

**MASS WASTING PRESCRIPTION-SCALE EFFECTIVENESS
MONITORING PROJECT (POST-MORTEM)
Quality Assurance /Quality Control (QA/QC) Report**

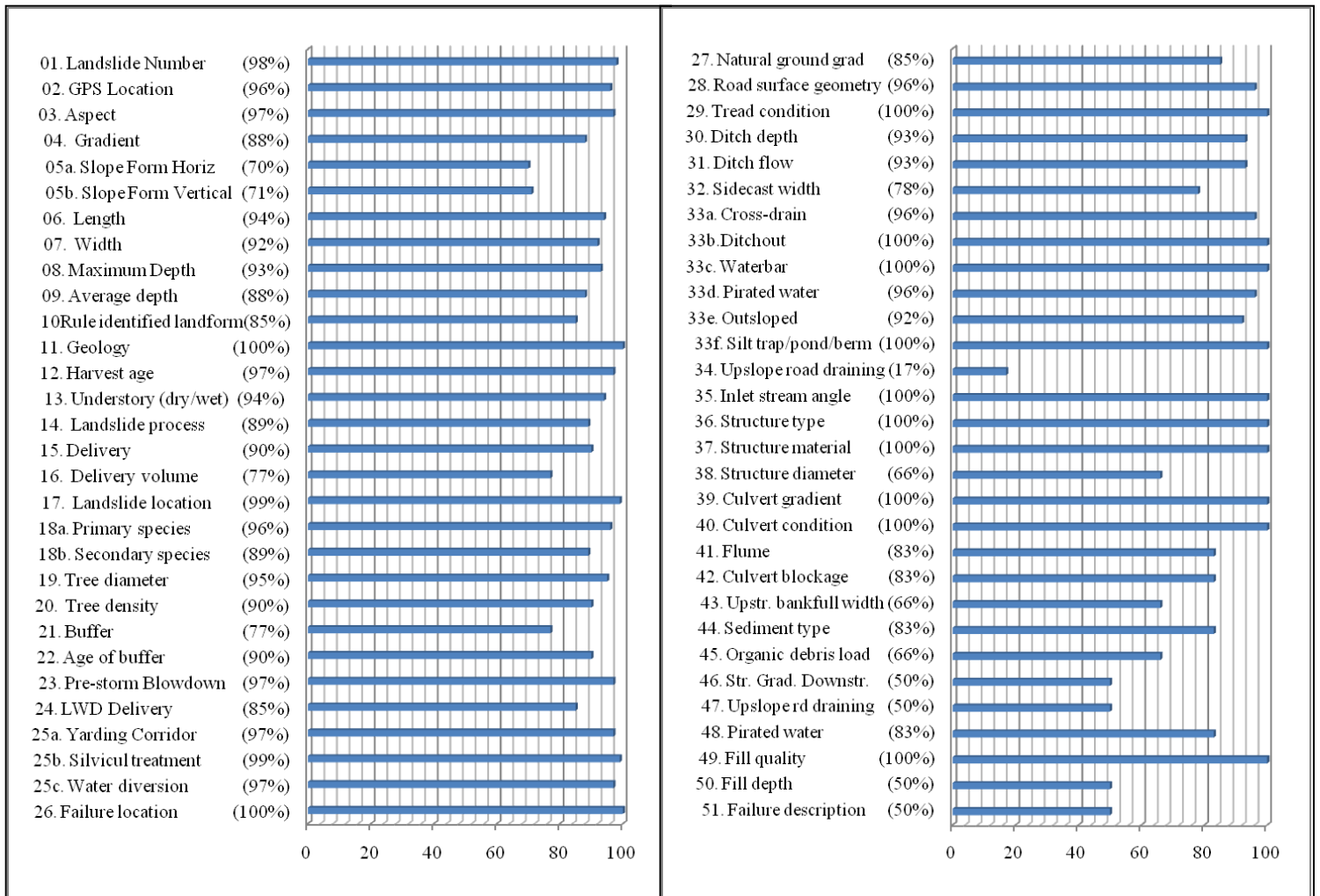
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Prepared by

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Executive Summary

This report presents the Quality Assurance/Quality Control (QA/QC) Team's findings of the Post-Mortem Team's data collection at individual landslides. The Post-Mortem Team collected 60 data categories to tabulate basic information about each landslide and to examine the relationships between forest management activities and the landslides produced by the December 2007 storm in Southwest Washington. Landslides were evaluated for physical attributes, initiation settings, sediment delivery, and relationships to forest management activities. The QA/QC Team evaluated observations made by the Post-Mortem Team. Approximately 10% of the landslides evaluated by the Post-Mortem Team were examined by the QA/QC Team for consistency and validity. The QA/QC Team's findings are summarized in the chart below and more completely on the following two pages.



**Summary showing the agreement between observations of the Post-Mortem Team
and the QA/QC Team on various parameters examined during this study**

Primary Data Sheet

1. Landslide number	98% agreement (162 of 165 landslides)
2. GPS location	96% agreement (144 of 150 landslides)
3. Aspect	97% agreement (140 of 144 landslides)
4. Gradient at failure site	88% agreement (126 of 144 landslides)
5. Slope form	
Slope form - horizontal (map view)	70% agreement (101 of 144 landslides)
Slope form - vertical (profile view)	71% agreement (103 of 144 landslides)
6. Length of a landslide	94% agreement (136 of 144 landslides)
7. Width of landslide	92% agreement (133 of 144 landslides)
8. Maximum depth of landslide	93% agreement (134 of 144 landslides)
9. Average depth of landslide	88% agreement (127 of 144 landslides)
10. Rule-identified landforms	85% of the time (123 of 144 landslides)
11. Geology	100% agreement (144 of 144 landslides)
12. Harvest unit age	97% agreement (140 of 144 landslides)
13. Understory vegetation	
at initiation site (dry or wet)	94% agreement (136 of 144 landslides)
14. Landslide process (debris slide, debris flow, debris avalanche, deep-seated landslide, dam break flood)	89% agreement (128 of 144 landslides)
15. Delivery to typed water	90% agreement (129 of 144 landslides)
16. Sediment delivery volume	77% agreement (111 of 144 landslides)
17. Landslide location (hillslope-no road, hillslope-road or stream crossing road)	99% agreement (143 of 144 landslides)

Hillslope – No-road Data Sheet

18. Overstory tree composition	
Primary species	96% agreement (106 of 110 landslides)
Secondary species	89% agreement (98 of 110 landslides)
19. Tree diameter	95 % agreement (104 of 110 landslides)
20. Tree density	90 % agreement (99 of 110 landslides)
21. Buffer of unstable landforms	77% agreement (85 of 110 landslides)
22. Age of buffer	82% agreement (90 of 110 landslides)
23. Pre-storm blowdown	97% agreement (107 of 110 landslides)
24. LWD delivery	85% agreement (92 of 108 landslides)
25. Contributing factors	
Yarding corridor	97% agreement (107 of 110 landslides)
Silvicultural treatment	99% agreement (109 of 110 landslides)
Water diversion	97% agreement (107 of 110 landslides)

Hillslope - Road Data Sheet

26. Failure location	100% agreement (27 of 27 landslides)
27. Natural ground gradient	85% agreement (23 of 27 landslides)
28. Road surface geometry	96% agreement (26 of 27 landslides)
29. Tread condition	100% agreement (27 of 27 landslides)
30. Ditch depth	93% agreement (25 of 27 landslides)
31. Ditch flow	93% agreement (25 of 27 landslides)
32. Sidecast width	78% agreement (21 of 27 landslides)
33. Drainage	
Cross-drain to failure site	96% agreement (26 of 27 landslides)
Ditchout to failure site	100% agreement (27 of 27 landslides)
Waterbar to failure site	100% agreement (27 of 27 landslides)
Pirated water from channel to site	96% agreement (26 of 27 landslides)
Outsloped road water to failure site	92% agreement (24 of 26 landslides)
Silt trap/pond/berm in fillslope	100% agreement (27 of 27 landslides)
34. Upslope road distance draining to site	26% agreement (7 of 27 landslides)

Stream Crossing Road Data Sheet

35. Inlet stream angle	100% agreement (6 of 6 landslides)
36. Structure type	100% agreement (6 of 6 landslides)
37. Structure material	100% agreement (6 of 6 landslides)
38. Structure diameter	66% agreement (4 of 6 landslides)
39. Culvert gradient	100% agreement (6 of 6 landslides)
40. Culvert condition	100% agreement (6 of 6 landslides)
41. Flume	83% agreement (5 of 6 landslides)
42. Culvert blockage	66% agreement (4 of 6 landslides)
43. Upstream bankfull width	66% agreement (4 of 6 landslides)
44. Sediment type	83% agreement (5 of 6 landslides)
45. Organic debris load	66% agreement (4 of 6 landslides)
46. Stream gradient downstream	50% agreement (3 of 6 landslides)
47. Upslope road draining to site	17% agreement (1 of 6 landslides)
48. Pirated water to site	83% agreement (5 of 6 landslides)
49. Fill quality	100% agreement (6 of 6 landslides)
50. Total fill depth at outlet	50% agreement (3 of 6 landslides)
51. Failure description	50% agreement (3 of 6 landslides)

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Introduction

This report summarizes a portion of the Quality Assurance and Quality Control (QA/QC) program used to evaluate the Post-Mortem Project. The Post-Mortem Project was implemented after the December 2007 storm in Southwest Washington to study landslides and their relationship to forest management activities. The project was designed to be a mass wasting prescription-scale effectiveness monitoring study implemented (as soon as possible) after a storm event that generated a sufficient population of landslides for statistical analysis. The study was intended to investigate landslides soon after their occurrence for maximized diagnostic value by reducing the obscuring effects of re-vegetation, road repair, or other post-landslide processes. Storm-related landsliding was to be analyzed in areas that contain a variety of forest management treatments.

