

USE OF THE REVISED UNIVERSAL SOIL LOSS EQUATION AND GIS TECHNIQUES TO MODEL SOIL EROSION RISK IN ROCKY MOUNTAIN NATIONAL PARK

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Abstract

The Revised Universal Soil Loss Equation (RUSLE) was used in conjunction with GIS raster modeling techniques to estimate potential soil erosion in Rocky Mountain National Park (ROMO). Currently, 6% of ROMO consists of soils with erosion rates greater than 5 tons/acre/year. The following regions have high erosion rates: 1) east of Long's Peak; 2) along Stormy Peaks Pass Trail; 3) along the Continental Divide near the southern edge of the Park's boundary; and 4) in the Hayden Lake area. Jim's Grove Trail, the Alluvial Fan Trail, East Long's Peak Trail, and Stormy Peaks Pass Trail have more than 30% of their extent underlain by highly erosive soils. Simulations were run to determine the effects of increased tree mortality from pine beetle kill on soil erosion rates. According to the post-pine beetle model, erosion rates greater than 5 tons/acre/year cover 33% of ROMO, a 28% increase from previous categorized high erosion areas. Bowen-Baker Gulch, Twin-Gem, Bear Lake Bypass, and Bierstadt Mountain Trails have more than 90% of their length underlain by highly erosive soils following the pine beetle disturbance. If a fire were to occur, soil erosion could enhance the frequency of debris flows and slides, especially during short, intense precipitation events. The methods employed in this study only identify high-risk areas of erosion, a useful management tool for narrowing sites from a larger geographic region; however, actual erosion rates should be verified in the field.

Introduction

Hiking, horse riding, and mountain biking can increase soil erosion, compact soil, be a source of excess soil nutrients, spread weeds or invasive species, change local hydrology and sediment load, widen trails, and expose roots, rocks, and bedrock (Pickering et al. 2010). In the US, soil is being lost at a rate about 10 times greater than natural soil formation. Soil erosion models simulate the effects of human activities in an attempt to develop appropriate intervention strategies such as soil conservation practices. The most extensively used model is the Revised Universal Soil Loss Equation (RUSLE). The RUSLE is an empirical equation that predicts annual erosion (tons/acre/year) resulting from sheet and rill erosion. Most often, it is used to assess erosion potential for agricultural land. The RUSLE is advantageous because it is simple, online data are readily available, and it can be calculated using Geographic Information System (GIS) techniques. Locations of high erosion, the influence of individual variables on the rate of erosion, and the spatial patterns of soil loss within a watershed can all be examined. GIS has been used in conjunction with the RUSLE to run scenarios dealing with changes in land cover because of natural disturbances or to set priorities for soil conservation (Yue-Qing et al. 2008; Dymond et al. 2010).

Objectives

The objectives of this project are to:

1. Determine soil erosion potential in ROMO using GIS data (soil type, land cover, Digital Elevation Model (DEM), slope, and rainfall erosivity) in conjunction with the RUSLE; and
2. Model the effects of increased tree mortality from pine beetle on soil erosion.

Methods

The RUSLE consists of the product of a combination of 6 variables:

$A = (R)(K)(L)(S)(C)(P)$, where

A = Annual soil loss (tons/acre) resulting from sheet and rill erosion;

R = rainfall-runoff erosivity;

K = soil erodibility;

L = slope length;

S = slope;

C = cover management; and

P = erosion controls.

Values less than 1 can reduce erosion; a value of 1 has no effect on erosion; and values greater than 1 increase the erosion potential. The R-factor is a summation of the various properties of rainfall including intensity, duration, size of droplets, etc. It is computed using rainfall energy and the maximum intensity over 30 minutes during typical storms. Rainfall erosivity (R) has been mapped for the entire US and is computed using meteorological station data. Precipitation data were downloaded, clipped to the extent of ROMO, and were converted to a 30 m grid. Rainfall-runoff erosivity values ranged from 15 to 52 with an average of 33 across ROMO (Figure 1).

The soil erodibility factor (K) measures the resistance of the soil to detachment and transportation by raindrop impact and surface runoff. Soil erodibility is a function of the inherent soil properties, including organic matter content, particle size, and permeability. Because these properties vary within a given soil, erodibility also varies. K-values of the major soils in ROMO were obtained from Soil Surveys Reports. An existing GIS layer of soil type was then reclassified, converted, and resampled to a 30 m grid. Soil erodibility varied between 0 and 0.37 with an average of 0.07 within ROMO (Figure 1).

The slope length factor (L) accounts for the effects of slope length on the rate of erosion, and the slope steepness factor (S) accounts for the effects of slope angle on erosion rates. These variables were estimated using a 30 m DEM and GIS hydrologic modeling techniques. The slope length factor (L) was combined with the slope (S) factor for simplicity. The average combined slope length-slope factor was 82 in ROMO.

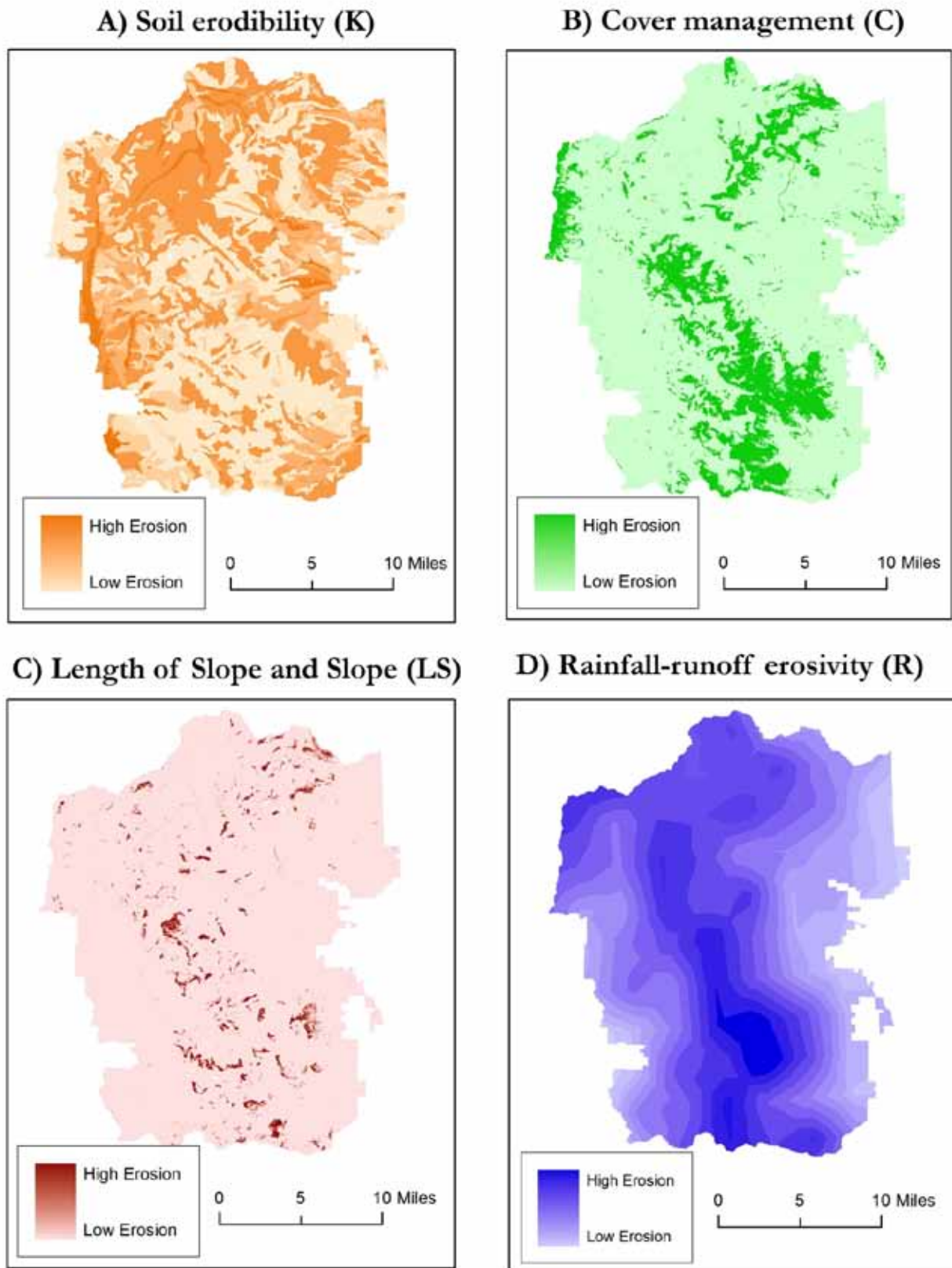


Figure 1 – Variables according to the RUSLE used to estimate soil erosion in ROMO.

