# COMPARISON OF PROTOCOLS AND OBSERVER PRECISION FOR MEASURING PHYSICAL HABITAT ATTRIBUTES OF STREAMS IN OREGON AND IDAHO

By

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# ABSTRACT

Many stream monitoring programs measure the same physical attributes to assess stream habitat. The ability to evaluate an attribute has been the focus of studies quantifying observer variability, but few studies have compared variability attributable to the use of a particular protocol by different individuals. I compared six protocols used by the USDA Forest Service and the Environmental Protection Agency on three streams in Oregon and Idaho to determine whether differences in protocol affect reported values for 11 physical stream attributes. Coefficients of variation, signal-to-noise ratios and root mean square error were used to evaluate measurement precision for each protocol, and to highlight protocols with higher repeatability for particular attributes. Statistical differences in means among protocols occurred on almost all stream attributes in both states and the combined region, while precision estimates varied for all attributes evaluated. In Oregon, differences due to protocol occurred in 10 of 11 attributes, while differences in 5 of 11 possible attributes on Idaho streams were attributable to protocol. Results from Oregon and Idaho were combined, with differences attributable to protocol in 8 of 10 possible attributes. Differences in attribute means and measurement precision among protocols were influenced by the length of stream evaluated by a crew, sampling approach and observer training. The benefits of data exchange are obvious, but they will not be realized unless the same protocols are used to measure a core group of physical stream attributes.

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# INTRODUCTION

Cumulative effects of past and present human activities have substantially degraded aquatic resources and spurred the development of monitoring programs throughout the country. These programs have long been considered essential for increasing understanding of the temporal and spatial variability associated with aquatic resources and in helping us understand the consequences of resource management actions (Larsen et al. 2001). In resource management, monitoring is used to justify the expenditure of funds for pollution control, restore degraded resources, optimize the allocation of funds among management alternatives, and is increasingly required in water pollution control programs (Platts et al. 1987; EPA 1991; MacDonald 1994).

Since the advent of the Federal Water Quality Act in 1965 (PL 89-234), scientists and land managers have continued to refine parameters and techniques to assess water quality and trend. Initially, these efforts focused on determining if legal requirements were met rather than on facilitating management decisions (Sanders and Ward 1978). Current monitoring efforts focus more on quantifying the status and trend of physical instream habitat and channel conditions (USFS Region 6 1996; Overton et al. 1997; Kaufmann et al. 1999; USFS Region 10 2001; Henderson et al. 2002; Gallo 2002). Characterization of physical habitat is now the basis of most impact assessments, resource inventories, species management plans, mitigation planning and environmental regulation (Bain and Stevenson 1999; Bain et al. 1999). When appropriately evaluated, these habitat parameters can provide managers with information needed to identify the

effects of management activities (McDonald et al. 1991; Conquest et al. 1994; Poole et al. 1997).

Studies have evaluated several sources of variability associated with measuring physical stream attributes. These studies have quantified variability among observers using the same protocol to assess particular habitat attributes (Hogle et al. 1993; Roper and Scarneccia 1995), determined which attributes can be measured with the most precision, and estimated the precision and accuracy of specific instruments used to measure physical habitat (Wang et al. 1996; Isaak et al. 1999; Bunte and Apt 2001; Roper et al. 2002). There has yet to be a comparison to quantify variability associated with the use of different protocols that measure the same physical stream attributes.

This study was part of a current effort by the USFS to standardize aquatic monitoring protocols. My objectives were to use statistical and qualitative comparisons to determine sources of variability among stream survey protocols used by the USFS and Environmental Protection Agency (EPA), and to evaluate measurement precision of stream attributes by estimating coefficients of variation (CV's), signal to noise ratios (S:N) and root mean square errors (RMSE).

*Background*

The accuracy and precision of habitat assessment techniques has been criticized by researchers and has led to concerns regarding the use of physical habitat measurement for monitoring land management effects (Platts et al. 1987; Bauer and Ralph 2001). While it is often possible to document the direct influence of activities such as timber harvest, road building, grazing, mining, recreation and dam building on physical stream

attributes (Konopacky et al. 1985; Platts 1985; Bisson et al. 1987; Clark and Gibbons 1991; Furniss et al. 1991; Norris et al. 1991; Knapp and Matthews 1996), it is difficult to distinguish the effect of one type of disturbance from another. Multiple activities that persist in time are often responsible for measurable cumulative watershed effects (MacDonald 2000), but the specific cause of the change is unknown. This difficulty has been one of the primary criticisms of using physical stream attributes as monitoring tools (MacDonald et al. 1991; Kaufmann et al. 1999; Bauer and Ralph 2001). Other factors confounding the ability to link changes in physical stream attributes with management activities include distance downstream from the source of impact (MacDonald 1989; Montgomery and MacDonald 2002), sensitivity of a particular stream attribute to human activity (MacDonald et al. 1991), and the complexity of geomorphological processes in a watershed, primarily the natural and anthropogenic changes in water and sediment flux. Impacts resulting from management practices can often be inferred, however, by linking changes in attributes to changes in land treatment (McDonald et al. 1991; Spooner and Line 1993). For example, sedimentation may have the same effect on percent fine particles in a stream whether the sediment resulted from logging, mining, road building or livestock grazing (Meehan 1991).

Another criticism of using physical stream attributes as indicators of change is the inconsistency with which different observers using the same protocol measure these attributes (Ralph et al. 1992; Roper and Scarnecchia 1995; Poole et al. 1997; Roper et al. 2002). Because variability among observers can mask true differences in a measured stream attribute, the ability to draw conclusions relative to the attribute may be compromised. Difficulty in measurement consistency is related to inconsistent training,

inconsistent application of protocols, and use of protocols that rely on imprecise measurement techniques such as visual estimation (Kondolf and Li 1992; Ralph et al. 1994; Wang et al. 1996; Kondolf 1997; Roper et al. 2002).

The challenges associated with measuring physical stream attributes have been exacerbated by the development of numerous and varied methods of analyzing and reporting habitat conditions. Different monitoring objectives and data requirements influence study design and implementation, leading to inherent differences in accuracy, precision and effort required. This further confounds the ability of government agencies and private interests to share and synthesize the information (Bain and Stevenson 1999; Johnson et al. 2001). In response to the proliferation of monitoring efforts and the need to enhance the comparability of data, the American Fisheries Society and the U.S. Fish and Wildlife Service organized a joint project in 1995. Their goal was to evaluate the wide array of habitat assessment methods and to select a set of standard techniques (Bain and Stevenson 1999). The study reviewed 52 methods and identified 705 different habitat variables used in assessment and monitoring programs and concluded that the large variation in habitat measurements precluded any meaningful synthesis across regions, provinces, states and even through time within single agencies (Bain and Stevenson 1999). The result of this study was a selection of methods and habitat attributes to help reduce the number of approaches and types of data used for habitat assessment. In a similar effort, Johnson et al. (2001) reviewed documents describing 429 protocols for measuring salmonid habitat and recommended establishing a consistent format for collecting habitat-related salmonid data. They eventually identified 68 protocols for use by volunteers and 93 for use by management/research personnel in the Pacific Northwest.

Standardized sampling protocols are required for data synthesis and comparison (McMahon et al. 1996). By standardizing protocols, monitoring efforts have the ability to share data and increase sample sizes, thereby increasing the statistical power to describe spatial and temporal trends. Financially, the ability to utilize data collected and paid for by other monitoring efforts reduces the need for large and redundant expenditures for aquatic habitat monitoring. The advantages of standardization have yet to be fully realized, primarily because monitoring programs are numerous, varied, and many have acquired historical data that may be difficult to assimilate into a different protocol. Most monitoring programs measure the same physical stream attributes, however, and understanding the variability associated with their measurement is critical for detecting change through time.

In this study I compared six stream habitat protocols. The Aquatic and Riparian Effectiveness Monitoring Program (AREMP) is a large-scale USFS program developed to monitor aquatic and riparian ecosystems on federal lands managed under the Northwest Forest Plan (Reeves et al. in preparation). The PACFISH/INFISH effectiveness monitoring program (PIBO) was developed by an interagency team to respond to monitoring needs addressed in the biological opinions for bull trout and steelhead (Kershner et al. 2004). PIBO conducts large-scale monitoring of aquatic and riparian resources in the Columbia River Basin. The Environmental Monitoring and Assessment Program (EMAP) protocol developed by the Environmental Protection Agency (EPA) is commonly used by state agencies, and in this study was used by the Oregon and Idaho Departments of Environmental Quality. Crews in USFS Region 6 (R6) use a protocol throughout Oregon and Washington common to many USFS regions and

districts. This habitat-based protocol is modeled after a basin-wide approach to fisheries assessment developed by Hankin and Reeves (1988). The Tongass National Forest in Alaska sent crews to represent the protocol used in USFS Region 10 (R10). This protocol was developed for Alaska streams and is also based on a basin-wide approach to habitat surveys. Four levels of assessment complexity were developed to meet specific stream survey objectives in R10, and range from basic reconnaissance information to more thorough and detailed assessments. Level II, and components from Level III, were used for this comparison. Two crews from Idaho represented USFS Region 4 (R4), which uses a protocol modeled after the Hankin and Reeves (1988) basin-wide fisheries assessment approach. These six protocols represented many of the types of monitoring programs used in the Columbia River Basin and reflected common habitat assessment protocols used by the USFS and EPA in the western United States.

In addition to measurement precision, accuracy of measurement is an important component of any monitoring effort. If attribute measurement does not reflect the actual physical stream environment, the attribute has little use as a monitoring tool. Accuracy may be obtained through rigorous quantification of stream channel morphology for attributes such as gradient, bankfull width, bankfull depth, width-to-depth ratio and channel entrenchment. Substrate attributes such as $D_{50}$, percent substrate fines and pool tail fines may also be accurately quantified through rigorous assessment by highly trained professionals. An assessment of accuracy by such professionals was beyond the scope of this study, and therefore no “true” answer was available for comparisons of measurement accuracy.

# METHODS

*Protocols*

Protocols from five different monitoring efforts including AREMP, EMAP, PIBO, R10 and R6 were evaluated on three streams in Oregon, with each group providing three crews. Surveys in Oregon were conducted from 28 July – 20 Aug 2002. Stream crews participating in Idaho represented AREMP, EMAP, PIBO and R4, with three crews each from AREMP and PIBO and two crews each from EMAP and R4. Surveys in Idaho were conducted on three streams from 03 July – 25 July 2002. In both regions, crews from each monitoring effort had three days to complete all streams (one crew per stream per day) before the next test began.

*Site Selection*

Streams were chosen to reflect the wide range of conditions in the Columbia River Basin, with streams in both states varying in size, elevation and channel complexity, as well as regional differences in geology and climate (Table 1).

**Table 1**. General characteristics of streams. Gradient and bankfull width values determined as averages from all protocols. Elevation of bottom of reach determined with ARCGIS software.

| State | Stream | Geology | Elevation (m) | Gradient | Bankfull Width (m) |
|---|---|---|---|---|---|
| Oregon | Linney | Volcanic | 800 | 1.62 | 10.47 |
| Oregon | Oak Grove | Volcanic | 990 | 0.95 | 10.22 |
| Oregon | Still | Volcanic | 1090 | 1.93 | 14.37 |
| Idaho | Anderson | Granitic | 1090 | 1.21 | 8.02 |
| Idaho | Pine | Granitic | 1150 | 3.23 | 4.96 |
| Idaho | Tripod | Granitic | 1550 | 0.88 | 1.69 |

Streams were selected to be accessible by road and were located in proximity to one another. All stream reaches were chosen to be entirely above or below major tributaries and significant changes in gradient. Streams sites in Oregon meeting these criteria were chosen from potential candidates provided by AREMP and R6 personnel. Streams were located in the Mount Hood National Forest west of the Cascade Mountains and included the Oak Grove Fork of the Clackamas River, Still Creek and Linney Creek. The starting point of each stream reach in Oregon was determined using reach breaks delineated in previous R6 surveys. Reach breaks are defined by R6 as changes in the relative uniformity of stream gradient, habitat width and depth, streambed substrate and degree of interaction of the stream with its floodplain (USFS Region 6 1996). Stream sites in Idaho represented those typical of a drier climate and were determined from potential candidates in the PIBO database, with subsequent map work and logistical assistance provided by PIBO personnel. Streams in Idaho were located in the Boise National Forest and included Anderson, Pine and Tripod Creeks. Stream sites in both states were field verified and the starting points for each site were marked with flagging for identification by crews.

*Study Design*

At each site, crews sampled physical stream attributes using the same reach starting point. Since R10, R6 and R4 typically survey an entire stream from mouth to source, survey distances (hereafter referred to as reach lengths) were established according to relative stream size, with start and finish points flagged prior to assessment

(Table 2). For AREMP, EMAP and PIBO crews, minimum reach length was determined according to methods dictated by each protocol (Appendix A).

Crews from each protocol measured similar physical stream attributes within each stream reach. Eleven common physical attributes were compared among as many protocols as possible, although it was not possible to compare all attributes among all protocols (Appendix A). Crews conducted surveys during stream baseflow and stream stage was recorded to ensure data were collected under comparable conditions (Appendix B). Chemical and biological stream attributes were not evaluated in this study.

**Table 2**. Predetermined reach lengths for crews using R10, R6 and R4 protocols.

| Protocol | State | Stream | Reach Length (m) |
|---|---|---|---|
| R10 & R6 | Oregon | Linney | 750 |
| R10 & R6 | Oregon | Oak Grove | 700 |
| R10 & R6 | Oregon | Still | 1000 |
| R4 | Idaho | Anderson | 750 |
| R4 | Idaho | Pine | 500 |
| R4 | Idaho | Tripod | 500 |

*Analysis*

Mean values for 11 physical stream attributes were calculated for each crew in the study. Attribute means for each crew of a particular protocol were averaged for an overall "protocol" mean. A 2-way analysis of variance was used to evaluate pairwise differences in attribute means among protocols. For these pairwise comparisons, a Tukey adjustment with significance level $\alpha = 0.05$ was used to help control Type I error rate, which is rejecting the null hypothesis (no mean difference between groups) when it is actually

true. Estimates of variance associated with streams and crews were evaluated using a random effects analysis of variance model (PROC MIXED of SAS), with streams treated as a random effect. All error in the model not associated with the natural variation among streams was attributed to crews (Appendix C). Estimates of means and variance were also used to calculate coefficients of variation [CV=(crew variance)$^{0.5}$/mean*100], signal to noise ratios (S:N=environmental variance/crew variance) and root mean square errors (RMSE=(crew variance)$^{0.5}$)(Kaufmann et al. 1999).