The December 2007 storm event fulfilled all of the criteria necessary to implement the Post-Mortem Project Plan. Post-storm aerial photographs were taken and analyzed to locate and map landslides as well as stratify harvest and road treatments. A team of field investigators consisting of up to twenty individuals with training in geology, geomorphology, hydrology, forestry, and/or forest engineering were hired to find and collect data on individual landslides. Landslide headscarp area was measured, the initiation point was mapped, potential triggering mechanisms were identified, and sediment delivery was documented. Field crews located landslides that were not observable on photos by traversing the stream network and driving or walking road networks to locate all road-related landslides.

A QA/QC Team was assembled and trained during the latter part of the Post-Mortem Project to investigate accuracy, consistency, and possible bias related to data collected in order to evaluate the validity of field data generated by the Post-Mortem investigation.

Methodology

The QA/QC Team consisted of a small group of geologists, biologists, and foresters with extensive experience in unstable slopes, forestry and/or forest practices. On September 3 and 4, 2008, six QA/QC investigators were trained in data collection and interpretation techniques used by the Post-Mortem field investigation team. The QA/QC investigators included: Teresa Moon, Jack Powell, Gabriel Legorreta-Paulin, Matt O'Connor, Amy Kurtenbach, and Garth Anderson. Day one was a classroom session summarizing key elements of the Post-Mortem Study Plan and the Post-Mortem Field Manual, followed by a minimum one-day field session working with the field staff. The classroom presentations served to familiarize the QA/QC Team with the Study Plan, Field Manual, field techniques, data collection format, and field equipment. Particular emphasis was given to discussion of various situations field personnel were likely to encounter during the project. Day two was a field session where QA/QC investigators worked alongside a field team to familiarize the investigators with the techniques used by the field team to ensure consistent interpretation.

To ensure consistency of observations with the QA/QC Team, Jack Powell and/or Teresa Moon participated in all QA/QC field investigations. Paper copies of landslide data sheets and location maps were generated by O'Connor Environmental and provided to the QA/QC Team for 5% of the landslides investigated by the Post-Mortem Teams in each of the 21 four square mile study clusters. The landslides to be reviewed were not selected randomly. Review sites needed to be somewhat accessible and in one continuous block such as within the same quarter section. The QA/QC Team spent one day in each of the 21 four square-mile clusters, evaluating as many of the landslides as possible. Landslides were measured and evaluated independently by the QA/QC Team, then compared to the Post-Mortem Team's observations to determine if they appeared reasonable. The QA/QC Team definition of reasonable varied with the parameter being reviewed, however, it generally referred to the Team's ability to reproduce the observation in the field or to determine that the observation variation had a small margin of error (e.g., within one standard deviation). The findings are discussed more specifically under the related observations below.

The QA/QC Team reviewed 165 landslides. Twelve landslides were not inventoried by the Post-Mortem Team or the data sheets were not available to the QA/QC Team during the field study, therefore, these were eliminated from any statistical comparisons. Eight additional landslides were eliminated from the evaluation due to the QA/QC Team's inability to determine whether or not they were investigating the same landslide as the Post-Mortem Team. This was largely due to two factors: 1) Poor GPS signal when the Post-Mortem Team mapped the landslides, making it difficult to re-locate or 2) Numerous landslides in close proximity that were not flagged making it difficult to know exactly which landslides should be evaluated. The number of landslides commonly used in most comparisons between the findings of the QA/QC Team and the Post-Mortem Team was 144, although in some cases landslides were omitted from some of the comparisons due to uncertainties related to specific elements being evaluated.

Findings

The findings of the QA/QC investigation will be discussed in the same order as they appear on the four field collection data sheets. The four data sheets are: primary data (data that was collected at all landslides), hillslope-no-roads, hillslope roads, or stream crossings at roads. Additionally, a spreadsheet (Appendix A) has been attached to this report summarizing the Post-Mortem Team's and QA/QC Team's field measurements and determinations for the 165 landslides evaluated during the QA/QC process.

Primary Data Sheet

1. Landslide number - 98% agreement (162 of 165 landslides)

Of the 165 landslides, only three were found to have been mis-numbered in the field. From approximately one third of the way through the field season, the Post-Mortem Team flagged and numbered landslides with survey ribbon. The un-flagged landslides surveyed early in the investigation created a problem for the QA/QC Team in

determining whether the correct landslide was being evaluated. This was especially true if landslides were closely spaced, GPS coverage was poor, or where potentially unmapped landslides were located by the QA/QC Team. If the QA/QC Team was not confident that they collected data at the correct landslide, it was determined that this data could not be used in the QA/QC analysis.

2. GPS location - 96% agreement (144 of 150 landslides)

GPS locations were generally excellent, however, in areas of thick canopy and/or topographic shading the Post-Mortem Team GPS locations of the landslides could vary from the actual location by up to 200 feet. These variations were based on topographic relationships and a 2008 Washington DNR 40 foot contour map program loaded onto a seemingly reliable Garmin 76csx GPS which was not notably affected by canopy cover and only rarely influenced by topographic shading. The QA/QC team only evaluated landslide locations that had been plotted on maps (not actual geographic coordinates). Transfer of data from field data recorders used by the Post-Mortem Teams to the GIS may have also introduced a slight error. The variation in GPS coordinates resulted in confusion or inability to identify specific landslides for the QA/QC Team where the landslides were not flagged and labeled in the field. At these locations, it was difficult for the QA/QC Team to know if they were reviewing the correct landslide. Six landslides were eliminated from QA/QC comparisons because the location error made it difficult to determine if the correct landslide was being evaluated.

3. Aspect - 97% agreement (140 of 144 landslides)

The QA/QC Team agreed with the Post-Mortem Team 97% of the time when evaluating this parameter (140 of 144 landslides). Overall the difference between the aspect determination by QA/QC and the Post-Mortem Team was 17°. This average difference was derived by dividing the difference between the aspect determination of the QA/QC and the Post-Mortem Teams by the number of landslides reviewed during the QA/QC process. The irregular shape of landslides could produce a wide variation in possible aspect readings. The QA/QC Team assumed that Post-Mortem Team's aspect readings were reasonable if it could be reproduced in the field or if it was within the same half quadrant (i.e., 45°). Four readings appeared truly anomalous (i.e., greater than 55° variation). In one case the readings were 180° off of any possible reading, indicating that possibly the Post-Mortem field crew recorded the reading from the wrong end of the compass.

The QA/QC Team used a magnetic declination correction of 18°. Some of the variation in aspect between the QA/QC Team and Post-Mortem Team may be partly due to the Post-Mortem Team using incorrect magnetic declination corrections. This may have provided a maximum 36° error (see Figure 1). Given the large potential for variation in this measurement from the irregular nature of landslides it was not possible to say whether any declination error was made in any given landslide.

Differences in aspect readings between the QA/QC Team and the Post-Mortem Team for 144 landslides.

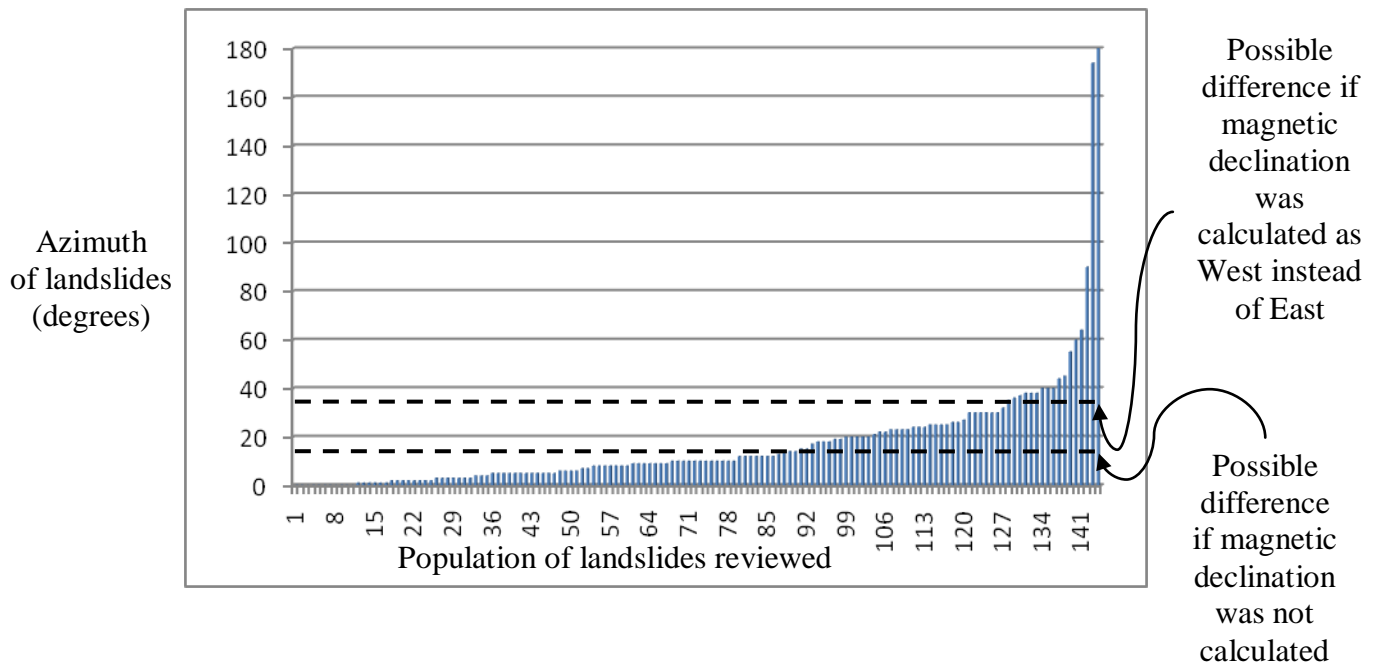


Figure 1. Graph showing the difference between aspect readings determined by the QA/QC Team and the Post-Mortem Team for landslides reviewed during the QA/QC process. Only four landslides were truly anomalous: however, disagreements between readings determined by the two teams were common, but still reasonable. Part of this may be due to the natural variation in determining aspect, although some of the error may be related to not using or misusing the magnetic declination correction.

