Background and Methods

The final contract report on water quality and road effects was submitted and approved by the CFLR in May 2014. At that time road sediment delivery analysis based on the Geomorphic Roads Analysis and Inventory Procedure (GRAIP) (Cissell et al. 2014) was available for seven of 11 stream sites monitored intensively for water quality in 2013 (Rieman and Wallenburn 2014). Since that time the GRAIP tool kit has been extended with a modeling procedure known as GRAIP-Lite (Nelson et al 2014). The new methods allow estimation of road sediment delivery for all watersheds across the Southwest Crown that lack a complete GRAIP inventory. GRAIP-Lite is a GIS based modeling approach that relies on existing road coverages and calibration with available GRAIP inventory and erosion plot information. Although GRAIP-Lite has important limitations, it does provide a method of estimating potential road-sediment delivery that should be more refined than simple metrics of road, or road-stream crossing, densities commonly used in the past.

Our original report concluded important differences did exist in water quality among 11 intensively sampled streams; that total P concentrations were associated with turbidity that could be influenced by upstream erosion; that turbidity, phosphorous and nitrogen tended to be elevated simultaneously in some streams but reflect different watershed processes; and that long-term changes in water quality associated with watershed conditions were detectable with our methods. We also observed direct road effects on some small, tightly connected road-stream networks. But the general associations between road effects and water quality were equivocal, limited by sample size (complete data were available for only 7 of the 11 streams), and the magnitude of estimated upstream road effects.

Here, we have extended the original work to associate estimates of road effects and in-stream measures of water quality to all available sites using the GRAIP-Lite information. We have added four sites (Deer Creek, Mountain Creek, Seeley Creek, and Rice Creek) that include complete water quality information (i.e. Total P, Total N and turbidity) and three sites (Drew Creek, Richmond Creek, Sawyer Creek) that
include only turbidity. Because this work was a pilot analysis we relied on simple scatter plots to examine possible relationships. Our methods were identical to those described in Rieman and Wallenburn (2014) with the exception that we use GRAIP-Lite estimates of road sediment delivery at the point of the water quality sample rather than the original GRAIP sediment delivery estimates from the complete inventory. We included a plot of the GRAIP estimates of sediment delivered to the seven original stream sites against the GRAIP-Lite estimates for those same streams as a validation of the new approach. We used estimated sediment delivery normalized by watershed area (tons/km²) as our measure of erosion for both GRAIP and GRAIP-Lite. Because watershed area is generally correlated with water discharge across streams in similar settings, it should relate directly to concentrations (e.g. mg/l) of suspended sediment and thus turbidity or related materials (e.g. phosphorous) that we measured in those streams.

Results

The original GRAIP estimates did show a positive association with the GRAIP-Lite estimates for available samples (Figure 1). This result supports the use of GRAIP-Lite as an index of road erosion in our watersheds. We note, however, that GRAIP-Lite tends to over predict sediment delivery measured by GRAIP at the lower effect levels.

There were no apparent associations between GRAIP-Lite estimated sediment delivery and water quality parameters (Total P, Total N, Turbidity) for the 11 intensively sampled streams (Figure 2) or for the 14 streams that included only turbidity measurements (Figure 3). The apparent bias in GRAIP-Lite estimates at lower effect levels does not contribute to the lack of an apparent relationship because any correction would shift the points with lower sediment delivery estimates even further to the left.

Discussion

GRAIP-Lite does appear to provide a simple index of the detailed full GRAIP inventory based erosion estimates and therefore a more spatially extensive set of road effects data that may be used to consider watershed conditions across the SWCC landscape. We found no apparent relationships, however, between the estimates of sediment delivery and in stream water quality measured in 2013.

