainage channels and greater drain density. In contrast, areas with low sensitivity to erosion have shorter channel length and lower drain density. In order to calculate the distance between drain pipes, we divided 41,500 m (total length of roads) by the number of existing pipes (81), which is equal to 512 m. According to the standard drain distances from each other (Sarikhani, 2006), which should be up to 250 m, the standard in the study area did not meet the condition and 86 drains had to be added. Areas in which culverts are constructed along forest roads should not be planned on ridges or in hollow sections (Öztürk, 2020).

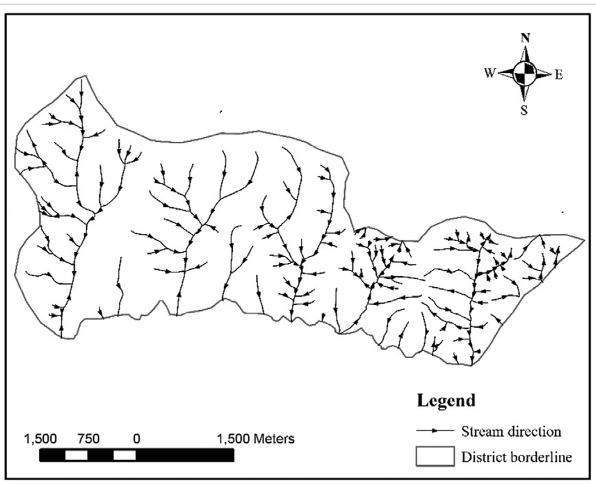

Figure 3.
Map of Stream Network and Direction in the Study Area.

Menemencioğlu et al. (2013) used Landsat images and GIS to determine the type and places of drainage structures on forest roads in 9626 ha of forest in Turkey. They demonstrated that a total of 4 bridges, 138 culverts, 15 pipe culverts (80 cm diameter), and 7 pipe culverts (60 cm diameter) at road–stream crossings and 222 pipe culverts (60 cm diameter) to cross-drain upslope ditch water are needed in the study area.

The reviewed sub-basins based on specific discharge potential showed that generally, lands with high gradients, changes of land use, and land with poor vegetation cover have the highest potential for floods. Watershed is the upslope area contributing flow to an outlet or pour point, which is usually the lowest point along the boundary of the watershed (Menemencioğlu et al., 2013).

To determine the diameter of the pipes in each sub-basin, the discharge is calculated for each sub-basin by converting it into cubic feet per second, with the diameter for drain pipes estimated in inches. As can be seen in Table 2, in some areas, due to the high flow rate of runoff and discharge, the pipe diameter calculated is high. In forest areas, due to transportation limit and cost savings, two or three alternative pipes can be used instead of large-diameter pipes. Of course, an optimized decision in terms of cost and equipment should be considered when dealing with this issue. In this study, considering the possibilities of co-operation, for diameters up to 90 cm, according to the instructions of the Virginia Forestry Department, alternative pipes that were the nearest to the intended diameter were suggested. To prevent the negative effects of poorly planned, located, designed, constructed, and drained forest roads, the places and sizes of drainage structures should be determined and constructed according to road and watershed conditions, with the best engineering and road management practices (Keller & Sherar, 2003; Menemencioğlu et al., 2013).

A close look at Table 2 reveals that the lowest instantaneous discharge is in sub-basins number 0, 2, and 4 (3 m^3/s) and the highest rate in number 16 (45 m^3/s), number 26 and 32 (55 m^3/s), number 33 (40 m^3/s), and number 34 (65 m^3/s) could be seen. Most drainage problems are related to sub-basins number 10, 16, 17, 26, 32, 33, 34, 38, and 39; therefore, more drainage (two drains or pipe replacement) has been proposed for them. Particular attention should be paid to the material selection for constructing drainage structures (Öztürk, 2020).

The main task of all drainage structures and walls is to protect the forest roads against external aggressors (Öztürk, 2020). In this study, it was found that the more the runoff production capacity based on the type of soil, and the more the vegetation cover, the less the runoff discharge seen. Therefore, the distance of lateral drainage pipes could increase. This result was proved by Brinker (1995) in the US, who stated that topography, soil, and vegetation play a dominant role in determining distances of transverse drainage pipes. Egan et al.