4. Gradient at failure site - 88% agreement (126 of 144 landslides)

The Post-Mortem Field Manual describes how to measure the gradient of the hillslope adjacent to the landslide initiation elevation. It states “Using a clinometer, measure the gradient of the hillslope ADJACENT to the landslide initiation (Figure 2). If the landslide initiated within a road fillslope, measure the adjacent fillslope gradient. If the landslide initiated within a road cutslope, measure the adjacent cutslope gradient. For consistency, the measurement should be taken facing down the slope and over a length of at least 20 feet where possible. (*Be careful to record the gradient in percentage (%), not degrees – both are displayed inside most clinometers.*)” Figure 2, taken from the Field manual, illustrates how to measure slope gradient.



Figure 2. Example of measuring hillslope gradient at the failure initiation site (from Post-Mortem Field Manual Photo: Julie Dieu).

The intent of the gradient reading was to determine the steepness of the slope that failed. The QA/QC Team found this straightforward measurement could be quite difficult to measure under certain field conditions. This difficulty produced a wide range of measurements that could be considered reasonable (i.e., reasonably reproducible in the field). The average difference between the QA/QC and Post-Mortem Team slope determination was 11.5 % slope gradient. In only two cases did the Post-Mortem Team slope appear to have anomalously high slope measurements (i.e., unreasonably steep slopes). In one of these cases it appeared that the Post-Mortem Team had measured a portion of the landslide head scarp and not the pre-landslide slope gradient. In the other it appeared that the Post-Mortem Team may have recorded their measurement in degrees rather than percentage to obtain a slope gradient approximately $\frac{1}{2}$ that determined by the QA/QC Team. 75% of the landslides reviewed by the QA/QC Team had slopes greater than those determined by the Post-Mortem Team; however, the QA/QC Team found all but 18 of the 144 landslides reviewed were within a reasonable range of measurement. In some cases the Post-Mortem Team appeared to have measured the gentler slope above the landslide initiation point. This appears to be explained by the head of the landslide continuing to fail into gentler slopes. A reasonable error for gradient was defined by the QA/QC Team as being able to reproduce readings in the field considering the variation in the landslide and the difficulties in taking a field measurement or within 15% (approximately 1 standard deviation).

Figure 3 graphs variations in slope gradient determinations between the QA/QC Team and the Post-Mortem Team. On the high end of the graph it appears the Post-Mortem Team may have been recording the slope of the landslide head scarp and not the slope gradient. At the low end of the chart it appears the Post-Mortem Team was measuring the gentler slope above the landslide head and not the slope that failed. Some of these low readings may have resulted from confusion between recording slope percent and slope degree measurements.

Graph showing gradient at the failure site where the Post-Mortem Team measurements (which were reviewed by the QA/QC Team) were sorted from gentlest to steepest slopes (in blue). The QA/QC Team measurement is paired to the right of each measurement (in red).

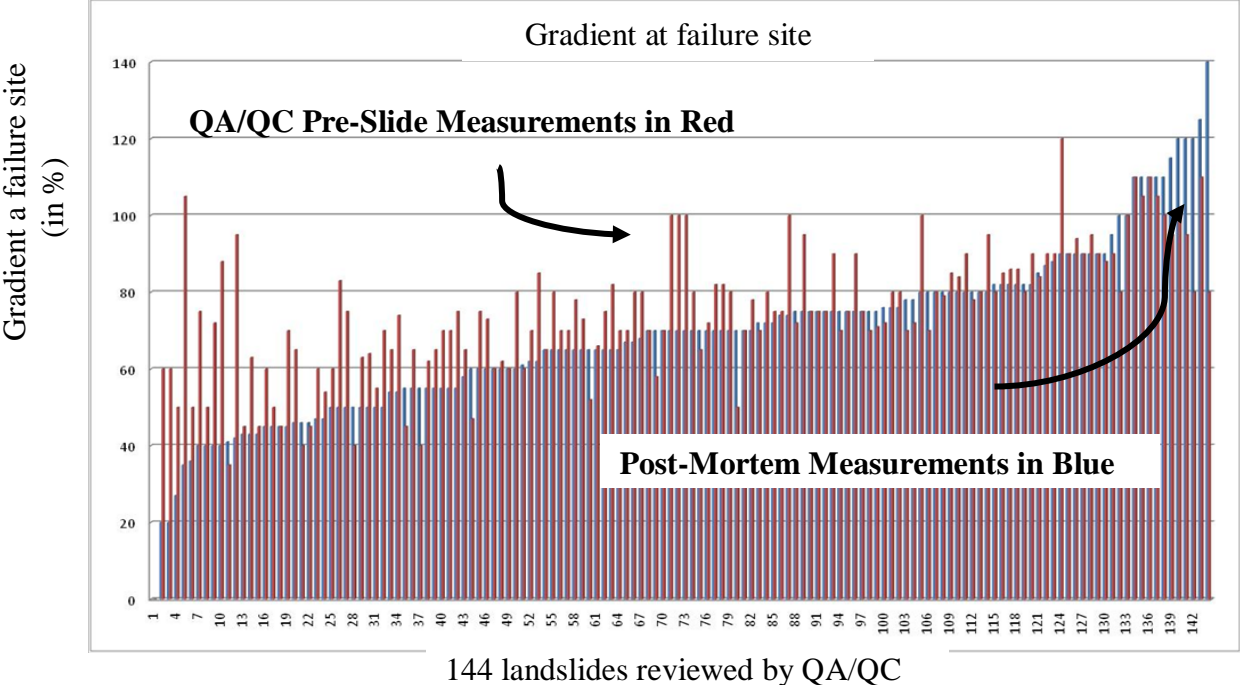


Figure 3. Although measurements were similar between the Post-Mortem and QA/QC Teams, some appear quite dissimilar at both ends of the spectrum.

Figure 4 is a graph of all slope gradients measured by the QC/QA Team and compared to the Post-Mortem Team measurements. The readings have been sorted in order from smallest to largest and appear to show consistently higher slope angle readings taken by the Post-Mortem Team than measurements taken by the QA/QC Team.

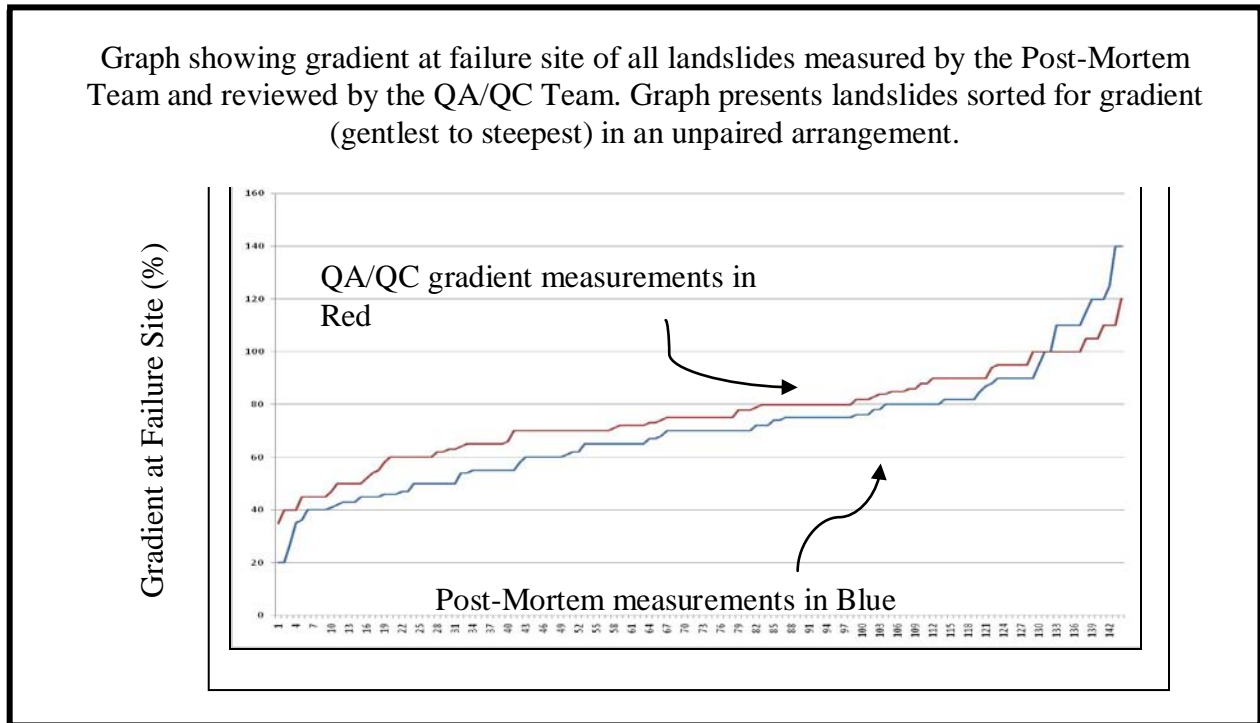


Figure 4. If the gradient at the failure site for all of the Post-Mortem Team landslides measured by the QA/QC Team are plotted in an unpaired arrangement, it appears the QA/QC Team measured steeper slope measurements than the Post-Mortem Team.

