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Monitoring Fine Sediment

Grande Ronde and John Day Rivers

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MONITORING FINE SEDIMENT:

GRANDE RONDE AND

JOHN DAY RIVERS

Final Report 2004

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ABSTRACT

Elevated levels of fine sediments in streams of the Columbia River basin caused by watershed development present a widespread environmental impact that is likely a significant determinant of reductions in salmonid productivity and survival. Recovery of severely depressed salmon and steelhead stocks under the Endangered Species Act will require watershed restoration such that the cumulative sources of elevated sediment delivery are controlled and the excessive stores of surface and subsurface fine sediments are reduced.

Trends in fine sediments in salmon and steelhead spawning areas were studied in four watersheds in northeastern Oregon in a multi-year effort to evaluate whether overall land management actions are being successful in improving fine sediment conditions. Fine sediment trends were evaluated by monitoring percentage surface fine sediment as well as fine sediment infiltration into cleaned spawning gravels embedded into spawning reaches in plastic buckets. Surface fines were measured using three techniques: visual estimation of fines as well as the full particle size distribution; a grid method, whereby a sample frame with a regular grid of wires defined sample points for evaluating whether a particle was less than or equal to the fine particle threshold size (6.35 mm median diameter); and the standard pebble count method. Fine sediment infiltration into the artificial redds (spawning gravel mixture where all fines had been removed) was measured over the entire egg incubation period at five transects per stream in terms of the percentage of total sample weight comprised by the fine sediment fractions. Fines were recorded in three size fractions—0.0-0.85 mm, 0.85-2.0 mm, and 2.0-6.35 mm.

An evaluation of regressions for 4-year trends in surface fine sediments indicated that surface fines in the Grande Ronde River (GR) and Granite Creek (GT) have significantly improved, while 4-year trends in Catherine Creek (CC) and the North Fork John Day River (NFJDR) exhibited significantly deteriorating conditions. Despite the worsening conditions in Catherine Creek, the mean surface fine sediment level was low in study reaches, indicating a low biological risk condition. However, in the North Fork John Day surface fines exceeded management agency goals (i.e., ≤ 20% fines)

A comparison of regression trends among streams indicates that the GR-GT pair had non-significant regression slope differences. This pair was distinct from the NFJDR which was distinct from CC.

Overwinter fine sediment (for fines <0.85 mm and <6.35 mm) infiltration monitoring in the cleaned gravels of “artificial redds” indicated no signficant 4-year trend for any stream, except

for the <6.35 size fraction in the NFJDR. The North Fork exhibited a highly significant increasing level of fine sediment (<6.35 mm) infiltrated into cleaned substrate in buckets over this time period. In three years, the GR and NFJDR had the highest levels of overwinter infiltration. In each of the four study years, GT and CC were not significantly different from one another in mean overwinter infiltration. In 2001, the NFJDR had the highest level of infiltrated fines (16.4%) less than 6.35 mm. Variation in infiltration of fines <0.85 mm produced fewer significant differences among streams within a single year than did fines <6.35 mm.

Given the lack of significant regression trends in overwinter fines infiltration, 4-years of data for each stream were lumped. Statistical comparison of 4-year mean overwinter fines infiltration among study streams revealed that for fines <6.35 mm, percentage infiltration for NFJDR and GR were 12.6 and 12.1%, respectively; for CC and GT infiltration was 7.8 and 7.5%, respectively. The NFJDR and GR were not statistically different from one another; likewise, CC and GT were not significantly different.

Over this 4-year period in the NFJDR, GR, CC, and GT, the maximum level of infiltration by fines <6.35 mm in the field was 22.5, 22.8, 22.7, and 14.5%. Laboratory tests of the maximum level of infiltration possible given the initial composition of framework material was approximately 23.9%. This information indicates that it is not uncommon for the initial void space in some buckets to become completely filled with matrix fines. This result was based on selection of only those buckets having a minimum final content of framework material, indicating that the fines present represented the infiltration process (and resuspension of some fines) rather than including buckets representing also the process of scour of framework particles followed by deposition of fines. While both processes occur in the field, the first one indicates the biological impact of fines infiltration on incubating salmon eggs, and the second includes the additional effect of direct scour and loss of eggs followed by replacement of framework material by fines.

Percentage surface fines were estimated using three independent methods. Although on the basis of theoretical principles it was considered that the grid method has the potential to provide the highest accuracy in estimating both the percentage fines <6.35 mm and the full particle size distribution, we had concerns that the spacing of grid intersection points did not provide an optimal estimate that minimized autocorrelation. Nonetheless, the three methods were highly correlated and did not produce estimates of mean surface fine sediment for study areas that differed significantly. Based upon ease of sampling, we favored the use of visual estimates of surface fines in regressions with infiltration rates. In future work, implementation of recommended modifications to the grid method would likely provide substantial improvement in accuracy and reliability.

Mean fine sediment infiltration rates for each stream and year were regressed against mean surface fine sediment. Mean surface fine sediment determined in the summer preceding as well as the summer following the collection of infiltration samples were used in the regression. Surface fine sediment conditions in the summer preceding emergence were more effective in explaining the variation in infiltration rates in the following overwinter incubation period than was the surface fine sediment condition in the summer following emergence. Surface fine sediment conditions are a statistically significant predictor of the likelihood that cleaned spawning gravels will be filled with fines <6.35 mm. The greater the level of surface fines, the greater the degree of infiltration. Regression of infiltration rates for each study stream individually on annual peakflows for the four study years did not indicate a statistically significant relationship. This seems to indicate that infiltration rates are more directly controlled by level of surface fine sediment than by annual variations in streamflows. Infiltration, then, occurs under all flow years to a level primarily dictated by level of surface fines.

Because sample buckets retaining high percentages of the original framework material on collection are able to index primarily infiltration processes and the maximum infiltration level feasible was approximately 23.9%, the biological impact of infiltration must be judged against this maximum. It was found that many artificial redds were infiltrated to capacity, but there was also considerable variation. This level of variation could be a factor responsible for allowing some egg/alevin survival in streams with high levels of fines. However, our findings also indicated that significant detrimental impacts are likely, based on numerous laboratory studies, when framework material becomes clogged to levels that are less than 23.9% (i.e., a level that would represent zero void volume for occupancy by eggs/alevins). Other studies have shown that surface fine sediment levels are signficantly related to average survival-to-emergence of Chinook salmon. Also, surface fine sediment levels tend to indicate fines levels that would be equalled or exceeded in the subsurface spawning gravels, thereby representing a minimal estimate of conditions to which eggs/alevins are subjected. Percentage surface area of fines, then, provides a convenient tool for monitoring trends in stream health. This indicator links directly to the magnitude of overwinter fine sediment infiltration, which itself provides an index to level of impact to salmon/trout egg and alevin survival. Long-term trends in surface fine sediment indicate trends in stream restoration and ability to meet the goals of agencies and tribes under regional salmon restoration plans.

ACKNOWLEDGEMENTS

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We are indebted to Jon Rhodes for his continued professional consultation on technical aspects of this project after leaving employment at CRITFC for private environmental work. He provided very substantial help by critiquing two drafts of the manuscript. His insights were always challenging and illuminating and resulted in significant improvements in the document.

All final map products, with the exception of grazing allotment maps, were created by Jennifer Brainard (CRITFC) using ArcMap (ESRI) from the best available source data. In addition, Jennifer provided invaluable assistance in producing the allotment maps. We want to thank Phil Roger (CRITFC) for directing additional CRITFC funding to final completion of this report and the mapwork needed.

We give our sincere thanks to John Piccininni (BPA), who provided us great encouragement and assistance in pursuit of this monitoring project over the years as our BPA COTR (contracting officer's technical representative). We also wish to thank Nancy Webster (BPA) for her contribution in significantly improving the final layout and presentation of the document.

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INTRODUCTION

Scientific Background

Fine sediment levels in spawning substrate can be a significant detriment to salmon survival from egg to smolt (Bjornn and Reiser 1991). Assessments have consistently concluded that fine sediment is a major problem for salmon in the Grande Ronde (Anderson et al. 1993; NMFS 1993; Huntington 1993; Mobrand et al. 1995), including Catherine Creek and the upper Grande Ronde (ODEQ 1995, NPPC 2004a) and the John Day River (OWRD 1986), including Granite Creek and the upper North Fork John Day (NPPC 2004b). Increases in fine sediments in streams by up to an order of magnitude can result from timber harvesting, road building, agricultural practices, and other watershed developments (Cederholm et al. 1981, Howard 1987, Van Lear et al. 1998, Dalecky 2001). The cumulative impact of multiple management activities on fine sediment accumulation in streams has been well documented (Everest et al. 1987, Rhodes et al. 1994, Spence et al. 1995, Quigley and Arbelbide 1997). Fine sediment accumulation in excess of natural levels in streams stemming from land management activities occurs in riffles used by salmonids for spawning and egg incubation (Megahan 1975, Huntington 1998) and also in pools (McIntosh et al. 2000), which are important rearing habitat. It is likely that surface and subsurface fine sediment levels in these rivers must be reduced if salmon survival from egg to smolt is to be increased (Rhodes et al. 1994, DEFRA 2002).

Significant recovery in substrate condition is possible in a 20+ year timeframe provided that sources of sediment delivery are controlled in watershed restoration and flows are sufficient to flush subsurface sediments downstream by mobilizing the armor layer (Platts et al. 1989). Surface sediments are more readily transported downstream (Platts et al. 1989). Dynamics of fine and coarse particle sediment transport and deposition in small forested streams can be monitored as bedload transport under rising and falling limbs of storm flows of various magnitudes and as accumulation in and release from pools as well as riffles (Jackson and Beschta 1984, Lisle 1979, Sidle 1988, Lisle and Hilton 1991). Fine sediments accumulate preferentially in pools, channel margins, and backwaters during low flow periods (Jackson and Beschta 1984) and may be a sensitive indicator of supply of fines in the stream environment (Lisle and Hilton 1992). However, surface area occupied by fines in spawning riffles also indicates the quality of bed material available for transport and subsequent deposition.

Sediment transport processes vary as the proportion of fines in the bed material increases and the bed shifts from a framework supported gravel bed to a matrix supported one. As framework material void spaces become filled and the bed material exceeds about 30% sand, fines increasingly form patches that reduce particle "hiding" and thereby increase the downstream transport (Wilcock and Kenworthy 2002). The increased mobility of riffle material at lower flows results from a decrease in form roughness and increase in bed shear stresses with increased sand delivery to the channel (Jackson and Beschta 1984).

This continuum of fine sediment availability and the basis for shifts in transport processes can be monitored via increases in fine particle infiltration rates and surface area of fines, the subject of this study. Winnowing and transport of fines from riffles can occur at low to moderate flows (Sidle 1988, Gomez 1983) and these fines can redeposit in cleaned spawning gravels during the salmonid egg/alevin incubation period by sediment intrusion processes (McDowell-Boyer et al. 1986). Fine sediment intrusion or infiltration can reduce porosity and permeability of spawning gravels (Platts et al. 1979, Schälchli 1992, McBain and Trush 2000, Reckendorf and Van Liew 1989) and oxygen flow to eggs/alevins, thereby causing suffocation. Both porosity and hydrologic conductivity influence survival of eggs/embryos in spawning gravels. These indices are influenced by the percentage composition by diameter classes of fines, particle packing, particle shape, and sorting (Kolterman and Gorelik 1995). Intrusion by particles <2 mm diameter has been attributed to >50% of the variability in gravel permeability (Barnard 1992). Presence of clay particles on the egg surface is considered to be an effective barrier to oxygen transport to the developing embryo. Infilling of void spaces among cleaned gravel particles or development of impermeable seals can cause entombment, interfering with fry emergence. Particles up to 6.35 mm increase the entombment effect. Infiltration of fines into spawning gravels can be a very significant impact of land management that can result in substantial reductions in smolt yield at a basin level. This can pose a serious threat to recovery of weak salmon stocks (Cederholm and Reid 1987).

Management Framework

The NMFS Biological Opinion (NMFS 1995) for the USFS Land and Resource Management Plans (LRMPs) and the salmon recovery plan of Columbia River Basin Treaty Tribes (CRITFC 1995) both set goals for surface fine sediment in spawning habitat at <20%. The NPPC (1994) recovery plan set a goal of <20% fine sediments in salmon redds. Recent NOAA (National Oceanographic and Atmospheric Administration) Fisheries habitat analysis done under the remand of the Biological Opinion on the status of the ESU's (evolutionarily significant units) of salmon and steelhead listed as threatened or endangered under the Endangered Species Act (ESA) indicate that the mass wasting and surface erosion in the upper Grande Ronde and North Fork John Day basins today are changed from their historic condition a relatively great amount compared with other basins. NOAA is heavily invested in the belief that habitat quality improvement can reverse the decline of listed ESUs and avoid the need to remove dams. However, despite these goals for fine sediment and the documented sediment-related problems, baseline and trends in surface fine sediment had not been annually monitored in these rivers prior to this project. The ability of multiple land management BMPs to successfully address aggregate sources or controls on stream channel sedimentation has not been well documented (Ziemer and Lisle 1993). This project was initiated, with funding from the Bonneville Power Administration in 1998, to monitor surface fine sediment levels and overwinter intrusion of fine sediment into cleaned gravels in artificially constructed redds in spawning habitat. The project also investigated the potential relationship between surface fine levels and overwinter sedimentation in cleaned gravel in an effort to provide a more cost-effective monitoring tool than coring or other extractive bulk substrate sampling methods.

Monitoring Objectives and Hypotheses

This project provided baseline and multi-year trend monitoring of surface fine sediment and overwinter fine sediment deposition in northeastern Oregon streams subject to significant land management activities and providing habitat for listed spring Chinook and/or steelhead, and bull trout. The key project objectives were as follows:

Objective 1. Determine if substrate goals of CRITFC (1995) and NMFS (1995) are met in monitored reaches. These goals are to achieve a condition of <20% surface fines in spawning habitat. Meeting these goals or achieving positive multi-year trends toward meeting these goals (see NPPC 1994, NMFS 1995, CRITFC 1995) would indicate that the aggregate effectiveness of land management actions on various watersheds is likely suitable for sustaining long-term recovery.

Objective 2. Measure surface fine sediment and overwinter sedimentation in cleaned gravels in spawning habitat to provide an indication of the amount of fine sediment in spawning gravels during the incubation period to determine compliance with NPPC FW program goals for substrate.

Objective 3. Estimate salmon survival from egg-to-emergence in monitored reaches based on measurements of fine sediment infiltration into cleaned spawning gravels and literature values for survival-to-emergence in substrate with variable levels of fines.

Objective 4. Determine multi-year trends in % surface fine sediment and overwinter sedimentation.

Objective 5. Determine if spawning habitats in different streams have different levels of percentage surface fine sediment and different levels of overwinter sedimentation within years and over time.

Objective 6. Determine the relationship between percentage surface fine sediment and overwinter sedimentation level in cleaned gravels.

In order to effectively satisfy the objectives itemized above and the hypotheses that generated them, essential data collection involved measures of surface fine sediment and overwinter sediment infiltration into cleaned spawning gravels. Although not essential for determining the compliance of in-channel sediment conditions with regional management standards, additional information about the streams and their watersheds was useful in attempting to interpret long-term trends and differences in mean surface fine and overwinter infiltration data. These data include drainage area to the study area, channel width and depth, channel gradient, road densities in the drainages, streamflow records, mean annual precipitation for each study watershed, land use, percentage wilderness, mean annual discharge, ecoregional composition, and land ownership.

METHODS AND MATERIALS

Data Sources

The study reaches are in spawning habitat for spring Chinook salmon in the Grande Ronde River, Catherine Creek (a Grande Ronde River tributary), the North Fork John Day River (NFJDR) and Granite Creek (tributary to the NFJDR). Typical views of channel transects and surrounding vegetation are shown in **Figure 1** from selected photos taken in 2002. The general locations of the four monitored streams in northeastern Oregon are shown in **Figure 2**. More detailed views of each study area and the locations of transects where artificial redds were created are shown in **Figure 3**.

Characteristics of the stream channels and watersheds contributing to the study reaches were interpreted from GIS data using ARCMAP (ESRI, Inc.). Land use data were obtained from the U.S. Geological Survey (USGS[1]). This land use classification contains 21 land cover types at a spatial resolution of 30 m and was produced from Landsat TM data. Level IV Ecoregion data were used to describe the vegetational, precipitational, and topographic zonation within the study watersheds. These data were available as Draft 8 (11/29/00) from the Oregon GIS Service Center [2]. Data on roads were obtained from the Bureau of Land Management (BLM)[3]. These data were compiled from various sources (USGS digital line graphs, US Forest Service (USFS) cartographic feature files, Washington DOT and DNR road data and BLM's Western Oregon road database (TRB)). Wilderness boundaries were obtained from ICBEMP data of the USFW and BLM[4]. These data were published in 1998 as Wilderness Areas in the Landscape Characterization Boundary. Land ownership data were obtained from the Oregon GIS Service Center[5]. Map scale was 1:24K and the data were produced by the Oregon Department of Forestry. Precipitation data were from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) analysis[6] and was based on average monthly and annual precipitation for the climatological period 1961-90. The PRISM model uses point data and a digital elevation model (DEM) to generate gridded

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[1] http://edcwww.cr.usgs.gov/programs/lccp/nationallandcover.html

[2] http://www.gis.state.or.us/data/alphalist.html

[3] http://www.or.blm.gov/gis/data/catalog/dataset.asp?cid=39

[4] http://www.icbemp.gov/spatial/polit/

[5] http://www.gis.state.or.us

[6] http://www.ocs.orst.edu/prism/prism_new.html

estimates of mean annual precipitation, among other indices. PRISM represents precipitation in mountainous terrain well because it incorporates orographic patterns of precipitation in modeling. More detailed information on modeling algorithms can be obtained from the National Resources Conservation Service[7]. Stream channel gradient was calculated from USGS 1:24K maps using GIS. These coverages were available as USGS scanned topographic digital raster graphic (DRG) files.[8]

Cattle grazing intensity was estimated from data provided from the Umatilla National Forest and Wallowa-Whitman National Forest GIS shops. Data were in the form of ArcInfo coverages of allotments and pastures within allotments, as well as database information on each allotment and pasture. A detailed compilation of data on allotments and pastures is found in **Appendix A Table 1**. Allotments can have multiple pastures and pasture boundaries can extend outside study watersheds. This table indicates area (acres) of individual pastures found within study watersheds. The pasture polygons were "clipped" by overlap with the study watershed boundary using ArcMap. The percentage of the entire pasture found within the study watershed boundaries was determined. The total area of each allotment is assigned a number of AUMs as a permitted grazing capacity. AUMs per area of the allotment is the intensity of grazing on each allotment. Applying this grazing intensity to the acres of each pasture within study watershed boundaries yields a potential grazing intensity per pasture (potential AUMs per "clipped" pasture) (**Appendix A Table 1**). Total estimated grazing intensity per study watershed was determined as the sum of all estimated AUMs for separate pastures within each study watershed (**Table 1**). Although the AUMs assigned to allotments represent the current grazing level for some allotments, in other cases it represents the previously permitted level where grazing is currently suspended (i.e., allotment vacant, see **Appendix A Table 1**). For allotments where grazing is currently suspended, the AUMs for these pastures were not summed in deriving the total estimated current grazing intensity.

USGS hydrological gaging sites are located in the North Fork John Day River near Dale, Oregon and also near Monument, Oregon. These sites have drainage areas of 525 and 2520 mi^2, respectively (or 1,359.74 and 6,526.77 km^2, respectively). There is also a gaging site on Catherine Creek near Union, Oregon with a drainage area of 105 mi^2 (or 271.95 km^2). However, study watersheds in the North Fork John Day and upper Grande Ronde basins range from 89 to 259 km^2. Consequently, the study watersheds can be considered to be ungaged and hydrological

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[7] http://www.ncgc.nrcs.usda.gov/branch/gdb/products/climate/docs/fact-sheet.html

[8] http//topomaps.usgs.gov/drg

characteristics must be inferred from existing gages using statistical techniques (see Orsborn 1990, p. III-53). By developing a power regression of mean annual discharge (QAA) from 12 historical gages in the North Fork John Day and Grande Ronde drainages vs. drainage area, the equation $QAA = 1.6122DA^{0.8455}$ ($R^2 = 0.859$) was calculated (**Fig. 4**). Detailed statistics on the 12 historical gages are given in **Table 2**. These gaging sites encompassed drainage area from 22 to 2520 mi^2 (or 56.98 to 6526.77 km^2). From this equation, QAA values for the study watersheds were estimated.

Description of the Project Area

The area of the Grande Ronde River watershed above the monitoring locations is 101.7 km^2 and ranges in elevation from about 1347 m to 2402 m (**Table 1**). Soils are primarily derived from granitic parent materials. Average annual precipitation derived from the PRISM database in GIS raster format depicts the distribution of precipitation on the landscape in 90-m pixels (**Fig. 5**). By use of GIS to sum the average annual precipitation in the study watershed, predicted by the PRISM database, it was determined that the Grande Ronde study watershed receives 8.710E+07 m3 of water (**Table 1**). The mean annual discharge was estimated as 35.91 cfs. Snow is the dominant form of precipitation and spring snowmelt comprises the bulk of the annual hydrograph. The watershed of the upper Grande Ronde River has been extensively grazed, logged, and roaded over the past 30 years (Anderson et al. 1993; McIntosh et al. 1994). The study watershed has 26.6% of its land base assigned to USFS grazing pastures (**Table 1**, **Fig. 6**). Based on the historic permitted grazing intensities for the allotments in this watershed, the estimated potential AUMs within the study watershed was 252.4 AUMs. However, currently all allotments are vacant. Land use is characterized as 78.4% evergreen forest, 10.2% shrubland, and 10.7% grasslands (**Table 1**, **Fig. 7**). Ecoregion composition is 89.6% Mesic Forest, 8.7% Maritime Influence, and 1.7% Subalpine Zone according to the Omernik Level IV Ecoregion classification (**Table 1**, **Fig. 8**). The entire watershed (100%) is owned by the US Forest Service (**Table 1**, **Fig. 9**). The Grande Ronde study area has no wilderness area (**Table 1**)(**Fig. 9**). Road density in the study watershed is 1.44 km/km^2. Based on the conversion factor 1 km/km^2 = 1.609 mi/mi^2, the road density in the Grande Ronde is 2.32 mi/mi^2 (**Table 1**). Portions of the floodplain and river were dredge-mined in the early 1900s (McIntosh et al. 1994). Parts of the watershed have been burned by wildfire over the past 10 years; flash floods from thunderstorms have also affected spawning and rearing areas. Most of the watershed above the sampling areas is on the Wallowa-Whitman National Forest (WWNF).

The monitoring sites for surface fine sediment and overwinter sedimentation in the Grande Ronde River are located upstream of the decommissioned Woodley Creek Campground to the west of

USFS Road 5125 on the WWNF.

The watersheds of the other three streams monitored are broadly similar to the Grande Ronde with respect to vegetation, geology, and climate. However, the ownership patterns, watershed area, and intensity of land use vary among watersheds.

The watershed area of Catherine Creek, above the most downstream monitoring site, is 172.6 km^2 (**Table 1**). The watershed ranges in elevation from 1015 to 2683 m. Average annual precipitation calculated from the PRISM database is 1.904E+08 m3 water, nearly 119% more than the Grande Ronde (**Table 1**, **Fig. 4**). The mean annual discharge was estimated as 56.16 cfs. 28% of the Catherine Creek watershed is within wilderness (**Table 1**, **Fig. 9**). Most of the watershed is grazed. The study watershed has 94.8% of its land base assigned to USFS grazing pastures (**Table 1**, **Fig. 6**). Based on the historic permitted grazing intensities for the allotments in this watershed, the estimated potential AUMs within the study watershed was 2091.8 AUMs. Currently, the estimated grazing intensity is 1983.7 AUMS in the study watershed. Outside of the wilderness, the watershed has been logged and roaded, with an overall road density in the study watershed of 1.99 km/ km^2 or 2.74 km/km^2 based upon the non-wilderness land base. Most of the watershed is on the WWNF; 94.2% is owned by the USFS, 0.42% BLM, and 5.4% private (**Table 1**, **Fig. 9**). The most downstream monitoring sites on Catherine Creek are located to the east of state highway 203 at a latitude of 45^o 7.92' N and longitude of 117^o 42.49' W, as measured with a gps unit in 1999. The most upstream monitoring sites are on the North Fork, upstream of the confluence with the South Fork of Catherine Creek, south of USFS Road 7785 (**Fig. 3**). Land uses are characterized as 89.8% evergreen forest, 6.0% shrubland, and 2.7% grasslands (**Table 1**, **Fig. 5**). Ecoregion coverage of the study watershed is 38.3% Wallowa/Seven Devils Mountains, 45.0% Mesic Forest, and 16.7% Subalpine Zone (**Table 1**, **Fig. 8**).

The watershed area of the NFJDR above the most downstream monitoring site is 89.3 km^2 (**Table 1**). The watershed above the study site ranges in elevation from 1597 to 2613 m. The NFJDR is the highest elevation study area, and consequently, imposes the greatest difficulty in accessing during the winter due to snow cover. Mean annual precipitation for the NFJDR is 7.857E+07 m^3, just slightly lower than the Grande Ronde (**Table 1**, **Fig. 4**). The mean annual discharge was estimated as 32.17 cfs. Most of this watershed area is on the WWNF; 97.9% is owned by the USFS and the remainder is private land (**Table 1**, **Fig. 9**). The watershed has been extensively logged and has a road density of 1.16 km/km^2 although it also has 61% wilderness. When road density is calculated on the basis of only the non-wilderness portion, road density is 3.01 km/km^2 (4.85 mi/mi^2), which is relatively high for developed forest watersheds (**Table 1**).

The study watershed has 22.3% of its land base assigned to USFS grazing pastures (**Table 1**, **Fig. 6**). Based on the historic permitted grazing intensities for the allotments in this watershed, the estimated potential AUMs within the study watershed was 120.7 AUMs. However, currently all allotments are vacant.. Some sections of floodplains and the stream have been intensively altered by gravel spoils from historic dredge mining. Parts of the watershed have burned in wildfires, the most recent of which burned in 1996. Land use composition is 81.8% Evergreen Forest, 10.6% Shrubland, and 5.3% Grasslands (**Table 1**, **Fig. 5**). Land distribution into ecoregions includes 77.2% Mesic Forest and 22.8% Subalpine Zone (**Table 1**, **Fig. 8**).

The most downstream monitoring site is to the south of county road 73, on the WWNF, about 0.8 km east of the junction of county road 73 and county road 52. The most upstream sites are also on the WWNF, south of county road 73, about 1.5 km east of the junction of county road 73 and county road 52 (**Fig. 3**).

The watershed area of Granite Creek, above the most downstream monitoring site, is 259.0 km^2 (**Table 1**) and encompasses the elevation range from 1365 to 2512 m. Mean annual precipitation for the study watershed, determined by GIS analysis of the PRISM database, was 1.883E+08 m3, nearly the same as Catherine Creek (**Table 1**, **Fig. 4**). The mean annual discharge was estimated as 79.14 cfs. The watershed of Granite Creek has been extensively roaded and logged although it has 17% wilderness. Land uses are distributed into 82.3% Evergreen Forest, 8.9% Shrubland, and 8.1% Grasslands (**Table 1**, **Fig. 5**). Ecoregion composition is 86.8% Mesic Forest, 5.0% Subalpine Zone, and 8.2% Melange (**Table 1**, **Fig. 8**). The road density in the watershed above the study area is 2.51 km/km^2 (4.04 mi/mi^2). Road density calculated on the non-wilderness land base amounts to 3.0 km/km^2, the same as the North Fork John Day (**Table 1**). Dredge mining has intensively altered significant portions of the floodplain and stream, including the areas flanking the monitoring sites. The study watershed has 12.1% of its land base assigned to USFS grazing pastures (**Table 1**, **Fig. 6**). Based on the historic permitted grazing intensities for the allotments in this watershed, the estimated potential AUMs within the study watershed was 289.7 AUMs. Currently, the estimated grazing intensity is 284.9 AUMs in the study watershed. Ownership of the watershed is interspersed and includes private land (5.0%), the WWNF, and the Umatilla National Forest (UNF) (95.0% combined USFS ownership) (**Table 1**, **Fig. 9**). The most downstream monitoring site is on the UNF to the south of USFS Road 1035, approximately 1.2 km to the west of the junction with state highway 24. The most upstream monitoring sites are to the south of USFS Road 1035 approximately 0.8 km from the junction with state highway 24 (**Fig. 3**).

Geographic Locations of Sample Transects

The latitude and longitude (measured using a Magellan GPS 2000 XL global positioning system (gps) unit) of the August 2001 transects at which artificial redds were created are shown in **Table 3**. The full set of locational data for all transects established on August or September 1998, 1999, and 2000 is provided in **Appendix B Tables 1, 2, and 3)**. On these dates artificial redds were constructed at these transects to measure overwinter sedimentation for the four study streams.

Environmental Data for Study Streams

Stream width and depth were measured using standard methods (Dunne and Leopold 1978). Stream gradient was measured via ArcMap GIS (ESRI[9]) using 1:24K USGS topographic coverage. Gradient was calculated as the difference in elevation from the point upstream of the study reach where the upstream contour line crossed the stream to the point downstream of the study area where the next contour line crossed, divided by the stream length (measured in the channel by GIS). Gradient is included as an index of fine sediment transport capacity that would be related to depositional and erosional processes at various stage heights (Lisle and Hilton 1992). All sampling locations were sketched into a schematic map of the monitored reaches. Watershed area was determined by use of GIS, as was percentage land use composition, road density, percentage composition by ecoregion (Omernik, Level IV), minimum and maximum watershed elevation, and watershed gradient (based on the 1:24K mapping of the mainstem blueline within the study watershed). Road density was calculated to provide an index of management effects on the instream sediment regime. Livestock grazing, which has been a significant source of perturbation common to all four study areas but is now active only in Catherine Creek and Granite Creek study watersheds, is another management effect that typically leads to elevated sediment delivery to stream channels.

Two USGS gages in the region were in operation during the period of this study (Lookingglass Creek, near Lookingglass, Oregon and the North Fork John Day River at Monument, Oregon) and one additional gage developed a streamflow record up to the initiation of this study (Catherine Creek near Union, Oregon). Details on the available stream gaging stations are reported in **Table 4**. Streamflow data available for streams in the region during or near the period covered by this monitoring indicate that annual peakflows for the period 1998-2001 were on a downward

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[9] Environmental Systems Research Institute, Redlands, CA.

trend. In 1999 annual peakflow for the North Fork and the Lookingglass Creek gaging sites were approximately 9000 and 900 cfs, respectively. In 2001 these values declined to approximately 5500 and 550 cfs, respectively (**Fig. 10**). Lookingglass Creek annual peakflows were highly statistically related to the peakflow levels for the North Fork John Day River for the years 1985-2001, despite the difference in drainage area of their contributing watersheds (**Fig. 11**). Plots of mean daily streamflows for 1998-2001 indicate relatively consistent year-to-year annual flow patterns using these two gages, although there is a slight downward trend in annual minimum mean daily flows as well as maximum daily mean flows in the NFJDR from 1997 to 2002 (**Fig. 12**). The correlation in flows between these two gages indicates that flow patterns for other streams in the region would likely be similar in pattern but would vary in magnitude due to basin size and area distribution with elevation.

Surface Fine Sediment Estimates

Surface fines in the study reaches were monitored concurrently with placement of sample containers representing artificially constructed redds in September 1998, September 1999, August 2000, and August 2001. On the five transects per stream at which buckets were installed to simulate introduction of cleaned spawning gravels at the start of the incubation period, surface fines were estimated immediately upstream from the container locations so as not to disturb the buckets and their contents. In each stream reach monitored, surface fine sediment was measured via visual, grid, and pebble count methods. These methods reflect the three principal types of surface sampling (areal, grid, and transect) described by Diplas and Sutherland (1988)(as cited by Dalecky 2001).

Visual estimates

Fines <0.635 mm

Visual estimates of surface fines were made at each of 10 transects that were established along the study reaches of the four streams. (See Appendix C for greater description of the visual sampling protocol, as written for field work). By imagining a 1-m wide band across the stream at each transect, the percentage material <6.35 mm diameter was estimated visually as percentage of surface area occupied. This size class is referred to as fine gravel in the American Geophysical Union (AGU) sediment classification system (USACE 1995). These estimates occasionally involved integrating several patches of different particle size distribution, where some patches were largely comprised of fine sediments. More commonly, the visual integration involved estimation of the percentage surface area covered by particles <6.35 mm within the entire band where the fine particles were more uniformly distributed among larger framework particles.

The commonly cited method of surface fine sediment estimation by Platts et al. (1983) is a visually-based estimation. Measures of embeddedness, correlated with percentage surface fines, are also commonly estimated by visual methods (Sylte and Fischenich 2002). Visual surface fine estimates by the Platts et al. method are made by stretching a measuring tape across a transect and estimating the dominant particle size class for each 1 ft-increment on the transect line. For example, if the 1 ft of stream bottom contained "4 inches rubble, 6 inches gravel, and 2 inches fine sediment," it "would be classified as 1 ft of gravel. All 1-ft increments are combined to derive the overall substrate composition. Using such a process, it is conceivable that each 1-ft increment could have a substantial amount of fine sediment, but if a larger size class were predominant, fines would not be recorded at all. For this reason, we favored a visual method that attempted to integrate conditions over the entire transect and that was based on evaluation on an areal basis rather than a linear one.

Full particle size distribution

In September 2002, the areal percentage of the full size range of substrate surface particles (including fines) was visually estimated at a few transects where pebble counts were made in previous years. This allowed comparison with pebble count results that describe simply particles <6.35 mm as well as the full particle size distribution. The value of this estimate is that it provides a comparison to the pebble count method for total particle size distribution and it also indicates the percentage comprised by the fine particle size fraction (i.e., <6.35 mm).

Ocular estimates were made by having two observers visually estimate the percentage of surface area occupied by substrate surface particles in a transect 1-m wide at the transect locations where overwinter samples were taken. This estimate is an integration of the entire band transect surface area. Percentages in the following diameter categories were estimated: <0.635 cm, 0.635-1 cm, 1-3, 3-6, 6-13, 13-25, 25-50, 50-100, and >100 cm. In these streams no bedrock or boulders >200 cm were detected. After independently recording the observations of two field staff, discrepancies between observers were discussed. If totals did not sum to 100% (note: deviation from 100% by 1-5% often occurred with unconstrained visual estimation), size fractions that most likely accounted for discrepancies in totals were discussed and adjusted if warranted. Otherwise, duplicate estimates per size fraction were averaged and no further attempt was made to adjust totals to 100%. That is, it was assumed that the relative percentages among size classes represented what was observed. Averaged observations per size class for each transect were then multiplied by a factor that would adjust each size fraction by an equal percentage so that totals equaled 100%.

Grid estimates

The grid method (Bauer and Burton 1993) was used at 10 transects across spawning riffles where the visual surface sediment method was also used. (See Appendix C for greater description of the grid sampling protocol, as written for field work). In locations where monitoring of overwinter sedimentation was conducted (5 of the 10 transects per stream), the grid method was used immediately upstream of the location of embedded buckets used to simulate constructed redds. At each transect, five placements of the grid frame were made at equidistant points across the channel width by dividing the stream width by 6 to calculate a distance increment between sampling locations and then measuring across the stream from the water's edge. The grid frame was a square, regular grid with 100 intersections and horizontal and vertical spacing between intersection points of 1.5 cm. At each of the 5 placements of the grid frame on the stream bottom along the transect, sighting was made vertically from 100 intersections on the grid frame to the streambed surface to estimate whether the intermediate diameter of the particle beneath each intersection point was less than or equal to the threshold for fines (i.e., ≤ 6.35 mm. The transect mean was reported as the percentage of 500 grid intersections meeting the particle size threshold. Surface fines at each transect were visually estimated by two independent observers, prior to measurement via the grid method by a third observer. To improve the accuracy of the grid counts, a below-water PVC viewing tube with Plexiglass window (Aquascope from Wildco Wildlife Supply Company) was used for counting grid intersections and eliminating surface glare and turbulence. The latitude and longitude of transects where surface fines were measured, were recorded using the gps unit.

Statistical tests on visual and grid estimates of surface fine sediment

Significance of statistical tests

For all statistical tests reported in this document, the level of significance selected a priori in tests is denoted as $\alpha = 0.05$. Probabilities returned by t or F tests are denoted by P, where $P=0.05$ would indicate that the test statistic just met the level of significance chosen as an α value. Statistical tests that have $0.01 > P \leq 0.05$ are termed significant (or statistically significant). Those with $P \leq 0.01$ are termed highly significant. Selection of an α value is somewhat arbitrary and 0.05 was selected primarily by convention (Zar 1999). If the probability of committing a Type I error is α, the probability of committing a Type II error is β. Given the selection of $\alpha = 0.05$, it is only possible to reduce the β probability by increasing the sample size. For a fixed sample size, such as we have in conducting statistical tests on past years' data, we can reduce the probability of committing a Type II error by increasing α—for example, to 0.10. In statistical testing making a Type I error means that the null hypothesis (H_o) is rejected when it is actually true (i.e., there is no difference in means, but we conclude that there is a difference). Making a Type II error means that when the null hypothesis (H_o) is false (i.e., a difference between means actually occurs), we accept the null (i.e., conclude that there is no difference). In environmental testing where it must be ensured that an endangered species is protected from habitat deterioration, it is important to reduce the Type II error, if possible. That is, if sediment conditions in the stream were becoming worse, but the α level is set too high, it then becomes more difficult to conclude that there is a statistically significant decline in conditions. Consequently, a very large deterioration from one year to the next must exist to be able to conclude statistically that a declining trend is true (i.e., that the mean in sample values from one year is statistically different from that in subsequent years). Given this debate about the best balance between making Type I and II errors, we simply used an α =0.05, but also frequently indicate exact P values where it might be useful to evaluate whether other considerations should be made in evaluating the null hypothesis.

Correlation

Correlation among surface fine sediment percentage data collected via different methods was examined with the Pearson correlation statistic (Microsoft Excel, and compared against Systat (SPSS, Inc.)).

Linear regression

Trends in percentage surface fine sediment data over the 4-year period of the study were calculated as linear regressions. The Microsoft Excel statistical package provided the regression program used. This gives the ANOVA table and F-statistic as well as the regression equation, R^2 value, t-value for regression coefficient, and 95% confidence limits for the regression coefficient. Trend lines were examined for significance of regression slopes. The purpose of these tests was to assess whether there were statistically significant ($P<0.05$) multi-year trends in surface fines (either increasing or decreasing levels of fines) for individual streams.

ANOVA

For each stream, differences in mean surface fine sediment among years, in which 10 estimates per stream were made, were tested by single factor ANOVA using the F-statistic for evaluating statistical significance. For each year, differences in mean fine sediment among streams were examined with ANOVA. When a significant F-test occurred, differences between all pairs of streams were assessed using a group comparison test (Tukey test, see Zar 1999). Zar indicated that it is generally not valid to examine differences between all means for stream pairs using simple t-tests.

Multiple comparison tests

Comparisons were made between all pairs of regression lines for study streams using an analysis of covariance test for multiple comparison of slopes and elevations (Zar 1999). The purpose of these tests was to determine whether study streams differed from one another in trend (rate of change in surface fines and direction of change) and mean level of fines. In comparison of multiple slopes the null hypothesis is H_o: $B_1 = B_2 = B_3 \ldots = B_k$. The alternate hypothesis is that the k regression lines were not all derived from the same population. The analysis of multiple comparison of slopes is based on the assumption that the variances of the visual and grid estimates, respectively, are equal for all streams (**Tables 5 and 6**). The analysis itself consists of an analysis of covariance and was computed via Excel spreadsheet using the formulas in Zar (1999, p. 370-374) (**Table**s **5 and 6**). In a practical sense, assessing long-term trends in surface fines is a key management responsibility in determining whether aggregate land management actions are resulting in improvement in salmonid habitat conditions that might control initial spawning gravel quality and potential for overwinter fine sediment infiltration. The test of differences in regression elevation indicates differences in the intercept of the slope on the y-axis. The y-axis in these regressions is mean surface fine sediment measured either by visual or grid methods. If slopes are equal, the regressions could still be significantly different if the intercepts are different.

In addition to multiple comparison tests on regressions, differences among the four study streams were examined by ANOVA, followed by a Tukey multiple comparison of differences in mean surface fine sediment (visual method) (see Zar 1999, his p. 211). The null hypothesis for this test was Ho: $\mu_1 = \mu_2 = \mu_3 = \mu_4$, where μ is the population mean. This test was based upon 10 visual estimates for each year from 1998 to 2001 for each of the study streams. The multiple comparison test was based on equal sample sizes (40) for the four study streams.

Pebble counts

We used the pebble count method of Wolman (1954) as another method to determine the amount of surface fine sediment in the channel substrate. (See **Appendix C** for greater description of the pebble count sampling protocol, as written for field work). Pebble counts are often used to estimate the amount of surface fine sediment (e.g., Bauer and Burton 1993; Clifton et al. 1999). The pebble count method was originally described as a random sampling procedure based on a grid system, but it has been modified to a process of sampling at regular intervals on cross-channel transects (Bevenger and King 1995, Milan et al. 2000).

In 1999, pebble counts were taken at four transects in the Grande Ronde River, where surface fine sediment was measured via the grid and visual methods, and at three transects in each of three other streams monitored. In 2000 and 2001, pebble counts were taken at four transects in each stream at which surface fine sediment was estimated. The locations of the transects where pebble counts, grid measurements, and visual estimates of surface fines were made are found in **Appendix B**.

Overwinter Sedimentation

To measure overwinter sedimentation, artificial "redds" were created in the channel substrate in late summer of each year of the study, which was immediately prior to spawning. This method has been used successfully to monitor fine sediment accumulation in channel substrate in northern California (Lisle 1989) and provides an indication of the ultimate sediment conditions in salmonid redds (Lisle and Eads 1991). Lisle and Eads (1991) discussed the relative merits and precision of this method of sampling fine sediment accumulation. We used a particle diameter of <6.35 mm to define the fine sediment fraction detrimental to salmon survival, after Stowell et al. (1983), although many descriptors of fine sediment sizes and distribution have been used to characterize substrate and effects on salmonid survival (Young et al. 1991). The percentage by weight of overwinter sedimentation by particles <6.35 mm in the collected containers was determined using standard particle size analysis methods. Fines deposited in artificial redds were sorted and reported in size classes <0.85 mm, 0.85-2.0 mm, and 2.0-6.35 mm, and also summarized as all material <6.35 mm. These size categories correspond to clays to coarse sand, coarse to very coarse sands, and very coarse sand to fine gravel on the AGU sediment classification system (USACE 1995).

The simulated redds were constructed by embedding plastic buckets filled with cleaned substrate material (1-3 inches or 2.5-7.5 cm diameter) in the channel substrate of riffle areas known to be used by spring Chinook spawners of each of the four study streams beginning in August 1998. Artificial redds were intended to mimic the attributes of salmon redds, based on the data in Bjornn and Reiser (1991). Other more recent studies validated the use of this particle size range as representative of spawning gravel. Schuett-Hames and Pleus (1996) defined particle sizes of salmonid spawning gravels as 0.8 to 12.8 cm diameter. A survey of 135 spawning gravels for a variety of salmonid species revealed that the range in median values of d_{50}s ranging from 2.2-7.8 cm (Kondolf and Wolman 1983). Of the entire set of d_{50} values, 50% occurred between 1.5 and 3.5 cm (Kondolf and Wolman 1993).

The solid-walled containers were tapered cylinders with a diameter of 0.18 m at the opening, a bottom diameter of 0.16 m, and a height of 0.185 m. The depth of the containers ensured that the bottoms of the containers were within the range of depths where egg centrums within natural redds are typically encountered, according to Chapman (1988) and Bjornn and Reiser (1991). These sample containers were retrieved in the spring (April-May) after the date of fry emergence. New buckets were placed in the streams the following August-September. Five "redds" were excavated in each stream monitored. Two containers of cleaned gravel were buried in each "redd," except for two "redds" each in the Grande Ronde River and Catherine Creek, which had three containers, so that one of the three at each site could be collected during mid-winter to provide some indication of the rate of sedimentation during the incubation period. The Grande Ronde River and Catherine Creek are the only two streams among the four study streams that are reasonably accessible during the winter period. Although mid-winter sampling or serial sampling during the winter period would be desirable to track the progression of infiltration during incubation, this was not feasible. Mid-winter sample placement or removal in streams posed significant logistical problems and safety risks. Also, during the winter, there was a risk of disturbing incubating eggs of listed species during sampling in the incubation season.

This procedure yielded a 4-year data set in which fine sediment infiltration within the coarse rock framework was measured. Fine sediments and the rock framework particles were air-dried in the laboratory, sieved, and weighed. When scouring of coarse rock framework particles in sample buckets occurred, infilling by fine particles often followed. Because this layer of surface fines that accumulated in such buckets does not represent infiltrated sediment but simply a surface deposit of fines, buckets that contained less than 6000 g of framework particles were eliminated from analysis. "Framework particles" is a term applied to the coarse particles comprising streambed material, whereas "matrix particles" refers to the fine sediment that infills the framework (Church et al. 1987, as cited by Dalecky 2001; Lisle 1989). Void spaces created by these particles may then be infilled by fines. 6000g of framework particles was considered to be a minimum level needed to represent initial bucket loading. Elimination of buckets that experienced loss of framework particles and random loss of buckets during the overwinter period resulted in unequal sample sizes among streams. For sample collection years 1999-2002, the sample sizes among the four streams per year were 6 to 10, 4 to 7, 7 to 10, and 5 to 11, respectively. The total number of overwinter samples collected in 1999-2002 for the Grande Ronde, Catherine Creek, North Fork John Day, and Granite Creek were 33, 29, 32, and 25 samples, respectively.

The latitude and longitude of the constructed "redds" were estimated using a hand-held gps unit. The gps unit is estimated to have an error in horizontal accuracy that rarely exceeds 15 m RMS (Magellan Systems 1998). We used gps coordinates, field benchmarks (flagging and noted landmarks), and sketch maps to construct the "redds" in 1999, 2000, and 2001 in the same locations as in 1998, to the extent possible. In cases where inter-annual channel change (e.g., the loss of a pool tailout) made a location fail to meet the location criteria (e.g., typical spawning habitats as in Bjornn and Reiser 1991), the site was moved to the most proximate location meeting the site criteria. Other methods related to the monitoring of overwinter sedimentation remained the same as in prior years.

