ERDC/CRREL TN-03-3

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Overland Erosion Due To Freeze–Thaw Cycling

Laboratory Experiments

Lawrence W. Gatto and Michael G. Ferrick

April 2003

ERDC/CRREL TN-03-3
April 2003

Overland Erosion Due To Freeze–Thaw Cycling

Laboratory Experiments

Lawrence W. Gatto and Michael G. Ferrick

Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755

Prepared for Office of the Chief of Engineers
Washington, DC

ABSTRACT

Ice that forms in soil voids during the freezing process pushes soil grains apart, reducing particle cohesion and soil strength, and making soil more erodible. This report summarizes 18 experiments to measure erosion rates in a soil that was frozen and thawed once and in the same unfrozen soil. We hypothesized that soil freeze–thaw (FT) processes significantly increase upland hill slope erosion during subsequent runoff events. We selected a frost-susceptible silt to provide an upper bound on this effect. For each experiment, we prepared two identical bins, one as an unfrozen control, the other to be frozen and thawed. We tested three soil-moisture ranges, three flow rates, and two slopes, and measured the cross-sectional geometry of the rills that developed and sediment losses through time for each bin. The cross-section measurements detailed erosion at specific locations along the bins; sediment loss measurements indicated erosion integrated along the entire bin. The results are the first to quantitatively define the differences in sediment loss and rill formation caused by FT cycling. We will analyze data from these experiments and do additional experiments to further define FT effects in the soil-erosion process. (However, these results already demonstrate the importance of FT weakening to soil erosion.) Good regional sediment management in cold climates requires that erosion prediction models accurately account for important processes such as soil-FT cycling to avoid significant underprediction of soil losses on hill slopes and in watersheds in cold climates.

CONTENTS

ILLUSTRATIONS

TABLE

PREFACE

This report was prepared by Lawrence W. Gatto, Research Geologist, and Michael G. Ferrick, Research Hydrologist, Environmental Sciences Branch, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

Funds for this research were provided by the Engineer Research and Development Center Regional Sediment Management project, “Freeze–Thaw Effects on Soil and Bank Erosion and Bank Stability” and BT25 project, “Soil Erodibility and Runoff Erosivity due to Soil Freezing and Thawing.”

The authors thank Dennis Lambert for designing and fabricating the CRREL soil-erosion simulator, and Lauren Raymond and Reed Harrison for assistance in preparing the soil bins, for collecting sediment samples during the experiments, and for analyzing the samples.

The Commander and Executive Director of the Engineer Research and Development Center is COL John W. Morris III, EN. The Director is Dr. James R. Houston.

Overland Erosion due to Freeze–Thaw Cycling

Laboratory Experiments

LAWRENCE W. GATTO AND MICHAEL G. FERRICK

1 INTRODUCTION

Soil erodibility

Soil is naturally eroded by water flowing down the surface of bare or partially vegetated hill slopes. The quantities and rates of erosion depend on the transport capacity of the runoff and the resistance of soil particles to detachment. In turn, the capacity of runoff to transport soil particles is a function of velocity and turbulence, and the detachability of soil particles is a function of interparticle friction, bonding, and interlocking.

The capability of a soil to resist erosion depends on soil-particle size and distribution, soil structure and structural stability, soil permeability, water content, organic matter content, and mineral and chemical constituents (Lal and Elliot 1994). Also, Pall et al. (1982) proposed soil erodibility as a time varying rather than static characteristic because of significant seasonal soil density and soil moisture changes. Many investigators have recognized that FT generally increases soil erodibility (Bryan 2000) and that this FT effect varies with soil texture, moisture, and the extent of freezing. Thus, many factors affect runoff erosivity and soil erodibility and determine the volume of sediment eroded during a runoff event.

Processes of soil FT cycling

As air temperature drops, heat is lost from the soil surface. When sufficient heat is lost, the water in the soil begins to freeze. Freezing and thawing of soils cause movement of soil water and solutes in the soil profile (Radke and Berry 1997, Gatto 2000). Water moves upwards towards the freezing front to fill soil voids and freeze or to form ice layers or lenses within a soil mass, thus depleting water from the soil below.

Three conditions must exist for ground ice to grow and become a substantial component of a soil mass: a source of soil water, sufficiently cold air temperatures to cause heat loss from a soil and subsequent freezing of soil water, and a frost-susceptible soil (usually a silty soil) (Anderson et al. 1978).

Silty soils absorb water rapidly because they have particles small enough to provide comparatively high capillary rise and large enough pore spaces to allow quick flow of water through the silt (Jumikis 1962). These characteristics lead to rapid increase in water content within soil voids upon freezing. More coarse- and fine-grained soils do not absorb water as rapidly. Thus, silty soils with available soil water are most susceptible to the substantial seasonal changes in soil strength and erodibility caused by FT cycling. However, Janson (1963) reports that even sand may become frost-susceptible if it is well compacted, and Chamberlain[*] has observed needle ice in almost any soil type.

In addition to soil texture, frost susceptibility depends upon vegetative cover, the depth and density of snow cover, initial soil temperature, air temperature regime, exposure to the sun, the temperature gradient within the soil, the mobility of soil water, the depth to the water table, overburden stress, and soil density (Jumikis 1962, Chamberlain 1981). As ice crystals form within soil voids, soil aggregates and particles are forced apart and ice pressure may compress or rupture the aggregates. The net effect of ice formation on soil structure depends on soil type, water content, and intensity of freezing.