Coefficients of variation, S:N and RMSE were used to compare crew precision for measurement of each physical stream attribute as well as provide estimates of overall protocol precision. Coefficients of variation provide a dimensionless measure of variability in which scaling is relative to the mean, with values $\leq$ 20 suggested for acceptable measurement precision (Ramsey et al. 1992; Zar 1996). Signal to noise ratio provides an estimate of precision relative to the inherent variation among streams, with values from 2-10 reflecting moderate to high precision (Kaufmann et al. 1999). Values of S:N reflect the ability of a protocol to distinguish differences among streams for the particular attribute measured. Because all crews in each state measured the same streams and started surveys at the same location, signal among protocols should be similar. Root mean square error represents the pooled standard deviation among crews of a particular protocol.

Non-parametric Friedman rank scores were initially evaluated due to concerns about violating assumptions of Analysis of Variance (ANOVA) (Zar 1996). Parametric statistics were used because rank comparisons and the 2-way parametric ANOVA results were identical for all but two stream attributes measured in Idaho (gradient, percent

fines). I assumed that crews within a protocol represented typical crews from the overall population. Differences among crews in each state were evaluated. Because AREMP, EMAP and PIBO participated in both states, differences among these protocols were also tested for the combined site effect.

# RESULTS

*Combined Regions*

Analysis of variance indicated differences ($p \leq 0.05$) in means among protocols for 8 of 10 physical attributes evaluated. Only percent pool tail fines and width-to-depth ratio had means that were not significantly different ($p = 0.7665$ and 0.7776 respectively) among protocols (Table 3).

Measurement precision varied among protocols for each stream attribute. Attributes measured with relative precision by all protocols were reach length, gradient, sinuosity, and percent fines. Crews from PIBO measured bankfull width with the highest precision, with CV's among protocols ranging from 10 to 38 (Table 3). Measurement of percent pools was imprecise with the exception of PIBO, with CV's ranging from 16 to 57. Attributes measured imprecisely by all protocols include $D_{50}$ and LWD/100m. Signal to noise and RMSE estimates reflect the same general precision pattern as CV's, with the exception of low to moderate precision for $D_{50}$ (S:N 2-5). Overall, PIBO had the highest measurement precision in 7 of 10 stream attributes.

**Table 3**. Means, precision estimates and pairwise differences ($p < 0.05$) in attribute means among protocols in the combined region.

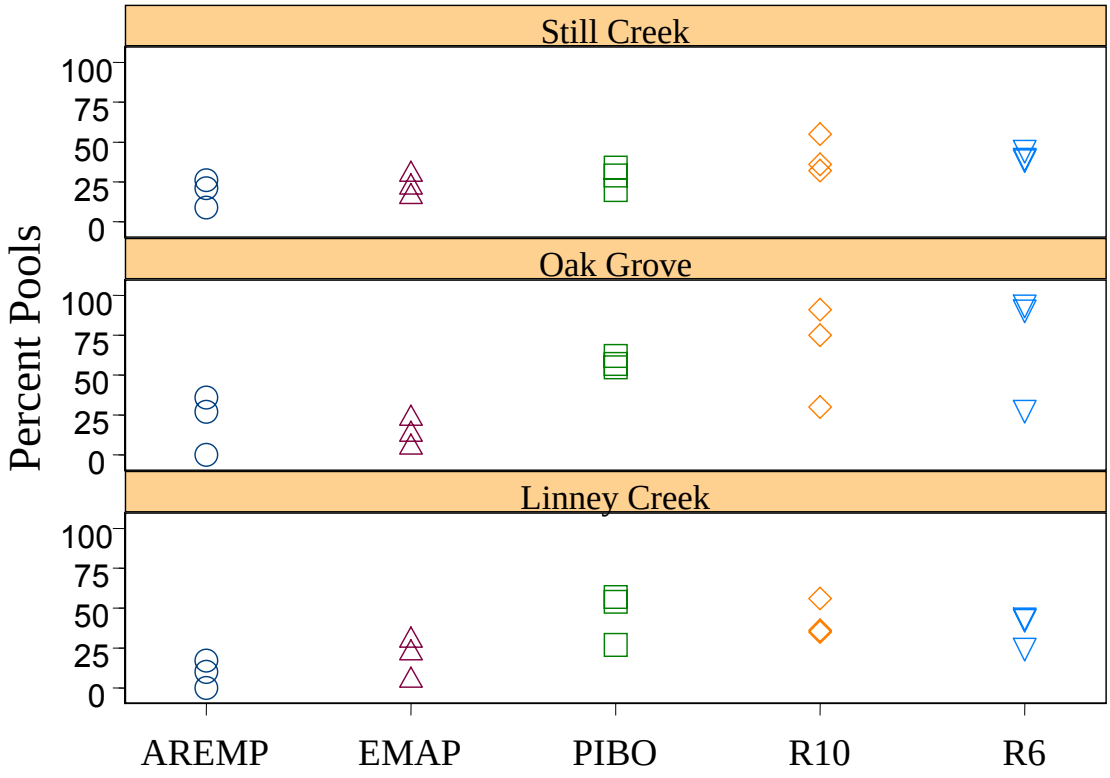
| Stream Attribute | Protocol[a] | Mean | RMSE | CV | S:N | Pairwise Differences | |
|---|---|---|---|---|---|---|---|
| Reach Length (m) | AREMP | 205.17 | 36.35 | 17.72 | 2.83 | AREMP | EMAP |
| | EMAP | 246.67 | 31.74 | 12.87 | 9.16 | AREMP | PIBO |
| | PIBO | 175.17 | 25.13 | 14.35 | 8.37 | EMAP | PIBO |
| Gradient | AREMP | 1.72 | 0.40 | 23.39 | 7.02 | AREMP | EMAP |
| | EMAP | 2.04 | 0.42 | 20.82 | 7.27 | AREMP | PIBO |
| | PIBO | 1.45 | 0.14 | 9.69 | 66.62 | EMAP | PIBO |
| Sinuosity | AREMP | 1.48 | 0.17 | 11.38 | 1.28 | AREMP | PIBO |
| | PIBO | 1.28 | 0.10 | 8.22 | 2.32 | | |
| Percent Pools | AREMP | 21.58 | 12.22 | 56.62 | 0.32 | AREMP | PIBO |
| | EMAP | 25.16 | 11.05 | 43.93 | 1.35 | EMAP | PIBO |
| | PIBO | 51.70 | 8.22 | 15.91 | 6.27 | | |
| Residual Pool Depth (m)[b] | PIBO | 0.53 | 0.05 | 10.07 | 37.31 | NA[c] | NA |
| Bankfull Width (m) | AREMP | 11.36 | 4.31 | 37.94 | 1.20 | AREMP | EMAP |
| | EMAP | 8.72 | 3.05 | 34.96 | 1.93 | AREMP | PIBO |
| | PIBO | 7.81 | 0.35 | 10.42 | 30.32 | | |
| BF W:D Ratio | AREMP | 25.90 | 10.97 | 42.36 | 0.53 | NA | NA |
| | PIBO | 26.94 | 5.14 | 19.07 | 4.01 | | |
| $D_{50}$ (mm) | AREMP | 22.88 | 11.85 | 51.77 | 5.10 | AREMP | PIBO |
| | EMAP | 31.47 | 21.06 | 66.90 | 2.39 | | |
| | PIBO | 36.50 | 12.85 | 35.20 | 5.13 | | |
| Percent Fines (<6mm) | AREMP | 51.25 | 6.38 | 12.45 | 21.72 | AREMP | EMAP |
| | EMAP | 44.93 | 3.72 | 8.28 | 69.94 | AREMP | PIBO |
| | PIBO | 36.06 | 7.26 | 20.14 | 21.24 | EMAP | PIBO |
| % Pool Tail Fines | AREMP | 34.86 | 18.95 | 54.37 | 2.24 | NA | NA |
| | PIBO | 33.49 | 7.31 | 21.84 | 22.21 | | |
| LWD / 100m | AREMP | 7.82 | 3.29 | 42.03 | 6.64 | AREMP | EMAP |
| | EMAP | 34.61 | 13.44 | 38.82 | 0.74 | AREMP | PIBO |
| | PIBO | 42.62 | 17.86 | 41.92 | 1.19 | | |

[a] Protocols missing in comparisons do not typically measure these attributes, or there is insufficient data gathered for comparison (See Appendix A for typical measurements).
[b] EMAP crews do not measure max pool depth or pool tail crest depth for RPD calc, Appendix A
[c] NA indicates no significant differences among protocols.

*Oregon*

Analysis of variance indicated differences ($p \leq 0.05$) in means among protocols for 10 of 11 stream attributes, with percent pool tail fines as the only exception ($p = 0.5784$). Attribute means for AREMP and EMAP were different from all other protocols for percent pools and percent fines (Table 4). Bankfull width means for AREMP were different from all other protocols except EMAP. Measurement of percent pools was imprecise for most crews, with means on Oak Grove ranging from 0-93 among protocols (Figure 1).

**Figure 1.** Percent pools comparison in three streams sampled in Oregon. Symbols represent attribute means for each crew.



Most crews measured reach length, sinuosity and mean residual pool depth with relatively high precision, while measurement precision for percent pools, $D_{50}$, pool tail fines and LWD/100m was low (Table 4). Five stream attributes – gradient, residual pool depth, bankfull width, width to depth ratio, and percent fines – had a wide range of precision, indicating poor agreement among protocols. The attribute measured with the most variability was percent substrate fines with a CV range of 15–67 and S:N values of 2-27. Overall PIBO had the highest measurement precision in 6 of 11 stream attributes (Table 4).

**Table 4**. Means, precision estimates and pairwise differences ($p < 0.05$) in attribute means among protocols in Oregon.

| Stream Attribute | Protocol[a] | Mean | RMSE | CV | S:N | Pairwise Differences | |
|---|---|---|---|---|---|---|---|
| Reach Length (m) | AREMP | 257.11 | 51.13 | 19.89 | 0.55 | EMAP | PIBO |
| | EMAP | 302.22 | 32.66 | 10.81 | 10.72 | | |
| | PIBO | 229.69 | 31.85 | 13.87 | 1.33 | | |
| Reach Length Fixed (m) | R10 | 800.76 | 22.41 | 2.80 | NA | NA[b] | NA |
| | R6 | 856.01 | 102.43 | 11.97 | NA | | |
| Gradient | AREMP | 1.48 | 0.52 | 35.02 | 0.38 | AREMP | EMAP |
| | EMAP | 2.02 | 0.48 | 23.78 | 1.27 | EMAP | PIBO |
| | PIBO | 1.30 | 0.18 | 13.71 | 5.44 | EMAP | R10 |
| | R10 | 1.23 | 0.39 | 31.78 | 1.37 | | |
| Sinuosity | AREMP | 1.41 | 0.16 | 11.69 | 0.75 | AREMP | PIBO |
| | EMAP | 1.26 | 0.10 | 7.67 | 5.18 | | |
| | PIBO | 1.17 | 0.09 | 7.65 | 0.00 | | |
| Percent Pools | AREMP | 16.63 | 12.62 | 75.89 | 0.00 | AREMP | PIBO |
| | EMAP | 19.47 | 9.44 | 48.47 | 0.00 | AREMP | R10 |
| | PIBO | 43.89 | 10.59 | 24.13 | 1.75 | AREMP | R6 |
| | R10 | 50.01 | 20.94 | 41.86 | 0.10 | EMAP | PIBO |
| | R6 | 49.16 | 22.37 | 45.50 | 0.35 | EMAP | R10 |
| | | | | | | EMAP | R6 |

**Table 4 Cont.** Means, precision estimates and pairwise differences (p< 0.05) in attribute means among protocols in Oregon.

| Stream Attribute | Protocol[a] | Mean | RMSE | CV | S:N | Pairwise Differences | |
|---|---|---|---|---|---|---|---|
| Residual Pool Depth (m)[c] | EMAP | 0.19 | 0.05 | 23.14 | 0.69 | EMAP | PIBO |
| | PIBO | 0.70 | 0.06 | 9.04 | 33.16 | EMAP | R10 |
| | R10 | 0.59 | 0.06 | 9.81 | 0.58 | EMAP | R6 |
| | R6 | 0.70 | 0.15 | 22.09 | 0.00 | | |
| Bankfull Width (m) | AREMP | 15.88 | 5.18 | 32.60 | 0.00 | AREMP | PIBO |
| | EMAP | 12.28 | 3.52 | 28.68 | 0.15 | AREMP | R10 |
| | PIBO | 11.26 | 0.35 | 9.71 | 8.67 | AREMP | R6 |
| | R10 | 11.54 | 3.39 | 29.35 | 0.57 | | |
| | R6 | 8.50 | 0.76 | 8.98 | 18.93 | | |
| BF W:D Ratio | AREMP | 34.39 | 12.98 | 37.74 | 0.00 | AREMP | R6 |
| | PIBO | 32.78 | 5.90 | 16.71 | 2.75 | PIBO | R6 |
| | R10 | 24.45 | 6.41 | 26.23 | 1.51 | | |
| | R6 | 19.97 | 5.12 | 25.63 | 0.55 | | |
| $D_{50}$ (mm) | AREMP | 32.19 | 15.29 | 47.51 | 5.16 | AREMP | R6 |
| | EMAP | 46.23 | 25.89 | 56.01 | 2.60 | EMAP | R6 |
| | PIBO | 52.44 | 16.71 | 31.87 | 3.18 | | |
| | R10 | 49.75 | 11.79 | 23.69 | 3.11 | | |
| | R6 | 69.50 | 9.15 | 13.17 | 35.16 | | |
| Percent Fines | AREMP | 39.26 | 8.67 | 22.09 | 9.79 | AREMP | PIBO |
| | EMAP | 29.25 | 4.42 | 15.13 | 27.34 | AREMP | R10 |
| | PIBO | 18.11 | 9.43 | 52.06 | 2.09 | AREMP | R6 |
| | R10 | 10.93 | 7.30 | 66.73 | 3.49 | EMAP | PIBO |
| | R6 | 19.05 | 6.32 | 33.16 | 7.24 | EMAP | R10 |
| % Pool Tail Fines | AREMP | 14.88 | 11.17 | 75.03 | 1.95 | NA[b] | NA |
| | PIBO | 12.11 | 8.71 | 71.88 | 0.91 | | |
| LWD / 100m | AREMP | 14.12 | 4.62 | 32.71 | 2.81 | AREMP | EMAP |
| | EMAP | 41.14 | 15.11 | 36.72 | 0.33 | AREMP | PIBO |
| | PIBO | 53.82 | 22.44 | 41.70 | 0.50 | AREMP | R10 |
| | R10 | 49.94 | 27.26 | 54.60 | 0.79 | EMAP | R6 |
| | R6 | 4.95 | 0.92 | 18.69 | 13.87 | PIBO | R6 |
| | | | | | | R10 | R6 |

[a] Protocols missing in comparisons do not typically measure these attributes, or there is insufficient data gathered for comparison (See Appendix A for typical measurements).
[b] NA indicates no significant differences among protocols.
[c] EMAP crews do not measure max pool depth or pool tail crest depth for RPD, Appendix A

*Idaho*

In Idaho, there were differences ($p \leq 0.05$) in means among protocols in 5 of 11 physical stream attributes (Table 5). There were no differences among protocol means in gradient, residual pool depth, bankfull width, width-to-depth ratio, percent fines and percent pool tail fines (p = 0.4863, 0.8613, 0.0891, 0.2744, 0.4457, 1.0000 respectively). Percent pools and LWD/100m were the only stream attributes with more than one pairwise statistical difference in means among protocols (Table 5).