Table 2.
Determine the Pipe Diameter in Inches

Sub-basin	Discharge (m^3/s)	Discharge (ft^3/s)	Pipe Diameter (cm)	Pipe Diameter (inch)	Two Alternative Pipes (cm)	Three Alternative Pipes (cm)
0	3.9	132.6	80	32		
1	4.2	142.8	80	32		
2	3.8	129.2	80	32		
3	4.9	166.2	80	32		
4	3.8	129.2	80	32		
5	4.3	146.2	80	32		
6	5.1	173.4	80	32		
7	4.1	139.4	80	32		
8	5.2	176.8	80	32		
9	4.8	163.2	80	32		
10	18.6	632	160	64	54, 42	42, 42, 42
11	5.9	600	80	32		
12	6.1	204	80	32		
13	5.9	200	80	32		
14	5.6	190	80	32		
15	5.5	187	80	32		
16	45.7	1530	160	64	42, 54	42, 42, 42
17	29.3	986	160	64	42, 54	42, 42, 42
18	6.5	221	80	32		
19	6.3	214.2	80	32		
20	7.2	244.8	80	32		
21	4.8	163.2	80	32		
22	5.4	186.6	80	32		
23	6.1	207	80	32		
24	9.7	329	80	32		
25	4.2	142	80	32		
26	55.8	1870	240	96	66, 72	66, 66, 66
27	6.4	217	80	32		
28	8.1	275.4	80	32		
29	6.3	214.2	80	32		
30	4.6	156.4	80	32		
31	10.6	360.4	80	32		
32	55.1	1870	240	96	66, 72	66, 66, 66
33	40	1360	240	96	66, 72	66, 66, 66
34	65.2	2210	240	96	66, 72	66, 66, 66
35	6.6	224.4	80	32		
36	13	442	80	32		
37	5.1	170	80	32		
38	25.2	850	160	64	42, 54	42, 42, 42
39	23.5	799	160	64	42, 54	42, 42, 42
40	5.7	193.8	80	32		
41	5.4	183.6	80	32		

(1998) in West Virginia found that water management and drainage of forest roads has the highest importance, and restoration of forest roads has the least importance in this issue. In this study, it was found that the volume of water that will pass through the road is based on runoff discharge and the existing pipes, and therefore, based on the results, we proposed that in order to protect the road and avoid erosion, establishment of technical structures including lateral drains such as altering some pipes is essential. Öztürk (2020) suggested that planning of all kinds of drainage structures used on forest roads should be done appropriately based on the calculations made based on field studies, measurements, and observations, which are very important in determining the type, size and location of the drainage structure.

Conclusion

Channel crossings must be carefully designed and constructed to allow maximum amount of water passage, to prevent road failures related to inadequate water passage structures, and to poor placement and construction practices (Food and Agriculture Organization [FAO], 2011; Menemencioğlu et al., 2013).

Drainage facilities ensure the protection of forest roads against all negative effects of rain waters (Öztürk, 2020). Overall, in this study, by dividing the area into different sub-areas and by determining the location for piping, the soil hydrology groups, land use, hydrological status, and the CN for each sub-basin, the discharge rate, diameter, and location of pipes were calculated.

Drainage structures like bridges, culverts, and pipe culverts are mostly constructed at the intersection points of streams and roads (Menemencioğlu et al., 2013).