Magnitude of FT effects

The FT-induced, physical changes in a soil affect soil-particle cohesion, soil density and strength, infiltration, runoff, and soil-surface geometry, which, in turn, affect that soil's erodibility and the erosivity of subsequent surface runoff. The magnitude of these effects varies with location. McCool (1990) reported that major FT-soil runoff events occurred in nine of 40 years in Whitman County, Washington, and that 41% of the total estimated soil loss in the 40-year period occurred during these nine years. Zuzel et al. (1982) concluded that snowmelt and/or frozen soil were responsible for 86% of the observed soil loss events in the Pacific Northwest. In spite of this general regional sense of the importance of FT cycling, Benoit and Voorhees (1990) and Kok and McCool (1990) reported that soil FT effects are some of the least understood aspects of the soil erosion process, even though FT processes have been investigated for years.

---

[*] Personal communication, Edwin J. Chamberlain, Jr., Research Civil Engineer, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Several investigators have used controlled laboratory experiments to define the magnitude of the FT effects. Formanek et al. (1984) found that the shear strength of a silt loam was reduced to less than half its original value after one FT cycle, but second and third cycles resulted in little additional change. Van Klaveren (1987) suggested that critical shear strength of soil might be half of its normal value after one FT cycle. Edwards and Burney (1987) used a laboratory rainfall simulator to determine that FT of a bare soil increased sediment loss by 90%, and that this loss increased significantly when overland flow was added.

Laboratory experiments by Van Klaveren and McCool (1998) on rill erosion following a single FT cycle revealed that rill erodibility of thawed soils was slightly higher than that from an unfrozen soil test. Edwards et al. (1995) conducted similar laboratory tests except that four diurnal cycles of freeze–thaw were performed prior to a final 12-hour freezing cycle. Erosion of this cycled and initially frozen soil produced a mean sediment yield 25% greater than a similar soil that had never been frozen.

These field and laboratory experiments did not use a control, which is required to define and model the quantitative differences caused by FT cycling. Still, this previous work suggests that FT is a primary process contributing to upland soil erosion and that inadequate modeling of FT effects could cause significant underprediction of soil losses in cold climates. However, further investigation is needed to build a more complete and quantitative understanding of FT effects and to accurately account for FT weakening in soil erosion prediction models applied to hill slopes and watersheds. Without this understanding, the effects of FT cannot be explicitly modeled and must be lumped with other processes, thereby prohibiting incorporation of future scenarios of varying temperature regimes into soil-erosion predictions. Good regional sediment management requires accurate modeling of all important processes, including soil-FT cycling.

2 EXPERIMENTS

Our goal was to isolate and quantify the effect of FT on soil erosion so that the only difference between erosion in our control soil and the frozen and thawed soil was the FT cycle. This allowed us to attribute the measured differences in soil loss and rill development to the FT process.

We used the frost-susceptible Hanover silt, a low-plasticity, inorganic clayey silt, with 82% silt- and clay-sized particles and 18% fine sand (Fig. 1) to obtain an upper bound on the effect of soil FT. This soil is classified as ML in the Unified Soil Classification System. It has a specific gravity of 2.72, a liquid limit of 28%, and a plastic index of 1 (Shoop and Gatto 1992).

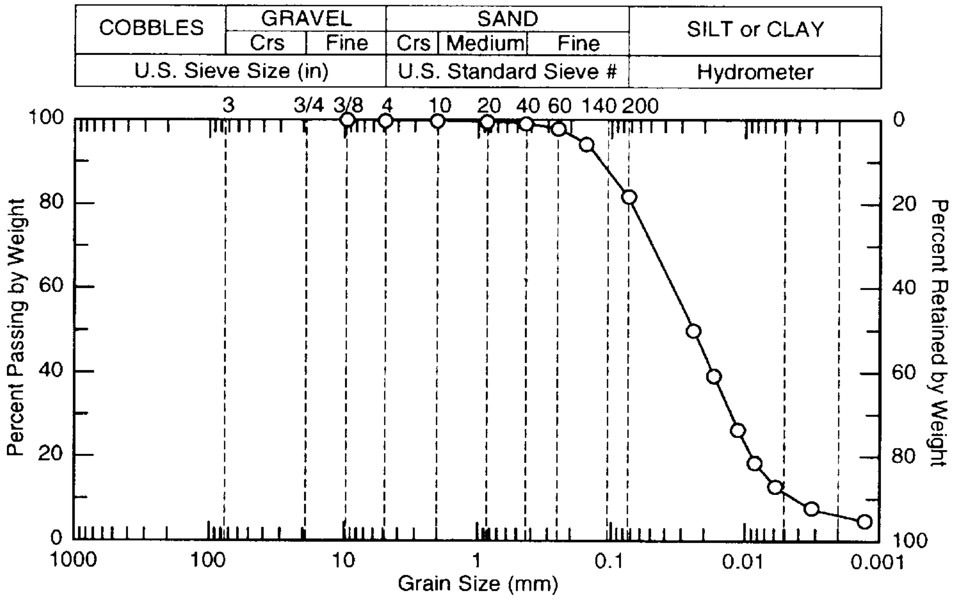

Figure 1. Grain-size distribution of the Hanover silt.