**Table 5**. Means, precision estimates and pairwise differences ($p < 0.05$) in attribute means among protocols in Idaho.

| Stream Attribute | Protocol[a] | Mean | StdDev | CV | S:N | Pairwise Differences | |
|---|---|---|---|---|---|---|---|
| Reach Length (m) | AREMP | 153.22 | 5.24 | 3.42 | 0.80 | AREMP | EMAP |
| | EMAP | 190.33 | 29.90 | 15.71 | 2.61 | | |
| | PIBO | 166.22 | 15.35 | 12.72 | 0.79 | | |
| Reach Length Fixed (m) | R4 | 520.92 | 38.14 | 7.32 | 0.81 | NA[b] | NA |
| Gradient | AREMP | 1.97 | 0.24 | 12.14 | 45.44 | NA | NA |
| | EMAP | 2.00 | 0.16 | 8.16 | 117.81 | | |
| | PIBO | 1.59 | 0.09 | 5.40 | 412.26 | | |
| | R4 | 1.62 | 0.29 | 17.78 | 0.00 | | |
| Sinuosity | AREMP | 1.55 | 0.17 | 11.09 | 1.99 | AREMP | PIBO |
| | PIBO | 1.38 | 0.11 | 7.85 | 3.21 | | |
| Percent Pools | AREMP | 26.54 | 11.17 | 42.10 | 0.72 | AREMP | PIBO |
| | EMAP | 30.61 | 12.71 | 41.52 | 2.38 | EMAP | PIBO |
| | PIBO | 59.51 | 4.81 | 8.08 | 29.90 | PIBO | R4 |
| | R4 | 26.50 | 16.65 | 62.82 | 0.00 | | |
| Residual Pool Depth (m)[c] | PIBO | 0.35 | 0.04 | 11.36 | 22.89 | NA | NA |
| | R4 | 0.35 | 0.02 | 5.38 | 67.33 | | |

**Table 5 Cont.** Means, precision estimates and pairwise differences (p< 0.05) in attribute means among protocols in Idaho.

| Stream Attribute | Protocol[a] | Mean | RMSE | CV | S:N | Pairwise Differences | |
|---|---|---|---|---|---|---|---|
| Bankfull Width (m) | AREMP | 6.83 | 2.86 | 41.93 | 0.00 | NA | NA |
| | EMAP | 5.30 | 1.73 | 32.66 | 3.66 | | |
| | PIBO | 4.37 | 0.36 | 8.22 | 61.23 | | |
| BF W:D Ratio | AREMP | 17.42 | 6.72 | 38.59 | 0.01 | NA | NA |
| | PIBO | 21.11 | 4.77 | 22.61 | 3.91 | | |
| $D_{50}$ (mm) | AREMP | 13.58 | 6.85 | 50.44 | 7.39 | AREMP | PIBO |
| | EMAP | 16.01 | 1.04 | 6.47 | 332.71 | | |
| | PIBO | 20.56 | 7.13 | 34.70 | 9.72 | | |
| Percent Fines (<6mm) | AREMP | 63.24 | 2.48 | 3.92 | 170.59 | NA | NA |
| | EMAP | 60.86 | 1.53 | 2.51 | 487.63 | | |
| | PIBO | 54.00 | 4.07 | 7.53 | 100.06 | | |
| | R4 | 59.27 | 37.93 | 64.00 | 0.24 | | |
| % Pool Tail Fines | AREMP | 54.94 | 23.41 | 42.61 | 1.35 | NA | NA |
| | PIBO | 54.94 | 5.15 | 9.38 | 57.53 | | |
| LWD / 100m | AREMP | 1.51 | 0.51 | 33.69 | 6.88 | AREMP | EMAP |
| | EMAP | 28.82 | 9.02 | 31.32 | 2.82 | AREMP | PIBO |
| | PIBO | 31.42 | 11.60 | 36.92 | 2.81 | EMAP | R4 |
| | R4 | 9.82 | 8.62 | 87.82 | 0.00 | PIBO | R4 |

[a] Protocols missing in comparisons do not typically measure these attributes, or there is insufficient data gathered for comparison (See Appendix A for typical measurements).
[b] NA indicates no significant differences among protocols.
[c] EMAP crews do not measure max pool depth or pool tail crest depth for RPD, Appendix A

Measurement precision varied among protocols for each stream attribute in Idaho. Attributes measured with relative precision were reach length, gradient, sinuosity, and residual pool depth. Three stream attributes – percent pools, bankfull width and percent fines - exhibited the same wide range in precision among protocols as occurred in Oregon. Measurement precision of pool tail fines and $D_{50}$ was also highly variable, with differences among protocol CV's greater than 300% (Table 5). Signal to noise estimates for gradient ranged from 0-412, reflecting the high variability in precision among

protocols. The stream attributes with consistently low measurement precision in both states were percent pools, bankfull width, $D_{50}$, and LWD/100m. Overall, PIBO had the highest measurement precision in 6 of 11 stream attributes evaluated.

# DISCUSSION

The results of this study suggest that variation among stream assessment protocols commonly used by the USFS and EPA may preclude comparison of data gathered by observers using different protocols. Variability in measurement of percent pools, bankfull width, $D_{50}$ and LWD/100m at the reach scale highlight the potential difficulties monitoring and assessment programs face when attempting to synthesize data for meaningful comparisons on local to regional scales. In the past, variability associated with the measurement of physical stream characteristics has been attributed to differences in channel complexity, how individual observers implement sampling protocols, seasonal survey timing, measurement error in the field, laboratory analysis error and extent of training (Hannaford and Resh 1995; Roper and Scarnecchia 1995; Wang et al. 1996; Hannaford et al. 1997; Larsen et al. 2001; Roper et al. 2002). This study also indicates variability exists among protocols used to measure the same stream attributes. Significant differences in means for many attributes occurred among most protocols. These differences can likely be attributed to variability among protocols in reach length, sampling approach and extent of training.

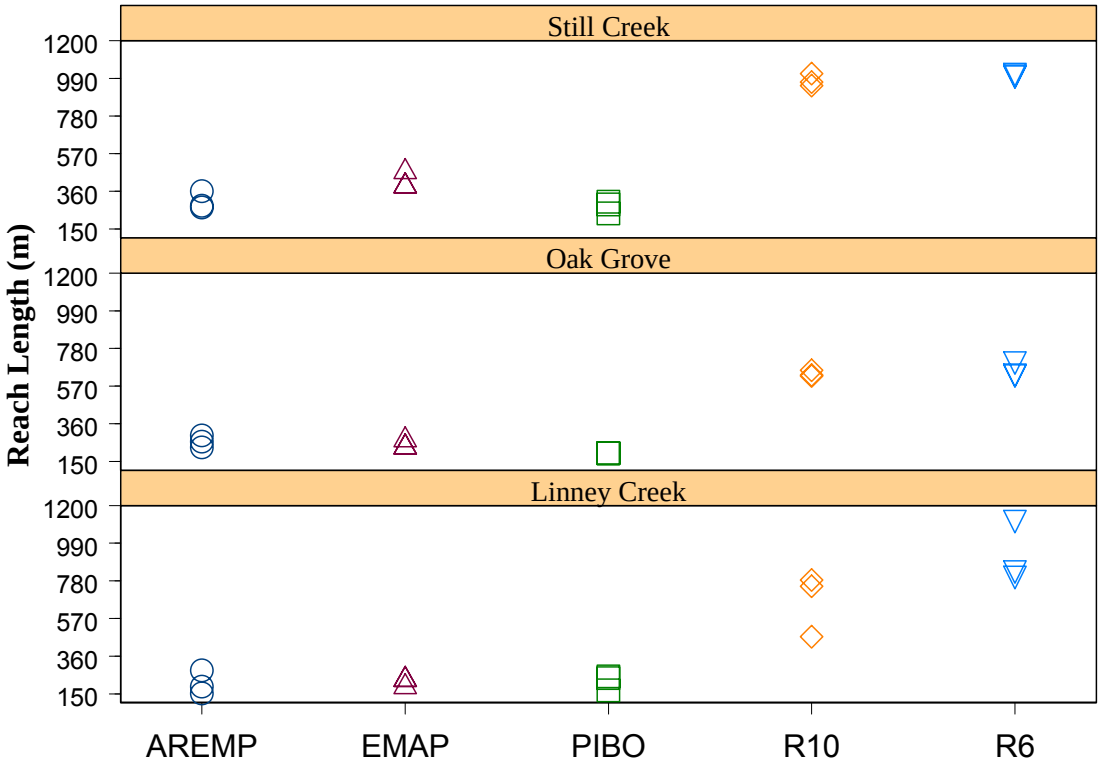
*Reach Length*

Criteria for determining a sufficient length of stream to sample vary among monitoring efforts and are often related to study objectives (Kershner et al. 1992; Simonson et al. 1994; Kaufmann et al. 1999). To ensure representative estimates of habitat, reach lengths long enough to incorporate repeating patterns of variation associated with riffle-pool sequences and meander bend morphology are used (Kaufmann et al. 1999). Crews in this study measured reach length as 40 times the low flow wetted width (EMAP), 20 times bankfull width (AREMP, PIBO) or from predetermined start and end points (R10, R6, R4; Appendix A).

Reach lengths varied among crews using the same protocols as well as among crews using different protocols. Both sources of variation influenced the means and measurement precision of other habitat attributes. Roper et al. (2003) found sample sizes needed to detect a 20% change in an attribute were smallest on sites relocated to distances < 10m from the original site and increased as reaches became farther apart. Based on Roper et al. (2003), many monitoring efforts in this study would have difficulty detecting trend on these streams if differences in overall reach length influence the ability to detect change in the same way as differences in distance from the original start location. All crews started stream surveys in exactly the same location and overall precision for reach length was relatively high (CV$\leq$20). However, in Oregon there were large discrepancies in reach lengths among crews using the same protocol as well as crews using different protocols. Reach lengths differed by 128m among AREMP crews on Linney Creek and by 90m on Still Creek (Figure 2). Reach lengths differed by 244m among EMAP and PIBO crews on Still Creek. Distances reported by crews measuring

reach lengths with predetermined, marked start and end points also differed. On Oak Grove, reach lengths differed by 72m among R6 crews and by 79m among R6 and R10 crews on Linney Creek. These differences resulted from variable estimates of bankfull width and wetted stream width among crews. In addition, differences in reach length were also influenced by a crew's ability to measure either along the thalweg or center of the channel (Appendix A).

**Figure 2.** Reach length comparison in Oregon. Symbols represent attribute means for each crew.




Reach length also influenced bankfull width estimates measured by AREMP and EMAP crews on Oak Grove in Oregon. Approximately 220m from the start, this stream changed from a more entrenched channel to an unconfined meadow complex. Some

crews measuring longer reach lengths had difficulty distinguishing bankfull width in this portion of the stream, with reported values ranging from 6.5-65.0m. These large values increased the average bankfull widths for both tests and resulted in higher mean values for this attribute (Tables 3-4).

*Sampling Approach*

Differences in sampling approach can influence statistical differences in attribute means and affect measurement precision among protocols. These differences occur in measurement method and location, instrumentation, and definition of the attribute. Several physical stream attributes evaluated in this study highlight the influence of these factors.

Gradient

Differences in instrumentation and measurement method influence the ability to detect significant differences in gradient at the reach scale. Although gradient was measured by all crews with relative precision, CV's in the combined region ranged from 9.69 to 23.39 and there were significantly different means among protocols in both states (Tables 3-5). In Oregon, mean values of gradient differed by up to 64%. Because gradient is often used for determining stream power and subsequent sediment delivery potential, differences in gradient values of this magnitude are of particular concern. Instruments used to evaluate gradient in this study included laser rangefinders by AREMP crews, surveyor's levels by PIBO and R10 crews, hand-held clinometers by EMAP crews and hand levels by R4 crews (Appendix A). Isaak et al. (1999) found clinometers and hand levels to have low precision when compared to other common instruments used to

measure gradient, yet EMAP crews reported gradient with higher precision than AREMP and R10 crews in Oregon, and higher than AREMP and R4 crews in Idaho (Tables 4-5). This high precision, despite the use of an imprecise instrument, can be attributed to measurement protocol. While AREMP and R10 crews use a single observation to estimate gradient, EMAP crews estimate gradient between 11 transect locations and then average the values. Averaging multiple gradient estimates through the reach increased EMAP precision of this attribute (Zar 1996; Wohl et al. 1996; Kaufmann et al. 1999). Measurement precision may be improved for protocols using a single observation by measuring a known benchmark at the beginning and end of a stream survey. This would ensure elevation data are within a specified tolerance, increasing both accuracy and repeatability among crews (Harrelson et al. 1994).

Measurement precision in R10 and R4 crews was likely influenced by measuring gradient in locations deemed representative of the reach by these crews. Gradient estimates are likely to vary when crews choose different locations for measurement. Another factor reducing repeatability among all crews was multiple movements of instruments due to channel complexity and decreased line-of-sight. The decrease in precision for all protocols on Linney and Still Creek compared with Oak Grove reflects the influence of this factor (Table 4). A combination of the above factors resulted in lower measurement precision for many crews as well as significantly different gradient means among protocols in Oregon.

The protocol with the most precise measurement of gradient was PIBO. The PIBO method differs significantly from AREMP and R10 because it combines precision

instrumentation with measurement redundancy (Appendix A). It also seems to be most effective on open, low gradient streams like Oak Grove in Oregon (Table 4).

Percent Pools

Pool metrics are commonly evaluated for use in trend assessment, contribute to habitat diversity and often influence management decisions by providing estimates of habitat area and fish abundance (Hankin and Reeves 1988; Kaufmann et al. 1999; Buffington et al. 2002 2002). The inability of most crews to precisely measure this attribute is disturbing considering the common use of pool attributes for regional target values in channel assessment (Buffington et al. 2002; INFS 1995). Differences in pool definitions and extent of training resulted in highly variable means and precision estimates among crews. (Figure 1; Tables 3-5).

Results from this study are in agreement with studies finding high variability among observers for the measurement of pool attributes. Roper and Scarnecchia (1995) found variation among observers when classifying primary habitat units, with increasing variation as pools were classified into secondary habitat types (scour, plunge, dam, etc.). Archer et al. (2003) also reported poor observer precision for percent pools when different crews measured the same reach, attributing 56% of the total variability at repeat sites to crew measurement. Identifying and measuring pools was identified by Poole et al. (1997) as a source of high variability associated with an observer's ability to correctly identify and describe the dimensions of a pool. These results are consistent with findings from other studies (Ralph et al. 1994; Woodsmith and Buffington 1996; Kaufmann et al. 1999).

