March 12, 2002

MEMORANDUM

TO: Bob Klampt, North Coast Regional Water Quality Control Board

FROM: Matt O'Connor, PhD, RG #6847
Contract Hydrological Consultant to GRWC

RE: Comments on North Coast Watershed Assessment Program Draft (NCWAP) Report for Gualala River-Sediment d50 as an Indicator of Water Quality

Introduction

The following discussion pertains to interpretations in the NCWAP draft report of data for d50 (the median sediment grain size determined from pebble count data), measured on streambed riffles. Monitoring data collected by Gualala Redwoods Inc. in cooperation with the GRWC includes a data set for d50 at several monitoring sites. These data have been compared to d50 collected by Knopp (1993), in a report entitled "Testing Indices of Cold Water Fish Habitat", prepared by the North Coast Regional Water Quality Control Board in cooperation with the California Department of Forestry. This memorandum presents evidence that this comparison is scientifically inappropriate given the data and methods used in the two studies.

Overview of Knopp Study

The Knopp study assumes that:

> *…native populations of cold water fish evolved in response to environmental conditions, and that the mean condition represented by undisturbed reaches…represents the mix of habitat elements conditions best able to maintain viable populations. Good quality habitat (relative to a specific geologic formation and channel type), is therefore defined as the mean condition existing under undisturbed conditions (p.13).*

The study design included the following limitations on channel conditions that were evaluated:

> *The sample design, site selection criteria, and the indices to be monitored were selected to limit the natural variability and to identify those components of habitat that are both important and quantifiable. To accomplish this, sampling locations were selected based on geology and channel type. Only the Franciscan Formation and channels exhibiting small cobble substrates and slopes between 1 and 4 percent…were sampled (p.8)* [emphasis added]

The Knopp study examined 60 streams, 18 of which had little or no disturbance ("Index All" sites), in the preceding 40 years. These were compared to two other groups, each about the same size, with "Mod" (moderate), and "High" levels of watershed disturbance.

Disturbance levels were determined from aerial photo interpretation of roads, stream crossings, forest harvest history, log yarding techniques, and landslides, which were synthesized to estimate sediment inputs from about 1960 to 1990. No field work was done to confirm or calibrate the aerial photo-based sediment source inventory.

The Knopp study also evaluated whether watershed drainage area or reach average slope from topographic maps influenced other stream variables. This was considered because of differences in the slope of field sites in the three different watershed disturbance categories: Index All (mean slope = 3.1%), Mod (mean slope = 2.4%) and High (mean slope = 1.9%). Excerpts from the Knopp report focusing on the differences between slope and d50 among the watershed disturbance groups are shown on the following pages.

Knopp found statistically significant differences between slopes for Index All and High sites using Analysis of Variance (F-test, $p<0.05$), but not between Index All and Mod sites. As can be seen in Knopp's Figure 4, however, it appears that the difference between Index All and Mod sites was marginally significant. Knopp concluded that neither reach average slope nor drainage area were significantly related to Riffle Armor Stability Index (RASI), d50 (median surface sediment diameter from pebble counts) and V* (a measure of proportion of pool volume filled by sand and fine gravel). This conclusion was based on analysis of a subset of the data comparing Index No, High and Mod sites with comparable slopes and drainage areas. These subsets of the data were described, but not specified, in the report. The results of statistical tests were included (p.18).

The Knopp study concludes that Index sites had low estimates of sediment input, whereas the Moderate and High sites had much higher levels of estimated sediment input. Furthermore, Knopp concludes that three variables measured at field sites were significantly related to upslope disturbance categories. These were the RASI, d50 and V*; d50 is the stream variable considered in the NCWAP draft report.

