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Comparison of WEPP:Road Batch Model and ABAG Model for Estimating Amount of Top Soil Erosion in Forest Road Fill Slopes

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Abstract

The bare surfaces formed on slopes in construction of forest roads become the most important sediment sources due to erosion. In this study, it was aimed to evaluate effectiveness of the WEPP (Water Erosion Prediction Project): Road Batch model in estimation of the annual soil loss from forest roads by comparing its performance with ABAG (Allgemeine Boden Abtrags Gleichung) model which is a metric system of the USLE (Universal Soil Loss Equation) model. In the study, analyzes were made on newly built (road coded 315), 5-year (road coded 307), and 10-year (road coded 269) sample forest roads located in the city of Trabzon in Türkiye. WEPP: Road Batch model and ABAG model were implemented on the sample roads to estimate for the amount of top soil erosion in fill slopes. The results indicated that for WEEP and ABAG models, annual soil loos per hectare were 7.93 and 15.5 T/ha/year, 1.46 and 1.59 T/ha/year, and 1.58 and 1.75 T/ha/year on newly built, 5-year, and 10-year forest roads, respectively. It was concluded that it would be more accurate to determine the annual soil loss precisely by taking samples only from newly built roads, where it is possible to use WEPP: Road Batch software on aged roads. Thus, a practical solution can be found for measuring the amount of erosion on forest roads.

Keywords: WEPP, forest road, fill slope, ABAG, soil erosion

1. Introduction

The global change has produced a dramatic transformation in the land cover on the planet's surface over the past decades. Among these effects, the increase in erosion stands out as a particularly worrying issue (Borelli et al., 2017). One of the most important reasons for the increase in erosion and global change are operations carried out in the forests. Forests play a key role in nutrient cycling, hydrology and ecosystem functioning, and any intervention can have major impacts (Hosseini et al., 2012). Forest systems also provide valuable natural resources that provide consumer products (building materials, paper, firewood, etc.) and services (outdoor recreation, environmental services) (Zhang and Pearse, 2011). In order to manage the forest resources in a sustainable way, it is necessary to establish forest road network.

During the construction of forest roads, forest vegetation is removed, forest floor is deteriorated and soil structure is damaged. Deep excavations and high fillings change the landscape, and more importantly, they can disrupt the natural balance (Parsakhoo et al., 2014). The fact that cut and fill slopes are deprived of vegetation for years results in the unpleasant and incompatible image with the natural environment, while lack of vegetation on slopes potentially cause soil erosion (Türk and Gümüş, 2010). Sediment yield as a result of erosion is the biggest pollutant of streams. With the exception of forest fires, forest road networks are often the main source of sediment in forest basins. Thus, well understanding of forest road related erosion processes is important to help predict sediment distribution from roads to streams (Elliot et al., 2009).

Road erosion models can be divided into two types, empirical and process-based. The main empirical models for road erosion are the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) and SedModl2 (Dube and McCalmon, 2004), while the process-based models are KINEROS (Woolhiser et al., 1990) and Water Erosion Estimation Project (WEPP) (Flanagan and Livingston, 1995). The USLE was originally developed for estimating erosion as the result of five factors; precipitation erosivity, soil erosiveness, slope length, slope, cover management factor and protection application. The model assumes that soil erosiveness is

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only a function of soil properties, so road surface condition and all other effects of traffic must be taken into account in the cover management factor. The WEPP model, on the other hand, is a continuous model with daily weather input. It is usually operated for weather conditions of 30 to 100 years. The weather file is stochastic based and generated by a program distributed with the WEPP model. WEPP processes also include daily evapotranspiration, soil water balance, plant growth, humus deposition and decay. On rainy days, the depth, duration and peak intensity of the event are combined with an infiltration algorithm to estimate the runoff. Most WEPP interfaces give estimates of average annual erosion and delivery. Outputs can be obtained for individual events or individual years, and turnaround analyzes can be performed for individual events or annual values (RMRS, 2009). It runs on web-based environment and has GIS interfaces (ARS, 2008).

In this study, the effectiveness of the WEPP model in estimation of the annual soil loss from forest road fill slope was evaluated by comparing the performance of WEPP:Road Batch model with ABAG model, which is the metric system of the USLE model. Thus, a practical solution will be created to determine the amount of erosion on newly built forest roads and the slope stability processes to be applied will be placed on a more accurate ground.