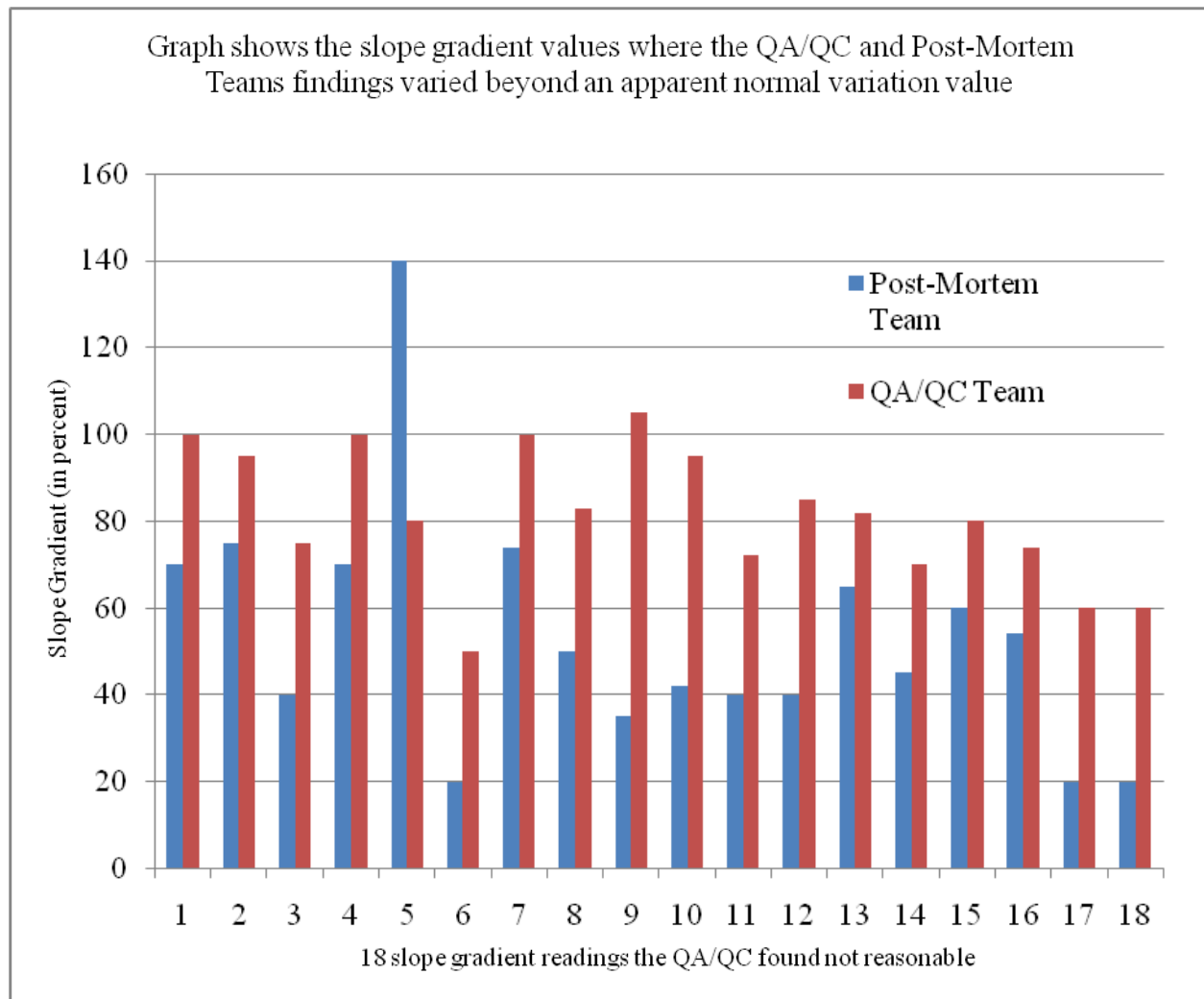


Figure 5. This graph of the 18 slope gradient readings the QA/QC Team found not reasonable, shows that all but one were below what the QA/QC Team had determined for the slope gradient adjacent to the landslide.

5. Slope form

Slope form - horizontal (map view) - 70% agreement (101 of 144 landslides)

Slope form - vertical (profile view) – 71% agreement (103 of 144 landslides)

The QA/QC Team and the Post-Mortem Team differed on pre-landslide slope form observations more often than any other type of field observation. The QA/QC Team found 30% (50 of 165) of the Post-Mortem Team’s slope form determinations to be unreasonable. In half of these cases (26 of 50) it appeared that the Post-Mortem Team determined the post landslide slope form to be convergent and concave even though the slope prior to this failure appeared to have been planar and convex or planar and concave (Figure 6). In twelve cases the Post-Mortem Team determined that landslides occurring within a bedrock hollow had failed on planar slopes. This appears to be contradictory

because bedrock hollows are convergent topographic features however it is not uncommon for bedrock hollows to contain planar areas. In 4 of 12 landslides the QA/QC Team was unable to find any planar areas in the convergent features and determined that the Post-Mortem Team's findings were in error. Two landslides which occurred where roads crossed streams were described as failing on planar slopes, however, the road fill appears to have had a convergent nature prior to its failure.

Diagram of Slope Form examples

Three examples of planar/convex or planar/planar slopes that the Post-Mortem Team commonly labeled "convergent/concave"

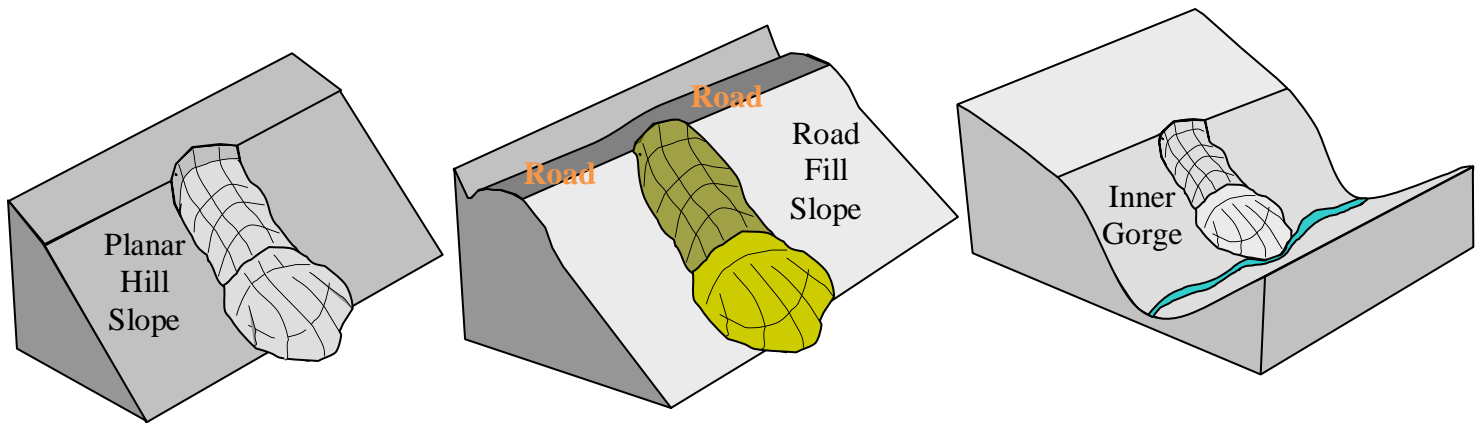


Figure 6. The Post-Mortem Team would commonly record a landslide as having occurred on a convergent/concave slope even though the slope was planar. It appeared the Post-Mortem Team was recording the post landslide slope form instead of the pre-landslide slope form. Examples of slope forms that were described as convergent/concave include planar hill slopes, planar road fill slopes, and planar side slopes of inner gorges.

6. Length of a landslide - 94% agreement (136 of 144 landslides)

The **Length** is the distance from the top of the head scarp to the point that represents the bottom of the initial failure volume; **Length** is measured as the slope distance. Indicators for the bottom of the initial failure volume include hummocky deposits and/or a narrow section of landslide width.

The QA/QC Team agreed with or found the Post-Mortem Team's measurement of the length of landslides reasonable 94% of the time. Difference in landslide length appears to have been related to one of the following factors:

1. The irregular nature of the landslide;
2. The difference between determining the length of the initial failure versus scour related to run out;
3. Confusion in measuring a shallow failure portion of a deep-seated landslide; and

4. Possible confusion in identifying the correct landslide when they were not flagged with a unique identification number in the field.

Only 8 of 144 landslides observed by the QA/QC Team had a significant variation between measurements made by the Post-Mortem Team where the QA/QC Team was unable to determine the cause of variation.

7. Width of landslide - 92% agreement (133 of 144 landslides)

The *Width* is defined in the Post-Mortem Field Manual as, “the distance between side scarps across the widest part of the scarp” (Figure 7). The irregular nature of some landslide head scarps created a fairly large variation in width measurements even among members of the QA/QC Team. Although there was significant variation between width measurements taken by the QA/QC Team and the Post-Mortem Team, most of the time rationale for this variation was apparent. This variation in measurement was especially problematic with shallow landslides occurring on active deep-seated landslides that had moved during the December 2-3, 2007 storm. All other variations in width measurement could be explained by the uncertainty of which landslide was being measured in areas where the landslides were not flagged with a unique number in the field; these were not used in this analysis.