With respect to d50, the full set of Knopp's data (see excerpts from Knopp on following pages), suggest positive correlations between reach mean slope and reach mean d50. The slope of Index All sites is significantly greater than High sites and is marginally greater than Mod sites (Knopp Figure 4, following page). The reach mean d50 of Index All sites is significantly greater than in Mod and High sites (Knopp Figure 7, second page following). Despite Knopp's conclusion that slope is not a significant controlling variable affecting d50 using a subset of the data, the full data set suggests that Index All sites have higher slopes and higher d50's and that Mod and High sites have lower slopes and lower d50's.

Excerpt from Knopp (1993), p. 17.

Figure 4. Comparison of slopes by groups.

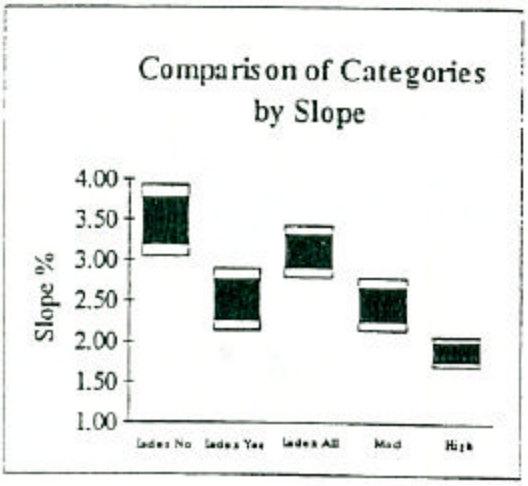


Figure 5. Total plot of slopes by group.

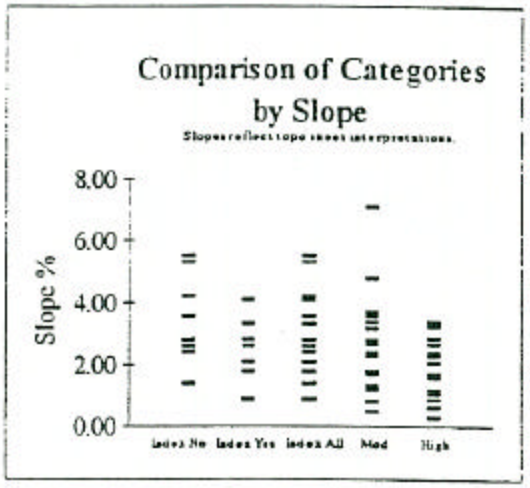


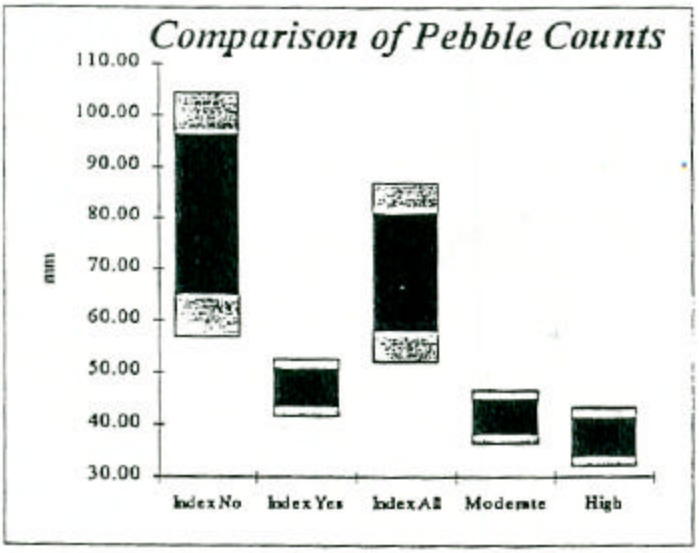
Figure 4. Slopes are significantly different between the Index All category and the High category and between the Index No and High categories.

Excerpt from Knopp (1993), p. 21.

Table 5. D50s by category. D50s reflect pebble count data collected to characterize RASI values in riffles. Values represent median particle sizes in millimeters.