Statistical analysis of overwinter fine sediment infiltration data

Linear regression

Trends in overwinter fines (<6.35mm and <0.85 mm) deposition were analyzed via linear regression analysis. The Microsoft Excel statistical package provided the regression program used. This gives the ANOVA table and F-statistic as well as the regression equation, R^2 value, t-value for regression coefficient, and 95% confidence limits for the regression coefficient. Trend lines were examined for significance of regression slopes. Differences in slopes and elevations of regression lines were analyzed by using methods of Zar (1999) calculated by use of Excel spreadsheets for multiple comparisons of regression lines with unequal sample size.

ANOVA

An ANOVA test was conducted on a four-year overwinter fine sediment (particles <6.35mm and <0.85 mm) infiltration data set for the four study streams. When each year was considered separately, the differences among streams were investigated with a single factor ANOVA.

Multiple comparison tests

When ANOVA revealed significant differences in mean overwinter sedimentation among streams, pairwise comparisons of means were made using a multiple comparison test (Tukey, see Zar 1999) for all stream pairs. This analysis was conducted with fine sediment size classes <6.35mm and <0.85 mm. Graphical comparisons of streams by year were also produced as histograms of overwinter fines deposition, including 95% confidence levels.

Comparisons were made between all pairs of regression lines for study streams (i.e., multi-year trend in overwinter fines deposition) using an analysis of covariance test for multiple comparison of slopes and elevations (Tukey, see Zar 1999). The purpose of these tests was to determine whether study streams differed from one another in trend (rate of change in overwinter fine sediment deposition and direction of the change) and mean level of overwinter fines. In a practical sense, assessing long-term trends in overwinter fines deposition is a key management responsibility in determining whether aggregate land management actions are resulting in improvement in salmonid habitat conditions in the egg incubation environment. The test of differences in regression elevation indicates differences in the intercept of the slope on the y-axis. The y-axis in these regressions is mean overwinter deposition of fine sediment measured in artificial redds (sample buckets). If slopes are equal, the regressions could still be significantly different if the intercepts are different. In such a case, the mean overwinter fine sediment at the first year of the study would differentiate each of the regression lines.

Measurement of fine sediment in overwinter sample buckets

Overwinter fine sediment samples were retrieved by extracting buckets simulating redds from study streams in the spring after spring Chinook emergence has occurred. Buckets were either returned intact to the laboratory with all sediments or the sediment was transferred to labeled plastic sample bags. Contents of each bucket were transferred to large trays for air-drying. Organic matter was removed by hand but samples were not ashed. Framework rocks were brushed to remove dry, clinging sediment particles. Dry sediments were sorted into particles of >6.35 mm (considered to be non-fines or framework) and three categories of fines (2.0-6.5 mm, 0.85-2.0 mm, and <0.85 mm) using a standard sieve set (Gilson). Each size fraction was weighed to the nearest 0.1 g. Percentage fines of any size category was calculated as percentage dry weight of the category relative to the total dry weight of the entire sample (framework plus fines).

Measurement of Void Volume in Overwinter Sample Buckets

During the analysis of the 2001 overwinter fine sedimentation data it became apparent that there were some uncertainties in data interpretation that could be clarified by analysis of the void space initially created among the framework particles. Questions that needed to be resolved included:

1) What was the initial void volume (mean and range) presented by a random selection of framework particles in artificial "redds."
2) Given the initial condition of the artificial "redds," what was the maximum percentage fines that could have been measured in buckets, given that only those buckets containing at least 6000 g of framework particles at collection were analyzed. This selected for buckets most likely to represent infiltration by fines rather than scouring of framework particles from the bucket and replacement by only fines. This selection is based on the assumption that in the few buckets in which large amounts of framework particles were lost and subsequently replaced by fines, it is not likely that buckets would be refilled to the maximum possible extent by new framework particles embedded in a fine sediment matrix. In other words, we assumed that framework particles initially placed in the bucket are predominantly the same as those retrieved on collection and that it is infiltration and not combinations of infiltration, scouring, and differential levels of replacement of framework particles among buckets that is being measured. If this were not the case, it would seem that there would be no compelling reason to fill buckets initially with any sediment or one would have to assume that sample buckets represent all erosional and depositional processes equally.

Potential void volume of framework particles

At the point where we recognized that data on initial void volume would be instructive in interpreting overwinter sedimentation results, we had four samples remaining to be analyzed that met the criterion of having framework particles filling the buckets to the top (i.e., >6000 g dry weight). These included one sample from the Grande Ronde and three from the North Fork John Day. Standard practice in sediment analysis was to dry and separate by sieving the framework particles and three size fractions of fines. Porosity was calculated as the ratio of void volume to the total volume of the sample (USACE 1995, p.7-5). For the four samples analyzed for initial void volume, the framework particles were placed back into plastic sample buckets in the manner that buckets were filled in the field prior to embedding them into the stream channel substrate in August or September. The volume of water required to completely cover the tops of all framework particles was taken to be that volume of fines that would completely fill all voids. Repeated measurements of this volume were made in each bucket by refilling buckets with framework particles, followed by adding water. Dry weights, dry volumes, and displacement volumes of each of the four size fractions were determined by standard methods. A 500-ml graduated cylinder was used to measure dry volumes and displacement volumes of each of the three fine sediment fractions. Density was measured as dry weight divided by displacement volume. For each fine sediment size fraction, void volume was also measured independently. Total dry volume of fines for each overwinter sample was determined by adding the separate dry volumes of each size fraction.

The various volumes of framework and fine sediment particle fractions and the interstitial voids are illustrated in **Figure 13**. This diagram depicts framework particles initially placed into sample buckets and the initial void space, depending upon degree of framework particle compaction, size, angularity, etc. After the incubation period, a portion of this initial void volume was filled by fines. The purpose for investigating the maximum capacity of fines to fill these voids was to determine the extent of infiltration and also to assess whether unfilled pockets were likely to exist within the framework that could be occupied by eggs/alevins and used as routes for emergence (**Fig. 13**, item I).

Testing the effect of variable void volume in overwinter sample buckets in determining overwinter deposition

A parent population of framework material was composited from two bucketsful of coarse substrate spanning the range of 2.5-7.5 cm intermediate diameter (the size range selected in the field to fill buckets). From this population of particles, 3 buckets were sequentially filled randomly without regard for particle size. Also, a fourth bucket was filled by deliberately selecting for coarser particles and a fifth bucket by deliberately selecting for smaller particles within this range. Particles were tossed into buckets in a fashion typical of that in the field. Buckets were filled to their tops with no particle surfaces rising above the bucket lip. Then, buckets were filled with water to measure the void volume within buckets. This procedure provided an approximate range of initial void volume that would have been presented in each stream, accounting for variations that occur due to degree of skewness in particle size selection and variation in compaction of particles or particle shapes.

Survival Estimates

Salmon survival from egg to fry was estimated from the fine sediment and overwinter sedimentation data via empirical relationships between subsurface fine sediment and survival-to-emergence. These relationships were summarized from various literature sources by Bjornn and

Reiser (1991) and from Weaver and Fraley (1991) for various salmonids (**Fig. 14**). The relationships expressed in these sources were contrasted with similar data of Stowell et al. (1983), Scully and Petrosky (1991), and Reiser and White (1988) to evaluate their utility for interior Columbia basin populations. We analyzed all samples of overwinter sedimentation for the percent composition in three fine sediment particle size classes: <6.35 mm, <2.0 mm, <0.85 mm. These size fractions were analyzed to provide greater detail on sedimentation in case overwinter sedimentation appeared to be more responsive to one threshold size class of fines than another. Although the level of overwinter deposition in artificial redds cannot be taken as an accurate reflection of average natural instream infiltration processes, they at least provide an index to annual extent of infiltration and a means to express the influence of surface fine sediment concentration on subsurface conditions.

Administrative details

A biological assessment (BA) of the project's effects was prepared for use in project consultation with NMFS under the Endangered Species Act (ESA) in 1998. The BA was prepared using the same format and approach as the BAs for Catherine Creek (La Grande Ranger District 1994a) and the Upper Grande Ronde River (La Grande Ranger District 1994b). The project BA tiered to La Grande Ranger District (1994a; b) and described potential project effects within the context of project actions, information on the study streams, and scientific literature related to possible effects. The project BA was submitted to BPA and NMFS in August 1998.

RESULTS

Method Comparisons

Are visual fine sediment level estimates comparable to those made by the grid method?

Over the period 1998-2001 visual and grid-based estimates were made of surface fine sediment on 10 transects for each of the 4 study areas (4 different streams in the Blue Mountains). This produced a data set of 160 x-y data pairs. A regression conducted on this data set evaluates the correspondence between visual and grid-based surface fine data from all streams in all years (**Table 7, Fig. 15**). The regression R^2 was 0.78; the regression equation was $Y = 0.914 X - 0.00166$. The linear regression was highly statistically significant ($P<<0.01$), indicating that visual estimates of fine sediment produced values statistically the same as those measured with the grid method. A slope of 1.0 would indicate that visual and grid estimates are identical, assuming no variance in the regression. The standard error of the regression slope was 3.86%, while the standard error of estimate ($s_{Y.X}$) was 5.74% (Zar 1999, see his p. 334).

Among the three methods for surface fine sediment level determination, which is to be preferred?

Over the period from 1998-2001, visual, grid, and pebble count estimates of surface fines were made at 3-5 transects per stream per year. In 2002 only one transect was able to be surveyed with all three methods due to salmon spawning. These estimates were made in August-September of each of these years, yielding a data set of 46 values for each surface fine sediment method. The Pearson correlation coefficient between the visual and grid methods was the greatest (R=0.86), while the poorest correlation was between the visual and pebble count methods (R=0.85). This analysis lends support to the use of the visual estimate as a reliable substitute for either the pebble count or the grid method.

An ANOVA test (**Table 8**) on this data set of surface fine sediment estimated by these three methods revealed no significant difference (P=0.59) among means of surface fine sediment, which were 13.0, 12.6, and 14.9%, respectively, for visual, grid, and pebble count methods. This data set of 46 records (a surface fine sediment estimate by each method for each record) incorporates four streams and four years of data collection.

Because there were 46 records having simultaneous estimates of percentage surface fine sediment by three methods each, we plotted the cumulative number of samples having less than various percentage surface fine levels. Surface fines were plotted in increments of 4% (**Fig. 16**). The visual estimates yielded the most uniform rate of increase in cumulative number of samples within surface fine bin categories. After approximately 38 samples were taken, the three methods converged. This indicates that 38 out of 46 records demonstrate that surface fines are less than or equal to approximately 25%. This seems to show that when percentage fines become more dominant, the three methods become more similar in their ability to reflect percentage fines.

Given the highly significant regression between visual and grid estimates of surface fines based on 160 observations over a 4-year period, we then computed regressions for the more limited data set having simultaneous measurements made by visual, grid, and pebble count methods. This data set was comprised of 46 measurements taken in a 5-year period from 1998 to 2002. This more limited data set also revealed a highly significant regression between visual and grid estimates of surface fines (**Fig. 17**). For this regression, the R^2 was 0.74, n=46, P<<0.01; the regression equation was $Y = 0.920X + 0.0064$. The regression slope less than 1 indicates a tendency of the grid method to overestimate percentage fine sediment relative to the visual method. A regression of pebble count data on visual estimates (**Fig. 18**) had an R^2 of 0.72, n=46, P<<0.01; the regression equation was $Y = 0.817X + 0.0424$. This regression was also highly significant. The regression slope less than 1 indicates a tendency of the pebble count method to overestimate percentage fine sediment relative to the visual method and the amount of this relative overestimation is greater than for the grid method.

Regression lines for the grid vs. visual and pebble count vs. visual methods were very nearly identical (**Fig. 19**), but the regression line based on pebble count data predicted slightly greater surface fine values than did the grid method for the lower levels of visual estimates. This direction of discrepancy is expected due to the bias of the pebble count method against small particles. It appears that when fines are scarce on a transect, it is less likely that the pebble count method would locate them amidst predominantly larger material.

Statistical tests of differences in slopes and elevations of the regressions for grid estimates vs. visual estimates and pebble count estimates vs. visual estimates were then performed (Zar 1999). This test revealed no significant difference in either slopes or elevations ($\alpha = 0.05$) between the two regressions. This argues for using a pooled regression to describe the relationship between visual estimates of surface fines and those made using both grid and pebble counts. This pooled regression is $Y = 0.00176 + 0.978X$.

By calculating the standard error for predicted values of Y in the pooled regression, the 95% confidence interval can be calculated for various levels of visual surface fines. For example, if visually-estimated surface fines were 1% the predicted surface fines from the pooled grid and pebble count data is 1.15% ±0.0495. If visual surface fines were 13% the predicted surface fines from the pooled grid and pebble count data is 12.89% ±0.0351. In other words, all three methods provide equivalent estimates.

How much do study areas vary in total substrate particle size composition based on the visual estimation method?

Ocular estimates were made on September 10-11, 2002 of total substrate sediment composition at transects where overwinter infiltration tests were completed. At this time spawning was observed in Granite Creek. Carcasses were observed at Grande Ronde River and Catherine Creek sites. For these reasons we were not able to enter the stream to take pebble count and grid measurements in 2002 in all streams. Averages for all pooled transects were calculated for each size fraction and these values were plotted as cumulative percentage surface area of sediment that is finer against size (cm) (**Fig. 20**). In addition, these data were plotted as a particle size histogram where percentage by surface area was placed into particle diameter classes (cm) (**Fig. 21**).

The cumulative particle size distribution indicated that the Grande Ronde River had the greatest percentage of particles <0.635 cm (**Figs. 20 and 21**). The Grande Ronde and North Fork John Day exceeded the goal of ≤ 20% surface fines set by CRITFC (1995) and NMFS (1995). These streams had mean surface fines of 24.4% (±10.0%, 95% CI) and 21.4% (±3.9%, 95% CI) (**Fig. 21**). Also, the Grande Ronde River, Granite Creek, and North Fork John Day River had a range of approximately 21 to 28% surface material <1 cm, whereas Catherine Creek was only about 7% finer than 1 cm at the transects studied. At <3 cm particle diameter, Catherine Creek substrate particles occupied only about 10% whereas the Grande Ronde had approximately 40% of the surface area in this size range. The particle size at which 84% of all material in the transect band was smaller in diameter (i.e., d_{84}) was about 12 cm for Granite Creek and the Grande Ronde but was nearly 20 cm for Catherine Creek and the North Fork John Day (**Fig. 22**). The transects surveyed indicated that Catherine Creek had the coarsest substrate and the North Fork John Day was similar, having about the same percentages (33 to 43%) of material from 13 to 50 cm.

How does the particle distribution assessed by pebble counts compare with the visual estimates?

The d_{84} values estimated on September 11, 2002 by visual observation of particle distribution on transects where overwinter buckets were located was 17, 24, 24, and 12 cm for the Grande Ronde, Catherine Creek, North Fork John Day, and Granite Creek, respectively. Average pebble counts for these same transects taken over the period 1999-2001 produced a d_{84} of 16, 20, 20, and 15 cm, respectively for these same streams (**Figs. 23 and 22**). Estimates of the average d_{50} for these same streams via the visual method were 6, 11, 9, and 4 cm, respectively. The average pebble count results were 7, 10, 7, and 5 cm, respectively. These results indicate that both the visual and pebble count methods produced very similar estimates of particle size distributions. For both the d_{50} and d_{84} the results were similar and arrayed streams in the same order by size of these particle categories. The results indicate that Catherine Creek and the North Fork John Day have the largest d_{84} values, indicating a coarser substrate. Reference to the surface particle size histogram (**Fig. 21**) also shows greater percentages of particles in each particle size category above 13 cm diameter for these two streams.

When pebble count data are plotted by year, the yearly average data for the five bucket transects showed minor variation around the 3-year mean values of d_{50} described above. However, the mean annual d_{16} values had greater variation. The ranges in these values for the four study streams were 0.5-2.0, 3-5, 0.25-0.4, and 0.2-1.7 cm, respectively (**Figs. 24**, **25, 26, and 27**). Pebble counts show the consistently high level of fine sediment in the North Fork John Day, as well as the high levels of fines in the Grande Ronde in 1999.

Surface Fine Sediment

Are there significant 4-year trends in surface fine sediment levels?

Surface fine sediment (<6.35mm) was estimated by both visual and grid methods for each of 10 transects over a 4-year period (August in each year 1998-2001) for each of the 4 study streams. Regression equations were computed to determine whether significant trends existed in surface fine sediment data collected via the grid method and visual estimates over 4 years. Results of regression analysis of temporal trends in surface fines are presented in **Tables 9 and 10**. Based upon visual estimates of surface fine sediment for this 4-year period, highly significant regression trends were detected in each stream. Highly significant decreasing trends (regression slopes were negative) in surface fine sediment levels were measured in the Grande Ronde and Granite Creek via both the grid and visual methods. Increasing trends were measured using the grid for Catherine Creek and the North Fork John Day, but the significance levels were P<0.086 for these streams (**Figs. 28 and 29**). The visual method identified significant increasing trends in surface fines in both Catherine Creek and the North Fork John Day (**Table 9**). Although there was a significant decreasing trend in surface fine sediment measured by visual and grid methods (**Figs. 28 and 29**) in the Grande Ronde River based on sampling in 1998-2001, the increase in fines measured in 2001 relative to 2000 indicates that some caution needs to be applied. That is, the Grande Ronde has had a high level of surface fines throughout this period and a conclusion that lasting improvement has been achieved will require that improvement be sustainable for the next several years.

Are there statistical differences in slopes and elevations of regression lines for 4-year trends in surface fine sediment among the four study streams?

The visual and grid estimates of surface fines measured in August each year during the period 1998-2001 comprise a data set of 10 observations per stream per year (one value per transect in the study spawning reach). These regression equations for individual streams were reported in **Tables 9 and 10** (also see **Figures 28 and 29)** and reported in the section above.

Regressions were then computed on grid and visual data on surface fine sediment trends using the entire data set of 160 observations for the four streams over the 4-year period for each method. Given that among the study streams there were 4-year trends exhibited that were both positive and negative, the two regressions (i.e., for grid and visual data) based on the total data set (i.e., all streams, all years) were statistically non-significant and had $R^2 < 0.004$. This indicated that all streams were not responding in the same manner. Given this result, regressions for 4-year trends were then calculated for individual streams. Tables of Σx^2, Σxy, Σy^2, residual SS, residual DF, and *b* were computed by using Excel. The residual SS and residual DF were computed for the pooled, common, and total regressions (Zar 1999, his p. 370). With these data it was possible to calculate the F-statistic to compare against a table value of $F_{(0.05)(1),\,3,\,152}$ for the multiple slope comparison and $F_{(0.05)(1),\,3,\,155}$ for the multiple comparison of elevations. The F-test indicates that for both the visual and the grid data the slopes, as well as elevations of the regression lines, do not come from the same population, so some significant pairwise differences would be expected between streams. In this aspect, both the grid method and visual estimate data yield the same results. Therefore, it can be assumed that there are some statistically significant differences in trends in surface fine sediment among the streams.

Given that differences among streams were found, the Tukey multiple comparison test was used.

When pairwise comparisons of slopes were tested for significance, a q-statistic was calculated for the comparison, where $q_{\alpha,\nu,\rho} = q_{0.05,152,4} = 3.685$ (**Table 11**). The parameters for the test include α, which is the significance level selected for the test, ν which is the pooled residual DF, and ρ which is the number of mean slope coefficients being compared. This analysis indicates that, based on the data from both the grid and visual estimate, Grande Ronde and Granite Creek regression slopes are not statistically different, but this pair is significantly different from the other two streams. Catherine Creek and the North Fork John Day have slopes that are significantly different from one another based on visual data, but not grid data.

In the analysis of grid data (**Table 11**), pairwise comparisons of surface fine trends using the q-statistic indicated that the slopes of the Grande Ronde and Granite Creek were statistically the same but were different from the pair Catherine Creek-North Fork John Day, which had statistically indistinguishable slopes.

The multiple comparison of elevations (i.e., Y-axis intercept) (**Table 12**) of regression lines for the 4-year trends in surface fine sediment was computed from visual and grid estimates. Again a q-statistic was calculated for each pairwise comparison, where $q_{0.05(2),152} = 3.685$. The comparison of calculated q-values for each regression pair indicated that for visually estimated surface fine sediment all four regressions differed significantly from one another in regression line elevations. In this comparison the order of elevations ranked high to low was Grande Ronde River, Granite Creek, Catherine Creek, and North Fork John Day. The significance of this statistic is that if any of the pairwise comparisons of regression slopes were statistically equal (as was found for the Grande Ronde and Granite Creek using visual as well as grid estimates and for Catherine Creek and the North Fork John Day with grid data), the regressions would still be statistically different (i.e., would not be estimates of the same population regression) because they intersect the Y-axis in different places. The conclusion from statistical comparisons of slopes and elevations is that all four regression lines are dissimilar, either by virtue of slope, elevation, or both. The intercepts are not particularly interpretive in a physical sense, however, because they represent an extrapolation beyond the period of years for which the regression is produced (Zar 1999, his p. 367). They are needed, though, to accurately compute the surface fine estimate for a given year in the study period. Consequently, a multiple comparison of mean annual surface fine sediment samples is also called for to interpret differences in magnitude of surface fine sediment.

A similar result in comparison of regression elevations was derived from grid data (**Table 12**). This group comparison test revealed the same order of elevations of regression lines. Again, every pairwise comparison of elevations indicated a significant difference at $\alpha = 0.05$.

Are there significant differences within streams among years in the surface fine sediment levels?

We also analyzed whether there were significant differences among years in surface fine sediment levels in each of the four streams. To test for significant differences within streams among years in surface fine sediment, a single factor ANOVA was done for each stream (**Table 13**). For each stream there were four years of data; for each year there were 10 transects on which surface fines were visually estimated.

For Catherine Creek the P-value was 0.056 for the ANOVA for surface fine estimates for years 1998-2001. This was slightly less than significant at an $\alpha = 0.05$ level. This indicates that there was little difference among years in Catherine Creek and also implies that the regression slope would not be statistically significant. For the other three streams the among year differences were all highly significantly different, as evidenced by $P \ll 0.01$ and the calculated $F > F_{crit}$.

The value of this statistical test was to determine whether, for any streams not having a significant regression trend of surface fine sediment over the study period, they had significant differences among years in surface fines. Significant fluctuations in surface fines from year to year that are non-directional could produce great uncertainty in the recovery process. The grid method produced non-significant regressions for surface fines only for Catherine Creek and the North Fork John Day (P= 0.086 and 0.064, respectively). Among year differences in fines for Catherine Creek were also non-significant (P=0.056).

Are there significant differences among streams over the entire study period in the surface fine sediment levels?

By pooling all surface fine sediment estimates made on each stream for the period from 1998 to 2001 (10 transects per stream, 4 years), a single factor ANOVA was computed to assess whether there were significant differences among any of the study streams based on all visual estimates made over the 4-year study period. The ANOVA indicated a highly significant difference among groups ($P \ll 0.01$) (**Table 14**). A multiple comparison test (Tukey) was then run to compare means of all pairs of streams. This test revealed that each stream was significantly different from every other stream. Mean visually-determined fine sediment levels produced a descending rank order of NFJDR>GR>GT>CC[10], where these streams had mean surface fines of 27.3, 16.2, 8.2, and 2.3%, respectively.

Mid-Winter Sedimentation

The results of the mid-winter monitoring of sedimentation in containers of cleaned gravels in constructed "redds" indicate that sedimentation occurred early in the incubation period for spring Chinook salmon eggs (**Fig. 30**). In at least one case, the sedimentation was significant. In "redd" 4 in the upper Grande Ronde River (**Fig. 30**), the container collected in December 1998 had ~17% fine sediments by weight for the fraction <6.35mm. This was as high as any of the samples collected later in April 1999 **(Fig. 31**), indicating that the sample was already near capacity for fine sediments in the container. Although fine sediment accumulation from September-December 1998 was variable between the two reaches (Grande Ronde and Catherine Creek) and at the two sites in the Grande Ronde (**Fig. 30**), it is clear that measurable overwinter sedimentation occurred during this period. It also appears, based on the limited sample numbers, that the amount of overwinter sedimentation for the <6.35mm fraction was higher from September-December 1998 in the Grande Ronde than in Catherine Creek (**Fig. 30**). This may be related to the amount of mobile fine sediment at the substrate surface that can be transported and re-deposited, even at low stream discharge levels (Leopold 1992, Booth and Jackson 1997, Garrett 1995:p.74). The mean surface fine sediment measured via the visual method was 28.8% in the Grande Ronde River study reach and 1.9% in Catherine Creek (**Table 13**). However, the limited sample numbers make it impossible to analyze the statistical significance and the apparent result may be due solely to the small sample size.

In Catherine Creek, sedimentation in containers collected December 1998 was almost solely comprised of fine sediment <0.85 mm (**Appendix B Table 3** and **Fig. 30**). The fine sediments in the Grande Ronde samples were more evenly distributed among the three size classes, but were primarily comprised of sediment <2.0 mm (**Appendix B Table 3** and **Fig. 30**). Collection notes indicated no bridging or surface sealing by fine sediment in the upper layers of the samples in Dec. 1998 (**Appendix B Table 3**). Other researchers have found that bridging or surface sealing from fine sediment occurs during the salmonid incubation period in northern California (Lisle 1989) and Idaho (King et al. 1992; Maret et al. 1993).

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[10] NFJDR (North Fork John Day River), GR (Grande Ronde River), GT (Granite Creek), CC (Catherine Creek).

Overwinter Fine Sediment Deposition

Are there significant 4-year trends in overwinter fine sediment deposition in study streams?

Trends were examined in overwinter fine sediment deposition in artificial redds based on particle deposition in the size classes <6.35mm and <0.85 mm (**Figs. 31-32**). Regressions were calculated for each stream individually for the 4-year period 1999-2002, where the year indicates the spring of sample collection after the overwinter infiltration period. Regressions were based on from 25 to 33 total samples of overwinter fine sediment deposition per stream accumulated over this 4-year period. The number of samples available varied among streams and was attributable to losses from scouring of streambeds during the winter period and the decision to accept only sample containers having >6000 g of framework particles after the incubation period.

Regression equations are reported in **Table 15**. Regressions indicate that only the North Fork John Day River overwinter sedimentation trends appeared to have a significant slope (i.e., significantly different from zero). Its trend is significantly increasing in fine sediment based on particles <6.35mm (P=0.0041). On the basis of particles <0.85 mm, no significant trend was noted. The North Fork John Day had a significantly increasing trend (visual) in surface fines (**Table 9**) that might be related to the increasing trend in overwinter deposition. Overwinter trends for all other study streams were non-significant, despite the fact that significantly increasing and decreasing trends in surface fines (<6.35 mm; visual) were found in all streams (**Table 9**).

Are there significant differences among streams within years in overwinter fine sediment deposition in simulated redds?

A key question of this study is whether there are differences in fine sediment deposition among streams. As explained in Zar (1999, his p. 208), it is generally not acceptable practice to use multiple *t*-tests to examine the differences between all pairs of means. Instead a multiple comparison test is performed after conducting a single-factor analysis of variance to test the null hypothesis Ho: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_k$. For the term μ_k, k represents the total number of means (u) being compared; k then represents 4 streams per year in a comparison between all pairs of streams. After determining from the analysis of variance that significant differences existed among streams within a given year (**Tables 16 and 17**), the multiple comparisons were conducted. Given the unequal sample sizes, a Tukey test for unequal sample sizes was used in these comparisons (Zar 1999, his p. 213) (**Tables 16 and 17**).

Fines <6.35 mm

Overwinter sedimentation data for the four winter periods of 1998-1999, 1999-2000, 2000-2001, and 2001-2002 were expressed as the percentage dry weight of fine sediments (<6.35mm) relative to the total sediment dry weight in sample buckets embedded in the stream channel in spawning riffles (**Tables 16a-d**). Samples are identified here more briefly by their year of collection (i.e., 1999, 2000, 2001, or 2002), which occurred at the conclusion to each overwinter incubation period. The 1999 samples indicated by group comparison statistics that the Grande Ronde overwinter sedimentation was significantly greater than that in the North Fork John Day. The computed q value was greater than q_{table} at $\alpha=0.05$ so the null was rejected in this comparison of the Grande Ronde vs. North Fork (group 1 vs. 3). The North Fork was not significantly different from Granite Creek, and Granite Creek was not significantly different from Catherine Creek, while the North Fork was significantly different from Catherine Creek. The overlap in statistical comparisons is shown in the colored bars under the mean values for overwinter sediment for each stream (e.g., **Table 16**). The Grande Ronde had overwinter sedimentation of 7.8 to 17.5% among the years 1999-2002 and was highest of the four streams in its sedimentation rate for 1999, 2000, and 2002.

Although fine sediment deposition was greatest in the Grande Ronde in three of four years studied, deposition in the North Fork John Day was greatest of the four streams in 2001. Overwinter sedimentation by particles <6.35mm exhibited its greatest range among the four streams in 2001 where the North Fork had a mean deposition of 16.4% and Granite Creek had 2.3% (**Table 16c**). The North Fork (16.4% ± 1.74% (95% CI)) was significantly different from the Grande Ronde (7.8% ± 1.48% (95% CI)) which was significantly different from Catherine Creek and Granite Creek. Mean overwinter fine sediment deposition in size classes <6.35mm and <0.85 mm is shown in **Figures 33 and 34** with 95% confidence intervals calculated simply from the standard deviation and sample size for each stream (i.e., without benefit of the ANOVA with a multiple comparison). By comparison, the $X\text{-}^{\text{bar}}$ ±95% CI from the ANOVA for the North Fork John Day was 16.4% ± 1.74% (95% CI) (see Zar 1999, his p. 216, calculation of confidence intervals from multiple comparison test with unequal sample sizes) whereas based on the North Fork samples alone (t-test, Microsoft Excel), the estimate was 16.4% ± 3.23% (95% CI). Despite the somewhat broader 95% CI estimated from the variance in each set of samples per stream individually, the confidence limits expressed in this manner indicate the degree of differentiation among streams quite well.

However, in 2001 the North Fork (16.4%) was significantly higher in sedimentation rate than the Grande Ronde (7.8%) and was the highest of the four streams. In the same year the Grande Ronde was significantly higher than Catherine Creek (4.0%). Catherine Creek had the lowest sedimentation rates in 1999 and 2002 (4.8 and 7.6%, respectively) and was not significantly different from the lowest in 2001 at 4.0%. In two years (2000 and 2002) the Grande Ronde and the North Fork John Day were not significantly different from one another in sedimentation rate, but in 1999 and 2001 they were (**Tables 16a-d**).

Fines <0.85 mm

On the basis of fine particle (<0.85 mm) sedimentation in sample buckets containing simulated spawning gravels, less differentiation was observed among streams than with particles <6.35 mm (**Tables 17a-d**). In 1999 and 2000 there was no significant difference in deposition of fine sediment <0.85 mm among the 4 streams based on ANOVA. In 2001 the North Fork (7.6%) was significantly higher than the Grande Ronde (4.5%) and Catherine Creek (3.4%), and Catherine Creek was significantly higher than Granite Creek (1.3%) based on the multiple comparison test. In 2002 there was no significant difference among the Grande Ronde, Granite Creek, and the North Fork. The pooled mean for these samples was 6.2% ± 0.78% (95% CI). Consequently, the UL and LL (upper and lower 95% confidence limit), respectively, were 7.0 and 5.4%. The only significant difference in mean overwinter deposition was between the Grande Ronde (7.7%) and Catherine Creek (4.3%).

In three years of the four in which overwinter sediment samples were taken (i.e., 1999, 2000, and 2002) the Grande Ronde was not significantly different from the highest in sedimentation by particles <0.85 mm or was the highest (**Tables 17 a,b,d**). The percentage by dry weight in these years ranged from 4.9 to 7.7%. In 2001, the Grande Ronde (4.5%) was significantly less than the North Fork, which was the highest at 7.6% (**Table 17 c**).

In 1999 there was no significant difference in percentage of total dry weight comprised by particles <0.85 mm among the four streams (**Table 17a**). The pooled mean computed from the ANOVA was 4.6% ± 0.53% (95% CI). Likewise, in 2000, there were no significant differences among means from overwinter samples observed in the <0.85 mm size fraction. The pooled mean for this year was 6.6% ± 0.93% (95% CI). And in 2002 there was also no significant difference in means among the Grand Ronde, Granite Creek, and the North Fork. The pooled mean percentage fines (<0.85 mm) for 2002 in these three streams was 6.2% ± 0.78% (95% CI). Consequently, on the basis of fine particles (<0.85 mm), there was considerable consistency among streams in magnitude of average overwinter sedimentation.

Are there significant differences among the four study streams in overwinter fine sediment deposition when data from 4-years of study are lumped?

Fines <6.35 mm

When mean overwinter sedimentation levels (fines <6.35) were evaluated among streams (ANOVA) by pooling the overwinter results for all four years for each stream, statistically significant differences were revealed by the F-test (calculated $F > F_{crit}$ and the $P << 0.01$) (**Table 18**). A Tukey group comparison test was then done to find which pairs of streams generated the significant differences among the four streams. Based on this statistical analysis, the highest sedimentation occurred with the Grande Ronde and North Fork John Day. Mean levels of fine sediment in simulated redds were 12.1 and 12.6%, respectively. These two streams were not significantly different in fine sediment accumulation (α=0.05) based on the calculated $q > q_{crit}$. Catherine Creek and Granite Creek, likewise, were not significantly different from one another, but each was significantly different from each of the other streams. Mean fine sediment levels (<6.35mm) for Catherine and Granite were 7.8 and 7.5%, respectively.

Fines <0.85 mm

On the basis of the particles <0.85 mm diameter, the ANOVA revealed a highly significant difference ($P < 0.01$), indicating that among the four study streams, there were at least two that were significantly different from one another (**Table 19**). To investigate further where the differences occurred, a multiple comparison test (Tukey) with unequal sample sizes was done (see Zar 1999, his p. 213). The Tukey test was used to calculate a q-value (α=0.05) with four groups (i.e., streams) for each stream pair comparison. Comparison of the pairwise calculations of q with the table q-value (i.e., $q_{0.05,115,4}$) determined whether the null hypothesis (i.e., that there was no difference in mean overwinter fines deposition between streams) was accepted or rejected. Over the four years of monitoring, the mean fine sediment levels in overwinter samples collected from the North Fork John Day, the Grande Ronde, and Granite Creek were 6.4, 5.7, and 4.4%, respectively. Differences in these means were not statistically different. Also, Granite Creek and Catherine Creek means (4.4 and 4.1%, respectively) could not be distinguished. Consequently, the Tukey test was not able to assign Granite Creek to either of the two groups at the 95% level.

Correlation of Overwinter Fine Sediment Deposition with Surface Fine Sediment

Overwinter fine sediment deposition in simulated redds was measured as the percentage fines by weight of the total substrate material contained in sample buckets at the end of the incubation period. Infiltration of fines into cleaned spawning substrate was hypothesized to be related to the availability of fine sediments in storage or transport in the stream during the incubation period. It is possible that the overwinter deposition of fines during the winter incubation period could be predicted from the surface fine sediment observed in the preceding August period when cleaned gravel was placed into sample buckets embedded in the stream substrate (Hypothesis 1). Alternatively, the surface fine sediment deposits observed in August-September might correspond better to the preceding winter's fine sediment infiltration amount (Hypothesis 2). These two hypotheses suggest calculating regression equations for overwinter fines (<6.35mm) in year X (i.e., year of collection) vs. surface fines (<6.35mm) in year X-1 (i.e., the preceding August) (**Fig. 35**) or also vs. surface fines (<6.35mm) in year X (i.e., the August following collection of the overwinter samples) (**Fig. 36**).

When mean overwinter fine sediment values per stream for each year in the sample collection period of 1999-2002 were regressed on visual estimates of surface fine sediment from the previous August, the regression equation derived was $Y= 7.460 +0.2191X$ ($n=16$, $R^2 = 0.257$, $P=0.045$). The regression was significant, as determined by the F-test. The same type of regression done using grid-based surface fine sediment estimates yielded a regression equation of $Y=7.745 +0.2285X$ ($n=16$, $R^2=0.241$, $P=0.053$). These regressions indicate that if the stream has a surface fine sediment level of 20% fines, the overwinter deposition of fines would be 11.84% (visually-estimated surface fines) or 12.31% (grid-estimated surface fines). When X = 20% surface fines, the 95% confidence limits for the predicted value of overwinter fines (Y^{hat}_{i}) are ± 2.65% (from visual surface fine regression statistics) or ± 5.18% (from grid-based surface fine regression statistics). For the visual estimates, the lower and upper 95% confidence limits, then, are 9.2 and 14.5% (see Zar 1999, p. 340). This indicates that buckets infiltrated with 9.2 to 14.5% fines by weight are indicative of 20% surface fines in spawning riffles observed during the preceding August. If 20% surface fines in turn is indicative of similar or worse conditions at egg pocket depth in natural redds, critical biological thresholds can be indicated in infiltration studies with loading by fines equal to about 40-60% of potential maximum levels of 23.9% fines.

When overwinter deposition as percentage fines in April of year X was regressed on visual or grid estimates of surface fines made in August-September of year X , similar regressions resulted. Based on visual estimates of fine sediment, the regression equation was Y= 7.719 +0.2000X (n=15, R^2=0.201, P=0.094). The F-test for the regression ANOVA indicated a non-significant regression slope. Grid-based estimates of surface fine sediment for the same year as overwinter fines sample collection produced a regression of Y= 8.098 +0.1836X (n=15, R^2=0.168, P=0.130). In this case, the F-test for the regression ANOVA indicated a non-significant regression slope.

The results above seem to indicate that the surface fine sediment at the onset of the incubation period is a better predictor of overwinter fine sediment deposition in cleaned gravels than fine sediment levels occurring after the incubation period.

Further Analysis of Overwinter Fine Sedimentation Data by Considering Void Volume

The use of buckets filled with coarse framework rock material to represent fine sediment infiltration has been used previously in other studies (Lisle 1989, Larkin and Slaney 1996, Rhodes and Purser 1998). Despite the past use of this method for measuring infiltration, a number of uncertainties became apparent in data interpretation near the conclusion to sample processing. These uncertainties were explored by conducting some simple analyses of a few remaining overwinter sediment collection buckets. (See **Appendix D** for a more detailed description of the methodology used in determination of void volume.) Those uncertainties that could not be resolved by investigation were itemized in order to understand the limits to interpretation of data.

We listed the various areas of uncertainty presented by the sampling methodology, hypotheses of interest, and some likely rationales for them:

1) *Degree of compaction of framework material.* In the process of filling buckets with coarse rock to construct a simulated egg pocket, the coarse rocks could vary in their

degree of compaction and consequent porosity (Lisle and Eads 1991:p.5). That is, rocks of even a known size composition could potentially vary in the volume of voids provided. The higher the initial degree of settling and compaction, the lower the void volume would be as a percentage of the total framework volume. Particle compaction, in addition to particle shape and packing attitude, determine the potential infiltration level and percentage of matrix material in the substrate framework (Carling and Glaister 1987).

2) *Influence of framework particle distribution on the initial potential void volume available to be filled by fines.* As the size frequency of framework particles varies within the range of particle sizes chosen in this study (i.e., 2.5-7.5 cm), the percentage of void volume might change (Lisle and Eads 1991:p.5). That is, it might be that a predominance of larger particles could create a greater void volume, or a more heterogeneous mixture of particles might create a more compact initial framework leading to a smaller void volume. A predominance of large and uniform-size particles might create large voids that are easier to penetrate by fine sediment infiltration all the way the bottom of the bucket and might be more difficult to bridge in surface layers to restrict further infiltration.
3) *Influence of framework particle distribution on potential bridging and subsequent infiltration.* If buckets had been filled initially by material ranging from the upper limit of "fines" (i.e., 6.35 mm) to 7.5 cm, different magnitudes of infiltration might have been determined owing to variation in the degree of bridging feasible with starting material and the openness of the lattice structure of the particles (Lisle and Eads 1991:p.5). Although this hypothesis would be interesting to have tested, it will have to be the subject of future work. It was not contemplated in this study and there was no way to make estimates of this effect from any sample analysis method available during our final sample processing.
4) *Screening samples for those with near original levels of framework material in order to measure only the infiltration process.* If no criterion had been applied for selection of overwinter buckets to analyze, the results would likely have indicated the influence of the combination of infiltration and scouring followed by redeposition (Lisle and Eads 1991:p.5; Larkin et al. 1998; p. 19, Naden et al. 003:p.12, 37; Larkin and Slaney 1996). Fraser (1935) (as cited by Frostick et al. 1984) suggested that when matrix fines represent greater than 30% of substrate sediment by weight, it indicates that both framework and matrix material are deposited simultaneously. Buckets that varied substantially in the final weights of framework material remaining at sample collection in spring would have reflected some combination of these two processes. However, there were reasons that samples were screened for those meeting the 6000 g final framework material weight

criterion: a) It seemed probable that the relative degree of influence of infiltration vs. scouring/redeposition would vary considerably in samples not screened, b) Samples undergoing large degrees of scour would tend to be those lost and not represented at all, c) Infiltration is a process of high interest, d) It seemed more probable that sample buckets whose framework material was heavily scoured out would be filled by thick layers of fines on the surface of remaining framework rather than being refilled by new framework-size material plus fines, e) It seemed more probable that given the influence of a sample bucket in creating the conditions to produce unique, site-specific results (e.g., limiting the ability of fines to infiltrate laterally within the substrate (Lisle 1989; Acornley and Sear 1999); creating a "dead zone" in which fines would preferentially deposit; creating an initial framework particle size distribution that influences both infiltration and scour potential; creating a lip at the bucket top that would concentrate scouring vortices or possibly shield framework from being moved or displaced (see Bloesch and Burns 1980)), the infiltration process is more likely to be adequately represented by the initial sampling conditions if a screening criterion is applied than if no screening is applied, given all the interacting processes of infiltration, bed movement, scour, bed aggradation, etc.

At the point where these questions were posed, four samples remained to be processed that met the criteria of (1) being filled to near the top of the bucket with sediment, meaning that significant scour had not removed material, and (2) having framework particles emerging through the fine-particle surface layer (indicating that framework particles probably had not been removed). One sample was from the Grande Ronde River and three were from the North Fork John Day River (transects 3, 4, and 5).

Potential void volume of framework particles

Among the four samples examined (i.e., one overwinter bucket collected from the Grande Ronde and three collected from the North Fork John Day), the range in coarse rock framework displacement volume was 2291 to 2348 ml in a plastic bucket with a volume of 4216 ml (**Table 20**). The estimated empty volume above the sediment surface within buckets ranged from 70 to 453 ml, meaning that comparable volumes of framework rock were available to estimate infiltration to a depth nearly equal to the depth of the buckets. That is, all buckets were nearly filled to the top with framework material, even at collection (see **Fig. 13**). The coarse rock framework had 39.3% initial void space in the Grande Ronde sample and ranged from 37.7

to 46.3% void space in the North Fork (**Table 20**). This void volume was filled to varying extents by fine sediments.

Percentage of potential void volume occupied by displacement volume of fines

In the Grande Ronde sample, the displacement volume of total fines occupied 36.8% of the void space in the coarse rock framework. In the three North Fork samples this percentage was 42.0, 27.4, and 24.7%, respectively.

Percentage of potential void volume occupied by dry volume of fines

In the Grande Ronde sample, which had 16.4% fines (by dry weight) the coarse rock framework void volume was filled to 63.0% by the dry volume of fines, leaving 37% of the original void volume empty, even after a winter of infiltration. The North Fork sample that had 18.9% fines by weight had 75.9% of its initial void volume occupied by the dry volume of fines. This means that for this sample, 24.1% of the initial void volume among the framework material was not filled by fines and would constitute space available as living space for eggs or alevins for actual redds (see **Fig. 13**). The North Fork sample with only 14.5% fines by weight had only 41.5% of its initial void volume taken up by dry volume of fines. This estimate is a maximum value because the dry volumes of the three fine sediment constituents were simply added. If fully mixed it is likely that the total dry volume would be slightly less than the sum of the constituents because the finest particles might occupy the voids created by the larger fine sediment particles, which fill the large voids in the coarse framework particles. These results indicate that even in buckets that appear to be totally filled with fines after the winter infiltration period, considerable unfilled voids can remain internally. Further these data indicate that there is a great deal of variation among samples in the completeness of filling of buckets in a single year.

The dominant size classes of fines

Fine sediment was sieved into size fractions of 2.0-6.35mm, 0.85-2.0 mm, and <0.85 mm. Initial framework particles were 2.5-7.5 cm but all particles greater than 6.35 mm were separated and distinguished from fines during sample processing. Among the four samples undergoing more extensive analysis, the <0.85 mm size fraction accounted for 41.5% of total fines in the Grande Ronde sample and 42.6 to 53.7% of total fines weight in the North Fork samples (**Table 20**). The 0.85-2 mm size fraction accounted for 35.2% of total fines in the Grande Ronde sample and from 25.5-38.2% in the three North Fork samples. The 2.0-6.35 mm size fraction accounted for

23.2% of total fines weight in the Grande Ronde and from 19.2 to 23.0% of total fines weight in the North Fork samples. From this limited information it appears that variations in the finer two of the three size fractions account for most of the dynamics of the infiltration process (i.e., the coarser fines were very consistent among samples in percentage by dry weight). The North Fork John Day had a greater percentage of the fines contributed by the finest size class than did the Grande Ronde, although sample sizes were too small for this to be a reliable conclusion.

The evaluation of fine particle size distribution described above was based only on four intensively studied samples collected in 2002. In order to assess the generality of the conclusions made from these samples to all four study streams, the distribution of fines into three particle size classes was calculated from all overwinter samples collected in 2002. In the Grande Ronde, Catherine Creek, North Fork John Day, and Granite Creek there were 6, 5, 11, and 5 samples, respectively. The mean percentage fines by dry weight and 95% confidence limits were calculated from these sample sizes (**Fig. 37**). The smallest particle size (<0.85mm) contributed the majority of fine sediment dry weight in all overwinter sample buckets. The mean percentage of total fines comprised by the smallest particle size class (i.e., <0.85mm) was 50.6, 57.0, 45.9, and 58.1%, respectively, for the four streams. In all streams, the 0.85-2.0mm size class comprised the next largest fraction of the fines (**Fig. 37**).

Total fines as percentage by weight of samples

Total fines (all particles ≤6.35mm) accounted for 16.4% of total sediment weight (fines plus framework particles) in the sample from the Grande Ronde and was 19.1, 13.9, and 14.5%, respectively, in buckets of the North Fork (**Table 20**).