Figure 7. Photograph from Post-Mortem Field Manual that illustrates how to measure the failure initiation dimensions. (Photograph: Julie Dieu)

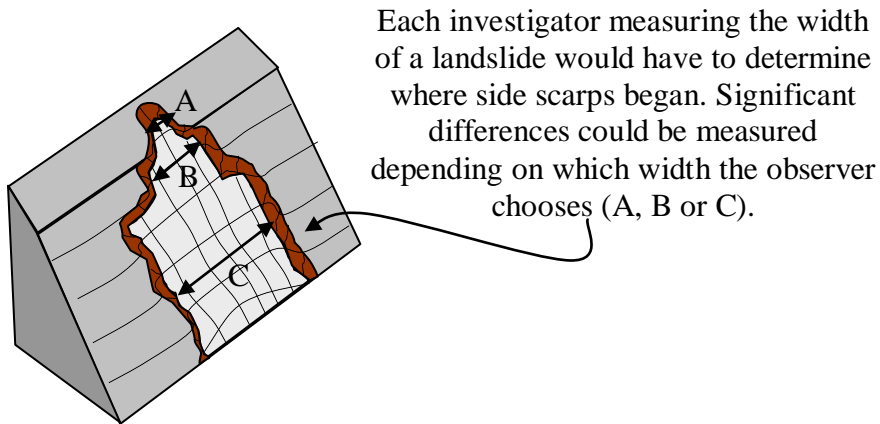


Figure 8. Major differences in determining the width of a landslide stemmed from the difficulty of determining the distance between side scarps across the widest part of the scarp.

8. Maximum depth of landslide - 93% agreement (134 of 144 landslides)

The field manual defines “*Average depth* and *Maximum depth* as the depth of material that failed during the landslide. These estimates require making some assumptions about the hillslope surface prior to the failure, and they are meant to be visualized as perpendicular to the *Length* (i.e., not measured in the vertical, but perpendicular to the hillslope).” It is easy to overestimate the depth of a landslide. The most common error observed in measuring the depth of a landslide was to record the height of the head scarp which is often a vertical measurement versus a measurement perpendicular to the hillslope (Figure 9). It was very difficult to physically measure the maximum depth of a landslide without crawling down onto the slip plane to allow measurement of the side scarp wall. Estimates of the maximum depth varied the most when an observer would stand above the head scarp to make an estimate. The QA/QC Team definition of reasonable varied depending on the size (scale) and irregular nature of the landslide. A reasonable observation was one that could be reproduced logically in the field or that was generally within 40% of the QA/QC Team measurement. The difficulty with using a set figure for reasonable agreement is the scale of the landslide. A 3 foot difference in maximum depth (5 vs 8 feet) is usually easy to see in a 10-foot-wide landslide but difficult to determine on a 50- foot-wide landslide. Figure 10 shows the Post-Mortem Team recorded greater maximum depths than the QA/QC Team.

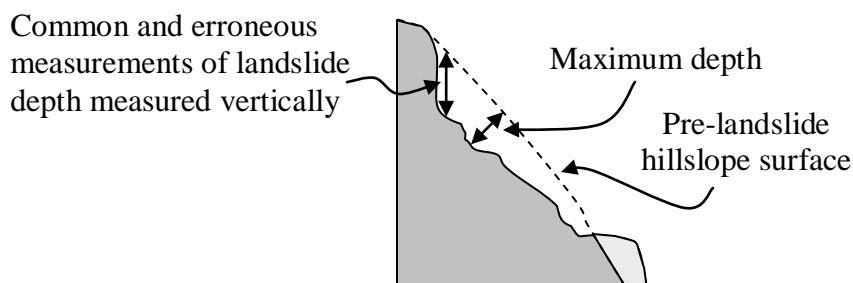


Figure 9. The major variation in depth measurements resulted from the tendency of some members of the Post-Mortem Team to measure the depth of a landslide vertically instead of perpendicular from the estimated pre-landslide hillslope surface.

Graph showing maximum depth of all landslides measured by the Post-Mortem Team which were reviewed by the QA/QC Team. Graph presents landslides sorted by depth in an unpaired arrangement.

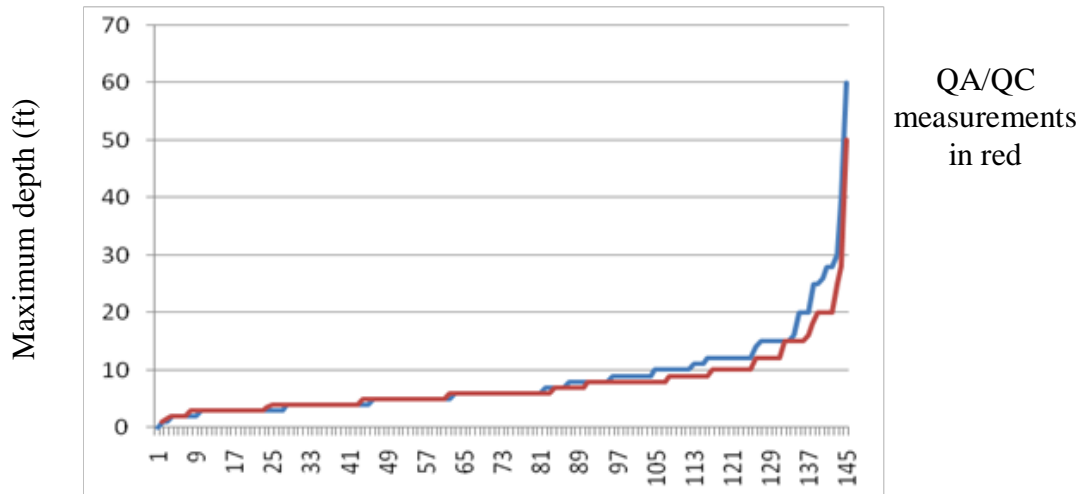


Figure 10. This graph demonstrates a tendency for the Post-Mortem Team to record greater maximum depths than the QA/QC Team.

9. Average depth of landslide - 88% agreement (127 of 144 landslides)

The average depth of a landslide was a measurement that was difficult for various individuals to reach consensus. The Post-Mortem Team would usually have a greater depth estimate, probably due to measuring this datum vertically instead of perpendicularly to the original hillslope surface (Figure 9).

10. Rule-identified landforms - 85% of the time (123 of 144 landslides).

The topographic settings of landslides were evaluated to determine whether they initiated in landforms identified in the forest practice rules (i.e., bedrock hollow, convergent headwall, inner gorge, toes of deep-seated landslides, outer edge of meander bends or null). Null indicates the landslide occurred outside of a defined landform. It does not differentiate between areas which are covered in the Forest Practice Rules as “*any areas containing features indicating the presence of potential slope instability*”. The QA/QC Team agreed with the measurements of the Post-Mortem Team on rule-identified landforms 85% of the time (123 of 144 landslides).

Figure 11 and Table 1 show how the QA/QC determinations varied from the Post-Mortem Team observations for each landform noted at each of the 144 landslide compared during the QA/QC process.

Rule-Identified Landform

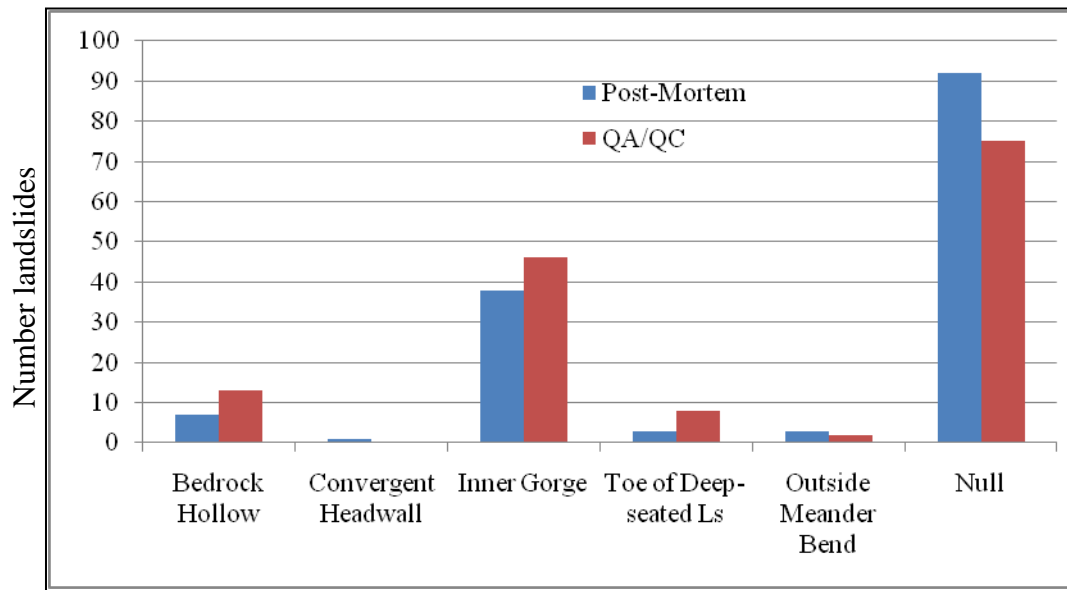


Figure 11. Graph shows the determinations of the presence of rule-identified landforms located at the initiation point for the 144 landslides reviewed by the QA/QC process.

