Sediment Dynamics in Vehicle Ruts

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Abstract: Vehicle ruts often concentrate (channel) surface flow much like natural rills. These channeled flows have higher velocities and greater turbulence than overland sheet flows and detach and transport more sediment downslope. The velocity and turbulence of rut and rill flows are directly related to channel roughness and cross-sectional geometry. This study measured the amount of change in vehicle ruts that resulted from in-rut sediment erosion and deposition. Five vehicle-tracking plots were established in October 1996 and re-trafficked in October 1998 on a slope at the Ethan Allen Firing Range (EAFR) in northwestern Vermont, USA. The newly formed ruts varied from less than 1 to 7 cm deep and from 25 to 60 cm wide. Changes in rut cross-sectional geometry were measured at 46 locations to define seasonal and long-term sediment dynamics. Changes were defined by a root-mean-square (RMS) difference and the maximum erosion and deposition between corresponding points on successive cross sections. Generally the high RMS differences occurred in the winter–spring period when soil water was high due to thaw and snowmelt. Knowledge of in-rut sediment dynamics will be useful in soil-erosion prediction and landscape-evolution models, and could be used to identify landscape conditions on military training lands that should be avoided because they result in increased soil erosion.
Keywords: sediment dynamics, erosion, deposition, rills, ruts

1 Introduction

During maneuvers on military training lands, tactical vehicles damage vegetation, change soil surfaces, weaken soil aggregates, compact soils, and form ruts. The compaction tends to increase the volume and period of surface water runoff (Mathier and Roy, 1993) and the ruts tend to channelize surface flow (Voorhees *et al*., 1979). Channeled flow has higher velocities and greater turbulence than overland sheet flows and can detach and transport more sediment downslope (Foltz, 1993), which often leads to a more dynamic sediment regime in ruts than on adjacent undisturbed soil. This increased potential for sediment erosion and deposition is a major concern of Army land managers who must conserve soil resources on training lands.

This paper summarizes the results of a five-year study on the dynamics of sediment in military-vehicle ruts caused by channelized flow down the ruts. This study is part of a larger research project to compare sediment dynamics in vehicle ruts to that in natural rills and to relate the dynamics to vehicle type, number of vehicle passes, number of freeze–thaw (FT) cycles, the duration of ground frost, precipitation, slope, runoff, and soil–water content. We are especially interested in the effects of soil FT cycling, because this cycling changes soil erodibility, increases soil–water content, and alters rill geometry by causing soil slumps along rill walls. This research will extend existing knowledge on the evolution of rills, and will be useful in physics-based soil-erosion models and in simulations of landscape evolution. Army land managers use such models in making land-capability decisions and planning land rehabilitation and maintenance operations.

2 Research site

Five vehicle-tracking plots were established in October 1996 on a hillside at the Army National Guard's Ethan Allen Firing Range (EAFR) in northwestern Vermont, USA (Fig. 1). The hillside has sandy silt soils, 4 to 17° slopes, 12 variably sized rills, and a mixed vegetative cover of mosses, grasses, and small brush interspersed with unvegetated areas having cryptogamic crusts on the soil surface. The EAFR receives about 60 cm of precipitation per year, and the mean length of the freezing season is 115 days.