Percentage of void space in dry fines volume

Despite the size fraction considered (i.e., >6.3, 2.0-6.3, 0.85-2.0, and <0.85 mm) the percentage of the dry sample volume (i.e., the volume occupied by a dry sediment sample, including the inter-particle void spaces) that is void space is approximately the same. In the Grande Ronde sample the percentage void for these four size classes ranged from 38.3 to 44.7%. For one North Fork sample this range was 37.7 to 46.8% and for the other in which these data are available, the range was 41.4 to 51.0% (**Table 20**).

Density of fines

Density (g/ml) of each size fraction was very similar among samples (**Table 20**). The coarse rock framework particles had the highest density, probably because they contained the least amount of organic material. Each sample was prepared by brushing sediment off the coarse rock and removing by hand distinguishable organic particles such as needles and twigs. However, fine organic material was not separated from inorganic fines and samples were not ashed. The density of coarse rock from the Grande Ronde sample was 2.72 and that from the three North Fork samples was 2.71, 2.66, and 2.61, respectively. Density of the <0.85 mm fraction of the Grande Ronde was noticeably less than that of other fractions and samples at 2.02. With the exception of this value for the <0.85 mm fraction, the other three samples had a density ranging from 2.43 to 2.55 for this finest size fraction. With the two coarser size fractions of fines, the density of this material ranged from 2.23 to 2.57 for all four overwinter samples. Density was similar among all size fractions of fines and samples, with the exception of the finest material in the Grande Ronde sample. This indicates that organic fines are not a significant component of the sediment and do not occur preferentially in any size fraction.

Potential percentage fines possible to achieve starting with the initial framework particle distribution

Considering the Grande Ronde sample, 39.3% of the dry volume of framework material was void space (**Table 20**), 63.0% of this initial void space was filled by the dry volume of fines, and the final percentage fines by weight was 16.4%. By calculating the unfilled volume of voids at the time of sample collection (i.e., after the overwinter infiltration period) and determining the weight of fines (0.85-2.0 mm at a density of 1.34 g/ml dry volume) required to fully occupy this void volume, the maximum potential percentage fines by dry weight was calculated. This sample from the Grande Ronde, when fully infiltrated by fines, could have a maximum percentage fines of 23.9%. The sample from the North Fork that had 19.1% fines at the end of the overwinter period was calculated by the same method to have a maximum potential percentage fines of 23.4% if its voids remaining after overwinter infiltration were completely filled. This calculation is significant in that it identifies the worst possible biological condition that can be achieved given a framework created initially by particles of 2.5-7.5 cm that were totally devoid of fines. These samples from the Grande Ronde and North Fork John Day rivers collected in spring 2002 revealed nearly identical potential infiltration values. Unless samples have biologically useable voids remaining within the framework particles, it seems unreasonable to conceive of any biological difference between a framework particle lattice totally infiltrated by fines with a maximum percentage fines of 23.9% and a redd constituted by 100% fines. If this is the case, it would seem that a bucket infiltration of approximately 16% fines would be a threshold of concern. As revealed by the Grande Ronde sample, this level of infiltration would still allow approximately 40% void space. This level of infiltration was produced at a surface fine particle level of approximately 10% surface fines in the Grande Ronde (**Fig. 28**). In the North Fork John Day a higher infiltration level (18.9%) was produced at surface fine levels of approximately 32% (**Table 13**). Even under these conditions, 24.1% of the original voids were still unfilled. In the other North Fork John Day sample, 58.5% of voids were still unfilled. This evidence reveals a considerable variation in percentage of voids remaining unfilled after the incubation period. Selection of a threshold surface fine sediment level to provide protection against high levels of infiltration should consider the statistical distribution of infiltration levels that occur. For example, based on the two North Fork John Day samples, a 32% surface fine level led to infiltration in two buckets to the extent that 24.1% and 58.5% of initial potential void space remained unfilled. Given the significant regression of overwinter deposition on visual surface fines (**Fig. 36**), it seems apparent that a lower mean (and probably lower maximum) overwinter infiltration would be expected with a reduction in surface fines.

It is interesting to compare the calculated maximum potential percentage fines in sample buckets from the four intensively studied buckets with all overwinter sample buckets meeting the criterion for minimum final weight of framework material. In overwinter sample collection years 1999, 2000, 2001, and 2002 there were 34, 23, 35, and 27 qualifying buckets, respectively, to base this estimate on. When all qualifying sample buckets were examined, it was calculated that the highest level of overwinter fines (<6.3 mm) in any individual bucket was approximately 23%. This condition was observed in the Grande Ronde, Catherine Creek, and the North Fork John Day. It is probable that these buckets in these streams were all completely filled by fines, leaving no voids except those voids in the fines themselves that produce some degree of permeability. This leaves no living space in these samples. Notably, Granite Creek had no overwinter sample with more than about 15% fines. Except for in 2000 when samples had as much as 23% fines, Catherine Creek had no sample exceeding approximately 11% fines (<6.3 mm) in the other three years studied. The low percentage surface fines in these two streams (**Fig. 28**) is most likely responsible for the low levels of overwinter sedimentation and low percentage filling of potential void spaces.

Reserving a significant void volume within the redd creates a certain amount of living space for egg/alevins. However, high levels of fines within the framework and in surface layers can create entombing conditions to impair emergence as well as reduce water flow through the egg pocket.

Although this study does not provide information on biological impacts of the kind of infiltration into framework material that was observed, it would seem that ≤ 20% surface fines, a declining trend in surface fines (based on at least a 5-year annual series), and ≤ 15% overwinter fines (by dry weight) infiltrated into sample buckets that were not subjected to deep scour and refill would indicate a potential for success in emergence. Evidence from four years' collection of overwinter fines samples indicates that achieving ≤ 15% overwinter fines (by dry weight) criterion might occur with greater frequency if surface fines were ≤ 10% (**Fig. 36**).

Variation in potential percentage fines attributed to variation in compaction of initial framework particle selection

In addition to the variation in percentage fines in overwinter samples caused by differential bucket infilling, some variation could likely exist in potential for fine sediment accumulation due to variation in initial degree of framework material compaction. Degree of compaction then could create slight variation in initial maximum potential void volume among the framework material (Lisle and Eads 1991). Among the 5 buckets sequentially filled with framework material to investigate the influence of particle selection within a target size range, there was a maximum variation of 150 ml in void volume (i.e., void volume among the framework particles ranged from 2266 to 2416 ml in a bucket with volume 4216 ml). Taking the Grande Ronde sample as a test case, the total fine sediment dry weight was 1218 g and the total sediment (framework plus fines) dry weight was 7449 g (**Table 20**). Consequently, fines comprised 16.4% by weight of the total sediment weight in the bucket. Given a maximum variation in maximum potential void volume within a bucket of 150 ml, there could have possibly been additional fine sediment weight in this bucket if that volume were totally filled by fines. The density of fines (0.85-2.0 mm fraction) in the Grande Ronde was 1.34 g/ml dry volume. The dry volume is the volume that the dry fines occupy, which includes the displacement volume of the particles plus the void spaces within the fines. The density as g/ml dry volume was used to estimate the dry weight of the volume of fines required to totally fill the 150 ml void. Assuming that this range in void volumes between most and least compacted framework material represents the deviation on either side of the Grande Ronde sample for which infiltration (and void volume) was measured, the variation in initial potential void space was ±75 ml. The maximum dry weight of fines that could occupy this volume is 100.5 g, which could increase the potential fines as a percentage of total sediment dry weight to 17.7%. This represents an increase of only 1.3% points. Variation among samples of 1.3% in percentage fines could be attributable simply to variation in framework particle selection and initial degree of compaction of framework particles within buckets.

Given that the maximum level of fine sediment infilling of buckets to completely fill all voids would represent approximately 23.9% fines by dry weight and that in the field the maximum level of infilling observed was approximately 23%, it seems that additional potential void volume created by framework particle level of compaction was not significant. At most it appears that it could create enough additional void volume to increase potential void volume by approximately 1.3%.

What is the Predicted Biological Effect of the Levels of Fine Sediment Found in Study Streams?

Placing coarse framework particles in sample buckets sets a limit on the potential amount of fines that can fill the bucket. Actual amounts of fines by depth in spawning riffles in the study streams appear to be much higher than in sample buckets on collection, based on visual inspection with a shovel in known spawning riffles immediately prior to spawning. Typically surface fines are less than fines at depth (Rhodes et al. 1994, Diplas 1994, Whiting and King 2003, Mullner et al. 2000). Ability of a female to dig a redd to winnow away the fines in order to create a particle mixture as coarse as that placed into sample buckets is probably unlikely, although considerable cleaning does occur (Everest et al. 1987, Garrett 1995, Barnard 1992, p. 41). Kondolf (2000) (as cited by Rowe et al. 2003) reported a 33% reduction in fine sediment levels in redds during the spawning period relative to adjacent subsurface sediments. However, other authors report substantial infiltration throughout incubation so that the improvement that occurred in the egg pocket during redd construction is largely reversed by infiltration (Garrett 1995). Reversal of the cleaned gravel composition to match that of uncleaned redd material can take as little as 25 days or less (Acornley and Sear 1999). Our infiltration studies simulated total cleaning of spawning gravels followed by infiltration. Infiltration results and information gleaned from tests of void volumes indicate that if 23.9% fines (by dry weight) represents approximately the highest level of infiltration possible in an original bucketful of framework material, all initial voids would be filled under these conditions. This is a condition that would likely lead to very low survival.

Studies summarized by Reiser and Bjornn (1991) for rainbow trout, cutthroat, steelhead, and Chinook salmon indicate varying degrees of impairment from additions of fine sediment to the incubation environment of developing embryos. Regressions of embryo survival vs. percentage fines (<6.35 mm) reflect with certain species and studies that survival can be relatively constant from 0 to 20% fines, whereafter survival declines precipitously. In other species and studies there is no impact threshold, and the decline in survival occurs with every increment in fine sediment from 0 to 60%. In a laboratory study Bjornn et al. (1998) (as cited by Rowe et al. 2003) determined that trout fry survival was significantly reduced when egg pocket fines (<0.25 mm) were approximately 5% by weight. Assuming that conditions do not improve with depth in the substrate, a 20% surface fine sediment index would provide a warning of potentially significant impacts occurring at depth. If fines increase at depths equal to egg pocket deposition, conditions for incubation would decline significantly when surface fines exceed 20% surface fines (Stowell et al. 1983, Chapman and McLeod 1987, Reiser and White 1988). When coarse infiltrating sediments (0.84-4.6 mm diameter) were 10% in laboratory gravel mixtures, green egg survival declined from >60% to <10% as percentage fine sediments (<0.84 mm) increased to 20% (Reiser and White 1988).

Under natural conditions during the overwinter period in redds (i.e., without the influence of protective bucket walls), redd material can be dislodged at depth during high scour events, mixed, and reburied with surface fines. This process might account for the apparent greater inclusion of fines with depth in natural spawning areas in the study streams. The reworking of near surface sediments during lower flow events can result in winnowing and downstream transport of fines, leaving greater relative concentrations of fines at depth in spawning gravel (e.g., egg deposition depths). Surface coarsening often occurs, however, as fines are removed during even lower streamflow events. The moderate flood flows tend to move greater percentages of fines as bedload than do the larger bankfull flows (Campbell and Sidle 1985). Natural flushing of fines from riffles and deposition in pools tends to occur during moderate flows as a means to maintain spawning gravel quality and to support riffle-pool structure. At higher flows, velocity reversal causes greater scouring of pools accompanied by deposition of coarser sediments on riffles (Campbell and Sidle 1985). Throughout these sequences of flows, fine particles moving in contact with the bed are able to penetrate into interstitial voids. Surface streambed armoring is a typical condition for stream channels (Gomez 1983, Whiting and King 2003). Surface coarsening and the typically greater concentration of fines in subsurface sediments provide reasons for concern about levels of surface fines exceeding 20% (Platts et al. 1989, Scrivener and Brownlee 1989). That is, if surface fines are >20% and the conditions are even worse in the subsurface where eggs develop, there is a great likelihood that the ability of adult salmonids to improve spawning gravel quality by winnowing of sediments will be swamped by high levels of surface fines that can infiltrate cleaned redds during the winter. This is especially true, given that fines are easily transported and deposited into voids during most winter-spring flows. Despite the tendency for subsurface fines to be greater than surface fines during recovery from past episodes of streambed sedimentation (i.e., the subsurface is the last to recover), there is a significant relationship between surface and subsurface fine sediment levels during recovery (Platts et al. 1989). During a period of continued watershed development activities (e.g., logging and roadbuilding), increases in both surface and subsurface fine sediments is expected, but seasonal and annual variation in surface fine sediment accumulation is more pronounced (Scrivener and Brownlee 1989). The greater variation in percentage surface fines can be seen as response to peak flows and intensity of logging (Scrivener and Brownlee 1989).

Platts (1988) (as cited by Rowe et al. 2003) recommended that subsurface fines (<6.3 mm) should not exceed 20%. Although Chapman and McLeod (1987:205, 257) were unwilling to make quantitative prediction models for egg mortality under fine sediment conditions in the field given the influence of variations in gravel composition and other factors, they did conclude that all studies show a general decrease in survival with increasing fines. This led them to recommend "minimal (or no) introduction of fines to the existing gravel matrix and every reasonable effort to reduce sediment recruitment from basin development."

DISCUSSION

Are Recovery Goals Being Met in Study Streams of the Grande Ronde and North Fork John Day Subbasins?

The NMFS Biological Opinion (NMFS 1995) for the USFS Land and Resource Management Plans (LRMPs) and the salmon recovery plan of Columbia River Basin Treaty Tribes known as *Wy-Kan-Ush-Mi Wa-Kish-Wit* (CRITFC 1995) both set goals for surface fine sediment in spawning habitat at <20%. The Northwest Power Planning Council (NPPC 1994) recovery plan set a goal of <20% surface fine sediments in salmon redds. Long-term recovery in both percentage surface fine sediment (Platts et al. 1989) as well as fines at depth (Nelson et al. 1996a, Nelson et al. 2001) were detected via trend analysis due to a cessation in logging and reduction in road-related sediment sources. Elevated fine sediment levels in streams of the Grande Ronde and John Day subbasins have been and continue to be a significant limiting factor to salmon and steelhead restoration due to their impacts on survival of eggs and alevins incubating in spawning gravels (NPPC 2001a, b). All study streams were listed in Oregon's 303(d) list of impaired water bodies for sedimentation (ODEQ 1998, ODEQ 2002). The North Fork John Day is impaired from Baldy Creek to the headwaters; Granite Creek from China Gulch to the headwaters; Grande Ronde from Five Points Creek to the headwaters; and Catherine Creek from Union Dam to the North Fork/South Fork confluence, as well as further up each of these forks. Elevated levels of fine sediments are also well linked in the literature to reduced macroinvertebrate and native fish abundance and diversity (Richardson and Jowett 2002, Chapman and McLeod 1987, Berkman and Rabeni 1987). Despite these goals for fine sediment and the documented sediment-related problems, baseline and trends in surface fine sediment had not been annually monitored in these rivers prior to this study. Except for the substrate monitoring programs on the Payette, Clearwater, and Boise national forests, little consistent effort has been devoted to sediment monitoring on either private or federal lands in the Region.

Although fine sediment is widely known to be a major impediment to salmon survival and recovery, the attitude toward sediment monitoring in streams is often that it is too variable, too inaccurate, and subject to excessive operator error (McDonald et al. 1991, Roper et al. 2002, Archer et al. 2004). Even if sediment monitoring presents technical challenges, choosing not to monitor an environmental parameter that is known to be a key limiting factor is unacceptable. Rationales for excluding fine sediment in spawning gravels frequently are that if other more easily measured parameters are monitored, there is less need to monitor fine sediment too. Measurement of changes in pool depth or volume and frequency, stream width, streambank condition, general level of watershed development, road density, turbidity and other factors might be argued to be surrogates for potential fine sediment in spawning gravel (Platts et al. 1989). Measurement of pool volumes and frequency may reflect fine sediment availability, but provide more direct indices of juvenile rearing or adult holding habitat quality or quantity than spawning conditions. Any of these surrogate measures must be correlated with measures of fines in spawning gravels for inferences of impact on incubation survival to be made. Otherwise, linkages of sediment producing conditions and fish population health tend to be made at coarser levels of resolution such as relating diversity of salmonid assemblages with overall basin development level (see Reeves et al. 1993). These linkages are important and represent aggregate effects to multiple life stages, but are further removed from specific causation when considering spawning gravel condition. A further link in the chain of causation is the correspondence between surface fines and fines by depth. This study provides some illumination of this link by contrasting overwinter infiltration with surface fine measurements.

The effect of the fine sediment levels detected in the years of sediment monitoring in the study streams of the Grande Ronde and John Day subbasins can be estimated on the basis of either surface fine sediment or the rate of fine sediment infiltration into simulated spawning gravels during the winter. The high levels (≥20%) of visually estimated fines (<6.35 mm) in the North Fork John Day, as well as their increasing levels (**Fig. 28**) indicate non-compliance with regional standards for surface fine sediments. The Grande Ronde did not comply with regional standards in 1998 (**Fig. 28**), but since then has been on a declining trend. For the period 1999-2001, the Grande Ronde, Catherine Creek, and Granite Creek have had either mean fines at levels lower than the standard (i.e., <20% surface fines) or declining trends with predicted values less than 20% surface fines.

Is Surface Fine Sediment Condition Improving Or Declining?

Significance of regressions by stream

When regression equations were calculated for the 4-year trends in visually-estimated surface fine sediment for the four study streams, significant or highly significant regression trends were found in each stream. R^2 values were relatively low (0.11-0.39), indicating considerable temporal and/or spatial variability in the regression. Regressions based on grid observations were somewhat less significant and R^2 values (0.08-0.16) somewhat lower (**Tables 9 and 10**). With both visual and grid estimates, the Grande Ronde and Granite Creek appeared to have significantly or highly significantly improving fine sediment trends, while Catherine Creek and the North Fork John Day had significantly worsening conditions (or near significant trends, given a critical α=0.05). (**Tables 9 and 10**, **Figs. 28 and 29**). The North Fork and Catherine Creek grid-based estimates of surface fine sediment were the only instances where slightly less than significant trends were observed.

Comparison of regressions by stream

A test for significant differences among the four study streams in slopes and elevations of surface fine sediment trend lines over the study period (**Table 5** and **6** for visual and grid surface fine data) revealed that there were significant differences among regression lines for both slopes and elevations based on the F-tests. When a Tukey multiple comparison test was used to investigate the significance of differences for each pair of regression line slopes (**Table 11**), the visually-estimated surface fines data produced a clearer distinction among streams than did grid data, with the Grande Ronde and Granite Creek having no significant difference in regression slopes. This pair was distinct from the North Fork John Day, which was distinct from Catherine Creek. The Grande Ronde had the greatest negative slope (−0.052), while Catherine Creek had the greatest positive slope (0.046). Regressions based on both visual and grid methods ordered streams in the same sequence based on regression slopes. Both methods indicated a declining trend in percentage surface fines for the Grande Ronde and Granite Creeks. Both methods indicated that Catherine Creek and the North Fork John Day had increasing trends in surface fines. Because percentage fines in Catherine Creek were low in study reaches for the 4 years (predicted values ranging from approximately 2 to 3% from visual data, with no transect mean in any year above about 5%) (**Fig. 28**) the increasing trend appears to have no immediate biological threat, at least in the study reach. Conditions in the North Fork John Day, however, exceeded all agency goals for surface fines during 1998 to 2001 based on visual and grid data (**Figs. 28 and 29**). Further, conditions appear to be worsening rapidly. Over this 4-year period, the regression trend indicated an increase from approximately 20% fines to 30-35% fines based on both visual and grid methods (**Figs. 28 and 29**).

A Tukey test of differences for each pair of regression lines based on regression line elevations (**Table 12**) revealed that the visually-estimated surface fines data again produced a clearer distinction between streams than did grid data, with each stream being significantly different from every other stream. Grande Ronde, Granite Creek, Catherine Creek, and North Fork John Day, respectively, were arrayed in order from highest to lowest regression elevations (103.8, 49.1, −7.0, and −91.7%, respectively), based on visual estimates). Visual and grid-based regressions produced very similar regression elevations. Regression elevations express where the line would be predicted to intercept the Y-axis. These values have meaning only in numerical calculation of Y values for the various study years (i.e., X-values). As a follow-up to examination of regression elevations, a more physically illuminating statistic would be a multiple comparison among years by stream.

Differences among years by stream

A single factor ANOVA was run on visually-estimated surface fine sediment data for each stream individually for the 1998-2001 period to determine if there were significant differences among years (**Table 13**). This analysis indicated that highly significant inter-annual differences occurred in the Grande Ronde, Granite Creek, and the North Fork John Day over this 4-year period. A near significant inter-annual difference occurred in the Catherine Creek data. By comparison, visual estimates produced a significant positive regression slope for Catherine Creek (**Table 9**). However, its significance was the lowest of all streams for both visual and grid data (**Table 9**, **10**). Significant differences in mean surface fines among years for a given stream can either be reflected in regression slopes or could represent non-directional annual variation. Regression analysis (**Table 9**) revealed significant trends in visual fines in all streams.

Are Trends In Overwinter Fine Sediment Deposition Increasing Or Decreasing?

In addition to the monitoring data on surface fine sediment trends, one can examine the trends in overwinter fine sediment deposition to look for evidence of improvement in stream channel substrate conditions that would affect the survival of incubating eggs or alevins.

Significance of trends in overwinter sedimentation

Regressions of overwinter fine (<6.35 mm and <0.85 mm) sediment deposition in simulated redds were studied by monitoring percentage fines that infiltrated into cleaned spawning gravel substrate in plastic buckets implanted in the four study streams in August-September and retrieved in April-May of the succeeding year. These regressions (**Figures 31 and 32**) indicate no significant trends over the four years of this study (samples collected in 1999-2002), except for the <6.35 mm size fraction in the North Fork John Day (**Table 15**). The North Fork exhibited a highly significant increasing level of fine sediment (<6.35 mm) infiltrated into cleaned substrate in buckets over the 4-year period (**Table 15**). The North Fork also exhibited a highly significant increase in surface fine sediment over this time frame (**Table 9**), based on visual estimates.

Are there annual differences among streams in overwinter sedimentation?

To test the significance of differences in mean overwinter fine sediment deposition among streams in any given year, a single factor ANOVA was run for each of the four years of sample collection (i.e., 1999-2002). On the basis of overwinter sedimentation levels by fine sediment (<6.35 mm) in sample buckets, significant differences were noted via F-tests among all four streams for each of the four years of monitoring (**Table 16**). Tukey multiple comparison tests then revealed that in 1999, 2001, and 2002 the Grande Ronde and the North Fork John Day had the highest levels of overwinter sediment accumulation in cleaned spawning gravels, while Granite Creek and Catherine Creek had the lowest levels of accumulation. In 2001 the North Fork had the highest mean level of fines (16.4%), which was significantly different from all three other streams. In all four years there was no significant difference in mean overwinter fine sediment accumulation between Granite Creek and Catherine Creek. In 1999, 2000, and 2002 the Grande Ronde had the highest level of overwinter fine sediment accumulation. In 1999 and 2001 the Grande Ronde and the North Fork were significantly different in overwinter accumulation. The Grande Ronde was significantly greater in overwinter fine sediment accumulation than Granite Creek in all four years. The North Fork was significantly greater than Catherine Creek in 1999, 2001, and 2002.

Fine sediment <0.85 mm produced less distinction among streams for any given year (**Table 17**). In fact, only in 2001 was there a significant difference ($P \leq 0.05$) among streams in the finest sediment fraction (<0.85 mm) accumulation. In this year, the North Fork John Day had the highest fine sediment accumulation (7.6%) and was significantly different from the Grande Ronde and Catherine Creek (4.5 and 3.4%, respectively), which were in turn significantly greater than Granite Creek (1.3%). Fine sediment <0.85 mm was less indicative of inter-stream variation than fines <6.35 mm within a single year. That is, if there were significant differences in the amount of surface fine sediment acting as a source of fines for transport during the winter period and creating different levels of infiltration into cleaned spawning gravels, this did not seem to be observed as differences in the deposition of the finest size fraction of fines in simulated redds over the winter period. Rather, by identifying fines as all particles ≤ 6.3 mm, a greater differentiation among streams was revealed in any given year.

The North Fork John Day had the highest percentage overwinter fines <0.85 mm in 1999, 2000, and 2001 (5.2, 7.9, and 7.6%, respectively). In the 1999 and 2000 overwinter samples, all streams were statistically the same (α=0.05). In 2002 the Grande Ronde had 7.7% fines (<0.85 mm), but Granite Creek and the North Fork John Day were not significantly different from one another (6.6 and 6.1%, respectively) or from the Grande Ronde.

Comparison of overwinter fine sediment intrusion among streams

Given the lack of significant regression trends in overwinter fine sediment intrusion for any of the study streams over the four-year period 1999-2002, we considered it reasonable to lump the overwinter fine sediment data for each stream. After this was done, we ran a single factor ANOVA on these data for the 4-year period to determine whether there was a significant difference among the streams (overwinter fines <6.3mm). The F-test for this ANOVA revealed a highly significant difference (**Table 18**). This test was followed by a Tukey test for comparing individual pairs of means. On the basis of fine sediment <6.35 mm this test revealed that overwinter sediment intrusion levels in the North Fork and the Grande Ronde were indistinguishable (α =0.05) as were overwinter intrusion levels in Catherine Creek and Granite Creek. Overwinter percentage fine sediment (total fines as a percentage of total sample) averaged 12.6 and 12.1%, respectively, for the first pair of streams above and 7.8 and 7.5%, respectively, for the second pair (**Table 18**).

On the basis of fine sediment <0.85 mm (**Table 19**), less distinction was detected between the pairs of streams in the Tukey multiple comparison test. Again the North Fork and the Grande Ronde had the highest overwinter intrusion of fines for the 4-year period (6.4 and 5.7%, respectively), but this pair was not significantly different (α=0.05) from Granite Creek (4.4%). The North Fork John Day River and Grande Ronde River were, however, significantly different from Catherine Creek (4.1%).

In the nearby Tucannon River originating in the Blue Mountain on the Umatilla National Forest, a previous monitoring project (Reckendorf and Van Liew 1989) revealed similar levels of fine sediment intrusion into cleaned spawning gravels. These spawning gravels were in situ gravel deposits cleaned by hand to winnow out fines and create artificial redds. Gravels were sampled via freeze-cores and indicated that by approximately April the percentage of fines <2.0 mm at sampling sites ranged from about 10 to 12%. These sites were distributed along the mainstem from the fish hatchery (the most upstream site) to the mainstem below Pataha Creek. Fines from 0.06 to 2.0 mm accounted for >90% of intruded sediment. Filling of cleaned gravels by fines occurred to approximately 85% of maximum. A study conducted on Freshwater Creek in northern California supporting coho spawning, by contrast, found no changes in percentage fines (<2 mm) over the incubation period in egg pockets by freeze-core analysis (Barnard 1992). The mean percentage fines inside egg pockets was 7.5% (upstream portion of the tailspill) and outside redds (undisturbed gravels upstream of the pit or adjacent to the redd) was 13.1%. Based on our results and those of other studies, it appears that the occurrence and significance of fine sediment infiltration vary according to environmental factors, which may include stream power, sediment supply, sediment characteristics, channel gradient, substrate composition, and other factors.

What was the average level of overwinter fine sediment infiltration, rate of infiltration, maximum levels of infiltration observed, and potential variation in percentage fines indicating 100% infiltration?

Differences among streams in overwinter sediment intrusion were considerably less with the size fraction <0.85 mm than with the <6.35 mm size fraction. For the <6.35 mm size fraction, the mean percentages of overwinter fines intrusion for the four-year period were 12.6, 12.1, 7.8, and 7.5%, respectively, for the North Fork, Grande Ronde, Catherine Creek, and Granite Creek (**Table 18**). However, the maximum percentage overwinter fines measured for individual samples for each of the study streams was 22.5, 22.8, 22.7, and 14.5%, respectively. Testing of the four intensively studied overwinter samples revealed that the maximum potential percentage fines (<6.3 mm) possible was approximately 23.9%. Variations in framework particle selection and compaction at the time of implanting sample buckets in spawning areas was estimated to provide a variation no greater than 1.3% points in the potential percentage fines. If 23.9% fine sediment represents the upper limit in percentage fines, maximum infiltration might also be produced at 23.9%−1.3% or 22.7% fines in more compacted initial framework mixtures. Note that Reckendorf and Van Liew (1989) found that in the Tucannon River, percentage fines <2.0 mm was approximately 13% in sample locations and filling of redd gravels was about 85% during the winter period. In our streams it appears that a small percentage of buckets were filled to capacity with fines <6.3 mm during the full overwinter period, even in streams with relatively high average overwinter intrusion rates. This indicates that infiltration is a spatially variable process that could lead to high mortality of incubating salmon eggs in locations represented by these buckets.

Another indicator of the rate of infiltration of fines during the winter period was obtained from mid-winter sampling (**Fig. 30**). Although mid-winter data were limited, they revealed that high levels of infiltration by fines in the sample buckets were occasionally observed even by mid-winter (i.e., with only approximately half the full exposure time in the stream). For example, approximately 17% fines <6.3 mm were measured in a sample bucket in the Grande Ronde in December 1998. For the remainder of the buckets retrieved in spring 1999, mean overwinter fines <6.3 mm was 11.6% (**Table 16**). This indicates that bucket infilling can be nearly complete after incubation periods of no greater than about 4 months. Although insufficient data were obtained to plot the course of bucket infilling during the entire overwinter period, it is likely that at least for some samples, the buckets were filled by mid-winter and further exposure to the stream environment did not result in further worsening of conditions. The ability of some buckets to become filled to capacity rapidly somewhat discounts the significance of year-to-year variations in length of time of exposure of buckets to the stream environment as a major cause for inter-stream differences in sedimentation.

Is There A Linkage Between Overwinter Sediment Intrusion And Surface Fine Sediment?

Influence of fine sediment availability

Trends in surface fine sediment and overwinter sediment intrusion in simulated redds are both good indicators of the condition and trends of the channel substrate in stream spawning areas.

Given the high degree of similarity in the three methods of estimating surface fines as determined by correlation analysis, lack of significant difference (non-significant F-test) determined by ANOVA, the highly significant regressions (grid vs. visual and pebble count vs. visual), and that the values predicted by one method from the regression were indistinguishable from those of the alternate method, it was concluded that the visual estimates were as good as the grid-based and pebble count estimates. The regression of grid estimates on visual estimates of surface fines for the 4-year period of observation 1998-2001 was highly significant ($P<<0.01$, $R^2 = 0.88$) (**Fig. 15**, **Table 7**). Use of an improved grid-based method with more suitable grid spacing is apt to result in a significant improvement in reliability in surface fine sediment estimates. But given the conventional reliance on the pebble count method and the high degree of correlation among the three methods, it is likely that the visual method can be a highly reliable and efficient monitoring method, given sufficient observer training.

Because the visual and grid estimation methods (as used in this study) of surface fine sediment (<6.3 mm) were equal in their ability to determine percentage surface fines on transects, it was considered acceptable to simply use visual estimates. However, both estimates were used in a plot of overwinter fine sediment intrusion vs. surface fines.

Regressions were calculated for mean overwinter fines vs. mean surface fines and revealed a statistically significant relationship. Mean overwinter fines were calculated as the mean of all buckets retrieved in spring by stream and year. Regressions were based on the 16 means derived from four streams and four years. Mean surface fines (visual and grid) were estimated by stream and year for the August-September following the overwinter sample collection (**Fig. 36**) and also the August-September preceding the overwinter sample collection (**Fig. 35**). It was determined via F-test that higher R^2 values as well as more significant P-values were obtained in the prediction of mean overwinter fines intrusion using either visual or grid estimates of surface fines from the preceding summer period rather than from the summer period following the overwinter infiltration bucket collection. That is, conditions in the summer preceding spawning set the stage for the extent of overwinter sediment intrusion that occurred. In conclusion, the percentage surface area of fine sediment in the summer seems to be a good predictor of fine sediment intrusion in simulated redds that occurs from late summer to early spring (i.e., overwinter sedimentation). This indicates that sediment availability on the streambed is a statistically significant indicator of future level of infiltration of fines into cleaned spawning gravels during the overwinter period.

In addition to surface fines, which indicate initial sediment availability at spawning time, other factors may also play a role in the extent of infilling. For example, it is possible that channel gradient and flow could cause inter-stream and inter-annual variations in extent of bucket infilling (Young et al. 1990a). Also, placement of individual buckets relative to local gradient and stream current patterns could cause individual variation. Variations could also exist in the sediment delivery occurring in the winter-early spring period. Peaks in overwinter sediment delivery could possibly heighten overwinter infilling. However, the average sediment delivery and transport (within the context of inherent watershed type and level of development) also set up the conditions that maintain a certain annual level of surface fine sediment in the channel, to which annual redd infiltration responds (Platts et al. 1989). Considering the potential role of these factors in creating some of the scatter in points observed (**Fig. 35**), a significant relationship between infiltration and surface fines exists despite the known variation that exists among study reaches in channel gradients, watershed size, and level of development.

Influence of flow

Channel morphology and gradient conditions in an individual stream typically remain relatively stable from year to year, while streamflows change. Streamflow variation might contribute to different levels of sediment transport and intrusion (Campbell and Sidle 1985). From 1998 to 2001 the highest annual peakflows, which occurred in 1999 in streams of this region (i.e., in Lookingglass Creek, near Lookingglass, Oregon and North Fork John Day River at Monument, Oregon), were 64.5% higher in each stream than the lowest annual peakflows, which occurred in 2001 (**Fig. 10**). There was a steady decline in annual peakflows from 1999 to 2001 in these streams. However, flows for 2002 were 14.1% higher than the peak that occurred in 1999. This presumably represents the pattern of peakflows for the four study streams that occur in this region. Annual flow peaks in these streams occurred almost entirely from February through May of each incubation period between 1985 and 2002. The overwinter sample buckets implanted in August 1998 were collected in April 1999. Consequently, in this year and others, flow peaks for the incubation period would have occurred just prior to bucket collection. North Fork John Day flow peaks in 1998-2002 occurred only in March and April of these five years. Therefore, if peakflows were to have an effect on infiltration levels for buckets collected in April, this effect would have occurred immediately prior to sample collection.

When mean overwinter fines accumulations (% fines <6.35 mm as % dry weight) for each of the four study streams individually for the collection period 1999-2002 were regressed on annual peakflows at the North Fork John Day gage (for 1999-2002), the regression slopes were all non-significant. Plots of these data showed an apparent negative relationship between overwinter percentage fines and peakflows for the North Fork John Day study reach. The trendlines for the other study sites were all positive. More years of study might reveal a statistically significant relationship, but based on data available, we cannot conclude that peakflow is clearly related to overwinter percentage fines.

Significant sediment delivery, transport, deposition, and infiltration events are frequently triggered by high precipitation, debris flows, and accompanying peakflows (Frostick et al. 1984, Acornley and Sear 1999, Havis et al. 1993), but mobilization of fine sediments from surface fine deposits can easily occur at flow levels equal to half of bankfull or less (Wathen et al. 1995, Whiting and King 2003). If this is the case, the ability to fill a sample bucket to capacity might have more to do with the availability of fines in the environment, expressed as percentage surface fines, and possibly time of exposure. VanSickle and Beschta (1983) indicated that the two most significant factors determining sediment transport in streams are streamflow and sediment supply. The rate of infiltration can be determined by concentration of sediment in transport (Acornley and Sear 1999, as cited by Naden et al. 2003). Variations in sediment supply occur during individual storm events and also over the course of a high flow season, leading to variations in concentration of sediment in transport (VanSickle and Beschta 1983). However, this study indicated that variations in bucket collection date that occurred were probably not of great importance. In addition, sediment supply, indicated by percentage surface fines, was a significant determinant of extent of infiltration of cleaned spawning gravels.

Influence of overall particle size distribution

The mean particle size distribution for the five transects per stream at which overwinter sedimentation was monitored revealed that Catherine Creek and the North Fork had higher percentages of particles >13 cm (**Figures 20 and 21**) when visually surveyed. Catherine Creek and the North Fork had 40-45% of the surface area occupied by particles >13 cm (**Fig. 20**) while the other streams had 22-28% of the surface area in this size class. This difference would seem to indicate a difference in channel gradient might control the surface particle distribution, although gradients of the Grande Ronde, Catherine, North Fork John Day, and Granite were 0.0257, 0.0158, 0.0151, and 0.00523 respectively, as calculated from nearest upstream-downstream topographic contours (1:24K) incorporating the study area. Catherine Creek had the second highest gradient and the coarsest substrate. The gradient of 0.0158 was computed from the nearest 40 ft contour above and below the study area. This reach length was 6.2 km long, given the large distance between transects 1-2 and 3-5. Gradients calculated for the upstream transects (1-2) and the downstream transects (3-5) by this same method yielded gradients of 0.0199 and 0.0136, respectively. The upper part of the Catherine Creek study reach was steeper than the downstream section, but was still less steep than the Grande Ronde. The North Fork John Day had a slightly less coarse average substrate condition and had a lower overall gradient than Catherine Creek.

The visual estimates of surface fine sediment (<6.3 mm) for Catherine Creek (**Fig. 28**, **Fig. 20**) indicate a relatively low mean level of fines, consistent with a relatively high gradient (0.0158), but those for the North Fork indicate the highest level of fines (**Fig. 28**, **Fig. 20**), despite its similar channel gradient (0.0151) associated with its coarse substrate composition. This indicates that the North Fork has a bimodal particle distribution with a high percentage of fines, but also high levels of particles >13 cm.

What Is The Predicted Biological Effect Of The Levels Of Fine Sediment Found In The Study Streams?

The North Fork John Day River exceeded percentage surface fine sediment targets (i.e., 20% fines <6.3 mm) of the region in all years studied (1998-2001) (**Fig. 28**). In 2000 and 2001 the

North Fork averaged surface fine sediment of 32%. The Grande Ronde far exceeded the surface fine sediment standard in 1998, but since then has averaged lower than this threshold (**Table 13**) and has been on a declining trend (**Fig. 28**). In 2000 and 2001, overwinter fines that infiltrated into simulated redds (buckets) in the North Fork averaged 13.4% and 16.4% fines by dry weight, respectively (**Table 16**). The highest average fine sediment infiltration into sample buckets was 17.5% (Grande Ronde River in 2000).

Surface fine sediment levels are typically correlated with fines at depth, but it may be expected that fines at depth will often be higher than levels at the surface (Bunte and Abt 2001a:130) due to selective winnowing of surface fines to create an armor layer. However, periods of high fine sediment supply can cause surface layers to be finer than subsurface sediments (Bunte and Abt 2001a:131). Armoring develops during periods when supply is less than the ability of streamflows to move sediment particles. Fine particle winnowing from surface materials to create an armored surface can occur at low flood flows when the stream is incompetent to move the coarse fractions (Gomez 1983). Median particle size (D_{50}) of surface particles is typically greater than the subsurface which in turn is greater than the bedload (Whiting and King 2003). Lisle (1995) proposed a ratio of median size of subsurface to bedload particles, which he termed D* to represent the size selective transport tendency of a stream.

The relationship between surface and subsurface sediments may indicate that if surface fines are near 20%, the fines at depth (i.e., in the vicinity of egg pockets) could easily be at levels harmful to various salmonids. Laboratory studies on the relationship between fine sediment and STE are normally based on fine sediment levels at depth, typically including substrate in cores at the spawning site that would include the egg pocket, but not solely surface fine sediment (but see Scully and Petrosky 1991). Scrivener and Brownlee (1989) explained STE of chum and coho in terms of D*g* of the surface and subsurface layers, respectively. In all four study reaches subjected to logging over a period from 1973 to 1986, D*g* was always greater in the surface layer than in the subsurface. Surface D*g* generally tracked subsurface D*g* closely, although it was more variable in response to major floods and logging activity peaks. In the field, mortality could be attributable to creation of surface seals that restrict oxygen transport through the gravel or create impenetrable barriers. In Carnation Creek, British Columbia dissolved oxygen was always greater than or equal to 60% of surface concentration when D*g* was greater than 18 mm, but varied from 18 to 96% of surface concentration when D*g* was 10 to 12 mm (Scrivener and Brownlee 1989). In their study, surface water oxygen concentrations varied from 7.5 to 9.5 mg/l. A reduction in Dg from 16 to 12 mm was sufficient to produce a reduction in survival-to-emergence (STE) of coho from 32% to 18% (Scrivener and Brownlee 1989). The point to note is that a surface fine sediment standard of <20% is essentially a trigger threshold for management response to stream sediment levels and may not indicate that conditions are biologically optimal at depth. Increases in surface fines from 20% provide a warning of probable negative effects (Rhodes et al. 1994). Mullner et al. (2000) found that in 97% of the 105 freeze-core samples taken in trout spawning habitat in Wyoming, when surface fines varied between 40 and 90% fines, the fines at depth were equal to or greater than this value and could range as high as 99% for each increment of 10% surface fines between 40 and 90%. This indicates that surface fines estimates can be minimal estimates of fines at egg pocket depth.

From data provided in Bjornn and Reiser (1991) and Weaver and Fraley (1991) a significant decline in survival to emergence of Chinook and steelhead at fines >20% (particle diameter <6.3mm) can be expected. For rainbow trout, bull trout, and cutthroat trout significant declines in survival can be expected at levels exceeding about 10-15%. In a study of survival from egg-to-parr stage of wild Chinook in several Middle Fork Salmon River tributaries, it was found that mean percentage survival was related to mean surface fine sediment level, with 29%, 12.6%, and 3.3% survival at surface fines levels of <30%, 30-40%, and >40%, respectively (Scully and Petrosky 1991). A predictive model constructed by Stowell et al. (1983) expressed the relationship between percentage fry emergence and percentage fine sediment (at depth) for Chinook as indicating a slight decline in survival between 0 and 20% fines. Fines content of 20% appears to be a threshold for steep decline in survival. In this model, Chinook survival to emergence is approximately 80% and 20% at fines levels of 20% and 40%, respectively. In their model, steelhead were more sensitive to fines at depth (approximately 10% survival at 30% fines).

A review by Chapman and McLeod (1987) concluded that any increment in fine sediment, where biologically significant particle sizes were 6.35 and 0.85 mm, should be considered to result in increased mortality of eggs and emerging fry. A great number of threshold particle diameters from 6.4 mm to 0.75 mm have been used to predict salmonid survival to emergence (see citations inYoung et al. 1991). Various studies have promoted the use of indices to describe the entire particle distribution in the incubation environment, such as geometric mean, median particle size, fredle index, skewness, etc. (as reviewed by Young et al. 1991). Young et al. (1991) found the geometric mean particle size to be the best predictor of STE, with a coefficient of determination of 0.58 to 0.65. However, percentage fines <6.3 mm had a coefficient of determination of 0.46 to 0.52. Despite their preference for geometric mean particle size as the best predictor of STE, these authors agreed with Beschta (1982) that percentage fine sediment less that a given size was the best indicator of land use impact on instream substrate. Our study indicates that surface fine sediment is a good indicator of sediment availability and is also a good predictor of the tendency of fines to infiltrate cleaned spawning gravels.

Overwinter fines intrusion is significantly related to visually estimated surface fines (P=0.045) and has a nearly significant regression on grid-estimated fines (P=0.053). Surface fine levels of approximately 30% are predictors of approximately 15% fines by weight in simulated redds (**Fig. 35**). However, these observations must be understood in the context of their test conditions. The sample buckets were initially filled with coarse rock particles that were cleaned of all fine sediment. Infiltration was measured over the winter incubation period as the amount of fine sediment deposited in these buckets. Because these buckets were not capable of containing >23.9% fines (as determined by laboratory testing) or presumptively about 23% (empirically determined in the field as the maximum observed level), this would indicate by the same regression that 20% fines at depth (i.e., similar to that found in sample buckets) would require approximately a mean surface fine sediment level of 45% (**Fig. 35**), although this requires an extrapolation well beyond the data for the four study streams. As stated, though, some observations of >20% fines in buckets were found at surface fine levels of about 30% or less.

Visual inspection of the substrate in many of the spawning areas revealed a very high concentration of fine sediment at depth in August-September. It is doubtful that spawning Chinook could winnow these materials to generate an initial sediment particle frequency composition similar to that placed into sample buckets (i.e., devoid of fines). It is uncertain whether the mixtures of substrate particles present in natural redds (including fines unable to be winnowed out of framework particles) would prevent further infiltration of fines better than occurred in simulated redds. Many of the simulated redds in plastic buckets were filled to capacity with fines, creating a very tightly packed sediment matrix. However, laboratory tests of void space available in several samples indicated a small amount of void space unfilled by fines. This could possibly give incubating alevins sufficient room to move so that fines above them would be dislodged, fall down amidst the framework particles, and allow alevins to repeat the process, continually moving upward as described by Bams (1969). However, the relatively small amount of void space in many samples makes it seem unlikely that this would result in a high percentage survival of the incubating embryos.

Any sample of redd material containing <20-30% depth fines (<6.35 mm) would indicate conditions where survival would begin to be worsening for most salmonids based on the salmonid literature (**Fig. 14**). But from laboratory tests conducted here, it was revealed that even if redd material has a rock framework consisting of particles 2.5-7.5 cm diameter, the voids in this framework can be totally filled even at 23.9% fines (<6.35 mm) or less, depending on degree of framework compaction, and this condition can be generated at mean surface fine levels less than 20% in some samples. Carling and Glaister (1987) and Church et al. (1987)(as cited by Milan et al. 2000) indicated that framework material is filled by fine sediment matrix at a concentration of 32%. Wilcock and Kenworthy (2002) indicated that filling of voids by sand can be complete at 10 to 30%, depending upon the ability of bridging of the framework material to occur. Beschta and Jackson (1979), studying infiltration of fines into sand-gravel mixtures of average diameter of 1.5 cm (range 0.01 to 5.0 cm), found that complete filling of voids occurred when fines equaled 25% of the total sample. Diplas and Sutherland (1988)(as cited by Dalecky 2001) stated that fluvial sediments typically have a porosity of 33.3%.

Larkin et al. (1998) measured a mean initial porosity of 28.1% in an "ideal" spawning gravel mixture comprised of a ratio 50:30:20 of gravel of 19.1, 9.5, and 4.8 mm diameter.