During soil preparation the water content was adjusted into the appropriate range and periodically checked using a Vitel Hydra Probe that measures the dielectric constant. A pair of identical soil bins (31 inches long, 15 inches wide, 7 inches deep) was prepared for each experiment. One bin was subjected to one FT cycle prior to the test and the other bin was kept as a control (C) to remain unfrozen. The FT bin was encased with 5-cm-thick insulation board and a freeze plate was placed on the soil surface to freeze the soil from the top, as in nature. For all experiments the FT bin was frozen once it reached full depth, then thawed. Both the C and FT bins were sealed to minimize gain or loss of soil moisture during the FT cycle. The FT and C bins were then placed side-by-side in the CRREL soil-erosion simulator and elevated to the same slope (Fig. 2). Equal incoming clear water entered the bins through pipes about 1 inch above the soil in each bin. Water discharged from the bins through V-shaped weirs (Fig. 3).

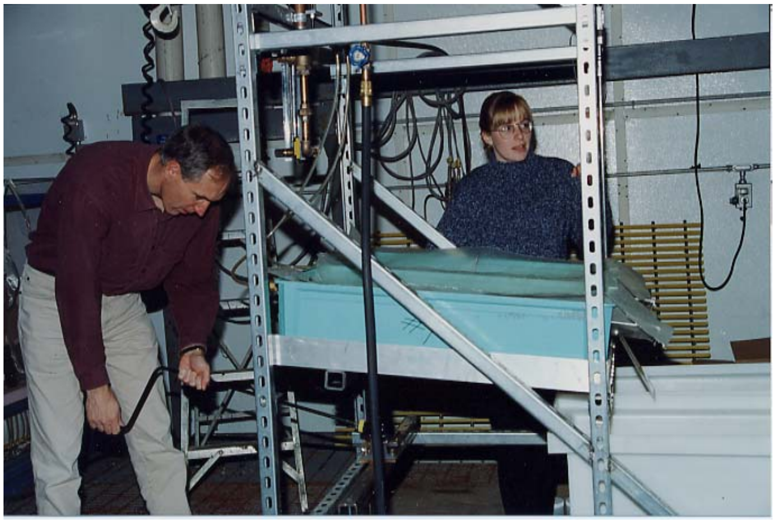

Figure 2. Soil bins in the CRREL soil-erosion simulator being set to the selected slope. Note the discharge-receiving reservoirs below and to the right of the bins.

Figure 3. Rills formed in the C (left) and FT (right) bins.

The experiments were conducted in three series of gradually increasing soil moisture content. Within each series three different flow rates were applied at two different slopes. We tested three soil-moisture ranges: 15–18%, 26–28%, and 36–38% (saturated soil) by volume; three flow rates, 0.2, 0.6, and 1.2 gpm; and two slopes: 8° and 15°. We collected discharge samples from each soil bin at planned intervals during each experiment to calculate the sediment losses. The total sediment mass contained in these runoff samples provides an integrated measure of erosion along the entire length of each bin. After each experiment, we measured the cross-sectional geometry of the rill that had formed in each bin (Fig. 4). We measured the rill shape at two locations, about 10 inches upstream of the weir (designated 0.3 *L*) and about 21 inches upstream of the weir (0.7 *L*) (where *L* is bin length). These measurements gave us site-specific erosion data. We also measured groundwater levels before, during, and after each experiment; water surface elevation and slope in the rill near the end of each experiment; and area of the eroded rill. This technical note discusses the results of our initial analyses of the sediment loss and cross-section measurements; more complete results and analyses will be published in journal papers being prepared.

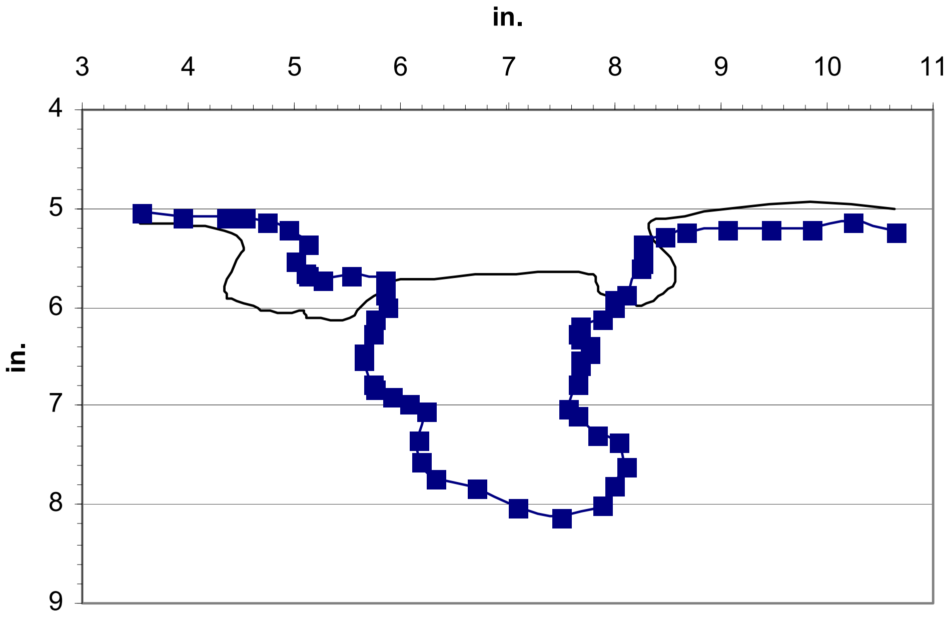

Figure 4. Rill cross sections measured at 0.3 *L* after experiment 13 (line with squares is the FT rill).