The cover management factor (C) represents the influence of soil and cover management, such as tillage practices, cropping types, crop rotation, or fallow on soil erosion rates. Because these practices do not occur in ROMO, this variable was modified to represent the effects of existing land cover types soil erosion. Weights were assigned for vegetation classes based on published data. Data were converted to a grid with a 30 m resolution. Values ranged from 0 to 1 with an average of 0.19. In general, grasses have greater erosion compared to forests; trees have the ability to intercept and slow falling water, thus soil particles are less likely to become dislodged.

The erosion control factor (P) describes the influence of conservation practices such as contouring, strip cropping, or terracing to reduce erosion. This variable was set as a constant (1) assuming that major erosion control practices are not being implemented in ROMO.

Each of the grid layers was then multiplied together using GIS map algebra to determine the potential total annual soil loss in tons per acre (A). The analysis involves a local (cell-by-cell) calculation of erosion based on the derived values for each category. In order to simulate the effects of loss of vegetation from increased tree mortality because of pine beetle infestation or Sudden Aspen Dieback (SAD), the land cover data (C) were reclassified based on outbreak extent from 2009 US Forest Service data. Potential annual erosion (A) was then recalculated using the modified land cover data, which included areas affected by pine beetle infestation. Potential soil erosion was then compared between pre- and post-pine beetle models to determine areas that may be at greater risk to experience erosion from increased tree mortality.

Results

Results of the erosion analysis for ROMO are shown in Figure 2. Results were classified into 3 categories: low (less than 3 tons per acres per year), medium (3 to 5 tons per acre per year), and high (greater than 5 tons per acre per year). Generally, areas that are greater than 5 tons/acre/year are of concern to Soil Conservationists; some believe that erosion rates greater than 3 tons/acre/year are too high and erosion need to be slowed by control methods. Approximately 6% of ROMO falls within the high erosion category.

According to the model, four areas of high erosion are evident. Each of the following areas has a cluster high potential erosion: 1) east of Long's Peak; 2) along Stormy Peaks Pass Trail; and 3) along the Continental Divide near the southern edge of the Park's boundary. These areas are more susceptible to erosion because they consist of tundra grasses, have higher than average rainfall-runoff (R) values, have erodible soil types, and have longer, gentle slopes that can channel and accumulate surface flow. Near Hayden Lake, a 4th unique cluster exists. In this area, it appears that the soils have high K-values, rainfall-runoff erosivity is greater than average, and land cover consists of tundra grasses and exposed rock and soil. Interestingly, the length of slope and slope factors suggest that the orientation of the cirques in these valleys maximizes the potential for erosion by concentrating water through overland flow.

Erosion potential increases significantly following vegetation loss from pine beetle dieback (Figure 3). In fact, 28% of the low erosion potential category was converted to high erosion potential (Table 1). In terms of contiguous spatial area, the northwestern portion of ROMO showed the most significant increase in potential

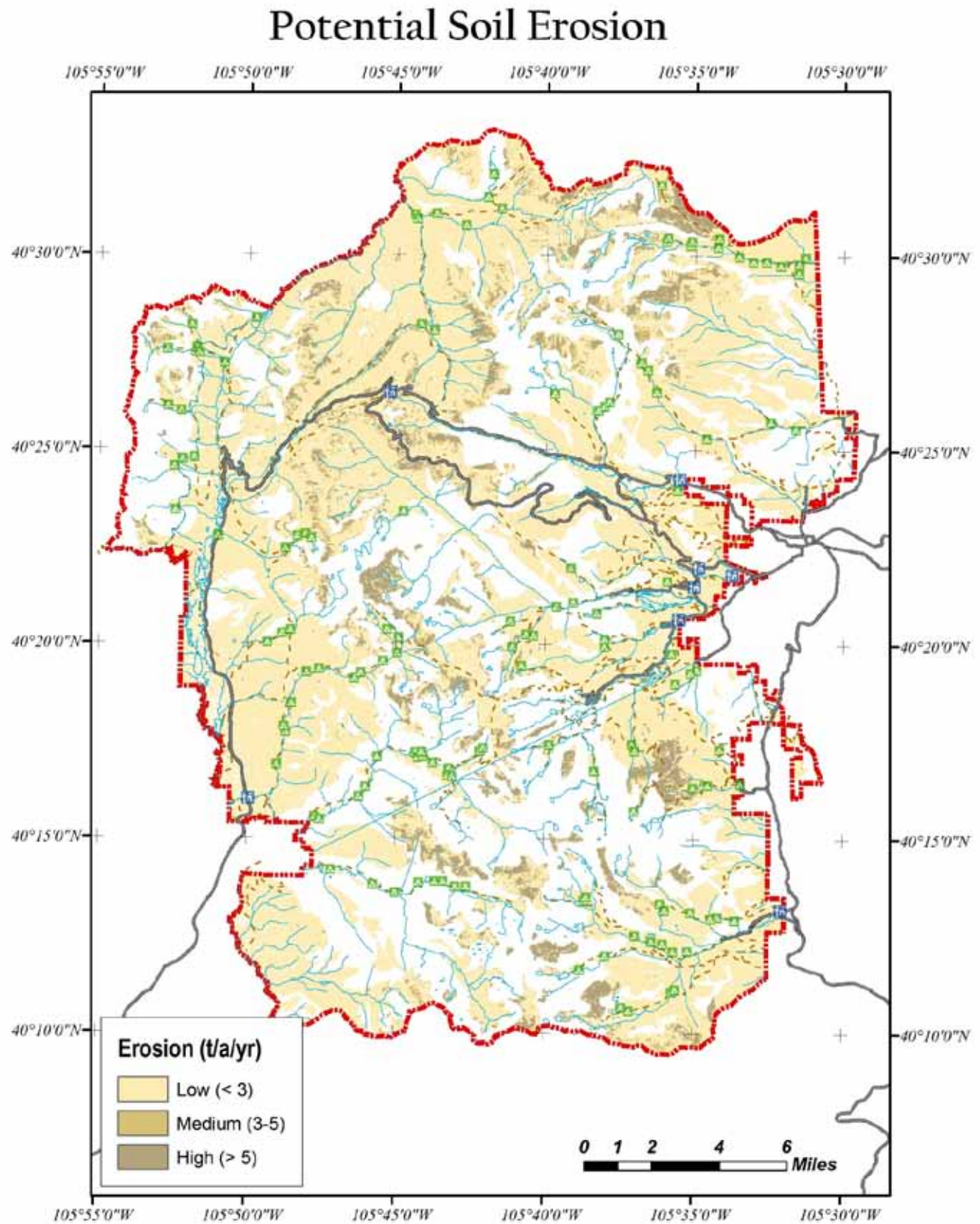


Figure 2 – Potential soil erosion in ROMO according to current vegetation distribution.

Potential Soil Erosion (Post-Pine Beetle)