2. Material and Methods

The study areas are located in Şalpazarı and Akçaabat districts of Trabzon in Türkiye (Figure 1 and 2). Trabzon, with an area of 4,664 km^2, is located on the north-facing slopes of the Kalkanlı mountainous mass in the middle of the arc formed by the Eastern Black Sea Mountains, between 38° 30' - 40° 30' east meridians and 40° 30' - 41° 30' north parallels (Trabzon governorship, 2022).

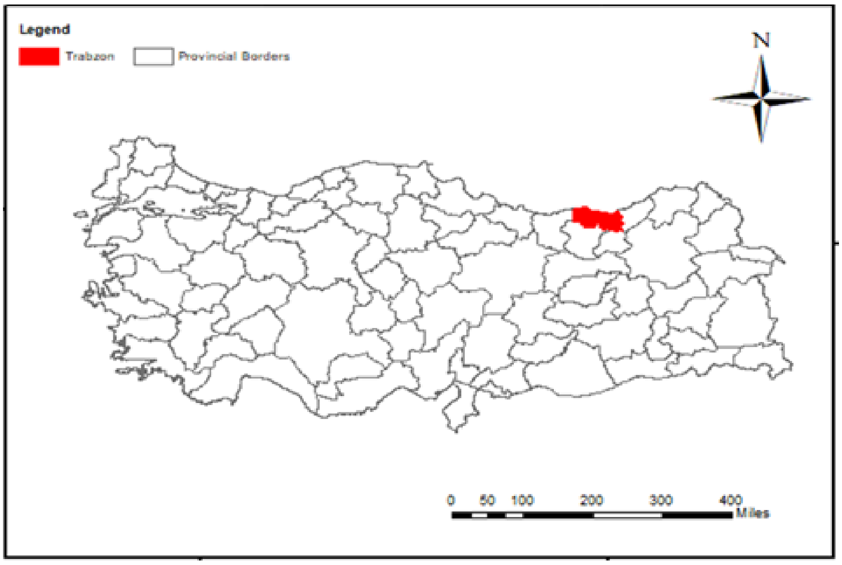


Figure 1. Trabzon province in Türkiye

Figure 2. The locations of Şalpazarı and Akçaabat districts

Figure 3. Locations of forest roads (a: Road coded 269, b: Road coded 307 and 315)

Soil loss analyzes were made on newly constructed (road coded 315), 5-year (road coded 307) and 10-year (road coded 269) forest roads in the study area. The interface of web-based WEPP: Road Batch model used for analysis is shown in Figure 4 (WEPP:Road Batch, 2022). In selection of road designs provided by the model (Figure 5), design option IV (insloped, vegetated or rocked ditch) was chosen for the 5-year and 10-year road because of vegetation existence, while design option IB (insloped, bare ditch) was chosen for newly built road as there was no vegetation available. Fill slope widths and slopes data were measured in the field. The same values (Figures 6 and 7) were used on all three road types. The cut slope data, which do not vary, was not obtained from the field.

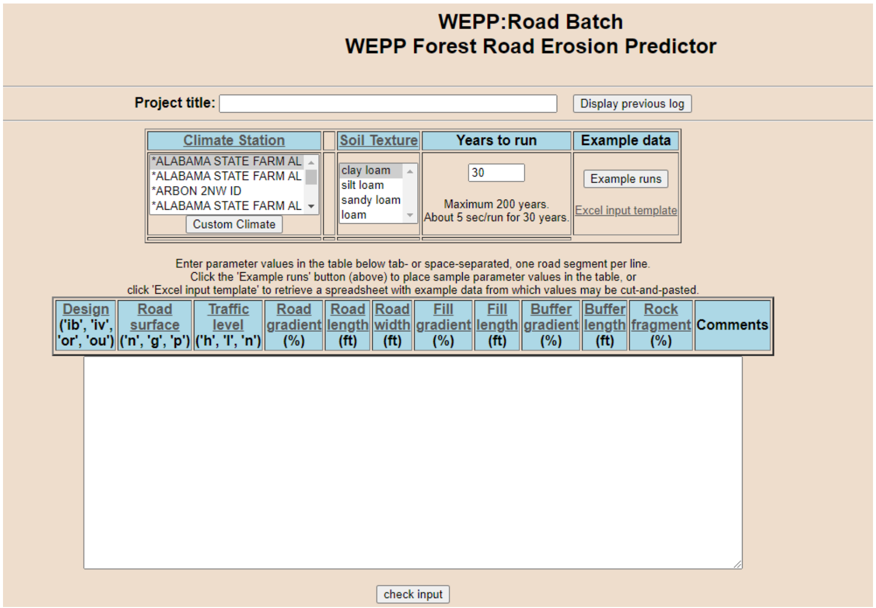


Figure 4. WEPP:Road Batch model interface (WEPP:Road Batch, 2022)