Filling of voids in coarse rock framework particles to capacity would undoubtedly cause an entombing effect and significantly reduce interstitial water flow and oxygen transport. It seems that initial fine sediment winnowing followed by particle bridging and retention of a significant percentage of the inter-particle void space is essential for enhancing the survival of incubating eggs/alevins. Negative biological consequences to salmonids in study streams can be expected for any stream having average fine sediment (<6.35 mm) levels >20% (Nelson and Platts 1988, as cited by Rowe et al. 2003; Thurow and King 1994) or fine sediment (<0.83 mm) of 10-20% (Reiser and White 1988), or fines (<6.35) levels trending upward from or toward 20% for periods of more than five years (Rhodes et al. 1994). Milan et al. (2000) used a threshold for survival to emergence (STE) of 14% for fines <0.83 mm and 30% for fines <6.35 mm that would allow 50% STE. This is consistent with conclusions of Kondolf (2000), who reviewed the studies of survival to emergence on several salmonid species in gravel with various percentages of fines less than 0.83, 2.0, 3.35, 6.35 and 9.5 mm. He found similar biological effects of fines in the size classes between 3.35 and 9.5 mm, but greater negative effect of the two smaller size classes.

Allowance of biologically significant levels of impairment to STE by fine sediment increases is inconsistent with efforts to restore ESA-listed salmonids. Many studies of STE on salmonids indicate there to be no safe threshold below which fines in stream substrates do not have a biologically significant effect (Chapman and McLeod 1987, Chapman 1988). This is inferred by the linear decline in STE with increases in fines from approximately 10% to 50% as opposed to responses with initial lags between 10 and 20%. However, other expressions of the relationship between fines and STE indicate minor impacts up to 20% fines followed by a significant decline in STE at fines between 20 and 45% (Stowell et al. 1983, Everest et al. 1985:p.217). It is sometimes argued that quantitative relationships between fines and STE are difficult to express with certainty at low levels of fines (e.g., Everest et al. 1987). Additional uncertainty arises where streambeds have high levels of fines prior to spawning, given that spawning females have an ability to clean gravels prior to egg deposition. This can lead to the egg pocket substrate composition being lower in fines than surrounding redd material (Chapman 1988). However, fine sediment intrusion into the egg pocket is also apt to occur, as indicated by infiltration indices from our study. Although increasing levels of fine sediment infiltration are linked to lowered survival rates, the overall particle distribution (ranging from uniform to skewed) can influence the survival rate as well (Young et al. 1991). In addition, egg pocket structure was identified as a contributor to variation in STE that must be measured (Young et al. 1990b and comment by Chapman to Young et al.). For reasons such as these, we investigated the relationship between void volume and percentage fines in overwinter samples. Even if infiltration to the depth of the egg pocket did not occur in the field, creation of impermeable seals above the egg pocket could have the effect of entombing alevins or could reduce oxygen exchange with waters surrounding eggs. Water flow through gravel substrates is limited by the permeability of the least permeable layer (Freeze and Cherry 1979, as cited by Rhodes et al. 1994).

If percentage fines in sample buckets tend toward 20%, it can be argued that substrate is at a critical threshold where serious impairment would begin to occur. However, the fact that at 20-23.9% fines in simulated redds, the voids are totally filled would argue that entombment can be a likely outcome, even when fines appear to be at a level considered generally to provide low level impacts. In streams with high clay and silt supply, other studies have found that in as few as 50 days, half the void space can be filled, leading to severe reduction in average interstitial velocity (cm/hr), lowering of the DO level (mg/l), and a reduction in mean embryonic survival to 28%, relative to the mean survivals of 71% found in redds with high interstitial velocities and DO (DEFRA 2002).

This study indicates that for simulated redds in certain locations, reliance on mean surface fine sediment conditions in transects in spawning areas may not be fully protective. The variation in overwinter sedimentation attributable to a number of experimental factors and natural differences among streams and years were explored. However, because the plastic buckets did not allow intragravel flow and fine particle infusion from adjacent subsurface zones, the overwinter infiltration measured was apt to be a minimum estimate (Lisle 1989, Acornley and Sear 1999, as cited by Naden et al. 2003, p. 11, 33). Acornley and Sear (1999, as cited by Naden et al. 2003) determined that up to 25% of infiltration can be derived from lateral flow. This pathway of infiltration can be significant due to the hydraulic head created by the redd morphology directing flow through the egg pocket. The conclusion that mean surface fines represent a minimum estimate of the biological threat posed by observed levels of overwinter sedimentation and subsurface fine sediment abundance is reflected by cautions in Rhodes et al. (1994).

Choice Of Methods For Estimation Of Surface Fine Sediment

Three methods for estimation of surface fine sediment were employed in this study: visual, grid, and pebble count. Each method has various strengths and weaknesses that might argue for its use. We considered the inherent characteristics of these methods and how these methods have been evaluated in the literature in the process of formulating a recommendation about which method to use and how best to employ it.

Visual Estimates

The time required to evaluate surface fines is approximately 5 minutes per transect, not including training and calibration. For a single transect, visual estimates require no appreciable office time. Visual estimates require relatively high water clarity and low surface turbulence. The output statistics from this method, as employed in this study, were either a single value per transect for surface fines as a percentage of transect band surface area between wetted edges of the stream, or consisted of visual estimates of percentage surface area occupied by each particle size class evaluated. The visual estimation of the percentage surface fines on the transect band allows a visual integration of patches of fines among larger material that might be inadequately sampled by the clustered point sampling done by the Bauer and Burton grid method. Visual estimation of the entire particle size distribution allows plotting of the cumulative particle size **(Fig. 20, 23)** frequencies from fines to boulders. The lower limit of surface fine sediment estimated visually was 6.35 mm. This might be the approximate lower limit of fines that can be visually discriminated in complex mixtures. For biological significance it is a reasonable size threshold (Chapman and McLeod 1987).

Visual estimates by trained observers correlate well with data generated by both other methods (i.e., grid and pebble count) and require the least time to conduct. Given its relatively low time requirement for collecting data, the visual evaluation of surface fines is conducive to spatially extensive analysis. This lessens the problem of selecting representative transects for characterizing overall trends in a stream reach, because it is possible for more extensive coverage to be made on the reach. However, we emphasize that if reliable results are to be obtained from visual estimates, it must be done by trained observers with frequent calibration against measurements by more objective techniques, as other experienced stream surveyors have noted (C. Huntington, Principal Biologist, Clearwater BioStudies, Inc., pers. comm.)

The use of the visual estimation of a full range of particle sizes appears to assist in ensuring that the estimate of fine particle percentage is balanced by equal effort devoted to estimating the percentage of all other size classes. This process would presumably help control any tendency to overestimate the percentage fines when this value must not exceed 100 minus the sum of percentages of all other larger size fractions.

Despite the known bias of the pebble count method against fine particles, there is often a perspective in the literature that visual estimation techniques should be avoided as deficient (Potyondy and Hardy 1994, Potyondy and Hardy 1995). However, Wang et al. (1996) determined that accuracy and precision of visual estimates of substrate fractions in stream substrate were high. They found that in three Wisconsin streams, 73% of the substrate percentage estimates by size category varied by less than 5 percentage points and none varied by greater than 12 points. Their results indicated moderate precision with confidence intervals around means equal to between 1 to 3 times the FMP (field measurement precision). FMP was determined as the 95% confidence interval of the means of measurements made by six independent observers. The FMP was the nearest percentage unit to which the habitat value was estimated. For substrate, values were recorded to the nearest 5%. Wang et al. (1996) took digitized estimates from photos as their estimate of the true value.

Grid method

We have assumed that the grid method has the greatest potential to yield accurate results of surface fine sediment levels for several reasons. First, it is based on measurement of the areal coverage by fine sediment of the surface sediment particles of the channel substrate. The method as described by Bauer and Burton (1993) allows for relatively rapid assessment of surface fine sediment particles as a percentage of the surface area in a transect band. Approximately 20 minutes are required in heterogeneous substrate to evaluate percentage surface fine sediment at five placements of the sample frame on a transect. The grid method uses a less subjective method of identifying particles to be measured than the pebble count method. Although particles can be measured, in practice it seems sufficient to visually determine whether a particle is smaller or larger than the threshold size for fine sediment. The exclusive focus on fine particles and visual classification of sizes as either meeting or not meeting the size specifications for fines reduces sampling effort on a transect. The grid method relies on relatively high water clarity. Surface turbulence effects can be eliminated by use of an underwater viewer tube.

The grid method is similar in essential ways to the pebble count method. Both methods depend upon a random selection of sample locations followed by measurement of the particle size. Although the pebble count method assesses the intermediate diameter of all particles selected, including particles larger than the fine sediment threshold size, it is still feasible to determine the percentage of all particles selected that are classified as fines. Typically, the pebble count method is used to measure 100 particles per transect, whereas the grid method employed here identified the frequency of fine sediment particles among a sample of 500 grid intersections per transect. There is no reason why 500 particles could not be identified using each method, in which case the methods would primarily differ in the manner of "random" selection of particles to sample. The toss of the grid frame with its fixed grid spacing into the vicinity of 5 equally spaced points on a transect line was performed in a non-directed manner (i.e., not selecting patches). However, once the frame settled to the bottom there existed varying degrees of autocorrelation among sample points because for any single point intersection on the grid, the adjoining points often were linked to the same sediment particle, when large particles were a dominant component of the stream bottom and these particles were larger than the grid spacing. This autocorrelation effect could be removed by ensuring that adjoining grid points were independent by making the grid spacing greater than the size of the largest particle (Bunte and Abt 2001a and Bunte, pers. comm., May 2004). In small streams where spacing between sample points equal to or greater than D_{max} is problematic, grid spacing of approximately D_{90} to D_{95} may be adequate (Bunte and Abt 2001b). Bunte (pers. comm., 2004) also suggested that greater accuracy could be achieved by stratifying the channel cross-sections that do express spatial patterning of particle size distribution (e.g., patches with fines in margins, etc.) and cobble framework elsewhere.

Over the years of this study the method of Bauer and Burton (1993) was applied as described. Precautions against this autocorrelation effect were not given and, consequently, grid spacing was not varied among streams or transects, but was applied in a uniform manner among sample locations. In many of the salmon spawning transects, substrate particle size distribution was not heavily dominated by large size particles and was more uniformly distributed across the channel. Under these conditions, the grid spacing used would have provided a more accurate representation of average particle distribution across the full transect.

Despite the autocorrelation effect described by Bunte and Abt (2001b) that can make the grid intersection method with fixed grid spacing vary in suitability with stream substrate composition, other authors have used this method. For example, Archer et al. (2004) used a 50-intersection grid randomly tossed in pool tailouts to estimate percentage fine sediment. Archer et al. (2004) do not identify grid spacing, but it is apparently fixed. In addition, they do not identify the D_{50} or D_{max} of the pool tailouts, so it is not feasible to conclude from information provided that the cautions of Bunte and Abt (2001b) were adhered to—that is, adjusting grid spacing to a size of approximately D_{max} so as to avoid autocorrelation of sample points. Archer et al. (2004) attribute a 19.6% variability in repeat measurement by different operators to this method. It is possible that a lower level of variation could have been achieved by varying the grid spacing to match substrate size or is using more than 50 intersection points. This grid method (Roper et al. 2002, Archer et al. 2004) relied on only three random tosses of a grid frame within a pool tailout. Even though the toss was reportedly random, three tosses are not sufficient to ensure representation of the entire channel cross-section, given its potential spatial heterogeneity. These authors concluded that alternative methods need to be developed to adequately describe stream substrate and reduce the level of variation due to streams and observers. Rather that simply imply that stream substrate measures are impractical (Roper et al. 2002: p. 1644), these authors should have discussed the obvious biases introduced in their sampling methodology as described by Bunte and Abt (2001b), whom they cite. Burton (2000) used a 100-intersection grid to follow trends in fine sediment (<6.4 mm) in streams on the Boise National Forest, but did not specify grid spacing. One would presume it would be a grid frame comparable to that recommended by Bauer and Burton (1993). Boundary Creek in Burton's study had a D_{50} of 25 mm prior to a 1988 fire/sedimentation event and 0.7 mm D_{50} after the event. Substrate with such a small median diameter would provide a more optimal size distribution for using the Bauer and Burton (1993) grid spacing.

To the credit of the grid method, the method is based upon identification of particle size under the intersection of fine wires on the grid frame. Such a method for random particle selection seems preferable and less subjectively determined than by groping under water with fingers for the first particle that can be touched as with the pebble count method. Bunte and Abt (2001a) described numerous reasons why this procedure in the pebble count method can yield spurious results. If particles are identified under the grid points, it makes less difference that the particle is hard to reach in the crevices between cobbles, provided it can be seen. The grid method, oriented toward identification of only the fine sediment fraction (application in current study), benefits from allowing a much larger sample size in a fixed period of time at a transect. This is feasible because particles are not individually picked up and measured. The method focuses only on fine sediment, thereby avoiding detailed data collection on larger particles. And in practice, it is relatively easy to visually identify the threshold particle size for fines. If the grid method is used as recommended by Bunte and Abt (2001b) to describe the total particle size distribution as a counterpart to the traditional pebble count method, it has the advantage of reducing bias against both the smallest and largest particles in the distribution.

This method is not totally free of subjectivity, however, because selection of a target particle below a grid point could be influenced by parallax and, consequently, choice between two adjoining particles. In addition, superimposition of a sand grain on top of a cobble forces the decision whether to count the sand grain beneath the grid intersection or the cobble below that. This might allow bias in selection among particles available in the vicinity of the grid point. Tossing a relatively small frame onto a streambed in flowing water can also cause certain particles not to be represented. For example, a large cobble or small boulder emerging above the streambed is not often sampled because the frame would tend to be swept off a high surface. Bunte and Abt (2001a, 2001b) also described how the pebble count method has a similar bias against boot placement on top of such material while wading a stream with a rough streambed. Another factor with potential for bias in the grid frame method vs. the visual and pebble count estimates for the entire transect, as used in our study, is the placement of the grid frame at five equally spaced locations on the transect. Grid frame placement, then, could possibly underrepresent fine sediment deposition along stream margins, which could be more adequately represented in the other two methods. However, in these study streams, patches of fines along stream margins occupied a small percentage of transect width; fines were generally abundant and distributed across the entire transect.

Pebble count method

The pebble count method (Wolman 1954) has a long history of use in characterizing particle size distribution on a streambed. Consequently, it has become essentially a standard method for substrate analysis of coarse bed material. Pebble counts have also been recommended as a technique for monitoring changes in particles less than 6 mm diameter as the most indicative of biological impact in Idaho streams (Potyondy and Hardy 1994). Sieving of particles through a standard sieve series is the primary technique for sediment analysis when working with material of a smaller size range. For evaluation of small size fractions, only sieving is feasible for distinguishing percentages of each category.

It is well-documented that pebble counts tend to underestimate the amount of surface fine sediment for several reasons, including that it is difficult to sample finer particles between the interstices of larger particles (Bauer and Burton 1993; Nelson et al. 1996b, Bunte and Abt 2001a)). In addition, the pebble count method has a tendency to under represent the largest particles in coarse bedded streams due to the tendency of operators to avoid such obstacles in heel-to-toe walks (Bunte and Abt 2001b). The time involved in measuring all particles by the pebble count method is far greater than required for visual identification of size by the grid method. However, note that Bunte and Abt (2001b) recommend use of a gridded frame for selection of particles that are then picked up and measured with a gravelometer. The pebble count method derives a measure of total particle size distribution which is useful to assess quality of the spawning environment, but may not be necessary when the primary objective is to assess fine sediment trends.

Archer et al. (2004) uses fine sediment (<6 mm) particle count data from pebble counts where n=100 total particles to estimate percentage surface fine sediment. This is similar to what was done in our work. Archer et al. found that repeat measurements with this technique had a 30.5% variability, which was greater than observed for their grid-intersection method (19.6%). This difference could have been produced from the tendency of the pebble count method to have difficulty in identifying fines. The much lower variability in repeat measurement of D_{50} using the pebble count method attests to the ability of this method to account for particle size distribution for the larger particles. Unfortunately, use of D_{50} is not a sensitive measure of trends in fine particles as a component of the bed (Kondolf 1995).

Archer et al. (2004) calculated that the pebble count method for identifying fine sediment particles would require 792 and 198 samples, respectively, to detect 10 and 20% change with Type 1 and 2 errors of 0.1. The 50-intersection grid method required 1003 and 251 samples to detect 10 and 20% change. However, the results in our study demonstrated an ability to detect significant change over a 4-year period with a pebble count and grid approach, as well as visually, based on 10 samples per stream per year. The Archer et al. study used only 3 to 4 riffles in pebble count measurements instead of 10 and only 50 grid intersections per grid frame instead of 100. In addition, their grid method used only 3 tosses per transect instead of 5.

Is there a standard for evaluation of surface fines?

For surface fine sediment, the correlation among the three different measures, visual, grid, and pebble counts, indicated no clear preference in estimation of percentage fines. In addition, individual regressions of grid and pebble count data on visual data were highly significant. Although the pebble count method has been extensively used for estimating particle size distributions, it appears to be more prone to bias than the grid method when surface fines are scarce (**Fig. 19**). Visual counts are definitely the most cost effective due to their rapidity of data collection. However, data obtained from this method should be calibrated against other methods that might require more intensive effort and consequently should be more accurate. Both the grid and pebble count methods are considerably more labor-intensive than the visual method. The pebble count method has been frequently criticized for its lack of sensitivity and bias against the finest particles (Bunte and Abt 2001a, 2001b). The grid method employed (Bauer and Burton 1993) appears to avoid the bias against fine particles caused by difficulty of grasping fine particles, but it, unfortunately, probably resulted in excessive sample variation due to the varying degree of mismatch between the fixed grid spacing used and the size of the dominant particles observed in transects (Bunte and Abt 2001a). Because bias due to grid spacing can only be eliminated by selecting a spacing greater than the largest particles encountered (Bunte and Abt 2001a, Bunte and Abt 2002, Bunte, pers. comm. 2004), the variation in particle size distribution among streams and also among transects within streams was apt to have contributed varying degrees of bias in surface fine particle estimation among samples. A fixed grid spacing of 1.5 cm would probably be adequate, given the target of identifying the surface area covered by particles <0.635 cm (i.e., a size less than the grid spacing), provided that fines were uniformly spread over the entire transect surface. However, with variability in patch sizes of fines, degree of clumping of these patches, and size of dominant particles among transects, the grid method, with a fixed grid spacing which is also much smaller than D_{95}, is likely, on theoretical grounds, not to provide an optimal estimate of fines for all study streams or to be the uncontested standard by which to judge the accuracy of the other methods. Despite this sampling factor, it is interesting how great a correspondence there was among the three methods of estimation. This seems to indicate a robustness in these methods and recommends the use of whichever method is most time efficient. Considerations expressed about these methods also suggest areas where method improvement and better calibration are possible.

We had assumed that the grid method would have the greatest potential for yielding relatively accurate results among the streams and transects surveyed for fine sediment. However, because the grid spacing employed over the years of this study was not matched to particle size distribution at each site, the grid method, unfortunately, cannot be assumed to maintain a consistent degree of accuracy or be a standard against which to contrast the other methods for this study. [Note: if grid spacing were adjusted to each site, we believe it would be the standard by which to compare the other methods.] Instead, we employed all three methods to evaluate common patterns and trends in fines (i.e., <6.35 mm). The high degree of correlation among the three methods lends greater credibility to each method. We cannot recommend one method (as employed in this study) above the others on the basis of accuracy because they all seem reflect the same average condition for the set of transects. Precision of these methods cannot be stated because extensive analysis of the variance associated with repeated measurement at a transect was not carried out. Nonetheless, these data were not used to assess multi-year trends in surface fine sediment for each transect individually. Trends were evaluated on the basis of the mean and variance found each year at each stream based on the 10 transects averaged per stream.

Potential Sources of Variation in Overwinter Infiltration Rates

Overwinter sedimentation in spawning areas was measured by assessing the overwinter infiltration of fines (<6.35 mm diameter) into cleaned spawning gravels that were randomly selected by hand and placed into plastic buckets, and which were then inserted in streambeds of study stream spawning reaches. Data on percentage of total substrate dry weight comprised by fine sediment was calculated for all overwinter buckets. There is some uncertainty concerning these data, however. Some sources of variation include:

Time of placement in the streambed

Buckets that were in place in the stream for longer periods might be expected to have greater percentages of fines (see Garrett 1995:p74), although such is not always the case (Larkin and Slaney 1996). All buckets were placed into the streambed at roughly the same time period during low summer flows (**Table 21**). Placement occurred over a 2-d period each year and spanned a 13-d variation in annual start date over the 4-year study period. The amount of fines expected to be transported in bedload or in suspension during the summer should be minimal, so variation in time of placement among buckets should account for little of the variation in infiltration (Acornley and Sear 1999:p. 454). Some buckets were designated to be recovered at the midway point of the overwinter incubation period. Because across the years of the study, winter snows prevented all buckets from being withdrawn from the four streams at the same time, there was as much as a month variation in time of retrieval of the midwinter buckets. Time of retrieval of all buckets at the conclusion of the “incubation” (infiltration measurement period) varied from April 12 to May 18, depending upon amount of snow blocking road access. In order to be able to retrieve samples during mid-winter and to prevent excessive scour from dislodging buckets, buckets were inserted into the streambed within approximately 2 m of the streambank. It did not appear that greatly different sediment deposition or substrate quality existed between the locations of buckets and mid-channel. Also, it would not be unusual for salmon to spawn in these near-bank areas. Regardless, it is possible that due to variations in locations of bucket placement, variation in infiltration could occur. This source of variation is part of what one expects to measure from bucket replicates.

Dates of artificial redd placement and collection varied due to logistical reasons and among these, principally due to the time of accessibility of these remote, high elevation sites. Accessibility in springtime was influenced by variability in melting and depth of accumulation of winter snowpack. This variability allowed the number of days during which sediment could collect in buckets (termed overwinter sediment deposition) to vary from 210 to 255 days (**Table 21**). For some buckets to be in the stream an additional 45 days than others could potentially result in increased fine sediment accumulation in those buckets.

The annual field measurement of infiltration of fines into cleaned spawning gravels provides key trend data that should reflect improvement in watershed condition and related restoration of instream habitat conditions associated with fine sediment availability. Fine sediment availability detected in terms of percentage surface fines and infiltration hopefully becomes less from year to year in damaged watersheds, indicating changing potentials for overwinter fine sediment infiltration. A large improvement in watershed condition and a reduction in fine sediment availability (the desired trend) could obscure interannual differences in infiltration within a stream due to slight variation in number of days that sample containers were in place. Although one might argue that interannual variation in number of days-in-place for sample buckets is a potential source of bias in detecting multi-year trends, there are reasons why this may not be significant. The amounts of intruded fine sediment may not actually vary substantially due to days-in-place from year to year for various reasons such as: 1) buckets might become filled with fines in a shorter period of time, 2) buckets might develop surface bridging that would exclude further infiltration of fines regardless of the variation in number of days allowed for accumulation, and 3) minor, non-directional variation in sediment availability could obscure slight differences in intrusion caused by variation in days-in-place.

Studies from the literature have shown variable effects of time of sample bucket emplacement. DeVries et al. (2002) studied fine sediment (<0.83 mm and <6.35 mm) intrusion in nine western Washington streams using Whitlock-Vibert boxes and frequently observed increases in percentage intrusion over incubation periods that ranged from approximately 25 days to a maximum of 170 days. For example, mean percentages fines (<0.85 mm) by weight at 35 days in Illabot Creek were from 7 to about 8.5%, but this increased to about 7.6% and 13% in samples taken at 77 days. For fines <6.4 mm, mean percentage fines of samples at 35 days were about 14 and 17.5%, but at 77 days this increased to 16 and 23%. In the N.F. Stillaguamish River, fines <0.85 mm increased from means of 1.4 to 3.8% at 25 days to 5.5% at 170 days. In other streams, however, the mean percentage fines at the initial determination did not appear to increase further during the incubation period. In addition, they found that scour depth was related to depth of fine sediment intrusion and that scour depth also was related to the influence of land use on hydrology and fine sediment delivery.

Given the potential reasons for no significant effect of variation in number of days of sample bucket emplacement (or variation not clearly attributable to days emplacement), it is unclear whether it would be warranted to apply a weighting factor to fine sediment accumulation in order to more meaningfully compare streams in a given year or for all years combined. Multiple types of evidence from this study give support to the contention that the degree of variation in duration of bucket emplacement did not cause significant variations in level of infiltration.

Variation in surface fine sediment availability and particle distribution

Streams likely vary in their magnitudes of stored fine sediment and in their sedimentological characteristics (Milan et al. 2000). For example, Milan et al. (2000) found major variations in the natural tendency of streams from three different hydrological regions of England (upland hardrock, chalk, and sandstone or limestone) to exhibit substratum percentage fines (<1 mm) content in freeze cores, as well as variation in fines composition by silts, clays, and sands. This is expected to be reflected in the amount of surface fine sediment, as well as in more difficult-to-measure depth fine sediments. Streams also vary in their capacity to transport these fines. Some of this variation can be attributable to different size streams, different channel gradients, and different water flow rates. Channel gradient and streamflow are linked to overall particle size distribution in the streambed and particle transport dynamics. Overwinter infiltration studies are intended to reveal differences in rate of filling of buckets with fines and these are some of the expected reasons for differences. By selecting stream reaches in a similar ecoregion, similar gradient, and reaches used by spring Chinook for spawning, many of these variables are controlled to some extent. This leaves variation in surface fine sediment as a major link to level of overwinter sedimentation.

Variation in size distribution of framework particles

Variation in percentage of fine sediments relative to total weight of sediments in buckets (original framework plus infiltrated fines) could also be attributable to variation in size distribution of framework particles. Diplas (1994) attributed the variations in intragravel flow and Reynolds numbers in gravel mixtures to substrate particle composition that can produce differences in depositional characteristics. However, Diplas (1991) and Carling (1984) found that high siltation rates can occur even with relatively low sediment concentrations, but the rate of infiltration is proportional to the concentration of suspended sediment. In addition to average sediment composition in a bucket, stratification that could occur in natural streambeds by depositional or infiltration processes can control further rates of infiltration (Frostick et al. 1984). Over the years in this study with the five-member field crew, employed three at a sampling period, there may have been individual variation in the size frequency of particles selected within the desired size range from bucket to bucket, among staff, or among years. Most particles selected were typically between 2.5 and 7.5 cm, but the distribution within this range could vary among buckets. However, framework material containing a greater percentage of particles nearer the upper size limit to fines (i.e., 6.4 mm) would likely create greater opportunities for bridging than would framework particles that were generally coarser (Lisle 1989). Frostick et al. (1984) determined that the coarser the framework material, the greater the tendency of this substrate to fill with sediment of a smaller median size. Ability of fines to infiltrate depends upon the ratio of the diameter of framework particles to the diameter of fines (Lisle 1989). The significance of variation in initial distributions of framework material on subsequent degrees of intrusion by fines is not well understood.

One alternative to uncertainty about the influence of initial framework particle size distribution on intrusion rates for future work would be to insert a known mixture of framework particles (i.e., known percentages of various sizes screened within the overall size range 2.5-7.5 cm) into buckets at the initiation of overwinter infiltration monitoring (Lisle 1989, Larkin and Slaney 1996). By this means, there would be equal opportunities for bridging of surface particles to occur, thereby sealing off the subsurface to continued infiltration. Variation might still occur due to differential scouring effects within buckets as well as to sediment transport differences. Data from infiltration into a "known" framework particle distribution would occur on a comparable basis among streams, but still it could not be inferred that the degree of infiltration into a standard initial particle distribution would accurately reflect the degree of infiltration that would occur in the mixtures of framework material typical of each stream after redd construction. That is, if one stream had a finer particle distribution in its framework material after redd construction, it might be more resistant to deep infiltration than another stream due to differential bridging and sealing. This could involve requiring a certain percentage of material between the fines threshold (6.35 mm) and the lower limit of framework material used (2.5 cm) that matches what is typical for newly constructed egg pockets. This would be informative because it is likely that the size distribution of the “cleaned” gravels is substantially different from that of natural egg pockets in having no fine sediments at initiation of incubation. A resolution to this question could only be assessed by either measuring redd material composition in situ after spawning or by inserting buckets into each stream with known different initial distributions of particles. If significant infiltration occurred consistently in buckets despite having a diverse range of particle distributions reflecting in-channel conditions, it could be inferred that infiltration invariably occurs despite the initial framework composition.

There could be some degree of variation in overwinter percentage fines relative to total bucket sediment weight due to a combination of framework particle size distribution and degree of settling (compaction) of the particles after adding them to buckets. This source of variation could result in variation in available void volume within the framework. The magnitude of this source of variation was examined and found to provide a variation in percentage fines that could vary by ±1.3 percentage points for a bucket that was maximally infiltrated.

Future Means of Enhancing Data Interpretation

1) Use a McNeil core device to determine the depth substrate composition prior to initiation of spawning and also at the conclusion of spawning. Relate this to percentage surface fines observed and the level of bucket infiltration. Determine whether particle distribution for particles >6.35 mm in known spawning areas differs significantly between spawning gravels prior to spawning vs. redds or egg pockets after spawning. This would provide a good guide to a recommended framework sediment mixture to use to generate the best estimator of percentage fines. Because listed fish cannot be subjected to destructive redd sampling, these data would need to be derived from other sources.

2) Monitor intergravel DO and hydraulic conductivity in the same locations at initiation, mid-point, and completion of incubation period.

3) Fill buckets with a framework material that simulates the particle frequencies for particles <6.35 mm observed in redds after spawning. Also, experiment with variations in these frequencies of framework particle classes to assess the significance of initial redd composition on infiltration. This method could be used to evaluate the significance of particles between 6.35 mm and 2.5 cm incorporated into the framework mixture in shielding the egg pocket from infiltration.

4) With the information gathered above, determine the relationships among surface fine sediment by area, overwinter infiltration into experimental framework particle mixtures,

and natural sediment cores (sampled to the typical depth of egg pockets—e.g., approximately 20 cm) taken at initiation and completion of incubation.

5) Determine the correlation between fine sediment infiltration in substrate mixtures where the particle range is (a) 2.5-7.5 cm, as in this study and (b) 0.635 cm to 7.5 cm, obtained by compositing material of standard percentages of the phi size classes within this range.

Recommendations for Improvement of Current Monitoring Techniques

1) Use a sampling frame (grid) for estimating surface fine sediment that has a regular grid spacing that is greater than that of the coarsest particle in the reach.

2) Determine the variance of repeat estimates of the grid method and the pebble count method for selected stream cross-sections representing various levels of D*g* and heterogeneity of substrate patches.

3) Determine the bias associated with visual estimates of the full range of particle size fractions for various stream cross-sections representing a range of fine sediment percentages by comparing visual and grid estimates. Determine whether surface fines are more accurately assessed by eye when present in low abundance than high.

4) Determine how the estimate of percentage surface fine sediment varies in mean or variance for 100 and 500 points where the grid spacing is set equal to various percentages of the largest particle diameter. Assess whether surface fines can be assessed by use of the grid method by varying the numbers of point estimates based upon percentage of material >13 cm (visual estimate).

5) If it can be assumed that visual estimates can properly classify the degree of surface fine sediment into the correct range, assess whether the grid method might be used as a second stage method to gain sampling efficiency by adjusting the number of estimation points according to the general level of fines present.

6) Assess the efficiency of pre-stratifying the transect band by visually distinguishable patch types (see Schuett-Hames and Pleus 1999, p. 18). Determine whether stratification of surface particle deposits in a transect band can speed the estimation of particle percentage composition. This process should reduce one source of error in particle size distribution estimates—error due to spatial heterogeneity (Bunte and Abt 2001b).

7) Assess the ability to optimize sample size, thereby reducing another key source of sampling error (Bunte and Abt 2001b), by first estimating the particle sorting coefficient for a uniform substrate patch. The greater this coefficient (standard deviation of particle diameters), the greater would be the sample size needed to characterize the particle size distribution of the patch to a desired sampling error.

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FIGURES

Figure 1. Selected transects at each of the study streams from 2002.

a. Grande Ronde, September 11, 2002, Transect 4.

b. Catherine Cr., April 18, 2002, Transect 5.

c. North Fork John Day, September 11, 2002, Transect 4.

d. Granite Cr., September 11, 2002, Transect 3.

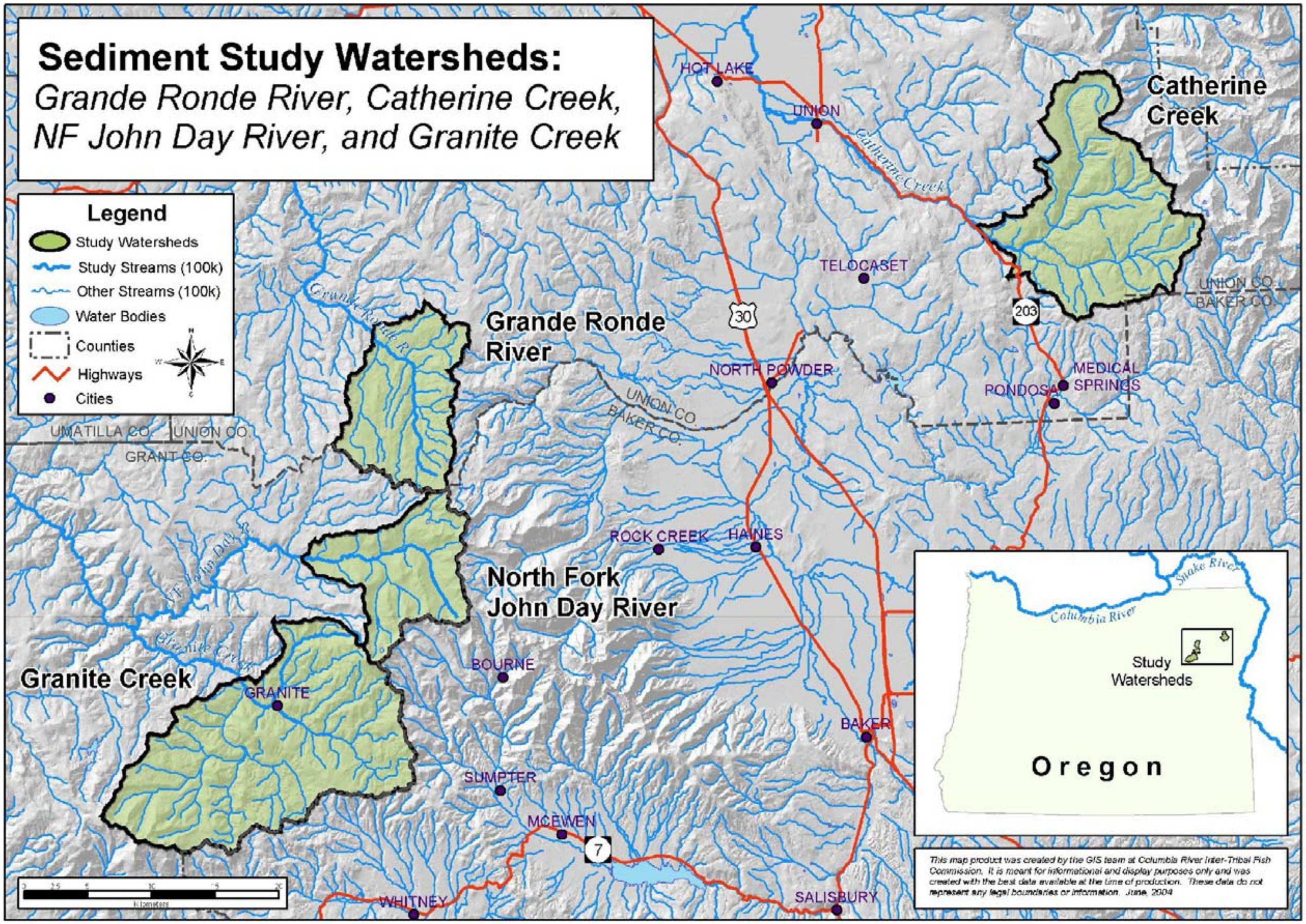


Figure 2. Overview map of the four study streams and their watersheds in northeastern Oregon.

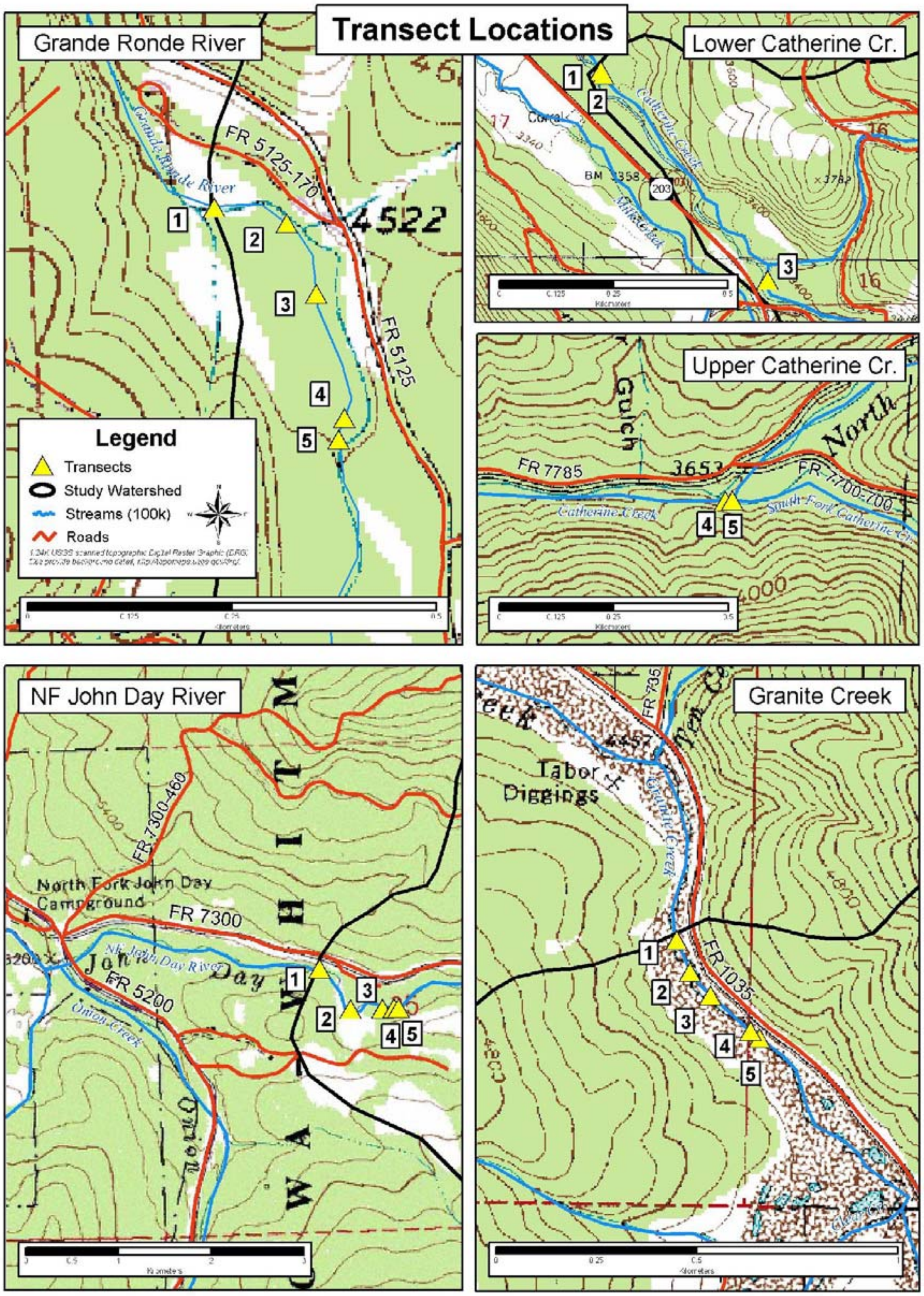


Figure 3. Enlarged view of study areas (Grande Ronde River, Catherine Creek, North Fork John Day River, and Granite Creek), showing locations of adjacent forest roads and transect locations.

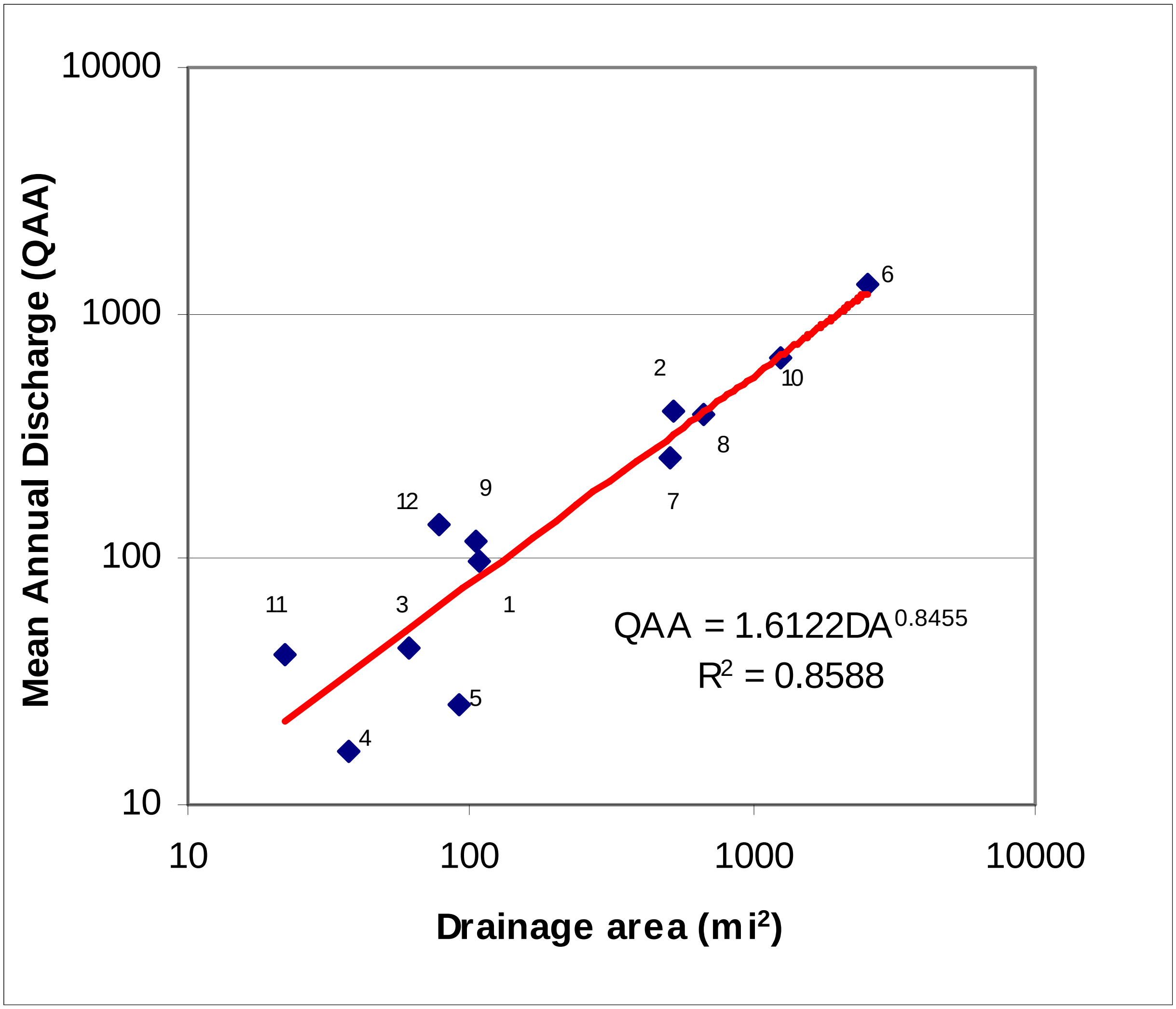


Figure 4. Estimation of mean annual discharge (QAA as cfs) from drainage area (mi^2) using a log-log regression.

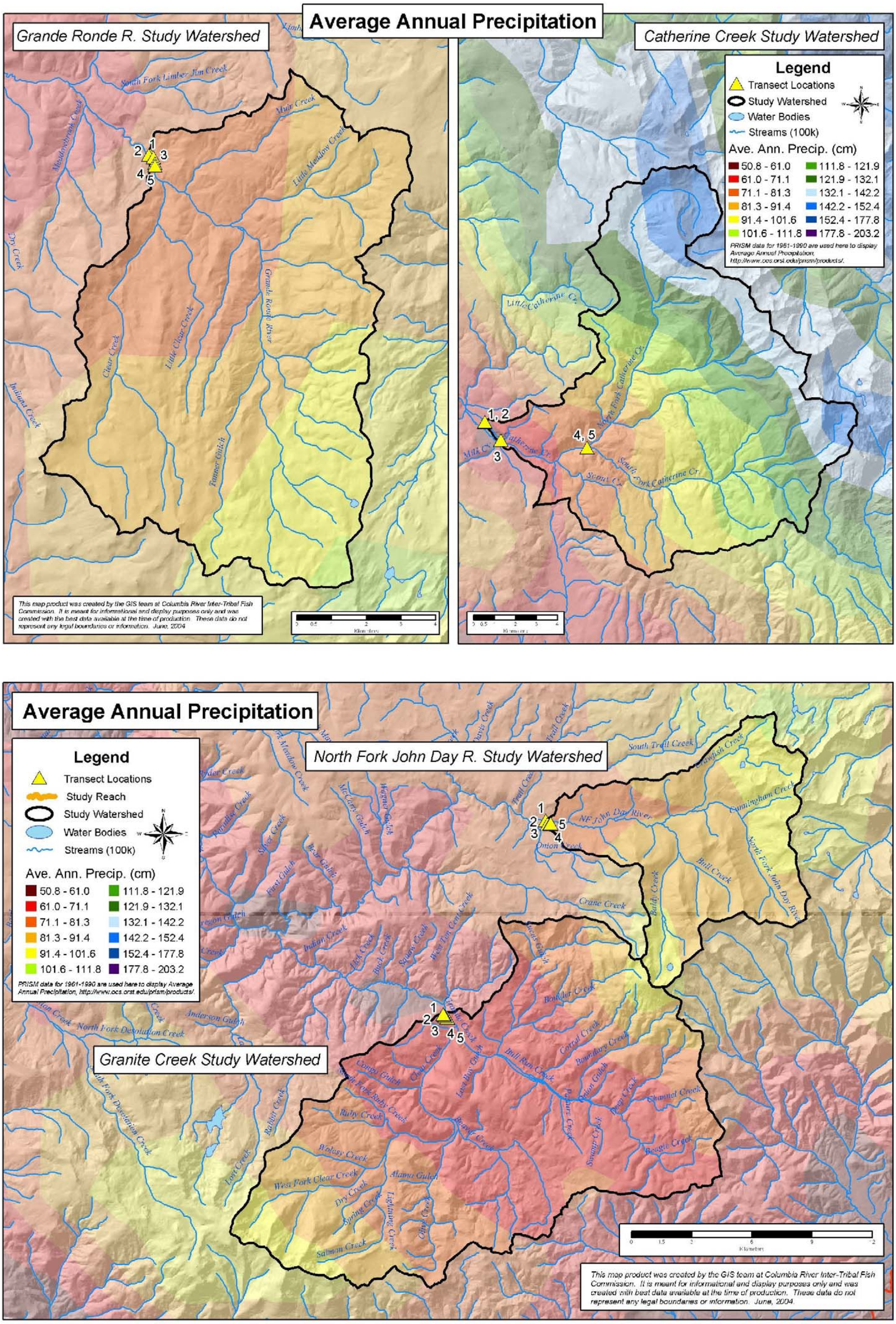


Figure 5. Average annual precipitation on the study watersheds and neighboring areas in northeastern Oregon. Data from PRISM modeling.