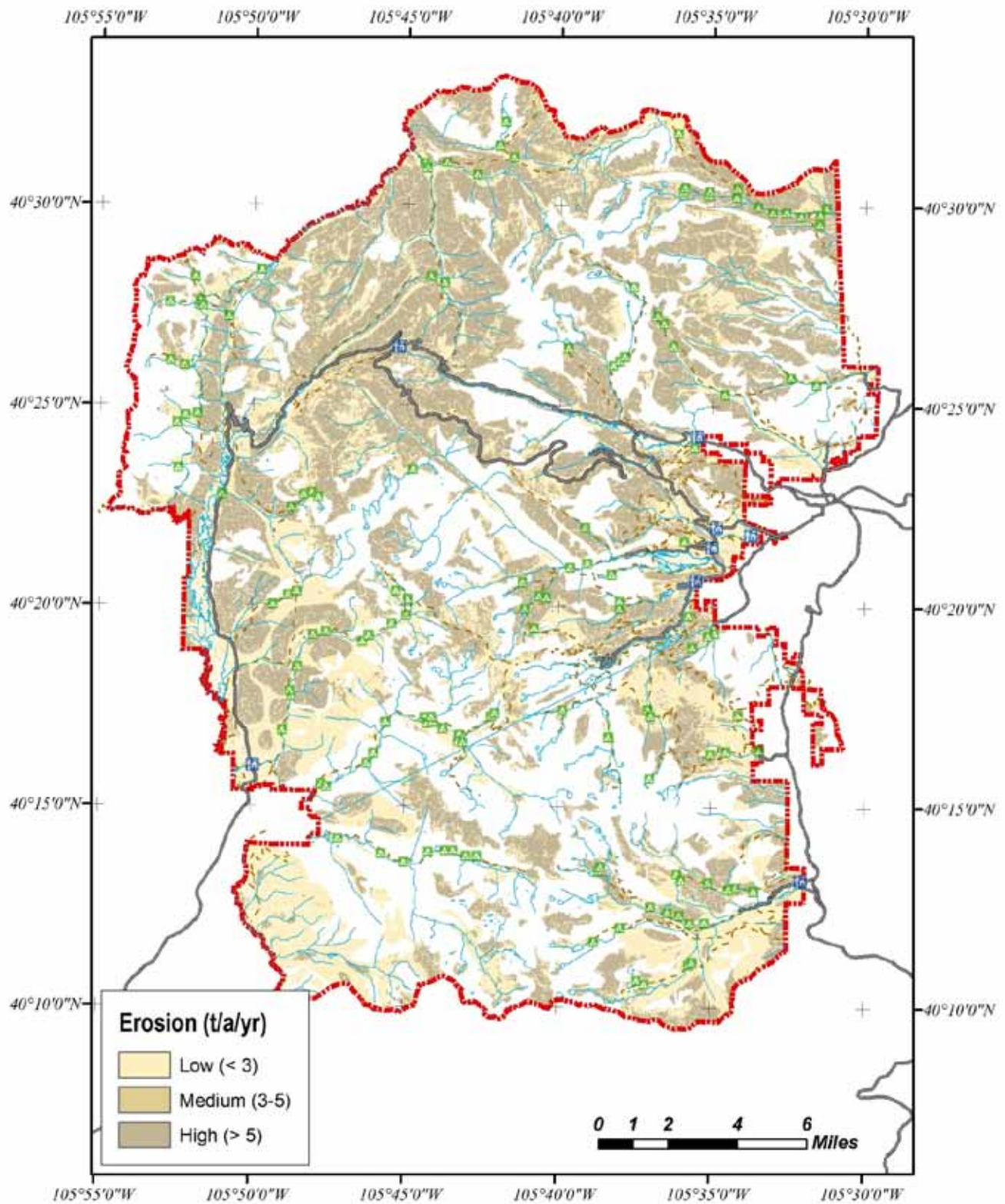


Figure 3 – Potential soil erosion in ROMO after pine beetle disturbance.

Table 1 – Percentage of ROMO susceptible to erosion in pre- and post-pine beetle environments.

	<i>Before Pine Beetle</i>	<i>After Pine Beetle</i>	Change
None	44%	44%	0%
Low	49%	20%	-28%
Medium	1%	2%	0%
High	6%	33%	28%

Table 2 – Erosion potential in each of ROMO's districts.

District	<i>Before Pine Beetle</i>				<i>After Pine Beetle</i>			
	None	Low	Medium	High	None	Low	Medium	High
COLORADO RIVER	42%	51%	2%	5%	42%	23%	2%	33%
FALL RIVER	42%	51%	2%	6%	41%	15%	2%	42%
THOMPSON RIVER	51%	41%	1%	6%	51%	17%	2%	30%
WILD BASIN	50%	43%	1%	7%	50%	25%	1%	24%

<i>Percent Change</i>				
District	None	Low	Medium	High
COLORADO RIVER	0%	-28%	0%	28%
FALL RIVER	0%	-36%	0%	36%
THOMPSON RIVER	0%	-25%	1%	24%
WILD BASIN	0%	-17%	0%	17%



erosion from tree mortality. In order to determine areas that are more susceptible to increased erosion risk from tree mortality, ROMO was divided into 4 regions and statistics were calculated within each region (Table 2). The Fall River district showed the greatest increase in erosion potential followed by the Colorado River District.

Susceptibility of trail erosion was estimated through overlay with the pre- and post-pine beetle erosion layers (Table 3). Jim's Grove Trail, the Alluvial Fan Trail, East Long's Peak Trail, and Stormy Peaks Pass Trail had more than 30% of their extent underlain by highly erosive soils. With increased tree mortality, the number of trails underlain by highly erosive soils significantly increases. In fact, Bowen-Baker Gulch, Twin-Gem, Bear Lake Bypass, and Bierstadt Mountain Trails have more than 90% of their length underlain by highly erosive soils following the pine beetle disturbance.

Figures 4 through 13 show pre- and post-pine beetle infestation in more detail for particular sections of ROMO. Digital raster layers are also available for inspection that is more thorough.

Discussion

The modeling results show a significant increase in erosion potential following a natural disturbance (pine-beetle kill). If a summer drought occurs, the increased fuel load from dead trees would increase wildfire potential. If a fire were to occur, erosion rates would be amplified. Surface erosion through overland flow has been shown to be an important response to wildfires in the Interior Northwest and Northern Rocky Mountains (Wondzell and King 2003). Severe fires which result in deep charring of soil can lower the water holding capacity of the soil, leading to greater overland flow and hence movement of soil (Chafer 2008). Fire history can also affect erosion rates; previous disturbances have greater soil erodibility compared to non-disturbed areas (Kaniewski et al. 2008). Immediately after a forest fire, the frequency of debris flows and slides can increase, especially during short, intense storms. The probability of major floods in a post-fire season can also increase by up to an order of magnitude without a significant change in precipitation (Rulli and Rosso 2007).

With greater basin sizes and resulting drainage, some areas may show increased incision that leads to deeper and more extensive rills and gullies (Gabet and Bookter 2008). This has the potential to deliver more sediment to river channels. In some areas, mean sediment yield from channels was significantly greater than from hillslopes (overland flow). This suggests that sediment availability may be more important than hillslope or soil erodibility (Moody and Martin 2009). Hillslope erosion is modeled through the length of slope (L), slope (S), and soil erodibility (K) values according to the RUSLE. It is difficult to quantify the sediment availability using GIS data without field measurements. The methods employed here are effective for approximating areas that are susceptible to erosion, serving as a precursor to a more detailed field study.

Several remediation strategies have been suggested to slow soil erosion. Time of vegetation recovery is an important variable. At sagebrush sites on rangelands, 60% groundcover was needed to significantly slow erosion following prescribed burns (Pierson et al. 2009). This is significant because there may not be enough time for vegetation to establish between intense, severe precipitation events. Some have suggested that in another 35 years, pines will be eliminated; it will take at least 50 years for the forest to recover. Thick anti-erosion logs are able to

Potential Soil Erosion

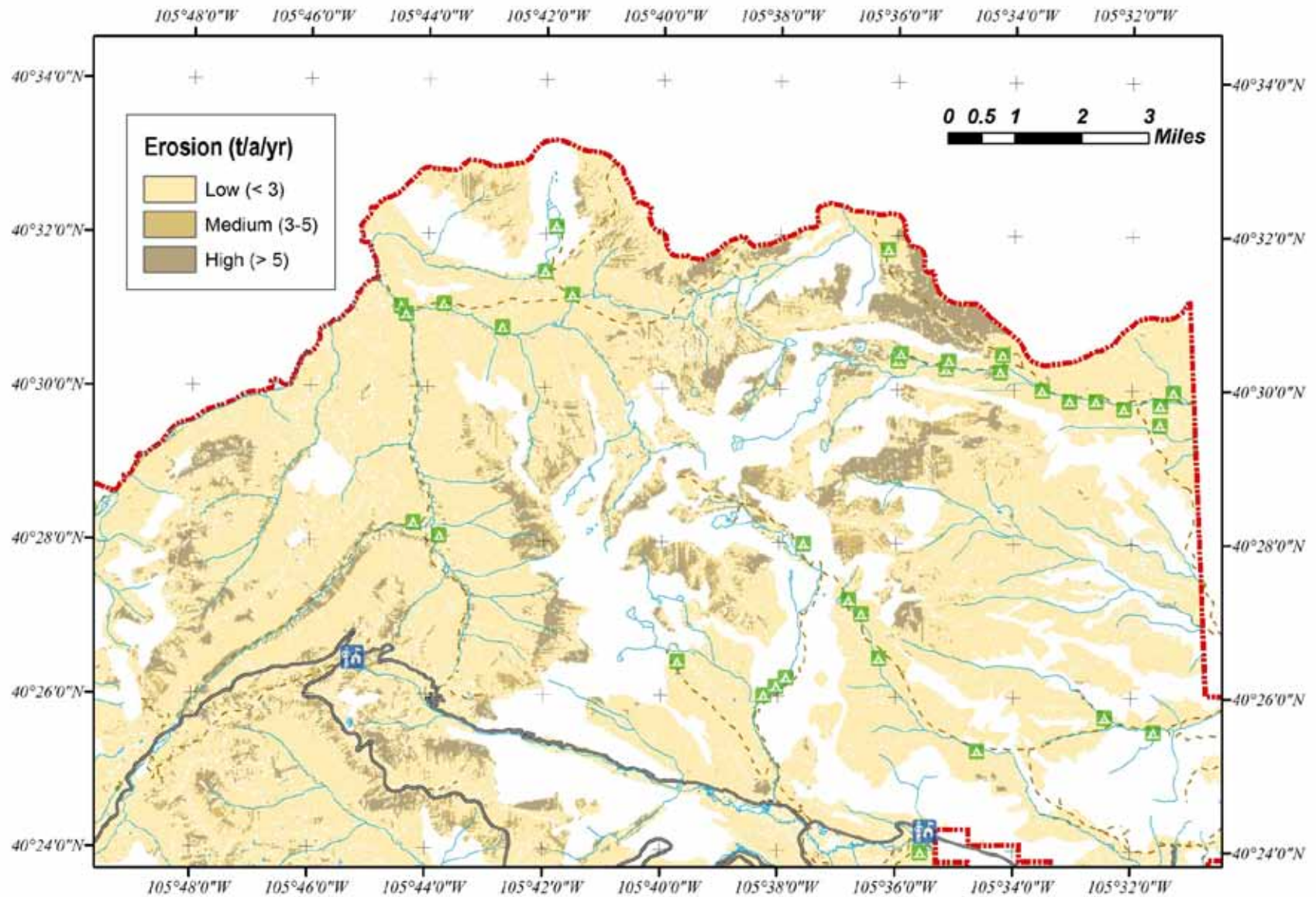


Figure 4 – Potential soil erosion (**North**) in ROMO according to current vegetation distribution.