Table 1. Table showing percent of the 144 landslides reviewed during the QA/QC process that initiated in each of the rule-identified landforms.

Rule Identified Landform	Post-Mortem	QA/QC
Bedrock Hollow	5%	9%
Convergent Headwall	1%	0%
Inner Gorge	26%	32%
Toe of Deep-seated Ls	2%	6%
Outside Meander Bend	2%	1%
Null	64%	52%

11. Geology – 100% agreement (144 of 144 landslides)

The maps with the landslide locations also indicated the geology present. The QA/QC Team noted if the geology found on site was different than what was indicated on the maps. The Post-Mortem Team and the QA/QC Team found that the geology indicated on the maps was generally correct.

12. Harvest unit age - 97% agreement (140 of 144 landslides)

The QA/QC Team estimate of harvest unit age was within 10 years of the Post-Mortem Team's estimate 97% of the time, with one exception (which may have been a recording error on the part of the Post-Mortem Team). Even if the two teams differed on the age of a tree (for example, 50 versus 70 years or 6 versus 15 years) the difference in ages did not cause the harvest stratum to be reclassified (i.e. it doesn't matter whether the forest is 50 or 75 years old, it is a mature stand of timber).

13. Determination of whether understory vegetation indicates a dry or wet site - 94% agreement (136 of 144 landslides)

There was 94% agreement between the QA/QC Team and the Post-Mortem Team on whether the understory vegetation indicated a wet or dry site. Eight of the nine sites where a difference occurred, the Post-Mortem Team determined that the understory vegetation indicated a wet site. This discrepancy can most likely be attributed to the fact that the Post-Mortem Team was trained to record a site as wet, even if only one "wet" plant species occurred on the site. The QA/QC Team determined a site to be wet if there were several "wet" plant species and the site appeared to be wet.

14. Landslide process (debris slide, debris flow, debris avalanche, deep-seated landslide, dam break flood, or other) - 89% agreement (128 of 144 landslides)

Classifying landslides as one landslide processes (debris slide, debris flow, debris avalanche, deep-seated landslide, dam break floods, or other) is problematic as one type often grades into another. The QA/QC Team agreed with the Post-Mortem Team's determination 89% of the time. The QA/QC Team could not find a rational explanation for 16 of the Post-Mortem Team's determinations out of 144 landslides.

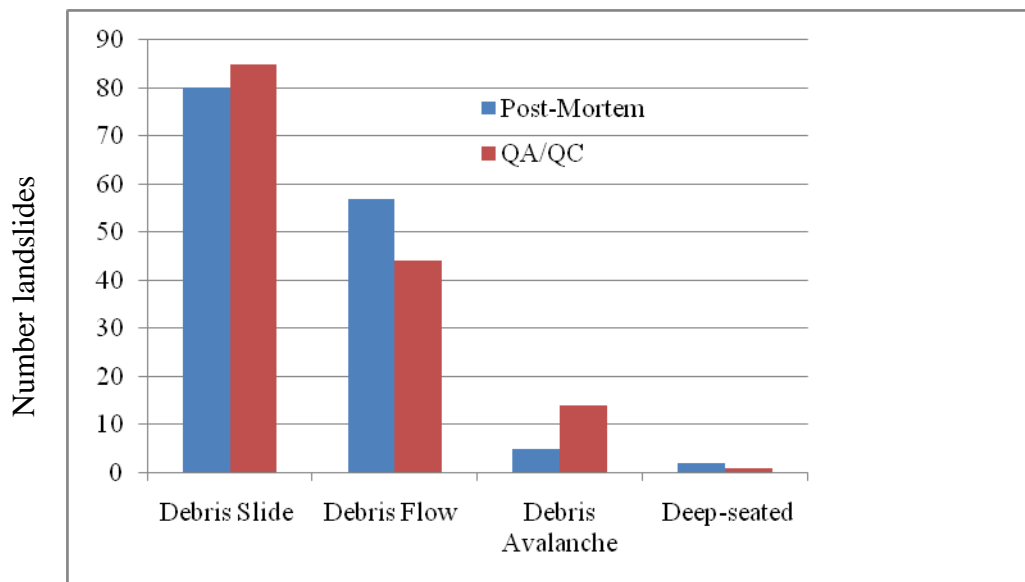


Figure 12. Graph shows the landslide process for each of the 144 landslides reviewed during QA/QC process.

Table 2. Table showing total number and percentage of landslide processes for each of the 144 landslides reviewed during QA/QC process

Landslide Process	Post-Mortem	QA/QC
Debris slide	80 LS (56%)	85 LS (59%)
Debris flow	57 LS (40%)	44 LS (31%)
Debris avalanche	5 LS (3%)	14 LS (10%)
Deep-seated landslide	2 LS (1%)	1 LS (1%)
Dam break flood	0 LS	0 LS
Other	0 LS	0 LS

15. Delivery to typed water - 90% agreement (129 of 144 landslides)

The Post-Mortem Team was directed to determine if a landslide delivered sediment to typed waters. This question was answered *Yes* or *No* which made it easy for the QA/QC Team to determine agreement. The QA/QC Team concurred with the Post-Mortem Team's determination 90% of the time (129 of 144 landslides). The Post-Mortem Field Manual instructions state "Choose *Yes* if any quantity of sediment from the landslide was routed into a stream channel or *No* only when no delivery of sediment to channelized water occurred. Seasonally intermittent streams that do not connect to the extended channel network are NOT defined as typed water; answer *No* where delivery occurred to such an untyped stream." Three of these cases involved only minor delivery (barely discernible) and 7 cases involved differing understanding of the definition of a typed stream. Some disagreement may have resulted from the requirement to have detailed knowledge of the stream typing rules that may have been beyond the Post-Mortem Team's knowledge of forest practice rules.

Table 3. This table lists the potential reasons the QA/QC and Post-Mortem Team differed as to whether a landslide delivered to a typed water.

Potential reason for difference	# of landslides
Minor delivery only	3
Post-Mortem Team failed to recognize a stream channel at the foot of the landslide	4
Debris was delivered to an un-channeled swale; not a typed stream	1
Stream was an isolated seasonal channel (not a typed stream)	2
Unexplained error in determining delivery	4
QA/QC Team agreement with Post-Mortem Team call	129

16. Sediment delivery volume - 77% agreement (111 of 144 landslides)

It is expected that the sediment delivery volume would vary considerably between different observers. To arrive at a similar delivered sediment volume the observers would have to measure the same width, length, average depth, and estimated percentage of the landslide mass that actually delivered to a stream channel. Sediment deposited on the slope is subtracted from the delivered volume and an estimate of channel scour would be added to this volume for debris flows. Each of these measurements requires a judgment call on the part of the observer. It is remarkable that the QA/QC Team agreed with or found the Post-Mortem Team calculations reasonable 77% of the time. Reasonable for this metric is defined as being reproducible in the field by measuring the landslide at slightly different locations or being within a multiple of two. It was somewhat surprising to see the delivered volumes agreeing closely even though different width, length, and average depth measurements were used in the calculations (variation in estimates sometimes average themselves out). Of the 144 landslides compared, the QA/QC Team disagreed with the calculated sediment delivery volumes on 33 landslides. Some of the potential reasons for this disagreement are shown in Table 4.

Table 4. Potential reasons for disagreement in calculating volume of sediment delivery.

Potential reason for disagreement	
Apparent math errors	1 landslide
Disagreement on the presence or absence of a typed stream	1 landslide
Differences in determining whether a landslide delivered or not	9 landslides
Post-Mortem Team's failure to calculate scour related to a debris flow	9 landslides
Disagreement related to significantly different measurement of landslide dimensions	3 landslides

17. Landslide location (hillslope (no road), hillslope road, or stream crossing road) - 99% agreement (135 of 137 landslides)

The QA/QC Team agreed with the Post-Mortem Team 99% of the time (143 of 144 landslides) as to whether a landslide initiated at a road, a stream crossing at a road, or on a hillslope. Where the landslide initiated determined which set of data was collected for a landslide. Data was incomplete for 2 landslides that the QA/QC Team differed in landslide location from the Post-Mortem Team because the incorrect data sheet was used.

Hillslope (No-Road) Data Sheet

18. Overstory tree composition

Primary overstory species - 96% agreement (106 of 110 landslides)

Secondary species - 89% agreement (98 of 110 landslides)

This data field asked the field crew to determine the *Primary* and *Secondary* overstory species in the stand adjacent (harvest unit) to the failure initiation site. With respect to the primary overstory species the QA/QC Team agreed with the Post-Mortem Team 96% of the time (106 of 110 landslides). The QA/QC Team agreed with the Post-Mortem Team 89% of the time (98 of 110 landslides) on the secondary species of trees adjacent to the landslide. Table 5 illustrates the differences between the QA/QC and Post-Mortem Team calls related to overstory as to whether Douglas-fir or western hemlock was the primary or secondary species. The presence of red alder in wet areas near landslides appeared to confuse the Post-Mortem Team as to whether alder was the secondary species in the harvest unit or an isolated occurrence.

Table 5. Table showing how the QA/QC and Post-Mortem Teams disagreed on which tree species was primary and secondary. The presence of red alder also confused the issue as to the composition of the harvest unit adjacent to the landslide.