	Disturbance Category				
D50 of Riffle	**Index No**	**Index Yes**	**Index All**	**Moderate**	**High**
Mean	80.66	47.07	69.46	41.46	37.61
Median	73.62	47.37	51.47	37.23	36.87
Std Deviation	42.17	6.97	37.82	12.20	13.20
Minimum	37.43	38.43	37.43	17.03	10.20
Maximum	183.13	57.70	183.13	61.93	60.83
Count	12	6	18.00	21	21

Figure 7. D50s by category. A D50 value of 65 millimeters (mm), means that 50 percent of the substrates were smaller than 65 mm, and 50 percent were larger. Figure 7 represents the 80 and 95 percent confidence bands around the category means.



Each reach was represented by (3) 200 count riffles. The data was collected as a component of the RASI evaluation. A clear trend of decreasing particle sizes in the riffles was evident with increasing upslope disturbance. Again, the 'Index Yes' reaches were not different from the 'Moderate or 'High' reaches, although both appear to exhibit smaller particle sizes. The 'Index No' reaches were significantly different from the 'Index Yes', 'Moderate' and 'High' categories at 80 and 95 percent. The 'Index All' category was significantly different from the 'Moderate' and 'High' category at 80 and 95 percent. The 'Moderate' category was not different from the 'High' category.

Application of Knopp Index d50 to Gualala River d50 Data

It is assumed in the NCWAP Gualala River draft report that the range of d50 found in Knopp's Index streams is an appropriate reference index of sedimentation conditions as they pertain to habitat for salmon and steelhead for streams in the Gualala watershed where d50 data area available. It is asserted that because d50 values in the Gualala are lower than the range of values in Knopp's Index streams, that sedimentation conditions at these sites are degraded with respect to fish habitat. In my professional opinion, the comparison and the conclusion are in several respects unsupported and contradicted by other available data and knowledge regarding downstream fining of sediment textures of river systems.

First, as shown in Table 1 and Figure 1 below, most of the monitoring sites with d50 data collected by GRWC and GRI have slopes much less than 1% (8 of 12 sites have slopes = 0.7%). The Knopp data are applicable for slopes of 1 to 4% (1 of 18 sites have slope < 1%, and only 4 of 18 sites have slope < 2%). Hence, comparison of Gualala River for channels with slopes < 1% is inappropriate based on the range of data from the Knopp study.

In addition, Figure 1 shows that the Gualala data for d50 are significantly related to reach mean thalweg slope (F test, $p < 0.008$). The GRWC/GRI survey protocol includes a topographic survey of channel slope over approximately 1000 ft of stream; slope data reported for these sites is the slope of the regression relating horizontal distance and vertical elevation. Figure 1 also shows the absence of a relationship between slope and d50 in Knopp's data. This suggests the possibility that Knopp did not find slope to be a significant variable because channel slope was not accurately measured in that study.

Table 1. Gualala River Watershed Council monitoring data for d50; slope data are from surveyed thalweg profiles. Eight of 12 sites have slopes = 0.7%.

Site Name	Site #	Slope	D50
Gua1	217	0.1	23
NFG4	473	0.3	28
Roc3	221	0.3	28
Buc1	231	0.3	24
NFG3	204	0.4	19
Buc3	223	0.4	30
LNF3	404	0.6	30
Dry3	211	0.7	50
Rob2	207	1.4	37
Ppw3	218	1.4	34
LNF1	203	1.5	40
Dry2	212	1.8	89

