FINAL REPORT

VALIDATION OF WATER YIELD THRESHOLDS ON THE KOOTENAI NATIONAL FOREST

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If you know how long it's going to take, how much it will cost, and what the results are going to be, it ain't research.

(W. Marlatt, professor emeritus, CSU)

It has long been a goal of individuals working with rivers to define and understand the processes that influence the pattern and character of river systems. The differences in river systems, as well as their similarities under diverse settings, pose a real challenge for study. One axiom associated with rivers is that what initially appears complex is even more so upon further investigation.

(Rosgen, 1994)

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Although the ideas expressed here are solely our responsibility, this report represents the contribution of many individuals, and their efforts were essential to the initiation, execution, and completion of the work reported here.

1. INTRODUCTION

This report summarizes the results of the project "Validation of Water Yield Thresholds on the Kootenai National Forest". The first phase of this project was sponsored by the Montana Department of State Lands, but since early 1993 the work has been supported directly by the Kootenai National Forest (KNF). Detailed interim reports were submitted in December 1992, June 1993, and November 1993, and a draft final report was submitted in July 1995. Following comments from the KNF, the final report -- principally Chapter 2 -- was extensively revised and extended.

In the interest of space, not all of the information contained in the interim reports is repeated here. In particular, this report references two M.S. theses and several journal articles that are in preparation, in press, or that have already been published. Copies of these documents, except for articles in preparation, have been provided to the KNF. Since the total length of these theses and articles exceeds four hundred pages, they also are not included in this report.

The work conducted under this project was organized around three objectives. The first objective was to "Evaluate the causative factors relating timber harvest and related activities to increases in (the size of) peak flows." The basic purpose of this task was to evaluate the effects of forest harvest on peak flows, and then analyse local hydrologic data to estimate the likely effects of forest harvest on runoff in the study region. The implicit assumption was that the larger peak flows (e.g., the uppermost 5-10% of the flow duration curve) are of primary concern because only these flows are important for sediment transport and controlling channel morphology. We also compiled and analysed all the existing hydrologic in order to better characterize the spatial variability within the study area and assess the validity of the three hydraulic regions defined by the KNF for peak flow analysis.

The second objective was to "Develop criteria for determining the amount, degree, and type of impact attributable to peak flow increases." The basic concept behind this objective is that adverse change in stream channel conditions are a primary concern of land managers. Changes in water yield or peak flows may in themselves be of limited interest, but these changes in flow can have adverse effects on fish habitat, downstream sedimentation, and riparian conditions. Each of these secondary effects is of immediate concern to regulatory agencies and related to the broader goal of sustainable ecosystem management.

To address this objective, we first reviewed the existing literature on the effects of forest management on stream channels, particularly changes in the size of peak flows. We then designed a field study to sample and measure channel characteristics across a range of conditions, channel types, and management intensities. Following our initial sample of 57 reaches in summer 1992, we adjusted our procedures and focus before sampling an additional 57 reaches in the summer of 1993. This data set of 114 reaches was the basis for much of the work under both objective 2 and objective 3 (defined below). These data were also used to evaluate two stream classification systems and the extent to which stream channel characteristics are associated with the hydraulic regions used for peak flow analyses by the KNF. The work on channel characteristics was summarized in a M.S. thesis (Madsen, 1994) and two journal articles (one in press and one in the final stages of preparation).

The third objective was to "Better characterize the peak flow increase thresholds to be used as planning tools for future timber harvest activities on the Kootenai N. F." This objective is basically an integration and extension of the work conducted under the first two objectives. The stream channel data collected under Objective 2 were plotted against a series of management variables. Of principal interest was the relationship between water yield increase as predicted for each reach by WATSED-PC (USFS, 1992) and the various channel response variables. Channel characteristics were also plotted against a series of other management variables obtained from WATSED-PC or the data base used to run WATSED-PC. The basic intent was to

assess the relationships between management indices and stream channel condition.

The following chapter summarizes the results obtained under the first objective. Results obtained under Objectives 2 and 3 are integrated and presented in Chapter 3 of this report. Chapter 4 discusses the implications of our results for management and presents our recommendations.

4. MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

4.1. Monitoring the Effects of Forest Management

From a legal perspective, the Clean Water Act requires land managers to maintain the designated beneficial uses and meet the appropriate antidegradation standard. Within the study area coldwater fisheries is the designated beneficial use most susceptible to forest management and thus of primary concern. Bull trout occur throughout much of the study area and have been designated as an indicator species by the USFS. Rieman and McIntyre (1993) identified five habitat characteristics of particular importance to bull trout, and these are channel stability, substrate composition, cover, temperature, and migratory corridors. Channel stability was not explicitly defined, but Rieman and McIntyre focussed on the stability of the channel bed and implied that high bedload transport, scour, and aggradation were all detrimental to bull trout.

Although stream temperature was not directly addressed in this study, both physical modeling and experimental evidence have shown that the use of buffer strips should minimize adverse changes in temperature (Beschta et al., 1987). Rieman and McIntyre (1993) note that bull trout appear to prefer colder water, and this implies that temperature increases should be held to a minimum. The exact width of the buffer strip should be set as a function of tree height, latitude, and topography, and various authors suggest a width of approximately 0.5 times the mature tree height or a maximum of approximately 30 m (Belt et al., 1992; Castelle et al., 1994).

Cover is maintained by providing large woody debris and minimizing channel infilling or aggradation. Recent fisheries literature suggests the more wood the better, and geomorphologists have noted a relationship between the number of pools and the amount of large woody debris (LWD) (Montgomery et al., 1995). Data from the present study also indicate increasing pool density in pool-riffle channels with increasing amounts of

LWD. Buffer strips slightly less than one tree height are necessary to maximize the input of LWD (Robison and Beschta, 1990).

Migratory corridors are beyond the scope of this study, but the other important habitat charactersitics all relate to changes in discharge and sediment supply. Table 3-21 summarized the significant changes in the morphologic variables with one or more of the management indices for each of the three channel types or subtypes. The predominant response was a fining of the substrate, particularly in pools. We also observed a significant increase in the depth and cover of fine sediment in pools in the pool-riffle reaches. Some substrate fining was also observed in the step cross-sections in the colluvial step-pool reaches and the riffles in the riffle-pool reaches. Both the pool-riffle and the colluvial step-pool reaches showed a significant increase in the amount of exposed bank with predicted water and sediment yield increases. An increase in the amount of exposed bank was not detected in the fluvial step-pool channels, but there was a statistically significant decrease in step height.

The observed changes in substrate and sediment deposition in pools can be directly related to the habitat requirements of bull trout. Rieman and McIntyre (1993, p. 6) note that while there probably is considerable variation in the sensitivity and response of bull trout populations to a change in substrate, "any increase in the proportion of fines in substrates should be considered a risk to productivity of an environment and the persistence of associated bull trout populations". The increase in exposed bank is probably an important source of sediment, but the absence of quantitative data on natural and anthopogenic sediment sources makes it difficult to quantitatively link forest management activities to an adverse change in the designated beneficial uses.

As discussed in Section 3.11, the relationships presented in Table 3-21 need to be viewed with caution. First, we used a weaker level of significance (0.10) because of the tremendous variability in stream systems, the uncertainty in the management indices, and we wanted to be more inclusive than exclusive in terms of identifying possible channel responses. Second, there was considerable regional variation in the observed responses. Third, we had relatively few reaches which were undisturbed or minimally-disturbed, and this made it difficult to determine reference conditions. We also cannot verify that our reference conditions were representative, and this lack of representativeness would make it more difficult to identify significant channel morphologic responses to management. Fourth, fourteen of the nineteen significant variables in Table 3-19 had to be adjusted for the effects of one or more of the local controls. Gradient was generally the most common control, particularly for the particle-size variables, but runoff efficiency, drainage area, and amount of large woody debris all accounted for a significant proportion of the variability in some of the response variables (Madsen, 1994). These local controls generally explained more of the variability in some of the response variables than the management indices. These data plots, which were all presented in Madsen (1994), show a great deal of scatter. Finally, the accuracy and relevance of the management indices is largely unknown.

Despite these limitations, the present study presents strong quantitative evidence for a change in key habitat variables with increasing management intensity for the three common channel types studied here. The reliability of these relationships is enhanced by the consistency among the observed responses, as well as the agreement with previous studies and basic principles of fluvial geomorphology. However, the usefulness of these relationships to set specific management guidelines is limited by: (1) the variability within the relationships; and (2) much of the variability in the response variables cannot be accounted for.