Landslide disagreement	Primary tree species		Secondary tree species		Tree age	
	PM Team call	QA/QC Team call	PM Team call	QA/QC Team call	PM Team call	QA/QC Team call
1207368658	western hemlock	Douglas-fir	red alder	western hemlock	37	25
1005338636	western hemlock	Douglas-fir	red alder	western hemlock	26	13
1005338635	western hemlock	Douglas-fir	red alder	western hemlock	26	26
1105095241	western hemlock	Douglas-fir	Douglas-fir	western hemlock	30	25

19. Tree diameter - 95 % agreement (104 of 110 landslides)

The QA/QC Team agreed with the Post-Mortem Team 95% of the time (104 of 110 landslides) on the diameter of trees adjacent to the landslide. Five of the six measurements were taken by one Post-Mortem Team member who collected and recorded diameter using the wrong side of the tape to determine tree diameter (feet

increment instead of the diameter increment). This crewmember was able to retroactively correct his data for landslides measured earlier in the field season.

Tree diameter was estimated based on measuring a tree that represented the average diameter of the trees in the adjacent stand. Even when QA/QC and Post-Mortem Teams measured different trees (14 inch vs 25 inch diameter trees) data still provided an adequate picture of the diameter of trees in the stand. Reasonable error related to stand variability is generally within a 33% correlation of values.

20. Tree density - 90% agreement (99 of 110 landslides)

The QA/QC Team agreed with the Post-Mortem Team 90% of the time (99 of 110 landslides) on tree density. There were differing results between the QA/QC Team and the Post-Mortem Team at 11 landslides. At 9 of the landslides the Post-mortem Team recorded > 150 trees/acre for trees 30 to 70 years old. At 2 of the landslides the Post-mortem Team recorded 75-150 trees/acre for trees 13-26 years old, which is not a typical stocking level for a stand this age unless it was thinned, which these stands were not.

Table 6. Differences between the QA/QC and Post-Mortem Teams determination of stand density.

Post-Mortem Team determination of stand density	QA/QC Team determination of stand density	Number disagreement	Age of trees in units
>150 trees/acre	75 to 150 trees/acre	9	30 to 70 years
75 to 150 trees/acre	>150 trees/acre	2	13 to 26 years

21. Buffer of unstable landforms -77% agreement (85 of 110 landslides)

The QA/QC Team agreed with the Post-Mortem Team 77% of the time when evaluating this parameter (85 of 110 landslides). This concept was confusing for both the Post-Mortem and QA/QC Teams. The Post-Mortem field Manual instructs the investigator to:

“Choose *Yes*, *No*, or *Unknown* to indicate whether the failure initiated in a buffer, *Null* if the adjacent stand is 21+ years of age, and *Yes – office verified* if the FPA shows a buffer that has been entirely destroyed by the landslide. This datum is reasonably applied to the three harvest strata where the replanted harvest unit is 20 years of age or less. Choose *Yes* if the failure initiated in a buffer of older trees left when the last harvest occurred, *No* if the failure initiated in a harvest unit which is 20 years of age or less and *Unknown* only if it is not possible to determine if there was a buffer or not. Choose *Null* if the harvest unit is 21+ years of age because this is beyond the three, 0-20 years of age, harvest unit strata where the identification of buffers is necessary. In rare instances, it may appear that no

buffer was left because all of it was destroyed in the landslide. If the FPA shows a buffer in this location, choose *Yes – office verified* instead of *Unknown* and replace the datum later (assume in good faith that the intended buffer was left unless other evidence such as an air photo shows otherwise).”

Of the 110 landslides checked, the Post-Mortem Team answered “No” 18 times and “Yes” 5 times when the correct answer was “Null” (“No” indicates a buffer should have been left and was not, “Null” indicates the unit hadn't been harvested).

After the field season the QA/QC Team had to correct their initial field determination by checking the age of the stand adjacent to the landslide. The chart below (Figure 13) illustrates this confusion between “No” and “Null.” Without this No/Null issue, agreement between the Post-Mortem and QA/QC Teams would have been 96%.

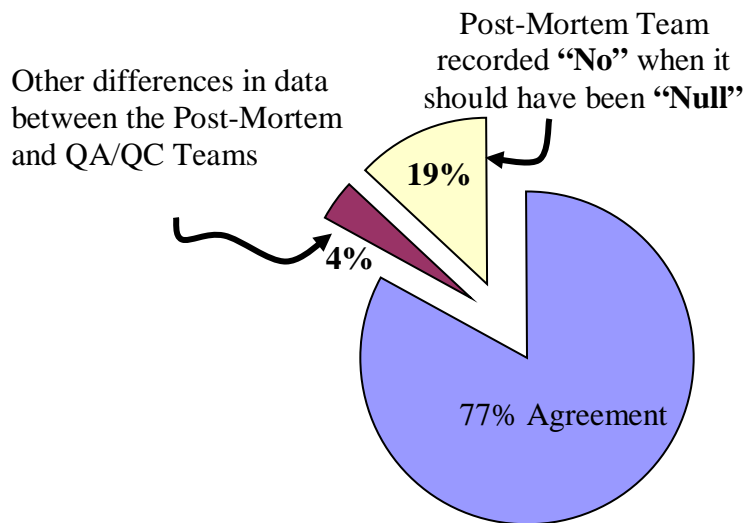


Figure 13. The major differences between the Post-Mortem and QA/QC Teams related to the question of whether the answer should have been "No" or "Null.”

22. Stand age of buffer - 81% agreement (90 of 110 landslides)

Similar to the buffer issue, this question confused both the Post-Mortem and QA/QC Teams. If the answer for the presence or absence of a buffer was "No" or "Null" the answer to the stand age of buffer should be "Null." The Post-Mortem Team would be able to correct their data as did the QA/QC Team by checking to see how the question of the presence or absence of a buffer was answered.

23. Pre-storm blowdown - 97% agreement (107 of 110 landslides)

The Post-Mortem Field Manual required an investigator to: "Estimate the amount of pre-storm blowdown in a stand immediately adjacent to the failure site. If the failure occurs in a stand that is 40+ years or in a buffer, estimate the percentage of blowdown in the

immediately adjacent stand ...” This datum collection was an attempt to determine the effects of blowdown on buffered areas; however, the QA/QC Team found it difficult to determine this parameter as it could have been a measure of the large woody debris lying on the forest floor. It was not until late in their investigation that the QA/QC Team fully understood what this question was evaluating. Therefore, the correlation between their findings and the Post-Mortem Team findings may not be meaningful. A reasonable correlation for this parameter was defined by the QA/QC Team as responses within +/- 10% meant that an answer of 20% was reasonable if the response was between 10% and 30%.

24. LWD delivery - 85% agreement (92 of 108 landslides)

The QA/QC Team had a low level of confidence in measuring agreement for this parameter due to confusion related to what LWD was during the field portion of their investigation. Initially the QA/QC Team was looking at whether the landslide delivered any LWD including large diameter logging slash and residual LWD from the original old-growth logging 60 to 100 years ago. Field results had to be adjusted when it became clear that they were not adhering to the strict definition provided in the Post-Mortem Field Manual. LWD (by definition) must be from a 40+ year stand, a buffer, or riparian management zone with tree diameters larger than 10 cm. Post field season this parameter was adjusted by evaluating whether or not the landslide had occurred in a 40+ year old stand, a buffer, or passed through a riparian management zone. Landslides that had occurred in younger stands or clearcuts that delivered directly to a stream may have had their field data changed because according to the Post-Mortem Field Manual this would not be considered LWD delivery.

25. Contributing factors

Yarding corridor - 97% agreement (107 of 110 landslides)

The QA/QC Team agreed with the Post-Mortem Team 97% of the time when evaluating this parameter (107 of 110 landslides).

Silvicultural treatment - 99% agreement (109 of 110 landslides)

This parameter asked if silvicultural treatments including pre-commercial thinning, commercial thinning, pruning, spraying of herbicides to control unwanted vegetation, and mechanical brushing were factors contributing to the landslide. The preliminary correlation between the findings of the QA/QC Team and the Post-Mortem Teams was not high due to a misunderstanding on whether 20 to 40 year old thinning was a silvicultural treatment. It was decided that these older thinnings were not relevant which increased the correlation between the two teams to nearly 100%.

Water diversion- 97% agreement (107 of 110 landslides)

The QA/QC and Post-Mortem Teams disagreed on three landslides that were evaluated for this parameter. Water diversions from roads or old skid trails delivered to headscarps of landslides and were contributing factors in the landslide occurring.

Hillslope Road Data Sheet

26. Failure location (cutslope, fillslope, entire road prism) - 100% agreement (27 of 27 landslides)

The QA/QC and Post-Mortem Teams agreed on all 27 landslides that were evaluated for failures located within the road prism.

27. Natural ground gradient - 85% agreement (23 of 27 landslides)

This parameter was measured using a clinometer to measure the gradient of the natural ground directly adjacent to the landslide. The natural ground gradient is the slope below the toe of the fillslope. 42% of the landslides reviewed by the QA/QC Team had slopes greater than those determined by the Post-Mortem Team, however, the QA/QC Team found all but 4 of the 27 landslides reviewed were within a reasonable range of measurement. This trend was also the same when measuring the gradient at the failure site, where the QA/QC Team tended to have higher slope measurements than the Post-Mortem Team. Reasonable agreement for this parameter was considered to be +/-15%.

28. Road surface geometry (crowned, insloped, outsloped, no slope) - 96% agreement (26 of 27 landslides)

The QA/QC Team agreed with the Post-Mortem Team 96% of the time when evaluating this parameter (26 of 27 landslides).

29. Tread condition (adequately graded, potholes, rutted) - 100% agreement (27 of 27 landslides)

The QA/QC and Post-Mortem Teams agreed on all 27 landslides that were evaluated for the tread condition of the road where the landslide failed.