Öztürk (2020) suggested that drainage structures must be placed on the road route at an angle of 30–45°, and they should not be placed perpendicular to the road. He also suggested that a longitudinal slope of 2–5% should be applied to the interior of the pipes and culverts.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – R.N., I.G., M.N., M.M., F.T.; Design – R.N., I.G., M.N., M.M., F.T.; Supervision – R.N., I.G., M.N., M.M., F.T.; Resources – R.N., I.G., M.N., M.M., F.T.; Materials – R.N., I.G., M.N., M.M., F.T.; Data Collection and/or Processing – R.N., I.G., M.N., M.M., F.T.; Analysis and/or Interpretation – R.N., I.G., M.N., M.M., F.T.; Literature Search – R.N., I.G., M.N., M.M., F.T.; Writing Manuscript – R.N.; Critical Review – I.G., M.N., M.M., F.T.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

- Akay, A. E., Erdas, O., Reis, M., & Yuksel, A. (2008). Estimating sediment yield from a forest road network by using a sediment prediction model and GIS techniques. *Building and Environment*, *43*(5), 687–695. [CrossRef]
- Berghuijs, W. R., Woods, R. A., & Hrachowitz, M. (2014). A precipitation shift from snow towards rain leads to a decrease in stream flow. *Nature Climate Change*, *4*(7), 583–586. [CrossRef]
- Boise, C., & Bestoun, F. (2008). *SEDMODL-Boise Cascade road erosion delivery model.* Technical documentation, (p. 19). Idaho: Boise Cascade Company.
- Brinker, R. W. (1995). Forest Road and Construction Associated Water Diverson Devises. *Alaban Cooperatives Extension System, ANR 916*. pp. 27, Alabama A & M and Auburn Universities. http://www.aces.edu/pubs/docs/A/ANR-0916/
- Condorachi, D. (2011). Geomorphological mapping using GIS for large tableland areas: An example for Falciu hills, in eastern Romania. *Carpathian Journal of Earth and Environmental Sciences*, *6*(2), 115–124.
- Dabi, K., Megahan, W., & McCalmon, M. (2004). *Washington Road Surface Erosion Model.* This application and manual were funded by the Washington Department of Natural Resources as part of contract, (p. 189). http://www.dnr.wa.gov/washington-road-surface-erosion-model
- Demir, M., Makineci, E., & Gungor, B. S. (2008). Plant species recovery on a compacted skid road. *Sensors*, *8*(5), 3123–3133. [CrossRef]
- Diane, M., & Sugimura, R. H. (2015). *Hydrologic analysis and design city of Seattle storm water manual*. Seattle: Department of Planning & Development Seattle Public Utilities.
- Dong, J., Zhang, K., & Guo, Z. (2012). Runoff and soil erosion from highway construction spoil deposits: A rainfall simulation study. *Transportation Research Part D*, *17*(1), 8–14. [CrossRef]
- Douvneck, F. (2000). *Cross drain placement to reduce sediment delivery from forest roads to streams* (p. 225) [Master thesis]. Seattle: University of Washington.
- Egan, A., Jenkins, A., & Rowe, J. (1998). *Forest road in West Virginia, USA: Identifying issues and challenges* (p. 8). West Virginia: College of Agriculture and Forestry West Virginia University Morgan Town.
- Fardad, H. (1982). *Design and management of drainage systems.* Science and Technology publications, (p. 464). Tehran, Iran.
- Food and Agriculture Organization (FAO). (2011). Drainage design (p. 63) (Chapter 4). *Corporate Document Repository, Forestry Department*. Retrieved from http://www.fao.org/docrep/006/t0099e/T0099e04.htm.
- Furniss, M. J., Roelofs, T. D., & Yee, C. S. (1991). Road construction and maintenance. *American Fisheries Society Special Publication*, *19*, 297–323.
- Gardner, R. B. (1997). Some environmental and economic effects on alternative forest road designs. *Transactions of the ASAE*, *22*(1), 63–68. [CrossRef]
- Gedney, N., Cox, P. M., Betts, R. A., Boucher, O., Huntingford, C., & Stott, P. A. (2006). Detection of a direct carbon dioxide effect in continental river runoff records. *Nature*, *439*(7078), 835–838. [CrossRef]
- Gumus, H., Acar, H., & Toksoy, D. (2007). Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. *Environmental Monitoring and Assessment*, *142*(1–3), 109–116. [CrossRef]
- Gustavsson, M., & Kolstrup, E. (2009). New geomorphological mapping system used at different scales in a Swedish glaciated area. *Geomorphology*, *110*(1–2), 37–44. [CrossRef]
- Gustavsson, M., Kolstrup, E., & Seijmonsbergen, A. C. (2006). A new symbol-and-GIS-based detailed geomorphological mapping system: Renewal of a scientific discipline for understanding landscape development. *Geomorphology*, *77*(1–2), 90–111. [CrossRef]
- Gustavsson, M., Seijmonsbergen, A. C., & Kolstrup, E. (2008). Structure and contents of a new geomorphological GIS database linked to a geomorphological map – with an example from Liden, Central Sweden. *Geomorphology*, *95*(3–4), 335–349. [CrossRef]
- Kayhan, M., Bayram, C., & Alkan, G. (2013). Determining the type and places of drainage structures on forest roads using remote sensing and GIS in Turkey. *Journal of Food, Agriculture and Environment*, *11*, 1487–1491.
- Keller, G., & Sherar, J. (2003). Low-volume roads engineering: Best management practices. *Transportation Research Record Eighth International Conference on Low-Volume Roads*, *1819*(1), 174–181. [CrossRef]
- Menemencioğlu, K., Cemil Bilgili, B., & Günlü, A. (2013). Determining the type and places of drainage structures on forest roads using remote sensing and GIS. *Journal of Food, Agriculture and Environment*, *11*(2), 1487–1491.
- Milliman, J. D., Farnsworth, K. L., Jones, P. D., Xu, K. H., & Smith, L. C. (2008). Climatic and anthropogenic factors affecting river discharge to the global ocean, 1951–2000. *Global and Planetary Change*, *62*(3–4), 187–194. [CrossRef]
- Mishra, R. K., & Rose, C. W. (2010). Application and sensitivity analysis of process-based model GUEST and SCS. *European Journal of Soil Science*, *47*, 593–604.