In terms of monitoring, the results clearly indicate that the focus should be on bed-material particle size, particularly in pools. In downstream pool-riffle reaches one should also evaluate the amount of fine sediment deposited in pools. In colluvial step-pool and in pool-riffle reaches the amount of exposed bank appears to be another useful indicator of management effects. We found no evidence of significant change in channel dimensions, and only a weak significant relationship between the predicted water yield increase and Pfankuch's (1978) channel stability evaluation.

On the other hand, components of our proposed channel condition assessment appeared to be strongly related to management intensity. Our analysis suggests that the most useful variables include the following: location of exposed banks, extent of sediment deposits, sediment trap capacity, and infilling of fine sediments. The procedure seemed to be more useful in pool-riffle than fluvial step-pool channels, but this may be partly due to the much smaller sample size for fluvial step-pool channels. Again the consistency of these qualitative or categorical responses with the quantitative data (Madsen, 1994) lends further credence to the basic trends.

The results of our study suggest that both quantitative and qualitative procedures could be used for evaluating channel condition and channel change. Quantitative methods would rely on procedures, such as Wolman pebble counts, to track bed material particle size, and the development of other, more rigorous procedures to quantify bank exposure or bank instability. With regard to the former, several cautionary notes need to be considered. First, particle size distributions can vary over time due to variation in flows (Lisle, 1982; De Jong, 1992; Ergenzinger et al., 1994). Second, particle size distributions are typically very patchy, and there needs to be consistency in the geomorphic unit being sampled and the methodology of selecting particles. Third, there may be considerable observer variability (Bevenger and King, 1995; Marcus et al., 1995; Wohl et al., in press). Fourth, natural controls -- such as gradient, drainage area, and runoff -- need to be taken into account. The careful evaluation of all these factors will greatly enhance the reliability of the data and resulting interpretations.

We would also recommend additional studies to develop a consistent and reliable procedure to quantify the amount of exposed bank. Our ocular estimates were adequate for the exploratory nature of the study because of the consistency in observers over the two years of data collection. The same approach is unlikely to be adequate when applied over time and across large areas by a variety of personnel. A possible quantitative technique would be to measure the total length of exposed banks on each side of a sample reach and divide that value by the reach length. Our data suggest that this would need to be adjusted for runoff efficiency; the amount of large woody debris, while not significant in our data set, may also be an important controlling factor. A possible qualitative approach would be to assess the presence or absence of exposed banks in specific locations (e.g., straight reaches, outside of bends, or localized in association with large woody debris).

Further testing and modification of our channel assessment procedure could lead to an improved qualitative technique to provide information on the: (1) likely sensitivity of a channel to management activities; (2) current channel condition; and (3) geomorphic processes at work. The use of a qualitative format would avoid the problems of assigning numerical values to each characteristic, weighting the importance of each characteristic, and then calculating a single score which can be compared across geographic regions and channel types.

The reality is that different channel types have differing sensitivities to management. Pfankuch's (1978) channel stability rating depends in part on channel type (Myers and Swanson, 1990), and the specific weighting scheme used in Phankuch (1978) has never been justified. One thus can argue that the Pfankuch rating is a number based on qualitative judgements. In this case it would be much more honest to simply utilize a qualitative system. Retaining the data as a series of qualitative judgements would both facilitate and force an understanding of the underlying condition and processes rather than relying on an arbitrary, integrated index.

4.2. Thresholds, Risk, and Management Guidelines

The establishment of specific management thresholds rapidly expands into the arena of economic and social values. Key questions -- such as how much change is acceptable, or how much risk is acceptable -- do not have a technical answer. The plot of exposed bank versus predicted peak monthly water yield increase shows that a basin with minimal management can have the same percent exposed bank as an intensively-managed basin (Figure 4-1). There is a clear and statistically significant trend, but the noise in the data precludes designating a threshold that can be applied in all cases. Support for a variety of thresholds could be developed by selectively choosing the appropriate variable, stream type, and value system. In many cases the trend in our data appear to be due to a change in the variability as much as a change in the absolute values.

Reviews of the effects of forest harvest on water yield (Bosch and Hewlett, 1982) and the change in peak flows (Section 2.1) both suggest that 15-20 percent of a basin has to be harvested in order to generate a detectable change in discharge. Hydrologic theory would suggest that lesser cuts would still yield a change in flow, but this is simply not detectable given current measurement techniques and statistical procedures. A similar problem confronts us with regard to setting limits on management activities, except that there are the additional complications of: (1) quantifying a variety of different management activities over time and space using a common currency; and (2) relating the change in a given channel characteristic to a change in a designated beneficial use.