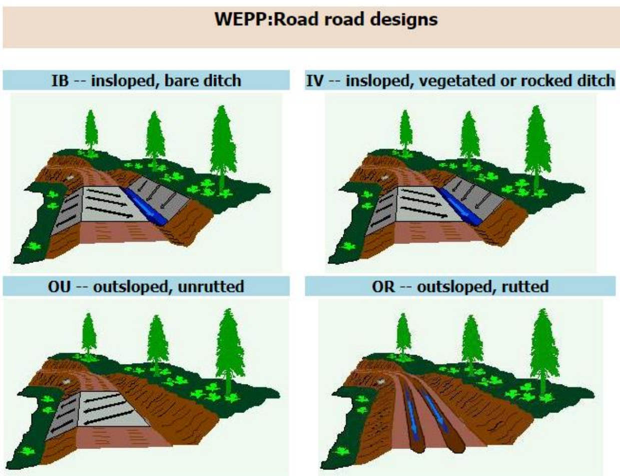


Figure 5. Forest road design types (WEPP:Road Batch, 2022)

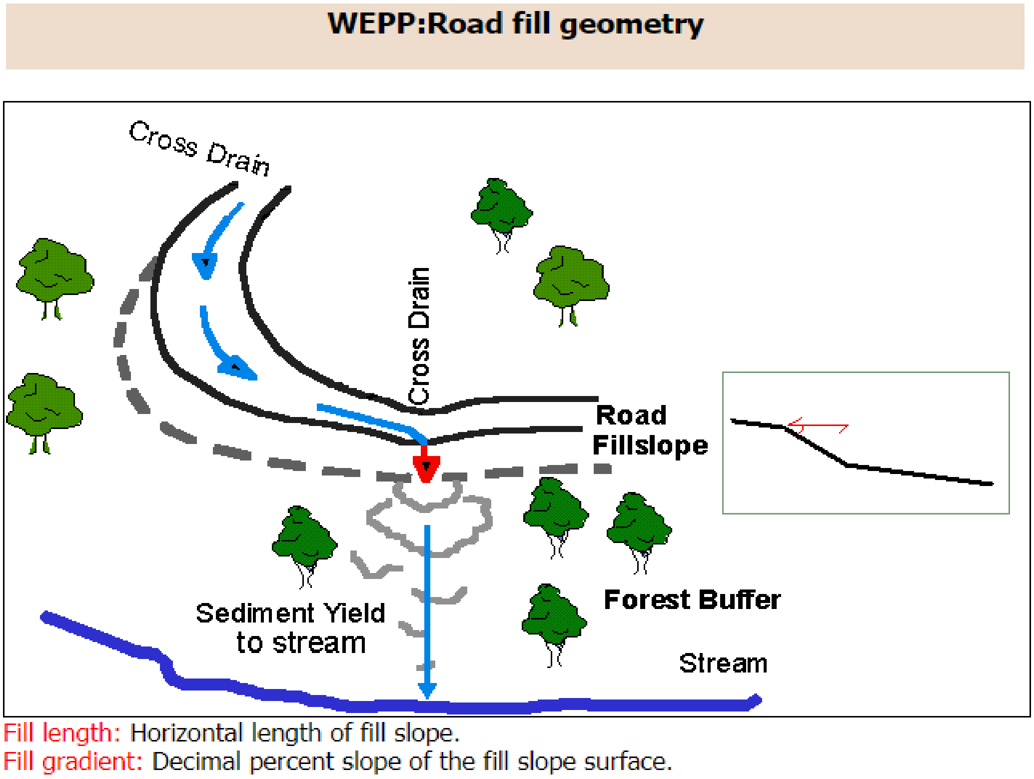


Figure 6. Fill geometry (WEPP:Road Batch, 2022)