3 RESULTS

The soil moisture content and time-weighted runoff emerging from the bins are given in Figure 5 for all tests (experiments). Test 4 had an anomalously low soil moisture relative to the other tests in its series, and the FT bin had somewhat lower soil moisture than the C bin in tests 1 and 15. Flow rates in the FT bin were low relative to the C bin in tests 10, 11, and 12. These differences are conservative in that they favor reduced erosion in the FT bins relative to the C bins, but generally more erosion occurred in the FT bin.

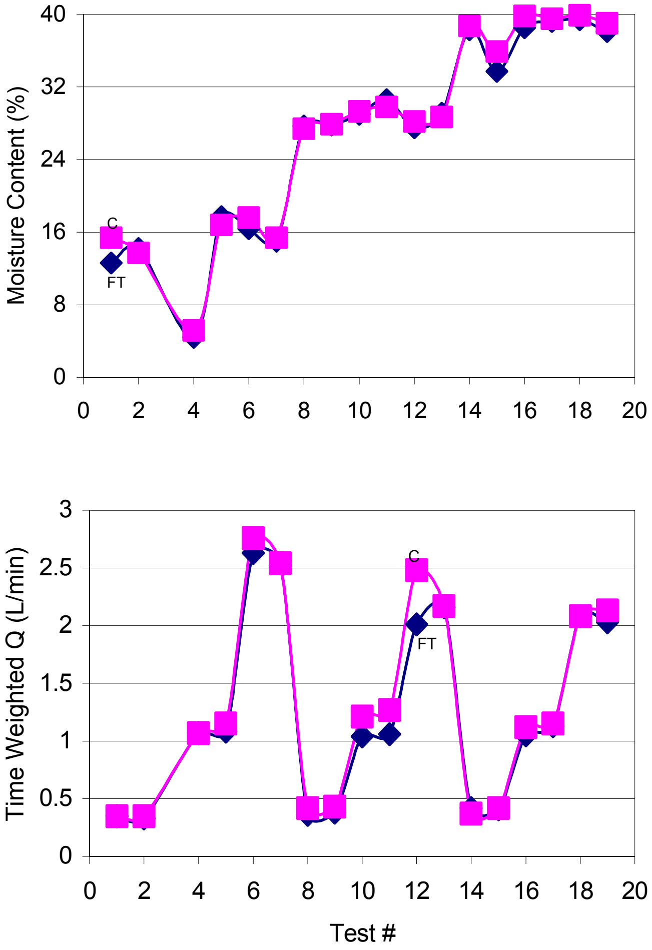

Figure 5. Soil moisture and discharge, Q; low-moisture series is tests 1–7; intermediate-moisture series is tests 8–13; high-moisture series is tests 14–19. Note that test 3 failed and test 4 replaced it.

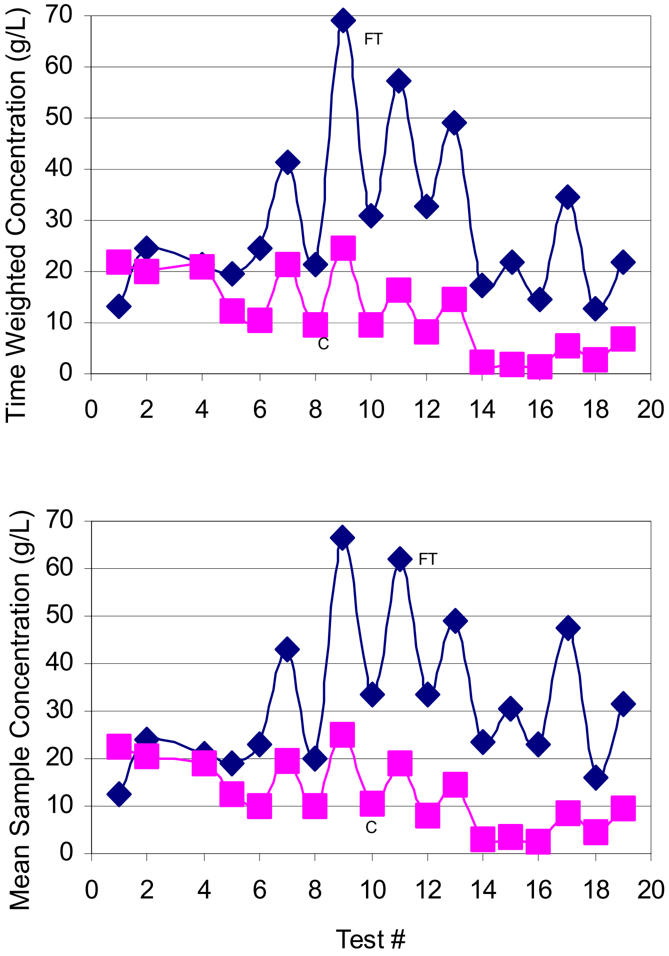

Figure 6. Time-weighted and mean sediment concentrations in samples from each bin.

Mean and time-weighted sediment concentrations are presented in Figure 6 for FT and C bins in each test. The concentration values are slightly different, but the overall patterns are the same. From test 6 on there is a strong and consistent dependence in both FT and C concentration parameters on the imposed slope.

Concentrations obtained in tests 1–5 are not related to slope. Differences in moisture content among this 15–18% group appear to dominate the effects of slope, suggesting to us a need for retesting. Test 15 concentrations are low for the C bin relative to other tests in the high moisture series (36–38%) and the FT contrast is significantly greater. Grouping the intermediate (26–28%) and high moisture series, the eroded concentrations generally diminish with both increased moisture content and flow.