A review of the significant pool-riffle plots presented in Madsen (1994) suggests a qualitative shift in the distribution of the response variables when the predicted increase in peak monthly water yield exceeds 6-8%. Similarly, there appears to be a qualitative shift in the response variables from the step-pool channels when the predicted increase in sediment yield exceeds 40-60 percent, or the ratio of predicted sediment to water yield increase is around five.

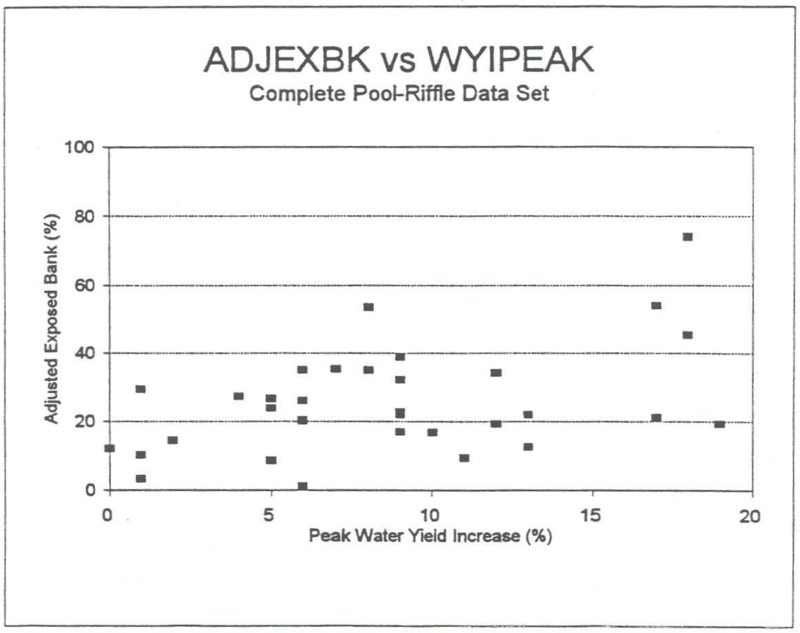

Figure 4-1. Plot of the adjusted amount of exposed bank versus the predicted peak monthly water yield increase for the complete pool-riffle data set.

It's quite possible that none of these values has any statistical significance, and it must be emphasized that the values are highly dependent upon the coefficients and relationships put into R1-WATSED. Nevertheless, they might represent zones where the risk of adverse management effects becomes detectable. If there is then an exceptional storm event or unusually rapid snowmelt, one might expect such basins to have more bank scour, road erosion, or sediment transport than if the basin were in an unmanaged state.

Unfortunately we cannot separate out the risk due to management activities from the risk due to natural events because there are no data on the change in any of our response variables with the natural variations in discharge or sediment supply. Thus periodic measurements of key variables in relatively undisturbed basins are urgently needed to both assess the natural variability and evaluate the magnitude of response to natural events. In the absence of such data the effects of management are inextricably confounded with the unquantified effects of natural processes. A risk-based assessment of channel change is the only way to account for the unpredictability of future climatic events, but this can only be done after we have data relating channel response to the range of events of concern.

From a statistical perspective, the data presented here can only be applied to the population of streams from which we sampled. This means that our results can only be directly applied to the three channel types in regions 2 and 3 in the KNF, and the Tally Lake Ranger District on the Flathead National Forest. In designing and executing this study, we explicitly retained this geographic focus and our focus on a limited number of channel types in order to maximize our chances of detecting significant relationships between management indices and channel morphology. The large amount of noise in our data, and the statistical limitations of the sample size after stratifying by channel type and hydraulic region, supports this decision to focus our efforts.

On the other hand, our understanding of hydrologic and fluvial processes, combined with the results of studies in other geographic areas, leads us to believe that the trends observed here are likely to be more widely applicable. The similarity in flow regimes suggests that the results from hydraulic region 2 could be relevant to hydraulic region 1, but this will also depend on the similarity in other processes, such as erosion rates.

Another issue is the choice of management indices to characterize management intensity. The most reliable index is the change in annual water yield, as that is based on numerous paired catchment experiments. The other water yield indices are less reliable, but their high intercorrelation suggests that one index is nearly as good as another. Thus we would expect the indices which were not evaluated, such as the predicted period with at least 75% of bankfull discharge, to yield very similar results to the predicted change in monthly peak water yield. Certainly there is little reason to believe that the use of another water yield index would substantially alter our basic results.