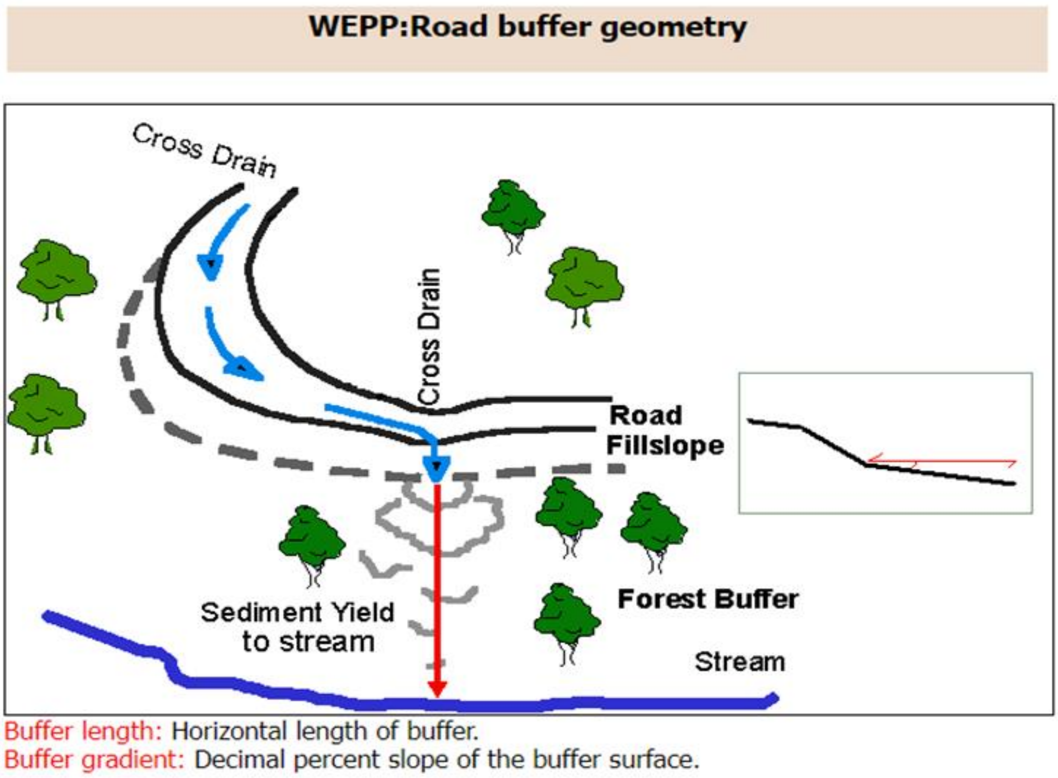


Figure 7. Buffer geometry (WEPP:Road Batch, 2022)

In the first stage of the analyzes, meteorological data (MGM, 2022.) of Trabzon province were entered into the model. The temperature data has been converted from Celsius to Fahrenheit using well know formula:

$$F = \frac{°\mathrm{C} \times 9}{5} + 3 \qquad (1)$$

Then, climatic parameters were calculated for each selected forest road, considering the latitude and altitude values (Figure 8-10).

Climate parameters for
Road Coded 269 + +

40.00°N 39.00°W

4550 feet elevation

Modify climate parameters below

40.06 °N 39.00 °W PRISM

(lat-long calculator) (degrees calculator)

4550 ft elevation

Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of wet days	Month	Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of wet days
51.44	40.46	3.21	13.37	January	51.44	40.46	3.21	13.37
51.44	39.92	2.58	12.88	February	51.44	39.92	2.58	12.88
56.04	41.72	2.39	14.04	March	56.04	41.72	2.39	14.04
59.90	47.66	2.28	13.40	April	59.90	47.66	2.28	13.40
66.56	56.22	1.97	14.09	May	66.56	56.22	1.97	14.09
73.76	62.60	2.08	11.54	June	73.76	62.66	2.08	11.54
76.80	67.82	1.37	9.16	July	76.80	67.82	1.37	9.16
79.88	68.72	1.91	10.05	August	79.88	68.72	1.91	10.05
74.84	63.32	3.18	12.22	September	74.84	63.32	3.18	12.22
68.18	56.66	4.52	13.29	October	68.18	56.66	4.52	13.29
61.70	50.00	3.88	12.50	November	61.70	50.06	3.88	12.50
56.40	44.06	3.40	13.09	December	56.40	44.06	3.40	13.09
		32.77	149.63	Annual			32.77	149.63
Change entire column (enter 0 to reset) > >					+/- 0 °	+/- 0 °	+/- 0 %	+/- 0 %