Identifying and measuring pool habitat was influenced by how pools were defined by each monitoring effort (Appendix A). Results from previous studies indicate precision and accuracy of habitat measurement is often related to how thoroughly and clearly attributes are defined, with thorough definitions reducing subjectivity and measurement variability (Hogle et al. 1993; Ralph et al. 1994; Wang et al. 1996). In this study, quantitative descriptions based on geomorphic descriptors resulted in higher measurement precision. The protocol with the most specific pool requirements was also the only protocol with high measurement precision (Tables 3-5). The low precision estimates obtained by crews using qualitative descriptions to define pools suggest that more objective definitions, in combination with increased training for the assessment of pool habitat, may be appropriate.

Bankfull Width

Mean bankfull width is commonly used to determine the channel geometry of a stream, which can provide insight into the physical stability of the channel through time (MacDonald et al. 1991; Rosgen 1994). In addition, bankfull width is a necessary component in estimating stream power (Dingman 1984; Knighton 1998). Measurement of bankfull elevation is often difficult and subjective, which can yield a range of results among observers (Johnson & Heil 1996). Although locations and numbers of bankfull width measurements differ among protocols, the same bankfull indicators are used by all crews to determine bankfull elevation in the channel (Harrelson et al. 1994; USFS Region 6 1996; Overton et al. 1997; Kaufmann et al. 1999; USFS Region 10 2001; Henderson et al. 2002; Gallo 2002).

Bankfull width was measured with a wide range of precision among crews, reflecting the difficulty many crews had repeating this measurement (Tables 3-5). Signal to noise ratios for bankfull width on Oregon streams ranged from 0-19 (Table 4). Generally, the higher the S:N ratio for a habitat metric the more the metric is able to discern differences among streams, with S:N ratios < 2.0 considered imprecise (Kaufmann et al. 1999). The low S:N ratios among some protocols imply that this metric was unable to distinguish among the sampled streams in Oregon, whose bankfull widths ranged from 8-14m (Table 1). For some protocols, measuring bankfull width may be problematic when applied as a monitoring tool. Difficulty measuring bankfull width has been discussed by other researchers (Platts et al. 1983; Harrelson et al. 1994) and its measurement has been eliminated in some habitat assessment programs because it is time intensive and has high observer variability (Simonson et al. 1994).

Crew experience and training influenced the sample means and precision estimates for bankfull width. Crews with the most experience measured bankfull width in Oregon more precisely (Table 4; Table 6). Bankfull width was also more precisely measured by crews who received the most training. Lack of training in a variety of channel types may also have been a factor in a crew's ability to measure bankfull width with precision. Many crews had difficulty recognizing bankfull indicators on Oak Grove in Oregon and Tripod Creek in Idaho. Oak Grove is spring fed and both streams are low gradient (1.06% and 0.88% respectively). Exit surveys of all crews indicated that many had not received adequate training on low gradient meandering channels. Hannaford et al. (1997) found that training received for one habitat type did not necessarily prepare observers to assess the same attribute in another habitat type.

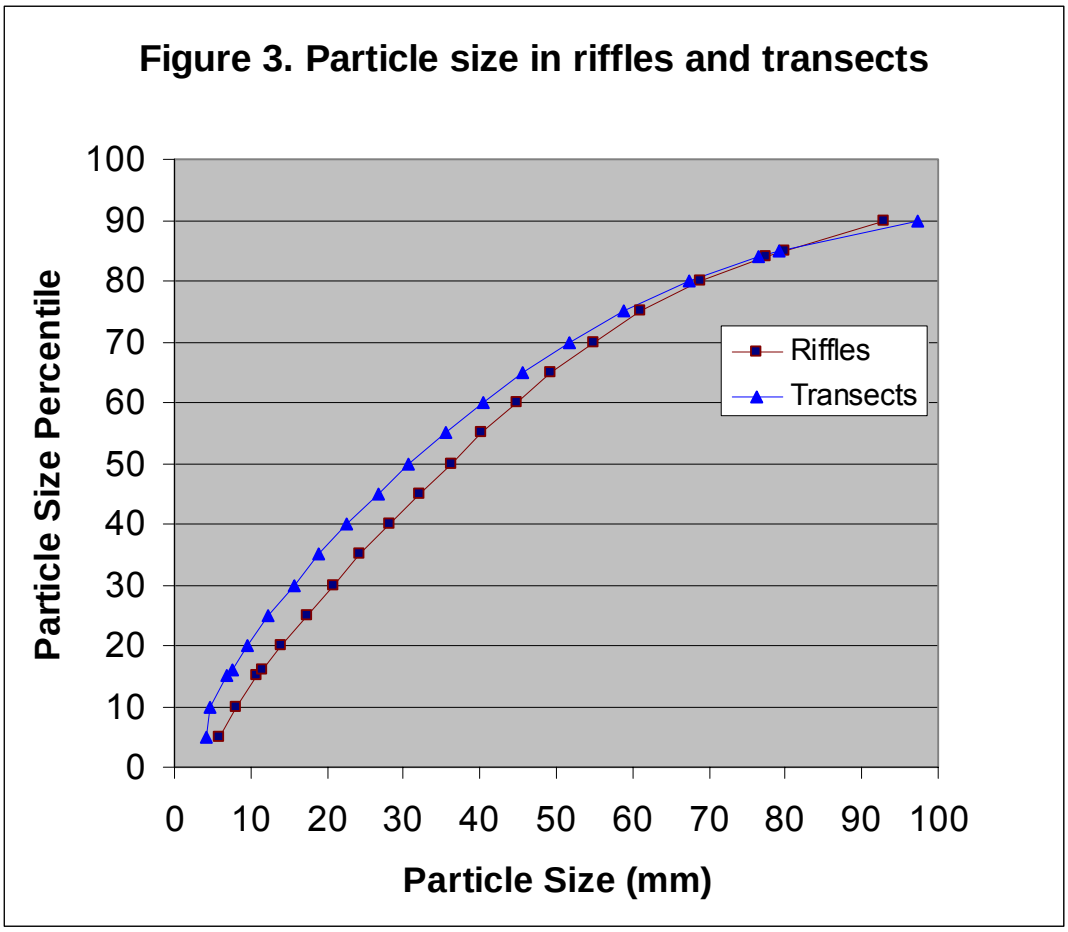
Median Particle Size ($D_{50}$)

Monitoring the size and composition of stream substrate can provide information on channel roughness and stability, habitat quality for benthic fish and macroinvertebrates and water quality (Platts et al. 1983; Wohl et al. 1996; Buffington and Montgomery 1999; Kaufmann 1999). Percent substrate fines and $D_{50}$ are the most common metrics used to quantify substrate among protocols in this study and in other state and federal monitoring programs.

Differences in how and what substrate populations were sampled likely influenced $D_{50}$ means and measurement precision among protocols. Crews used many techniques to describe particle size distribution including gravelometers (R10, R6), direct measurement of each particle (AREMP, PIBO), and visual estimation (EMAP). Crews using visual assessments had the lowest measurement precision in Oregon and the combined sites while crews using gravelometers had the highest precision (Tables 3-4). This pattern is confounded, however, by the high precision of EMAP crews using visual assessments in Idaho. Kaufmann et al. (1999) found visually-assessed substrate metrics to be reasonably precise and suggested that carefully designed visual estimates made at multiple locations within a reach can be nearly as precise as quantitative measurements. Others suggest that fisheries biologists prefer quantitative measurement of at least 100 pebbles and consider this a better alternative than visual techniques in fisheries and instream flow studies (Kondolf and Li 1992). The use of gravelometers appeared to improve $D_{50}$ measurement precision (Table 4). This is consistent with authors suggesting the use of gravelometers or other mechanical devices as a means to improve the accuracy

and precision of pebble counts at well-sorted sites (Wohl et al. 1996; Kondolf 1997; Bunte and Apt 2001).

The location of substrate measurements within the channel may also influence the reported particle size distribution. For example, AREMP and EMAP measured substrate at equally spaced transects with no regard to whether transects were in a riffle or pool habitat. $D_{50}$ reported by AREMP and EMAP crews were smaller than sizes reported by crews evaluating substrate only in riffles (PIBO, R10, R6). Significant differences in $D_{50}$ occurred between transect-based protocols and riffle-based protocols in both states (Tables 4-5). In a recent study conducted by Archer et al. (personal communication) pebble counts conducted in riffles and equally spaced transects were compared on 48 streams. Results indicated slightly smaller (~4mm) particle sizes for transect-based $D_{50}$ than for $D_{50}$ measured in riffles (Figure 3).




Differences of at least 50% in mean $D_{50}$ values occurred among protocols in both states. While it is difficult to pinpoint the individual factors responsible for differences in means and measurement precision, the strongest trends emerge when considering measurement technique and location. Variability among protocols may also be influenced by the high natural variability in stream substrate, in contrast to attributes such as gradient and sinuosity, which have very low natural variability for a particular stream reach. The multiple approaches to $D_{50}$ assessment in this study highlight the need for a consistent protocol that would make substrate comparisons possible among monitoring efforts.

Large Woody Debris

Large wood is important to the physical and biological processes occurring within a stream. It influences channel width and meander patterns, traps organic matter, provides storage for sediment and bed load, and is a factor in pool formation in small streams, providing critical cover for fish and aquatic insects (Bilby 1984; Ralph et al. 1994; Beechie and Sibley 1997). All protocols in this study attempt to quantify number and size of LWD pieces in their stream surveys.

Differences in size categories, habitat complexity and definition of LWD influenced counts of LWD among protocols. Minimum length and width requirements for qualifying pieces are influenced by regional differences in size and amount of LWD. Protocols used by AREMP and R6, whose sampling effort is focused in the Pacific Northwest, have larger minimum size criteria than protocols designed for sampling in drier regions with fewer and smaller trees. Every protocol except AREMP and R6 had different size categories to evaluate LWD (Appendix A), and LWD counts from both states reflect these differences (Tables 3-5). Counts of LWD vary by an order of magnitude among some protocols as a result of size category differences, with values for AREMP and R6 significantly lower than EMAP, PIBO and R10. Count differences between AREMP and R6 crews are due to different definitions of LWD. In contrast to all other protocols in the study, R6 crews only count trees that come in contact with water at bankfull discharge, while others include trees that span the bankfull channel. This difference, as well as size requirements allowing only larger pieces of wood to be counted, explains why R6 had the lowest LWD count among protocols in Oregon (Table 4).

All protocols had lower precision estimates for LWD/100m in Oregon compared to Idaho (Table 4-5). Stream complexity and the amount of wood were much higher in Oregon and likely influenced precision, particularly on Linney and Still Creek. This trend supports other studies relating poor precision to complexity of habitat (Simonson 1993; Wang et al. 1996)

If size categories could be established to overlap at a common length and width, it may be possible to compare counts of LWD among protocols. Comparison difficulties will likely arise due to differences in definition of LWD. Philosophies concerning wood measurement versus estimation in streams with log jams or high wood loading will need to be reconciled if LWD comparisons are to be made among monitoring efforts.

*Experience and Training*

Studies have shown observer experience and training influence the accuracy and precision of habitat measurement, as well as being an important component of monitoring programs with high turnover among personnel from year to year (Hogle et al. 1993; Roper and Scarneccia 1995; Penrose and Call 1995; Wang et al. 1996; Wohl et al. 1996; Hannaford et al. 1997; Thorne et al. 2002; for an exception see Smith 1944). A major consideration for all monitoring programs is the time dedicated to training. In this study, experience and training was assessed for all crews via questionnaire (Table 6).

**Table 6**. Average stream assessment experience and training level of crews

| Protocol | Number of Crews | Overall Assessment Experience (months) | Field Experience with Protocol (months) | Typical Training For New Field Techs (days) |
|---|---|---|---|---|
| PIBO | 6 | 8 | 3 | 10 |
| EMAP | 5 | 23 | 5 | 5 |
| AREMP | 6 | 6 | 3 | 5 |
| R10 | 3 | 145 | 13 | 4 |
| R6 | 3 | 36 | 34 | 4 |
| R4 | 2 | 8 | 5 | 3 |

Results indicate that measurement precision was likely linked to the amount of time each protocol spent training new employees, and not necessarily to overall experience. Crews with the most training also had the highest overall precision for attribute measurement (Table 7).

**Table 7.** Time spent training new stream technicians and highest measurement precision among protocols for measured stream attributes.

| | | Highest Measurement Precision | | |
|---|---|---|---|---|
| **Protocol** | **Training Days** | **Oregon** | **Idaho** | **Combined** |
| PIBO | 10 | 6 | 6 | 7 |
| EMAP | 5 | 2 | 3 | 3 |
| AREMP | 5 | 0 | 1 | 0 |
| R10 | 4 | 0 | NA | NA |
| R6 | 4 | 3 | NA | NA |
| R4 | 3 | NA | 1 | NA |

Quality of training also likely influenced overall measurement accuracy and precision. Although difficult to quantify, differences in training quality were evident through communication with crews and participation in several training sessions. Training that includes exposure to a variety of habitat types (Hannaford et al. 1997), qualified training personnel, consistency among trainers, and quality assurance testing of

new and returning employees are important components of a successful training program. Results from this study suggest high-quality training conducted over a sufficient time period may be the best combination for high measurement precision among crews.

*Statistical versus Physical Significance*

Most stream attributes in this study had means that were statistically different among protocols, but in many cases the physical significance was negligible; for some attributes, however, the opposite was true. For example, mean gradient values between AREMP and R10 in Oregon were not statistically significant although they differed by 20% (Table 4). Gradient values have a direct multiplicative effect on calculations of stream power and shear stress, two parameters commonly used in sediment transport models. A 20% change in magnitude for these parameters represents a very different physical reality, and can greatly influence estimates of stream power and sediment transport. In contrast, a 20% difference in mean sinuosity values such as occurred between AREMP and PIBO crews in Oregon, although statistically significant, is not as physically meaningful. The context and physical consequences of differences in attribute means should always be considered when determining whether or not these differences are “significant”.