30. Ditch depth - 93% agreement (25 of 27 landslides)

The QA/QC Team agreed with the Post-Mortem Team on 25 of 27 landslides evaluated for ditch depth of the road. The two landslides where the ditch depth was in disagreement, the QA/QC Team measured them deeper than the Post-Mortem Team.

31. Ditch flow (continuous, discontinuous, ponded) - 93% agreement (25 of 27 landslides)

The QA/QC Team agreed with the Post-Mortem Team on 25 of 27 landslides evaluated for ditch flow. Both of the landslides where the ditch flow was in disagreement, the QA/QC Team called it discontinuous where the Post-Mortem Team called it ponded.

32. Sidecast width - 78% agreement (21 of 27 landslides)

The QA/QC Team estimated the sidecast width as wider than the Post-Mortem Team's estimate at all six landslides that were not in agreement with the Post-Mortem Team. This underestimation of sidecast width could be due to the Post-Mortem Team measuring only the sidecast material outside of the road's driving surface and not including the sidecast material that was used to construct the road's driving surface. The sidecast width should be measured at the intersection of the fill and the natural ground by the visual projection of the intersection of the original hillslope onto the road surface.

33. Drainage

Cross-drain to failure site - 96% agreement (26 of 27 landslides)

The QA/QC Team agreed with the Post-Mortem Team 96% of the time when evaluating for a cross-drain draining to the failure site.

Ditchout to failure site - 100% agreement (27 of 27 landslides)

Waterbar to failure site - 100% agreement (27 of 27 landslides)

Pirated water from channel to site - 96% agreement (26 of 27 landslides)

The QA/QC Team only disagreed from the Post-Mortem Team on one landslide measured for pirated water draining to the site. A landslide that occurred during the December 2007 storm up the road from this landslide, blocked a culvert which pirated a stream to this location. The QA/QC team was unclear if the pirated stream needed to drain to the site prior to the storm. If so, then there would be 100% agreement on this parameter.

Outsloped road water concentrated to failure site - 92% agreement (26 of 27 landslides)

Silt trap/pond/berm in fillslope - 100% agreement (27 of 27 landslides)

34. Upslope road distance draining to site - 26% agreement (7 of 27 landslides)

The QA/QC Team could not determine why there was such a poor agreement on this measurement. On the vast majority of landslides (15 out of the 20) the Teams disagreed on, the QA/QC Team had a larger measurement. For the longer measurements, the QA/QC Team used a GPS to determine the distance; however this was checked several times using a laser rangefinder and was found to be within a reasonable degree of accuracy (+\ -20%).

Stream Crossing Road Data Sheet

Only seven landslides were investigated that initiated where a road crossed a stream during the QA/QC process. The data for one of these landslides was recorded by the Post-Mortem Team on the Hillslope Road Data Sheet which meant that for most of the parameters collected, only six landslides were evaluated. Five of those landslides occurred within the same cluster. This small population of reviewed landslides reflects the observations of two Post-Mortem crew members. This review may have been biased because it is not a random sample of the data collected by the entire Post-Mortem Team at the road-stream crossings.

35. Inlet stream angle (0°-30°, 30°-60°, 60°-90°) - 100% agreement (6 of 6 landslides)

36. Structure type (bridge, culvert, waterbar, unknown) - 100% agreement (6 of 6 landslides)

37. Structure material (metal, concrete, plastic, wood, null, unknown) - 100% agreement (6 of 6 landslides)

38. Structure diameter - 66% agreement (4 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 66% of the time (4 of 6 landslides) when evaluating the structure diameter located at the stream crossing. It appeared the Post-Mortem Team estimated the diameter of two of the culverts from a distance and misjudged the diameters.

39. Culvert gradient - 100% agreement (6 of 6 landslides)

40. Culvert condition (intact, holes, inlet damaged, null, unknown) - 100% agreement (6 of 6 landslides)

41. Flume (yes/no/unknown) - 83% agreement (5 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed on the presence or absence of a flume at the stream crossing structure on all but one landslide evaluated. The one disagreement occurred where the structure and/or flume was not visible so it was unknown whether a flume was present. The Post-Mortem Team answered no, the QA/QC Team answered unknown since it was not visible.

42. Culvert blockage (partially blocked, blocked, not blocked, null, unknown) - 66% agreement (4 of 6 landslides)

The QA/QC and Post-Mortem Teams disagreed on two landslides when evaluating whether the stream crossing culvert was blocked or not. For one culvert, the QA/QC Team answered that the culvert was completely blocked, the Post-Mortem Team answered that it was only partially blocked. For the other culvert the QA/QC Team

answered that the culvert was completely blocked and the Post-Mortem Team answered that it was not blocked

43. Upstream bankfull width - 66% agreement (4 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed on all but two landslides when evaluating the bankfull width upstream of the stream crossing culvert. The two landslides where the bankfull width was in disagreement, the Post-Mortem Team measured them wider than the QA/QC Team. This was most likely due to the Post-Mortem Team being influenced by the scoured out, post-storm bankfull width, rather than the average bankfull width outside of the storm influence. In general, measurements of bankfull width were compromised by the tremendous scouring effects of such a large storm event, “Unknown” became an acceptable answer for this datum because of this problem.

44. Sediment type (bedrock, boulders, coarse gravel and cobbles, fines, sand and fine gravel) - 83% agreement (5 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 83% of the time (5 of 6 landslides) when evaluating the sediment type upstream from the stream crossing. The QA/QC Team could not determine why there was disagreement on this measurement.

45. Organic debris load (sparse, non-contiguous, contiguous) - 66% agreement (4 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 66% of the time (4 of 6 landslides) when evaluating the organic debris load upstream from the stream crossing. The QA/QC Team could not determine why there was poor agreement on this measurement.

46. Stream gradient downstream - 50% agreement (3 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 50% of the time (3 of 6 landslides) when evaluating the stream gradient downstream from the stream crossing. The QA/QC Team answers were lower in two out of the three answers where there was disagreement. It appears that the disagreement may be from the Post-Mortem Team measuring the stream gradient above the road at the failure site not the gradient downstream at the failure site. A reasonable agreement for this parameter was considered to be +/-15%.

47. Upslope road distance draining to site - 17% agreement (1 of 6 landslides)

The agreement between the Post-Mortem Team and the QA/QC Team was generally poor when evaluating upslope road distance draining to the site and no explanation was ever discovered for this discrepancy.

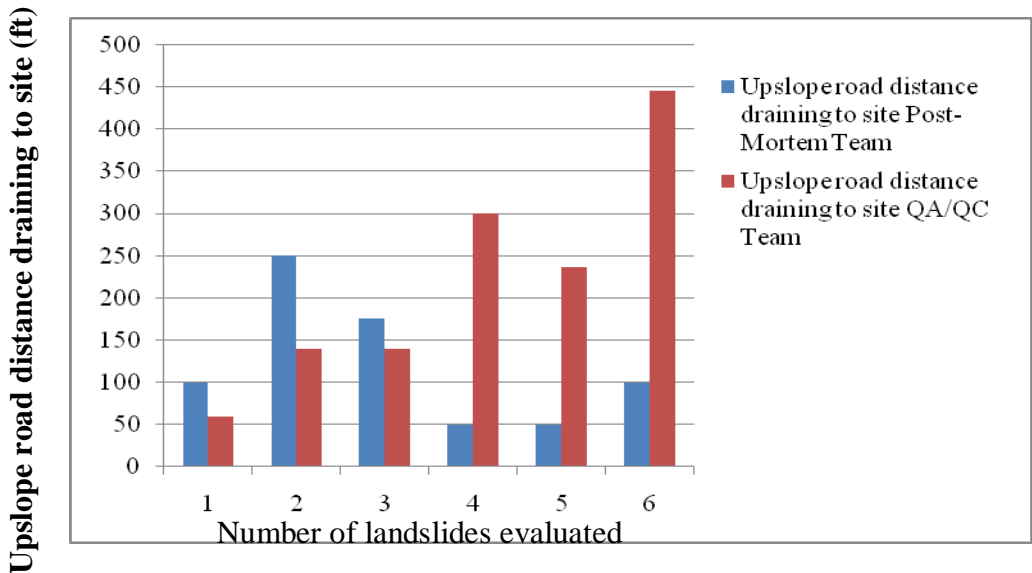


Figure 14. Graph showing comparison of the upslope road distance that drained to the site of the landslide being evaluated. This agreement was generally poor and no explanation was discovered for this discrepancy.

48. Pirated water to site - 83% agreement (5 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 83% of the time (5 of 6 landslides) when determining if water was being pirated to the site. The one landslide where there was disagreement, there was a small amount of water being pirated to the site which may have been difficult to tell depending on the weather conditions during the site visit. The Post-Mortem Team answered that there was no water pirated to the site; the QA/QC Team answered yes.

49. Fill quality (good, poor, unknown) - 100% agreement (6 of 6 landslides)

50. Total fill depth at outlet - 50% agreement (3 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 50% of the time (3 of 6 landslides) when evaluating the total fill depth at the outlet of the stream crossing culvert. In the three cases where there was disagreement, the Post-Mortem Team measured the fill depth from the top of the culvert to the surface of the road tread. This underestimated the fill depth by the diameter of the culvert and any fill below the pipe.

51. Failure description (plugged pipe – washout, plugged pipe – debris flow, plugged pipe – fill edge collapse, fill edge collapse – no plugging, other) - 50% agreement (3 of 6 landslides)

The QA/QC and Post-Mortem Teams agreed 50% of the time (3 of 6 landslides) when evaluating the description of why the stream crossing failed. The QA/QC Team could not determine why there was such poor agreement on this measurement, but note that the variance could be the result of such a small sample size.

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