Adjust temperature for elevation by lapse rate

New Climate Name: Road Coded 269

Use these values | Share these values

Retreat

Figure 8. Climatic parameters for road coded 269 (WEPP:Road Batch, 2022)

Climate parameters for
Road Coded 307 + + +

40.00°N 39.00°W

5317 feet elevation

Modify climate parameters below

40.00 °N 39.00 °W PRISM

(lat-long calculator) (degrees calculator)

5317 ft elevation

Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of wet days	Month	Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of wet days
48.91	38.36	3.21	13.37	January	48.91	38.36	3.21	13.37
40.91	37.82	2.56	12.88	February	40.91	37.82	2.56	12.88
52.51	39.62	2.39	14.04	March	52.51	39.62	2.39	14.04
57.37	45.56	2.28	13.40	April	57.37	45.56	2.28	13.40
64.03	53.12	1.97	14.09	May	64.03	53.12	1.97	14.09
71.23	60.50	2.08	11.54	June	71.23	60.50	2.08	11.54
76.27	65.72	1.37	9.16	July	76.27	65.72	1.37	9.16
77.35	66.62	1.91	10.06	August	77.35	66.62	1.91	10.06
72.31	61.22	3.18	12.22	September	72.31	61.22	3.18	12.22
65.65	54.56	4.52	13.29	October	65.65	54.56	4.52	13.29
59.17	47.90	3.88	12.50	November	59.17	47.90	3.88	12.50
52.87	41.96	3.40	13.09	December	52.87	41.96	3.40	13.09
		32.77	149.63	Annual			32.77	149.63
Change entire column (enter 0 to reset) > >					+/- 0 °	+/- 0 °	+/- 0 %	+/- 0 %

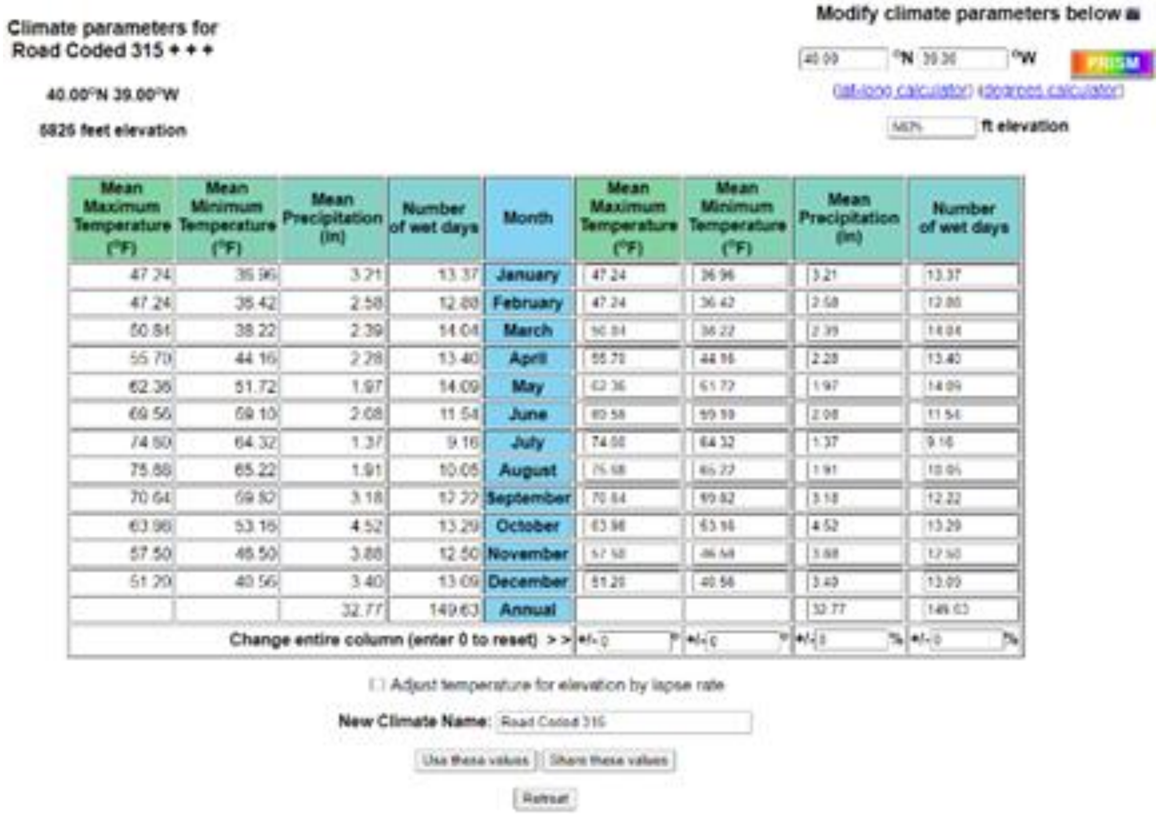
Adjust temperature for elevation by lapse rate