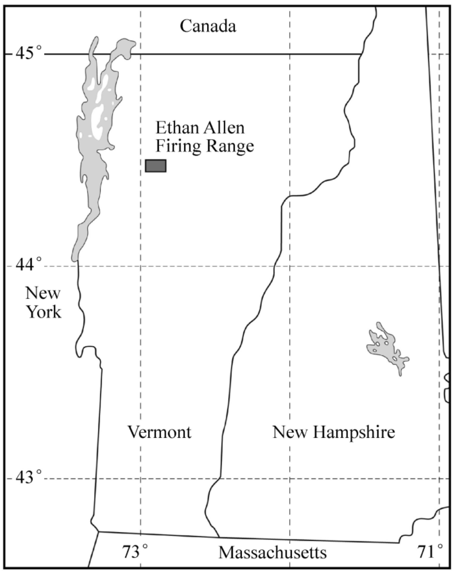

Fig.1 Location of Ethan Allen Firing Range in northwestern Vermont, USA

3 Methods

Vehicle ruts were formed on 25 October 1996 with an Abrams tank (tracked vehicle) and a HMMWV (High-Mobility Multipurpose Wheeled Vehicle) and on 17 October 1998 with an Abrams tank and a fuel-tanker HEMTT (Heavy Expanded Mobility Tactical Truck, a wheeled vehicle). The vehicles were driven up and down the slope perpendicular to the topographic contours of the slope (Fig. 2). This orientation of the ruts was selected because naturally occurring rills are oriented thus and part of this research project (not addressed in this paper) is a comparison of sediment dynamics in natural rills and in-rut rills. This rut orientation produced the maximum potential for sediment erosion and deposition in the ruts but is not necessarily the most common path taken by military drivers along slopes. Vehicles are driven up and down slopes in whatever fashion is required during maneuvers.

In October 1996 each vehicle made two passes, and in 1998 each vehicle made four, six, or eight passes (Gatto, in press). Volumetric soil–water content at the time of trafficking was 15%—38% (33%—76% saturation). The ruts, when newly formed, varied from less than 1 cm to up to 7 cm deep and from 25 to 60 cm wide. The tank tracks broke the moss mat/cryptogamic crust on the soil to expose soil mineral particles on the surface. The pads on the tank tracks formed a roughened and irregular soil surface with depressions up to 4 cm deep across a 60-cm-wide rut during the 1996 trafficking; tank ruts were up to 7 cm deep during the 1998 trafficking (Fig. 3). The HMMWV wheels did not break the mat/crust and formed a smooth elliptical rut less than 1 cm deep and 25 cm wide. The wheels on the tanker HEMTT roughened the soil surface more than the HMMWV but less than the tank and formed ruts 2—4 cm deep and 30 cm wide.

Fig.2 Vehicle-tracking plot 3, 17° slope, 29 February 2000

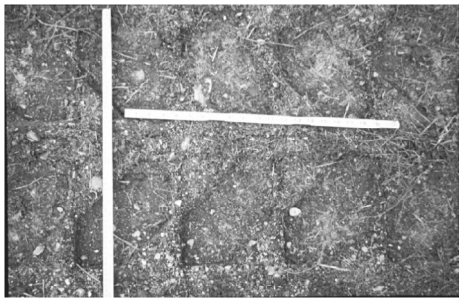

Fig.3 Depressions made by rubber pads on tank treads, vehicle-tracking plot 1, 4° slope, 25 October 1996. Stick=50cm

Cross sections of ruts were measured with a stick scaled in mm and an aluminum bar mounted on two pieces of 1-m-long rebar that were driven into the ground on either side of a rut or rill. The bar (scaled in millimeters) was placed over the rut and the millimeter stick was used to measure the vertical distance from the bar to the soil surface in the rut (Fig. 4). The stick was aligned parallel to marks on the bar to ensure that all the vertical measurements were made with the stick in the same orientation. This technique is similar to the transect, surface profile, pin meter (TSPPM) method discussed by Skidmore and others (1994). These vertical distances were measured every 2.5 cm horizontally across each rut unless more closely spaced vertical measurements were necessary to adequately define the shape of the soil surface. The estimated maximum error of these vertical measurements was 4 mm. Cross sections were constructed from the combined horizontal and vertical distances (Fig. 5). Cross sections were measured at 21 locations from October 1996 to October 1998, and at 45 locations from 1998 to 2001. The sequence of cross sections showed the evolution of the rut shape from which in-rut sediment dynamics were determined.