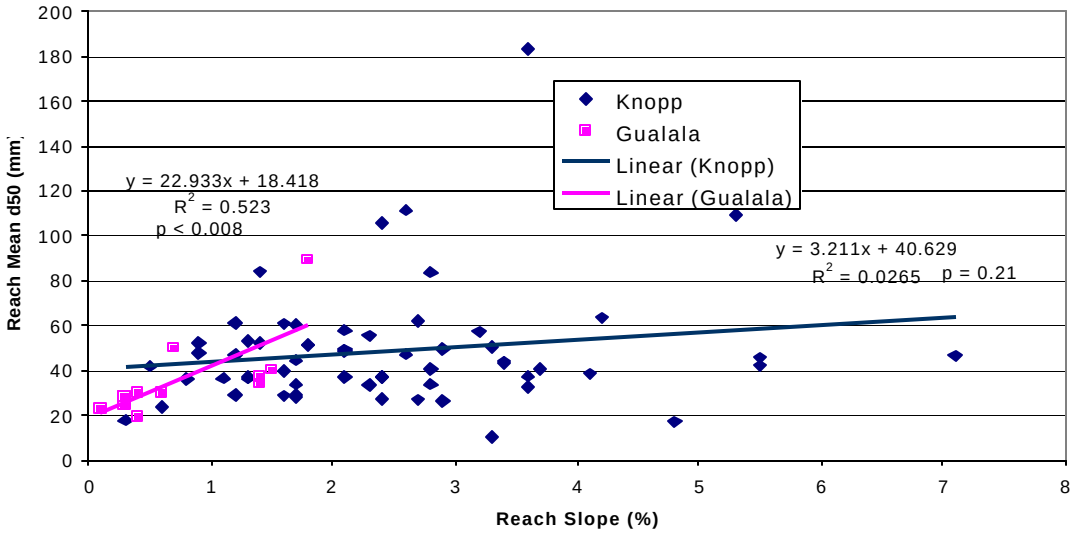


Figure 1. Gualala data and Knopp data; Gualala data are significantly related to slope.

Figure 2 shows the Gualala data and Knopp data separated according to watershed disturbance levels, and demonstrates Knopp's conclusion that d50 is larger in watersheds with little disturbance. This appears to be true when the data are separated into watershed disturbance categories, however, as shown in Figure 3, if d50 is plotted as a function of the estimated sediment input in the watershed, there is only a weak trend and no statistically significant relationship (F test, p = 0.25). Figure 3 shows that Knopp's quantitative index of sediment supply is not a good predictor of d50, suggesting that factors other than sediment supply (watershed disturbance) control d50.

Another potential problem with Knopp's analysis is the description of watershed geology used in that study. Watershed bedrock was described as Franciscan Formation. It is not clear whether any of the study watersheds included Franciscan mélange terrain, or whether this included both the Coastal Belt and Central Belts of the Franciscan Formation. The latter typically contains much higher proportions of deep seated landslide and rockslides. These variations could significantly skew sediment production and grain size data because of high levels of erosion from mélange and deep landslides. Hence, the Knopp study may not have adequatelycharacterized the watersheds with respect to geologic controls on erosion rates. The NCWAP report documents the wide extend of deep landslides (both active and dormant) and mélange in the Gualala River, and therefore it might be reasonable to expect relatively fine sediment size distributions even under undisturbedconditions. As in almost all locations, however, there is little or not data for specific watersheds of interest regarding sediment size distributions or water quality under undisturbed conditions.