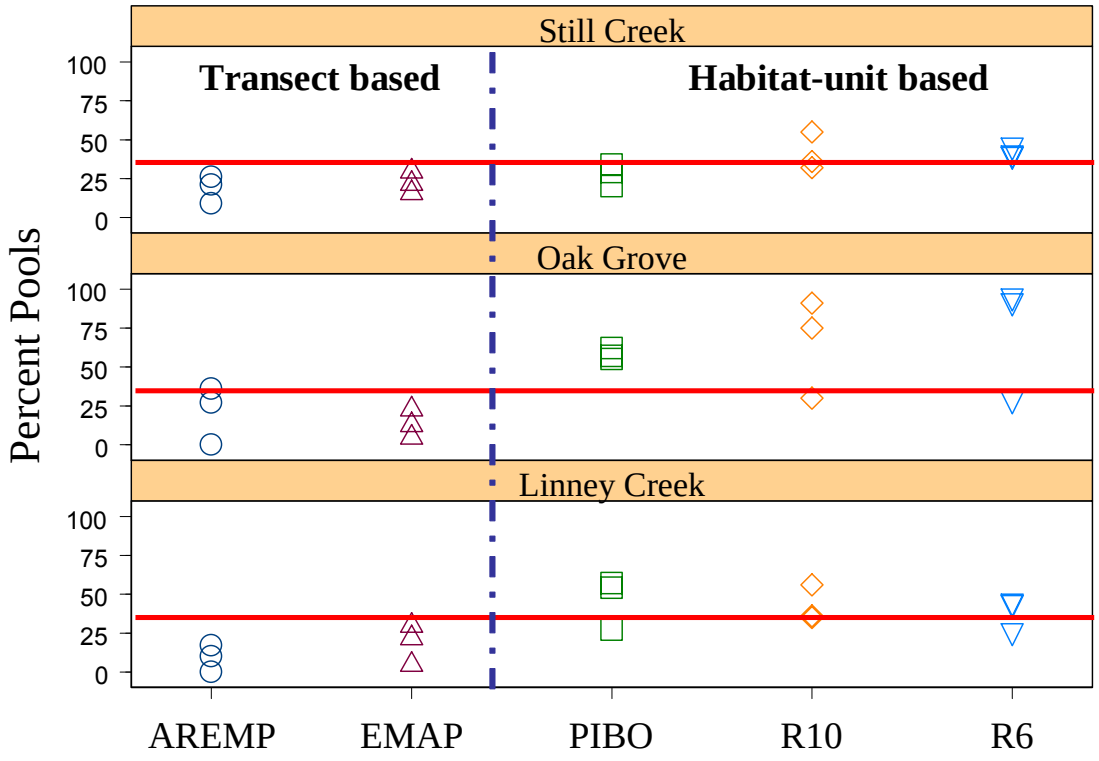
## CONCLUSION

While stream survey methods have continued to be refined (Kaufmann et al. 1999; Roper et al. 2002), this study highlights the difficulty in synthesizing and comparing data when different protocols are used to evaluate the same stream attributes. Statistical differences in means among protocols occurred for every stream attribute

except percent pool tail fines, and the precision with which every attribute was measured was influenced by the protocol used for measurement.

Understanding the sources of variation in stream habitat surveys allows conclusions to be drawn relative to the stream attributes measured. Components of variance attributable to observer variability include protocol implementation, and measurement and laboratory analysis error. While these components can be improved with training (Roper et al. 1995; Hannaford et al.1997; Larsen et al. 2001), variation attributable to protocol may be more difficult to minimize. Differences in protocol may influence land management decisions in many cases. For example, federal and state resource managers often use forest standards to determine whether a particular stream is in its “properly functioning condition”. A common forest standard for the percent of a stream comprised of pool habitat is 35% (USDA 1995; NMFS 1996). The high measurement variability associated with several protocols in this study would make the determination of a “properly functioning condition” dependent upon which protocol a crew uses to survey the stream. In the case of Oak Grove in Oregon, management decisions may vary depending on whether a crew measures pools using a transect-based approach or a habitat-unit based approach. Oak Grove would meet the Forest Standard if measured by most PIBO, R10 and R6 crews, but would not meet the standard if measured by AREMP and EMAP crews (Figure 4). Ultimately, monitoring programs must make the effort to minimize differences among protocols in order for management decisions to be made with confidence and consistency.

**Figure 4.** Management implications of a hypothetical Forest Standard of 35% on reported percent pool values in Oregon.




There are at least two possibilities which would facilitate data comparisons among monitoring efforts. The first is to standardize a core set of physical stream attributes commonly measured by different monitoring efforts which represent channel cross-section, substrate, LWD and reach scale characteristics of streams. Standardization should include size categories, measurement location, attribute definitions, calculation methods and observer training. The second is to establish cross-walk tables to quantify habitat measurement relationships among protocols for this core set of attributes. This may be accomplished by funding a large scale comparison incorporating streams with a broad range of physical variability and management regimes. For example, such a comparison may show crews using clinometers measure gradient 50% higher than crews

using surveyor's levels. Establishing this relationship over a variety of stream conditions including dominant geology, geomorphic form, gradient, and disturbance regime (managed versus unmanaged) may allow gradient comparisons to be made among protocols using different methods and instruments.

The physical stream attributes with the easiest potential integration into a standardized approach are gradient, sinuosity, bankfull width, width to depth ratio and percent pool tail fines. Although measurement precision for each of these attributes varied among protocols, definitions and measurement approach were similar. Attributes requiring more effort to standardize due to larger discrepancies among protocols include reach length, percent pools, residual pool depth, $D_{50}$, percent fines and LWD. With each particular attribute in this study, certain protocols had higher measurement precision than others, indicating potential to adopt specific techniques for improved precision.

Currently, differences among monitoring protocols may preclude the ability to compare and synthesize data and can lead to redundancy in collection efforts, decreased defensibility of the data due to low statistical power, higher cost and failure to detect negative trends in time to mitigate their effects. Standardizing a core set of physical stream attributes or establishing cross-walk relationships among protocols would make a mutually beneficial exchange of data among monitoring programs possible.

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APPENDIX A – Protocol Sampling Methods, Calculations, Data Elements

| **Common Definition of Measured Attributes** | **AREMP Sampling Method/ Protocols/Elements** | **EMAP Sampling Method/ Protocols/Data Element** | **PIBO Sampling Method/ Protocols/Data Elements** | **REGION 10 Sampling Method Protocols/Data Elements** | **REGION 6 Sampling Method/ Protocols/Data Elements** | **REGION 4 Sampling Method/ Protocols/Data Elements** |
|---|---|---|---|---|---|---|
| **Reach Length**<br><br>The overall length of stream evaluated by each crew. | Reach lengths based on 20x the average of five BF measurements that are evenly spaced at a width equal to the initial BF measurement. Minimum length of 150m. | Defines the length of each sampling reach proportional to wetted stream width at the time of sampling (based on average of 5 readings of "typical" width). Field crews measure upstream and downstream distances of 20x the wetted channel width from predetermined randomized midpoints (X-sites). Minimum reach length is 150 m. | Reach lengths are at least 20x the average bankfull width with a minimum length of 80m. Bankfull width measured at a representative point in each of first four riffles, averaged, then placed in one of the following width categories:<br>0 to 4m average bankfull, width category 4, minimum reach length 80m:<br>4.1 - 6m, WC 6<br>6.1 - 8m, WC 8<br>8.1 - 10m, WC 10<br>10.1 - 12m, WC 12<br>12.1 - 14m, WC 14 | For Tier levels II – IV, habitat length is recorded for each channel type. A hip chain is run up the center line of the channel (not thalweg) to determine survey length. Minimum reach length is based on 100m minimum for channel types. Reach length depends on channel type length and management needs. | Each reach numbered sequentially from downstream start point of survey (usually mouth of stream). Sampling frequency sufficient to cover 10 pools, riffles, and 10% total pools and riffles. 1st pool and riffle in sequence chosen randomly. | Survey reaches numbered consecutively from the mouth to the end of survey. Survey reaches classified into reach types A, B, and C determined by gradient. Upper and Lower survey reach boundaries determined by reach breaks such as tributaries, reach type (gradient change) Rosgen channel type, or management boundary. |

| **Gradient** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| Gradient is calculated by dividing the average elevation change from the bottom to the top of the reach by total reach length (Harrelson et al. 1994). | Uses a laser rangefinder to take line-of-sight measurements from start to end of reach. Makes one pass up the reach.<br><br>Calculated by dividing the average elevation change of the streambed (to the nearest cm) by valley length, measured by tape. | Measured with clinometer between equally spaced transects, inter-transect slope values are averaged for a mean reach value.<br><br>Calculated by dividing average elevation change (to nearest cm) of waters surface by reach length, measured up the thalweg by tape. | Uses a surveyors level to take line of sight measurements from start to end of reach. Two passes through reach are made, if values are not within 10% of each other another pass is made and values are averaged.<br><br>Calculated by dividing average elevation change (to nearest cm) of waters surface by reach length, measured up the thalweg by tape. | Uses a surveyors level to take line-of-sight measurements over at least 20 channel widths, or from one distinct channel feature to a similar feature for slope over a shorter distance.<br><br>Calculated by dividing change in elevation of the water surface by valley length, measured by tape. | Uses 1:24,000 scale USGS topographic maps to measure slope. For special cases uses a hand level to measure representative segments every 200-300m.<br><br>Calculated using 1:24,000 scale USGS topographic maps as change in elevation divided by channel length. For special cases uses a hand level and divides change in water surface by measured habitat length. | Uses a hand level to measure representative segments every 200-300m.<br><br>Calculated by dividing average elevation change (to nearest cm) of waters surface by segment length, measured up stream centerline tape. |

| **Sinuosity** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| Sinuosity is determined by dividing the reach length by the straight line distance of the reach. The straight line distance was determined according to methods described by each protocol. | Measurements obtained in the longitudinal profile. Calculated as the length of the stream channel along the thalweg divided by the straight line distance between the top and bottom of the sample reach. | Calculated as the length of the reach divided by the straight line distance. Compass bearings and distances between cross section stations determined by "backsiting" with a clinometer and compass downstream between transects. | Calculated as the length of the stream channel along the thalweg divided by the straight line distance between the top and bottom of the sample reach. | Calculated as the channel thalweg length and the valley floor length. Measured with a hip chain along the stream thalweg. Valley floor length defined as the straight-line distance between the start and end of the stream segment surveyed. Measured on an orthophoto.<br><br>Not determined in this study. | Calculated by dividing the mapped channel length between reach endpoints by the mapped valley length between the same reach endpoints.<br><br>Not determined in this study. | Collected (optional) under Rosgen stream type on "Form 1: Header Data" via USGS maps before crews go into field.<br><br>Not determined in this study. |

| **Percent Pools**<br><br>Percent pools is the percent of the reach comprised of pool habitat. This is determined by summing pool lengths and dividing by the reach length. | AREMP<br><br>Pool defined as characterized by “slower” flow of water and reduced turbulence, identified by a zone of scour, longer than it is wide, with at least 50% scour. Measurements of max depth, pool head and tail crest depths are taken along thalweg profile.<br><br>Calculated as the sum of the lengths of each pool divided by the total reach length. | EMAP<br><br>Pool defined as still water, low velocity, smooth, glassy surface, usually deep compared to other parts of the channel. Pools categorized as plunge pool, trench pool, lateral scour pool, backwater pool, dam pool, unspecified. Needs to be at least as long as the channel is wide.<br><br>Calculated as the sum of the lengths of each pool divided by the total reach length | PIBO<br><br>Pool defined as being bounded by a head crest and tail crest, only consider main-channel pools (thalweg runs through pool), must occupy greater than half the wetted width and be longer than it is wide, depth is at least 1.5 times the pool tail depth.<br><br>Calculated as the sum of the lengths of each pool divided by the total reach length | USFS Region 10<br><br>Defined as a noticeable change in bed elevation caused by the pool forming element(s). “Macro pools” per channel type are recorded, and must meet minimum residual pool depth requirements, pool length or width must be $\geq$ 10% of the average channel bed width, and the pool head and tail crest must be identified.<br><br>Calculated as the sum of the lengths of each pool divided by the total reach length | USFS Region 6<br><br>Defined as a portion of stream that usually has reduced surface turbulence and an avg. depth > riffles when viewed during low flow conditions, bowl or tub appearance, always has a hydraulic control across full width of channel on DS end. Pool length measured along thalweg must be $\geq$ the wetted width, with the exception of channel spanning plunge pools.<br>Calculated as sum of pool lengths / total reach length | USFS Region 4<br><br>Defined as a portion of the stream with reduced current velocity, often with water deeper than the surrounding areas. Pool habitat divided into types of pools/complexes including: dammed pools, scour pools and step pool complex. These divisions are further delineated into position and formative feature of pool habitat.<br><br>Calculated as the sum of the lengths of each pool divided by the total reach length |
|---|---|---|---|---|---|---|

| **Residual Pool Depth** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| Mean residual pool depth is determined by summing residual pool depths throughout the reach. Residual pool depths are typically calculated by subtracting the pool tail depth from the maximum pool depth (Lisle 1987). | Same pool definition applies. Pool tail crest, max pool depth, and pool head locations measured with laser rangefinder along the longitudinal profile.<br><br>Not calculated in AREMP protocol. | Same pool definition applies. Average depth along each subtransect determined during thalweg profile and used in RPD calculation.<br><br>Calculates residual pool depth based on a graphically represented residual surface along a longitudinal depth profile, with corrections made for reach slope | Same pool definition applies. Maximum and riffle crest depth are measured with a depth rod to the nearest centimeter.<br><br>Calculated by subtracting pool tail depth from maximum depth for each identified pool, then summing and averaging these values for a reach mean. | Same pool definition applies. The max depth and pool tail crest depth are measured with a depth rod to nearest centimeter.<br><br>Calculated by subtracting pool tail depth from maximum depth for each identified pool, then summing and averaging these values for a reach mean. | Same pool definition applies. Pool tail crest and max pool depth measured with a depth rod wherever depth is less than 4 ft. If >4 ft. depth is estimated.<br><br>Calculated by subtracting pool tail depth from maximum depth for each identified pool, then summing and averaging these values for a reach mean. | Same pool definition applies. Pool max depth and pool crest depth are measured with a depth rod.<br><br>Calculated by subtracting pool tail depth from maximum depth for each identified pool, then summing and averaging these values for a reach mean. |

| **$D_{50}$** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| $D_{50}$ is the diameter of the intermediate axis of the median particle collected in pebble counts (Wolman 1954). | Determined by measuring 10 particles at systematic intervals within the 11 intermediate cross sections for non-constrained and at the six transects plus the intermediate transects for constrained reaches, using EMAP protocols (Wolman 1954, Bain et al. 1985, Platts et al. 1983, and Plafkin et al. 1989).<br><br>Measurements extend to bankfull stage on each side of stream. | Substrate size and embeddedness are evaluated at each of the 11 cross-sections. Methods adapted from those described in Wolman (1954), Bain et al. (1985), Platts et al. (1983), and Plafkin et al. (1989). Procedure is a systematic selection of 5 substrate particles taken at left and right banks, 25%, 50% and 75% the wetted width in each of the 11 cross-sections. Total of 105 particles sampled within each reach.<br><br>Substrate size estimated visually and placed in particle size class. | Uses Wolman (1984) method. Samples in the 1st four riffle/runs. Minimum of 100 particles to be sampled in each reach, with measurement location within each riffle randomly determined via random number generator. Entire streambed is sampled beginning with the heel of the boot at the point where the streambed and stream bank meet.<br><br>Particles are only sampled in riffle habitats, not in pools if the transect happens to cross into pool habitat. | Conduct a pebble count (Wolman 1954) at each cross section site (minimum one per channel type) with five transects placed at 5m increments if riffle is large enough. First transect located under cross section tape, with two transects upstream and two downstream. Twenty boot-tip samples taken at each transect for a total of 100 pebbles. Pebbles are placed into size categories determined by gravel templates. Cross sections are located in straight riffle sections. | Wolman (1954) pebble counts performed in riffles and extend to bankfull stage on each side. Conducted in a representative of reach located at either 1/3 and 2/3 of total reach length, or in one riffle large enough for a 100 pebble count. This is a Forest Option parameter. Region 6 requires a visual estimate of the percent that each size class of substrate comprises of wetted streambed area (if > 10%). | $D_{50}$ not estimated by Region 4 in this study.<br><br>As a Forest Option, substrate composition determined by visual estimates or Wolman Pebble Count (1954). Substrate classes based on Wentworth Scale and modified from Lane (1947). Transects located perpendicular to the stream in the scour pool tailout or low gradient riffle.<br><br>Particles measured with a ruler then placed in size classes. |