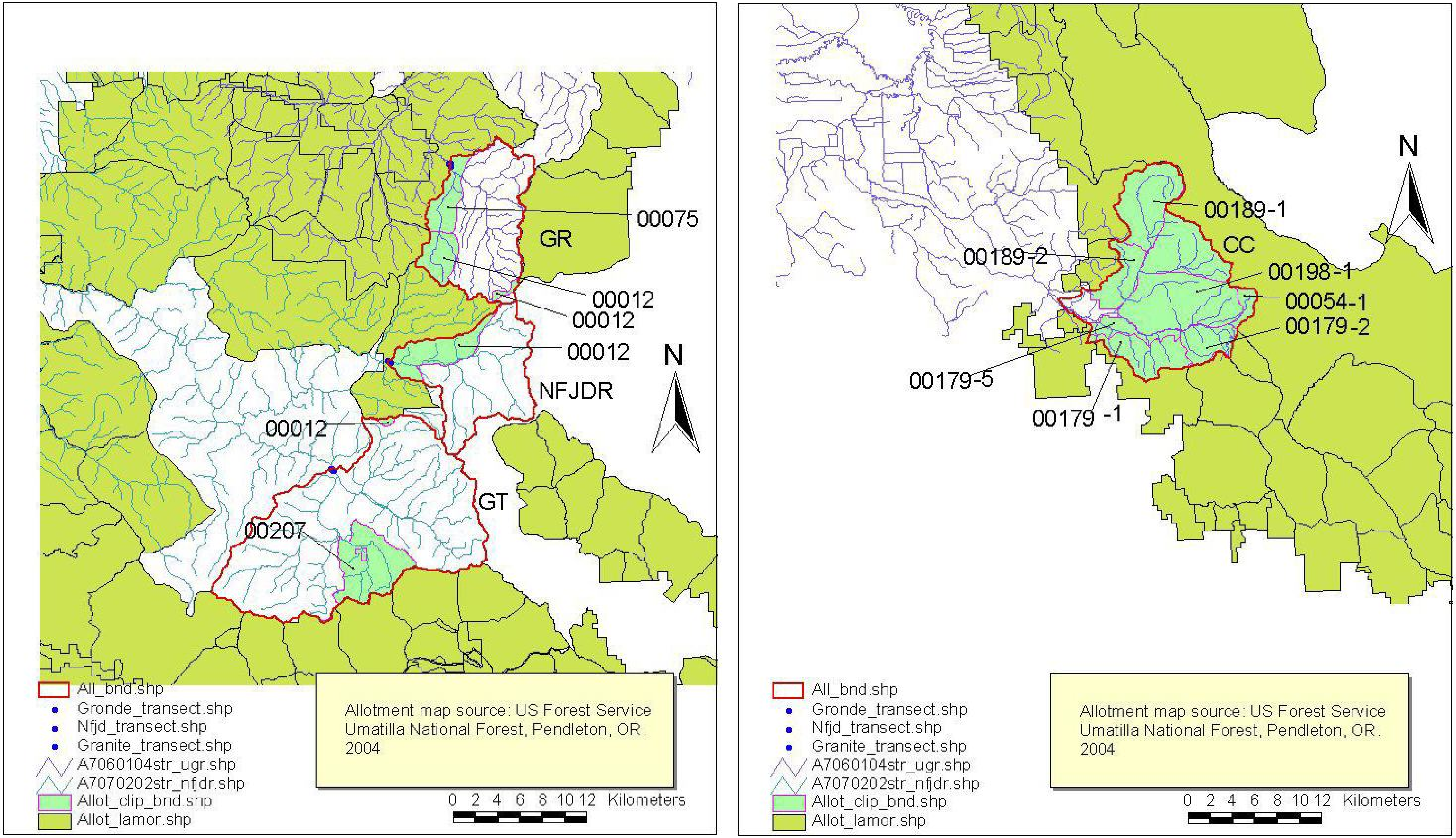


Figure 6. Allotments and pastures on the study areas and in the neighboring areas of the Wallowa-Whitman National Forest and Umatilla National Forest.

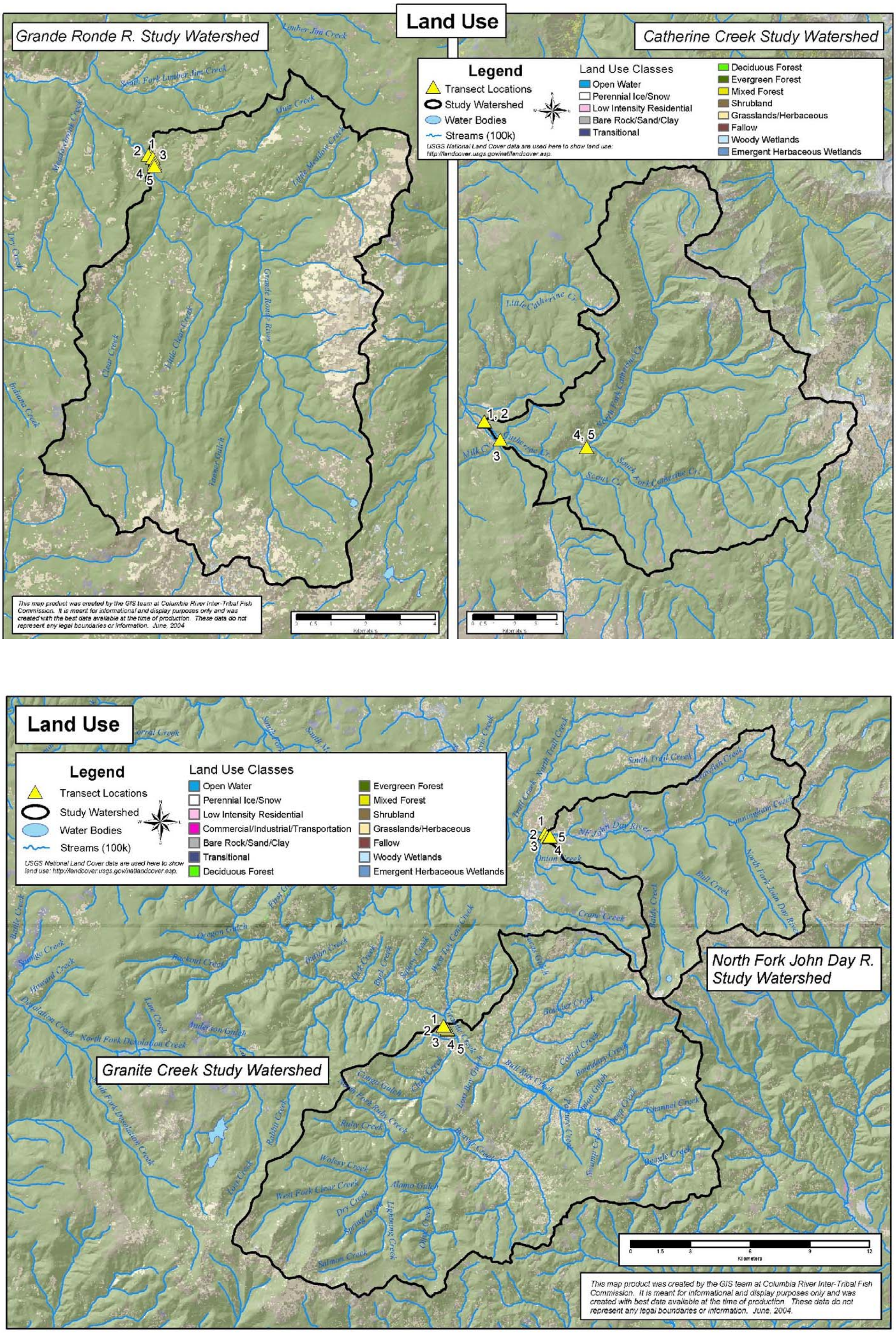


Figure 7. Land use on the study watersheds and neighboring areas in northeastern Oregon.

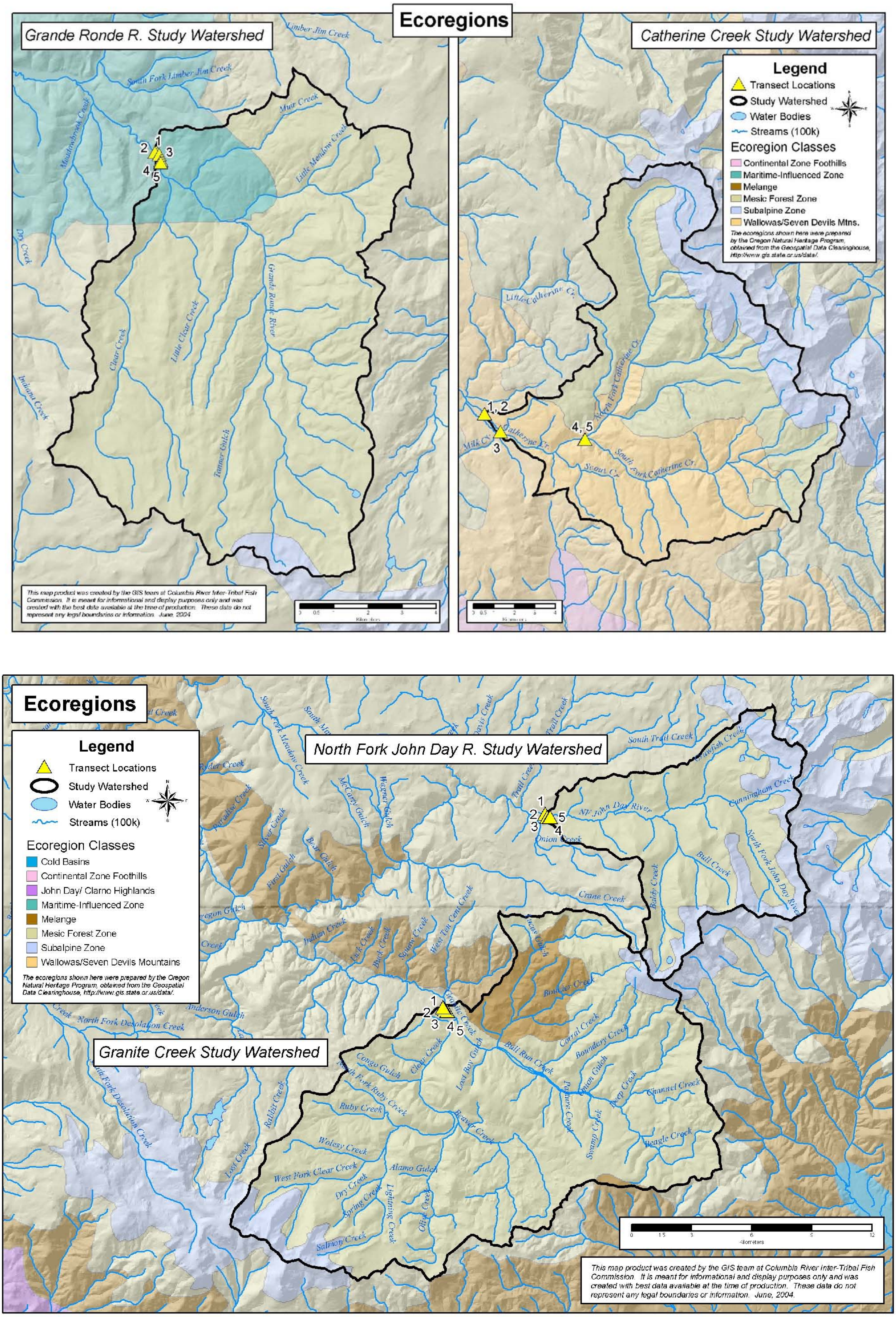


Figure 8. Ecoregions (Level IV) of the study watersheds and neighboring areas in northeastern Oregon.

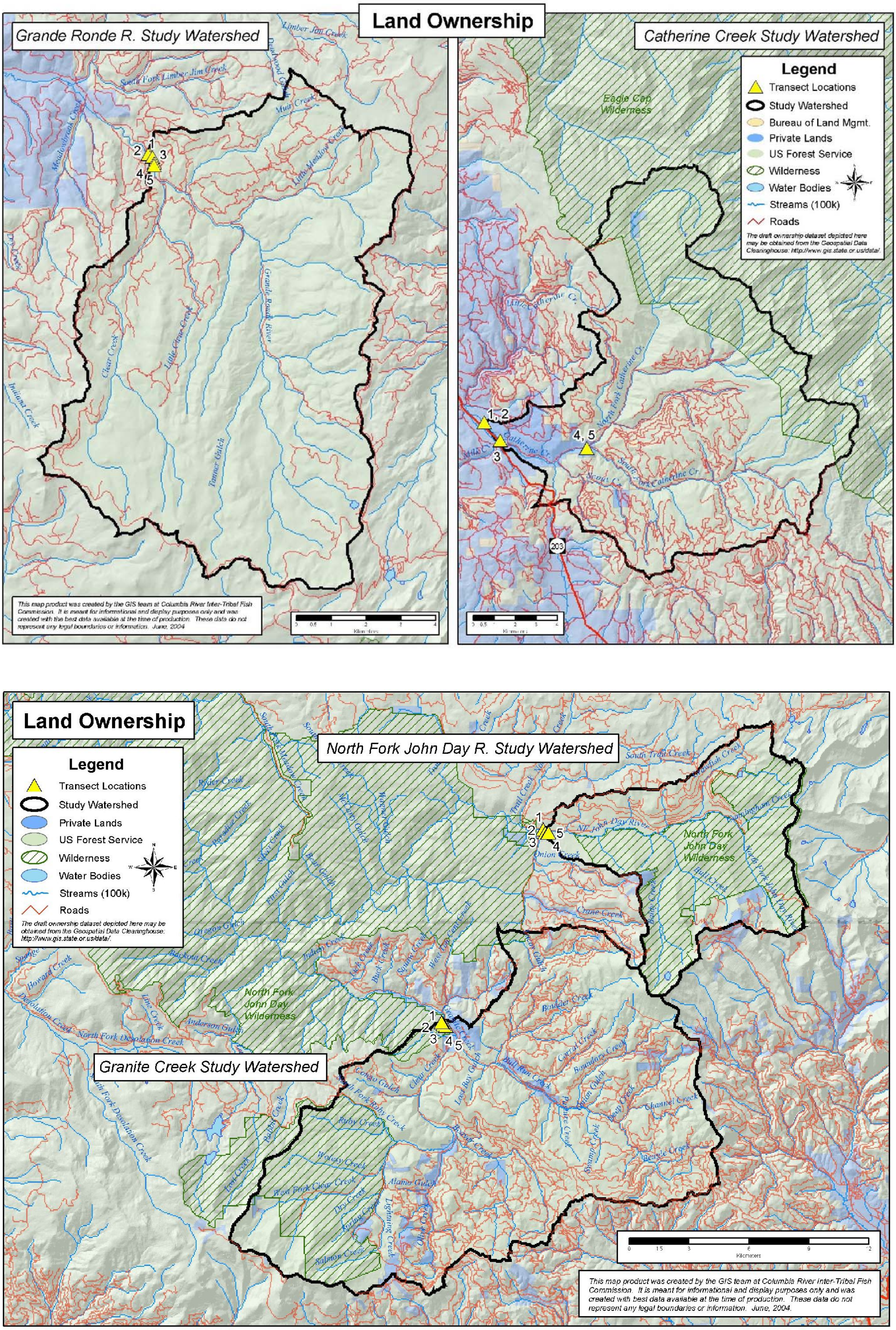


Figure 9. Land ownership of the study watersheds and neighboring areas in northeastern Oregon.

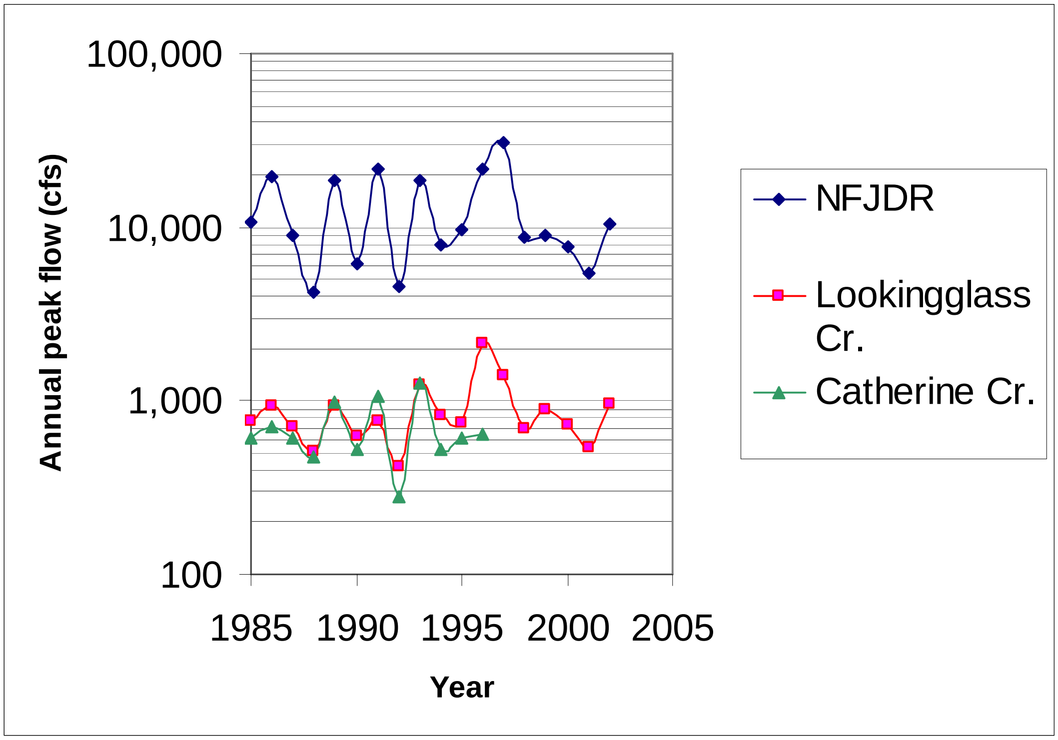


Figure 10. Annual peak flows at USGS gaging stations in the Grande Ronde and North Fork John Day basins. 14046000 Catherine Creek near Union, OR; 13324300 Lookingglass Creek near Lookingglass, OR; 13320000 North Fork John Day River at Monument, OR. Years plotted are 1985-2001.

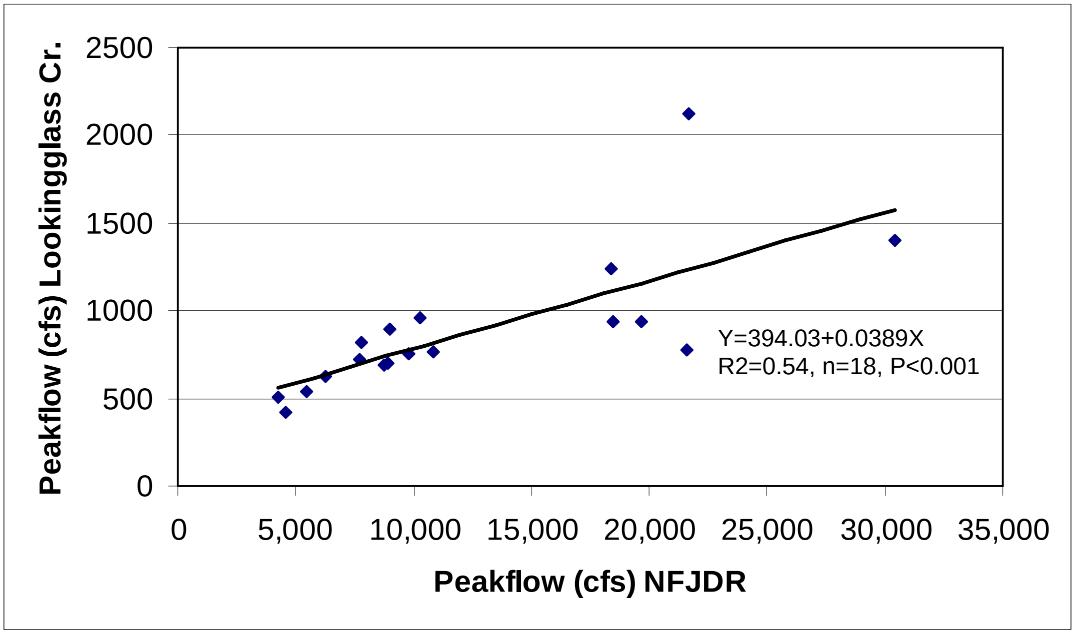
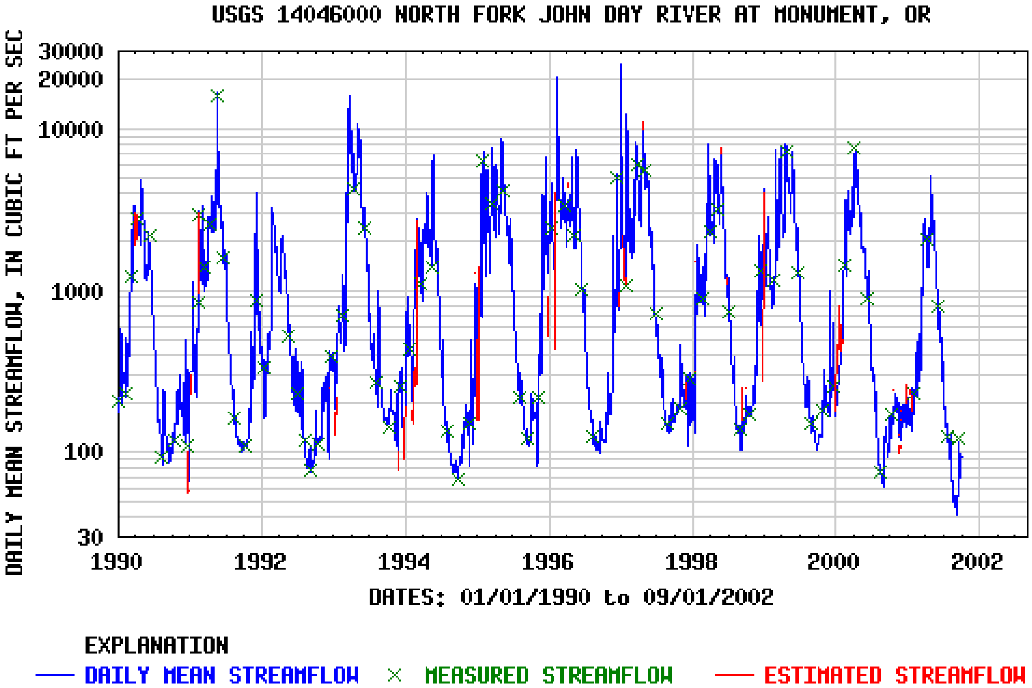


Figure 11. Regression of annual peak flows at USGS gaging stations 13324300 Lookingglass Creek near Lookingglass, OR vs. 13320000 North Fork John Day River at Monument, OR. Years plotted are 1985-2002.



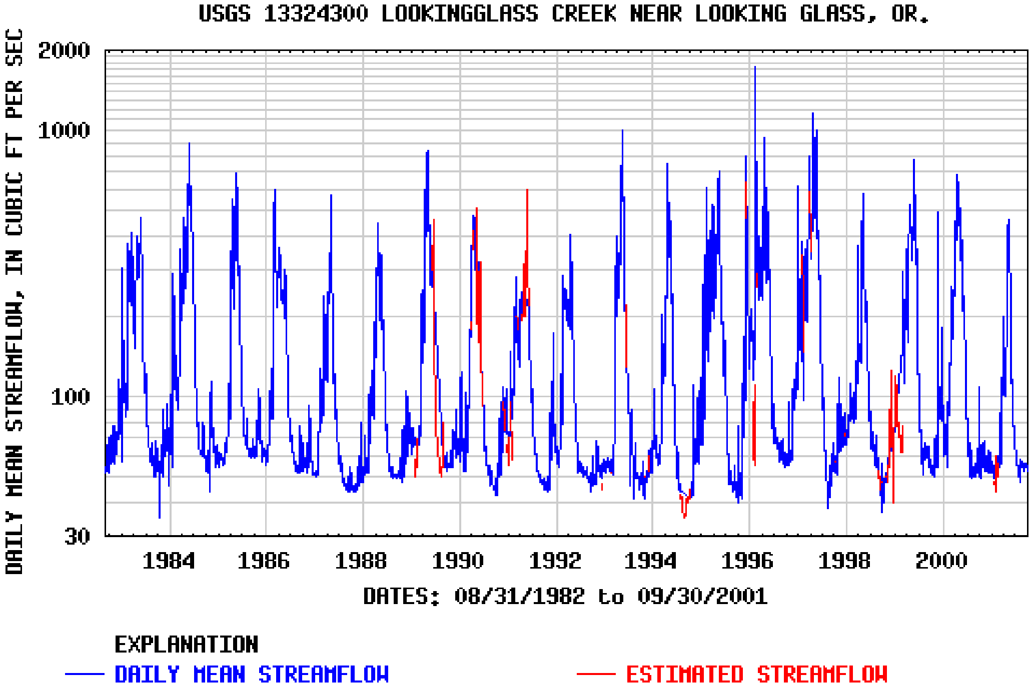


Figure 12. Daily mean streamflow for Lookingglass Creek, OR near Lookingglass, OR and the North Fork John Day River at Monument, OR.

Key to elements of diagrams:

- ○ ○ Framework particles of intermediate diameter 2.5-7.5 cm.
- 🟦 Initial interstitial void volume among the framework particles.
- 🟧 Initial framework void volume filled by fine sediment particles (i.e., <6.4 mm) and measured as a volume of dry fine sediment (sum of displacement volume of fines and their own interstitial voids).
- ☐ Interstitial void volume among the fine sediment particles.
- ⬛ A void space not occupied by fines, but which could be occupied by salmon eggs or alevins.
- 🟨 Unfilled space in bucket above framework particles
- ▩ Enlarged view of the fine particles, showing their own voids.
- ▒ Displacement volume of framework particles.
- 🟥 Displacement volume of fine sediment particles.

Key to diagrams:

A Empty bucket to be inserted in streambed in spawning gravels.
B Bucket, with initial void volume highlighted.
C Bucket filled with cleaned framework particles.
D Bucket with framework particles. Remainder of initial void volume is highlighted within the framework. Unfilled volume above framework particles is indicated. Porosity is the unfilled void volume divided by the sum of the unfilled void volume and the framework particle displacement volume. The bucket volume occupied by framework particles is the total bucket volume minus the unfilled volume above framework particles.
E Representation of the abstracted total volumes from Diagram D: the unfilled volume above the framework particles, the total displacement volume of framework particles, and the total void volume constituting framework particle interstices.
F The framework particles as in Diagram D, but with the framework interstitial voids filled by fines.
G Representation of the abstracted total volumes from Diagram F: the unfilled volume above the framework particles, the total dry volume occupied by fines (i.e., the volume occupied by dry fines when placed into a 500-ml graduated cylinder), and the total displacement volume of framework particles.
H Refined representation of the abstracted total volumes from Diagram F: the unfilled volume above the framework particles, the total dry volume occupied by fines, showing the fines with their own interstitial spaces (i.e., voids within the volume occupied by fines), and the total displacement volume of framework particles.
I The bucket filled with framework particles with interstitial spaces partially filled by fines and withsmall pockets of the initial void space (i.e., interstitial voids of framework particles) being unfilledby fines.
J Representation of the abstracted volumes from Diagram I: the unfilled volume above the framework particles; the initial interstitial volume among framework particles that is unfilled by fines (i.e., the pockets that could be occupied by salmon eggs or alevins); the void volume constituting the interstitial spaces among fine sediment particles; the displacement volume occupied by fines; and the total displacement volume of framework particles. The total initial volume within the bucket is that locatedabove the framework particles and that volume occupied by a combination of the displacement volume of framework particles and fines, the interstitial voids within the fines, and any additional voids not filledby fines (i.e.,pockets that could be occupied by eggs/alevins). The initial framework particle interstitial void volume equals the sum three component volumes after the "incubation" period: the displacement volume of fines, the void volume among the fine sediment particles, and the unfilled voids that can be occupied by salmon eggs or alevins.

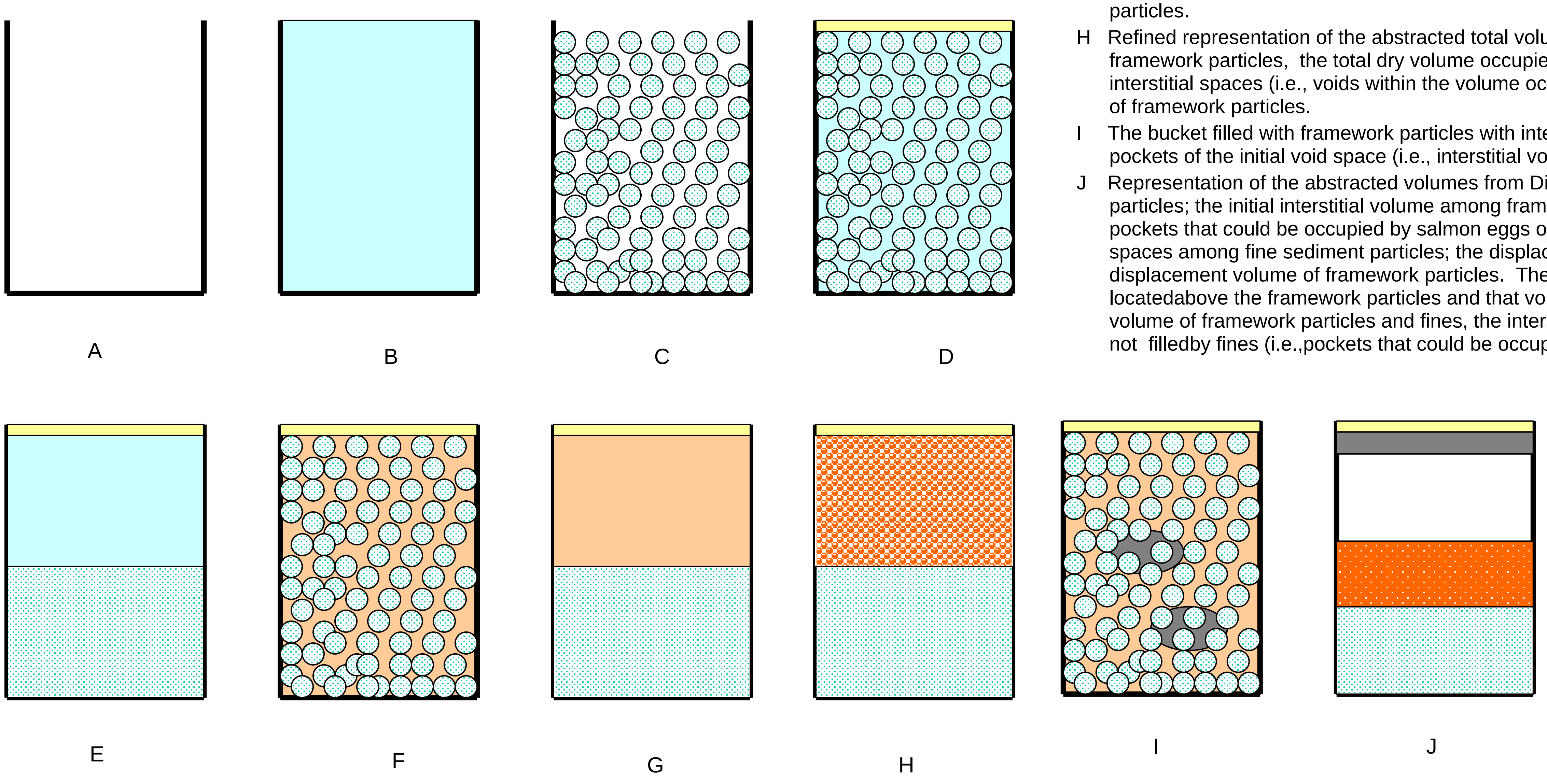


Figure 13. The framework particles, fine sediment particles, interstitial voids, and unfilled interstitial pockets within a sample bucket used to measure overwinter infiltration.

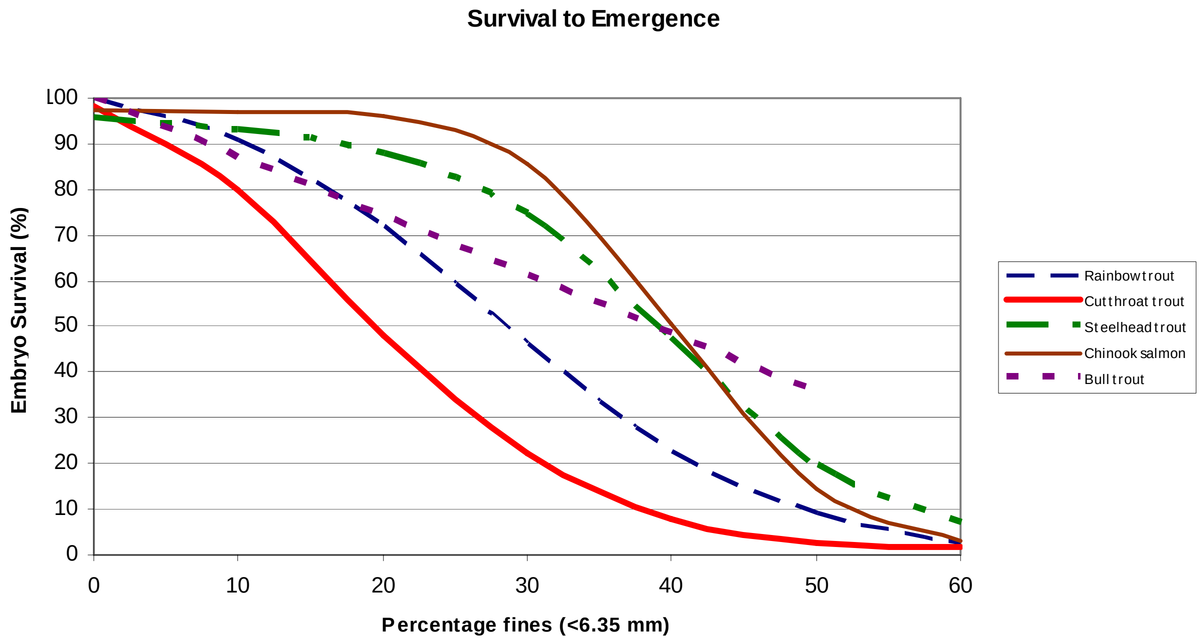


Figure 14. Survival to emergence for five species of salmonids. Adapted from Reiser and Bjornn (1991) and Weaver and Fraley (1991).

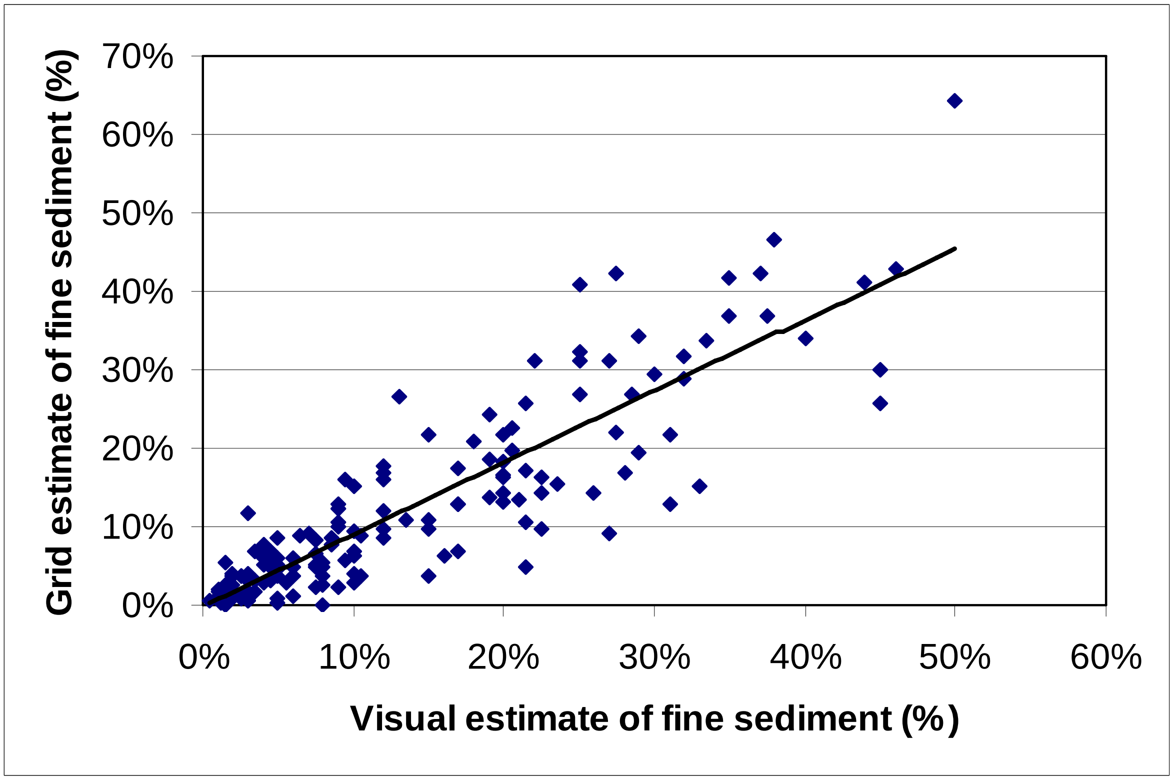


Figure 15. Regression of grid estimates vs. visual estimates of surface fine sediment (<6.3 mm) based on estimates at 10 transects per stream for four streams over a 4-year period (1998-2001).

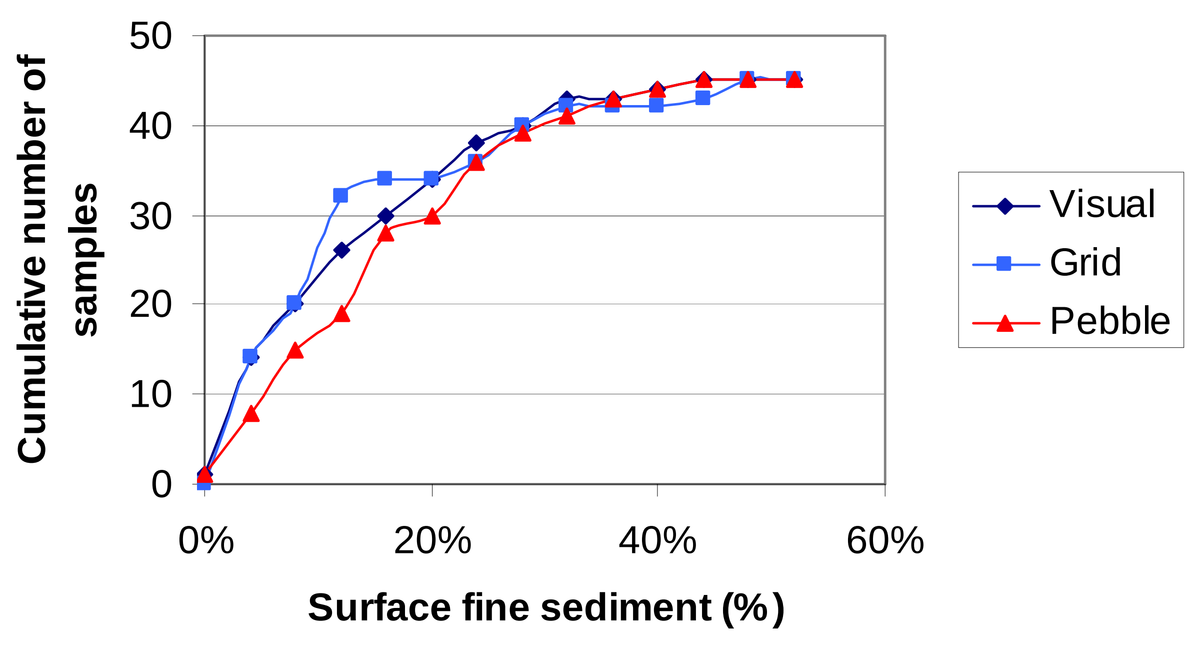


Figure 16. Cumulative numbers of samples in the comparison among three methods for surface fine sediment estimation that are less than a series of bin values.

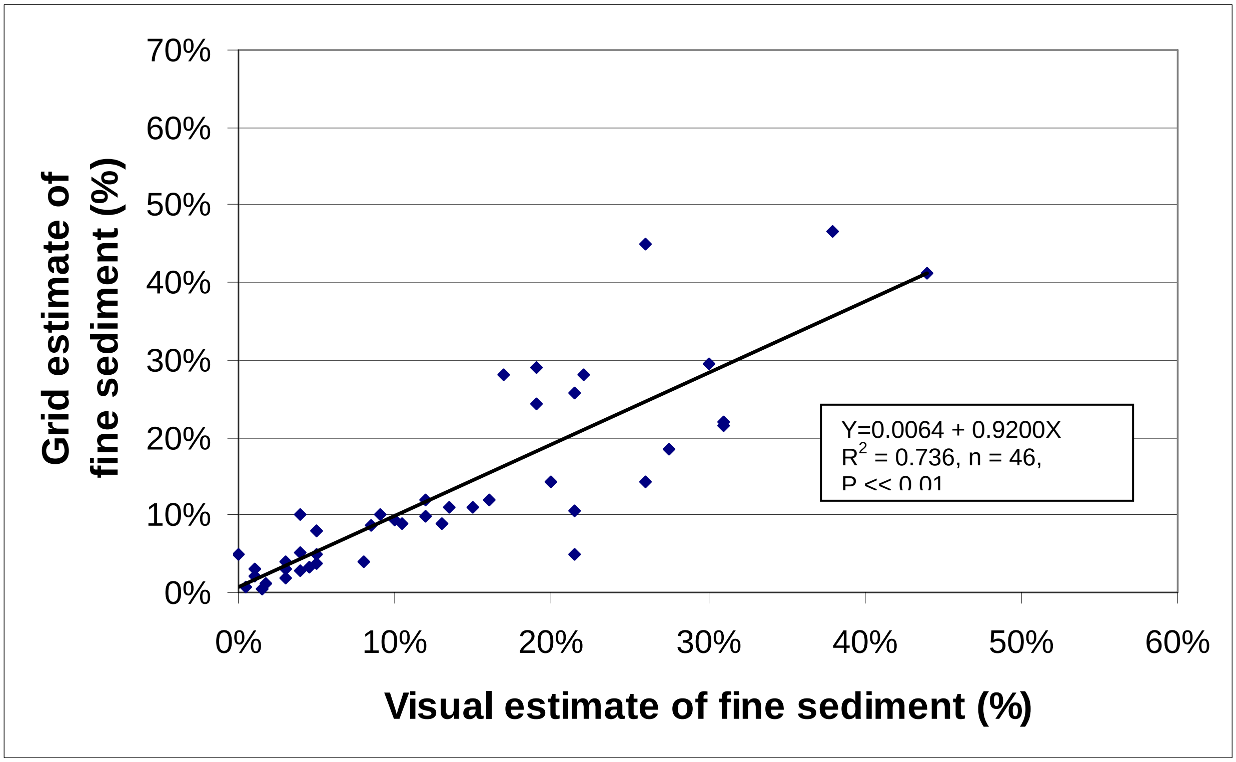


Figure 17. Regression of grid vs. visual estimates of fine sediment for 46 samples in which all three methods of estimation were used in August of 1998-2001.

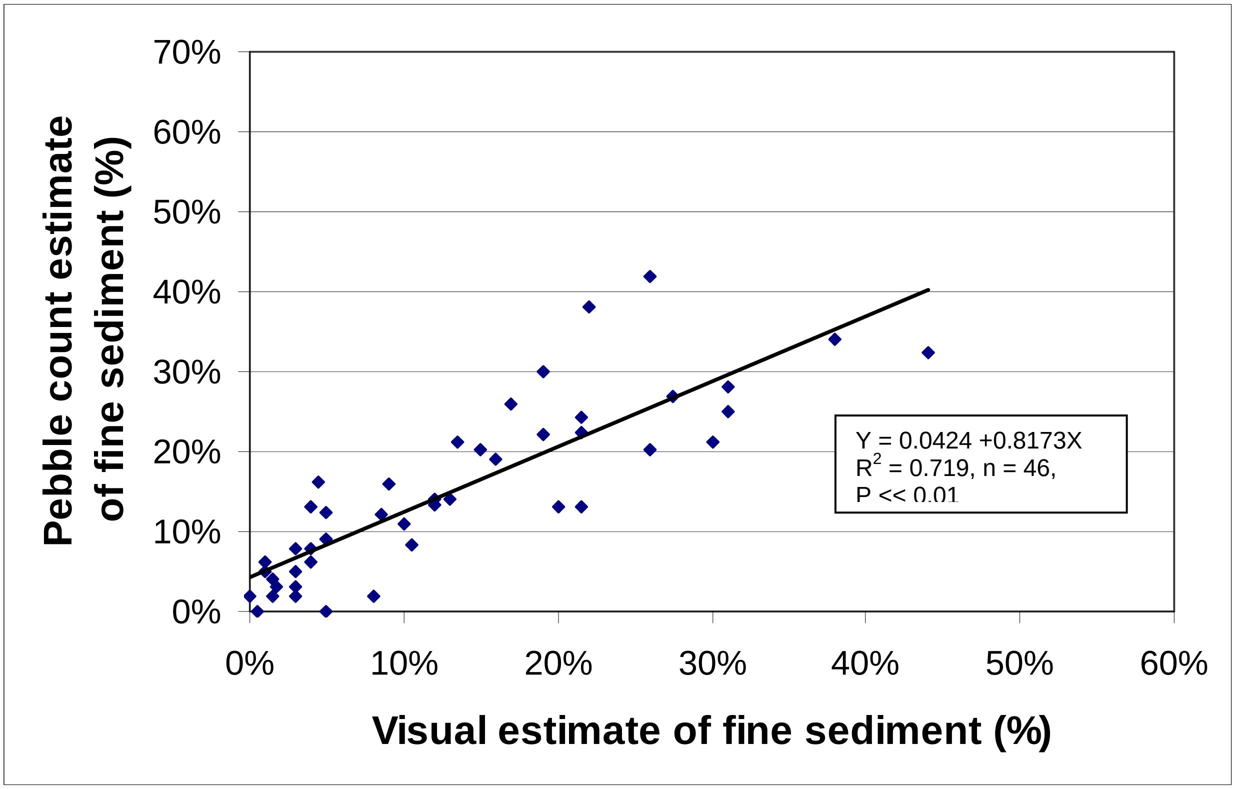


Figure 18. Regression of pebble count vs. visual estimates of fine sediment for 46 samples in which all three methods of estimation were used in August of 1998-2001.