Sediment transport and erosion in both the FT and C bins of the intermediate moisture series were consistently greater than corresponding tests of the high moisture series. The high moisture series had saturated soil conditions, and measurable settlement of the soil surface occurred between pre-test and post-test. Our initial hypothesis is that the decrease in erodibility with increased moisture resulted from soil consolidation. The pattern displayed by the median sediment concentration in Figure 7 is substantially the same as those of the mean and time-weighted concentrations in Figure 6.

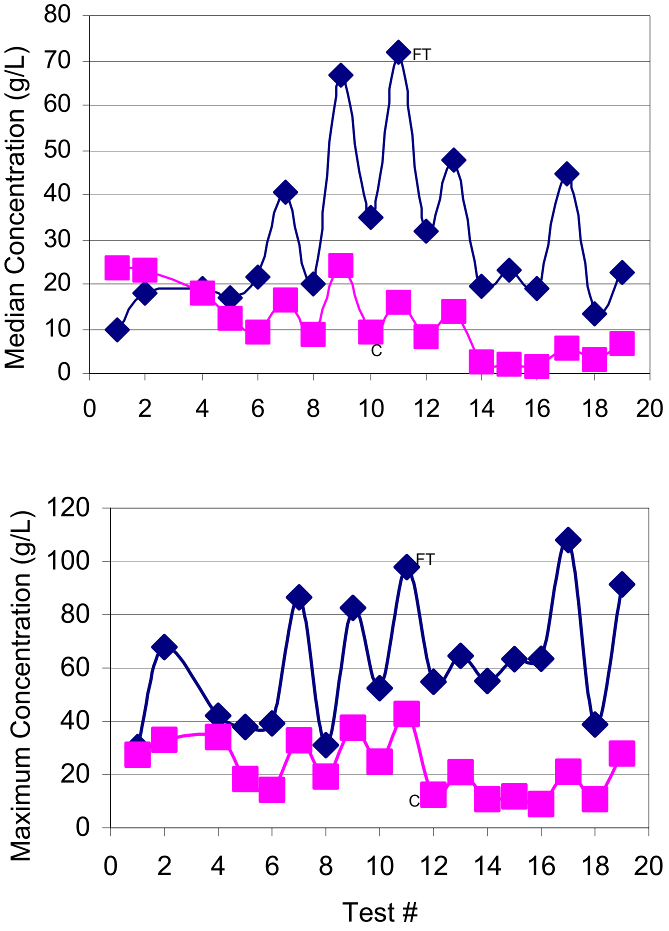

Figure 7. Median and maximum sediment concentrations.

However, the maximum concentrations given in Figure 7 are not completely consistent with the other measures, but are clearly affected by slope at intermediate and high soil moisture. Again, test 15 concentrations are anomalously low.