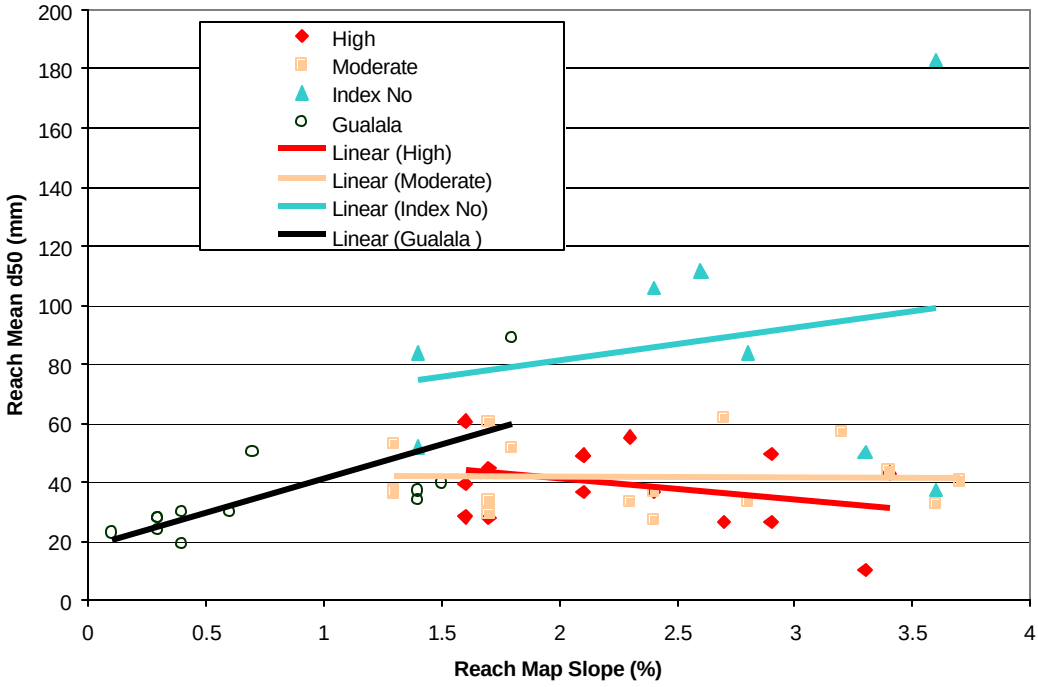


Figure 2. Gualala data and Knopp data classified by watershed disturbance category; Knopp data are selected for comparable slopes across disturbance categories.

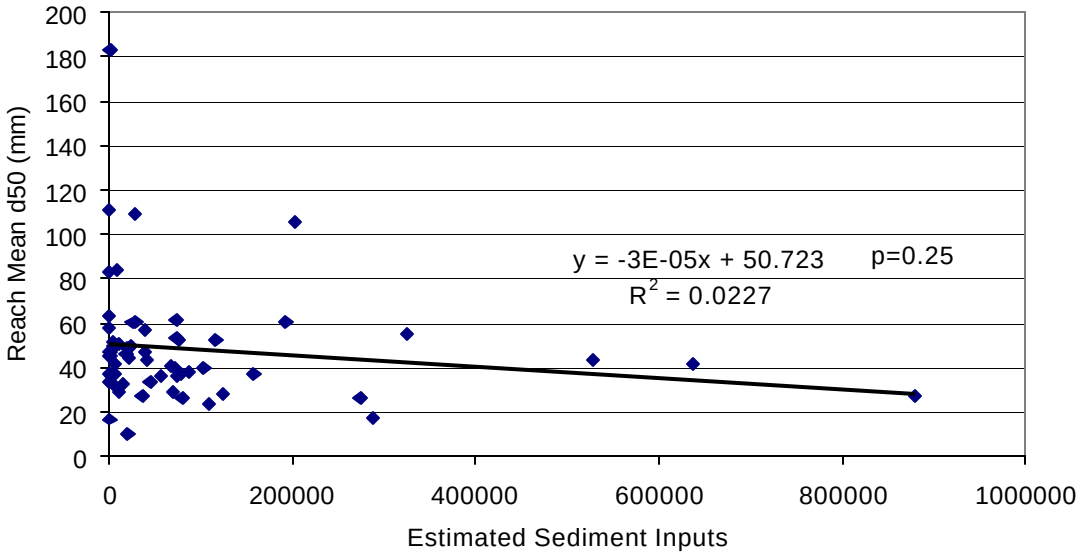


Figure 3. Knopp d50 data plotted as a function of sediment input; the trendline is not statistically significant.