New Climate Name: Road Coded 307

Use these values | Share these values

Retreat

Figure 9. Climatic parameters for road coded 307 (WEPP:Road Batch, 2022)



Climate parameters for Road Coded 315 + + +

40.00°N 39.00°W

5826 feet elevation

Modify climate parameters below

40.00 °N 39.36 °W PRISM

(lat-long calculator) (degrees calculator)

5826 ft elevation

Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of wet days	Month	Mean Maximum Temperature (°F)	Mean Minimum Temperature (°F)	Mean Precipitation (in)	Number of wet days
47.24	35.96	3.21	13.37	January	47.24	36.96	3.21	13.37
47.24	36.42	2.58	12.80	February	47.24	36.42	2.58	12.80
50.84	38.22	2.39	14.04	March	50.84	38.22	2.39	14.04
55.70	44.16	2.28	13.40	April	55.70	44.16	2.28	13.40
62.36	51.72	1.97	14.09	May	62.36	51.72	1.97	14.09
69.56	59.10	2.08	11.54	June	69.58	59.10	2.08	11.54
74.80	64.32	1.37	9.16	July	74.00	64.32	1.37	9.16
75.88	65.22	1.91	10.05	August	75.58	65.22	1.91	10.05
70.64	59.82	3.18	12.22	September	70.64	59.82	3.18	12.22
63.98	53.16	4.52	13.29	October	63.98	53.16	4.52	13.29
57.50	46.50	3.88	12.50	November	57.50	46.50	3.88	12.50
51.20	40.56	3.40	13.09	December	51.20	40.56	3.40	13.09
		32.77	149.63	Annual			32.77	149.63
Change entire column (enter 0 to reset) > >					+/- 0 °F	+/- 0 °F	+/- 0 %	+/- 0 %

Adjust temperature for elevation by lapse rate

New Climate Name: Road Coded 315

Use these values | Share these values

Retreat

Figure 10. Climatic parameters for road coded 315 (WEPP:Road Batch, 2022)

For the soil texture information, which is another input file of the software, a total of 105 soil samples were taken from the fill slopes for each road and then texture analysis was performed. Based on the data obtained as a result of the analysis, the soil textures of the roads are shown in the table below (Table 1).

The width of the roads has been taken as 5 meters in accordance with the B Type secondary forest road standards according to the road standards specified by the General Directorate of Forestry (GDF) (Figure 11) (GDF, 2008).

The stoniness ratios were obtained as a result of the analysis of soil samples taken from the forest roads (Table 2). After processing all the technical features of the roads into the software, the result obtained was compared with the amount of erosion obtained by the ABAG method of the same roads.

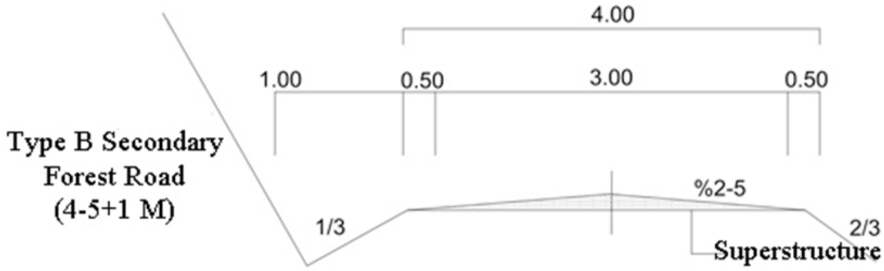


Figure 11. B type forest road standards (GDF, 2008)