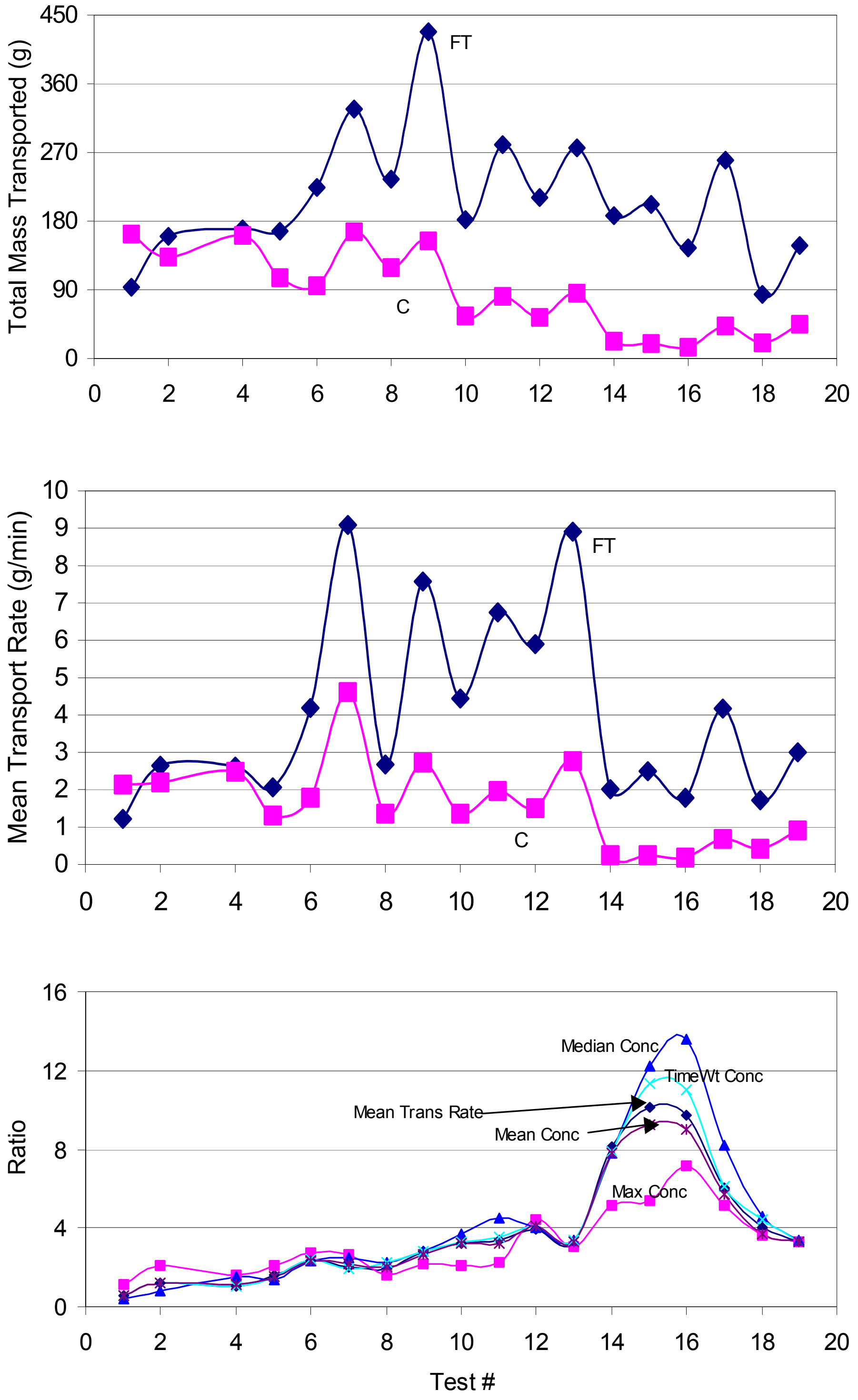

Figure 8. Sediment transported.

The total sediment mass transported during each test, as reflected in the sediment samples, is given in Figure 8. The controls show a generally decreasing trend with increasing moisture content of the soil, while the FT show an increasing and then decreasing trend with soil moisture.

The mean sediment transport rate, derived from the total mass transport, is also given in Figure 8 for each experiment. The low and intermediate moisture controls eroded more rapidly than the high moisture controls. The intermediate moisture FT sediment transport rates were much higher than those of the high moisture series. The effect of slope can again be clearly seen in both C and FT results.

The ratio of FT to C for each of the parameters discussed above is given in Figure 8 for the test series. The ratios of the median, time weighted, and mean concentrations and the mean transport rate are all tightly grouped and generally increasing through the low and intermediate soil moisture series. These ratios separate at high soil moisture, but each shows the same trends. Maximum concentration ratios oscillate around the grouped ratios through the low and intermediate series, and show a similar though less extreme trend through the high soil moisture tests. The relative importance of FT as increasing with soil moisture is clearly shown in these results.

The results presented thus far were all derived from the sediment transported from the soil bins by the applied surface runoff. We developed two norms or measures of cross-sectional change that are reported in Figure 9. L_2 is a root–mean–square measure of the change in bed elevation at a section resulting from the flow event, and L_{inf} is a measure of the maximum bed elevation change at any point along a cross section.

Our first observation is that both measures are providing very similar information concerning cross-sectional change. They indicate small change in the controls for both the intermediate and high soil moisture series, with all less than 1 cm throughout the high soil moisture series. The measures of both FT cross sections generally increase through the low and intermediate soil moisture series, indicating enhanced erosion with increasing slope and applied runoff.

At high soil moisture the slope dependence of cross-sectional change is again clear, but the dependence on runoff rate is not indicated. The differences between the measures of the FT and C cross sections in the low soil moisture experiments are greatly reduced from those at higher moisture.

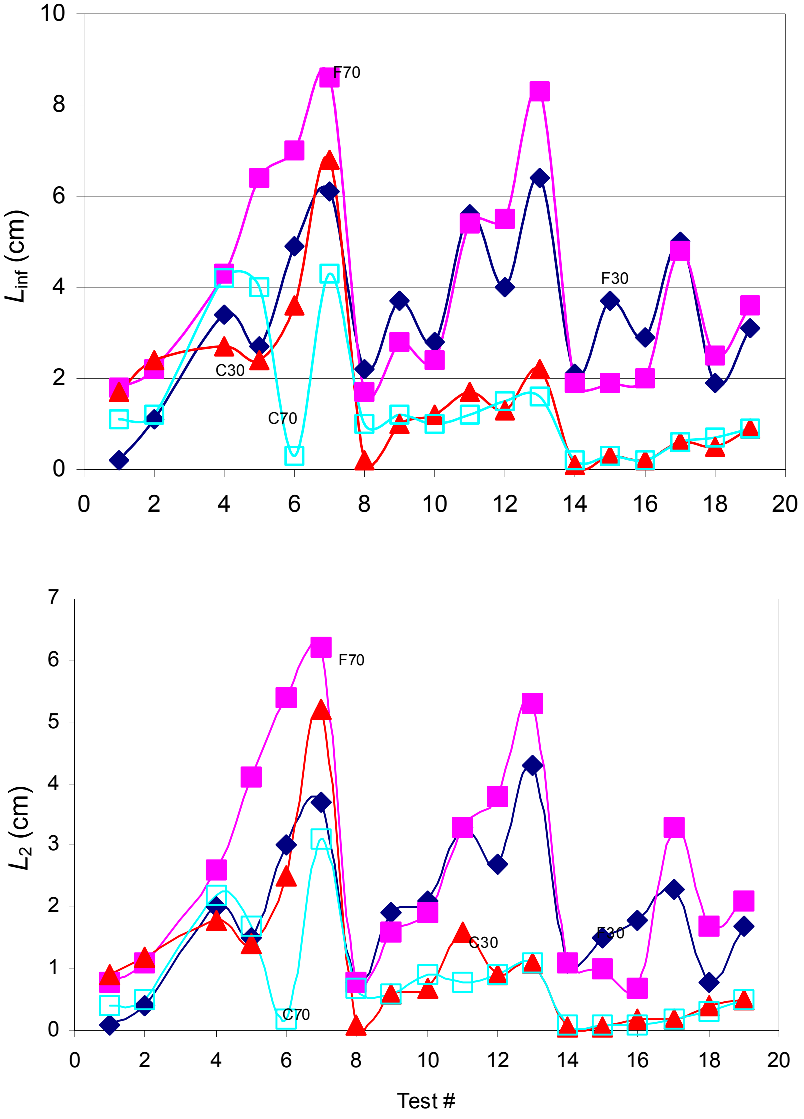

Figure 9. L_{inf} and L_2 values from cross-sectional data.