| **$D_{50}$ Cont.** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| $D_{50}$ is the diameter of the intermediate axis of the median particle collected in pebble counts (Wolman 1954). | Particles are measured with a ruler to nearest Centimeter. Measurements are conducted in both riffles and pools.<br><br>AREMP calculates by query in Access database.<br><br>In this study, calculated using percentile function in Excel. | Calculated by assigning particles in each size class an integer value from 6 (bedrock, concrete, hardpan) to 1 (clay/silt), then uses 1 of 2 equations based<br><br>on particle size (> or < 2.5mm) to calculate the $\log_{10}$ of geometric mean substrate diameter.<br><br>In this study, calculated using the upper boundary of each size class in a cumulative frequency distribution curve. | Particles are measured with a ruler to the nearest centimeter.<br><br>Calculated using percentile function in Excel. | Calculated using the upper boundary of each size class in a cumulative frequency distribution curve. | Size classes include sand/silt/clay, gravel, cobble, boulder and bedrock.<br><br>Particles measured in primarily riffle habitat, but pool habitat may also be used when channel dimensions decrease and habitats become smaller.<br>Measured with gravel templates.<br>Calculated using the upper boundary of each size class in a cumulative frequency distribution curve. | Transects extending to bankfull stage on each side. |

| **Percent Fines**<br><br>Percent fines was determined as the percent of the substrate collected for $D_{50}$ assessment that had an intermediate axis diameter of less than 6mm. | AREMP<br><br>These are particle fines determined from data obtained in the $D_{50}$ substrate assessment.<br><br>Substrate Fines are considered particles $\leq$ 6mm.<br><br>Calculated by dividing the number of particles <6mm by total number of particles in count. | EMAP<br><br>These are particle fines determined from data obtained in the $D_{50}$ substrate assessment.<br><br>Substrate Fines are considered particles $\leq$ 6mm.<br><br>Calculated using a cumulative frequency distribution curve. | PIBO<br><br>These are particle fines determined from data obtained in the $D_{50}$ substrate assessment.<br><br>Substrate Fines are considered particles $\leq$ 6mm.<br><br>Calculated by dividing the number of particles <6mm by total number of particles in count. | USFS Region 10<br><br>These are particle fines determined from data obtained in the $D_{50}$ substrate assessment.<br><br>Substrate Fines are considered particles $\leq$ 6mm.<br><br>Calculated using a cumulative frequency distribution curve. | USFS Region 6<br><br>These are particle fines determined from data obtained in the $D_{50}$ substrate assessment.<br><br>Substrate Fines are considered particles $\leq$ 6mm.<br><br>Calculated using a cumulative frequency distribution curve. | USFS Region 4<br><br>Particles <6 mm recorded for the wetted, flowing area of scour pool tail crests (or tailouts) and low gradient riffles. Particles are either visually estimated alone or with a 49 intersection grid (used in this study).<br><br>Calculated as average of values obtained on 49 intersection grid toss. |
|---|---|---|---|---|---|---|

| **Pool Tail Fines** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| A 50-intersection grid (Bunte and Apt 2001) is tossed in three locations in a pool tail. Percent pool tail fines are calculated by dividing the number of intersections underlain with fine sediment by the total number of intersections (150). | Use USFS Region 5 SCI protocol. A 50 intersection grid is used to measure particles ≤ 2mm in diameter with 1st measurement in thalweg and 2nd and 3rd measurements on either side. Fines only measured in the lower 10% of scour pools. Fines determined in each pool tail crest (up to 12) in the sample reach. Calculated by dividing number of intersections underlain with sediment ≤ 2mm by total number of intersections. | Not calculated. | Uses Overton et al. 1997 methodology. A 50 intersection grid is used to measure particles ≤ 6mm in diameter, with grid placement perpendicular to the pool tail crest at 25%, 50%, and 75% of the distance across the wetted, flowing area of the crest (no measurements within stagnant water or the adjacent riffle). Collected in the 1st four scour pools of each reach beginning at the downstream end. Calculated by dividing the number of intersections underlain with sediment ≤ 6mm by the total number of intersections. | Not calculated. | Not calculated. | Not calculated. |

| **Bankfull Width**<br><br>Bankfull width is defined as the width of the channel at bankfull discharge, which is the level at which water just begins to overflow into the active floodplain. Bankfull indicators are the same for all protocols and are described in Harrelson et al. 1994. | AREMP<br><br>Measures bankfull at each of 11 cross sections in non-constrained reaches, and at 6 cross sections in constrained reaches.<br><br>Calculated as the average of bankfull measurements determined at cross sections. | EMAP<br><br>Measures bankfull at each of 11 channel cross sections.<br><br>Calculated as the average of bankfull measurements determined at cross sections. | PIBO<br><br>Measures bankfull at each of 4 channel cross sections, and each of 20 transects throughout the reach.<br><br>Calculates average bankfull for cross sections and also for transects.<br><br>Transect bankfull widths were used for average values in this comparison. | USFS Region 10<br><br>Streams are delineated by channel types. Bankfull width is measured at a minimum rate of once per channel type. A channel cross section is located in a place deemed representative of the channel type and bankfull is determined at this location.<br><br>Calculated as the bankfull width of the surveyed cross section. (No average value). | USFS Region 6<br><br>Bankfull determined at measured riffles, which occur at a frequency that captures 10% of the pools and riffles in the stream.<br><br>Calculated as the average of bankfull measurements determined at measured riffles.<br><br>Number of measured riffles between crews differed as follows:<br>Linney – 6,7,6<br>Oak - 2,3,2<br>Still – 3,8,9 | USFS Region 4<br><br>Collection optional. Bankfull width not determined in this study. |
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| | | | | | | |
|---|---|---|---|---|---|---|
| **Width to Depth Ratio**<br><br>Width to depth ratio is the average bankfull width divided by the average channel depth. | AREMP<br><br>Bankfull width to depth ratios determined at every transect (11) regardless of whether the reach is constrained or non-constrained.<br><br>Calculated as average bankfull width divided by the average depth at transect locations. | EMAP<br><br>Bankfull width and bankfull height measured at each transect (11) in reach. Visual estimates of bankfull height above present water level (surveyors rod as a guide) are recorded at each transect.<br><br>BF W:D Ratio not calculated.<br><br>Not calculated in this study because BF height is taken from water surface, not as an average of depths across channel – the procedure EMAP uses for wetted W:D ratio calculations. | PIBO<br><br>Bankfull width measured to the nearest 0.1 m, perpendicular to stream channel, at each transect and cross-section. Mean bankfull depth determined from 10 measurements of depth in each cross section, taken at equal distances after random start from bankfull mark on left bank. Distance along tape and depth from streambed to the bankfull elevation is recorded.<br><br>Calculated as average bankfull width divided by the average depth at cross section locations. | USFS Region 10<br><br>Bankfull width and depth (mean and max) measurements recorded on cross section surveys with measure tape strung across the channel (at least one cross section per channel type). Calculated by dividing the cross-sectional area by bankfull width. Depth measurements in this calculation cover bankfull, top of bank, bottom of bank, edge of water, thalweg, and the same locations on the other side of the channel. | USFS Region 6<br><br>BFW determined to nearest 0.1 ft at each measured riffle, as are avg. and max bankfull depth (BFD). Measured at intervals of 25, 50 and 75% of BFW from streambed to taut, level measuring tape at bankfull height on either side of stream.<br><br>Calculated as average bankfull width divided by average cross section depth at each measured riffle. Differences in number of measured riffles same as BFW. | USFS Region 4<br><br>Collection optional. BF width and depth may be subsampled to calibrate the observer's eye for bankfull stage, aid in Rosgen stream typing, obtain basic hydrology data such as bankfull discharge, or monitor channel change over time.<br><br>Specific technique not covered in manual. |

| | | | | | | |
|---|---|---|---|---|---|---|
| **LWD/100m**<br><br>LWD/100m is calculated by dividing the total number of pieces of LWD by the reach length and multiplying by 100. This attribute is not commonly calculated among protocols in this study but served to normalize count comparisons among protocols. | AREMP<br><br>AREMP protocol adapted from ODFW (Moore et al. 1999). Includes pieces of large wood if they have a minimum length of 3m and are at least 0.3m DBH. Length and DBH are visually estimated for each piece. Pieces contained partially within or suspended above the channel (spanners and leaners) are counted. Pieces in logjams (>5 pieces) are not counted. Measurements of length and DBH are taken on the first 10 pieces in the reach and every 5th piece thereafter. | EMAP<br><br>Methods adapted from Robison and Beschta (1990). LWD defined as woody material with small end diameter of at least 0.1m, and length of at least 1.5 m. For each LWD piece, length and both end diameters are estimated in order to place it in one of twelve diameter and length categories. Diameter classes are 0.1 to < 0.3m, 0.3 to < 0.6m, 0.6 to < 0.8 m, and > 0.8m, based on large end diameter. Length classes are 1.5 to < 5.0m, 5.0 to < 15m, and ≥ 15m, based on the portion of LWD that is > 0.1m diameter | PIBO<br><br>Uses Overton et al. methodology. To be considered large wood, a piece must be at least 1m in length or must have a length equal to or greater than 2/3 the wetted width of the stream AND must have a diameter of at least 0.1m as measured one-third of the way up from the base. Pieces are also divided into those within the active BF channel and those that extend above the active BF channel (spanners and leaners).<br><br>Length and circumference are measured for every 5th tallied piece at reaches with <20 pieces and every 10th piece at reaches with >20 pcs. | USFS Region 10<br><br>For Tier 2-4 survey all pieces are counted that meet minimum qualifying dimensions and that are in zones one and two of the channel (zone 1 = within wetted width, zone 2 = area within the bankfull width that is above wetted height and below the bankfull height). Minimum diameter to qualify is 0.1m at widest point, and 1m minimum length.<br><br>Tier 3-4 use two cluster categories (Cat. 1= 5-9 pieces touching, Cat. 2 = 10+ pieces). | USFS Region 6<br><br>Pieces meeting size criteria that occur within the bankfull channel of each habitat unit are counted. Three size classes (small, med, large) used with size criteria dependant upon location of stream east or west of High Cascades (East = .15m diameter 6.5m from large end. West = .3m diameter, 3m from large end). All size classes based on the tree bole diameter as measured a prescribed distance from the large end. | USFS Region 4<br><br>LWD dimensions (lengths/diameters) and counts collected on survey reaches "B" and "C" (gradient 0 – 4.0%). Counts only collected on "A" (>4% gradient). All LWD within the bankfull channel considered, including "spanners". Single piece LWD must be at least 3m in length or have a length ≥ 2/3 wetted width of stream and be at least 0.1m in diameter 1/3 the way up from the base. Ocular estimates or measurements with stadia rod used. |
| **LWD/100m Cont.**<br><br>LWD/100m is calculated by dividing | AREMP | | PIBO | | | |

| **LWD/100m Cont.** | AREMP | EMAP | PIBO | USFS Region 10 | USFS Region 6 | USFS Region 4 |
|---|---|---|---|---|---|---|
| LWD/100m is calculated by dividing the total number of pieces of LWD by the reach length and multiplying by 100. This attribute is not commonly calculated among protocols in this study but served to normalize count comparisons among protocols. | | Included are pieces at least partially in the channel up to bankfull height, then those that span above, but not into, the bankfull channel. | | Tier 4 further delineates LWD into 12 length and width size categories. LWD key pieces are based on the average channel bed width and put USFS Region 10 in one of four size categories: Average bed width 0 – 4.9m, 5 – 9.9m, 10 – 19.9m, ≥ 20m. Each bed width category has concomitant diameter and length minimums. | Also included are pieces of large wood longer than 2 times the average bankfull width for the reach. Minimum diameter for these USFS Region 6 pieces measured at a distance from the large end equal to 2x the bankfull width. The tree bole or root swell of live or dead trees must interact with the streamflow at bankfull conditions (spanners and leaners are not counted). | Number of pieces in aggregates (2 or more LWD touching) are counted or estimated. LWD USFS Region 4 rootwads (boles or root masses attached to logs < 3m in length and at least 0.1m in diameter 1/3 the way up the log, and dead standing trees < 3m in height also qualify if root mass is visible are also counted in each habitat unit. |

# APPENDIX B
## Oregon Stream Stage Readings

Appendix B. Stage measurements taken from numbered metal stream gauges. One 2 increment jump (11.36 - 11.34) equals 3mm.

| Date | Stream | Protocol | Crew | Stage | Largest Difference Start---->Finish |
|---|---|---|---|---|---|
| 7/28/2002 | Linney | AREMP | 8100 | 11.36 | 1.50cm |
| 7/30/2002 | Linney | AREMP | 8200 | 11.36 | |
| 7/31/2002 | Linney | PIBO | 7200 | 11.34 | |
| 8/1/2002 | Linney | PIBO | 7100 | 11.26 | |
| 8/2/2002 | Linney | PIBO | 7300 | 11.36 | |
| 8/5/2002 | Linney | EMAP | 6300 | 11.34 | |
| 8/6/2002 | Linney | EMAP | 6200 | 11.34 | |
| 8/7/2002 | Linney | EMAP | 6100 | 11.34 | |
| 8/13/2002 | Linney | R6 | 4200 | 11.3 | |
| 8/14/2002 | Linney | R6 | 4300 | 11.3 | |
| 8/15/2002 | Linney | R10 | 9100 | 11.3 | |
| 8/16/2002 | Linney | R10 | 9200 | 11.3 | |
| 8/17/2002 | Linney | R10 | 9300 | 11.3 | |
| | | | | | |
| 7/28/2002 | Oak Grove | AREMP | 8300 | 8.52 | 3.30cm |
| 7/31/2002 | Oak Grove | PIBO | 7300 | 8.44 | |
| 8/1/2002 | Oak Grove | PIBO | 7200 | 8.42 | |
| 8/2/2002 | Oak Grove | PIBO | 7100 | 8.42 | |
| 8/5/2002 | Oak Grove | EMAP | 6200 | 8.44 | |
| 8/7/2002 | Oak Grove | EMAP | 6300 | 8.38 | |
| 8/6/2002 | Oak Grove | EMAP | 6100 | 8.32 | |
| 8/13/2002 | Oak Grove | R6 | 4200 | 8.32 | |
| 8/15/2002 | Oak Grove | R10 | 9200 | 8.31 | |
| 8/16/2002 | Oak Grove | R10 | 9300 | 8.31 | |
| 8/17/2002 | Oak Grove | R10 | 9100 | 8.3 | |
| | | | | | |
| 7/29/2002 | Still | AREMP | 8200 | 6.18 | 1.65cm |
| 7/30/2002 | Still | AREMP | 8100 | 6.19 | |
| 7/31/2002 | Still | PIBO | 7100 | 6.16 | |
| 8/1/2002 | Still | PIBO | 7300 | 6.16 | |
| 8/2/2002 | Still | PIBO | 7200 | 6.16 | |
| 8/5/2002 | Still | EMAP | 6100 | 6.15 | |
| 8/6/2002 | Still | EMAP | 6300 | 6.14 | |
| 8/7/2002 | Still | EMAP | 6200 | 6.14 | |
| 8/12/2002 | Still | R6 | 4300 | 6.1 | |
| 8/13/2002 | Still | R6 | 4200 | 6.1 | |
| 8/15/2002 | Still | R10 | 9300 | 6.08 | |
| 8/16/2002 | Still | R10 | 9100 | 6.09 | |
| 8/17/2002 | Still | R10 | 9200 | 6.08 | |