Fig.4 Setup for measuring rut cross sections, vehicle-tracking plot 5, 12° slope, 9 January 1997

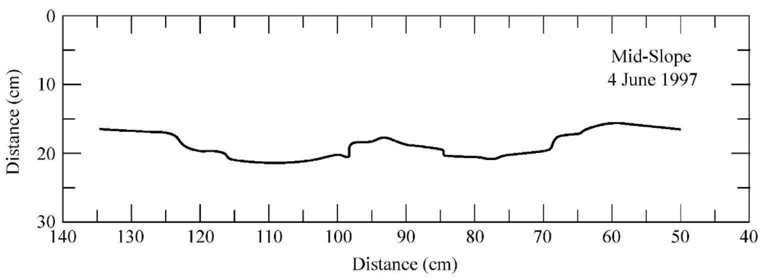

Fig.5 Cross section of tank rut 1T1S mid-slope, 4 June 1997

4 Results

Three measures were used to define the cross-sectional change that occurred during the interval between cross-section surveys; a root-mean-square (RMS) difference, maximum erosion, and maximum deposition at corresponding points of successive surveys of a particular cross section. The RMS difference gives a sense for the amount of change, erosion or deposition, which occurred between surveys. This approach provides only the net erosion or deposition that occurs and gives no information on changes that occurred during time spans less than the survey intervals.

1996—1998

Only tank rut cross sections were measured because the HMMWV ruts were no deeper than soil surface depressions in adjacent untrafficked soil and thus ineffective in channeling surface water. Over the two years no erosion occurred in the HMMWV ruts in any of the tracking plots and observations made on 16 October 1998 verified that HMMWV ruts were no longer visible.

On 19 September 1997, nearly one year after the tank ruts were formed, some of the pad depressions made by the rubber pads on the tank track (see Fig. 3) in plots 1 and 2 had partially filled with sediment (Fig. 6) and sections of the soil ridges between the depressions had eroded or collapsed. However, none of the tank ruts in these plots showed evidence of channel flow or rill formation. The 4° slope at plot 1 was not sufficient to generate surface flows in the ruts to cause extensive sediment movement. In addition, the moss mat and grass on the soil surface before trafficking was imbedded into the upper 1–3 cm of soil, much like vegetation residue, which helped hold soil particles in place when flows occurred.

More of the soil surface in plots 3 to 5 is exposed without vegetation and these plots are steeper (12° and 17°) than plots 1 and 2. These differences contributed to the increased sediment dynamics in the ruts along plots 3 to 5. Cross-sectional surveys were made more frequently in the ruts that appeared to have the most dynamic sediment regime. The net cross-sectional change measured during different intervals is shown in Table 1.

Cross sections at 3T2S and 4T1S, measured over 16.1 and 18.5 months, respectively, changed about the same amounts but at different parts of the slope. The most dynamic part along 3T2S was the lower section where maximum deposition was 2.7 cm; the middle and upper sections were similarly dynamic but with opposite maxi-mum erosion and deposition. Along 4T1S most change was measured at the mid-slope location; the up- and downslope sections showed similar RMS difference and maximum erosion and deposition. The variability in sediment dynamics displayed at the three locations on these two ruts was typical along the entire lengths of the ruts. For example, a few feet up- and downslope of the cross-section sites in 4T1S, in-rut rills up to 14 cm deep (Fig. 7) had eroded from 1996 to 1998. These rills were much larger than any rill formed at the cross-section sites. Often the most erosion starts where cobble-sized rocks are at the rut surface and cause turbulence in the flows once they protrude into the flow.

Fig.6 Sediment in tank track depressions, Vehicle-tracking plot 1, 4° slope, 19 September 1997

Fig.7 14-cm-deep in-rut rill formed in tank rut 4T1S in vehicle-tracking plot 4, 17° slope, 16 October 1998

The cross sections along 5T2S show the variability in sediment dynamics during shorter time intervals. The RMS difference measured during 1.6- and 1.1-month intervals (Table 1) were similar and less than that for the 2.8- and 15.7-month intervals. The cross-sectional change during these longer intervals was similar even though one interval was nearly 13 months longer. Clearly, rut changes caused by sediment dynamics were highly variable within and between ruts.