3. Results and Discussion

In order to determine the annual soil loss, calculations were made by entering the necessary data in the software after all components were obtained (Table 1). According to the information obtained as a result of the soil analysis, the soil textures of the roads are shown in the table below (Table 2). The stoniness ratios obtained in the soil analysis was also shown in Table 2. At the end of all calculations, the annual amount of soil loss was found (Table 3). As a result of the analyzes made with the soil samples taken from the sample roads, the annual soil losses calculated by using the ABAG formula are shown in Table 4.

Table 1. Technical specifications of forest roads

Road Code	Design	Surface/ traffic	Road grade (%)	Road length (ft)	Road width (ft)	Fill grad (%)	Fill length (ft)	Rock cont. (%)
269	Insloped, vegetated or rocked ditch	Graveled /low	9	1000	16	30	20	10
307	Insloped,vegetated or rocked ditch	Graveled /low	10	1000	16	30	20	20
315	Insloped, bare ditch	Native /low	9	1000	16	30	20	70

Table 2. Soil textures of forest roads

Roads code	Soil textures	Stoniness Rates (%)
269	Sandy loam	10
307	Sandy loam	20
315	Clay loam	70

Table 3. Annual soil loss amounts of WEPP software

Road Code	Average annual sediment leaving road (T/ha/year)	Average annual sediment leaving buffer (T/ha/year)
269	1.46	1.44
307	1.58	1.54
315	7.93	7.48

Table 4. Annual soil loss amounts by ABAG method (Yorulmaz, 2021)

Road Code	Factor A (T/ha/year)
269	1.59
307	1.75
315	15.5

The estimated soil loss was 1.59 T/ha/year using the ABAG formula for the 10-year road coded 269, while it was 1.44 T/ha/year in the WEPP model. For the 5-year road coded 307, soil loss was 1.75 T/ha/year using the ABAG formula and 1.54 T/ha/year using the WEPP model. Finally, soil loss was estimated as 15.5 T/ha/year using ABAG formula for the new road coded 315, while it was 7.48 T/ha/year using the WEPP model. In a study conducted by Hacısalihoğlu et al. (2019), soil samples were taken from the fill slope, cut slope and the surface of the forest road, and the annul soil loss was estimated using ABAG formula based on the analysis of these soil samples. As a result of the study, it was found that the soil loss was 2.191 T/ha/year on the fill slope, 4.940 T/ha/year on the cut slope and 0.717 T/ha/year on the road surface. The soil loss values from fill slope of existing roads were close to the results obtained from the study presented here.

The results indicated that the difference between the 5-year and 10-year roads was negligible, but the difference in the newly built road was remarkable. It was strongly believed that this difference was due to the “C Factor” value, one of the ABAG formula components, is a distinguishing criterion. The “C factor” value is referred to as the product management factor, and since vegetation has not yet occurred on the newly built road, this value was taken as 0% in the ABAG formula. The soil texture was sandy loam in the existing roads while it was clay loam in new road, therefore, another reason behind the high value could be the high clay content.

As a result of the information obtained by Breibart (2007), as a result of a study using the WEPP: Road Batch model, it was stated that reducing the slope on the road from 16% to 10% reduces the amount of potential erosion caused by the road by 10%.

In another study conducted by Elliot et al. (2009), it was stated that if the roads have low or no traffic, the road surface may become armored and reduce erosion rates by 70 to 80%, and if there is no traffic and the road is covered with vegetation, the erosion can be reduced by 99%. While various laboratory analyzes are required to calculate the K (soil erodibility), C (product management) and LS (slope length and slope) factors in the ABAG formula, only laboratory and field studies are required for the texture calculation and the slope and length of the slopes in the WEPP model.

4. Conclusions

Since the results obtained from WEPP:Road Batch and ABAG methods are close to each other for sample roads, it is thought that the WEPP:Road Batch model can be used in areas where climate data and soil types are known. Since the WEPP:Road Batch model is more practical and does not require laboratory procedures, it is recommended to use this model on existing roads. Since there is no available data on new roads, the annual amount of soil loss should be determined by making necessary analyzes.

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