Potential Soil Erosion (Post-Pine Beetle)

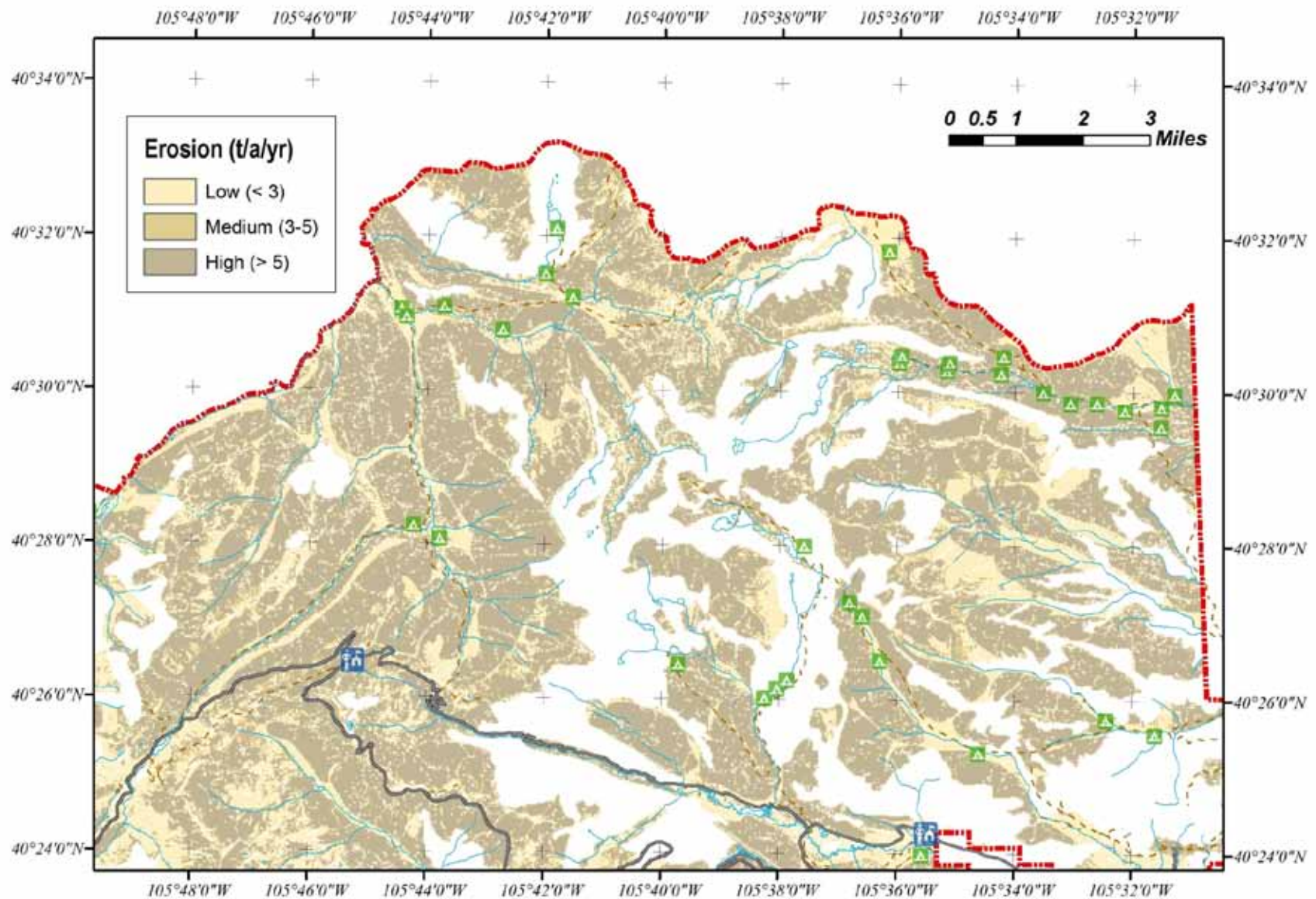


Figure 5 – Potential soil erosion (**North**) in ROMO after pine beetle disturbance.

Potential Soil Erosion

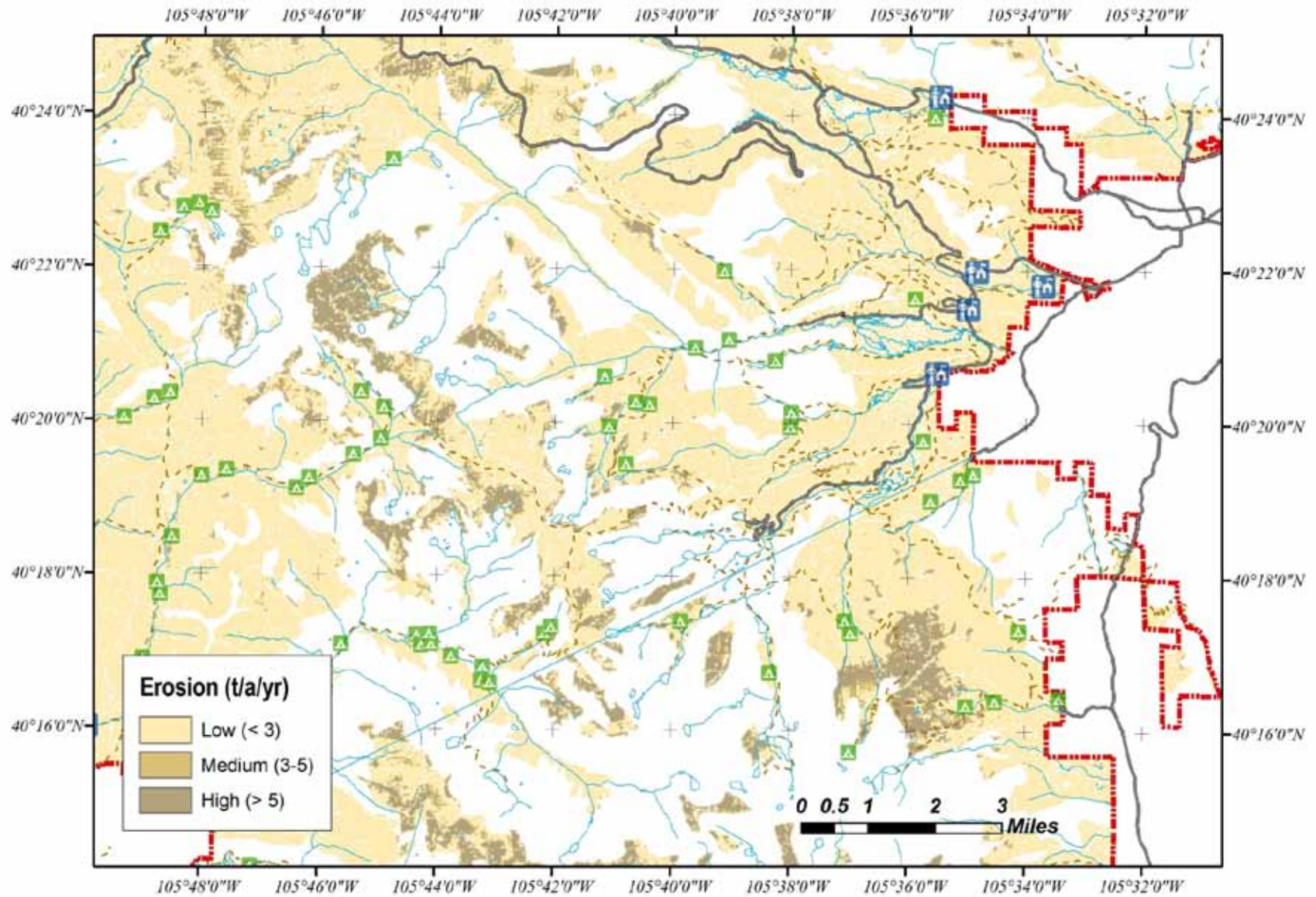


Figure 6 – Potential soil erosion (**East**) in ROMO according to current vegetation distribution.