FT/C ratios of the two measures were obtained for both cross sections of each test; results are presented in Figure 10. Like the ratios derived from the concentration data, the ratios are generally small and increasing through the low and intermediate soil moisture series. The sections at 0.7 *L* in test 6 and at 0.3 *L* in test 8 have anomalously high ratios, indicating excessive erosion in a part of the FT bin at low and moderate soil moisture.

In the high soil moisture series the ratios are generally high, a result of very minor erosive change in the C bins. Greater relative erosion of the C bins in the high flow tests of this series produce the smallest ratios of the group. Table 1 gives the average norms for each section and test series, and the ratio of these norms. At 0.3 L the ratios of the norms are approximately equal for each test series, and increase dramatically with soil moisture. The same rough equality of norm ratios exists at 0.7 L, but the ratios at low soil moisture are much larger and the increase with soil moisture is less extreme. Together, these results indicate that erosion of the FT bin relative to that of the C bin increased with soil moisture and approached an order of magnitude difference at saturated soil conditions.

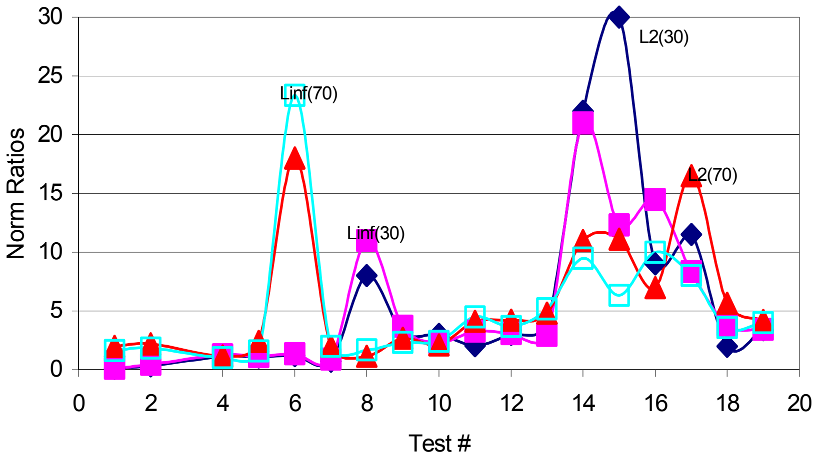

Figure 10. L_{inf} and L_2 ratios.

Table 1. Average norms (cm) and their ratios by test series.

Test series	F30 L_2	C30 L_2	R30 L_2	F30 L_{inf}	C30 L_{inf}	R30 L_{inf}	F70 L_2	C70 L_2	R70 L_2	F70 L_{inf}	C70 L_{inf}	R70 L_{inf}
1–7	1.8	2.2	0.82	3.1	3.3	0.94	3.4	1.4	2.5	5.1	2.5	2.0
8–13	2.5	0.8	3.0	4.1	1.3	3.3	2.8	0.8	3.3	4.4	1.3	3.5
14–19	1.5	0.2	6.6	3.1	0.4	7.2	1.7	0.2	7.7	2.8	0.5	5.8

4 CONCLUSIONS

The average width of the rills that developed in the control and FT bins was similar, but rill depth was 2 cm greater in the FT bin when the soil moisture was 15–18%. The rill depths developed in the FT bins when the soil moisture was 36–38% ranged from 2 to 10 times larger than in the control bin. At low soil moisture, the sediment mass from FT samples exceeded that of corresponding control samples by 39%.

For mid-range soil moisture the mass contained in the FT samples exceeded that of the controls by a factor of 2.9, and at high soil moisture this factor increased to 6.2. The differences in rates and quantity of soil eroded increased dramatically with the water content due to the FT cycle. These results are the first to quantitatively define the differences in sediment loss in rill formation caused by FT cycling.

We will complete additional analyses and experiments with the frost-susceptible soil used here to further define the effects of FT in the soil-erosion process. However, further investigation of FT affects on other soils is needed to establish a more complete and quantitative understanding with which to build a robust, soil-erosion model for regional sediment management.

REFERENCES

Anderson, D.M., R. Pusch, and E. Penner (1978) *Geotechnical Engineering for Cold Regions*. New York: McGraw–Hill, 566 p.

Benoit, G.R., and W.B. Voorhees (1990) Effect of freeze–thaw activity on water retention, hydraulic conductivity, density, and surface strength of two soils frozen at high water content. In *Proceedings, International Symposium on Frozen Soil Impacts on Agricultural, Range and Forest Lands* (K.R. Cooley, Ed.). U.S. Army Cold Regions Research and Engineering Laboratory Special Report 90-1: 45–53.

Bryan, R.B. (2000) Soil erodibility and processes of water erosion on hillslope. *Geomorphology*, 32: 385–415.