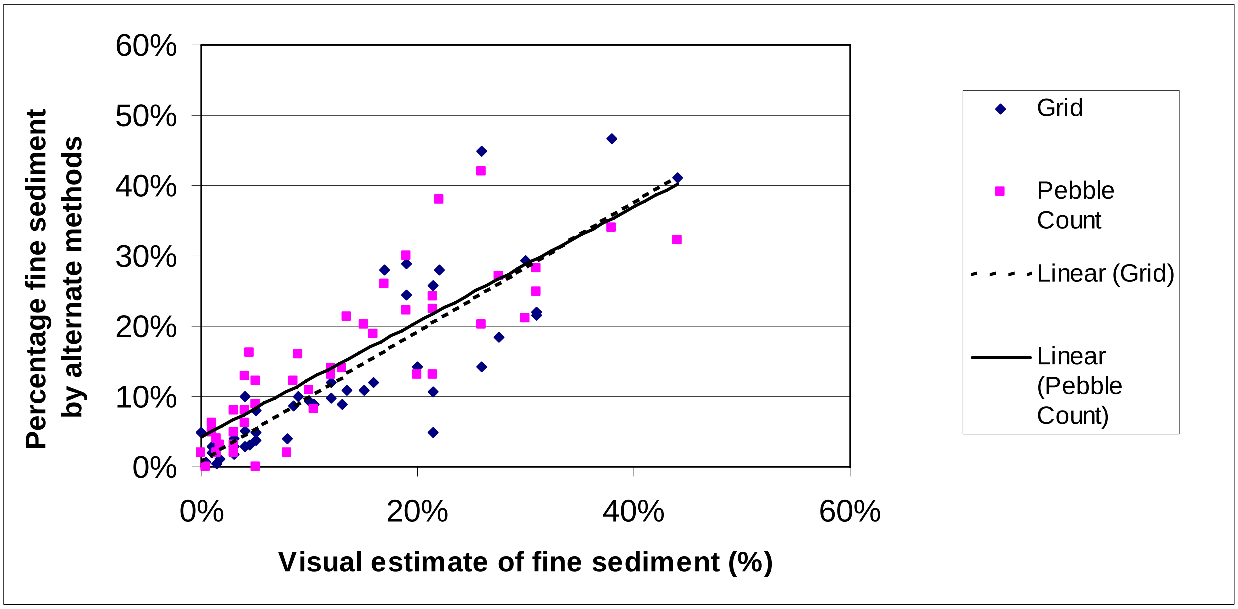


Figure 19. Composite regressions of grid vs. visual and pebble count vs. visual estimates of fine sediment for 46 samples in which all three methods of estimation were used in August of 1998-2001.

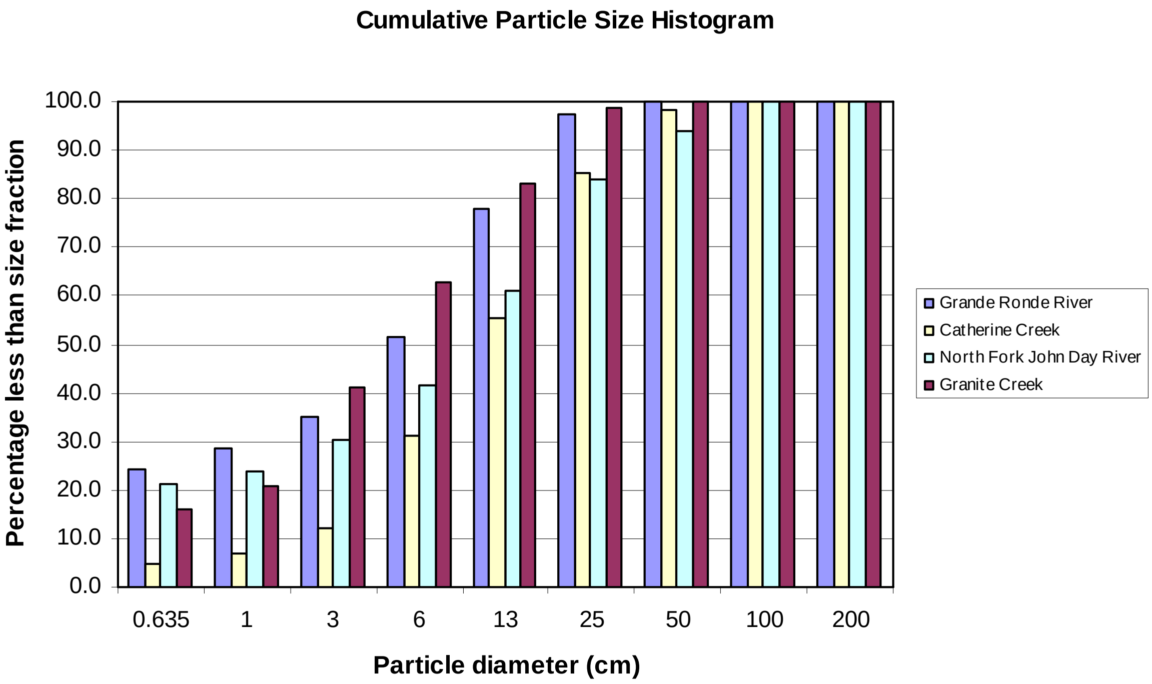


Figure 20. Average cumulative particle size distribution histogram of surface substrate composition based on estimates made visually at each of five transects per stream where overwinter buckets are embedded. Estimates were made September 11-12, 2002.

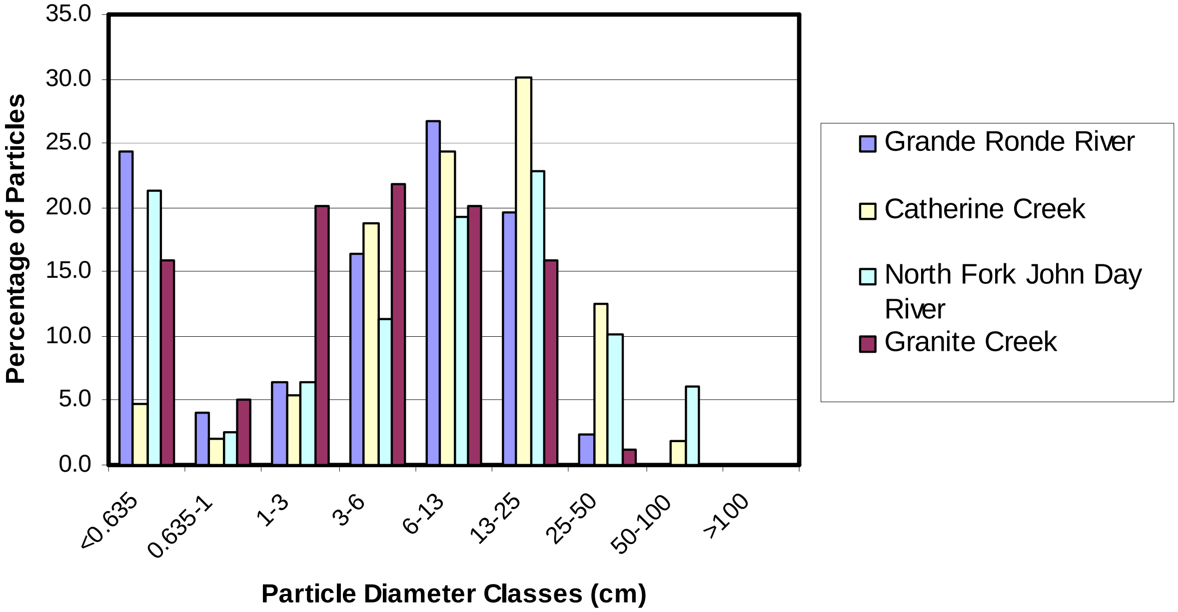


Figure 21. Average particle size distribution histogram of surface substrate composition based on estimates made visually at each of five transects per stream where overwinter buckets are embedded. Estimates were made September 11-12, 2002.

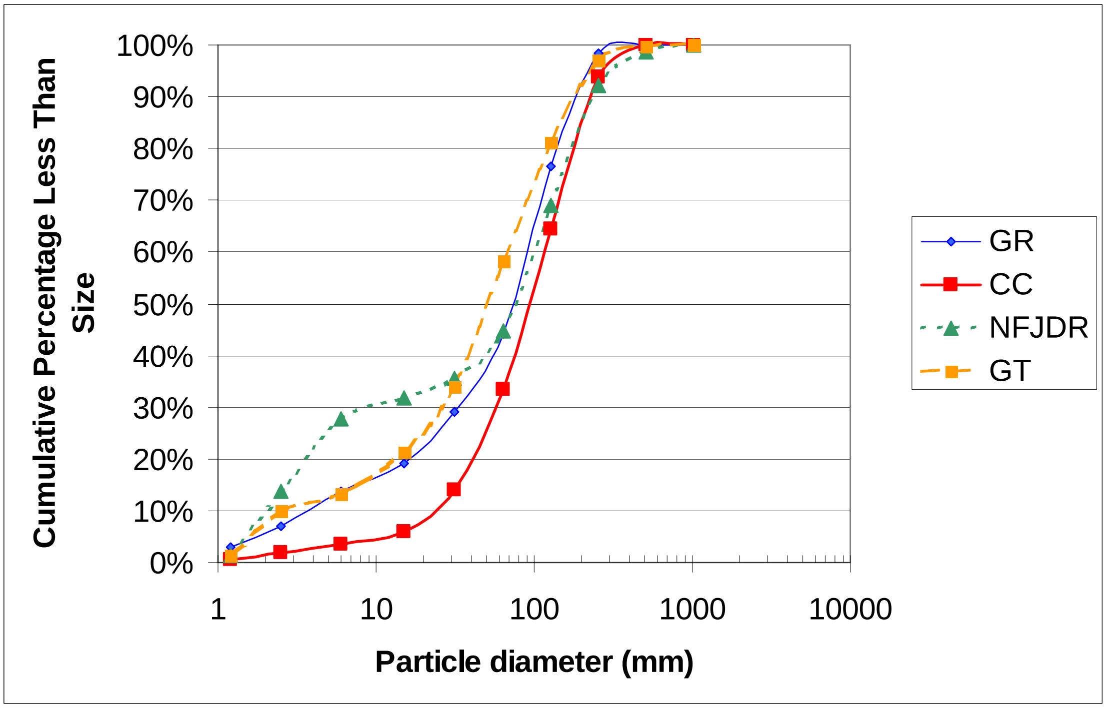


Figure 22. Average cumulative particle size distribution of surface substrate composition based on pebble count estimates made at transects where overwinter buckets were embedded. Data were collected in the 3-year period from 1999-2001 at the time of bucket placement.

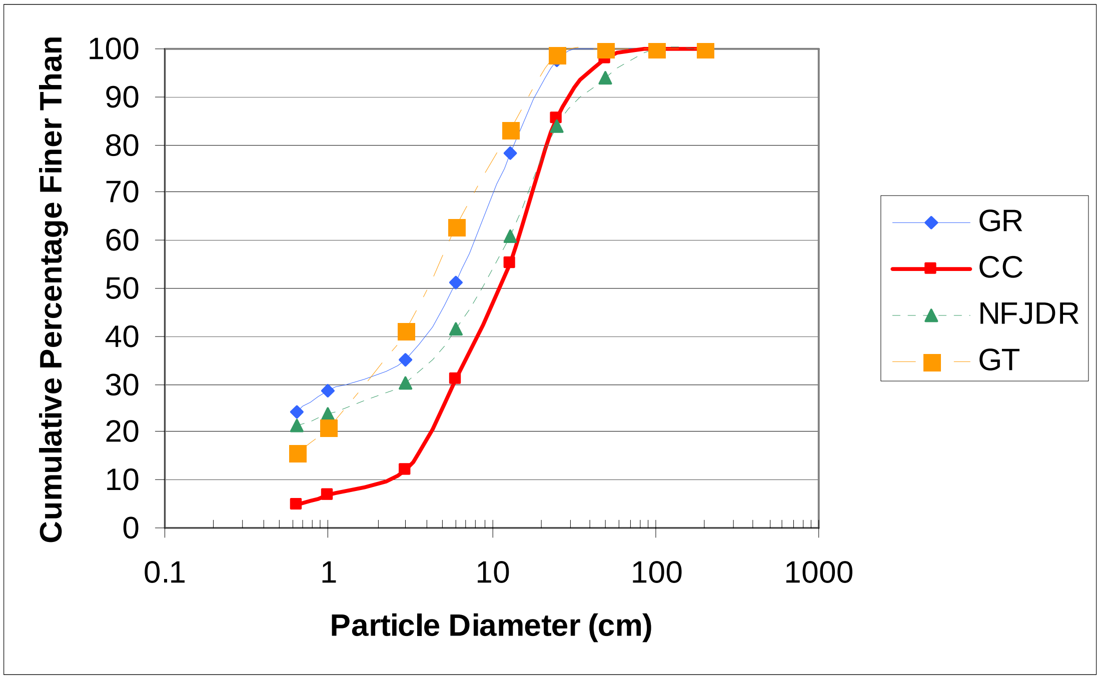


Figure 23 . Average cumulative particle size distribution of surface substrate composition based on estimates made visually at each of five transects per stream where overwinter buckets are embedded. Estimates were made September 11-12, 2002.

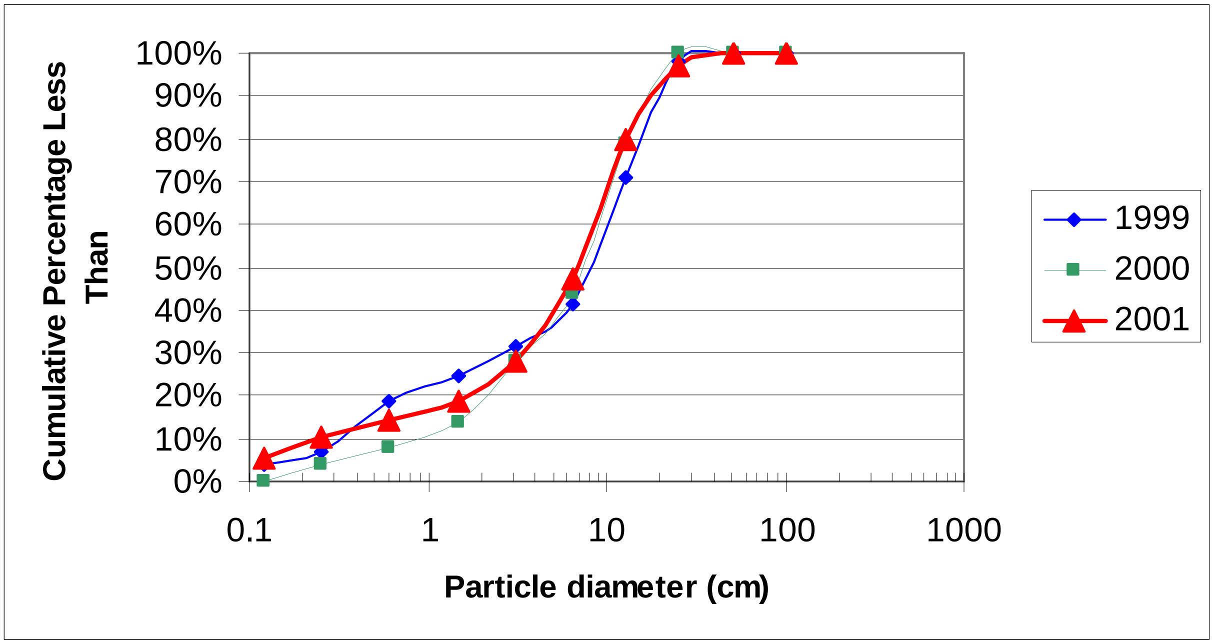


Figure 24. Mean pebble count evaluation of particle size distribution for years 1999-2001 on the Grande Ronde River.

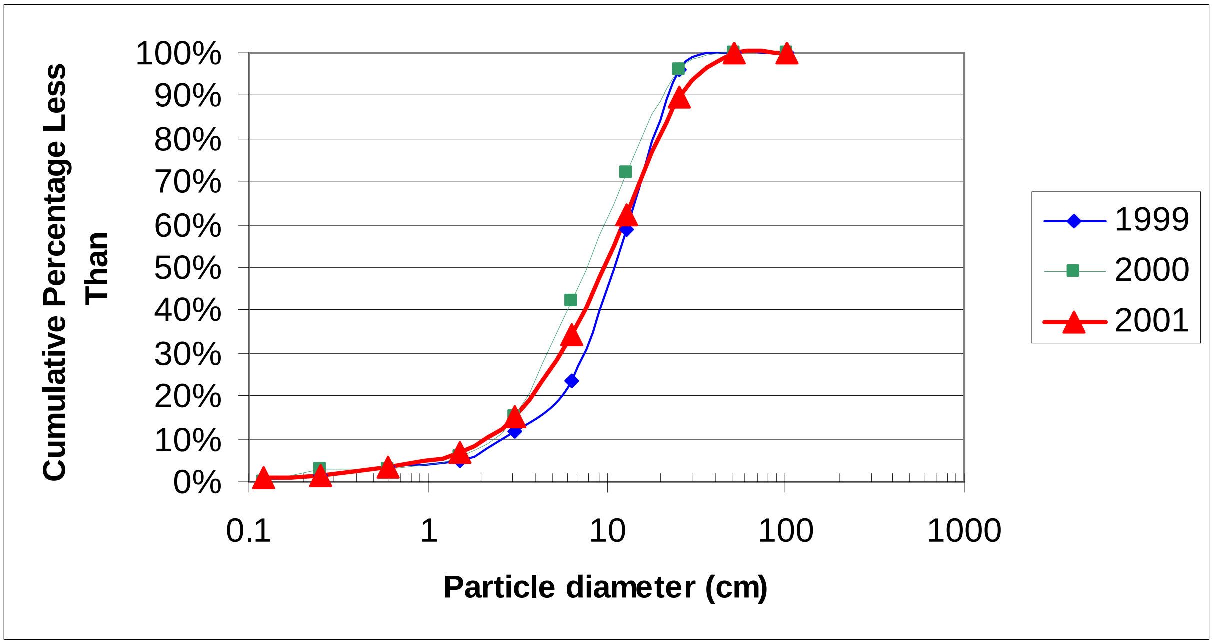


Figure 25. Mean pebble count evaluation of particle size distribution for years 1999-2001 on Catherine Creek.

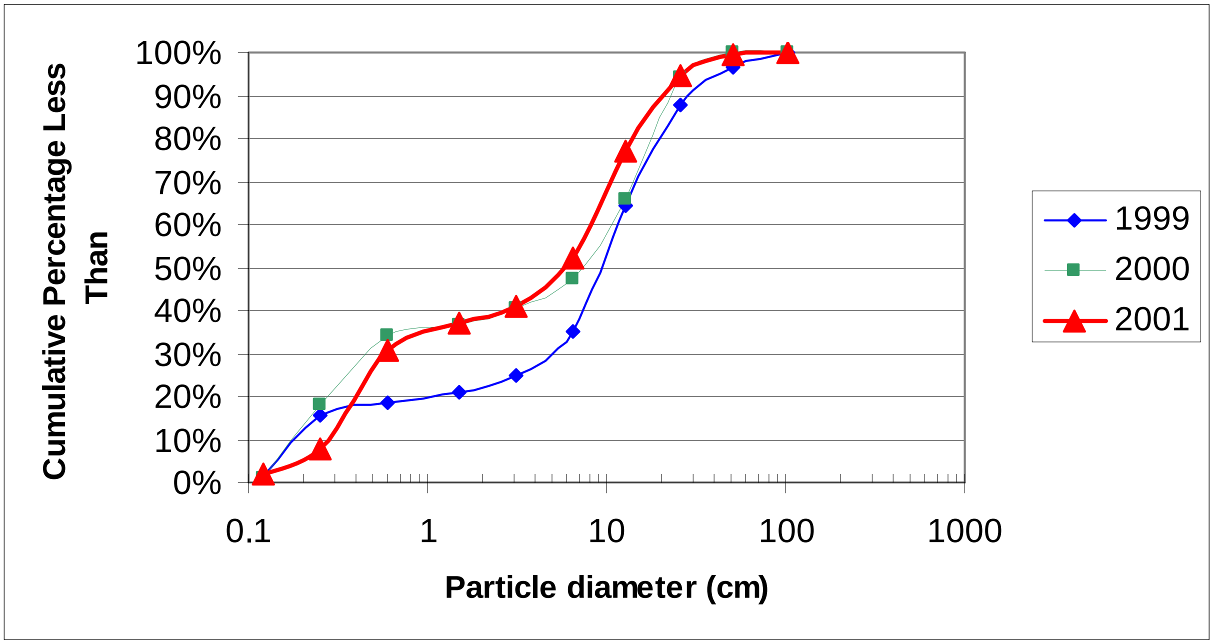


Figure 26. Mean pebble count evaluation of particle size distribution for years 1999-2001 on North Fork John Day River.

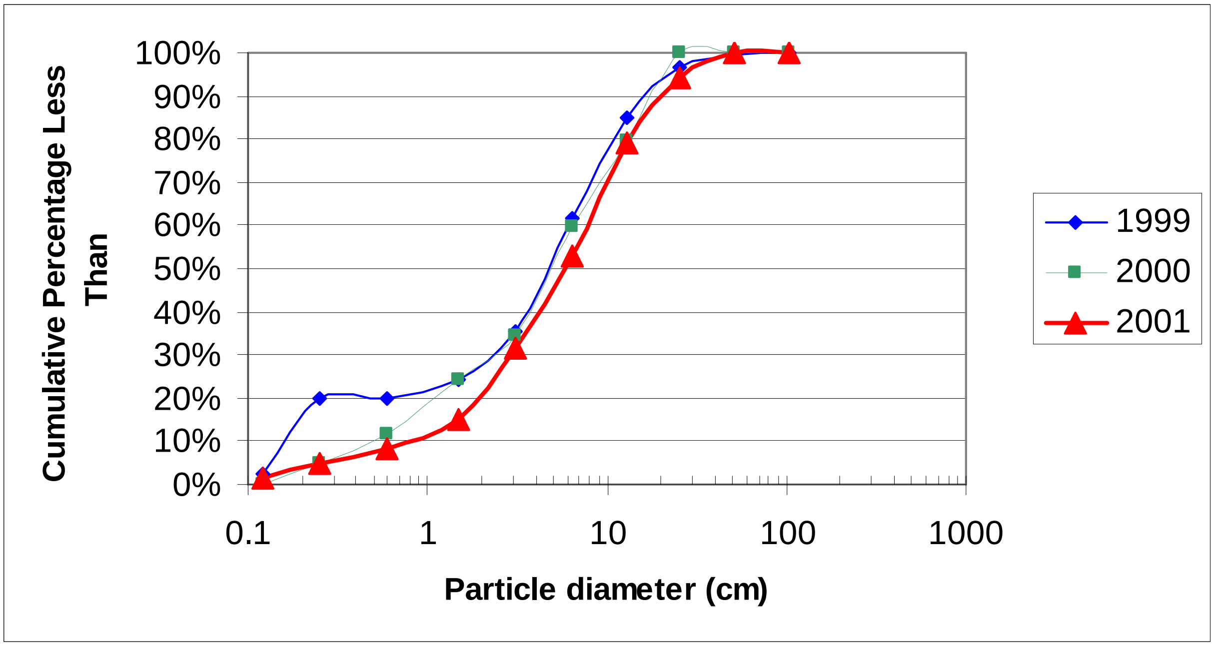


Figure 27. Mean pebble count evaluation of particle size distribution for years 1999-2001 on Granite Creek.

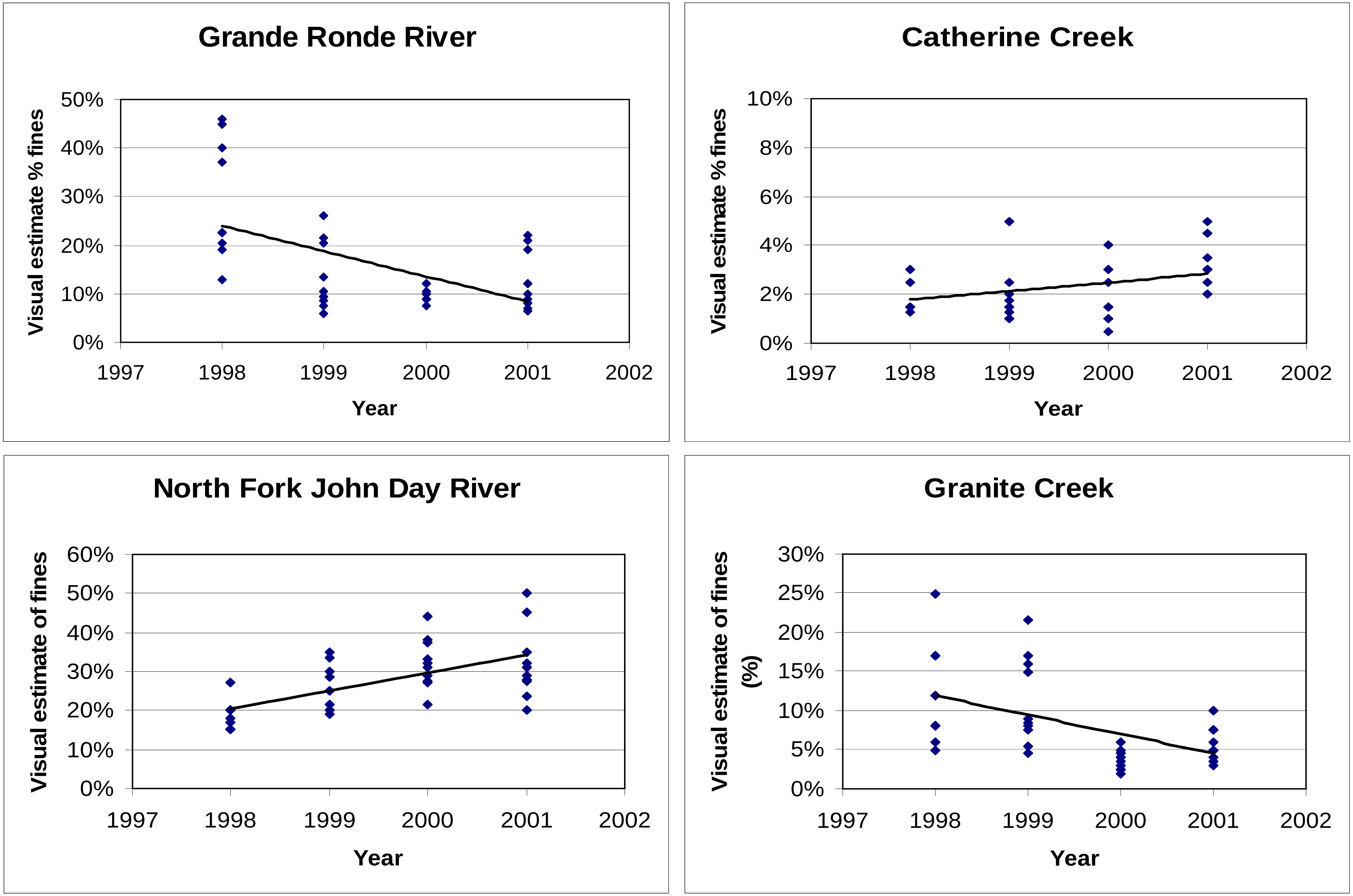


Figure 28. Trends in visual estimates of surface fine sediment (<6.3 mm) from 1998-2001.

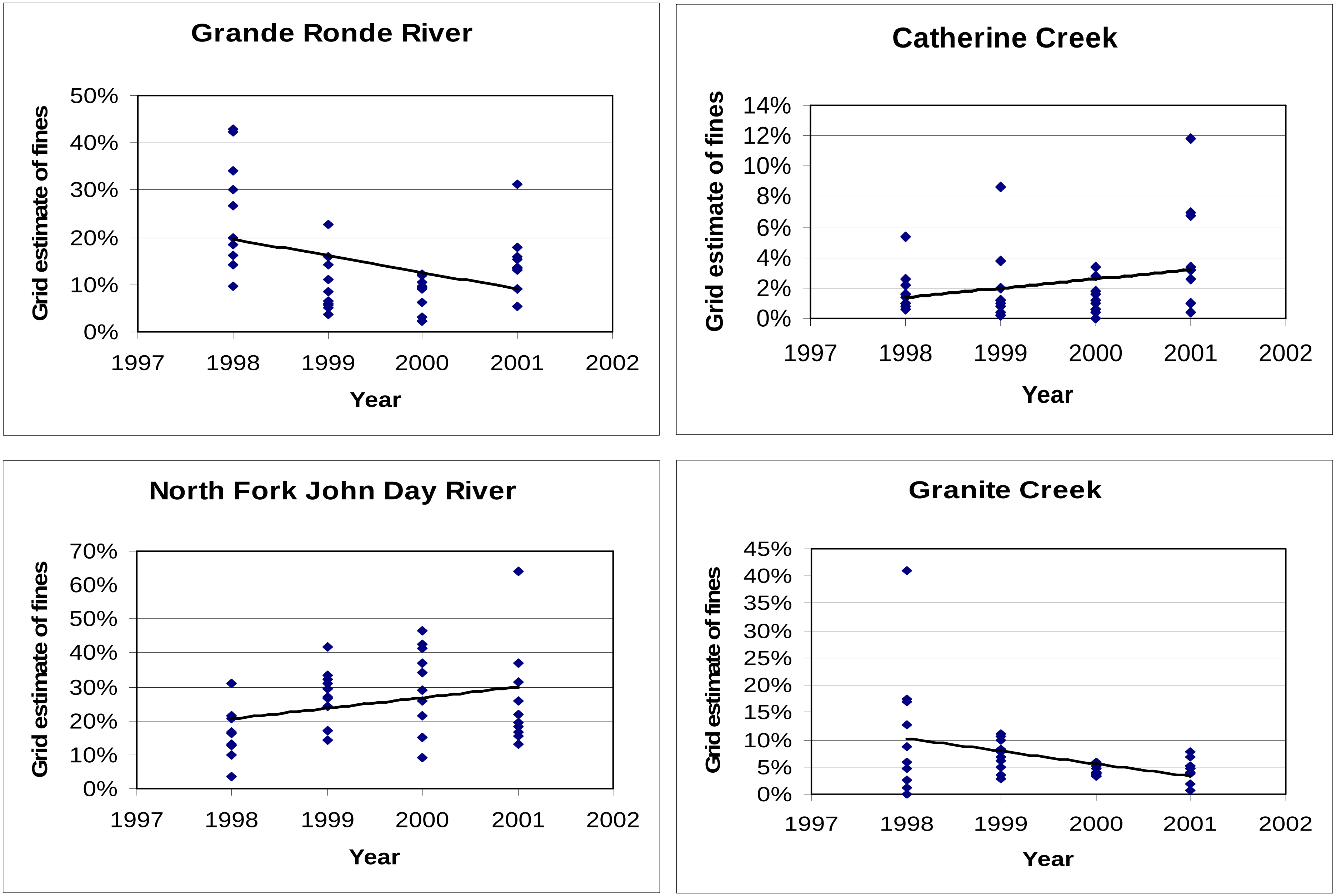


Figure 29. Trends in grid estimates of surface fine sediment (<6.3 mm) from 1998-2001.

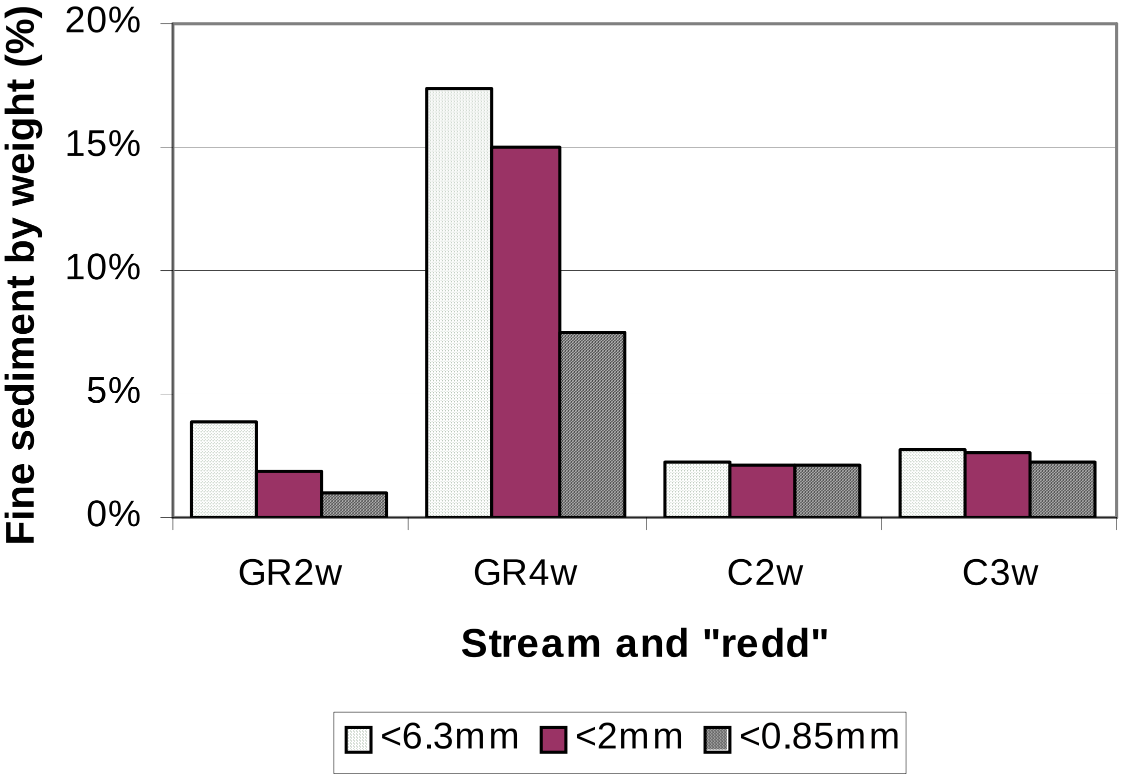
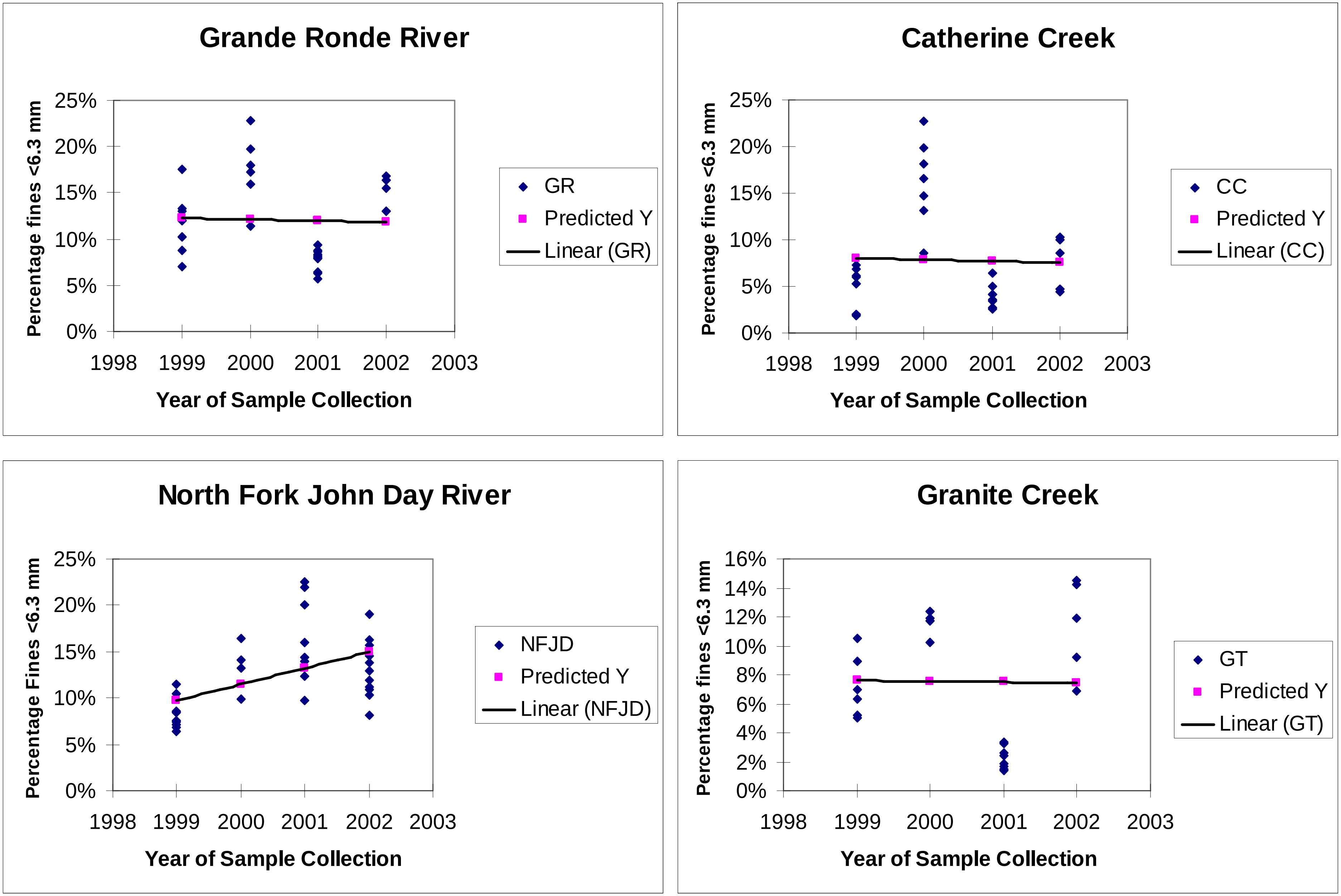


Figure 30. Fine sediment by weight for three size fractions in constructed redds in containers of cleaned gravels collected in Dec. 1998 (a mid-winter collection).



Grande Ronde River

Catherine Creek

North Fork John Day River

Granite Creek

Figure 31. Overwinter fine sediment (<6.3 mm) deposition trends in the four study streams over the years of sample collection 1999-2002.

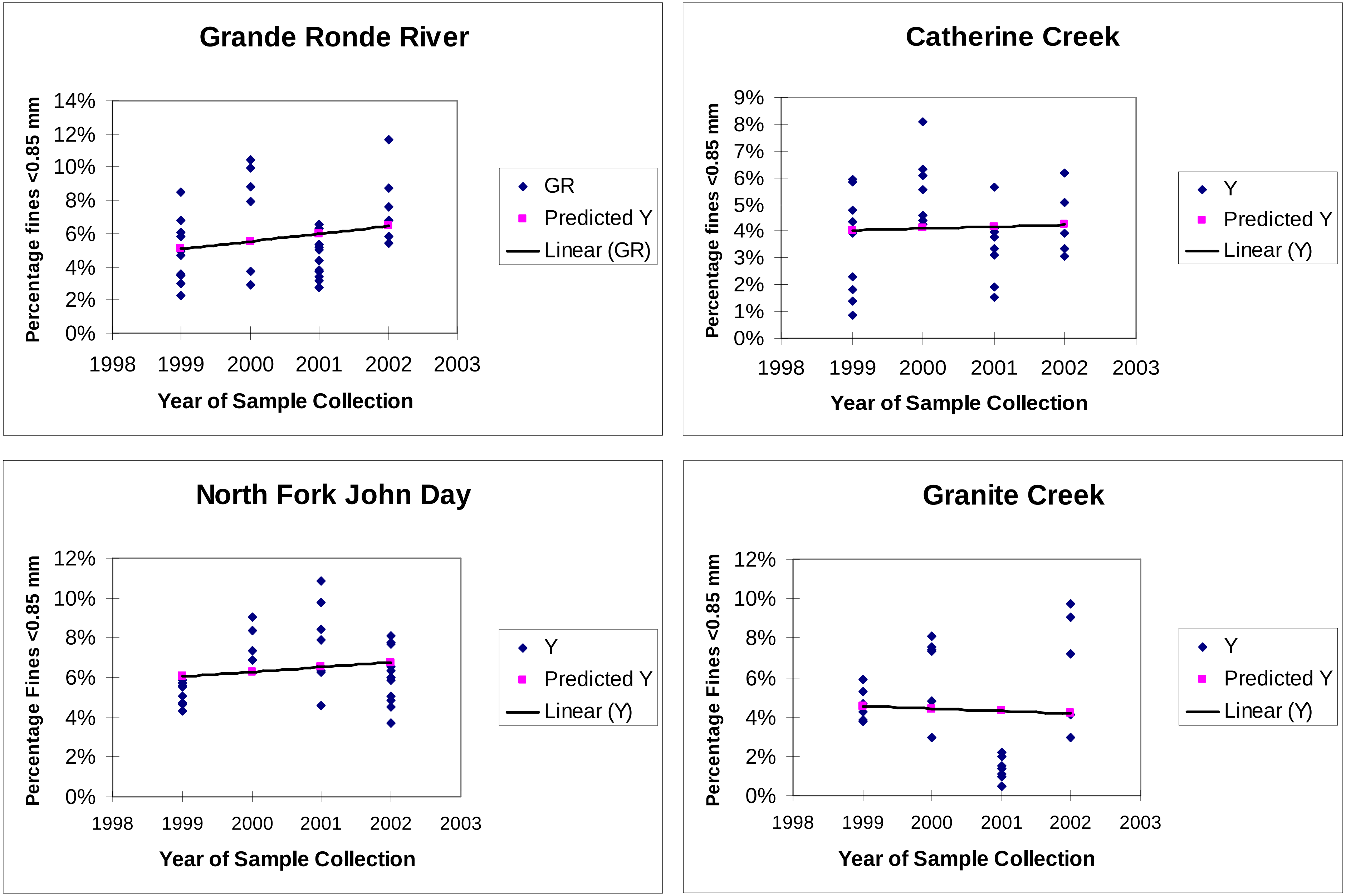


Figure 32. Overwinter fine sediment (<0.85 mm) deposition trends in the four study streams over the years of sample collection 1999-2002.

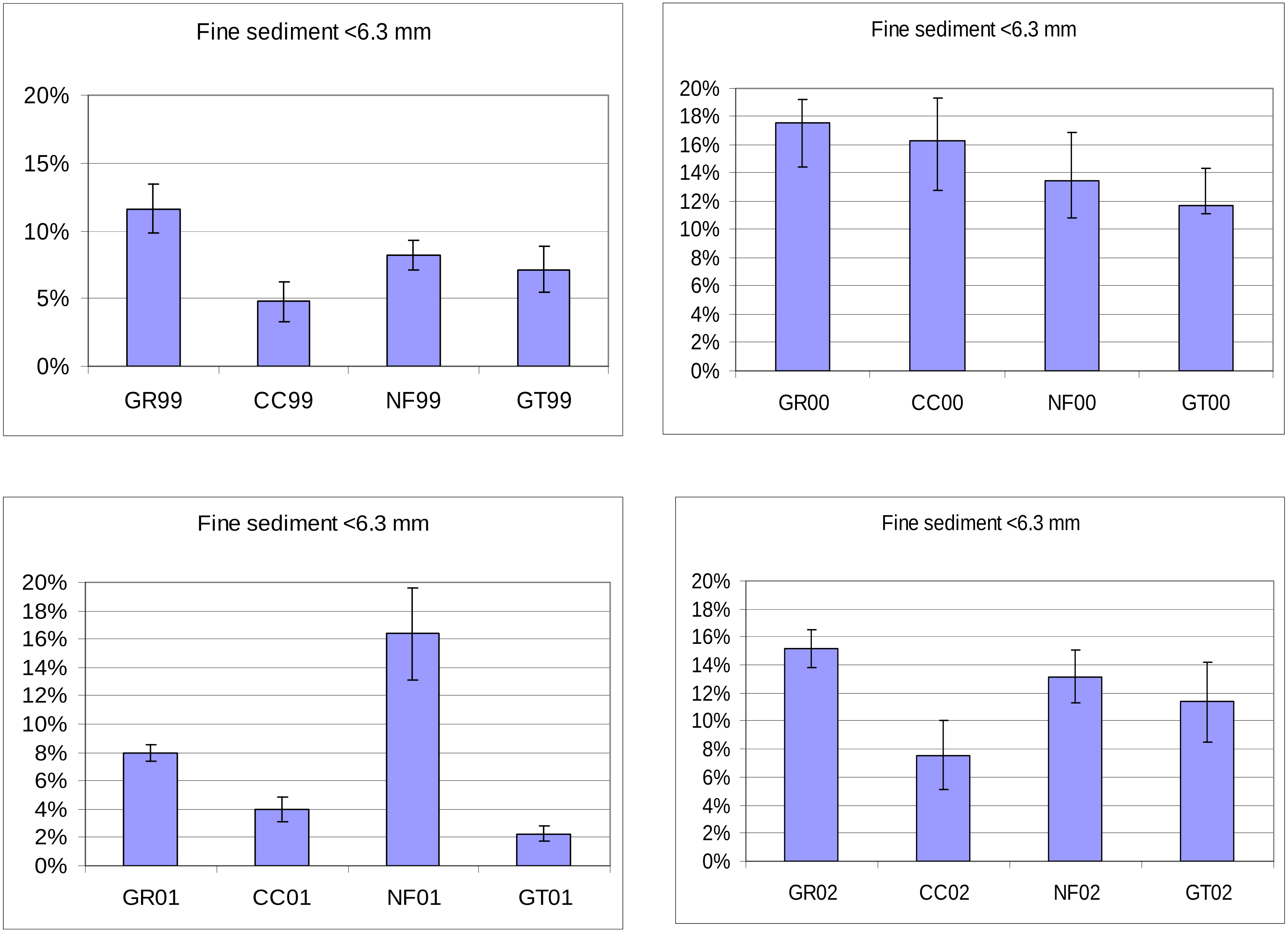


Figure 33. Overwinter fine sediment deposition (<6.3 mm) in simulated redds for each of 4 study streams for individual years. Confidence limits (95%) are calculated for each stream singly and not calculated by use of ANOVA.