Potential Soil Erosion (Post-Pine Beetle)

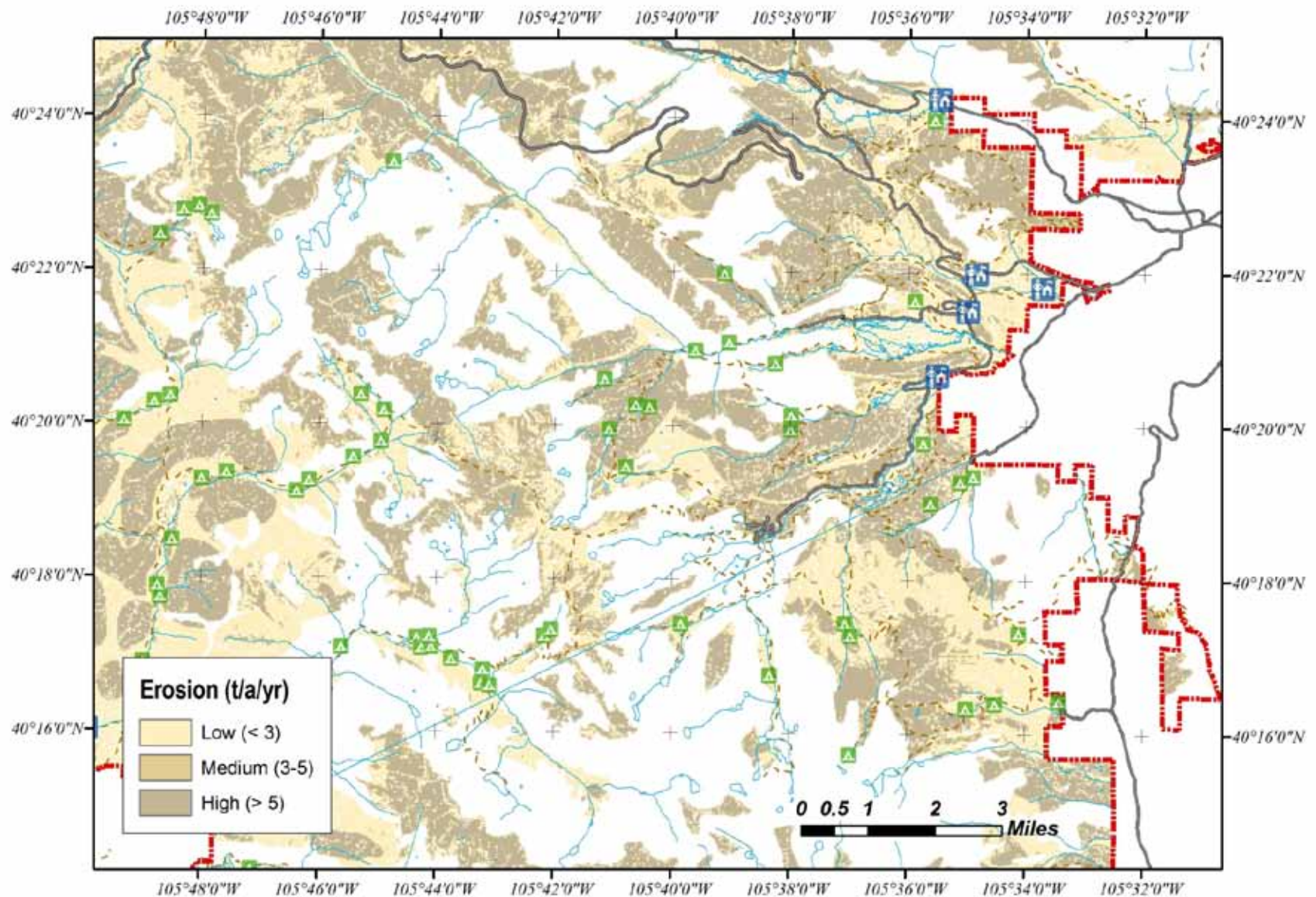


Figure 7 – Potential soil erosion (**East**) in ROMO after pine beetle disturbance.

Potential Soil Erosion

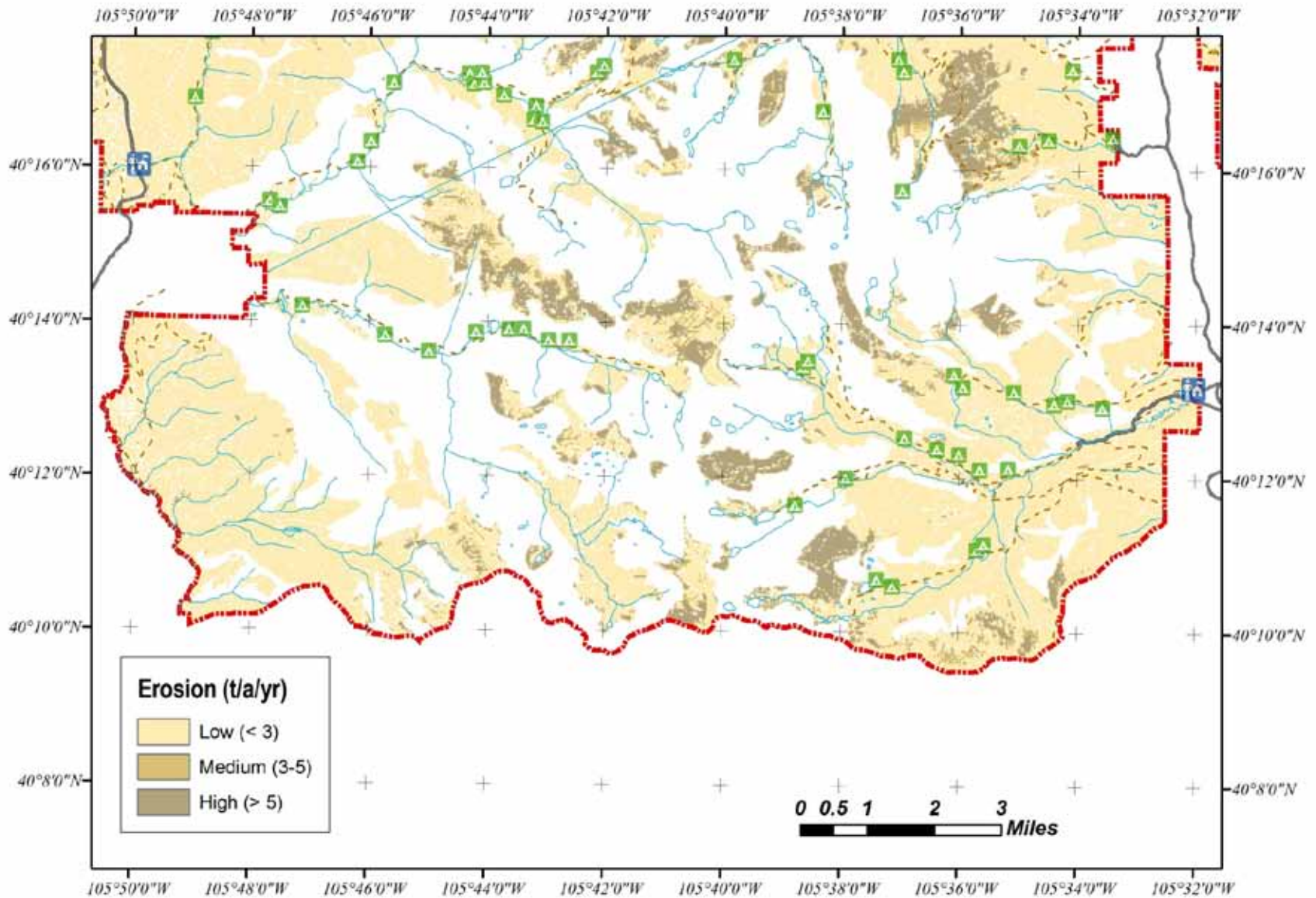


Figure 8 – Potential soil erosion (**South**) in ROMO according to current vegetation distribution.