The predicted increases in sediment yield are much less reliable because we have little calibration data and only very crude techniques to route sediment into and through the channel network (e.g., USFS, 1981; Walling, 1983). Different coefficients between the Kootenai and Flathead National Forests resulted in large differences in predicted sediment yields between otherwise similar basins. These results suggest that the management indices derived from R1-WATSED, like most cumulative effects models, are most useful as relative rather than absolute indices. It should also be noted that use of the more absolute indices, such as road density or percent area cut, generally did not yield better correlations. Road density may be of limited value because it represents only one management activity, and percent area cut is limited because it does not account for recovery over time.

The problem of quantifying management is a long-standing issue in forest management, and it is one that is not easily resolved. R1-WATSED is preferable to the models using equivalent roaded or clearcut areas (e.g., Cobourn, 1989) because it at least separates the model for predicting changes in discharge from the model for predicting changes in sediment yield. There is still the problem of adding effects from different management activities, and the location of the activities relative to the location of interest. R1-WATSED considers the slope location of the management activities when calculating the predicted impact, but does not individually consider the location of each activity within the basin. Yet most scientists would agree that a sediment input from higher up in the catchment will usually have less effect on downstream channel conditions than a similar input closer to the reach of concern. The advent of GIS-based models may help resolve the latter issue, but the complexity of any quantitative cumulative effects model precludes true validation (Oreskes et al., 1994). Thus we can expect some improvements in the quantification of management indices, but the basic problem of quantifying the predictive variable ("management") is unlikely to be resolved.

An approach that completely avoids the issue of quantifying management is to adopt a performance-based standard. In other words, if a channel exhibits certain characteristics, regardless of cause, then management activities in that basin should be severely restricted. Our draft channel condition assessment could potentially be used for this purpose, as it qualitatively identifies a series of conditions that can be directly linked to poor habitat quality for coldwater fish. The disadvantage of such an approach is that it would allow all channels to be degraded to the threshold of detectability.

4.3. Additional Research Needs

A number of applied research needs have already been identified, and these include: (1) validation of R1-WATSED; (2) development of an improved procedure to quantify bank erosion;

(3) additional sampling of stream reaches to verify our preliminary results; (4) evaluating change in channel characteristics with natural events; (5) modifying and verifying our proposed channel assessment procedure; and (6) improving the management indices used to predict channel change. While all these would provide better guidance to land managers, we believe that the single most critical need is to evaluate the sources of sediment supply.

The driving concern for this study was the effect of forest management activities on discharge, and the basic objective -- as expressed in the title of the study -- was to validate the water yield thresholds currently in use on the KNF. However, the only channel response variables which could be directly linked to a change in discharge was the observed increase in exposed bank in the pool-riffle and colluvial step-pool reaches. All the other significant responses are consistent with an increase in sediment supply rather than an increase in discharge. Even the increase in percent exposed bank might be due to an increase in sediment supply, but the absence of any significant change in width or depth suggests that the primary cause is a change in the size of peak flows.

There are several possible sources of the observed increase in sediment, and these include: (1) surface erosion from roads and cut units; (2) bed and bank scour in the downstream pool-riffle reaches; (3) bed and bank scour in the upstream step-pool reaches; and (4) mass movements. Since the management actions necessary to minimize each source are different, the relative importance of each source must be determined prior to the development of appropriate management guidelines. If bed and bank scour are the primary sources, then this would imply that an increase in the size of peak flows should be of primary concern, and the observed fining and pool infilling is simply a secondary result of the change in peak flows. On the other hand, if the primary sources are surface erosion or mass movements, then the basic problem is an increase in sediment supply, and management actions should focus on minimizing these sources rather than a change in the size of peak flows.

Since the project objective and design were intentionally directed towards changes in flow, the data collected under this project do not allow us to resolve this basic issue. We therefore suggest that the first priority for future research should be to construct an approximate sediment budget for several catchments with an area of 10-20 square miles. Drs. Leslie Reid and Thomas Dunne have recently published a guide to the construction of sediment budgets (Reid and Dunne, 1996), and discussions with several geomorphologists indicate that it might be possible to analyse several catchments in one field season. Ideally this would be done on a basin with some sediment yield data, but this may not be essential. Until this is done managers can't identify the true cause of habitat degradation, and this severely limits their ability to develop effective BMPs, set management guidelines, and design efficient monitoring programs.

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