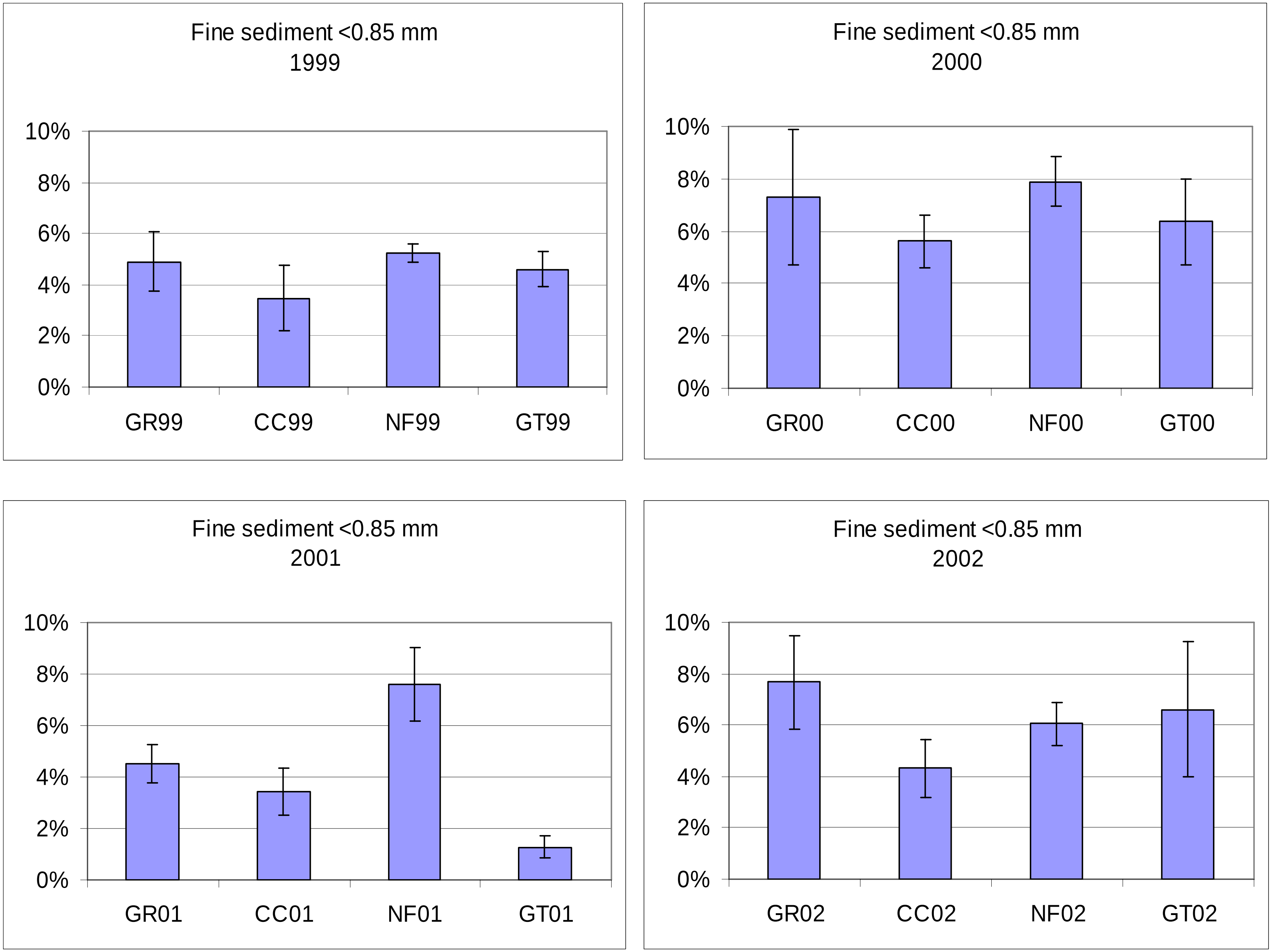
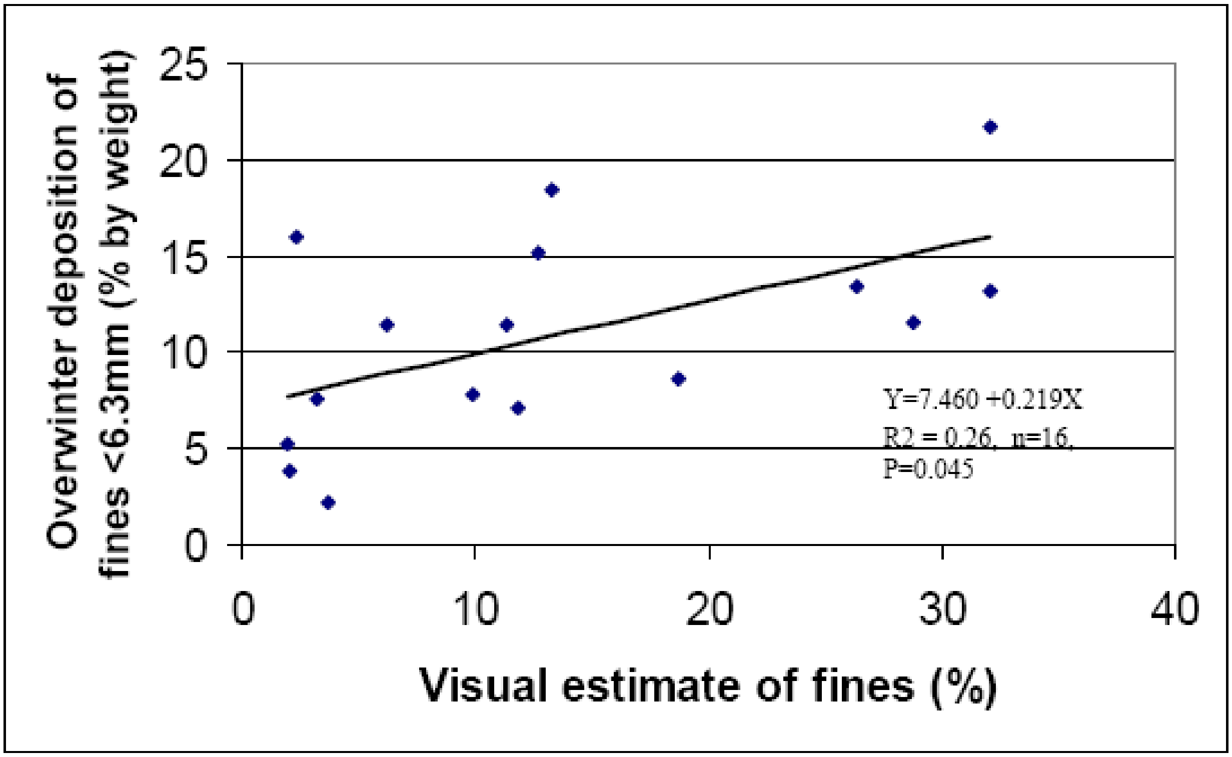


Figure 34. Overwinter fine sediment deposition (<0.85 mm) in simulated redds for each of 4 study streams for individual years. Confidence limits (95%) are calculated for each stream singly and not calculated by use of ANOVA.



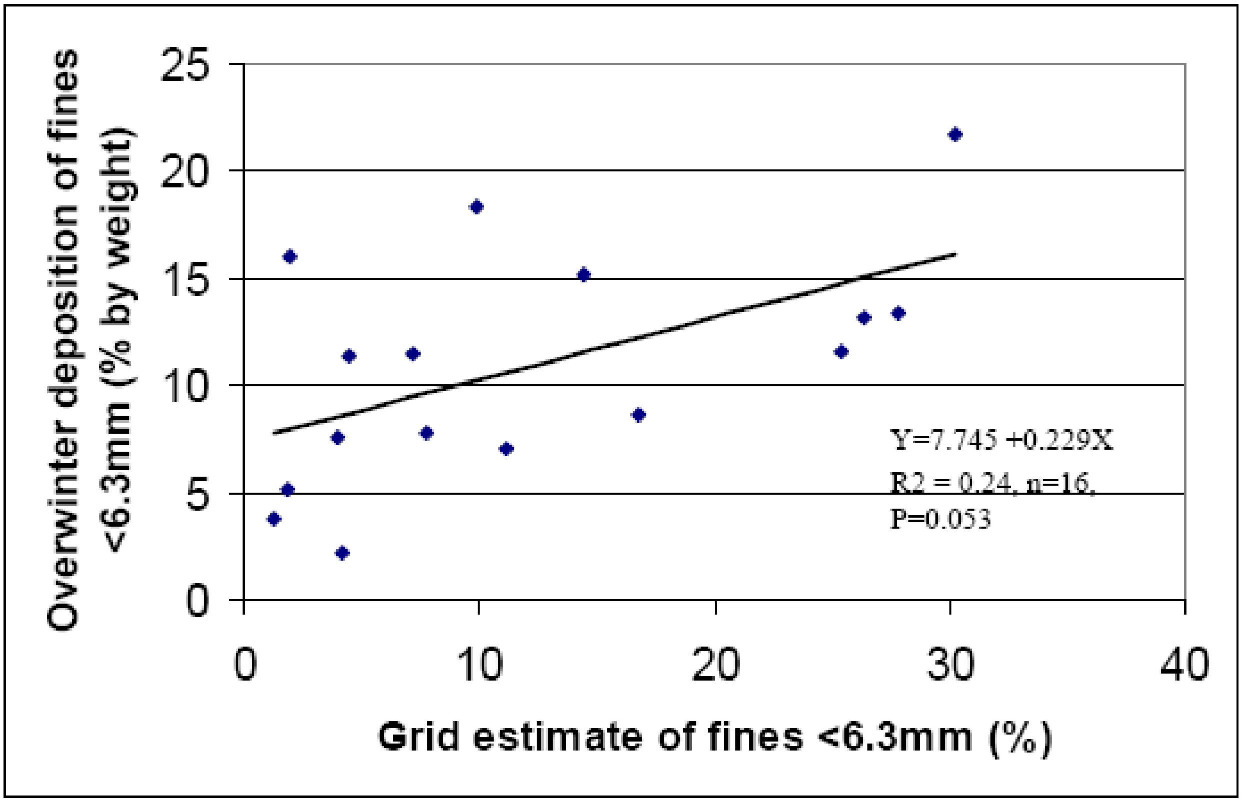


Figure 35. Prediction of overwinter fine sediment (<6.3 mm) deposition for samples collected in April from visual and grid estimates of fines made in August of the previous year.

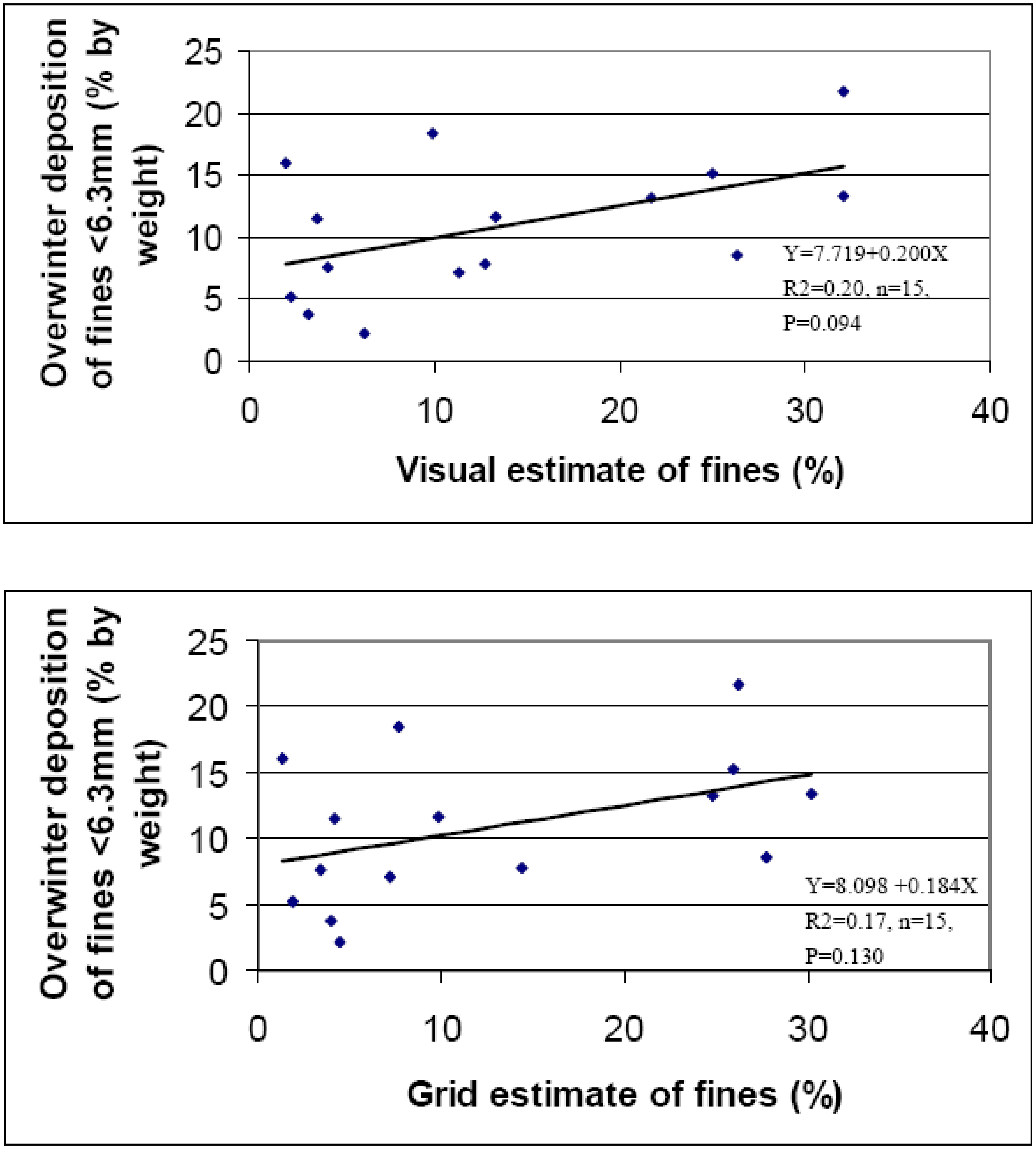


Figure 36. Prediction of overwinter fine sediment (<6.3 mm) deposition for samples collected in April from visual and grid estimates of fines made in August of the same year.

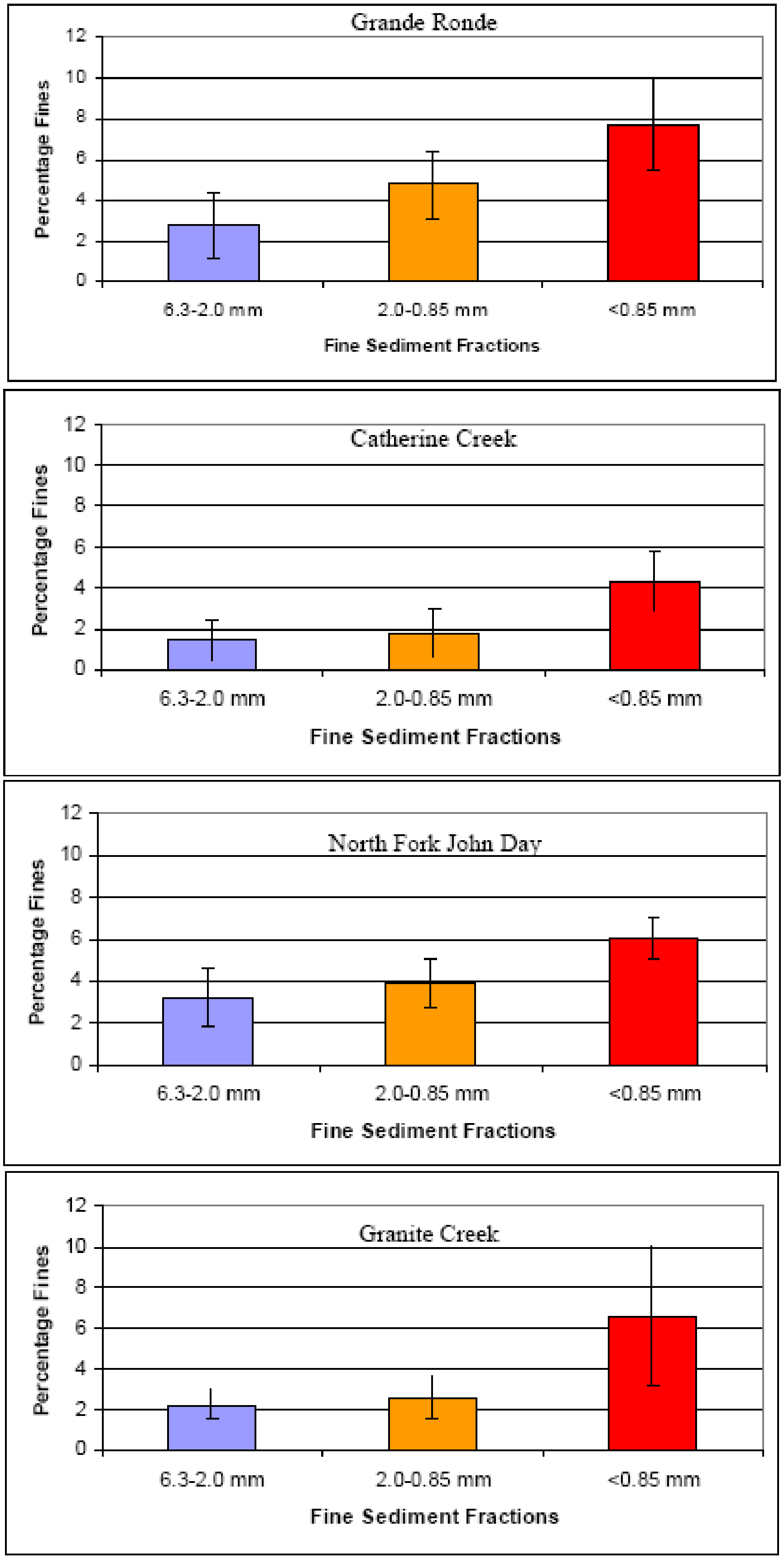


Figure 37. Mean percentage fines by weight in all overwinter samples collected in 2002 in the four study streams meeting the 6000 g framework particle criterion.

TABLES

Table 1. Hydrologic data from the USGS gages in the North Fork John Day and upper Grande Ronde drainages (USGS 2004).

ID No.	USGS Gaging Station Name	USGS Gage No	QAA cfs	cfs/mi^2	DA mi^2	Latitude (deg,min,sec)	Longitude (deg,min,sec)	Elev. ft	HUC	No. Yr. Data
1	Desolation Creek nr Dale, OR	14041000	97.90	0.906	108.0	44 59 20	118 55 10	2907	17070202	8
2	N Fk John Day River nr Dale, OR	14041500	397.43	0.757	525.0	44 59 55	118 56 25	2776	17070202	28
3	Camas Creek nr Lehman, OR	14042000	43.16	0.711	60.7	45 10 16	118 43 53	3970	17070202	19
4	Snipe Creek nr Ukiah, OR	14043560	16.57	0.448	37.0	45 11 05	118 56 20	3430	17070202	3
5	Fox Creek at Gorge nr Fox, OR	14044500	25.35	0.281	90.2	44 37 10	119 15 45	4240	17070202	27
6	N Fk John Day River at Monument, OR	14046000	1294.77	0.514	2520.0	44 48 50	119 25 50	1960	17070202	74
7	Grande Ronde River nr Hilgard, OR	13318500	261.94	0.519	505.0	45 19 00	118 16 00	3058	17060104	18
8	Grande Ronde River at La Grande, OR	13319000	381.64	0.563	678.0	45 20 47	118 07 26	2826	17060104	11
9	Catherine Creek near Union, OR	13320000	118.36	1.127	105.0	45 09 20	117 46 26	3082	17060104	71
10	Grande Ronde River near Elgin, OR	13323500	666.68	0.533	1250.0	45 30 45	117 55 35	2660	17060104	25
11	Indian Creek near Imbler, OR	13323600	41.22	1.874	22.0	45 26 00	117 49 20	3800	17060104	11
12	Lookingglass Creek nr Lookingglass, OR	13324300	138.39	1.767	78.3	45 43 55	117 51 50	2520	17060104	20

Table 2. Statistics on study reaches and their watersheds.

		GR	CC	NFJDR	GT
Basin Physiography	Area (km$_2$)	101.7	172.6	89.3	259
	Maximum Elevation (km)	2.4018	2.6383	2.6213	2.5116
	Minimum Elevation (km)	1.3472	1.0150	1.5972	1.3655
	Watershed Length (km)	14.91	24.47	17.40	14.47
	Watershed gradient	0.0546	0.0502	0.0308	0.0497
Study Reach	Study Reach Length (km)	0.42	6.04	0.39	0.30
	Study Reach Gradient	0.0218	0.0156	0.0234	0.0000
	Reach Length Between Nearest Contours (km)	0.4837	6.5560	1.7152	1.5779
	Reach Gradient-Nearest Contours	0.0252	0.0167	0.0142	0.0077
Roads	Roads (km)	146.6	342.7	103.6	650.1
	Road Density (km/km^2)	1.44	1.99	1.16	2.51
	Road Density (mi/mi^2)	2.32	3.19	1.87	4.04
	Wilderness (%)	0.00	0.28	0.61	0.17
	Road Density (roaded area) (km/km^2)	1.44	2.74	3.01	3.01
	Road Density (roaded area) (mi/mi^2)	2.32	4.41	4.85	4.85
Precipitation	Weighted av. Ppt.(inches/yr)	33.72	43.42	34.64	28.62
	cm/yr	85.65	110.29	87.99	72.69
	Area (m^2)	1.017E+08	1.726E+08	8.930E+07	2.590E+08
	Ppt.(m/yr)	0.8565	1.1029	0.8799	0.7269
	Volume ppt. (m^3)	8.710E+07	1.904E+08	7.857E+07	1.883E+08
	Percentage of max. volume	0.46	1.00	0.41	0.99
Hydrology	QAA (cfs) *	35.91	56.16	32.17	79.14
Land Use (%)	No code	0.00	0.00	0.00	0.00
	Open Water	0.01	0.00	0.05	0.00
	Perennial Ice/Snow	0.04	0.00	0.04	0.00
	Low Intensity Residential	0.00	0.00	0.02	0.00
	Commercial/Industrial/Transportation	0.00	0.00	0.00	0.01
	Bare Rock/Sand/Clay	0.44	1.52	0.93	0.17
	Transitional	0.09	0.01	1.05	0.45
	Deciduous Forest	0.00	0.00	0.00	0.01
	Evergreen Forest	78.43	89.82	81.78	82.25
	Mixed Forest	0.00	0.02	0.00	0.00
	Shrubland	10.21	5.97	10.61	8.86
	Grasslands/Herbaceous	10.66	2.65	5.32	8.06
	Woody Wetlands	0.00	0.00	0.00	0.00
	Emergent Herbaceous Wetlands	0.12	0.00	0.21	0.19
Ecoregion-Level IV (%)	Maritime Influenced Zone	8.66	0.00	0.00	0.00
	Melange	0.00	0.00	0.00	8.17
	Wallowas/Seven Devils Mountains	0.00	38.29	0.00	0.00
	Mesic Forest Zone	89.62	45.03	77.21	86.84
	Subalpine Zone	1.72	16.68	22.79	4.99
Ownership (%)	Private	0.00	5.38	2.13	4.99
	US Forest Service	100.00	94.20	97.87	95.01
	Bureau of Land Management	0.00	0.42	0.00	0.00
Wilderness	Area (mi^2)	0.00	18.38	21.20	16.66
	Area (km^2)	0.00	47.60	54.91	43.14
	Wilderness (%)	0.00	27.58	61.49	16.66
Grazing	Total Potential AUMs/Clipped Pasture	252.4	2091.8	120.7	289.7
	Current AUMs/Clipped Pasture	0.0	1983.7	0.0	284.9
	Total Pasture (acres)	6692.1	40422.7	4931.8	7771.5
	Total Pasture (km$_2$)	27.1	163.6	20.0	31.4
	Pasture (% of watershed area)	26.6	94.8	22.3	12.1

* based on the regression equation
$QAA = 1.6122DA^{0.8455}$
$R^2 = 0.8588$

Table 3. Geographic location of transects at which artificial redds were created in study streams from the August 2001 fieldwork.

Stream	Transect	Latitude		Longitude		Channel width m
		degrees	min.	degrees	min.	
Grande Ronde	GR1	45	4.18	118	18.84	6.7
Grande Ronde	GR2	45	4.17	118	18.82	6.2
Grande Ronde	GR3	45	4.14	118	18.80	8.8
Grande Ronde	GR4	45	4.05	118	18.78	7.3
Grande Ronde	GR5	45	4.04	118	18.79	7.0
Catherine Cr.	CC1	45	7.91	117	42.51	7.0
Catherine Cr.	CC2	45	7.92	117	42.51	7.0
Catherine Cr.	CC3	45	7.44	117	41.98	9.0
Catherine Cr.	CC4	45	7.22	117	38.78	9.2
Catherine Cr.	CC5	45	7.22	117	38.77	7.9
NFJDR	NFJDR1	44	54.76	118	23.38	10.1
NFJDR	NFJDR2	44	54.67	118	23.31	8.5
NFJDR	NFJDR3	44	54.66	118	23.21	10.1
NFJDR	NFJDR4	44	54.67	118	23.20	10.8
NFJDR	NFJDR5	44	54.67	118	23.19	9.8
Granite Cr	GT1	44	49.61	118	27.44	7.0
Granite Cr	GT2	44	49.59	118	27.42	7.4
Granite Cr	GT3	44	49.56	118	27.37	6.7
Granite Cr	GT4	44	49.51	118	27.29	4.7
Granite Cr	GT5	44	49.50	118	27.28	10.2

Table 4. USGS stream gaging stations in the vicinity of the study areas.

Stream	Catherine Cr.	Lookingglass Cr.	North Fork JDR
Gage number	13320000	13324300	14046000
Site description	Near Union, OR	Near Looking Glass, OR.	River at Monument, OR
HUC	17060104	17060104	17070202
County	Union	Union	Grant
Latitude	45°09'20"	45°43'55"	44°48'50",
Longitude (NAD27)	117°46'26"	117°51'50"	119°25'50"
Drainage area (mi2)	105.00	78.30	2,520.00
Elevation (feet above sea level NGVD29)	3,081.76		1,959.64
Years of streamflow record	1911-1996	1982-2001	1928-2001

Table 5. Determination of significance of differences in slopes and elevations of regressions for four streams of visually estimated surface fine sediment data vs. year (1998-2001).

Calculations for testing for significant differences among slopes and elevations of k simple linear regression lines for **visually estimated** sediment data

See Zar Table 18.1, p. 370

Visual		Σx^2	$\Sigma(xy)$	Σy^2	**Residual SS**	**Residual DF**	*n*	*b*
Regression 1	Catherine	50	0.17625	0.00549	0.00487	38	40	0.0035
Regression 2	Grande Ronde	50	-2.59250	0.42337	0.28895	38	40	-0.0518
Regression 3	Granite	50	-1.22500	0.11810	0.08809	38	40	-0.0245
Regression 4	NFJDR	50	2.30000	0.27350	0.16770	38	40	0.0460
Pooled regression					0.54960	152		
Common regression		200	-1.34125	0.82046	0.81146	155		
Total regression					2.21132	158		
	Test of multiple slopes	F=		24.14 reject Ho				
	see Zar, p. 370	$F_{(0.05)(1),3,152}$		2.66				
	Test of multiple elevations	F=		89.13 reject Ho				
		$F_{(0.05)(1),3,155}$						

Table 6 . Determination of significance of differences in slopes and elevations of regressions for four streams of grid-estimated surface fine sediment data vs. year (1998-2001).

Calculations for testing for significant differences among slopes and elevations of k simple linear regression lines for **grid-estimated** sediment data

See Zar Table 18.1, p. 370

Grid		Σx^2	$\Sigma(xy)$	Σy^2	**Residual SS**	**Residual DF**	*n*	*b*
Regression 1	Catherine	50	0.30300	0.02431	0.02247	38	40	0.00606
Regression 2	Grande Ronde	50	-1.77300	0.39968	0.33681	38	40	-0.05185
Regression 3	Granite	50	-1.15400	0.17724	0.15061	38	40	-0.02450
Regression 4	NFJDR	50	1.56100	0.55949	0.51075	38	40	0.03122
Pooled regression					1.02064	152		
Common regression		200	-1.0630	1.1607	1.15506	155		
Total regression					2.36992	158		
	Test of multiple slopes	F=		6.67 reject Ho				
	see Zar, p. 370	$F_{(0.05)(1),3,152}$		2.66				
	Test of multiple elevations	F=		54.34 reject Ho				
		$F_{(0.05)(1),3,155}$		2.66				

Table 7. Regression statistics for regression of visual- vs. grid-based estimates of surface fine sediment. This analysis is based upon measurements at each of 10 transects per year per stream for the period 1998-2001.

SUMMARY OUTPUT Visual vs. grid estimates of surface fines

Regression Statistics	
Multiple R	0.88347
R Square	0.78053
Adjusted R Square	0.77914
Standard Error	0.05744
Observations	160

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.85420	1.85420	561.90851	6.66765E-54
Residual	158	0.52137	0.00330		
Total	159	2.37557			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.00166	0.00690	-0.24034	0.81038	-0.01530	0.01198
X Variable 1	0.91384	0.03855	23.70461	0.00000	0.83770	0.98998

Table 8. ANOVA conducted on the surface fine sediment estimates made using all three methods of estimation employed in this study.

Anova: Single Factor

SUMMARY

Groups	***Count***	***Sum***	***Average***	***Variance***
Visual	46	5.983	0.130	0.0124
Grid	46	5.796	0.126	0.0142
Pebble count	46	6.840	0.149	0.0115

ANOVA

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0135	2	0.0067	0.5304	0.5896	3.0632
Within Groups	1.7162	135	0.0127			
Total	1.7297	137				

Table 9. Regression equations for the study streams for surface fine sediment levels estimated visually each August for the period 1998-2001. * indicates a significant regression.

Stream	**Regression for fines <6.3 mm**	**Slope direction**	**R^2**	**n**	**P-value for slope coefficient**
Grande Ronde	Y= 103.84 – 0.052X	Decreasing	0.32	40	0.00015*
Catherine Creek	Y= -7.03 + 0.0035X	Increasing	0.11	40	0.034*
North Fork John Day	Y= -91.70 + 0.046X	Increasing.	0.39	40	0.000018*
Granite Creek	Y= 49.1 – 0.025X	Decreasing	0.25	40	0.00091*

Table 10. Regression equations for the study streams for surface fine sediment levels estimated by the grid method each August for the period 1998-2001. * indicates a significant regression.

Stream	Regression for fines <6.3 mm	Slope direction	R^2	n	P-value for slope coefficient
Grande Ronde	Y= 71.05 – 0.035X	Decreasing.	0.16	40	0.011*
Catherine Creek	Y= -12.09 + 0.0061X	Increasing.	0.076	40	0.086
North Fork John Day	Y= -62.17 + 0.031X	Increasing.	0.087	40	0.064
Granite Creek	Y= 46.22 – 0.023X	Decreasing.	0.15	40	0.013*

Table 11. Tukey test for multiple comparison of slopes for pair-wise comparisons of regressions of visually- and grid-estimated surface fine sediment data vs. year (1998-2001).

Multiple Comparison among Slopes Zar, p. 372

see Zar, p. 362 for calc. of SE

n=40 df=38 for each stream

Visual Calculation of test statistic *q*

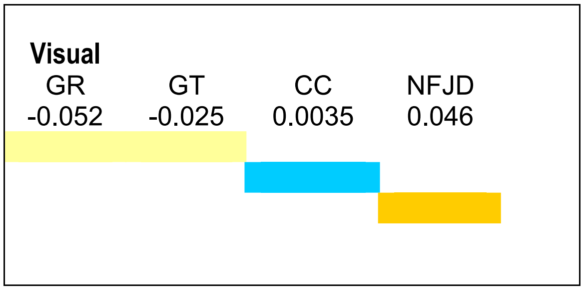
	b	Residual SS	Catherine	Grande Ronde	Granite	NFJDR
Catherine	0.00352	0.00487				
Grande Ronde	-0.05185	0.28895	6.2974			
Granite	-0.02450	0.08809	5.6662	-2.7457		
NFJDR	0.04600	0.16770	-6.3029	-8.9261	-8.5930	

Grid Calculation of test statistic *q*

	b	Residual SS	Catherine	Grande Ronde	Granite	NFJDR
Catherine	0.00606	0.02247				
Grande Ronde	-0.03546	0.33681	4.2700			
Granite	-0.02308	0.15061	4.3177	-1.0931		
NFJDR	0.03122	0.51075	-2.1240	-4.4648	-4.1160	

$q_{0.05,152,4}$ = 3.685

Graphical display of the statistical differences and/or similarities in regression slopes via Tukey multiple comparison testing.



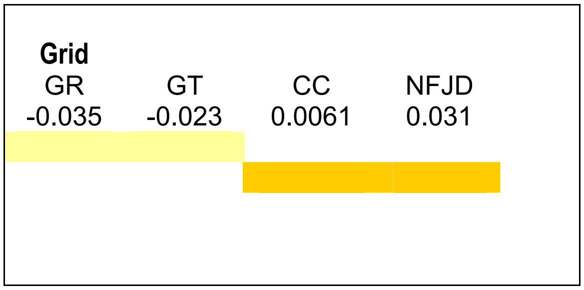


Table 12. Tukey test for multiple pairwise comparison of four streams for elevations of the regression lines expressing visually and grid estimated surface fine sediment vs. year (1998-2001).

Visual

Multiple Comparison among Elevations

Zar, p. 372

see Zar, p. 371 for calc of common regression coefficient (b_c) $b_c =$ -0.0067062

see Zar, p. 374 for calc. of SE

Visual n=40 df=38 for each stream

Calculation of test statistic ***q*** residual MS for common regr.= 0.00745

	X-bar	**Y-bar**	**Σx^2**	see p. 365 for calc. of residual MS for common regr.
Catherine	1999.5	2.31%	0.17625	
Grande Ronde	1999.5	16.16%	-2.59250	
Granite	1999.5	8.23%	-1.22500	
NFJDR	1999.5	27.28%	2.30000	

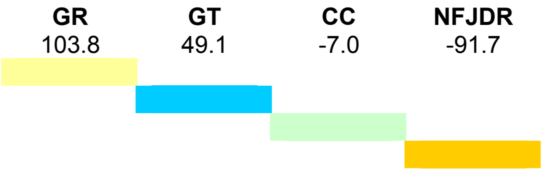
SE= 0.01365

Calculation of test statistic ***q***

	Catherine	**Grande Ronde**	**Granite**	**NFJDR**
Catherine				
Grande Ronde	10.15			
Granite	4.34	5.82		
NFJDR	18.29	8.14	13.96	

$q_{0.05(2),152}=$ 3.685

Graphical display of the statistical differences and/or similarities in regression elevations via Tukey multiple comparison testing.



Grid

Multiple Comparison among Elevations

Zar, p. 372

see Zar, p. 371 for calc of common regression coefficient (b_c) $b_c =$ -0.005315

see Zar, p. 374 for calc. of SE

Grid n=40 df=38 for each stream

Calculation of test statistic ***q*** residual MS for common regr.= 0.00745

	X-bar	**Y-bar**	**Σx^2**	see p. 365 for calc. of residual MS for common regr.
Catherine	1999.5	2.29%	0.30300	
Grande Ronde	1999.5	14.36%	-1.77300	
Granite	1999.5	6.74%	-1.15400	
NFJDR	1999.5	25.28%	1.56100	

SE= 0.01365

Calculation of test statistic ***q***

	Catherine	**Grande Ronde**	**Granite**	**NFJDR**
Catherine				
Grande Ronde	8.34			
Granite	3.26	5.58		
NFJDR	16.84	8.00	13.58	

$q_{0.05(2),152}=$ 1.976

Graphical display of the statistical differences and/or similarities in regression elevations via Tukey multiple comparison testing.

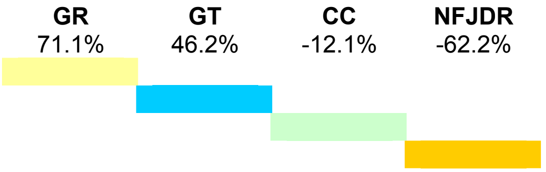


Table 13. Determination of statistical significance of differences in means of the annual series of visual estimates of surface fine sediment for each of 4 study streams by single factor ANOVA.

Anova: Single Factor Grande Ronde River
based on visual estimates for each of 10 transects per year

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1998	10	2.88	0.28800	0.01427
1999	10	1.33	0.13300	0.00475
2000	10	0.99	0.09900	0.00019
2001	10	1.27	0.12650	0.00344

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.21946	3	0.07315	12.91477	0.00001	2.86627
Within Groups	0.20391	36	0.00566			
Total	0.42337	39				

Anova: Single Factor Catherine Creek
based on visual estimates for each of 10 transects per year

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1998	10	0.18750	0.01875	0.00005
1999	10	0.22500	0.02250	0.00023
2000	10	0.19500	0.01950	0.00012
2001	10	0.31500	0.03150	0.00009

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001028	3	0.000343	2.76235	0.05607	2.86627
Within Groups	0.004466	36	0.000124			
Total	0.005494	39				

Anova: Single Factor North Fork John Day River
based on visual estimates for each of 10 transects per year

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1998	10	1.87	0.18700	0.00133
1999	10	2.63	0.26250	0.00297
2000	10	3.21	0.32050	0.00419
2001	10	3.21	0.32100	0.00849

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.12066	3	0.04022	9.47394	0.00009	2.86627
Within Groups	0.15284	36	0.00425			
Total	0.27350	39				

Anova: Single Factor Granite Creek
based on visual estimates for each of 10 transects per year

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1998	10	1.18	0.11800	0.00391
1999	10	1.13	0.11250	0.00323
2000	10	0.37	0.03700	0.00016
2001	10	0.62	0.06150	0.00064

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.04671	3	0.01557	7.85249	0.00037	2.86627
Within Groups	0.07139	36	0.00198			
Total	0.11810	39				

Table 14. Single factor ANOVA evaluating differences among means in surface fine sediment of a 4-year period in study streams and a Tukey multiple comparison test of differences between individual pairs of streams in surface fines.

Anova: Single Factor
SUMMARY

	Groups	*Count*	*Sum*	*Average*	*Variance*
1	Grande Ronde	40	6.465	0.16163	0.01086
2	Catherine Cr	40	0.923	0.02306	0.00014
3	NFJDR	40	10.910	0.27275	0.00701
4	Granite Creek	40	3.290	0.08225	0.00303

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.39986	3	0.46662	88.72	1.507E-33	2.66
Within Groups	0.82046	156	0.00526			
Total	2.22032	159				

Tukey Multiple Comparison Test with equal sample sizes see Zar (1999), p. 211

SE	Comparison	Diff.	q	$q_{0.05(2),156,4}$	Conclusion
0.01147	1vs.2	0.1386	12.084	3.633	Reject H_o
0.01147	1vs.3	0.1111	9.691	3.633	Reject H_o
0.01147	1vs.4	0.0794	6.922	3.633	Reject H_o
0.01147	2vs.3	0.2497	21.775	3.633	Reject H_o
0.01147	2vs.4	0.0592	5.162	3.633	Reject H_o
0.01147	3vs.4	0.1905	16.613	3.633	Reject H_o

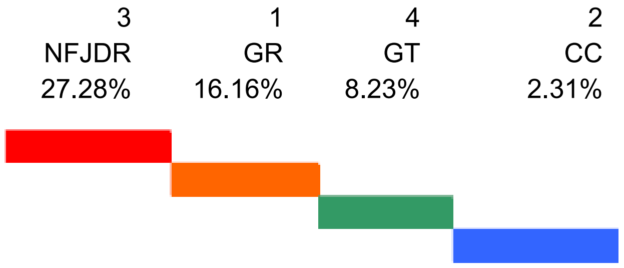


Table 15. Regression equations for the study streams for overwinter fine sediment deposition (<0.85 mm and <6.3 mm), indicated as percentage of total sample dry weight in simulated redds. * indicates significant regression.

Stream	**Regression for fines <0.85 mm**	**Slope direction**	**R^2**	**n**	**P-value for slope coefficient**
Grande Ronde	Y= -9.05 + 0.0046X	Increasing	0.044	33	0.24
Catherine Creek	Y= -1.30 + 0.00067X	Increasing	0.0019	29	0.82
North Fork John Day	Y= -4.78 + 0.0024X	Increasing	0.031	32	0.33
Granite Creek	Y= 2.72 - 0.0013X	Decreasing	0.0027	25	0.81
	Regression for fines <6.3 mm		**R^2**	**n**	**P-value for slope coefficient**
Grande Ronde	Y= 3.01 – 0.0014X	Decreasing	0.0013	33	0.84
Catherine Creek	Y= 3.27 - 0.0016X	Decreasing	0.00095	29	0.87
North Fork John Day	Y= -34.53 + 0.017X	Increasing	0.24	32	0.0041*
Granite Creek	Y= 1.13 - 0.00053X	Decreasing	0.00017	25	0.95

Table 16. ANOVA with a Tukey multiple comparison test of the significance in differences between means of overwinter sedimentation (fines <6.3 mm) for the 4 streams for year 1999, 2000, 2001, and 2002 collections.

Anova: Single Factor 1999 Fines <6.3mm

SUMMARY A

Groups	Count	Sum	Average	Variance
1 GR99	10	1.16370	0.11637	0.00082
2 CC99	9	0.42873	0.04764	0.00049
3 NF99	9	0.74052	0.08228	0.00028
4 GT99	6	0.42850	0.07142	0.00046

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.02309	3	0.00770	14.54639	0.00000	2.92228
Within Groups	0.01587	30	0.00053			
Total	0.03897	33				

Tukey Multiple Comparison Test see App.64
Year 1999 see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,30,4}$	Concl.
0.00747	1 vs.2	0.0687	9.1967	3.8450	Reject Ho
0.00747	1 vs.3	0.0341	4.5613	3.8450	Reject Ho
0.00840	1 vs.4	0.0450	5.3517	3.8450	Reject Ho
0.00767	2 vs.3	0.0346	4.5180	3.8450	Reject Ho
0.00857	2 vs.4	0.0238	2.7739	3.8450	Accept Ho
0.00857	3 vs.4	0.0109	1.2671	3.8450	Accept Ho

1	3	4	2
GR	NF	GT	CC
11.6%	8.23%	7.14%	4.76%
GR≠	NF=	GT=	CC
🟨			
	🟧	🟧	
		🟩	🟩

Anova: Single Factor 2000 Fines <6.3mm

SUMMARY B

Groups	Count	Sum	Average	Variance
1 GR00	6	1.05137	0.17523	0.00146
2 CC00	7	1.13840	0.16263	0.00217
3 NF00	4	0.53675	0.13419	0.00072
4 GT00	6	0.70312	0.11719	0.00006

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.01238	3	0.00413	3.44000	0.03762	3.12735
Within Groups	0.02279	19	0.00120			
Total	0.03517	22				

Tukey Multiple Comparison Test see App.64
Year 2000 see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,30,4}$	Concl.
0.013624	1 vs.2	0.0126	0.9248	3.9580	Accept Ho
0.015807	1 vs.3	0.0410	2.5963	3.9580	Accept Ho
0.014138	1 vs.4	0.0580	4.1053	3.9580	Reject Ho
0.015349	2 vs.3	0.0284	1.8529	3.9580	Accept Ho
0.013624	2 vs.4	0.0454	3.3354	3.9580	Accept Ho
0.015807	3 vs.4	0.0170	1.0756	3.9580	Accept Ho

1	3	4	2
GR	CC	NF	GT
17.50%	16.30%	13.40%	11.70%
GR=	CC=	NF=	GT
🟨	🟨	🟨	
	🟧	🟧	🟧

Anova: Single Factor 2001 Fines <6.3mm

SUMMARY C

Groups	Count	Sum	Average	Variance
1 GR01	11	0.85406	0.07764	0.00013
2 CC01	8	0.31891	0.03986	0.00016
3 NF01	8	1.30957	0.16370	0.00217
4 GT01	8	0.18064	0.02258	0.00006

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.09483	3	0.03161	54.26746	0.00000	2.91134
Within Groups	0.01806	31	0.00058			
Total	0.11289	34				

Tukey Multiple Comparison Test see App.64
Year 2001 see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,30,4}$	Concl.
0.00793	1 vs.2	0.0378	4.7640	3.8450	Reject Ho
0.00793	1 vs.3	0.0861	10.8520	3.8450	Reject Ho
0.00793	1 vs.4	0.0551	6.9436	3.8450	Reject Ho
0.00853	2 vs.3	0.1238	14.5123	3.8450	Reject Ho
0.00853	2 vs.4	0.0173	2.0255	3.8450	Accept Ho
0.01224	3 vs.4	0.1411	11.5250	3.8450	Reject Ho

1	3	4	2
NF	GR	CC	GT
16.37%	7.76%	3.99%	2.26%
NF≠	GR≠	CC=	GT
🟨			
	🟧		
		🟩	🟩

Anova: Single Factor 2002 Fines <6.3mm

SUMMARY D

Groups	Count	Sum	Average	Variance
1 GR02	6	0.90975	0.15163	0.00030
2 CC02	5	0.37915	0.07583	0.00080
3 NF02	11	1.45043	0.13186	0.00096
4 GT02	5	0.56766	0.11353	0.00109

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.01735	3	0.00578	7.12537	0.00149	3.02800
Within Groups	0.01866	23	0.00081			
Total	0.03601	26				

Tukey Multiple Comparison Test see App.64
Year 2002 see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,30,4}$	Concl.
0.12197	1 vs.2	0.0758	6.2143	3.9010	Reject Ho
0.010223	1 vs.3	0.0198	1.9338	3.9010	Accept Ho
0.012197	1 vs.4	0.0381	3.1231	3.9010	Accept Ho
0.010864	2 vs.3	0.0560	5.1571	3.9010	Reject Ho
0.012739	2 vs.4	0.0377	2.9596	3.9010	Accept Ho
0.010864	3 vs.4	0.0183	1.6867	3.9010	Accept Ho

1	3	4	2
GR	NF	GT	CC
15.20%	13.20%	11.40%	7.58%
GR=	NF=	GT=	CC
🟨	🟨		
	🟧	🟧	
		🟩	🟩

Table 17. ANOVA with a Tukey multiple comparison test of the significance in differences between means of overwinter sedimentation (fines <0.85 mm) for the 4 streams for year 1999, 2000, 2001, and 2002 collections.