Potential Soil Erosion (Post-Pine Beetle)

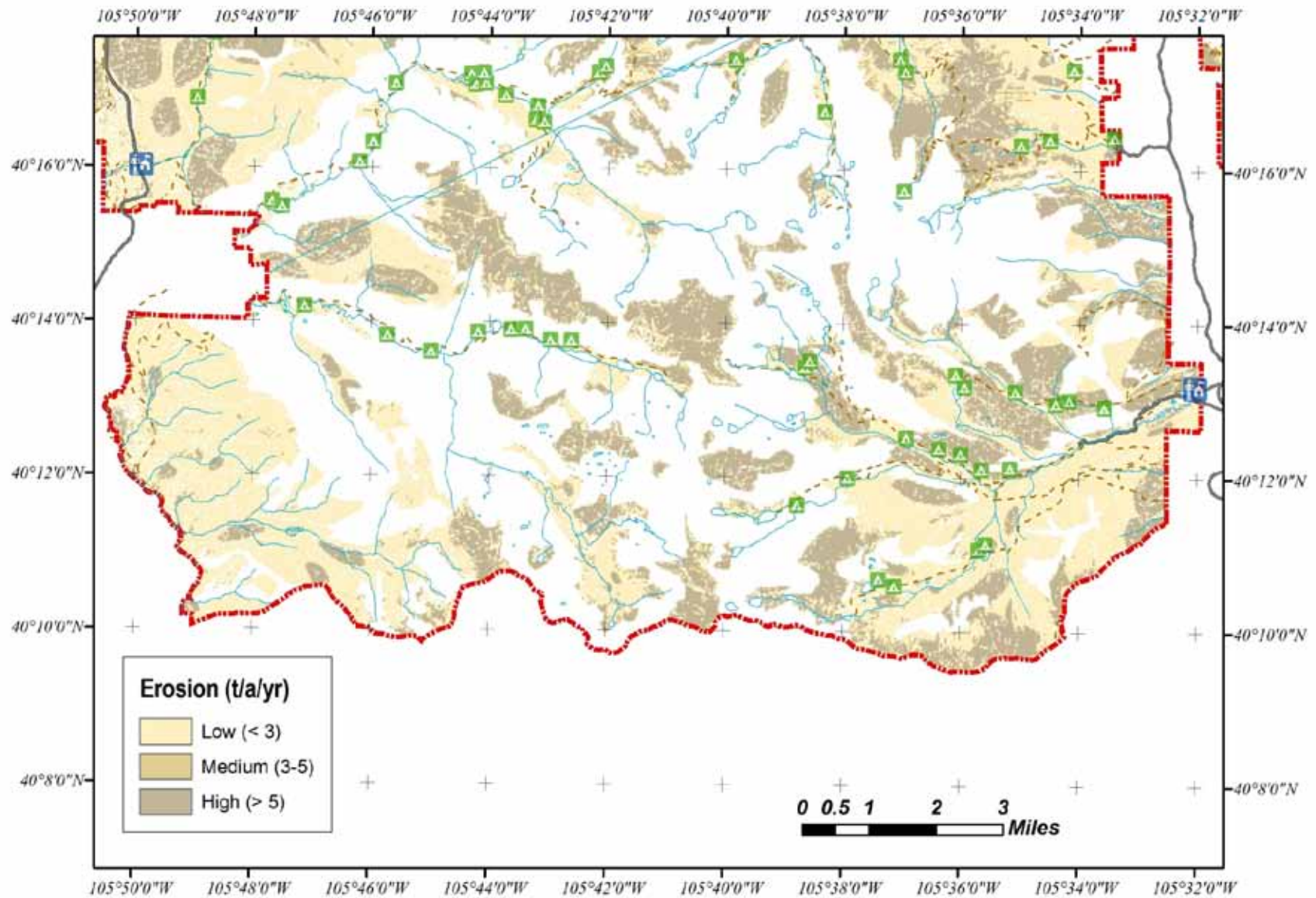


Figure 9 – Potential soil erosion (**South**) in ROMO after pine beetle disturbance.

Potential Soil Erosion

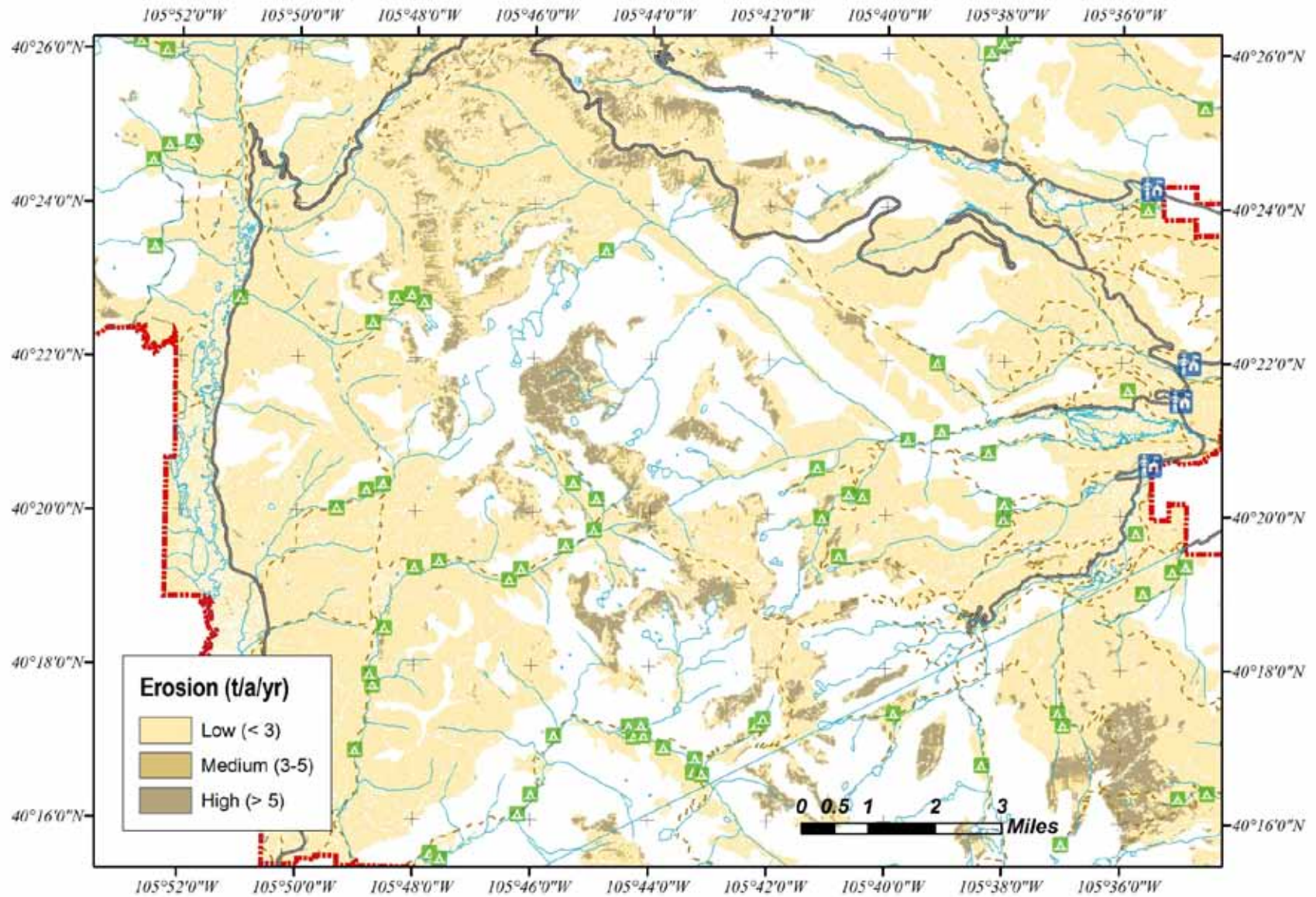


Figure 10 – Potential soil erosion (**West**) in ROMO according to current vegetation distribution.

Potential Soil Erosion (Post-Pine Beetle)