# Idaho Stream Stage Readings

Appendix B. Stage measurements taken from numbered metal stream gauges. One 2 increment jump (7.88 - 7.86) equals 3mm.

| Date | Stream | Protocol | Crew | Stage | Largest Difference Start----->Finish |
|---|---|---|---|---|---|
| 7/6/2002 | Anderson | PIBO | 7200 | 7.88 | 2.70cm |
| 7/7/2002 | Anderson | PIBO | 7300 | 7.86 | |
| 7/8/2002 | Anderson | PIBO | 7100 | 7.86 | |
| 7/14/2002 | Anderson | AREMP | 8100 | 7.78 | |
| 7/14/2002 | Anderson | AREMP | 8300 | 7.82 | |
| 7/15/2002 | Anderson | AREMP | 8200 | 7.8 | |
| 7/17/2002 | Anderson | EMAP | 5100 | 7.77 | |
| 7/18/2002 | Anderson | EMAP | 5200 | 7.8 | |
| 7/23/2002 | Anderson | R4 | 3100 | 7.78 | |
| 7/25/2002 | Anderson | R4 | 3200 | 7.76 | |
| | | | | | |
| 7/6/2002 | Pine | PIBO | 7100 | 11.16 | 3.00cm |
| 7/7/2002 | Pine | PIBO | 7200 | 11.13 | |
| 7/8/2002 | Pine | PIBO | 7300 | 11.11 | |
| 7/15/2002 | Pine | AREMP | 8300 | 11 | |
| 7/14/2002 | Pine | AREMP | 8100 | 11.03 | |
| 7/15/2002 | Pine | AREMP | 8200 | 11.02 | |
| 7/17/2002 | Pine | EMAP | 5200 | 10.98 | |
| 7/18/2002 | Pine | EMAP | 5100 | 10.99 | |
| 7/23/2002 | Pine | R4 | 3200 | 10.98 | |
| 7/24/2002 | Pine | R4 | 3100 | 10.96 | |
| | | | | | |
| 7/6/2002 | Tripod | PIBO | 7300 | 5.84 | 1.20cm |
| 7/7/2002 | Tripod | PIBO | 7100 | 5.82 | |
| 7/8/2002 | Tripod | PIBO | 7200 | 5.82 | |
| 7/14/2002 | Tripod | AREMP | 8300 | 5.8 | |
| 7/14/2002 | Tripod | AREMP | 8200 | 5.8 | |
| 7/15/2002 | Tripod | AREMP | 8100 | 5.8 | |
| 7/17/2002 | Tripod | EMAP | 5100 | 5.8 | |
| 7/18/2002 | Tripod | EMAP | 5200 | 5.76 | |
| 7/24/2002 | Tripod | R4 | 3200 | 5.8 | |
| 7/25/2002 | Tripod | R4 | 3100 | 5.79 | |

# APPENDIX C

## Variance Estimates Combined Region

| **Attribute** | ***Reach Length*** | | | **Attribute** | ***Bankfull Width*** | | |
|---|---|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | Protocol | **AREMP** | **EMAP** | **PIBO** |
| Intercept (Mean) | 205.17 | 246.67 | 175.17 | Intercept (Mean) | 11.36 | 8.7166 | 7.8131 |
| Stream_ID | 3735.37 | 9228.17 | 5288.94 | Stream_ID | 22.21 | 17.9388 | 20.0885 |
| Residual | 1321.06 | 1007.30 | 631.64 | Residual | 18.56 | 9.2857 | 0.6625 |
| Total Var | 5056.43 | 10235.47 | 5920.58 | Total Var | 40.76 | 27.22 | 20.75 |
| % obs var | 26.13 | 9.84 | 10.67 | % obs var | 45.53 | 34.11 | 3.19 |
| S:N | 2.83 | 9.16 | 8.37 | S:N | 1.20 | 1.93 | 30.32 |
| Stddev Resid | 36.35 | 31.74 | 25.13 | Stddev Resid | 4.31 | 3.05 | 0.81 |
| CV Resid | 17.72 | 12.87 | 14.35 | CV Resid | 37.94 | 34.96 | 10.42 |
| CV Total | 34.66 | 41.01 | 43.93 | CV Total | 56.22 | 59.86 | 58.30 |
| RMSE | 36.35 | 31.74 | 25.13 | RMSE | 4.31 | 3.05 | 0.81 |

| **Attribute** | ***Gradient*** | | | **Attribute** | ***BF_WD Ratio*** | | |
|---|---|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | Protocol | **AREMP** | **EMAP** | **PIBO** |
| Intercept (Mean) | 1.72 | 2.04 | 1.45 | Intercept (Mean) | 25.90 | NA | 26.94 |
| Stream_ID | 1.14 | 1.31 | 1.31 | Stream_ID | 64.13 | NA | 105.96 |
| Residual | 0.16 | 0.18 | 0.02 | Residual | 120.39 | NA | 26.39 |
| Total Var | 1.30 | 1.49 | 1.33 | Total Var | 184.52 | NA | 132.35 |
| % obs var | 12.46 | 12.09 | 1.48 | % obs var | 65.25 | NA | 19.94 |
| S:N | 7.02 | 7.27 | 66.62 | S:N | 0.53 | NA | 4.01 |
| Stddev Resid | 0.40 | 0.42 | 0.14 | Stddev Resid | 10.97 | NA | 5.14 |
| CV Resid | 23.39 | 20.82 | 9.69 | CV Resid | 42.36 | NA | 19.07 |
| CV Total | 66.25 | 59.89 | 79.67 | CV Total | 52.44 | NA | 42.70 |
| RMSE | 0.40 | 0.42 | 0.14 | RMSE | 10.97 | NA | 5.14 |

| **Attribute** | ***Sinuosity*** | | | **Attribute** | ***D50*** | | |
|---|---|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | Protocol | **AREMP** | **EMAP** | **PIBO** |
| Intercept (Mean) | 1.48 | NA | 1.28 | Intercept (Mean) | 22.88 | 31.47 | 36.50 |
| Stream_ID | 0.04 | NA | 0.03 | Stream_ID | 715.53 | 1058.14 | 847.04 |
| Residual | 0.03 | NA | 0.01 | Residual | 140.35 | 443.43 | 165.11 |
| Total Var | 0.06 | NA | 0.04 | Total Var | 855.88 | 1501.57 | 1012.15 |
| % obs var | 43.88 | NA | 30.15 | % obs var | 16.40 | 29.53 | 16.31 |
| S:N | 1.28 | NA | 2.32 | S:N | 5.10 | 2.39 | 5.13 |
| Stddev Resid | 0.17 | NA | 0.10 | Stddev Resid | 11.85 | 21.06 | 12.85 |
| CV Resid | 11.38 | NA | 8.22 | CV Resid | 51.77 | 66.90 | 35.20 |
| CV Total | 17.17 | NA | 14.97 | CV Total | 127.85 | 123.12 | 87.16 |
| RMSE | 0.17 | NA | 0.10 | RMSE | 11.85 | 21.06 | 12.85 |

| Attribute | Percent Fines | | |
|---|---|---|---|
| Protocol | AREMP | EMAP | PIBO |
| Intercept (Mean) | 51.25 | 44.93 | 36.06 |
| Stream_ID | 883.80 | 967.55 | 1119.78 |
| Residual | 40.69 | 13.83 | 52.72 |
| Total Var | 924.49 | 981.38 | 1172.50 |
| % obs var | 4.40 | 1.41 | 4.50 |
| S:N | 21.72 | 69.94 | 21.24 |
| Stddev Resid | 6.38 | 3.72 | 7.26 |
| CV Resid | 12.45 | 8.28 | 20.14 |
| CV Total | 59.33 | 69.72 | 94.97 |
| RMSE | 6.38 | 3.72 | 7.26 |

| Attribute | Residual Pool Depth | | |
|---|---|---|---|
| Protocol | AREMP | EMAP | PIBO |
| Intercept (Mean) | NA | NA | 0.53 |
| Stream_ID | NA | NA | 0.11 |
| Residual | NA | NA | 0.00 |
| Total Var | NA | NA | 0.11 |
| % obs var | NA | NA | 2.61 |
| S:N | NA | NA | 37.31 |
| Stddev Resid | NA | NA | 0.05 |
| CV Resid | NA | NA | 10.07 |
| CV Total | NA | NA | 62.30 |
| RMSE | NA | NA | 0.05 |

| Attribute | PT Fines | | |
|---|---|---|---|
| Protocol | AREMP | EMAP | PIBO |
| Intercept (Mean) | 34.86 | NA | 33.49 |
| Stream_ID | 804.11 | NA | 1187.98 |
| Residual | 359.16 | NA | 53.49 |
| Total Var | 1163.27 | NA | 1241.47 |
| % obs var | 30.88 | NA | 4.31 |
| S:N | 2.24 | NA | 22.21 |
| Stddev Resid | 18.95 | NA | 7.31 |
| CV Resid | 54.37 | NA | 21.84 |
| CV Total | 97.84 | NA | 105.21 |
| RMSE | 18.95 | NA | 7.31 |

| Attribute | Percent Pools | | |
|---|---|---|---|
| Protocol | AREMP | EMAP | PIBO |
| Intercept (Mean) | 21.58 | 25.16 | 51.70 |
| Stream_ID | 47.82 | 164.76 | 423.69 |
| Residual | 149.32 | 122.14 | 67.62 |
| Total Var | 197.14 | 286.90 | 491.31 |
| % obs var | 75.74 | 42.57 | 13.76 |
| S:N | 0.32 | 1.35 | 6.27 |
| Stddev Resid | 12.22 | 11.05 | 8.22 |
| CV Resid | 56.62 | 43.93 | 15.91 |
| CV Total | 65.05 | 67.33 | 42.88 |
| RMSE | 12.22 | 11.05 | 8.22 |

| Attribute | LWD_100m | | |
|---|---|---|---|
| Protocol | AREMP | EMAP | PIBO |
| Intercept (Mean) | 7.82 | 34.61 | 42.62 |
| Stream_ID | 95.47 | 134.21 | 381.17 |
| Residual | 11.92 | 180.54 | 319.15 |
| Total Var | 107.39 | 314.75 | 700.32 |
| % obs var | 11.10 | 57.36 | 45.57 |
| S:N | 8.01 | 0.74 | 1.19 |
| Stddev Resid | 3.45 | 13.44 | 17.86 |
| CV Resid | 44.17 | 38.82 | 41.92 |
| CV Total | 132.56 | 51.26 | 62.09 |
| RMSE | 3.45 | 13.44 | 17.86 |

# Variance Estimates Oregon

| **Attribute** | ***Reach Length*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 257.11 | 302.22 | 229.69 | 800.76 | 856.01 |
| Stream_ID | 1441.93 | 11437.00 | 1352.83 | 9707493 | 29866.00 |
| Residual | 2614.67 | 1066.67 | 1014.52 | 502.41 | 10491.00 |
| Total Var | 4056.60 | 12503.67 | 2367.35 | 9707995.41 | 40357.00 |
| % obs var | 64.45 | 8.53 | 42.85 | 0.01 | 26.00 |
| S:N | 0.55 | 10.72 | 1.33 | 19321.85 | 2.85 |
| Stddev Resid | 51.13 | 32.66 | 31.85 | 22.41 | 102.43 |
| CV Resid | 19.89 | 10.81 | 13.87 | 2.80 | 11.97 |
| CV Total | 24.77 | 37.00 | 21.18 | 389.10 | 23.47 |
| RMSE | 51.13 | 32.66 | 31.85 | 22.41 | 102.43 |

| **Attribute** | ***Gradient*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 1.48 | 2.02 | 1.30 | 1.23 | NA |
| Stream_ID | 0.10 | 0.29 | 0.17 | 0.21 | NA |
| Residual | 0.27 | 0.23 | 0.03 | 0.15 | NA |
| Total Var | 0.37 | 0.53 | 0.21 | 0.36 | NA |
| % obs var | 72.32 | 44.00 | 15.52 | 42.19 | NA |
| S:N | 0.38 | 1.27 | 5.44 | 1.37 | NA |
| Stddev Resid | 0.52 | 0.48 | 0.18 | 0.39 | NA |
| CV Resid | 35.02 | 23.78 | 13.71 | 31.78 | NA |
| CV Total | 41.18 | 35.85 | 34.81 | 48.92 | NA |
| RMSE | 0.52 | 0.48 | 0.18 | 0.39 | NA |

| **Attribute** | ***Sinuosity*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 1.41 | 1.26 | 1.17 | NA | NA |
| Stream_ID | 0.02 | 0.05 | 0.00 | NA | NA |
| Residual | 0.03 | 0.01 | 0.01 | NA | NA |
| Total Var | 0.05 | 0.06 | 0.01 | NA | NA |
| % obs var | 57.30 | 16.19 | 100.00 | NA | NA |
| S:N | 0.75 | 5.18 | 0.00 | NA | NA |
| Stddev Resid | 0.16 | 0.10 | 0.09 | NA | NA |
| CV Resid | 11.69 | 7.67 | 7.65 | NA | NA |
| CV Total | 15.44 | 19.07 | 7.65 | NA | NA |
| RMSE | 0.16 | 0.10 | 0.09 | NA | NA |

| **Attribute** | ***Bankfull Width*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 15.88 | 12.28 | 11.26 | 11.54 | 8.50 |
| Stream_ID | 0.00 | 1.87 | 10.37 | 6.51 | 11.02 |
| Residual | 26.80 | 12.40 | 1.20 | 11.47 | 0.58 |
| Total Var | 26.80 | 14.27 | 11.57 | 17.97 | 11.60 |
| % obs var | 100.00 | 86.86 | 10.34 | 63.81 | 5.02 |
| S:N | 0.00 | 0.15 | 8.67 | 0.57 | 18.93 |
| Stddev Resid | 5.18 | 3.52 | 1.09 | 3.39 | 0.76 |
| CV Resid | 32.60 | 28.68 | 9.71 | 29.35 | 8.98 |
| CV Total | 32.60 | 30.77 | 30.20 | 36.75 | 40.08 |
| RMSE | 5.18 | 3.52 | 1.09 | 3.39 | 0.76 |