It is generally accepted that sediment size on stream beds is determined by two factors: the energy of stream flow, most commonly expressed as the bed shear stress for bankfull flow, which is modulated by channel roughness factors, and sediment supply (Dietrich et al., 1989, Buffington and Montgomery, 1999). Knopp was evidently cognizant of these factors, but did not collect data hydraulic data at the measurement sites for d50 and RASI that could resolve whether or not stream hydraulics are an important predictor of d50. Consequently, the Knopp report's finding that slope was not an important control on d50 may be inconclusive owing to insufficient data. Desirable data include accurate measurements of channel slope for the reach and/or the measurement location, and the mean bankfull depth measured at riffles in the reach and/or the at the measurement location. These data could be used to compute the total bed shear stress, which would be much more likely to correlate with d50 than the reach mean slope estimated from a topographic map as was done in the Knopp study.

Streamflow magnitude and frequency are correlated with drainage area and annual rainfall and could also serve as predictors of average stream energy. Knopp examined drainage area as a potential controlling variable, but did not consider regional hydrologic factors such as mean annual rainfall. In Knopp's study area, rainfall generally increases with latitude. In addition, topography induces strong orographic rainfall gradients throughout the study area. Finally, one cluster of Index No sites (#34, 35 & 36) is located in southeastern Trinity County, a region where snow-melt may be a significant element of runoff. Snow-melt dominated regions often have very different runoff regimes than coastal, rain-dominated streams (Naiman et al., 1992), and this could be expected to affect fluvial geomorphic characteristics as well. Hydrologic variablility may thus be another significant factor affecting Knopp's results that has not been controlled in his study.

Another issue that may confound application of Knopp's findings to the existing GRWC monitoring sites in the Gualala watershed is the phenomena of downstream fining of sediment texture in gravel bed rivers (Gomez et al., 2001). This effect is particularly pronounced in rivers approaching a topographic base level such as the ocean. As the river slope declines, its competence to transport sediment declines, and sediment transported by higher energy flows upstream is increasingly deposited. This effect appears to be pronounced in the estuary of the Gualala, and could be expected to extend upstream in areas of alluvial valley fill associated with sea level rise (as described in the NCWAP draft report). The Knopp study sites are generally located in smaller, steeper watersheds where downstream fining would not be expected to be a strong controlling factor. The mean drainage area of Knopp's index sites is 6.4 mi^2, with 3 of 18 > 10 mi^2, and a maximum of 30 mi^2. Six of the 8 GRWC sites with slopes < 1% are located on the mainstems of Super Planning Watersheds where drainage areas are > 30 mi^2. Again, these considerations indicate that the Knopp data may not be applicable to several monitoring sites in the existing set of GRWC monitoring data. The downstream fining phenomena does not rule out potential increases in deposition or decreases in d50 that could occur in association with increased sediment supply. It does, however, strongly suggest that d50's observed in low-gradient alluvial channels near the estuary (which includes many of the GRWC monitoring sites) may be expected to relatively fine.

Conclusion

In the NCWAP Gualala River draft report, the working hypotheses and conclusions pertaining to water quality using d50 as an indicator should be revised to account for the considerations discussed above. The chief problem, however, is comparing data from smaller and steeper Index streams to larger streams with lower stream gradients. This comparison is not scientifically justifiable. Targets for d50 in low-gradient alluvial channels in large watersheds where downstream fining occurs based on Knopp's Index sites are likely to be geologically unattainable.

The GRWC is in the process of selecting new monitoring sites. Sites are being selected in a manner that will make the number of sites in a given slope class proportional to the total length of that channel slope class in the watershed. This will result in a large number of new monitoring sites with channel slopes in the 1-2% and 2-4% slope classes that Knopp's study examined. These sites may be more comparable to Knopp's Index sites with respect to channel slope. GRWC intends to continue to explore the relationship between slope, other hydraulic parameters, and d50. The planned study of the Gualala River estuary may also provide an opportunity to investigate downstream fining phenomena.

One means to address these concerns would be to limit the comparison between Knopp's data and Gualala River monitoring data to monitoring sites with slopes > 1% and to acknowledge the limitations of applying Knopp's Index stream data as targets.

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