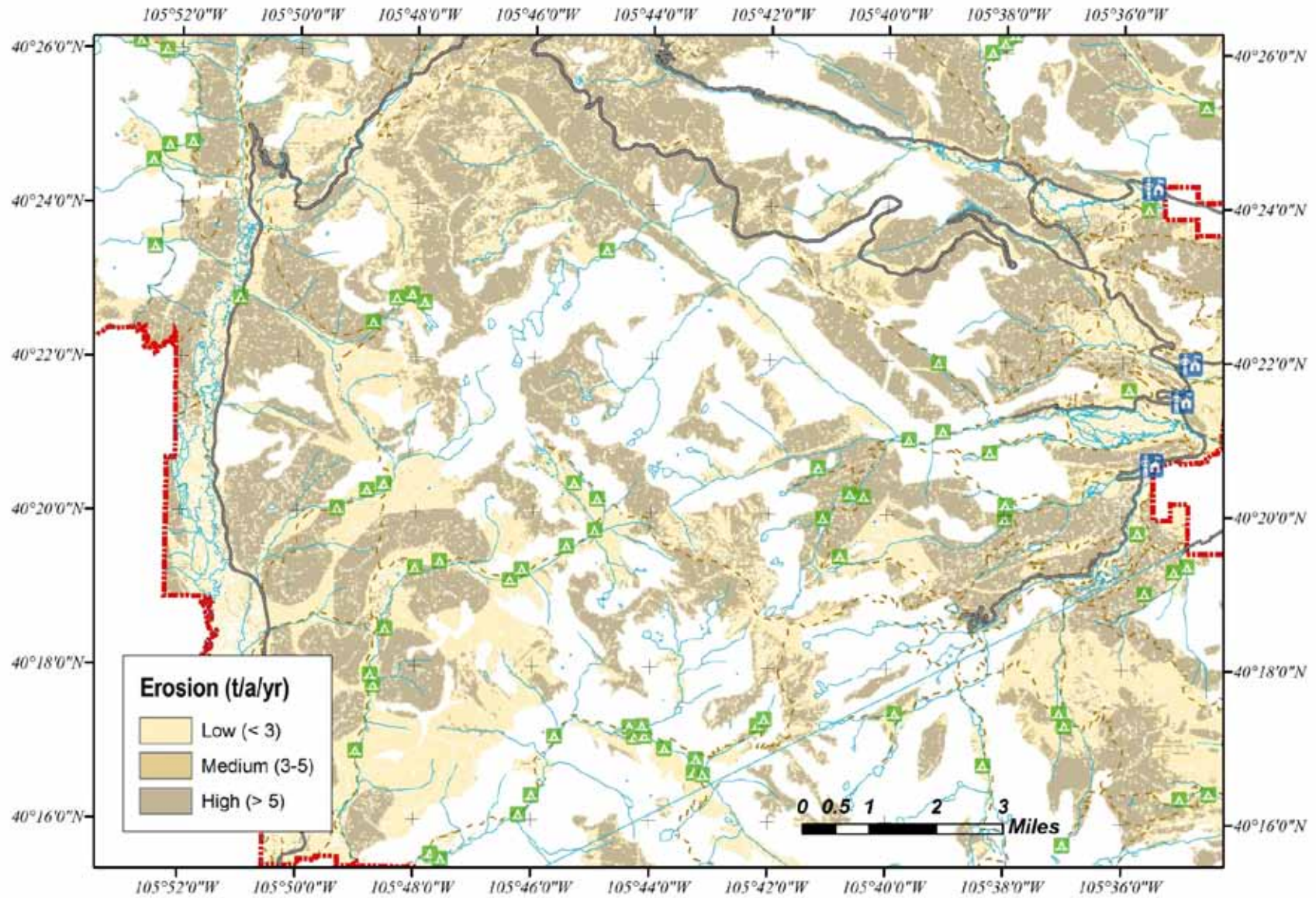


Figure 11 – Potential soil erosion (**West**) in ROMO after pine beetle disturbance.

Potential Soil Erosion

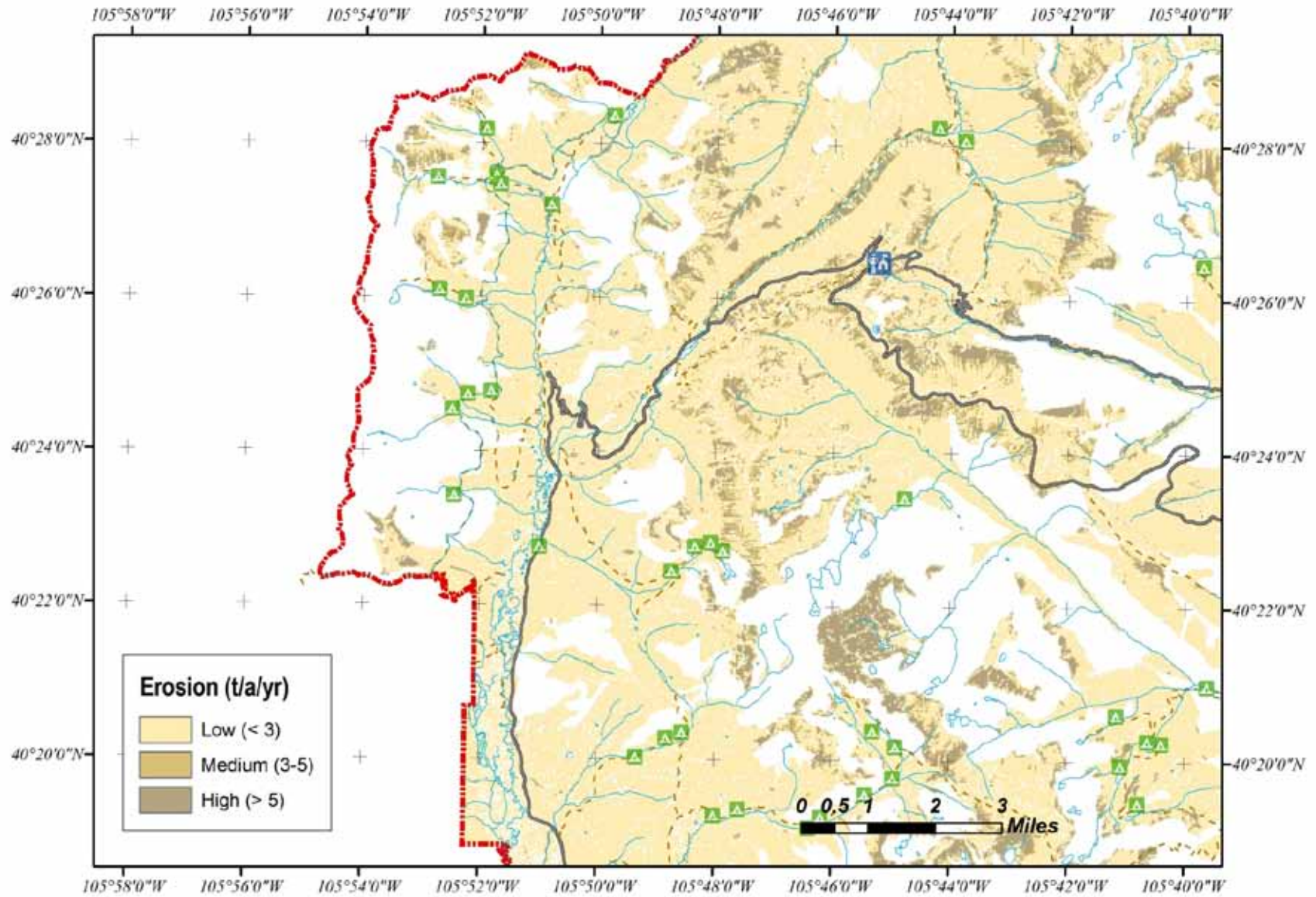


Figure 12 – Potential soil erosion (**Northwest**) in ROMO according to current vegetation distribution.

Potential Soil Erosion (Post-Pine Beetle)

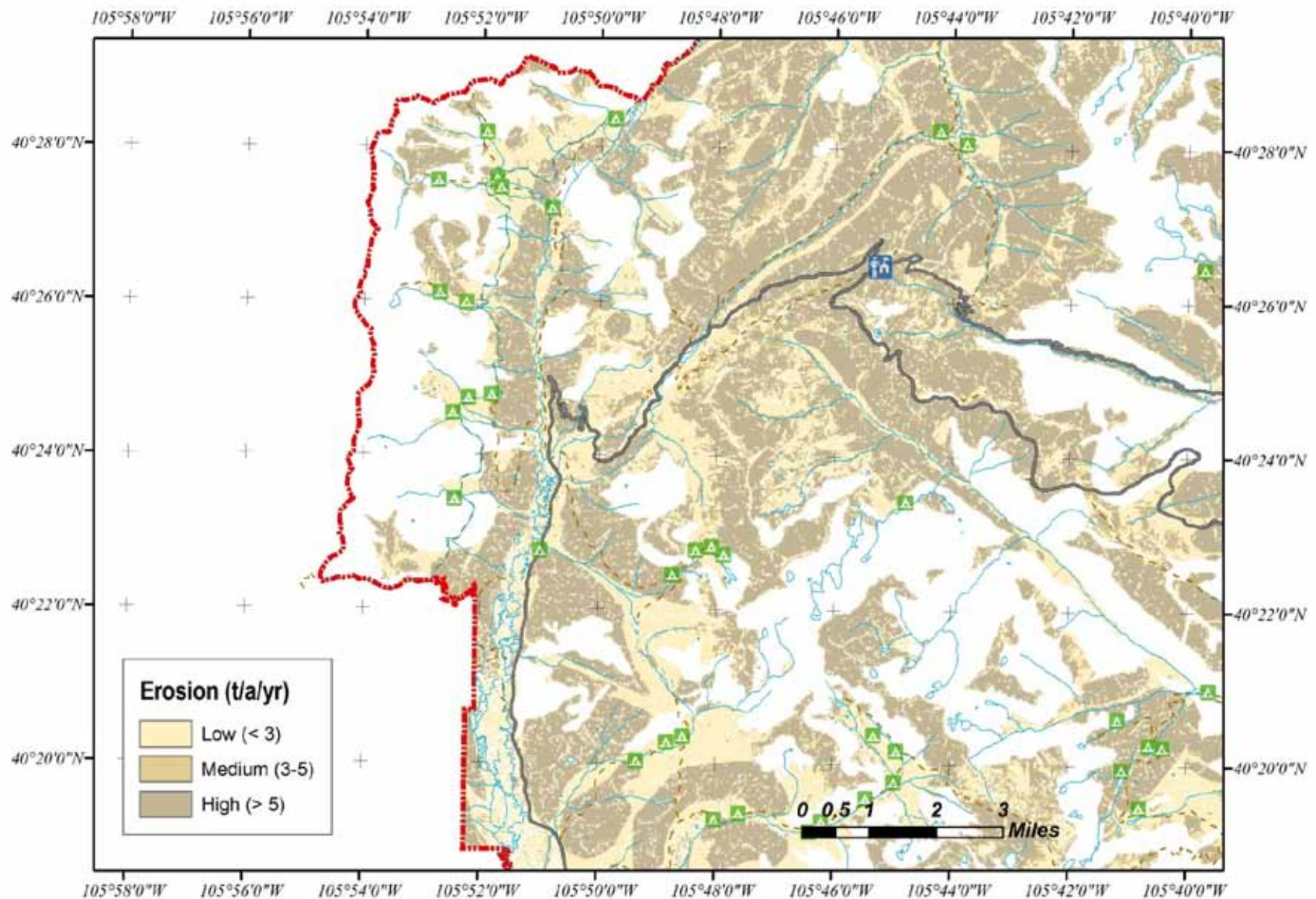


Figure 13 – Potential soil erosion (**Northwest**) in ROMO after pine beetle disturbance.