| **Attribute** | ***BF_WD Ratio*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 34.39 | NA | 32.78 | 24.45 | 19.97 |
| Stream_ID | 0.00 | NA | 82.53 | 61.87 | 14.31 |
| Residual | 168.42 | NA | 30.01 | 41.11 | 26.20 |
| Total Var | 168.42 | NA | 112.54 | 102.99 | 40.51 |
| % obs var | 100.00 | NA | 26.67 | 39.92 | 64.68 |
| S:N | 0.00 | NA | 2.75 | 1.51 | 0.55 |
| Stddev Resid | 12.98 | NA | 5.48 | 6.41 | 5.12 |
| CV Resid | 37.74 | NA | 16.71 | 26.23 | 25.63 |
| CV Total | 37.74 | NA | 32.36 | 41.51 | 31.87 |
| RMSE | 12.98 | NA | 5.48 | 6.41 | 5.12 |

| **Attribute** | ***D50*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 32.19 | 46.23 | 52.44 | 49.75 | 69.50 |
| Stream_ID | 1206.10 | 1742.48 | 887.59 | 432.58 | 2944.33 |
| Residual | 233.81 | 670.39 | 279.33 | 138.96 | 83.75 |
| Total Var | 1439.91 | 2412.87 | 1166.92 | 571.54 | 3028.08 |
| % obs var | 16.24 | 27.78 | 23.94 | 24.31 | 2.77 |
| S:N | 5.16 | 2.60 | 3.18 | 3.11 | 35.16 |
| Stddev Resid | 15.29 | 25.89 | 16.71 | 11.79 | 9.15 |
| CV Resid | 47.51 | 56.01 | 31.87 | 23.69 | 13.17 |
| CV Total | 117.89 | 106.26 | 65.14 | 48.05 | 79.18 |
| RMSE | 15.29 | 25.89 | 16.71 | 11.79 | 9.15 |

| **Attribute** | ***Percent Fines*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 39.26 | 29.25 | 18.11 | 10.93 | 19.05 |
| Stream_ID | 736.60 | 535.10 | 185.63 | 185.98 | 289.06 |
| Residual | 75.24 | 19.57 | 88.89 | 53.23 | 39.93 |
| Total Var | 811.84 | 554.67 | 274.52 | 239.21 | 328.99 |
| % obs var | 9.27 | 3.53 | 32.38 | 22.25 | 12.14 |
| S:N | 9.79 | 27.34 | 2.09 | 3.49 | 7.24 |
| Stddev Resid | 8.67 | 4.42 | 9.43 | 7.30 | 6.32 |
| CV Resid | 22.09 | 15.13 | 52.06 | 66.73 | 33.16 |
| CV Total | 72.57 | 80.52 | 91.48 | 141.46 | 95.19 |
| RMSE | 8.67 | 4.42 | 9.43 | 7.30 | 6.32 |

| **Attribute** | ***PT Fines*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 14.88 | NA | 12.11 | NA | NA |
| Stream_ID | 243.61 | NA | 69.11 | NA | NA |
| Residual | 124.71 | NA | 75.78 | NA | NA |
| Total Var | 368.32 | NA | 144.89 | NA | NA |
| % obs var | 33.86 | NA | 52.30 | NA | NA |
| S:N | 1.95 | NA | 0.91 | NA | NA |
| Stddev Resid | 11.17 | NA | 8.71 | NA | NA |
| CV Resid | 75.03 | NA | 71.88 | NA | NA |
| CV Total | 128.95 | NA | 99.39 | NA | NA |
| RMSE | 11.17 | NA | 8.71 | NA | NA |

| **Attribute** | ***Percent Pools*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 16.63 | 19.47 | 43.89 | 50.01 | 49.16 |
| Stream_ID | 0.00 | 0.00 | 196.00 | 42.67 | 173.18 |
| Residual | 159.19 | 89.06 | 112.11 | 438.29 | 500.38 |
| Total Var | 159.19 | 89.06 | 308.11 | 480.96 | 673.56 |
| % obs var | 100.00 | 100.00 | 36.39 | 91.13 | 74.29 |
| S:N | 0.00 | 0.00 | 1.75 | 0.10 | 0.35 |
| Stddev Resid | 12.62 | 9.44 | 10.59 | 20.94 | 22.37 |
| CV Resid | 75.89 | 48.47 | 24.13 | 41.86 | 45.50 |
| CV Total | 75.89 | 48.47 | 39.99 | 43.85 | 52.79 |
| RMSE | 12.62 | 9.44 | 10.59 | 20.94 | 22.37 |

| **Attribute** | ***Residual Pool Depth*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | NA | 0.19 | 0.70 | 0.59 | 0.70 |
| Stream_ID | NA | 0.00 | 0.13 | 0.00 | 0.00 |
| Residual | NA | 0.00 | 0.00 | 0.00 | 0.02 |
| Total Var | NA | 0.00 | 0.14 | 0.01 | 0.02 |
| % obs var | NA | 59.14 | 2.93 | 63.10 | 100.00 |
| S:N | NA | 0.69 | 33.16 | 0.58 | 0.00 |
| Stddev Resid | NA | 0.05 | 0.06 | 0.06 | 0.15 |
| CV Resid | NA | 23.14 | 9.04 | 9.81 | 22.09 |
| CV Total | NA | 30.09 | 52.84 | 12.35 | 22.09 |
| RMSE | NA | 0.05 | 0.06 | 0.06 | 0.15 |

| **Attribute** | ***LWD_100m*** | | | | |
|---|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R10** | **R6** |
| Mean | 14.12 | 41.14 | 53.82 | 49.94 | 4.95 |
| Stream_ID | 92.20 | 75.81 | 251.04 | 588.65 | 11.86 |
| Residual | 23.59 | 228.22 | 503.75 | 743.28 | 0.86 |
| Total Var | 115.79 | 304.03 | 754.79 | 1331.93 | 12.72 |
| % obs var | 20.37 | 75.06 | 66.74 | 55.80 | 6.72 |
| S:N | 3.91 | 0.33 | 0.50 | 0.79 | 13.87 |
| Stddev Resid | 4.86 | 15.11 | 22.44 | 27.26 | 0.92 |
| CV Resid | 34.39 | 36.72 | 41.70 | 54.60 | 18.69 |
| CV Total | 76.20 | 42.38 | 51.04 | 73.09 | 72.07 |
| RMSE | 4.86 | 15.11 | 22.44 | 27.26 | 0.92 |

# Variance Estimates Idaho

| **Attribute** | ***Reach Length*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 153.22 | 190.33 | 120.66 | 520.92 |
| Stream_ID | 22 | 2333.33 | 186.19 | 1171.73 |
| Residual | 27.4444 | 894.00 | 235.56 | 1454.58 |
| Total Var | 49.44 | 3227.33 | 421.75 | 2626.31 |
| % obs var | 55.51 | 27.70 | 55.85 | 55.38 |
| S:N | 0.80 | 2.61 | 0.79 | 0.81 |
| Stddev Resid | 5.24 | 29.90 | 15.35 | 38.14 |
| CV Resid | 3.42 | 15.71 | 12.72 | 7.32 |
| CV Total | 4.59 | 29.85 | 17.02 | 9.84 |
| RMSE | 5.24 | 29.90 | 15.35 | 38.14 |

| **Attribute** | ***Gradient*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 1.97 | 2.00 | 1.59 | 1.62 |
| Stream_ID | 2.59 | 3.14 | 3.05 | 0.00 |
| Residual | 0.06 | 0.03 | 0.01 | 0.08 |
| Total Var | 2.64 | 3.17 | 3.05 | 0.08 |
| % obs var | 2.15 | 0.84 | 0.24 | 100.00 |
| S:N | 45.44 | 117.81 | 412.26 | 0.00 |
| Stddev Resid | 0.24 | 0.16 | 0.09 | 0.29 |
| CV Resid | 12.14 | 8.16 | 5.40 | 17.78 |
| CV Total | 82.73 | 88.95 | 109.75 | 17.78 |
| RMSE | 0.24 | 0.16 | 0.09 | 0.29 |

| **Attribute** | ***Sinuosity*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 1.55 | NA | 1.38 | NA |
| Stream_ID | 0.06 | NA | 0.04 | NA |
| Residual | 0.03 | NA | 0.01 | NA |
| Total Var | 0.09 | NA | 0.05 | NA |
| % obs var | 33.48 | NA | 23.77 | NA |
| S:N | 1.99 | NA | 3.21 | NA |
| Stddev Resid | 0.17 | NA | 0.11 | NA |
| CV Resid | 11.09 | NA | 7.85 | NA |
| CV Total | 19.17 | NA | 16.11 | NA |
| RMSE | 0.17 | NA | 0.11 | NA |

| **Attribute** | ***Bankfull Width*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 6.83 | 5.30 | 4.37 | NA |
| Stream_ID | 0.00 | 10.96 | 7.87 | NA |
| Residual | 8.21 | 3.00 | 0.13 | NA |
| Total Var | 8.21 | 13.95 | 8.00 | NA |
| % obs var | 100.00 | 21.47 | 1.61 | NA |
| S:N | 0.00 | 3.66 | 61.23 | NA |
| Stddev Resid | 2.86 | 1.73 | 0.36 | NA |
| CV Resid | 41.93 | 32.66 | 8.22 | NA |
| CV Total | 41.93 | 70.48 | 64.81 | NA |
| RMSE | 2.86 | 1.73 | 0.36 | NA |

| **Attribute** | ***BF_WD Ratio*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 17.42 | NA | 21.11 | NA |
| Stream_ID | 0.63 | NA | 89.11 | NA |
| Residual | 45.20 | NA | 22.78 | NA |
| Total Var | 45.83 | NA | 111.89 | NA |
| % obs var | 98.62 | NA | 20.36 | NA |
| S:N | 0.01 | NA | 3.91 | NA |
| Stddev Resid | 6.72 | NA | 4.77 | NA |
| CV Resid | 38.59 | NA | 22.61 | NA |
| CV Total | 38.86 | NA | 50.11 | NA |
| RMSE | 6.72 | NA | 4.77 | NA |

| **Attribute** | ***D50*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 13.58 | 16.01 | 20.56 | NA |
| Stream_ID | 346.35 | 357.30 | 494.85 | NA |
| Residual | 46.89 | 1.07 | 50.89 | NA |
| Total Var | 393.24 | 358.37 | 545.74 | NA |
| % obs var | 11.92 | 0.30 | 9.32 | NA |
| S:N | 7.39 | 332.71 | 9.72 | NA |
| Stddev Resid | 6.85 | 1.04 | 7.13 | NA |
| CV Resid | 50.44 | 6.47 | 34.70 | NA |
| CV Total | 146.07 | 118.24 | 113.65 | NA |
| RMSE | 6.85 | 1.04 | 7.13 | NA |

| **Attribute** | ***Percent Fines*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 63.24 | 60.86 | 54.00 | 59.27 |
| Stream_ID | 1048.40 | 1142.42 | 1656.59 | 339.23 |
| Residual | 6.15 | 2.34 | 16.56 | 1438.60 |
| Total Var | 1054.55 | 1144.76 | 1673.15 | 1777.83 |
| % obs var | 0.58 | 0.20 | 0.99 | 80.92 |
| S:N | 170.59 | 487.63 | 100.06 | 0.24 |
| Stddev Resid | 2.48 | 1.53 | 4.07 | 37.93 |
| CV Resid | 3.92 | 2.51 | 7.53 | 64.00 |
| CV Total | 51.35 | 55.59 | 75.75 | 71.14 |
| RMSE | 2.48 | 1.53 | 4.07 | 37.93 |

| **Attribute** | ***PT Fines*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 54.94 | NA | 54.94 | NA |
| Stream_ID | 740.08 | NA | 1527.09 | NA |
| Residual | 548.11 | NA | 26.54 | NA |
| Total Var | 1288.19 | NA | 1553.63 | NA |
| % obs var | 42.55 | NA | 1.71 | NA |
| S:N | 1.35 | NA | 57.53 | NA |
| Stddev Resid | 23.41 | NA | 5.15 | NA |
| CV Resid | 42.61 | NA | 9.38 | NA |
| CV Total | 65.32 | NA | 71.74 | NA |
| RMSE | 23.41 | NA | 5.15 | NA |

| **Attribute** | ***Percent Pools*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 26.54 | 30.61 | 59.51 | 26.50 |
| Stream_ID | 90.22 | 385.17 | 691.59 | 0.00 |
| Residual | 124.84 | 161.57 | 23.13 | 277.14 |
| Total Var | 215.06 | 546.74 | 714.72 | 277.14 |
| % obs var | 58.05 | 29.55 | 3.24 | 100.00 |
| S:N | 0.72 | 2.38 | 29.90 | 0.00 |
| Stddev Resid | 11.17 | 12.71 | 4.81 | 16.65 |
| CV Resid | 42.10 | 41.52 | 8.08 | 62.82 |
| CV Total | 55.26 | 76.39 | 44.93 | 62.82 |
| RMSE | 11.17 | 12.71 | 4.81 | 16.65 |

| **Attribute** | ***Residual Pool Depth*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | NA | NA | 0.35 | 0.35 |
| Stream_ID | NA | NA | 0.04 | 0.02 |
| Residual | NA | NA | 0.00 | 0.00 |
| Total Var | NA | NA | 0.04 | 0.02 |
| % obs var | NA | NA | 4.19 | 1.46 |
| S:N | NA | NA | 22.89 | 67.33 |
| Stddev Resid | NA | NA | 0.04 | 0.02 |
| CV Resid | NA | NA | 11.36 | 5.38 |
| CV Total | NA | NA | 55.52 | 44.50 |
| RMSE | NA | NA | 0.04 | 0.02 |

| **Attribute** | ***LWD_100m*** | | | |
|---|---|---|---|---|
| Protocol | **AREMP** | **EMAP** | **PIBO** | **R4** |
| Mean | 1.51 | 28.82 | 31.42 | 9.82 |
| Stream_ID | 1.79 | 229.92 | 378.49 | 0.00 |
| Residual | 0.26 | 81.45 | 134.54 | 74.38 |
| Total Var | 2.05 | 311.37 | 513.03 | 74.38 |
| % obs var | 12.70 | 26.16 | 26.22 | 100.00 |
| S:N | 6.88 | 2.82 | 2.81 | 0.00 |
| Stddev Resid | 0.51 | 9.02 | 11.60 | 8.62 |
| CV Resid | 33.69 | 31.32 | 36.92 | 87.82 |
| CV Total | 94.56 | 61.23 | 72.10 | 87.82 |
| RMSE | 0.51 | 9.02 | 11.60 | 8.62 |