- Nash, J. E. (2016). *Determining runoff from rainfall* (pp. 163–184), Paper no. 6282. Minnesota: Hydraulics Research Station, Department of Scientific and Industrial Research, University of Minnesota.
- Öztürk, T. (2010). *Determination of necessary basis for positioning of drainage structures in forest roads (sample of Belgrad Forest)* (vol. *2*) (pp.494–504). Proceedings of the 3rd National Blacksea Forestry Congress, Artvin.
- Öztürk, T. (2020). Temporal change of drainage structures in forest roads (Study of Bentler Forest Enterprise 2009-2019). *European Journal of Forest Engineering*, *6*(2), 52–59. [CrossRef]
- Öztürk, T., & İnan, M. (2010). Use of GIS for determination of positioning and sizes of drainage constructions at forest roads (pp.736–744). 3rd National Remote Sensing and GIS Symposium, İstanbul.
- Piao, S., Friedlingstein, P., Ciais, P., de Noblet-Ducoudré, N., Labat, D., & Zaehle, S. (2007). Changes in climate and land use have a larger direct impact than rising CO_2 on global river runoff trends. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(39), 15242–15247. [CrossRef]
- Sarikhani, N., & Majnounian, B. (2006). Guidelines for the design, implementation and exploitation of forest roads (in Persian). *Publications Planning Department of Iran*, *131*, 170.
- Sterling, S. M., Ducharne, A., & Polcher, J. (2013). The impact of global land-cover change on the terrestrial water cycle. *Nature Climate Change*, *3*(4), 385–390. [CrossRef]
- Toland, C., & Band, I. (2004). Simulating the impact of road construction and forest harvesting on hydrological response. *Earth Surf Process Land*, *26*, 131–151.
- Xu, K., Milliman, J. D., & Xu, H. (2010). Temporal trend of precipitation and runoff in major Chinese rivers since 1951. *Global and Planetary Change*, *73*(3–4), 219–232. [CrossRef]
- Zahang, B., & Hohang, Y. (2009). Effect of vegetation restoration on soil and water erosion and nutrient losses of a severely eroded in southeastern China. *Catena*, *57*, 77–90.
- Zeki Bafikent, E., & Keles, S. (2005). Developing alternative wood harvesting strategies with linear programming in preparing forest management plans. *Turkish Journal of Agriculture and Forestry*, *30*(1), 67–79.