Table 3 – Trails potentially affected by soil erosion.

<i>Before Pine Beetle</i>					<i>After Pine Beetle</i>				
Trail Name	None	Low	Medium	High	Trail Name	None	Low	Medium	High
JIMS GROVE TRAIL	7%	40%	5%	48%	BOWEN-BAKER GULC	0%	0%	0%	100%
ALLUVIAL FAN TRA	52%	6%	0%	42%	TWIN-GEM TRAIL	3%	0%	0%	97%
EAST LONGS PEAK	11%	52%	3%	34%	BEAR LAKE BYPASS	3%	0%	0%	97%
STORMY PEAKS PAS	9%	59%	3%	30%	BIERSTADT MORAIN	8%	0%	0%	92%
UPPER SECTION PO	9%	52%	9%	29%	EMERALD MOUNTAIN	7%	4%	0%	89%
BIERSTADT LAKE T	11%	53%	7%	29%	HANDICAMP TRAIL	13%	0%	0%	88%
CHASM LAKE TRAIL	47%	24%	0%	29%	LOWER BIERSTADT	5%	10%	0%	85%
CHAPIN CREEK TRA	11%	59%	9%	21%	NORTH DEER MOUNT	8%	9%	0%	84%
NORTH LONGS PEAK	17%	63%	0%	20%	SPRUCE LAKE TRAI	16%	0%	0%	84%
LILY LAKE TRAIL	73%	9%	0%	19%	BEAR LAKE-MILL C	14%	4%	0%	82%
WEST CREEK FALLS	21%	54%	7%	18%	SPECIMEN MOUNTAI	12%	5%	2%	82%
ANDREWS GLACIER	49%	34%	0%	17%	YPSILON LAKE TRA	16%	3%	0%	81%
HUTCHESON LAKE T	16%	69%	0%	14%	ASPENGLN CMPGD	19%	0%	2%	79%
SADDLE TRAIL	20%	60%	6%	14%	BEAVER MOUNTAIN	7%	14%	1%	78%
FLATTOP MOUNTAIN	43%	44%	0%	13%	UTE-BEAVER MOUNT	14%	10%	0%	76%
CRYSTAL LAKE TRA	57%	25%	7%	11%	SANDBEACH LAKE T	10%	16%	0%	73%
MACGREGOR FALLS	19%	69%	1%	11%	CHAPIN CREEK TRA	10%	15%	3%	73%
EAST SHORE TRAIL	11%	79%	0%	10%	JIMS GROVE TRAIL	8%	19%	1%	71%
BEAR LAKE-FERN L	13%	77%	0%	10%	BEAR LAKE TRAIL	29%	0%	0%	71%
CHAPIN CLIMBERS	12%	77%	3%	8%	BEAR-MILL-BIERST	21%	8%	2%	70%

reduce the rate at which sediment flows over the logs, repositioning sediment along the slope rather than downslope (Grab and Kalibbala 2008). It may be possible to contour naturally fallen dead trees along the hillslope to slow downslope displacement of soil. Seeding and fertilization does little to reduce erosion; in fact, seed mixes outcompeted native species following a disturbance and reduced the number of tree seedlings (Dodson and Peterson 2009). Removing dead trees or snags through salvage logging may seem logical, but also has implications. Salvage logging can reduce biological native species following a disturbance and reduced tree seedlings (Dodson and Peterson 2009). Removing dead trees or snags through salvage logging may seem logical, but also has implications. Salvage logging can reduce biological legacies, modify rare habitats, alter populations and community composition, impair natural recovery, increase erosion, alter soil nutrients, modify the hydrologic regime, or increase invasive species occurrence (Lindenmayer and Noss 2006).

Conclusions

About 6% of ROMO currently consists of high-risk areas with erosion potential greater than 5 tons/acre/year. Four regions of ROMO were identified that have high erosion potential: 1) east of Long's Peak; 2) along Stormy Peaks Pass Trail; 3) along the Continental Divide near the southern edge of the Park's boundary; and 4) in the Hayden Lake area. Jim's Grove Trail, the Alluvial Fan Trail, East Long's Peak Trail, and Stormy Peaks Pass Trail have more than 30% of their extent underlain by highly erosive soils. Rates of soil erosion could be adversely affected by reducing vegetation cover from pine beetle dieback. After tree mortality, approximately 33% of ROMO has potential erosion rates greater than 5 tons/acre/year. In the future, soils in these areas will be exposed to falling precipitation that was previously shielded and slowed by interception from the pine trees. Fire can further increase the erosion potential by reducing the moisture holding capacity of the soil, leading to greater runoff. In areas of excessive dieback and high erosion, trees that have fallen should be contoured with the hillslope to slow the movement of sediment from upslope areas. The GIS methods employed in this study provide a cost-effective method to identify high-risk areas over a large geographic region; however, the model results should be verified and monitored in the field.

References

- Chafer, C.J., 2008. A comparison of fire severity measures: An Australian example and implications for predicting major areas of soil erosion. *Catena*, 74(3): 235-245.
- Descroix, L. et al., 2008. Gully and sheet erosion on subtropical mountain slopes: Their respective roles and the scale effect. *Catena*, 72(3): 325-339.
- Dodson, E.K. and Peterson, D.W., 2009. Seeding and fertilization effects on plant cover and community recovery following wildfire in the Eastern Cascade Mountains, USA. *Forest Ecology and Management*, 258(7): 1586-1593.

- Dymond, J.R., Betts, H.D. and Schierlitz, C.S., An erosion model for evaluating regional land-use scenarios. *Environmental Modelling & Software*, 25(3): 289-298.
- Gabet, E.J. and Bookter, A., 2008. A morphometric analysis of gullies scoured by post-fire progressively bulked debris flows in southwest Montana, USA. *Geomorphology*, 96(3-4): 298-309.
- Grab, S. and Kalibbala, F., 2008. 'Anti-erosion' logs across paths in the southern uKhahlamba-Drakensberg Transfrontier Park, South Africa: Cure or curse? *Catena*, 73(1): 134-145.
- Kaniewski, D., Paulissen, E., De Laet, V. and Waelkens, M., 2008. Late Holocene fire impact and post-fire regeneration from the Bereket basin, Taurus Mountains, southwest Turkey. *Quaternary Research*, 70(2): 228-239.
- Keay-Bright, J. and Boardman, J., 2007. The influence of land management on soil erosion in the sneeuberg mountains, central Karoo, south Africa. *Land Degradation & Development*, 18(4): 423-439.
- Lindenmayer, D.B. and Noss, R.F., 2006. Salvage logging, ecosystem processes, and biodiversity conservation. *Conservation Biology*, 20(4): 949-958.
- Moody, J.A. and Martin, D.A., 2009. Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States. *International Journal of Wildland Fire*, 18(1): 96-115.
- Pickering, C.M., Hill, W., Newsome, D. and Leung, Y.F., Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. *Journal of Environmental Management*, 91(3): 551-562.
- Pierson, F.B., Moffet, C.A., Williams, C.J., Hardegree, S.P. and Clark, P.E., 2009. Prescribed-fire effects on rill and interrill runoff and erosion in a mountainous sagebrush landscape. *Earth Surface Processes and Landforms*, 34(2): 193-203.
- Rulli, M.C. and Rosso, R., 2007. Hydrologic response of upland catchments to wildfires. *Advances in Water Resources*, 30(10): 2072-2086.
- Wondzell, S.M. and King, J.G., 2003. Postfire erosional processes in the Pacific Northwest and Rocky Mountain regions. *Forest Ecology and Management*, 178(1-2): 75-87.
- Yue-Qing, X., Xiao-Mei, S., Xiang-Bin, K., Jian, P. and Yun-Long, C., 2008. Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. *Environmental Monitoring and Assessment*, 141(1-3): 275-286.