1998—2001

Table 2 lists RMS differences and maximum erosion and deposition that capture the variability of the measurements made from 1998 to 2001. During this three-year period, sediment dynamics were highly variable among and within ruts. Tank ruts in plot 1 once again show low sediment dynamics for a 20.4-month interval. The HEMTT ruts in the same plot and interval appeared to be more dynamic, but much of the deposition was actually a measure of the extent that the moss mat had re-established in the wheel ruts. Measurement of this newly grown moss gave an erroneous impression that deposition had occurred. In plot 2, in-rut sediment dynamics were also generally low, with points on particular cross sections where erosion and deposition were as high as 2.8 cm.

Sediment dynamics along the plot 3 and 4 ruts were generally higher and far more variable. Maximum RMS difference and maximum erosion were 3.0 and 7.3 cm, respectively, in rut 3T2Su, which occurred during a winter–spring period when soil water had increased by 3 to 6% because of thaw and snowmelt. Soil FT cycling tends to reduce soil density and strength in compacted ruts in the upper 5 cm of the ruts, which often contributes to soil erodibility. However, the minimum RMS difference, 0.3, also occurred over a winter–spring interval.

Table 1 Sediment dynamics, 1996—1998

Cross Section #	RMS Difference (cm)	Maximum Erosion (cm)	Maximum Deposition (cm)
3T2Su	1.0	2.7	1.4
3T2Sm	0.9	1.4	2.2
3T2Sd	1.2	0.2	2.7
4T1Su	0.5	1.4	1.1
4T1Su	1.4	0.9	2.6
4T1Su	0.2	0.9	0.9
5T2Su[1]	0.6	1.4	0.4
5T2Sm	0.6	0.3	2.4
5T2Sd	0.2	1.3	0.6
5T2Su[2]	0.3	0.9	0.2
5T2Sm	0.8	1.8	0.1
5T2Sd	0.3	0.7	1.7
5T2Su[3]	1.4	1	1.1
5T2Sm	0.5	0.6	2.4
5T2Sd	0.5	1.8	1.3
5T2Su[4]	0.6	0.2	1.5
5T2Sm	0.5	1.8	1.4
5T2Sd	1.1	0.6	2.4

Notes: 3T2Su = plot 3, tank track 2, south rut, upslope cross section
u, m, d = upslope, mid-slope, downslope cross section
3T2S interval = 13 Jun 97 to 16 Oct 98 (16.1 months)
4T1S interval = 2 Apr 97 to 16 Oct 98 (18.5 months)
5T2S intervals = (1) 9 Jan 97 to 28 Feb 97 (1.6 months)
(2) 28 Feb 97 to 2 Apr 97 (1.1 months)
(3) 2 Apr 97 to 26 Jun 97 (2.8 months)
(4) 26 Jun 97 to 16 Oct 98 (15.7 months)

Penetrometer measurements showed that, in some deeper ruts, the compacted soil persisted over the winter, which reduced infiltration and increased runoff. On several occasions during spring thaw, flows 1 to 5 mm deep were observed in ruts while no surface flow occurred on the adjacent unrutted soil.

Additional observations showed that sediment in tank ruts is more dynamic than in wheel ruts and that rills formed more often in tank ruts than wheel ruts. However, rills up to 10 cm deep formed in HEMTT ruts on the 17° slope. During the five years of this study, no new rills formed in adjacent, unrutted soil.

5 Conclusions

Vehicle ruts are features with highly dynamic sediment regimes. The locations within ruts where sediment erosion and deposition occur change with time. The amounts of erosion or deposition that occur over short and long periods are often similar. Tank ruts are more dynamic than wheel ruts, possibly because the tank treads tear the soil surface more than tires, which may enhance flow turbulence and, thus, carrying capacity of the flow. The ongoing studies to relate sediment dynamics to vehicle type, number of vehicle passes, number of freeze–thaw cycles, duration of ground frost, precipitation, slope, runoff, and soil–water content will help to understand how military maneuvers affect the evolution of rills and gullies on, and sediment dynamics along, hill slopes.