Chamberlain, E.J. (1981) Frost susceptibility of soil, review of index tests: U.S. Army Cold Regions Research and Engineering Laboratory Monograph 81-2, 110 p.

Edwards, L.M., and J.R. Burney (1987) Soil erosion losses under freeze/thaw and winter ground cover using a laboratory rainfall simulator. *Canadian Agricultural Engineering*, 29(2): 109–115.

Edwards, L.M., J.R. Burney, and P.A. Frame (1995) Rill sediment transport on a Prince Edward Island (Canada) fine sandy loam. *Soil Technology*, 8: 127–138.

Formanek, G.E., D.K. McCool, and R.I. Papendick (1984) Freeze–thaw and consolidation effects on strength of a wet silt loam. *Transactions of the ASAE*, 27(6): 1749–1752.

Gatto, L.W. (2000) Soil freeze–thaw induced changes to a simulated rill: Potential impacts on soil erosion. *Geomorphology*, 32: 147–160.

Janson, L. (1963) *Frost Penetration in Sandy Soil*. Goteborg, Sweden: Elanders Boktrychkeri, 165 p.

Jumikis, A.R. (1962) *Soil Mechanics*. Princeton, New Jersey: Van Nostrand, 791 p.

Kok, H., and D.K. McCool (1990) Freeze–thaw effects on soil strength. In *Proceedings, International Symposium on Frozen Soil Impacts on Agricultural, Range and Forest Lands* (K.R. Cooley, Ed.). U.S. Army Cold Regions Research and Engineering Laboratory Special Report 90-1: 70–76.

Lal, R., and W. Elliot (1994) Erodibility and erosivity. In *Soil Erosion Research Methods* (R. Lal, Ed.). Soil Water Conservation Society, Delray Beach, Florida: St. Lucie Press, 181–208.

McCool, D.K. (1990) Crop management effects on runoff and soil loss from thawing soil. In *Proceedings, International Symposium on Frozen Soil Impacts on Agricultural, Range and Forest Lands* (K.R. Cooley, Ed.). U.S. Army Cold Regions Research and Engineering Laboratory Special Report 90-1: 171–176.

Pall, R., W.T. Dickinson, D. Green, and R. McGirr (1982) Impacts of soil characteristics on soil erodibility: Recent developments in the explanation and prediction of erosion and sediment yield. IAHS Publ. No. 137: 39–47.

Radke, J.K., and E.C. Berry (1997) Freezing and thawing effects on soil water and solute movement in repacked soil columns. In *Proceedings, International Symposium on Physics, Chemistry, and Ecology of Seasonally Frozen Soils, Fairbanks, Alaska, June 1997* (I.K. Iskandar, E.A. Wright, J.K. Radke, B.S. Sharratt, P.H. Groenevelt, and L.D. Hinzman, Ed.). U.S. Army Cold Regions Research and Engineering Laboratory Special Report 97-10: 17–23.

Shoop, S.A., and L.W. Gatto (1992) Geology and geohydrology at CRREL, Hanover, New Hampshire: Relationship to subsurface contamination. U.S. Army Cold Regions Research and Engineering Laboratory Special Report 92-24, 89 p.

Van Klaveren, R.W. (1987) Hydraulic erosion resistance of thawing soil. Ph.D dissertation, Washington State University, Pullman, Washington.

Van Klaveren, R.W., and D.K. McCool (1998) Erodibility and critical shear of a previously frozen soil. *Transactions of the ASAE*, 41(5): 1315–1321.

Zuzel, J.F., R.R. Allmaras, and R. Greenwalt (1982) Runoff and soil erosion on frozen soils in northeastern Oregon. *Journal of Soil and Water Conservation*, 37(6): 351–354.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)* April 2003

2. REPORT TYPE Technical Note

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

Overland Erosion Due To Freeze–Thaw Cycling:
Laboratory Experiments

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Lawrence W. Gatto and Michael G. Ferrick

5d. PROJECT NUMBER 392005 (RSM-A6)

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/CRREL TN-03-3

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of the Chief of Engineers
Washington, DC 20314-1000

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Ice that forms in soil voids during the freezing process pushes soil grains apart, reducing particle cohesion and soil strength, and making soil more erodible. This report summarizes 18 experiments to measure erosion rates in a soil that was frozen and thawed once and in the same unfrozen soil. We hypothesized that soil freeze–thaw (FT) processes significantly increase upland hill slope erosion during subsequent runoff events. We selected a frost-susceptible silt to provide an upper bound on this effect. For each experiment, we prepared two identical bins, one as an unfrozen control, the other to be frozen and thawed. We tested three soil-moisture ranges, three flow rates, and two slopes, and measured the cross-sectional geometry of the rills that developed and sediment losses through time for each bin. The cross-section measurements detailed erosion at specific locations along the bins; sediment loss measurements indicated erosion integrated along the entire bin. The results are the first to quantitatively define the differences in sediment loss and rill formation caused by FT cycling. We will analyze data from these experiments and do additional experiments to further define FT effects in the soil-erosion process. (However, these results already demonstrate the importance of FT weakening to soil erosion.) Good regional sediment management in cold climates requires that erosion prediction models accurately account for important processes such as soil-FT cycling to avoid significant underprediction of soil losses on hill slopes and in watersheds in cold climates.

15. SUBJECT TERMS

Freeze–thaw effects	Soil erosion
Rill development	Watershed sediment
Sediment losses	

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	23	