Anova: Single Factor 1999 Fines <0.85 mm

SUMMARY A

Groups	Count	Sum	Average	Variance
GR99	10	0.49090	0.04909	0.00037
CC99	9	0.31253	0.03473	0.00037
NF99	9	0.47192	0.05244	0.00003
GT99	6	0.27626	0.04604	0.00007

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00161	3	0.00054	2.34001	0.09329	2.92228
Within Groups	0.00687	30	0.00023			
Total	0.00848	33				

Tukey Multiple Comparison Test
Year 1999
see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,30,4}$	Concl.	95% C.I. of Diff.
0.00492	1 vs.2	0.0144	2.9215	3.845	Accept Ho	0.0189
0.00492	1 vs.3	0.0033	0.6804	3.845	Accept Ho	0.0189
0.00553	1 vs. 4	0.0030	0.5513	3.845	Accept Ho	0.0212
0.00504	2 vs.3	0.0177	3.5108	3.845	Accept Ho	0.0194
0.00564	2 vs. 4	0.0113	2.0068	3.845	Accept Ho	0.0217
0.00564	3 vs. 4	0.0064	1.1333	3.845	Accept Ho	0.0217

3	1	4	2
NF	GR	GT	CC
5.24%	4.91%	4.60%	3.47%
🟧	🟧	🟧	🟧
NF =	GR =	GT =	CC

see p.216	$X_{1,2,3,4}$=	0.045635			0.050935	UL
X-bar +/-	95%CI=	0.045635	"+/-"	0.00530	0.040336	LL
			$t_{0.05(2),30=}$	2.042		

Anova: Single Factor 2000 Fines <0.85 mm

SUMMARY B

Groups	Count	Sum	Average	Variance
GR00	6	0.43805	0.07301	0.00103
CC00	7	0.39305	0.05615	0.00019
NF00	4	0.31580	0.07895	0.00009
GT00	6	0.38136	0.06356	0.00041

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00168	3	0.00056	1.22752	0.32712	3.12735
Within Groups	0.00865	19	0.00046			
Total	0.01032	22				

Tukey Multiple Comparison Test
Year 2000
see App.64
see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,20,4}$	Concl.	95% C.I. of Diff.
0.00839	1 vs.2	0.0169	2.0088	3.958	Accept Ho	0.0332
0.00974	1 vs.3	0.0059	0.6102	3.958	Accept Ho	0.0385
0.00871	1 vs. 4	0.0094	1.0850	3.958	Accept Ho	0.0345
0.00945	2 vs.3	0.0228	2.4115	3.958	Accept Ho	0.0374
0.00839	2 vs. 4	0.0074	0.8829	3.958	Accept Ho	0.0332
0.00974	3 vs. 4	0.0154	1.5807	3.958	Accept Ho	0.0385

3	1	4	2
NF	GR	GT	CC
7.90%	7.30%	6.36%	5.62%
NF =	GR =	GT =	CC
🟧	🟧	🟧	🟧

see p.216	$X_{1,2,3,4}$=	0.066446			0.075756	UL
X-bar +/-	95%CI=	0.066446	"+/-"	0.00931	0.057136	LL
			$t_{0.05(2),19=}$	2.093		

Anova: Single Factor 2001 Fines <0.85 mm

SUMMARY C

Groups	Count	Sum	Average	Variance
GR01	11	0.49469	0.04497	0.00016
CC01	8	0.27439	0.03430	0.00017
NF01	8	0.60773	0.07597	0.00042
GT01	8	0.10139	0.01267	0.00004

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.01668	3	0.00556	28.45726	0.00000	2.91134
Within Groups	0.00606	31	0.00020			
Total	0.02274	34				

Tukey Multiple Comparison Test
Year 2001
see App.64
see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,20,4}$	Concl.	95% C.I. of Diff.
0.00459	1 vs.2	0.0107	2.3239	3.8450	Accept Ho	0.0177
0.00459	1 vs.3	0.0310	6.7489	3.8450	Reject Ho	0.0177
0.00459	1 vs. 4	0.0323	7.0326	3.8450	Reject Ho	0.0177
0.00494	2 vs.3	0.0417	8.4315	3.8450	Reject Ho	0.0190
0.00494	2 vs. 4	0.0216	4.3759	3.8450	Reject Ho	0.0190
0.00494	3 vs. 4	0.0633	12.8074	3.8450	Reject Ho	0.0190

3	1	2	4
NF	GR	CC	GT
7.60%	4.50%	3.43%	1.27%
NF neq.	GR =	CC neq.	GT
🟨			
	🟧	🟧	
			🟩

Anova: Single Factor 2002 Fines <0.85 mm

SUMMARY D

Groups	Count	Sum	Average	Variance
GR02	6	0.45990	0.07665	0.00052
CC02	5	0.21619	0.04324	0.00017
NF02	11	0.66555	0.06050	0.00020
GT02	5	0.32984	0.06597	0.00090

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00315	3	0.00105	2.71372	0.06833	3.02800
Within Groups	0.00890	23	0.00039			
Total	0.01205	26				

Tukey Multiple Comparison Test
Year 2002
see App.64
see p. 213 Zar

SE	Comparison	Diff.	q	$q_{0.05,20,4}$	Concl.	95% C.I. of Diff.
0.00842	1 vs.2	0.0334	3.9665	3.9010	Reject Ho	0.0329
0.00706	1 vs.3	0.0161	2.2869	3.9010	Accept Ho	0.0275
0.00842	1 vs. 4	0.0107	1.2681	3.9010	Accept Ho	0.0329
0.00750	2 vs.3	0.0173	2.3012	3.9010	Accept Ho	0.0293
0.00880	2 vs. 4	0.0227	2.5836	3.9010	Accept Ho	0.0343
0.00750	3 vs. 4	0.0055	0.7283	3.9010	Accept Ho	0.0293

1	4	3	2
GR	GT	NF	CC
7.67%	6.60%	6.05%	4.32%
GR =	GT =	NF =	CC
🟨	🟨	🟨	
			🟥
	🟩	🟩	🟩

see p.216	$X_{1,2,3}$=	0.061907			0.069741	UL
X-bar +/-	95%CI=	0.061907	"+/-"	0.00783	0.054073	LL
			$t_{0.05(2),23=}$	2.069		

Table 18. Test of the differences in means of overwinter fine sediment deposition (<0.85 mm) in simulated redds over the years of sample collection 1999-2002.

Anova: Single Factor Overwinter fines deposition 1999-2002

Particles <0.85mm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
GR	33	1.88354	0.05708	0.00059
CC	29	1.19616	0.04125	0.00030
NF	32	2.06099	0.06441	0.00029
GT	25	1.08886	0.04355	0.00079

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01090	3	0.00363	7.61717	0.00011	2.68350
Within Groups	0.05484	115	0.00048			
Total	0.06574	118				

Tukey Multiple Comparison Test

Comparison *(B vs. A)*	*Difference* *(X-bar$_B$ - Xbar$_A$)*	*SE*	*q*	$q_{0.05,115,4}$	*Conclusion.*
GR vs. CC	0.01583	0.00393	4.0276	3.737	Reject Ho
GR vs. NFJD	-0.00733	0.00383	-1.9130	3.737	Accept Ho
GR vs. GT	0.01352	0.00409	3.3028	3.737	Accept Ho
CC vs. NFJD	-0.02316	0.00396	-5.8497	3.737	Reject Ho
CC vs. GT	-0.00231	0.00421	-0.5475	3.737	Accept Ho
NFJD vs. GT	0.02085	0.00412	5.0589	3.737	Reject Ho

NFJDR	GR	CC	GT
6.44%	5.71%	4.36%	4.12%
🟨	🟨		
	🟩	🟩	
		🟧	🟧

Table 19. Test of the differences in means of overwinter fine sediment deposition (<6.3 mm) in simulated redds over the years of sample collection 1999-2002.

Anova: Single Factor   Overwinter fines deposition 1999-2002

Particles <6.3 mm

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
GR	33	3.97888	0.12057	0.00193
CC	29	2.26519	0.07811	0.00326
NF	32	4.03726	0.12616	0.00189
GT	25	1.87993	0.07520	0.00198

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.06457	3	0.02152	9.55704	0.00001	2.68350
Within Groups	0.25901	115	0.00225			
Total	0.32358	118				

Tukey Multiple Comparison Test

Comparison	*Difference*				
(B vs. A)	$(X\text{-bar}_B - \text{Xbar}_A)$	*SE*	*q*	$q_{0.05,115,4}$	*Conclusion.*
GR vs. CC	0.4246	0.00854	4.97128	3.737	Reject Ho
GR vs. NFJD	-0.00559	0.00833	-0.67171	3.737	Accept Ho
GR vs. GT	0.04537	0.00890	5.09959	3.737	Reject Ho
CC vs. NFJD	-0.04805	0.00860	-5.58535	3.737	Reject Ho
CC vs. GT	0.00291	0.00916	0.31805	3.737	Accept Ho
NFJD vs. GT	0.05097	0.00896	5.968992	3.737	Reject Ho

NFJDR	GR	CC	GT
12.62%	12.06%	7.81%	7.52%
🟨	🟨		
		🟧	🟧

Table 20. Data on dry weights, dry volume, displacement volume, density, percentage voids, and percentage fines for four overwinter sediment deposition samples collected in April-May 2002.

Grande Ronde River Sample Collected 4/19/02

	Size fractions					
	>6.3 mm	**2-6.3 mm**	**0.85-2 mm**	**<0.85**	**Total fines**	**Total sediment**
Dry weight (g)	6231	283	429	506	1218	7449
Displacement volume (ml)	2291	120	177	250	547	2838
Dry volume (ml)	3776	210	320	405	935	4711
Density (g/ml)	2.72	2.36	2.42	2.02		
% voids in dry vol.	39.33	42.86	44.69	38.27		
% of total fines weight	23.23	35.22	41.54			
Fines as% by weight of total sediment wt.	**16.35**					

Bucket volume	4216
Empty volume above sediment surface	440
Effective volume	3776
Large rock displacement vol.	2291
Void for large rock	1485
Total fine sed. Displacement	547
Unfilled volume of large rock void	938
% of effective void filled by fines	36.84
Total volume of dry fines (ml)	935
Estimate of % void volume filled by dry fines	62.96

North Fork John Day River Collected 5/16/02 Sample 3A

	Size fractions					
	>6.3 mm	**2-6.3 mm**	**0.85-2 mm**	**<0.85**	**Total fines**	**Total sediment**
Dry weight (g)	6346	287	570	636	1493	7839
Displacement volume (ml)	2346	115	230	250	595	2941
Dry volume (ml)	3763	200	405	470	1075	4838
Density (g/ml)	2.71	2.50	2.40	2.54		
% voids in dry vol.	37.66	42.50	43.21	46.81		
% of total fines weight	19.22	38.18	42.60			
Fines as% by weight of total sediment wt.	**19.05**					

Bucket volume	4216
Empty volume above sediment surface	453
Effective volume	3763
Large rock displacement vol.	2346
Void for large rock	1417
Total fine sed. Displacement	595
Unfilled volume of large rock void	822
% of effective void filled by fines	41.99
Total volume of dry fines (ml)	1075
Estimate of % void volume filled by dry fines	75.86

North Fork John Day River Collected 5/16/02 Sample 4B

	Size fractions					
	>6.3 mm	**2-6.3 mm**	**0.85-2 mm**	**<0.85**	**Total fines**	**Total sediment**
Dry weight (g)	6244	231	312	461	1004	7248
Displacement volume (ml)	2348	100	140	190	430	2778
Dry volume (ml)						
Density (g/ml)	2.66	2.31	2.23	2.43		
% voids in dry vol.	40.04					
% of total fines weight	23.01	31.08	45.92			
Fines as% by weight of total sediment wt.	**13.85**					

Bucket volume	4216
Empty volume above sediment surface	300
Effective volume	3916
Large rock displacement vol.	2348
Void for large rock	1568
Total fine sed. Displacement	430
Unfilled volume of large rock void	1138
% of effective void filled by fines	27.42
Total volume of dry fines (ml)	
Estimate of % void volume filled by dry fines	

North Fork John Day River Collected 5/16/02 Sample 5A

	Size fractions					
	>6.3 mm	**2-6.3 mm**	**0.85-2 mm**	**<0.85**	**Total fines**	**Total sediment**
Dry weight (g)	6002	213	260	548	1021	7023
Displacement volume (ml)	2296	83	103	215	401	2697
Dry volume (ml)	3919	162.5	210	425	797.5	4716.5
Density (g/ml)	2.61	2.57	2.52	2.55		
% voids in dry vol.	41.41	48.92	50.95	49.41		
% of total fines weight	20.86	25.47	53.67			
Fines as% by weight of total sediment wt.	**14.5**					

Bucket volume	4216
Empty volume above sediment surface	297
Effective volume	3919
Large rock displacement vol.	2296
Void for large rock	1623
Total fine sed. Displacement	401
Unfilled volume of large rock void	1222
% of effective void filled by fines	24.71
Total volume of dry fines (ml)	797.5
Estimate of % void volume filled by dry fines	49.14

Table 21. Dates of placement and removal of plastic buckets containing cleaned gravel to simulate redd material for estimation of overwinter fine sediment infiltration into spawning gravels.

Stream	Date of Bucket Placement	Date of Bucket Removal	No. Days in Place
Grande Ronde River	September 5, 1998	April 12, 1999	210
Catherine Creek	September 5, 1998	April 12, 1999	210
North Fork John Day	September 6, 1998	April 25, 1999	222
Granite Creek	September 6, 1998	April 13, 1999	210
Grande Ronde River	September 4, 1998	April 21, 2000	220
Catherine Creek	September 4, 1998	May 18, 2000	247
North Fork John Day	September 5, 1998	April 22, 2000	220
Granite Creek	September 5, 1998	May 4, 2000	232
Grande Ronde River	August 26, 2000	April 20, 2001	228
Catherine Creek	August 26, 2000	April 20, 2001	228
North Fork John Day	August 27, 2000	April 21, 2001	228
Granite Creek	August 27, 2000	April 20, 2001	228
Grande Ronde River	August 24, 2001	April 19, 2002	229
Catherine Creek	August 24, 2001	April 19, 2002	229
North Fork John Day	August 25, 2001	May 16, 2002	255
Granite Creek	August 25, 2001	May 16, 2002	255

APPENDIX A Details on Allotments and Pastures within Study Watersheds

Table 1. Details on Allotments and Pastures within Study Watersheds

Index to Table 1:

1. **RMU_ID** is the allotment number, or resource management unit identifier.
2. **Pasture No.** is the pasture number, identifying the pasture within an allotment.
3. **RMU_NAME** is the resource management unit name.
4. **Area of clipped pasture** gives the acres of a pasture that fall within the boundaries of a study watershed. Area is derived from the GIS map table.
5. **Area of entire pasture** gives the total acres of the pasture, whether they are inside or outside of the study watershed. Area is derived from the GIS map table.
6. **Study Watershed** is identified as GR (Grande Ronde River), CC (Catherine Creek), NFJDR (North Fork John Day River), and GT (Granite Creek).
7. **% of Entire Pasture** gives the percentage of the entire pasture comprised by the acres of the pasture falling within the study watershed boundaries.
8. **Allotment TOTAL_AREA** is the total area of the entire allotment derived from the Tri-Forest database.
9. **Allotment NFS_AREA** is the National Forest Service portion of the allotment, derived from the Tri-Forest database.
10. **Allotment TOTAL CAPABLE AREA** is the acres of the allotment suitable for grazing.
11. **Allotment NFS CAPABLE AREA** is the acres of the allotment in the national forest system that is suitable for grazing.
12. **NFS AUMs** is the number of AUMs for which the national forest portion of the allotment is capable.
13. **RMU_TYPE** is the type of resource management unit allotment.
14. **AUMs/ 100 acre** is the number of AUMs permitted divided by 100.
15. **AUMs/capable 100 acre** is the number of AUMs permitted divided by the total capable area., divided by 100.
16. **Potential AUMs per clipped pasture** is the permitted AUMs divided by the acres of each pasture falling within the study watershed boundaries.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	6
RMU_ID	Pasture No.	RMU_NAME	Area of Clipped Pasture (acres)	Area of Entire Pasture (acres)	Study Watershed	% of Entire Pasture	Allotment TOTAL_AREA (acres)	Allotment NFS_AREA (acres)	Allotment TOTAL CAPABLE (acres)	Allotment NFS CAPABLE (acres)	NFS_AUMS	RMU_TYPE	AUMS/ 100 Acre	AUMS/Capable 100 Acre	Potential AUMs/ Clipped Pasture	Study Watershed
00012	1	INDIAN CRANE	4931.8	42916.1	NFJD	11.49	42896	42515	40783	40783	1050	VACANT ALLOTMENT	2.45	2.57	120.7	NFJD
	1		373.7	42916.1	GR	0.87							2.45		9.1	GR
	1		195.1	42916.1	GT	0.45							2.45		4.8	GT
Total			***5500.7***	***42916.1***		***12.82***							2.45		134.6	
00054	1	MINAM RIVER	1093.2	111732.1	CC	0.98	111667	111627	81931	81931	1500	VACANT ALLOTMENT	1.34	1.83	14.7	CC
	1		6953.6	111732.1	CC	6.22							1.34		93.4	CC
Total			***8046.8***	***111732.1***		***7.20***							1.34		108.1	
00075	1	LIMBER JIM	3369.3	25164.9	GR	13.39	25158	24994	20000	20000	1392	VACANT ALLOTMENT	5.53	6.96	186.4	GR
00149	1	CHICKEN HILL	2949.1	16485.0	GR		16604	16457	1548	1548	320	VACANT ALLOTMENT	1.93	20.67	56.8	GR
00179	1	BIG CREEK	4893.3	12345.7	CC	39.64	42442	41884	21176	21176	2893	DEFERRED-ROTATION	6.82	13.66	333.5	CC
	2		3204.1	5447.0	CC	58.82							6.82		218.4	CC
	5		2041.2	2148.5	CC	95.01							6.82		139.1	CC
Total			***10138.6***	***19941.2***		***50.84***							6.82		691.1	
00189	1	CATHERINE CREEK	7256.2	14241.4	CC	50.95	21466	20933	6421	6061	1375	DEFERRED-ROTATION	6.41	21.41	464.8	CC
	2		3758.1	6636.1	CC	56.63							6.41		240.7	CC
Total			***11014.3***	***20877.6***	***CC***	***52.76***							6.41		705.5	
00198	1	POLE CREEK	11223.1	11226.1	CC	99.97	11221	11154	6300	6300	587	DEFERRED	5.23	9.32	587.1	CC
00207	4	CAMP CREEK	7576.3	7616.2	GT	99.48	30816	30308	25000	25000	1159	DEFERRED-ROTATION	3.76	4.64	284.9	GT

APPENDIX B Locations and Site Characteristics of Transects

Table 1. Locations and site characteristics of areas excavated Sept. 5-6, 1998 to mimic redds for monitoring of overwinter sedimentation in clean gravels in containers. Site numbers with an asterisk (*) had 3 containers of cleaned gravels placed within the excavated redd site, with one bucket collected in Dec. 1998. Sites marked with a plus sign (+) had bulk substrate samples collected by shovel in Sept. 1998.

Stream	"Redd" No.	Latitude		Longitude		Wetted Channel Width (m)	Water Column Depth (m)	Visually estimated surface fine sediment (%)	Notes/Site Description
		Deg.	min.	Deg.	min.				
Grande Ronde	GR1	45	4.28	118	18.82	6.0	0.15	37	Glide tailout downstream of pool at river bend
Grande Ronde	GR2*+	45	4.18	118	18.83	10.2	0.13	40	Glide tailout below log weir ~200 m upstream of GR1
Grande Ronde	GR3	45	4.12	118	18.79	9.9	0.20	10	Tailout below pocket pool
Grande Ronde	GR4*+	45	4.06	118	18.79	6.5	0.10	35	Glide tailout
Grande Ronde	GR5	45	3.99	118	18.8	10.4	0.12	30	Shallow glide tailout.
Catherine Cr.	C1	45	7.92	117	42.55	7.7	0.05	5	Glide tailout downstream of exclosure fence
Catherine Cr.	C2*+	45	7.92	117	42.55	7.7	0.05	5	Glide tailout downstream of exclosure fence
Catherine Cr.	C3*+	45	7.44	117	41.99	13.3	0.12	2	Glide tailout
Catherine Cr.	C4	45	7.48	117	38.78	9.7	0.10	7	Shallow glide tailout
Catherine Cr.	C5	45	7.48	117	41.99	1.2	0.10	7	Shallow glide tailout, ~3 m upstream of C4
NFJDR	N1	44	54.81	118	23.39	10.6	0.14	25	Glide tailout below overhanging LWD
NFJDR	N2	44	54.69	118	23.31	8.05	0.10	20	Glide tailout
NFJDR	N3	44	54.63	118	23.27	11.3	0.10	15	Shallow glide tailout at riffle transition
NFJDR	N4+	44	54.73	118	23.25	10.3	0.10	30	Shallow glide tailout near N. bank
NFJDR	N5	44	54.68	118	23.23	10.1	0.07	30	Shallow glide tailout near N. bank
Granite Cr	GT1	44	49.75	118	27.43	7.7	0.15	6	Glide tailout
Granite Cr	GT2	44	49.49	118	27.3	10.0	0.10	10	Glide tailout
Granite Cr	GT3++	44	49.5	118	27.24	9.6	0.10	10	Glide tailout
Granite Cr	GT4	none taken				7.5	0.13	8	Shallow glide tailout at riffle transition
Granite Cr	GT5	44	49.36	118	27.13	7.5	0.13	8	Shallow glide tailout at riffle transition

Table 2. Locations and site characteristics of areas excavated September, 5-6, 1999 to mimic redds for monitoring of overwinter sedimentation in containers of clean gravels. Site numbers with an asterisk (*) had 3 containers of cleaned gravels placed within the excavated redd site, with one bucket collected in Dec. 1999. Sites marked with a plus sign (+) had bulk substrate samples collected by shovel in Sept. 1999.

Stream	"Redd"	Latitude		Longitude		Wetted Channel Width	Water Column Depth	Visually estimated surface fine sediment	Notes/Site Description
	No.	Deg.	min	Deg.	min.	(m)	(m)	(%)	
Grande Ronde	GR1	45	4.17	118	18.85	4.5	0.20	18	Low sand levels; redistributed onto point bars
Grande Ronde	GR2*	45	4.15	118	18.84	7.2	0.20	18	Pool tailout
Grande Ronde	GR3	45	4.12	118	18.81	5.7	0.20	21.5	Inboard of root wad, downstream of log weir
Grande Ronde	GR4*+	45	4.01	118	18.78	4.5	0.12	20	Green marker flag on downed log on W. bank, blue flag on downed log on E side
Grande Ronde	GR5+	45	4.04	118	18.78	6.9	0.27	32.5	Pool tailout
Catherine Cr.	C1*+	45	7.92	117	42.49	12.0	0.10	4.5	Pool tailout
Catherine Cr.	C2	45	7.92	117	42.49	12.0	0.21	4.5	Significant bank damage from grazing in Hall Ranch near buckets. Pool tailout
Catherine Cr.	C3*+	45	7.45	117	41.98	13.0	1.70	2	Pool/glide tailout
Catherine Cr.	C4	45	7.22	117	38.79	6.5	0.18	5	Pool tailout
Catherine Cr.	C5	45	7.22	117	38.79	6.5	0.17	2	Pool tailout
NFJDR	N1+	44	54.74	118	23.38	11.9	0.20	21	Pool tailout, cobble-size surface armor
NFJDR	N2+	44	54.71	118	23.33	10.6	0.20	30	Pool tailout
NFJDR	N3	44	54.67	118	23.23	12.1	0.12	30	Pool tailout
NFJDR	N4+	44	54.67	118	23.2	12.2	0.15	25	Pool tailout
NFJDR	N5	44	54.67	118	23.19	11.9	0.20	30	Pool tailout
Granite Cr	GT1	44	49.59	118	27.42	9.5	0.11	6	Glide tailout
Granite Cr	GT2+	44	49.59	118	27.42	10.0	0.10	6	Glide tailout
Granite Cr	GT3	44	49.55	118	27.34	9.5	0.15	10	Pool tailout
Granite Cr	GT4+	44	49.53	118	27.33	8.5	0.33	10	Pool tailout
Granite Cr	GT5	44	49.49	118	27.26	9.6	0.35	10	Pool tailout

Table 3. Locations and site characteristics of areas excavated August 25-26, 2000 to mimic redds for monitoring of overwinter sedimentation in containers of clean gravels. Site numbers with an asterisk (*) had 3 containers of cleaned gravels placed within the excavated redd site, with one bucket collected in Dec. 2000. Sites marked with a plus sign (+) had bulk substrate samples collected by shovel in Aug. 2000.

Stream	"Redd"	Latitude		Longitude		Channel Width	Water Column Depth	Visually estimated surface fine sediment	Notes/Site Description
	No.	Deg.	min.	Deg.	min.	(m)	(m)	(%)	(all distances approximate)
Grande Ronde	GR1	45	4.18	118	18.84	5.6	0.12	10	Tailout at shallow glide/pool. Fines higher at depth - armored substrate. Much higher levels of fine sediment in pools/glides than in riffles. Differential levels higher than in past years. Signs of wood loss/ bank scouring from spring events
Grande Ronde	GR2*+	45	4.17	118	18.82	6.0	0.22	12	Tailout shallow glide/pool
Grande Ronde	GR3	45	4.14	118	18.8	4.4	0.24	9	Mid glide below log weir
Grande Ronde	GR4*+	45	4.05	118	18.77	6.5	0.07	22	Riffle site, but benchmarked to prev. yr.'s site
Grande Ronde	GR5	45	4.03	118	18.79	6.6	0.25	31	Pool tailout near rock bar
Catherine Cr.	C1	45	7.92	117	42.51	6.8	0.07	2.3	Glide tailout. At all sites, fines higher at depth - armored substrate. No signs of major channel change from spring flows. Reach in Hall Ranch site has had major bank loss (~1m) from livestock trampling upstream of C1 and C2. Significant trespass in "exclosures," fence down and not a livestock barrier.
Catherine Cr.	C2*+	45	7.92	117	42.51	6.8	0.09	2.3	Glide tailout
Catherine Cr.	C3*+	45	7.44	117	41.98	9.0	0.25	2.7	End of opening on E. bank, pool tailout
Catherine Cr.	C4	45	7.23	117	38.78	9.7	0.06	5	Glide tailout
Catherine Cr.	C5	45	7.23	117	38.77	7.5	0.18	5	Edge of tailout between glide and riffle
NFJDR	N1	44	54.77	118	23.4	9.8	0.12	29.5	Small glide tailout. Severe deposition over entire reach: bar deposits, duning sands behind rocks and in pools, and reduced complexity. Substrate highly bimodal: only large rocks protruding through a blanket of fines. Fines may be higher at depth, but substrate surface is sandy, not armored.
NFJDR	N2+	44	54.67	118	23.31	8	0.12	27	Glide tailout
NFJDR	N3+	44	54.67	118	23.22	12	0.05	24	Shallow glide tailout near 30 m high fir
NFJDR	N4	44	54.67	118	23.2	10.6	0.13	28	Glide tailout
NFJDR	N5	44	54.68	118	23.2	9.8	0.1	35	Small glide tailout
Granite Cr	GT1+	44	49.59	118	27.42	7.0	0.10	3	Glide tailout. At all sites, fine sediment much higher at depth; substrate armored. Significant bars and flood deposits on channel margins, from spring flows, mainly gravel/cobbles.
Granite Cr	GT2	44	49.59	118	27.42	7.0	0.12	3	Glide tailout
Granite Cr	GT3	44	49.56	118	27.38	8.3	0.10	10	Tail out - lg. Pool - 30% fines in pool
Granite Cr	GT4+	44	49.51	118	27.29	10.5	0.09	11	Side pool tailout next to flood deposit
Granite Cr	GT5	44	49.5	118	27.28	10.8	0.11	11	Glide tailout near collapsed bank

Table 4. Locations and site characteristics of areas excavated August 24-25, 2001 to mimic redds for monitoring of overwinter sedimentation in containers of clean gravels. Site numbers with an asterisk (*) had 3 containers of cleaned gravels placed within the excavated redd site. Sites marked with a plus sign (+) had bulk substrate samples collected by shovel in Aug. 2001.

"Redd" No.	Latitude		Longitude		Channel Width (m)	Water Column Depth (m)	Visually estimated surface fine sediment (%)	Notes/Site Description (all distances approximate)
	Deg.	min.	Deg.	min.				
GR1	45	4.18	118	18.84	5.6	0.12	10	Tailout at shallow glide/pool
GR2*+	45	4.17	118	18.82	6.0	0.22	12	Tailout shallow glide/pool, bulk--3 buckets
GR3	45	4.14	118	18.8	4.4	0.24	9	Mid glide below log weir
GR4*+	45	4.05	118	18.77	6.5	0.07	22	Riffle site, but bench marked to prev. yr.'s site, bulk sample--3 buckets
GR5	45	4.03	118	18.79	6.6	0.25	31	Pool tailout near rock bar
C1	45	7.92	117	42.51	6.8	0.07	2.3	Glide tailout
C2*+	45	7.92	117	42.51	6.8	0.09	2.3	Glide tailout 3 buckets - bulk
C3*+	45	7.44	117	41.98	9.0	0.25	2.7	End of opening in left bank, pool tailout, 3 buckets + bulk
C4	45	7.23	117	38.78	9.7	0.06	5	Glide tailout
C5	45	7.23	117	38.77	7.5	0.18	5	Edge of tailout between glide and riffle
N1	44	54.77	118	23.4	9.8	0.12	29.5	Small glide tailout
N2+	44	54.67	118	23.31	8	0.12	27	Glide tailout 1 bulk sample
N3+	44	54.67	118	23.22	12	0.05	24	Riffly glide tailout, twined into 30 m high fir on bank, bulk sample
N4	44	54.67	118	23.2	10.6	0.13	28	Glide tailout
N5	44	54.68	118	23.2	9.8	0.1	35	Very small glide tailout
GT1+	44	49.59	118	27.42	7.0	0.10	3	Glide tailout twined into unflagged alder, bulk
GT2	44	49.59	118	27.42	7.0	0.12	3	Glide tailout twinded into unflagged alder
GT3	44	49.56	118	27.38	8.3	0.10	10	Tail out - lg. Pool - 30% fines in pool
GT4+	44	49.51	118	27.29	10.5	0.09	11	side pool tailout next to flood deposit, bulk
GT5	44	49.5	118	27.28	10.8	0.11	11	Glide tailout near collapsed bank mainly below flagged alder almost to bank
GR1	45	4.18	118	18.84	6.7	0.2	10	Fines much higher at depth
GR2*+	45	4.17	118	18.82	6.2	0.3	13	3 buckets, bulk, fines much higher at depth
GR3	45	4.14	118	18.8	8.8	0.2	14	Fines much higher at depth
GR4*+	45	4.05	118	18.78	7.3	0.17	16	3 buckets, bulk, fines much higher at depth
GR5	45	4.04	118	18.79	7	0.15	15	Fines much higher at depth
C1	45	7.91	117	42.51	7	0.07	5	Fines much higher at depth
C2*+	45	7.92	117	42.51	7	0.1	5	3 buckets, bulk, fines much higher at depth
C3*+	45	7.44	117	41.98	9	0.17	4	Fines slightly higher at depth
C4	45	7.22	117	38.78	9.2	0.18	3	Fines slightly higher at depth
C5	45	7.22	117	38.77	7.9	0.08	2	
N1++	44	54.76	118	23.38	10.1	0.08	25	2 bulk samples taken
N2	44	54.67	118	23.31	8.5	0.14	25	
N3	44	54.66	118	23.21	10.1	0.07	25	No finer gradation w/depth
N4	44	54.67	118	23.2	10.8	0.08	40	No finer gradation w/depth
N5	44	54.67	118	23.19	9.8	0.06	30	No finer gradation w/depth
GT1	44	49.5	118	27.28	9.5	0.16	12	Fines much higher at depth
GT2+	44	49.51	118	27.29	7.5	0.08	3.5	Fines higher at depth, bulk sample taken to 4" depth
GT3	44	49.56	118	27.37	9.3	0.06	6	Fines higher at depth and surface cobbles are smaller than for T4 or T5
GT4	44	49.59	118	27.42	8	0.06	7	Fines much higher at depth
GT5	44	49.61	118	27.44	9.7	0.02	10	Armored but very high fines at depth

APPENDIX C Sediment Project Sampling Protocol Methods

<u>Grid Method</u>. At 10 transects across riffles within the monitored area in each stream fine sediment is measured via the grid method. These transects are called **surface fine transects** with the lowest number (1) marking the most downstream transect and increasing moving upstream. At each transect, five measurements are taken at equidistant points across the channel width. The procedure for this measurement is to first measure the channel's current width and to then place the grid in the water at each of the equidistant points in the stream. The grid consisting of 100 points (in a 10X10 square) should be laid just above and parallel to the channel floor. With a below-water viewer (water scope or see-through pan) the observer counts where grid intersections are directly above fine sediment on the channel substrate. **Fine sediment is defined as that with a diameter of <6.4mm (.25in.)**. Record the number of grid points out of 100 under which fine sediment dwells at each equidistant point in the channel. The average of these 5 measurements is the grid method fine sediment measurement for the transect. The location of the transect relative to the redds should be recorded on the form, along with the GPS coordinates. The surface fine transects should also be illustrated in the sketch of the monitored area. At each transect, the channel width and interval length should be measured.

Equipment needed for grid measurement: Measuring tape, Grid (w/100 intersections marked off), Viewer/Scope, Field forms (Rite in Rain preferred), Clipboard, GPS unit

Reference: Lisle and Eads

<u>Visual Estimate.</u> Although there is a mental process involved in performing the visual estimate, an exact detailed procedure is somewhat subjective. Regardless of the strategy employed, the observer is attempting to estimate the percent area of the transect that is occupied by fine sediment (diameter<6.4). The observers should familiarize themselves with the terrain and components of the particular area of the stream, then make a judgement of the percentage of fine sediment within the transect. It is highly recommended that observers calibrate estimates with measurements prior to estimating. The observer should not estimate the result of the grid, pebble count, or any other method of measurement. Visual estimates are performed by at least 2 observers at all surface fine and bucket transects. The average of the estimates of all observers stands as the recorded visual estimate.

<u>Pebble Count.</u> An observer performs the pebble count by pulling approximately 100 samples from the stream and measuring them. The particles are selected by taking random paces across

the transect. After each step (without looking at the substrate), the observer should select the particle directly below the tip of their boot. The intermediate axis of the particle is measured (see Bauer and Burton). After the measurement has been taken (with a hand-held measuring stick) the observer places the sample into one of twelve size classes. Because of the high number of samples pulled, the observer will cross the channel multiple times. Pebble counts are taken at any 4 of the 10 surface fine transects.

Equipment for pebble count: Metric ruler, Forms, Waders

Reference: Bauer and Burton

Bulk Samples**.** Bulk samples of substrate are collected at each stream concurrent with the placement of containers of cleaned gravels in artificial redds. The samples are taken by removing a shovel full of substrate from the streambed. The samples are then placed in plastic zip lock bags for analysis. Two bulk samples are to be taken from each stream at 2 of the 5 bucket transects. The person taking bulk samples should be careful not to allow any sediment to come off of the shovel blade. Zip lock bags should be immediately labeled or pre-labeled with location, transect number, bulk sample, and date. Record collection position on “redd” data form. Notes are taken (redd form) on gradation in sediment composition with depth and other observations.

Equipment: 2 ziplocks/sample, sharpie, and shovel

Reference: Grost or Young (see most recent annual report)

Implanting of artificial redds. Ten buckets of cleaned gravels are implanted for over winter collection for each stream. Two buckets of cleaned gravels are implanted for mid-winter collection for both Grande Ronde and Catherine Creek. To implant the artificial redds excavate a hole large enough for two 1-gallon buckets (three if including a mid-winter bucket). Excavating the hole usually requires the use of a shovel as well as hand removal. Fill each bucket with substrate excluding any fine sediment (<6.3mm). A large portion of the cleaned gravels used to fill the buckets can be the substrate excavated from the channel bed. Excavated “redd” should be about 6 sq. m. and should be located at pool tailouts to the extent possible (see Bjornn and Reiser 1991). Place the filled buckets back into the hole and make sure that the tops of the buckets are level with the channel floor. Secure the buckets with rocks and make sure that the bucket handles are up for removal. If necessary, tie the bucket handles to an object on the bank or a stake in the bank. Concurrently, depth and channel width should be measured. The distances to flagged markers from the buckets should also be measured and recorded on the data form, along with GPS coordinates. The markers, distances, and redds should be included in sketches for the reach. Discharge should be estimated and recorded on the form. Notes should include general observations and particles size conditions with depth in the “redd.”

Equipment for implanting: Buckets (10-12 per stream, 2-3 per transect), Shovel, 5 Tent stakes, String

Equipment list: Summer (Aug. –Sept.) Artificial Redd implanting and bulk sample collection

Waders
1 hand held measuring stick -- metric
3 clipboards
1 GPS unit
2 10X10 grids
    (100 intersections marked off)
1 pack of 20 ziplock bags
50 1 gallon buckets
1 roll of durable string
2 rolls of ribbon
20 tent stakes

1 water scope
1 measuring tape
1 calculator
1 package of 8 extra batteries (GPS)
All appropriate forms
    (sf, redd location, pebble count)
Paper (preferably write-in-the-rain paper)
15 sharpened pencils
2 hand held pencil sharpeners
1 knife
5 sharpies

Equipment List: Mid-Winter Pulls (Dec.)

Waders
1 GPS unit
1 pack of 20 ziplock bags
1 water scope
1 measuring tape

1 package of 8 extra batteries (GPS)
5 sharpies
All appropriate forms
1 laundry basket

Equipment List: Winter Pulls (April)

- Waders
- 1 GPS unit
- 1 pack of 20 ziplock bags
- 1 water scope
- 1 measuring tape
- 1 package of 8 extra batteries (GPS)
- 5 sharpies
- All appropriate forms
- 5 laundry baskets

Important dates during the study year.

August 2001

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25 XXXX XXXX
26 **Summer**	27 **Implants**	28 **(Pre-spawn)**	29 **Critical Time**	30 XXXXX XXXXX	31 XXXXX XXXXX	

December 2001

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5	6	7	8
9	10 XXXX XXXX	11 XXXX XXXX	12 XXXX XXXX	13 XXXX XXXX	14 **Optimal date for mid-winter pulls**	15 XXXX XXXX
16 XXXX XXXX	17 XXXX XXXX	18 XXXX XXXX	19	20	21	22
23	24	25	26	27	28	29
30						

April 2002

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2	3	4	5	6
7	8	9	10 XXXXX XXXXX	11 **Optimal**	12 **Time**	13 **Window**
14 **For Winter**	15 **Pulls**	16 XXXXX XXXXX	17 XXXXX XXXXX	18	19	20
21	22	23	24	25	26	27
28	29	30				

Protocols for particle size analysis (M.Purser)

I. Preparation

A. In the past, samples have generally been air-dried in the bag for several months, stirred occasionally. This was primarily due to space concerns. A preferable method would be to dry the samples in large, rectangular pans or cookie sheets. It needs to be a container that will not degrade when wet, can be handled easily when full of sample, and works for your space and budget. A kitchen supply store (industrial) would be the best place to pick up some shallow, large rectangular metal pans. Large plastic containers (flat, rectangular or round) would probably work as well and be cheaper. A half dozen would be sufficient if they were large enough to be able to spread the sample over the bottom to a depth of less than ½"/D50. Be sure and label the container or otherwise unmistakably identify which sample is in which container at all times.

Note: We now have shallow plastic containers approximately 2' x 3' and 6 inches deep.

B. Check the samples regularly to see if they are drying evenly and remove any organic matter, brushing it free of any silt or sand grains. They will dry within two weeks, can be processed or re-bagged, and the next set can be dried. Brush or sponge the pans in between samples. Remove any buildup in the pans.

C. This method of drying will prevent many of the problems which caused the analyses of past years to be so time consuming by preventing the majority of formation of "clods," hardened, mechanically deformed, composites or aggregates of silt (in our situation).

II. Processing

A. Weigh each sieve, and the pan, and record to the nearest 0.1 gram. Prepare the stack of sieves, pan on the bottom, finest mesh screen (0.85 mm) on top of that, then 2.00 mm, 6.35mm, and lid like this:

    6.35mm sieve
    2.0 mm sieve
    0.85 mm sieve
    Pan

B. You will want to get the feel of the set of sieves without any sample in it. The trick is to be able to grasp the pan and sieves in such a way that the lid can't come off and the sieves don't come apart.

C. Quantitatively transfer the sample to the set of sieves and replace the lid. This should ideally be done while the set of sieves is on or over a pan (cookie sheet) or paper (newspaper okay) to be able to recover the sample should an accident occur in the transfer. The set of sieves is not “locked” together and unintentional separation of the sieves should be guarded against.

D. Observe the material which remains on the 6.35mm sieve. Brush (I used old toothbrushes) silt and sand from the larger particles and 1) transfer the remaining particles which are greater than 6.35mm to a tared container (bottom of a gallon milk jug? Tupperware container?) or 2) weigh on the sieve. Transfer to the balance and record the mass (>6.35mm fraction) to the nearest gram. Pour this fraction back into the sample bag. I generally returned the >6.35fraction to one bag and the rest of the sample to a separate bag. Both should be double-bagged and labeled unless you fit the bag with the smaller particles inside the bags with the larger particles. Then you would need only two labeled bags for the big stuff and one labeled bag for the smaller stuff.

   Note: Our scale only weighs to within 1 gram.

E. Shaking the sieves is best done with a mechanical shaker. Relatively inexpensive ones shouldn’t be more than $150. Instead of or until such time as one is available, the type of samples we generally have can be shaken by hand with little bias. Samples must be shaken in a horizontal direction, back and forth, side to side. A circular motion in the horizontal plane is also okay. Shaking should be done in all directions to ensure that all particles have sufficient chance to fall through the holes. In other words, don’t just shake in a clockwise circular direction, shake also in the counterclockwise direction.

   Note: A sieve shaker would be a very good acquisition for this project, however in researching prices the lowest was $650. We should ask Mike Purser, but even if the price has gone up, it would remain a good idea to buy one. The shaker would eventually pay for itself ($ for power to run shaker <$ to pay someone to shake).

E. Shaking should occur for a minimum of 1 minute. At that time check the 2 mm screen and see if there are any aggregated (stuck together) particles. If so, gently or not so gently break apart with a brush or wooded spoon/spatula, etc. A brush is needed anyway to clean sieves, but for breaking up aggregate, the main requirement is that the instrument should not be harder than soil (e.g., no metal) as this may lead to alteration of the sample through crushing of integral particles into smaller pieces than they were when collected.

F. If you brushed or crushed aggregate you need to reshake for one minute. Repeat up to three times of necessary to disperse aggregated “clods” or material in rock joints. Remove the 2 mm sieve and weigh or quantitatively transfer to a tared container for weighing. Record mass to the nearest 0.1 gram. Return this fraction to the sample bag.

G. Repeat the steps II. B.-F. above on the 0.85 mm sieve. Record mass (2.0-0.85 mm fraction) to the nearest 0.1 gram.

H. Weigh the pan plus <0.85mm fraction or quantitatively transfer the sample to a tared container and record the mass (<0.85 mm fraction) to the nearest 0.1 gram. Return this fraction to the sample bag.

APPENDIX D Process for Sediment Analysis of Void Spaces for Grande Ronde and John Day River Sediments

Void space of the large rocks

Measure rocks to intermediate diameter so that they are all a standard size. These would be drawn from the matrix rocks in pails.
Fill pail with rocks to simulate redd construction as done in the field for this experiment.
Weigh rocks that fill the pail.
Determine the volume of void spaces in the pail by filling pail w/ rocks until water just overflows.
Re-fill the pail several times with the same rocks, making sure the rocks do not extend above the top of the pail. This will simulate various degrees of compaction of the rocks to determine the variability of the void space. Repeat the determination of void space—do it about 5 times.
Measure the volume of an empty pail.

Volume by weight of fine sediment fractions

Measure the volume by weight of the various fine sediment fractions by doing the following steps: Weigh a sample of fine sediment from a stream. Transfer the sediment into a graduated cylinder that will contain the entire sample. Determine the dry volume of the sample.

Pour the sample back out of the graduated cylinder. If the volume of the sample is 50 ml, use the 100 ml cylinder. Fill the cylinder with 40 ml of water. Add the dry sample back into the cylinder. Determine the new volume of the sample plus water. The displacement volume is the volume of the material.

Repeat this process with the 3 size fractions for a particular stream. Do this same process with each of the other streams to determine whether there are any differences among streams.

Calculations and inference

The pails had varying amounts of large rock in them when they were collected because flows probably scoured some of the rock out. Void space then is a function of the voids between rock and the volume of pail above the rock surface. We need to determine for a given weight of rock, what the void space is in the pail. A bucket then should be able to hold a certain weight of rock, assuming that the rock is a consistent size. If a pail holds 1000 g of rock (500 ml, just for purposes of explanation), the empty pail volume is 1000 ml, and the void space equals 50% of the pail volume, we should find that this volume is occupied by a certain weight of fine material. If we calculate that there is additional volume that was not occupied by rocks or fines, this might be voids within the fines that water can occupy. Also, fine particle bridging might leave large voids within the bucket.

If the pail only contained 800 g of rock, this would equate to 400 ml rock volume, and the pail would have 600 ml of void space in it. If 1000g of rock has 500 ml of rock and 500 ml of void, 800 g would have 400 ml of rock and 400 ml of void. The remaining 200 ml of void in the pail would be above the rock surface. This could then be occupied by any size particle that moved along the streambed, and probably mostly fine sediment.
The amount of fines in a pail requires adjustment for the amount of large rock. The fines that occupy the void above the rock surface should be removed. The amount of fines below the rock surface should be determined.

The fines that are either above or below the rock surface cannot be distinguished in these samples. This material is totally mixed but is sieved into 3 fine particle size fractions. The percentage composition of these size fractions may be a signature indicator of the sediment transport environment of newly constructed redds. This is the material that is available to infiltrate into cleaned redd material.

If the simulated redds had been constructed of a natural range of particles available in the stream bed that is >6.35mm, the rate of infiltration into this substrate composition might be far different than that into the coarse particle matrix provided. The more diverse mixture would allow sediment bridging at the surface that might restrict further infiltration.