Acknowledgements

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Table 2 Sediment dynamics, representative of the changes measured from 1998 to 2001

Cross Section #	RMS Difference (cm)	Maximum Erosion (cm)	Maximum Deposition (cm)
1T1Su	0.2	0.4	0.4
1T1Sm	0.5	1	0.4
1T1Sd	0.3	0.4	0.8
1W1Su	0.8	1.9	1.3
1W1Sm	1.3	0.8	1.7
2T1Su	0.8	0	1.5
2T1Sm	0.8	0.3	1.5
2T1Sd	0.4	1	0.9
2W1Sm	0.5	0.2	0.8
2W2Sm	0.4	0.4	1
2W3Sm	1	0.2	1.4
2T3Su	1.5	2.8	2
2T3Sm	0.6	0.6	1.5
2T3Sd	0.5	0.9	1.2
3T2Su[1]	3	7.3	1
3T2Sm	1.6	4.8	1.3
3T2Sd	1.4	4.2	1.7
3T2Su[2]	0.9	2.3	2.2
3T2Sm	1.5	4.5	1.5
3T2Sd	0.8	1.4	3.1
3T2Su[3]	0.5	0.3	2.2
3T2Sm	0.6	1.5	1.7
3T2Sd	0.5	1.1	1.1

Continuded

Cross Section #	RMS Difference (cm)	Maximum Erosion (cm)	Maximum Deposition (cm)
3T2Su[4]	0.5	1.5	1.2
3T2Sm	0.6	1.7	1
3T2Sd	1	4	1.2
4T1Sm[1]	2.2	4.8	2.5
4T1Sm[2]	1.1	1.2	3.2
4T1Sm[3]	0.7	2.5	1.6
4T1Sm[4]	0.7	1.3	2.8
4W1Sm[1]	0.6	1.3	1.3
4W1Sm[2]	1.6	2.1	3.4
4W1Sm[3]	0.3	0.3	0.5
4W1Sm[4]	0.5	1	0.4

Notes: T = tank, W = wheeled HEMTT

1T1S, 1W1S interval = 1 Dec 98 to 11 Aug 00 (20.4 months)

2T1S, 2W1S, 2W2S, 2W3S, 2T3S interval = 4 Dec 98 to 25 Aug 00 (20.7 months)

3T2S intervals = (1) 12 Nov 98 to 14 Apr 99 (5 months)
(2) 14 Apr 99 to 2 Nov 00 (18.6 months)
(3) 2 Nov 00 to 24 May 01 (6.7 months)
(4) 24 May 01 to 26 Oct 01 (5 months)

4T1Sm intervals = (1) 22 Oct 98 to 14 Apr 99 (5.7 months)
(2) 14 Apr 99 to 5 Oct 00 (4.7 months)
(3) 5 Oct 00 to 24 May 01 (7.6 months)
(4) 24 May 01 to 26 Oct 01 (5 months)

4W1Sm intervals =(1) 22 Oct 98 to 14 Apr 99 (5.7 months)
(2) 14 Apr 99 to 2 Nov 00 (18.6 months)
(3) 2 Nov 00 to 24 May 01 (6.7 months)
(4) 24 May 01 to 26 Oct 01 (5 months)

References

Foltz, R.B. 1993. Sediment Processes in Wheel Ruts on Unsurfaced Forest Roads. PhD Thesis. University of Idaho, Moscow.

Gatto, L.W. in press. Overwinter Changes to Vehicle Ruts and Natural Rills and Effects on Soil Erosion Potential. Proceedings, 10th ISCO Conference.

Mathier, L., A.G. Roy. 1993. Temporal and Spatial Variations of Runoff and Rainwash Erosion on an Agricultural Field. Hydrological Processes, vol.**7**: p. 1–18.

Skidmore, E.L., L.J. Hagen, D.V. Armbrust, A.A. Durar, D.W. Fryrear, K.N. Potter, L.E. Wagner, T.M. Zobeck. 1994. Methods for Investigating Basic Processes and Conditions Affecting Wind Erosion. Chapter 12, in R. Lal (Ed.), *Soil Erosion Research Methods*, Soil and Water Conservation Society, Ankeny, Iowa, USA, p. 295–330.

Voorhees, W.B., R.A. Young, L. Lyles. 1979. Wheel Traffic Considerations in Erosion Research. Transactions American Society Agricultural Engineers, vol.**22**: p. 786–790.