We were surprised by the results. Despite these data we do have several indications that roads and watershed disruption associated with roads can have important effects on in-stream water quality that neither GRAIP nor GRAIP-Lite seemed to capture. First, we observed turbidities in Drew Creek more than an order of magnitude higher than any other streams (Figure 3); observations that were clearly and directly influenced by road runoff (Rieman and Wallenburn 2014). Second, in 2013 Blind Canyon Creek had the second highest turbidity and among the highest total P observed in any stream. In 2013, we traced the source of turbidity to a failed
road prism and avalanche chute that did not appear to cause any increased turbidity in 2014. Third, Deer Creek, a stream with a history of water quality problems associated with intensive logging, had relatively low estimates of current sediment delivery. The GRAIP-Lite field calibration observed very high values of road surface vegetation cover leading to low current erosion rates. Although our water quality work showed substantial improvement in Deer Creek nutrient concentrations in the last 40 years, turbidities and nutrient concentrations were still among the highest in our sample of streams (Rieman and Wallenburn 2014).

These observations are largely anecdotal, but they do suggest that care is required when relating average annual sediment delivery results to storm-event scale turbidity observations. We know for example that road surface erosion is strongly influenced by road maintenance and use. Existing erosion plots used to calibrate the models show nearly an order of magnitude increase in road surface erosion between open and closed roads (Black et al 2014, Cissel et al 2014). The GRAIP models used here were calibrated assuming an average level of road use and road-stream connectivity common across all roads and watersheds. Drew Creek drains a portion of the Double Arrow subdivision with very heavy road traffic, poorly designed road drainage (see Rieman and Wallenburn 2014, Figure 16) and other maintenance issues. Accounting for very high levels of use and unusual stream-road connectivity might substantially increase the estimates of sediment delivery from the roads in the Drew Creek watershed.

In Blind Canyon, the original GRAIP inventory did identify the failed road segment as an important source of sediment to the stream. That effect was relatively minor at the watershed scale and essentially diluted in the estimates of sediment delivered to the water quality sampling point. It also appears that the turbidity we observed in Blind Canyon Creek may be more episodic than chronic. Although GRAIP clearly identified the problem area, the estimates may better reflect watershed averages through time rather than maximums observed in individual years. GRAIP-Lite cannot account for mass failures, and also reflects averages for similar watersheds across the range of watersheds used to calibrate the underlying model. The bottom line is that the GRAIP models may be more useful for long-term estimates of erosion and water quality responses that are not strongly influenced by year to year variation or episodic events.

In Deer Creek few if any roads have actually been removed from the landscape, but many roads have been gated or otherwise limited in use and it may be that traffic has greatly reduced from that during the intensive forest harvest of the 1970s. Perhaps the sediment and nutrient concentrations observed in recent years are the lagged effects of erosion also associated with much more intensive road use in the past.

**Conclusions**
Road effects on in-stream conditions definitely occur, but could not be resolved in our analysis of GRAIP-Lite erosion estimates and water quality measurements.

GRAIP-Lite does correlate with the full GRAIP inventory, but a better understanding of road use, stream connectivity, and the storage and fluvial transport of eroded road sediment may be needed to understand local conditions and legacy road effects.

Water quality does vary substantially among streams and within streams across time. Roads can have an important influence on that, but other processes are likely important as well.

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References


Rieman, B. and J. Wallenburn. 2014. Water quality monitoring to determine the influence of roads and road restoration on turbidity and downstream nutrients:

Figure 1. Scatter plot of estimated sediment delivered to stream sites based on the original GRAIP road inventory against the GRAIP-Lite estimates for those same sites. The 7 stream sites are those intensively sampled for water quality in 2013 that also had complete GRAIP inventory available (see Rieman and Wallenburn 2014). The line represents a 1:1 relationship.
Figure 2. Scatter plots of turbidity, total Phosphorous, and total Nitrogen from 11 intensively sampled streams in 2013 against estimated sediment delivery from GRAIP-Lite. The three columns of figures represent different summaries of the data as described in Rieman and Wallenburn (2014).
Figure 3. Scatter plots of turbidity from 14 streams sampled in 2013 against estimated sediment delivery from GRAIP-Lite. The 14 streams include 11 streams in Figure 2 and 4 additional streams that were sampled by volunteers only for turbidity. Three points are highlighted in the middle figure: Drew Creek (highest turbidity), Blind Canyon Creek (second highest), and Deer Creek (third highest). Drew and Blind Canyon had clear road related effects on turbidity. Deer Creek has a history of water quality impairment associated with intensive forest management and roads. Note the log scale for turbidity.